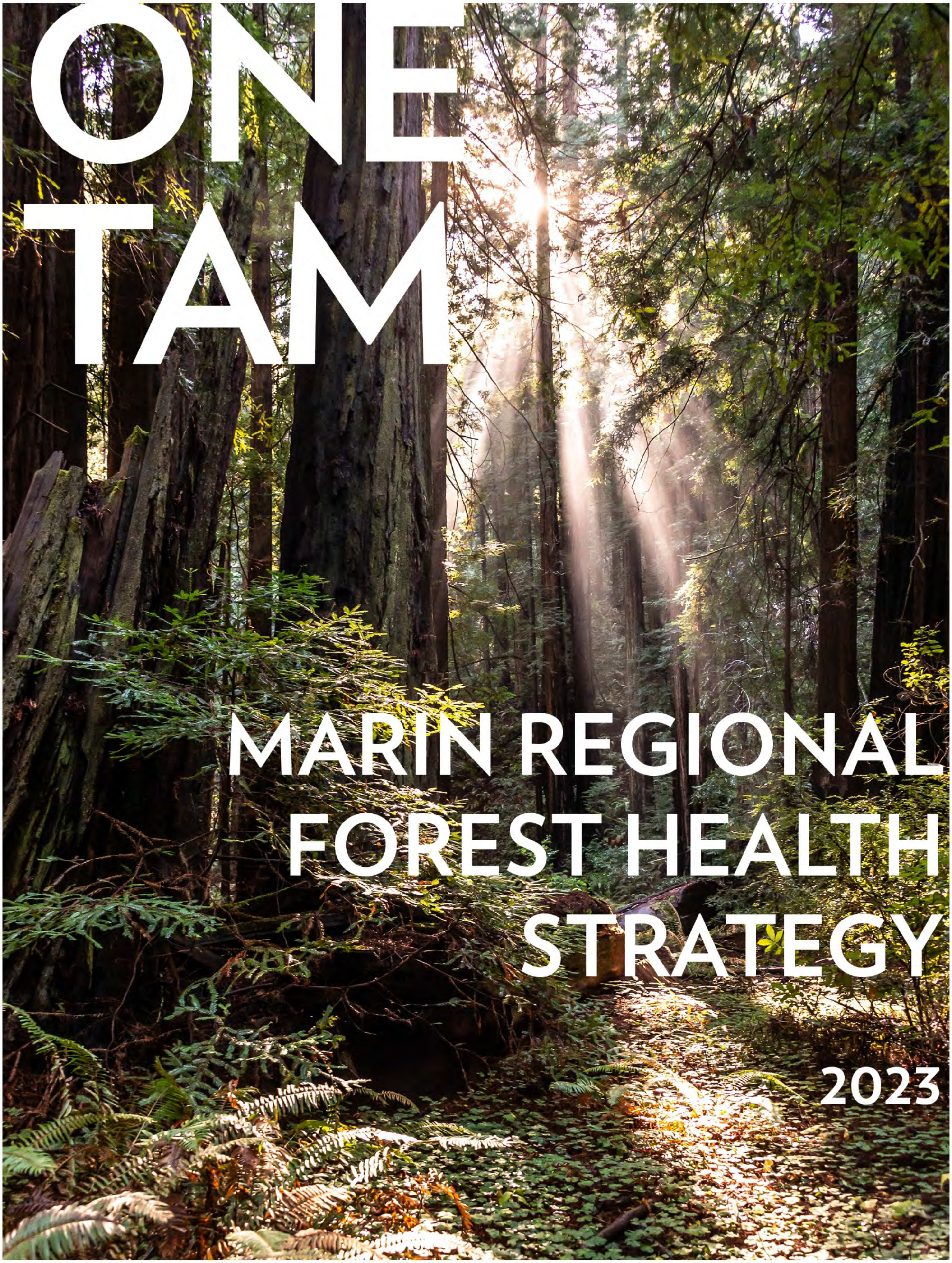
ONE TAM

MARIN REGIONAL FOREST HEALTH STRATEGY

2023



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LAND ACKNOWLEDGEMENT

The Tamalpais Lands Collaborative (One Tam) acknowledges that all the lands within the area known as Marin County are Coast Miwok land. Today, the Coast Miwok are represented by the Federated Indians of Graton Rancheria (Tribe), a federally recognized Tribe that includes both Coast Miwok and Southern Pomo. The Tribe is the **only** federally recognized Tribe with ancestral lands in Marin County. The Tribe's ancestral territory is recognized by the federal government and includes all of Marin and Sonoma counties. The lands, waters, forests, plants, animals, and other aspects of the environment as well as the traces of Tribal ancestral activities and belongings in Marin County constitute Tribal Cultural Resources (TCRs) of special interest to the Tribe. The *Marin Regional Forest Health Strategy* (*Forest Health Strategy)* exemplifies the work of the One Tam partners – the National Park Service, California State Parks, Marin Water, Marin County Parks, and the Golden Gate National Parks Conservancy – and represents our collective knowledge of the composition and conditions of key forest types in Marin County. The *Forest Health Strategy* stems from western academic conventions and perspective, and the regulatory frameworks in which the One Tam partner agencies operate. We recognize that for millennia Coast Miwok people have created and possessed knowledge about the forested lands of the region, which includes the Tribe's contemporary scholars and scholarship. While we tried, wherever possible, to integrate the perspectives of the Federated Indians of Graton Rancheria into elements of the *Forest Health Strategy*, the Tribe retains special knowledge beyond what is included in this document. **The information provided in Chapter 3: Stewardship and Partnership with the Federated Indians of Graton Rancheria is intended to inform and educate the audience about California Native American land tending practices and opportunities for public land management agencies and the Tribe to collaborate and partner on future forest management. Information in the chapter or elsewhere in the *Forest Health Strategy* does not, in any way, constitute tribal consultation under NHPA, NEPA, or CEQA, nor does it replace a land management agency's responsibility to conduct research, field investigation, and Tribal consultation when planning or designing forest treatments.**

EXECUTIVE SUMMARY

The Federated Indians of Graton Rancheria (the Tribe) are the original inhabitants and stewards of the lands and waters in Marin County and have lived sustainably with right relationships to the world around them since time immemorial. Marin County's residents, policymakers, and land managers have a responsibility to address the legacies of colonialism that have disrupted these relationships and work collaboratively with the Tribe to steward this remarkably diverse and well-loved expanse of forested lands. Part of the Golden Gate Biosphere region – a UNESCO designation recognizing global areas of significant biological diversity – the 118,000 acres of forests and woodlands in Marin County are rich ecosystems that have numerous benefits including cultural value, wildlife habitat, clean air, drinking water, carbon sequestration, and world-class recreational opportunities.

The unique and vital role of Marin's forests as providers of natural beauty, abundant life, and community well-being, requires that land managers thoughtfully consider the overall health and condition of these complex systems. To effectively care for Marin County forests it is important to identify and evaluate the impact that stressors such as plant disease, introduced weeds, present and past land-use, the legacy of colonization, and a changing climate may have on long-term forest resilience, defined as the capacity of forest ecosystems to absorb or recover from disturbance while undergoing change to retain desired ecosystem services and functions.

The *Marin Regional Forest Health Strategy* (*Forest Health Strategy*) is a crucial step forward in understanding the condition of key forest communities in Marin County. Utilizing best available data, local knowledge, and expert analysis, the *Forest Health Strategy* provides essential insight into the threats currently impacting forest resilience in Marin. In addition, it furnishes a science-based framework for identifying how and where agencies can work both independently and together across jurisdictional boundaries to increase and protect forest health in our region. The *Forest Health Strategy* does not answer all the questions that managers have about the forests in Marin; in some cases, it reveals how much more there is to learn about the intricate and dynamic forest systems present in the county. Nevertheless, this strategic plan establishes a meaningful baseline that decision-makers can use to measure future changes in forested environments, develops critical datasets and assessment metrics to build upon, and delivers a thoughtful path forward for projects and programs designed to protect and improve forest health and resilience in Marin County over the next decade.

KEY FINDINGS & PROPOSED ACTIONS

Through the work of the Forest Health Strategy, One Tam partner agencies are uniquely positioned to advance projects and programs that will address the effects of these stressors on forest ecosystems.

Forests are naturally resilient ecosystems, and analysis conducted as part of the *Forest Health Strategy* underscores that the mosaic of forest types in Marin County is diverse, dynamic, and has been able to persist to this point despite the presence of multiple ecological stressors. However, the impacts from threats to forest health are measurable and widespread, with higher concentrations in some areas. Through the work of the *Forest Health Strategy*, Tamalpais Lands Collaborative (One Tam) partner agencies are uniquely positioned to advance projects and programs that will address the effects of these stressors on forest ecosystems.

The Federated Indians of Graton Rancheria continue to steward the lands, waters, and forests in what is now referred to as Marin County, maintaining relationships and responsibilities in these places since time immemorial. The combination of colonization, settlement, urbanization, fire suppression, past and present land-use, and policies that prevent or avoid forest management have disrupted the Tribe's relationships with some areas in the county and created a departure from healthy conditions in many of Marin's forests. As climate change continues to advance, forest ecosystems that are currently resilient to ecological stressors may potentially further degrade or disappear entirely from the landscape, diminishing all that the forests provide. The *Forest Health Strategy* gives land managers a baseline understanding, decision support tools, and a pathway for implementing management actions that align with the mandate of individual One Tam partners and other land management agencies, while also providing the ability to plan and work across jurisdictional boundaries and in partnership with the Tribe.

This *Forest Health Strategy* informs, but is different from, wildfire risk reduction work being done by One Tam partners and Marin County's fire agencies. The *Forest Health Strategy* is intended to support this work, where feasible, and the framework provided by the *Forest Health Strategy* can strengthen collaboration between One Tam partners and the Marin Wildfire Prevention Authority and highlight ways that risk reduction work can increase or protect forest resilience. As agencies work to reduce wildfire risk to communities through home-hardening, creating defensible space, and targeted vegetation management in the interface between urban and wildland areas, the One Tam partners can utilize and share the *Forest Health Strategy* to help those agencies design and implement treatment approaches that are ecologically beneficial.

The framework provided by the Forest Health Strategy can strengthen collaboration between One Tam partners and the Marin Wildfire Prevention Authority by highlighting ways that risk reduction work can increase or protect forest resilience.

FOREST CONDITION ASSESSMENT HIGHLIGHTS

- While the county's **Bishop Pine** forests are not currently at imminent risk of disappearing from the mosaic of forest types in Marin, the lack of fire is preventing regeneration in late-seral stands, and plant pathogens are measurably affecting the composition of both mid- and late-seral stands around Tomales Bay and on the Point Reyes peninsula. Without stewardship and management, this serotinous species could be lost in some areas and become less resilient to climate change and stressors in other areas.
- Marin's iconic **Coast Redwood** forests are generally healthy; however, plant diseases and fire exclusion are changing their structure and floristic composition. Many previously logged, second-growth Coast Redwood stands share structural similarities with groves of old-growth trees, indicating opportunities to encourage late-seral conditions through active management are present in a variety of areas. Future analysis will help identify Coast Redwood areas most vulnerable to climate change, and where refugia for this invaluable forest type may persist.
- **Douglas-fir** forests, the most widespread conifer type in the county, are in overall healthy condition; however, pathogens and fire exclusion are making them less resilient to wildfire in key areas and altering vegetation assemblages. In some areas, absent a natural disturbance regime, Douglas-fir is expanding to the detriment of biological diversity by reducing or modifying grassland, shrubland, and oak woodland habitat.
- **Open Canopy Oak Woodlands**, collectively nearly as abundant in Marin County as Douglas-fir, continue to be a vital part of the mosaic of forest types in the county. Pathogens, drought stress, and fire exclusion are undoubtedly negatively impacting the composition of these hardwood forests as well as their overall health and resilience, and both stewardship and active management are needed in key areas across Marin County.
- **Sargent Cypress** forests remain relatively stable and foster tremendous biological diversity; however, continued monitoring by land managers is needed to ensure stands do not senesce before being able to regenerate through natural fire processes. Continued fire exclusion would likely threaten long term resilience of the species in Marin.

RECOMMENDATIONS

The *Forest Health Strategy* serves as a critical step forward for One Tam partners to work with Marin's other land managers, the Federated Indians of Graton Rancheria (the Tribe), fire prevention agencies, and communities to protect and improve the health and resilience of Marin's forests. The *Forest Health Strategy* is a scientific and data-driven decision-support tool to help focus future research, monitoring, and management efforts in collaboration and consultation with the Tribe. The Tribe retains Traditional Knowledge (TK) and Traditional Ecological Knowledge (TEK) about the lands, waters, environments, beings, and relationships that are essential to land stewardship and cultural and natural resource management in Marin County. The Tribe's TK and TEK are the intellectual property and cultural patrimony of the Tribe, and care should be taken to ensure that the confidentiality of information shared by the

Tribe is maintained and protected. The Tribe's TK and TEK should also be considered on the same level of intellectual merit as western science even though these two knowledge systems represent different and sometimes incommensurable perspectives.

It should be noted that both cultural and natural resources constitute Tribal Cultural Resources (TCRs), such as an ancient village site, a mountain, a stream, or a forest. These elements of the environment are interconnected with each other and with the Tribe today through stewardship and active use to perpetuate cultural lifeways and fulfill the Tribe’s responsibilities to maintain forest health and sustainability. Consultation and collaboration with the Tribe in all land management activities within the Tribe's territory acknowledges and supports the Tribe's sovereignty and ability to steward these lands for future generations. Suggestions and ideas for forest resilience actions are presented in the following chapters of the *Forest Health Strategy*. Overall recommendations include:

- One Tam partners should partner with the Tribe to integrate Tribal knowledge and perspectives into the study, use, and management of forests, which are a significant Tribal Cultural Resources (TCRs). Engaging in dialogue with the Tribe and the Tribal Heritage Preservation Officer (THPO) and ensuring the Tribe has decision making authority in the development and implementation of projects and programs related to these TCRs is the best way to accomplish this.
- In addition to consultation and relationship building between agencies and the Tribe to establish and implement routine land management, agencies should also address issues of access and opportunity for the Tribe to engage with these lands for the betterment of the ecosystem and wellbeing of the Tribe, to include but not be limited to access for gathering of traditional plants and resources for cultural, medicinal, and subsistence uses (see Chapter 3: Stewardship and Partnership with the Federated Indians of Graton Rancheria, for additional discussion on these topics). This may include the implementation of Traditional Knowledge (TK), Traditional Ecological Knowledge (TEK), Indigenous science, co-stewardship, co-management, and other activities. Any Tribal cultural information or knowledge shared is the intellectual property and cultural patrimony of the Tribe, and care should be taken to ensure that the confidentiality of this information is maintained and protected.
- The One Tam partners should continue to work together to advance opportunities to fundraise for, plan, develop, and implement projects and programs to increase forest health and resilience in Marin County. As outlined in the *Forest Health Strategy*, this includes partnering across jurisdictional boundaries and collaborating with Marin’s fire agencies to expand the use of beneficial fire in Marin.
- Where applicable, land managers should use demonstration projects and/or partner with researchers to evaluate treatment approaches and measure outcomes, which will help refine methods and determine best management practices. Coordinated countywide treatment tracking should be developed to support planning, design, cross jurisdictional collaboration, and monitoring.

- The results of the analysis performed, and foundational datasets generated by, the *Forest Health Strategy* should be shared widely with agencies, decision-makers, researchers, and consultants advancing forestry work, fire prevention projects, and general vegetation management in Marin County, so that these efforts can be shaped by the strategy's findings and, wherever possible, address threats to forest health and ensure the ecological resilience of forests and woodlands. To this end, strategy documents are available on the One Tam website, and anyone can access spatial datasets via the One Tam Forest Health Web Map.
- One Tam partners should continue to create and sustain community engagement to build awareness and support for forest health and resilience work; existing programs such as the One Tam Community Stewardship Program, Youth Programs, and workshops and conferences such as the bi-annual One Tam Science Summit are effective tools for engagement.
- Additional and ongoing field-based assessments are necessary to develop comprehensive understanding of the dynamics surrounding forest health and resilience in Marin County. Data on factors that contribute to forest health such as wildlife occupancy, presence/absence of invasive species, rare plant occurrences, soil microbiology, pollinator-plant interactions, and lichen occurrences, was not available at scales needed to include in the *Forest Health Strategy's* countywide Forest Condition Assessment. One Tam partners should continue to collaborate on strengthening data collection and evaluation efforts of these and other important indices of forest health as part of field-based inventories and community science initiatives, such as Marin Wildlife Watch, One Tam's Rare Plant Program, Bat Monitoring Program and others.
- Non-native invasive species, notably woody species such as eucalyptus, French broom, acacia, and cotoneaster, degrade forest and woodland habitat and can increase wildfire hazard. One Tam agencies should continue to partner on invasive plant removal and habitat restoration projects, and strengthen programs designed to address this threat to forest health and resilience, such as the Early Detection Rapid Response Program and Invasive Plant Monitoring and Management Program.
- Foundational datasets used to develop the *Forest Health Strategy* such as the 2018 6-inch aerial imagery, 2019 quality level-1 lidar, and countywide fine scale vegetation map were mission-critical inputs that provided remarkable insight into the dispersal, floristic composition, and structure of forests in Marin County. One Tam partners should work together to fund and execute updates to these databases, which would allow for comparative analysis, change detection over time, measurements of management efficacy, and future analysis using metrics like those in the *Forest Health Strategy.*

BACKGROUND

With its sweeping views, miles of trails, and ancient forests, Mount Tamalpais in Marin County is a beloved local treasure. Mount Tamalpais is a culturally significant place for the Federated Indians of Graton Rancheria, and the Tribe and California State Parks are engaged in government-to-government consultation about the stewardship and management of this very important place. The legacy of settler colonialism, including anthropogenic climate change, introduced weeds and pathogens, and past management choices, threatens the long-term health and resilience of Marin's forests. In 2014 One Tam came together to mobilize the skills and resources of the mountain's land managers – Marin Water, National Park Service, California State Parks, and Marin County Parks – along with their non-profit support partner the Golden Gate National Parks Conservancy, and communities in Marin, to collaborate on caring for the long-term health of Mount Tamalpais.

Recognizing the need to improve understanding among land managers and the general public about the status and trend of key natural resources on Mt. Tamalpais, in 2016 One Tam partners published *Measuring the Health of a Mountain: A Report on Mount Tamalpais' Natural Resources* (*2016 Peak Health Report*). The *2016 Peak Health Report* evaluated the condition of the mountain's plant and animal communities using a suite of metrics that provided insight into health and condition trends of several key ecological indicators. The report also identified data gaps and areas for additional study necessary to support decision-making, including the need for regionally consistent spatial vegetation data to understand the distribution of vegetation assemblages and analyze change over time. Critically, the *2016 Peak Health Report* found that while in certain cases the condition trend for key ecological indicators, including forest and woodland areas, was cautionary or declining, conditions were at a point where their trajectory could still be improved through active management.

Climate change, introduced weeds, pathogens, past management choices, and the legacy of colonization threaten the long-term health and resilience of Marin's forests.

Based on the *2016 Peak Health Report's* recommendation, the One Tam partners embarked on an effort to develop a comprehensive and systematic spatial vegetation dataset to facilitate future landscape scale analyses. The Marin Countywide Fine Scale Vegetation Map and Landscape Database project was completed in 2021, for the first time giving public agencies and natural resource managers in Marin a spatial tool for regional-scale examination of the distribution, floristic composition, and structure of more than 100 unique vegetation communities, including 27 native forest and woodland assemblages containing conifer, evergreen and deciduous hardwood, and riparian forest species.

Critically, the Peak Health report found that while in certain cases the condition trend for key ecological indicators, including forest and woodland areas, was cautionary or declining, conditions were at a point where their trajectory could still be improved through active management.

As indicated in the *2016 Peak Health Report*, forests in Marin County face multiple ecological stressors which have a measurable impact on the condition trend of these invaluable resources. **This reality, coupled with a growing need to increase the pace and scale of vegetation management to address wildfire risk in key areas**

of Marin, precipitated the One Tam collaborative to seek funding to develop the Marin Regional Forest Health Strategy from the statewide Regional Forest and Fire Capacity Program through a grant from the California State Coastal Conservancy.

PURPOSE & PROCESS

The One Tam partners came together to assess current conditions of Marin's forests and create a strategy for increasing forest health and resilience. The *Forest Health Strategy* outlines our science-based approach toward this goal and provides abasis for selecting, designing, funding, and implementing future projects. To develop the *Forest Health Strategy*, environmental scientists and natural resource managers at the One Tam partner agencies came together with a team of consultants and expert technical reviewers under the umbrella of the One Tam Forest Health Working Group. The Working Group identified five key forest communities to profile in the strategic plan – Coast Redwood, Douglas-fir, Bishop Pine, Sargent Cypress, and Open Canopy Oak Woodlands – and developed landscape level goals for each. Using the Marin Countywide Fine Scale Vegetation Map as the basic unit of analysis, the Working Group developed a suite of metrics to assess conditions of each key forest type and identified priority focus areas and approaches to implementing projects and programs that will increase forest resilience, ecological health, and community well-being in Marin County.

The Forest Health Strategy outlines our science-based approach towards the goal of increasing forest health and resilience, and for selecting, designing, funding, and implementing future projects.

Early on in this process the Forest Health Working Group recognized that, as the sole federally recognized Indian Tribe and California Native American Tribe that is culturally affiliated with Marin County, the Federated Indians of Graton Rancheria have rights to government-to-government consultation and should be a decision maker in all projects that concern the Tribal Cultural Resources (TCRs), lands, and waters of Marin County. California Assembly Bill 52 establishes California Native American Tribes as the subject matter experts on what constitutes TCRs, and the Federated Indians of Graton Rancheria considers forests among other aspects of the environment as a TCR. Furthermore, the Tribe possesses specific knowledge about TCRs such as the forests of this region. Tribal access, stewardship, and use of these TCRs and areas are integral to the health and sustainability of the forests and other ecosystems, and the forests are integral to the health and wellbeing of the Tribe. Working with National Park Service and California State Parks cultural resource staff, the working group reached out to the Tribe to share the purpose for developing the *Forest Health Strategy* and to invite the Tribe to be a part of creating the strategic plan. The Tribe identified a representative to participate as a technical reviewer of strategy documents, and to author a stand-alone chapter focused on Traditional Ecological Knowledge (TEK) and recommendations for Tribal partnership (see Chapter 3: Stewardship and Partnership with the Federated Indians of Graton Rancheria). While this collaboration is a meaningful step forward for strengthening Tribal participation in planning for Marin's forests and woodlands, the Tribe retains special knowledge and proprietary understanding about the interconnectedness and function of the lands in Marin County. Work to include the Tribe in all aspects of forest management in Marin County is critical and ongoing.

STRUCTURE & CONTENT

The *Forest Health Strategy* is divided into 10 chapters (Table 1). A list of references cited is included at the end of each chapter, except for Chapter 5: Goals, which list references at the end of each key forest type section, and Chapter 9: Treatment Descriptions, which lists references after each treatment type. There are several appendices to the Forest Health Strategy which provide important background information for forest health assessment, treatment implementation, and recommendations for future study.

To make the spatial datasets developed and used to understand forest conditions and identify management opportunities accessible, a Forest Health Web Map was developed as a companion to the *Forest Health Strategy.* A Marin Forest Health Watershed Report Downloader tool was also created to provide an easy way for managers and collaborators to access pre-generated maps and tables summarizing landcover conditions, fire history, and other metrics useful for understanding and assessing forest health at landscape scale.

Table 1. Structure of the Forest Health Strategy, with chapter number/name and purpose.

Chapter Number/Name	Purpose
1: Introduction	Overview of *Forest Health Strategy* with summary of purpose, process, key findings, and recommendations
2: Resilience	Provides a shared definition of resilience used to develop *Forest Health Strategy* goals and recommendations, summarizes existing literature and relevant case studies.
3: Stewardship and Partnership with the Federated Indians of Graton Rancheria[1]	Synopsis of historical context for Federated Indians of Graton Ranchera affiliation to Marin County, background on Native American stewardship in regional forests, discusses the impacts of colonialism, and provide recommendations for stronger partnership between the Tribe and Marin's land managers.
4: Climate Change and other Forest Health Stressors	Review of stressors threatening the health and resilience of forest ecosystems in Marin County including climate change, fire exclusion, recreation, and pathogens.
5: Goals	Discussion of goals for each of the five key forest types. Includes life history summaries, notes on distribution, fire regime, unique threats to forest resilience, conceptual models of ecosystem function, and results chains for various treatment approaches.

[1] Written by Dr. Peter Nelson, Coast Miwok and Tribal Citizen of the Federated Indians of Graton Rancheria, and Associate Professor at UC Berkeley.

6: Metrics	Detailed description of individual metrics developed for modelling forest conditions and the methods and foundational data used to create them. Includes description of the geospatial data used to develop modelled geographic information system (GIS) products depicting forest conditions in Marin County.
7: Condition Assessment	Evaluates and summarizes the conditions of key forest types, establishes baseline data which can serve as the foundation for future assessments and to monitor the efficacy of management actions. Provides status of key forest types used to develop multi-benefit treatment opportunities described in Chapter 8.
8: Prioritization Framework and Implementation Analysis	Defines multi-benefit treatments, provides a framework and spatial tools for identifying opportunities to restore or enhance ecological health and resilience in forested areas, and considers both wildfire hazard and proximity to community, where applicable Results of this analysis are presented as areas that can be prioritized as a potential multi-benefit treatment location for each One Tam land managing agency.
9: Treatment Descriptions	Discussion of treatment approaches: forest thinning, biomass management, beneficial fire, restoration, fuel breaks, and pest and pathogen management. Includes expected benefits and considerations including access, costs, resource impacts, and suggested post-treatment monitoring.
10: Monitoring	Outlines recommended field-based and geospatial monitoring approaches for forest resiliency treatments and change detection over time, a necessary component for adaptive management and learning.
Appendix A: Bishop Pine	Includes: *Bishop Pine Forest Health White Paper* (Harvey & Agne, 2021) and *Bishop Pine Forest Health and Pitch Canker Disease Field Study on Point Reyes Peninsula, CA* (Harvey et al., 2022).
Appendix B: Wildfire History	*Marin County Wildfire History Mapping Project* (Dawson, 2021). Dawson documented historical fires over a longer period and to a higher degree of geographical and temporal precision than in previous fire mapping projects in Marin County and used GIS to map all fires in Marin between 1859 and 2020 which were greater than 160 acres in size.
Appendix C: Regulatory Compliance	Regulatory compliance guidance to aid in planning and implementation of forest health projects.
Appendix D: Example Pre-Generated Watershed Report	One example of a pre-generated Forest Health Watershed Report from the [Marin Forest Health Watershed Report Downloader.]
Appendix E: Opportunities for Additional Study	Describes several areas for additional study to support planning and management to improve forest health, identified during development of the *Forest Health Strategy*.

ACKNOWLEDGEMENTS

The One Tam partners would like to express their gratitude to the Federated Indians of Graton Rancheria and Dr. Peter Nelson for participating in the *Forest Health Strategy* and sharing their perspective. The *Forest Health Strategy* would not have been possible without a grant from the California State Coastal Conservancy, in partnership with the California State Natural Resources Agency's Regional Forest and Fire Capacity Program, administered by the Department of Conservation and the California Climate Investments fund. Special thanks to the members of the Forest Health Working Group representing the One Tam partners including Alison Forrestel, Ph.D. (NPS), Bree Hardcastle (California State Parks), Carl Sanders (Marin Water), Daniel Franco (Parks Conservancy), Greg Jones (NPS), Janet Klein (Parks Conservancy), Loraine Parsons (NPS), Michela Gentile (Parks Conservancy), Mischon Martin (Marin County Parks), Rachel Hendrickson (NPS), Rosa Schneider (California State Parks), Sarah Minnick (Marin County Parks), Shaun Horne (Marin Water), Sherry Adams (Marin Water), and Zac Stanley (County of Marin). Several technical reviewers and subject matter experts generously provided their time and knowledge in reviewing *Forest Health Strategy* documents including Brian Harvey, Ph.D. (University of Washington), Christy Brigham, Ph.D. (NPS), Diana Humple (Point Blue), Hilary Allen (Point Blue), Kristen Dybala, Ph.D. (Point Blue), Maggi Kelly, Ph.D. (UC Berkeley), Mark Brown (MWPA), Marti Witter, Ph.D. (NPS), Mia Monroe (NPS), Michelle Agne, Ph.D. (University of Washington), Peter Nelson, Ph.D. (UC Berkeley), and Reed Noss, Ph.D. (Conservation Science Inc.). Thanks are due to the excellent team of supporting consultants that contributed to this effort including Arthur Dawson (Baseline Consulting), Brittany Burnett (Tukman Geospatial), Carol Rice (Wildland Resource Management), Caroline Christman (Collective Agency LLC), Dylan Loudon (Tukman Geospatial), Eddie Fitzsimmons (Tukman Geospatial) Esther Mandeno (Digital Mapping Solutions), Heather Blair (Ascent Environmental), Julia Murphy (Tukman Geospatial), Kass Green (Kass Green and Associates), Lara Rachowicz (Ascent Environmental), Mark Tukman (Tukman Geospatial), and Vance Russell (VR Conservation Collective). Finally, acknowledgement is due to the staff of numerous partner organizations without which this effort could not have happened; thank you to all One Tam partner staff, and employees of all our agency collaborators and organizational colleagues.

CHAPTER 1: INTRODUCTION

Marin County's nearly 118,000 acres of forest and woodland are a vital resource for wildlife, residents, and visitors. These lands have been home to Coast Miwok peoples since time immemorial. The natural processes that occur in Marin's forests provide benefits for all beings in the region, and all these natural processes and beings benefit from Tribal use and stewardship of the forests according to the Tribe's Traditional Ecological Knowledge and relationships with the environment. Forest soils allow rain to infiltrate, preventing erosion and providing clean water. Trees drink carbon dioxide, sequestering carbon and purifying the air. But left to themselves, forests can also grow large and dense, putting the entire system in danger of catastrophic wildfire, loss of life and livelihoods, and extreme carbon emissions. These forests need care, and Tribal stewardship responsibilities to gather, hunt, fish, burn, and tend in coordination with management rooted in the best available science will continue to improve and maintain these ecosystems into the future. Whether Northern Spotted Owl (*Strix occidentalis caurina*) or human (from many backgrounds and worldviews), we all rely on forests for our well-being, and the forests rely on us, each working in collaboration from our respective positions for the betterment of the whole.

PURPOSE

Forests are naturally resilient, they can adapt with nature's changing conditions and recover from damage, but the combination of threats such as fire exclusion, drought, non-native invasive species, plant pathogens, and climate change threaten to reduce the many benefits of healthy forest ecosystems. The *Marin Regional Forest Health Strategy* (*Forest Health Strategy*) was developed by the One Tam partners to provide a science-based and data-driven framework for public land managers and decision-makers in Marin County to assess forest health and prioritize forest treatments to help forests remain resilient in the face of these threats. To achieve this goal, the *Forest Health Strategy* developed and utilized best-available data, expert analysis, scientific understanding, and local knowledge to explore the distribution, composition, and conditions of key forest types in Marin, assess the impacts of forest stressors, and provide a multi-benefit framework, where treatments and solutions are designed to provide cultural and community benefits in addition to restoring forest health and ecosystem resilience. Protected public lands in Marin County are shown in Figure 1.1.

Tribal stewardship has been an integral part of maintaining the health and sustainability of the forests and ecosystems in what is now known as Marin County for millennia (see Chapter 3: Stewardship and Partnership with the Federated Indians of Graton Rancheria). The combination of colonization, settlement, urbanization, fire suppression, past and present land-use, and policies that prevent or avoid forest management have created a departure from healthy conditions in many of Marin's forests. As climate change continues to advance, forest ecosystems that are currently resilient to ecological stressors may potentially degrade or disappear entirely from the landscape, diminishing all that the forests provide. The *Forest Health Strategy* gives land managers a baseline understanding, decision support tools, and a pathway for implementing management actions that align with the mandate of individual One Tam partners and other land management agencies, while also providing the ability to plan and work across jurisdictional boundaries.

The *Forest Health Strategy* informs, but is different from, wildfire risk reduction work being done by One Tam partners and Marin County's fire agencies. The *Forest Health Strategy* is intended to support wildfire risk reduction work where feasible, and the framework provided by the *Forest Health Strategy* can strengthen collaboration between One Tam partners and the Marin Wildfire Prevention Authority and highlight ways that risk reduction work can increase or protect forest resilience. As agencies work to reduce wildfire risk to communities through home-hardening, creating defensible space, and targeted vegetation management in urban and wildland interface areas, the One Tam partners can utilize and share the *Forest Health Strategy* to help those agencies design and implement treatment approaches that are ecologically beneficial. See Chapter 7: Condition Assessment and Chapter 8: Prioritization Framework and Implementation Analysis for additional details.

SETTING

Marin County is globally recognized for its biological diversity, with an exceptional variety of abiotic and biotic resources, and is a part of the UNESCO-designated Golden Gate Biosphere region. Marin County includes more than 330,000 acres of land split by the San Andreas fault running north to south from Tomales Bay through Bolinas Lagoon. The combination of rich and active geology, diversity of soils, microclimates, topographic complexity, and Mediterranean climate (warm, dry summer; cool, rainy winters) supports rich plant diversity (Buck-Diaz et al., 2021; Edson et al., 2016; Howell, 1970). Typical rainfall varies across Marin, with a marked distinction between foggy, Pacific Ocean-moderated areas of Douglas-fir and Coast Redwood forests to the west and xeric inland areas to the east, dominated by rolling grasslands, Open Canopy Oak Woodlands, and rocky chaparral (Howell, 1970).

The 2018 Marin Countywide Fine Scale Vegetation Map (2018 Fine Scale Vegetation Map) depicts 110 unique vegetation communities and landcover classes in Marin, including 24 distinct native forest assemblages containing conifers, evergreen and deciduous woodlands, and riparian forests (Figure 1.2). For more detailed information and interactive maps, explore the online Forest Health Web Map.

Figure 1.1. Protected open space lands in Marin County, including One Tam partner agencies California State Parks, Marin County Parks, Marin Water, and National Park Service units.

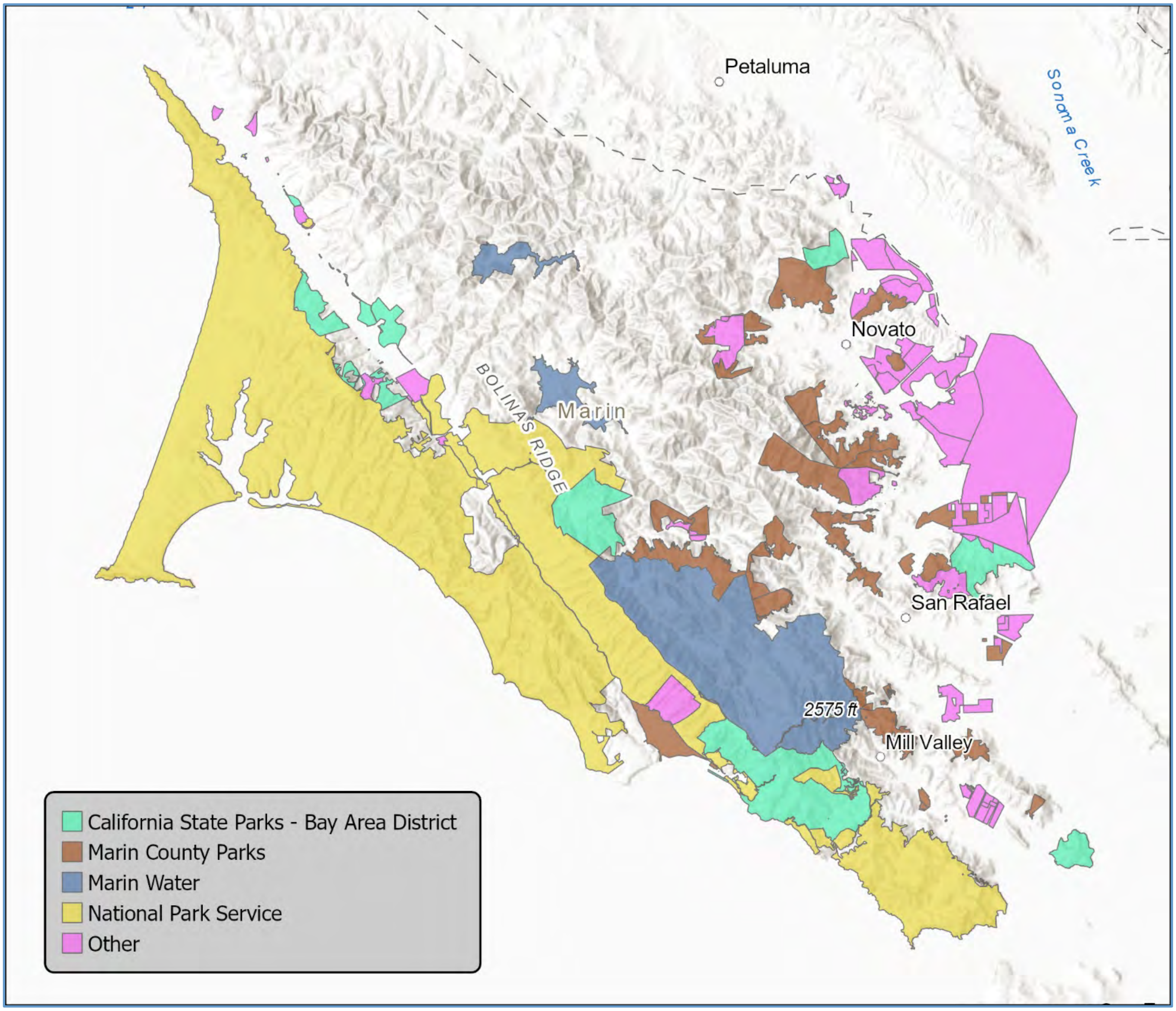
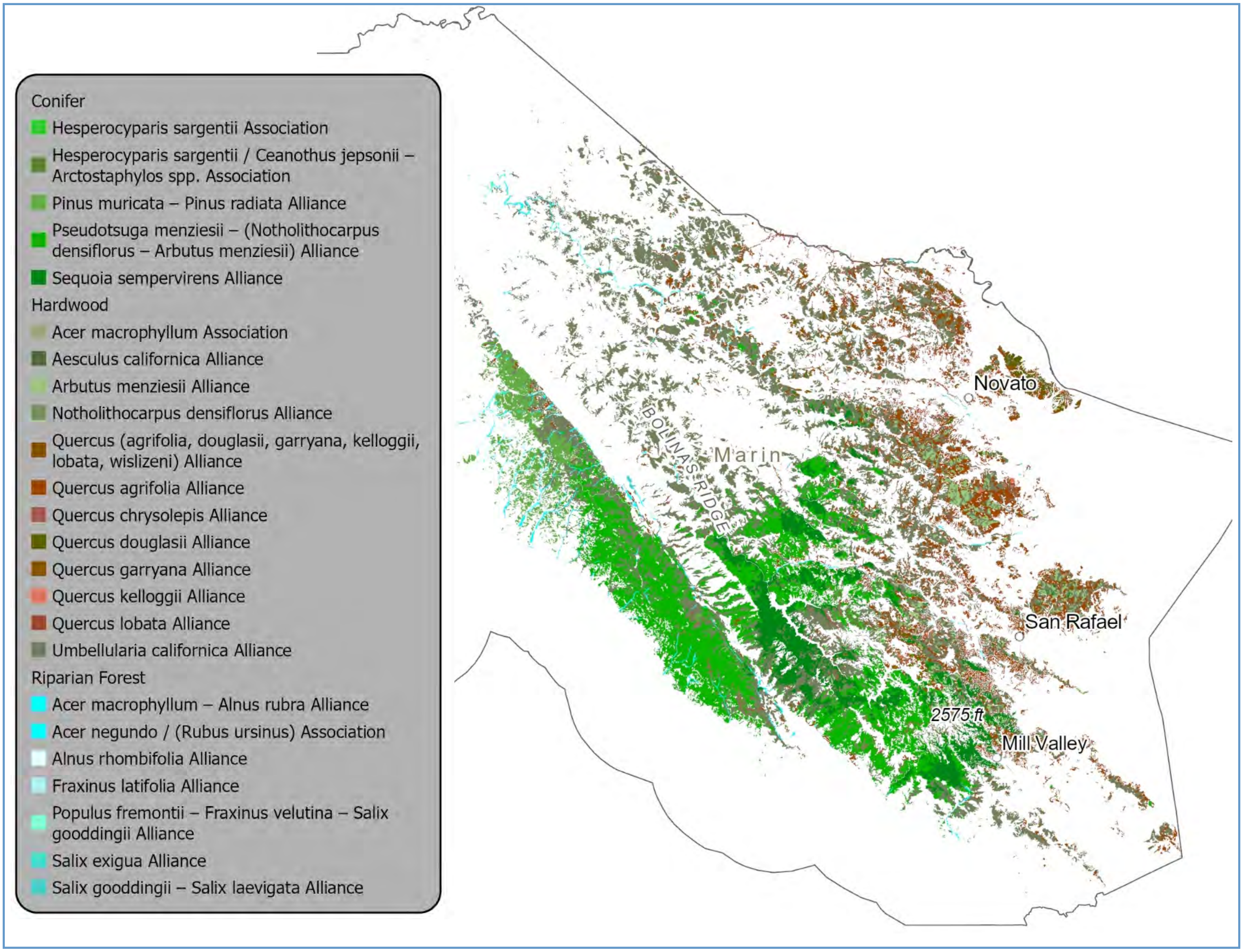


Figure 1.2. Native forest communities depicted in the 2018 Marin Countywide Fine Scale Vegetation Map.



PROCESS

In 2016, the Tamalpais Lands Collaborative (One Tam) published a detailed assessment of the health of Mount Tamalpais' natural resources entitled *Measuring the Health of a Mountain: A Report on Mount Tamalpais' Natural Resources* (*2016 Peak Health Report*), which used a suite of metrics to determine condition trends for key ecological indicator species (Edson et al., 2016). The *2016 Peak Health Report* also identified data gaps, including the need for consistent, mountain-wide, vegetation community spatial data. The 2018 Fine Scale Vegetation Map, completed in 2021, was developed by One Tam to close this data gap, facilitate cross-jurisdictional analysis, and provide land managers, decision-makers, and residents with a tool for understanding the distribution and composition of vegetation communities, including forested areas, across Marin County. Floristic classification analysis of more 6,407 field surveys from Marin County and adjacent areas was performed concurrently with the fine scale vegetation mapping effort, resulting in descriptions of 110 alliances and 280 associations that occur in Marin, consistent with the Survey of California Vegetation and the United States National Vegetation Classification (USNVC) system (Buck-Diaz et al., 2021).

The *2016 Peak Health Report* also highlighted that while the condition trend for key forest types in Marin was declining in some areas, conditions were still at a point where their trajectory could be improved (Edson et al., 2016, p. 9). The *Forest Health Strategy* was initiated to increase understanding of forest conditions in Marin, identify threats to forest health, and highlight opportunities to advance projects and programs that could protect or increase forest resilience in Marin County. In late 2019 the One Tam collaborative was awarded funding to develop the *Forest Health Strategy* from the California Department of Conservation's Regional Forest and Fire Capacity Program, in partnership with the California State Coastal Conservancy.

An updated Peak Health Report will be released in 2023. Visit the One Tam Peak Health webpage for more information.

FOREST HEALTH STRATEGY WORKING GROUP & CONTRIBUTORS

To implement the *Forest Health Strategy*, One Tam convened the Marin Forest Health Strategy Working Group (Working Group). The Working Group is an interdisciplinary team of One Tam partner staff and supporting consultants, with subject matter experts with local, regional, national, and international experience engaged to act as technical reviewers (Table 1.1). The *Forest Health Strategy* kick-off meeting took place in March 2020. Initial meetings focused on developing a shared definition of resilience and conceptual models of ecological function for five focal forest types that would be evaluated in the strategy. Partners met bi-monthly from 2020 through 2022 to discuss approach and review components of the *Forest Health Strategy*. Throughout the strategic planning effort Working Group members met regularly to develop the content for each *Forest Health Strategy* chapter.

Early on in this process the Forest Health Working Group recognized that, as the sole federally recognized Indian Tribe and California Native American Tribe that is culturally affiliated with Marin County, the Federated Indians of Graton Rancheria (the Tribe) have rights to government-to-government consultation and should be a decision maker in all projects that concern the Tribal Cultural Resources (TCRs), lands, and waters of Marin County. California Assembly Bill 52 of CEQA establishes California Native American Tribes as the subject matter experts on what constitutes TCRs, and the Federated Indians of Graton Rancheria considers forests among other aspects of the environment as a TCR. Furthermore, the Tribe possesses specific knowledge about TCRs such as the forests of this region. Their access, stewardship, and use of these TCRs and areas are integral to the health and sustainability of the forests and other ecosystems, and the forests are integral to the health and wellbeing of the Tribe. Working with National Park Service (NPS) and California State Parks cultural resource staff, the Working Group reached out to the Tribe to share the purpose for developing the *Forest Health Strategy* and to invite the Tribe to be a part of creating the strategic plan. The Tribe identified a representative to participate as a technical reviewer of strategy documents, and to author a stand-alone chapter focused on Traditional Ecological Knowledge and recommendations for Tribal partnership (see Chapter 3: Stewardship and Partnership with the Federated Indians of Graton Rancheria). While this collaboration is a meaningful step for strengthening Tribal participation in planning for Marin's forests and woodlands, the Tribe retains special knowledge and understanding about the interconnectedness and function of Marin County lands. Work to include the Tribe in all aspects of Marin County forest management is critical and ongoing.

Table 1.1. Marin Forest Health Strategy Working Group, comprised of One Tam partner staff, technical reviewers, and supporting consultants.

ONE TAM PARTNER STAFF		
NAME	**TITLE**	**AFFILIATION**
Alison Forrestel, Ph.D.	Chief, Natural Resources & Science, Golden Gate National Recreation Area	National Park Service
Bree Hardcastle	Environmental Scientist	California Department of Parks & Recreation
Carl Sanders	Natural Resources Program Manager	Marin Water
Daniel Franco	Senior Project Manager	Golden Gate National Parks Conservancy
Greg Jones	Fire Management Officer, San Francisco Network of Bay Area National Parks	National Park Service
Janet Klein	Vice President of Community Stewardship & Conservation Science	Golden Gate National Parks Conservancy
Lorraine Parsons	Vegetation Ecologist, Point Reyes National Seashore	National Park Service
Mischon Martin	Chief, Natural Resources & Science	Marin County Parks

Rachel Hendrickson	Vegetation Biologist, Point Reyes National Seashore	National Park Service
Rosa Schneider	Senior Environmental Scientist-Specialist	California Department of Parks & Recreation
Sarah Minnick	Vegetation & Fire Ecologist	Marin County Parks
Shaun Horne	Watershed Resources Manager	Marin Water
Sherry Adams	Senior Ecologist	Marin Water
Zac Stanley	GIS Specialist	Golden Gate National Parks Conservancy

TECHNICAL REVIEWERS		
Brian Harvey, Ph.D.	Assistant Professor	University of Washington
Christy Brigham, Ph.D.	Chief, Resources Management and Science, Sequoia Kings Canyon National Parks	National Park Service
Maggi Kelly, Ph.D.	Professor and Cooperative Extension Specialist	U.C. Berkeley
Marti Witter, Ph.D.	Fire Ecologist	National Park Service
Michelle Agne	Ph.D. Candidate	University of Washington
Peter Nelson, Ph.D.	Assistant Professor	U.C. Berkeley
Reed Noss, Ph.D.	Chief Scientist	Conservation Science, Inc.

SUPPORTING CONSULTANTS		
Arthur Dawson	Principal	Baseline Consulting
Brittany Burnett	Botanist/Analyst	Tukman Geospatial
Buffy McQuillen	Tribal Heritage Preservation Officer (THPO)	Federated Indians of Graton Rancheria
Carol Rice	President	Wildland Resource Management
Caroline Christman	Senior Project Manager	Collective Agency, LLC
Dylan Loudon	Senior Geospatial Analyst	Tukman Geospatial
Eddie Fitzsimmons	GIS Analyst	Tukman Geospatial
Esther Mandeno	Principal	Digital Mapping Solutions

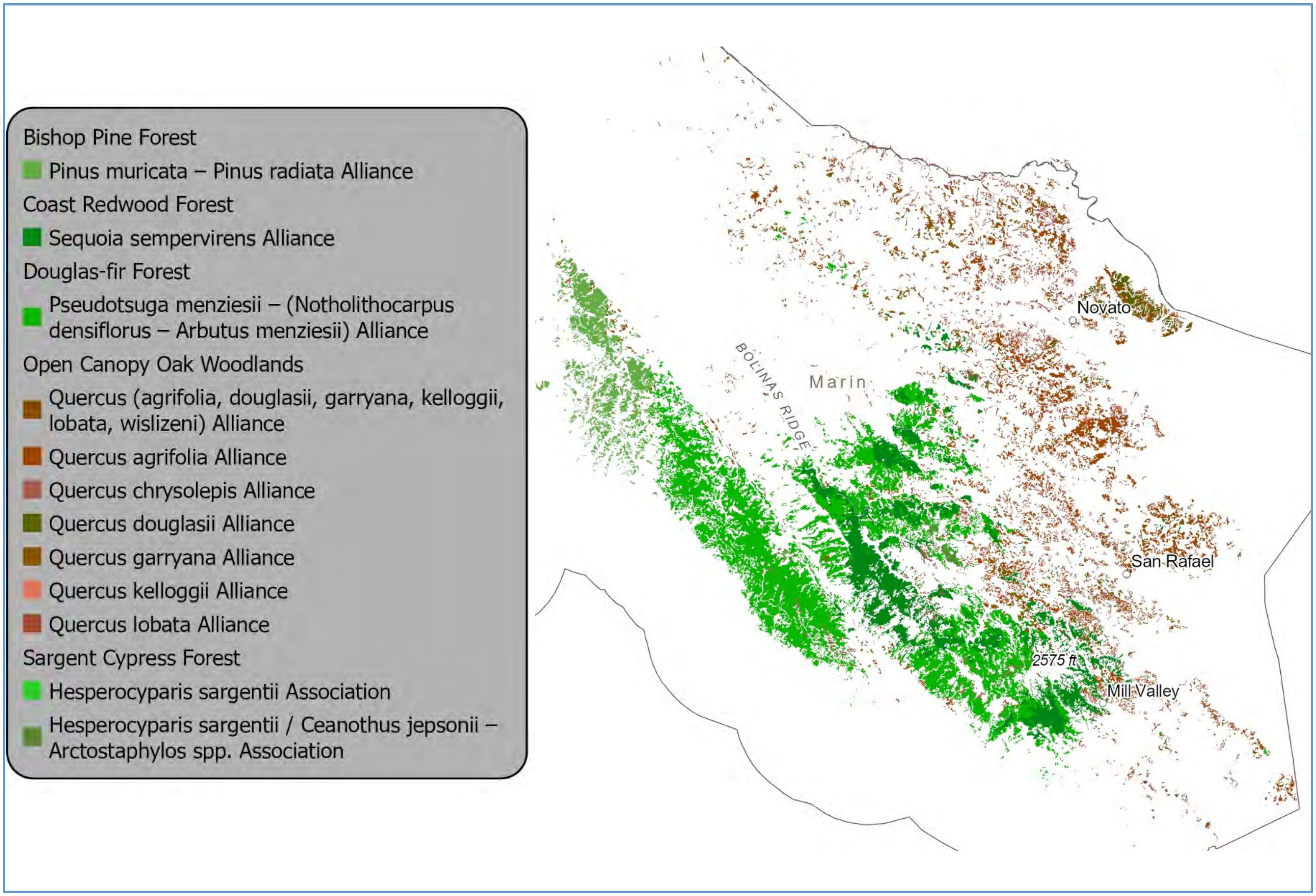
Heather Blair	Senior Project Manager	Ascent Environmental
Julia Murphy	Geospatial Analyst	Tukman Geospatial
Kass Green	Principal	Kass Green & Associates
Lara Rachowicz	Senior Ecologist, Project Manager	Ascent Environmental
Mark Tukman	Principal	Tukman Geospatial
Vance Russell	Principal	VR Conservation Collective

KEY FOREST TYPES

Due to constraints including time, budget, and available data, the Working Group determined that the *Forest Health Strategy* should focus on examining conditions for five key forest and woodland types in Marin County: Bishop Pine, Coast Redwood, Douglas-fir, Open Canopy Oak Woodlands, and Sargent Cypress. Note that key forest types are capitalized throughout the *Forest Health Strategy*. The five forest types were chosen by the Working Group for two reasons: 1) concerns about stand health and resiliency due to threats such as an altered fire regime, disease, and climate change; and 2) the important ecosystem services provided by these forest ecosystems, such as biodiversity, habitat, carbon sequestration, cultural values, and others.

The 2018 Fine Scale Vegetation Map, which depicted forest communities to the alliance or association level of the USNVC, was used as the basic unit of analysis for the *Forest Health Strategy*. Consequently, there are twelve fine scale map classes that correspond to the five key forest types profiled in the strategy (Figure 1.3). Of the 117,858 acres of native forests depicted in the 2018 Fine Scale Vegetation Map, 54% (63,279 acres) are included in the five key forest types profiled in the *Forest Health Strategy*. Recognizing that other forest types present in Marin County have important ecological, cultural, and recreational value, spatial datasets generated as part of the *Forest Health Strategy* were developed to include all native forest types wherever possible.

Figure 1.3. Five key forest types assessed as part of the Forest Health Strategy and corresponding 2018 Fine Scale Vegetation Map classes.

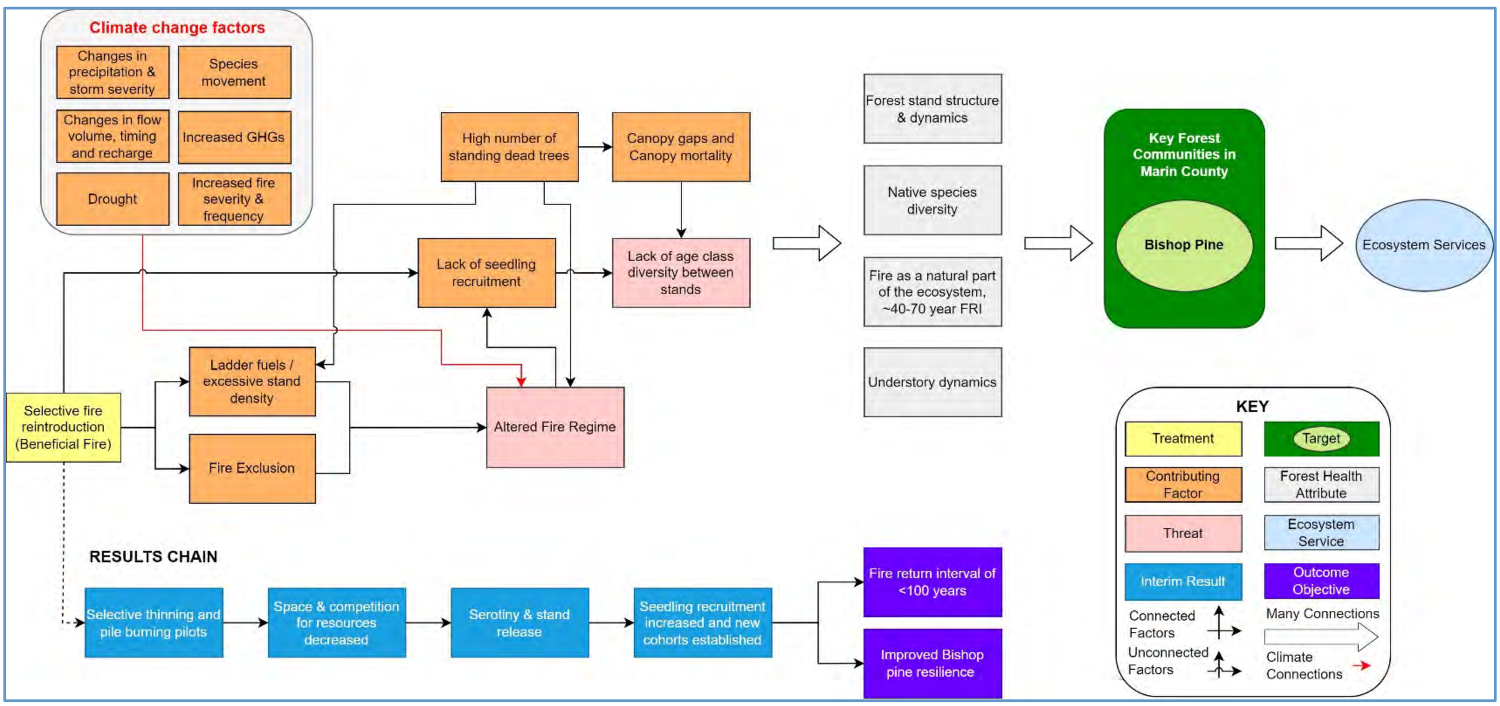


CONCEPTUAL MODELS & RESULTS CHAINS

The first step toward creating goals for each forest type in the *Forest Health Strategy* was to develop a collective understanding of their ecological function using conceptual models. These conceptual models were foundational for illustrating the interconnected pathways of forest ecosystem function, depicting healthy attributes of forest communities, threats to forest resilience, and potential metrics that analysts and land managers could use to assess forest conditions (Conservation Measures Partnership, 2020). The conceptual models show connections between ecosystem services, forest health attributes, threats to forest health, and treatments to reduce threats, thereby increasing forest resilience. The Working Group developed results chains from the conceptual models to illustrate the specific pathway associated with each forest health attribute, threat or contributing factor, and identify treatments or actions to address threat impacts.

Although a simplification of each forest ecosystem, the box-and-arrow diagrams of the conceptual model helped the Working Group acknowledge assumptions related to ecosystem function, identify threats to forest health, and consider management approaches. For example, a simplified conceptual model for Bishop Pine shows four forest health attributes affected by an altered fire regime and lack of age class diversity among stands (Figure 1.4). As the diagram shows, these threats are influenced by several contributing factors such as climate change, fire suppression, and lack of seedling recruitment. The intervention to address these threats is selective fire reintroduction. The associated results chain shows how the intervention and successive interim results lead to outcome objectives tied to improved forest health and resilience. For more details and to see the full conceptual model diagrams, results chains, and goals for each key forest type see Chapter 5: Goals.

Figure 1.4. Simplified conceptual model and results chain for Bishop Pine. This example illustrates how these diagrams were used by the Forest Health Working Group to develop Forest Health Strategy components.



GOALS FOR KEY FOREST TYPES

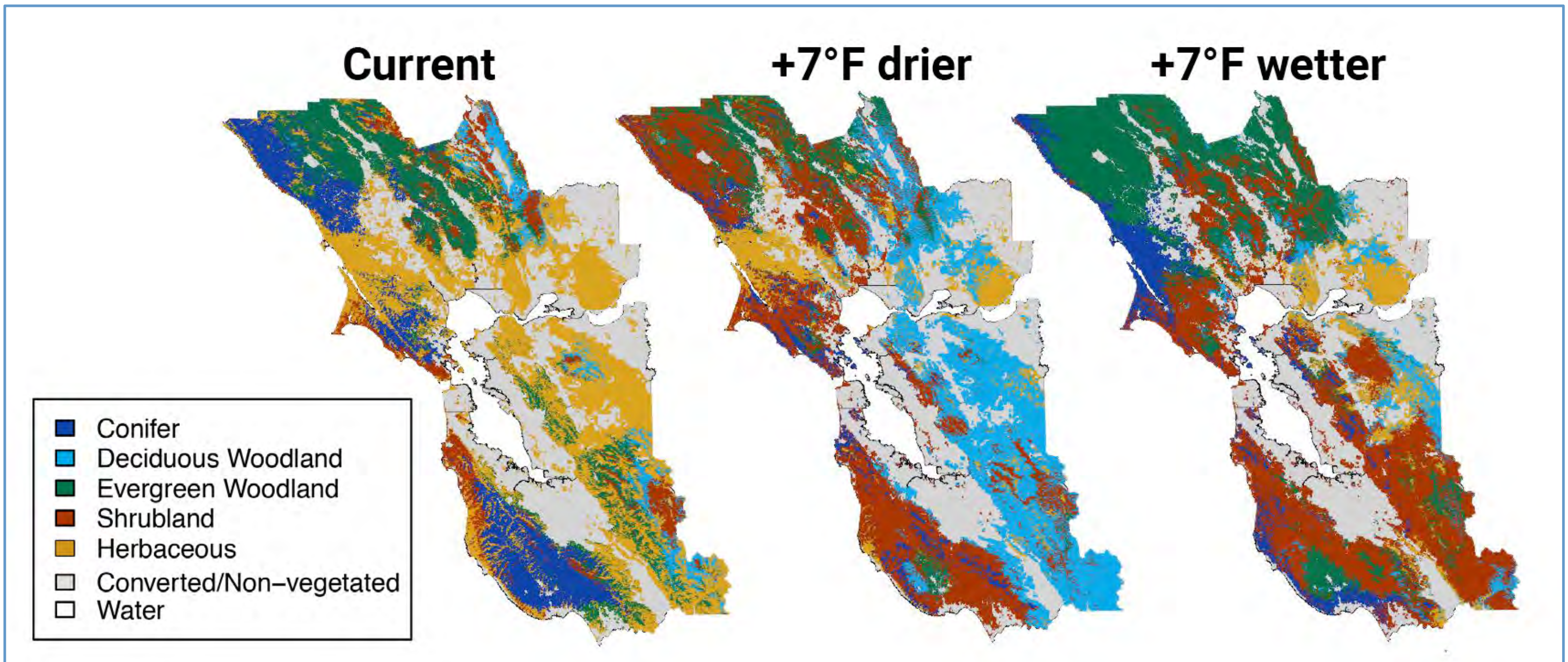
The conceptual models and results chains helped articulate landscape-level goals for each forest type which focus on retaining each key forest community as a part of the mosaic of forest types in Marin County, protecting or enhancing ecosystem services provided by each forest type, and addressing threats to forest resilience (see Chapter 2: Resilience). Goals are accompanied by potential treatments or management actions, which are mapped in results chains, each showing an expected interim results and condition goals. The condition goals will jointly contribute to reaching the landscape-level goals through various management methods. Goals sections for each key forest type includes a discussion of life history, distribution, and description of threats (see Chapter 5: Goals).

CLIMATE CHANGE CONSIDERATIONS

The changing climate will affect the five key forest communities in the *Forest Health Strategy* in myriad complex ways which are difficult to capture in the conceptual models. Climate change impacts are therefore discussed in detail in Chapter 4: Climate Change and Other Forest Health Stressors.

By the end of the 21st century, average temperatures in the Bay Area will likely rise by 1.7 to 2.2 degrees Celsius, possibly as much as 4.4 degrees Celsius, depending on the future greenhouse gas emissions trajectory (Micheli et al., 2016). Vegetation may become increasingly incompatible with extremes of heat and drought (Ackerly et al., 2015; Chornesky et al., 2015). The Bay Area's future climate could be less suitable for evergreen conifer forests, such as Coast Redwood and Douglas-fir, and more favorable for hotter and drier-adapted vegetation such as chaparral and grasslands (Figure 1.5).

Figure 1.4. Current vs. predicted vegetation types for the bay area modeled using temperature (winter min, summer max), annual precipitation, and climatic water deficit predictions under +7° F drier and wetter climate models (Ackerly et al., 2015; Chornesky et al., 2015).



Vegetation exposure to climate change is complex and influenced by multiple local factors. The Golden Gate Biosphere Network (GGBN) is currently working with EcoAdapt, Pepperwood Preserve, and others to conduct a climate vulnerability assessment for 10 ecosystems and 12 species, the outcome of which will be similar to analysis completed by the Santa Cruz Mountains Stewardship Network (EcoAdapt 2021) (Table 1.2). This assessment will analyze climate exposure and vulnerability of forests in Marin County and will be a helpful resource for Marin land managers.

The effects of climate change will vary depending on which of the likely climate change scenarios ultimately occurs. Thorne et al. (2016, 2017) modeled potential climate change impacts to landscape-scale natural vegetation in California using two climate models and two emissions levels (RCP 4.5 and 8.5) and provided additional local insight into future climate change impacts. They found that Central Western California's vegetation (including the Bay Area) experienced the least impact within the state, with 16% climatically exposed (stressed by changing climate conditions) by end-of-century under wetter scenarios and 19% climatically exposed under drier scenarios. Since this area is relatively less climatically exposed than other areas in California it may offer opportunities to protect climate refugia.

Table 1.2. Golden Gate Biosphere Network (GGBN) Climate Vulnerability Assessment focal ecosystems and species (EcoAdapt, 2022).

Focal Ecosystems	Focal Species
Coast redwood forests	Belted kingfisher
Coastal dunes	California black oak
Coastal prairie	California red-legged frog
Coastal scrub	Coho salmon and steelhead trout
Freshwater marshes	Mission blue butterfly
Maritime chapparal	Mountain lion
Mixed evergreen forests	San Bruno elfin butterfly
Open oak woodlands/savanna	San Francisco common yellowthroat
Riparian forests/woodlands	Sanderlings
Tidal Marshes	Serpentine endemic rare plants
	Western leatherwood

The long-term resilience of Marin County's forest ecosystems is linked to which climate change scenario occurs; for example, whether the future brings hotter-wetter or hotter-drier conditions is likely to be an important factor in forest climate exposure and refugia. For species such as coast redwood (*Sequoia sempervirens*), climate impacts may vary along north-south geographic distribution lines (Fernández et al., 2015). Coast redwood can derive 30-40% or more of total water input from fog and low cloud cover during the dry season, and reductions in fog frequency, particularly in the summer, could lower the species' resilience, especially if precipitation also declines in the future (Johnstone & Dawson, 2010; Limm et al., 2009; Torregrosa et al., 2020). However, coast redwoods, particularly in the northern part of their range, are currently growing at faster than expected rates and playing an important role in climate mitigation despite their limited geographic distribution (Sillett & Van Pelt, 2007). Long-lived trees like coast redwood may not be able to reach equilibrium with new climate conditions quickly enough to keep up with the pace of the changing climate, and, due to climate vegetation mismatch, may be vulnerable to vegetation transition in the event of a disturbance (Ackerly et al., 2015; Hill et al., 2023).

Climate change is already increasing the frequency and severity of fires, which result in carbon emissions. Forest management, including use of beneficial fire, may reduce long-term carbon loss and help accelerate carbon sequestration by moving towards larger, more mature, and more fire-resilient forest stands (Volkova et al., 2021, Bedsworth et al., 2018). Coast Redwood forests are projected to be relatively resilient to fire, even in high-fire severity regimes (Simler et al., 2018). A study of canopy burn severity and level of epicormic regeneration following the 2020 CZU Lightning Complex Fire is currently underway in Santa Cruz and San Mateo counties, and results could help managers understand how pre-fire landcover variables and treatments may influence Coast Redwood forest resilience to high-severity wildfire (San Mateo Resource Conservation District et al., 2022). Sonoma County Agricultural Preservation and Open Space District conducted a similar study after the 2017 Sonoma Complex Fire, which helped managers by identifying pre-fire landcover variables more frequently associated with woody canopy damage (Green et al., 2020)

Protecting substantial areas of habitat for wildlife, such as on Marin County's public lands, will be critical to implementing climate-wise corridors for species movement and climate change adaptation (Bedsworth et al., 2018). As climate change impacts manifest, It is crucial to the health and wellbeing of Coast Miwok and Southern Pomo peoples that climate change response strategies and actions in the culturally affiliated lands of the Tribe are made in collaboration with the Tribe so that Indigenous interests, rights, and responsibilities are accounted for. Traditional Ecological Knowledge, including using fire as an adaptation tool and managing forest species, will be another vital component of climate change adaptation (Goode et al., 2018; see Chapter 3: Stewardship and Partnership with the Federated Indians of Graton Rancheria).

FOREST HEALTH METRICS & ASSESSMENT

One of the goals for the *Forest Health Strategy* was to support managers in assessing forest health and prioritizing locations for different types of management actions or treatments. Assessing the health of a forest is a complicated process as health cannot be measured directly and there are many related factors involved. The *2016 Peak Health Report* (Edson et al., 2016) used metrics to assess the health of natural communities, and was used as a starting point for the *Forest Health Strategy*. Metrics are measurable data points which can be used to represent different components of forest health; forest health metrics were developed to locate and measure specific attributes related to forest structure, ecological health, and ecosystem function for the five target forest types. See Chapter 6: Metrics for more information. All of the metric information was developed as part of the *Forest Health Strategy* and is available to explore via the Forest Health Web Map and 2018 Marin Countywide Fine Scale Vegetation Map.

Metrics analysis was used to better understand forest conditions in Marin County. The outcome of metrics analysis is presented in Chapter 7: Condition Assessment. The Forest Condition Assessment highlights broad trends and patterns across the five key forest types by acres and distribution, diversity, stand structure, canopy mortality, and fire history dynamics. It also establishes baseline conditions which can serve as the foundation for future assessments. The Forest Condition Assessment is the foundation for identifying potential treatment areas described in Chapter 8: Prioritization Framework and Implementation Analysis.

STRUCTURE & CONTENT OF THE *FOREST HEALTH STRATEGY*

The *Forest Health Strategy* is divided into 10 chapters, some with associated appendices (Table 1.3). A list of references cited is included at the end of each chapter, except for Chapter 5: Goals, which list references at the end of each key forest type section, and Chapter 9: Treatment Descriptions, which lists references after each treatment type. There are several appendices to the Forest Health Strategy which provide important background information for forest health assessment, treatment implementation, and recommendations for future study.

Table 1.3. Forest Health Strategy chapters and appendices, with purpose and notes where applicable.

Chapter Number/Name	Purpose	Notes
1: Introduction	Overview of *Forest Health Strategy* with summary of purpose, key findings, and recommendations.	
2: Resilience	Provides a shared definition of resilience used to develop *Forest Health Strategy* goals and recommendations, summarizes existing literature and relevant case studies.	
3: Stewardship and Partnership with the Federated Indians of Graton Rancheria	Synopsis of historical context for Federated Indians of Graton Ranchera affiliation to Marin County, background on Native American stewardship in regional forests, overview of impacts from colonialism, and recommendations for stronger partnership between the Tribe and Marin's land managers.	Written by Dr. Peter Nelson, Coast Miwok and Tribal Citizen of Federated Indians of Graton Rancheria, and Assistant Professor, UC Berkeley
4: Climate Change and other Forest Health Stressors	Review of stressors threatening the health and resilience of forest ecosystems in Marin County including climate change, altered fire regimes, recreation, and pathogens.	
5: Goals	Discussion of goals for each of the five key forest types. Includes life history summaries, notes on distribution, fire	

	regime, unique threats to forest resilience, conceptual models of ecosystem function, and results chains for various treatment approaches.	
6: Metrics	Detailed description of individual metrics developed for modelling forest conditions and the methods and foundational data used to create them. Includes description of the geospatial data used to develop modelled geographic information system (GIS) products depicting forest conditions in Marin County.	Includes: Appendix 6A: 2018 Marin Countywide Fine Scale Vegetation Map Attribute Table Appendix 6B: One Tam Forest Health Web Map Layers, Service Endpoints, and Sources with Links to Download/Access GIS Data Appendix 6C: 2018 Marin Countywide Fine Scale Vegetation Map Crosswalk to CDFW Sensitive Natural Communities Ranking
7: Condition Assessment	Evaluates and summarizes the conditions of the five key forest types, establishes baseline data which can serve as the foundation for future assessments and to monitor the efficacy of management actions. Provides current status of key forest types used to develop multi-benefit treatment opportunities described in Chapter 8.	Includes: Appendix 7A: Forest Health Strategy Target Forest Type Acres and Distribution Amongst Public Land Management Agencies
8: Prioritization Framework and Implementation Analysis	Defines multi-benefit treatments, provides a framework and spatial tools for identifying opportunities to restore or enhance ecological health and resilience in forested areas, and considers both wildfire hazard and proximity to community, where applicable. Results of this analysis are presented as areas that can be prioritized as a potential multi-benefit treatment location for each One Tam land managing agency.	Includes: Appendix 8A: Potrero Meadows Fuel Model Changes Appendix 8B: Review of the 2020 Marin County 5m Fuel Model
9: Treatment Descriptions	Discussion of treatment approaches: forest thinning, biomass management, beneficial fire, restoration, fuel breaks, and pest and pathogen management. Includes expected benefits and considerations including access, costs, resource impacts, and suggested post-treatment monitoring.	

10: Monitoring	Outlines recommended field-based and geospatial monitoring approaches for forest resiliency treatments and change detection over time, a necessary component for adaptive management and learning.	Includes: Appendix 10A: CDFW-CNPS Post-Fire Rapid Assessment/ Relevé Protocol and Field Form
Appendix A: Bishop Pine	Includes: *Bishop Pine Forest Health White Paper* (Harvey & Agne, 2021) and *Bishop Pine Forest Health and Pitch Canker Disease Field Study on Point Reyes Peninsula, CA* (Harvey et al., 2022).	
Appendix B: Wildfire History	*Marin County Wildfire History Mapping Project* (Dawson, 2021). Dawson documented historical fires over a longer period and to a higher degree of geographical and temporal precision than in previous fire mapping projects in Marin County, and used GIS to map all fires in Marin between 1859 and 2020 which were greater than 160 acres in size.	
Appendix C: Regulatory Compliance	Regulatory compliance guidance to aid in planning and implementation of forest health projects.	
Appendix D: Example Pre-Generated Watershed Report	One example of a pre-generated Forest Health Watershed Report from the Marin Forest Health Watershed Report Downloader	
Appendix E: Opportunities for Additional Study	Describes several areas for additional study to support planning and management to improve forest health, identified during development of the *Forest Health Strategy*.	

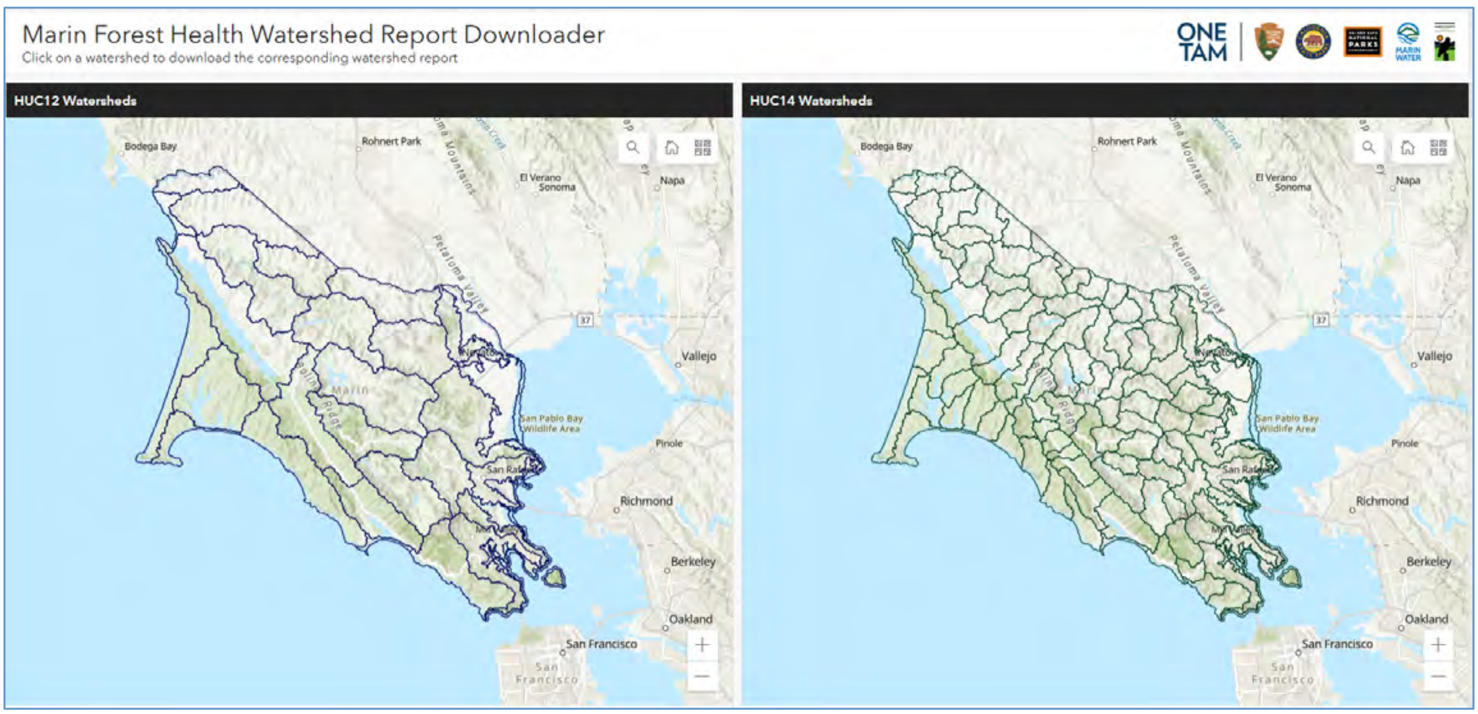
FOREST HEALTH WEB MAP

The *Forest Health Strategy* both relied on and developed multiple geographic information system (GIS) databases to facilitate evaluation of the distribution, composition, and conditions of forests in Marin County on a landscape scale. The foundational database used in these analyses is the 2018 Fine Scale Vegetation Map, and in many cases additional attributes were developed and added to the 2018 Fine Scale Vegetation Map dataset to further characterize forest stand conditions and structure, to quantify impacts from stressors where applicable, and to develop a prioritization framework for multi-benefit treatments. Methods used to create layers from the fine scale vegetation map and other data sources are described in Chapter 6: Metrics. All GIS databases used in the different aspects of the *Forest Health Strategy*, including data used in Chapter 7: Condition Assessment and Chapter 8: Prioritization Framework and Implementation Analysis, are compiled and accessible online via the Forest Health Web Map.

FOREST HEALTH WATERSHED REPORTS

To support landscape-scale planning and analysis, reports summarizing forest health metrics and other landcover variables for each of Marin's HUC-12 and HUC-14 watersheds were developed. These pre-generated watershed-scale reports, which include maps, statistics, and summary tables of data relevant to forest conditions, are sized to 11"x17" in order to be compatible with standard printers. They are available via the online Marin Forest Health Watershed Report Downloader. Metrics and maps provided in each watershed report include fire history, forest structure, vegetation communities, topography, hydrology, invasive species, rare plants, treatment feasibility, and other useful information. See Appendix D: Example Pre-generated Watershed Report for an example.

Figure 1.6. Marin Forest Health Watershed Report Downloader Tool, developed for the Forest Health Strategy.



FOREST CONDITION ASSESSMENT KEY FINDINGS & HIGHLIGHTS

Broad trends and patterns across all five key forest types assessed in the *Forest Health Strategy* are summarized in this section by distribution, fire exclusion, mortality, and non-native invasive species. The Forest Condition Assessment highlights the diverse mosaic of forest types in Marin and provides insight into areas where stressors such as fire exclusion, pathogens, and climate change are having measurable impacts on forest health and resilience. A more detailed discussion is presented in Chapter 7: Condition Assessment.

DISTRIBUTION

According to data provided by the 2018 Fine Scale Vegetation Map, native forests are the predominant vegetation community in Marin, accounting for 32% (almost 118,000 acres) of total landcover in the county. This includes roughly 66,890 acres of evergreen hardwood forests such as California bay (*Umbellularia californica*) and coast live oak (*Quercus agrifolia*) woodland, 43,064 acres of conifer forests dominated by Douglas-fir (*Pseudotsuga menziesii*) and coast redwood, approximately 6,014 acres of deciduous hardwood forest such as valley oak (*Quercus lobata*) and Oregon white oak (*Q. garryana*) woodlands, and 2.908 acres of riparian forest types such as big leaf maple (*Acer macrophyllum*) and red alder (*Alnus rubra*). Protected open space land managers in Marin collectively care for 64,033 acres of all native forests in the county, or 54% of all forested lands. Management of the key forests and woodland communities analyzed in the *Forest Health Strategy* is summarized in Table 1.4 and explored in greater detail in Chapter 7: Condition Assessment. The distribution of key forest types, and the extent to which they are managed by a given agency, influences where opportunities to conserve and increase forest resilience exist. The importance of distribution is represented in discussions of treatment opportunities in Chapter 8: Prioritization Framework and Implementation Analysis.

Table 1.2. Number of acres managed and percent of total acres in Marin County by agency for key forest types.

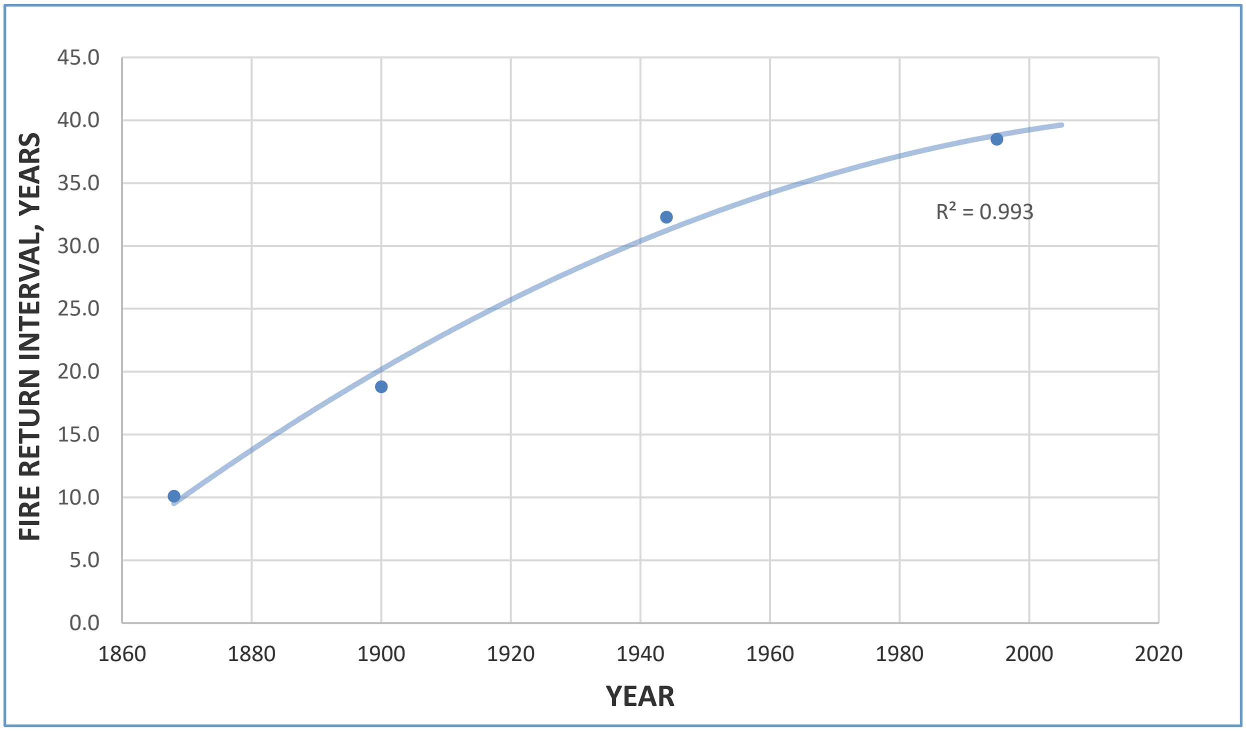
Agency	Bishop Pine	Coast Redwood	Douglas-fir	Open Canopy Oak Woodlands	Sargent Cypress
California State Parks – Bay Area District	922 (19.7%)	952 (8.5%)	3,075 (11.7%)	1,013 (4.9%)	0.6 (0.1%)
Marin County Parks	6 (0.1%)	850 (7.6%)	866 (3%)	3,154 (15.3%)	117 (25.8%)
Marin Water	31 (0.7%)	4,108 (36.5%)	3,968 (15%)	1,473 (7.1%)	331 (73.4%)
NPS – GGNRA	0	442 (4%)	793 (3%)	165 (0.8%)	0
NPS – GGNRA Northern District (PRNS managed)	24.15 (0.5%)	1,361 (12%)	1,878 (7%)	176 (0.9%)	0
NPS – PRNS	3,090 (66%)	58 (0.5%)	10,148 (38.7%)	272 (1.3%)	0
Other protected lands	78 (1.7%)	371 (3%)	395 (1.5%)	1,322 (6.4%)	0
Total Protected Acres in Marin	**4,152 (89%)**	**8,142 (72%)**	**21,123 (80%)**	**7,575 (37%)**	**451 (99%)**

FIRE EXCLUSION

The term fire exclusion includes both modern fire suppression and the interruption of Tribal stewardship with fire due to colonization (see Chapter 3: Stewardship and Partnership with the Federated Indians of Graton Rancheria). Many plant species in Marin County, including Sargent cypress and Bishop pine, are adapted to disturbance regimes such as fire, and in some cases are dependent on these processes for regeneration (Hessburg et al., 2021, Long, 2009, Sawyer et al., 2009). Thus, development and examination of fire history spatial data was an important component of the *Forest Health Strategy* and used extensively as a metric for assessing forest conditions and identifying areas that may benefit from active management, including the use of beneficial fire (see the *Marin County Wildfire History Mapping Project* (Dawson, 2021), Appendix B: Wildfire History). It should be noted that fire history analysis was limited to fires greater than or equal to 160 acres between 1852-2020, the period during which Euro-American record-keeping began, and therefore provides limited evidence of the fire frequency and spatial patterning maintained through cultural burning by Native peoples or prescribed fire used by early ranchers. For additional information on the limitations of these kinds of ecological studies and our knowledge of fire histories, especially as it relates to Native American peoples, see the work of Frank Lake (2013).

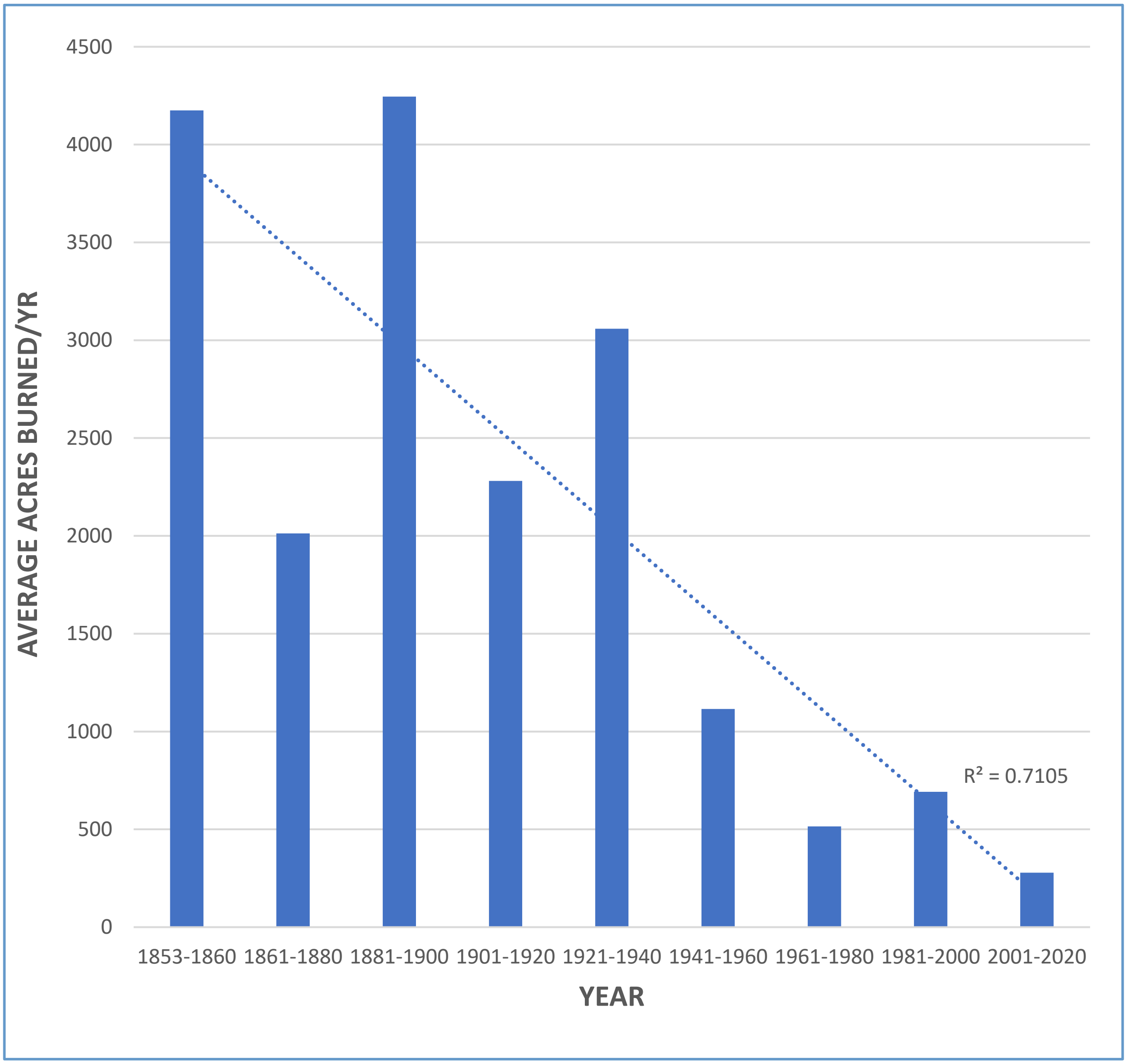
The overall trend in Marin County is one of increasing fire return intervals and decreasing wildfire extent (Dawson, 2021, p. 13). Fire return intervals increased dramatically between 1860 and the 1990s, rising from approximately 10 years to more than 38 years (Figure 1.7) (Dawson, 2021). Concurrently, the average acres burned per year has significantly decreased, falling from on average 1% of the total county area between 1852 and 1900 to just 0.1% since 1960 (Figure 1.8) (Dawson, 2021). These trends were reinforced significantly beginning in the

Figure 1.7. Average fire return intervals in Marin County using mid-points of early & later pre-CAL FIRE, and early & recent CAL FIRE eras: 1868, 1900, 1944, 1995 (Dawson 2021).



1940s when advances in equipment, the prevalence of lookouts, and widespread fire suppression rapidly increased in scope and scale. It should be noted that fire return intervals prior to colonization and Euro-American record-keeping were highly variable, and while some areas may have experienced fire more frequently as a result of Tribal cultural burning, return intervals of several hundred years have been documented, particularly in mesic areas. Therefore, management based solely on a departure from estimated mean or median historic fire return intervals may not be appropriate (Jones & Russell, 2015).

Figure 1.8. Average acres burned per year in Marin County in 20-year increments, 1852 – 2020.

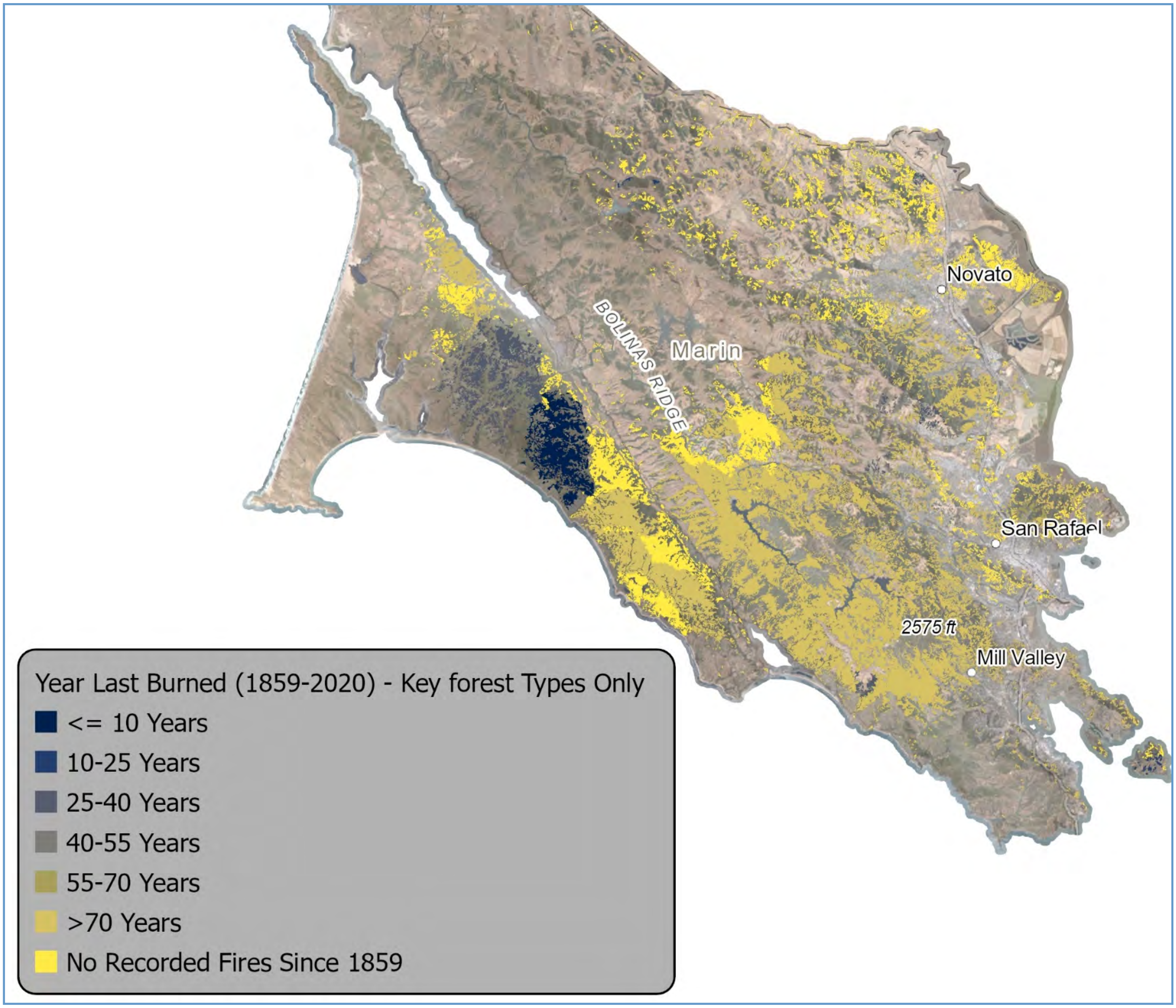


The impact of fire exclusion on Marin forest ecology is far reaching. Of the 63,279 acres of key forest and woodland types analyzed in the *Forest Health Strategy*, 27% (approximately 17,000 acres) have not experienced a wildfire[1] since 1859, and 62% (roughly 39,000 acres) have not burned in more than 70 years (Figure 1.9). The implications of these trends vary by forest type and are explored further in Chapter 7: Condition Assessment. Key findings include:

- The long-term resilience of serotinous conifer species, namely Bishop pine and Sargent cypress, is at risk due to lack of regeneration and seedling recruitment in the absence of fire. Currently there are no early seral stands of Sargent Cypress forest in Marin County, and very few (if any) early seral stands of Bishop Pine.[2]
- Fire exclusion produces changes in the fuel structure, forest structure, and floristic composition (e.g., shift to more shade-tolerant species) of Coast Redwood and Douglas-fir forests (Arno, 2000; Brown et al., 1999; Brown & Baxter, 2003; Lorimer et al., 2009; Norman et al., 2009; Ramage et al., 2010). Fire and other forms of disturbance are important drivers for structural and floristic heterogeneity. In the absence of fire Douglas-fir forest is expanding into grassland, shrubland, and oak woodland habitat and reducing biological diversity in these areas (Cocking et al., 2015; Hsu et al., 2012; Startin, 2022). Douglas-fir expansion coupled with fire exclusion is also threatening the persistence of rare chaparral species, including Mason's ceanothus (*Ceanothus masonii*) and Marin manzanita (*Arctostaphylos virgata*) (PRNS, 2004). Fire exclusion can also contribute to unnatural fuel arrangements, which may impact the resilience of Douglas-fir given its lower resistance to high-intensity wildfire compared to coast redwood trees (Lavender & Hermann, 2014; Metz et al., 2017). It should be noted that research into recent wildfires in California indicates that weather plays an important role in the destructive potential of wildfires (Keeley & Syphard, 2019; Syphard & Keeley, 2019).
- Fire exclusion is impacting the resilience of Open Canopy Oak Woodlands by facilitating conifer encroachment and type conversion. Of the 20,649 acres of Open Canopy Oak Woodlands in Marin, 7% (approx. 1,450 acres) are actively converting to conifer forest (most likely Douglas-fir), and an additional 39% (roughly 8,000 acres) are threatened with conifer conversion. The altered fire regime in Marin, which includes the prevention of Tribal stewardship of this important Tribal Cultural Resource (see Chapter 3: Stewardship and Partnership with the Federated Indians of Graton Rancheria), is likely also impacting fecundity and seedling recruitment in at least some Open Canopy Oak Woodlands.

[1] Spatial analysis performed as part of the Marin County Wildfire History Mapping Project was limited to fires greater than or equal to 160 acres. See Appendix B: Wildfire History for additional detail.
[2] Monitoring of effects from the 2020 Woodward Fire (NPS, 2021) on Point Reyes National Seashore ecosystems is ongoing. It remains to be seen if new stands of Bishop pine emerge in the impacted area.

Figure 1.9. Classified time since last fire for key forest and woodland types in Marin County analyzed in the Forest Health Strategy. See Appendix B: Wildfire History for additional details. Fire history spatial data can be explored via the [Forest Health Web Map.](#)



MORTALITY & OTHER PATHOGEN IMPACTS

The *Forest Health Strategy* developed metrics useful for locating and assessing pathogen impacts in Marin's forests at landscape scale. This analysis built on previous methods used by Aerial Information Systems (AIS) and Marin Water in response to widespread impacts from *Phytophthora ramorum*, the introduced pathogen that causes sudden oak death (SOD), first documented in the United States on Marin Municipal Water District and California State Park lands in Marin County in 1995 (Garbelotto & Rizzo, 2005). Vegetation mapping completed by AIS in 2004 and 2009 tracked the rapid spread of the disease and related tree mortality on Tamalpais Watershed lands, and the 2014 update found that over 90% of oak woodlands within the study area were affected by the disease along with 84% percent of forested areas (AIS, 2015; Williams et al., 2020). For additional information on methods used to develop these metrics for the 2018 Fine Scale Vegetation Map and *Forest Health Strategy* see Chapter 6: Metrics. Results of mortality analysis are discussed in detail for each key forest type in Chapter 7: Conditions Assessment, key findings include:

- The vast majority (98,428 acres or almost 84%) of native forests in Marin County have no detectable mortality in the tree canopy; however, a substantial portion have trace to moderate canopy mortality (13,696 acres or 12%), with an additional 5,736 acres (5%) classified as having relatively high levels of canopy mortality in 2018. Areas with mapped concentrations of canopy mortality align with those known to be impacted by forest pathogens including *Phytophthora ramorum* and *Fusarium circinatum* (Figure 1.10). This analysis was limited to mortality detectable in the forest canopy, and thus likely underrepresents the extent of pathogen impacts in the understory, particularly in areas where resprouting sudden oak death-affected tanoaks (*Notholithocarpus densiflorus*) succumb to pathogen impacts before reaching the overstory. Canopy gap analysis was combined with mortality indices to further detect and characterize areas impacted by pathogens. See Chapter 6: Metrics for details.
- Native forested areas with concentrations of canopy mortality had relatively higher incidence of lidar-detected canopy gaps formed between 2010 and 2019. Forest areas with little to no canopy mortality had a relatively smaller percentage of gaps formed, compared to forests with elevated levels of canopy mortality which showed higher incidence of canopy gap formation (Figure 1.11). Taken together, canopy mortality and canopy gap metrics provide insight into locations where pathogen impacts may be more extensive, and further investigation or active management could be beneficial.
- Mortality and pathogen impacts were detected across all key forest types analyzed in the *Forest Health Strategy*, altering the structure and composition of the affected forests (Figure 1.12). While the species of affected trees is not discernible with the remote sensing methods used, it is reasonable to conclude that:
    - Mortality in Bishop Pine forests is related to impacts from pitch canker disease, caused by the pathogen *Fusarium circinatum,* and western gall rust, caused by the native pathogen *Endocronartium harknessii.* Mortality could also potentially be connected to tree senescence in late-seral stands or natural self-thinning in

mid-seral stands. Hardwood tree types susceptible to *Phytophthora ramorum*, such as tanoak or coast live oak could also be contributing to mapped mortality in mixed Bishop pine-hardwood stands.

- Canopy mortality in Coast Redwood and Douglas-fir forests is related to pathogen impacts to hardwood associates of these species. Pathogen-induced decline of common associates of coast redwood and Douglas-fir, such as tanoak and Pacific madrone (*Arbutus menziesii*), is well documented in Marin County; this assessment shows the extent to which *Phytophthora ramorum* is causing canopy mortality and altering the floristic composition and structure of these forests. *Phytophthora cinnamomi* has also been detected on Marin Water's Tamalpais Watershed lands and observed to cause hardwood tree species decline and mortality in some Douglas-fir and Coast Redwood forested areas. Pathogen impacts can contribute to unnatural fuel arrangements and may reduce wildfire resilience in Douglas-fir forests (Lavender & Hermann, 2014; Metz et al., 2017).
- Canopy mortality was mapped across all open canopy oak woodland types but was higher in stands dominated by species known to be affected by sudden oak death. *Phytophthora ramorum*, the pathogen that causes sudden oak death, is understood to impact several open canopy oak species including coast live oak, California black oak (*Q. kelloggii*), and canyon live oak (*Q. chrysolepis*), as well as hardwood associates of these species such as tanoak. (Garbelotto et al., 2003; Murphy & Rizzo, 2003, Rizzo et al., 2002, Buck-Diaz et al., 2021). Although sudden oak death is the most widespread and well-documented *Phytophthora*-linked oak disease in Marin County, mortality in these and other open canopy oak species could be caused by other species of *Phytophthora* (e.g., *P. cinnamomi*), other pathogens, pests, drought stress, or a combination of stressors.
- Factors contributing to mortality detected in Sargent Cypress forests could be decline of species other than Sargent cypress (*Hesperocyparis sargentii*), for example, Douglas-fir mortality due to nutrient-poor serpentine soils, but may also be an indication of decadence in older Sargent cypress trees.

Figure 1.5. Classified percent canopy mortality for all native forest stands in Marin County.

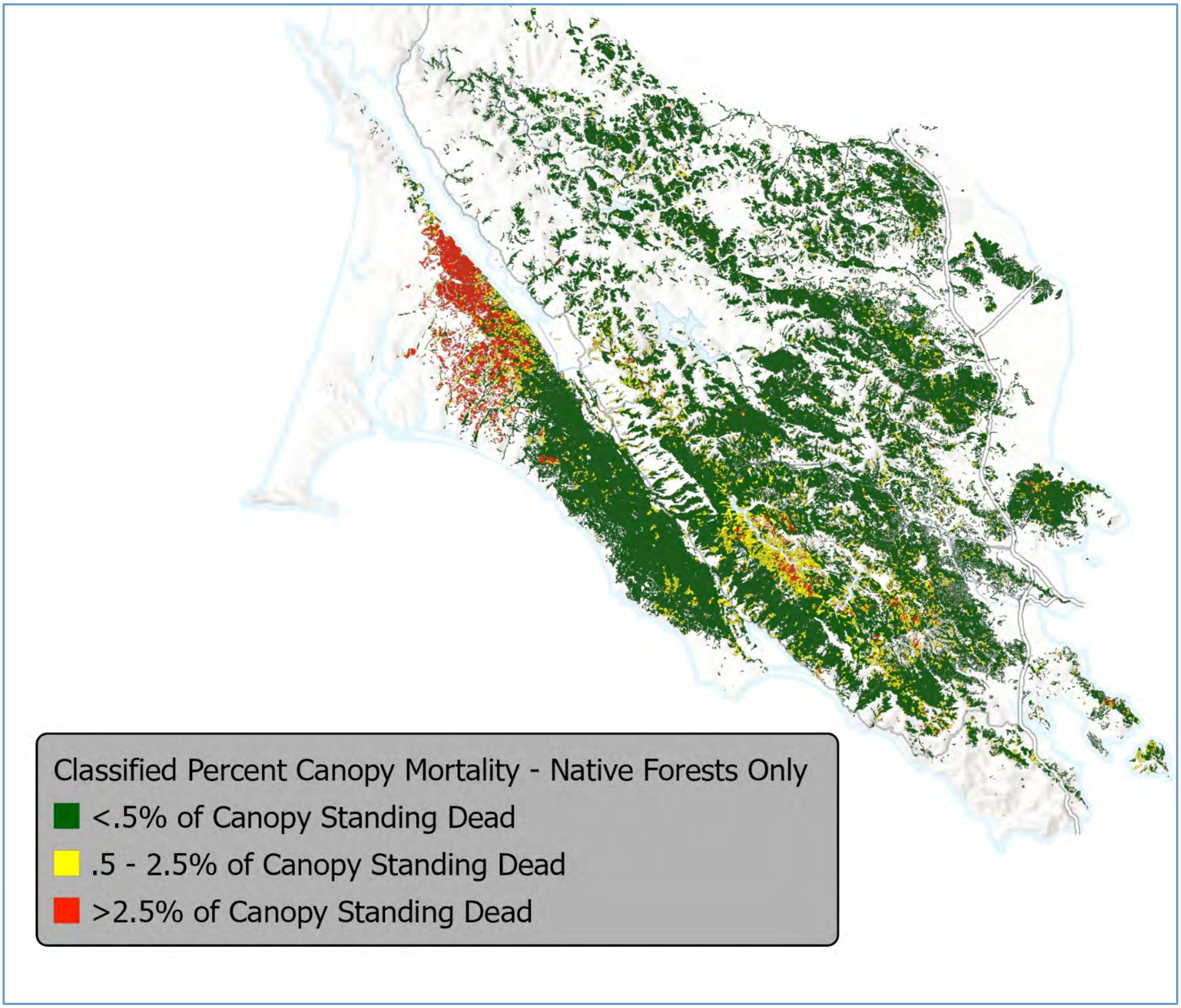


Figure 1.6. Classified percent canopy gaps formed between 2010 and 2019 for each percent canopy mortality (canopy standing dead) class, expressed as a percentage of the total acres in Marin County, for all native forest stands.

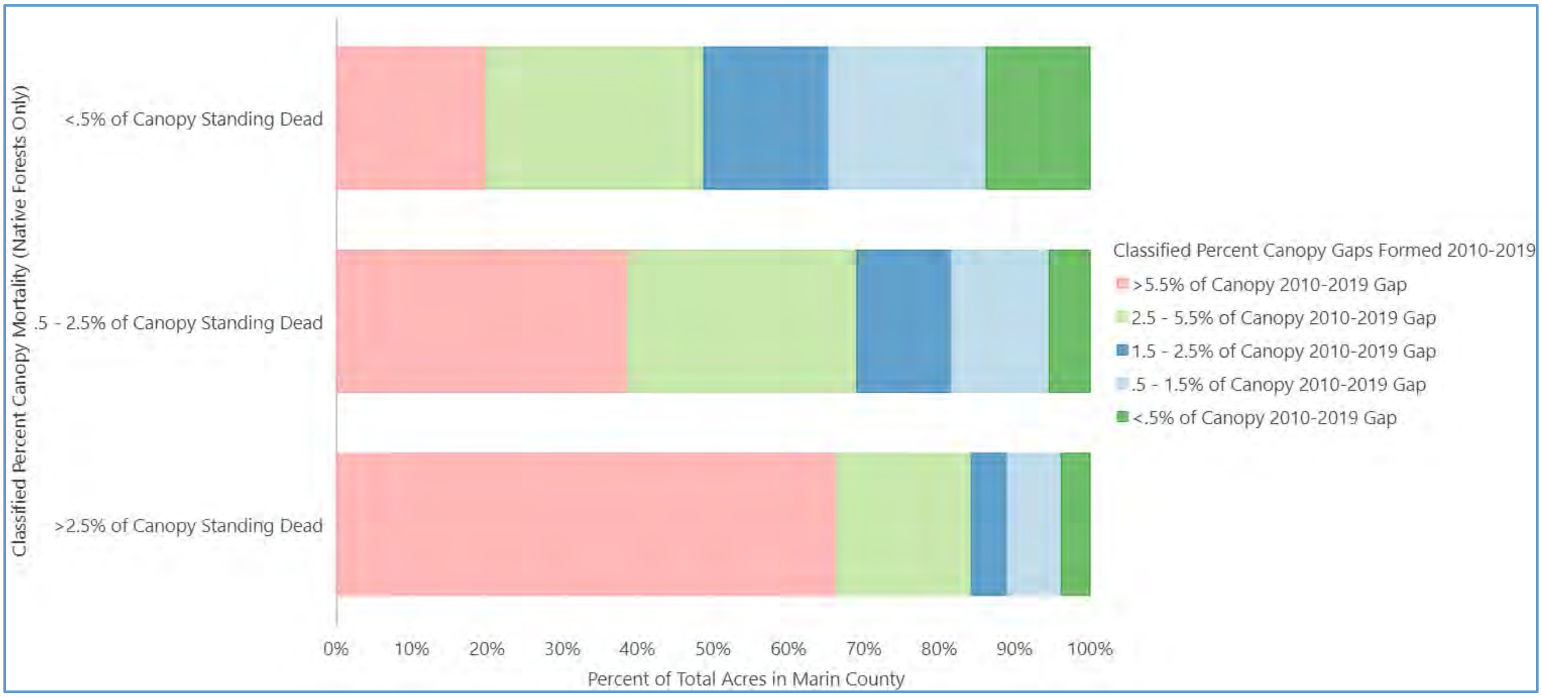
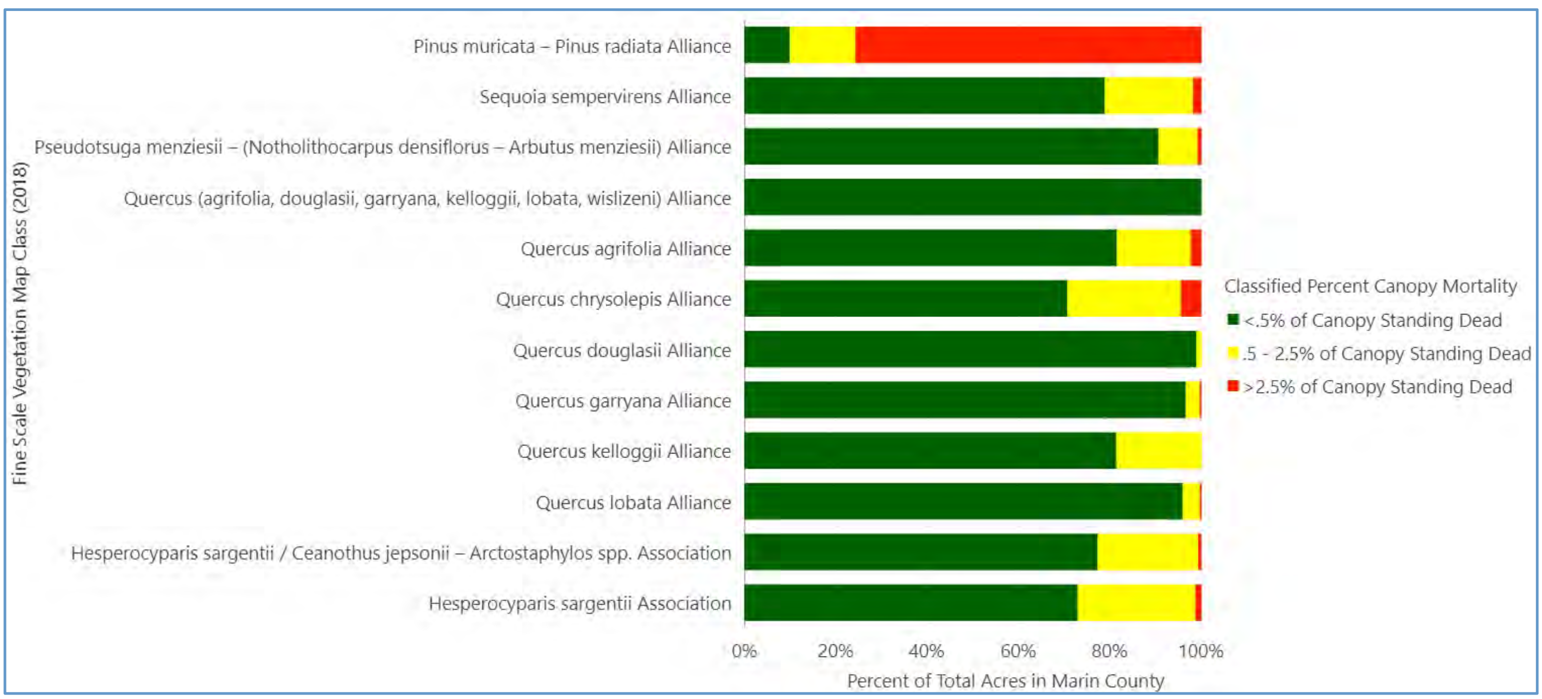


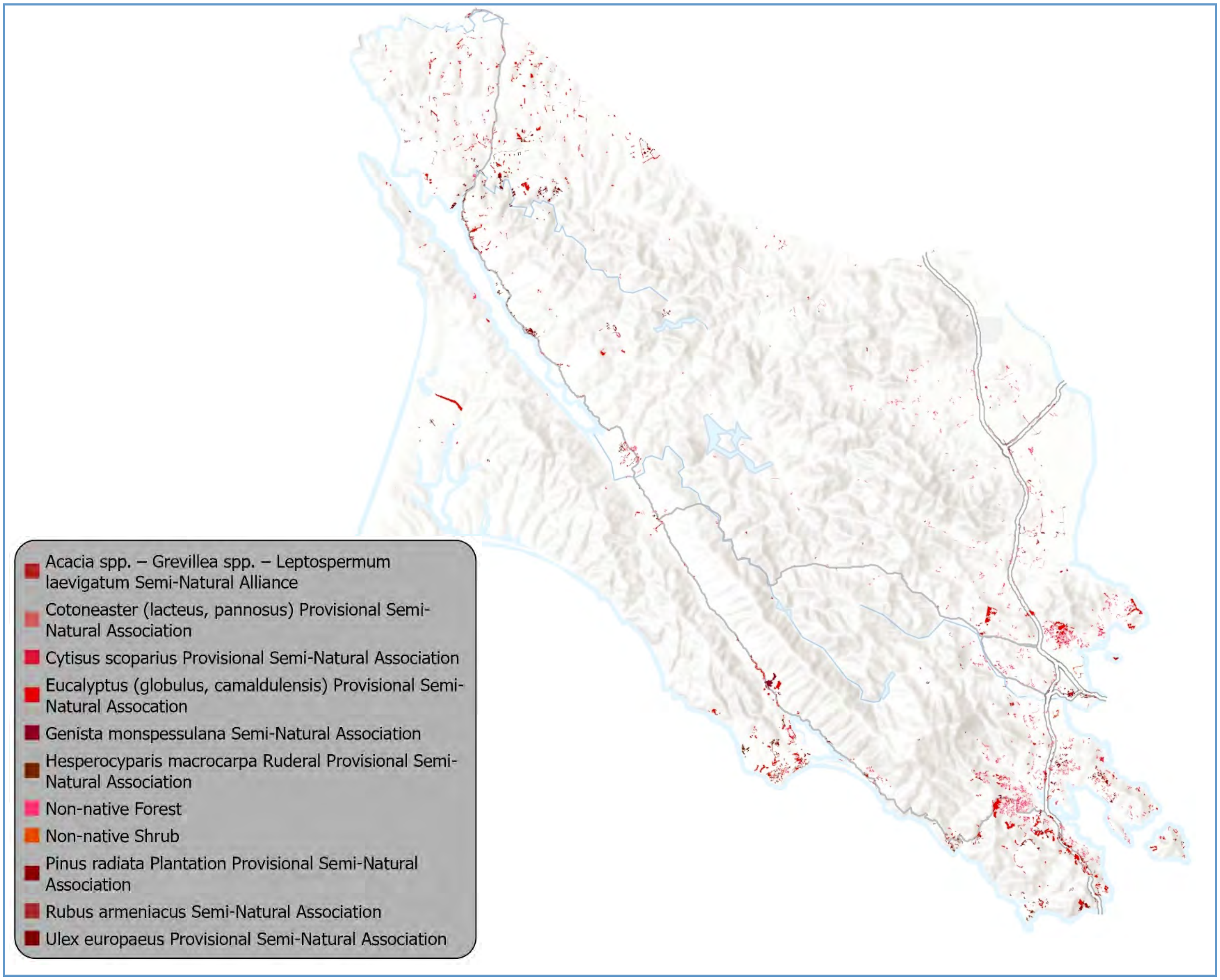
Figure 1.7. Classified percent canopy mortality (canopy standing dead) by 2018 Fine Scale Vegetation Map class, expressed as a percentage of the total acres in Marin County, key forest types only.



NON-NATIVE INVASIVE SPECIES

Insufficient data exists at the countywide scale to use presence or absence of non-native invasive species in the understory of forests as a metric for assessing forest health. Nevertheless, the 2018 Fine Scale Vegetation Map is a useful dataset for highlighting the distribution of non-native invasive trees and shrubs at landscape scale in Marin (Figure 1.13). The ability of non-native invasive species to reduce biological diversity and degrade habitat, coupled with evidence that some types, such as eucalyptus (NPS, 2006, Wolf & DiTomaso, 2016), can contribute to fuel conditions associated with hazardous wildfire behavior, makes a compelling case for active management to protect and increase forest resilience and ecological function, where feasible. These efforts would leverage ongoing work of the One Tam partners on invasive plant monitoring and management. See Chapter 8: Prioritization Framework and Implementation Analysis for additional discussion.

Figure 1.8. Stands of non-native invasive trees and shrubs, 2018 Fine Scale Vegetation Map.



PRIORITIZATION FRAMEWORK & MULTI-BENEFIT TREATMENT IMPLEMENTATION ANALYSIS

The One Tam partner agencies approach land management through the lens of stewardship and science. Thus, the prioritization framework advanced by the *Forest Health Strategy* centers on approaches to improving or conserving overall forest ecosystem health and resilience while also considering the potential benefit that treatments can have to other values, for example restoring cultural resources and practices as defined by the Tribe (see Chapter 3: Stewardship and Partnership with the Federated Indians of Graton Rancheria), improving or safeguarding wildlife habitat, protecting critical infrastructure, or enhancing community safety. For additional information on the prioritization process see Chapter 8: Prioritization Framework and Implementation Analysis. The spatial datasets and decision-support tools developed to assist One Tam partners in identifying opportunities to protect or improve ecological health and resilience in forested areas exist at the countywide scale and across jurisdictional boundaries, and are available via the Forest Health Web Map. These datasets could be useful to researchers, agencies, private landowners, and decision-makers seeking to advance forest resilience in Marin County, and include:

- **Departure from desired conditions index** useful for locating areas where fire exclusion, pathogen impacts, structural conditions, and non-native invasive species are impacting forest resilience.
- **Wildfire hazard index** that combines topography, wildland fuels, modeled wildfire behavior, extreme fire weather potential and other variables to assess the relative potential for hazardous wildfire in Marin.
- **Classified building density layers** to assist in identifying developed areas and number of structures per acre within a fixed distance.
- **Manual-mechanical feasibility raster** to assist managers within identifying areas that may be suitable for forestry management based on a series of constraints such as slope, access, and proximity to streams.

RECOMMENDATIONS & PROPOSED ACTIONS

Forests are naturally resilient ecosystems, and analysis conducted as part of the *Forest Health Strategy* underscores that the mosaic of forest types in Marin County is diverse, dynamic, and has persisted to this point despite the presence of multiple ecological stressors. However, the analysis also shows that impacts to forest health are measurable and widespread, with higher concentrations in some areas. Through the work of the *Forest Health Strategy*, One Tam partner agencies are uniquely positioned to advance projects and programs that will address the effects of these stressors on forest ecosystems. The *Forest Health Strategy* serves as a critical step forward for One Tam partners to work with Marin's other land managers, fire prevention agencies, the Tribe, and neighboring communities to protect and improve the health and resilience of Marin's forests. The *Forest Health Strategy* provides a scientific and data-driven decision-support tool to help focus future research, monitoring, and management efforts. Suggestions and ideas for forest resilience actions are presented in the following chapters of the *Forest Health Strategy*. Overall recommendations include:

- One Tam partners should partner with the Federated Indians of Graton Rancheria (the Tribe) to integrate Tribal knowledge and perspectives into the study, use, and management of forests, which are a significant Tribal Cultural Resources (TCRs). Engaging in dialogue with the Tribe and the Tribal Heritage Preservation Officer (THPO) and ensuring the Tribe has decision making authority in the development and implementation of projects and programs related to these TCRs is the best way to accomplish this.
- In addition to consultation and relationship building between agencies and the Tribe to establish and implement routine land management, agencies should also address issues of access and opportunity for the Tribe to engage with these lands for the betterment of the ecosystem and wellbeing of the Tribe, to include but not be limited to access for gathering of traditional plants and resources for cultural, medicinal, and subsistence uses (see Chapter 3: Stewardship and Partnership with the Federated Indians of Graton Rancheria, for additional discussion on these topics). This may include the implementation of Traditional Knowledge (TK), Traditional Ecological Knowledge (TEK), Indigenous science, co-stewardship, co-management, and other activities. Any Tribal cultural information or knowledge shared is the intellectual property and cultural patrimony of the Tribe, and care should be taken to ensure that the confidentiality of this information is maintained and protected.
- The Tribe's access and use of their traditional and culturally affiliated lands and waters should be expansive and continuous, not limited to the space of a single project or program. Envisioning and implementing these solutions for facilitating Tribal access, stewardship, and use of spaces in Marin County must be coordinated in consultation and collaboration with the Tribe. Some potential first steps toward facilitating access are as follows: Waive parking and entrance fees for the Tribe to access city, county, state, and federal parks, open space, and other lands and waters in Marin County. Remove bureaucratic/economic barriers that make it difficult for the Tribe to access and interact with their traditional and culturally affiliated lands and waters. Facilitate cross-agency collaborations and government-to-government consultations to establish agreements about fishing, hunting, gathering, burning, and building cultural and environmental spaces for the benefit of the Tribe and the ecosystem. The Tribe's access, stewardship, and use of these lands and waters are integral to the health of the environment and the health of the Tribe.
- The One Tam partners should continue to work together to advance opportunities to fundraise for, plan, develop, and implement projects and programs to increase forest health and resilience in Marin County. As outlined in the *Forest Health Strategy*, this includes partnering across jurisdictional boundaries and collaborating with the Marin Wildfire Prevention Authority and its member agencies to expand the use of beneficial fire in Marin County. See *California's Strategic Plan for Expanding the Use of Beneficial Fire* (California Wildfire and Forest Resilience Task Force, 2022).

- Where applicable, land managers should use demonstration projects and/or partner with researchers to evaluate treatment approaches and measure outcomes, which will help refine methods, determine best management practices, and support scaling-up treatment efforts. Coordinated countywide treatment tracking should be developed per the recommendations in Chapter 10: Monitoring.
- The results of the analysis performed, and foundational datasets generated by, the *Forest Health Strategy* should be shared widely with agencies, decision-makers, researchers, and consultants working to advance forestry work, fire prevention projects, and general vegetation management in Marin County, so these efforts can be shaped by the *Forest Health Strategy's* findings and, wherever possible, address threats to forest health and benefit the ecological resilience of forests. To this end, *Forest Health Strategy* documents are available on the One Tam website, and anyone can access spatial datasets via the One Tam Forest Health Web Map
- One Tam partners should continue to create and sustain community engagement to build broad awareness and support for forest health and resilience work. Working with existing programs such as the One Tam Community Stewardship Program, Youth Programs, and workshops and conferences such as the bi-annual One Tam science symposium, is a good avenue for ongoing community engagement.
- Additional and ongoing field-based assessments are necessary to develop comprehensive understanding of the dynamics surrounding forest health and resilience in Marin County. Data on factors that contribute to forest health, such as wildlife occupancy, presence/absence of invasive species, rare plant occurrences, soil microbiology, pollinator-plant interactions, and lichen occurrences, was not available at scales needed to include in the *Forest Health Strategy's* countywide Forest Condition Assessment. One Tam partners should continue to collaborate on strengthening data collection and evaluation efforts of these and other important indices of forest health as part of field-based inventories and community science initiatives, such as Marin Wildlife Watch, One Tam's Rare Plant Program, Bat Monitoring Program and others.
- Non-native invasive plant species, especially woody species such as eucalyptus, broom, acacia, and cotoneaster, degrade forest and woodland habitat and can increase wildfire hazard. One Tam agencies should continue to partner on invasive plant removal and habitat restoration projects, and strengthen programs designed to address this threat to forest health and resilience, such as the Early Detection Rapid Response Program and Invasive Plant Monitoring and Management Program.
- Foundational datasets used to develop the *Forest Health Strategy* such as the 2018 6-inch aerial imagery, 2019 quality level-1 lidar, and 2018 countywide fine scale vegetation map were mission-critical inputs that provided remarkable insight into the distribution, floristic composition, and structure of forests in Marin County. One Tam partners should work together to fund and execute updates to these datasets, which would allow for comparative analysis, change detection over time, measurements of management efficacy, and future analysis using metrics like those in the *Forest Health Strategy*.

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CHAPTER 2: RESILIENCE

The *Marin Regional Forest Health Strategy* (*Forest Health Strategy*) will outline a comprehensive plan to restore and steward the health and resilience of forests in Marin County. Resilient and healthy forests are better able to recover following disturbance. Incorporating resilience into restoration and forest management activities is a feasible approach with tangible implementation methods for adapting to climate change in forested Marin County public lands and beyond.

The purpose of the Resilience Chapter is three-fold. First, it presents a shared definition of resilience developed by the One Tam partners for forests in Marin County. The resilience statement will guide the development of the *Forest Health Strategy*, including goals and objectives of conservation actions and treatments. Second, it summarizes the concept of ecological resilience in existing literature from academia and from local, state, and federal agencies to demonstrate that the Marin Forest Health resilience definition is broadly consistent with the best available science and regional understanding. Third, it provides language that can be used to increase public awareness of the value of resilient forests.

The *Forest Health Strategy* resilience statement is:

Resilience is the capacity of systems to absorb or recover from disturbance while undergoing change to retain desired ecosystem services and functions within a mosaic of forest types.

LITERATURE REVIEW

The concept of resilience is increasingly used by ecologists and land managers to guide decision-making in the face of climate change and massive anthropogenic-induced alterations to natural ecosystems. For some it is a combination of ***resilience*** and ***resistance***, where resilience is the ability of an ecosystem to experience disturbance and then return to its pre-disturbance condition and resistance is the ability of an ecosystem to withstand disturbance without any measurable ecosystem changes. Brand and Jax (2007) offer a useful resilience synthesis with an organizing typology, noting there is a tension between the original ecological descriptive definition of resilience and the more recent, vague, and malleable notions of resilience used in the present. Peterson-St Laurent et al. (2021) observe that resilience has become a vague concept "with meanings ranging across a spectrum from resisting changes, absorbing changes, and even allowing for transformative changes through self-organization" (Peterson-St Laurent et al., 2021). Still, most scientists and natural resources managers likely accept a general definition of resilience as the ability of a system to maintain key functions when disturbed (Gunderson & Holling, 2002).

Resilience is a complex concept. Resilience attributes could include diversity/diversity redundancy (multiple species that perform a similar function such as nitrogen fixation), stand age, reserves (e.g., capacity to re-mobilize system features post-disturbance such as seed banks), connectivity, new stressors vs. co-evolved disturbance (systems respond to co-evolved disturbances such as fire), functional diversity (e.g., hydraulic diversity), exposure to disturbance (fire suppression leads to loss of resilience or serotiny), and shock response (how an ecosystem reacts to disturbance), speed, and scale (Carpenter et al., 2012; Ibanez et al., 2019; Walker, 2020). Though it is often referred to conceptually or qualitatively, new research is attempting to quantify resilience and use it as a forest conservation management planning tool in the field.

ORIGINS

From an ecological perspective, C.S. Holling was among the first to define the term resilience as a natural system's ability to withstand disturbance and then reorganize to essentially the same structure and function (Bryant et al., 2019; Holling, 1973). The existence of multiple stable states and transitions between them have been described for a range of ecological systems as determined by dominant plant forms, e.g., transition from woodland to grassy arid rangelands, but transitions could also include changes in population dynamics and dominance of primary producers resulting from changes such as altered temperature or light availability (Gunderson, 2000).

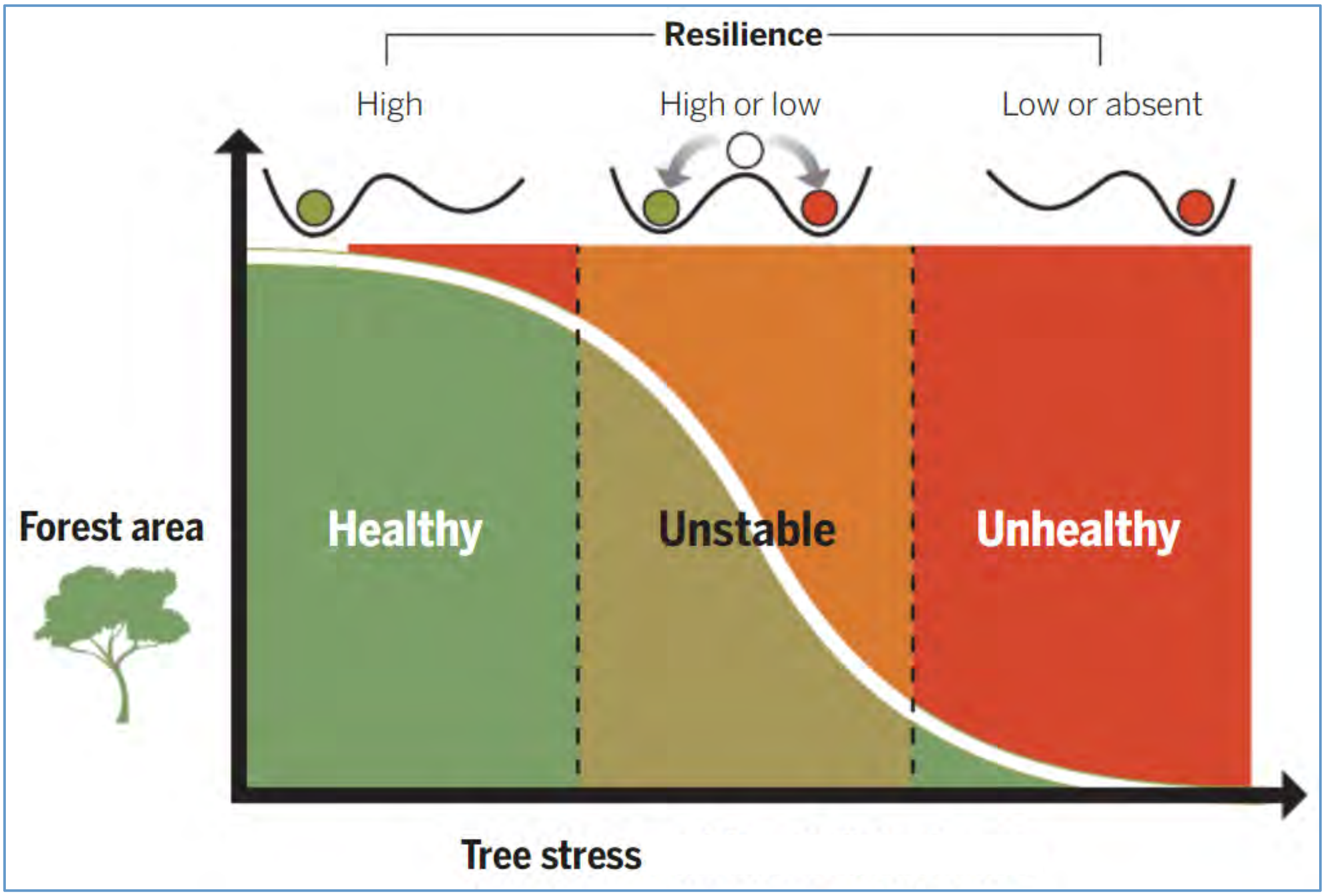
However, Holling conflated resistance and resilience, using the term resilience for both types of stability. Presently, most authors follow Pimm (1984) in defining resilience as the speed at which variables return to equilibrium following perturbation and resistance as the degree to which a variable is changed after a perturbation. Both are important and can be thought of as part of a resistance-resilience framework (Nimmo, 2015).

The resilience concept is closely related to concepts of biological and ecological integrity. For example, Karr and Dudley (1981) noted that a system possessing integrity can withstand, and recover from, most perturbations imposed by natural environmental processes, as well as many major disruptions induced by humans. Andreasen et al. (2001) support the same definition but also add the concepts of sustainability (continuing provision of ecosystem goods, services, and processes), naturalness (a system unchanged by the arrival of Europeans), and stability (similar definition to Holling, e.g., resistant to change and recovery to same state following perturbation).

TRANSITION STATES

To describe the relationship between forest health and ecological resilience, a ball-and-cup analogy is often used to depict multiple states of forest resilience and the ability of a system to experience stress and stay in its current vegetation state (Figure 2.1). In the graphic, the healthy forest on the left experiences little stress, has high resilience, and is likely to stay healthy and is unlikely to shift to a different vegetation type. As forest stress increases, resilience shifts towards a threshold or "tipping point" as indicated by the ball and cup diagrams in Figure 2.1. As the forest experiences more stress, the area of forest with high resilience decreases. Eventually the forest could cross a threshold resulting in a transition to a novel forest type or even a non-forest vegetation community (Trumbore et al., 2015). In this conceptual framework, resistance is the measure of the system's opposition to transformation -- to tolerate or persist through disturbance -- and can be thought of as the depth of the cup in Figure 2.1 (Falk et al., 2019). A successful conceptual model of ecosystem resilience must recognize the role of cultural stewardship as part of the processes that have co-developed what we see in ecological systems. In the area now known as Marin County, this translates into a recognition that thousands of years of Tribal stewardship are an intrinsic part of the baseline conditions of forest resilience and ecological patterning (see Chapter 3: Stewardship and Partnership with the Federated Indians of Graton Rancheria).

Figure 2.1. Graphic depiction of changes in forest resilience as a function of tree stress and forest disturbance (from Trumbore et al., 2015*).*



For some fire-dependent savannas and open woodlands, species richness increases continuously with fire frequency, up to the most frequent fire possible, with fuel being the limiting factor. This frequent-fire state is the most resistant and resilient state. For these ecosystems, exclusion of fire is the perturbation that ultimately leads the shift to an alternative stable state—a dense forest with low species richness that ultimately becomes very resistant to fire due to low flammability. Many oak and conifer woodlands in California, including Open Canopy Oak Woodlands, conform at least partially to this model.

RESISTANCE-RESILIENCE FRAMEWORK

The terms resistance and resilience are often conflated. As described above, resistance is the ability to withstand disturbance or the tendency of a system to remain in its current state (Nimmo, 2015; Trumbore et al., 2015) and resilience is the capacity to recover following disturbance (Nimmo, 2015). As Nimmo indicates (2015) adopting a resistance-resilience framework may be a better approach than solely addressing resilience since they are two very different components of an ecosystem. Resilience is an attribute of community persistence and stress tolerance and should not be conflated with fire resistance (Stephens et al., 2020). Consequent to increased disturbance variability (Millar & Stephenson, 2015) and potential species range shifts (Rehfeldt et al., 2006), Bryant et al. (2019) suggest a combined usage of resilience and resistance since a forest is more likely to recover to a pre-disturbance state (resilience) if it has characteristics that limit the severity of the perturbation (resistance). It is useful to think of resistance as shorter-term resilience and often implies minimal changes to stand structure, including species composition (Bryant et al., 2019).

Multiple stable states or stability domains can exist for a single ecosystem (Gunderson, 2000). Considering what mediates the transition between stable states is important when studying resilience and state dynamics. For example, it has been known since the early 20th century that sites topographically protected from fire, which are otherwise physically identical to frequent-fire sites, support different ecosystem states. There is still significant debate on whether or not alternative stable states exist outside of anthropogenic-induced change (Dublin et al., 1990).

A complication to this framework is that resistance and resilience can be negatively correlated. For example, a fertilized forest may grow back faster after a hurricane (higher resilience) but could be more vulnerable to the next windstorm because the trees grew rapidly and have less dense wood (lower resistance). A forest that has both high levels of resistance and resilience, especially on a landscape scale, is the desired state.

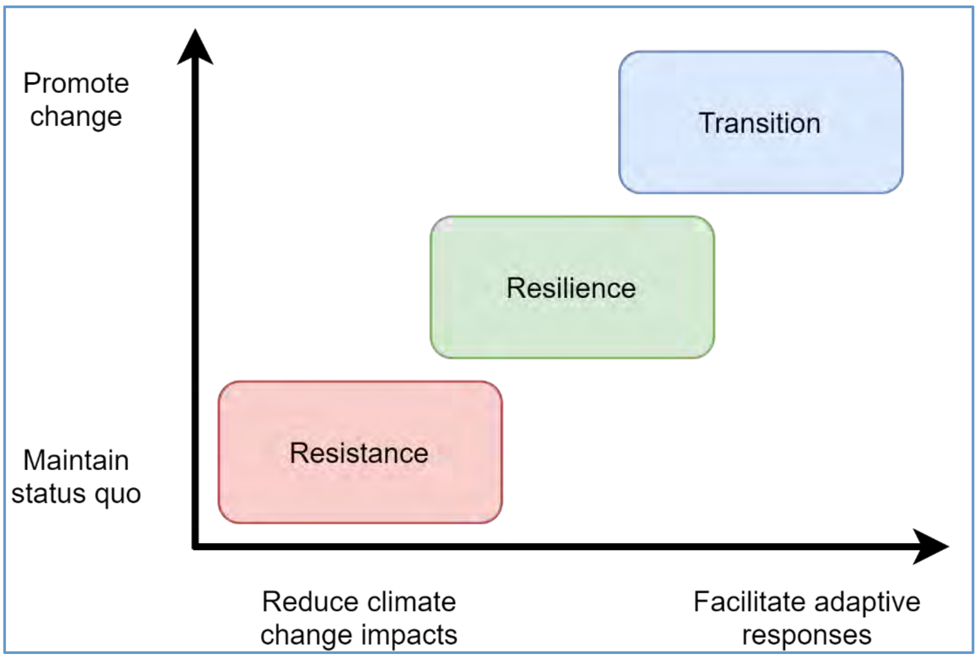
CLIMATE CHANGE & RESILIENCE

Climate change poses a whole new realm of challenges faced by forests and will negatively impact resistance and resilience as an increasingly prominent disturbance. In some systems after an extreme degree of climate change, e.g., increased heat and drought, a regime shift from forest to open woodland, savanna, or grassland becomes more likely. Under the new conditions the grassland is the more resistant and resilient state and going back to forest is virtually impossible without very intensive management.

From a management perspective, increasing ecological resilience can also increase the elasticity of moving from an undesirable state back to a desirable healthy state (Millar et al., 2007). However, the healthy state under current or recent past climate may not be a healthy state under a hotter, drier climate in the future. Managers may find management actions that increase resilience attractive since proposed actions are slight adjustments to, rather than significant departures from, current trajectories (Swanston et al., 2016). For example, thinning, mastication, or beneficial fire may be utilized to improve forest resilience to stressors such as drought, wildfire, and some diseases through reductions in stand density, reduced competition for resources such as light and water, and spatial fuel connectivity and the subsequent behavior of wildfire (Falk et al., 2019). Thinning may help to reduce climate stresses such as reduced soil moisture due to reduced rainfall or prolonged drought (Kolb et al., 2007). North et al. (2022) argue that many dry western U.S. forests had similar frequent, low-intensity fire regimes and historical stand density values suggest that thinning for restoring forest resilience may need to be more intensive than is being implemented under current fuels reduction approaches.

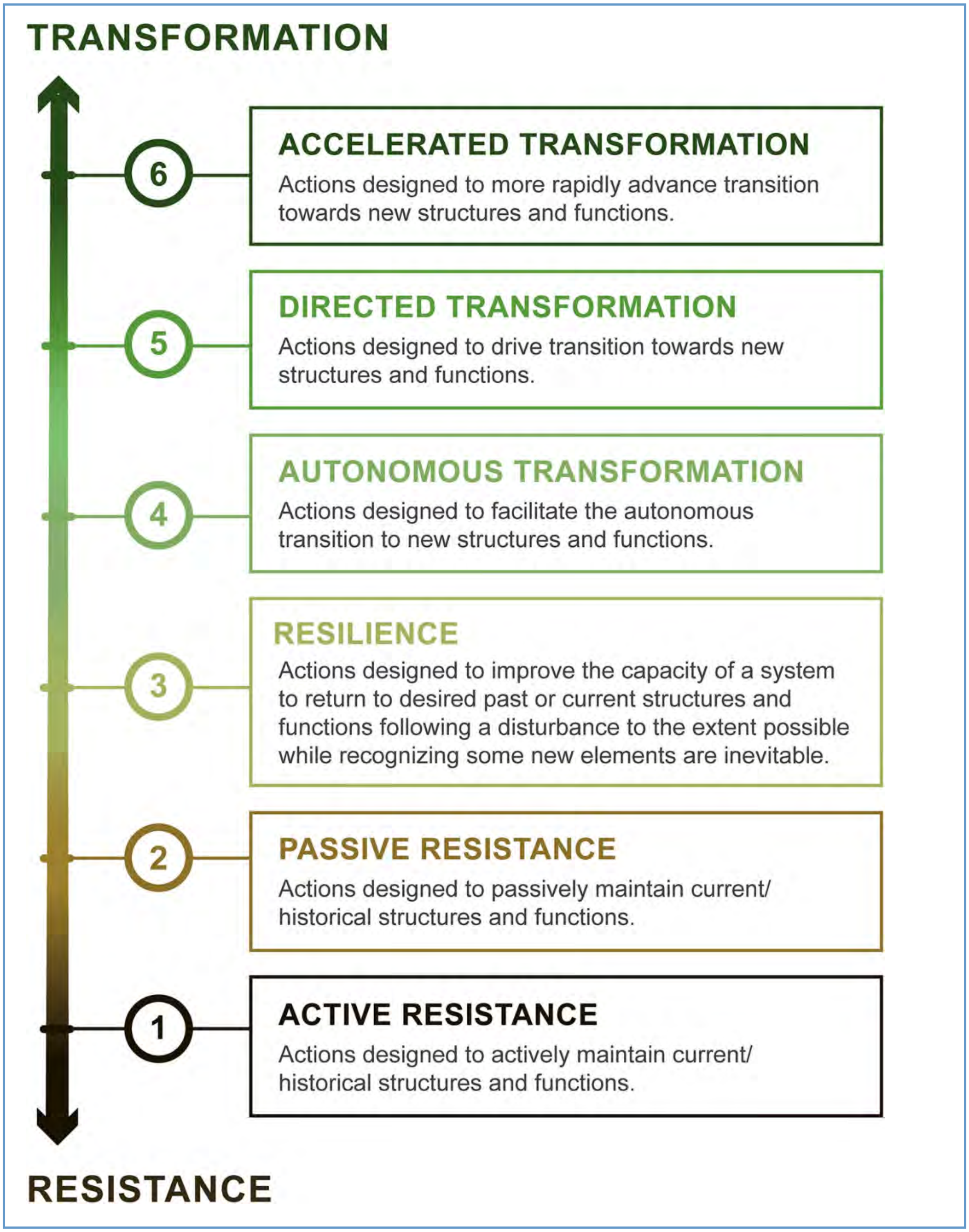
Nagel et al., (2017) provide a useful graphic to describe adaptation options along a continuum of management goals (Figure 2.2). In the figure the x-axis represents mechanisms for coping with climate change and the y-axis represents changes implemented to influence ecosystem attributes. Shifts in values along both axes change from resistance to resilience, then transition to a new system state.

Figure 2.2. Climate change adaptation options showing the continuum between resistance, resilience, and transition (Adapted from Nagel et al., 2017).



Transformation, which is a newer concept basically analogous to directing or redirecting change, is a more controversial idea because it accepts or even embraces novel ecosystems, a concept that has been critiqued on several grounds, including lack of rigor and clear guidance to practitioners (e.g., Murcia et al., 2014). Nevertheless, in a case study of 104 adaptation projects funded since 2011, Peterson-St Laurent et al. (2021) identified a trend towards acceptance of some form of transformation, although varying across ecosystems (Figure 2.3).

Figure 2.3. The resistance-resilience-transformation (R-T-T) scale with definitions. The 6-point scale ranges from actively resisting changes to accelerating transformation toward new conditions better adapted to an altered climate. From Peterson-St Laurent et al. (2021).



Forested ecosystems may pose challenges for incorporating resilience into conservation efforts since the distribution of longer-lived sessile tree species may substantially lag behind climate change (IPCC, 2018). Exacerbating this challenge, many forests in North America originated during what is colloquially referred to as the Little Ice Age (500-1800 AD) which was significantly cooler and wetter than the conditions predicted for the latter portion of the 21st century (Mann et al., 2009). As a result, increasing the resilience of current tree species stands may not match the future climatic envelope, requiring more drastic adaptation interventions not tied to reference conditions or a specific topoclimatic geography and involving actions implemented on a larger spatial scale and over a longer time period to fully address these challenges (Falk et al., 2019). In the U.S., post-colonization disruption of natural processes, including the exclusion of natural and cultural fire, will continue to increase the impacts on these tree stands during disturbances. Working to restore natural processes, while addressing the impacts from historic disruptions to these processes, can help guide future management scenarios aimed at increasing forest resilience.

MANAGEMENT SCENARIOS

To further the resilience connection to natural resource management, Gunderson (2000) describes a range of three management scenarios: 1) Actively manage the system to return to desired state; 2) Admit the system is irreversibly changed and the new management strategy is to adapt to the newly altered system; and 3) Do nothing and wait to see if system returns to an acceptable state, meaning that social and natural benefits are essentially lost during the waiting period.

However, future ecosystem states are inherently uncertain and difficult, if not impossible, to predict. Consequently, active interventions which attempt to steer systems towards a preferred state are likely to fail (Walker, 2020). Instead, the management approach must have multiple options and shepherd the system within a natural range of variation to avoid crossing into unwanted states. Determining when transformation is inevitable is another challenging management question and may benefit from multiple metrics to assess this tipping point or transition state.

Resilience-oriented management could help align scales at which management and ecological processes occur (Allen et al., 2011). Connecting to the landscape scale as an example, varying intensity and scale of fuels treatments or, when feasible, letting wildfires burn both aim to maintain the natural spatial and temporal properties of the forested ecosystem (Yocom-Kent et al., 2015). Although resilience is a complex concept, commonly used metrics, such as relative stand index, may be a useful measurement for forest stand resilience in some systems, especially those with frequent, low-intensity fire regimes in the Western United States (North et al., 2022).

Cobb et al. (2017) tested resilience management in tanoak stands of Marin and Humboldt Counties in order to increase forest resilience due to catastrophic forest loss from *Phytophthora* pathogens. They found that resilience treatments of tanoak thinning greatly reduced disease impacts, but the authors did not attempt to quantify or specifically measure resilience.

LIMITATIONS

Although resilience is a useful concept, particularly in the face of climate change, it is not a forest management panacea (Millar et al., 2007). Pimm (1984) noted that increased resilience in some populations implies decreasing population variability. This may be true particularly as changes in climate accumulate over time and more intensive management actions are required, including increased scale of beneficial fire, assisted migration, protecting climate refugia while creating new refugia or protected areas, and triage to prioritize landscapes most vulnerable to change (Millar et al., 2007).

Resilience is often criticized for its use as a qualitative concept; it is often referred to in policy documents, but frequently not defined, let alone quantified. Even with quantitative estimations of key pre- and post-disturbance variables to measure resilience, a potential problem of these estimates is that they usually do not account for the impact inflicted by the disturbance, which could underestimate resilience in heavily affected systems (Lloret et al., 2011). Furthermore, recovery after disturbance at the individual organism level is due to response to stochastic extrinsic factors such as competition and to intrinsic microsite factors such as genetic variability (Lloret et al., 2011).

STATE AGENCY DEFINITIONS

California state agencies have created a framework for describing and assessing resilience which has been used in developing the *Forest Health Strategy*. The California Department of Forestry and Fire Protection (CAL FIRE), California Environmental Protection Agency (CAL EPA), and the California Natural Resources Agency (Resources Agency) frequently use the term resilience regarding climate and forests in policy documents, websites and other agency materials. The Resources Agency's *Safeguarding California Plan* (2018) defines resilience as "…the capacity of any entity—an individual, a community, an organization, or a natural system—to prepare for disruptions, to recover from shocks and stresses, and to adapt and grow from a disruptive experience." The Plan couples resilience with adaptation defining the latter as "…adjustment in natural or human systems in response to actual or expected climatic stimuli or their effects, which moderates harm or exploits beneficial opportunities." In *California's Wildfire and Forest Resilience Action Plan*, a joint planning effort of CAL FIRE, CAL EPA, and the Resources Agency, the "10 Pillars of Resilience" are used to "provide a framework for assessing progress under the environmental, social, and economic goals of landscape-scale forest management projects and programs" (California Forest Management Task Force, 2021, p.43).

Recovering from disruption or returning to a pre-disturbance state is repeated in the *California Forest Carbon Plan* (Forest Climate Action Team, 2018) where resilience is defined as "The capacity of an ecosystem to return to the pre-condition state following a perturbation, including maintaining its essential characteristic taxonomic composition, structures, ecosystem functions, and process rates (p.7)." This definition is supported by other regional forest health working groups. While this holds true for vegetation communities that are still relatively intact, in highly disturbed vegetation communities intensive management in conjunction with the restoration of natural processes may be needed to return to the pre-disturbance state.

CASES

There are several instructive examples for managing for resilience from the Lake Tahoe West Collaborative, Marin Water (formerly Marin Municipal Water District), and Yosemite National Park. The examples vary widely in time scales from a few months to 40 years. Accordingly, it is not yet clear how the results of managing forested stands will play out, but there are some promising initial results, especially from the longer-term Yosemite example.

LAKE TAHOE WEST

Lake Tahoe West Restoration Partnership is a multi-stakeholder collaborative initiative convened by multiple federal & state agencies as well as non-profits and local stakeholders. Wildfire, drought, and disease—pressures that are amplified by climate change—threaten forests, watersheds, and communities across the Lake Tahoe West landscape. The goal of Lake Tahoe West is to restore the resilience of the west shore's forests, watersheds, recreational opportunities, and communities to such threats. The planning area includes approximately 59,000 acres of federal, state, local, and private lands, from Emerald Bay to Squaw Valley.

The Lake Tahoe West Restoration Partnership spent a good deal of time defining resilience and using the concept to prioritize restoration across the landscape. Since this effort is relatively recent, we can learn from the prioritization process. Generally, incorporating resilience into the process consisted of the following steps:

1. Identified the ecosystems managers wanted to be resilient (e.g., forests, meadows, and aquatic ecosystems) and stressors and threats to ecosystem values and services (e.g., fire, flood, drought, insects, disease, climate change, erosion, air pollution and development).
2. Identified indicators of resilience; these included indicators such as mean condition class, fire severity, trees per acre, thermal tolerance, climatic water deficit, snowpack, fire risk index, water quality, species diversity, vertical and horizontal heterogeneity, and vegetation type.
3. Specified a range of conditions from resilient to least resilient and ranked the indicators using those resilience ranks.
4. Analyzed geospatial data for each indicator to determine current resilience.
5. Combined multiple indicators into composite indicators to identify resilience to a disturbance and resilience of value or service.[1]

[1] One problem with combining multiple indicators into a composite is known as eclipsing. See Andreasen et al. (2001) for more information.

In the analysis, researchers found that 24% of the forested landscape is resilient and those areas are located generally at higher elevations and in wilderness areas. Canyons in lower elevations around the shore of Lake Tahoe are more resilient. As indicated in the literature, quantification of resilience in the landscape is much needed and provides a useful tool in the planning process. In this case it was a useful organizing rubric to integrate science and practice throughout the landscape and identify where to apply limited resources to increase resilience in the Tahoe Basin.

MARIN WATER

Marin Water's *Biodiversity, Fire and Fuels Integrated Plan* (*BFFIP*) defines resiliency as:

> …an ecosystem's ability to absorb shocks or perturbations and still retain desirable ecological functions such as the ability to provide breeding and foraging habitat for wildlife, the ability to support significant biological resources such as rare, threatened, or endangered species, the ability to regenerate desired plant communities following a disturbance, the ability to cycle nutrients, and the ability to protect water quality (Holling, 1973; Marin Water, 2019, pp. 2-18; Walker et al., 2004).

This definition conflates resilience and resistance, and is more a definition of resistance as discussed above.

With regards to forest management, the BFFIP states that Marin Water proposes to address the threats to natural areas by implementing activities that improve the overall resilience of forests on Marin Water lands by 1) increasing both above ground and soil carbon storage and retention, 2) optimizing water yield for both human consumption and aquatic ecosystem health, 3) improving natural recruitment of native tree species, and 4) improving wildfire resilience by reducing the likelihood of crown fires.

Marin Water is implementing several forest health demonstration projects including one at Bolinas Ridge for Coast Redwood and another at Potrero Meadow for Douglas-fir. Both projects include removal of sudden oak death (SOD) impacted dead and dying trees, thinning of smaller diameter Douglas-fir and removing Douglas-fir that are invading grasslands. Treatments are combined with studies on carbon sequestration, water yield, seedling recruitment and bird surveys.

Since the *BFFIP* was recently approved by Marin Water in 2019 and the demonstration projects are still in their infancy, it is too early to tell what the results of incorporating resilience into forest management efforts will be in Marin Water's service area.

YOSEMITE NATIONAL PARK

The National Park Service has long held a progressive approach to wildfires. The Illilouette Creek Basin in Yosemite National Park has experienced 40 years of managed wildfire, reducing forest cover by 22%. Wildfires increased meadow areas by 200% and shrublands by 24% (Boisrame´ et al., 2017). Managed wildfire's diversification of an originally fire-suppressed landscape appears to increase landscape heterogeneity and likely improves resilience to disturbances such as fire and drought (Boisrame´ et al., 2017). The 2014 Rim Fire was severe through much of the fire-suppressed area of Stanislaus National Forest, but it burned closer to the ground within the Yosemite National Park areas which had experienced managed wildfire, and thus this area did not experience the stand-replacing conditions exhibited in the neighboring Stanislaus National Forest.

In fact, burn severity in the Illilouette Creek Basin has been shown to decrease with the introduction of managed wildfire (Collins et al., 2009; van Wagtendonk et al., 2012). California drought conditions from 2011-2015 are estimated to have killed over 10 million trees in the southern Sierra Nevada. However, forest mortality in the Illilouette Creek Basin during this period appears to be minimal and multiple persistent wetlands in the area were observed throughout the drought (Boisrame´ et al., 2017). Further study has shown that introducing a fire regime to a montane watershed increases streamflow and soil carbon storage and decreases transpiration for both historical and future climates (Rakhmatulina et al., 2018).

WESTERN KLAMATH MOUNTAINS

There is a lot to be learned from cultural management models that rely less on single species management and more on understanding and facilitating ecosystem processes. The cultural landscape in the Klamath River corridor from Requa to Happy Camp, where tribal communities are actively creating their fire future based on beneficial fire management practices, is instructive from this perspective.

The Western Klamath Restoration Partnership's initial focus was on instream fish habitat restoration. In recognition of the controversial issues surrounding forest management in the region, participants chose to wait to focus on upslope restoration until facilitators capable of bringing the group from conflict to understanding and general conceptual agreement were identified.

As the group evolved, shared values emerged through identification of six Conservation Targets: fire-adapted communities; restored fire regimes; healthy river systems; resilient bio-diverse forests/plants/animals; sustainable local economies; and cultural and community vitality. The identification of critical threats to conservation values were based on real-world threats to the viability of the Klamath landscape and community. These threats included lack of stable jobs; erosion of community and cultural values, including Karuk traditional practices; lack of beneficial fire; altered forest structure and composition; high fuel loading; lack of defensible space; terrestrial and aquatic habitat degradation; and impaired fisheries.

Many restoration actions in the Klamath have been successful because tribal biologists and cultural practitioners, similar to the best western science, use keen observation and historical reference to understand what management actions can have the largest benefits. For coho salmon, it was creating off-channel habitat that had been virtually removed from the system. For fire, it was restoring cultural burning practices that have been evolving for millennia. Practitioners are seeing a strong convergence between the best available science and traditional ecological knowledge in the Western Klamath Mountains.

MOVING FORWARD

Integrating resilience concepts into the *Forest Health Strategy* will be critical to ensuring long-term forest health for Marin County. Accumulation of change and disturbance are inevitable in forested ecosystems, particularly as climate change increases in scale and impact, and exacerbates other anthropogenic changes in long-resilient systems. The concept of resilience allows incorporation of those accumulated changes into the understanding of a healthy forest by linking the forest health concept with critical ecosystem services and considering the forest on a landscape scale. By accepting a level of change in forest ecosystems we can focus on management strategies that do not attempt to maintain a static forest system, but rather enhance and protect the role of the forest in providing ecosystem services such as biodiversity, carbon sequestration, water infiltration and dry-season yield, and recreation.

Considering resistance and resilience as part of the forest health attributes for each of the priority forest stands in Marin County has been crucial for the *Forest Health Strategy*. In developing conceptual models of ecosystem function, stressors and threats were connected to specific forest health attributes. Key treatments were identified to move towards landscape-level goals along goal pathways (see Chapter 5: Goals). Considering how treatments may influence resistance and resilience will be critical to the viability of the treatments and subsequent health of the target forest ecosystems in Marin: Bishop Pine, Coast Redwood, Douglas-fir, Open Canopy Oak Woodlands, and Sargent Cypress.

Similarly, careful measurement and analysis of metrics that could demonstrate a shift in transitional states can be used to focus management actions to avoid negative shifts or more significant transitions in the forest ecosystem. Measurement and quantification of resilience metrics in Marin County has greatly increased the precision of integrating resistance and resilience information into the *Forest Health Strategy* and will be an important asset to assist managers in improving forest management as part of the *Forest Health Strategy*.

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CHAPTER 3: STEWARDSHIP & PARTNERSHIP WITH THE FEDERATED INDIANS OF GRATON RANCHERIA

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OVERVIEW & PURPOSE

The *Marin Regional Forest Health Strategy* (*Forest Health Strategy)* will provide agencies and land managers in Marin County with urgently needed information on the state of Marin forests as well as informed treatment methods to improve them. From the inception of this process, it has been essential to understand that all land in Marin County is Coast Miwok land, forests and other resources and features of these lands and waters are Tribal Cultural Resources (TCRs), and policy decisions about land and resources in the county should be considered collaboratively and determined in direct consultation with the Federated Indians of Graton Rancheria (FIGR or Tribe), a sovereign nation and the federally recognized Tribe whose ancestral territory is Marin and Sonoma Counties. The Tribe is comprised of Southern Pomo and Coast Miwok peoples. As the only federally recognized tribe whose cultural and ancestral lands are all of Marin County, the Tribe has a strong interest in forest health, resiliency, resource management and land stewardship. With the Tribe's participation, this ensures the strategies developed here align with tribal values and needs, but it also provides an opportunity for agencies to draw on the deep cultural and historical knowledge of FIGR tribal elders, citizens, and scholars. The purpose of this chapter within the overall *Forest Health Strategy* is to provide a framework for how projects and agencies can work collaboratively with the Tribe to reintegrate Tribal knowledges and practices into land stewardship in Marin County, which is the Tribe's ancestral territory.

This chapter has several goals. The first goal is to provide historical context for the Tribe's cultural affiliation to Marin County, relevant cultural and natural resource laws that establish the mandate for agencies to engage in government-to-government consultation with the Tribe, and strategies and considerations for working in collaboration with the Tribe to steward cultural and natural resources, which are not mutually exclusive. Within this framework for working collaboratively with the Tribe, it is crucial to establish a more holistic understanding and treatment of cultural and natural resources as interrelated and not mutually exclusive.

Maintaining and building stronger partnerships between Marin's land managing agencies and the Tribe will allow for discussions about specific projects and strategies that may be place and resource dependent.

Some knowledge about specific resources and places will be confidential and not shared through documents. Sensitivities will exist around resources that could be damaged/stolen if discovered by the public, knowledge about places or resources that are not shared outside of the Tribe for cultural or religious reasons, or cultural practices that have the potential to be misappropriated by agencies or the public thus subverting the Tribe's sovereignty over these practices and the Tribe's role in stewardship. Consultation with the Tribe will facilitate the development of an ethical and appropriate framing for projects taking into account these sensitivities.

The second goal of this chapter is to provide background on Native American stewardship and Marin County forests. This discussion will cover the cultural importance of various plants and animals to Coast Miwok people and the kinds of stewardship practices that the Tribe deems are appropriate. The third goal is to outline the impacts of colonialism that have led to environmental degradation and/or presented barriers to the continuance of certain Coast Miwok cultural practices or maintaining relationships with land and resources. The discussion of colonial impacts will lead to a fourth goal of this chapter, which is a discussion of community health and well-being of the Tribe and prospects for working toward a sustainable future. The final goal is to offer recommendations for how to achieve stronger partnerships and better collaboration with the Tribe, how to appropriately work with and integrate tribal cultural knowledge, perspectives, and practices into agency projects and management policy in collaboration with the Tribe, and how to manage public lands in mutually beneficial ways that consider the Tribe's health, well-being, and future.

COMPLIANCE WITH CULTURAL RESOURCE LAWS: THE AUTHORITY & EXPERTISE OF TRIBES

Throughout the world, Indigenous peoples have rights to the specific cultural and ecological resources and lands with which they are historically and culturally affiliated. Articles 26 and 32 of the United Nations Declaration on the Rights of Indigenous Peoples (UNDRIP) articulates these rights and recognizes the need for colonial governments to "consult and cooperate in good faith with the indigenous peoples concerned through their own representative institutions in order to obtain their free and informed consent prior to the approval of any project affecting their lands or territories and other resources" (United Nations, 2007, p.16). In the United States, the federal government has a fiduciary responsibility and legal obligation to protect the Tribal sovereignty and rights of federally recognized Indian Tribes (see Glossary for a definition) established through treaties and agreements. The California state government (including the city and county levels) has further reaffirmed its responsibilities and legal obligations to protect the rights and sovereignty of California Native American Tribes (see glossary for a definition). The federal register lists one entity that qualifies as a federally recognized Native American or Indian Tribe from Marin County, California, which is the Federated Indians of

Graton Rancheria. The Native American Heritage Commission lists one entity that qualifies as a California Native American Tribe from Marin County, California, which is also the Federated Indians of Graton Rancheria. The responsibility of U.S. federal agencies to consult with Tribes that attach cultural or religious significance to a property is recognized in 54 U.S.C. 302706(b) (Historic Preservation Programs And Authorities For Indian Tribes And Native Hawaiian Organizations, 2014). The State of California understood the need to consult with the passage of Senate Bill 18 (Traditional Tribal Cultural Places, 2004) that requires local agencies to consult with Tribes prior to making certain planning decisions. These governmental relationships, rights, and access to land and resources must be protected and reserved for the Tribe in Marin County to ensure the survival and perpetuation of their culture and religious practices.

In the United States, treaties and agreements between the federal government and Indian Tribes recognize the sovereignty of these Tribes as domestic dependent nations (Kalt & Singer, 2004). Though the 18 original treaties in California were never ratified by the U.S. Senate, court cases throughout the twentieth century rectified the situation that had previously left Tribes without formal recognition or reservation lands before this time (Akins & Bauer, 2021; Heizer, 1972; Johnston-Dodds, 2002; Miller, 2013; Shipek, 1989). The Tribe experienced a similar history, being afforded land in 1920 for all of the Native American peoples within Marin and Southern Sonoma Counties, but then was wrongfully terminated in 1958, and finally having the Tribe's federal recognition restored through an Act of Congress in 2000 (H.R. Rep. No. 106-677, 2000). Restored federal status affords the Tribe all the rights and responsibilities of a federally recognized Tribe, including the inherent rights of self-governance, tribal jurisdiction, a government-to-government relationship with the United States, and shares in the trust responsibility the United States affords to all federally recognized tribes. As a federally recognized Tribe, FIGR has a government-to-government relationship with the State of California, Marin and Sonoma Counties, and the local towns and cities and agencies within the Tribe's traditional and culturally affiliated territory. These rights and responsibilities as they pertain to traditional cultural properties, culturally affiliated lands, and tribal cultural resources, are protected under federal and state cultural resource laws including but not limited to Marin County Municipal Code Section 10.04.050 "Archaeological and Historical Resources," the California Environmental Quality Act (CEQA), National Environmental Protection Act (NEPA), National Historic Preservation Act (NHPA), National Register Bulletin 38 Guidelines for Evaluating and Documenting Traditional Cultural Properties (TCPs), California Native American Graves Protection and Repatriation Act (CalNAGPRA), Native American Graves Protection and Repatriation Act (NAGPRA), American Indian Religious Freedom Act (AIRFA) (42 U.S.C. § 1996), and the United Nations Declaration on the Rights of Indigenous Peoples (UNDRIP) as well as the U.S. Constitution.

While it is not within the scope of this chapter to comprehensively review these laws as it relates to Tribal cultural resources and heritage, it is important to highlight the authority, expertise, and knowledge of Tribes in identifying, assessing, and protecting traditional cultural properties and tribal cultural resources. Revisions to both federal and state laws have afforded much clearer mandates and guidance on consulting with Tribes about traditional ancestral lands and resources. On the federal level, NHPA was amended in 1992 to incorporate the provisions in National Register Bulletin 38 (Hinds, 2017, p.145). The current text of NHPA also states very clearly in 36 CFR § 800.4(c)(1) (Identification of Historic Properties, 2022), that "…The agency official shall acknowledge that Indian Tribes and Native Hawaiian organizations possess special expertise in assessing the eligibility of historic properties that may possess religious and cultural significance to them." Executive Order 13175 "Consultation and Coordination with Indian Tribal Governments" issued in 2000 and Joint Secretarial Order 3403 "Fulfilling the Trust Responsibility to Indian Tribes in the Stewardship of Federal Lands and Waters" issued in 2021 also recognize the responsibilities of federal agencies to engage in government-to-government relationships with Tribes to co-steward resources on federal lands.

A similar amendment acknowledging the specific knowledge and concerns of California Native American Tribes was made to CEQA in Assembly Bill Number 52, Chapter 532, which was enacted in 2014 (Native American Historic Resource Protection Act, 2014). In section 1(a)(3) of AB 52, the State acknowledged that CEQA failed to account for Native American knowledge and concerns. This failure "resulted in significant environmental impacts to tribal cultural resources and sacred places, including cumulative impacts, to the detriment of California Native American tribes and California's environment." Section 1(a)(4) is a strong affirmation by the State that "California Native Americans have used, and continue to use, natural settings in the conduct of religious observances, ceremonies, and cultural practices and beliefs, these resources reflect the Tribes' continuing cultural ties to the land and their traditional heritages." In formal recognition of tribal expertise and authority in these matters, section 1(b)(4) states that it is the intent of the Legislature to:

> Recognize that California Native American tribes may have expertise with regard to their tribal history and practices, which concern the tribal cultural resources with which they are traditionally and culturally affiliated. Because the California Environmental Quality Act calls for a sufficient degree of analysis, tribal knowledge about the land and tribal cultural resources at issue should be included in environmental assessments for projects that may have a significant impact on those resources.

AB 52 also acknowledges in section 1(b)(8) that agencies have a responsibility to "enable California Native American Tribes to manage and accept conveyances of, and act as caretakers of, tribal cultural resources." AB 52 and recognizes the ability of Tribes to identify and protect tribal cultural resources. Federal and state laws provide robust justification for consultation on the basis of tribal sovereignty and the specific knowledge and relationships that Tribes have with their culturally affiliated territories, such as the relationship that the Tribe has with all of Marin County and Sonoma County in California.

COAST MIWOK ETHNOBOTANY

> My people have lived on the coast for at least 8,000 years. To live in spiritual and physical balance in the same small area for thousands of years without feeling the need to go somewhere else requires restraint, respect, knowledge and assurance of one's place in the world. (Ortiz, 1993, p. 4)

These words from Kathleen Smith, a Coast Miwok and Dry Creek Pomo elder, who was a citizen of the Tribe and is now deceased, express the strength and resilience of the Tribe and the depth of knowledge that we collectively share as a Tribe. This knowledge is the foundation for our understanding of the world/environment and how we care for that environment to maintain good relationships with everything around us.

Expressed through traditional understandings of our relationships and place in the world, Kathleen Smith's words are again very insightful:

> …my grandmother, taught her [Kathleen's mother, Lucy Smith] that 'we had many relatives and we all had to live together; so we'd better learn how to get along with each other': She said it wasn't too hard to do. It was just like taking care of your younger brother or sister. You got to know them, find out what they liked and what made them cry, so you'd know what to do. If you took good care of them, you didn't have to work as hard. Sounds like it's not true, but it is. When that baby gets to be a man or a woman, they're going to help you out. You know, I thought she was talking about us Indians and how we are supposed to get along. I found out later by my older sister that Mother wasn't just talking about Indians, but the plants, animals, birds-everything on this earth. They are our relatives and we better know how to act around them or they'll get after us. (Smith, 2014, pp. 94-95).

In addition to eloquently expressing how everything in the world is interrelated, this passage expresses the fact that our relationships are dynamic and reciprocal. Reciprocity and being in right relationships with the plants, animals, and world around us is centrally important to Coast Miwok and Southern Pomo cultural traditions.

The purpose of the following sections is to provide some context for culturally important plants and animals in Marin County forests. This information is not intended to be comprehensive or exhaustive but rather illustrative examples of how and why land managers need to consult with the Tribe to ensure land stewardship and management in Marin County is done equitably and collaboratively with the Tribe – the original peoples of this area. This consultation and engagement is mandated by the federal trust responsibility and state laws governing tribal consultation and cultural resource protections. It is imperative for the survival of cultural practices to engage in mutually beneficial and adaptive management of the Tribe's ancestral lands.

BACKGROUND ON COAST MIWOK ETHNOBOTANY

The information presented in this chapter is derived from publicly available reports and publications on Coast Miwok traditional knowledge and ethnobotany. The main source of information is Isabel Kelly's ethnography of Tom Smith and Maria Copa from the 1920s (Collier & Thalman, 1991), which is the most comprehensive ethnography of Coast Miwok people written to date. Other ethnohistoric sources of information include observations by the Spanish/Mexicans in the late 1700s through the 1850s and the Russians at Bodega Bay in the 1820s through 1840s, including items they took back with them to Russia and are curated at the Kustkamera Museum in Saint Petersburg (Blackburn & Hudson, 1990; Hudson & Bates, 2014; Stross, 1974), and observations by early Spanish, Mexican, and American settlers from the late 1700s through early 1900s (e.g., Altimira, 1823, 1860; Dietz, 1976; Moorehead, 1910; Munro-Fraser, 1880a, 1880b). During the late 1800s and early 1900s, there is some overlap between observations by untrained American settlers, amateur artifact collectors and linguists, and the very earliest trained anthropologists performing more standard ethnographies. These scholars primarily include Stephen Powers (1877), Henry W. Henshaw (1890) , C. Hart Merriam (1910), and Alfred Kroeber (1925), though Samuel Barrett (1908) and others (e.g., Barrett, 1952; Chesnut, 1902; Goodrich et al., 1980; Peri et al., 1982; Peri et al., 1985; Welch, 2013) working primarily with neighboring Tribes also comment on Coast Miwok peoples and culture.

Robert Heizer and many other archaeologists completed early archaeological studies in Marin County and the surrounding Central California region (Beardsley, 1948, 1954a, 1954b; Heizer, 1941, 1947). While these studies included some discussion of foodways and environments based on direct evidence from faunal remains and indirect evidence based on stone tool technologies, much of their work relied on ethnography and previously known information about the region's ecology rather than more intensive and integrated studies of botanical and faunal materials within sites. The field of paleoethnobotany - the study of how people in the past have interacted with the environment and specific plants as food, medicine, and tools- developed rather late in the history of archaeology, in the mid to late twentieth century (Pearsall, 2000), and it was even later that these methods were consistently employed in California (Hammett & Lawlor, 2004). One early microbotanical study employing pollen cores to reconstruct the environment in Southern Marin County was completed by Faith Louise Duncan (1992). Some other scholars studying primarily macrobotanical materials (e.g. charred seeds, wood, and plant parts), including Eric Wohlgemuth, Rob Cuthrell, and Peter Nelson used these methods to reconstruct the environment and foodways in Marin and Sonoma Counties as well as Central California more broadly in the first few decades of the 2000s (Lightfoot et al., 2020; Nelson, 2017a, 2017b; Schneider et al., 2018; Wohlgemuth, 2004,). Paleoethnobotanical studies, however, are rarely employed in this area, especially in the field of Cultural Resource Management (CRM), and most environmental archaeological information continues to be derived from faunal remains and stone tool technologies present at sites. It is important for such studies to be done by archaeologists who are working in close collaboration with the Tribe in order to identify appropriate and relevant questions and methods within studies such as these. Co-created studies can produce information that directly informs and support the Tribe's knowledge and goals, such as environmental restoration and food sovereignty.

There are a few other sources of information that are noteworthy that fall outside the categories of ethnohistory, early ethnography, and archaeology. A student in the late 1980s and early 1990s, Brenda Beckwith, completed both her M.A. and B.A. theses at CSU Sacramento on the topic of Coast Miwok ethnobotany (Beckwith, 1989, 1995). Beckwith's (1989, 1995) core information comes from Isabel Kelly's ethnography and is supplemented by her experiences taking traditional skills classes offered by the Miwok Archaeological Preserve of Marin (MAPOM), attending regular meetings and gatherings of the Federated Coast Miwok (the former name of the Federated Indians of Graton Rancheria), assisting with the rebuilding of a demonstration village at Olompali, and conducting extensive interviews with Native and non-Native consultants (Beckwith, 1989,p.4). There are some interviews with Coast Miwok elders, Sam Carrio, Kathleen Smith, and others, that are also available in *News from Native California* (Baker, 1992; Ortiz,1990, 1998; Smith, 1990a, 1990b, 1990c, 1991), and a longer book on Coast Miwok and Dry Creek Pomo foodways by Kathleen Smith (2014). These interviews and writings directly from Coast Miwok elders represent additional perspectives on the matter of Coast Miwok foodways and environmental knowledge. All of these sources are being compiled, interpreted, and presented here by the author who is a citizen of the Tribe, cultural practitioner, and scholar. This Chapter of the *Forest Health Strategy* was reviewed by the Tribal Heritage Preservation Officer (THPO), the Tribe's cultural resources staff, and members of the Sacred Sites Protection Committee to include more Tribal perspectives in the information presented than any one individual or source alone could provide in the framing and drafting of this document.

It should be noted that in any of these direct sources from elders or ethnography, the information that is shared is not comprehensive as much of this knowledge is retained in communities and families and not for public consumption. In a modern legal sense, it is the intellectual property of the Tribe. The following descriptions of the environmental knowledge, stewardship, and foodways should not be taken to be a direct guide or recipe book for non-Native people to use for their own purposes without further consultation. To receive guidance and broader context for how to integrate the Tribe's perspectives appropriately and ethically into into land stewardship or management practices, agencies and individuals need to engage in official consultation with the appropriate representatives designated by the Federated Indians of Graton Rancheria Tribal Council. This ensures a respect for the Tribal sovereignty and Tribal leadership. Tribal leadership, citizens and appropriate tribal staff are able to determine how best to protect the cultural heritage and lands of the Tribe in collaboration with agencies and others within the Tribe's ancestral territory.

STEWARDSHIP OF PLANT & ANIMAL COMMUNITIES

The land within what is now Marin County is home to an abundance of plant and animal species that live in a diverse variety of habitat types. Several of these are forest types that are the focus of the *Forest Health Strategy*, such as Coast Redwood, Douglas-fir, Open Canopy Oak Woodlands, Sargent Cypress, and Bishop Pine. In this discussion of ethnobotany Coast Redwood, Douglas-fir, Sargent Cypress, and Bishop Pine will be addressed together as conifer forest. The reason for this is that there are fewer food, tools, and medicines in the conifer forest types than in oak woodlands and other areas, so less space is needed to discuss these forest types. Oak woodlands will be addressed alone, as well as chapparal and shrubland, grasslands and meadows, riparian and wet environments, and coastal and intertidal environments, as these ecological zones are also very important to the Tribe's people and culture. As all things are related, and the stewardship of one area impacts another, the stewardship of forests further inland or higher up the watersheds may have dramatic impacts on the fisheries and environments further downstream and out on the coast. These sections will provide a sketch of culturally significant plants and stewardship practices to illustrate relationships and the importance of working with the Tribe in designing and implementing appropriate projects. Maintaining good communication and working relationships will ensure better protection and informed decision-making about tribal cultural and ecological heritage and facilitate tribal stewardship on the Tribe's culturally affiliated lands into the future.

CONIFER FORESTS

The predominant conifer species of Marin County are coast redwood (*Sequoia sempervirens*), Douglas-fir (*Pseudotsuga menziesii*), Sargent cypress (*Hesperocyparis sargentii*), and Bishop pine (*Pinus muricata*). The nuts of Bishop pine can be eaten even though they are not the most highly sought after by California Native Americans in regions where gray pine (*Pinus sabiniana*) and sugar pine (*Pinus lambertiana*) grow abundantly (Chesnut, 1902; Goodrich et al., 1980, p.92; Welch, 2013). Considering the limited range of Bishop pine in Marin County and the fact that the other major conifers do not produce usable nut foods, conifer forests are probably more significant for their uses by Coast Miwok people as tools, construction materials, and medicines rather than a major source of food. Redwood bark, for instance, can be used as siding for houses and other structures (Collier & Thalman, 1991), and the branches and leaves of many different conifers can be used for controlling the flow of water during acorn leaching. While redwoods do not produce a lot of sap or pitch that is readily accessible on the exterior of the tree, Douglas-fir (especially when recently burned or damaged), Bishop pine, and other various pines are good producers of pitch for glue. Pitch glue is used to secure stone projectile points and feathers to arrow shafts as well as aid in the construction of many other tools and ceremonial items (Collier & Thalman, 1991).

In thinking about the cultural value of conifer forests, it is important to consider that the condition of these forests is very different today than what it was in the past. For instance, logging has increased the prominence of Douglas-fir forests (as opposed to mixed evergreen forest or redwood) on the coast in the past 100 years (Goodrich et al., 1980, p.2). Douglas-firs in particular are voracious growers that pierce through the canopy of smaller hardwoods and crowd them out. Without the Tribe's stewardship of these forests in Marin County, conifer forests become overgrown and reduce the abundance and productivity of their culturally significant associates.

Some significant associates of redwood and Douglas-fir are tanoak (*Notholithocarpus densiflorus*), hazel/hazelnut (*Corylus cornuta*), and berry plants such as strawberry (*Fragaria vesca*), blackberry (*Rubus ursinus*), and huckleberry (*Vaccinium ovatum*), which are all used for food. Hazelnut is also used for tools such as arrow shafts and basketry, but it needs to be burned in order to produce useable material (Marks-Block et al., 2021). Some significant associates of Sargent cypress are manzanita (*Arctostaphylos* spp.) and California lilac (*Ceanothus* spp.), used for food and soap respectively (Collier & Thalman, 1991; Goodrich et al., 1980). These types of woody plants that are also abundant in chaparral environments have provided a regular supply of hardwood firewood, in addition to the use of other hardwoods and conifers for firewood throughout thousands of years of living in Central California (Cuthrell, 2013; DeAntoni, 2015; Nelson, 2017b). Many of the herbaceous understory plants within conifer forests also provide food for deer and other forest creatures that are a source of food and tools for Coast Miwok people. As is stated by Bowcutt (2013), "By design they [California Native Americans] created cultural landscapes with fire where grassland and tanoak groves thrived in a region naturally dominated by coniferous forests" (p. 72). Stewardship of conifer forests, especially the use of fire to thin and open up the tall, dense canopy, allows for their associate species like tanoak, hazelnut, and huckleberries to thrive and creates much more food and habitat for humans and animals in areas that would otherwise become similar to food deserts if left untended (Anderson, 2005; Lightfoot & Parrish, 2009; Marks-Block et al., 2021).

OAK WOODLANDS

Oak woodlands are a very important and culturally significant forest type for food, medicine, and cultural materials. Oaks provide acorns, which are one of the most important traditional staple foods for Coast Miwok and many other Native American peoples in California. Acorns are made into many different products but most notably acorn mush/soup or acorn bread (Collier & Thalman, 1991; Smith, 2014). Oaks also provide many other products used for tools such as acorn mush stirring sticks, baskets, firewood, teeth cleaning agents, and dye (Anderson, 2009; Collier & Thalman, 1991). Stewarding oak woodlands with fire enhances acorn production as well as stimulating the growth of new strong and flexible shoots from the basal portions of the tree (Anderson, 2005, 2009). As with many other culturally significant plants, removing stewardship practices from oak forests has made it increasingly difficult to find highly productive acorn trees as well as shoots with the right qualities for specific tools.

In previous centuries, mature oaks that were good producers of acorns were tended very closely and cared for by individuals and families who marked these trees so others would know who was caring for and gathering from them (Collier & Thalman, 1991, p.193). Stewardship of woodlands involves a year-round process of weeding, coppicing, and burning at appropriate times to keep the understory of oaks and other trees clear and free of debris (Anderson, 2005). In the fall when the acorns ripen, the immature and pest infested acorns will fall first and can be burned to reduce the pest population for the next year (Anderson, 2005). Clearing the forest floor through burning or other means can also facilitate the efficiency of gathering, which is not possible in much of the Tribe's territory today due to "hands-off" policies (e.g., wilderness areas in National Parks) and a patchwork of different private ownerships of land that have not allowed for such Indigenous stewardship practices in Marin County. In August 2021, the Tribe and Point Reyes National Seashore (PRNS) entered into a General Agreement which creates a solid partnership in the management of PRNS in cultural resource protection and stewardship, traditional ecological knowledge, education, research, revitalization of community and tradition, and the overall stewardship of Park lands and places. These types of agreements and co-management agreements lend themselves to creative and beneficial strategies for land stewardship but also for forest health strategies.

Acorns gathered in the fall are dried, and stored until they are needed (Anderson, 2005; Collier &Thalman, 1991). Acorns can be gathered as they fall or are knocked from the tree. The practice of knocking nuts or berries from many different trees and bushes was, and still is a common practice in some areas, that not only facilitated the efficiency of gathering but also served to break off old, dead, and weakened limbs from trees to keep them healthy (Anderson, 2005). These old limbs of oak or other trees and shrubs can then be used as firewood or otherwise burned with no harm to a productive nut or food tree. Young trees and shrubs growing in between productive, mature trees can also be taken as firewood in the stewardship of woodlands and forests (Anderson, 2009).

The two most highly sought oak species for food in the northern and coastal areas of Central California, especially for acorn mush, are tanoak and black oak (*Quercus kelloggii*), though other varieties of oak are also used (Chesnut, 1902; Collier & Thalman, 1991; Goodrich et al., 1980; Smith, 2014; Welch, 2013). There is some sense that people in the past used the acorns they had in their area regardless of type, but people in the past, as well as today, also sought out and continued to gather preferred acorns despite being more distant from these sources. Some species with lower fat content acorns, such as Valley oak (*Quercus lobata*), can also be mixed with a higher fat variety such as black oak to improve the flavor and richness of the mush (Anderson, 2009).

There are many associates of oak woodlands that also have cultural significance for Coast Miwok people. California bay laurel (*Umbellularia californica*) produces an edible fruit and nut that are used for food by many Tribes in Central California as well as elsewhere (Anderson, 2005; Chesnut, 1902; Collier & Thalman, 1991; Goodrich et al., 1980; Lightfoot & Parrish, 2009; Smith, 2014; Welch, 2013). Generally, the nuts are roasted and then pounded to make a cake or ball of the nut flour, used for food at home or for extra energy while traveling (Collier & Thalman, 1991; Smith, 2014). The leaves of bay laurel can also be used for medicinal purposes, as a scent blocker while hunting, and for pest control. Madrone (*Arbutus menziesii*) has berries that are edible and also bark that can be used medicinally. Angelica (*Angelica* spp.) is a plant with edible greens, stalks, and root that can also be used medicinally (Collier & Thalman, 1991). The bulbs of soaproot (*Chlorogalum pomeridianum*) can be baked and eaten or used for glue or soap, and the fibers can be made into brushes for a variety of different purposes. Winter Purslane (*Claytonia perfoliata*), yerba buena (*Clinopodium douglasii*), and many other herbaceous plants in woodlands can also be eaten or have medicinal uses (Collier & Thalman, 1991; Smith, 2014). California Buckeye (*Aesculus californica*) is another very important woodland associate producing edible nuts for food, though they also require leaching and processing before they can be eaten. The shoots and branches can also be used for hand drill kits to start fires (Collier & Thalman, 1991, pp.186,194), and they factor into many stories about the origins and place of fire in the world of Miwok peoples (Merriam, 1910).

There is some overlap in animal species between different plant communities, but the oak woodlands are the most productive food areas and thus hold many of these species as well. Deer and elk, for instance, can be found in conifer forests, woodlands, chaparral, and grasslands and meadows depending on what time of year it is and where they can find food, water, and protected bedding locations. As aggravating as the crunchy, dry fall leaves of oaks and madrones are for hunters and other predators, these environments provide the perfect natural alarm bells and locations for deer to bed down safely. Deer and elk provide a large amount of meat as well as other products such as bone awls for basketry, antler tines for flintknapping, antler wedges for splitting logs, and sinew for cordage, binding, and bowstrings (Collier &Thalman, 1991). These areas also hold squirrels and other small mammals that are hunted for food and many species of birds, including robins, quail, Northern flickers, hawks, and eagles, some of whom are hunted for food and others whose feathers are used in basketry or to make the brilliantly orange and black head rolls of a dancer's regalia (Collier & Thalman, 1991).

When forests are stewarded for ecological benefit and increased habitat, deer populations will increase, as is common in many areas of the Midwest and Eastern United States where deer populations are large enough to be considered a nuisance. Recent research has also shown the benefits of broadcast cultural burns as opposed to jackpot or hand-pile prescribed burns with no follow-up for promoting and maintaining elk habitat and populations (Connor et al., 2022). These benefits include an increase in winter forage such as grasses and forbs as well as a reduction in predation risk (Connor et al., 2022, pp.1880-1881). This research strongly supports the assertion that it is imperative to work with the Tribe to plan and implement prescribed burns informed by Traditional Ecological Knowledge (TEK). Where habitat for deer and elk is good, these large ungulate populations can negatively impact populations of rare and important native species if not kept in check by the presence of human and non-human (lions, grizzly bears, wolves, etc.) predation (Waller & Reo, 2018). Robust hunting programs such as those in place on the Ojibwe reservations of the Great Lakes region have been shown to keep deer populations in check to the benefit of rare native species of understory plants (Waller & Reo, 2018). Taking plants and animals for cultural use and adhering to Indigenous TEK protocols is just as important as habitat creation and increasing species populations for maintaining balance and sustainability within the overall cultural-environmental system.

CHAPARRAL & SHRUBLAND

Some culturally significant chaparral and scrubland plants are manzanita, toyon (*Heteromeles arbutifolia*), ceanothus, chamise (*Adenostoma fasciculatum*), California sagebrush (*Artemisia californica*), and yerba buena. Small hardwood shrubs such as manzanita were and still are preferred for firewood, specifically for heating hot rocks and producing parching coals for different culinary techniques (Collier & Thalman, 1991, p.186; Smith, 2014, p.49). Before contact with Europeans, coyote brush (*Baccharis pilularis*) and ceanothus were prevalent species used for firewood in the Tolay Valley in the eastern part of the Tribe's territory, even though they are rarely found in the valley (or not at all in the case of ceanothus) today because of more than a century of ranching and agricultural activities and impacts (DeAntoni, 2015; Nelson, 2017b). These shrubs were most likely selected for the ease of breaking off or trimming limbs from these plants, some of which may have fallen or broken off while knocking manzanita trees for berries. This type of pruning helps keep these plants healthy and producing abundant berries while gathering a sustainable source of firewood. Aside from berries, firewood, and some tools, the other plants within chaparral are mainly used for their medicinal properties, such as California sagebrush and yerba buena (Collier & Thalman, 1991; Smith 2014).

Stewardship techniques such as the knocking and pruning of manzanita as well as burning chaparral is important for maintaining the health and productivity of these plants, and it also provides pathways for travel and hunting. If untended, chaparral can become so overgrown that it is nearly impenetrable. If the patches of shrubs are spaced out, rabbits, quail, and other animals will have plenty of areas to protect themselves from predators, but the pathways between will facilitate flushing animals out of hiding and into basket traps or into the open where hunters have a clear shot. Rabbits are eaten and their furs used for blankets, and quail are also eaten and their topknots incorporated into the beautiful designs of baskets (Collier & Thalman, 1991). One animal that loves the dense cover of un-stewarded chaparral and mixed-conifer forests is the wood rat (*Neotoma fuscipes*). These animals can build cone shaped dens of sticks and debris that enhance the clutter and fire danger in these areas. Opening up chaparral and conifer forest allow hunters and predators to access wood rats and keep down the buildup of fuels that they produce in these areas, and they also provide a delicious source of food (Collier & Thalman, 1991).

GRASSLANDS & MEADOWS

Grasslands and meadows are areas with very productive seed food plants as well as greens, roots, and materials for tools. Some common plants include a wide variety of grasses (*Poaceae* spp.), tarweed (*Hemizonia* spp., *Madia* spp., etc.) red maids (*Calandrinia menziesii*), Indian potatoes (*Dipterostemon capitatus*, *Brodiaea* spp. and *Triteleia* spp.) soaproot, and clovers (*Trifolium* spp.). Seed foods are beaten into a conical burden basket with a paddle shaped seed beater (Collier & Thalman, 1991). This gathering technique intentionally spreads seeds on the ground at the same time that most of them are gathered so that the gatherer does not deplete the seedbank and ensures that new plants will grow in subsequent years (Anderson, 2005). Grasslands, and forests surrounding grasslands and meadows, can also be burned to increase water flow and hydrologic connection, increasing the productivity of the plant life in these areas (Long et al., 2021). Often what is seen in grasslands that are burned and actively managed is a return of many wildflowers that were not present or very rare before burning is introduced. This is the situation that is being seen on the ground currently at Audubon Canyon Ranch's Bouverie Preserve in Glen Ellen, California (Coy, 2019).

RIPARIAN & WET ENVIRONMENTS

Riparian areas that are woven through the different forest types also have many culturally significant plants including oak, conifers, California bay laurel, various berry plants as mentioned with conifer forests, and a few others such as thimbleberry (*Rubus parviflorus*) and salmonberry (*Rubus spectabilis*) that are also found in conifer forests, willow (*Salix* spp.), sedge (*Carex* spp.), tule (*Schoenoplectus acutus*), and sundry herbaceous plants such as mugwort (*Artemisia douglasiana*). Since many of these plants have been discussed in other sections, the focus of this section will be willow and sedge, which are very important basketry plants. Willow has many different uses such as frames for shade structures, houses, and granaries as well as many other tools in addition to baskets. Gray willow (*Salix exigua* var. *hindsiana*) is especially preferred for basketry (Collier & Thalman, 1991). Twined baskets can be made exclusively from willow; some of these baskets can be large and conical for trapping fish, quail, and other birds while others can be made flat for drying seaweed, or very broad, tall, and tightly woven to facilitate gathering and carrying foods (Collier & Thalman, 1991; Shanks & Woo Shanks, 2006). Similar twined baskets can be made more expediently from tule, which is a very versatile material that is also used for building boats and thatching on houses and granaries, but willow will make a stronger and longer-lasting basket (Collier & Thalman, 1991).

Very fine coiled basketry can be made from peeled and split sedge roots that are threaded around a core of two or three finely peeled willow sticks (Collier & Thalman, 1991; Shanks & Woo Shanks, 2006). These coiled techniques can produce intricate and elaborate designs in combination with other plant materials, bird feathers, and shell beads and pendants. Coiled basketry can also produce baskets that are so finely and tightly woven that they can hold water and be used with hot rocks to boil water and cook foods, including acorn mush.

The craft of basketry heavily depends on the relationship of the weaver with the materials they tend and the stewardship practices that enhance the qualities of each of these materials. Some of these materials, such as hazel, need to be burned. Others, like willow, may only need to be coppiced but can be burned as well, which is beneficial for the plant (Lake, 2007; Ortiz, 2008). Burning and coppicing removes dead limbs and prompts willow to grow new, straight shoots. These fresh, young shoots are more regular and usable for basketry than old ones, because many more of the old shoots can become infested with insects. The larva grow inside the willow branches and the willow creates a gall around the insect. This creates many irregular bumps throughout the sticks that are also hollow and weak. They cannot be shaved or bent or else they will break. Similarly, sedge must be stewarded, otherwise it will grow irregularly in the ground with tighter clusters of plants that produce shorter rhizomes. Tending sedge involves thinning out these plants as well as removing obstructions in the ground so that the roots grow unobstructed and straight from plant to plant as it fills in the sedge bed throughout the next year after it was last gathered.

Rainbow trout/steelhead trout (*Oncorhynchus mykiss*), coho salmon (*Oncorhynchus kisutch*), Chinook salmon (*Oncorhynchus tshawytscha*), and sturgeon (*Acipenser* spp.) are culturally significant fish in riparian areas as well as the bays and ocean off the coast of Marin. These fish are eaten, and the skin or organs can be used to make glue (Collier & Thalman, 1991; Welch, 2013). Though there is little published information on the connection between fish and fire, some studies in Northern California are showing how fish habitat benefits from fire (Long et al., 2021; Norgaard, 2016). When other trees and plants are burned on a landscape scale, it releases more water increasing the flow in the watershed (Long et al., 2021, p.10; Norgaard, 2016, p.83). After fire, gravel and wood debris also wash into streams and rivers which help produce structure and habitat for fish (Norgaard, 2016, p.83).

COASTAL & INTERTIDAL ENVIRONMENTS

Many coastal plants, animals, and fish are culturally significant for Coast Miwok people as well. Some of these coastal species are the anadromous fish discussed in the riparian and wet environment section. Others include a very diverse array of saltwater fishes, sea mammals, and shellfish as well as various types of seaweeds (Baker, 1992; Collier & Thalman, 1991; Ortiz, 1998). These plants and animals are used for food as well as for tools. In the case of shellfish, thick white clamshells are made into disk beads and abalone shells are made into pendants (Collier &Thalman, 1991). Driftwood is also gathered for cooking and heating, such as after abalone gathering (Smith, 2014). Many of these marine resources were also stewarded in the past; for example, by having specific gathering areas for clams that were cared for by specific individuals or families (Collier & Thalman, 1991), and the Tribe's citizens still practice sustainable pruning techniques for gathering seaweed that invigorate growth without removing an entire plant by the holdfast. Beach strawberries (*Fragaria chiloensis*), wild onion (*Allium* spp.), and lupine (*Lupinus* spp.) are some other examples of significant coastal plants. Strawberries and onion are eaten, and the roots of lupine can be made into cordage (Collier & Thalman, 1991; Goodrich et al., 1980; Ortiz, 1998; Smith, 2014).

Connections between land and sea are very important for Coast Miwok people and the plants and animals living in what is now Marin County. Stewardship practices from the tallest mountains will have impacts, positive or negative, that can affect the productivity of the system downstream all the way out to the ocean. Creating habitat for anadromous fishes upstream ensures that these species are abundant in the oceans, and larger animals in the ocean can continue to feed on them as well. Burning within forests and woodlands to increase the water flow of streams and creeks may also help lessen or slow the intrusion of salt from sea level rise into the mouths of rivers and streams and coastal dunes where many culturally significant plants grow. However, sedimentation and erosion from deforested hillsides and poorly built or maintained roads can cause major shifts in waterways and impact fish and other organisms in streams and bays.

IMPACTS FROM COLONIALISM

> Because national territories were small—and boundaries strictly observed—tribes took great care not only of their relationships with other groups of people but also of their relationship with the land. No part of the landscape was unknown to aboriginal Californians, and they managed their resources carefully. We knew where quail nested, and we kept waterways clear of brush for ducks and geese, both to encourage the migratory waterfowl to nest and to make hunting them easier. Sedge roots were thinned and pruned to grow longer, stronger fibers for basket making, and the land was regularly burned for a variety of reasons related to the plants and animals we depended on for survival. One of the first laws the Spanish explorers and settlers imposed on us was against controlled burning, as they believed we were setting the land on fire to starve their livestock. In fact, we practiced controlled burning for a number of reasons, one of the most important being for the health of the oak trees, which gave us the acorn, our staple food. (Sarris, 2018, p. 111)

Tribal stewardship before the disruptions of colonization produced a diverse landscape of many different forest types and environmental areas that were interconnected and supported habitat for animals as well as sustainable sources of food, tools, and medicines. Instead of massive areas of a single resource type such as Douglas-fir, many smaller grasslands, shrublands, woodlands, and forests were woven together in a patchwork across the landscape that facilitated efficient and productive access to these resources for people in those local areas. Today, we see remnants of what the landscape used to be before contact with Europeans, as well as vast swaths of variously managed public and private lands that have undergone significant changes due to economic pursuits, environmental degradation, environmental policies, conservation efforts, and climate change.

Colonization brought successive waves of invaders to the shores of Coast Miwok people's lands. The first began as a trickle of English and Spanish ships scouting the West Coast throughout the 1500s through 1700s (Lightfoot & Simmons, 1998). In the late 1700s, the Spanish established missions, pueblos, and presidios beginning with San Diego in 1769 and ending with San Francisco Solano (Sonoma) in 1823 (Bauer, 2016; Hackel, 2005; Jackson & Castillo, 1995). These missions forcibly removed many people from their homes to serve as laborers at the various mission sites around the San Francisco Bay Area from 1776 to the early 1830s, after Mexico won its independence from Spain and the missions were finally secularized. In the 1830s, Coast Miwok people within the mission system were moved again to ranchos where they were expected to provide labor for various Mexican landowners such as Mariano Vallejo on his Rancho Petaluma (Silliman, 2004). The restrictions on Coast Miwok people's lives and livelihoods became even greater in the mid- to late- 1800s during the first decades of California statehood within the United States. Events like the massacre at Clear Lake in 1850 and other acts of violence against California Native Americans resulted in a tremendous loss of life (Madley, 2016). Around this same time in the late 1800s, Coast Miwok people in Marin County fought and lost court battles over the title to their lands in Nicasio or 'echcha tamal. Land dispossession led many to move to the edges of now American-owned ranches along the shores of Tomales Bay. Coast Miwok people made their living through wage labor on farms and continued to hunt, fish, and gather to supplement their diets and trade oysters and clams at the market for store credit into the mid-1900s, even though stewardship relationships with these areas were impacted. Early bans on Native American burning and criminalization of setting fire to the landscape, as presented by Johnston-Dodds (2002), as well as other federal policies of wilderness on public lands and parks, served as barriers to Tribal stewardship in what is now Marin County.

The last of the land dispossessions came during the years following World War II. Many people were forced to leave their homes because they could not pay the newly required taxes on the places where they were living. Many people moved to major cities in the various Bay Area counties such as Santa Rosa, Petaluma, Vallejo, Oakland, and San Francisco. One Coast Miwok and Pomo family held on to a 1-acre parcel of land from the Graton Rancheria, a rancheria originally designated for Indian peoples from Southern Sonoma and Marin Counties. The Tribe was wrongfully terminated along with many other Tribes during the post-WWII termination policies instituted by the U.S. federal government. It was not until the early 1990s that Coast Miwok and Southern Pomo peoples reorganized, and the Tribe finally had its federal recognition restored in the year 2000. This change in status, as a federally recognized Tribe, brought with it certain rights, including the rights of self-government, Tribal sovereignty and jurisdiction, acquiring trust lands in 2010 and again in 2023, economic development, formal government-to-government relationships with local, state, and federal agencies, and the ongoing trust relationship with the federal government. (H.R. Rep. No. 106-677, 2000).

BARRIERS TO ACCESS

Though the Tribe's story is one of success, there are still barriers and access issues within the Tribe's ancestral territory that make it difficult to engage with tribal lands and resources. Much of the land in Marin County is owned privately and there is no access for the Tribe's citizens to hunt, fish, gather, or engage with those areas. Ocean fishing is the best opportunity to engage with legally permitted traditional animal resources, however fish such as salmon and steelhead trout in freshwater environments are endangered and cannot be fished. On public land there are only a few opportunities for hunting, primarily waterfowl, because there is no Bureau of Land Management or U.S. Forest Service land within the Tribe's territory. The only publicly permitted opportunities to gather plants in parks include berries and mushrooms. A few additional resources, such as basketry materials, are made available to California Native Americans through negotiations by Tribes in California and continue to be gathered. However, many California Native Americans continue to gather in unpermitted areas in order to access resources they need to continue cultural practices and access traditional foods (California Indian Museum and Cultural Center, 2020).

Aside from purely permitting and permission issues, the other major barrier to accessing resources has been the removal of the Tribe's stewardship from the land that has made many areas unproductive or very inefficient for cultural gathering purposes. For example, oak woodlands that are not burned produce acorns riddled with weevils and other pests and are unusable for food. Acorns in unburned woodlands are also more difficult to see on the ground amongst the leaf litter making gathering much less efficient. And unburned hazel will not produce the long, straight, young shoots that are used in basketry. Currently, many public lands are managed very minimally, hardly any are burned, and some are designated as "wilderness" areas that are left to themselves and become severely overgrown. This type of land management is guided by an idealized pristine version of nature from which humans and cultural influences are viewed as separate and even negative. These ideas are very clearly outlined in how the Wilderness Act of 1964 defines the concept of wilderness as an area "where the earth and its community of life are untrammeled by man, where man himself is a visitor who does not remain…land retaining its primeval character and influence, without permanent improvements or human habitation" (Section 2c). This separation of people from nature in the Wilderness Act, or how it plays out in Marin County as the removal or exclusion of the Tribe's citizens and stewardship from the Tribe's territory, is contrary to the Tribe's traditional relationships with and responsibilities to these ancestral lands and waters.

While the Wilderness Act of 1964 is problematic in many ways, and some scholars such as Laura Watt and David Lowenthal (2017) have critiqued the inconsistent application of it within Point Reyes National Seashore (PRNS), it does provide protection for these areas and allows for existing non-conforming commercial uses and non-motorized activities. Tribes were not intimately involved in the creation of these policies or the implementation of them in Marin County. Thus, agencies and land managers will need to think more inclusively and creatively about these laws and policies and work collaboratively with the Tribe to ensure TEK and stewardship practices are appropriately incorporated in land management activities on the Tribe's ancestral lands. By entering into the General Agreement with the Tribe, PRNS has demonstrated its commitment to partnering with the Tribe in all areas of land management. This is a bold example of what cities, counties and the state can do to achieve not only forest health, but strong stewardship practices for generations to come.

ENVIRONMENTAL IMPACTS FROM COLONIALISM

Preston (1997) presents five main sources of environmental disturbances to landscapes in California from colonialism. These sources are grazing and ranching, agriculture, mining, hunting and fishing, and timber. Though evidence for the early appearance of nonnative and/or invasive species in California has been found in the foundational mud bricks of Mission San Diego from 1769, these species became even more pronounced and established with the ranching practices of American settlers grazing cattle throughout the last 170 years (Hendry, 1931; Hendry & Kelly, 1925; Mensing & Byrne, 1998; Nelson, 2017a). It is estimated that upwards of 90 percent of the grasses in California are now nonnative species (Mensing & Byrne, 1998, p.757; Preston, 1997, p.273). Agriculture and mining have involved using and reshaping land in aggressive ways that have also caused damage to waterways through sedimentation and chemicals seeping into groundwater (Preston, 1997).

Overhunting and fishing have completely extirpated Grizzly bears and wolves as well as fur seals (Preston,1997). Sea otters are rare along most of the coastline due to overhunting, which has caused a tremendous imbalance in kelp forests with the recent decline of sea stars (Steinbauer, 2020). This decline has caused an increase in urchins feeding on and destroying kelp forests, which are also habitat for abalone, resulting in the closure of the abalone fishery for the next several years. Abalone are a culturally significant species for food, tools, and ceremonial items, and they also play a central role in origin stories about how sunlight was brought into the world (Collier & Thalman, 1991; Merriam, 1910). An inability to interact with these species will have impacts on the Tribe and its citizens, and these impacts will persist into the future unless care is taken to restore balance in the coastal ecosystems where these sea creatures live.

The timber industry has also caused massive devastation within old growth forests by clear-cutting many of the oldest trees. This industry aggressively killed culturally-significant trees such as tanoak during the late 1800s and much of the 1900s in order to maximize space for the most economically profitable trees sold as lumber (Roy, 1956). Tom Smith, a Coast Miwok elder, also recalled that many tanoak trees were cut down for the use of their bark to tan hides in the decades preceding the 1920s, when he was interviewed (Collier & Thalman, 1991, p.37). In addition to more than a century's worth of assaults on one of the most significant nut-bearing food trees in the Tribe's ancestral territory, tanoaks are now dying from sudden oak death (SOD, caused by *Phytophthora ramorum*), a disease to which tanoaks are especially susceptible (Bowcutt, 2013). Given that these trees have been continually abused, current agency efforts to manage tanoaks and sudden oak death should be marshalled to facilitate new growth of tanoak trees that provided Coast Miwok people with sustenance for thousands of years.

The extremes of land and forest management in the wilderness settings of public lands and timber practices on private lands continue to cause challenges to the Tribe's cultural practices and engagement with ancestral lands. Settler colonial policies and practices left massive fuel loads building in forests that, paired with extreme drought and weather patterns due to human-induced climate change, have caused and will continue to perpetuate some of the worst fires in California state history, such as those that have been recorded by CAL FIRE (2021) in the last decade. These fires are of grave concern with expanding urbanization around open space and wilderness areas, and present challenges to public safety and private property. Fire suppression alone cannot address the fire crisis in the Western United States, and so land managers need to be working with the Tribe to steward these areas in more sustainable ways (Schelenz, 2022).

As the previous discussion illustrates, these stewardship and management decisions can have severe impacts on tribal cultural and environmental resources that dramatically change the resources that are available and accessible to the Tribe's cultural practitioners. Regulating access or denying access is another form of land dispossession that continues to separate the Tribe, Tribal citizens, and Tribal youth from the Tribe's ancestral lands. Stewardship decisions and policies generated through consultation, collaboration and co-management with the Tribe will begin to address this less visible form of settler colonialism and allow for restoration of the Tribe's cultural traditions and relationship with culturally affiliated lands. Stewardship decisions and policy generated through collaboration with the Tribe will begin to address this less visible form of settler colonialism and allow for the restoration of the Tribe's cultural traditions and relationships within their culturally affiliated lands.

CULTURE, HEALTH, WELLBEING, & THE FUTURE

These are the words of Coast Miwok elder, Tom Smith (Ortiz, 1993):

> Listen all of you who have come here for these doings. Listen to what the Father has revealed. A man with no family has no history and no eyes to see the future. He goes about blind. Our family, our relatives, are not only those around us, they are also those who have gone before us. They are our history. They gave us our ways and we are to be the teachers of our tradition. If we lose our ways, our history, we will be lost and there will be no one to tell us where to go. That's why those Indian things and doings are so important; they are our eyes and our children's eyes. The Father commanded this be said to all of you here. (p.1)

Cultural traditions and identity are very important components of human health and wellbeing that have undergone several attacks from settler colonialism including attempts to convert Coast Miwok people to Catholicism, removal from lands and forced labor practices, attempts to assimilate Coast Miwok children in boarding schools, and contemporary challenges and barriers to cultural, language, and land restoration efforts (Ortiz,1993). Agencies and residents in Marin County have an opportunity to work with the Tribe to provide support for Coast Miwok and Southern Pomo peoples, open access to land, and support the perpetuation and protection of tribal cultural and environmental resources and practices. As Tom Smith's words indicate, these practices and relationships to land, resources, and heritage will keep the Tribe strong and healthy and allow the Tribe's citizens many more possibilities for how they determine their futures. As climate change intensifies, land managers and the Tribe's leadership and representatives will undoubtedly be faced with difficult decisions about how we shape our future. It is crucial to the health and wellbeing of the Federated Indians of Graton Rancheria that these decisions about and in the Tribe's culturally affiliated lands are made with the Tribe so the Tribe’s interests, rights, and responsibilities are accounted for now and far into the future.

RECOMMENDATIONS

CONSULTATION & COLLABORATION

- County, local government, and agencies in Marin County have a responsibility to conduct meaningful consultation with the Tribe in good faith. The Tribe should have decision-making authority as a partner, meeting early and often with other partners and decision-makers, so that projects can be co-developed. In developing these partnerships and projects, a priority should be to establish access agreements that enable the Tribe to perpetually use and steward the areas considered according to cultural protocols and responsibilities beyond the single project or program.
- The Tribe’s history, culture, and TEK or TK are the intellectual property and cultural patrimony of the Tribe. Information and data sharing about these topics is a matter of Tribal sovereignty and the Tribe’s ability to self-determine appropriate protection of this patrimony for future generations. In educating others or sharing any information about the Tribe and the Tribe’s TEK or TK, great care and measures for maintaining the confidentiality of sensitive information must be considered and implemented in consultation and collaboration with the Tribe—that is, working directly with the Tribe’s government on these issues or officials who have been tasked by the Tribe’s government with these specific responsibilities.
- Develop deeper and more meaningful partnerships with the Tribe for planning efforts and for future management of public lands for ecosystems health and to provide access to traditional resources (co-management, gathering specific plants, hunting, etc.).
- Meetings between the Tribe, One Tam partners, and others should take place early and often to engage in the development and planning of projects, programs, and initiatives. Use these meetings to increase shared learning and understanding between the Tribe and Marin land managing agencies, and to look for opportunities to partner.
- Identify research questions and data gaps that exist for the Tribe and use these as opportunities for collaboration with One Tam land managers.
    - For example, and not to be used in lieu of official Tribal consultation, a few suggestions for research questions could be:
        - Where do plant and animal species occur in Marin County? Create a baseline plant and wildlife map/database through ongoing surveys and continue to update it and share these resources with the Tribe.
        - How do different land management techniques (no treatment, cutting/thinning, grazing, prescribed burning, cultural burning, planting/restoration, etc.) impact different plant and animal communities positively and negatively?
        - How is climate change impacting plant and animal populations? What strategies can help slow down or halt these impacts?

    - How can the impacts of sudden oak death (SOD) be slowed? What preventative measures and treatments are available?

STEWARDSHIP IN PRACTICE

- Work in collaboration with organizations, the Tribe, and tribal citizens designated by the Tribe who are studying the efficacy of different stewardship techniques such as prescribed and cultural burning. This could include monitoring efforts and adaptively managed areas and resources that could inform best practices throughout Marin County.
- Work collaboratively with the Tribe to plan and implement prescribed burns, including cultural burns on public and private lands within Marin County.
- Gathering native species of plants is a traditional Tribal practice, and the Tribe and its citizens must be able to obtain permission and access to gather food, medicine, basketry/tool materials, and other plant and animal products throughout Marin County. The Tribe's gathering practices must also be included when considering how to steward or manage public lands in Marin County. Ensure that cultural plant species are safe for handling and traditional uses. For example, consider whether chemicals are used on or around cultural species for treatments such as slowing the regrowth of brush around power lines and roadsides, controlling the spread of invasive species, using drip torches for prescribed burns, using retardants for fire suppression, etc. Considering how chemicals are used on Marin County lands should be planned and implemented in consultation with the Tribe, and this effort may involve creating and sharing a layer of GIS data showing any areas where chemicals or other materials of concern are used. Also consider facilitating gathering culturally significant resources by Tribal citizens prior to or during fuels reduction or prescribed burn projects. For example, some fire-killed trees or snags that may not have obvious cultural value, may serve as perfectly seasoned wood for bows or other tools rather than being chipped or completely burned.
- Despite there being little or no public land where the general public can hunt (depending on species), hunting is a traditional Tribal practice, and the Tribe and its citizens must be able to obtain permission and access to hunt throughout Marin County. The Tribe's hunting practices must also be included in considering how to steward or manage public lands in Marin County. Research shows there is an overabundance of deer in Marin County (Furnas et al., 2020), and hunting and wildlife management decisions should be made based on these scientific realities. Importantly, the Tribe’s rights and responsibilities to access and steward these cultural resources and animal relatives should be considered.
- Black oak and tanoak are necessary for the health of the Tribe's people and the continuance of their food traditions. Protect these preferred oak species for acorn gathering. These species are more susceptible to sudden oak death, so it is crucial to work collaboratively with the Tribe, Tribal and non-Tribal scholars, and others to better understand how they can be protected.
    - Plan further study on tanoaks; looking for sudden oak death resistance.
    - Long-term tanoak care and management units; are there practices that reduce sudden oak death while not adversely affecting tanoak/black oak populations?

- Increase public education about preventing spread of sudden oak death – signs, website, add to trail maps, explore other creative ideas.

- Increase education and awareness in appropriate ways about FIGR Traditional Ecological Knowledge, cultural burning, and how stewarding healthy forests helps the Tribe and its citizens to continue cultural practices and is essential to the Tribe and its citizen's health and wellbeing. What work are the Tribe and land managing agencies in Marin County undertaking, and how can it be complemented and integrated across the landscape? Any education and outreach should be coordinated in consultation and collaboration with the Tribe to maintain the confidentiality of the Tribe's sensitive information and intellectual property.
- Protect cultural sites during large and small projects initiated by public land managers and fire agencies. All actions should be done in coordination and consultation with the Tribe.
- Collaboratively generate appropriate resources with the Tribe designed for land managers to facilitate their daily work in stewarding and managing Marin County forests. An example of such a resource could be comprehensive or representative lists of ethnobotanically and ethnozoologically significant taxa for the Tribe.
- Provide resources and build capacity for representatives of the Tribe to be able to visit sites as much as possible and as appropriate. Decisions about resources often involves developing relationships with these areas, and some areas have been inaccessible to Tribal citizens for decades or centuries. Opening access will ensure that the Tribe's leadership and representatives have the most information possible to make informed decisions to appropriately steward cultural and ecological resources.

TRIBAL ACCESS TO ANCESTRAL LANDS

- The Tribe's access and use of their traditional and culturally affiliated lands and waters should be expansive and continuous, not limited to the space of a single project or program. Envisioning and implementing these solutions for facilitating Tribal access, stewardship, and use of spaces in Marin County must be coordinated in consultation and collaboration with the Tribe. Some potential first steps toward facilitating access are as follows:
    - Waive parking and entrance fees for the Federated Indians of Graton Rancheria to access city, county, state, and federal parks, open space, and other lands and waters in Marin County.
    - Remove bureaucratic/economic barriers that make it difficult for the Tribe to access and interact with their traditional and culturally affiliated lands and waters. Work as partners with the Tribe to develop cultural easements on lands.
    - Facilitate cross-agency collaborations and government-to-government consultations to establish agreements about fishing, hunting, gathering, burning, and building cultural and environmental spaces for the benefit of the Tribe and the ecosystem. The Tribe's access, stewardship, and use of these lands and waters are integral to the health of the environment and the health of the Tribe.

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CHAPTER 4: CLIMATE CHANGE & OTHER FOREST HEALTH STRESSORS

This chapter reviews the stressors threatening the health and resilience of forest ecosystems in Marin County. Stressors were identified during the conceptual model phase of the project and include climate change, altered fire regimes (especially fire exclusion), recreation, soil compaction, pests and pathogens, and hydrological modification. The forest health stressors are interdependent, and one may exacerbate others. For example, climate change results in increased temperatures and altered precipitation, creating favorable conditions for pests, pathogens, fire, and non-native, invasive species. Non-native invasive species, habitat loss, and habitat fragmentation are widely acknowledged as major forest health stressors. However, these stressors are not addressed here since they are addressed in other plans and programs in Marin County. For example, see the One Tam Peak Health Report (Edson et al., 2016), Marin Wildlife Watch program, and One Tam Early Detection Rapid Response program.

CLIMATE CHANGE PLANS & ASSESSMENTS

Conceptual models developed for the five key forest types profiled in the *Marin Regional Forest Health Strategy* (*Forest Health Strategy*; Bishop Pine, Coast Redwood, Douglas-fir, Open Canopy Oak Woodland, and Sargent Cypress) identified stressors that negatively affect each forest type. The conceptual models provide a simplified depiction of how anticipated impacts from climate change, such as increased severity of storms, drought, and fire, are expected to impact forest health. In reality, interactions between climate change impacts and forest health attributes are highly complex, and multiple climate change impacts can compound one another, create feedback loops, or have runaway effects that are difficult to fully represent in a conceptual model diagram (Marin Water, 2019). To support deeper analysis beyond the conceptual models, this section summarizes anticipated climate change impacts from global to Marin County spatial scales and discusses the latest scientific evidence. Geographic and thematic scales organize this section, concluding with a focus on potential management and climate adaptation strategies that can be applied to improve forest health in the face of climate change.

IPCC & NATIONAL ASSESSMENTS

The Intergovernmental Panel on Climate Change (IPCC) *Fifth Assessment Report* states that greenhouse gases (GHGs) need to be stabilized to 450 ppm CO_2 equivalent or lower, and mitigation efforts must be strengthened immediately, to avoid two degrees or more of warming during the 21st century (IPCC, 2014).[1] The *Fifth Assessment* is unequivocal about anthropogenic causes of climate change, especially since the mid-20th century, maintaining that many of the observed changes are unprecedented: the atmosphere and oceans have

[1] The IPCC released the *Sixth Assessment Report* on March 20, 2023. In August 2021, the IPCC released *Climate Change 2021: The Physical Science Basis* (IPCC, 2021).

warmed, snow and ice have diminished, and sea levels have risen (IPCC, 2014). The August 2021 contribution of the IPCC Working Group I to the *Sixth Assessment* concluded with high confidence that atmospheric CO_2 concentrations in 2019 were higher than at any time in the previous two million years. Additionally, global surface temperature has increased faster since 1970 than in any other 50-year period over at least the last 2000 years (IPCC, 2021).

In the United States effects of climate change are projected to vary by region, as described in the U.S. Global Change Research Program's (USGCRP) *4th National Climate Assessment (NCA4) Volume I* (USGCRP, 2017) and *Volume II* (USGCRP, 2018), the most recent authoritative assessment of climate-change science, impacts, and risks to the United States[2]. A more recent report, *Advancing the National Fish, Wildlife, and Plants Climate Adaptation Strategy into a New Decade*, builds on observed climate change impacts on natural systems (National Fish, Wildlife, and Plants Climate Adaptation Network, 2021). A significant recommendation from this report is to integrate people into climate adaptation efforts associated with wildlife and ecosystems on which people depend. Additional recommendations include investing time and resources in education and training opportunities related to climate adaptation, employing adaptive management, integrating adaptation strategies across multiple jurisdictions, and integrating Tribal Knowledge and participation. Indigenous and local knowledge systems are increasingly used to further our understanding of the ecological transformations expected under climate change (Lam et al., 2020; Long et al., 2020). Unfortunately, the "sense of place" that underpins indigenous and other place-based stewardship practices may be disrupted as the species composition and appearance of places shift with climate change, potentially threatening cultural values and identities (Adger et al., 2013).

CALIFORNIA STATE CLIMATE PLANS & ASSESSMENTS

California has demonstrated a state-wide commitment to carbon reduction through several state laws. For example, the 2006 *California Global Warming Solutions Act* (AB 32) requires a sharp reduction in greenhouse gas emissions. It sets the stage for the State's transition toward a decarbonized, sustainable future (California Air Resources Board, 2018). Governor Brown signed Executive Order B-55-18 in 2018, which established a goal for the State to achieve carbon neutrality by 2045 and to maintain net-negative emissions, which means that more carbon must be sequestered (e.g., in vegetation) than released into the atmosphere (Ackerly et al., 2018).

California agencies have developed numerous strategies, plans, and reports devoted to addressing climate change, including ecosystem health and forest resilience-focused planning documents which provide helpful guidance for local decision-making. Agency collaboration produced California's *Fourth Climate Change Assessment*, compiling the information needed to make decisions to safeguard the people, economy, and resources of California during climate change (Bedsworth et al., 2018). California's *Climate Change Research Plan* (California Climate Action Team, 2015), *Indicators of Climate Change Report* (California Office of Environmental Health Hazard Assessment, 2018), and *Safeguarding California Plan: California Climate Adaptation Strategy* (California Natural Resources Agency, 2018) guide the *Fourth Assessment*.

[2] NCA5 is underway and is anticipated to be completed in 2023.

California's *Fourth Assessment* uses 10 Global Climate Models (GCMs) and two Representative Concentration Pathways (RCPs), selected to be most appropriate to predict climate change impacts to water resources in California (Bedsworth et al., 2018). To model climate extremes at a higher spatial resolution, climate variables were downscaled to finer grid cells using a consistent Localized Constructed Analogs (LOCA) method. The *Fourth Assessment* contains a regional report focused on the Bay Area that includes impact predictions for Marin County. A *Fifth Climate Change Assessment* is due in 2026 (Governor's Office of Planning and Research, n.d.).

The Fourth Assessment included a *Summary Report from Tribal and Indigenous Communities within California*, which provides an overview of climate science, strategies to adapt to impacts, and research gaps critical to making progress on addressing the impact on Tribal Communities from climate change (Goode et al., 2018). Notably the report includes a compelling case for approaches to climate change mitigation and adaptation that incorporates Traditional Ecological Knowledge (TEK) and underscores the disproportionate effect that climate impacts have on important resources for Indigenous communities including water. Climate impacts are exacerbated by the legacy of colonization, including lack of access for gathering or harvesting foods and medicines. The report includes a series of valuable recommendations, including the need for co-managers of land to form alliances and cooperatives with Tribes to share knowledge and techniques to include TEK, and to change policies to include tribal partnerships across all sectors of climate action. See Chapter 3: Stewardship and Partnership with the Federated Indians of Graton Rancheria for additional information and recommendations specific to Marin County

The *Fourth Assessment* states that implementing climate-wise movement corridors for terrestrial species will be a critical conservation outcome, which will start with connectivity assessments based on land use and land cover. An important conclusion for forested areas is that reducing stand density and restoring beneficial fire can improve climate resilience, decrease the likelihood of severe wildfire, and minimize the long-term carbon losses from forested areas (Bedsworth et al., 2018).

The California Air Resources Board (CARB) first published a climate scoping plan in 2008 to outline the state's strategy for meeting 2020 GGH emissions as described in AB 32 (CARB, 2008). The climate scoping plan update in 2017 (CARB, 2017) includes healthy forests as a priority for cap-and-trade auction resources, maintaining natural and working lands to sequester carbon, minimizing black carbon emissions from wildfire, and improved utilization of forest biomass from thinning projects. It is worth noting that remote sensing-based analysis indicates that stricter standards may be needed to increase confidence in the carbon benefits of California's cap-and-trade program (Coffield et al., 2022).

The CARB *Climate Change 2022 Scoping Plan Update* (CARB, 2022) outlines how California will get to carbon neutrality by 2045 and includes sections on carbon sequestration, reducing wildfires, and biomass management and utilization. CARB has produced other important planning documents, including a draft of the *California 2030 Natural and Working Lands Climate Change Implementation Plan* (CARB, 2019) and a *Climate Adaptation and Resilience Guidance* document in 2021 (CARB, 2021). The *Guidance* document identifies high wildfire risk areas and notes increasing fire insurance costs and risk to the community from wildfire (CARB, 2021).

The interagency *California Forest Carbon Plan* examines opportunities to reduce climate change impacts on forests and create resilient forests that act as carbon sinks rather than as sources of greenhouse gas and black carbon emissions (Forest Climate Action Team, 2018). The plan offers goals and actions to increase the pace and scale of forest and watershed improvements on nonfederal lands, support federal goals to improve forest health, prevent forest land conversion through conservation easements and acquisitions, create wood product and biomass utilization solutions, address research needs, and enhance the carbon sequestration potential of urban forests.

In October 2020, Governor Newsom issued *Nature-Based Solutions* Executive Order N-82-20 (Office of Governor Newsom, 2020), directing State agencies to accelerate actions to combat climate change, protect biodiversity, and build resilient nature-based solutions, including improved forest management. As part of that effort and building on the *Forest Carbon Plan* and California Forest Management Task Force (now California Wildfire and Forest Resilience Task Force), *California's Wildfire and Forest Resilience Action Plan* was developed (California Forest Management Task Force, 2021). The *Action Plan* discusses climate resilience, adaptation, and mitigation related to forest health management, with several goals aligning biodiversity, forest health, and climate change adaptation/mitigation strategies, and recognizes the work of One Tam as a regional leader in advancing landscape-scale reliance efforts (California Forest Management Task Force, 2021, p.75).

The *Climate Change Vulnerability Assessment of California's Terrestrial Vegetation* (Thorne et al., 2016) is a companion report to the California Department of Fish and Wildlife (CDFW) State Wildlife Action Plan (CDFW, 2015). This report (Thorne et al., 2016) develops a vegetation climate vulnerability model and presents a statewide vulnerability analysis under two global climate models and two emission scenarios by vegetation type. In 2019, CDFW conducted a habitat vulnerability analysis for 522 species identified as climate vulnerable to assess climate change impacts to habitat, based on Thorne et al.'s (2016) model (Gogol-Prokurat & Hill, 2019).

Additional State agency plans related to climate include:

- California Vegetation Treatment Program (CalVTP). Describes the value of vegetation treatment in implementing state policies for wildfire risk and GHG reduction. Section 3.8 of the CalVTP Environmental Impact Report (EIR) addresses greenhouse gas emissions (Board of Forestry and Fire Protection, 2019). Climate-related discussions in this section are derived from California State climate reports, such as the Climate Adaptation Strategy (California Natural Resources Agency, 2018) and Forest Carbon Plan (Forest Climate Action Team, 2018)
- California Energy Commission's *Integrated Energy Policy Report*. Updated annually, it contains a chapter focused on greenhouse gas emission reduction examining pathways to reduce emissions, including afforestation, bioenergy, and carbon sequestration in forests.

- *Natural and Working Lands Climate Smart Strategy Draft* (California Natural Resources Agency, 2021). Strategy that emphasizes nature-based climate solutions on all working lands throughout the State, including forests.
- *California State Climate Adaptation Strategy* . Outlines the all-hands-on-deck approach to building climate resilience across California, including community adaptation strategies, natural systems, and nature-based climate solutions.
- *Pathways to 30x30* . This is part of an international movement to protect 30% of land and oceans by 2030 through biodiversity conservation and combatting climate change. In addition to protected area conservation, the *Pathway* outlines climate-smart land management practices to provide functional ways to build resilience and achieve carbon neutrality.CaliforniaNature.ca.gov serves as a portal for the initiative and includes a 30x30 Climate Explorer. The explorer compares the base layer to a comparison layer for different climate models, scenarios, and years, summarizing the differences.
- The State Wildlife Action Plan (CDFW, 2015), spearheaded by CDFW, incorporates climate change impacts and adaptation strategies.

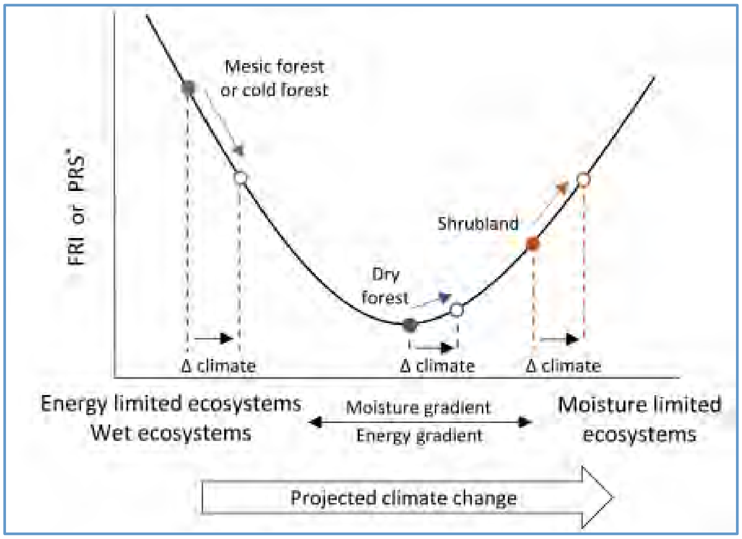
REGIONAL CLIMATE TRENDS & EXPECTED CHANGES

Under the current rate of climate change, temperatures in most seasons will increase by at least twice as much as the current natural variability by the end of the century (Warren et al., 2018). Most GCMs agree that by 2100 summers will be drier than they are currently, regardless of changes to annual precipitation (Butz & Safford, 2015). The Southwestern United States[3] will dry throughout the current century, driving a general reduction in winter precipitation and a poleward expansion of the subtropical dry zones (Seager & Vecchi, 2010). However, precipitation for the North coast may decrease or increase, depending on location. It is possible that radiative forcing coupled with the drying climate and altered La Niña climate pattern of the tropical Pacific system will create even greater drying and drought scenarios (Seager & Vecchi, 2010).

Projections indicate that the climatic moisture deficit will increase across the Western United States in the coming decades (Wang et al., 2016). There will be regional differences, however. For example, wetter regions with currently low climatic moisture deficits, such as the Coast Range, may experience decreasing fire return intervals (i.e., more frequent fire), whereas dry regions may encounter increased fire return intervals due to reduced growth of fuels (Figure 4.1). However, for every 1° C of global warming, lightning strikes are projected to increase by 12%, or about 50% over this century, potentially increasing wildfire ignitions (Romps et al., 2014).

[3] Great Plains to Pacific Coast and Oregon border to Mexico.

Figure 4.1. Conceptual model depicting projected climate change shifts in fire return interval (FRI) or percent replacement severity (PRS) defined as >75% average top-kill within a typical fire perimeter for a given vegetation type along a resource gradient for wet or dry forests ([Parks et al., 2018](#)).



In addition to climate variables such as temperature and precipitation, climate change velocity is essential to understanding regional trends. Climate velocity is the rate and direction an organism needs to migrate to maintain a given climate envelope or isocline of a given climate variable (Dobrowski et al., 2013; Loarie et al., 2009). Climate velocity accounts for topographic heterogeneity and regional climate change and demonstrates how species respond locally to survive (Bachelet et al., 2016; Dobrowski et al., 2013). Portions of the California coast may show lower rates of change in climate velocities than much of the rest of the country, primarily due to its topographic heterogeneity, e.g., mountainous, steep terrain (Dobrowski et al., 2013). This terrain may provide microrefugia and habitat niches that allow some species to adapt to changes in climate *in situ* or to disperse relatively short distances to favorable microclimates on north-facing aspects or higher elevations. Climate change microrefugia identified in northern California include old-growth and intact forests on north-facing slopes and canyon bottoms, lower- and middle-elevations, and wetter coastal mountains (Olson et al., 2012)

CALIFORNIA

Climate change exacerbates drought across the entire West, but most severely in California and the Southwest. California is experiencing another severe multi-year drought after a brief respite following the 2012-2016 drought (Becker, 2022). Across California, climate change is causing sea-level rise, increased temperatures, and changed precipitation patterns, with projections indicating these changes will intensify over the next century depending on emissions scenarios (Ackerly et al., 2015; California Natural Resource Agency, 2009). Wildfires, heatwaves, and droughts may become more frequent and severe in the future (Chornesky et al., 2015). Statewide temperatures are projected to increase from 2-4°C (under medium-emissions scenario RCP 4.5) to 4-7°C (under high-emissions scenario RCP 8.5) by the end of the century (Pierce et al., 2018). Mean annual precipitation shows a modest increase in the northern part of the state, but year-to-year variability is projected to increase with more incidence of dry years, fewer wet days, and an increase in daily extreme precipitation. (Pierce et al., 2018).

As a largely Mediterranean-climate region, California is vulnerable to drought/flood cycles. Due to climate change, extreme dry-to-wet precipitation events are projected to increase by 25-100%, despite modest changes in mean precipitation (Swain et al., 2018). Many species have already shifted their ranges in response to climate change in California (Moritz et al., 2008; Rapacciuolo et al.,2014).

NORTHERN CALIFORNIA/NORTH BAY AREA

According to Ackerly et al. (2018), the Bay Area will likely see a significant temperature increase by mid-century. Future increases in temperature will likely cause longer and deeper California droughts, posing major problems for water supplies, natural ecosystems, and agriculture.

Historical Trends

The Bay Area's average annual maximum temperature increased by 0.95° C from 1950-2005 (Ackerly et al., 2018). Although changes are variable within regions and topographies, during the 20th century, annual mean, minimum, and maximum temperatures in Marin County increased. Within the boundaries of the Golden Gate National Recreation Area (GGNRA), Muir Woods, and Point Reyes National Seashore (PRNS), temperatures increased at statistically significant rates up to 2.4 +/- 0.7° C (mean +/- standard error) from 1950-2010 with the greatest increases in spring (Gonzalez, 2016). At the same time, though Bay Area-wide precipitation trends were not statistically significant, annual total precipitation decreased north of the Golden Gate. Throughout the Bay Area the climatic water deficit, a quantification of the difference between precipitation and actual evapotranspiration, substantially increased, indicating more arid conditions. (Figure 4.2; Gonzalez, 2016). Figure 4.3 shows historical change in climatic water deficit from 1951-2010, with higher deficits along the coastal portions of Marin County and lower increase moving inland and north with much variability across those landscapes, presumably due to topographical changes and other localized factors (Flint et al., 2013; Gonzalez, 2016).

The drought ending in 2016 led to the most severe moisture deficits in the last 1,200 years and a 1-in-500-year low in Sierra snowpack. The dry period exacerbated an ongoing trend of groundwater overdrafts (Ackerly et al., 2018). The four-year drought had severe consequences, with $2.1 billion in economic losses and 21,000 jobs in the agricultural and recreational sectors. Under various scenarios of future climate change, ecosystem services, such as water provision, decline under most future trajectories (Shaw et al., 2011).

In California's North Coast mountains, including portions of Marin County, Huang et al. (2020) observed significantly increased burn area size and severity from 1984-2017. Burned areas had lower fuel moisture and higher climatic water deficit in drier years, and the percentage of high-severity burn areas doubled during the 2012-16 drought. Aspect, slope, fuel type/availability, and temperature were critical drivers of burn severity. In the North Bay, average regional fire return intervals were reduced by approximately 30%, and the historic average projected fire probability increased by 17% from 1971-2000 (Micheli et al., 2016).

Figure 4.2. Changes in mean, minimum, and maximum annual temperature (temp), total annual precipitation (precip), actual evapotranspiration (AET), and climatic water deficit (CWD) across California during the 20th century (From Rapacciulo et al., 2014).

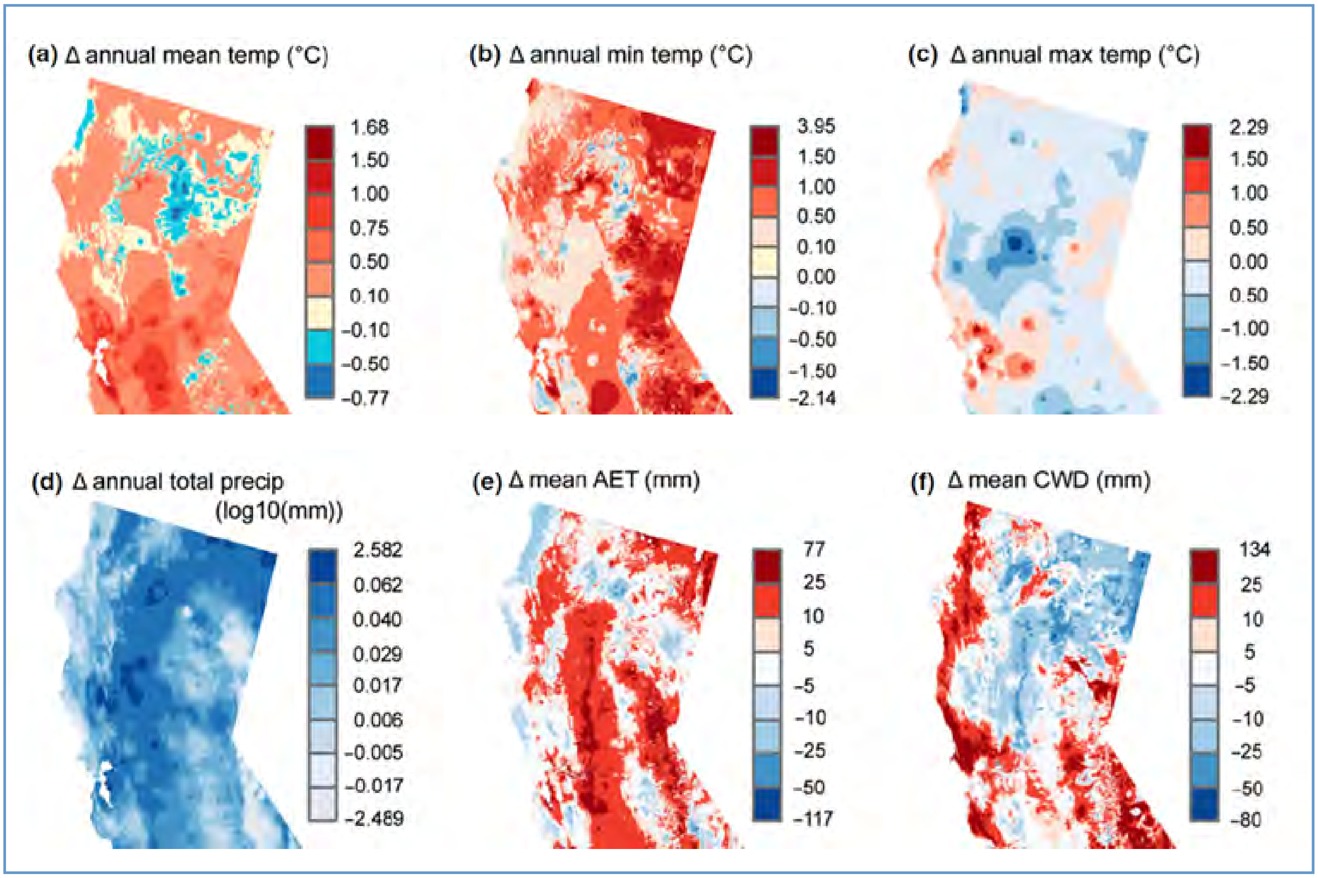
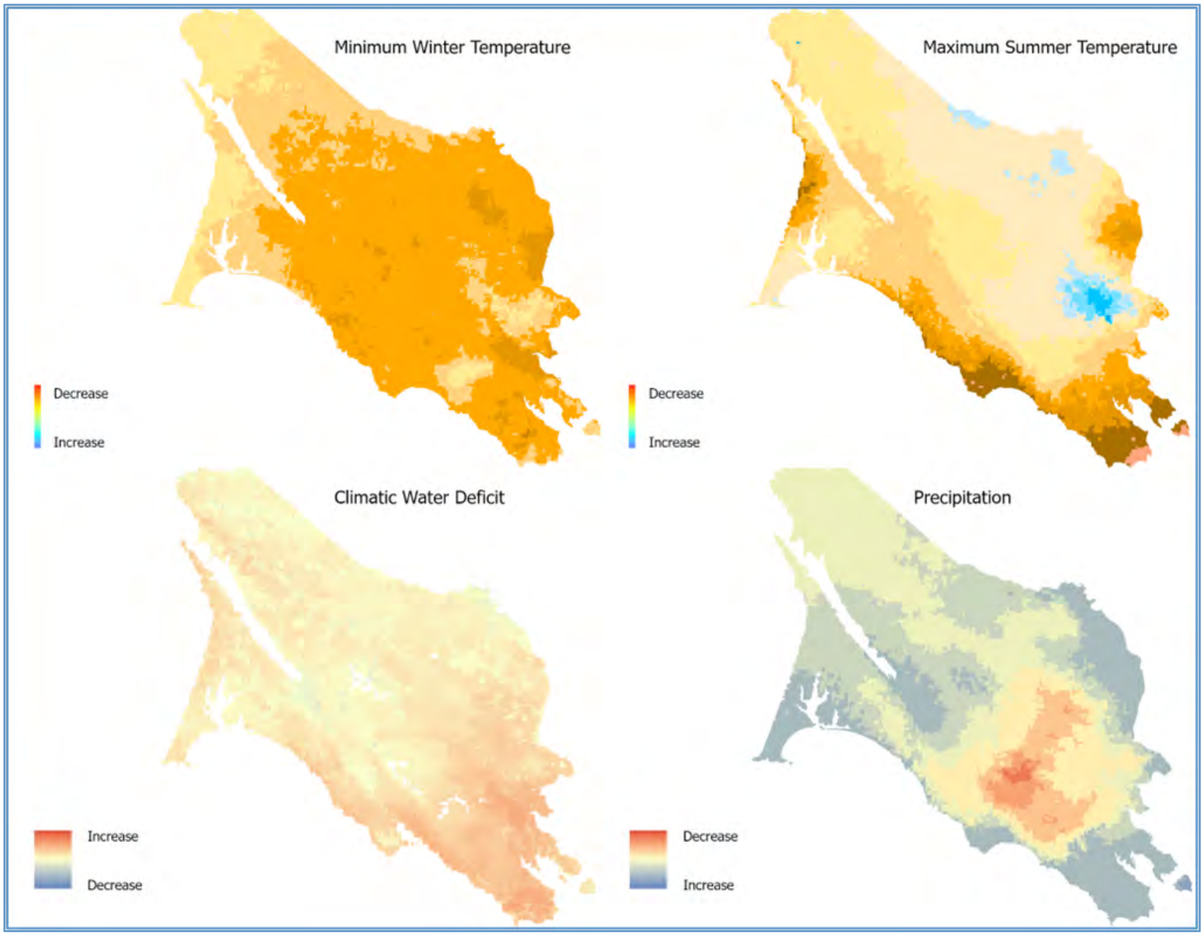


Figure 4.3. Historical changes in minimum winter temperature (top left), maximum summer temperature (top right), climatic water deficit (bottom left), and precipitation (bottom right) across Marin County 1951-2010 (data from Flint et al., 2013)



Summer fog in the Bay Area has decreased by 33% since the early 20th century (Johnstone & Dawson, 2010). A regional climate model simulation of coastal fog driven by the National Oceanic and Atmospheric Administration's (NOAA) 20th-century reanalysis data set shows a century-long decline along the California coast (O'Brien, 2011). A climate projection using the same model hints at a slight decline in the future (O'Brien et al., 2013). However, this result is highly uncertain because the development and incidence of coastal marine fog depends upon interactions among three systems—atmospheric, oceanic, and terrestrial—subject to broad ranges of variability. Indeed, experts are cautious about linking summer fog declines to climate change due to the complex relationship between heat and humidity from the ocean, air, and land (Ackerly et al., 2018; Torregrosa et al., 2014). Nevertheless, declines in marine fog are expected to have negative effects on coastal ecosystems that depend on fog drip in summer, such as coast redwood (*Sequoia sempervirens*), due to increasing drought stress (Johnstone & Dawson, 2010).

Projected Changes

Even with substantial efforts to reduce greenhouse gas emissions in the coming years, the Bay Area will see significant increases in temperature by mid-century, with inland areas increasing more than coastal areas (Ackerly et al., 2018). By the end of the 21st century, average temperatures in the Bay Area likely will have risen by 1.7 to 2.2 ° C, possibly as much as 4.4 ° C, depending on the future GHG emission trajectory (Micheli et al., 2016). Rising temperatures and increased variability in precipitation will increase the likelihood and intensity of drought (Diffenbaugh et al., 2015; Gonzalez, 2016; Mann & Gleick, 2015; Swain et al., 2016; Williams et al., 2015). A summary of findings from the *North Bay Vulnerability Assessment* included the following future trends (Micheli et al., 2016):

- **Rising regional temperatures** will generate unprecedented warm conditions for both the summer and winter seasons. Due to rising temperatures, the North Bay region is becoming more arid (subject to drier soil conditions).
- **Rainfall** will likely be more variable including both low and high annual extremes.
- **Runoff** may be increasingly flashy, with groundwater recharge rates relatively more variable over time. Protecting available recharge areas will be critical to water supply sustainability.
- **Water demand** for agriculture may increase on the order of 10%.
- **Fire frequencies** are projected to increase on the order of 20%, requiring additional readiness planning.
- **Vegetation** may be in transition, meriting additional monitoring and consideration of a more drought-tolerant planting palette for restoration. However, vegetation transition is complex and may be driven by multiple local to climate-level factors.

The authors emphasize that regardless of rainfall variability, climatic water deficit will increase in Marin County under all future climate scenarios (Micheli et al., 2016). It is important to note that vegetation changes will be highly complex and site-specific. The same authors note that regional strategies should promote watershed resilience to drought, focusing on protecting groundwater recharge and drought tolerance in forest systems, including more aggressive approaches to fuel load reduction.

WILDFIRE

Fire potential will substantially increase in the coming century (Abatzoglou et al., 2019). Climate change is causing longer, drier, and hotter summers, which combined with a century or more of active fire exclusion, is leading to more frequent fires, larger fires, and higher severity fires across the west. (Hagmann et al., 2021) Temperature increases in the western U.S. have led to a greater than 1,200% increase in areas burned by wildfire during the past four decades (Westerling, 2016). Across western North American forests, wildfires moved upward in elevation and into forest types less adapted to fire (Schwartz et al., 2015).

A number of interrelated factors can increase fire frequency, size, and burn severity. Extensive and severe wildfires are associated with warm and dry conditions and often high wind speeds, and these conditions will increase in frequency due to climate change (Halofsky et al., 2020). Shorter-term climatic conditions are also important drivers in fire behavior. For example, spatial variability in burn severity is affected by slope, minimum temperature, fuel amounts, and fuel moisture in warm, dry years and climatic water deficit and short-term weather are primary drivers of burn extent and severity during wetter years. (Huang et al., 2020). The effects of climate-fire interactions on vegetation are likely to amplify fire size and emissions (Hurteau et al., 2019). Drought-fire interactions will influence post-fire regrowth and potentially land cover type, alter future carbon balances, and accentuate landscape fragmentation, altering future fire risks and burn severity (Bolton et al., 2015; Goss et al., 2020; van Mantgem et al., 2013). In addition, increases in small tree density are associated with increased climatic water deficit (McIntyre et al., 2015).

While it is clear that climate change is increasing fire potential, interrelated drivers and scales complicate wildfire predictions under future conditions. This results in heterogeneous annual area-burned predictions across western North America, with California showing slight increases in annual area burned compared to a larger increase for the rest of the Western U.S. and Boreal forests (Kitzberger et al., 2017). Extreme weather manifested through prolonged drought, high wind, and concentrated precipitation events may need further evaluation in predicting burn severity since they tend to be underrepresented in fire models (Huang et al., 2020). In addition to climate influence, direct anthropogenic influence on fire is significant and must be incorporated into models to avoid omitted variable bias (Mann et al., 2016). For example, anthropogenic variables in Southern California's wildland urban interface (WUI) explain approximately 50% of the total fire count (Mann et al., 2016).

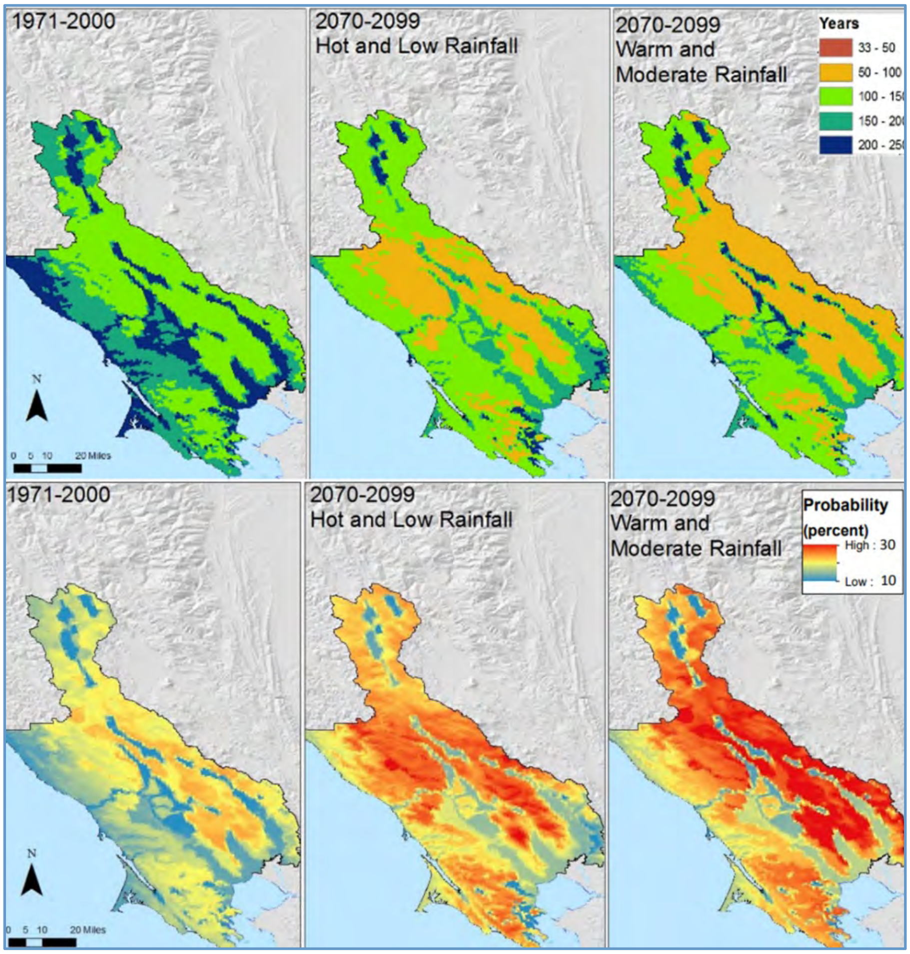
Altered fire regimes are principally due to fire exclusion over the past century, logging, and anthropogenic ignitions (Abatzoglou & Williams, 2016; Marlon et al., 2012; Parks et al., 2015). Lack of fire in some forested systems has led to increased tree density and fuels, increasing the severity and extent of wildfires (Hagmann et al., 2021; Noss et al., 2006; Stephens et al., 2018). Effects of climate change such as increased drought, higher temperatures, and higher vapor pressure deficits can increase the frequency of large fires (Dobrowski et al., 2013: Jolly et al., 2015; Seager et al., 2015). However, due primarily to fire exclusion, the fire regimes that have declined most across the west are characterized by low to moderate severity (Hagmann et al., 2021). See the Altered Fire Regimes section later in this chapter for a more detailed discussion.

Fire frequency, area burned, and biomass consumption will increase in California ecosystems due to increased temperature and precipitation variability coupled with changing fuels (Bachelet et al., 2007; Restaino & Safford, 2018). Extreme weather caused by climate change coupled with historical fire suppression has increased the number of high-severity burns in California (Goss et al., 2020; Keyser & Westerling, 2019). The frequency and total area burned by wildfires in California have increased significantly in the past 20 years: the wildfire season is nearly year-round, and the yearly peak comes a month earlier (Li & Banerjee, 2021). Severe fire risk hotspots, once limited to Los Angeles County, are now found throughout California, with new hotspots emerging along the coast (Li & Banerjee, 2021). Moreover, climate change is increasing extreme autumn wildfires (Goss et al., 2020). Across Marin County, fire return intervals will decrease under hot/low rainfall and warm/moderate rainfall models (Micheli et al., 2016). Projected fire probabilities will increase from the historical average of 17% to 23% (Figure 4.4).

Fire can act as a catalyst for forest ecosystem change under projected climate change scenarios because climatic tolerance differs among species and can vary according to tree age, with juveniles typically having a narrower climatic niche (Liang et al., 2018). Post-fire climate conditions are becoming increasingly unfavorable to seedling recruitment in many montane and foothill locations even if seed sources are nearby, and similar trends may occur in Marin (Kemp et al., 2019; Liang et al., 2017). Despite seed source availability, more than 50% of the suitable area for montane forests in the Klamath region could have minimal post-fire conifer regeneration by the latter part of this century (Tepley et al., 2017). Interactions between species movement, range shift gaps, shorter fire return intervals, and phenology mismatches may worsen post-fire recovery efforts (Coop et al., 2020).

Coast redwood are projected to be relatively resilient, even in high fire severity regimes (Simler et al., 2018). A study of canopy burn severity and level of epicormic regeneration post-2020 CZU Lightning Complex Fire, which significantly impacted coast redwood in Big Basin State Park, is currently underway in Santa Cruz County. Results may help managers understand how coast redwood's resilience to high severity fire is influenced by pre-fire landcover and management.

Figure 4.4. Change in projected fire return interval (top) and fire probability under two future climate models (Micheli et al., 2016).



HYDROLOGY

Further temperature increases will likely cause longer, more severe droughts and increased precipitation variability in the future (Ackerly et al., 2018). At the same time, extreme winter storms in the Bay Area will become more intense and damaging (Ackerly et al., 2018). Increasing air temperatures will increase water temperatures in rivers and reservoirs and cause higher evaporation rates from waterbodies, as well as evapotranspiration from vegetation and soil, causing an increase in climatic water deficit levels. Coastal cooling processes may moderate temperature increases and climatic water deficit along the coast, however there is uncertainty surrounding the impact warming temperatures will have on coastal breeze and fog. A warmer atmosphere is able to hold more moisture, which has highly heterogenous effects in California. In some years atmospheric rivers will bring heavy rainfall to small areas. Generally, precipitation will be highly variable from year to year, with extremely wet and extremely dry years and the potential for sudden changes between extremes (Ackerly et al., 2018). Highly variable annual precipitation with more frequent droughts will reduce water quantity and reservoir levels, threatening community and irrigation water supplies. Extreme storms will increase 1) polluted runoff into streams and water bodies, 2) pressure on outdated stormwater systems, and 3) flooding. High-runoff events will also increase erosion in streambanks and channels, threatening riparian vegetation and aquatic species. As with other climate impacts, changes will be heterogeneous over the landscape (Ackerly et al., 2018).

SOILS

Soil is an important component of carbon storage; around 80% of terrestrial carbon is stored in soil (Busse et al., 2014). Soil response to climate change is somewhat uncertain. Soils are affected in multiple ways depending on local soil/vegetation interactions, elevation, topography, and temperature increases, among other variables (Busse et al., 2014). However, reduced soil moisture, rising temperatures, changes in precipitation, and increased evapotranspiration reduce soil moisture and presumably soil productivity and biota. In Northern California, projected temperature increases and precipitation variation will lead to reduced soil moisture, especially during the latter half of summer, negatively impacting forests and associated vegetation (Busse et al., 2014). However, impacts on soils and vegetation may be complicated by increases in carbon dioxide, which promote increased vegetation growth and forest floor organic matter.

VEGETATION

Most vegetation change will depend on ecosystem type and fire-vegetation feedback cycles (Coop et al., 2020). A comparison of herbarium records for 4426 California plant species between 1895-2009 found that 12% of endemic species shifted upslope (Wolf et al. 2016). The same study found that more non-native plant species may shift upslope than native species (Wolf et al. 2016).

Changes in plant phenology due to climate change are variable and complex, often dependent on local conditions. In samples taken from 1901-2013, mostly from Western states, the length of the flowering season increased among early-flowering taxa but decreased among latest-flowering taxa; intraspecific variation and taxonomic composition shifts among floras contributed to this pattern (Park & Mazer, 2019). Golden Gate National Recreation Area has multiple monitoring sites for the phenology of various plant species, with data sent to the California/National Phenology Network.

Thorne et al. (2017) modeled potential climate change impacts to landscape-scale natural vegetation in California using two climate models and two emissions levels (RCP 4.5 and 8.5) and provided additional local insight into future climate change impacts. They found that Central Western California's vegetation (including the Bay Area) experienced the least impact within the state, with 16% climatically exposed (stressed by changing climate conditions) by end-of-century under wetter scenarios and 19% under drier scenarios. Since this area is less climatically exposed than other areas in California it may offer opportunities to protect climate refugia. More detailed analysis of climate exposure and vulnerability of key forest types in Marin is currently underway in partnership with the National Park Service, Golden Gate Biosphere Network, and EcoAdapt. A similar analysis was completed by the Santa Cruz Mountains Stewardship Network in 2021 (EcoAdapt, 2021).

Forest Ecosystems

There is no question that forested ecosystems are changing in response to climate change, particularly forest fire regimes and post-fire vegetation dynamics (Coop et al., 2020; McDowell et al., 2016; Millar et al., 2007). Douglas-fir (*Pseudotsuga menziesii*) forests sampled in the western United States exhibited a threshold response to changing annual climate conditions resulting in fewer recruitment opportunities (Davis et al., 2019). The authors found that stand-replacing fires in areas crossing climatic thresholds for regeneration may result in abrupt ecosystem transitions to unforested states (Davis et al., 2019).

In any region, trailing edge forests (forests at the latitudinal or elevational limits of their distribution) are likely to experience type conversion to shrub, grassland, or other forest types (Coop et al., 2020). Moreover, species with small ranges and climatic envelopes may be especially vulnerable to climate change. Coast redwood, for instance, is experiencing drought stress in the southern, drier edges of its range (which includes Marin County) and is already being heavily impacted by increased fire severity and frequency (Burns & Sillett, 2019). However, coast redwoods, particularly in the northern part of their range, are growing faster than expected and playing an essential role in climate mitigation as a carbon sink (Sillett & Van Pelt, 2007; Sillet et al., 2020). Lidar-based measurements of changes in Coast Redwood forest canopy density in Marin County between 2010 and 2019 showed 83% (9,404 acres) with positive growth rates, 21% of which had canopy growth greater than 5% (2,318 acres). In contrast, only 1% (150 acres) of Coast Redwood forest showed canopy density loss greater than 5% (see the Forest Health Web Map to explore the canopy density change layer).

Shifts in coast redwood habitat suitability may cause range expansion in the northern, wetter areas of coast redwood range and contraction in the southern or inland, drier range (Fernandez et al., 2015). With climate change, and related stressors such as pathogens and changing fire regimes, some studies suggest that forest ecosystem conversion is more likely to occur through conversion events (such as fire) rather than through gradual processes (Thorne et al., 2017). Long-lived trees like coast redwood may not be able to reach equilibrium with new climate conditions quickly enough to keep up with the pace of changing climate, and, due to climate vegetation mismatch, may be vulnerable to vegetation transition in the event of a disturbance (Ackerly et al., 2015; Hill et al., 2023).

Reduced summer fog would cause drought stress in coast redwood, Sargent cypress *(Hesperocyparis sargentii),* Bishop pine (*Pinus muricata*), and Douglas-fir (Baguskas et al., 2014; Johnstone & Dawson, 2010). Fog frequency was the most critical variable in predicting redwood distribution at Mt. Tamalpais, although counterintuitively, the highest fog frequency (>30%) translated to low redwood densities (Francis et al., 2020). Reductions in fog frequency, particularly in the summer, could lower coast redwood's resilience, since they can get 30-40% or more of total water input from fog and low cloud during the dry season (Johnstone & Dawson, 2010; Limm et al., 2009; Torregrosa et al., 2020). As mentioned, however, the causal links between climate change and fog decline are complex (Ackerly et al., 2018).

Bay Area

The *Fourth Assessment San Francisco Bay Region Report* (Ackerly et al., 2018) described the following expected climate change impacts for terrestrial ecosystems in the Bay Area:

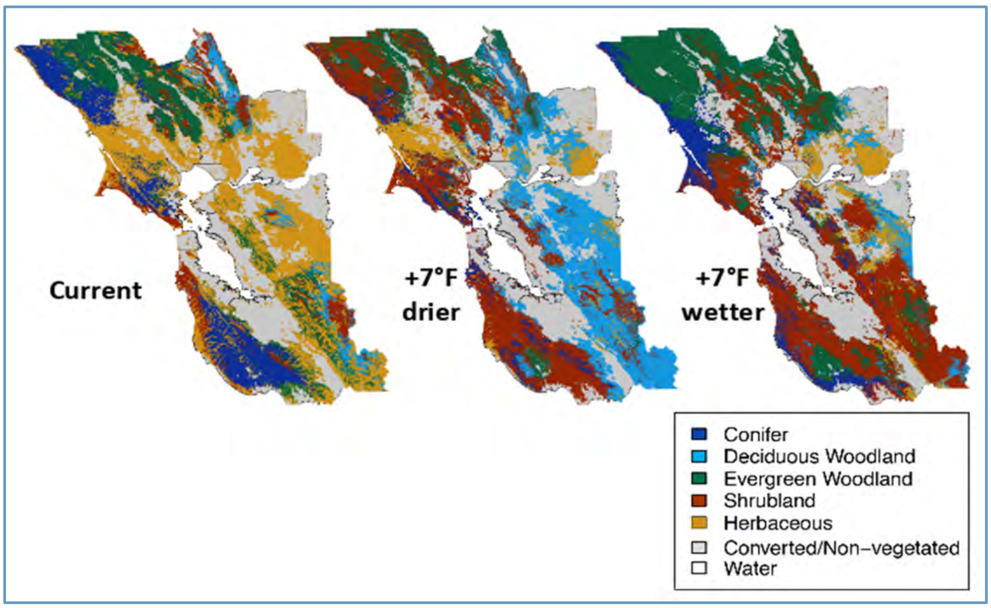
- The Bay Area's future climate will become less suitable for evergreens, such as coast redwood and Douglas-fir, and more favorable to hotter/drier adapted vegetation such as chaparral and grasslands. However, grassland projections are unclear, and active management such as burning and grazing will likely be more influential than climate change.
- Vegetation may be increasingly out of sync with climate and vulnerable to heat and drought. However, vegetation response to climate change is still poorly understood and influenced by multiple local factors. Phenological changes due to climate change may negatively impact both plant, insect, and vertebrate populations.
- Dispersal in response to vegetation shifts, temperature, and precipitation changes will be necessary for some taxa. However, climate change is occurring today in landscapes that have been highly fragmented and degraded by human activities. Species that once could have tracked shifting climate zones through natural dispersal no longer can do so. Due to urbanization and habitat fragmentation, impediments and barriers to movement are substantial. Regional conservation efforts that include open space protection, landscape corridors, climate-smart conservation, and restoration will help enhance adaptation to change.
- Decreased or more variable precipitation, increased heating, and drought will negatively impact ectotherms such as amphibians and reptiles. Increased heat and wildfires may negatively affect many species, including upland birds, mammals, amphibians, and reptiles.
- Fuel and fire management will be critical to reducing carbon loss from forests and help accelerate carbon sequestration in larger, more mature stands of trees.

Bay Area projections (Figure 4.5) show that conditions will become less suitable for conifer forests such as coast redwood and Douglas-fir, with greater impacts in models incorporating declining rainfall and fog (Ackerly et al., 2015). Future projections are less consistent for mixed evergreen forests and depend on local conditions, tree species, and other finer-scale factors (Ackerly et al., 2015). For instance, under hotter/drier scenarios, blue oak (*Quercus douglasii*) or valley oak (*Quercus lobata*) may expand while cool, moist adapted forests such as tanoak (*Notholithocarpus densiflorus*), canyon live oak (*Quercus chrysolepis*), and Oregon white oak (*Quercus garryana)* may decline (Ackerly et al., 2015). The *Climate Ready North Bay Vulnerability Assessment* predicts reduced suitable conditions for coast redwood, Douglas-fir, and montane woodlands and increased suitable conditions for coast live oak woodlands, knobcone pine *(Pinus attenuata),* shrublands, and Bishop pine (Micheli et al., 2016).

Thorne et al.'s (2017) statewide model predicts Sargent cypress will likely experience low to moderate climate exposure in the mid-century. This low exposure may be due to the location of these stands within the core area of Marin County along ridge lines, which can buffer the impacts of increased temperatures (Thorne et al., 2017). The same model shows a wide range of variability in the warm/wet and warm/dry futures for oak woodlands, which occur predominantly along the eastern portion of the One Tam focus area, where the models are in the least agreement (Thorne et al., 2017). How these predicted climate changes will impact the health of the oak woodlands depends on individual species' adaptive capacity related to seed longevity and fecundity (Thorne et al., 2016).

Type conversion may be accelerated due to climate change-induced feedback loops related to increased wildfires (extent, severity, and reduced return intervals), non-native invasive species invasions, and disease. Models for Marin County suggest an expansion of drought-tolerant plant species and communities, e.g., coastal sage scrub and chamise chaparral, as well as increased populations of non-native invasive weeds (Ackerly et al., 2018, Micheli et al., 2016).

Figure 4.5. Current vs. predicted vegetation types for the Bay Area modeled using temperature (winter min, summer max), annual precipitation, and climatic water deficit predictions under +7° F drier and wetter climate models (Ackerly et al., 2015; Cornwell et al., 2012).



CLIMATE CHANGE MANAGEMENT STRATEGIES

Historically, conservation managers could mitigate many stressors, but a reversal of damage or even maintaining the status quo is increasingly costly and challenging in the face of climate change (Schuurman et al., 2020). On a global scale, managing forests during climate change includes reducing deforestation, conserving forested ecosystems, and promoting forests as carbon sinks. Due to the extraordinarily challenging threats to forests, biodiversity, and people in the Bay Area, what are practical, meaningful, cost-effective, and timely management actions and next steps for managers? What are key research questions that could assist in adapting to climate change? How do managers prioritize actions and weigh these trade-offs to maximize biodiversity conservation? Given the uncertainties related to climate change, these are difficult questions to answer, and responses will need to vary with the landscape and actors involved. Since vulnerability to climate change varies spatially, so should adaptation strategies (Schuurman et al., 2020). Each manager should adopt practices based on the most reliable evidence appropriate to local conditions.

ADAPTATION & MITIGATION PLANNNING RESOURCES

There are a number of helpful guidance documents and resources to use in developing adaptive climate change management actions. Millar et al. (2007) offered a flexible approach incorporating reversible and incremental steps with no single solution fitting all future challenges. This flexible model focused on facilitating the transition of ecosystems from current to new conditions. The same authors include mitigation strategies (carbon sequestration and reducing greenhouse gas emissions) and triage for rapidly changing conditions when needs exceed the available response capacity.

Kershner et al. (2020) offer a helpful implementation guide for integrating climate change considerations into natural resource planning. This includes guidance for acquiring and using downscaled climate change projections, procedures for using these data to make site-specific determinations of the appropriate management approaches, lists of adaptation strategies and actions, and supplemental information regarding adaptation strategies to help managers choose among them.

Two recently published guides created with the Conservation Measures Partnership (CMP), *Conservation Standards Applied To Ecosystem-Based Adaptation* and *Climate-smart Conservation Practice (GIZ & CMP, 2020a, 2020b)*, integrate climate change adaptation planning with the Open Standards for the Practice of Conservation (CMP, 2020).

Schuurman et al. (2020) offer an adaptation framework that connects science and management to resist, accept, or redirect change to natural systems from climate change in a practical manner that is widely adopted by the National Park Service (NPS). Another related NPS publication for managers and planners is focused on planning for a changing climate (NPS, 2021). The guide offers a useful adaptation planning framework that is flexible to meet a wide range of planning and management needs incorporating managing for persistence AND change, linking actions with climate impacts, and developing forward-looking goals for natural areas and park infrastructure.

The National Fish, Wildlife, and Plants Climate Adaptation Network *Climate Adaptation Strategy* offers 13 management recommendations for adaptation to climate change, including investment in education/training, review of conservation goals, conservation of habitat at multiple scales, and management of refugia (National Fish, Wildlife, and Plants Climate Adaptation Network, 2021). Identifying and protecting climate refugia and maintaining or improving habitat connectivity promotes population and species persistence, genetic diversity, and adaptive dispersal as climate changes (Morelli et al., 2017).

The USDA California Climate Hub recently published the *Adaptation Strategies and Approaches for California Forest Ecosystems* (Swanston et al., 2020). Organizing ten clear strategies by three broad adaptation options of resistance, resilience, and transition, the report provides a framework for translating these general concepts into actionable management tactics to implement adaptation. Managers can select from a suite of actions best suited to specific conditions and management goals. Notably, the strategies consider integrating vulnerability assessments, adaptation strategies, and Traditional Ecological Knowledge (TEK) into conservation and land management efforts. The California Climate Hub has healthy forest briefs for coast redwood and blue oak woodlands (Science Advisory Panel of the California Governor's Forest Management Task Force). Prescribed fire is considered an adaptation strategy for coast redwood and regeneration of blue oak woodlands.

The *Conservation Lands Network 2.0 Report* is a regional land conservation strategy for the Bay Area with a recent revision to include climate change (Bay Area Open Space Council, 2019). The report's output includes interactive mapping tools and descriptions of climate adaptation approaches such as conserving large intact landscapes with topographic and climatic diversity, maintaining hydrological connectivity across the landscape, and protecting drought refugia. The Conservation Lands Network data can support local and regional climate adaptation decision-making and align with adaptation approaches that include conserving biodiversity and hydrological connectivity and maintaining suitable areas for range shifts.

Locally, Pepperwood Preserve is investing in research, planning, and management for climate change adaptation. The Pepperwood Preserve *Strategic Plan for 2020-2025* recognizes the importance of increasing community and ecosystem resilience to climate change and the importance of Indigenous Knowledge in both (Pepperwood Preserve, 2020). Pepperwood supports the Terrestrial Biodiversity Climate Change Collaborative (TBC3.org) to increase community capacity in the face of wildfire and climate change, interpret high-resolution natural resource data to support real-time hazard warning, and inform regional fire and water strategies. Pepperwood is also part of the Mayacamas to Berryessa Connectivity Network, a habitat corridor studied to quantify and implement climate-wise connectivity across a topographically diverse landscape (Gray et al., 2020). Finally, Pepperwood Preserve's Building Climate & Fire Resilience initiative is focused on increasing resilience to accelerating climate and fire hazards while maintaining or enhancing the health of watersheds and ecosystems.

Other useful guidance documents, resources, and programs include:

- The Climate Toolbox, web tools for visualizing past and projected climate and hydrology in the US.
- Climate Adaptation Knowledge Exchange, cakex.org, a source for climate adaptation case studies and resources.
- *Climate-Smart Conservation* offers guidance for designing and carrying out conservation in the face of a rapidly changing climate (Stein et al., 2014).
- The USDA California Climate Hub, California-specific resources for understanding, monitoring and preparing for, responding to, and recovering from wildfire.
- The California Landscape Conservation Partnership, whose mission is to enhance collaboration and focus on advancing landscape/seascape-level, climate-smart actions that address water, wildfire, connectivity, ecosystem services, and biodiversity.
- California Landscape Conservation Partnership's Climate Commons Database, a digital library providing access to climate change science for conservation practitioners.
- The North Bay Climate Adaptation Initiative (NBCAI) offers several fact sheets and reports (Di Pietro et al., 2014), including a *Roadmap for Climate Resilience in Sonoma County* and *Healthy Forests in a Changing Climate for People Who Steward Forestland* (NBCAI, 2013).
- Climate Ready North Bay, a climate adaptation knowledge base, including climate vulnerability assessments, for planning the future of North San Francisco Bay Area watersheds.
- North Coast Resource Partnership is a collaboration among Northern California Tribes, counties, and diverse stakeholders; they are developing a Regional Priority Plan for forest health and fuel load reduction.
- The Bay Area Climate Action Network (BayCAN) has a Drought Resource Guide with links to current drought-related portals (BayCAN, 2021).
- Point Blue's Climate Smart Restoration Toolkit
- MarinCAN, formerly known as Drawdown: Marin
- Audubon Canyon Ranch's Fire Forward Program

CLIMATE CHANGE ADAPTATION IN MARIN COUNTY FORESTS

Moore et al. (2012) analyzed climate change planning tools for managers in Marin County. They concluded that approaches most helpful to resource managers might require a combination of scenario planning, agency collaboration, experimental/monitoring, and other tools.

An important step in developing climate change strategies is assessing areas of vulnerability and resilience. Recent work on the statewide level demonstrates approaches to assessment. The *Climate Change Vulnerability Assessment of California's Terrestrial Vegetation* develops a vegetation climate vulnerability model and presents a statewide vulnerability analysis under two global climate models and two emission scenarios by vegetation type (Thorne et al., 2016). In this statewide analysis, the forest macrogroups found in Marin County had vulnerability rankings of Mid-High (North Coastal Mixed Evergreen and Montane Conifer Forests) and Moderate (North Coastal Riparian and Montane Riparian Forest and Woodland; Foothill and Valley Forests and Woodlands) under both the low-emission (RCP 4.5) and high-emission (RCP 8.5) scenarios. Thorne et al. (2020) created consensus vegetation refugia using CAL FIRE's FRAP (Fire and Resource Assessment Program) vegetation data and analyzed changes within each vegetation type under two GCMs (CNRM-CM5/warmer wetter future and MIROC-ESM/hotter drier future).

However, to develop management strategies at the local landscape scale, land managers need downscaled models to create place-based climate vulnerability and refugia assessments. These models can identify areas of greatest risk and possible vegetation refugia that will remain climatically suitable for extant vegetation. To address this need, One Tam partner agencies and the Golden Gate Biosphere Network are developing additional localized climate vulnerability analyses for key vegetation communities, habitat types, and individual plant and animal species in the Golden Gate Biosphere, including protected open space lands in Marin County. This will be similar to work done in 2021 for the Santa Cruz Mountains ecoregion (EcoAdapt, 2021)

Forest-specific adaptation strategies in Marin County will likely need to target areas prone to high burn severity, particularly during extended drought periods. However, some forest types in Marin County, such as Bishop Pine forest, require high burn severity for regeneration and different management approaches are needed in these areas. The *Marin County Wildfire History Mapping Project* (Dawson, 2021) and the *Forest Health Strategy* Condition Assessment can help identify priority treatment areas for all forest types and the necessary adaptation or mitigation treatments to be used, e.g., mechanical fuel reduction and prescribed fire. Priority treatment areas may need to be shifted from year to year depending on weather patterns which alter areas of greatest fire risk (Huang et al., 2020). See Appendix B: Wildfire History and Chapter 7: Condition Assessment for more information.

Coop et al. (2020) proposed four themes to support decisions between scientists and practitioners to enhance climate adaptation response to fire. These include characterizing vulnerability to fire-driven conversion, providing plausible scenarios of post-fire ecological futures under shifting climate and fire regimes, assessing the feasibility of directing or resisting conversion, and understanding the social and ecological consequences of the choice to resist, accept, or direct change. From a philosophical and practical management perspective, managers must ask if their target actions focus on increasing resilience in the most vulnerable forest stands, helping the currently most resilient stands persist, or both.

Other strategies to take into consideration include carbon sequestration through protecting old-growth stands or accelerating second-growth stands towards old-growth conditions; mitigating climate change by protecting soil carbon stocks, especially in forested and grassland regions, and tracking phenological changes in non-native invasive weed species as a part of early detection rapid response efforts which may help revise restoration treatment regimens (Taylor et al., 2020).

As fires become more frequent, it will become increasingly important for land managers to develop strategies to manage lands post-fire. Fires can be an opportunity to increase biodiversity, but also can be an opening for non-native invasive species. Following the 2020 Woodward Fire in PRNS, the first species to arrive was wild cucumber (*Marah* spp.), followed by blackberry (*Rubus ursinus*), fern spp., and many non-native invasive species (W. Rehlaender, Lead Fire Effects Monitor, PRNS, personal communication, 2022). The species dominating the landscape two years post-fire include the native species wild cucumber (*Marah* spp.), hedge nettle *(Stachys ajugoides),* miner's lettuce *(Claytonia* spp)., and yellow bush lupine *(Lupinus arboreus*) (R. Hendrickson, Vegetation Biologist, PRNS, personal communication, 2022). Yellow bush lupine is a concern due to its nitrogen-fixing properties; it may act as a facilitator for non-native invasive species. Non-native species dominating the landscape during this period include tocalote (*Centaurea melitensis),* yellow star thistle *(C. solstitialis),* upright veldt grass *(Ehrharta erecta),* and rosy sandcrocus *(Romulea rosea)*. *Upright veldt grass* appears to be spreading in low-severity understory burn areas, coastal scrub, and chaparral. Rosy sandcrocus spreads on all roads and trails surrounding the burn and seems to thrive due to a lack of competition from other vegetation (R. Hendrickson, personal communication, 2022). All thistles are of concern post-fire, but only star thistles have been found following the Woodward Fire.

Marin County land management agencies are incorporating climate change adaptation and mitigation into their management strategies. Marin Water's *Biodiversity, Fire and Fuels Integrated Plan* (*BFFIP*) has several approaches to meet plan goals related to climate change, including restoring ecosystem function and resilience, controlling forest diseases, and monitoring vegetation stressors (Marin Water, 2019). The *BFFIP* suggests climate mitigation strategies such as carbon sequestration in forests and grasslands. The Marin County Park and Open Space District's *Vegetation and Biodiversity Management Plan* includes treatments to address climate change in terrestrial/ upland habitats from such as removing non-native invasive species, fire management, assisted migration, restoration, and other activities (MCOSD, 2015). The NPS mitigates climate change by reducing its GHGs through long-term climate-related monitoring and research and restoration projects (NPS, 2010). The NPS also recognizes the link between rising temperatures and greater visitation during summer, straining park resources and staff. Impacts from recreation are discussed below.

In general, assessments of vulnerability to climate change must move beyond the common focus on climate exposure and also consider two other components of vulnerability: sensitivity and adaptive capacity (Butt et al., 2016). Adaptation should be understood in a broad sense that includes evolutionary, ecological, and social changes that are likely to reduce the vulnerability of ecosystems to climatic disruption (Moore & Schindler, 2022).

TRIBAL CLIMATE ADAPTATION & INDIGENOUS KNOWLEDGE

The Yurok Traditional Ecological Knowledge project found that elders were deeply aware of how the local environment had changed over the past 200 years (Sloan & Hostler, 2014). According to Flavelle and Goodluck (2021), Tribes are experiencing an environmental peril exacerbated by policies–first imposed by white settlers and then the United States government–that forced them onto the country's least desirable lands. Climate change is exacerbating the challenges of Tribal existence on marginal lands, sometimes making those lands uninhabitable. Governmental neglect of Tribes compounds the issue since federal agencies are less likely to assist Native communities following extreme weather events or protect them against future storms (Flavelle & Goodluck, 2021).

Consequently, many Tribes are taking climate adaptation into their own hands. The *Tribal and Indigenous Communities Summary Report* for California's *Fourth Climate Change Assessment* highlights that Traditional Ecological Knowledge is unique to each Tribe and underpins many of their environmental management and community and economic development approaches (Goode et al., 2018). Tribal climate actions and solutions combine ancient history, generational, and place-based Knowledge on the symbiotic relationship between climate, environment, and human activity (Goode et al., 2018). Using beneficial fire is an example of applying Traditional Ecological Knowledge Science to mitigate and adapt to climate change impacts (Goode et al., 2018). The expertise from Indigenous Knowledge may include many species not considered by natural resource managers that are important to Native communities for cultural, spiritual, medicinal, and ecological reasons (National Fish, Wildlife, and Plants Climate Adaptation Network., 2021). The *Karuk Climate Change Adaptation Plan* merges Traditional Ecological Knowledge with western science to restore healthy forests and wildlife in the Klamath region (Karuk Tribe, 2019).

The Tribal Climate Adaptation Menu framework integrates Indigenous and Traditional Knowledge, culture, language, and history into the climate adaptation planning process (TAMT, 2019). The menu includes strategies, approaches, tactics, and an overview of guiding principles for working with Indigenous peoples. The menu is adaptable to other Indigenous communities. *Guidelines for Considering Traditional Knowledges in Climate Change Initiatives* is an in-depth resource of information for Tribes, agencies, and organizations seeking to collaborate with Tribes on the respectful inclusion and protection of Indigenous Knowledges in climate initiatives (Climate and Traditional Knowledge Working Group, 2014). University of Oregon's Tribal Climate Change Project has additional resources that link Tribal and non-tribal organizations seeking to integrate climate change understanding and adaptation strategies into natural resource management. The Climate and Traditional Knowledges Workgroup website offers guidelines for considering Traditional Knowledges in climate change initiatives.

The *Tribal Climate Change Guidebook* is another in-depth and valuable resource (Dalton et al., 2018).

One Tam agencies recognize the importance of collaborating with Native people in developing climate change adaptation strategies and choosing and implementing forest health treatments. Please see Chapter 3: Stewardship and Partnership with the Federated Indians of Graton Rancheria, for an in-depth discussion on collaboration with Native peoples.

MONITORING & RESEARCH

Ongoing monitoring will be critical to better understand the complicated impacts of climate change and evaluate the effectiveness of management strategies. The *North Coast Resources Partnership Climate & Natural Resource Analyses Final Technical Report* suggests long-term monitoring of native forest vegetation to better inform models with an improved understanding of mechanisms and trajectories of potential change (Micheli et al., 2018). Particularly germane to the Bay Area are models of fog and low cloud cover indices to assist land managers in making informed restoration and forest health decisions (Torregrosa et al., 2016).

The *Climate Ready North Bay Vulnerability Assessment Data Products* technical memorandum offers many important lessons for scientists and land managers when applying climate adaptation efforts using high-resolution data (Micheli et al., 2016). Key lessons include allowing enough time to develop data products and tools across multiple stakeholders, working with translators who can facilitate discussions between parties, and testing across viable models to ensure that products are robust. The report offers lessons for land managers that include avoiding averaging model results across multiple scenarios, identifying additional support needed for translating results to specific planning applications, and crafting practical outreach tools and training tailored to diverse audiences to reach equitable outcomes.

Please see Chapter 10: Monitoring, for more guidance on climate change and forest health monitoring, and Appendix E: Opportunities for Additional Study, for recommendations for future research.

ALTERED FIRE REGIMES

Disruption in natural disturbance processes, such as fire, diminishes the resilience of fire-adapted ecosystems (Cocking et al., 2015). Fire exclusion is a major driver of altered fire regimes (Cocking et al., 2012; Enright et al., 2015; Keeley et al., 1999; Syphard et al., 2007). Other factors contributing to altered fire regimes include climate change, habitat fragmentation, invasive non-native species, and human-caused ignitions.

Altered fire regimes are likely to affect a wide range of taxa, not only vegetation. "Pyrodiversity begets biodiversity" is a concept introduced by Martin and Sapsis (1992). They hypothesized that diverse fire regimes, with variation in regime variables such as fire return interval, size, and intensity, would increase the diversity of successional stages in an area and thus increase the variety of ecological niches available and increase biodiversity (Jones & Tingley, 2022). Jones and Tingley (2022) mention that a central element of Martin and Sapsis' work is a loss of pyrodiversity, particularly indigenous fires. Jones and Tingley (2022) conducted a worldwide literature review across multiple taxa to examine the support for the pyrodiversity begets biodiversity hypothesis. They found wide variation in results depending on the fire's mechanism, history, and scale.

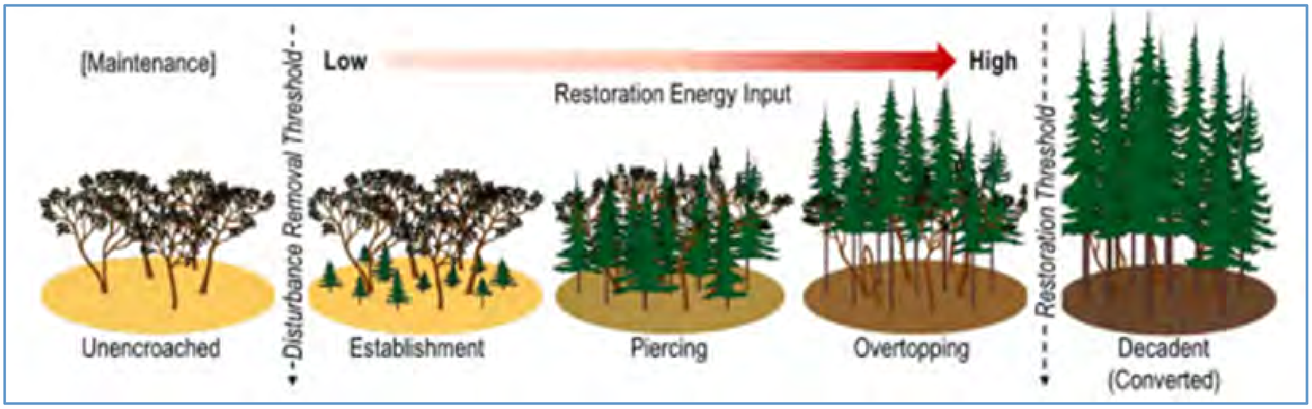
Fire exclusion is a major stressor impacting woody vegetation in fire-adapted forests. In the absence of fire, tree density and biomass accumulate, leading to competition for growth resources and reduced tree vigor (North et al., 2022). Vigorous growth (e.g., large growth rings) increases a tree's defenses against various stressors including pests and wildfire (Cailleret et al., 2017; Das et al., 2011; Zhang et al., 2019; North et al., 2022). Therefore, increased competition among trees and other vegetation creates long-term stress in forested ecosystems. Fire exclusion can also contribute to unnatural fuel arrangements, which may impact the resilience of Douglas-fir given its low resistance to high-intensity wildfire (Lavender & Hermann, 2014; Metz et al., 2017).

Fire and other forms of disturbance are important drivers for structural and floristic heterogeneity. Lack of fire produces changes in the fuel structure, forest structure, and floristic composition (e.g., shift to more shade-tolerant species) of Coast Redwood and Douglas-fir forests (Arno, 2000; Brown et al., 1999; Brown & Baxter, 2003; Lorimer et al., 2009; Norman et al., 2009; Ramage et al., 2010), as well as potential reductions in herbaceous biomass and species richness (Moore et al., 2006; Stoddard et al., 2011).

Fire exclusion, leading to changes in fire frequency, is a major stressor for serotinous species (Sargent cypress and Bishop pine) which rely on fire for much of their reproduction and are vulnerable to both higher and lower fire frequency. See Chapter 5: Goals, for discussions on impacts of altered fire regimes for these species.

Open canopy oak woodlands, chaparral, and native grasslands are also significantly impacted by altered fire regimes and fire exclusion. Lack of fire in an ecosystem may allow the spread of fire-sensitive species that would otherwise be limited by fire. Woody plant encroachment due to fire exclusion may not always alter habitat (Eldridge et al., 2011), but does likely reduce biodiversity (Ratajczak et al., 2012) and can lead to type conversion to a different plant community (Cocking et al., 2014; Huff, 1995; Uchytil, 1991).

Figure 4.6. Conceptual model showing stages and energy change required during conifer encroachment (Engber et al., 2011). Dashed arrows mark conversion thresholds. The stages at the far right are more difficult to revert to previous states than those to the left.



In oak woodlands, the lack of fire frequently leads to canopy piercing Douglas-fir (Figure 4.6). Conifer encroachment into grasslands, shrublands, and oak woodlands changes fuel structure and composition by replacing herbaceous understory fuels with woody fuels, reducing biodiversity, and degrading native vegetation (Engber et al. 2011). Thinning treatments can be costly and prescribed fire may not always work to restore the ecosystem. Livingston et al. (2016) found increased understory diversity with mechanical removal and fire treatments in the oak woodlands of the Bald Hills in Redwood National Park. However, the increased diversity included non-native species, and only high-severity fire successfully reduced conifer dominance in the sampled stands.

On Marin Water lands northwest of Mt. Tamalpais at Bolinas Ridge, a vegetation change assessment of woody plant encroachment between 1952 and 2018 found herbaceous plant communities and shrubland shrank by 62% and 51%, respectively. By comparison, forests increased in the same study area by 307% (Startin, 2022). Overall, the vegetation change analysis found that 44% of total woody plant encroachment consisted of woodland replacing shrubland, 39% of woodland replacing grassland, and 17% of shrubland replacing grassland. Over time, the most common woodland species replacing grassland and shrubland was Douglas-fir. The author also noted that more shrubland was lost than gained, and the most common shrub species replacing grassland was coyote bush (*Baccharis pilularis).*

In Marin County, according to the *Marin County Wildfire History Mapping Project* completed as part of *Forest Health Strategy* development, 95% of classified stands of Open Canopy Oak Woodlands have experienced no fire for more than 70 years or have no known recorded fires (Dawson, 2021). According to the Forest Condition Assessment completed as part of the *Forest Health Strategy,* many of these stands (45%) are classified as actively converting or threatened with conversion to Douglas-fir forest. See Appendix B: Wildfire History and Chapter 7: Condition Assessment for more information.

Outside the *Forest Health Strategy* forest types, woody species impacted by fire exclusion in Marin include obligate-seeding chaparral species such as Marin manzanita (*Arctostaphylos virgata),* Mason's ceanothus *(Ceanothus masonii),* and glory brush *(Ceanothus gloriosus* var. *exaltatus)* (A. Forrestel, Chief of Natural Resources and Science, GGNRA; S. Adams, Senior Ecologist, Marin Water, personal communications, 2022). In addition, the following coastal prairie species are threatened by Douglas-fir encroachment and are of concern to NPS staff: tarweed *(Hemizonia congesta ssp. congesta),* Pt. Reyes blennosperma *(Blennosperma nanum* var. *robustum), Fritillaria affinis* var. *tristulis,* fragrant fritillary *(Fritillaria liliacea),* Thurber's reed grass *(Calamagrostis crassiglumis),* Franciscan thistle *(Cirsium andrewsii),* and California bottle brush grass *(Elymus californicu*s) (R. Hendrickson, personal communication, 2022).

Rare species dependent on fire may be threatened by fire exclusion and non-native invasive species (S. Adams, personal communication, 2022). The perennial herb Brewer's calandrinia (*Calandrinia breweri*) is a fire follower not seen in recent years. Seed bank viability is hard to know for various species; seeds have a finite life span with limits to how long they persist. An aggressive invasive, such as broom species, may also establish in the seedbank and will respond to fire. The presence of broom and lack of fire creates a double jeopardy for the re-establishment of the native species.

Another phenomenon noted in relation to altered fire regimes is the occurrence of manzanita graveyards (S. Adams, personal communication, 2022). The graveyards feature dead stands of the common species Eastwood manzanita (*A. glandulosa*) and young conifers and are evidence of type conversion from shrub to conifer forest, likely due to fire exclusion. Similar stands of shaded out Marin manzanita are also likely to occur. Rare species in the affected communities may also be negatively impacted. The overall impact of fire exclusion is typically landscape homogenization, although Marin Water has not gathered data to document this phenomenon (S. Adams, personal communication, 2022).

Fire exclusion may negatively impact plant communities which are dominated by common woody species but also host a variety of rare species. For example, Mt. Tamalpais manzanita (*A. montana)* is locally abundant, is not an obligate seeder, and has a long-lived seed bank and long fire return interval, and is therefore not directly impacted by lack of fire. However, many Mt. Tamalpais manzanita habitat areas also support rare species, such as annuals with shorter-lived seed banks which require some disturbance to thrive. If longer periods pass without fire, this could impact the entire plant community and the rare species it supports, particularly those annual species. These same communities would be expected to decline with encroaching Douglas-fir in the absence of fire, further compounding the stress on this system (S. Minnick, Vegetation and Fire Ecologist, Marin County Parks and Open Space District, personal communication, 2022).

Another example of fire exclusion impact can be seen in a patch of grassland with active Douglas-fir encroachment in the Gary Giacomini Open Space Preserve. Coast rock cress (*Arabis blepharophylla*) still grows here, and Marin County Parks has been actively removing Douglas-fir in the grassland habitat where coast rock cress is found. One patch tripled in size after removing a large 30 to 40-year-old Douglas-fir. These patches are at the edge of *coast rock cress's* range, i.e., well inland, so they may demonstrate the importance of preserving more unique locations and possible associated genotypes (S. Minnick, personal communication, 2022).

The interaction of pathogens and fire is another landscape-scale stressor. Research has shown that beneficial fire can temporarily reduce sudden oak death in oak woodlands (Goheen et al., 2017; Kanaskie et al., 2008, Lee, 2009, Valachovic et al., 2008, 2011). There are also indirect pathogen impacts which can affect fire behavior and species composition. For example, a more diverse species composition may reduce pathogen impacts, which would reduce the amount of dead and dying materials, and in turn reduce fire severity (S. Adams, personal communication, 2022).

RECREATION

Across the United States, public lands face a popularity crisis with record visitor numbers in many protected areas. For instance, there were 331 million visitors to the nation's public lands during 2016-2017, the highest ever recorded (Simmonds et al., 2018). High visitorship is not new. As far back as 1926, the NPS noted that the overuse of parks was a principal threat to the character and health of natural areas (Ketcham, 2021). Some believe that such factors as the Covid-19 pandemic and social media may have driven higher visitor concentrations to photo-friendly sites (Simmonds et al., 2018). While COVID-19 temporarily paused heavy recreational pressure when public lands were closed, the respite was short-lived. As soon as public lands were re-opened, visitors returned in droves to escape the pandemic, sometimes creating even more damage (Thompson, 2021).

Though high levels of recreation can be damaging, it can also be an important avenue leading to awareness and education on environmental issues. The California Department of Fish and Wildlife (CDFW) acknowledges the complex relationship between outdoor recreation, human health, and ecological conservation, and dedicated a special issue of the CDFW Journal to its study (CDFW, 2020).

Marin County features world-renowned parks and open spaces with high visitor pressures (Edson et al., 2016). PRNS averaged roughly 2.4 million visitors annually from 2010-2020, and Muir Woods approximately one million visitors/year. The GGNRA is one of the most highly visited parks in the NPS system, in 2022 it was the second most visited national park in the country with 15.6 million visitors (GGNRA, 2023). Heavy use can lead to braided trails, higher erosion, off-road parking, human waste removal problems, soil compaction, pests, pathogens, and non-native invasive species spread. These recreational impacts can degrade built trails, especially boardwalks designed to protect sensitive soils or wetland habitats. In addition to roads and trails acting as pathogen and weed vectors, species are hitching rides to natural areas through firewood movement and vehicular transport (GGNRA, 2011).

The leave-no-trace movement has existed for decades but largely focused on leaving wild areas as you found them, e.g., take your waste with you, clean up campsites, or no campfires. New guidance at the Leave No Trace website to mitigate social media impacts and reduce negative impacts on natural areas include:

- Think before you geotag.
- Be mindful of your posted images.
- Encourage others to leave no trace.
- Shaming is not the answer.
- Give back to places you love.

RECREATION & CLIMATE CHANGE

Climate change has already negatively impacted recreational experiences on public lands, most notably due to extreme weather events. On the one hand, droughts have increased temperatures, and fires may deter visitors from coming to parks or lead to closures (Kiparsky & Gleick, 2003; Saunders et al., 2006). However, these same impacts may increase visitorship through tourists escaping urban heat islands, pandemics, and poor air quality due to fire. Coastal and forested regions may see further increased concentrations of visitors due to cooler temperatures and swimming opportunities.

VISITOR MANAGEMENT

Land management agency's plans must balance recreation and access goals with natural and cultural resource protection. There are increasing calls throughout public lands to provide more protections, such as limiting access to sensitive areas by increasing visitation permit requirements and asking the public to pack out their human waste. The Marin County Parks and Open Space District (MCOSD) *Road and Trail Management Plan* presents a framework for maintaining sustainable roads and trail systems, reducing their environmental impact, and improving visitor experience and safety (MCOSD, 2014). In addition to laying out a decision-making process, the Plan describes best management practices (BMPs) for trail standards and environmental impacts. The BMPs are design-focused and include vegetation enhancement, controlling and removing weeds, and a broad climate adaptation mandate principle. The Marin Water *BFFIP* also addresses trails, particularly their management during broadcast burns, protecting visitors during heavy equipment use, and other related BMPs for biodiversity, fire, and fuels management (Marin Water, 2019).

Although visitor carrying capacities are long-debated and controversial in the recreation community, some parks limit visitation through the reservation system, reductions in total parking, or even daily limits (Schreyer, 1984; Watson & Kopachevsky, 1996; Williams & Gill, 2012). Muir Woods, for example, enacted a parking reservation system, a ban on street parking, and a reduction of total parking spots, resulting in 200,000 fewer annual visitors (Simmonds et al., 2018). Reducing visitorship during heavy visitation periods also has the added benefit of reduced greenhouse gas emissions.

ADDITIONAL STRESSORS

Other stressors identified in the conceptual models include ecosystem type conversion, soil compaction, hydrological modification, pests and pathogens, and lack of age-class and understory diversity. These stressors are related to and impacted by climate change. Lack of age-class and/or understory diversity and ecosystem type conversion are discussed separately for each target forest type in the Threats section of Chapter 5: Goals.

SOIL COMPACTION

Soil compaction is often associated with braided trail use, recreational use, or machinery used for vegetation treatments. It creates stress for forested systems by inhibiting understory recruitment of both woody and herbaceous species and decreasing biodiversity in understory plant life (Cole, 2004). In addition, soil compaction can increase run-off from rainfall events, thereby reducing groundwater recharge and water availability for vegetation and increasing erosion and sediment pollution from storm events.

HYDROLOGICAL MODIFICATION

River systems are among the most highly modified ecosystems in California. Modifications, including channel straightening and armoring, levees, native vegetation removal, and non-native invasive species, lead to altered hydrographs, reduced biodiversity, and temporal changes to water release that affect forested systems. Climate change compounds hydrological modifications through increased variation in precipitation, namely more intense storms and prolonged drought. Additional discussion of forest health and riparian systems can be found in the Restoration section of Chapter 9: Treatment Descriptions.

PESTS & PATHOGENS

Pests and pathogens act as direct forest health stressors by increasing mortality throughout forest stands. Climate change increases pest and pathogen infestations through warming temperatures, which stop the natural seasonal disruption of pest life cycles (Dale et al., 2001; Ramsfield et al., 2016). Typically, colder temperatures kill or inhibit pest and pathogen spread or survival, but this is more applicable to climates north of Marin County or at higher elevations to the east. Drought and increased fire frequency or severity may also directly stress forest stands, making them more vulnerable to pest and pathogen invasion (Clark et al., 2016; Dale et al., 2001; Kolb et al., 2016). Pitch canker (*Fusarium circinatum*) and *Phytophthora ramorum*, the pathogen that causes sudden oak death (SOD), are two particularly acute pathogens causing widespread tree mortality in Marin County. Native to Mexico, pitch canker affects a variety of pine species throughout southern and central coastal California and causes high mortality of Bishop pine in Marin County. See Appendix A: Bishop Pine for a detailed discussion of pine pitch canker impacts to Bishop pine in Marin.

In Marin County, sudden oak death affects hardwoods, particularly tanoak, and can cause mortality in oak species as well. It can reproduce on bay laurel (*Umbellularia californica*) and a wide variety of other species. Tanoak has been completely lost in some areas as a subdominant species, with devastating cultural and ecological consequences. Other

Phytophthora spp. impact Marin County forests as well: *P. cinnamomi*, first documented on Marin Water lands in 2012, is known or suspected in madrone *(Arbutus menziesii*) die-offs in several locations.

Anecdotally, canopy gaps in Bishop pine forests since the 1995 Vision Fire footprint are, at least in part, caused by pine pitch canker (A. Forestel, personal communication, 2022). Historically, sudden oak death appeared in the hardwood components of Bishop pine forests on the Point Reyes peninsula in the early 2000s, and pine pitch canker began impacting the forest, especially the young Bishop pines, about five years later with widespread disease impacting the forest in 2010. Thus, mortality and gaps in pure Bishop pine stands are caused by pine pitch canker, whereas canopy caps in stands with a significant hardwood component are likely caused by sudden oak death. A separate phenomenon of western gall rust (caused by *Endocronartium harknessii*) impacts large Bishop pines in Tomales Bay State Park.

For more information on pests and pathogens, see Chapter 9: Treatment Descriptions, Pests and Pathogens. Results of canopy gaps and mortality analysis are described in Chapter 7: Condition Assessment.

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CHAPTER 5: GOALS

The Marin Forest Health Strategy Working Group (See Chapter 1: Introduction, Table 1.1) developed strategic goals for five important forest types found in Marin County: Bishop Pine, Coast Redwood, Douglas-fir, Open Canopy Oak Woodland, and Sargent Cypress. The five forest types were chosen for two reasons: 1) concerns about stand health and resiliency due to threats such as an altered fire regime, disease, and climate change; and 2) the important ecosystem services provided by these forest ecosystems, such as biodiversity, habitat, carbon sequestration, cultural values, and others. Forest health metrics, including forest structure, canopy mortality, and canopy gaps, and fire history were used to evaluate conditions for each forest type and assess conditions for each key forest type at the countywide scale. While specific goals were not developed for other important forest types in Marin County, including other hardwood-dominated stands such as madrone (*Arbutus menziesii* Forest Alliance), tanoak (*Notholithocarpus densiflorus* Forest Alliance) and California bay (*Umbellularia californica* Forest & Woodland Alliance), many of the landscape-level goals described in this chapter can be applied to other forest types where similar threats to health and resilience exist. Additionally, many of the metrics developed and used to assess forest conditions were developed for all forest stands in Marin County, not only the key types in the *Marin Regional Forest Health Strategy* (*Forest Health Strategy*).

This chapter aims to provide background information and a conceptual framework for understanding goals for each forest type and intended outcomes. Creating goals was the first step to identifying appropriate treatments to maintain or move towards desired forest health conditions and more resilient stands. The overarching forest health goals are to preserve each forest type in the mosaic of habitat types in Marin; protect or enhance ecosystem services such as water quality/quantity, soil health, recreation, and cultural resources; protect or maintain habitat and biodiversity; and increase awareness, support, and collaborative efforts to improve forest health in Marin County.

PROCESS

Conceptual models of ecological function for each forest type were developed with the Marin Forest Health Strategy Working Group (Working Group) as the first step toward identifying goals for each key forest type. The conceptual models are a foundational tool to describe forest health and map interconnected pathways of ecosystem function. They graphically represent connections between people, ecosystem services, biodiversity, forest health attributes, threats negatively impacting health attributes, and possible interventions or treatments to reduce or mitigate the threat to forest health and resilience. Results chains were then developed from the conceptual models; these show the specific pathway associated with each forest health attribute, threat, and treatment/intervention to reduce the impact of the threat (see Glossary for definition of conceptual model and results chain)

The Working Group developed conceptual model drafts at an in-person workshop in 2019. Results chains were created from suggested treatments in the conceptual models for each forest type and then reviewed by the Working Group during a virtual workshop. Conceptual model and results chains drafts for each forest type were revisited and revised throughout the development of the *Forest Health Strategy*.

The revised conceptual models and results chains are the basis for the forest health goals. Each forest type has **landscape-level goals** focused on preserving the forest types within the Marin habitat mosaic and protecting the ecosystem services and biodiversity they provide, as represented in the conceptual models. Results chains describe actions that can be applied to achieve landscape-level goals, with **interim results** and **condition goals** as steps along this goal pathway. Each goal pathway is associated with a health attribute, threat, and treatment method mapped in the results chains. The condition goals will jointly contribute to landscape-level goals through the active treatment methods.

Conceptual models, results chains, and goals for the five forest types are presented in the following sections of this chapter. Each section also includes a brief life history, map of distribution in Marin County, fire regime, and threats description as context for each forest type.

Geospatial modeling using metrics derived from conceptual models was used to assess forest conditions and locate areas where treatments can be applied to move toward landscape-level goals. See Chapter 2: Resilience and Chapter 4: Climate Change and Other Forest Health Stressors for a detailed discussion on forest resilience and threats to forest health. See Chapter 6: Metrics and Chapter 7: Condition Assessment for information on development and use of forest health metrics in the Marin countywide forest health condition assessment. See Chapter 8: Prioritization Framework and Implementation Analysis for information on how the forest condition assessment supports prioritization of treatment areas. Detailed treatment information for treatment methods included in results chains is in Chapter 9: Treatment Descriptions.

BISHOP PINE FOREST

LIFE HISTORY

Pinus muricata, commonly known as Bishop pine, is one of the closed cone pines species. Bishop pine is generally distributed along the Pacific coast from southwest Oregon to southern California, including Baja California (Mexico) and the Channel Islands (Axelrod, 1967; Barbour et al., 2007). Current research recognizes two varieties on the mainland: the northern var. *borealis*, distributed north of Monterey, California and southern var. *muricata*, which occurs to the south of Monterey, California. The Channel Island variety (var. *stantonii*) is found on both Santa Rosa and Santa Cruz islands (Millar, 1986b; Millar, 1983). In Marin County there are distinct coastal and inland Bishop Pine forests. The coastal populations are found on the northern section of Inverness Ridge on granitic quartz-diorite loams. Inland populations are generally found east of the San Andreas Fault and north of Mt. Tamalpais on sandstone-derived gravelly-loam soils (Millar, 1986a). Even-aged stands of Bishop pine grow to heights of 15-25 meters, and trees live from 100-120 years. Nearly all closed cone pine species are serotinous, and Bishop pine have moderately serotinous cones (Harvey & Agne, 2021). See Appendix A: Bishop Pine for a more detailed life history description.

The floristic classification report that accompanied the 2018 Marin Countywide Fine Scale Vegetation Map (2018 Fine Scale Vegetation Map, Golden Gate National Parks Conservancy et al., 2021) describes the Bishop Pine alliance and member associations found in Marin County following standards established by the US National Vegetation Classification (USNVC) and the Manual of California Vegetation (MCV). The floristic classification for Marin County was developed in partnership with the California Department of Fish and Wildlife Vegetation Classification and Mapping Program (CDFW VegCAMP) and California Native Plant Society Vegetation Program. Table 5.1 lists member associations found in Marin County for Bishop pine alliance and described in the Marin classification report (Buck-Diaz et al., 2021, Appendix D).

Table 5.1. Bishop Pine 2018 Fine Scale Vegetation Map class (Pinus muricata – Pinus radiata Forest & Woodland Alliance) (Golden Gate National Parks Conservancy et al., 2021) and member associations described in the corresponding floristic classification report (Buck-Diaz et al., 2021, Appendix D).

2018 Fine Scale Vegetation Map Class	Associations in Marin County
Pinus muricata – Pinus radiata Alliance	• *Pinus muricata* • *Pinus muricata – (Arbutus menziesii) / Vaccinium ovatum* • *Pinus muricata / Arctostaphylos glandulosa* • *Pinus muricata / Ceanothus thyrsiflorus – Baccharis pilularis*

KEY ECOSYSTEM SERVICES

As a unique assemblage with limited distribution in Marin County, key ecosystem services of Bishop Pine forest are biodiversity and habitat. However, air quality, carbon sequestration, hydrologic function, cultural values, and recreation are also important benefits of this forest type. Bishop pine is significant to the Tribe for tool, construction material, and medicinal uses. For more details on cultural practices and tending related to Bishop pine, see Chapter 3: Stewardship and Partnership with the Federated Indians of Graton Rancheria.

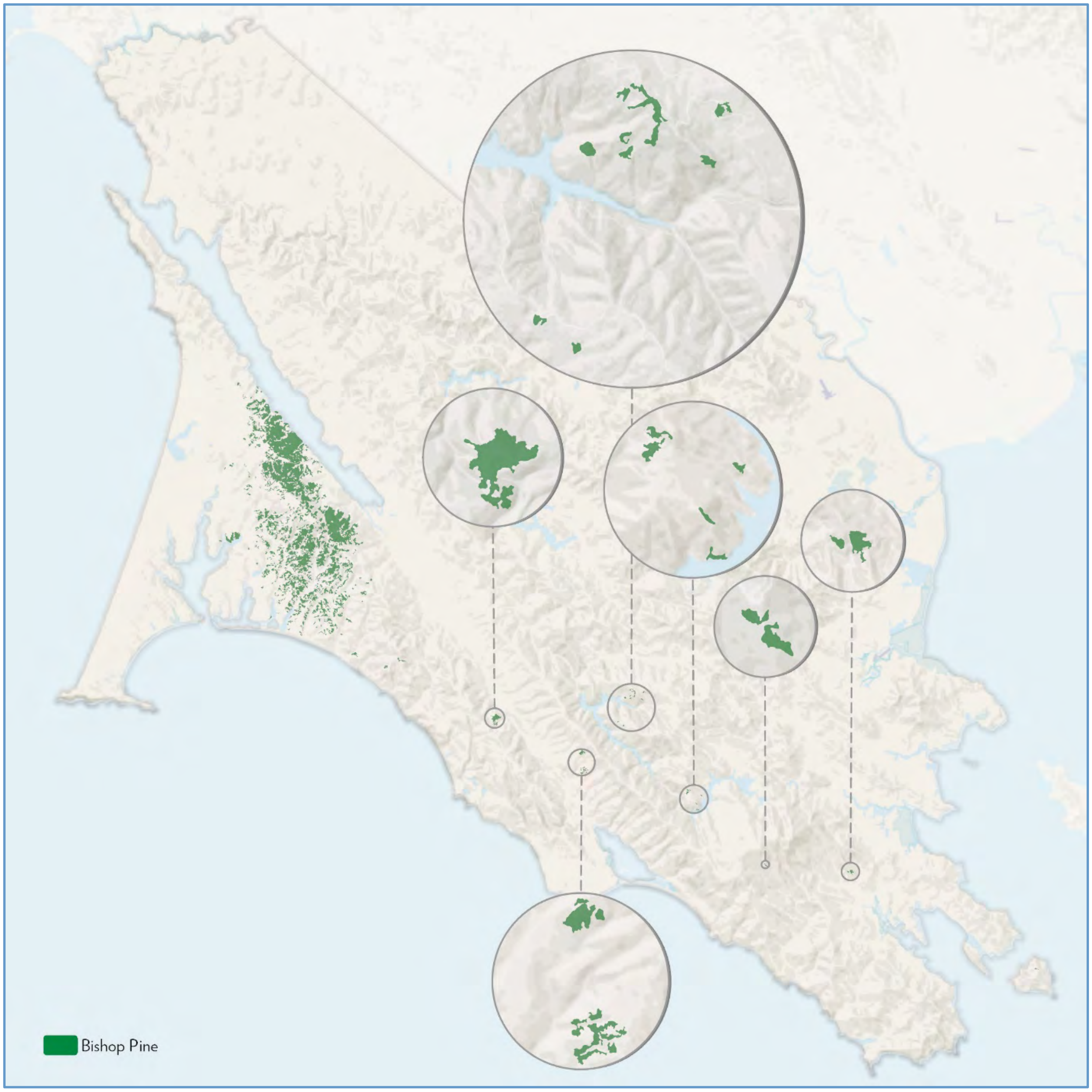
DISTRIBUTION

The 2018 Fine Scale Vegetation Map depicts the distribution of *Pinus muricata* at the alliance levels (Figure 5.1; Golden Gate National Parks Conservancy et al., 2021). A closer inspection of each stand can be accessed at the One Tam Forest Health Web Map.

FIRE REGIME

The fire regime for Bishop Pine forest varies from northern to southern populations. Northern populations burn infrequently and fires are smaller in size (Borchert & Davis, 2018; Duffield, 1951; Greenlee, 1990). Bishop pine is an obligate seeder, and stand-replacing; high severity fires are typical, with mortality approaching 100% (Barbour, 2007; Harvey & Agne, 2021; Stephens et al., 2018). Reproduction is possible between fires but is not as prolific (Millar, 1986a).

Figure 5.1. Bishop Pine distribution in Marin County. Insets show smaller, isolated stands.



Fire from Indigenous peoples was an important Bishop Pine fire regime component during the Holocene (Keeley, [2002](#), [2005](#)). Historical fire return intervals (FRI) from Point Reyes National Seashore (PRNS) are approximately 40-70 years (Harvey & Agne, 2021). Inland Marin County populations are likely on the shorter end of the 40-70 year historic FRI as described by Harvey and Agne (2021).

Post-fire reproduction and expansion can be highly successful. Following the stand-replacing 1995 Mt. Vision fire, the total area of Bishop Pine forest in PRNS increased by 85% ([Forrestel et al., 2011](#); [Harvey et al., 2011](#)). While Bishop Pine expanded into predominantly coastal scrub and some Douglas-fir and grassland habitats, 40% of the previous Bishop Pine forest area reverted to *Ceanothus* spp., demonstrating the dynamic nature of the vegetation mosaics in the area. Species richness and diversity peaked in the two years following the fire (Harvey & Holzman, 2014).

Table 5.2. Summary of Bishop Pine fire regime (CNPS, n.d.). See Appendix A: Bishop Pine for a more detailed description of fire characteristics. FRI=fire return interval.

Alliance	Season	FRI (years)	Size	Intensity/ Severity	Type
Pinus muricata - Pinus radiata Forest & Woodland Alliance	Summer-Fall	Truncated medium (40+)	Small-Large	Very High	Multiple

THREATS

Threatened by habitat loss, fire suppression, and altered fire regimes throughout its range, Bishop Pine forest is classed as vulnerable under several conservation ranking systems. Due to the relatively limited distribution of Bishop pine, coupled with threats to the persistence of the species, Bishop pine's global status on the International Union for Conservation of Nature (IUCN) Red List is vulnerable, with severely fragmented populations (IUCN, n.d.). In California, the *Pinus muricata – Pinus radiata* Alliance is considered a Sensitive Natural Community (CDFW, n.d.a.) with a Conservation Status Rank of S3, meaning that the community is vulnerable and "at moderate risk of extirpation in the jurisdiction due to a fairly restricted range, relatively few populations or occurrences, recent and widespread declines, threats, or other factors" (NatureServe, n.d.). Some Bishop pine associations found in Marin County, including *Pinus muricata – (Arbutus menziesii – Notholithocarpus densiflorus) / Vaccinium ovatum* Association, are ranked as (S2) or imperiled and at high risk of extirpation in the jurisdiction due to restricted range, few populations or occurrences, steep declines, severe threats, or other factors (CDFW, 2022).

ALTERED FIRE REGIME

Bishop Pine stands may be threatened by both senescence risk from fire exclusion and immaturity risk from frequent fires (Buma et al., 2013; Enright et al., 2015; Keeley et al., 1999). With fire exclusion, Bishop Pine stands are at risk of disappearing from the landscape through senescence without a stand replacing fire event and recruitment of a new generational cohort, and there may be less viable seed available on aging trees. With too frequent fires, immature trees may be killed before they are able to produce viable cones and seed.

Fire return intervals of 80 years or more greatly increase Bishop Pine stand susceptibility to disease and are increasingly common due to fire suppression (CNPS, n.d.; Cope, 1993). A high number of standing dead trees in even-aged stands were recorded in a Tomales Bay State

Park forest inventory, indicating the possibility of senescence risk (Gaman, 2019). The same inventory noted only one Bishop pine seedling in all sample plots.

Yet, senescence risk may not be as important in Bishop pine as in other serotinous species. For instance, 100-200 year old Channel Island stands were not extirpated through senescence despite widespread dying trees because reproduction was found to occur without fire on hot days (Hobbs, 1980; Ostoja & Klinger, 1999; Walter et al., 2005; Wehtje, 1994). However, Island populations (*Pinus muricata* var. *stantonii*) may have a different fire regime from continental populations, and the potential for days hot enough to open cones may vary (Linhart, 1978). Senescence risk is an area recommended for future study. See Appendix E: Opportunities for Additional Study for more research recommendations.

Immaturity risk may become increasingly significant given increasing fire frequency across this forest type's distribution. Northern populations are capable of inter-fire reproduction, but this type of recruitment is not as prolific as stand-replacing fires (Millar, 1986a; Gaman, 2019). Trees can mature and produce cones as early as five years old. However, a young stand with too few cones may have difficulty regenerating following a fire (Harvey & Agne, 2021).

The Forest Health Strategy Condition Assessment (see Chapter 7: Condition Assessment) and *Marin County Wildfire History Mapping Project* (Dawson, 2021) found that nearly all mid-seral stands of Bishop Pine are located within the 1995 Vision Fire footprint, making the time since last fire there 27 years. The last recorded fire before the Vision and Woodward Fires (2020) was in 1976. A more detailed Marin County fire history can be found in Appendix B: Wildfire History. See Chapter 4: Climate Change and other Forest Health Stressors, for additional discussion of fire exclusion and other stressors. The fire history impacts on Bishop Pine stand structure, mortality and diversity can be found in Chapter 7: Condition Assessment.

PINE PITCH CANKER

Pinus muricata is threatened by pine pitch canker spreading rapidly throughout California coastal forest regions. Pitch canker is a disease caused by the fungus *Fusarium circinatum*. It causes die-back of individual pine branches, leading to a decline in tree health and, in some cases, premature death. First recognized in California in 1986, the disease is mostly limited to coastal areas from San Diego to Mendocino Counties (Storer et al., 2020). Pitch canker is spread by the wind and carried by native insect vectors such as bark, twig, and cone beetles. Wind and insect vector transmission are key elements of the pitch canker disease cycle (Gordon, 2001). In Marin County, pitch canker primarily affects Bishop pine, Monterey pine (*Pinus radiata*), and Douglas-fir (*Pseudotsuga menziesii*); Monterey and Bishop pines are the most susceptible species to the disease. A more detailed review of pitch canker can be found in Chapter 9: Treatment Descriptions and in Appendix A: Bishop Pine. Western gall rust, a disease caused by the native pathogen *Endocronartium harknessii*, is also a concern for Bishop pine in some areas. Older Bishop pine trees not exposed to fire may succumb to western gall rust and die without reproducing (Vogl et al., 1988).

Recent analysis of field-plot data collected in Bishop Pine forest by Harvey et al. (2022) on the Point Reyes peninsula in 2011 and 2021 showed that nearly all sampled trees exhibited some pine pitch canker disease symptoms (In 2021, mid-seral stands with greater pitch canker severity were associated with higher coarse surface fuel loads, more crown die-back/canopy openness, and greater plant community diversity and forb cover. However, other stand structure variables, such as live and dead tree size, basal area, density, and reproductive potential, were not different across stands with high or low severity pitch canker and overall did not suggest a major departure from expected stand structural developments (Harvey et al., 2022). Significantly, coarse surface fuel loads, as well as live and dead standing Bishop pine basal area were similar between mid-seral and old-growth plots. Harvey et al. (2022) recommend experimental treatments to reduce fuel loads and fire hazards or decrease competition in mid-seral stands to improve disease resistance. See Appendix A: Bishop Pine for detailed information on the field study on the Point Reyes peninsula.

There are no practical, direct methods to control pitch canker (Camilli et al., 2013). However, best management practices similar to other pathogen reduction measures can be taken to slow its spread (Gordon, 2001). Some control methods, such as debarking recently killed trees and moving diseased or insect-infested tree material away from nearby susceptible trees, are unlikely to be feasible at scale in wildland areas. Using best management practices, such as not moving contaminated wood, are recommended to avoid long-distance pathogen spread via humans.

Some Monterey pine trees are resistant to pitch canker and are not expected to die from the disease unless new strains are introduced into the state (Storer et al., 2020). Some Bishop pines may show the same resistance traits, but more study is warranted to determine their extent. However, resistance may lose effectiveness since it may lag behind changes in pathogen populations over time, with more virulent strains developing through genetic recombination and mutations (Swett & Gordon, 2022).

CONCEPTUAL MODEL

The Marin Forest Health Strategy Working Group (Working Group) developed a conceptual model for Bishop Pine forest showing ecosystem services, forest health attributes, direct/indirect threats, and treatments (Figure 5.2). The Working Group established condition goals for Bishop Pine forest and accompanying results chains from the conceptual model.

Figure 5. 2. Conceptual model key.

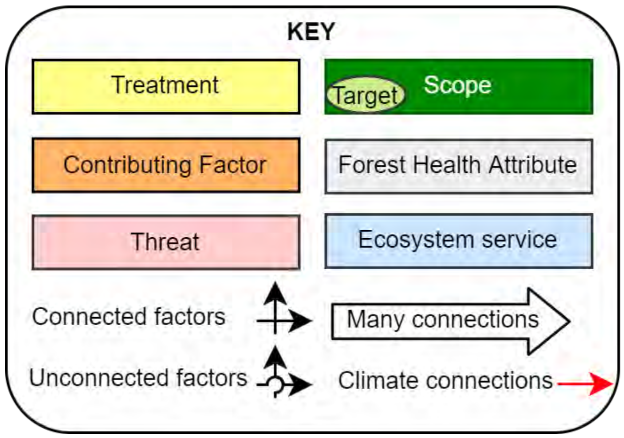
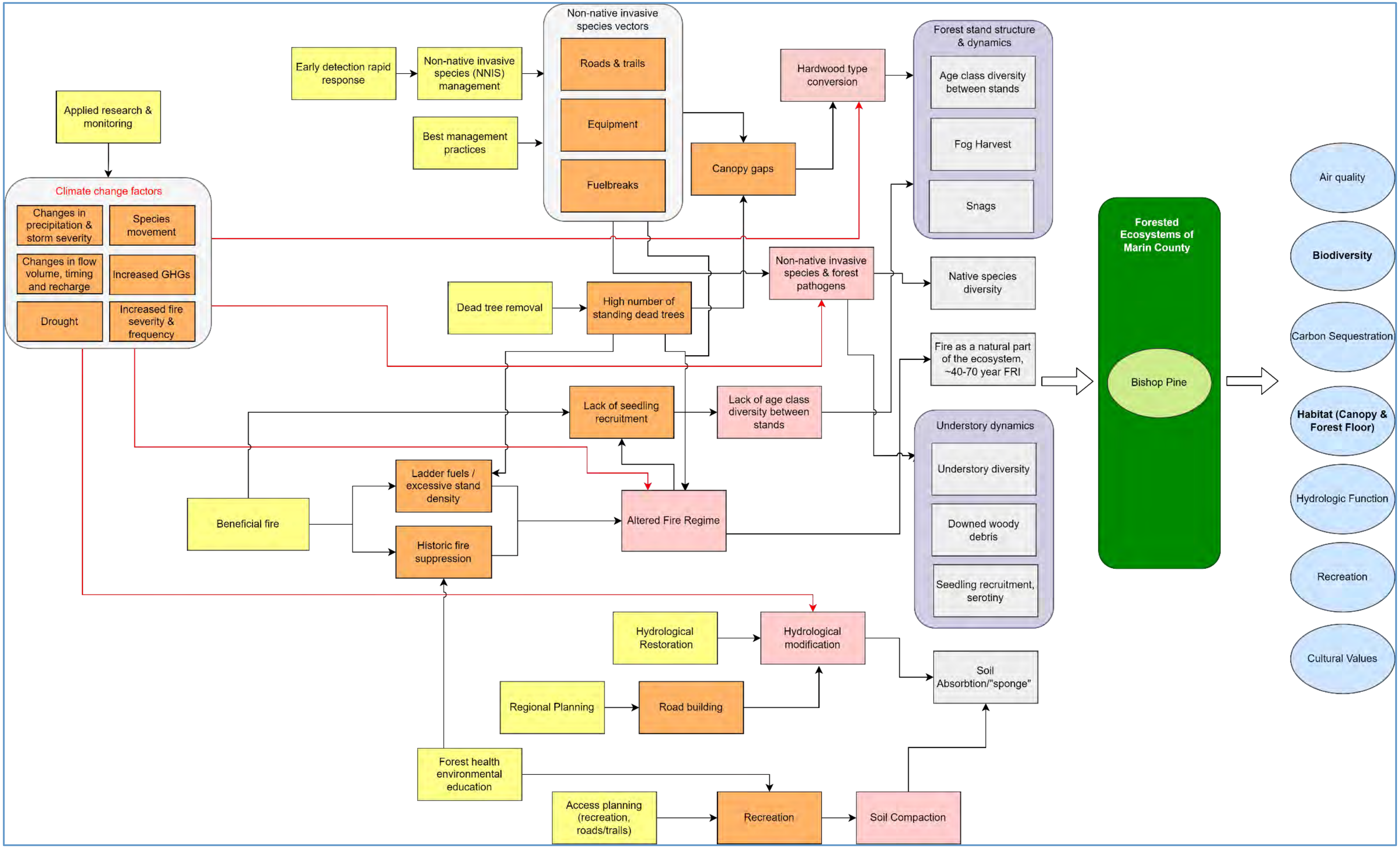


Figure 5.3. Bishop Pine Conceptual Model.



BISHOP PINE GOALS

The primary conservation goal for Bishop Pine in Marin County is maintaining the forest type within the larger landscape mosaic of forested ecosystems and habitats. Protecting and maintaining the overall Marin County population of Bishop Pine does not mean zero loss in all stands. There may be losses over time due to climate change, pitch pine canker, invasive species, and other threats. In this section, broad landscape-level goals to preserve the forest type within the larger landscape mosaic are followed by more specific interim results and conditions goals.

To preserve the benefits of Bishop Pine stands in Marin, a better understanding of pine pitch canker disease and stand health changes over time is needed. The *Forest Health Strategy* establishes baseline conditions in both cases, but monitoring is necessary for an increased understanding of Bishop Pine and appropriate management approaches. The actions outlined in the results chains will include research and monitoring to fill critical knowledge gaps. Approaches to measuring management outcomes in relationship to Bishop Pine goals are described in Chapter 10: Monitoring.

LANDSCAPE-LEVEL GOAL 1: FOREST HEALTH

One Tam agencies will work together to protect and maintain Bishop Pine throughout its range in Marin County and to preserve and promote healthy stands with multiple seral states including regeneration and recruitment of new age cohorts.

Landscape-Level Goal 1a: Treatment Feasibility

One Tam agencies will work together to design, implement, and monitor treatments to maximize forest health in Bishop Pine stands. Treatments may include testing and piloting different prescriptions aimed at promoting stand health and seedling recruitment, which could include cone collection, seed germination, thinning, pile burning, and other fire surrogate methods. See Chapter 9: Treatment Descriptions for more information.

LANDSCAPE-LEVEL GOAL 2: ECOSYSTEM SERVICES

Healthy stands of Bishop Pine provide the priority ecosystem services of biodiversity and habitat. Other ecosystem services include cultural values, hydrologic function, carbon sequestration, air quality, and recreation. One Tam agencies will manage Bishop Pine forest to continue to provide and strengthen these ecosystem services.

LANDSCAPE-LEVEL GOAL 3: APPLIED RESEARCH & MONITORING

One Tam agencies will collaborate to study Bishop Pine forests, including monitoring pilot treatments and the results of various prescriptions designed to promote Bishop Pine ecological health, as well as the response of Bishop Pine stands to adjacent active management treatments, e.g., Douglas-fir removal to promote oak woodland and hardwood forest health.

CONDITION GOALS & RESULTS CHAINS

Results chains are goal pathways which lay out a series of treatments and interim goals which cumulatively will allow managers to achieve landscape-level goals. Interim results and conditions goals are steps along the pathway to the desired conditions described in the landscape-level goals. See Chapter 9: Treatment Descriptions for a detailed discussion of treatment approaches and methods.

Specific treatments to reach condition goals could be tailored to different Bishop Pine habitat types such as open stands, mixed hardwood, conifer-chapparal, and pure stands. For more information on the floristic composition of these stands see the Vegetation Classification of Alliances and Associations in Marin County (Buck-Diaz et. al, 2021) and Bishop Pine Structural Classification in Chapter 6: Metrics.

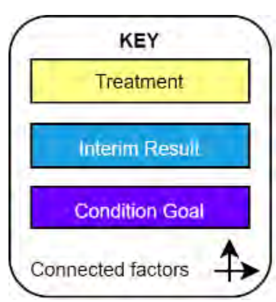
BENEFICIAL FIRE

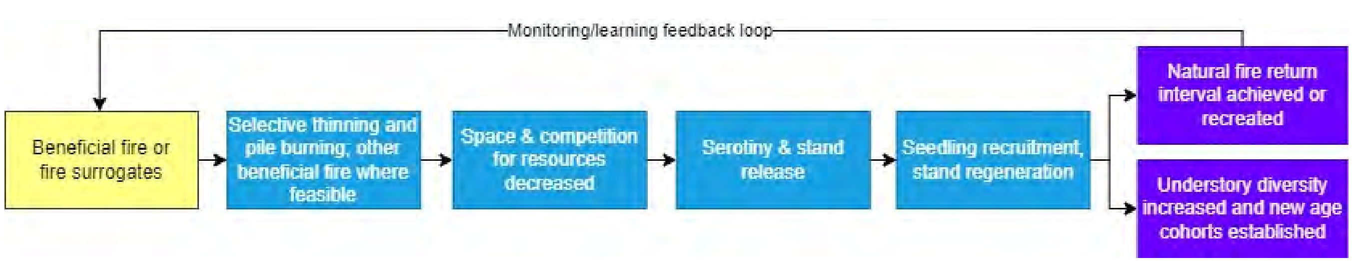
Beneficial fire includes prescribed fire, cultural burning, and fire managed for resource benefit (California Wildfire and Resilience Task Force, 2022). Pre-treatment thinning may be necessary to conduct burns safely.

Beneficial fire results chains and condition goals do not attempt to recreate a natural range of variation for fire return intervals using beneficial fire. The fire return interval is a baseline for understanding historical conditions and considering the range and timing of management actions, not a condition goal unto itself. Beneficial fire can be an important tool to facilitate Bishop pine regeneration. Pile burning can be used as a surrogate for broadcast burning where the latter is not feasible. See Chapter 3: Stewardship and Partnership with the Federated Indians of Graton Rancheria for more information on the importance of beneficial fire for cultural values.

Please note that the same key is used for all results chains.

Figure 5.4. Results chain key.





Interim Result 1: Selective thinning and pile burning treatments to test regeneration efficacy and make refinements to treatment prescription approaches.

Interim Result 2: Explore feasibility of beneficial fire use, including cultural burning in collaboration with Federated Indians of Graton Rancheria (the Tribe), prescribed fire, or fire managed for resource benefit. See Chapter 9: Treatment Descriptions for a detailed discussion of beneficial fire treatments.

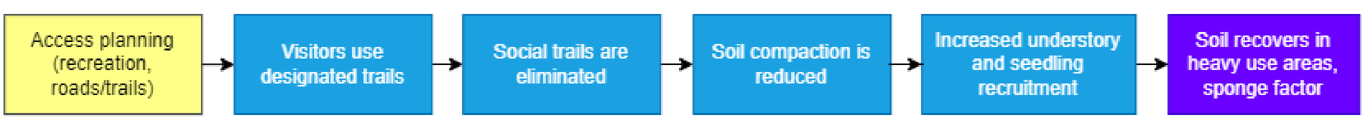
Interim Result 2: Pile burning and wildfires increase seedling recruitment and reduce dead/dying and small-diameter trees leading to stand release and increased seedling recruitment. Additional fire surrogate treatments such as chipping cones, controlled oven seed processing, soil scarification, raking, and other potential treatments could be undertaken as pilot or demonstration project work to determine the feasibility of assisting Bishop pine regeneration. Monitoring of results should be included to test assumptions and inform future work.

Condition Goal 1: Managers will aim to achieve or recreate natural fire return intervals.

Condition Goal 2: Understory diversity will increase and new age cohorts will be established.

SOIL & ACCESS PLANNING

Soil compaction can be a threat to Bishop Pine forest with a series of impacts. Initially soil compaction can lead to reduced understory vegetation and water infiltration, which in turn leads to a reduction in water available to vegetation and increased run-off, causing erosion and contributing sediment to streams. Soil compaction and introduction of non-native invasive species (NNIS) may be caused by recreational use and can be addressed through thoughtfully designed trails and signage (Cole, 2004).



Interim Result 1: Effective access planning, including signs and agency websites, explain the importance of using designated trails.

Interim Result 2: Visitors use designated trails; social trails and soil compaction are reduced, resulting in reduced spread of pathogens and non-native invasive species (NNIS) and increasing health of soil which acts as a sponge for water and nutrients.

Condition Goal 1: Soil health improves resulting in increased water filtration, seedling recruitment, tree vigor, and understory diversity.

NON-NATIVE INVASIVES PLANT SPECIES

Careful non-native invasive species detection and removal may improve the health and resilience of stands, especially those already stressed by pitch pine canker, drought, or natural decline due to age senesce. Maintenance over time will be necessary after initial NNIS removal treatments.

Interim Result 1: Countywide invasive plant mapping and early detection rapid response (EDRR) programs identify new and track existing non-native species invasions resulting in decreased new invasions.

Interim Result 2: Non-native invasive species management decreases the number of invasive species present and total invaded acres.

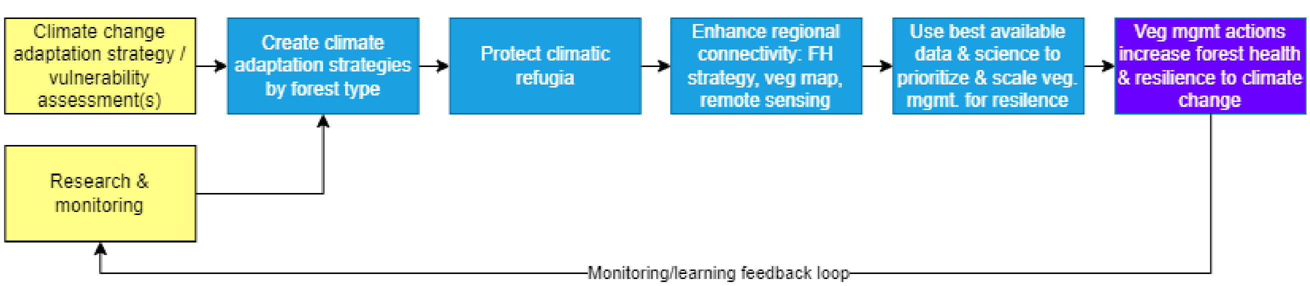
Interim Result 3: The invasion curve is flattened.

Interim Result 4: Costs are reduced for non-native invasive species control.

Condition Goal 1: Bishop Pine stands experience increased native species diversity and resilience.

CLIMATE CHANGE

Climate change threatens healthy forests in many complex and interconnected ways. For example, increasing temperatures and prolonged drought increases vulnerability to pests and pathogens as well as reducing germination success. See Chapter 4: Climate Change and Other Forest Health Stressors for an in-depth discussion of climate change impacts. Managing for climate change will involve an ongoing cycle of monitoring and assessing conditions; determining priority treatment areas to protect sensitive species, habitat corridors, and climate refugia; and adapting management actions as conditions change



Interim Result 1: Land managers create climate adaptation strategies by forest type based on vulnerability assessments, regional connectivity, and considerations regarding the distribution of species, threats, stressors, and management feasibility. Research and monitoring inform these strategies. Continued field monitoring will help fill knowledge gaps related to this species and refine approaches to managing for resilience.

Interim Result 2: Climatic refugia are protected. Areas predicted to remain suitable habitat for conservation targets (i.e., Bishop Pine) are prioritized for management.

Interim Result 3: Regional connectivity, collaboration, and collective impact is increased through use of the *Forest Health Strategy*, 2018 Fine Scale Vegetation Map and future updates, and additional landscape-scale remote sensing analysis.

Interim Result 4: By leveraging the best available spatial data, models, and climate science, managers can prioritize areas for management and work together to scale up treatments focused on increasing climate resilience for Bishop Pine forest.

Condition Goal 1: Vegetation management actions informed by landscape scale climate adaptation strategies increase Bishop Pine's resilience to climate change and bring stands within the new predicted range of natural variability.

BEST MANAGEMENT PRACTICES

Best Management Practices (BMPs) largely focus on reducing the spread of non-native invasive species and pathogens from site to site, protecting uninfected sites, and complying with environmental regulations. BMP practices for weeds and pathogens differ from EDRR and are focused on limiting introduction and spread. The intended outcomes for effective BMP practices are protecting the health of Bishop Pine stands and understory biodiversity. Additional BMPs developed in collaboration with the Tribe may include protecting cultural plants and gathering areas and protecting cultural sites during management activities.

Interim Result 1: Best management practices are reviewed with staff and contractors.

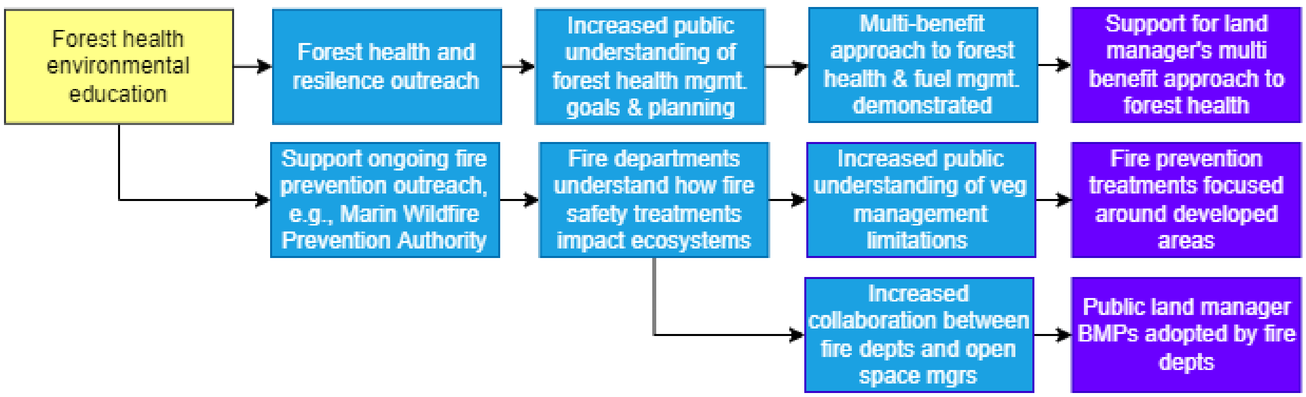
Interim Result 2: Comprehensive and effective best management practices are consistently implemented.

Interim Result 3: Forest pathogens and new non-native invasive species infestations are reduced.

Condition Goal 1: Forest stand structure and understory diversity are protected.

ENGAGEMENT & COLLABORATION

Managing forests for resilience requires collaborative efforts from the entire Marin community. Ongoing education and communication is necessary to ensure all groups are working together to meet overarching goals for forest health, cultural use, recreation, and fire safety. See Chapter 3: Stewardship and Partnership with the Federated Indians of Graton Rancheria for a discussion on collaboration with the Tribe.



Interim Result 1: Education and community outreach increases public understanding of the value of healthy and resilient forests. Bishop Pine environmental education will focus on serotinous life history and careful fire management needed for the forest type's long-term persistence in Marin County.

Interim Result 2: Increased education and signage about forest health, including plant pathogens and related impacts (such as pine pitch canker) to help prevent further spread.

Interim Result 3: Collaboration between the Tribe, fire departments, Marin Wildfire Prevention Authority (MWPA), and land managers increases.

Interim Result 4: Working with local groups, such as MWPA, fire prevention outreach focuses on actions in developed residential and commercial areas.

Interim Result 5: Best management practices are coordinated with the MWPA/Ecologically Sound Practices Partnership (ESP Partnership, 2022).

Interim Result 6: Forest resilience and fire management treatment prescriptions are developed in collaboration with the Tribe, cultural plants are protected for collection by Native peoples, and applicable cultural practices are restored.

Condition Goal 1: Increased support for land managers' multi-benefit approach to forest health.

Condition Goal 2: Fire departments adopt best management practices created and implemented by community groups, public land managers, the Tribe, and researchers.

Condition Goal 3: Fire prevention treatments focus on reducing risk to developed, residential, and commercial areas; critical infrastructure; and evacuation routes.

Condition Goal 4: Public land management agencies, the Tribe, community groups, and Marin Fire agencies develop coordinated multi-benefit projects to protect forest health, increase climate resilience, and address non-natural fuel arrangements (where applicable) in select locations at multiple scales.

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COAST REDWOOD FOREST

LIFE HISTORY

Sequoia sempervirens, or coast redwood, is endemic to a narrow strip of land approximately 750 kilometers in length and up to 75 kilometers in width along coastal areas of northern California and southwestern Oregon from 30-750 meters in elevation (Farjon, 2005). Typically found in heavy seasonal rainfall areas of the coast range, coast redwood grow in flood-prone areas such as alluvial streamside terraces (Edson et al., 2016). Coast redwood is a species of superlatives; living 2,200 years or more and reaching heights of 115 meters, it is the tallest living tree on earth. Coast Redwood stands have more standing carbon, biomass, and leaf area than any other forest species globally (Van Pelt et al., 2016).

In Marin, relatively little old-growth Coast Redwood forest remains. Old-growth stands have complex structures and are more resilient to wildfire and other stressors than second growth stands. Characteristics of old-growth stands include a mid-story with shade-tolerant species and an understory with shrubs and herbaceous species (Edson et al., 2016).

The floristic classification report that accompanied the 2018 Marin Countywide Fine Scale Vegetation Map (2018 Fine Scale Vegetation Map, Golden Gate National Parks Conservancy et al., 2021) describes the Coast Redwood alliance and member associations found in Marin County following standards established by the U.S. National Vegetation Classification (USNVC) and the CNPS *Manual of California Vegetation* (MCV). The floristic classification for Marin County was developed in partnership with the California Department of Fish and Wildlife Vegetation Classification and Mapping Program (CDFW VegCAMP) and California Native Plant Society Vegetation Program. Table 5.3 lists the fine scale map class for Coast Redwood along with member associations found in Marin County and described in the Marin classification report (Buck-Diaz et al., 2021, Appendix D).

Table 5.3. Coast Redwood 2018 Fine Scale Vegetation Map class (Sequoia sempervirens Forest & Woodland Alliance) (Golden Gate National Parks Conservancy et al., 2021) and member associations described in the corresponding floristic classification report (Buck-Diaz et al., 2021, Appendix D).

2018 Fine Scale Vegetation Map Class	Associations in Marin County
Sequoia sempervirens Alliance	• *Sequoia sempervirens – Acer macrophyllum – Umbellularia californica.* • *Sequoia sempervirens – Arbutus menziesii / Vaccinium ovatum* • *Sequoia sempervirens – Chrysolepis chrysophylla / Arctostaphylos glandulosa* • *Sequoia sempervirens – Notholithocarpus densiflorus / Vaccinium ovatum*

	• *Sequoia sempervirens – Pseudotsuga menziesii – Notholithocarpus densiflorus* • *Sequoia sempervirens – Pseudotsuga menziesii – Umbellularia californica* • *Sequoia sempervirens – Umbellularia californica* • *Sequoia sempervirens / (Pteridium aquilinum) – Woodwardia fimbriata* • *Sequoia sempervirens / Polystichum munitum*

KEY ECOSYSTEM SERVICES

Key ecosystem services identified for Coast Redwood are carbon sequestration, hydrologic function, and recreation. In addition, Marin's Coast Redwood forests provide important habitat for several mammals and birds, including the state and federally threatened Northern Spotted Owl (*Strix occidentalis caurina*). Endangered Coho Salmon (*Oncorhynchus kisutch*) and threatened Steelhead Trout (*O. mykiss*) reside in the Lagunitas and Redwood Creek Watersheds. Progression towards old-growth Coast Redwood forest communities benefits these species through increased shade, water temperature regulation, and increased instream and water table water quantity (Burns et al., 2018; Edson et al., 2016).

DISTRIBUTION

The 2018 Fine Scale Vegetation Map shows the distribution of *S. sempervirens* alliances at the stand level (Figure 5.5; Golden Gate National Parks Conservancy et al., 2021). A closer inspection of each stand can be accessed at the One Tam Forest Health Web Map.

FIRE REGIME

Coast redwood is a fire-enhanced facultative sprouter with site-specific fire dependence qualities (Stuart & Stephens, 2006). Coast redwood, especially larger trees, tend to survive fire, even high intensity fires (Douglas & Bendure, 2012; Lazzeri-Aerts & Russell, 2014; Ramage et al., 2010). However, there is some debate among researchers about the evolutionary significance of fire for Coast redwood trees. Some argue that the associated Coast Redwood understory may be more fire dependent than the redwood trees themselves (Lorimer et al., 2009; Stuart & Stephens, 2006).

Coast Redwood fire return intervals are widely variable, with estimates from 6-500 years (Stephens & Fry, 2005; Stuart & Stephens, 2006), ranging on the low end at xeric sites and high end at mesic sites (Jacobs et al., 1985; Lorimer et al., 2009; Veirs, 1980). Coast Redwood forest does not show a positive relationship between fire return intervals and fire severity, unlike mixed evergreen and bigcone Douglas-fir (*Pseudotsuga macrocarpa*)(Steel et al., 2015), meaning that, in Coast Redwood forests, fire severity is more dependent on climate conditions and ignition frequency rather than available fuel loads.

Figure 5.5. Coast Redwood distribution in Marin County.

In Marin County, fire return intervals (FRIs) depend on proximity to the coast, fog days, and topography. Jacobs et al. (1985) measured coast redwood fire return intervals from coast to inland in Marin. Results from sampling along the ridgelines bracketing Muir Woods showed the average interval was 27 years at the coast, decreasing to 22 years inland. They concluded that using an average fire interval is inappropriate given fog gradients, geographical variability of fire frequency, and skewed interval frequency distribution.

At Point Reyes National Seashore, FRIs of 8-13 years were reported in one stand of coast redwood (Brown et al., 1999). In Sonoma County, Finney and Martin (1992) found a return interval in Annadel State Park of 6-23 years for coast redwood. A fire history study compiled from coast redwood stump samples along Bolinas Ridge found a mean composite FRI ranging from 7.5 to 45+ years (Finney, 1990). Data from Finney (1990) also suggested that mean FRIs on Bolinas Ridge have increased dramatically since the 1800s. A fire history study of coast redwood in the Santa Cruz mountains analyzed fire scar samples from approximately 1650–1860 and found a mean FRI of 12 years (Stephens & Fry, 2005).

Though Coast Redwood forest in Marin historically experienced fire at regular intervals, fire frequency has changed with modern fire suppression. The overwhelming majority of Coast Redwood stands in Marin have not experienced fire in the last 70 years or have no recorded fires since 1859. In a recent Marin fire history study, only two acres out of 11, 265 acres of Coast Redwood were categorized with time since last fire of 25-40 years, with all others recorded in the >70 years or no recorded fires categories (Dawson, 2021). A detailed Marin County fire history can be found in Appendix B: Wildfire History. The fire history impacts on Coast Redwood stand structure, mortality and diversity can be found in Chapter 7: Condition Assessment.

In areas where Coast Miwok people tended the landscape, a regular, low-intensity fire regime of approximately every two years was observed in a mosaic across the landscape to increase the yield for tanoak (*Notholithocarpus densiflorus*) acorns, herbaceous plants, and basket weaving materials (Anderson, 2018; Noss, 2000). Frequent burning by Native Americans before Spanish settlement in the early 1800s maintained limited accumulations of understory and surface fuels, which were discontinuous in many places (Finney, 1990). Cultural burning decreased fire return intervals before European invasion; Coast Redwood, without anthropogenic burning, would support much longer return intervals (Greenlee & Langenheim, 1990; Stuart & Stephens, 2006). Fire dependence in the understory might be due to Native American tending in and around Coast Redwood stands for game, fiber, safety, and other food sources (Anderson, 2018; Finney, 1990; Noss, 2000). The Tribe's access, stewardship, and use of these lands and waters are interrelated with and integral to the health, sustainability, and wellbeing of the environment, and a healthy and well-stewarded environment directly contributes to the health, sustainability, and wellbeing of the Tribe. See Chapter 3: Stewardship and Partnership with the Federated Indians of Graton Rancheria, for additional discussion on these topics.

As shown in Table 5.4, Coast Redwood typically burns in summer and early fall with variable intervals (CNPS, n.d.; Stuart & Stephens, 2006). When burning, the fires tend to be moderate intensity surface fires with occasional crown fires in drier portions of the range.

Table 5.4. Summary of fire regime characteristics for Coast Redwood (adapted from Stuart & Stephens, 2006).

Temporal	Seasonality	Summer-fall
	Fire return	8-45+ years

	interval	
Spatial	Size	Small-medium
	Complexity	Moderate
Magnitude	Intensity	Moderate
	Severity	Low
	Fire type	Surface/occasional crown

THREATS & POST-LOGGING LEGACY

Coast redwood is a globally important species of conservation concern. Despite international importance, they are threatened by logging, burl poaching, climate change, and habitat fragmentation. The species is listed as endangered on the International Union for Conservation of Nature (IUCN) Red List (IUCN, n.d.). In Marin County, the primary threats to Coast Redwood forest have historically come from logging, whereas more recent threats come from climate change, soil compaction, hydrological modification, forest type conversion, non-native invasive species, fire suppression, low canopy closure, or lack of age class diversity. Threats found in *Measuring the Health of a Mountain: A Report on Mount Tamalpais' Natural Resources* (*2016 Peak Health Report*) are sudden oak death, climate change, non-native invasive species, Douglas-fir encroachment, and soil compaction (Edson et al., 2016).

Historical logging occurred primarily during the early part of the 19th-century and accelerated during the gold rush of 1849. Logging greatly affected Redwood populations at the landscape scale, impacting 93% of their original extent. Repeated burning, largely to reduce logging slash, selected against Douglas-fir (*Pseudotsuga menziesii*), grand fir (*Abies grandis*), Sitka spruce (*Picea sitchensis*), and western hemlock (*Tsuga heterophylla*) and selected for redwood and hardwoods (Noss, 2000). The shift to steam-railroad logging, and then to tractor-truck logging, during the Industrial Age of the late 19th to 20th-centuries produced extensive areas of disturbed soils and favored tree species other than coast redwood, such as Douglas-fir and western hemlock (Noss, 2000). The remaining Marin County old-growth Coast Redwood stands are at Muir Woods National Monument, Steep Ravine and Fern Creek (Mt. Tamalpais State Park), Roy's Redwoods Preserve (Marin County Parks), and Samuel P. Taylor State Park.

Post-logging management practices and fire suppression have shifted forest composition away from historic coast redwood dominance and toward increasing tanoak and Douglas-fir (Burns et al., 2018). High tanoak densities in second-growth Coast Redwood stands in the mesic portions of Mt. Tamalpais show this logging/fire suppression history and a need for treatments designed to increase coast redwood recruitment (Edson et al., 2016).

Second-growth Coast Redwood stands, which are stands logged at least once, are short in stature, dense, missing most or all of the original old trees, and exhibit lower biodiversity and reduced carbon storage relative to old-growth stands (Burns et al., 2018). Fifty percent of young second-growth stands have an average tree diameter of 20 centimeters and grow in high densities of nearly 5,000 trees/hectare due to prolific stump-sprouting (Burns et al., 2018). Because of intensive logging impacts, many of the species associated with old-growth, along with forest structure, function, hydrology, and biological assemblages, have disappeared in second-growth stands and are difficult to restore (Thornburgh et al., 1999). There is also evidence that genetic diversity is depleted in second-growth Coast Redwood forests—partially logged old-growth stands at Big Basin Redwoods, Humboldt Redwoods, and Prairie Creek State Parks exhibited less than half the coast redwood genetic diversity of undisturbed old-growth stands (Narayan, 2015).

Save the Redwoods League's 2018 *State of the Redwood Conservation Report* noted that mature second-growth Coast Redwood forests (those last logged in the 19th century) are relatively rare. These forests have old-growth characteristic such as lower tree densities and large diameter trees; however, habitat complexities such as downed logs and tree cavities are not yet abundant in most mature second-growth forests (Burns et al., 2018, p.17). However, selective thinning of second-growth Coast Redwood forests on the north coast of California has been shown to accelerate the development of old-growth characteristics and may be an effective tool for both forest restoration and long-term carbon sequestration (Soland et al., 2021).

SUDDEN OAK DEATH

While coast redwood trees are not affected by sudden oak death, important understory associates, such as tanoak (*Notholithocarpus densiflorus*) are. Stand level treatments to explore approaches to managing sudden oak death forest impacts in Coast Redwood and Douglas-fir forest were compared by Cobb et al. (2017). Researchers compared a “restoration” treatment in an area heavily impacted by sudden oak death on Tamalpais Watershed lands (mastication plus hand thinning in Douglas-fir - tanoak and Redwood-tanoak) and a “resilience treatment” focused on an at-risk but unaffected forest (manual tanoak thinning). Both treatment approaches greatly reduced the density of key sporulation supporting hosts and illustrate potential approaches to addressing the complex management challenges presented by sudden oak death-impacted forests including fuels accumulation, loss of biodiversity, and desire to retain carbon storage. This study found only a small difference in carbon sequestration between treated and untreated reference (control) areas since basal area was conserved by focusing management on smaller diameter stems (Cobb et al., 2017).

CONCEPTUAL MODEL

The Marin Forest Health Strategy Working Group (Working Group) developed a conceptual model for Coast Redwood forest showing ecosystem services, forest health attributes, direct/indirect threats, and treatments. The key for the conceptual model is shown in Figure 5.6 and the conceptual model is Figure 5.7. The Working Group established condition goals for Coast Redwood forest and accompanying results chains from the conceptual model.

Figure 5.6. Conceptual model key.

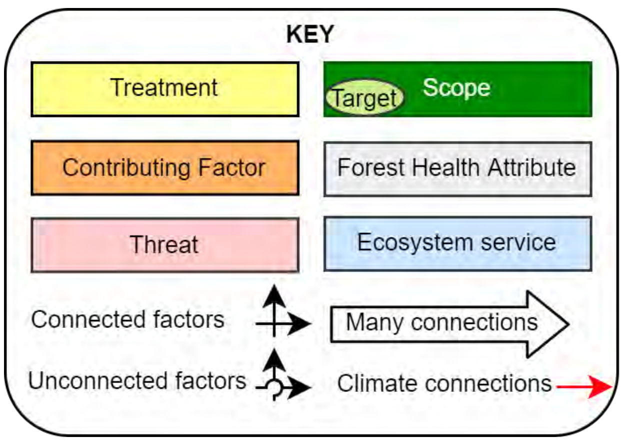
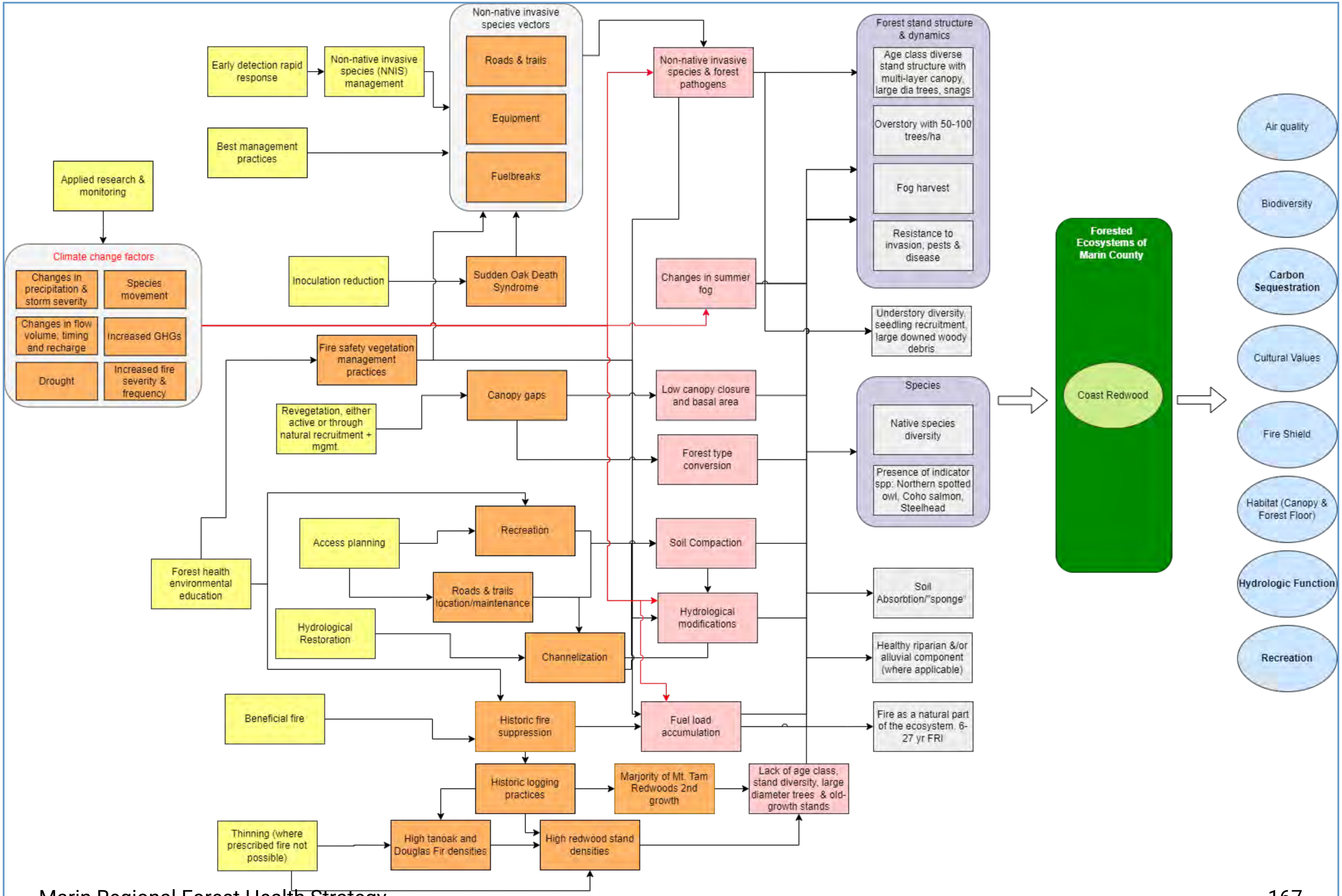


Figure 5.7. Coast Redwood conceptual model.



COAST REDWOOD GOALS

The One Tam agencies and partners will work towards broader landscape-level goals described below through treatments designed to meet interim results and conditions goals. According to the *2016 Peak Health Report*, the desired condition for old-growth Coast Redwood forest is stands which sustain complex species composition and multi-aged/storied stand structure, and contain coarse woody debris, tree cavities, and nesting structures. Desired conditions for second-growth is stands which are on a path toward old-growth features, including reduced stem density, increased number of large-diameter trees, and multi-storied stand structure (Edson et al., 2016).

For Coast Redwood, infrequently burned stands are less likely to experience high burn severities, possibly due to intact stands creating shady and mesic microclimates resistant to fire (Engber et al., 2011; Steel et al., 2015). Therefore, accelerating stands toward old-growth conditions using a variety of treatments could be a benefit in reducing burn severity.

With the additional stressors of climate change, decreased precipitation, and possibly decreasing fog, restoration treatments may need to be considered to move towards old-growth conditions. Managers may consider the lack of fire in Coast Redwood forests a form of disturbance and can examine if there is a link between lack of fire and observed departure from desired conditions. In which case, introducing beneficial fire or fire surrogates (e.g., thinning) where needed and feasible can be a useful management tool.

See Chapter 4: Climate Change and Other Forest Health Stressors for additional discussion of fire exclusion and other stressors and the results chains below related to fire and thinning for suggested approaches. The historic fire impacts on Coast Redwood stand structure, mortality, and diversity can be found in Chapter 7: Condition Assessment. Approaches to measuring management outcomes in relationship to Coast Redwood goals are described in Chapter 10: Monitoring.

LANDSCAPE-LEVEL GOAL 1: FOREST HEALTH

One Tam agencies will work together to increase resilience of Coast Redwood stands and move them towards old-growth conditions by maintaining and enhancing healthy attributes such as structural diversity, snags, understory native species diversity, and absorbent soil which acts as a sponge, infiltrating water and decreasing runoff. Resilience-focused management will recognize fire as a part of Coast Redwood ecosystem function and increase resistance to and limit the spread of pests and pathogens.

Landscape-level Goal 1a: Old Growth Distribution

One Tam agencies will work to improve old growth distribution mapping, including historical Coast Redwood logging research to understand extraction patterns and timing.

Landscape-level Goal 1b: Stand Integrity

One Tam agencies will protect the integrity of existing old-growth stands using early detection rapid response for non-native invasive weeds, recreation planning, and hydrological restoration. Integrity protection may include selective management of old-growth stands to address SOD impacts in the understory or unnatural stand structure due to fire exclusion.

Landscape-level Goal 1c: Second-growth Stand Active Management

One Tam agencies will prioritize second-growth stands for active management using thinning, beneficial fire, and other management practices to move second-growth towards old-growth conditions. Where second growth closely coincides with old growth, create a blended approach to meet both stand characteristic goals. See Chapter 9: Treatment Descriptions for more information.

LANDSCAPE-LEVEL GOAL 2: ECOSYSTEM SERVICES & BIODIVERSITY

Healthy stands of Coast Redwood provide the priority ecosystem services of carbon sequestration, hydrologic function, and recreation, and maintain or improve biodiversity in associated habitats. One Tam agencies will work to protect and improve ecosystem services provided by Coast Redwood forest. Management actions will protect or expand habitat for indicator species such as salmonids and Northern Spotted Owls.

Landscape-level Goal 2a: Climate Refugia

Managers will assess the potential for Coast Redwoods stands to act as climate refugia for sensitive species and work together to encourage this process.

CONDITION GOALS & RESULTS CHAINS

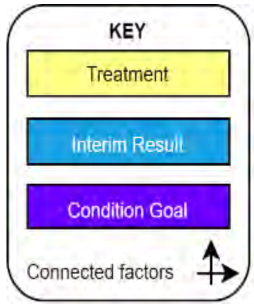
Results chains are goal pathways which lay out a series of treatments and interim goals which cumulatively will allow managers to achieve landscape-level goals. Interim results and conditions goals are steps along the pathway to the desired conditions described in the landscape-level goals. See Chapter 9: Treatment Descriptions for a detailed discussion of treatment approaches and methods.

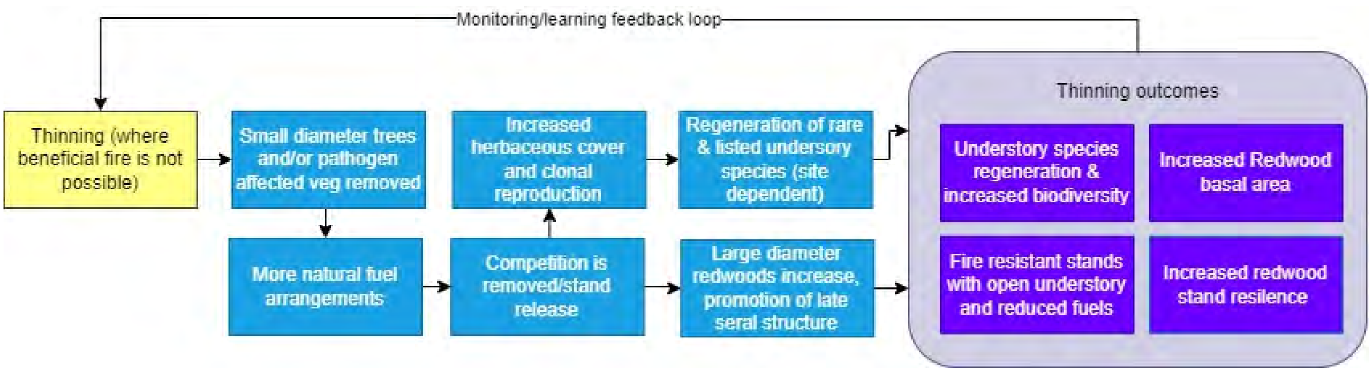
THINNING

Thinning second-growth stands can be useful for managing pest and pathogen-impacted vegetation, controlling Douglas-fir encroachment, and can act as a fire surrogate by removing small-diameter coast redwood where appropriate. It can be used where beneficial fire is difficult or prohibitive to employ. Old-growth stands could be selectively thinned if conditions resulting from pathogen impacts or fire exclusion threaten stand resilience. Although the outcomes of the thinning and prescribed fire treatments are the same, thinning is not a replacement for beneficial fire. For example, rare, fire-dependent redwood associates such as Marin manzanita (*Arctostaphylos virgata*) and Mason's ceanothus (*Ceanothus masonii*) will likely not benefit from thinning alone. In some cases, thinning treatments will need to be a precursor to beneficial fire to reduce fuel loads. Thinning will require a monitoring feedback loop to measure Coast Redwood stand health outcomes and determine future management actions.

Please note the same key is used for all results chains.

Figure 5.8. Results chain key.





Interim Result 1: Thinning reduces competition, increasing light penetration in the forest canopy, increasing mid- and understory diversity, and promotes more natural fuel arrangements in stands impacted by fire exclusion.

Interim Result 2: Pathogen-affected vegetation (where present) is removed resulting in more natural fuel arrangements and reduced sudden oak death (SOD) spread. Where possible, alternatives for diseased tanoak removal will be explored to reduce SOD pathogen spread and encourage healthy tanoak for cultural and biodiversity benefit.

Interim Result 3: Where appropriate, small-diameter coast redwood and other species are removed, resulting in more natural fuel arrangements, competition removal, stand release, and increased large-diameter coast redwood trees.

Interim Result 4: Following thinning, herbaceous cover and redwood clonal reproduction increases resulting in regeneration of rare and listed shrub species at specific priority sites.

Condition Goal 1: Increased species regeneration and germination of the understory and shrub layer in Coast Redwood stands. Note that some understory species will require beneficial fire for regeneration.

Condition Goal 2: Fire resilient stands with more natural fuel arrangements.

Condition Goal 3: Increased resilience for Coast Redwood stands.

Condition Goal 4: Persistence of a multi-layered stand structure dominated by native tree species in Coast Redwood forest stands (Edson et al., 2016, p. 45).

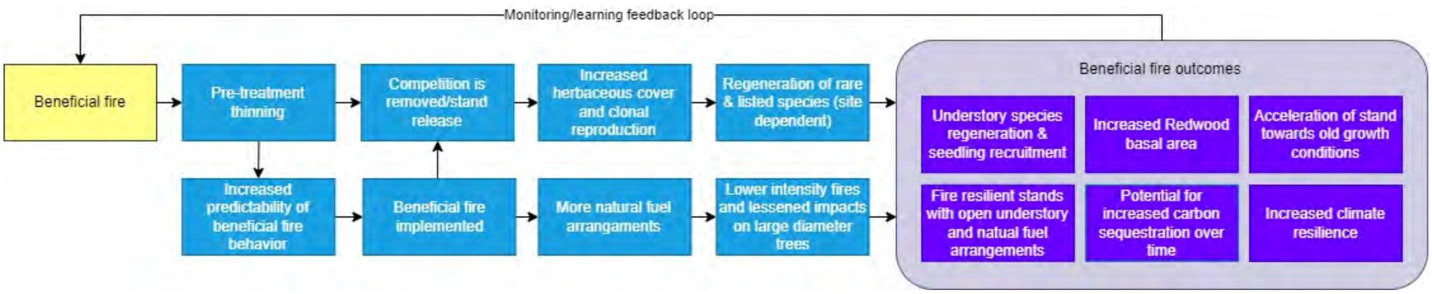
Condition Goal 5: Tree density at or moving towards Coast Redwood forest reference conditions of 460 ± 70 trees per hectare with approximately 18% of trees > 100 cm in diameter (Edson et al., 2016, p. 42).

BENEFICIAL FIRE

Beneficial fire includes prescribed fire, cultural burning, and fire managed for resource benefit (California Wildfire and Resilience Task Force, 2022). Pre-treatment thinning may be necessary to conduct burns safely.

Beneficial fire results chains and condition goals do not attempt to recreate a natural range of variation for fire return intervals using beneficial fire. The fire return interval is a baseline for understanding historical conditions and considering the range and timing of management actions, not a condition goal unto itself.

See Chapter 3: Stewardship and Partnership with the Federated Indians of Graton Rancheria for more information on the importance of beneficial fire for cultural values.



Interim Result 1: Pre-treatment thinning increases the predictability of beneficial fire while also reducing competition, increasing light penetration in the forest canopy, increasing mid- and understory diversity, and creating more natural fuel arrangements.

Interim Result 2: Beneficial fire results in more natural fuel arrangements, potentially like those created through Indigenous stewardship, and increases herbaceous cover/seedling recruitment.

Interim Result 3: Following pre-treatment thinning and beneficial fire, herbaceous cover and redwood clonal reproduction increases resulting in regeneration of rare endemic chapparal species at specific priority sites.

Interim Result 4: Where possible, cultural burning sites will be identified and burned in collaboration with the Federated Indians of Graton Rancheria (the Tribe).

Condition Goal 1: Increased species regeneration and germination of the understory and shrub layer in Coast Redwood stands.

Condition Goal 2: Fire & climate resilient stands with more natural fuel arrangements.

Condition Goal 3: Potential for increased carbon sequestration over time.

Condition Goal 4: Cultural burning recruits specific desired understory plants and protects other cultural values as identified by the Tribe.

Condition Goal 5: Persistence of a multi-layered stand structure dominated by native tree species in Coast Redwood forest stands (Edson et al., 2016, p. 45).

Condition Goal 6: Tree density at or moving towards Coast Redwood forest reference conditions of 460 ± 70 trees per hectare with approximately 18% of trees > 100 cm in diameter (Edson et al., 2016, p. 42).

HYDROLOGY

Addressing hydrologic modification through restoration includes decommissioning or improving drainage on roads and trails to improve hydrological function and promote water infiltration into the soil (Sosa-Pérez & MacDonald, 2017; Switalski et al., 2004; Weaver et al., 2014). Reducing sediment transport from roads and trails improves water quality and protects aquatic habitat as well. Reduced soil disturbance and runoff also decreases the chance of non-native species invasions (Mortensen et al., 2009).

Restoration of riparian corridors can slow drainage out of watersheds, increase groundwater recharge, and increase water availability for redwoods and associated species to help accelerate second-growth stands to old-growth conditions. As climate change causes increased temperatures and longer drought periods, retaining water in the watersheds will become increasingly important for resilience (GGNRA, 2011).

Interim Result 1: Identify priority areas to benefit from hydrological restoration.

Interim Result 2: Hydrological restoration projects identified, funded, and implemented by land managers.

Interim Result 3: Soil is protected from runoff and erosion by protecting native mulch and understory vegetation.

Interim Result 4: Functioning upland hydrology is restored to prioritized Coast Redwood streams as measured by stream gauge hydrographs.

Interim Result 5: Increased dry season surface flow and improved aquatic species habitat.

Condition Goal 1: Hydrological restoration retains water and accelerates growth rates, promoting old growth characteristics.

Condition Goal 2: Water retention improves resilience to climate change.

SOIL & ACCESS PLANNING

Soil compaction can be a threat to Coast Redwood forest with a series of impacts. Initially soil compaction can lead to reduced understory vegetation and water infiltration, which in turn leads to a reduction in water available to vegetation and increased runoff, causing erosion and contributing sediment to streams. Soil compaction may be caused by recreational use and can be addressed through thoughtfully designed trails and signage (Cole, 2004; Voigt, 2016).

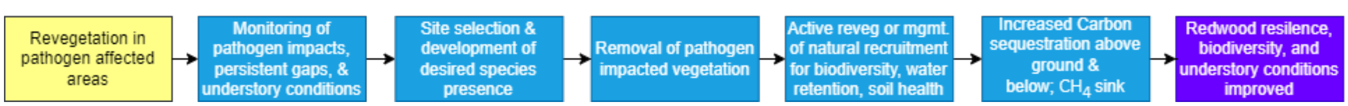
Interim Result 1: Effective access planning, including effective trail design and signage, support the use of designated trails.

Interim Result 2: Visitors use designated trails; social trails and soil compaction are reduced, resulting in reduced spread of pathogens and non-native invasive species (NNIS) and increasing health of soil which acts as a sponge for water and nutrients.

Condition Goal 1: Soil health improves resulting in increased water filtration, tree vigor, recruitment of herbaceous layer, and overall understory diversity.

UNDERSTORY / PERSISTENT GAP REVEGETATION

In some areas heavily impacted by pathogens, the dieback of tanoak and other hardwoods can create canopy gaps in or adjacent to redwood forests. Without monitoring and management, these gaps may persist or in-fill with non-native invasive species and could impact redwood resilience or lead to forest type conversion. Active revegetation and/or supported natural recruitment can be useful tools for protecting and restoring species diversity, healthy soil, and redwood resilience. Revegetation can focus on herbaceous and shrub species in areas where understory vegetation is damaged or on desirable tree species in areas where canopy gaps persist and are a threat to the forest type.



Interim Result 1: Site selection priorities and desired native species plant palette developed, or natural recruitment targets established.

Interim Result 2: Diseased hardwoods removed at prioritized sites to reduce pathogen loads. Where possible, alternatives for diseased tree removal will be explored.

Interim Result 3: Survivorship of plantings is increased through regular weeding, browse control, stewardship, and maintenance actions.

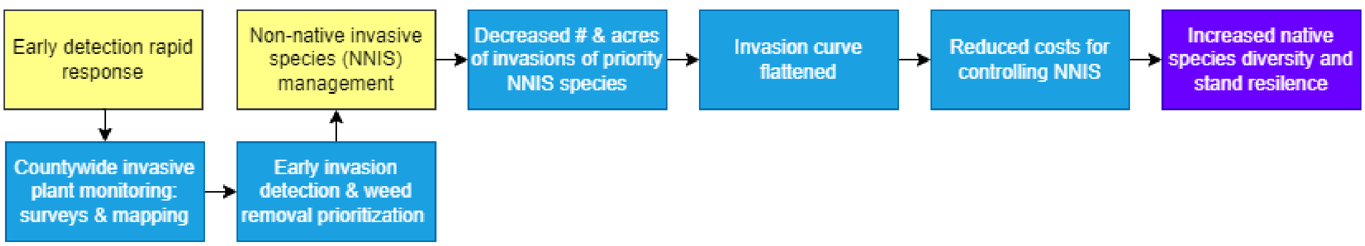
Interim Result 4: Active planting and/or management of natural recruitment leads to increased species diversity, water retention, soil health, and carbon sequestration.

Condition Goal 1: Redwood stand structure, understory diversity, and seedling recruitment approaching desired conditions (Edson et al., 2016, p. 42).

Condition Goal 2: Persistent canopy gaps and/or degraded understory conditions created by pathogen impacts are reduced.

NON-NATIVE INVASIVE PLANT SPECIES

Non-native invasive species (NNIS) threaten native species diversity and may displace native vegetation which provides essential food and shelter for sensitive wildlife. In addition, some NNIS can contribute to unnatural fuel loads and reduce forest resilience.



Interim Result 1: Countywide invasive plant mapping and early detection rapid response (EDRR) programs identify new and track existing non-native species invasions resulting in decreased new invasions.

Interim Result 2: Non-native invasive species management decreases the number of invasive species and total invaded acres.

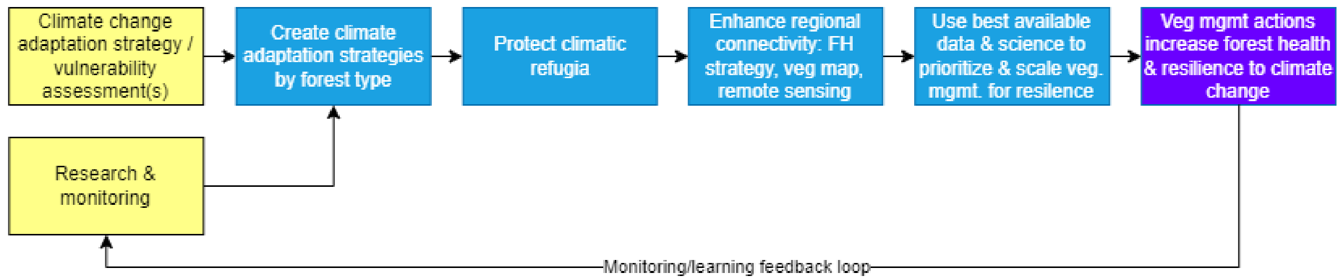
Interim Result 3: The invasion curve is flattened.

Interim Result 4: Costs are reduced for non-native invasive species control.

Condition Goal 1: Ninety percent of priority redwood stands are at or below maintenance levels for targeted invasive species (Edson et al., 2016, p. 48).

CLIMATE CHANGE

Climate change threatens healthy forests in many complex and interconnected ways. For example, increasing temperatures and prolonged drought increases vulnerability to pests and pathogens as well as reducing germination success. See Chapter 4: Climate Change and Other Forest Health Stressors for an in-depth discussion of climate change impacts. Managing for climate change will involve an ongoing cycle of monitoring and assessing conditions; determining priority treatment areas to protect sensitive species, habitat corridors, and climate refugia; and adapting management actions as conditions change.



Interim Result 1: Land managers create climate adaptation strategies by forest type based on vulnerability assessments, habitat connectivity, and considerations regarding the distribution of species, threats, stressors, and management feasibility. Research and monitoring inform these strategies.

Interim Result 2: Climatic refugia are protected. Areas predicted to remain suitable habitat for conservation targets (i.e., coast redwood) are prioritized for conservation and management.

Interim Result 3: Regional connectivity, collaboration and collective impact is increased through use of the *Forest Health Strategy*, 2018 Fine Scale Vegetation Map and future updates, and additional landscape-scale remote sensing analysis.

Interim Result 4: By leveraging the best available spatial data, models, and climate science, managers can prioritize areas for management and work together to scale up treatments focused on increasing climate resilience for priority Coast Redwood stands.

Condition Goal 1: Vegetation management actions informed by landscape scale climate adaptation strategies increase priority Coast Redwood stand resilience to climate change and bring stands within the new predicted range of natural variability.

BEST MANAGEMENT PRACTICES

Best Management Practices (BMPs) largely focus on reducing the spread of non-native invasive species and pathogens from site to site, protecting uninfected sites, and complying with environmental regulations. BMP practices for weeds and pathogens differ from EDRR and are focused on limiting introduction and spread. The intended outcomes for effective BMPs are protecting Coast Redwood habitat and understory diversity. Additional BMPs developed in collaboration with the Tribe may include protecting cultural plants and gathering areas and protecting cultural sites during management activities.

Interim Result 1: Best management practices are reviewed with staff and contractors.

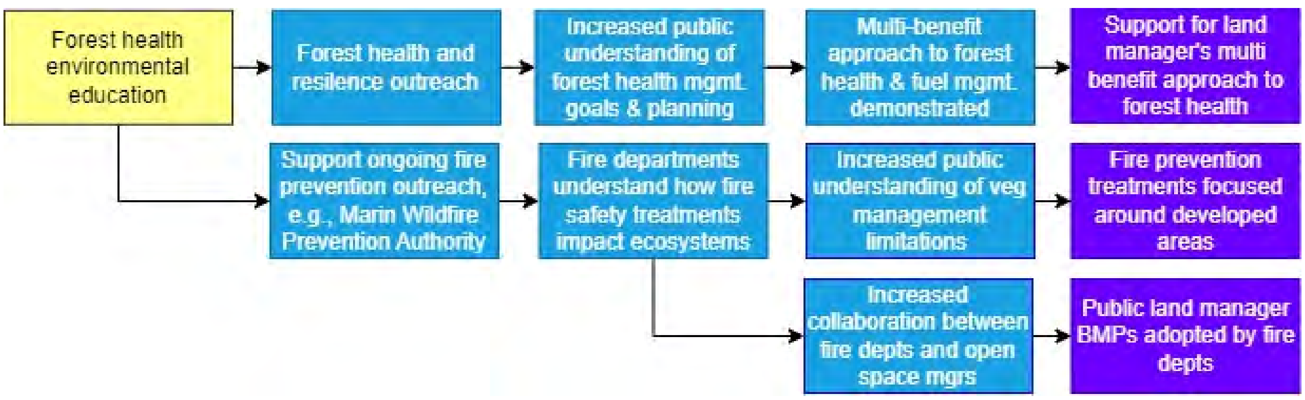
Interim Result 2: Comprehensive and effective best management practices are consistently implemented.

Interim Result 3: Forest pathogens and new non-native invasive species infestations are reduced.

Condition Goal 1: Forest understory diversity and stand health is protected.

ENGAGEMENT & COLLABORATION

Managing forests for resilience requires collaborative efforts from the entire Marin community. Ongoing education and communication is necessary to ensure all groups are working together to meet overarching goals for forest health, cultural use, recreation, and fire safety. See Chapter 3: Stewardship and Partnership with the Federated Indians of Graton Rancheria for a discussion on collaboration with the Tribe.



Interim Result 1: Education and community outreach increases public understanding of the value of healthy and resilient redwood forests, including water quality and retention, and salmonid and Northern Spotted Owl habitat.

Interim Result 2: Increased education and signage about forest health, including plant pathogens and related impacts (such as sudden oak death) to help prevent further spread.

Interim Result 3: Collaboration between the Tribe, fire departments, Marin Wildfire Prevention Authority (MWPA), and land managers increases.

Interim Result 4: Working with local groups, such as MWPA, fire prevention outreach focuses on actions in developed residential and commercial areas.

Interim Result 5: Best management practices are coordinated with the MWPA/Ecologically Sound Practices Partnership (ESP Partnership, 2022).

Interim Result 6: Forest resilience and fire management treatment prescriptions are developed in collaboration with the Tribe, cultural plants are protected for collection by Native peoples, and applicable cultural practices are restored.

Condition Goal 1: Increased support for land managers' multi-benefit approach to forest health.

Condition Goal 2: Fire departments adopt best management practices created and implemented by community groups, public land managers, the Tribe, and researchers.

Condition Goal 3: Fire prevention treatments focus on reducing risk to developed, residential, and commercial areas; critical infrastructure; and evacuation routes.

Condition Goal 4: Public land management agencies, the Tribe, community groups, and Marin Fire agencies develop coordinated multi-benefit projects to protect forest health, increase climate resilience, and address non-natural fuel arrangements (where applicable) in select locations at multiple scales.

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DOUGLAS-FIR FOREST

LIFE HISTORY

Pseudotsuga menziesii, or Douglas-fir, is an evergreen conifer in the *Pinaceae* family but is not a true fir, as the name implies. Trees typically reach 100 meters in height, achieving reproductive maturity at 20 years. Ages of more than 500 years are not uncommon, and individuals over 1,400 years old have been recorded (Burns & Honkala, 1990). Douglas-fir species can grow under a wide variety of conditions from the northern Rockies to the Pacific Northwest. They prefer neutral to acidic, well-drained soils from 0-3,200 meters in elevation (Hermann & Lavender, 1990).

The floristic classification report that accompanied the 2018 Marin Countywide Fine Scale Vegetation Map (2018 Fine Scale Vegetation Map, Golden Gate National Parks Conservancy et al., 2021) describes the Douglas-fir alliance and member associations found in Marin County following standards established by the U.S. National Vegetation Classification (USNVC) and the CNPS *Manual of California Vegetation* (MCV). The floristic classification for Marin County was developed in partnership with the California Department of Fish and Wildlife Vegetation Classification and Mapping Program (CDFW VegCAMP) and California Native Plant Society Vegetation Program. Table 5.5 lists the fine scale map class for Douglas-fir along with member associations found in Marin County and described in the Marin classification report (Buck-Diaz et al., 2021, Appendix D).

Table 5.5. Douglas-fir 2018 Fine Scale Vegetation Map class (Pseudotsuga menziesii – (Notholithocarpus densiflorus – Arbutus menziesii Alliance) (Golden Gate National Parks Conservancy et al., 2021) *and member associations described in the corresponding floristic classification report (Buck-Diaz et al., 2021, Appendix D).*

2018 Fine Scale Vegetation Map Class	Associations in Marin County
Pseudotsuga menziesii – (Notholithocarpus densiflorus – Arbutus menziesii) Alliance	• *Pseudotsuga menziesii / (Toxicodendron diversilobum) Association* • *Pseudotsuga menziesii – Arbutus menziesii Association* • *Pseudotsuga menziesii – Chrysolepis chrysophylla – Notholithocarpus densiflorus Association* • *Pseudotsuga menziesii – Quercus chrysolepis Association* • *Pseudotsuga menziesii – Notholithocarpus densiflorus / Vaccinium ovatum Association* • *Pseudotsuga menziesii – Notholithocarpus densiflorus – Umbellularia californica / Toxicodendron diversilobum Association* • *Pseudotsuga menziesii – Quercus agrifolia Association*

	• *Pseudotsuga menziesii – Umbellularia californica / (Toxicodendron diversilobum) Association* • *Pseudotsuga menziesii – Umbellularia californica / Frangula californica Association* • *Pseudotsuga menziesii – Umbellularia californica / Polystichum munitum Association* • *Pseudotsuga menziesii / Baccharis pilularis Association* • *Pseudotsuga menziesii / Corylus cornuta / Polystichum munitum Association*

KEY ECOSYSTEM SERVICES

Key ecosystem services identified for Douglas-fir forest are air quality, biodiversity, carbon sequestration, habitat, hydrologic function, and recreation. Carbon sequestration is the priority service provided by Douglas-fir. Managing Douglas-fir to continue to provide and strengthen these ecosystem services is an important goal for the One Tam agencies.

DISTRIBUTION

The 2018 Fine Scale Vegetation Map shows the distribution of *Pseudotsuga menziesii* stands at the alliance level (Figure 5.9; Golden Gate National Parks Conservancy et al., 2021). A closer inspection of each stand can be accessed at the One Tam Marin Forest Health Web Map.

FIRE REGIME

Douglas-fir occupies landscapes with diverse topography, climate, and fire regimes (Uchytil, 1991). Douglas-fir is fire-adapted, with young saplings highly susceptible to low-severity fires; however, post-wildfire survival increases as trees age and bark thickens. Adaptations such as thick bark along the lower bole and main roots allow mature Douglas-fir to survive moderate-intensity fires, and survivorship is generally linked to tree size and ability to avoid crown damage (Franklin & Waring, 1980; Lavender & Hermann, 2014, p. 270). Fires in Douglas-fir stands may crown and create canopy gaps of varying sizes. Stands with mature individuals may establish within two years following a low-severity fire or take as long as a century following a high-severity fire (Huff, 1995; Spies & Franklin, 1988). However, many other local stand conditions factor into establishing early-seral stands following fire (Spies et al., 2018).

Moving geographically from north to south, the size and severity of fires in Douglas-fir generally decreases while frequency increases (Morrison & Swanson, 1990). As shown in Table 5.6, general Douglas-fir fire seasonality in California is summer to early fall. Fire size ranges from small to large, and fire complexity, intensity, and severity range from small to large. All fire metrics depend on localized stand characteristics (CNPS, n.d.).

In the absence of fire, Douglas-fir's longevity allows it to continue as a canopy dominant until the next catastrophic fire. For example, in the Pacific Northwest it can take up to 1,000 or more years to be succeeded by hemlock and red cedar (Huff, 1995; Uchytil, 1991). Early indications are that the mixed-severity 2020 Woodward Fire, which burned Douglas-fir forests on the Point

Reyes peninsula, may produce net positive ecological effects including increased heterogeneity and the reemergence of rare fire-follower species (O'Gallagher et al., 2021).

Figure 5.9. Douglas-fir distribution in Marin County.

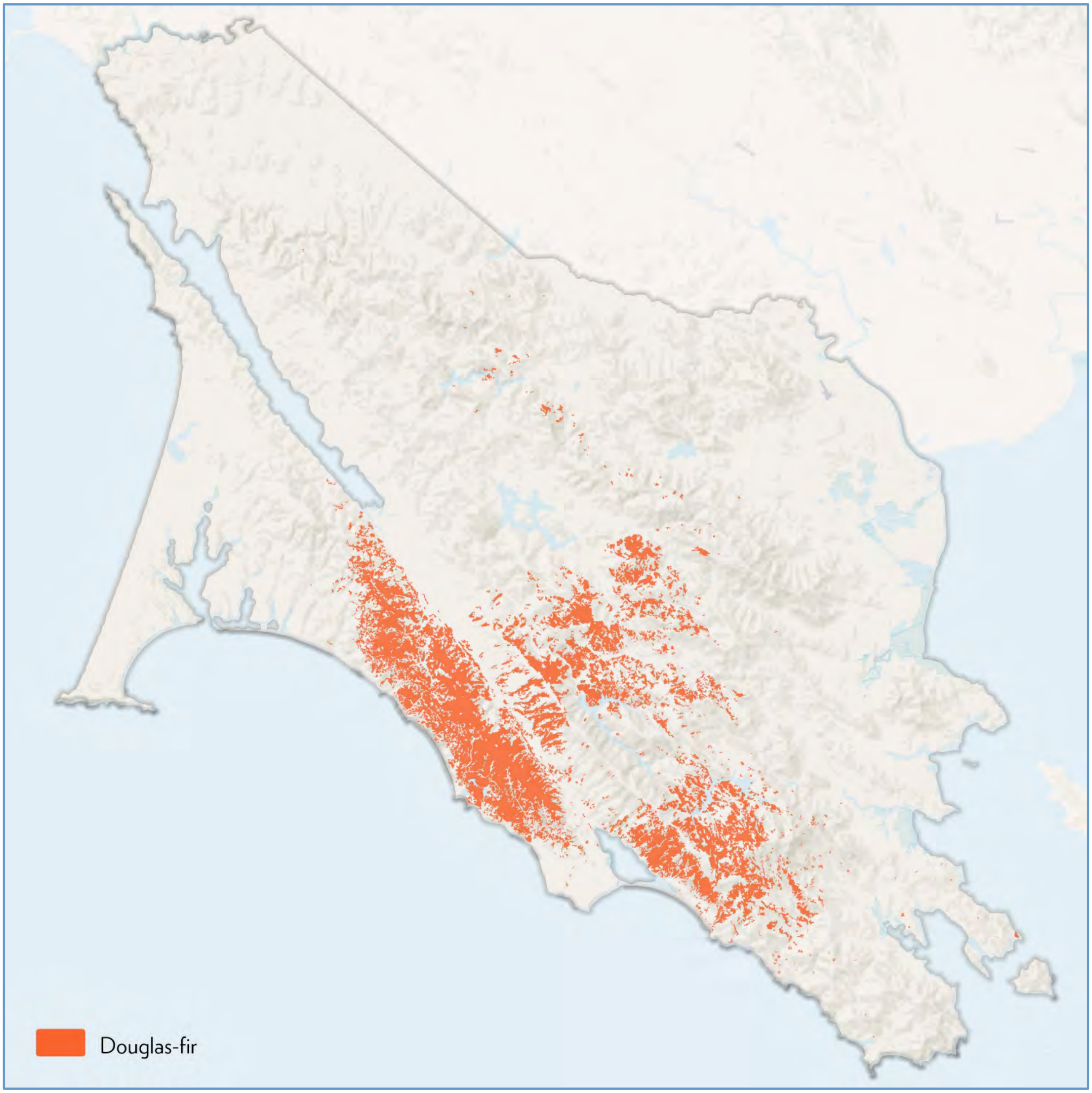


Table 5.6. Summary of Douglas-fir fire regime based on statewide vegetation description (CNPS, n.d.). FRI=fire return interval.

Alliance	Season	FRI (years)	Size	Intensity/ Severity	Type
Douglas-fir *(P. menziesii)/* tanoak *(N. densiflorus)*	Summer-early fall	Low to moderate	Small-Large	Low-High	Multiple

Coastal Douglas-fir stands were estimated to have a long average fire return interval of 100 years prior to European colonization (Van de Water & Safford, 2011). Douglas-fir forests in California experience moderately long fire intervals, and both *P. menziesii* and *N. densiflorus* are able to reproduce without fire. With frequent fires, stands of Douglas-fir can convert to hardwood forest (Hermann & Lavender, 1990; McDonald & Tappeiner, 1990; McMurray, 1989; Stuart & Stephens, 2006; Uchytil, 1991). Historically, in drier locations, fires were relatively more frequent but intervals also increased during the modern fire suppression era (Everett et al., 2000; Sensenig et al., 2013; Taylor & Skinner, 1998).

Pre-European colonization, fire intervals tended to be shorter in lower elevation Douglas fir stands near Indigenous communities. Throughout the Bay Area, Indigenous Peoples' management practices transformed some woodlands and chaparral areas into grasslands; some of these practices were maintained by ranchers (Keeley, 2005). When ranching ceased in what are now public lands, successional changes to shrub and woodland occurred (Keeley, 2005). At Point Reyes National Seashore, historical evidence indicates Douglas-fir stands were established on Limantour Ridge in the early 1900s; before this time, the area had few trees (Brown et al., 1999). The same study showed little historical evidence of stand-replacing fires; fires were highly variable in size, and the average fire return intervals ranged from 7-13 years over approximately the past two centuries. Surface fires ceased in the early to mid-20th century, with only one fire scar found in any stand following 1945. Fires before human settlement would have been less common due to the infrequency of lightning strikes (Brown et al., 1999).

Some infrequently burned Douglas-fir stands may be less likely to experience high burn severities, possibly due to intact stands creating shady and mesic microclimates resistant to fire (Engber et al., 2011; Steel et al., 2015). Therefore, utilizing a variety of treatments to accelerate stands towards lower density conditions with larger diameter trees could reduce burn severity and increase stand resilience to low-moderate intensity fire.

ALTERED FIRE REGIME

Fire regimes vary widely across the range of Douglas-fir, however in parts of the southern range, including northern California, Douglas-fir forests are likely to have experienced frequent low- and moderate-intensity and infrequent stand replacing fires (Brown et al. 1999; Lavender & Hermann, 2014, p. 293). Due to the lack of fires over the last century, Douglas-fir is expanding into grasslands, shrublands, and oak woodlands; a pattern that has been well documented throughout coastal California (Cocking et al., 2015; Hsu et al., 2012; Startin, 2022).

Using historical imagery, change analysis of vegetation types on Bolinas Ridge found that Douglas-fir is invading grasslands, hardwood forests, and shrublands (Startin, 2022). Determining at what point, spatially and temporally, Douglas-fir changes from a desired forest type to a successional species that can contribute to habitat loss and type conversion is important to land managers. Where Douglas-fir is encroaching on stands of Open Canopy Oak Woodland and Sargent Cypress due to fire exclusion, treatments to remove it are recommended to avoid type conversion (Cocking et al., 2014; Huff, 1995; Uchytil, 1991).

The Marin Forest Health Strategy Condition Assessment and *Marin County Wildfire History Mapping Project* (Dawson, 2021) found that nearly all the Douglas-fir stands in Marin experienced infrequent fire and are classified as greater than 70 years since the last fire. Douglas-fir stands with the longest time since last fire tend to have low relative hardwood cover. Most Douglas-fir stands lie within the areas classified as 1-2 times burned since 1859 (Dawson, 2021).

The detailed *Marin County Wildfire History Mapping Project* report (Dawson, 2021) can be found in Appendix B: Wildfire History. The fire history impacts on Douglas-fir stand structure, mortality, and diversity can be found in Chapter 7: Condition Assessment. For more information on the Douglas-fir/tanoak alliance and related Native American tending, see Chapter 3: Stewardship and Partnership with the Federated Indians of Graton Rancheria.

THREATS & POST-LOGGING LEGACY

Douglas-fir is listed as a stable population and species of least concern on the International Union for Conservation of Nature (IUCN) Red List (IUCN, n.d.). However, old-growth stands are threatened by logging. As late as the 1980s, foresters still regarded old-growth Douglas-fir forests as decadent and believed logging was necessary to avoid rotting in the stands (Yuskavitch, 2017). Habitat degradation was exacerbated by replanting clearcuts in monocultural Douglas-fir plantations with short-term harvest schedules. Although populations of coastal Douglas-fir are not endangered, ancient stands of old-growth are exceedingly rare, largely due to clearcutting that began in the 1850s and greatly intensified from 1850-1880 (Martin, 2018). Strittholt et al. (2006) estimated that only 28% of old-growth forests in the Pacific Northwest remain.

Loss of old-growth Douglas-fir decreases carbon sequestration, forest canopy, and understory diversity. Douglas-fir's multilayered vegetation provides important habitat for various wildlife species, including salmon (*Oncorhynchus* spp.), goshawks (*Accipiter* spp.), and Northern

Spotted Owl (*Strix occidentalis caurina)*.[1] Overall diversity in Douglas-fir stands is very high, with estimates of 1,084 species associated with this species (Strittholt et al., 2006).

SUDDEN OAK DEATH

While Douglas-fir are not affected by sudden oak death, important understory associates, such as tanoak (*Notholithocarpus densiflorus*) are. Surface fuels in sudden oak death-affected stands have been shown to increase over long periods (8–12 years) in Douglas-fir - tanoak forests of Sonoma, Mendocino, and Humboldt Counties (Valachovic et al., 2011). Changes in surface fuels can lead to increased fire severity around impacted trees (Rizzo & Garbelotto, 2003).

Stand level treatments to explore approaches to managing sudden oak death forest impacts in Coast Redwood and Douglas-fir forest were compared by Cobb et al. (2017). Researchers compared a "restoration" treatment in an area heavily impacted by sudden oak death on Tamalpais Watershed lands (mastication plus hand thinning in Douglas-fir - tanoak and Redwood-tanoak) and a "resilience treatment" focused on an at-risk but unaffected forest (manual tanoak thinning). Both treatment approaches greatly reduced the density of key sporulation supporting hosts and illustrate potential approaches to addressing the complex management challenges presented by sudden oak death-impacted forests including fuels accumulation, loss of biodiversity, and desire to retain carbon storage. This study found only a small difference in carbon sequestration between treated and untreated reference (control) areas since basal area was conserved by focusing management on smaller diameter stems (Cobb et al., 2017).

CONCEPTUAL MODEL

Marin Forest Health Strategy Working Group (Working Group) developed a conceptual model for Douglas-fir showing ecosystem services, forest health attributes, direct/indirect threats, and potential treatments. The key for the conceptual model is shown in Figure 5.10 and the conceptual model is Figure 5.11. The Working Group established condition goals for Douglas-fir forest and accompanying results chains from the conceptual model.

[1] Intensive logging caused the decline of the Northern Spotted Owl leading to its threatened listing on the endangered species and the subsequent Timber Wars of the 1990s.

Figure 5. 10. Conceptual model key.

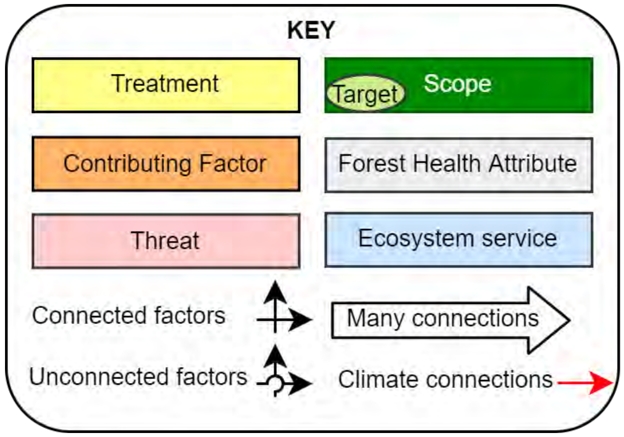
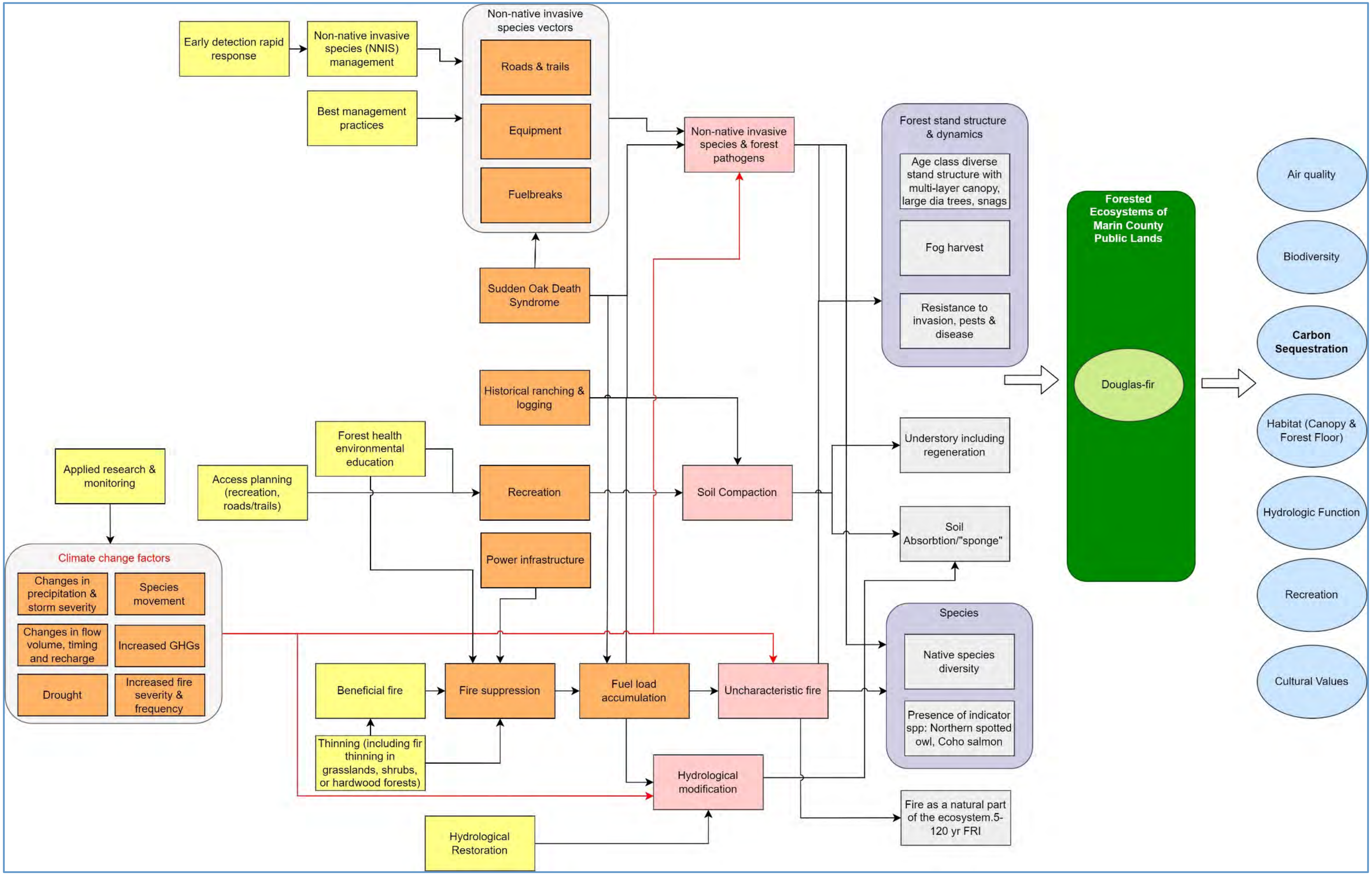


Figure 5.11. Douglas-fir conceptual model.



DOUGLAS-FIR GOALS

The One Tam agencies and partners will work towards broader landscape-level goals described below through treatments designed to meet interim results and conditions goals.

Retention of Douglas-fir forest among the mosaic of Marin County forest types is important for carbon sequestration and providing habitat for sensitive wildlife such as salmonids (*Oncorhynchus* spp.) and northern spotted owl. Accelerating stands toward larger diameter trees using a variety of treatments could be a benefit in reducing burn severity and increasing or protecting carbon sequestration and biodiversity. Where Douglas-fir is the dominant species, thinning Douglas-fir stands to break up horizontal and vertical fuel structures is a component of this strategy. Removal of early successional Douglas-fir where it is encroaching into grasslands, oak woodlands, and chaparral will be a critical practice to avoid type conversion in these habitats in the absence of fire or where fire return intervals are increasing due to fire exclusion.

While Douglas-fir appears stable in Marin County, One Tam agencies will manage Douglas-fir forests to continue to provide and strengthen ecosystem services such as air quality, biodiversity, carbon sequestration, habitat, hydrologic function, and recreation.

LANDSCAPE-LEVEL GOAL 1: FOREST HEALTH

One Tam agencies will encourage Douglas-fir stands to move in the direction of more fire-resilient mature stands while maintaining important habitat values of structural diversity, snags, diverse understory vegetation, resistance to threats such as drought and pathogens, and increasing absorbent soil which acts as a sponge, infiltrating water and decreasing run off.

LANDSCAPE-LEVEL GOAL 2: ECOSYSTEM SERVICES & BIODIVERSITY

Healthy stands of Douglas-fir provide the priority ecosystem service of carbon sequestration, and also provide cultural values, wildlife habitat, biodiversity, hydrologic function, air quality, and recreational values. One Tam agencies will work to protect and improve ecosystem services provided by Douglas-fir forest. Management actions will protect or expand habitat for indicator species such as salmonids and spotted owls.

CONDITION GOALS & RESULTS CHAINS

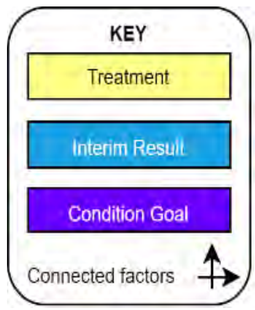
Results chains are goal pathways which lay out a series of treatments and interim goals which cumulatively will allow managers to achieve landscape-level goals. Interim results and conditions goals are steps along the pathway to the desired conditions described in the landscape-level goals. See Chapter 9: Treatment Descriptions for a detailed discussion of treatment approaches and methods.

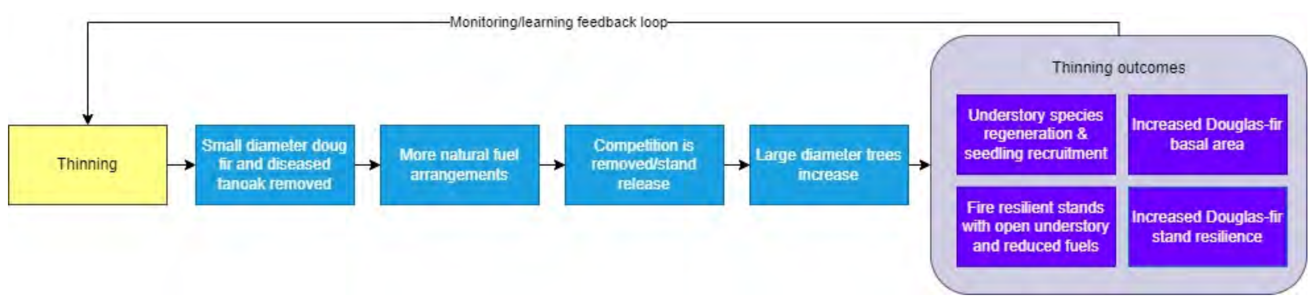
Thinning

Selective thinning can be useful for managing pest and pathogen-impacted understory vegetation, reducing stand density and competition by removing small trees to accelerate move towards old-growth conditions, and managing Douglas-fir encroachment. Thinning can be a fire surrogate where the use of beneficial fire is not possible. Although the thinning and beneficial fire general outcomes are listed as the same, thinning is not a replacement for beneficial fire, which could have additional benefits such as further reducing pathogen loads, protecting, or enhancing cultural values, or recruitment of understory species dependent on fire for regeneration. In some cases, thinning will need to be performed as site preparation for the reintroduction of beneficial fire. See Chapter 3: Stewardship and Partnership with the Federated Indians of Graton Rancheria for more information on the importance of beneficial fire for cultural values.

Please note the same key is used for all results chains.

Figure 5.12. Results chain key.





Interim Result 1: Thinning increases the predictability of beneficial fire while reducing competition, increasing light penetration in the forest canopy, increasing mid- and understory diversity, and results in more natural fuel arrangements.

Interim Result 2: Pathogen-affected vegetation (where present) is removed resulting in more natural fuel arrangements and reduced sudden oak death (SOD) spread. Where possible, alternatives for diseased tanoak removal will be explored to reduce SOD pathogen spread and encourage healthy tanoak for cultural and biodiversity benefit.

Interim Result 3: Where appropriate, small-diameter Douglas-fir and other species are removed, resulting in more natural fuel arrangements, competition removal, stand release, and increased large-diameter Douglas-fir trees.

Condition Goal 1: Increased species regeneration and germination of the understory and shrub layer in Douglas-fir stands. Note that some understory species will require beneficial fire for regeneration.

Condition Goal 2: Fire resilient stands with more natural fuel arrangements.

Condition Goal 3: Increased resilience for Douglas-fir stands.

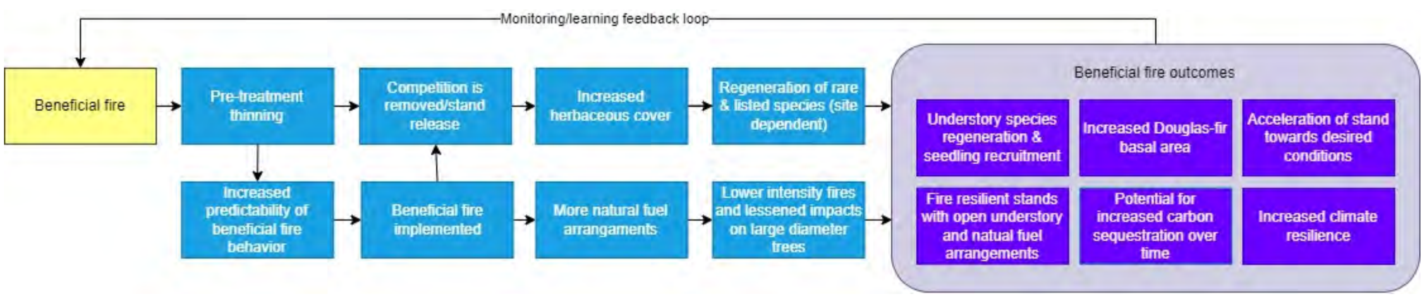
Condition Goal 4: Persistence of a multi-layered stand structure dominated by native tree species in Douglas-fir stands.

BENEFICIAL FIRE

Beneficial fire includes prescribed fire, cultural burning, and fire managed for resource benefit (California Wildfire and Resilience Task Force, 2022). Pre-treatment thinning may be necessary to conduct burns safely.

Beneficial fire results chains and condition goals do not attempt to recreate a natural range of variation for fire return intervals using beneficial fire. The fire return interval is a baseline for understanding historical conditions and considering the range and timing of management actions, not a condition goal unto itself.

See Chapter 3: Stewardship and Partnership with the Federated Indians of Graton Rancheria for more information on the role of cultural burning as a form of beneficial fire.



Interim Result 1: Pre-treatment thinning increases the predictability of beneficial fire while also reducing competition, increasing light penetration in the forest canopy, increasing mid- and understory diversity, and creating more natural fuel arrangements.

Interim Result 2: Beneficial fire results in more natural fuel arrangements, potentially like those created through Indigenous stewardship, and increases herbaceous cover/seedling recruitment.

Interim Result 3: Following pre-treatment thinning and beneficial fire, herbaceous cover increases, and regeneration of rare endemic chapparal species occurs in applicable areas.

Interim Result 4: Where possible, cultural burning sites will be identified and burned in collaboration with the Federated Indians of Graton Rancheria (the Tribe).

Condition Goal 1: Increased species regeneration and germination of the understory and shrub layer in Douglas-fir stands.

Condition Goal 2: Fire & climate resilient stands with more natural fuel arrangements.

Condition Goal 3: Potential for increased carbon sequestration over time.

Condition Goal 4: Cultural burning recruits specific desired understory plants and protects other cultural values as identified by the Tribe.

Condition Goal 5: Persistence of a multi-layered stand structure dominated by native tree species in Douglas-fir forest stands.

HYDROLOGY

Restoration to address impacts of hydrologic modification includes decommissioning or improving drainage on roads and trails to improve hydrological function and promote infiltration of water into the soil (Sosa-Pérez & MacDonald, 2017; Switalski et al., 2004; Weaver et al., 2014). Reduction of sediment transport from roads and trails improves water quality and protects aquatic habitat. Reductions in bare soil and runoff may reduce invasions of non-native species, which are commonly associated with roads (Menuz & Kettenring, 2013).

Interim Result 1: Identify locations and methods for small-scale projects to recreate natural drainage patterns and improve water retention. Potential sites adjacent to roads, trails, fuel reduction sites, capital improvement projects, or other restoration projects should be identified.

Condition Goal 1: Decreased run-off and erosion.

Condition Goal 2: Increased infiltration into the soil and groundwater retention, possible increase in stream baseflows.

Condition Goal 3: Improved aquatic species habitat.

SOIL & ACCESS PLANNING

Healthy, absorbent soil acts as a sponge, infiltrating water and decreasing runoff. Soil compaction can be a threat to Douglas-fir forest with a series of impacts. Initially soil compaction can lead to reduced understory vegetation and water infiltration, which in turn leads to a reduction in water available to vegetation and increased runoff, causing erosion and contributing sediment to streams. Soil compaction may be caused by recreational use and can be addressed through thoughtfully designed trails and signage (Cole, 2004).

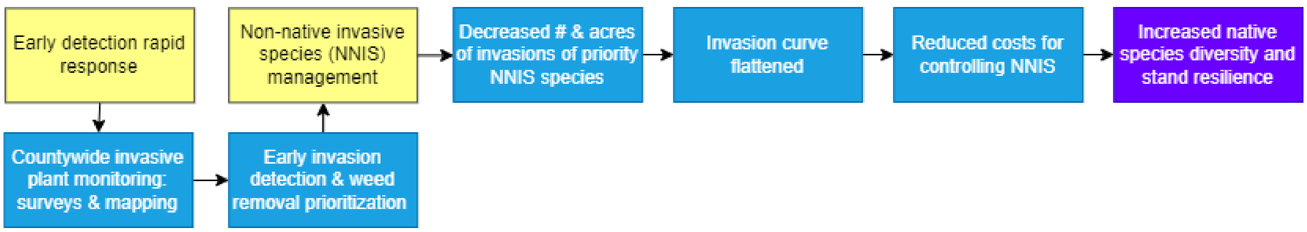
Interim Result 1: Effective access planning, including effective trail design and signage, supports the use of designated trails.

Interim Result 2: Visitors use designated trails; social trails and soil compaction are reduced, resulting in reduced spread of pathogens and non-native invasive species (NNIS) and increasing health of soil which acts as a sponge for water and nutrients.

Condition Goal 1: Soil health improves resulting in increased water filtration, tree vigor, recruitment of herbaceous layer, and overall understory diversity.

NON-NATIVE INVASIVE PLANT SPECIES

Non-native invasive species (NNIS) threaten native species diversity and may displace native vegetation which provides essential food and shelter for sensitive wildlife. In addition, some NNIS can contribute to unnatural fuel loads and reduce forest resilience.



Interim Result 1: Countywide invasive plant mapping and early detection rapid response (EDRR) programs identify new and track existing non-native species invasions resulting in decreased new invasions.

Interim Result 2: Non-native invasive species management decreases the number of invasive species and total invaded acres.

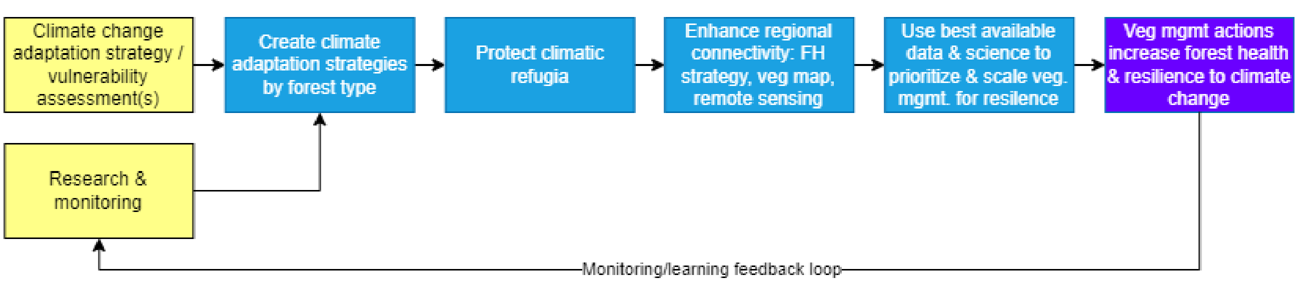
Interim Result 3: The invasion curve is flattened.

Interim Result 4: Costs are reduced for non-native invasive species control.

Condition Goal 1: Douglas-fir stands experience increased native species diversity and resilience.

CLIMATE CHANGE

Climate change threatens healthy forests in many complex and interconnected ways. For example, increasing temperatures and prolonged drought increases vulnerability to pests and pathogens as well as reducing germination success. See Chapter 4: Climate Change and Other Forest Health Stressors for an in-depth discussion of climate change impacts. Managing for climate change will involve an ongoing cycle of monitoring and assessing conditions;



determining priority treatment areas to protect sensitive species, habitat corridors, and climate refugia; and adapting management actions and priorities as conditions change and new data is available.

Interim Result 1: Land managers create climate adaptation strategies by forest type based on vulnerability assessments, regional connectivity, and considerations regarding the distribution of species, threats, stressors, and management feasibility. Research and monitoring inform these strategies.

Interim Result 2: Climatic refugia are protected. Areas predicted to remain suitable habitat for conservation targets (i.e., Douglas-fir) are prioritized for conservation and management.

Interim Result 3: Regional collaboration and collective impact is increased through use of the *Forest Health Strategy*, 2018 Fine Scale Vegetation Map and future updates, and additional landscape-scale remote sensing analysis.

Interim Result 4: By leveraging the best available spatial data, models, and climate science, managers can prioritize areas for management and work together to scale up treatments focused on increasing climate resilience for priority Douglas-fir stands.

Condition Goal 1: Vegetation management actions informed by landscape scale climate adaptation strategies increase priority Douglas-fir stand resilience to climate change and bring stands within the new predicted range of natural variability.

BEST MANAGEMENT PRACTICES

Best Management Practices (BMPs) largely focus on reducing the spread of non-native invasive species and pathogens from site to site, protecting uninfected sites, and complying with environmental regulations. BMPs for weeds and pathogens differ from EDRR and are focused on limiting introduction and spread. The intended outcomes for effective BMPs are protecting Douglas-fir habitat and understory diversity. Additional BMPs developed in collaboration with the Tribe may include protecting cultural plants and gathering areas and protecting cultural sites during management activities.

Interim Result 1: Best management practices are reviewed with staff and contractors.

Interim Result 2: Comprehensive and effective best management practices are consistently implemented.

Interim Result 3: Forest pathogens and new non-native invasive species infestations are reduced.

Condition Goal 1: Forest stand structure and understory diversity are protected.

ENGAGEMENT & COLLABORATION

Managing forests for resilience requires collaborative efforts from the entire Marin community. Ongoing education and communication is necessary to ensure all groups are working together to meet overarching goals for forest health, cultural use, recreation, and fire safety. See Chapter 3: Stewardship and Partnership with the Federated Indians of Graton Rancheria for a discussion on collaboration with the Tribe.

Interim Result 1: Education and community outreach increases public understanding of the value of healthy and resilient forests. Douglas-fir environmental education will concentrate on explaining the value of thinning to accelerate stands towards old-growth conditions and how Douglas-fir can encroach on other ecosystem types in the absence of fire.

Interim Result 2: Increased education and signage about forest health, including plant pathogens and related impacts (such as sudden oak death) to help prevent further spread.

Interim Result 3: Collaboration between the Tribe, fire departments, Marin Wildfire Prevention Authority (MWPA), community groups, and land managers increases.

Interim Result 4: Working with local groups, such as MWPA, fire prevention outreach focuses on actions in developed residential and commercial areas.

Interim Result 5: Best management practices are coordinated with the MWPA/Ecologically Sound Practices Partnership (ESP Partnership, 2022).

Interim Result 6: Forest resilience and fire management treatment prescriptions are developed in collaboration with the Tribe, cultural plants are protected for collection by Native peoples, and applicable cultural practices are restored.

Condition Goal 1: Increased support for land managers' multi-benefit approach to forest health.

Condition Goal 2: Fire departments adopt best management practices created and implemented by community groups, public land managers, the Tribe, and researchers.

Condition Goal 3: Fire prevention treatments focus on reducing risk to developed, residential, and commercial areas; critical infrastructure; and evacuation routes.

Condition Goal 4: Public land management agencies, the Tribe, community groups, and Marin Fire agencies develop coordinated multi-benefit projects to protect forest health, increase climate resilience, and address non-natural fuel arrangements (where applicable) in select locations at multiple scales

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OPEN CANOPY OAK WOODLANDS

LIFE HISTORY

In California, Open Canopy Oak Woodlands are typically defined as stands with oak canopy cover ranging from 10-60% (Sawyer et al., 2009). Although Open Canopy Oak Woodlands have many tree species in common with mixed hardwood forests, Oak Woodland's lower density and patchier distribution create a distinct habitat structure for both herbaceous plants and wildlife (Edson et al., 2016). Understory species include a distinct and more varied array of grasses, sedges, and forbs than closed canopy forests. Incredibly biodiverse, oak woodlands in California support 1,400 species of flowering plants and over 300 species of vertebrates, which is more species than any other habitat type in the state (Barrett, 1980; Pavlik et al., 1991; Tyler et al., 2006; Verner, 1980).

Changes in the health of Open Canopy Oak Woodlands in Marin can be used as an indicator of forest disease, drought stress, altered fire regimes, biodiversity, air quality, and habitat quality. For instance, lace lichen (*Ramalina menziesii)*, California's state lichen, primarily grows in Open Canopy Oak Woodlands and is a good indicator of air quality (Flegal et al., 2010). Between 80-90% of California's oak woodlands are on private land, making conservation of this forest type on public lands a high priority (Edson et al., 2016).

Open Canopy Oak Woodlands are an important resource for the Federated Indians of Graton Rancheria (the Tribe). A discussion of Traditional Ecological Knowledge, cultural significance, and tending related to Open Canopy Oak Woodlands and other vegetation can be found in Chapter 3: Stewardship and Partnership with the Federated Indians of Graton Rancheria.

The floristic classification report that accompanied the 2018 Marin Countywide Fine Scale Vegetation Map (2018 Fine Scale Vegetation Map, Golden Gate National Parks Conservancy et al., 2021) describes Open Canopy Oak Woodland alliances and member associations found in Marin County following standards established by the U.S. National Vegetation Classification (USNVC) and the CNPS *Manual of California Vegetation* (MCV). The floristic classification for Marin County was developed in partnership with the California Department of Fish and Wildlife Vegetation Classification and Mapping Program (CDFW VegCAMP) and California Native Plant Society Vegetation Program. Table 5.7 lists the fine scale map classes (alliances) and member associations found in Marin County for Open Canopy Oak Woodland forest types and described in the Marin classification report (Buck-Diaz et al., 2021, Appendix D).

In *Measuring the Health of a Mountain: A Report on Mount Tamalpais' Natural Resources* (*2016 Peak Health Report*), vegetation alliances for Open Canopy Oak Woodlands were limited to forest types found on Mount Tamalpais (Edson et al., 2016). For the *Marin Regional Forest Health Strategy* (*Forest Health Strategy*), the definition of Open Canopy Oak Woodland was expanded to include the *Quercus douglasii* Alliance (Blue oak woodland and forest), which does not form stands on Mount Tamalpais, but is prevalent in the northeastern portions of Marin County near Novato, including Rush Creek Open Space Preserve. The *Forest Health Strategy* also includes the *Quercus chrysolepis* (tree) Alliance (Canyon live oak forest and woodland), since it was distinguished from the *Quercus wislizeni – Quercus chrysolepis* (shrub) Shrubland Alliance in both the 2018 Fine Scale Vegetation Map (Golden Gate National Parks Conservancy, et al., 2021) and corresponding floristic classification report. The *Quercus chrysolepis* (tree) Alliance can form stands with an open to continuous tree canopy with a sparse to open shrub understory (Buck-Diaz et. al, 2021).

Table 5.7. Open Canopy Oak Woodland 2018 Fine Scale Vegetation Map classes (Golden Gate National Parks Conservancy et al., 2021) and member associations described in the corresponding floristic classification report (Buck-Diaz et al., 2021, Appendix D).

*Included in *2016 Peak Health Report* (Edson et al., 2016). **Added in the *Forest Health Strategy*.

2018 Fine Scale Vegetation Map Classes	Member Associations in Marin County (Buck-Diaz et. al. 2021)
Quercus (agrifolia, douglasii, garryana, kelloggii, lobata, wislizeni) Alliance*	*Quercus agrifolia – Quercus garryana – Quercus kelloggii*
Quercus agrifolia Alliance*	*Quercus agrifolia – Arbutus menziesii – Umbellularia californica*
	Quercus agrifolia – Arbutus menziesii / Corylus cornuta – Rubus spp.
	Quercus agrifolia – Quercus kelloggii
	Quercus agrifolia – Umbellularia californica / Heteromeles arbutifolia – Quercus berberidifolia
	Quercus agrifolia / Adenostoma fasciculatum – (Salvia mellifera)
	Quercus agrifolia / grass
	Quercus agrifolia / Toxicodendron diversilobum
Quercus chrysolepis (tree) Alliance**	*Quercus chrysolepis – Arbutus menziesii – Notholithocarpus densiflorus var. densiflorus*
	Quercus chrysolepis – Umbellularia californica
	Quercus chrysolepis / Quercus (wislizeni, parvula)
Quercus douglasii Alliance**	*Quercus ×eplingii /* Grass *Provisional Association*
	Quercus douglasii – Quercus agrifolia Association
Quercus garryana Alliance*	*Quercus garryana – Umbellularia californica – Quercus (agrifolia, kelloggii)*
	Quercus garryana / (Cynosurus echinatus – Festuca californica)
Quercus kelloggii Alliance*	*Quercus kelloggii – Arbutus menziesii – Quercus agrifolia*
	Quercus kelloggii – Pseudotsuga menziesii – Umbellularia californica
Quercus lobata Alliance*	*Quercus lobata – Quercus agrifolia /* grass
	Quercus lobata / grass

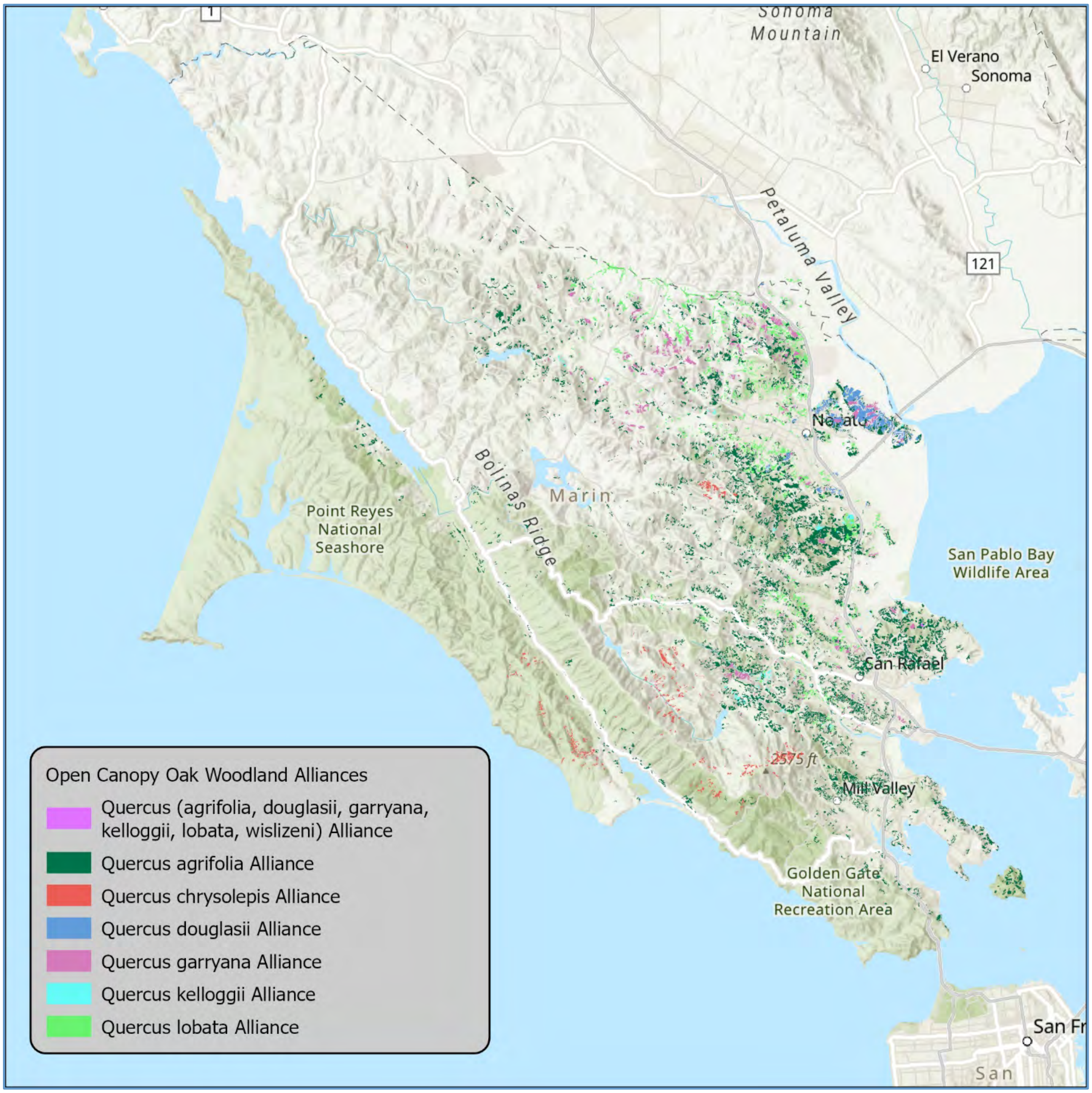
KEY ECOSYSTEM SERVICES

Open Canopy Oak Woodlands provide the priority ecosystem services of biodiversity and cultural values, in addition to air quality, carbon sequestration, habitat, hydrologic function, and recreation.

DISTRIBUTION

The 2018 Fine Scale Vegetation Map shows the distribution of Open Canopy Oak Woodland alliances at the stand level (Figures 5.13; Golden Gate National Parks Conservancy et al.,

Figure 5.13. Open Canopy Oak Woodland distribution in Marin County, showing each Alliance.



2021). A closer inspection of each stand can be accessed at the One Tam Forest Health Web Map.

FIRE REGIME

Fire is an important component of Open Canopy Oak Woodlands. The presence of fire may have several benefits including promoting acorn germination and seedling survival by reducing competition from understory vegetation, reducing litter-born pathogens, and releasing soil nutrients (Holmes et al., 2008). For example, densities of black oak *(Q. kelloggii*) seedlings were up to nine times greater in burned vs. unburned plots (Kauffman & Martin, 1987). Dagit (2002) found an increase in native species' cover in the understory of a coast live oak (*Q. agrifolia*) woodland after a wildfire, although non-native invasive species (NNIS) were gradually replacing natives as time since fire increased. More research on such effects is needed.

Fire can pose a risk to mature oaks. In a meta-review examining fire effects on all California oak species mortality rates ranged from 1-11% for mature oaks, 2-10% for saplings, and 17-52% for seedlings (Holmes et al., 2008). Oak species may respond differently to fire. For example, coast live oak tolerates fire better than black oak and canyon live oak (*Q. chrysolepis*) (Plumb, 1980).

Prior to European settlement, fires were typified by high frequency, low intensity, and relatively rare occurrence of crown fires (Anderson, 2019; Holmes et al., 2008). During this time, fire was a common occurrence in California. The success of indigenous communities depended on setting fires for tending oak acorn crops, primarily tanoak (*Notholithocarpus densiflorus*) and black oak (Anderson, 2018). These managed fires also served to improve village safety by reducing severe fires; helped to increase wildlife abundance; decrease disease or insect pests; and improve the production of medicinal plants, basketry material, and other tended crops or vegetation (Anderson, 2018). Fires were frequent near settlements but otherwise distributed throughout a patchy mosaic, with some areas burning annually and others less frequently (Anderson, 2018; Noss, 2000). Oak woodlands stewardship was year-round, involving weeding, coppicing, and burning to clear the understory (Anderson, 2005). Additional burning occurred in autumn when infested acorns fell first and were burned to reduce pest populations in the coming year (Anderson, 2005).

The fire return interval for Open Canopy Oak Woodland is widely variable and often dependent on stand composition, topography, surrounding vegetation, and degree of fire exclusion. In some sources, the return is listed as 8-16 years (USDA Forest Service, 2012), but others vary from 1 to 100+ years (CNPS, n.d.a.; van Wagtendonk et al., 2018). A detailed Marin County fire history can be found in Appendix B: Wildfire History (Dawson, 2021). The fire history impacts on Open Canopy Oak Woodland stand structure, mortality, and diversity can be found in Chapter 7: Condition Assessment.

Table 5.8 summarizes the fire regimes for Open Canopy Oak Woodland alliances. The fire regime depends on each mixed oak forest and woodland stand composition and structure (CNPS, n.d.b.). The historical fire seasonality for each alliance is summer to early fall.

Table 5.8. Fire regime summary for Open Canopy Oak Woodland alliances (CNPS, n.d.a.; Kauffman & Martin, 1987; Stuart & Stephens, 2006; Tollefson, 2008; van Wagtendonk et al., 2018; Warner, 1980). FRI=fire return interval. M=medium, L=large. NB: Q. kelloggii FRI is from Kings Canyon National Park, not Marin County (Warner, 1980).

Alliance	FRI (years)	Size	Intensity/Severity	Type
Q. agrifolia	30-100+	M-L, up to/beyond stand size	Low-high	Surface; passive crown; passive-active crown
Q. chrysolepis (tree)	5-100+	Medium	Low-high	Surface-passive crown to passive-active crown
Q. garryana	3-30	M-L, up to stand size	Low	Surface-passive crown
Q. lobata	5-100+	M-L, up to/beyond stand size	Low-moderate	Surface-passive crown
Q. kelloggi	3.5	M-L, up to stand size	Low-moderate	Surface-passive crown

THREATS

Threats to Open Canopy Oak Woodland include altered fire regime and associated Douglas-fir encroachment, sudden oak death, wild turkey (*Meleagris gallopavo*) acorn predation, and over-browsing due to a lack of apex predators (Edson, et al. 2016). Open Canopy Oak Woodland's trend is declining in the *2016 Peak Health Report* (Edson et al., 2016, p. 69).

ALTERED FIRE REGIME

In the past 150 years, altered fire regimes due to fire exclusion changed Oak Woodland stand structure, arrangement of fuel loads, and fire effects (Holmes et al., 2008). Fire exclusion also likely negatively impacts seedling recruitment in some open canopy oak species (Biswell, 1989; McClaran & Bartolome, 1989).

The absence of fire is responsible for the widely reported success of Douglas-fir invading grasslands and oak woodlands along the north coast of California dating back several decades (Barnhart et al., 1996; Sugihara et al., 1987). Conifer invasion leads to significant structural and compositional shifts in oak woodland stands, and eventually can lead to forest type conversion (Engber et al., 2011). Fire exclusion may also be linked to abundant oak mistletoe in blue oak (*Q. douglasii*) and interior live oak (*Q. wislizeni*) stands (Haggerty, 1994).

Conifer encroachment in the absence of fire is a growing concern in Oak Woodlands (Cocking et al., 2014; Engber et al., 2011). Without repeated disturbance such as fire, the succession tendency of oak woodlands is toward conifer dominant stands, principally Douglas-fir (Cocking et al., 2014). As stands age, Douglas-fir becomes co-dominant and causes declines in oak health in as little as 20 years (Schriver et al., 2018). Results from the Forest Health Strategy Condition Assessment show that nearly all (95% or 19,633 acres) of Open Canopy Oak Woodlands are in less frequently burned areas with either >70 years since fire or no recorded fires since 1859. However, the Forest Condition Assessment also included a threatened and converting oak stands analysis, which showed only 44% of all Open Canopy Oak Woodland acres are classified as threatened with or actively converting to Douglas-fir, indicating that fire exclusion may not be the only factor contributing to type conversion. Interestingly, a small number of Open Canopy Oak Woodland acres (0.34%) with more frequent fires are also threatened or converting to Douglas-fir, which could indicate that not all fire is effective for maintaining oak stand health. . A more detailed Marin County fire history can be found in Appendix B: Wildfire History. More information on the threatened and converting oak stands analysis can be found in Chapter 6: Metrics. The fire impacts on Open Canopy Oak Woodland stand structure, mortality, and diversity can be found in Chapter 7: Condition Assessment.

SUDDEN OAK DEATH

Open Canopy Oak Woodlands are threatened by the pervasive disease sudden oak death (SOD) caused by the pathogen *Phytophthora ramorum*. A 2014 Marin Water Survey found that over 90% of Open Canopy Oak Woodlands were impacted by sudden oak death (AIS, 2015). Not all oak species are susceptible to sudden oak death-caused decline and mortality, thus impacts vary depending on species assemblages, with stands containing coast live oak, canyon live oak, black oak, and tanoak most affected. Sudden oak death--induced decline and mortality creates canopy gaps, reduces wildlife food sources, may reduce gene flow and genetic diversity within impacted species, and can increase the potential for higher severity fires around impacted trees (Rizzo & Garbelotto, 2003). Given the widespread distribution of *P. ramorum* within the county, the decline and death of tanoaks, coast live, and black oaks in Marin is anticipated to continue into the foreseeable future (Cunniffe et al., 2016) More information on sudden oak death can be found in Chapter 9: Treatment Descriptions, Pests & Pathogens.

CONCEPTUAL MODEL

The Marin Forest Health Strategy Working Group (Working Group) developed a conceptual model for Open Canopy Oak Woodland showing ecosystem services, forest health attributes, direct/indirect threats, and treatments The key for the conceptual model is shown in Figure 5.14 and the conceptual model is Figure 5.16. The Working Group established condition goals for Open Canopy Oak Woodland and accompanying results chains from the conceptual model.

Figure 5.14. Conceptual model key.

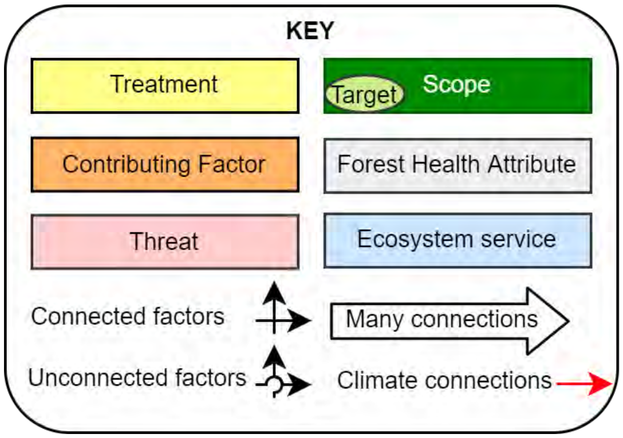
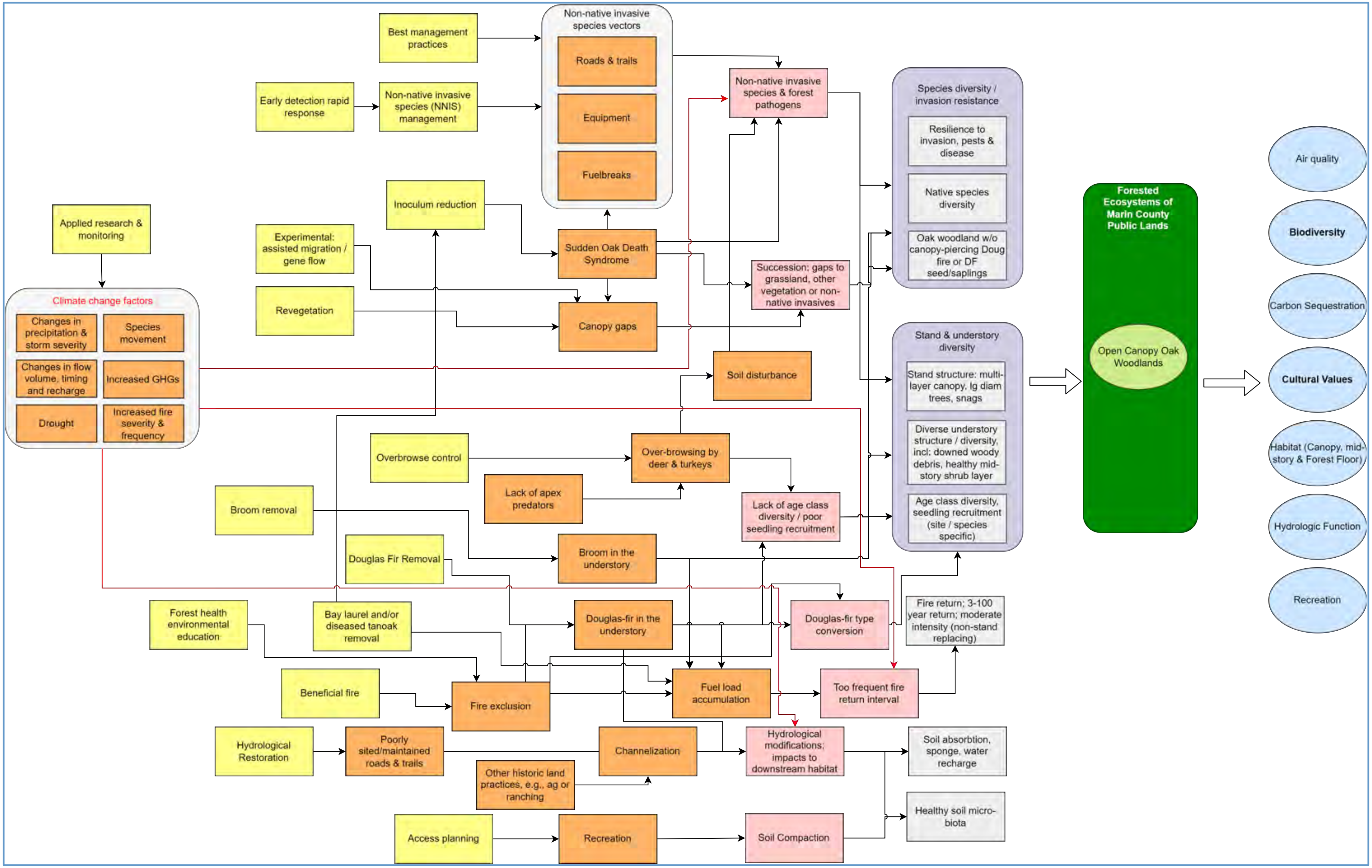


Figure 5.15. Open Canopy Oak Woodland conceptual model.



OPEN CANOPY OAK WOODLAND GOALS

The One Tam agencies and partners will work towards broader landscape-level goals described below through treatments designed to meet interim results and conditions goals. According to the *2016 Peak Health Report* the desired condition for Open Canopy Oak Woodlands is maintenance of the full spatial extent of the forest type, the persistence of a discontinuous canopy dominated by trees from the genus *Quercus*, a discontinuous shrub layer, and an herbaceous layer dominated by native species (Edson et al., 2016). The high priority ecosystem services of biodiversity and cultural values are factored into condition and landscape-level goals.

LANDSCAPE-LEVEL GOAL 1: TRIBAL COLLABORATION

Partner with the Tribe to plan and implement protection of acorn-producing trees, active management, conservation, cultural burning, sudden oak death interventions, and research opportunities.

LANDSCAPE-LEVEL GOAL 2: FOREST HEALTH

One Tam agencies will work together to increase resilience of Open Canopy Oak Woodland in order to protect and maintain the current acreage of Open Canopy Oak Woodlands with a diverse understory of native shrubs, forbs, and grasses.

LANDSCAPE-LEVEL GOAL 3: ECOSYSTEM SERVICES & BIODIVERSITY

Healthy stands of Open Canopy Oak Woodland provide the priority ecosystem service of biodiversity and cultural values. Open Canopy Oak Woodlands also provide habitat, hydrologic function, and air quality. One Tam agencies will manage Open Canopy Oak Woodlands to continue to provide and strengthen these ecosystem services.

CONDITION GOALS & RESULTS CHAINS

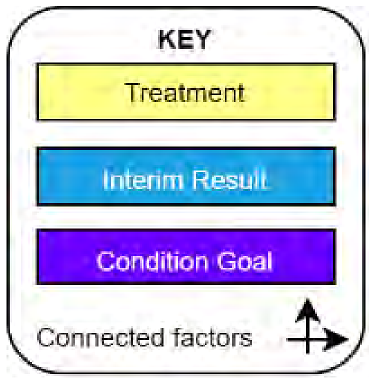
Results chains are goal pathways which lay out a series of treatments and interim goals which cumulatively will allow managers to achieve landscape-level goals. Interim results and conditions goals are steps along the pathway to the desired conditions described in the landscape-level goals. See Chapter 9: Treatment Descriptions for a detailed discussion of treatment approaches and methods.

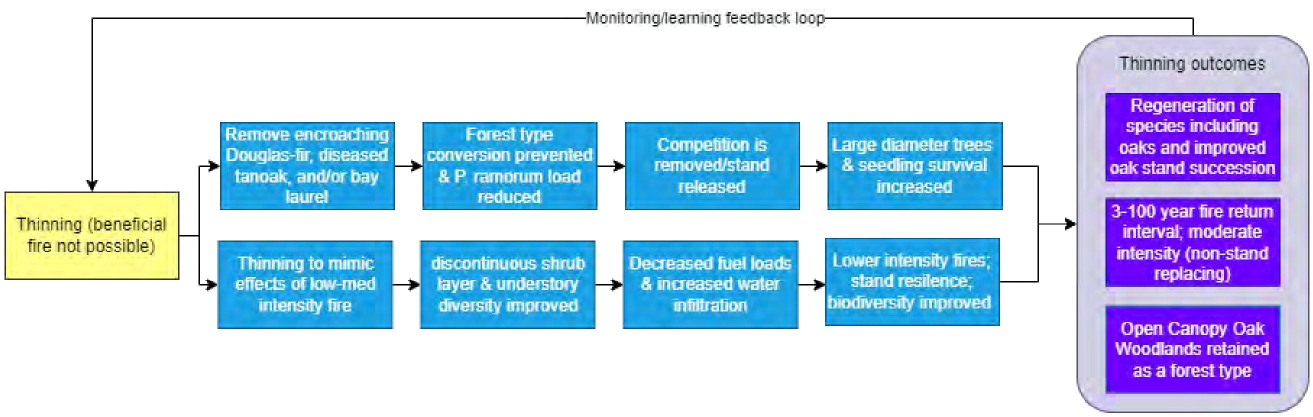
THINNING

Thinning can be useful for managing pest and pathogen-impacted vegetation and in managing Douglas-fir encroachment. Thinning can take place where prescribed fire is difficult or prohibitive to employ. Although thinning and beneficial fire general outcomes are listed as the similar, thinning is not a replacement for beneficial fire. Fire, unlike thinning, stimulates the emergence of fire-adapted understory shrubs and herbaceous species, and may be more effective in reducing phytophthora inoculum loads, and likely plays an important role in oak woodland regeneration (Phytosphere, 2012). In some cases thinning will be a precursor to prescribed fire to reduce fuel loads. Thinning will require a monitoring feedback loop to measure Open Canopy Oak Woodland stand health outcomes and determine future management actions.

Please note that the same key is used for all results chains.

Figure 5.16. Results chain key.





Interim Result 1: Thinning to mimic the effects of a low to mid-intensity fire recreates the discontinuous shrub and canopy layer, increases light penetration in the forest canopy, increasing mid- and understory diversity, and reduces fuel loads.

Interim Result 2: Targeted thinning to remove sudden oak death affected tanoak and/or sporulating bay laurel (especially those sporulating during extended drought) reduces pathogen load and increases stand resilience (for additional information see Pests and Pathogens Management in Chapter 9: Treatment Descriptions).

Interim Result 3: Removal of small diameter Douglas-fir and non-native invasive weeds (if present) results in decreased fuel loads, competition removal, stand release, and increased stand resilience to drought and fire.

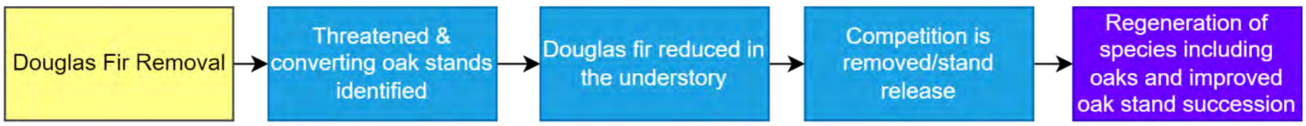
Condition Goal 1: Increased native species germination and regeneration of a diverse understory and shrub layer.

Condition Goal 2: Fire-resilient stands with reduced pathogen and fuel loads, with fire return interval of 3-100 years depending on stand conditions.

Condition Goal 3: Maintain approximately 7,350 acres of Open Canopy Oak Woodlands with oak canopy cover between 25-60% on One Tam agency-managed public lands, as identified in the 2018 Fine Scale Vegetation Map (Golden Gate National Parks Conservancy et al., 2021).

DOUGLAS-FIR REMOVAL

Douglas-fir removal is targeted at canopy-piercing Douglas-fir in Oak Woodlands. These trees are successional in the absence of fire. When beneficial fire is not possible to manage Douglas-fir, hand or mechanical removal is a viable substitute. Note that Douglas-fir removal may be combined with thinning treatments in the field.



Interim Result 1: Threatened and converting oak stands are identified using countywide fine scale vegetation map data and Forest Condition Assessment, as shown in the One Tam Forest Health Web Map.

Interim Result 2: Douglas-fir is reduced in the understory leading to reduced competition and stand release.

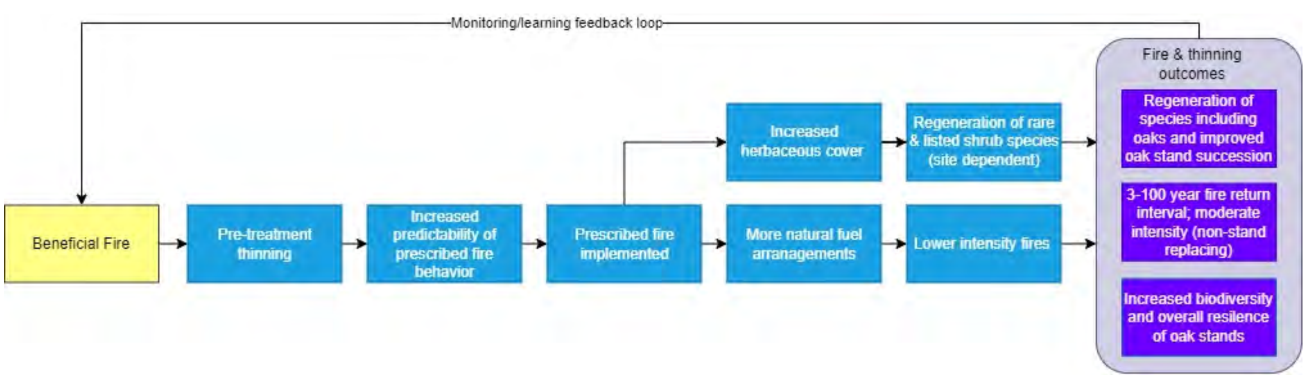
Condition Goal 1: Maintain approximately 7,350 acres of Open Canopy Oak Woodlands with oak canopy cover between 25-60% on One Tam agency-managed public lands, as identified in the 2018 Fine Scale Vegetation Map (Golden Gate National Parks Conservancy et al., 2021).

BENEFICIAL FIRE

Beneficial fire includes prescribed fire, cultural burning, and fire managed for resource benefit (California Wildfire and Resilience Task Force, 2022). Pre-treatment thinning may be necessary to conduct burns safely.

Beneficial fire results chains and condition goals do not attempt to recreate a natural range of variation for fire return intervals using beneficial fire. The fire return interval is a baseline for understanding historical conditions and considering the range and timing of management actions, not a condition goal unto itself.

In an alternative to tanoak removal to address sudden oak death, Bowcutt (2013) advocates for a collaborative process with Tribal leadership to identify areas with mature tanoaks where traditional indigenous burning practices can be tested in combination with restoration practices informed by western science. New approaches are needed to tend tanoaks given the



impacts of sudden oak death and other threats. See Chapter 3: Stewardship and Partnership with the Federated Indians of Graton Rancheria for more information on the importance of beneficial fire for cultural values.

Interim Result 1: Pre-treatment thinning increases the predictability of beneficial fire while also reducing competition, increasing light penetration in the forest canopy, increasing mid- and understory diversity, and reducing unnatural fuel arrangements.

Interim Result 2: Beneficial fire decreases unnatural fuel arrangements and increases herbaceous cover/seedling recruitment to complement inter-fire recruitment. Fire may reduce sudden oak death spread or infection, but this needs to be tested as indicated in the monitoring feedback loop. If a relationship is established, add sudden oak death reduction as an interim result in the results chain.

Interim Result 3: Where possible, cultural burning sites will be identified and burned in collaboration with the Federated Indians of Graton Rancheria (the Tribe).

Condition Goal 1: Increased species regeneration and germination of the understory and shrub layer.

Condition Goal 2: Fire-resistant stands with natural fuel arrangements or fuel arrangements associated with Indigenous stewardship, and fire return interval of 3-100 years depending on stand conditions.

Condition Goal 3: Increased understory diversity and overall resilience of Open Canopy Oak Woodland stands.

Condition Goal 4: Maintain approximately 7,350 acres of Open Canopy Oak Woodlands with oak canopy cover between 25-60% on One Tam agency-managed public lands, as identified in the 2018 Fine Scale Vegetation Map (Golden Gate National Parks Conservancy et al., 2021).

Condition Goal 5: Cultural burning recruits specific desired understory plants and protects other cultural values as identified by the Tribe.

HYDROLOGY

Decommissioning or improving drainage on roads and trails can improve hydrological function and promote infiltration of water into the soil (Sosa-Pérez & MacDonald, 2017; Switalski et al., 2004; Weaver et al., 2014). Reducing sediment transport from roads and trails improves water quality and protects aquatic habitat. Reduced runoff also decreases opportunities for invasion by non-native species, which typically disperse along road corridors (Jodoin et al., 2008).

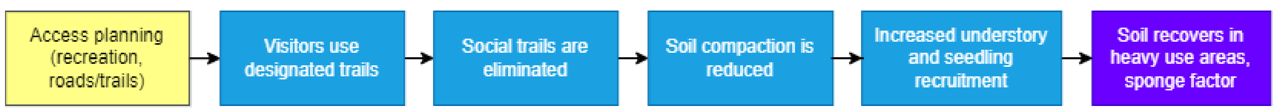
Interim Result 1: Identify locations and methods for small-scale projects to recreate natural drainage patterns and improve water retention. Potential sites adjacent to roads, trails, fuel reduction sites, capital improvement projects, or other restoration projects should be identified.

Condition Goal 1: Decreased run-off and erosion.

Condition Goal 2: Increased infiltration into the soil and groundwater retention, possible increase in stream baseflows.

SOIL & ACCESS PLANNING

Healthy, absorbent soil acts as a sponge, infiltrating water and decreasing runoff. Soil compaction can be a threat to Open Canopy Oak Woodland with a series of impacts. Initially soil compaction can lead to reduced understory vegetation and water infiltration, which in turn leads to a reduction in water available to vegetation and increased runoff, causing erosion and contributing sediment to streams. Soil compaction may be caused by recreational use and can be addressed through thoughtfully designed trails and signage (Cole, 2004).



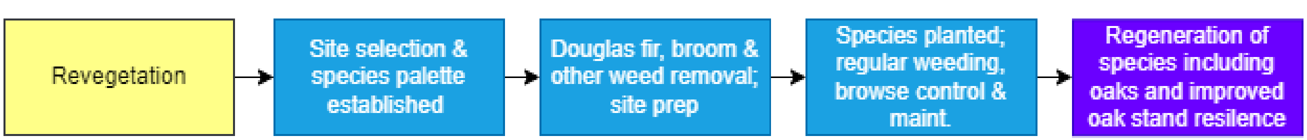
Interim Result 1: Effective access planning, including signs and agency websites, explain the importance of using designated trails.

Interim Result 2: Visitors use designated trails; social trails and soil compaction are reduced, resulting in reduced spread of pathogens and non-native invasive species (NNIS) and increasing health of soil which acts as a sponge for water and nutrients.

Condition Goal 1: Soil health improves resulting in increased water filtration, seedling recruitment, tree vigor, and understory diversity.

REVEGETATION

With pathogens, fire exclusion, predation, drought, and climate change threatening oaks, managers may consider the role of targeted revegetation in conserving and maintaining healthy stands of Open Canopy Oak Woodland. Revegetation efforts could potentially replace pathogen- impacted vegetation with disease-resistant native oak and hardwood plantings, as well as select native understory species. Collaboration with Tribe will help managers ensure that Tribal priorities are highlighted including selection of desirable acorn producing trees or other species. See Chapter 3: Stewardship and Partnership with the Federated Indians of Graton Rancheria for a deeper discussion.



Interim Result 1: Site selection priorities and native species palette established for targeted Open Canopy Oak Woodland stands. Could include pathogen-resistant native oak and hardwood species, if available and appropriate.

Interim Result 2: Removal of Douglas-fir, broom, and other non-native invasive species at prioritized sites as part of site preparation and maintenance.

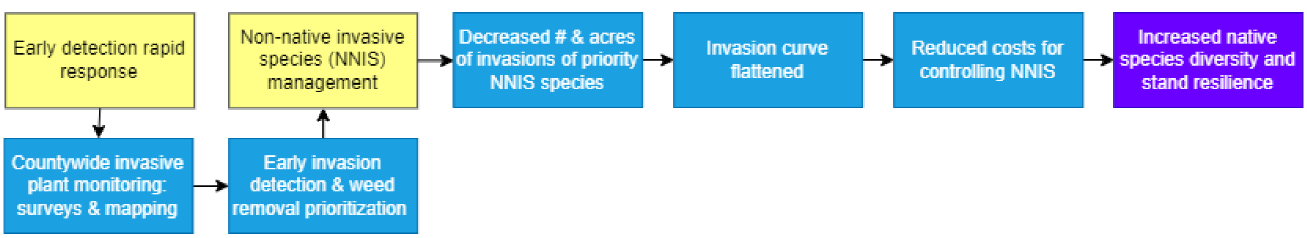
Interim Result 3: Survivorship of plantings is increased through regular weeding, browse control, stewardship, and maintenance actions.

Interim Result 4: Active planting and/or management of natural recruitment leads to increased species diversity, water retention, soil health, and carbon sequestration.

Condition Goal 1: Maintain approximately 7,350 acres of Open Canopy Oak Woodlands with oak canopy cover between 25-60% on One Tam agency-managed public lands, as identified in the 2018 Fine Scale Vegetation Map (Golden Gate National Parks Conservancy et al., 2021)

NON-NATIVE INVASIVE PLANT SPECIES

Non-native invasive species (NNIS) threaten native species diversity and may displace native vegetation which provides essential food and shelter for sensitive wildlife. In addition, some NNIS can contribute to unnatural fuel loads and reduce forest resilience.



Interim Result 1: Countywide invasive plant mapping and early detection rapid response (EDRR) programs identify new and track existing non-native species invasions resulting in decreased new invasions.

Interim Result 2: Non-native invasive species management decreases the number of invasive species and total invaded acres.

Interim Result 3: Focused broom removal continues to open the understory for native vegetation and reduce fuels.

Interim Result 4: The invasion curve is flattened.

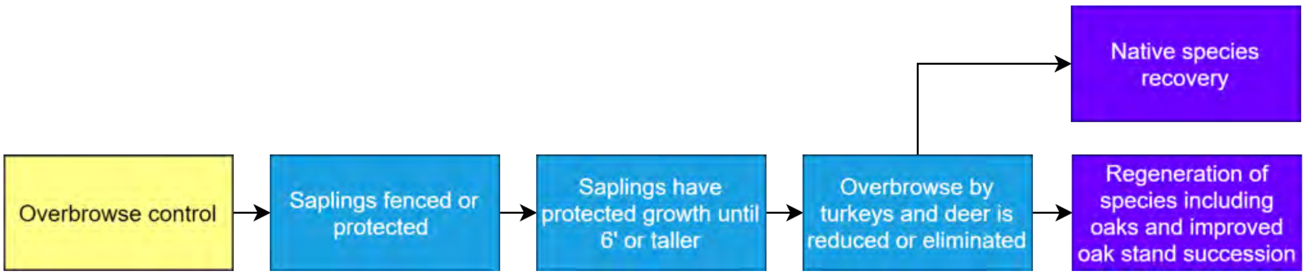
Interim Result 5: Costs are reduced for non-native invasive species control.

Condition Goal 1: Open Canopy Oak Woodland stands experience increased native species diversity and are more resilient.

Condition Goal 2: High-priority invasive species cover reduced in priority Open Canopy Oak Woodland habitat (Edson et al., 2016, p. 70).

OVERBROWSE CONTROL

Deer populations have increased in Marin due to a lack of apex predators such as mountain lions, wolves, and human hunters. Elevated deer populations put pressure on broadleaf tree seedlings and saplings, such as *Quercus* spp. In addition, introduced wild turkeys are responsible for heavy acorn consumption limiting oak recruitment (Edson et al., 2016, p. 65).



Intermediate Result 1: Oak saplings are fenced/protected.

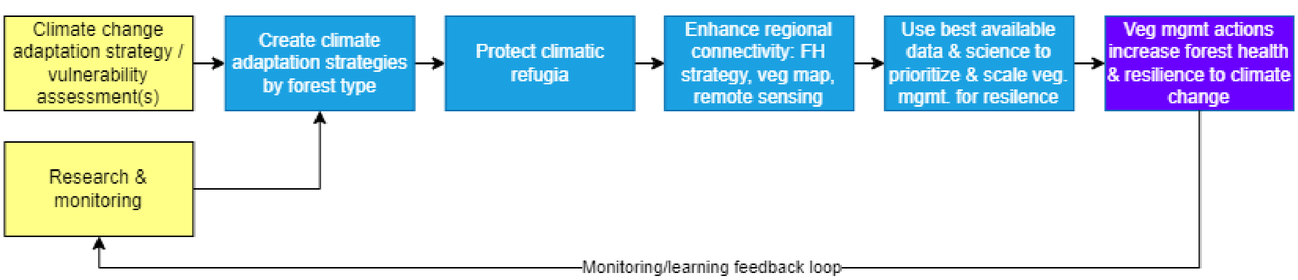
Intermediate Result 2: Turkey/deer overbrowse reduced through hunting and trapping. The potential for Tribal hunting will be explored where feasible and possible (also see Chapter 3: Stewardship and Partnership with the Federated Indians of Graton Rancheria).

Condition Goal 1: Oak regeneration at the individual and stand level.

Condition Goal 2: Native species recover in the understory.

CLIMATE CHANGE

Climate change threatens healthy forests in many complex and interconnected ways. For example, increasing temperatures and prolonged drought increases vulnerability to pests and pathogens as well as reducing germination success. See Chapter 4: Climate Change and Other Forest Health Stressors for an in-depth discussion of climate change impacts. Managing for climate change will involve an ongoing cycle of monitoring and assessing conditions; determining priority treatment areas to protect sensitive species, habitat corridors, and climate refugia; and adapting management actions and priorities as conditions change and new data is available.



Interim Result 1: Land managers create climate adaptation strategies by forest type based on vulnerability assessments, regional connectivity, and considerations regarding the distribution of species, threats, stressors, and management feasibility. Research and monitoring inform these strategies.

Interim Result 2: Climatic refugia are protected. Areas predicted to remain suitable habitat for conservation targets (i.e., Open Canopy Oak Woodlands) are prioritized for conservation and management.

Interim Result 3: Regional collaboration and collective impact is increased through use of the *Forest Health Strategy*, 2018 Fine Scale Vegetation Map and future updates, and additional landscape-scale remote sensing analysis.

Interim Result 4: By leveraging the best available spatial data, models, and climate science, managers can prioritize areas for management and work together to scale up treatments focused on increasing climate resilience for priority Open Canopy Oak Woodlands stands.

Condition Goal 1: Vegetation management actions informed by landscape scale climate adaptation strategies increase priority Open Canopy Oak stand resilience to climate change and bring stands within the new predicted range of natural variability.

BEST MANAGEMENT PRACTICES

Best Management Practices (BMPs) largely focus on reducing the spread of non-native invasive species and pathogens from site to site, protecting uninfected sites, and complying with environmental regulations. BMPs for weeds and pathogens differ from EDRR and are focused on limiting introduction and spread. The intended outcomes for effective BMPs are protecting Oak Woodland habitat and understory diversity. Additional BMPs developed in collaboration with the Tribe may include protecting cultural plants and gathering areas and protecting cultural sites during management activities.

Interim Result 1: Best management practices are reviewed with staff and contractors.

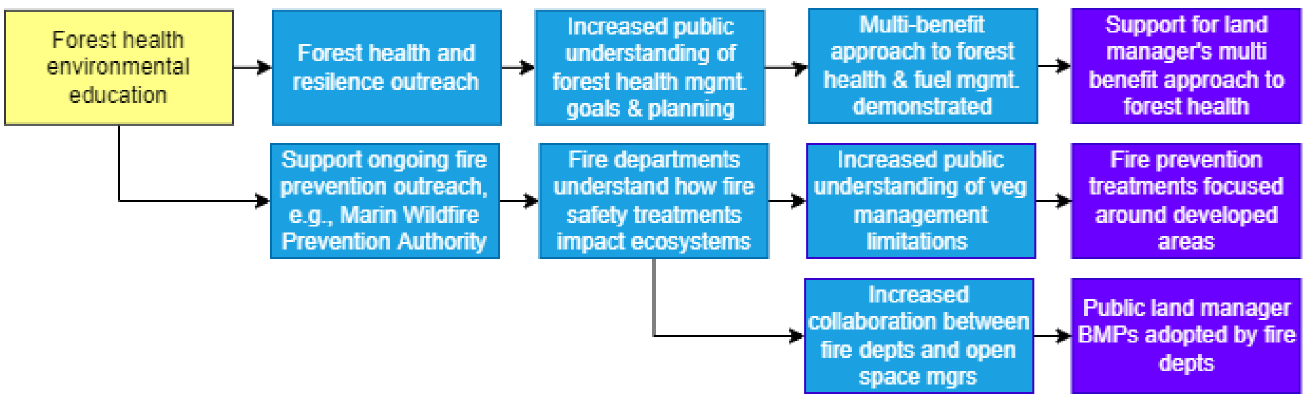
Interim Result 2: Comprehensive and effective best management practices are consistently implemented.

Interim Result 3: Forest pathogens and new non-native invasive species infestations are reduced.

Condition Goal 1: Forest understory diversity and stand health is protected.

ENGAGEMENT & COLLABORATION

Managing forests for resilience requires collaborative efforts from the entire Marin community. Ongoing education and communication is necessary to ensure all groups are working together to meet overarching goals for forest health, cultural use, recreation, and fire safety. See Chapter 3: Stewardship and Partnership with the Federated Indians of Graton Rancheria for a discussion on collaboration with the Tribe.



Interim Result 1: Education and community outreach increases public understanding of the value of healthy and resilient forests. Open Canopy Oak Woodlands environmental education will focus on cultural values and the role of fire in life history, regeneration, and conservation of the forest type.

Interim Result 2: Increased education and signage about forest health, including plant pathogens and related impacts (such as sudden oak death) to help prevent further spread.

Interim Result 3: Collaboration between the Tribe, fire departments, Marin Wildfire Prevention Authority (MWPA), community groups, and land managers increases.

Interim Result 4: Working with local groups, such as MWPA, fire prevention outreach focuses on actions in developed residential and commercial areas.

Interim Result 5: Best management practices are coordinated with the MWPA/Ecologically Sound Practices Partnership (ESP Partnership, 2022).

Interim Result 6: Forest resilience and fire management treatment prescriptions are developed in collaboration with the Tribe, cultural plants are protected for collection by Native peoples, and applicable cultural practices are restored.

Condition Goal 1: Increased support for land managers' multi-benefit approach to forest health.

Condition Goal 2: Fire departments adopt best management practices created and implemented community groups, public land managers, the Tribe, and researchers.

Condition Goal 3: Fire prevention treatments focus on reducing risk to developed, residential, and commercial areas; critical infrastructure; and evacuation routes.

Condition Goal 4: Public land management agencies, the Tribe, community groups, and Marin Fire agencies develop coordinated multi-benefit projects to protect forest health, increase climate resilience, and address non-natural fuel arrangements (where applicable) in select locations at multiple scales.

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SARGENT CYPRESS FOREST

LIFE HISTORY

Endemic to California, *Hesperocyparis sargentii* is a serotinous conifer species of the *Cupressaceae* family known by the common name Sargent cypress.[1] Largely restricted to monospecific stands on mesic sites with serpentine soils, Sargent cypress may grow in or adjacent to coniferous forests and montane chaparral (Armstrong, 1978; Farjon & Filer, 2013). Their preference for serpentine soils, serotiny, and seeds lacking wings all limit Sargent cypress dispersal ability (McNamara et al., 2019). Stands of Sargent Cypress, surrounded by chapparal, are located in the Coast Range and distributed from Red Mountain in Mendocino County southwards to Zaca Peak in Santa Barbara County. Sargent Cypress stands may often follow fog lines that cause patchy distribution (Ray, 2021).

Sargent cypress generally grows 5 to 15 meters in height, but some individuals are known to exceed 22 meters. In Marin County, stands of Sargent Cypress near San Geronimo Ridge generally grow on serpentine soils as a pygmy forest, attaining mean stand heights no greater than 8.5 meters. Stands located on serpentine soils are resistant to non-native invasive weed invasion and Douglas-fir encroachment. A second Marin population of Sargent Cypress forest, located on Mount Tamalpais, grows on non-serpentine soils and is somewhat taller on average. See the Sargent Cypress Structural Classification section in Chapter 6: Metrics for more information.

Stand age on the Central California Coast varies from 25-95 years (Ne'Eman et al., 1999). However, in the absence of disease and fire, Sargent cypress has an estimated lifespan of 300 years (Lanner, 1999). Cones are produced on 5-7 year-old trees and need two years to mature (CNPS, n.d.; Esser, 1994; Wolf & Wagener, 1948).

For the Tribe, Sargent cypress was an important species for toolmaking, construction materials, and medicine. For more details on cultural practices and tending, see Chapter 3: Stewardship and Partnership with the Federated Indians of Graton Rancheria.

The floristic classification report that accompanied the 2018 Marin Countywide Fine Scale Vegetation Map (2018 Fine Scale Vegetation Map, Golden Gate National Parks Conservancy et al., 2021) describes the Sargent cypress *Hesperocyparis (sargentii, macnabiana)* Woodland Alliance and member associations found in Marin County following standards established by the U.S. National Vegetation Classification (USNVC) and the CNPS *Manual of California*

[1] In 2009 the genus name for New World cypresses changed from *Cupressus* to *Hesperocyparis* (Adams et al., 2009), however Mao et Al. (2010) found evidence that Cupressus is monophyletic with weak support and suggested a reversion to *Cupressus* (Christenhusz et al., 2010). For purposes of the *Marin Regional Forest Health Strategy*, we use *Hesperocyparis* to conform with the naming convention used for *Hesperocyparis sargentii* in the 2018 Marin Countywide Fine Scale Vegetation Map (Golden Gate National Parks Conservancy et al., 2021) and corresponding floristic classification report (Buck-Diaz et al., 2021, Appendix D), as well as the current Jepson treatment (Bartel, 2012).

Vegetation (MCV). The floristic classification for Marin County was developed in partnership with the California Department of Fish and Wildlife Vegetation Classification and Mapping Program (CDFW VegCAMP) and California Native Plant Society Vegetation Program. Table 5.9 lists member associations found in Marin County for Sargent Cypress and described in the Marin classification report (Buck-Diaz et al., 2021, Appendix D).

Sargent Cypress is the only key forest type in the *Marin Regional Forest Health Strategy (Forest Health Strategy)* that was mapped to the Association level. In general, forest types in the 2018 Fine Scale Vegetation Map were mapped to the Alliance level because Associations are indistinguishable using remote sensing methods. However, in the case of Sargent Cypress, mappers were able to distinguish between two of the three Associations found in Marin County and thus could map to a finer scale, see Table 5.9. For the third Association, *Hesperocyparis sargentii / Rhododendron occidentale,* the floristic classification analysis that accompanied the 2018 Fine Scale Vegetation Map included only one occurrence of this Association sampled in Marin County (Lagunitas Creek watershed; Buck-Diaz et al., 2021, p. 51). Any stands of the *Hesperocyparis sargentii / Rhododendron occidentale* Association in Marin County were mapped as one of the other two Associations.

Table 5.9. Sargent Cypress 2018 Fine Scale Vegetation Map classes (Golden Gate National Parks Conservancy et al., 2021) and member association described in the corresponding floristic classification report (Buck-Diaz et al., 2021, Appendix D).

2018 Fine Scale Vegetation Map Classes	Other Associations in Marin County
Hesperocyparis sargentii Association	• *Hesperocyparis sargentii / Rhododendron occidentale*
Hesperocyparis sargentii / Ceanothus jepsonii – Arctostaphylos spp. Association	

KEY ECOSYSTEM SERVICES

One Tam partners identified biodiversity as a priority ecosystem service provided by Sargent Cypress forests. Other important services are cultural values, air quality, carbon sequestration, habitat, hydrologic function, and recreation. Managing Sargent Cypress to continue to provide and strengthen these ecosystem services is an important goal for the One Tam agencies. Some services, such as carbon sequestration, are limited due to the limited presence of Sargent Cypress stands in the County.

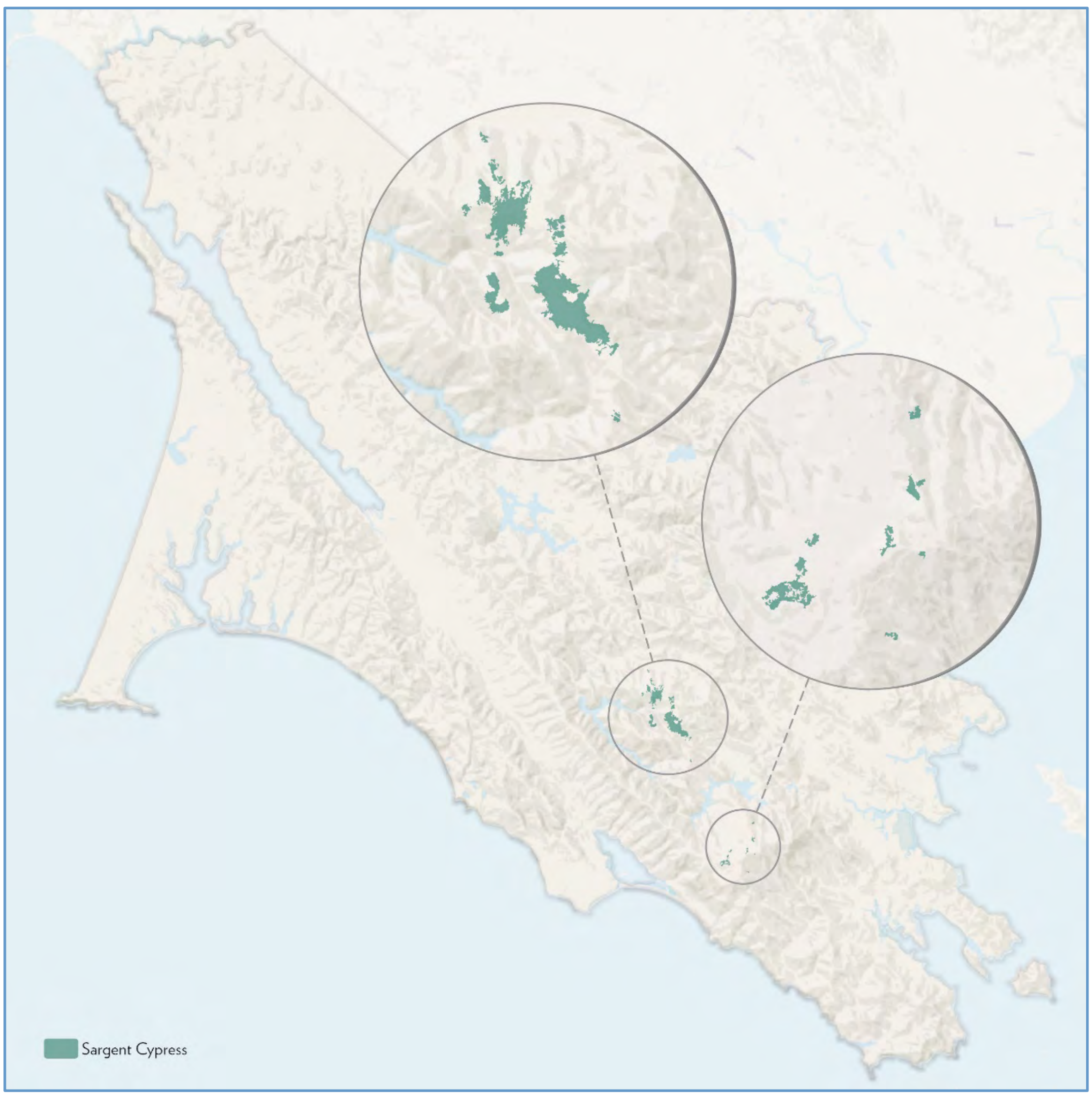
The Sargent Cypress community is characterized by an understory of navarretias (*Navarretia* spp.), Indian warrior (*Pedicularis densiflora*), jewelflowers (*Streptanthus* spp.), and Mt. Tamalpais manzanita (*Arctostaphylos montana* ssp. *montana*) in the One Tam focal area (Edson et al., 2016). Mt. Tamalpais manzanita is a serpentine endemic listed as a California rare plant (1B). (Buck-Diaz et al., 2021, Appendix D, p. 253). Sargent Cypress communities also provide habitat for the locally rare species large ground cone (*Kopsiopsis strobilacea*) and pleated gentian (*Gentiana affinis* ssp. *ovata*) (Edson et al., 2016).

A limited range of species invades serpentine soils because of their abiotic environments, and canopy shade may further limit potential invasions. Field observations indicate that most non-native, invasive species in Sargent Cypress communities exist at the periphery along roads and trails where shade is low and disturbance is high (S. Adams, Senior Ecologist, Marin Water, personal communications, 2022).

DISTRIBUTION

The 2018 Fine Scale Vegetation Map shows the distribution of *Hesperocyparis sargentii* Associations at the stand level (Figure 5.17; Golden Gate National Parks Conservancy et al., 2021). A closer inspection of each stand can be accessed at the One Tam Forest Health Web Map.

Figure 5.17. Sargent Cypress stand distribution in Marin County. Insets show detail for the San Geronimo population to the north and the Mt. Tamalpais population to the south.



FIRE REGIME

Sargent cypress are adapted to stand-replacing fires. The species is a crown-fire vegetation type and an obligate seeder. *H. sargentii* stands feature low-branching thickets making stand-replacing crown fires likely (IUCN, n.d.). Due to their tendency to experience stand-replacing crown fires, even-aged stands that date from the last wildfire event are typical (Wolf & Wagener, 1948). Other species in this genus exhibit variation in even- vs. uneven-aged stands. For instance, a study of McNab cypress (*H. macnabiana*) in Northern California noted that uneven-aged stands were not linked to post-fire recruitment. The uneven-aged stands were older, larger, and had higher senescence rates compared to even-aged stands suggesting that inter-fire tree mortality and inter-fire establishment may be linked (Mallek, 2009).

During a fire in Sargent Cypress stands, cones open as the resin melts and boils. Rapid charring of the thick cone scales leaves seeds unburned. Seeds then fall on exposed rocky and mineral soil (IUCN, n.d.). Sargent cypress typically show a low germination rate under controlled laboratory conditions, which indicates the species may have other germination requirements such as diurnal photoperiod, moisture exposure, and temperature related to their specific climate (Milich et al., 2012).

For obligate seeding species, a longer interval between fires is beneficial in order to generate a larger seed crop and greater potential for successful postfire recruitment (Pausas & Keeley, 2014). However, obligate seeding species face immaturity risk due to frequent fires and senescence risk if the fire return interval exceeds the lifespan of the seedbank (Keeley et al., 1999; Lamont et al., 1991; Ne'eman et al., 1999; Zedler, 1995). Some *Hesperocyparis* species show no evidence of immaturity or senescence risk. For example, Zedler (1995) found that fire intervals as infrequent as 100 years posed no risk to Tecate cypress (*H. forbesii*) and Mallek (2009) found no evidence of immaturity risk in stands of McNab cypress.

In the Santa Lucia Mountains, San Luis Obispo County, Ne'eman, et al. (1999) studied post-fire Sargent cypress regeneration in serpentine soil-based stands. Before a 1994 burn, the stands had mixed fire return intervals ranging from 21-96 years. They found substantial regeneration in stands as young as 20 years, indicating fire intervals would need to be shorter to pose an immaturity risk. Although they found reduced seedling recruitment in stands which were nearly 100 years old, indicating a potential senescence risk, even the lowest density seedling recruitment was many times greater than the density of mature forests. They concluded that Sargent cypress is resilient to a wide range of fire return intervals (Ne'eman, et al.,1999). At Cuesta Ridge Botanical Special Interest Area in the Los Padres National Forest, multiple downfall Sargent cypress snags were sampled following the 1994 Highway 41 fire. Botanists found an average age of death of 110 years from the sampling effort (John Chestnut, personal communication, 2020).

Fire intensity is a critical concern for Sargent cypress. Milich et al. (2012) investigated the specific heating conditions required to break cone serotiny and to promote seed dispersal in all *Hesperocyparis* species. Their study found that seed germination ability is negatively impacted across the genus by prolonged exposure to high temperatures; there appears to be a trade-off between temperature and exposure time for stimulating seed release while simultaneously maintaining viable seed.

Results from a recent Marin fire history study (Dawson, 2021), show that the fire return interval since 1859 for most Sargent Cypress stands is 15-30 years, although a small number of acres experienced a 30-45 year fire return interval. All the Sargent Cypress stands are in the greater than 70 years since last fire category. The serpentine San Geronimo population is classified as 3-4 times burned. The non-serpentine Mt. Tamalpais population is split between 3-4 times and 5-6 times burned since 1859. A detailed Marin County fire history can be found in Appendix B: Wildfire History. More information on Sargent Cypress stand structure, mortality, and diversity can be found in Chapter 7: Condition Assessment.

A summary of the Sargent Cypress fire regime is shown in Table 5.10. Burn seasonality is spring-fall, with low complexity due to monospecific stands. Intensity and severity are high. Although more study is needed, the current understanding indicates that fire management which allows fire frequency and intensity approaching the natural range of variation is critical to conserving this species (IUCN, n.d.).

Table 5.10. Summary of H. sargentii fire regime (CNPS, n.d.) FRI=fire return interval.

Alliance	Season	FRI (years)	Size	Intensity/ Severity	Type
H sargentii	Spring-summer -fall	40-200	M-L, up to or beyond stand size	High to very high/Moderate to very high	Crown

THREATS & POST-FIRE SUPPRESSION LEGACY

Sargent Cypress is threatened by wildfire, fire suppression, Douglas-fir encroachment, and overgrazing. Sargent Cypress' global status on the International Union for Conservation of Nature Red List is vulnerable with a current population trend of decreasing and severely fragmented (IUCN, n.d.). This forest type was selected for inclusion in the *Forest Health Strategy* due to its limited California distribution, global rarity, and providing habitat for several rare plant species.

ALTERED FIRE REGIME

Due to the lack of data across stands, and the potential double jeopardy (immaturity and senescence risk) Sargent cypress may face, several authors indicate the ideal fire return interval ranges are no less than 10-15 years and no longer than 150 years (Bartel, 1993; Esser, 1994; IUCN, n.d.; Zedler, 1995). However, due to increased fire frequency with climate change, senescence may not be a risk for remote stands which are allowed to burn. Some isolated Sargent Cypress stands close to infrastructure, such as those immediately south of San Geronimo in the Gary Giacomini Open Space Preserve, may face senescence risk due to fire exclusion.

CONCEPTUAL MODEL

The Marin Forest Health Strategy Working Group (Working Group) developed a conceptual model for Sargent Cypress showing ecosystem services, forest health attributes, threats, and treatments. The key for the conceptual model is shown in Figure 5.18 and the conceptual model is Figure 5.19. The Working Group established condition goals for Sargent Cypress forest and accompanying results chains from the conceptual model.

Figure 5.18. Conceptual model key.

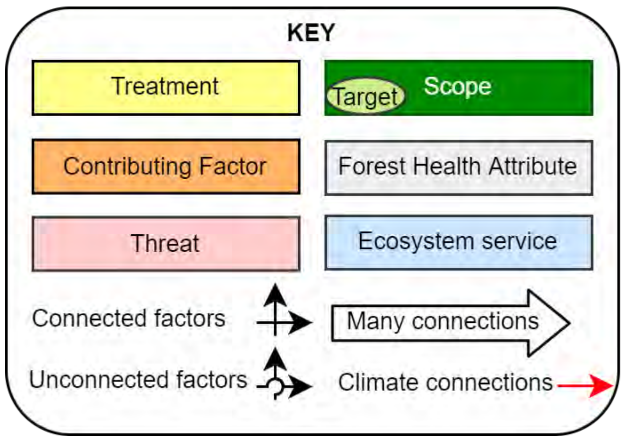
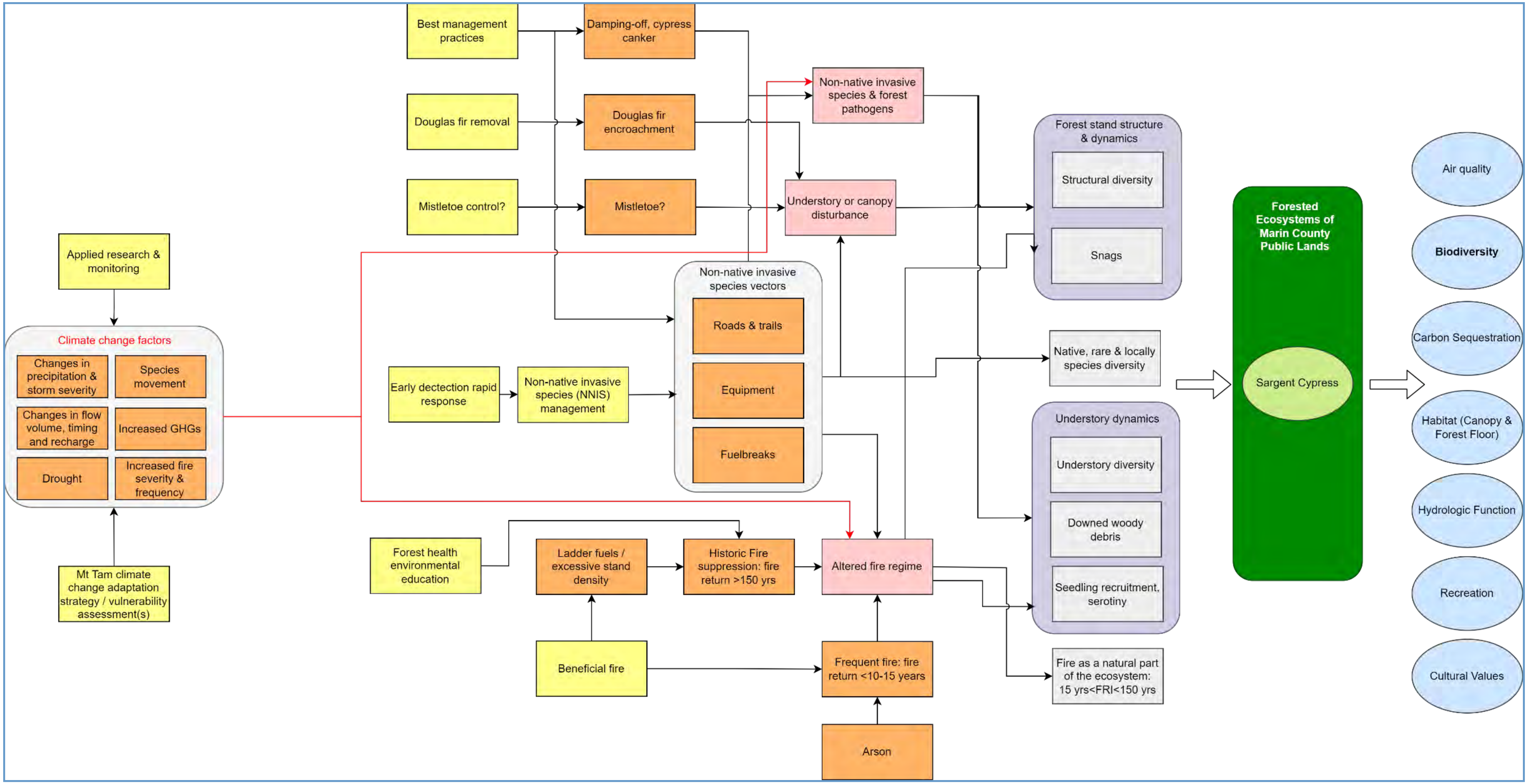


Figure 5.19. Sargent Cypress conceptual model.



SARGENT CYPRESS GOALS

The One Tam agencies and partners will work towards broader landscape-level goals described below through treatments designed to meet interim results and conditions goals. According to *Measuring the Health of a Mountain: A Report on Mount Tamalpais' Natural Resources (2016 Peak Health Report)* the desired condition for Sargent Cypress is to maintain Sargent Cypress communities at the current spatial extent, support natural recruitment of Sargent cypress saplings, and protect the current species richness and structural diversity, with minimal invasive species (Edson et al., 2016). The 2018 Fine Scale Vegetation Map includes a total of 138 Sargent Cypress stands covering 451 acres; 345 acres mapped as *Hesperocyparis sargentii / Ceanothus jepsonii – Arctostaphylos spp.* Association, and an additional 106 acres mapped as *Hesperocyparis sargentii* Association.

Sargent Cypress stands throughout the Marin landscape could have populations in different stages of the postfire recovery continuum. There are many unanswered ecological and management questions related to climate change and fire impacts on Sargent Cypress. For example, is the species vulnerable to immaturity and/ or senescence risk? Will frequency of large fires increase with climate change and threaten the species with short fire return intervals? See Appendix E: Opportunities for Additional Study for research questions related to Sargent Cypress.

LANDSCAPE LEVEL GOAL 1: FOREST HEALTH

One Tam agencies will work together to protect and maintain existing Sargent Cypress stands in Marin County and preserve their healthy attributes. These include forest stand structure and understory dynamics, species diversity, fire as an ecosystem process, soil health, cultural values, and native species diversity.

Landscape Level Goal 1a: Treatment Feasibility

One Tam agencies will work together to implement and test treatments to maximize forest health in Sargent Cypress stands. Treatments may include implementing and testing pile burning, cone collection, seed germination, planting, and fire surrogate practices.

LANDSCAPE LEVEL GOAL 2: ECOSYSTEM SERVICES & BIODIVERSITY

One Tam agencies will protect and manage Sargent Cypress stands to continue to provide and strengthen ecosystem services, especially the priority service of biodiversity.

LANDSCAPE LEVEL GOAL 3: APPLIED RESEARCH & MONITORING

One Tam agencies will collaborate to monitor and study Sargent Cypress stands, including monitoring stands adjacent to other active management treatments, e.g., Douglas-fir removal. Applied research on population viability and altered fire regimes are particularly needed.

CONDITION GOALS & RESULTS CHAINS

Results chains are goal pathways which lay out a series of treatments and interim goals which cumulatively will allow managers to achieve landscape-level goals. Interim results and conditions goals are steps along the pathway to the desired conditions described in the landscape-level goals. See Chapter 9: Treatment Descriptions for a detailed discussion of treatment approaches and methods.

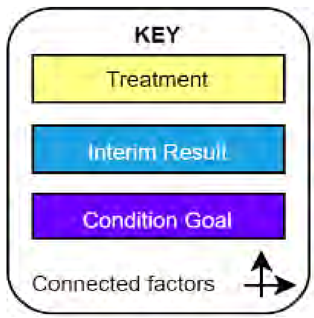
BENEFICIAL FIRE

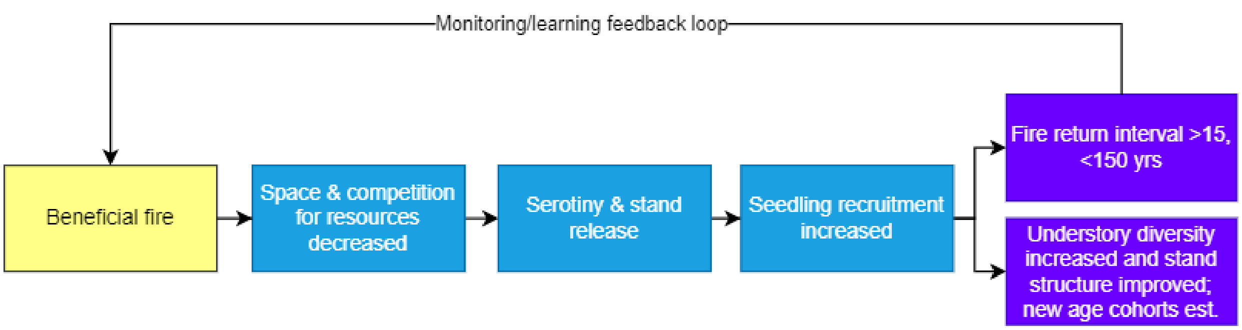
Beneficial fire includes prescribed fire, cultural burning, and fire managed for resource benefit (California Wildfire and Resilience Task Force, 2022). Pre-treatment thinning may be necessary to conduct burns safely.

Beneficial fire results chains and condition goals do not attempt to recreate a natural range of variation for fire return intervals using beneficial fire. The fire return interval is a baseline for understanding historical conditions and considering the range and timing of management actions, not a condition goal unto itself.

Please note the keys for subsequent results chains are the same.

Figure 5.20. Results Chain key.





Interim Result 1: Beneficial fire results in stand replacement, and the space and competition for resources are decreased. This result could include a burn box fire plot pilot project to measure seedling recruitment densities (Edson et al., 2016, p. 62). Where beneficial fire is impossible, test seedling germination and survival from fire-treated seeds (Edson et al., 2016, p. 62). Where it is not, examine the feasibility and test additional fire surrogate treatments such as chipping cones, strategic pile burning, controlled oven seed processing, soil scarification, and raking.

Interim Result 2: Serotinous cones open and germinate following wildfire.

Condition Goal 1: Seedling/sapling presence is greater than tree mortality in burned stands (Edson et al., 2016, p. 58).

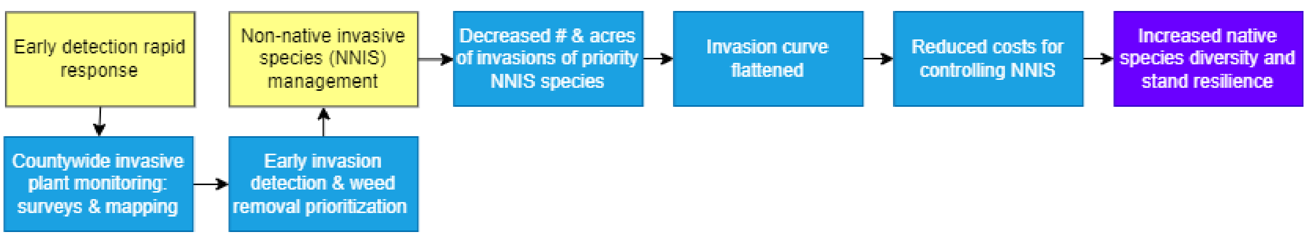
Condition Goal 2: If beneficial fire, including prescribed broadcast burning, cultural burning, or fire managed for resource benefit, is appropriate as a treatment, implement beneficial fire such that at least 80% of Sargent Cypress habitat has experienced a broadcast burn event within the last 150 years, with a return interval of less than one fire every ten years (Edson et al., 2016, p. 59).

Condition Goal 3: The fire return interval approaches a range of greater than 15 years and less than 150 years.

Condition Goal 4: Understory diversity increases, stand structure improved, and new Sargent cypress cohorts are established.

NON-NATIVE INVASIVE PLANT SPECIES

Serpentine stands of Sargent Cypress at San Geronimo ridge tend to have much fewer weeds. At the landscape scale, non-native invasive species control could focus more on the non-serpentine stands at Mt. Tamalpais. Targeted weeding or early detection rapid response (EDRR) in serpentine stands may be needed. In general, non-native invasive species (NNIS) threaten native species diversity and may displace native vegetation which provides essential food and shelter for wildlife. In addition, some NNIS can reduce forest resilience.



Interim Result 1: Countywide invasive plant mapping and early detection rapid response (EDRR) programs identify new and track existing non-native species invasions resulting in decreased new invasions.

Interim Result 2: Non-native invasive species management decreases the number of invasive species and total invaded acres.

Interim Result 3: The invasion curve is flattened.

Interim Result 4: Costs are reduced for non-native invasive species control.

Condition Goal 1: Sargent Cypress stands experience increased native species diversity and are more resilient.

Condition Goal 2: Priority Sargent Cypress stands are weed free or have low non-native invasive plant cover (Edson et al., 2016, p. 60).

DOUGLAS-FIR REMOVAL

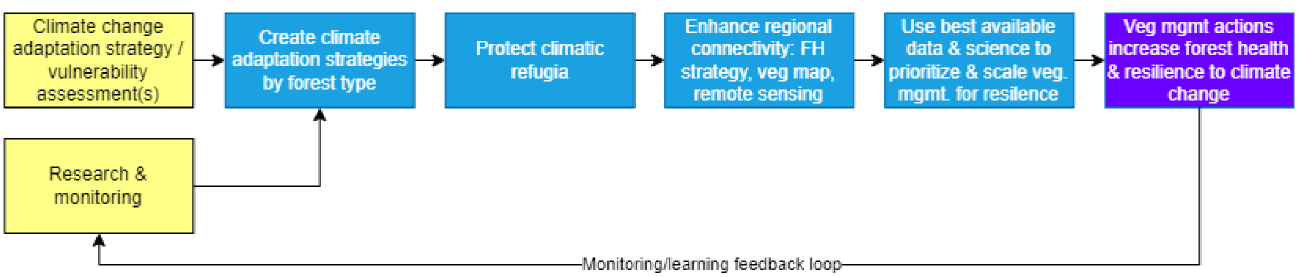
Monitor for Douglas-fir encroachment in Sargent Cypress stands, especially in non-serpentine stands.

Interim Result 1: Douglas-fir is reduced in the understory resulting in competition removal and stand release.

Condition Goal 1: At a minimum, maintain approximately 451 acres of Sargent Cypress forest within or adjacent to the spatial extent shown in the 2018 Fine Scale Vegetation Map (Golden Gate National Parks Conservancy et al., 2021).

CLIMATE CHANGE

Climate change threatens healthy forests in many complex and interconnected ways. For example, increasing temperatures and prolonged drought increases vulnerability to pests and pathogens as well as reducing germination success. See Chapter 4: Climate Change and Other Forest Health Stressors for an in-depth discussion of climate change impacts. Managing for climate change will involve an ongoing cycle of monitoring and assessing conditions; determining priority treatment areas to protect sensitive species, habitat corridors, and climate refugia; and adapting management actions and priorities as conditions change and new data is available.



Interim Result 1: Land managers create climate adaptation strategies by forest type based on vulnerability assessments, regional connectivity, and considerations regarding the distribution of species, threats, stressors, and management feasibility. Research and monitoring inform these strategies.

Interim Result 2: Climatic refugia are protected. Areas predicted to remain suitable habitat for conservation targets (i.e., Sargent Cypress) are prioritized for conservation and management.

Interim Result 3: Regional collaboration and collective impact is increased through use of the *Forest Health Strategy*, 2018 Fine Scale Vegetation Map and updates, and additional landscape scale remote sensing analysis.

Interim Result 4: By leveraging the best available spatial data, models, and climate science, managers can prioritize areas for management and work together to scale up treatments focused on increasing climate resilience for priority Sargent Cypress stands.

Condition Goal 1: Vegetation management actions informed by landscape scale climate adaptation strategies increase priority Sargent Cypress stand resilience to climate change and bring stands within the new predicted range of natural variability.

BEST MANAGEMENT PRACTICES

Best Management Practices (BMPs) largely focus on reducing the spread of non-native invasive species and pathogens from site to site, protecting uninfected sites, and complying with environmental regulations. BMPs for weeds and pathogens differ from EDRR and are focused on limiting introduction and spread. The intended outcomes for effective BMPs are protecting Sargent Cypress habitat and understory diversity. Additional BMPs developed in collaboration with Federated Indians of Graton Rancheria (the Tribe) may include protecting cultural plants and gathering areas and protecting cultural sites during management activities.

Interim Result 1: Best management practices are reviewed with staff and contractors.

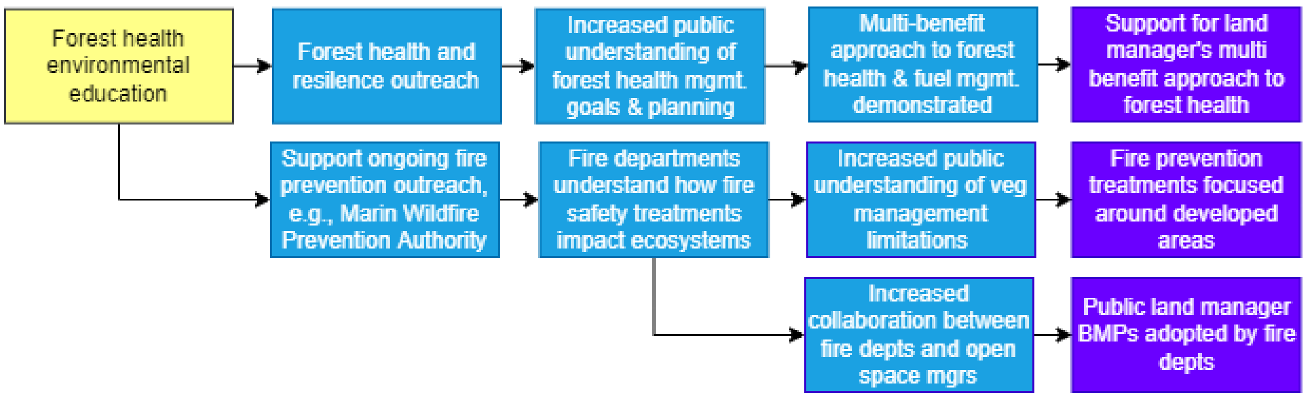
Interim Result 2: Comprehensive and effective best management practices are consistently implemented.

Interim Result 3: Forest pathogens and new non-native invasive species infestations are reduced.

Condition Goal 1: Forest understory diversity and stand health is protected.

ENGAGEMENT & COLLABORATION

Managing forests for resilience requires collaborative efforts from the entire Marin community. Ongoing education and communication is necessary to ensure all groups are working together to meet overarching goals for forest health, cultural use, recreation, and fire safety. See Chapter 3: Stewardship and Partnership with the Federated Indians of Graton Rancheria for a discussion on collaboration with the Tribe.



Interim Result 1: Education and community outreach increases public understanding of the value of healthy and resilient forests. For Sargent Cypress, education will be focused on rarity, serotiny, and conservation of the forest type

Interim Result 2: Collaboration between the Tribe, fire departments, Marin Wildfire Prevention Authority (MWPA), community groups, and open space managers increases.

Interim Result 3: Working with local groups, such as MWPA, fire prevention outreach focuses on actions in developed residential and commercial areas.

Interim Result 4: Best management practices are coordinated with the MWPA/Ecologically Sound Practices Partnership (ESP Partnership, 2022).

Condition Goal 1: Increased support for land managers' multi-benefit approach to forest health.

Condition Goal 2: Fire departments adopt best management practices created and implemented by community groups, public land managers, the Tribe, and researchers.

Condition Goal 3: Fire prevention treatments focus on reducing risk to developed, residential, and commercial areas; critical infrastructure; and evacuation routes.

Condition Goal 4: Public land management agencies, the Tribe, community groups, and Marin Fire agencies develop coordinated multi-benefit projects to protect forest health, increase climate resilience, and address non-natural fuel arrangements (where applicable) in select locations at multiple scales.

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CHAPTER 6: METRICS

Assessing the health of a forest is a complicated process as health cannot be measured directly. Metrics are measurable data points which can be used to represent different components of forest health, such as tree density, and thus to measure attributes of forest health. The metrics described in this chapter were developed to locate and measure specific attributes related to forest structure, ecological health, and ecosystem function for the five target forest types[1] identified in the *Marin Regional Forest Health Strategy* (*Forest Health Strategy*). See Chapter 5: Goals for information on each target forest type.

This chapter provides a detailed description of the geospatial data used to develop modelled geographic information system (GIS) products depicting forest conditions in Marin County. Individual metrics developed for modeling forest conditions and the methods and foundational data used to create them are described in detail. The framework for using the modeling results to assess forest health through the Forest Health Strategy Condition Assessment (Forest Condition Assessment) will be explored in-depth in Chapter 7: Condition Assessment.

The metrics and corresponding GIS datasets developed as part of the *Forest Health Strategy* are valuable resources for land managers and decision-makers as they provide a means to quantify key forest characteristics that experts have identified as important indicators of health or stress within these forest systems. When multiple metrics are used in combination for a forest stand, they can help managers understand conditions in that stand. By combining the outcomes of metric analysis (modelled GIS data) and Forest Condition Assessment with expert ecological understanding, local knowledge, infrastructure locations, input from the Federated Indians of Graton Rancheria, and field reconnaissance, One Tam agencies, partners, and other stakeholders will be able to identify and prioritize areas for potential multi-benefit forest revitalization work. In addition, metrics can be monitored over time to understand changes in forest conditions and the impact of different forest health treatments, and thus adjust treatments to be more effective. See Chapter 8: Prioritization Framework and Implementation Analysis for discussion of prioritizing areas for forest health treatments and Chapter 10: Monitoring for recommendations on monitoring approaches.

PROCESS FOR IDENTIFYING & SELECTING METRICS

The 2016 report *Measuring the Health Of A Mountain: A Report On Mount Tamalpais' Natural Resources* (*2016 Peak Health Report*; Edson et al., 2016) utilized conditions assessments of key indicator species, natural communities, and physical processes as proxies for evaluating ecological health across Mount Tamalpais and the surrounding watersheds. The *2016 Peak*

[1] Note that some metrics developed as part of the *Forest Health Strategy*, such as percent canopy mortality, were created for all forested stands in Marin County and not limited to the five target forest types. See the 2018 Marin Countywide Fine Scale Vegetation Map (Golden Gate National Parks Conservancy, 2021) or the One Tam Marin Forest Health Web Map to explore available metric data for other forest types.

Health Report authors used specific metrics to assess the trends of a given indicator species or community. For example, to assess the condition trend of Coast Redwood forests the report analyzed available field data to develop a trees per hectare metric, which was then used to estimate redwood stand densities in second-growth forests as compared to those measured in old-growth stands. The *2016 Peak Health Report* authors then extrapolated the results of the metrics analysis to assign a condition trend for Coast Redwood forests across the mountain. The *Forest Health Strategy* uses metrics in a comparable manner to the *2016 Peak Health Report*: Healthy forest attributes or threats to forest health are correlated with metrics to assess conditions for the five target forest types across Marin County. For results of the assessment process see Chapter 7: Condition Assessment.

Conceptual models of forest health were developed for each of the forest types profiled in the *Forest Health Strategy* – Bishop Pine, Coast Redwood, Douglas-fir, Open Canopy Oak Woodlands, and Sargent Cypress. These conceptual models were developed through extensive discussion with One Tam natural resource managers and environmental scientists and were reviewed by a panel of technical experts, the Marin Forest Health Strategy Working Group (Working Group). Each conceptual model identifies a conservation target (forest type), health attributes associated with that forest type, direct threats to those attributes, and factors contributing to direct threats (Figure 6.1[2]). See Chapter 5: Goals for conceptual models for all forest types.

The *2016 Peak Health Report* included several metrics for key forest types which were used in the development of forest health conceptual models. For example, in the Coast Redwood conceptual model, the forest health attribute of "overstory with 50-100 trees per hectare" represents a healthy Coast Redwood forest density; this forest health attribute is from the trees per hectare metric where the density value falls within the healthy condition range identified in the *2016 Peak Health Report* and supported by current science and research (Figure 6.2, yellow arrow; Lorimer, et al., 2009; Noss, 2000). The conceptual models formed the basis for identifying potential metrics that could be used as proxies for quantifying and locating both forest health attributes and threats.

[2] Unless otherwise noted, figures were created for the *Forest Health Strategy* by the Golden Gate National Parks Conservancy.

Figure 6.1.Generic conceptual model listing forest health attributes, direct threats, and contributing factors.

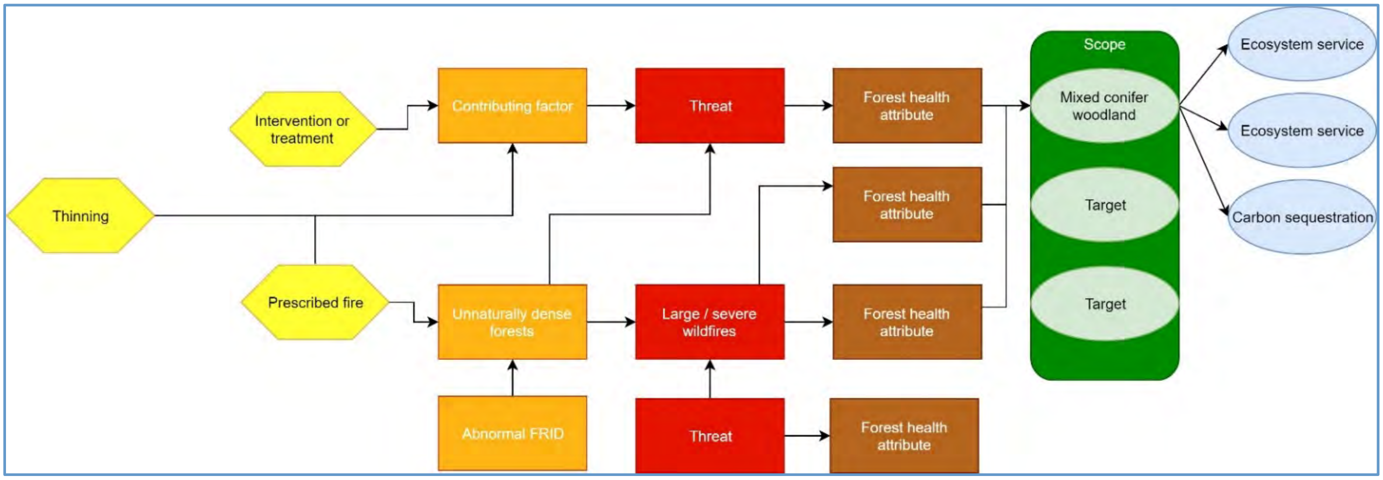
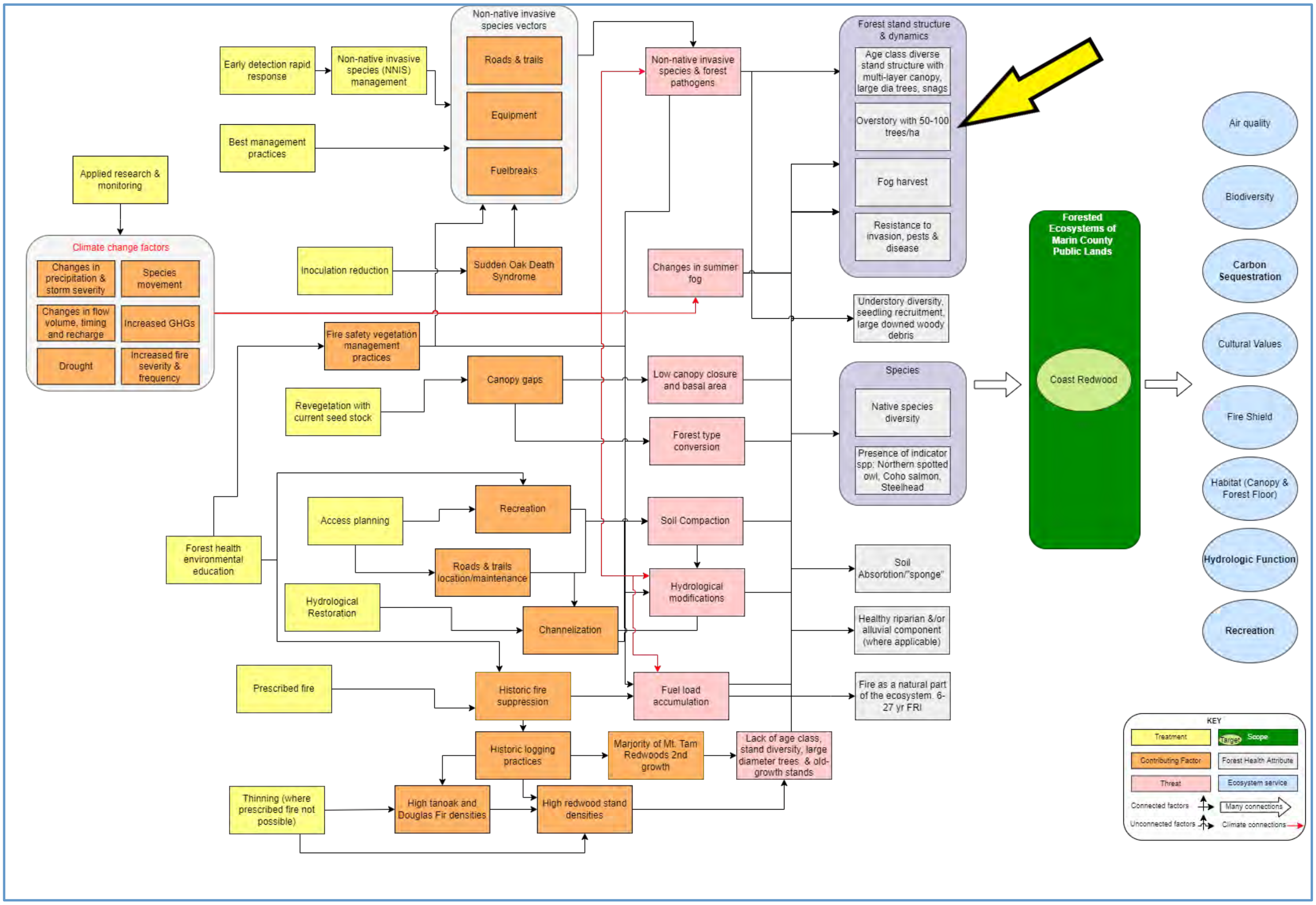


Figure 6.2. Coast Redwood conceptual model of forest health, showing forest health attribute derived from stand density forest health metric (yellow arrow) from 2016 Peak Health Report ([Edson et al., 2016](#)).



Metrics included in the *2016 Peak Health Report* and healthy attributes or threats in forest health conceptual models formed the basis for a broad list of potential metrics for the Forest Condition Assessment and *Forest Health Strategy* (Table 6.1). This initial list of potential metrics was further expanded by exploring case studies and other forest assessment efforts completed in California and throughout the West (Table 6.2). In August 2020, the Working Group held a workshop to evaluate metrics for further development and inclusion in the Forest Condition Assessment based on several factors including availability of requisite input data, cost for development, recommendations from technical experts, and degree of expected accuracy/utility. Table 6.3 below lists the final forest health metrics developed as part of this strategy and the applicable forest type. Unless otherwise noted, data to inform metrics were developed using remote-sensing technology (both optical imagery and lidar) and may have inherent limitations at very fine scales. Each metric selected for development is described in detail below, including methodology, intended uses, and limitations of the data.

Table 6.1. Initial list of potential metrics to develop for Forest Condition Assessment.

Stand Structure/Dynamics	Forest/Stand Change 2010 v 2019
	Structure-Based Classification of Seral Stage
	Variations in tree height using canopy volume profiles
	Classified stand density (no. of trees per hectare)
Pathogens and Type Conversion	Invasive species (presence/absence) within and adjacent to forest stand (incl. non-native trees)
	Canopy gap/Mortality mapping (pathogen effects)
	Classified standing dead by size
	Classified standing dead by density
	Relative hardwood vs. conifer
	Canopy piercing Douglas-fir mapping
	Oak woodland / Grassland type conversion
	Douglas-fir invaded grasslands or shrublands
Understory Dynamics	Seedling recruitment
Biodiversity/Habitat	Native plant species richness
	Wildlife (vertebrate) species presence
	Single species proxies for biodiversity
	Special status species (Northern Spotted Owl)
	Special status species (salmonids)
	Special status species (frogs - yellow or red legged)
	Rare plants
	Presence of State or Federally Listed Species
Soil Infiltration	Catchment Area
	Impervious/Permeable Mapping
Hydrology	Functional riparian (floodplain, channel, top-of-bank)
	Temporal soil moisture (groundwater retention)
	Channel morphology/incision

Fire Behavior	Countywide 2020 5 m fuels model
	Ladder Fuels
	Fire history and historic ignitions
	Topography (aspect/slope; proximity to streams)
Fire and Public Safety	Proximity to structures, major roads/evac routes
	Presence of fuel breaks
Carbon	Above ground carbon and biomass
	Below ground carbon
	Potential future carbon by stand growth
	Potential carbon saved by doing fuel treatment
Management	Revegetation or weeding; active management area
	Previous forest health treatments

Table 6.2. Case studies referenced for potential metrics/approaches.

Case Study	More Information
Amador Calaveras Consensus Group (ACCG)	see project development support process
Aspen Center for Environmental Studies (ACES)	see ACES Forest Health Index (FHI)
California Tahoe Conservancy	see Lake Tahoe Basin Forest Action Plan
Cascadia Partner Forum	see TerrAdapt Cascadia
Center for Large Landscape Conservation	N/A
Lake Tahoe West Restoration Partnership	see Lake Tahoe West Landscape Resilience Assessment
National Forest Foundation (NFF)	see the NFF Yuba Project
Sierra to California All-Lands Enhancement (SCALE) project	N/A
TNC Conservation Gateway	N/A
US Forest Service Dinkey Collaborative	N/A
Western Klamath Restoration Partnership	N/A
Y2Y. Yellowstone to Yukon Conservation Initiative	N/A
YSS: Yosemite Stanislaus Solutions	See Social and Ecological Resilience Across the Landscape (SERAL) Project

Table 6.3. Final list of metrics developed and used for assessing forest conditions, with applicable forest types.

Metrics	Coast Redwood	Bishop Pine	Douglas - Fir	Open Canopy Oak Woodlands	Sargent Cypress	Data Location[3]
Relative Percent Hardwood vs. Conifer	X	X	X	X	X	2018 Fine Scale Veg Map
Structural Classification	X	X	X		X	Forest Health Web Map Only
Oak Woodlands at Risk of Conversion to Douglas-fir				X		Forest Health Web Map Only
Percent Standing Dead (Canopy Mortality)	X	X	X	X	X	2018 Fine Scale Veg Map
Percent Canopy Gaps Formed 2010-2019	X	X	X	X	X	2018 Fine Scale Veg Map
Stand Change 2010-2019 (only stand density change used in Forest Condition Assessment)	X	X	X	X	X	Forest Health Web Map Only
Fire History	X	X	X	X	X	Forest Health Web Map Only
Ladder Fuels	X	X	X	X	X	2018 Fine Scale Veg Map
Aboveground Live Carbon	X	X	X	X	X	2018 Fine Scale Veg Map

[3] Development of some metrics was undertaken concurrently in 2020-2021 with finalization of the 2018 Marin Countywide Fine Scale Vegetation Map (Golden Gate National Parks Conservancy et al., 2021) and are therefore included in the 2018 Fine Scale Vegetation Map attribute table as well as the One Tam Marin Forest Health Web Map. Metrics developed after 2018 Fine Scale Vegetation Map completion can only be accessed via the Forest Health Web Map.

2018 MARIN COUNTYWIDE FINE SCALE VEGETATION MAP & FOREST HEALTH METRICS

In 2021, One Tam finalized the 2018 Marin Countywide Fine Scale Vegetation Map (2018 Fine Scale Vegetation Map) a comprehensive, fine scale vegetation community map at the countywide scale (Golden Gate National Parks Conservancy et al., 2021; Tukman Geospatial et al., 2021), which included a California Native Plant Society (CNPS) led effort to update the floristic classification of Marin County (Buck-Diaz et al., 2021). The vegetation map follows mapping standards developed by the California Department of Fish and Wildlife Vegetation Classification and Mapping Program (CDFW VegCAMP) which groups vegetation communities into GIS polygons that represent stands of vegetation. In the CNPS *Manual of California Vegetation*, a stand is defined as:

> The basic physical unit of plant communities in a landscape. It has no set size. Some vegetation stands are very small, such as certain wetland types, and some may be several square kilometers in size, such as certain forest types. A stand is defined by two main unifying characteristics:
>
> 1. It has compositional integrity. Throughout the stand, the combination of species is similar. The stand is differentiated from adjacent stands by a discernible boundary that may be abrupt or occur indistinctly along an ecological gradient.
>
> 2. It has structural integrity. It has a similar history or environmental setting that affords similar horizontal and vertical spacing of plant species. For example, a hillside forest originally dominated by the same species that burned on the upper part of the slopes but not the lower would be divided into two stands. Likewise, a sparse woodland occupying a slope with very shallow rocky soils would be considered a different stand from an adjacent slope with deeper, moister soil and a denser woodland or forest of the same species.

The structural and compositional features of a stand are often combined into a term called homogeneity. For an area to meet the requirements of a stand, it must be homogeneous at the scale being considered (Buck-Diaz et al., 2021, Appendix C, pg. C-1).

In addition to water, agricultural, developed areas, and other landcover types, the 2018 Fine Scale Vegetation Map contains detailed information about the location of forest and woodland assemblages (see Figure 6.3), and composition data such as the height of tree stands, visible mortality, hardwood and conifer densities, and the presence of gaps in the tree canopy (Golden Gate National Parks Conservancy et al., 2021). See the full list of 2018 Fine Scale Vegetation Map attributes in Appendix 6A of this chapter.

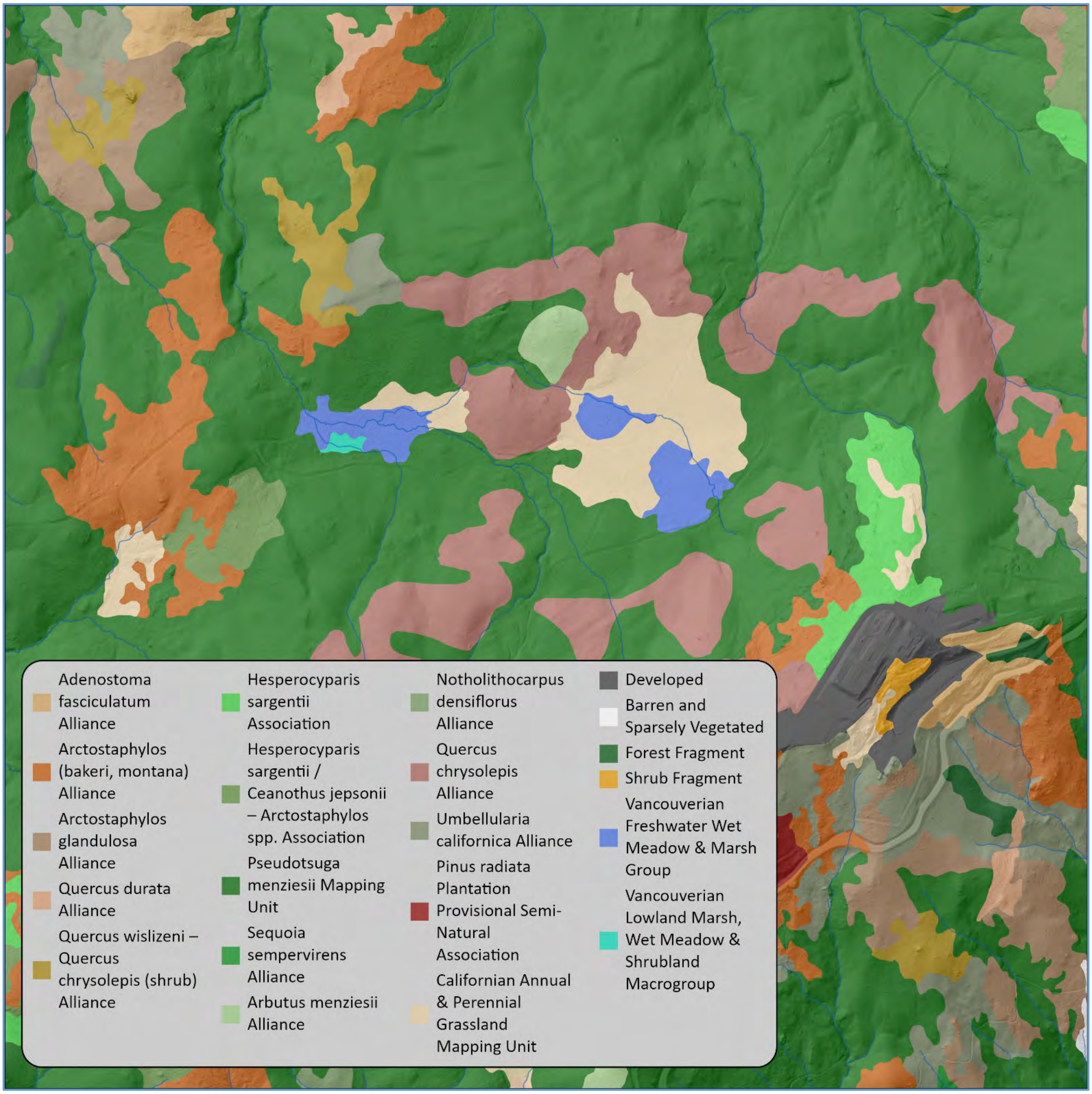
FOUNDATIONAL DATA

The 2018 Fine Scale Vegetation Map provides foundational data required for performing analysis on the condition of key forest types across Marin County. Many of the metrics selected to assess forest conditions were developed by combining data from the 2018 Fine

Scale Vegetation Map with additional lidar and imagery data, and other ancillary data analysis. The 2018 Fine Scale Vegetation Map relied on 6-inch, 4-band aerial imagery collected in June, 2018 as the primary input for manual photointerpretation and object-based image analysis. The lidar data used to support fine scale vegetation map creation and attribution was collected in winter of 2019 at Quality Level 1(8 points per square meter; [USGS, n.d.).](#)

Independent quality assurance/quality control (QA/QC) was performed for the 2018 4-band aerial imagery and 2019 lidar as part of initial data acquisition, and a formal accuracy

Figure 6.3. 2018 Fine Scale Vegetation Map, Area near Potrero Meadows, Mount Tamalpais Watershed.



assessment (AA) was conducted for the 2018 Fine Scale Vegetation Map (see Final Report). It should be noted, however, that formal accuracy assessments were not conducted for derivative layers used in the Forest Conditions Assessment. Additional information on imagery data is available in the *Marin County Imagery Technical Data Report* (Quantum Spatial, 2018). Information on Lidar data can be found in the Marin County QL1 LiDAR Technical Data Report (Quantum Spatial, 2019). A detailed description of the methods used to develop the 2018 Fine Scale Vegetation Map are included in the Marin Fine Scale Vegetation Map Final Report and accuracy assessment (Tukman Geospatial et al., 2021). For many of the metric analyses, the results were added directly into the 2018 Fine Scale Vegetation Map attribution for each polygon, see Table 6.3.

In Marin County, two complete countywide lidar datasets exist, one collected in late-spring of 2010 and one collected mid-winter of 2019. Therefore, in addition, to mapping current conditions in forested stands, the 2018 Fine Scale Vegetation Map and foundational data provided the opportunity to locate and quantify changes in forest stands between 2010 and 2019.

ONE TAM MARIN FOREST HEALTH WEB MAP

Once metrics were finalized, GIS layers were developed for each metric and added to a web-based map to facilitate data access for managers, stakeholders, and interested members of the public. The One Tam Marin Forest Health Web Map (Forest Health Web Map) is intended to be used to further explore the data described and represented in this chapter. Figures included here are intended to illustrate the availability of the data. Interested readers can explore in-depth and at different scales using the Forest Health Web Map.

Layers in the Forest Health Web Map correspond to the metrics listed in Table 6.3, with additional layers not specifically developed for the *Forest Health Strategy*, such as hydrography, soils, and boundaries, included for context. Links to the individual GIS service endpoints (for importing into GIS applications such as ArcMap or QGIS) for each layer are provided in Appendix 6B of this chapter.

METHODOLOGIES FOR FOREST HEALTH STRATEGY METRICS

The following sections describe the *Forest Health Strategy* metrics including development methodology, source data used for development, example applications, intended uses, and inherent limitations of the data. In some cases, raw metric data was classified into bins to summarize or simplify results and increase utility for end-users and for the Forest Condition Assessment, and descriptions of classification rationale are provided.

RELATIVE PERCENT HARDWOOD VS. CONIFER

Relative percent hardwood vs. conifer metrics are useful for understanding the structure and composition of forested stands, for identifying mixed hardwood/conifer stands and distinguishing them from relatively pure stands of conifer forest types, and seeing the distribution of these forest stands across the landscape. In oak woodlands, a high relative conifer value may be an indication that a stand may be transitioning to conifer forest (see Threatened and Converting Open Canopy Oak Woodlands metric below). Monitoring of relative hardwood metrics can also help managers assess impacts from sudden oak death (SOD) and other *Phytophthora sp.* on tanoak (*Notholithocarpus densiflorus)* and other susceptible hardwood species. A relative hardwood classification was developed for each of the five target forest types in the *Forest Health Strategy*.

Relative hardwood cover represents the percent of trees in a stand that are hardwoods rather than conifers (as seen from above), and the percent relative hardwood cover plus percent relative conifer cover always sums to 100. During 2018 Fine Scale Vegetation Map creation, relative hardwood cover was estimated during manual editing of the polygons by Aerial Information Systems (AIS) using photo interpretation of the 2018 4-band, 6-inch resolution orthoimagery. Each vegetation map polygon was assigned estimated percent conifer and hardwood attribution of the tree canopy greater than 15 feet high (Table 6.4).

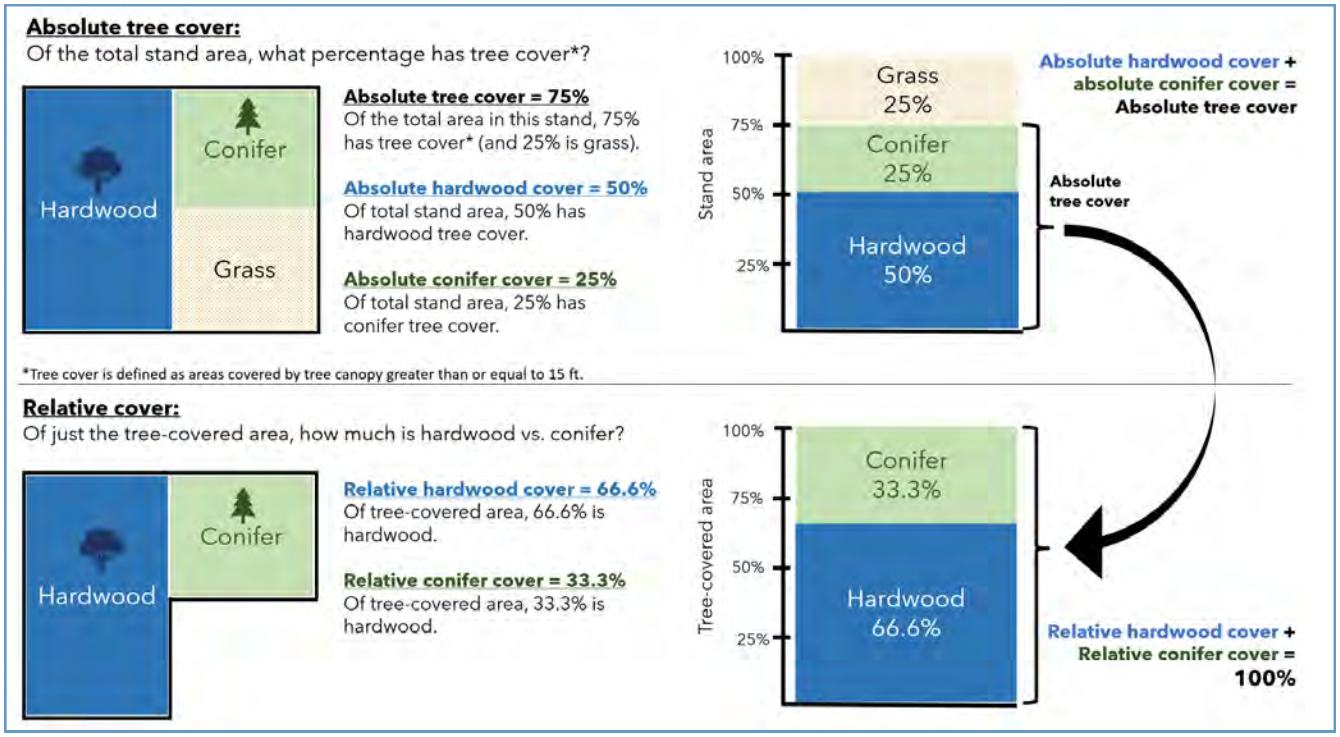
Table 6.4. 2018 Fine Scale Vegetation Map attributes for relative percent hardwood and conifer.

REL_CON_COV_18/Relative % Conifer Cover in ‘18	Relative conifer cover, estimating the percent of tree canopy >= 15 ft. is conifer. Derived from manual image interpretation of ‘18 imagery.
REL_HDW_COV_18/Relative % Hardwood Cover in ‘18	Relative hardwood cover, estimating the percent of tree canopy >= 15 ft. is hardwood. Derived from manual image interpretation of ‘18 imagery.

INTERPRETATION

As opposed to absolute cover, relative percent cover represents the percentage of total tree-covered area that is occupied by one type of tree (conifer) relative to another (hardwood). Thus, in a blue oak (*Quercus douglasii*) stand with 75% relative hardwood cover, *Q. douglasii* and other hardwood species comprise three quarters of the total tree cover as viewed from above in the 2018 imagery, while conifer species make up the other quarter. (Figure 6.4). A limitation of this metric is that understory species composition is generally difficult to measure using remote methods. Estimates of percent hardwood in conifer stands are likely higher in stands where conifers are shorter, or where there are significant gaps in conifer canopy. Nevertheless, the relative hardwood metric is useful for understanding the general distribution of mixed conifer-hardwood stands at landscape scale.

Figure 6.4. Absolute versus relative tree cover. Source: Tukman Geospatial.

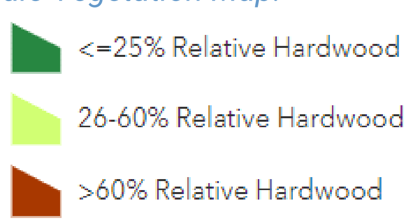


Metric Classes

For the purposes of summarizing the raw percent hardwood cover values for forested stands in the 2018 Fine Scale Vegetation Map for use in the Forest Condition Assessment, the relative percent hardwood vs. conifer attribution was divided into three bins based on simplified Braun-Blanquet cover classes for classifying vegetation-abundance cover (Figure 6.5; [Braun-Blanquet, 1964](#).).

- **Less than 25% Relative Hardwood**: Relatively pure conifer stand.
- **26% to 60% Relative Hardwood**: Mixed conifer and hardwood stand.
- **Greater than 60% Relative Hardwood**: Hardwood dominated stand.

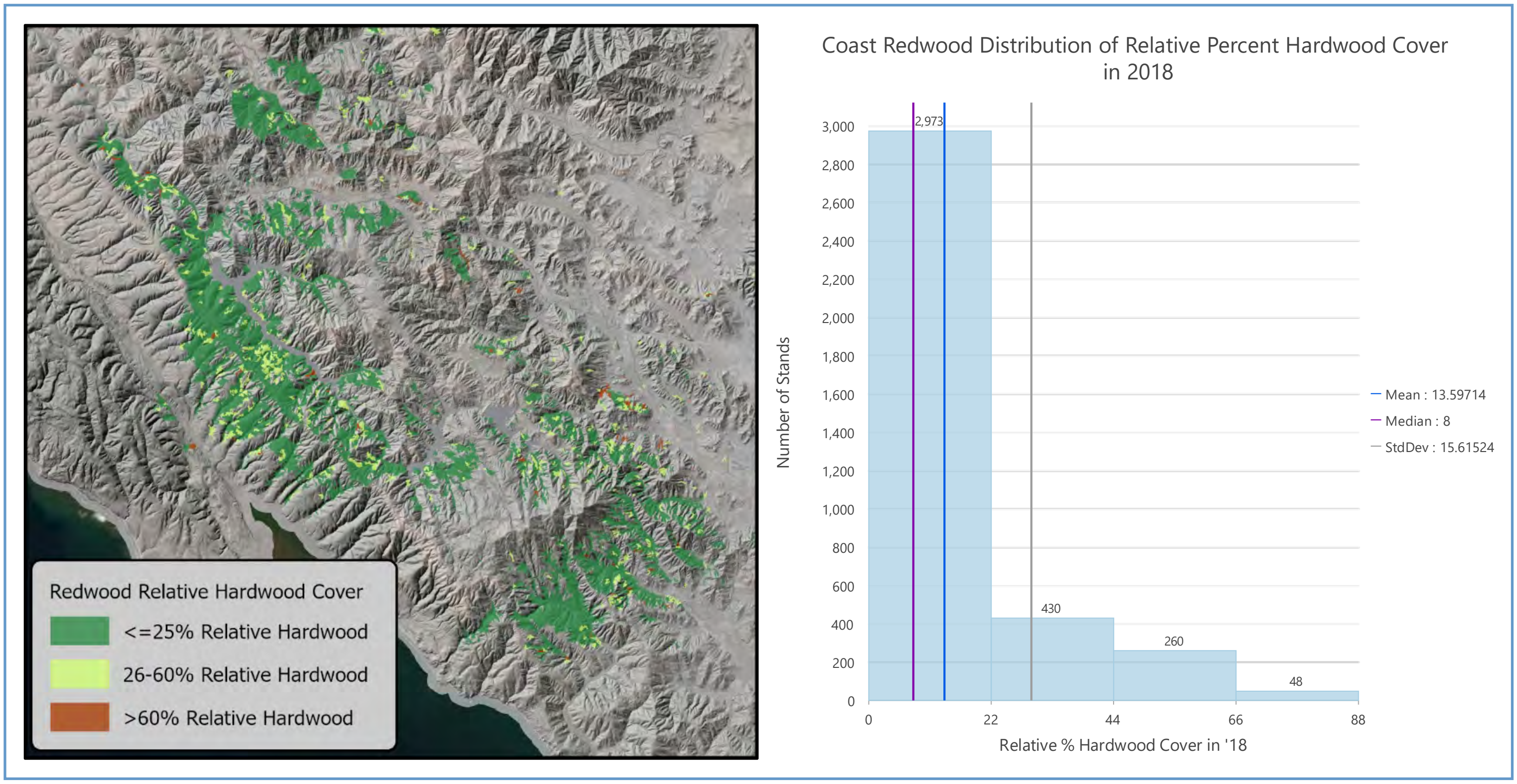
Figure 6.5. Relative percent hardwood classification, 2018 Fine Scale Vegetation Map.



Mixed Conifer and Hardwood Stands

While not specifically identified as a conservation target in the *Forest Health Strategy*, the presence and distribution of mixed stands of coast redwood (and other conifers) and hardwood forest (Figure 6.6) are of interest. Managers would like to see conifer forests retain, or develop in the case of second-growth forests, complex species composition, including a well-developed midstory with hardwood species such as tanoak and California bay laurel (*Umbellularia californica*) (Edson et al., 2016).

Figure 6.6. Distribution of classified relative hardwood in Coast Redwood stands, 2018 Fine Scale Vegetation Map.



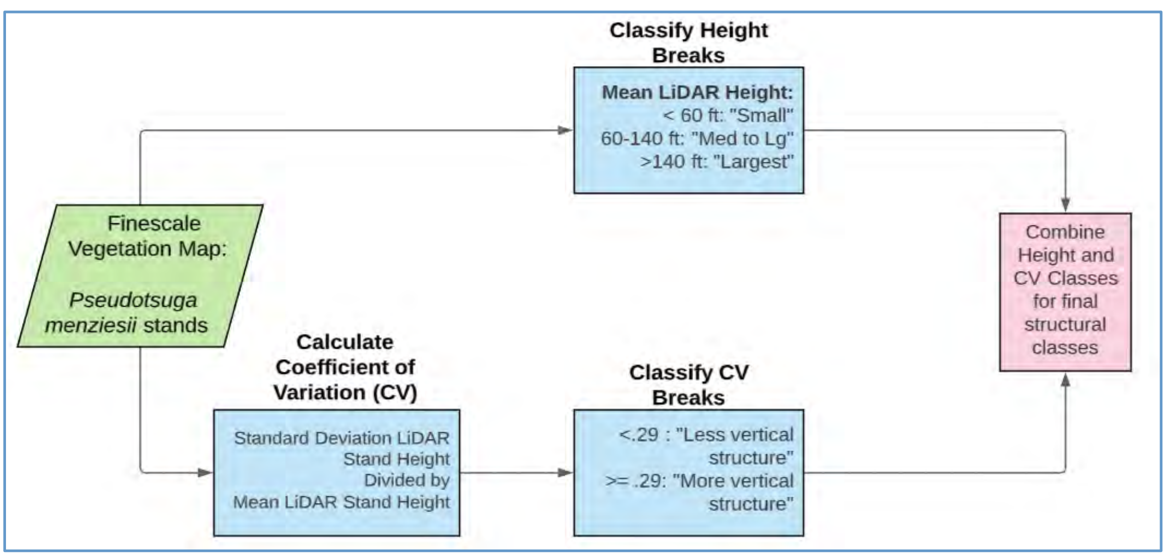
STRUCTURAL CLASSIFICATION OF CONIFER FOREST TYPES

Structural classification uses mean lidar-derived stand height and other data particular to each forest type to assess the structure of conifer forest stands and classify them into categories for assessment purposes. This classification is helpful for approximating seral stage and understanding the stand composition, distribution of different structural classes across the landscape, and relationship of structural classes to other site characteristics such as fire history, hydrology, soils, etc. The same data and metric workflow are used for Coast Redwood and Douglas-fir forest, although the interpretation of results is different. Bishop Pine and Sargent Cypress use additional data specific to the ecology of each species, as well as forest health attributes and threats for the structural classification of these forest types. This classification method was not used for Open Canopy Oak Woodlands because the growth habit of oak trees and resulting stand structure is different from conifer tree types and the age/structural class of oak stands is not directly linked to stand height.

COAST REDWOOD AND DOUGLAS-FIR STRUCTURAL CLASSIFICATIONS

This metric classified each Coast Redwood and Douglas-fir stand in Marin County, assigning it a structural class that represents tree height and vertical structure. Structural classes were assigned using a combination of the stand's lidar-derived mean height and coefficient of variation, which is the standard deviation of mean stand height divided by mean stand height, representing vertical structure (Figure 6.7). Using these two variables, five structural classes were developed using both the distribution of the lidar-derived structural metrics and ground condition data from One Tam land managers as a guide (Figure 6.8). Tree height is represented first in the classification as "Small", "Medium to Large", or "Largest". Vertical structure is represented second, as "LESS" or "MORE". The "Largest Stands" category includes all stands of over 140 feet mean height. This metric represents the state of the landscape in winter 2019, when countywide lidar was collected.

Figure 6.7. Workflow diagram for Coast Redwood and Douglas-fir structural classification, figure shows Douglas-fir input. Source: Tukman Geospatial.



INTERPRETATION

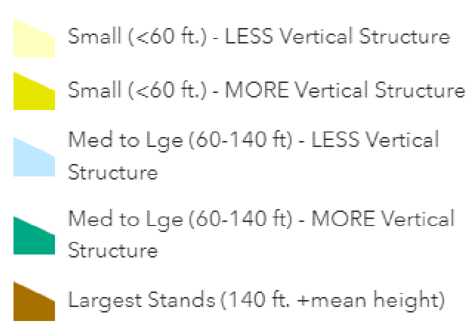
It is important to recognize that tree height does not necessarily reveal tree age due to confounding factors such as site quality, tree position in the canopy, and stand density, all of which can affect tree height. The height bins in this structural classification are used to reasonably separate out the youngest ("small") and most mature ("largest") stands from intermediate stands. While lidar data provides an accurate assessment of the mean height of redwood stands in the 2018 Fine Scale Vegetation Map, height can be influenced by the variation in site-specific characteristics and does not provide a complete picture of forest conditions, including seral stage (Figure 6.9). Therefore, using lidar alone will not provide all the information needed to accurately assess seral stage. Existing studies on and methods for remote detecting of late-seral forest relied on field-collected sampling and verification of lidar (Falkowski et al., 2009; Kane et al., 2010a, 2010b), and field data collection was outside the scope of work for this analysis. Future refinements to this structural classification would be possible using field calibration and validation. Tree-approximate-object methodology (Jeronimo et al., 2018) was evaluated to provide more information for assessing stand conditions, but ultimately not incorporated into the structural classification due to the limited ability to reliably reflect stand density, especially in complex mixed conifer-hardwood stands, without additional fieldwork and analysis which was beyond the scope of this work.

Coefficient of variation (standard deviation of mean stand height divided by mean stand height) was used to classify vertical structure (Leonard & Van Dyke, 2012). A low coefficient of variation results from low variability in tree heights, meaning trees in the stand are close to the same height (less vertical structure). This may indicate an even-aged stand. A high coefficient of variation indicates more variability in tree heights (more vertical structure), which could have multiple causes. It could indicate an uneven-aged stand, a mixed stand of hardwood and conifer with different heights, or a stand that has not undergone canopy closure**.** In the five structural classifications, the vertical structure bin was used to differentiate stands that had "MORE" complexity or variation in the vertical structure versus "LESS" complexity or variation.

Metric Classes

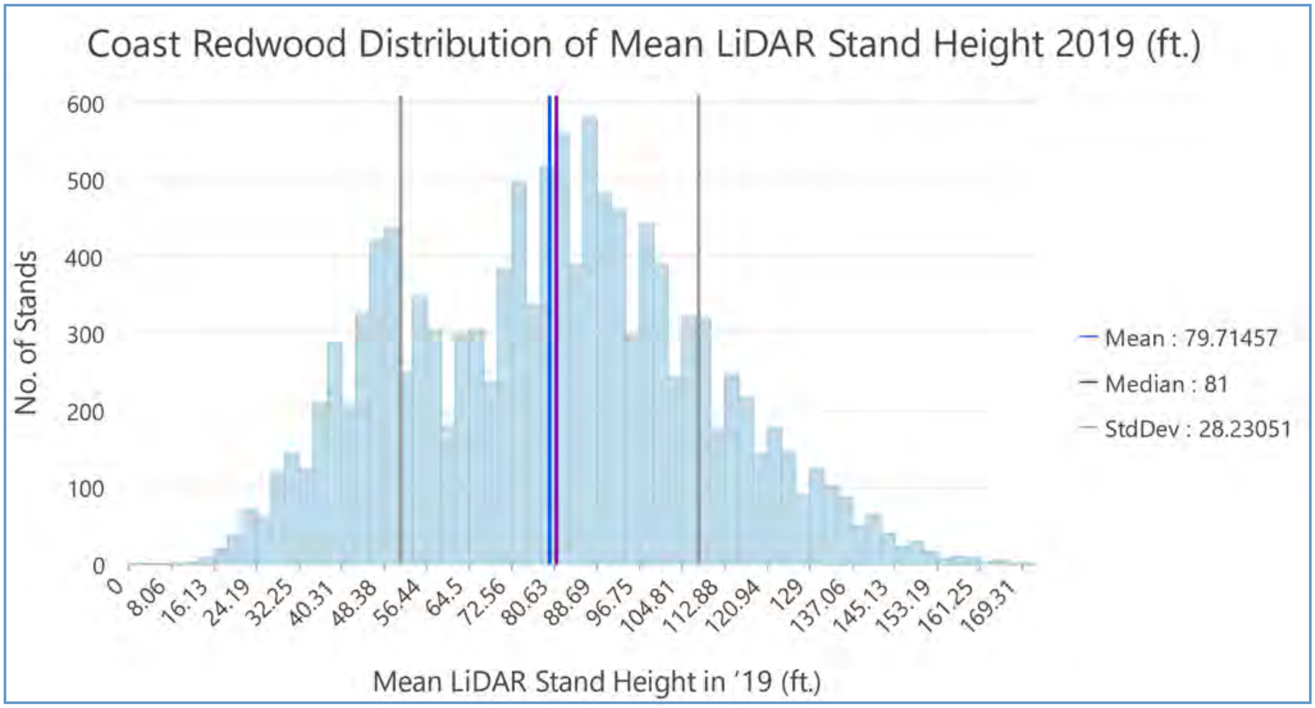
- **Small, Less Vertical Structure**: Likely younger stand, mean canopy height less than 60 feet in height; less vertical structure.
- **Small, More Vertical Structure**: Likely younger stand, mean canopy height less than 60 feet in height; more vertical structure.
- **Medium to Large, Less Vertical Structure**: Likely medium-aged stand, mean canopy height 60-140 feet in height; less vertical structure.

Figure 6.8. Coast Redwood and Douglas-fir structural classification.



- **Medium to Large, More Vertical Structure**: Likely medium-aged stand, mean canopy height 60-140 feet in height; more vertical structure.
- **Largest Stands**: Likely oldest stands, mean canopy height greater than140 feet in height.

Figure 6.9. Coast Redwood distribution of mean lidar stand height (2019).



COAST REDWOOD DISCUSSION

There is significant interest in using lidar to identify stands of old-growth (previously unlogged or late-seral) Coast Redwood; however, as discussed above, current research by Kane et al. 2010a, 2010b) demonstrates that field-based measurements are a critical input to developing a reliable lidar-informed seral classification of Coast Redwood. Collecting field measurements across the countywide distribution of Coast Redwood in Marin was outside the scope of work for the *Forest Health Strategy*. The value and limitations of data developed for the *Forest Health Strategy*, and opportunities for additional study, are made clear when exploring lidar-derived stand metrics and Coast Redwood structural classification in combination with local knowledge of large diameter trees, old growth-like stands, and logging history. For example, Muir Woods National Monument, an area dominated by previously unlogged Coast Redwood forest, shows significant variation in both the stand height and vertical structure classes (Figure 6.10). This suggests that additional study is needed to understand how variations in stand height and vertical structure relate to stand age, understory diversity, and other characteristics associated with late-seral Coast Redwood forests in Marin.

Figure 6.10. Muir Woods National Monument, from left to right: 2018 imagery (left), 2018 Fine Scale Vegetation Map (center), and Coast Redwood structural classification (right).

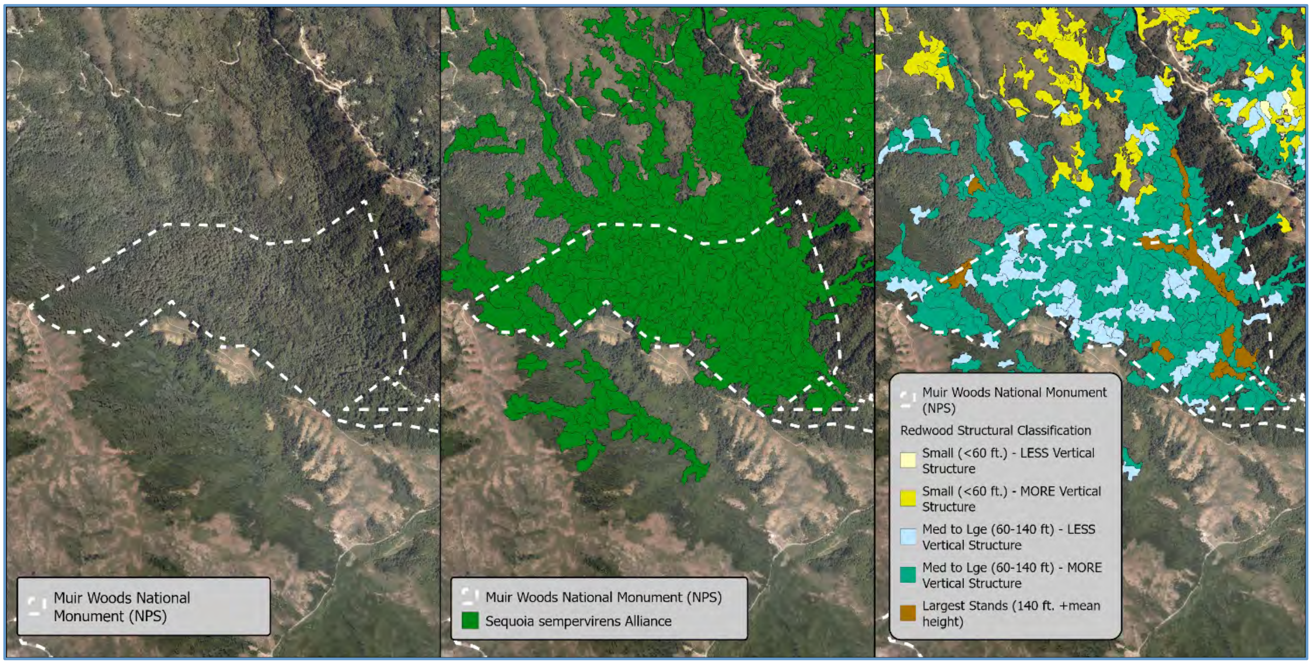
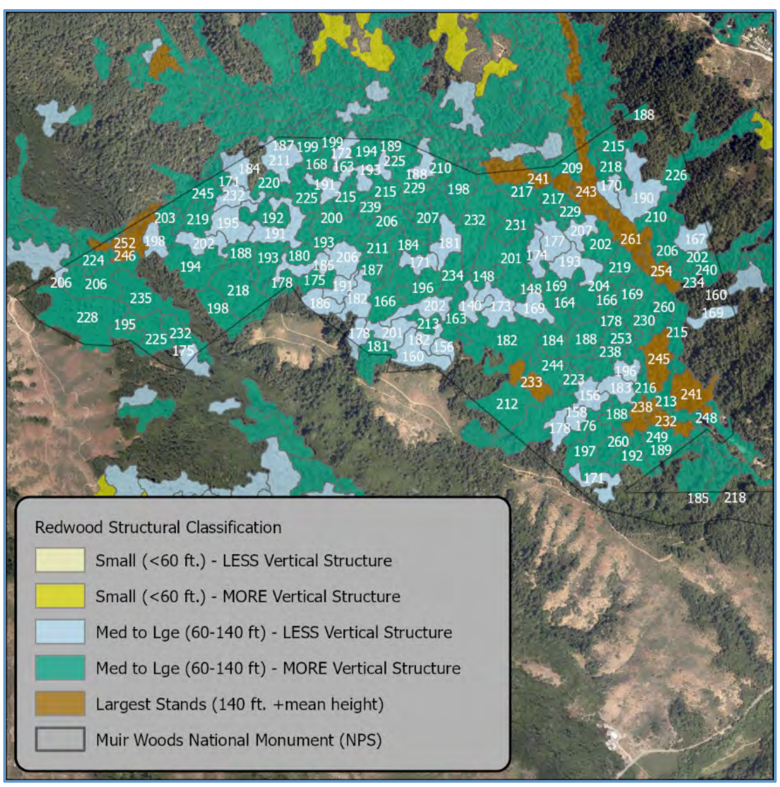


Figure 6.11. Muir Woods National Monument, Coast Redwood structural classification overlaid with maximum lidar-derived stand height values for each stand shown in white text.



Other areas flagged by local experts as retaining large-diameter tall trees and stands indicative of old-growth Coast Redwood conditions include Carson Falls area (Marin Water), Samuel P. Taylor State Park, Roy's Redwoods Open Space Preserve (Marin County Parks), and Steep Ravine (Mt. Tamalpais State Park). Interestingly, while not all Coast Redwood stands mapped in these areas were classified as structurally the largest or most vertically complex, many of these stands include maximum (as compared to mean) lidar-derived stand heights greater than 210 feet, representing the maximum height of the tallest tree within a given stand, making them among the stands with the tallest trees relative to the rest of Marin County (Figures 6.11, 6.12, 6.13).

Figure 6.12. Potential old-growth Coast Redwood in Marin based on local knowledge include Carson Falls (top left), Samuel P. Taylor State Park (top right), Roy's Redwoods (bottom left), and Steep Ravine (bottom right). Coast Redwood structural classification overlaid with maximum lidar-derived stand height values for each stand shown in white text.

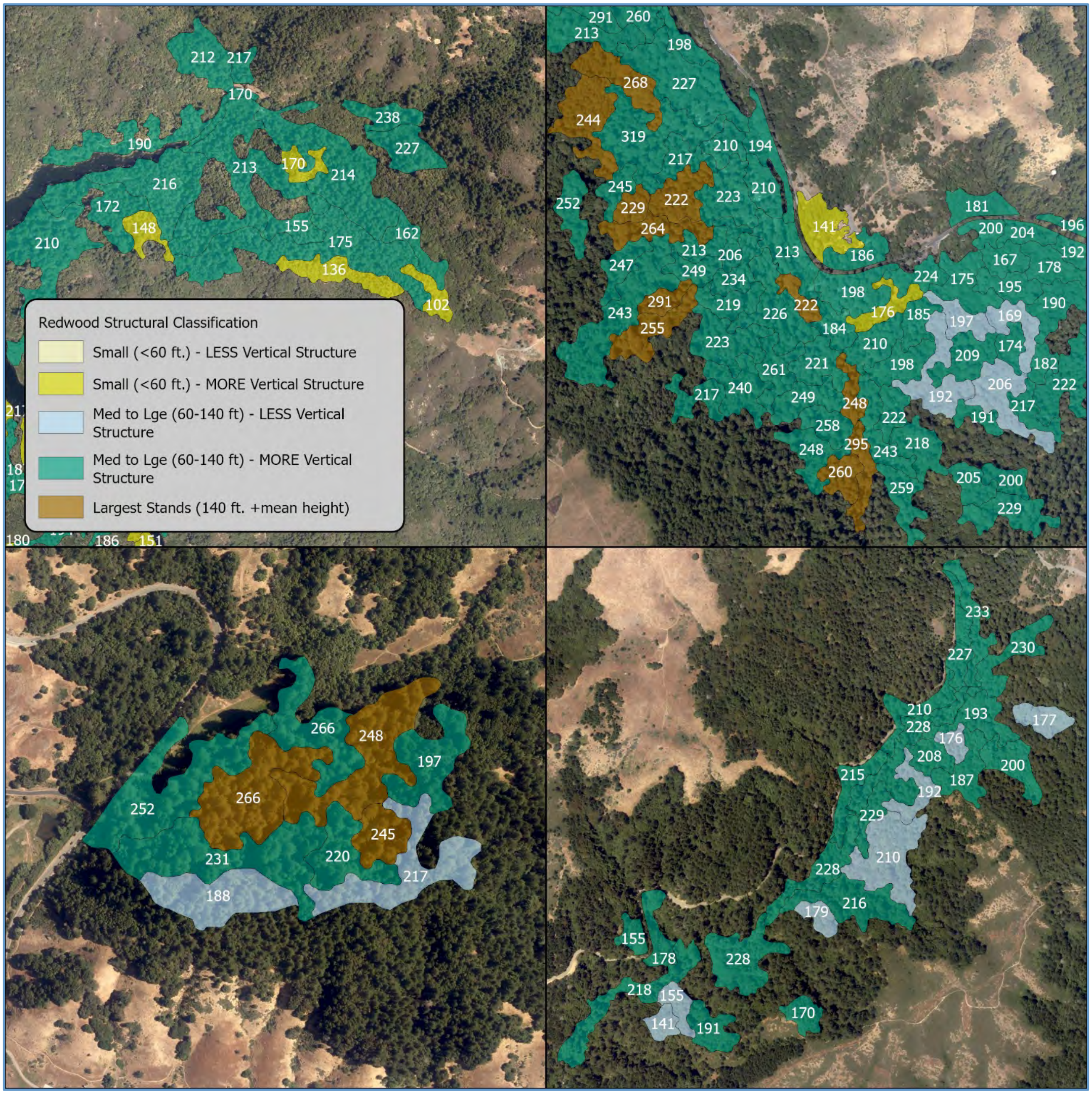
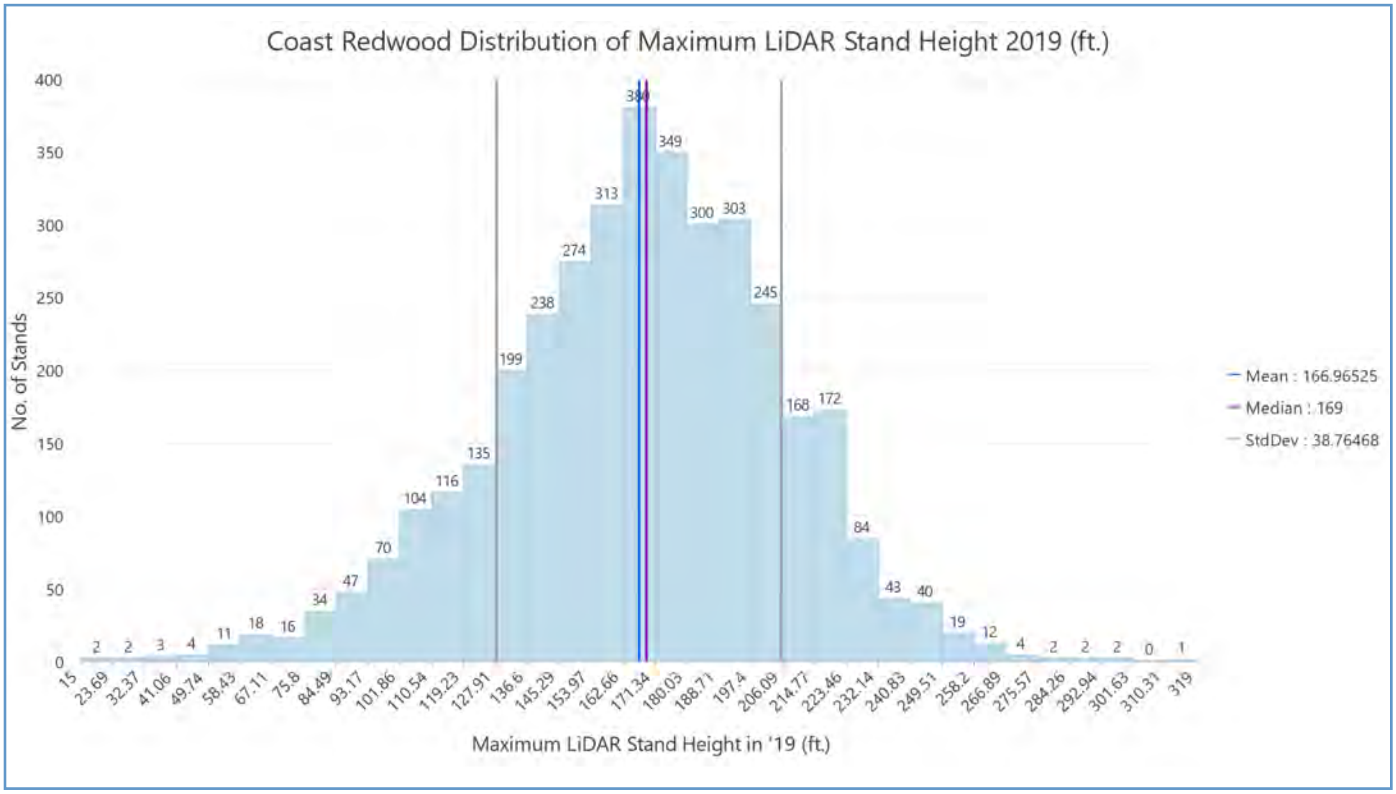


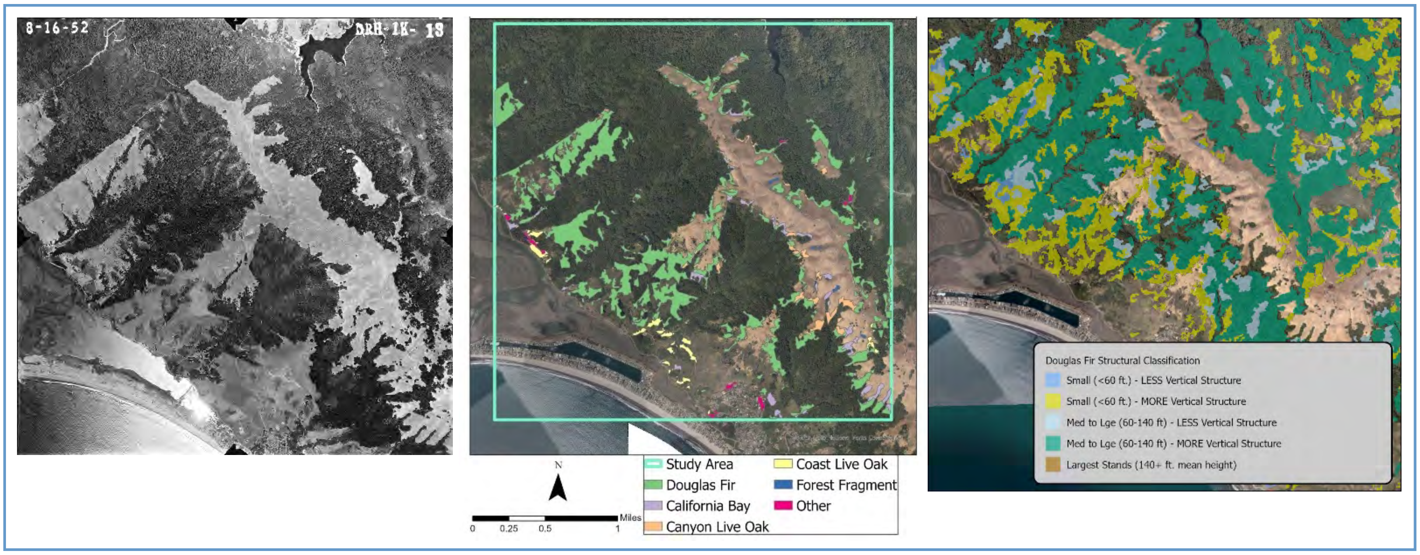
Figure 6.13. Distribution of Coast Redwood maximum lidar-derived stand height in Marin County (2019).



DOUGLAS-FIR DISCUSSION

As a result of fire exclusion, Douglas-fir encroachment and conversion of grassland and oak woodland habitat in Marin County have been widely observed by land managers, which increases homogeneity on the landscape, thereby reducing biodiversity over time (Cocking et al., 2015). Analysis of woody plant encroachment in Marin County using historical aerial imagery from 1952 compared to 2018 found that 485 acres of grassland were replaced by woodland within the 4,745-acre study area, and that Douglas-fir encroachment accounted for 81% of that conversion (Figure 6.14; Startin, 2022). While Douglas-fir forest remains an important part of the mosaic of forest types within Marin County, and the lidar-derived structural classification provides insight into the distribution of tall and structurally complex stands, it also can be used to identify shorter stands that may be considered a threat to grasslands, Open Canopy Oak Woodlands, and other key habitats in the absence of fire.

Figure 6.11. West Ridgecrest Blvd., Bolinas Ridge intersection with Mount Tamalpais, from left to right: 1952 aerial imagery (left; [Startin, 2022]), woodland that replaced grassland 1952-2018 (center; [Startin, 2022]), Douglas-fir structural classification (right).



BISHOP PINE STRUCTURAL CLASSIFICATION

This metric mapped structural classes for Bishop Pine based on lidar-derived canopy cover, lidar-derived canopy gap information, mapping of standing dead trees (see Canopy Mortality and Canopy Gaps sections below), relative conifer cover, and fire history. Presence within the 1995 Vision Fire footprint was used to determine late-seral versus mid-seral status. Mortality and canopy gaps were used to further divide both mid-seral and late-seral classes. Canopy cover and relative conifer cover were used to further divide the late-seral stands into more detailed structural classes (Figures 6.15 and 6.16).

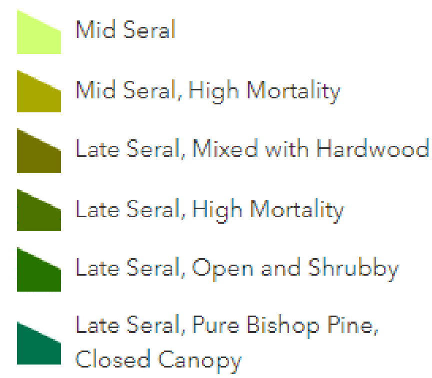
INTERPRETATION

Bishop Pine forests are characterized by stand-replacing fire regimes, as a result, they regenerate in even-aged cohorts that proceed through distinct seral stages (Figure 6.17). Because the most recent stand-replacing fire in Marin Bishop Pine was the 1995 Vision Fire, only two of these seral stages exist in Marin County: mid-seral (originating from the Vision Fire) and late-seral or old-growth (Harvey & Agne, 2021).

Mid-seral stands, generally composed of dense Bishop pine trees, are divided into two classes: mid-seral and mid-seral with high mortality, to help track the spread of pitch pine canker disease. Late-seral stands, which can range from mixed shrub, mixed hardwood, to pure Bishop pine, are classified by stand composition. A high mortality class is also included for late-seral stands.

Metric Classes

Figure 6.12. Bishop Pine structural classification.



- **Mid Seral**: Within 1995 Vision Fire footprint. Mortality as determined by canopy gaps and standing dead less than 15%.
- **Mid Seral, High Mortality:** Within 1995 Vision Fire footprint. Mortality as determined by canopy gaps and canopy standing dead greater than 15%.
- **Late Seral, Mixed with Hardwood**: Not within 1995 Vision Fire footprint. Mortality as determined by canopy gaps and standing dead less than 20%. Absolute canopy cover greater than 70% and relative conifer cover less than 80%.
- **Late Seral, High Mortality:** Not within 1995 Vision Fire footprint. Mortality as determined by canopy gaps and canopy standing dead greater than 20%.
- **Late Seral, Open and Shrubby:** Not within 1995 Vision Fire footprint. Mortality as determined by canopy gaps and standing dead less than 20%. Absolute canopy cover less than 70%.
- **Late Seral, Pure Bishop Pine, Closed Canopy:** Not within 1995 Vision Fire footprint. Mortality as determined by canopy gaps and standing dead less than 20%. Absolute canopy cover greater than 70% and relative conifer cover greater than 80%.

Figure 6.14 .Workflow diagram, Bishop Pine structural classification.

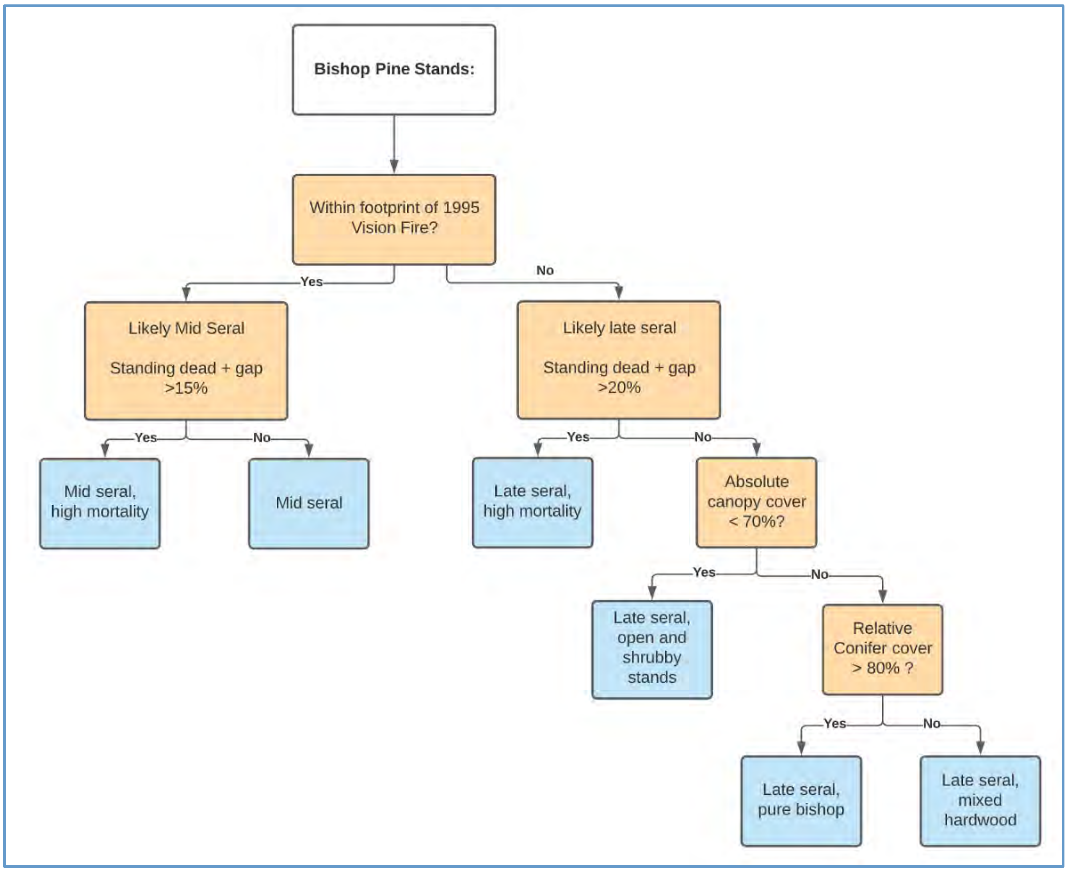
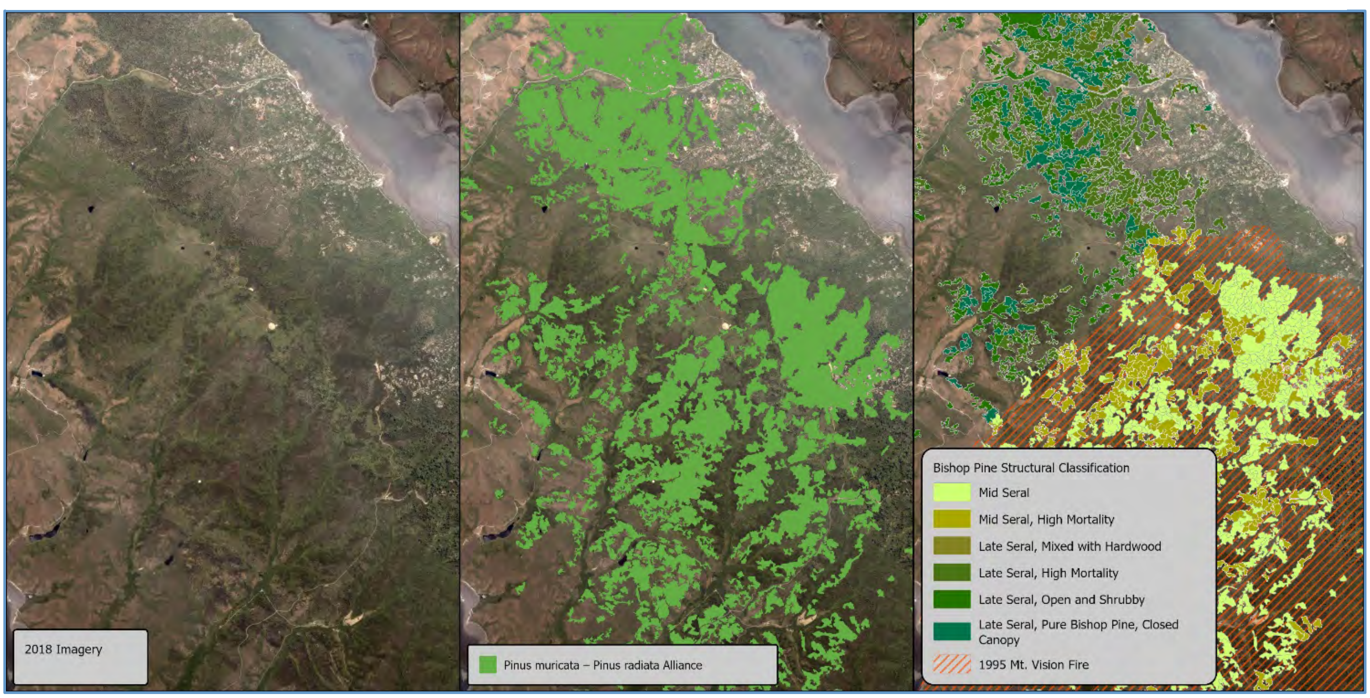


Figure 6.13. Tomales Bay area, from left to right: 2018 aerial imagery (left), 2018 Fine Scale Vegetation Map Bishop Pine Alliance (center), Bishop Pine structural classification (right).



SARGENT CYPRESS STRUCTURAL CLASSIFICATION

This metric uses mean lidar-derived stand height to classify the 138 Sargent Cypress stands in Marin County into two classes. Soil type is then used to divide these into four total classes, described below (Figures 6.18, 6.19). Unlike for Bishop Pine, fire history for Sargent Cypress was not an obvious predictor of stand height or density; rather, soil substrate was a better correlate for stand structure.

INTERPRETATION

There are two distinct populations of Sargent Cypress in Marin County: the stands on San Geronimo Ridge, which occur on serpentinite, and a smaller population on Mt. Tamalpais (generally taller) on a mix of different soils, though none on serpentinite according to the Marin County soil survey (Figure 6.20; SSURGO, 2021). Soil data is included as a layer in the Forest Health Web Map.

Metric Classes

- **Taller, non-Serpentinite**: mean stand height greater than or equal to 20 feet, stand does not intersect a soil polygon with a taxonomic class of Clayey-skeletal, serpentinitic, thermic Lithic Argixerolls.
- **Shorter, non-Serpentinite**: mean stand height less than 20 feet, stand does not intersect a soil polygon with a taxonomic class of Clayey-skeletal, serpentinitic, thermic Lithic Argixerolls.
- **Taller, Serpentinite**: mean stand height greater than or equal to 20 feet, stand intersects (or is very close to) a soil polygon with a taxonomic class of Clayey-skeletal, serpentinitic, thermic Lithic Argixerolls.
- **Shorter, Serpentinite**: mean stand height less than 20 feet, stand intersects (or is very close to) a soil polygon with a taxonomic class of Clayey-skeletal, serpentinitic, thermic Lithic Argixerolls.

Figure 6.18. Sargent Cypress structural classification.

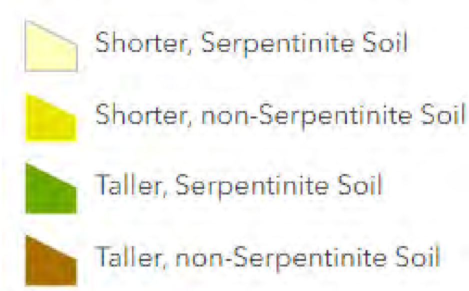


Figure 6.15. Workflow diagram, Sargent Cypress structural classification.

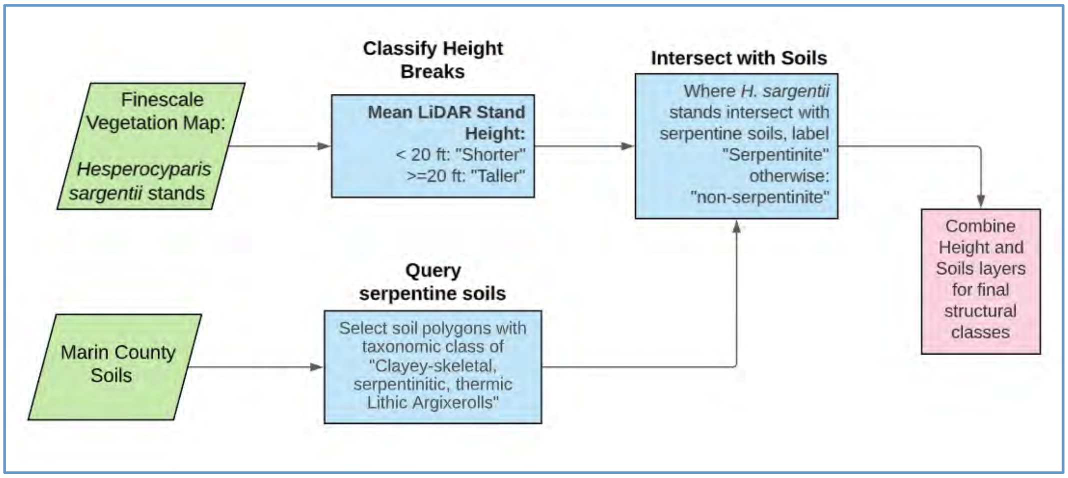
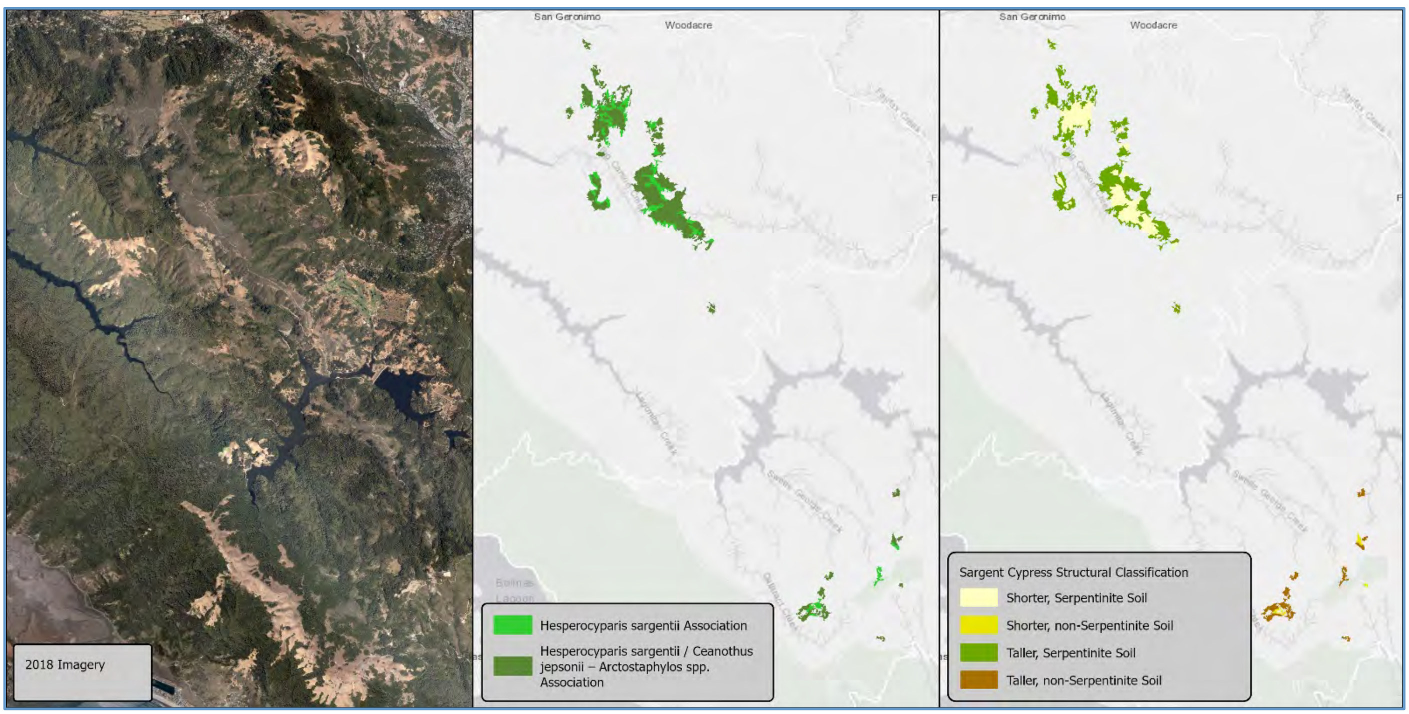


Figure 6.20. Sargent Cypress populations, from left to right: 2018 aerial imagery (left), 2018 Fine Scale Vegetation Map Sargent Cypress Associations (center), Sargent Cypress structural classification (right).



OPEN CANOPY OAK WOODLAND STANDS THREATENED WITH OR CONVERTING TO CONIFER FOREST

In California and throughout the west coast of North America, many areas of oak woodland are converting to Douglas-fir forests. This conversion stems from fire exclusion and other changes in land use and land management (Cocking et al., 2015). This metric uses relative conifer cover and proximity to conifer stands data from the 2018 Fine Scale Vegetation Map to create two classes, actively converting to conifer forest or threatened with conversion to conifer forest (Figure 6.21).[4]

INTERPRETATION

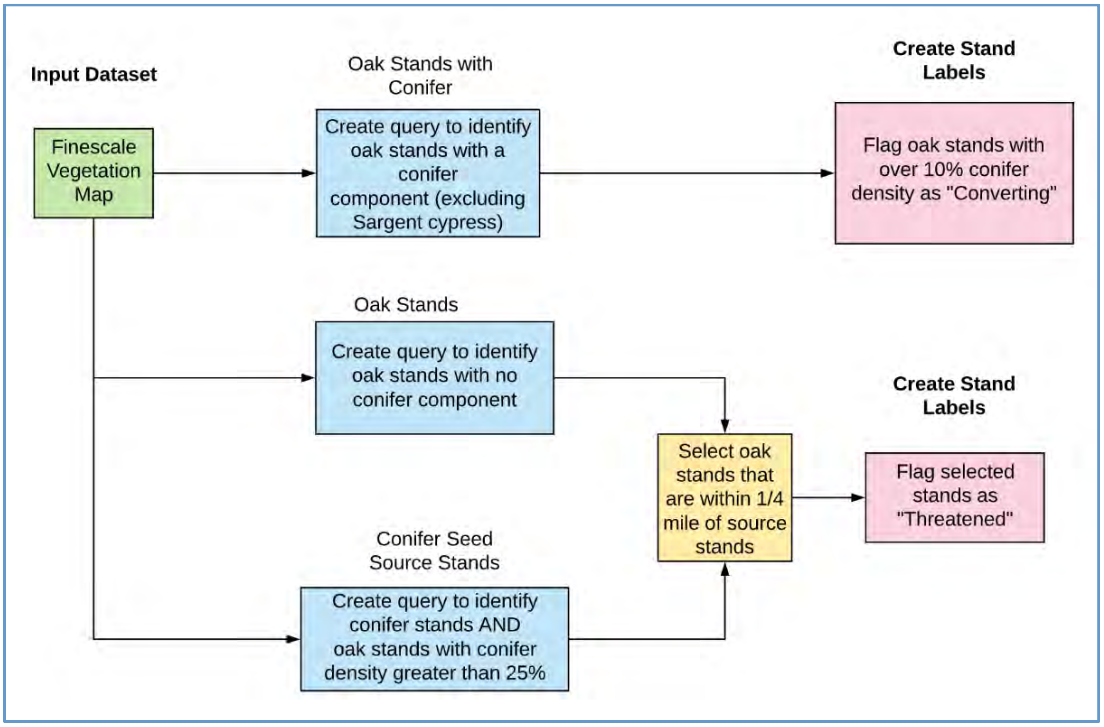
This metric identifies Open Canopy Oak Woodland stands mapped in the 2018 Fine Scale Vegetation Map that may be either threatened with conversion or actively in the process of converting to Douglas-fir forest (Figure 6.22)[5]. Open Canopy Oak Woodland alliances are described in the *2016 Peak Health Report* (Edson et al., 2016) and generally defined as alliances dominated by oak (*Quercus sp.)* that form open (rather than closed) stands ranging from 10% to 60% canopy cover (Sawyer et al., 2009). Development of this metric as part of the *Forest Health Strategy* did not use canopy closure to filter stands of these alliances; however, the shrublike oak alliances in the 2018 Fine Scale Vegetation Map, namely *Q. durata* (leather oak) Alliance and *Q. wislizeni* (interior live oak) – *Q. chrysolepis* (canyon live oak) (shrub) Alliance, were excluded from this metric and subsequent analysis.

All Open Canopy Oak Woodland forest stands with greater than or equal to 10% relative conifer cover were flagged as actively converting to conifer forest. Open Canopy Oak Woodland stands within 0.25 miles of any 2018 Fine Scale Vegetation Map stand with greater than 25%

[4] In Marin County Douglas-fir is the conifer species most observed by land managers as encroaching on oak woodland. Coast redwood is included in this analysis because it often co-dominates with Douglas-fir. Other conifer species, such as Monterey pine and Monterey cypress, have limited distribution relative to Douglas-fir but are also included in this metric analysis. The Forest Health Web Map refers to Douglas-fir because it is the type most associated with type conversion and habitat loss, though all conifers (except Sargent cypress) are included.

[5] The percent relative conifer attribution in the 2018 Fine Scale Vegetation Map can be used to assess conifer encroachment for other hardwood forest types such as madrone and tanoak. Note that this approach would not distinguish between different conifer species.

Figure 6.21. Workflow diagram, Open Canopy Oak Woodland threatened with or converting to conifer forest metric.



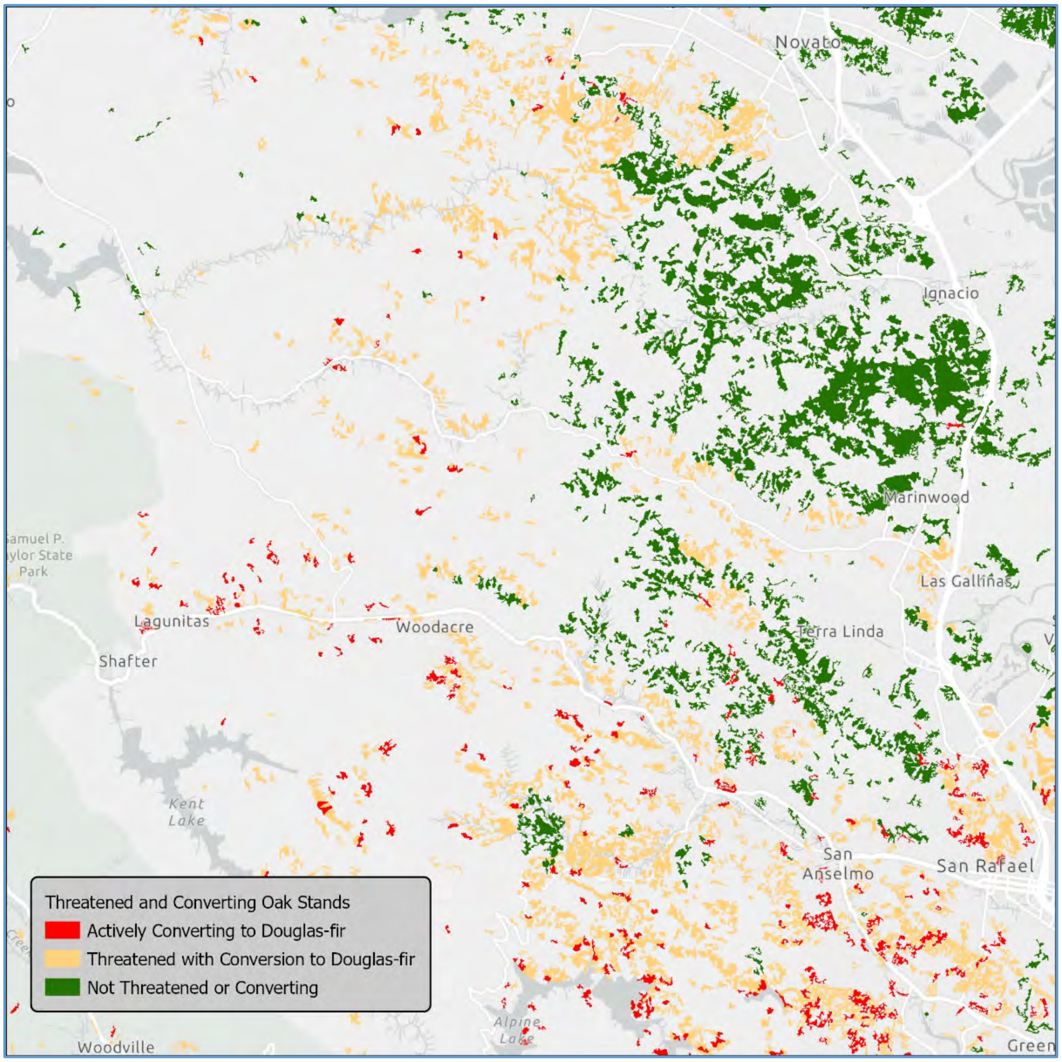
conifer cover were flagged as threatened with conversion[6]. Both queries included Douglas-fir and non-native conifer stands of Monterey pine (*Pinus radiata*) and Monterey cypress (*Hesperocyparis macrocarpa*), however Sargent Cypress stands are not included because they are not likely to encroach on oak stands.

Metric Classes

- **Actively Converting to Douglas-fir** (or any other conifer species except Sargent cypress): Oak stands with greater than or equal to 10% relative conifer cover.
- **Threatened with Conversion to Douglas-fir** (or any other conifer species except Sargent cypress): Open Canopy Oak Woodland stands within 0.25 miles of any 2018 Fine Scale Vegetation Map polygon stand (excluding Sargent cypress) with a relative conifer cover of greater than or equal to 25%.

[6] Douglas-fir encroachment is observably driven by expansion of existing stands. The 0.25-mile distance was selected as an inclusive value for the intended use of this metric, which is flagging stands "at-risk" of Douglas-fir conversion that warrant field investigation, monitoring, and potential management before onset of active type conversion. From Hermann and Lavender (1990, p.532): "Although reports of fully stocked stands resulting from seedfall from sources 1 to 2 km (0.6 to 1.2 mi) distant are not rare, the great majority of Douglas-fir seeds fall within 100 m (330 ft) of a seed tree or stand edge."

Figure 6.16. Open Canopy Oak Woodland alliances threatened with or converting to conifer forest.



PERCENT CANOPY MORTALITY (CANOPY STANDING DEAD)

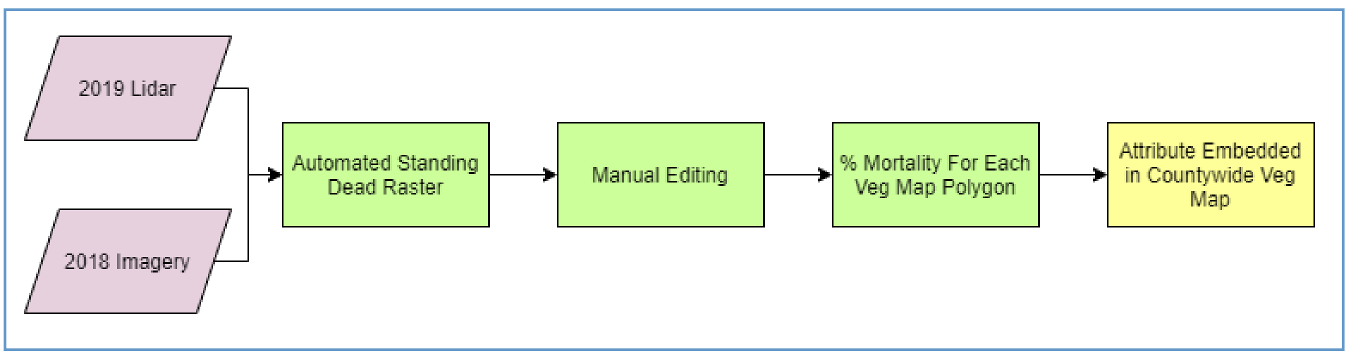
Tree mortality is an increasingly important component of Marin County's forest dynamics: pathogens such as those that cause sudden oak death and pitch pine canker have resulted in widespread mortality, and drought stress has the potential to weaken and kill trees (Allen et al., 2015). The ability to map areas of mortality is an essential tool for assessing the health of key forest types across Marin (see Chapter 7: Condition Assessment) as well as establishing baseline conditions for identifying patterns, trends, or changes in forest mortality.

Countywide canopy mortality, also referred to as canopy standing dead, represents areas where dead trees are still standing and part of the canopy, as compared to canopy gaps, which is where trees have fallen (see Canopy Gaps section below). Canopy mortality was mapped using semi-automated techniques that combine automated object-based image analysis with manual photointerpretation. Standing dead areas were initially identified using object-based image analysis of the 2018 high-resolution countywide imagery (Quantum Spatial, 2018). This analysis resulted in a 1-meter raster of "living v. dead" areas. This raster was then used to assign a percentage of dead canopy for each forested stand in the 2018 Fine Scale Vegetation Map. The percent dead attribute was then manually reviewed and edited up or down based on expert image interpretation, adjusting the attribute upward where automated techniques underestimated standing dead area and adjusting the attribute downward where automated techniques overestimated standing dead area. The final percent mortality is then assigned to each 2018 Fine Scale Vegetation Map polygon in the attribute field "Field Name = STANDING_DEAD_19/Field Alias=% Standing Dead 2019" (Table 6.5, Figure 6.23).

Table 6.5. 2018 Fine Scale Vegetation Map attributes for Standing Dead 2019.

STANDING_DEAD_19/% Standing Dead 2019	Estimate of percent standing dead vegetation in forested stands. Estimates the percent of the woody canopy > 7 feet tall that did not have a living crown in late 2018/early 2019.

Figure 6.17. Workflow diagram, percent canopy standing dead (% tree mortality) attribution.



Additional parameters used for creating the mortality or standing dead data product include:

- Standing dead/ mortality was applied to woody vegetation greater than or equal to 7 feet in height (2019 lidar).

- Standing dead areas included entire tree crowns and parts of tree crowns that had died back.
- All 2018 Fine Scale Vegetation Map polygons, except for polygons mapped as developed land uses and water, were analyzed and labeled with a percent of the polygon that was standing dead.
- The percent mortality number was calculated by the area of the polygon over 7 feet in height that was dead, divided by the total area of the polygon over 7 feet in height.
- Living v. dead was defined by the presence of green leaves as viewed from above in the June 2018 high resolution imagery.
- It was assumed that some errors would occur; for example, areas mapped as dead could be fire or insect-affected trees that could potentially regrow leaves after 2018.

INTERPRETATION

Canopy mortality, especially when taken in combination with canopy gaps (see next section), can be an indicator of forest decline from factors such as pathogens, drought stress, and age. Users should note this metric has several limitations. It does not provide species-specific mortality information; for example, in a stand with 50% mortality labeled *Sequoia sempervirens* Alliance in the 2018 Fine Scale Vegetation Map, the actual species of the dead trees may be some mix of hardwood tree types rather than *Sequoia sempervirens*. Another data limitation is there is no distinction made between 0% mortality and trace mortality between 0.1% and 0.5%; therefore, stands with mortality present but at less than 0.5% are labeled as "no mortality". Thus, false negatives are likely to occur in the map, particularly in the 0.5% to 1% range.

For the purposes of the Forest Condition Assessment, standing dead attribution was divided into 3 classes based on the distribution of values across the data (Figure 6.24, 6.25). As the histogram in Figure 6.26 shows, few polygons had greater than 2.5% standing dead making this a useful cutoff for the highest mortality classification.

Metric Classes

- **No mortality or less than 0.5%** of Canopy has Standing Dead.
- **0.5% – 2.5%** of Canopy has Standing Dead.
- **Greater than 2.5%** of Canopy has Standing Dead.

Figure 6.24. Percent canopy standing dead (% tree mortality) classification.

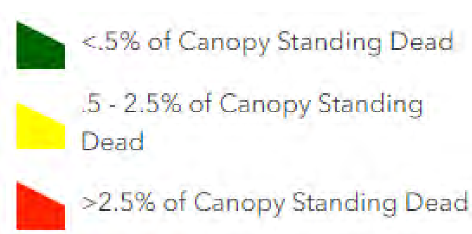
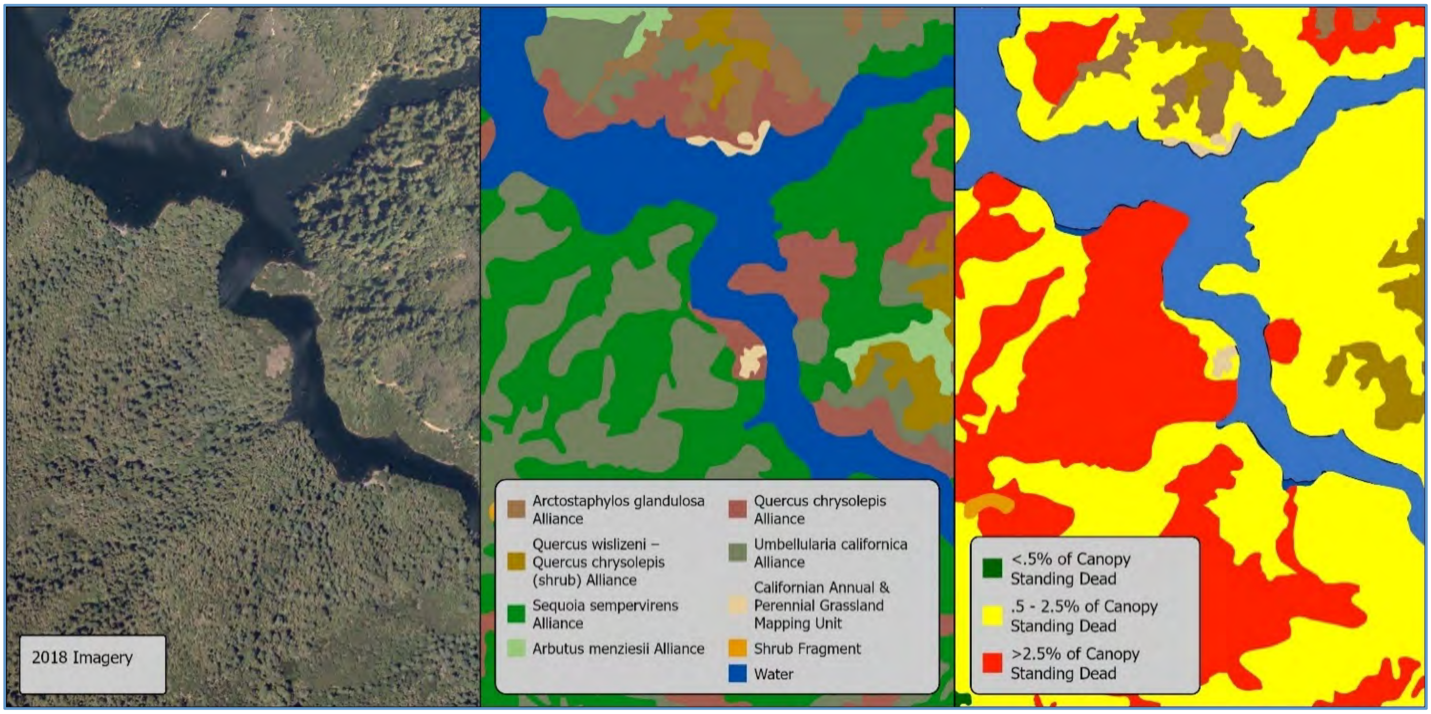
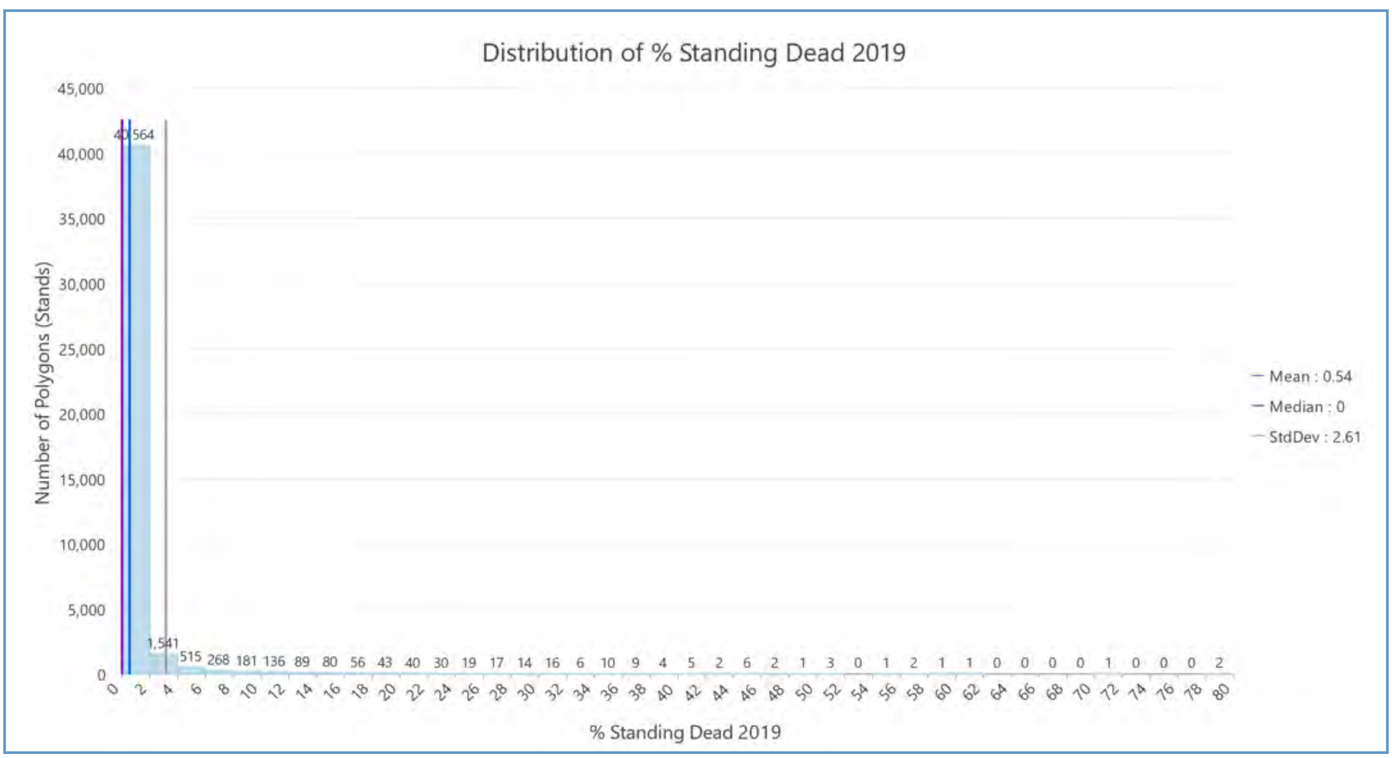


Figure 6.19. Kent Lake, from left to right: 2018 4-band 6-inch aerial imagery (left), 2018 Fine Scale Vegetation Map (center), 2018 classified percent canopy standing dead (right).*



** In the percent canopy standing dead figure on the right, brown polygons representing shrub and grassland vegetation classes from the 2018 Fine Scale Vegetation Map are visible. They are not covered by the percent canopy standing dead layer because mortality mapping was completed only for forested stands.*

Figure 6.18. Distribution of percent standing dead attribution (2019), 2018 Fine Scale Vegetation Map.



CANOPY GAPS

In Marin County, two complete countywide lidar datasets exist, one collected in late-spring of 2010 and one collected mid-winter of 2019. Therefore, in addition, to mapping visible mortality to locate decline, disease, and/or pathogen dynamics in forested stands, the 2018 Fine Scale Vegetation Map and foundational data provided the opportunity to locate and quantify "gaps" that had formed between 2010 and 2019 within forested stands. Although canopy gaps play important roles in forest ecology and are generally considered to enhance biodiversity (Muscolo et al., 2014), the presence of canopy gaps can be an indication of decline or disease, especially when combined with the canopy mortality/standing dead attribution described above. Canopy gap analysis was conducted using Canopy Height Model (CHM) differencing. Analysts calculated the difference between the CHM value in 2019 minus the CHM value in 2010. This analysis was performed in Trimble® eCognition®, and lidar CHM differencing was followed by noise removal to remove anomalous gaps. Very small gaps (less than 40 square feet) were also removed to reduce noise in the gap analysis. The resulting canopy gaps were reviewed by photo-interpretation analysts, who removed false positive gaps along the coast and in urban areas (Figure 6.27).

Areas were considered a canopy gap if their canopy height changed in any one of the following ways between 2010 and 2019 at the 1-meter raster scale:

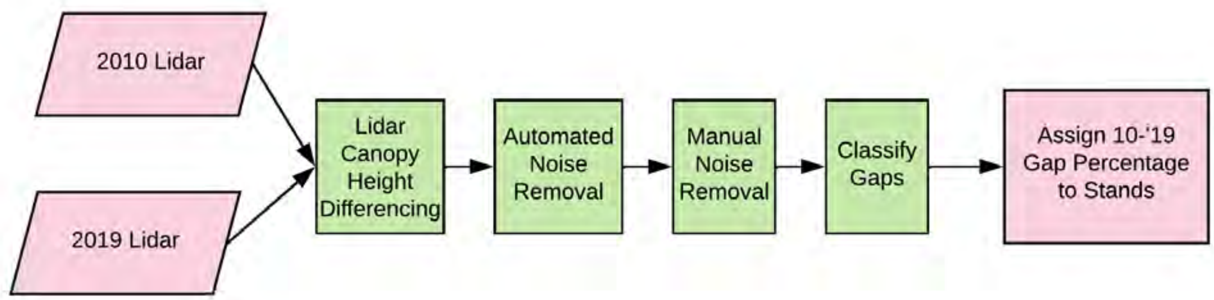
- **Low Gap**: Areas greater than or equal to 7 feet in height in 2010 and less than 2 feet in 2019 that lost more than 7 feet of canopy height between 2010 and 2019.
- **Medium Gap**: Areas greater than or equal to 12 feet in height in 2010 and less than 7 feet in height in 2019.
- **High Gap**: Areas greater than or equal to 15 feet in height in 2010 that lost greater than 40% of their total height between 2010 and 2019.
- **Very High Gap**: Areas greater than or equal to 100 feet in height in 2010 that lost greater than 25% of their total height between 2010 and 2019.

The final canopy gap dataset was integrated into the 2018 Fine Scale Vegetation Map (Table 6.6). Each forested stand in the 2018 Fine Scale Vegetation Map was assigned an attribute indicating the percent of its woody canopy over 7 feet in height in 2010 that was determined to be a gap in 2019, quantifying the percent of canopy gap formed between 2010 and 2019 (Field Name = CANOPY_GAP_10_19/%). A second attribute in the 2018 Fine Scale Vegetation Map provides information for each forested stand's largest contiguous gap and the size in square feet (Field Name = LARGEST_GAP_10_19).

Table 6.6. Fine Scale Vegetation Map attributes for Canopy Gaps formed between 2010 and 2019.

CANOPY_GAP_10_19/% Canopy Gap formed '10- '19	% of stand that is a canopy gap that formed between 2010 and 2019.
LARGEST_GAP_10_19/Sq. Feet of Largest '10-'19 Gap	Largest canopy gap that formed between 2010 and 2019 in square feet.

Figure 6.20. Workflow diagram, canopy gaps formed between 2010 and 2019.



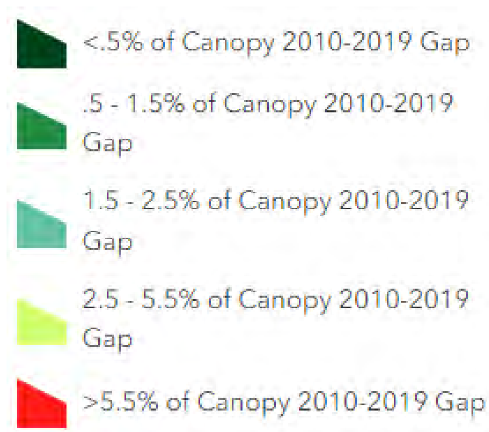
INTERPRETATION

It is important to note that the presence of gaps alone should not be interpreted as confirmation of degraded forest conditions or decline due to drought, pathogens, or disease. For example, gaps could be caused by limbing and/or clearing under powerlines, or tree removal associated with building homes or infrastructure. Gaps also contribute to forest biodiversity in many cases. Using canopy gap information in combination with other data such as canopy mortality, canopy density change, or proximity to infrastructure would offer greater insight as to the cause or significance of gap formation in relation to impacts from pathogens, drought, or other stressors.

In Figure 6.29, 2010 National Agriculture Imagery Program (NAIP; EROS Center, 2018) imagery shows areas of visible tree mortality near Olema Creek on the west side of Bolinas Ridge, an area mapped as Coast Redwood in the 2018 Fine Scale Vegetation Map. Lidar differencing between the 2010 and 2019 canopy height models detected gaps formed in the canopy from natural or human removal of standing dead trees, classified into 5 classes (center) developed based on distribution of values in the data (see Figure 6.30).

For the purposes of the Forest Condition Assessment, canopy gap attribution was divided into 5 classes based on the distribution of values across the data (Figure 6.28). As Figure 6.30 shows, few stands had greater than 5.5% standing dead making this a useful cutoff for the highest mortality classification.

Figure 6.28. Percent canopy gap formed 2010-2019 classification.



Metric Classes

- **Less than 0.5%** of stand is a canopy gap formed between 2010 and 2019.
- **0.5% – 1.5%** of stand is a canopy gap.
- **1.5%-2.5%** of stand is a canopy gap.
- **2.5% -5.5%** of stand is a canopy gap.
- **Greater than 5.5%** of stand is a canopy gap.

Figure 6.21. Bolinas Ridge, from left to right: 2010 NAIP imagery (left), canopy gap classification (center), 2018 imagery (right).

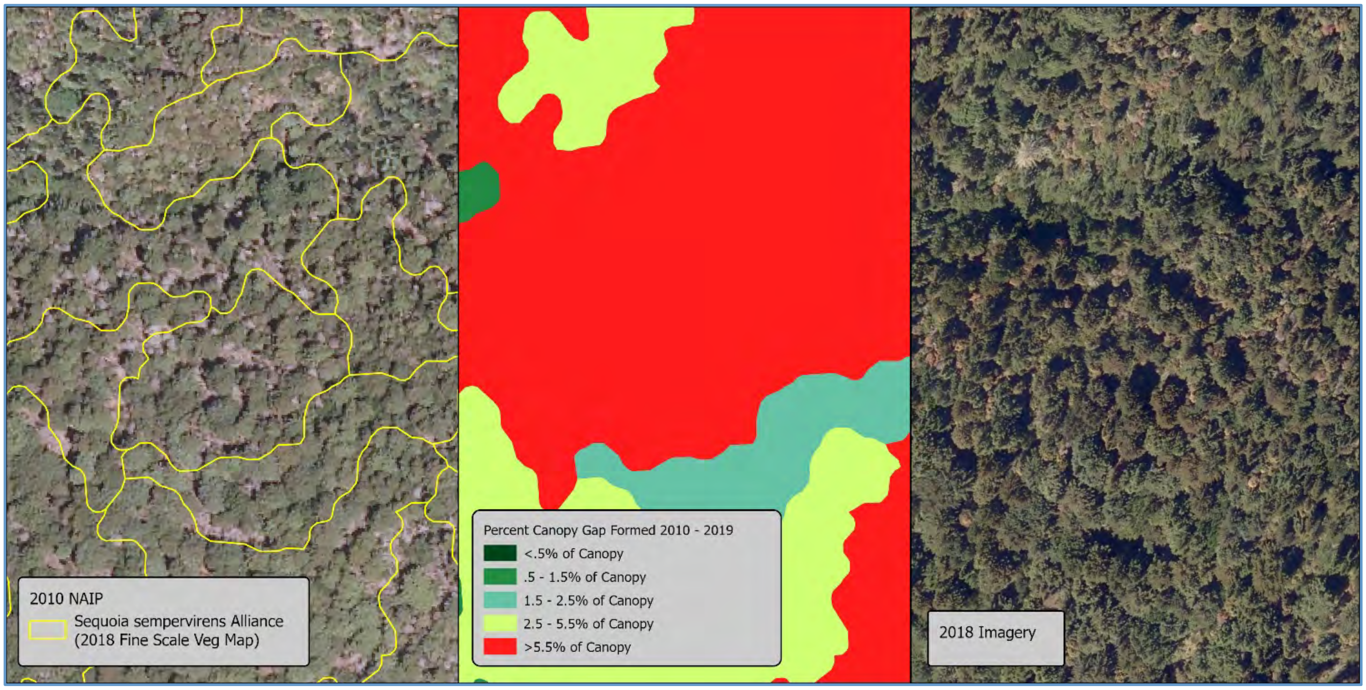
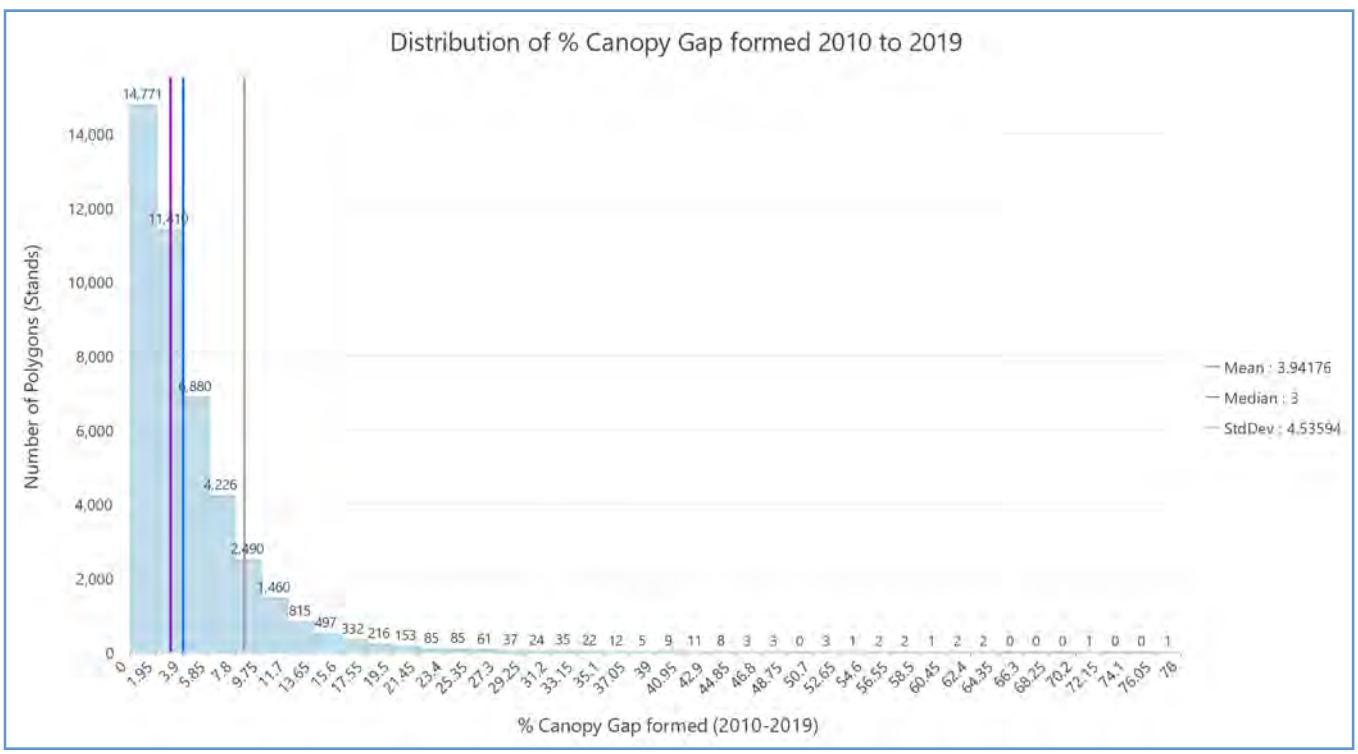


Figure 6.30. Distribution of canopy gap attribution, 2018 Fine Scale Vegetation Map.



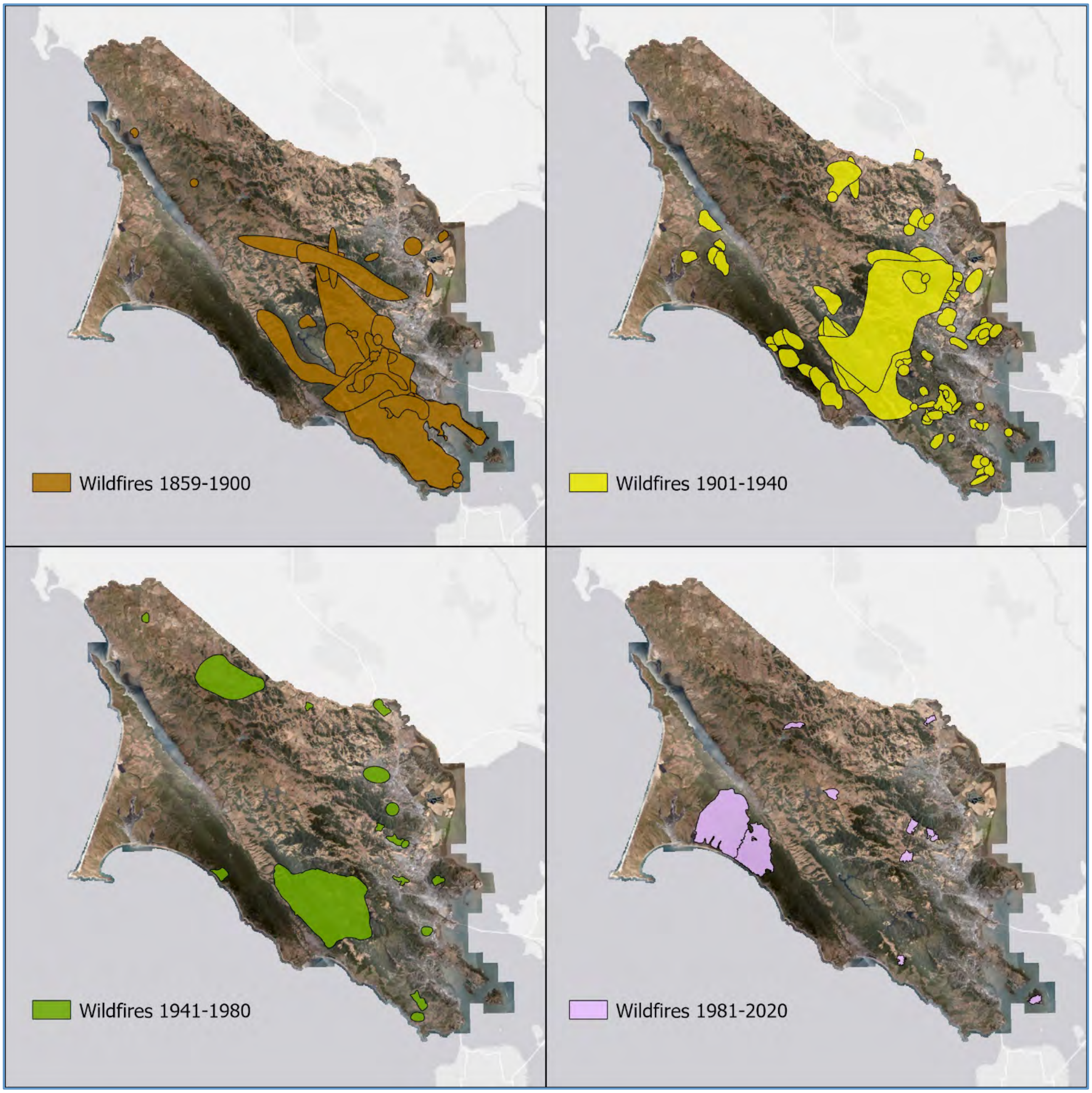
FIRE HISTORY

Given the significant role of fire in the ecological function of Marin's forests, fire history information is critical for assessing current forest conditions. In 2020, the Marin County Fire Department released an updated *Marin Community Wildfire Protection Plan* that indicated the fire history for Marin is incomplete (Lavezzo et al., 2020). As part of the *Forest Health Strategy*, the Marin Forest Health Strategy Working Group partnered with historical ecologist Arthur Dawson to improve understanding of Marin's fire history. By combining existing records with additional research, Dawson's work documented and spatially located historical fires over a longer period and to a higher degree of geographical and temporal precision than in previous fire mapping projects (Dawson, 2021). Dawson's *Marin County Wildfire History Mapping Project* used GIS to map all fires in Marin County between 1859 and 2020 which were greater than 160 acres in size. For details on methods and findings see Appendix B: Wildfire History.

INTERPRETATION

Dawson (2021) developed GIS polygons representing wildfire perimeters for four eras dating to 1859 (Figure 6.31). It is important to note that Dawson's spatial reconstruction of Marin's fire history does not include undocumented fires or pre-1930 wildfires less than 160 acres in size. The accuracy of pre-1940 fire perimeters is much lower than that of more recent fires. Dawson's polygons (Dawson, 2021) were used to develop three metrics, which were then grouped into classes to support the Forest Condition Assessment. The number of times burned from 1859 – 2020 metric results were grouped into five classes (Figure 6.32). The same polygons were intersected with native forest stands from the 2018 Fine Scale Vegetation Map to develop GIS layers depicting early fire return interval for forested stands from 1859-1940, which is pre-Mt. Tam Fire Lookout construction. Results from this analysis were then divided into five classes (Figure 6.33). The time since last fire metric also intersected fire perimeter polygons with native forest stands, the results were grouped into seven classes (Figure 6.34). More detailed information can be viewed in the Forest Health Web Map.

Figure 6.22. Recorded fires in Marin County, 1859-2020 (Dawson, 2021).

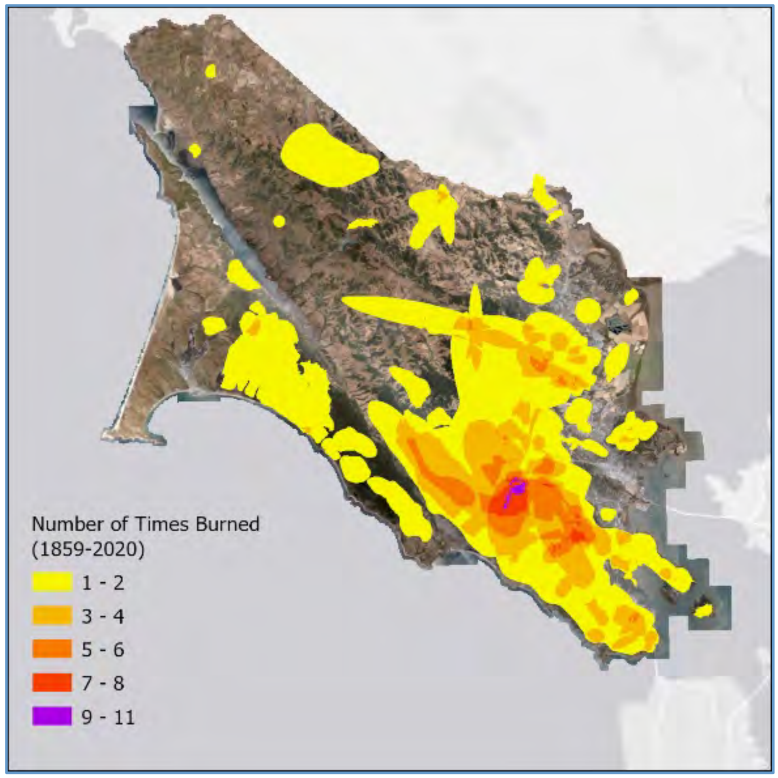


Metric Classes

Metric Classes for Number of Times Burned (1859-2020)

- Burned 1-2 times.
- Burned 3-4 times.
- Burned 5-6 times.
- Burned 7-8 times.
- Burned 9-11 times.

Figure 6.32. Number of Times Burned (1859-2020).



Metric Classes for Fire Return Interval 1859-1940 (Native Forest)

- Fire Return Interval (FRI) 5 -15 years.
- FRI 15 - 30 years.
- FRI 30 - 45 years.
- FRI greater than 45 years.
- No Recorded 1859-1940 fires.

Figure 6.33. Fire return interval in native forests (1859 – 1940).

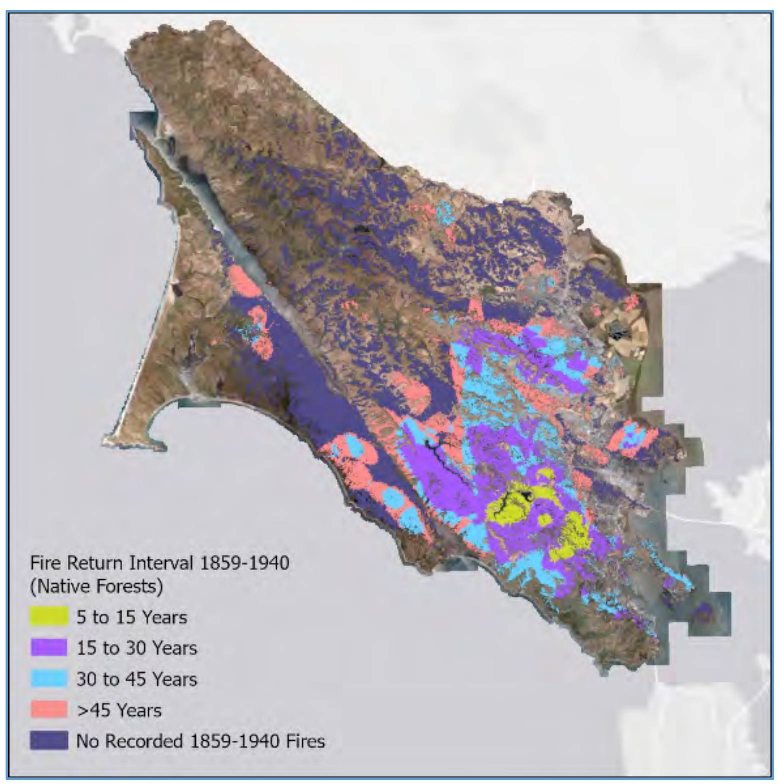
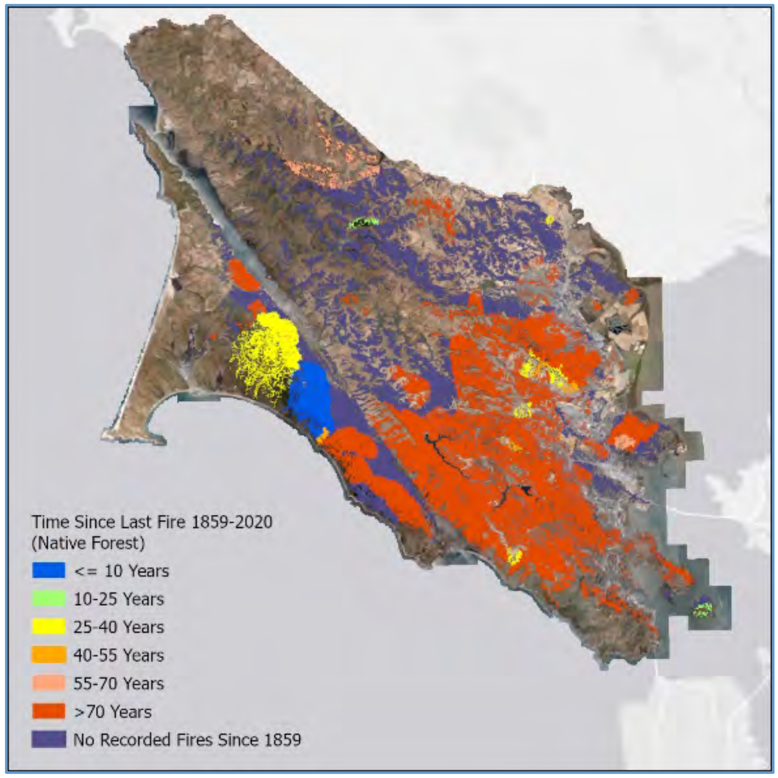


Figure 6.34. Time since last fire in native forests (1859 – 2020).



Metric Classes for Time Since Last Fire 1859-2020 (Native Forest)

- Time less than or equal to 10 years.
- 10-25 years.
- 25-40 years.
- 40-55 years.
- 55-70 years.
- Greater than 70 years.

CLASSIFIED LADDER FUELS

Managers have long understood that, in certain conditions, ladder fuels play a role in moving fire from the forest surface into the tree canopy and have targeted ladder fuels in hazardous fuel reduction treatments. Green et al. (2020) mapped woody canopy damage after the 2017 Sonoma Complex Fire and found that lidar-derived measurements of ladder fuels mapped pre-2017 Sonoma Complex Fire were among the landcover variables most associated with canopy-burn severity, with larger amounts of mapped ladder fuels correlating with higher canopy-burn severity. Research by Kramer et al. (2014, 2016) demonstrates that lidar can be a reliable tool for quantifying ladder fuels in forested areas.

Ladder fuels were mapped in Marin County by using the 2019 lidar to calculate the density of vegetation (or other matter) between 3 feet and 12 feet (1 and 4 meters) above the ground surface. Lidar was used to derive a 64-foot pixel-sized raster depicting the number of lidar returns between 1 and 4 meters from the ground surface divided by the total number of returns below 4 meters from the ground surface. Each pixel in the resulting raster receives a value between 0 and 1, representing the percentage of lidar returns within the 1- 4 meter stratum, or density of ladder fuels (Figure 6.36, center). Lidar-derived ladder fuel density (expressed as a decimal value between 0-1) was assigned to each forested stand (polygon) in the 2018 Fine Scale Vegetation Map using the zonal statistics function (mean value) in ArcGIS (Table 6.7). See the *Marin County Ladder Fuels Datasheet* for more information (Golden Gate National Parks Conservancy and County of Marin, 2019).

Table 6.7. 2018 Fine Scale Vegetation Map attribute for 2019 lidar-derived ladder fuels.

MEAN_LADDER_FUELS/Mean Ladder Fuels 1-4 Meters (0-1)	Mean lidar derived ‘ladder fuels’ for forested stands. Represents density of lidar returns between 1-4 meters above ground. Integrated from the 2019 lidar derived ladder fuels raster using the zonal statistics (mean) function in ArcGIS. The ladder fuel metric is a 0-1 metric; 0 is lowest, 1 is highest.

INTERPRETATION

To support the Forest Condition Assessment, four ladder fuel classes were created (Figure 6.35). Classes were created by dividing the distribution of mean ladder fuels values for each forest lifeform class in the 2018 Fine Scale Vegetation Map into quartiles based on their distribution in that lifeform class, making the ladder fuel classification relative for each forest lifeform type. It is important for ladder fuel classification to be relative to each forest lifeform class as different forest types have different levels of ladder fuels; for example, deciduous hardwood forest as compared to conifer forest. This methodology allows assessment within and across forest types. See the *Marin County Forest Lifeform Datasheet* for more information on forest lifeform classes (Golden Gate National Parks Conservancy & Tukman Geospatial, 2021).

Metric Classes

- Low
- Medium
- High
- Very High

Figure 6.35. Ladder Fuel Classes.

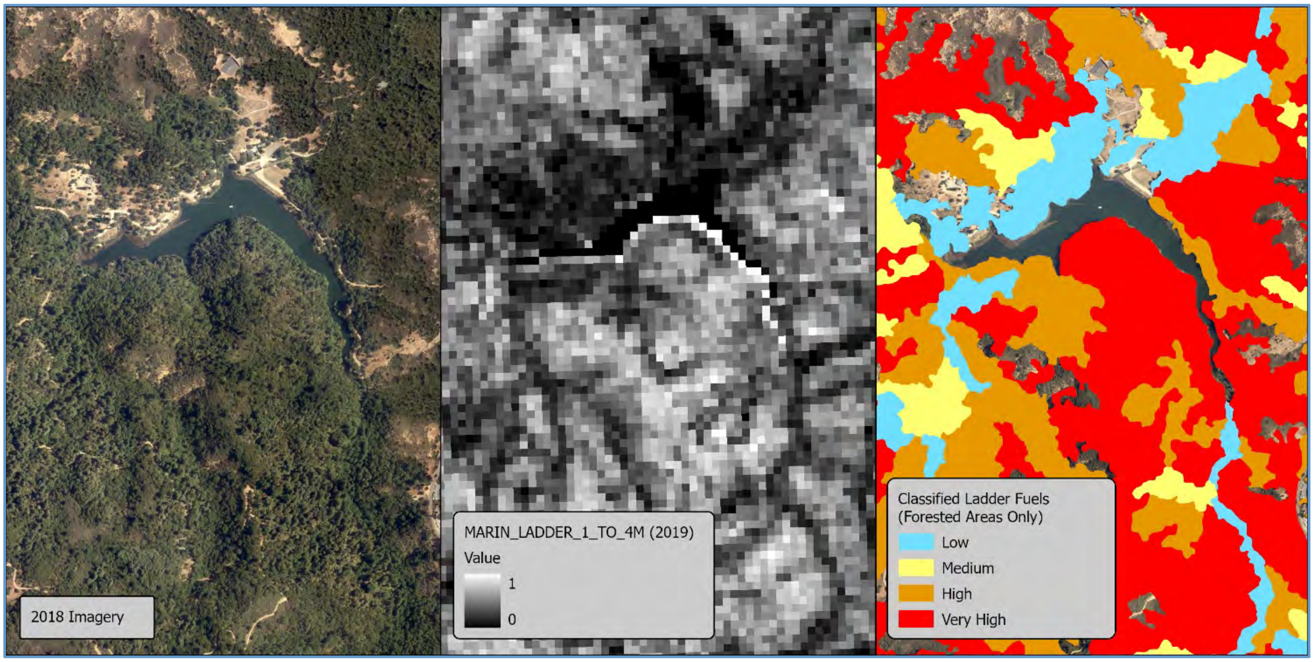
As with other metrics derived from remotely sensed data, this metric has limitations inherent with the data. For example, the data cannot distinguish between live and dead vegetation, or parse vegetation from other matter that may be in the same portion of the understory, such as small buildings. Additionally, vegetation structure, including the presence of ladder fuels, is not the exclusive driver of high intensity fire behavior in our region; other factors such as weather conditions and fuel moisture are also important to consider.

Table 6.8 shows mean ladder fuel cut-offs for each forest type. The lowest quartile in each forest lifeform class became "low" in the ladder fuel classification, the next lowest became “medium” and so on to create four ladder fuel classes. Thus, within each forest lifeform class, there are roughly the same number of polygons in the low, medium, high, and very high ladder fuel class. As a result, the countywide number of polygons within each ladder fuel class for each forest lifeform class is equivalent given the ladder fuels values for each forest lifeform class (Figure 6.36, right).

Table 6.8. Mean ladder fuel cut-offs for each forest lifeform class used to create ladder fuel classes.

Forest Lifeform	Mean Lidar-Derived Ladder Fuel Density (Quartiles)			
	Low	**Medium**	**High**	**Very High**
Evergreen Hardwood	0-.19	.2-.24	.25-.31	.32+
Riparian Forest	0-.24	.25-.28	.29-.33	.34+
Deciduous Hardwood	0-.15	.16-.19	.20-.23	.24+
Conifer	0-.22	.23-.30	.31-.39	.4+
Non-native Forest	0-.11	.12-.18	.19-.24	.25+

Figure 6.36. Phoenix Lake, Mount Tamalpais Watershed. Classified ladder fuels in forested areas, from left to right: 2018 imagery (left), 2019 raw ladder fuels 1 – 4 meters (center), classified ladder fuels (right).



ABOVEGROUND LIVE BIOMASS AND CARBON

Forest management considerations include developing strategies and incorporating treatments to protect and enhance carbon storage to reduce the impacts of climate change. This metric was developed to provide managers with an approximation of biomass density and stored carbon in Marin's native forests.

The data are derived from the work of the Landscape Ecology Modeling, Mapping & Analysis (LEMMA) group, a research team led by US Forest Service (USFS) Pacific Northwest Research Station and Oregon State University and supported by collaboration with USFS Rocky Mountain Research Station, USFS Pacific Northwest Region, and the USFS Forest Inventory and Analysis Program (FIA). To map the biomass of aboveground live trees, the LEMMA group utilized gradient nearest neighbor (GNN) analysis based on 30-meter Landsat imagery supplemented by training data for GNN derived from FIA data (LEMMA, n.d.a., n.d.b.). Mean value aboveground live biomass was then integrated into native forest stands in the 2018 Fine Scale Vegetation Map using the zonal statistics (mean) function in ArcGIS. Each native forest polygon in the 2018 Fine Scale Vegetation Map was assigned an aboveground live biomass tons/hectare attribution (Table 6.9). Note that aboveground forest carbon is calculated from the biomass value by using the biomass to carbon conversion factor of 0.47 (IPCC, 2006).

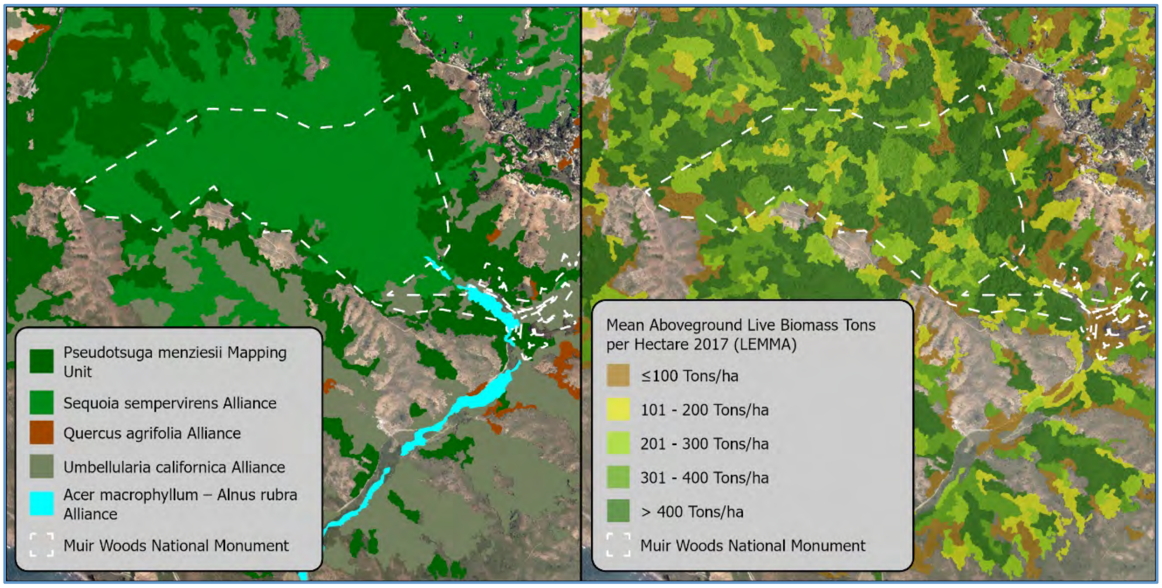
Table 6.9. Aboveground live biomass attribution estimates for native forest polygons in the 2018 Fine Scale Vegetation Map.

AGL_BIOM_2017_RATE/ Mean Aboveground Live Biomass Tons per Hectare 2017 (LEMMA)	Aboveground live biomass in tons per hectare for forestlands. Data integrated from 2017 LEMMA using the zonal statistics function.
AGL_BIOM_2017_TOT/ Total Aboveground Live Biomass Tons 2017 (LEMMA)	Aboveground live biomass in tons for forestlands. Data integrated from 2017 LEMMA using the zonal statistics function.

INTERPRETATION

LEMMA biomass is mapped at the regional scale and is derived from moderate resolution satellite imagery. It provides an approximation of biomass density that is not field-checked or refined at the local scale. LEMMA data products are not created with high resolution datasets such as lidar or high-resolution imagery, therefore this metric provides very rough estimates of aboveground live carbon only. This attribution and corresponding biomass/ carbon estimates does not include lifeforms other than forests, such as shrubs or herbaceous plant communities, nor does it include dead biomass or belowground/ soil carbon. In addition, the LEMMA dataset is a coarse raster that breaks down at a fine scale, and some areas of Marin County with visible aboveground live carbon had null values in the data. While valuable as a reference, this data certainly underestimates biomass and carbon stores in Marin County. Finer scale carbon mapping is recommended to better understand current levels of above ground and below ground carbon storage in Marin, and to support monitoring to determine carbon storage efficacy over time (see Appendix E: Opportunities for Additional Study). To support the Forest Condition Assessment, the tons/hectare attribution was grouped into five classes based on the distribution of values (Figure 6.37).

Figure 6.37. Muir Woods National Monument, 2018 Fine Scale Vegetation Map (left), classified aboveground live carbon estimates in tons per hectare (right).



Metric Classes

- Biomass less than or equal to 100 tons/hectare.
- Biomass 101-200 tons/hectare.
- Biomass 201-300 tons/hectare.
- Biomass 301-400 tons/hectare.
- Biomass greater than 400 tons/hectare.

Table 6.10 summarizes above ground live biomass and carbon estimates for forested lands in Marin County. According to this data, the California bay laurel (*Umbellularia californica)* Alliance stores nearly 40% of Marin's aboveground forest carbon.

Table 6.10. Estimated live aboveground biomass and carbon, 2018 Fine Scale Vegetation Map and 2017 LEMMA GNN data.

Forest Type (2018 Fine Scale Vegetation Map Alliance/Association)	Aboveground Live Biomass (tons)	Aboveground Live Carbon, rounded to nearest one (tons)	% Total Carbon Estimated in Marin Native Forests
Acer macrophyllum – Alnus rubra Alliance	124,893	58,700	1.15%
Acer macrophyllum Association	6,359	2,989	0.06%
Acer negundo / (*Rubus ursinus*) Association	1,814	853	0.02%
Aesculus californica Alliance	1,729	813	0.02%
Alnus rhombifolia Alliance	1,1954	5,618	0.11%
Arbutus menziesii Alliance	261,248	122,787	2.41%
Conifer (Urban Window)	161	76	0.00%
Deciduous Hardwood (Urban Window)	20,973	9,857	0.19%
Evergreen Hardwood (Urban Window)	16,461	7,737	0.15%
Fraxinus latifolia Alliance	447	210	0.00%
Hesperocyparis sargentii / Ceanothus jepsonii – Arctostaphylos spp. Association	4,813	2,262	0.04%
Hesperocyparis sargentii Association	4,930	2,317	0.05%
Notholithocarpus densiflorus Alliance	5,191	2,440	0.05%
Pinus muricata – Pinus radiata Alliance	464,980	21,8541	4.29%
Populus fremontii – Fraxinus velutina – Salix gooddingii Alliance	97	46	0.00%
Pseudotsuga menziesii – (*Notholithocarpus densiflorus – Arbutus menziesii*) Alliance	3,161,600	1,485,952	29.19%
Quercus (*agrifolia, douglasii, garryana, kelloggii, lobata, wislizeni*) Alliance	1,709	803	0.02%
Quercus agrifolia Alliance	726,935	341,660	6.71%

Quercus chrysolepis Alliance	89,309	41,975	0.82%
Quercus douglasii Alliance	39,355	18,497	0.36%
Quercus garryana Alliance	108,840	51,155	1.00%
Quercus kelloggii Alliance	14,620	6,871	0.13%
Quercus lobata Alliance	117,219	55,093	1.08%
Salix exigua Alliance	71	33	0.00%
Salix gooddingii – Salix laevigata Alliance	7,290	3,426	0.07%
Salix lucida ssp. lasiandra Association	8,662	4,071	0.08%
Sequoia sempervirens Alliance	1,388,583	652,634	12.82%
Umbellularia californica Alliance	4,239,991	1,992,796	39.15%
TOTAL	**10,830,234**	**5,090,212**	**100%**

STAND CHANGE 2010 – 2019 (STAND LEVEL METRICS)

A series of four metrics were developed to provide insight into changes in individual stand structure over time by utilizing the 2010 and 2019 Marin lidar data, specifically changes in the vertical height of the stand as well as changes in the density of the tree canopy. Measuring these changes gives managers insight into the vertical structure of forested stands, and helps identify both vigorously growing, healthy stands and stands that may be in decline or under stress from drought or pests. The following four metrics were developed and resulting attributes were assigned to each native forest stand polygon in the Forest Health Web Map. Unlike the other metrics described in this chapter, these metrics (with the exception of Canopy Density Change) are only available at the individual stand level and were not analyzed or aggregated at the landscape scale.

- Canopy Height Change 2010 – 2019 (CHMDIFF)
- 95th percentile (P95) Stand Height Change 2010 – 2019 (PHS)
- Canopy Volume Profiles 2010 – 2019 (CVPS)
- Canopy Density Change (greater than 10 feet) 2010 – 2019 (DENSITY)

Each native forest polygon has an associated series of four bar charts which provide results of the analysis for the four metrics. Links to these bar charts are embedded in the attribute table for native forest stands (polygons) in the Forest Health Web Map (Figure 6.38). See example charts below, Figures 6.40, 6.42, 6.44, 6.46.

Figure 6.38. Screenshot of Forest Health Web Map attribute table with links to stand level charts.

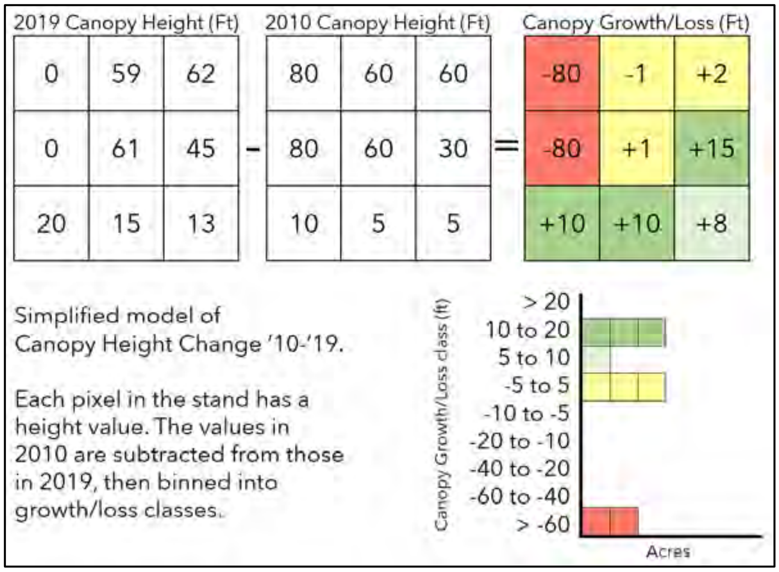
CHART_CHMDIFF	View
CHART_PHS	View
CHART_CVPS	View
CHART_DENSITY	View

The discussion below includes a description of each of these stand change metrics, interpretation guidance for land managers, discussion of data limitations, and example use cases. Note that only one of the stand change metrics, Canopy Density Change, was used in the Forest Condition Assessment (see Chapter 7: Condition Assessment).

CANOPY HEIGHT CHANGE 2010 – 2019

To quantify canopy height change, the 2010 canopy height raster (3x3 foot resolution) is subtracted from the 2019 canopy height raster. Each pixel in the resulting raster represents the change in height between 2010 and 2019 for that 9 square foot area. Negative values indicate a loss of height (e.g., from trees falling or being removed) and positive values indicate growth. Individual values were binned into canopy growth/loss classes (Figure 6.39). The canopy height change bar graph shows a distribution of how heights changed across the stand between 2010 and 2019 (Figure 6.40). The chart displays the amount of area (in acres) in a stand that experienced the different classes of growth and loss. The Canopy Height Change bar chart is included in the attribute table for native forest stands (polygons) in the Forest Health Web Map.

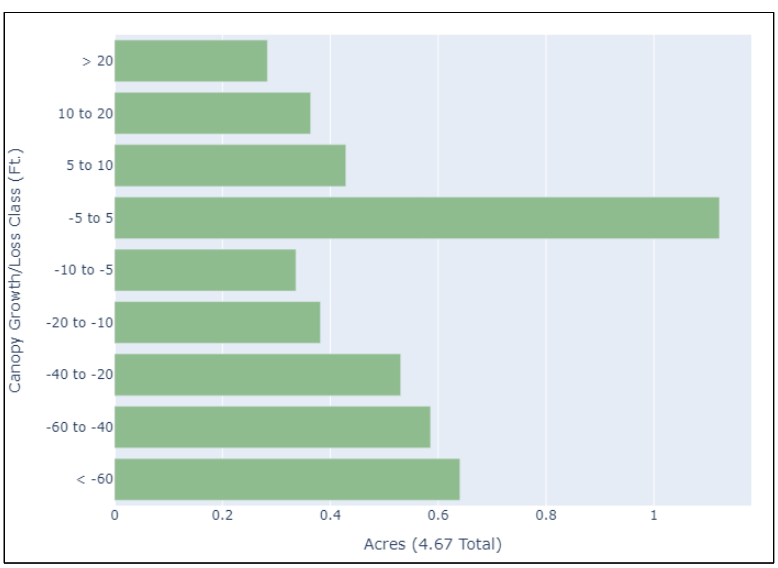
Figure 6.23. Canopy height change 2010 - 2019 methodology.



INTERPRETATION

This metric and corresponding bar chart helps illustrate the variability and magnitude of growth and loss across a stand (Figure 6.40). This metric does not differentiate between vegetation types. The positive classes show different levels of vigor in growth, from smaller increases (5 to 10 feet over a 9-year period) to much larger ones (greater than 20-foot increases). Negative classes show the loss of any vegetation type within the stand, from a loss of 10-foot shrubs to the loss of 100-foot trees. The -5 foot to 5-foot class can be understood as no change, to account for noise and error in the canopy height rasters. Because this chart shows the acreage of each growth/loss class, it can show how portions of a stand

Figure 6.40. Example canopy height change 2010 - 2019 chart.

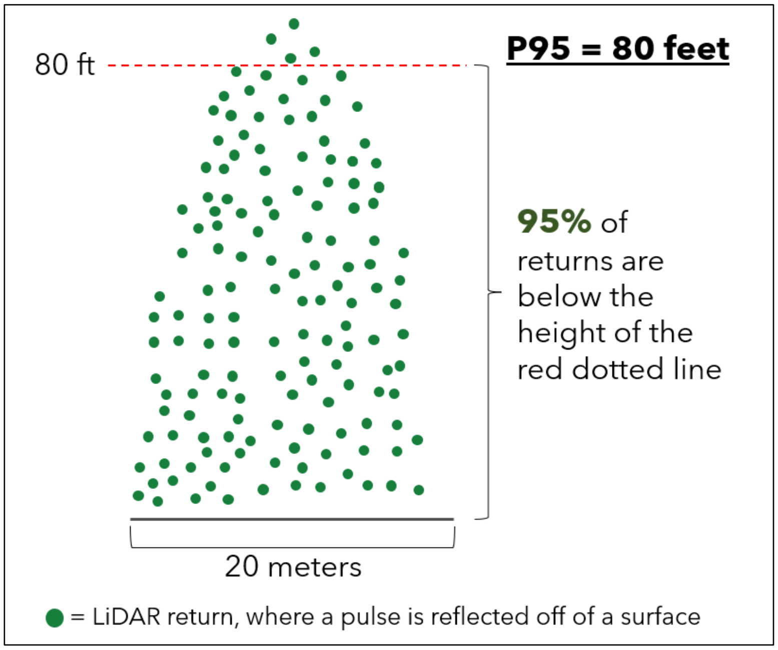


experienced growth while other portions experienced loss, adding nuance to the other charts (95th percentile heights and canopy density) which show values that are averaged across the stand.

NINETY-FIFTH (95th) PERCENTILE HEIGHTS 2010 – 2019

This metric and corresponding bar chart compares 95th percentile (P95) stand heights in 2010 and 2019. The P95 height is the height that 95% of LiDAR returns are below, excluding returns below 4.5 feet (1.37 meter, or breast height). It is essentially maximum height, but less sensitive to outliers or anomalous heights. P95 heights calculated from the point cloud for 20x20 meter pixels are averaged across the stand to calculate P95 stand height for both 2010 and 2019. Figure 6.41 shows an example of calculating P95 for one set of lidar returns for which the P95 is 80 feet. Comparison of 2010 and 2019 heights are presented in a bar chart (Figure 6.42). The 2010 and 2019 P95 stand height bar chart is included in the attribute table for native forest stands (polygons) in the Forest Health Web Map.

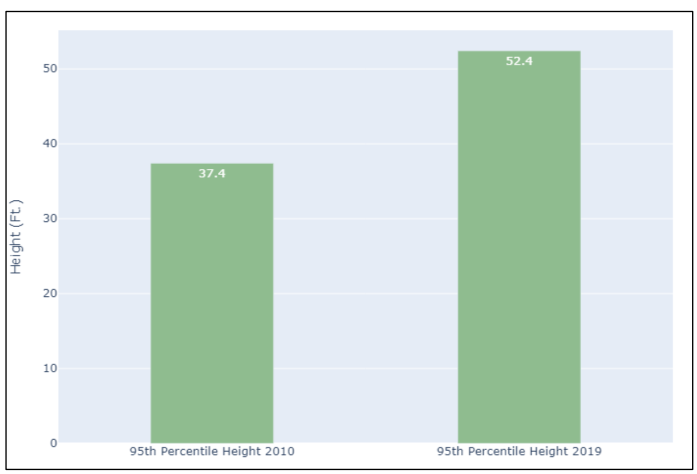
Figure 6.41. 95th percentile heights methodology.



INTERPRETATION

The bar chart shows the difference in P95 stand heights between 2010 and 2019 (Figure 6.42). It is important to appreciate that the P95 heights represent an averaged maximum height for the whole stand, rather than heights of single trees. Increases in P95 height over time mean that a stand has, on average, gained height. A decrease between 2010 and 2019 P95 height means that a stand has, on average, lost height. This could have a variety of causes: loss of trees, growth of new trees over the 4.5-foot threshold for inclusion (reducing the stand average height), or a combination of the two. A lack of change may also be deceptive

Figure 6.42. Example 95th percentile height 2010-2019 chart.



because growth of some trees in the stand may offset the loss of others. Using all the forest health metrics and charts in combination, along with field observation, can help better identify the drivers of stand changes.

CANOPY VOLUME PROFILES 2010 – 2019

Canopy volume profiles help visualize the changes in stand vertical structure between 2010 and 2019 by stratifying the percentage of LiDAR returns into different height categories (Figure 6.43). Height categories are for 10-foot intervals, i.e., 10 - 20 feet. The stratum of 0-10 feet was excluded from the chart to eliminate noise and avoid confusing ground surface returns for vegetation or fuels. Comparing the lidar returns for strata between the two years can pinpoint canopy locations where there was growth or loss of vegetation/biomass. Figure 6.43 shows an example of calculating canopy volume profiles for one set of lidar returns over 5 strata. The 2010 and 2019 Canopy Volume Profile bar chart is accessed via the attribute table for native forest stands (polygons) in the Forest Health Web Map (Figure 6.44).

Figure 6.43. Canopy volume profiles methodology.

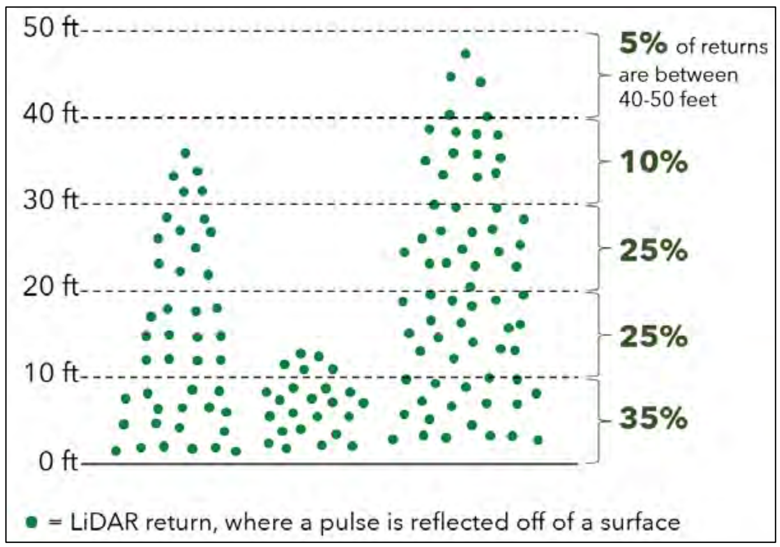
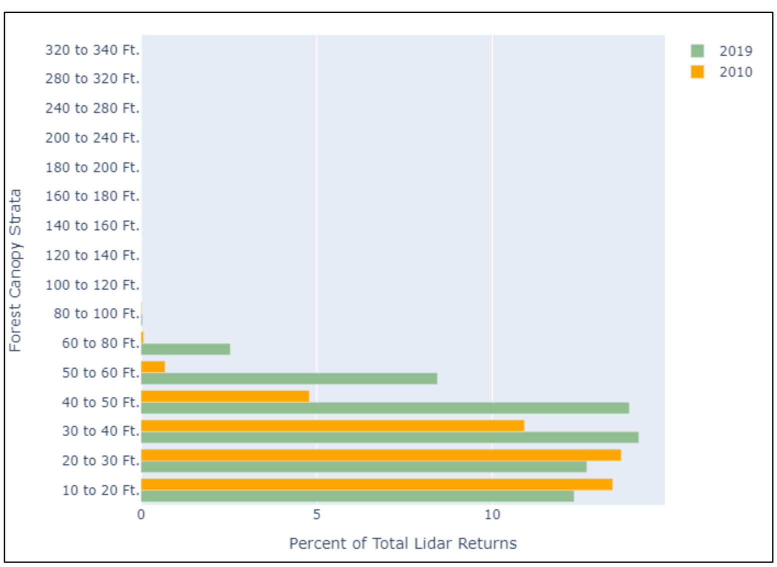


Figure 6.44. Example canopy volume profile 2010 - 2019 chart.



INTERPRETATION

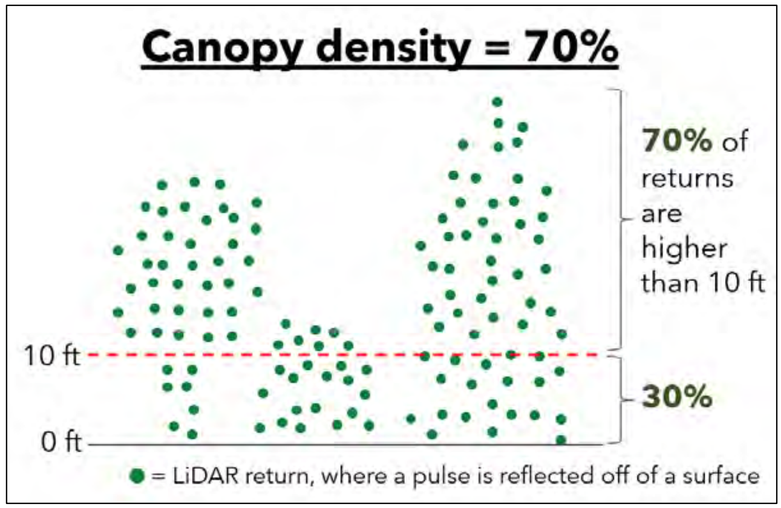
Methodology for the canopy volume profile metric is supported by recent research in forest structure classification using remote sensing methods (Adnan et al., 2019; Moran et al., 2018.) Canopy volume profile charts can be useful for understanding where in the vertical structure, on average, the stand is gaining and losing vegetation (Figure 6.44). Gains in the upper strata can be interpreted as height growth of existing vegetation into new strata, while losses might be due to harvest, tree fall, or other mortality events.

Managers may be especially interested in the lower strata, which will include young trees, shrubs over 10 feet tall, and/or growth of other ladder fuels that might be of interest for treatment and restoration. Caution should be exercised in interpreting these charts for stands containing deciduous trees. The 2019 lidar was collected in mid-winter and the 2010 lidar was collected during the late spring, thus, the density of lidar returns may be driven by leaf phenology rather than changes in the amount of vegetation in certain strata.

CANOPY DENSITY CHANGE (GREATER THAN 10 FEET) 2010 – 2019

This metric quantifies the difference in canopy density between 2010 and 2019. Canopy density is defined as the percentage of total lidar returns that are from heights greater than 10 feet from the ground. Ten feet is the defined cutoff height for tree canopy, as opposed to understory, shrub, or other vegetation and fuels below 10 feet. Figure 6.45 shows an example of calculating canopy density for one set of lidar returns in which 70% of lidar returns are from heights higher than 10 feet. Access to the 2010 and 2019 Canopy Density Change bar chart is included in the attribute table for native forest stands (polygons) in the Forest Health Web Map (Figure 6.46).

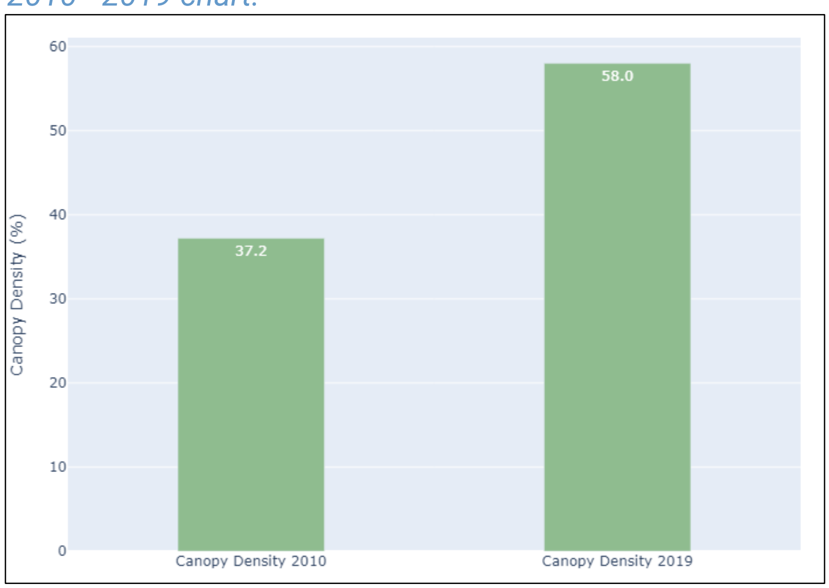
Figure 6.45. Canopy density change methodology.



INTERPRETATION

An increase in canopy density between 2010 and 2019 is reflected in a higher percentage of lidar returns from heights greater than 10 feet, meaning there is a greater ratio of material in the tree canopy to material below the canopy than there was in 2010. This change could have several causes, depending on the vegetation type and any management actions undertaken for that stand: e.g., height growth and increased branches in tall trees, young trees growing into the canopy, defoliation or other

Figure 6.46. Example canopy density change 2010 - 2019 chart.



changes in leaf density in deciduous stands, and vegetation treatments such as thinning of small trees and shrubs. Similarly, losses in canopy density from 2010 to 2019 could have a variety of drivers, including loss, mortality, or removal of canopy trees, increases in shrub or other material under 10 feet, or some combination of these. Measurable losses in canopy density for evergreen forest types could be an indication of disease or drought-induced decline.

Caution should be exercised in interpreting these charts, especially for stands containing deciduous trees. Since the 2019 lidar was collected in mid-winter and the 2010 lidar was collected during late spring, a loss in canopy density may be driven by leaf phenology and not meaningful changes in density or vigor.

Canopy Density Change is the only one of the stand level metrics used in the Forest Condition Assessment. To support landscape level analysis and the Forest Condition Assessment, the 2010 to 2019 canopy density change value was calculated for all native forest stands and grouped into 9 classes (Figure 6.47, 6.48). To calculate the canopy density change value, the 2010 canopy density was subtracted from the 2019 density. Appropriate classes were determined based on the distribution and frequency of canopy density change percentages seen in native forests, where relatively few stands have a gain or loss greater than 10% (see histogram, Figure 6.49).

Metric Classes for Native Forest Stands

- Canopy Density Loss, greater than 10%.
- Canopy Density Loss, 5-10%.
- Canopy Density Loss, 2.5-5%.
- Canopy Density Loss, 0-2.5%.
- No Change.
- Density Gain, 0-2.5%.
- Density Gain, 2.5-5%.
- Density Gain, 5-10%.
- Density Gain, greater than 10%.

Figure 6.47. Canopy density change 2010 - 2019 classes.

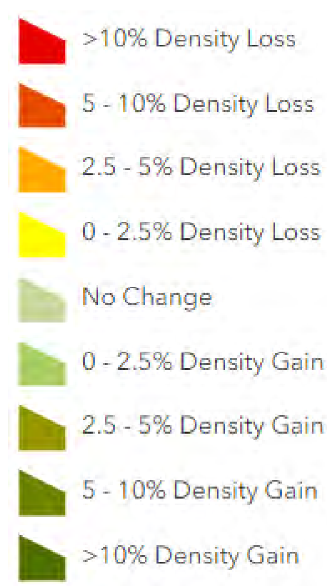


Figure 6.48. Portions of Point Reyes National Seashore and Tomales Bay State Park, from left to right: 2018 imagery (left), 2018 Fine Scale Vegetation Map (center), classified canopy density change 2010 - 2019 (right).

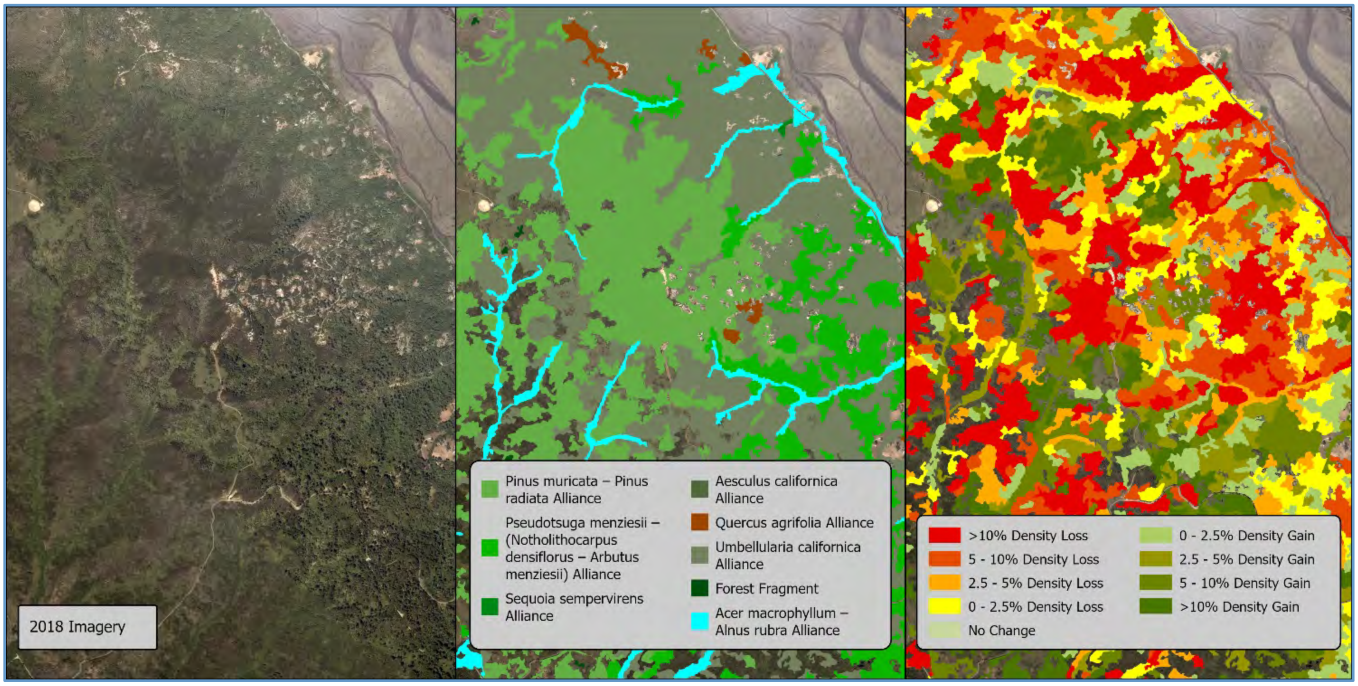
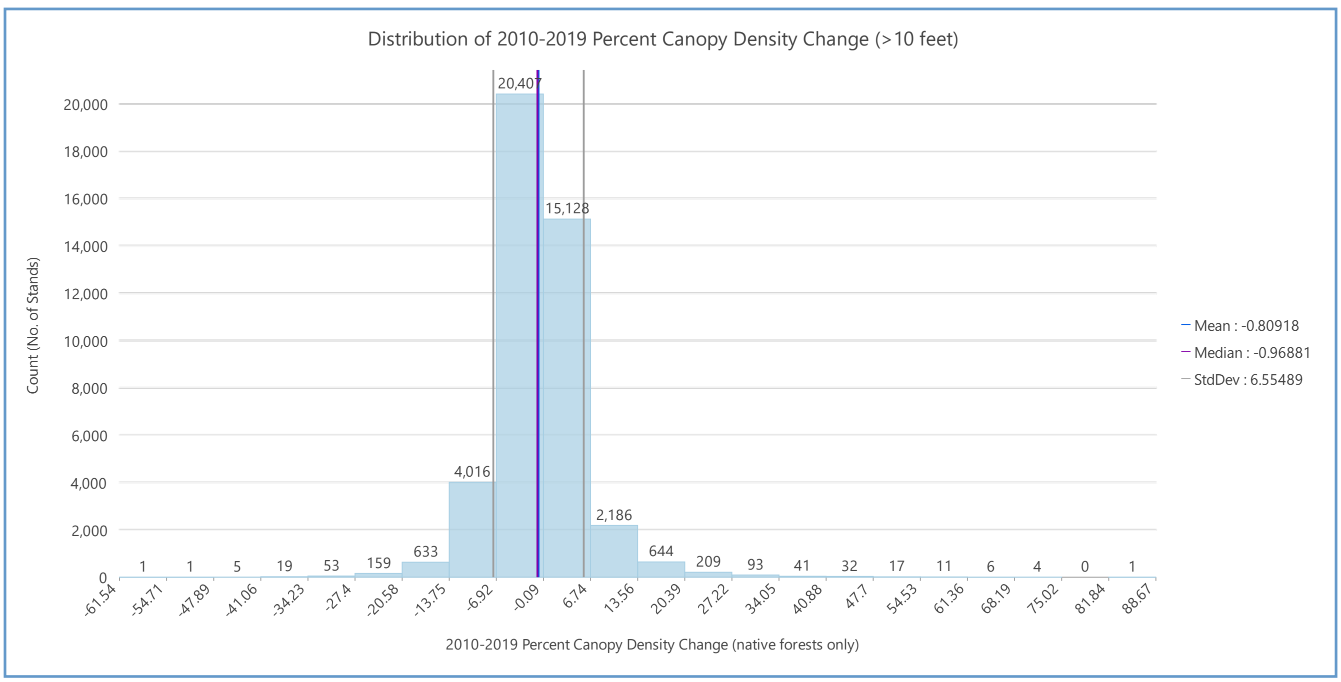


Figure 6.49. Distribution of raw percent canopy density change values between 2010 – 2019 for vegetation greater than 10 feet in height in native forest stands.



EXAMPLE APPLICATIONS

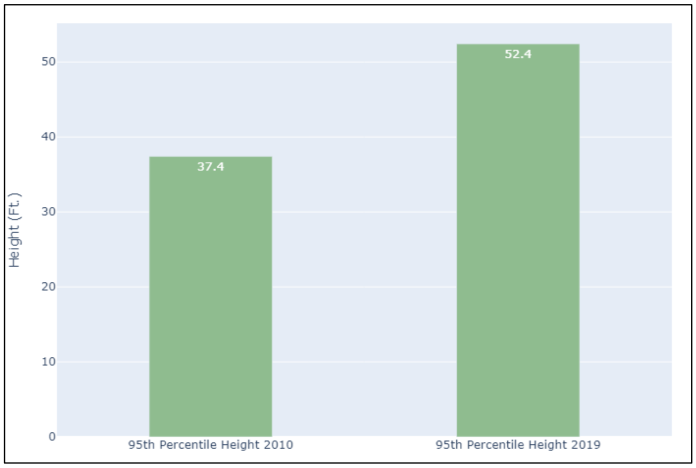
The above stand change metrics can be used together to understand changes in stand characteristics over time. In the following sections, 2018 Fine Scale Vegetation Map polygons will be used to exemplify several ways these metrics can be used. Individual polygons, or forest stands, will be referred to using their GIS Object ID, or OID, number.

QUANTIFYING STAND GROWTH

The young Douglas-fir (*Pseudotsuga menziesii* Alliance) stand surrounded by shrubs in Figure 6.50 had visible, significant growth from 2010 (left) to 2019 (right). This growth is also reflected in the other stand change metrics, which show increases in 95th percentile height (P95), canopy density, and in upper height strata of the canopy volume profile. The growth of the stand can be quantified using the results of the metrics analysis.

Figure 6.50. Example stand growth: 2010 NAIP imagery (left), 2018 imagery (right), 2018 Fine Scale Vegetation Map OID 39093.

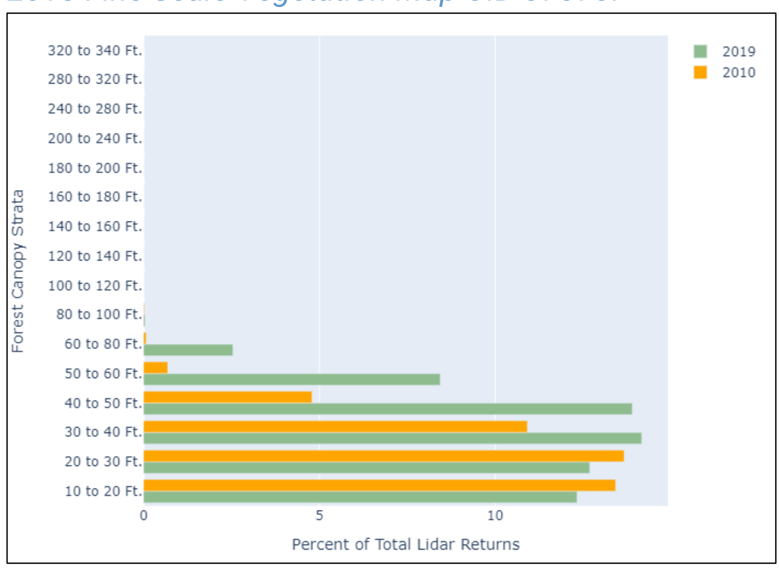
Figure 6.51. 95th percentile height 2010 - 2019, 2018 Fine Scale Vegetation Map OID 39093.



The corresponding P95 height chart shows an increase from 37.4 feet in 2010 to 52.4 feet in 2019 (Figure 6.51).

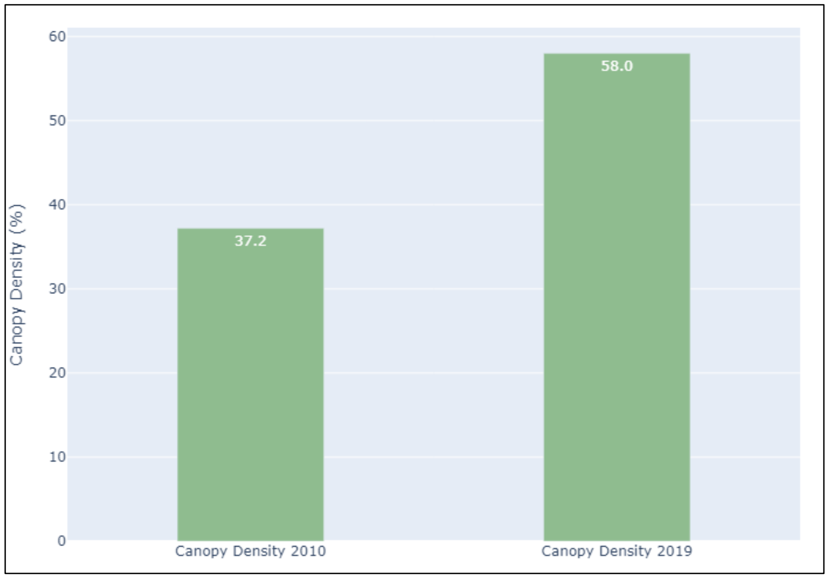
The canopy volume profile chart shows that, overwhelmingly, the growth in the stand was trees growing from shorter (between 10 and 40 feet) to taller strata (Figure 6.52). In 2010, 5% of returns were in the 40-50 feet stratum. By 2019, around 14% of returns were in that stratum, with large increases in 50 – 60 and 60 – 80 feet strata as well.

Figure 6.52. Canopy volume profile 2010 - 2019, 2018 Fine Scale Vegetation Map OID 39093.



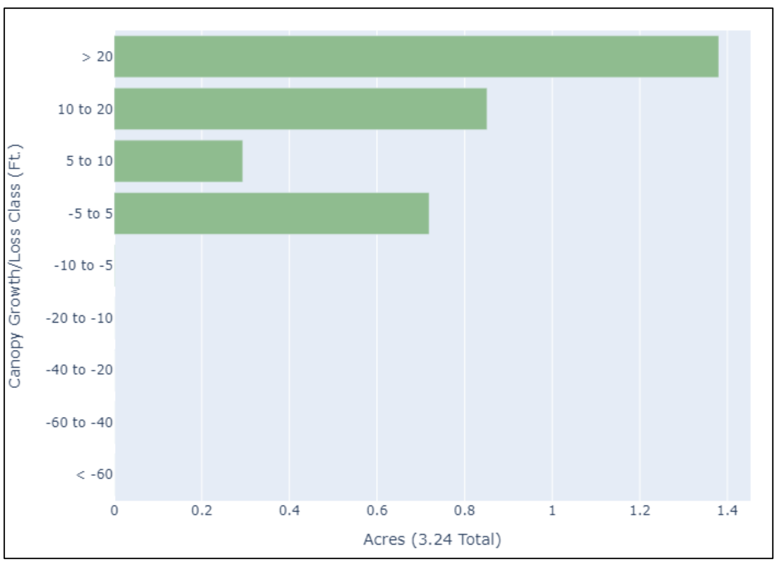
The canopy density change chart shows similar growth for this same Douglas-fir stand (Figure 6.53). In 2010, only 37.2% of returns were from heights greater than 10 feet, with a majority of returns not in the tree canopy. In 2019, canopy density had increased to 58%, highlighting the increase of vegetation in the tree canopy relative to vegetation below 10 feet.

Figure 6.53. Canopy density change 2010 – 2019, 2018 Fine Scale Vegetation Map OID 39093.



The canopy height change chart reinforces the conclusion drawn from the other charts that this Douglas-fir stand experienced vigorous growth between 2010 and 2019 (Figure 6.54). Of the 3.24 total acres in this stand, 1.4 acres experienced growth greater than 20 feet between 2010 and 2019, 0.8 acres experienced 10-20 feet of growth, 0.3 acres experienced 5-10 feet of growth, and the rest did not change significantly. There were no registered losses in height.

Figure 6.54. Canopy height change 2010-2019, 2018 Fine Scale Vegetation Map OID 39093.



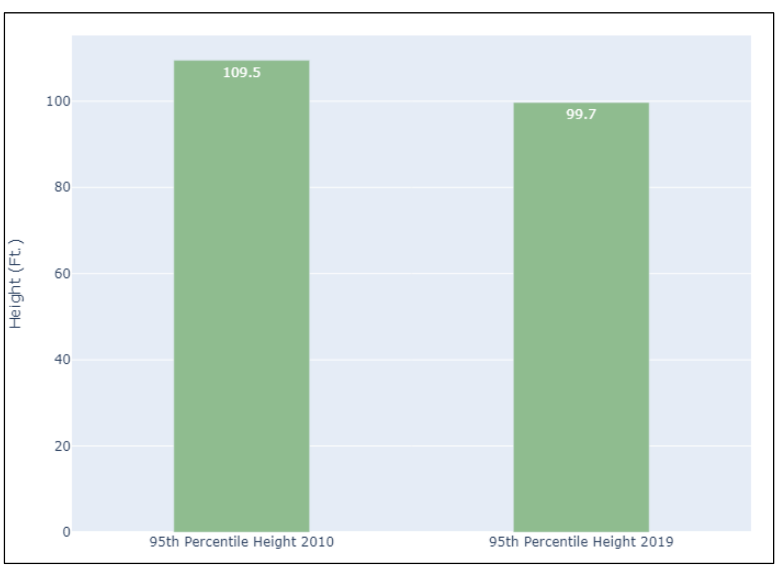
QUANTIFYING STAND LOSS

The 2018 Fine Scale Vegetation Map stand shown in Figure 6.55 is a 4.6-acre *Umbellularia californica* (California bay) Alliance stand. The 2010 imagery (left) shows dead and dying trees, possibly tanoak which have been impacted by sudden oak death and fallen naturally or been removed by 2019 (right). Each of the corresponding stand level metric charts reflect this loss of canopy trees.

Figure 6.24. Example stand loss: 2010 NAIP imagery (left), 2018 imagery (right), 2018 Fine Scale Vegetation Map OID 42606.

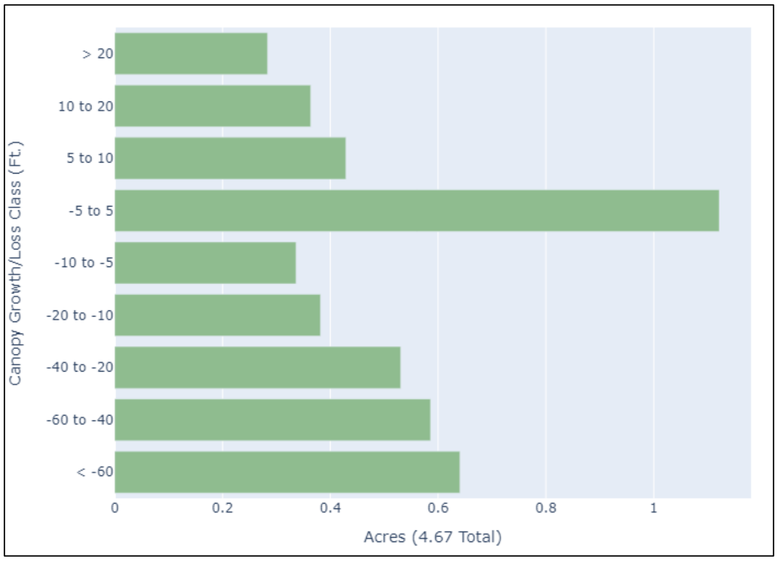
Stand 95th percentile height (P95) decreased from 109.5 feet in 2010 to 99.7 feet in 2019 (Figure 6.56). Though individual healthy trees in the stand may have grown, the stand average was significantly decreased by the loss of multiple canopy trees.

Figure 6.56. 95th percentile height 2010 - 2019, 2018 Fine Scale Vegetation Map OID 42606.



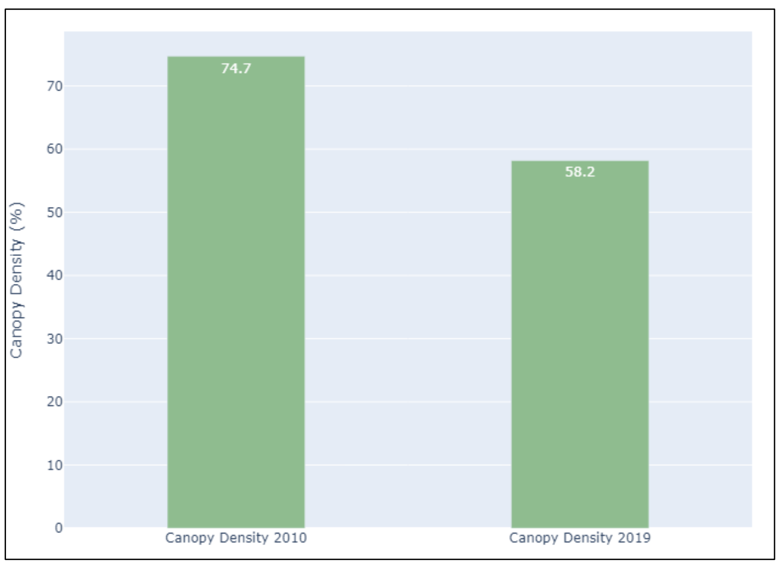
The canopy height change chart shows a complex mix of height growth and loss across the stand (Figure 6.57). Of the 4.67 total acres in this stand, roughly one quarter registered no change in height. A little more than one acre experienced growth, with a small portion of that growth being greater than 20 feet. The rest of the stand lost height, ranging from small losses to full trees greater than 60 feet.

Figure 6.57. Canopy height change 2010 - 2019, 2018 Fine Scale Vegetation Map OID 42606.



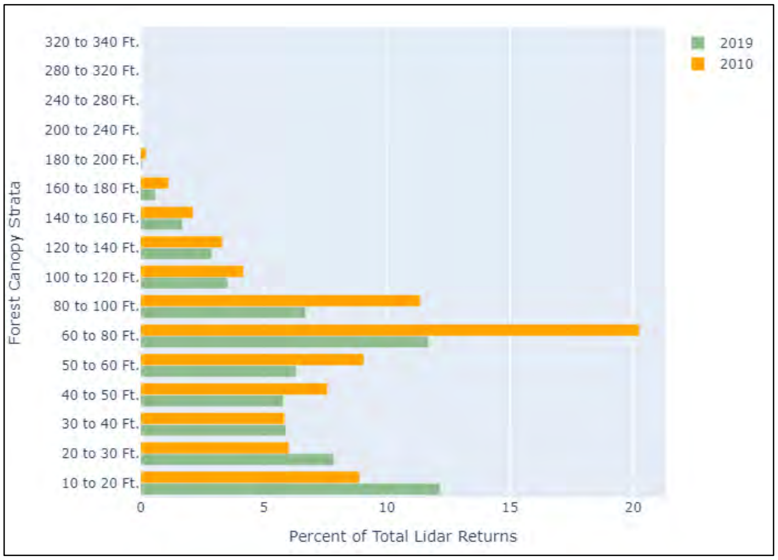
Canopy density also decreased, from 74.7% to 58.2%, meaning that fewer returns in 2019 were in the canopy and more were on the surface or sub-canopy, below 10 feet (Figure 6.58).

Figure 6.58. Canopy density change 2010 – 2019, 2018 Fine Scale Vegetation Map OID 42606



The canopy volume profile shows lower percentages of total returns in most canopy strata in 2019 compared to 2010, with the greatest differences in the 60–80 feet range (Figure 6.59). Some of that loss is offset by an increase in returns from 10-20 feet, potentially from new growth in the gaps from the loss of canopy trees. The rest would be in the 0-10 feet stratum; this stratum is not shown in the chart because the lidar pulses may reflect from the ground and create confusion between low-strata vegetation and fuels versus ground surface returns.

Figure 6.59. Canopy volume profile 2010 - 2019, 2018 Fine Scale Vegetation Map OID 42606.



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APPENDIX 6A: 2018 MARIN COUNTYWIDE FINE SCALE VEGETATION MAP ATTRIBUTE TABLE

Fine Scale Map Attributes (Name/Alias)	Description
OID_COPY/ OID_COPY	Unique index for internal use.
MAP_CLASS_18/Fine Scale Map Class in ‘18	National Vegetation Classification (NVCS) map class label for all stands, as defined in Marin’s fine scale mapping key.
ABBRV/Fine Scale Map Class Abbreviation	Map class abbreviations for use in cartography and visualization. A key to abbreviations is available here: https://vegmap.press/marin_vegmap_abbrevs
LIFEFORM_18/Lifeform in ‘18	26-class lifeform label for all stands. Labels are floristically more general than the fine scale map class and forest lifeform.
FOREST_LIFEFORM_18/Forest Lifeform in ‘18	30-class lifeform label for all stands. Labels are floristically more general than the fine scale map class.
ABS_COVER_19/Absolute % Tree Canopy Cover in ‘19	Absolute cover of trees greater than 15 feet in height. Derived from 2019 lidar data.
REL_CON_COV_18/Relative % Conifer Cover in ‘18	Relative conifer cover, estimating the percent of tree canopy >= 15 ft. is conifer. Derived from manual image interpretation of ‘18 imagery.
REL_HDW_COV_18/Relative % Hardwood Cover in ‘18	Relative hardwood cover, estimating the percent of tree canopy >= 15 ft. is hardwood. Derived from manual image interpretation of ‘18 imagery.
HDW_COVER_18/Absolute % Hardwood Cover in ‘18	Absolute hardwood cover, derived as: ((relative % hardwood cover/100) x (absolute % hardwood/100)) * 100
CON_COVER_18/Absolute % Conifer Cover in ‘18	Absolute conifer cover, derived as: ((relative % conifer cover/100) x (absolute % cover/100)) * 100
SHB_COVER_18/Absolute % Shrub Cover in ‘18	Absolute shrub cover for herbaceous and shrub stands. Derived from manual image interpretation of ‘18 imagery.
STAND_HT_MN_19/Mean LiDAR Stand Height in ‘19 (ft.)	Mean stand height from LiDAR-derived canopy height model (CHM).
STAND_HT_MX_19/Maximum LiDAR Stand Height in ‘19 (ft.)	Maximum stand height from LiDAR-derived canopy height model (CHM).
STAND_HT_SD_19/Standard Deviation LiDAR Stand Height in ‘19 (ft.)	Standard deviation stand height from LiDAR-derived canopy height model (CHM).
STANDING_DEAD_19/% Standing Dead 2019	Estimate of percent standing dead vegetation in forested stands. Estimates the percent of the woody canopy > 7 feet tall that did not have a living crown in late 2018/early 2019.
FRACAL_MORTALITY_18/% Standing Dead Frangula Californica ‘18	Estimate of the % standing dead cover of *Frangula Californica* in mapped coffeeberry stands. Estimate is relative to total coffeeberry cover in the stand.

Fine Scale Map Attributes (Name/Alias)	Description
CANOPY_GAP_10_19/% Canopy Gap formed '10- '19	% Of stand that is a canopy gap that formed between 2010 and 2019.
LARGEST_GAP_10_19/Sq. Feet of Largest '10-'19 Gap	Largest canopy gap that formed between 2010 and 2019 in square feet.
CON_CHANGE_14_18/% Conifer Change '14- '18	% Conifer cover change between 2014 and 2018. Only applies to Marin County Parks and Marin Water lands.
HDW_CHANGE_14_18/% Hardwood Change '14- '18	% Hardwood cover change between 2014 and 2018. Only applies to Marin County Parks and Marin Water lands.
AGL_BIOM_2017_RATE/ Mean Aboveground Live Biomass Tons per Hectare 2017 (LEMMA)	Aboveground live biomass in tons per hectare for forestlands. Data integrated from 2017 LEMMA using the zonal statistics function.
AGL_BIOM_2017_TOT/ Total Aboveground Live Biomass Tons 2017 (LEMMA)	Aboveground live biomass in tons for forestlands. Data integrated from 2017 LEMMA using the zonal statistics function.
MEAN_LADDER_FUELS/Mean Ladder Fuels 1-4 Meters (0-1)	Mean lidar derived 'ladder fuels' for forested stands. Represents density of lidar returns between 1-4 meters above ground. Integrated from the 2019 lidar derived ladder fuels raster using the zonal statistics (mean) function in ArcGIS. The ladder fuel metric is a 0-1 metric; 0 is lowest, 1 is highest.
SLOPE_MEAN/Mean Slope Degrees	Mean slope degrees, derived from the 2019 lidar data.
SLOPE_STD/Standard Deviation Slope Degrees	Standard deviation slope degrees, derived from the 2019 lidar data.
SLOPE_MAX/Maximum Slope Degrees	Maximum slope degrees, derived from the 2019 lidar data.
Orig_Map_Class/Original Map Class	Map class from the 2004-2014 fine scale mapping efforts.
WOODWARD_FIRE_SEVERITY/ Burn Severity for Woodward Fire	Burn severity classes (from WERT burn severity data) for stands within the footprint of the 2020 Woodward fire.
ACRES/ Acres	Acres of land encompassed by the stand.
DIRT_RD_18/% Dirt and Gravel Road in '18	Percent of stand that was dirt or gravel road in 2018. Integrated from the Marin County impervious surface map.
OTHER_PAVED_18/% Other Paved in '18	Percent of stand that was a paved, non-road surface (such as a paved parking lot) in 2018. Integrated from the Marin County impervious surface map.
BUILDING_18/% Buildings in '18	Percent of stand that was a building in 2018. Integrated from the Marin County impervious surface map.
OTHER_DIRT_18/% Other Dirt and Gravel in '18	Percent of stand that was an unpaved, non-road impervious surface (such as a gravel parking lot) in 2018. Integrated from the Marin County impervious surface map.
PAVED_RD_18/% Paved Road in '18	Percent of stand that was paved road in 2018. Integrated from the Marin County impervious surface map.

Fine Scale Map Attributes (Name/Alias)	Description
IMPERVIOUS_18/% Impervious in ‘18	Percent of stand that was impervious in 2018. Integrated from the Marin County impervious surface map.
PERVIOUS_18/% Pervious in ‘18	Percent of stand that was pervious in 2018. Integrated from the Marin County impervious surface map.

APPENDIX 6B: ONE TAM FOREST HEALTH WEB MAP LAYERS, SERVICE ENDPOINTS, AND SOURCE(S)

Web Map Group	Metric/Data	ArcGIS REST Service Endpoint	Note
Prioritization Support Layers	Classified Building Density (within stand)	Link	
	Classified Building Density (within ¼ mile)	Link	
	Departure From Desired Conditions Index	Link	
	Classified Mean Wildfire Hazard Within Stand	Link	
	Classified Wildfire Hazard and Building Density	Link	
	Marin Wildfire Hazard Index	Link	
	Treatment Feasibility	Link	
Forest Structure	Redwood Structural Classification	Link	
	Douglas Fir Structural Classification	Link	Simplified to 3 classes; see attribute table for additional class (>60-110 feet)
	Bishop Pine Structural Classification	Link	
	Sargent's Cypress Structural Classification	Link	
	Threatened and Converting Oak Woodlands	Link	
	2010 - 2019 Canopy Density Change	Link	
	2010 - 2019 Classified Forest Gaps Formed	Link	
	2018 Classified Canopy Mortality	Link	2019 Standing Dead (Native Forest Lifeform)
	Relative Hardwood Cover (Redwood)	Link	
	Relative Hardwood Cover (Douglas Fir)	Link	
	Relative Hardwood Cover (Bishop Pine)	Link	
	Relative Hardwood Cover (Sargent Cypress)	Link	
	Relative Hardwood Cover (Open Canopy Oak Woodland Alliances)	Link	

	Lemma Biomass Density	Link	LEMMA | Forest Biomass Mapping in California and Western Oregon (oregonstate.edu)
	Classified Ladder Fuels	Link	2019 Lidar derived Marin raw ladder fuels
2019 Lidar Derived Hydrology	NHD Flowline	Link	Available in the USGS National Map (Technical Report)
	NHD Area	Link	
	NHD Waterbody	Link	
	WBD HUC 12 Watersheds	Link	
	WBD HUC 14 Watersheds	Link	
Key Forest and Vegetation Types	Redwood Stands	Link	2018 Fine Scale Vegetation Map
	Douglas Fir Stands	Link	
	Bishop Pine Stands	Link	
	Sargent's Cypress Stands	Link	
	Open Canopy Oak Woodland Stands	Link	
	High Fire Hazard Weedy Woody Vegetation	Link	
	2018 Countywide Fine Scale Vegetation Map	Link	
Fire History	Wildfires 1859-1900	Link	Marin Fire History Report, Dawson 2021
	Wildfires 1901-1940	Link	
	Wildfires 1941-1980	Link	
	Wildfires 1981-2020	Link	
	Number of Times Burned (1859-2020)	Link	
	Years Since Last Fire (1859-2020)	Link	
	Fire Return Interval (1859-1940)	Link	
Built Environment	Building Footprints	Link	2018/19 Countywide Impervious Surface Mapping
	Defensible Space Buffers (100 feet from building footprints)	Link	
	Classified Percent Impervious for Forest Stands	Link	
	Countywide Impervious Surfaces (2018/19)	Link	

CDFW Environmental Data	Spotted Owl Predicted Habitat	Link	CDFW California Wildlife Habitat Relationships (CWHR)
	Foothill Yellow Legged Frog Predicted Habitat	Link	
	California Red Legged Frog Predicted Habitat	Link	
	Marbled Murrelet Predicted Habitat	Link	
	American Badger Predicted Habitat	Link	
	Sensitive Natural Communities (S1-S3)	Link	Crosswalked from 2018 Fine Scale Veg Map and CNPS Marin Floristic Classification Report; CDFW definition
Boundaries	Parks and Open Space Boundaries	Link	California Protected Areas Database (CPAD), 2022
	Marin County Fire Protection Districts	Link	County of Marin
	Marin County WUI	Link	Marin Community Wildfire Protection Plan (CWPP), 2020
Soils and Geology	Marin County Soil Survey by Order	Link	USDA SSURGO and Marin County Soils Survey (Kashiwagi, 1985)
	Geologic Map of California	Link	CA Dept. of Conservation, Generalized Rock Types (2010)

APPENDIX 6C: 2018 MARIN COUNTYWIDE FINE SCALE VEGETATION MAP CROSSWALK TO CDFW SENSITIVE NATURAL COMMUNITIES RANKING (FROM CNPS FLORISTIC CLASSIFICATION REPORT, MARIN)

* - refers to types that were not included in the CNPS classification report due to lack of field data

Fine Scale Map Class	Member Alliance(s)	Global Rarity Rank	State Rarity Rank	Sensitive Natural Community Status	Member Associations	Global Rarity Rank	State Rarity Rank	Sensitive Natural Community	From Mapping Key	Lifeform
Acacia spp. – Grevillea spp. – Leptospermum laevigatum Semi-Natural Alliance	Acacia spp. – Grevillea spp. – Leptospermum laevigatum Shrubland Provisional Semi-Natural Alliance	GNA	SNA	Map class is not a Sensitive Natural Community	Acacia (cyclops, dealbata)	GNA	SNA	N	Acacia (cyclops, dealbata) Association	Non-native Forest
Acer macrophyllum – Alnus rubra Alliance	Acer macrophyllum – Alnus rubra Forest & Woodland Alliance	GNR	SNR	Map class is not a Sensitive Natural Community, but contains one or more Sensitive Natural Communities (Alliances or Associations with S1-S3 ranking)	Acer macrophyllum / (Rubus ursinus)	GNR	SNR	N	Acer macrophyllum Association	Native Forest
					Alnus rubra / Rubus spectabilis – Sambucus racemosa	G3G4	SNR	N	Alnus rubra / Rubus spectabilis – Sambucus racemosa Association	
					Alnus rubra / Salix lasiolepis – Rubus spp.	G4	S3	Y	Alnus rubra / Salix lasiolepis – Rubus spp. Association	
					Umbellularia californica – Acer macrophyllum	G3	S3?	Y	Umbellularia californica – Acer macrophyllum Association	
					Umbellularia californica / Rhododendron occidentale	G3	S3?	Y	Umbellularia californica / Rhododendron occidentale Association	
Acer negundo / (Rubus ursinus) Association	Acer negundo Forest & Woodland Alliance	G5	S2	Map class is a Sensitive Natural Community (S1-S3 ranking)	Acer negundo / (Rubus ursinus)	GNR	SNR	Y	Acer negundo / (Rubus ursinus) Association	Native Forest
Adenostoma fasciculatum Alliance	Adenostoma fasciculatum Shrubland Alliance	G5	S5	Map class is not a Sensitive Natural Community, but contains one or more Sensitive Natural Communities (Alliances or Associations with S1-S3 ranking)	Adenostoma fasciculatum	G5	S5	N	Adenostoma fasciculatum Association	Native Shrub
					Adenostoma fasciculatum – Diplacus aurantiacus	G4	S4	N	Adenostoma fasciculatum – Diplacus aurantiac us Association	
					Adenostoma fasciculatum – (Arctostaphylos glandulosa – Ceanothus jepsonii)	G2	S2?	Y	Adenostoma fasciculatum – (Arctostaphylos glandulosa – Ceanothus jepsonii) Association	
Aesculus californica Alliance	Aesculus californica Forest & Woodland Alliance	G3	S3	Map class is a Sensitive Natural Community (S1-S3 ranking)	Aesculus californica – Umbellularia californica	G3	S3?	Y	Aesculus californica – Umbellularia californica Association	Native Forest
					Aesculus californica / Toxicodendron diversilobum / Moss	GNR	SNR	Y	Aesculus californica / Toxicodendron diversilobum / Moss Association	
Alnus rhombifolia Alliance	Alnus rhombifolia Forest & Woodland Alliance	G4	S4	Map class is not a Sensitive Natural Community, but contains one or more Sensitive Natural Communities (Alliances or Associations with S1-S3 ranking)	Alnus rhombifolia – Umbellularia californica – (Quercus chrysolepis)	G3	S3	Y	Alnus rhombifolia – Umbellularia californica – (Quercus chrysolepis) Association	Native Forest
					Alnus rhombifolia – Acer macrophyllum*				Alnus rhombifolia – Acer macrophyllum Associ ation	
Ammophila arenaria Semi-Natural Alliance	Ammophila arenaria Herbaceous Semi-Natural Alliance	GNA	SNA	Map class is not a Sensitive Natural Community	Ammophila arenaria Semi-Natural	GNA	SNA	N	Ammophila arenaria Semi-Natural Association	Non-native Herbaceous
					Baccharis pilularis / Ammophila arenaria Semi-Natural	GNR	SNR	N	Baccharis pilularis / Ammophila arenaria Semi-Natural Association	
Arbutus menziesii Alliance	Arbutus menziesii Forest Alliance	G4	S3	Map class is a Sensitive Natural Community (S1-S3 ranking)	Arbutus menziesii – (Quercus agrifolia)	G3	S3?	Y	Arbutus menziesii – (Quercus agrifolia) Associa tion	Native Forest
					Arbutus menziesii – Umbellularia californica	GNR	SNR	Y	Arbutus menziesii – Umbellularia californica Association	
Arctostaphylos (bakeri, montana) Alliance	Arctostaphylos (bakeri, montana) Shrubland Alliance	G3	S3	Map class is a Sensitive Natural Community (S1-S3 ranking)	Arctostaphylos montana	G1	S2	Y	Arctostaphylos montana Association	Native Shrub
					Arctostaphylos montana – Adenostoma fasciculatum	G2	S2	Y	Arctostaphylos montana – Adenostoma fascic ulatum Association	
Arctostaphylos (canescens, manzanita, stanfordiana) Alliance	Arctostaphylos (canescens, manzanita, stanfordiana) Shrubland Alliance	G3	S3	Map class is a Sensitive Natural Community (S1-S3 ranking)	Arctostaphylos canescens	G3	S3	Y	Arctostaphylos canescens Provisional Association	Native Shrub
					Arctostaphylos canescens – Arctostaphylos glandulosa – Adenostoma fasciculatum	GNR	SNR	Y	Arctostaphylos canescens – Arctostaphylos glandulosa – Adenostoma fasci culatum Provisional Association	
					Arctostaphylos manzanita	G3	S3	Y	Arctostaphylos manzanita Association	
Arctostaphylos (nummularia, sensitiva) – Chrysolepis chrysophylla Alliance	Arctostaphylos (nummularia, sensitiva) – Chrysolepis chrysophylla Shrubland Alliance	G2	S2	Map class is a Sensitive Natural Community (S1-S3 ranking)	Arctostaphylos sensitiva	GNR	SNR	Y	Arctostaphylos sensitiva	Native Shrub
					Chrysolepis chrysophylla – Arctostaphylos glandulosa Association	GNR	SNR	Y	Chrysolepis chrysophylla – Arctostaphylos glandulosa	
					Chrysolepis chrysophylla / Vaccinium ovatum Association	GNR	SNR	Y	Chrysolepis chrysophylla / Vaccinium ovatum	
Arctostaphylos glandulosa Alliance	Arctostaphylos glandulosa Shrubland Alliance	G4	S4	Map class is not a Sensitive Natural Community, but contains one or more Sensitive Natural Communities (Alliances or Associations with S1-S3 ranking)	Arctostaphylos glandulosa	G3G4	SNR	N	Arctostaphylos glandulosa Association	Native Shrub
					Arctostaphylos glandulosa – Adenostoma fasciculatum	GNR	SNR	N	Arctostaphylos glandulosa – Adenostoma fasci culatum Association	
					Arctostaphylos glandulosa – Adenostoma fasciculatum – Quercus wislizeni	G3	S3?	Y	Arctostaphylos glandulosa – Adenostoma fasci culatum – Quercus wislizeni Association	
Arid West Freshwater Marsh Group	Schoenoplectus (acutus, californicus) Herbaceous Alliance	GNR	S3S4	Map class is not a Sensitive Natural Community, but contains one or more Sensitive Natural Communities (Alliances or Associations with S1-S3 ranking)	Schoenoplectus acutus	GNR	SNR	Y	Schoenoplectus acutus Association	Freshwater Wetland
					Schoenoplectus californicus	GNR	SNR	Y	Schoenoplectus californicus Association	
	Typha (angustifolia, domingensis, latifolia) Herbaceous Alliance	G5	S5		Typha (latifolia, angustifolia)	GNR	SNR	N	Typha (latifolia, angustifolia) Association	
					Typha domingensis	GNR	SNR	N	Typha domingensis Association	
Artemisia californica – (Salvia leucophylla) Alliance	Artemisia californica – (Salvia leucophylla) Shrubland Alliance	G5	S5	Map class is not a Sensitive Natural Community, but contains one or more Sensitive Natural Communities (Alliances or Associations with S1-S3 ranking)	Artemisia californica	G4	S4	N	Artemisia californica Association	Native Shrub
					Artemisia californica – Diplacus aurantiacus	G3	S3	Y	Artemisia californica – Diplacus aurantiacus Association	
					Artemisia californica / Nassella (pulchra)	GNR	SNR	N	Artemisia californica / Nassella (pulchra) Association	
Artemisia pycnocephala Association	Eriophyllum staechadifolium – Erigeron glaucus – Eriogonum latifolium Herbaceous Alliance	G3	S3	Map class is a Sensitive Natural Community (S1-S3 ranking)	Artemisia pycnocephala	GNR	SNR	Y	Artemisia pycnocephala Association	Native Shrub
Atriplex prostrata – Cotula coronopifolia Semi-Natural Alliance	Atriplex prostrata – Cotula coronopifolia Herbaceous Semi-Natural Alliance	GNA	SNA	Map class is not a Sensitive Natural Community	Atriplex prostrata*				Atriplex prostrata Semi-Natural Association	Tidal Wetland
					Cotula coronopifolia	GNA	SNA	N	Cotula coronopifolia Semi-Natural Association	
					Baccharis pilularis	G4	SNR	N	Baccharis pilularis Association	
					Baccharis pilularis – Artemisia californica	G5	S5	N	Baccharis pilularis – Artemisia californica Association	
					Baccharis pilularis – Ceanothus thyrsiflorus	G3	S3?	Y	Baccharis pilularis – Ceanothus thyrsiflorus Association	

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Fine Scale Map Class	Member Alliance(s)	Global Rarity Rank	State Rarity Rank	Sensitive Natural Community Status	Member Associations	Global Rarity Rank	State Rarity Rank	Sensitive Natural Community	From Mapping Key	Lifeform
Baccharis pilularis Alliance	Baccharis pilularis Shrubland Alliance	G5	S5	Map class is not a Sensitive Natural Community, but contains one or more Sensitive Natural Communities (Alliances or Associations with S1-S3 ranking)	Baccharis pilularis – (Frangula californica) – Rubus spp.	GNR	SNR	N	Baccharis pilularis – (Frangula californica) – Rubus spp. Association	Native Shrub
					Baccharis pilularis – Toxicodendron diversilobum	G5	S5?	N	Baccharis pilularis – Toxicodendron diversilobum Association	
					Baccharis pilularis / (Nassella pulchra – Elymus glaucus – Bromus carinatus)	G3	S3	Y	Baccharis pilularis / (Nassella pulchra – Elymus glaucus – Bromus carinatus) Association	
					Baccharis pilularis / Annual Grass – Herb	G5	S5	N	Baccharis pilularis / Annual Grass – Herb Association	
					Baccharis pilularis / Carex obnupta – Juncus patens Provisional	G3	S3?	Y	Baccharis pilularis / Carex obnupta – Juncus patens Provisional Association	
					Baccharis pilularis / Danthonia californica	G2	S2	Y	Baccharis pilularis / Danthonia californica Association	
					Baccharis pilularis / Deschampsia cespitosa	G2	S1.2	Y	Baccharis pilularis / Deschampsia cespitosa As sociation	
					Baccharis pilularis / Eriophyllum staechadifolium	G3	S3	Y	Baccharis pilularis / Eriophyllum staechadifoliu m Association	
Bolboschoenus maritimus Alliance	Bolboschoenus maritimus Herbaceous Alliance	G4	S3	Map class is a Sensitive Natural Community (S1-S3 ranking)	Bolboschoenus maritimus*			Y	Bolboschoenus maritimus Association	Tidal Wetland
					Bolboschoenus maritimus – Sarcocornia pacifica	GNR	SNR	Y	Bolboschoenus maritimus – Sarcocornia pacifica Association	
Calamagrostis nutkaensis Alliance	Calamagrostis nutkaensis Herbaceous Alliance	G4	S2	Map class is a Sensitive Natural Community (S1-S3 ranking)	Calamagrostis nutkaensis	GNR	SNR	Y	Calamagrostis nutkaensis Association	Non-native Herbaceous
					Calamagrostis nutkaensis – Carex (obnupta) – Juncus (patens)	G2	S2.1	Y	Calamagrostis nutkaensis – Carex (obnupta) – Juncus (patens) Association	
					Calamagrostis nutkaensis / Baccharis pilularis	G2	S1.2	Y	Calamagrostis nutkaensis / Baccharis pilularis Association	
	Amsinckia (menziesii, tessellata) – Phacelia spp. Herbaceous Alliance	G5	S5							
	Eschscholzia (californica) – Lupinus (nanus) Herbaceous Alliance	G4	S4		Bromus hordeaceus – Lupinus nanus – Trifolium spp.	GNR	SNR	N	Bromus hordeaceus – Lupinus nanus – Trifolium spp. Association	
					Eschscholzia californica	GNR	SNR	N	Eschscholzia californica Association	
					Lupinus bicolor Provisional	G3	S3	Y	Lupinus bicolor Provisional Association	
	Lasthenia californica – Plantago erecta – Vulpia microstachys Herbaceous Alliance	G4	S4		Hemizonia congesta – Lolium perenne	GNR	SNR	N	Hemizonia congesta – Lolium perenne Association	
					Lasthenia californica – Plantago erecta – Hesperevax sparsiflora	GNR	SNR	N	Lasthenia californica – Plantago erecta – Hesperevax sparsiflora Asso ciation	
					Lotus humistratus – Plantago erecta – Lomatium spp.	GNR	SNR	N	Lotus humistratus – Plantago erecta – Lomatium spp. Provisional Association	
					Plantago erecta – Lolium perenne lichen-rocky	GNR	SNR	N	Plantago erecta – Lolium perenne lichen-rocky Association	
					Vulpia microstachys – Plantago erecta – Calycadenia (truncata, multiglandulosa)	G2	S2?	Y	Vulpia microstachys – Plantago erecta – Calycadenia (truncata, multig landulosa) Association	
	Corethrogyne filaginifolia - Eriogonum (elongatum, nudum) Alliance	G4	S4		Eriogonum nudum	GNR	SNR	N	Eriogonum nudum Provisional Association	
	Nassella spp. – Melica spp. Herbaceous Alliance	G3G4	S3S4		Elymus multisetus – (Eschscholzia californica – Plantago erecta)	GNR	SNR	Y	Elymus multisetus – (Eschscholzia californica – Plantago erecta) Association	
					Melica californica	GNR	SNR	Y	Melica californica Association	
					Melica torreyana	GNR	SNR	Y	Melica torreyana Association	
					Nassella pulchra	GNR	SNR	Y	Nassella pulchra Association	
					Nassella pulchra – Avena spp. – Bromus spp.	G3	S3?	Y	Nassella pulchra – Avena spp. – Bromus spp. Association	
					Nassella pulchra – Hemizonia congesta	GNR	SNR	Y	Nassella pulchra – Hemizonia congesta Association	
					Nassella pulchra – Lolium perenne – Plantago erecta Serpentine	GNR	SNR	Y	Nassella pulchra – Lolium perenne – Plantago erecta Serpentine Association	
					Nassella pulchra – Lolium perenne – (Trifolium spp.)	G3	S3?	Y	Nassella pulchra – Lolium perenne – (Trifolium spp.) Association	
	Avena spp. – Bromus spp. Semi-Natural Herbaceous Alliance	GNA	SNA		Avena barbata – Avena fatua	GNA	SNA	N	Avena barbata – Avena fatua Semi-Natural Association	
					Brachypodium distachyon	GNA	SNA	N	Brachypodium distachyon Semi-Natural Association	
					Briza maxima Provisional	GNA	SNA	N	Briza maxima Provisional Semi-Natural Association	
					Bromus diandrus	GNA	SNA	N	Bromus diandrus Semi-Natural Association	
					Bromus hordeaceus – Erodium botrys	GNA	SNA	N	Bromus hordeaceus – Erodium botrys Semi-Natural Association	
					Hypochaeris glabra – Vulpia bromoides	GNA	SNA	N	Hypochaeris glabra – Vulpia bromoides Semi-Natural Association	
	Brassica nigra – Centaurea (solstitialis, melitensis) Herbaceous Semi-Natural Alliance	GNA	SNA		Brassica nigra	GNA	SNA	N	Brassica nigra Semi-Natural Association	
					Raphanus sativus	GNA	SNA	N	Raphanus sativus Semi-Natural Association	
					Carduus pycnocephalus – Silybum marianum Provisional	GNA	SNA	N	Carduus pycnocephalus – Silybum marianum Provisional Semi-Natural Association	

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Fine Scale Map Class	Member Alliance(s)	Global Rarity Rank	State Rarity Rank	Sensitive Natural Community Status	Member Associations	Global Rarity Rank	State Rarity Rank	Sensitive Natural Community	From Mapping Key	Lifeform
Californian Annual & Perennial Grassland Mapping Unit				Map class is not a Sensitive Natural Community, but contains one or more Sensitive Natural Communities (Alliances or Associations with S1-S3 ranking)	Centaurea solstitialis*				Centaurea solstitialis Semi-Natural Association	Herbaceous
	Cynosurus echinatus – Arrhenatherum elatius Herbaceous Semi-Natural Alliance	GNA	SNA		Cynosurus echinatus – (Danthonia pilosa – Nassella manicata)	GNA	SNA	N	Cynosurus echinatus – (Danthonia pilosa – Nassella manicata) Provisional Semi-Natural Association	
	Lolium perenne Herbaceous Semi-Natural Alliance	GNA	SNA		Lolium perenne	GNA	SNA	N	Lolium perenne Semi-Natural Association	
					Lolium perenne – Hordeum marinum – Ranunculus californicus	GNA	SNA	N	Lolium perenne – Hordeum marinum – Ranunculus californicus Semi-Natural Association	
					Lolium perenne – Lotus corniculatus	GNA	SNA	N	Lolium perenne – Lotus corniculatus Semi-Natural Association	
	Poa pratensis – Agrostis gigantea – Agrostis stolonifera Herbaceous Semi-Natural Alliance	GNA	SNA		Festuca arundinacea	GNA	SNA	N	Festuca arundinacea Provisional Semi-Natural Association	
	Phalaris aquatica – Phalaris arundinacea Herbaceous Semi-Natural Alliance	GNA	SNA		Phalaris aquatica	GNA	SNA	N	Phalaris aquatica Provisional Semi-Natural Association	
					Phalaris aquatica – Avena barbata	GNA	SNA	N	Phalaris aquatica – Avena barbata Provisional Semi-Natural Association	
	Holcus lanatus – Anthoxanthum odoratum Herbaceous Semi-Natural Alliance	GNA	SNA		Holcus lanatus Semi-Natural	GNA	SNA	N	Holcus lanatus Semi-Natural Association	
					Holcus lanatus – Anthoxanthum odoratum	GNA	SNA	N	Holcus lanatus – Anthoxanthum odoratum Semi-Natural Association	
	Bromus carinatus – Elymus glaucus Herbaceous Alliance	G3	S3		Bromus carinatus	G3	S3	Y	Bromus carinatus Association	
					Elymus glaucus	G3	S3	Y	Elymus glaucus Association	
					Pteridium aquilinum – Grass	G3	S3	Y	Pteridium aquilinum – Grass Association	
					Thermopsis californica – Bromus carinatus – Annual Brome	G3	S3	Y	Thermopsis californica – Bromus carinatus – Annual Brome Association	
	Festuca idahoensis – Danthonia californica Herbaceous Alliance	GNR	S3		Danthonia californica – Nassella pulchra	GNR	SNR	Y	Danthonia californica – Nassella pulchra Association	
					Danthonia californica Coastal	GNR	SNR	Y		
					Festuca californica	GNR	SNR	Y	Festuca californica Association	
					Festuca idahoensis – (Danthonia californica – Koeleria macrantha)	GNR	SNR	Y	Festuca idahoensis – (Danthonia californica – Koeleria macrantha) Association	
					Festuca idahoensis – Nassella pulchra	GNR	SNR	Y	Festuca idahoensis – Nassella pulchra Provisional Association	
					Festuca idahoensis Ultramafic	GNR	SNR	Y	Festuca idahoensis Ultramafic Provisional Association	
					Festuca rubra	GNR	SNR	Y	Festuca rubra Association	
					Heterotheca sessiliflora – Danthonia californica	G3	S3	Y	Heterotheca sessiliflora – Danthonia californica Provisional Association	
					Perideridia kelloggii – Danthonia californica	GNR	SNR	Y	Perideridia kelloggii – Danthonia californica Provisional Association	
	Deschampsia cespitosa – Hordeum brachyantherum – Danthonia californica Herbaceous Alliance	GNR	S3		Deschampsia cespitosa – Danthonia californica	G2	S2	Y	Deschampsia cespitosa – Danthonia californica Association	
					Deschampsia cespitosa – Eryngium armatum	GNR	SNR	Y	Deschampsia cespitosa – Eryngium armatum Association	
					Deschampsia cespitosa – Horkelia marinensis	G3	S1?	Y	Deschampsia cespitosa – Horkelia marinensis Association	
					Deschampsia cespitosa – Iris douglasiana	GNR	SNR	Y	Deschampsia cespitosa – Iris douglasiana Association	
					Deschampsia (cespitosa, holciformis)	GNR	SNR	Y	Deschampsia (cespitosa, holciformis) Association	
					Hordeum brachyantherum Lowland	G2	SNR	Y	Hordeum brachyantherum Lowland Association	
Californian Cliff, Scree & Rock Vegetation Group	Dudleya cymosa – Dudleya lanceolata / Lichen – Moss Sparsely Vegetated Alliance	G4	S4	Map class is not a Sensitive Natural Community, but contains one or more Sensitive Natural Communities (Alliances or Associations with S1-S3 ranking)	Dudleya farinosa / Lichen – Moss	GNR	SNR	N	Dudleya farinosa / Lichen – Moss Provisional Association	Barren
	Allium spp. –Streptanthus spp. – Hesperolinon spp. Serpentinite Sparsely Vegetated Alliance	G2G3	S2S3		Allium falcifolium – Eriogonum luteolum – Streptanthus (batrachopus, morrisonii)	G2	S2?	Y	Allium falcifolium – Eriogonum luteolum – Streptanthus (batrachopus, morrisonii) Association	
					Streptanthus glandulosus – Dudleya abramsii / Lichen – Moss	GNR	SNR	Y	Streptanthus glandulosus – Dudleya abramsii / Lichen – Moss Association	
	Sedum spathulifolium Herbaceous Provisional Alliance	G4?	S4?		Sedum spathulifolium – Polypodium californicum / Lichen – Moss	GNR	SNR	N	Sedum spathulifolium – Polypodium californicum / Lichen – Moss Provisional Association	
	Selaginella (bigelovii, wallacei) Herbaceous Alliance	G4	S3		Selaginella wallacei / Lichen – Moss	GNR	SNR	Y	Selaginella wallacei / Lichen – Moss Provisional Association	
Californian Vernal Pool / Swale Bottomland Group	Eryngium aristulatum Herbaceous Alliance	G2	S2	Map class is a Sensitive Natural Community (S1-S3 ranking)						Herbaceous
	Lasthenia glaberrima Herbaceous Alliance	G2	S2		Lasthenia glaberrima – Pleuropogon californicus	GNR	SNR	Y	Lasthenia glaberrima – Pleuropogon californicus Association	
	Eleocharis (acicularis, macrostachya) Herbaceous Alliance	GNR	S3S4		Eleocharis macrostachya	GNR	SNR	Y	Eleocharis macrostachya Association	
	Trifolium variegatum Herbaceous Alliance	G3?	S3?		Trifolium variegatum	GNR	SNR	Y	Trifolium variegatum Association	
Carthamus lanatus Invasive Mapping Unit	Brassica nigra – Centaurea (solstitialis, melitensis) Herbaceous Semi-Natural Alliance	GNA	SNA	Map class is not a Sensitive Natural Community	Carthamus lanatus (Mapping Unit)	GNA	SNA	N	Carthamus lanatus Invasive Mapping Unit	Non-native Herbaceous
					Ceanothus cuneatus	G4?	SNR	N	Ceanothus cuneatus Association	

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Ceanothus cuneatus Alliance	Ceanothus cuneatus Shrubland Alliance	G4	S4	Map class is not a Sensitive Natural Community	Ceanothus cuneatus – Adenostoma fasciculatum	GNR	SNR	N	Ceanothus cuneatus – Adenostoma fasciculatum Association	Native Shrub
Ceanothus thyrsiflorus Alliance	Ceanothus thyrsiflorus Shrubland Alliance	G4	S4	Map class is not a Sensitive Natural Community, but contains one or more Sensitive Natural Communities (Alliances or Associations with S1-S3 ranking)	Ceanothus thyrsiflorus – Baccharis pilularis – Toxicodendron diversilobum	G4?	SNR	N	Ceanothus thyrsiflorus – Baccharis pilularis – Toxicodendron diversilobum Association	Native Shrub
					Ceanothus thyrsiflorus – (Rubus ursinus)	G3	S3?	Y	Ceanothus thyrsiflorus – (Rubus ursinus) Association	
					Ceanothus thyrsiflorus – Vaccinium ovatum – Rubus parviflorus	G3	S3?	Y	Ceanothus thyrsiflorus – Vaccinium ovatum – Rubus parviflorus Association	
Conium maculatum – Foeniculum vulgare Semi-Natural Alliance	Conium maculatum – Foeniculum vulgare Herbaceous Semi-Natural Alliance	GNA	SNA	Map class is not a Sensitive Natural Community	Conium maculatum	GNA	SNA	N	Conium maculatum Semi-Natural Association	Non-native Herbaceous
					Foeniculum vulgare*				Foeniculum vulgare Semi-Natural Association	
					Dipsacus (fullonum, sativus)	GNA	SNA	N	Dipsacus (fullonum, sativus) Provisional Semi-Natural Association	
					Ageratina adenophora*				Ageratina adenophora Invasive Mapping Unit	
Cortaderia (jubata, selloana) Semi-Natural Alliance	Cortaderia (jubata, selloana) Herbaceous Semi-Natural Alliance	GNA	SNA	Map class is not a Sensitive Natural Community	Cortaderia (jubata, selloana)	GNA	SNA	N	Cortaderia (jubata, selloana) Provisional Semi-Natural Association	Non-native Herbaceous
					Echium candicans*				Echium candicans Semi-Natural Association	
Corylus cornuta / Polystichum munitum Association	Corylus cornuta var. californica Shrubland Alliance	G3	S2?	Map class is a Sensitive Natural Community (S1-S3 ranking)	Corylus cornuta / Polystichum munitum	G2	S2?	Y	Corylus cornuta / Polystichum munitum Association	Native Shrub
Cotoneaster (lacteus, pannosus) Provisional Semi-Natural Association	Cytisus scoparius – Genista monspessulana – Cotoneaster spp. Shrubland Semi-Natural Alliance	GNA	SNA	Map class is not a Sensitive Natural Community	Cotoneaster (lacteus, pannosus)	GNA	SNA	N	Cotoneaster (lacteus, pannosus) Provisional Semi-Natural Association	Non-native Herbaceous
Cytisus scoparius Provisional Semi-Natural Association	Cytisus scoparius – Genista monspessulana – Cotoneaster spp. Shrubland Semi-Natural Alliance	GNA	SNA	Map class is not a Sensitive Natural Community	Cytisus scoparius	GNA	SNA	N	Cytisus scoparius Provisional Semi-Natural Association	Non-native Shrub
Distichlis spicata Alliance	Distichlis spicata Herbaceous Alliance	GNR	S4	Map class is not a Sensitive Natural Community, but contains one or more Sensitive Natural Communities (Alliances or Associations with S1-S3 ranking)	Distichlis spicata*				Distichlis spicata Association	Tidal Wetland
					Distichlis spicata – annual grasses	GNR	SNR	N	Distichlis spicata – annual grasses Association	
					Distichlis spicata – Frankenia salina – Jaumea carnosa	G3	S2.2	Y	Distichlis spicata – Frankenia salina – Jaumea carnosa Association	
					Distichlis spicata – (Sarcocornia pacifica)	GNR	SNR	N	Distichlis spicata – (Sarcocornia pacifica) Association	
					Frankenia salina – Limonium californicum – Monanthochloe littoralis – Sarcocornia pacifica*				Frankenia salina – Limonium californicum – Monanthochloe littoralis – Sarcocornia pacifica	
Eriophyllum staechadifolium – Erigeron glaucus – Eriogonum latifolium Alliance	Eriophyllum staechadifolium – Erigeron glaucus – Eriogonum latifolium Herbaceous Alliance	G3	S3	Map class is a Sensitive Natural Community (S1-S3 ranking)	Erigeron glaucus – Fragaria chiloensis	GNR	SNR	Y	Erigeron glaucus – Fragaria chiloensis Association	Herbaceous
					Artemisia pycnocephala	GNR	SNR	Y	Artemisia pycnocephala Association	
					Eriophyllum staechadifolium – Eriogonum latifolium	GNR	SNR	Y	Eriophyllum staechadifolium – Eriogonum latifolium Association	
Eucalyptus (globulus, camaldulensis) Provisional Semi-Natural Assocation	Eucalyptus spp. – Ailanthus altissima – Robinia pseudoacacia Woodland Semi-Natural Alliance	GNA	SNA	Map class is not a Sensitive Natural Community	Ailanthus altissima*				Ailanthus altissima Semi-Natural Association	Non-native Forest
					Acacia melanoxylon	GNA	SNA	N	Acacia melanoxylon Provisional Semi-Natural Association	
Frangula californica ssp. californica – Baccharis pilularis / Scrophularia californica Association	Baccharis pilularis Shrubland Alliance	G5	S5	Map class is not a Sensitive Natural Community	Frangula californica ssp. californica – Baccharis pilularis / Scrophularia californica	G4	S4	N	Frangula californica ssp. californica – Baccharis pilularis / Scrophularia californica Association	Native Shrub
Fraxinus latifolia Alliance	Fraxinus latifolia Woodland Alliance	G4	S3	Map class is a Sensitive Natural Community (S1-S3 ranking)	Fraxinus latifolia*			Y	Fraxinus latifolia Association	Native Forest
					Fraxinus latifolia – Alnus rhombifolia*			Y	Fraxinus latifolia – Alnus rhombifolia Association	
Garrya elliptica Provisional Association	Baccharis pilularis Shrubland Alliance	G5	S5	Map class is not a Sensitive Natural Community	Garrya elliptica	GNR	SNR	N	Garrya elliptica Provisional Association	Native Shrub
Gaultheria shallon – Rubus (ursinus) Alliance	Gaultheria shallon – Rubus (ursinus) Shrubland Alliance	GNR	S4	Map class is not a Sensitive Natural Community, but contains one or more Sensitive Natural Communities (Alliances or Associations with S1-S3 ranking)	Gaultheria shallon – Vaccinium ovatum / Pteridium aquilinum	GNR	SNR	N	Gaultheria shallon – Vaccinium ovatum / Pteridium aquilinum Association	Native Shrub
					Holodiscus discolor – Baccharis pilularis – Rubus ursinus	G3	S3?	Y	Holodiscus discolor – Baccharis pilularis – Rubus ursinus Association	
					Rubus parviflorus	GNR	SNR	N	Rubus parviflorus Association	
					Rubus ursinus	GNR	SNR	N	Rubus ursinus Association	
Genista monspessulana Semi-Natural Association	Cytisus scoparius – Genista monspessulana – Cotoneaster spp. Shrubland Semi-Natural Alliance	GNA	SNA	Map class is not a Sensitive Natural Community	Genista monspessulana	GNA	SNA	N	Genista monspessulana Semi-Natural Association	Non-native Shrub
Grindelia stricta Provisional Association	Grindelia (stricta) Herbaceous Provisional Alliance	G2G3	S2S3	Map class is a Sensitive Natural Community (S1-S3 ranking)	Grindelia stricta	GNR	SNR	Y	Grindelia stricta Provisional Association	Tidal Wetland
Hesperocyparis macrocarpa Ruderal Provisional Semi-Natural Association	Hesperocyparis macrocarpa – Pinus radiata Woodland Semi-Natural Alliance	GNA	SNA	Map class is not a Sensitive Natural Community	Hesperocyparis macrocarpa Ruderal	GNA	SNA	N	Hesperocyparis macrocarpa Ruderal Provisional Semi-Natural Association	Native Forest
Hesperocyparis sargentii / Ceanothus jepsonii – Arctostaphylos spp. Association	Hesperocyparis (sargentii, macnabiana) Alliance	G3	S3	Map class is a Sensitive Natural Community (S1-S3 ranking)	Hesperocyparis sargentii / Ceanothus jepsonii – Arctostaphylos spp.	G1	S1.2	Y	Hesperocyparis sargentii / Ceanothus jepsonii – Arctostaphylos spp. Association	Native Forest
Hesperocyparis sargentii Association	Hesperocyparis (sargentii, macnabiana) Woodland Alliance	G3	S3	Map class is a Sensitive Natural Community (S1-S3 ranking)	Hesperocyparis sargentii	G2	SNR	Y	Hesperocyparis sargentii Association	Native Forest
Lepidium latifolium – (Lactuca serriola) Semi-Natural Alliance	Lepidium latifolium – (Lactuca serriola) Herbaceous Semi-Natural Alliance	GNA	SNA	Map class is not a Sensitive Natural Community	Lepidium latifolium	GNA	SNA	N	Lepidium latifolium Semi-Natural Association	Freshwater Wetland
Lotus scoparius – Lupinus albifrons – Eriodictyon spp. Alliance	Lotus scoparius – Lupinus albifrons – Eriodictyon spp. Shrubland Alliance	G5	S5	Map class is not a Sensitive Natural Community	Eriodictyon californicum / Herbaceous	GNR	SNR	N	Eriodictyon californicum / Herbaceous Association	Herbaceous
					Lupinus albifrons	G3?	SNR	N	Lupinus albifrons Association	
Lupinus arboreus Alliance	Lupinus arboreus Shrubland Alliance	G4	S4	Map class is not a Sensitive Natural Community, but contains one or more Sensitive Natural Communities (Alliances or Associations with S1-S3 ranking)	Baccharis pilularis – Lupinus arboreus	G3	S3?	Y	Baccharis pilularis – Lupinus arboreus Association	Native Shrub
					Lupinus arboreus	GNR	SNR	N	Lupinus arboreus Association	

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Fine Scale Map Class	Member Alliance(s)	Global Rarity Rank	State Rarity Rank	Sensitive Natural Community Status	Member Associations	Global Rarity Rank	State Rarity Rank	Sensitive Natural Community	From Mapping Key	Lifeform
Lupinus chamissonis – Ericameria ericoides Alliance	Lupinus chamissonis – Ericameria ericoides Shrubland Alliance	G3	S3	Map class is a Sensitive Natural Community (S1-S3 ranking)	Ericameria ericoides	GNR	SNR	Y	Ericameria ericoides Association	Native Shrub
					Lupinus chamissonis	GNR	SNR	Y	Lupinus chamissonis Association	
					Lupinus chamissonis – Ericameria ericoides	G2	S2.2	Y	Lupinus chamissonis – Ericameria ericoides As sociation	
Mesembryanthemum spp. – Carpobrotus spp. Semi-Natural Alliance	Mesembryanthemum spp. – Carpobrotus spp. Herbaceous Semi-Natural Alliance	GNA	SNA	Map class is not a Sensitive Natural Community	Carpobrotus (edulis)	GNA	SNA	N	Carpobrotus (edulis) Semi-Natural Association	Non-native Herbaceous
Notholithocarpus densiflorus Alliance	Notholithocarpus densiflorus Forest Alliance	G4	S3	Map class is a Sensitive Natural Community (S1-S3 ranking)	Notholithocarpus densiflorus – Arbutus menziesii	G3	S3	Y	Notholithocarpus densiflorus – Arbutus menziesii Association	Native Forest
					Notholithocarpus densiflorus – Quercus chrysolepis	GNR	SNR	Y	Notholithocarpus densiflorus – Quercus chrysolepis Association	
					Notholithocarpus densiflorus / Vaccinium ovatum	GNR	SNR	Y	Notholithocarpus densiflorus / Vaccinium ovatum Association	
Pacific Coastal Beach & Dune Macrogroup	Abronia latifolia – Ambrosia chamissonis Herbaceous Alliance	G3	S3	Map class is a Sensitive Natural Community (S1-S3 ranking)	Ambrosia chamissonis	GNR	SNR	Y	Ambrosia chamissonis Association	Herbaceous
					Abronia latifolia – Calystegia soldanella – Lathyrus littoralis	GNR	SNR	Y	Abronia latifolia – Calystegia soldanella – Lathyrus littoralis Association	
	Leymus mollis Herbaceous Alliance	G4	S2		Leymus mollis – Abronia latifolia – (Cakile spp.)	GNR	SNR	Y	Leymus mollis – Abronia latifolia – (Cakile spp.) Association	
Pinus muricata – Pinus radiata Alliance	Pinus muricata - Pinus radiata Forest & Woodland Alliance	G3	S3	Map class is a Sensitive Natural Community (S1-S3 ranking)	Pinus muricata	G3?	S3?	Y	Pinus muricata Provisional Association	Native Forest
					Pinus muricata – (Arbutus menziesii – Notholithocarpus densiflo rus) / Vaccinium ovatum	G2	S2	Y	Pinus muricata – (Arbutus menziesii – Notholithocarp us densiflorus) / Vaccinium ovatum Association	
					Pinus muricata / Ceanothus thyrsiflorus – Baccharis pilularis	GNR	SNR	Y	Pinus muricata / Ceanothus thyrsiflorus – Baccharis pilularis Association	
					Pinus muricata / Arctostaphylos glandulosa	G2	S2	Y	Pinus muricata / Arctostaphylos glandulosa Provisional Associat ion	
Pinus radiata Plantation Provisional Semi-Natural Association	Hesperocyparis macrocarpa – Pinus radiata Woodland Semi-Natural Alliance	GNA	SNA	Map class is not a Sensitive Natural Community	Pinus radiata Plantation Provisional	GNA	SNA	N	Pinus radiata Plantation Provisional Semi-Natural Association	Native Forest
Populus fremontii – Fraxinus velutina – Salix gooddingii Alliance	Populus fremontii - Fraxinus velutina - Salix gooddingii Forest & Woodland Alliance	G4	S3.2	Map class is a Sensitive Natural Community (S1-S3 ranking)	Populus fremontii / Acer negundo*			Y	Populus fremontii / Acer negundo Association*	Native Forest
					Populus fremontii / Salix exigua*			Y	Populus fremontii / Salix exigua Association*	
Pseudotsuga menziesii – (Notholithocarpus densiflorus – Arbutus menziesii) Alliance	Pseudotsuga menziesii – (Notholithocarpus densiflorus – Arbutus menziesii) Forest & Woodland Alliance	G5	S4	Map class is not a Sensitive Natural Community, but contains one or more Sensitive Natural Communities (Alliances or Associations with S1-S3 ranking)	Pseudotsuga menziesii – (Umbellularia californica) / Frangula californica	G4	S4?	N	Pseudotsuga menziesii – Umbellularia californica / Frangula californica Association	Native Forest
					Pseudotsuga menziesii – Arbutus menziesii	GNR	SNR	N	Pseudotsuga menziesii – Arbutus menziesii Association	
					Pseudotsuga menziesii – Chrysolepis chrysophylla – Notholithocarpus densiflorus	G3	S3	Y	Pseudotsuga menziesii – Chrysolepis chrysoph ylla – Notholithocarpus densiflorus Association	
					Pseudotsuga menziesii – Notholithocarpus densiflorus – Umbellularia californica / Toxicodendron diversilobum	GNR	SNR	N		
					Pseudotsuga menziesii – Notholithocarpus densiflorus / Vaccinium ovatum	GNR	SNR	N		
					Pseudotsuga menziesii – Quercus agrifolia	G3	S3?	Y	Pseudotsuga menziesii – Quercus agrifolia Association	
					Pseudotsuga menziesii – Quercus chrysolepis	G3?	S3?	Y	Pseudotsuga menziesii – Quercus chrysolepis Association	
					Pseudotsuga menziesii – Umbellularia californica / (Toxicodendron diversilobum)	GNR	SNR	N	Pseudotsuga menziesii – Umbellularia californica / (Toxicodendron diversilobum) Association	
					Pseudotsuga menziesii – Umbellularia californica / Polystichum munitum	G4	S4?	N	Pseudotsuga menziesii – Umbellularia californica / Polystichum munitum Association	
					Pseudotsuga menziesii / (Toxicodendron diversilobum)	G4	S4	N	Pseudotsuga menziesii / (Toxicodendron diversilobum) Association	
					Pseudotsuga menziesii / Baccharis pilularis	G4	S4?	N	Pseudotsuga menziesii / Baccharis pilularis Association	
					Pseudotsuga menziesii / Corylus cornuta / Polystichum munitum	GNR	SNR	N	Pseudotsuga menziesii / Corylus cornuta / Polystichum munitum Association	
Quercus (agrifolia, douglasii, garryana, kelloggii, lobata, wislizeni) Alliance	Quercus (agrifolia, douglasii, garryana, kelloggii, lobata, wislizeni) Forest & Woodland Alliance	G4	S4	Map class is not a Sensitive Natural Community	Quercus agrifolia – Quercus garryana – Quercus kelloggii	GNR	SNR	N	Quercus agrifolia – Quercus garryana – Quercu s kelloggii Provisional Association	Native Forest
Quercus agrifolia Alliance	Quercus agrifolia Forest & Woodland Alliance	G5	S4	Map class is not a Sensitive Natural Community, but contains one or more Sensitive Natural Communities (Alliances or Associations with S1-S3 ranking)	Quercus agrifolia – Arbutus menziesii – Umbellularia californica	G3	S3	Y	Quercus agrifolia – Arbutus menziesii – Umbellularia californica Association	Native Forest
					Quercus agrifolia – Arbutus menziesii / Corylus cornuta – Rubus spp.	GNR	SNR	N	Quercus agrifolia – Arbutus menziesii / Corylus cornuta – Rubus spp. Association	
					Quercus agrifolia – Quercus kelloggii	GNR	SNR	N	Quercus agrifolia – Quercus kelloggii Association	
					Quercus agrifolia – Umbellularia californica / Heteromeles arbutifolia – Quercus berberidifolia	GNR	SNR	N		
					Quercus agrifolia / Adenostoma fasciculatum – (Salvia mellifera)	G3	S3	Y	Quercus agrifolia / Adenostoma fasciculatum – (Salvia mellifera) Association	
					Quercus agrifolia / grass	GNR	SNR	N	Quercus agrifolia/ grass Association	
					Quercus agrifolia / Toxicodendron diversilobum	GNR	SNR	N	Quercus agrifolia / Toxicodendron diversilobum Association	
					Quercus chrysolepis – Arbutus menziesii – Notholithocarpus densiflorus var. den siflorus	G4	S4?	N	Quercus chrysolepis – Arbutus menziesii – Notholithocarpus densiflor us var. densiflorus Association	

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Fine Scale Map Class	Member Alliance(s)	Global Rarity Rank	State Rarity Rank	Sensitive Natural Community Status	Member Associations	Global Rarity Rank	State Rarity Rank	Sensitive Natural Community	From Mapping Key	Lifeform
Quercus chrysolepis Alliance	Quercus chrysolepis (tree) Forest & Woodland Alliance	G5	S5	Map class is not a Sensitive Natural Community	Quercus chrysolepis – Umbellularia californica	G4?	SNR	N	Quercus chrysolepis – Umbellularia californica Association	Native Forest
					Quercus chrysolepis / Quercus (wislizeni, parvula)	GNR	SNR	N	Quercus chrysolepis / Quercus (wislizeni, parvula) Association	
Quercus douglasii Alliance	Quercus douglasii Forest &Woodland Alliance	G4	S4	Map class is not a Sensitive Natural Community, but contains one or more Sensitive Natural Communities (Alliances or Associations with S1-S3 ranking)	Quercus × eplingii / Grass	GNR	SNR	Y	Quercus × eplingii / Grass Provisional Association	Native Forest
					Quercus douglasii – Quercus agrifolia	GNR	SNR	N	Quercus douglasii – Quercus agrifolia Association	
					Quercus douglasii / Mixed herbaceous*				Quercus douglasii / Mixed herbaceous Association	
Quercus durata Alliance	Quercus durata Shrubland Alliance	G4	S4	Map class is not a Sensitive Natural Community, but contains one or more Sensitive Natural Communities (Alliances or Associations with S1-S3 ranking)	Quercus durata – Adenostoma fasciculatum	GNR	SNR	N	Quercus durata – Adenostoma fasciculatum Provisional Association	Native Forest
					Quercus durata – Arctostaphylos glandulosa	G3	S3	Y	Quercus durata – Arctostaphylos glandulosa Association	
					Quercus durata – Ceanothus jepsonii	GNR	SNR	N	Quercus durata – Ceanothus jepsonii Association	
Quercus garryana Alliance	Quercus garryana (tree) Forest & Woodland Alliance	G4	S3	Map class is a Sensitive Natural Community (S1-S3 ranking)	Quercus garryana – Umbellularia californica – Quercus (agrifolia, kelloggii)	GNR	SNR	N	Quercus garryana – Umbellularia californica – Quercus (agrifolia, kelloggii) Association	Native Forest
					Quercus garryana / (Cynosurus echinatus – Festuca californica)	GNR	SNR	N	Quercus garryana / (Cynosurus echinatus – Festuca californica) Association	
Quercus kelloggii Alliance	Quercus kelloggii (tree) Forest & Woodland Alliance	G4	S4	Map class is not a Sensitive Natural Community	Quercus kelloggii – Arbutus menziesii – Quercus agrifolia	G3	S3	Y	Quercus kelloggii – Arbutus menziesii – Quercus agrifolia Association	Native Forest
					Quercus kelloggii – Pseudotsuga menziesii – Umbellularia californica	GNR	SNR	N	Quercus kelloggii – Pseudotsuga menziesii – Umbellularia californica Association	
Quercus lobata Mapping Unit	Quercus lobata Forest &Woodland Alliance	G3	S3	Map class is a Sensitive Natural Community (S1-S3 ranking)	Quercus lobata – Quercus agrifolia / Grass	GNR	SNR	Y	Quercus lobata – Quercus agrifolia / Grass Association	Native Forest
					Quercus lobata / Grass	GNR	SNR	Y	Quercus lobata / Grass Association	
Quercus wislizeni – Quercus chrysolepis (shrub) Alliance	Quercus wislizeni – Quercus chrysolepis (shrub) Shrubland Alliance	G4	S3S4	Map class is a Sensitive Natural Community (S1-S3 ranking)	Quercus agrifolia – Quercus chrysolepis – Quercus parvula (shrub)	GNR	SNR	Y	Quercus agrifolia – Quercus chrysolepis – Quercus parvula (shrub) Provisional Association	Native Forest
					Quercus parvula (shrub)	GNR	SNR	Y	Quercus parvula (shrub) Provisional Association	
					Quercus (parvula, wislizeni) – Arctostaphylos glandulosa	G3	S3?	Y	Quercus (parvula, wislizeni) – Arctostaphylos glandulosa Association	
Rhododendron columbianum - Gaultheria shallon / Carex obnupta Association	Rhododendron columbianum Shrubland Alliance	G4	S2?	Map class is a Sensitive Natural Community (S1-S3 ranking)	Rhododendron columbianum - Gaultheria shallon / Carex obnupta	G2	SNR	N	Rhododendron columbianum - Gaultheria shallon / Carex obnupta Association	Non-native Shrub
Rubus armeniacus Semi-Natural Association	Rubus armeniacus – Sesbania punicea – Ficus carica Shrubland Semi-Natural Alliance	GNA	SNA	Map class is not a Sensitive Natural Community	Rubus armeniacus	GNA	SNA	N	Rubus armeniacus Semi-Natural Association	Non-native Shrub
Rubus spectabilis – Morella californica Alliance	Rubus spectabilis – Morella californica Shrubland Alliance	G4	S3	Map class is a Sensitive Natural Community (S1-S3 ranking)	Sambucus racemosa – (Rubus ursinus)	GNR	SNR	Y	Sambucus racemosa – (Rubus ursinus) Provisional Association	Native Shrub
					Morella californica – Rubus spp.	G3	S3	Y	Morella californica – Rubus spp. Provisional Association	
					Rubus spectabilis	G4	S2.2?	Y	Rubus spectabilis Association	
Salix exigua Alliance	Salix exigua Shrubland Alliance	G5	S4	Map class is not a Sensitive Natural Community	Salix exigua	GNR	SNR	N	Salix exigua Alliance	Native Shrub
Salix gooddingii – Salix laevigata Alliance	Salix gooddingii – Salix laevigata Forest & Woodland Alliance	G4	S3	Map class is a Sensitive Natural Community (S1-S3 ranking)	Salix laevigata – (Cornus sericea – Ribes spp.) / Scirpus microcarpus – Carex spp.	G3	S3?	Y	Salix laevigata – (Cornus sericea – Ribes spp.) / Scirpus microcarpus – Carex spp. Association	Native Forest
					Salix laevigata / Salix lasiolepis	GNR	SNR	Y	Salix laevigata / Salix lasiolepis Association	
Salix hookeriana – Salix sitchensis – Spiraea douglasii Alliance	Salix hookeriana – Salix sitchensis – Spiraea douglasii Shrubland Alliance	GNR	SNR	Map class is not a Sensitive Natural Community	Salix sitchensis	GNR	SNR	N	Salix sitchensis Association	Native Shrub
Salix lasiolepis Alliance	Salix lasiolepis Shrubland Alliance	G4	S4	Map class is not a Sensitive Natural Community, but contains one or more Sensitive Natural Communities (Alliances or Associations with S1-S3 ranking)	Salix lasiolepis	GNR	SNR	N	Salix lasiolepis Association	Native Shrub
					Salix lasiolepis – Rubus spp.	G4	S4?	N	Salix lasiolepis – Rubus spp. Association	
					Salix lasiolepis – Salix lucida	G3	S3?	Y	Salix lasiolepis – Salix lucida Association	
Salix lucida ssp. lasiandra Association	Salix lucida ssp. lasiandra Woodland Alliance	G4	S3	Map class is a Sensitive Natural Community (S1-S3 ranking)	Salix lucida ssp. lasiandra	GNR	SNR	Y	Salix lucida ssp. lasiandra Association	Native Forest
Sarcocornia pacifica (Salicornia depressa) Herbaceous Alliance		G4	S3	Map class is a Sensitive Natural Community (S1-S3 ranking)	Sarcocornia pacifica – Cotula coronopifolia	GNR	SNR	Y	Sarcocornia pacifica – Cotula coronopifolia Association	Tidal Wetland
					Sarcocornia pacifica – Jaumea carnosa – Distichlis spicata	G3	S3	Y	Sarcocornia pacifica – Jaumea carnosa – Distichlis spicata Association	
					Sarcocornia pacifica Tidal	GNR	SNR	Y	Sarcocornia pacifica Tidal Association	
					Triglochin maritima	GNR	SNR	Y	Triglochin maritima Association	
Sequoia sempervirens Alliance	Sequoia sempervirens Forest & Woodland Alliance	G3	S3	Map class is a Sensitive Natural Community (S1-S3 ranking)	Sequoia sempervirens – Acer macrophyllum – Umbellularia californica	G3	S3	Y	Sequoia sempervirens – Acer macrophyllum – Umbellularia californica Association	Native Forest
					Sequoia sempervirens – Alnus rubra / Rubus spectabilis*			Y	Sequoia sempervirens – Alnus rubra / Rubus spectabilis Association	
					Sequoia sempervirens – Arbutus menziesii / Vaccinium ovatum	G3	S3	Y	Sequoia sempervirens – Arbutus menziesii / Vaccinium ovatum Association	
					Sequoia sempervirens – Chrysolepis chrysophylla / Arctostaphylos glandulosa	G2	S2?	Y	Sequoia sempervirens – Chrysolepis chrysophylla / Arctostaphylos glandulosa Association	
					Sequoia sempervirens – Notholithocarpus densiflorus / Carex globosa – Iris douglasiana*			Y	Sequoia sempervirens – Notholithocarpus densiflorus / Carex globosa – Iris douglasiana Association	
					Sequoia sempervirens – Notholithocarpus densiflorus / Vaccinium ovatum	G3	S3	Y	Sequoia sempervirens – Notholithocarpus densiflorus / Vaccinium ovatum Association	

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Fine Scale Map Class	Member Alliance(s)	Global Rarity Rank	State Rarity Rank	Sensitive Natural Community Status	Member Associations	Global Rarity Rank	State Rarity Rank	Sensitive Natural Community	From Mapping Key	Lifeform
					Sequoia sempervirens – Pseudotsuga menziesii – Notholithocarpus densiflorus	GNR	SNR	Y	Sequoia sempervirens – Pseudotsuga menziesii – Notholithocarpus d ensiflorus Association	
					Sequoia sempervirens – Pseudotsuga menziesii – Umbellularia californica	GNR	SNR	Y	Sequoia sempervirens – Pseudotsuga menziesii – Umbe llularia californica Association	
					Sequoia sempervirens – Umbellularia californica	G3	S3	Y	Sequoia sempervirens – Umbellularia californica Association	
					Sequoia sempervirens / (Pteridium aquilinum) – Woodwardia fimbriata Native	G3	S3	Y	Sequoia sempervirens / (Pteridium aquilinum) – Woodwardia fimbriata Native Association	
					Sequoia sempervirens / Polystichum munitum	GNR	SNR	Y	Sequoia sempervirens / Polystichum munitum Association	
Spartina foliosa Association	Spartina foliosa Herbaceous Alliance	G3	S3	Map class is a Sensitive Natural Community (S1-S3 ranking)	Spartina foliosa	GNR	SNR	Y	Spartina foliosa Association	Tidal Wetland
Toxicodendron diversilobum – (Baccharis pilularis) Association	Toxicodendron diversilobum Shrubland Alliance	G4	S4	Map class is not a Sensitive Natural Community	Toxicodendron diversilobum – (Baccharis pilularis)	GNR	SNR	N	Toxicodendron diversilobum – (Baccharis pilularis) Association	Native Shrub
Triglochin maritima Association	Sarcocornia pacifica (Salicornia depressa) Alliance			Map class is not a Sensitive Natural Community	Triglochin maritima	GNR	SNR	N	Triglochin maritima Association	Tidal Wetland
Ulex europaeus Provisional Semi-Natural Association	Cytisus scoparius – Genista monspessulana – Cotoneaster spp. Shrubland Semi-Natural Alliance	GNA	SNA	Map class is not a Sensitive Natural Community	Ulex europaeus	GNA	SNA	N	Ulex europaeus Provisional Semi-Natural Association	Non-native Herbaceous
Umbellularia californica Alliance	Umbellularia californica Forest & Woodland Alliance	G4	S3	Map class is a Sensitive Natural Community (S1-S3 ranking)	Umbellularia californica	G3	S3	Y	Umbellularia californica Association	Native Forest
					Umbellularia californica – Notholithocarpus densiflorus	G3	S3	Y	Umbellularia californica – Notholithocarpus densiflorus Association	
					Umbellularia californica – Quercus agrifolia / Toxicodendron diversilobum	GNR	SNR	Y	Umbellularia californica – Quercus agrifolia / Toxicodendron diversilobum Association	
					Umbellularia californica – Quercus wislizeni	GNR	SNR	Y	Umbellularia californica – Quercus wislizeni Association	
					Umbellularia californica / Polystichum munitum	GNR	SNR	Y	Umbellularia californica / Polystichum munitum Association	
Vancouverian Lowland Marsh, Wet Meadow & Shrubland Macrogroup	Bidens cernua – Euthamia occidentalis – Ludwigia palustris Herbaceous Provisional Alliance	GNR	S4	Map class is a Sensitive Natural Community (S1-S3 ranking)	Bidens frondosa Euthamia occidentalis*	GNR	SNR	N	Bidens frondosa Provisional Association Euthamia occidentalis Association	Freshwater Wetland
	Leymus cinereus – Leymus triticoides Herbaceous Alliance	G3	S3		Leymus triticoides	GNR	SNR	Y	Leymus triticoides Association	
	Carex barbarae Herbaceous Alliance	G2?	S2?		Carex barbarae	GNR	SNR	Y	Carex barbarae Association	
	Carex nudata Herbaceous Alliance	G3	S3		Carex nudata	GNR	SNR	Y	Carex nudata Association	
	Mimulus (guttatus) Herbaceous Alliance	G4?	S3?		Mimulus guttatus	GNR	SNR	Y	Mimulus guttatus Association	
Vancouverian Freshwater Wet Meadow & Marsh Group	Juncus (effusus, patens) - Carex (pansa, praegracilis) Herbaceous Alliance	G4?	S4?	Map class is not a Sensitive Natural Community, but contains one or more Sensitive Natural Communities (Alliances or Associations with S1-S3 ranking)	Carex amplifolia – Carex gynodynama	G3	S2?	Y	Carex amplifolia – Carex gynodynama Provisio nal Association	Freshwater Wetland
					Carex densa	GNR	SNR	N	Carex densa Association	
					Carex pansa	GNR	SNR	N	Carex pansa Provisional Association	
					Carex praegracilis	GNR	SNR	N	Carex praegracilis Provisional Association	
					Carex serratodens	GNR	SNR	N	Carex serratodens Association	
					Carex tumulicola	GNR	SNR	N	Carex tumulicola Provisional Association	
					Juncus covillei	GNR	SNR	N	Juncus covillei Provisional Association	
					Juncus effusus	G4	S4?	N	Juncus effusus Association	
					Juncus patens	G4	S4?	N	Juncus patens Association	
					Juncus patens – Holcus lanatus	GNR	SNR	N	Juncus patens – Holcus lanatus Provisional Association	
					Juncus patens – Juncus occidentalis	GNR	SNR	N	Juncus patens – Juncus occidentalis Provisional Association	
					Juncus phaeocephalus	GNR	SNR	N	Juncus phaeocephalus Association	
	Carex obnupta – Oenanthe sarmentosa – Scirpus microcarpus Herbaceous Alliance	G4	S3		Carex obnupta	GNR	SNR	Y	Carex obnupta Association	
					Carex obnupta – Juncus patens	G3	S3?	Y	Carex obnupta – Juncus patens Association	
					Juncus lescurii	GNR	SNR	Y	Juncus lescurii Association	
					Argentina egedii – (Juncus lescurii)	GNR	SNR	Y	Argentina egedii – (Juncus lescurii) Association	
					Carex obnupta – Argentina egedii	GNR	SNR	Y	Carex obnupta – Argentina egedii Provisional Association	
					Festuca rubra – (Argentina egedii)*			Y	Festuca rubra – (Argentina egedii) Provisional Association	
					Oenanthe sarmentosa	GNR	SNR	Y	Oenanthe sarmentosa Association	
					Scirpus microcarpus Pacific Coast	GNR	SNR	Y	Scirpus microcarpus Pacific Coast Association	
	Polygonum lapathifolium – Xanthium strumarium Herbaceous Alliance	G5	S4		Alisma (triviale)	GNR	SNR	N	Alisma (triviale) Provisional Association	
					Polygonum (amphibium, lapathifolium)	GNR	SNR	N	Polygonum (amphibium, lapathifolium) Association	
					Xanthium strumarium	GNR	SNR	N	Xanthium strumarium Association	
Western North American Freshwater Aquatic Vegetation Macrogroup	Ludwigia (hexapetala, peploides) – Eichhornia crassipes Herbaceous Provisional Semi-Natural Alliance	GNA	SNA	Map class is not a Sensitive Natural Community, but contains one or more Sensitive Natural Communities (Alliances or Associations with S1-S3 ranking)	Ludwigia (hexapetala, peploides)	GNA	SNA	N	Ludwigia (hexapetala, peploides) Provisional Semi-Natural Association	Aquatic Vegetation
	Azolla (filiculoides, mexicana) Herbaceous Alliance	G5	S5		Azolla (filiculoides, microphylla)	G5	S5	N	Azolla (filiculoides, microphylla) Association	
	Ceratophyllum demersum Herbaceous Provisional Alliance	G5	S4		Ceratophyllum demersum Western	G5	S4	N	Ceratophyllum demersum Western Provisional Association	
	Nuphar lutea Aquatic Herbaceous Provisional Alliance	GNR	SNR		Nuphar lutea ssp. polysepala	GNR	SNR	N	Nuphar lutea ssp. polysepala Provisional Assoc iation	

* - refers to types that were not included in the CNPS classification report due to lack of field data

Fine Scale Map Class	Member Alliance(s)	Global Rarity Rank	State Rarity Rank	Sensitive Natural Community Status	Member Associations	Global Rarity Rank	State Rarity Rank	Sensitive Natural Community	From Mapping Key	Lifeform
	Hydrocotyle (ranunculoides, umbellata) Herbaceous Alliance	G4	S3?		Hydrocotyle ranunculoides	GNR	SNR	Y	Hydrocotyle ranunculoides Association	
	Sparganium (angustifolium) Herbaceous Alliance	G4	S3?		Sparganium eurycarpum	GNR	SNR	Y	Sparganium eurycarpum Provisional Association	
Zostera (marina, pacifica) Pacific Aquatic Alliance	Zostera (marina, pacifica) Pacific Aquatic Herbaceous Alliance	GNR	S3	Map class is a Sensitive Natural Community (S1-S3 ranking)	Zostera marina	GNR	S3	Y	Zostera marina Association	Eel Grass

CHAPTER 7: CONDITION ASSESSMENT

The *Marin Regional Forest Health Strategy* (*Forest Health Strategy*) Condition Assessment (Forest Condition Assessment) evaluates the conditions (ca. 2010-2019[1]) of the five target forest types of the *Forest Health Strategy*: Bishop Pine, Coast Redwood, Douglas-fir, Open Canopy Oak Woodlands, and Sargent Cypress. The Forest Condition Assessment process included developing conceptual models, goals, objectives, results chains, and forest health metrics, followed by metrics analysis to understand forest conditions in Marin County. The Forest Condition Assessment establishes baseline conditions which can serve as the foundation for future assessments. As new data become available, new assessments will increase understanding of forest system dynamics and change over time and will support monitoring the efficacy of management actions. In addition, the Forest Condition Assessment is the underpinning for identifying potential treatment areas described in Chapter 8: Prioritization Framework and Implementation Analysis.

In this chapter a broad, countywide description of forest condition trends is followed by more detailed assessments for each of the five target forest types.

METRICS USED FOR ASSESSMENT

Metrics vary by forest type (Table 7.1) and were used to analyze forest stands identified in the 2018 Marin Countywide Fine Scale Vegetation Map (2018 Fine Scale Vegetation Map; Golden Gate National Parks Conservancy et al., 2021). Detailed information on *Forest Health Strategy* metrics, including data used in analysis, is available in Chapter 6: Metrics. Information on metric development and methodology, a detailed discussion of data limitations, and definitions for terms related to stand structure, mortality, and fire history dynamics can all be found in Chapter 6: Metrics as well.

All of the metric information summarized in the Forest Conditions Assessment, including statistics provided in the text, or presented as charts/maps, was developed as part of the *Forest Health Strategy* and is available to explore via the One Tam Marin Forest Health Web Map and 2018 Marin Countywide Fine Scale Vegetation Map. Information on methods used to create the metrics is discussed in Chapter 6: Metrics. Managers can also download pre-generated reports summarizing this information at the watershed (HUC 12 and HUC 14) and County scales via the Marin Forest Health Watershed Report Downloader.

[1] See Foundational Data in Chapter 6: Metrics and Appendix B: Wildfire History for more information on data used in the Forest Condition Assessment.

Table 7.1. Summary of metrics and data by forest type.

Metrics	Coast Redwood	Bishop Pine	Douglas-fir	Open Canopy Oak Woodland	Sargent Cypress
Acres	X	X	X	X	X
Stand Diversity: Relative Percent Hardwood/Conifer Cover	X	X	X		X
Stand Diversity: Oaks				X	
Stand Structure/ Structural Class	X	X	X		X
Oak Woodlands at Risk of Conversion to Douglas-fir				X	
Percent Standing Dead (Tree Mortality)	X	X	X	X	X
Percent Canopy Gaps Formed 2010-2019	X	X	X	X	X
Stand Density Change	X	X	X	X	X
Fire Frequency	X	X	X	X	X
Fire Return Interval	X	X	X	X	X

DATA LIMITATIONS

Data for the Forest Condition Assessment were derived from the best available remote sensing data for Marin County, including 2018 4-band aerial imagery, 2019 lidar, and the 2018 Fine Scale Vegetation Map. The value of using remote sensing data for conducting the Forest Condition Assessment is it allows for landscape-scale analysis in a more cost and time-efficient manner than conducting a traditional field-based inventory. However, many factors important for understanding forest conditions cannot be reliably analyzed using remotely sensed data such as locating non-native invasive species, rare plants, lichens, soil microbes, and wildlife occupancy. Independent quality assurance/quality control (QA/QC) was performed for the 2018 4-band aerial imagery (Quantum Spatial, 2018) and 2019 lidar (Quantum Spatial, 2019) as part of initial data acquisition, and a formal accuracy assessment (AA) was conducted for the 2018 Fine Scale Vegetation Map (see Final Report; Tukman Geospatial et al., 2021). It should be noted, however, that formal accuracy assessments were not conducted for derivative layers used in the Forest Conditions Assessment. See Chapter 6: Metrics for additional information on methods used to develop the metrics analyzed and summarized in this chapter.

While the Forest Condition Assessment and Forest Health Web Map provide valuable insight into the distribution and status of forest stands in Marin County, managers should use discretion when interpreting results and drawing conclusions because of the limitations of remote sensing data. In many cases, additional information from ground-based assessments will be required to fully characterize individual forest stand conditions. The Forest Condition Assessment identifies where further data analysis and field investigation may be warranted.

Spatial datasets used in the Forest Conditions Assessment do not include knowledge and expertise retained by the Federated Indians of Graton Rancheria (the Tribe). Traditional Ecological Knowledge and Tribal insight into the conditions of forests and the landscape is critical to understanding the state of these natural and cultural resources, therefore partnership with the Tribe will be a necessary component to advancing this work beyond the results presented in this chapter. See Chapter 3: Stewardship and Partnership with the Federated Indians of Graton Rancheria for additional discussion.

COUNTYWIDE FOREST CONDITION TRENDS

Broad trends and patterns across all five key forest types in the *Forest Health Strategy* are summarized in this section by acres and distribution, diversity, stand structure, canopy mortality, and fire history dynamics; the same assessment metrics are then applied to each target forest type separately in the following sections. Additional metrics quantifying forest stand vigor and canopy change between 2010 and 2019 are available for each forested stand in the 2018 Fine Scale Vegetation Map and can be accessed via the attribute tables in the Forest Health Web Map; these include canopy height change, 95th percentile stand height change, and canopy volume profiles. More information on each target forest type, including a brief life history and known threats, is included in Chapter 5: Goals.

ACRES & DISTRIBUTION

The 2018 Fine Scale Vegetation Map assigned vegetation and landcover classes to 366,290 acres. Acres and distribution data for this and following sections are from the 2018 Fine Scale Vegetation Map. The total acres[2] and general distribution descriptions for each *Forest Health Strategy* target forest type are shown in Table 7.2.

Table 7.2. Target forest type area and distribution. Data from 2018 Fine Scale Vegetation Map (Golden Gate National Parks Conservancy et al., 2021).

Species	Acres	General Distribution
Bishop Pine	4,668	Primarily Point Reyes National Seashore and Tomales Bay State Park
Coast Redwood	11,265	Southern Marin County, Bolinas Ridge, Mount Tamalpais, Redwood Creek Watershed, and San Geronimo Valley
Douglas-fir	26,245	Point Reyes peninsula and east at higher elevations
Open Canopy Oak Woodlands	20,649	Countywide with concentrations in east Marin
Sargent Cypress	451	North slope Mt. Tamalpais and San Geronimo Ridge

Figure 7.1 below shows the distribution of each *Forest Health Strategy* target forest type in Marin County as depicted in the 2018 Fine Scale Vegetation Map, and Figure 7.2 shows the total number of acres for each target forest type by fine scale vegetation map class. To further explore the distribution of forest stands, managers can visit the Forest Health Web Map. See Appendix 7A to this chapter for summary information about the distribution of the five key forest types amongst Marin County land management agencies.

[2] For ease of reading, acres were rounded to the nearest whole number throughout the Forest Condition Assessment. The data contained in the Forest Health Web Map attribute tables has more precise numbers.

Figure 7.1. Forest Health Strategy key forest types, 2018 Fine Scale Vegetation Map.

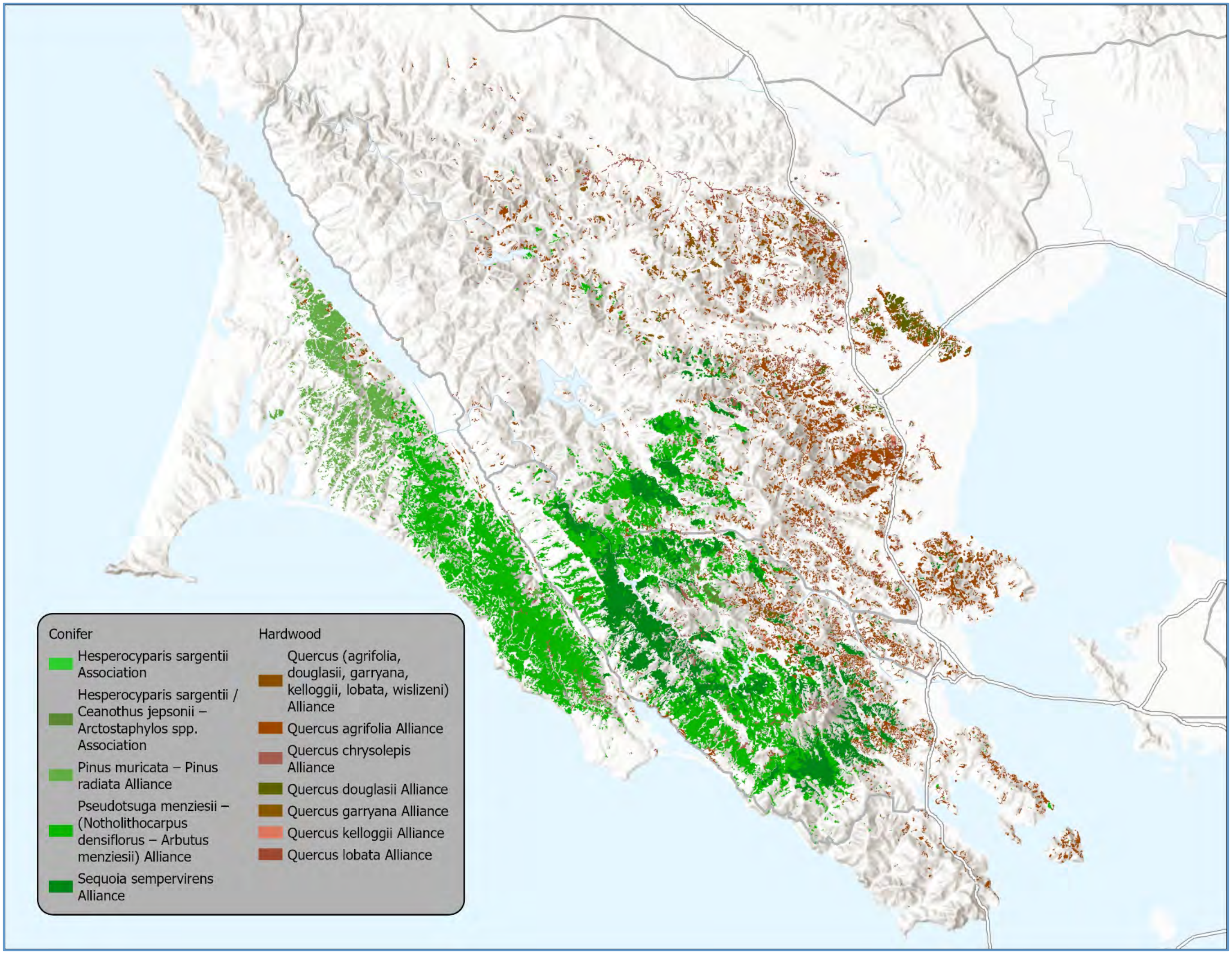
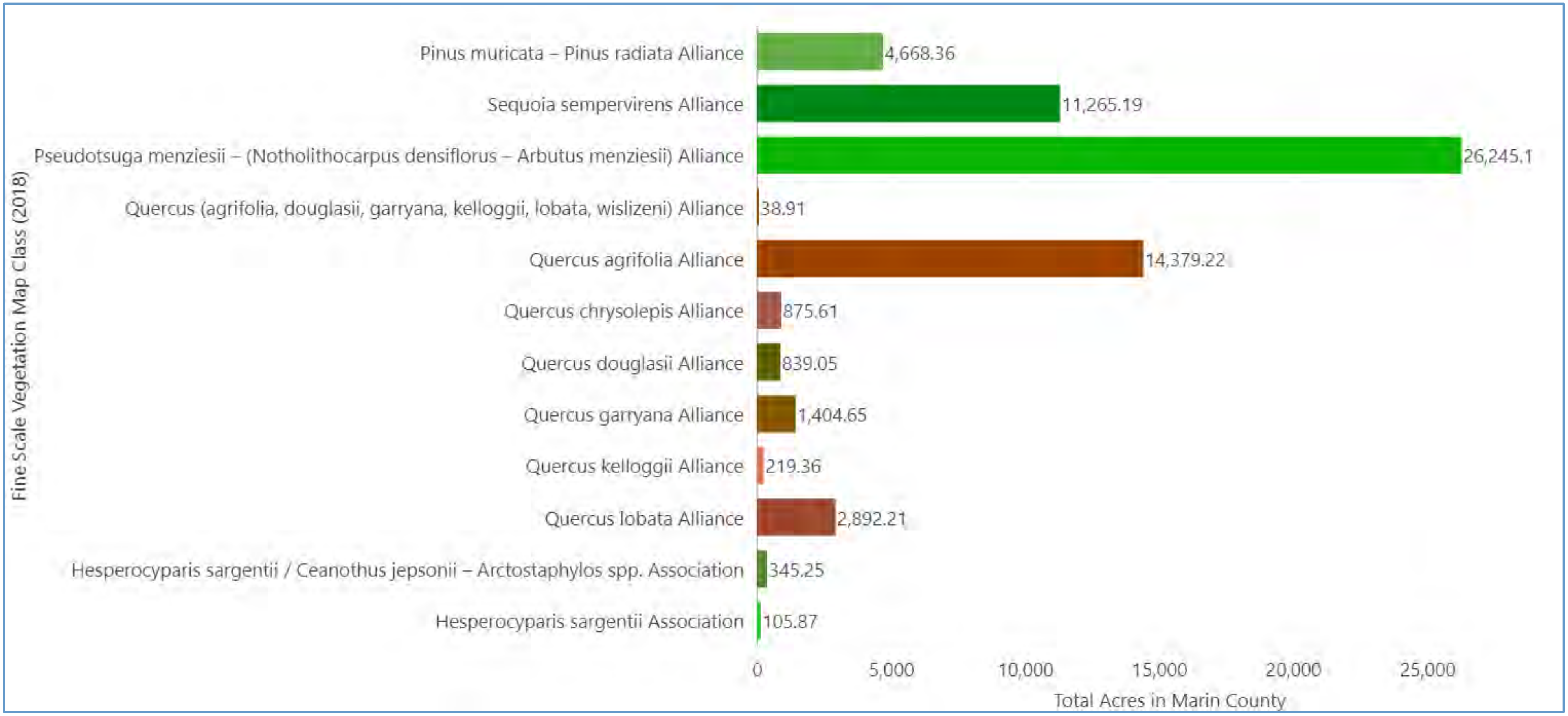


Figure 7.2. 2018 Fine Scale Vegetation Map class acres for Forest Health Strategy *key forest types.*

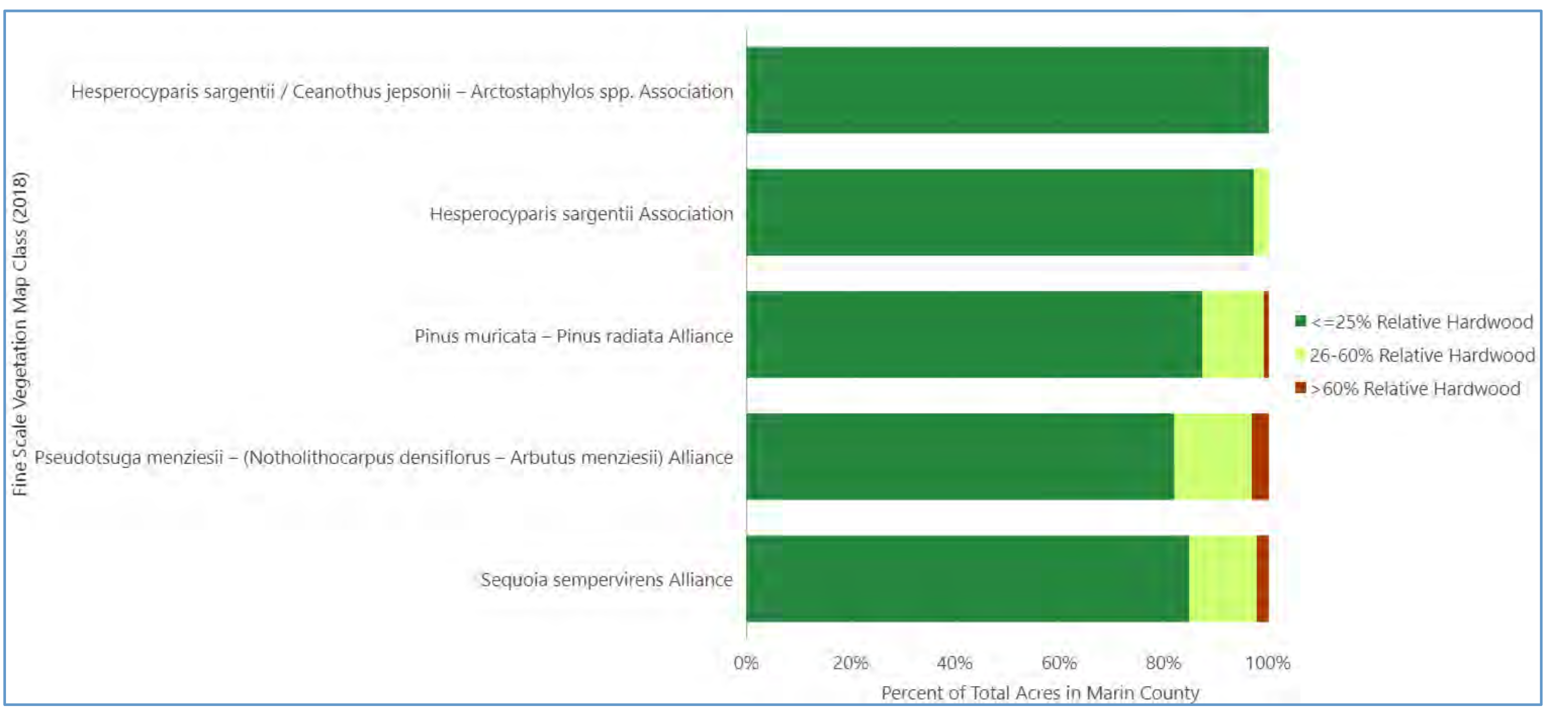


CONIFER-HARDWOOD DIVERSITY

For the Forest Condition Assessment relative hardwood cover was analyzed to understand the distribution, abundance, and composition of mixed conifer-hardwood forest stands using the relative percent hardwood vs. conifer metric. The relative hardwood metric does not identify the species of understory trees, shrubs, or herbaceous vegetation and is thus a limited proxy for overall stand biodiversity. More details can be found in the forest type sections, but highlights include:

- **Most Bishop Pine, Coast Redwood, Douglas-fir, and Sargent Cypress stands were classified with relatively low (less than 25%) hardwood cover** (Figure 7.3). Understanding the presence, composition, and distribution of mixed conifer-hardwood stands is important to tracking forest dynamics in Marin County. In some cases, mixed conifer-hardwood stands may be a conservation target with the goal of retaining these assemblages as part of the mosaic of forest types in Marin, but in other cases conifer presence in hardwoods may be an indication of type conversion and potential loss of biological diversity. (see Chapter 2: Resilience).
- **Sargent Cypress have especially low relative hardwood cover**, with 97% *Hesperocyparis sargentii* Association stands classed as less than 25% relative hardwood, and 100% of *Hesperocyparis sargentii / Ceanothus jepsonii – Arctostaphylos* spp. Association stands classified with less than 25% hardwood cover. Low hardwood cover is an indication of this species' tendency towards monospecific stands and affinity for serpentine, volcanic, or other ultramafic substrates (Buck-Diaz et al., 2021, p. 55).

Figure 7.3. Classified percent relative hardwood cover for key conifer types.



While relative hardwood cover for Open Canopy Oak Woodlands was not assessed as part of the Forest Condition Assessment, this attribute is included for all hardwood forest stands in the 2018 Fine Scale Vegetation Map. Future forest condition assessments could look at changes in relative hardwood density for Open Canopy Oak Woodlands or other hardwood stands compared to 2018 values to assess impacts from drought, pathogens, climate change, or other stressors.

STAND STRUCTURE

Structural classifications were developed for the four conifer forest types assessed in the *Forest Health Strategy*. Because interpretation of structural classes is specific to each forest type, countywide results or inferences across forest types are not presented. Methods used to create the structural classifications are described in Chapter 6: Metrics.

- **There are no verified early-seral Bishop Pine stands in Marin County.** The Bishop Pine structural classification is a proxy for seral stage based on time since last fire, and differentiates stands based on canopy mortality and hardwood presence/absence. Mid- and late-seral stands are spatially separated by the 1995 Vision Fire footprint. New cohorts may be developing in the 2020 Woodward Fire footprint but are not present in the source data used for this analysis.
- **Fifty-eight percent of Douglas-fir stands (15,294 acres) in Marin County are classified as medium to large height (60-140 feet) with more vertical structure** (Figure 7.4). While the structural classification is not a direct measure of seral stage, the medium structural classes of Douglas-fir generally align with both the logging history in Marin County and areas that have been observed by managers as Douglas-fir expansion areas.
- **The second most prevalent Douglas-fir structural class, small (less than 60 feet) with more vertical structure (26% of all Douglas-fir in Marin County or 6,801 acres),** closely aligns with areas shown by Startin (2022) to have more recently converted to Douglas-fir based on analysis of aerial imagery from 1952.
- **The majority (73% or 8,253 acres) of Coast Redwood stands are in the medium to large (60-140 feet) with more vertical structure class** (Figure 7.5). The medium to large structural class likely contains both previously logged, second-growth stands as well as old-growth stands that, for reasons that require additional field study and analysis, are not as tall as other old-growth areas which are in the largest stand class. The stand structure metric is a reasonable proxy for identifying old-growth stands or those with old-growth potential, and for differentiating between structurally more or less complex second-growth stands, but is not equivalent to seral stage classification. Stands classified as largest (more than 140 feet mean height) overlap closely with areas that are understood to contain old-growth, previously unlogged Coast Redwood stands in Marin County, such as Muir Woods National Monument. However, there are also medium to large stands in some of these old-growth areas, suggesting that more study is needed to better understand the relationship between old-growth conditions and lidar-derived stand structure metrics.

- **There are two distinct populations of Sargent Cypress in Marin County**: 1) stands on San Geronimo Ridge, which occur on serpentine soils, and 2) smaller, more disparate stands on Mt. Tamalpais that inhabit a mix of different, non-serpentine soils. Structural classification for Sargent Cypress divides stands by soil type and height. The Mt. Tamalpais population is generally taller than the San Geronimo Ridge population, possibly due to the absence of serpentine soils underlying these stands.

Figure 7.4. Lidar-derived Douglas-fir structural class by acres.

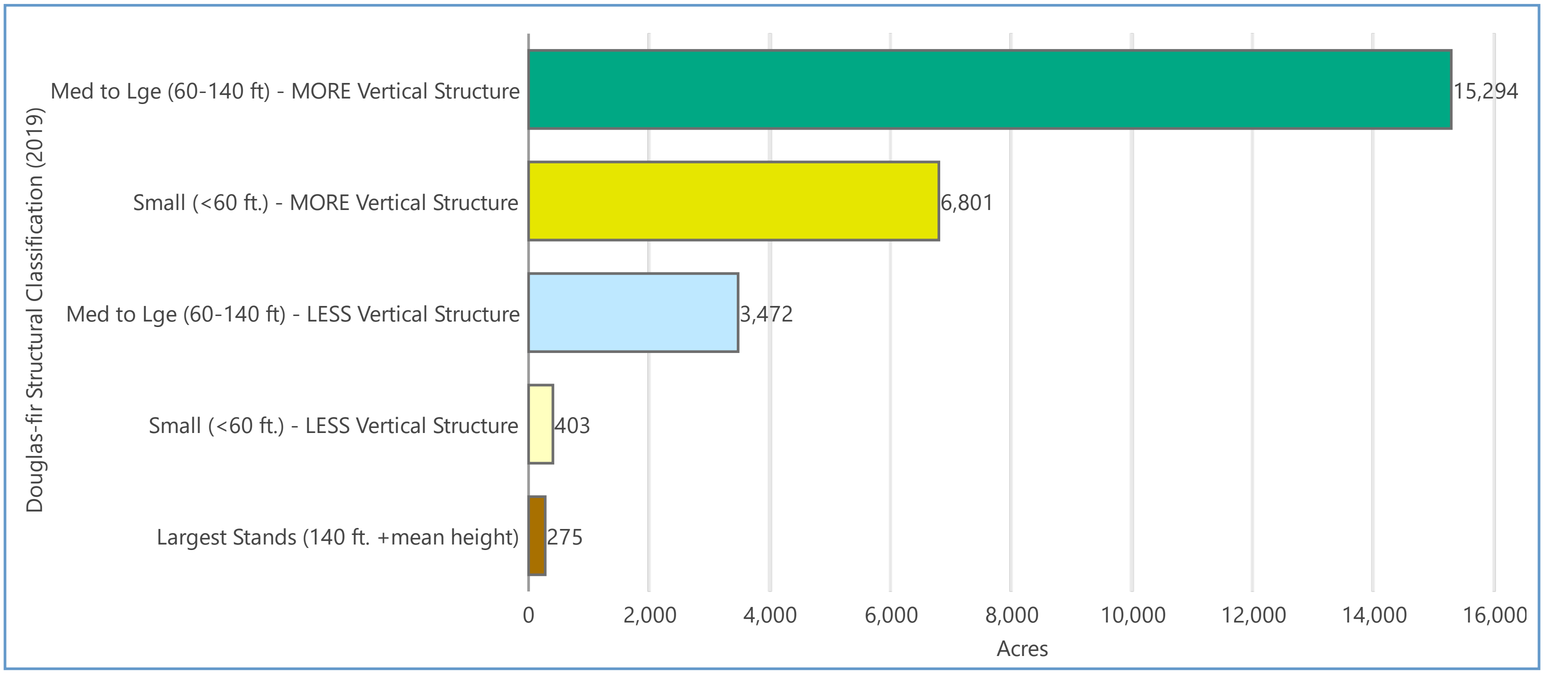
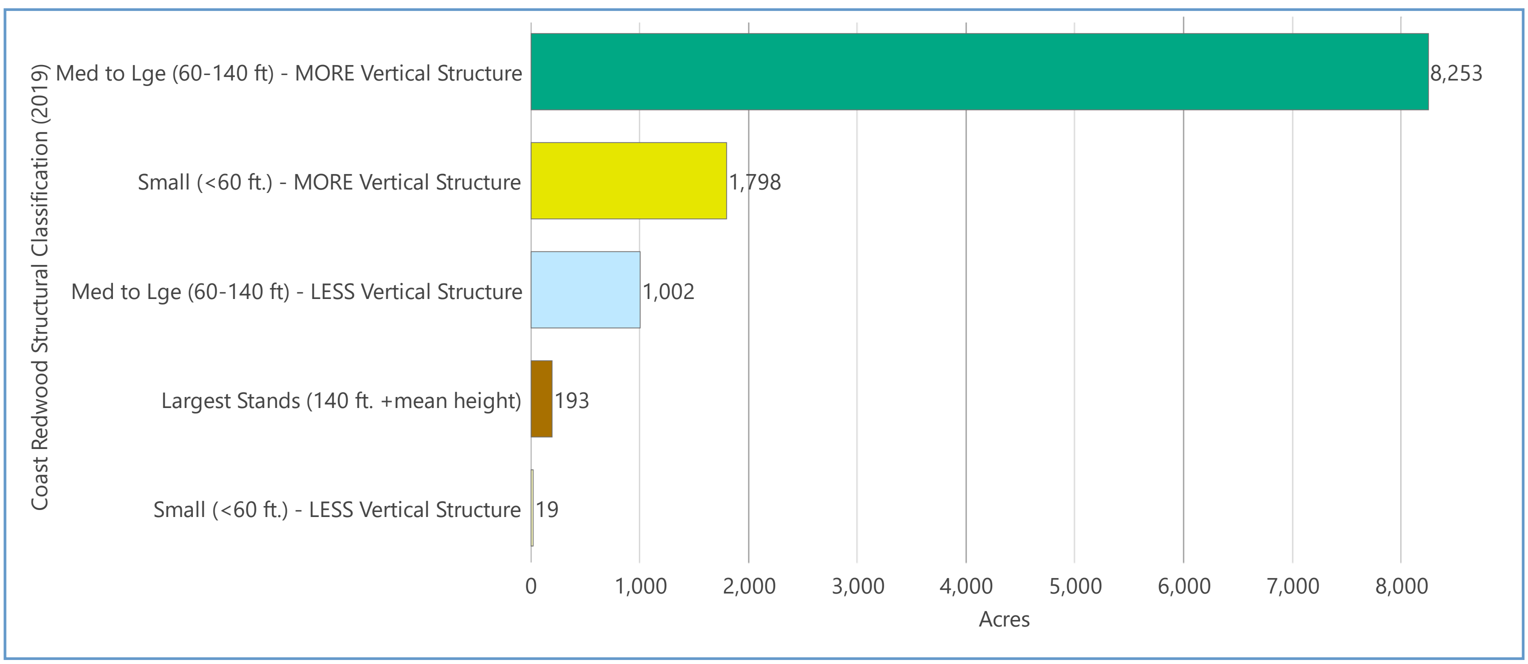


Figure 7.5. Lidar-derived Coast Redwood structural class by acres.



CANOPY MORTALITY & DYNAMICS

Percent canopy mortality, canopy gaps, and canopy density change metrics are useful, especially when analyzed together, for assessing impacts from stressors such as pathogens, drought, and senescence. Percent canopy mortality, also called percent standing dead, was mapped using semi-automated techniques that combine automated object-based image analysis with manual photointerpretation. The canopy mortality metric includes all visible mortality in the tree canopy regardless of dominant species. Percent canopy gaps was derived by detecting changes between the 2010 and 2019 lidar derived canopy height models which locates and quantifies "gaps" formed between 2010 and 2019 within forested stands. Canopy density change quantifies the difference in canopy density between 2010 and 2019. See Chapter 6: Metrics for a more thorough explanation of methods used.

These three metrics combined can provide an overview of changes in forest stands impacted by diseases such as sudden oak death, pitch pine canker, or other stressors such as drought. As the impact from stressors progresses and trees fall, stands experiencing the greatest disease impacts may have lower percentages of standing dead trees and more canopy gaps. Gap analysis provides a useful way to track disease impacts though the cycle of stand decline. It should be noted that this remote sensed data cannot identify the cause of gap formation, for example canopy gaps can be created by the removal of trees during construction or as part of intentional clearing around infrastructure. In addition, in some forest types it is healthy and natural for gaps to form as part of stand maturation, such as self-thinning in mid-seral Bishop Pine forest. In the case of old-growth coast redwood forest, canopy gaps are necessary for regeneration and contribute to biological diversity. Nevertheless, when taken in combination with canopy mortality and other indicators of forest decline, gaps can be useful for locating and tracking forest stressor impacts. For a more detailed discussion of pathogens and disease, please see Chapter 4: Climate Change and Other Forest Health Stressors and Pests and Pathogens in Chapter 9: Treatment Descriptions.

- **Across the five target forest types, most stands had zero to less than 0.5% canopy mortality**. Percent canopy mortality is high on Tomales Bay's western edge and around the Kent and Bon Tempe Lakes (Figure 7.6). Percent canopy mortality by forest type, expressed as a percentage of the total countywide acres is shown in Figure 7.7.
- **Percent canopy gap formed between 2010 and 2019 shows a similar but more widespread pattern to standing dead.** Areas of greatest canopy gap increase are along the eastern side of Inverness Ridge and eastern Bolinas ridge (Figure 7.8). They are also scattered in smaller stands in the more urban areas of the south-eastern portion of the County near San Rafael, which could be a result of new development or intentional clearing around communities. Care should be taken when drawing conclusions about forest decline from gap data absent other indicators of stress such as canopy mortality. Classified canopy gaps formed between 2010 and 2019 by forest type, expressed as a percentage of the total countywide acres, are shown in Figure 7.9.
- **Interpretation of canopy density change requires consideration of forest type.** Because 2019 lidar was collected in mid-winter and 2010 lidar was collected during the late

spring, a loss in canopy density may be driven by leaf phenology and not meaningful changes in density or vigor. Therefore, care should be taken when evaluating results for stands of deciduous hardwood species, including *Quercus douglasii* (blue oak), *Quercus garryana* (Oregon white oak), *Quercus kelloggii* (California black oak), and *Quercus lobata* (California white oak). However, a decrease in canopy density for evergreen hardwoods could be an indication of stand decline due to drought or other stressors. **Canopy density changes could also correlate to geography, as the western portions of Marin County tend to be more mesic, and eastern portions more xeric.** See discussion of this metric for each key forest type below. Classified canopy density change between 2010 and 2019 across Marin County is shown in Figure 7.10, and by key forest type, expressed as a percentage of the total countywide acres, is shown in Figure 7.11.

Figure 7.6. Classified percent canopy mortality (standing dead) for the five key forest types.

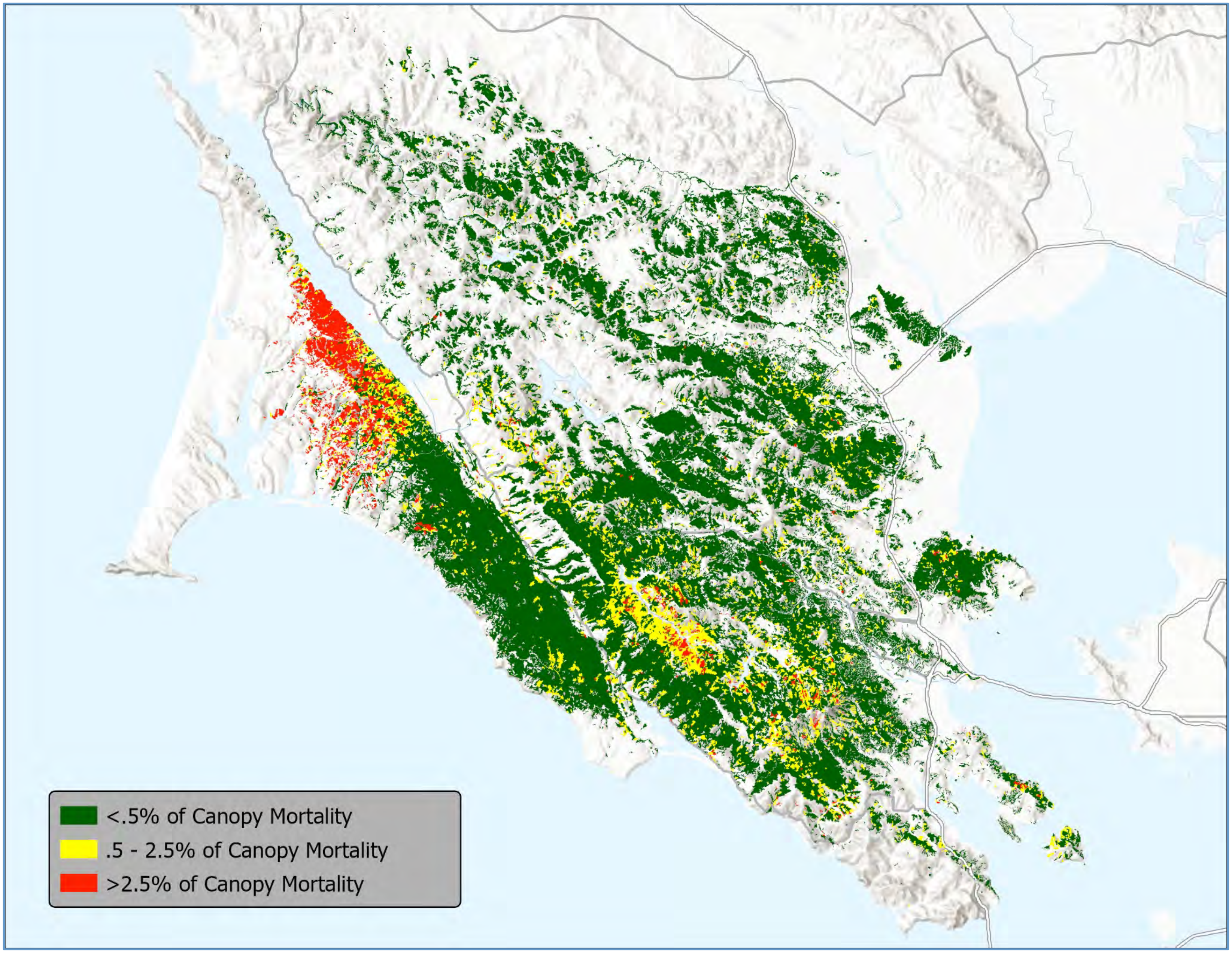


Figure 7.7. Classified percent canopy mortality (standing dead) by forest type, expressed as a percentage of the total countywide acres.

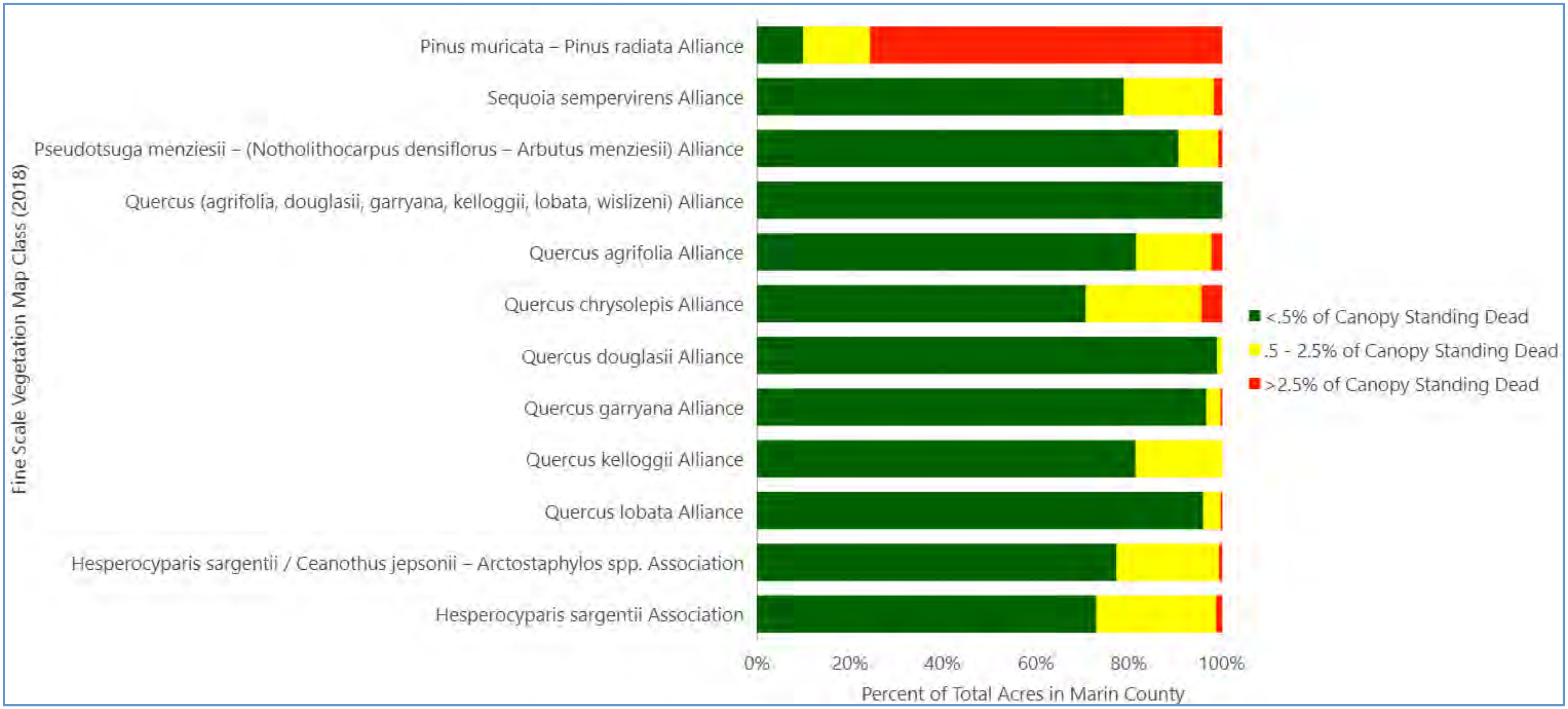


Figure 7.8. Canopy gaps formed between 2010 and 2019 for the five key forest types.

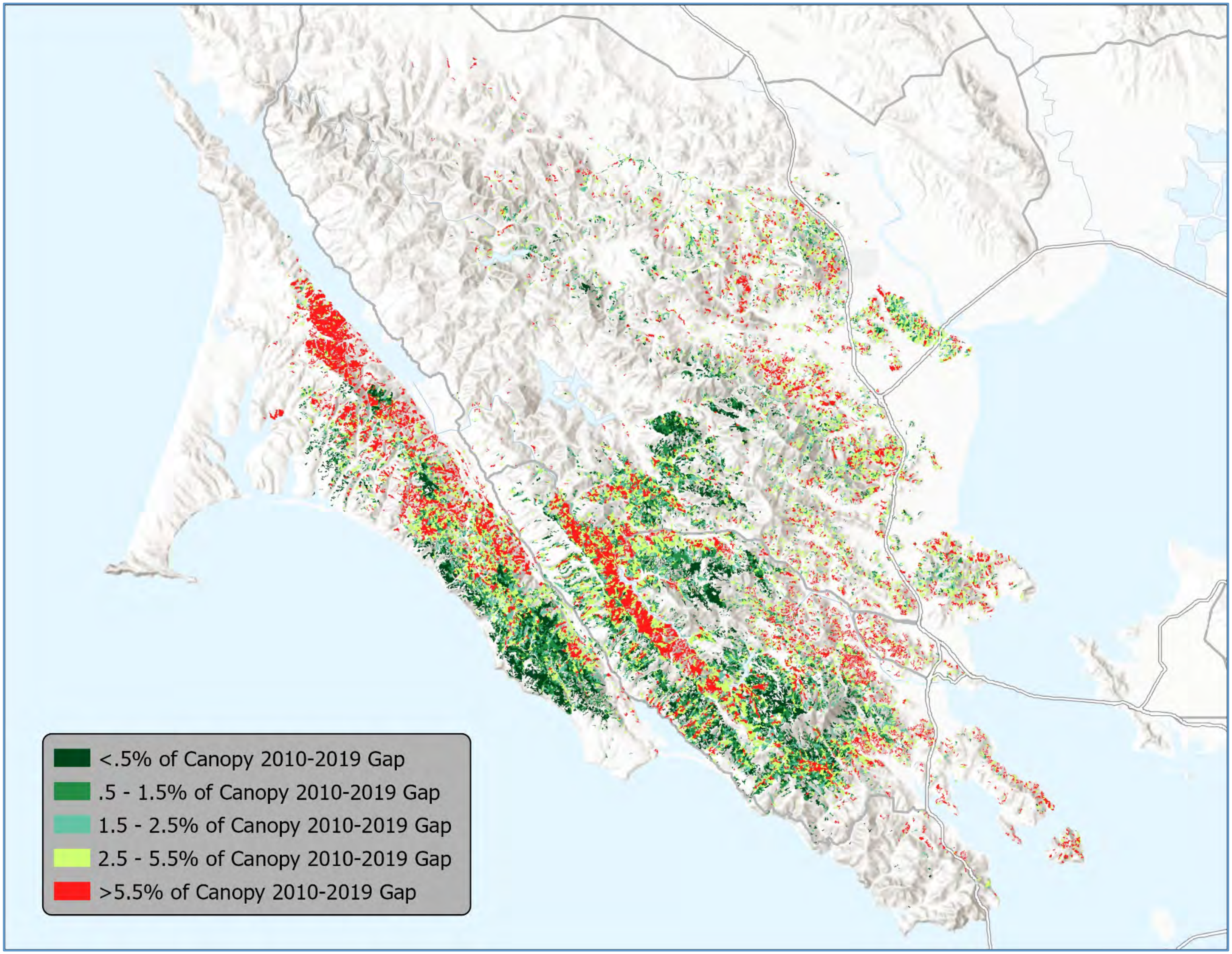


Figure 7.9. Classified canopy gaps formed between 2010 and 2019 by forest type, expressed as a percentage of the total countywide acres.

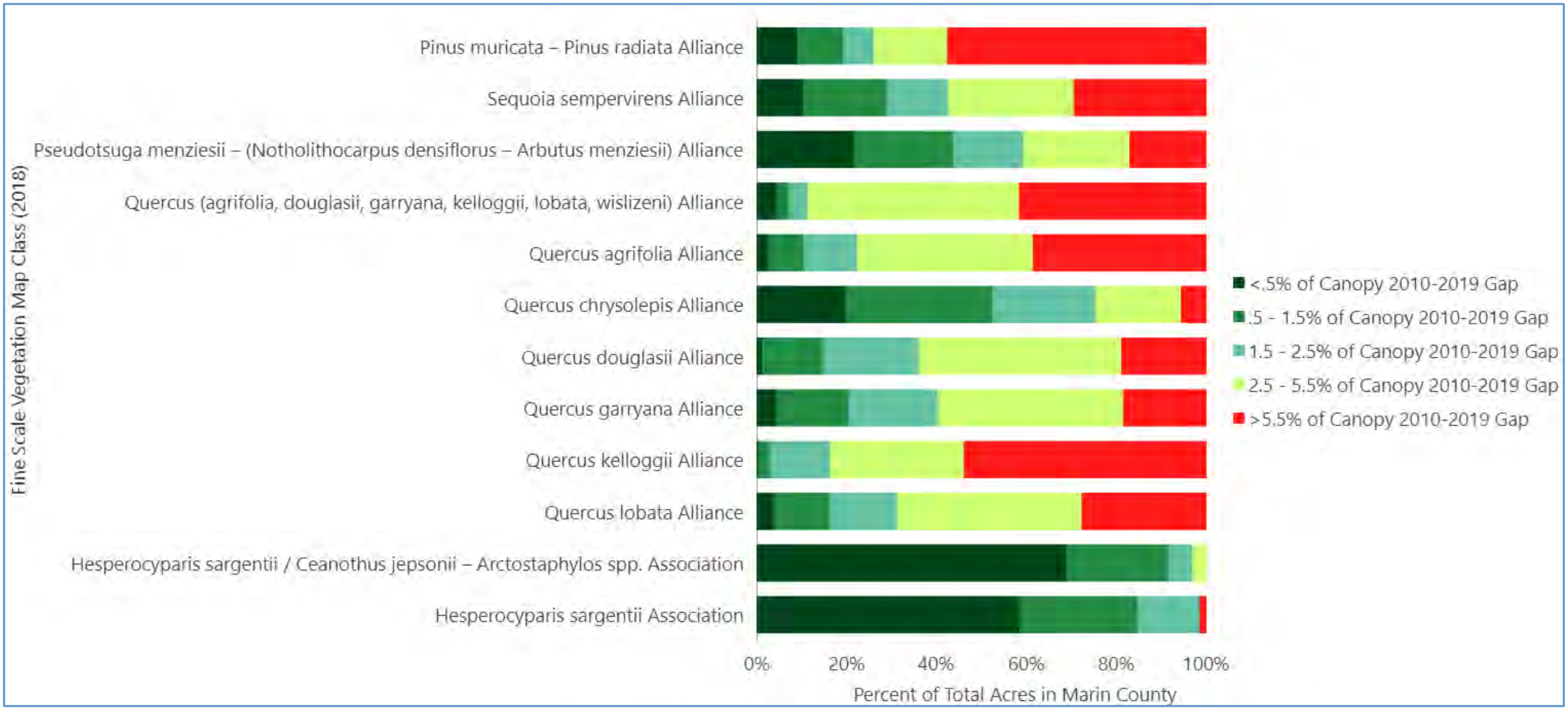


Figure 7.10. Classified percent canopy density change between 2010 and 2019 for the five key forest types.

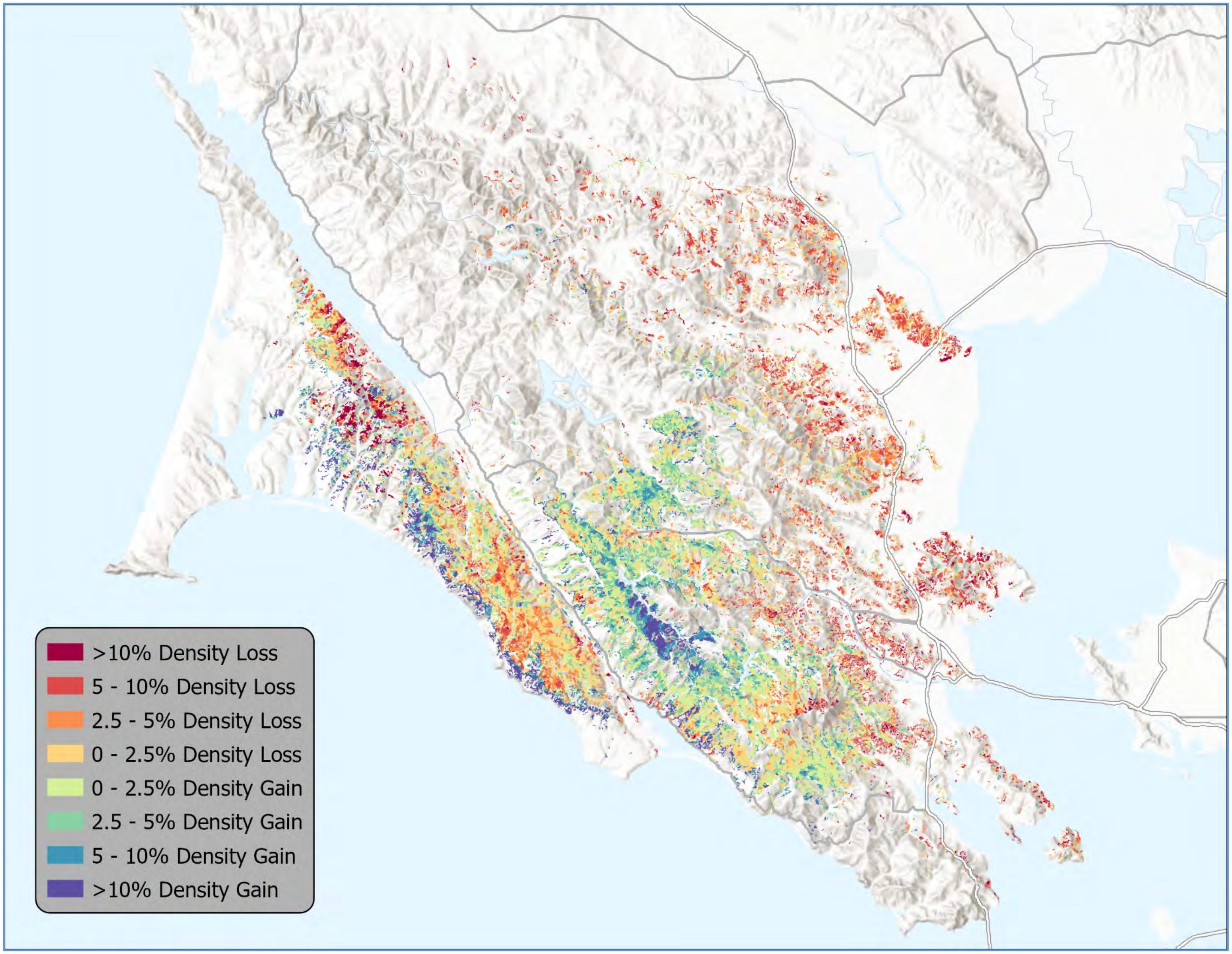
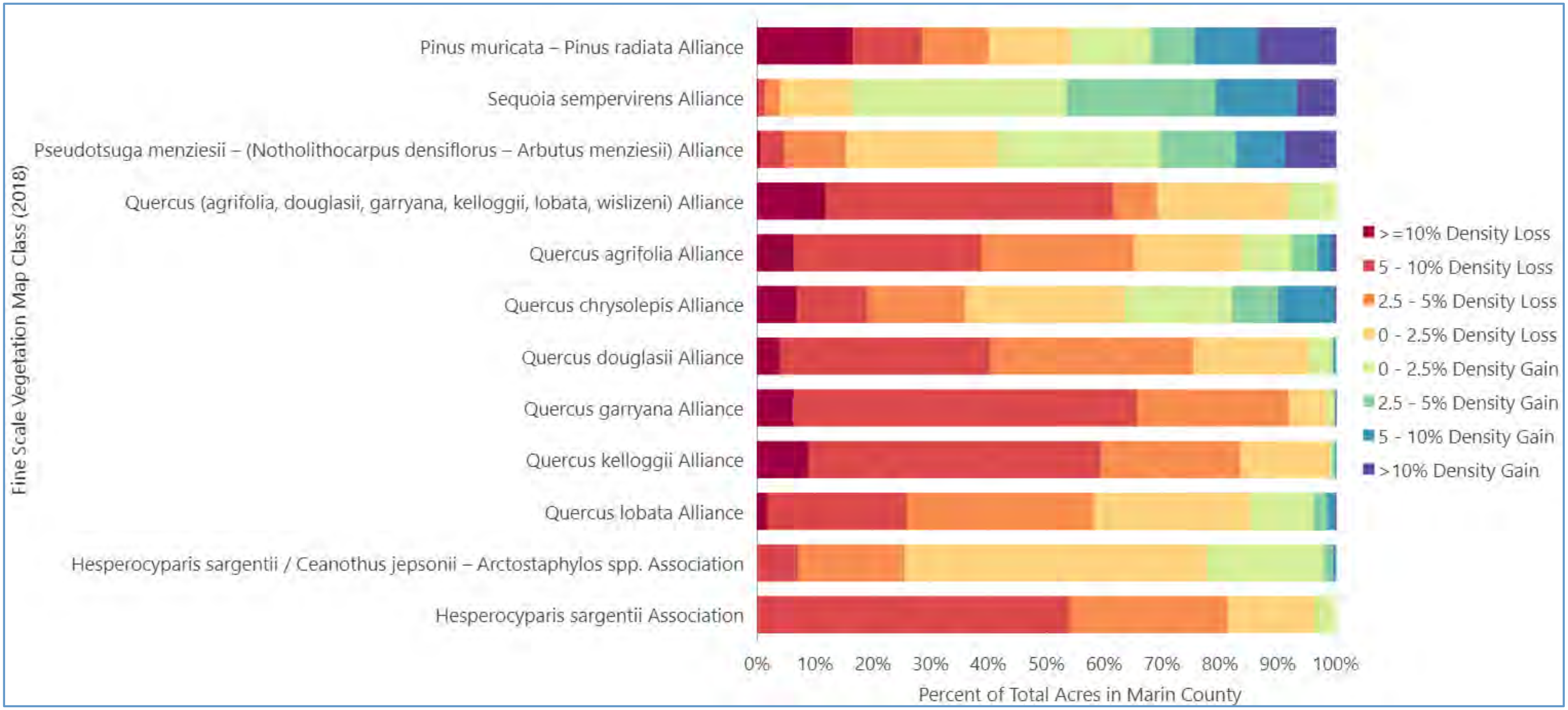


Figure 7.11. Classified canopy density change between 2010 and 2019 by key forest type, expressed as a percentage of the total countywide acres.



FIRE HISTORY DYNAMICS

A deeper understanding of wildfire history, fire return intervals, and time since last fire was developed from the *Marin County Wildfire History Mapping Project* (Dawson, 2021 in Appendix B: Wildfire History). Fire history results included here and in the following sections are from this project[3]. See Appendix B: Wildfire History and Chapter 6: Metrics for more detailed information. GIS data derived from this study are available in the [Forest Health Web Map]. Select results include the following:

- **Overall, fire return intervals increased four-fold since the mid-19th century, from 10.1 years between fires in the late 19th century to 38 years today**. Fire scar data, although limited, showed fire return intervals of as little as ten years in some areas during the years 1450-1850 (Dawson, 2021). These results suggest that the fire return interval did not change throughout the early colonization of Marin.
- **During the late 19th century, due to fire suppression and the removal of Coast Miwok people from their land, fire return intervals diverged from those observed before 1852**. Average fire return intervals increased from 9.9 years before 1852 to 28.4 years between 1852 and 2020. The average fire return interval in the past one-hundred years (1917-2020) is 37.6 years. However, averaging fire return intervals across the landscape can be misleading. There are a variety of fire return intervals in Marin County; some areas saw shorter intervals due to cultural burning practices prior to 1852, but other areas experienced less frequent fires and had longer return intervals.
- **There was a significant decrease in acres burned in Marin County after 1940**, presumably due to the fire lookout built on Mt. Tamalpais and the increased fire suppression approach following World War II. Wildfire extent declined by nearly 25% during the period 1852-1940.
- According to the study, **41% of Marin County lies within a rare burn zone, where no fires have been documented since 1859**. Most of this rare burn zone is in the grazed lands in the northern portions of the County. At the other end of the fire frequency spectrum, the upper slopes of Mt. Tamalpais burned 7-11 times between 1852 and 2020, with fire return intervals between 17-28 years. Neighboring slopes burned 5-8 times with fire return intervals of 24-42 years. Another frequent burn zone is Big Rock Ridge on the northern side of Lucas Valley, which burned 4-6 times from 1852-2020, with fire return intervals from 34-56 years.
- **Sixty-two percent of all five key forests profiled in the *Forest Health Strategy* (39,054 acres) have not experienced a fire (greater than or equal to 160 acres) in more than 70 years** (Figure 7.12). For a countywide breakdown of fire history by key forest type see Figure 7.13.

[3] Note that the study period for the *Marin County Wildfire History Mapping Project* (Dawson, 2021) is 1852-2020, but insufficient information was available to create maps for fires before 1859. Only fires greater than 160 acres in size were included in this study.

Figure 7.12. Classified time since last fire 1859-2020 (Dawson 2021), key forest types only.

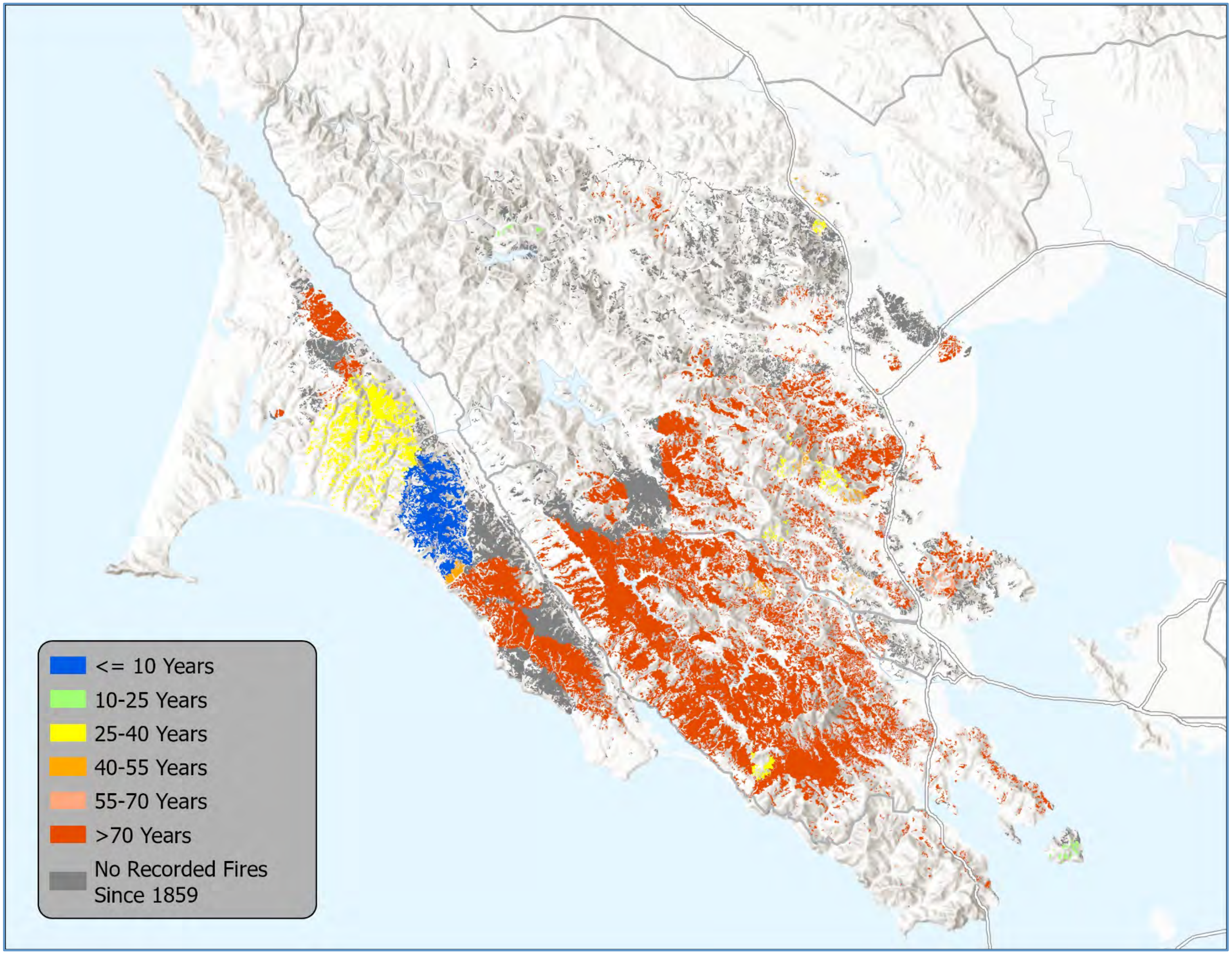
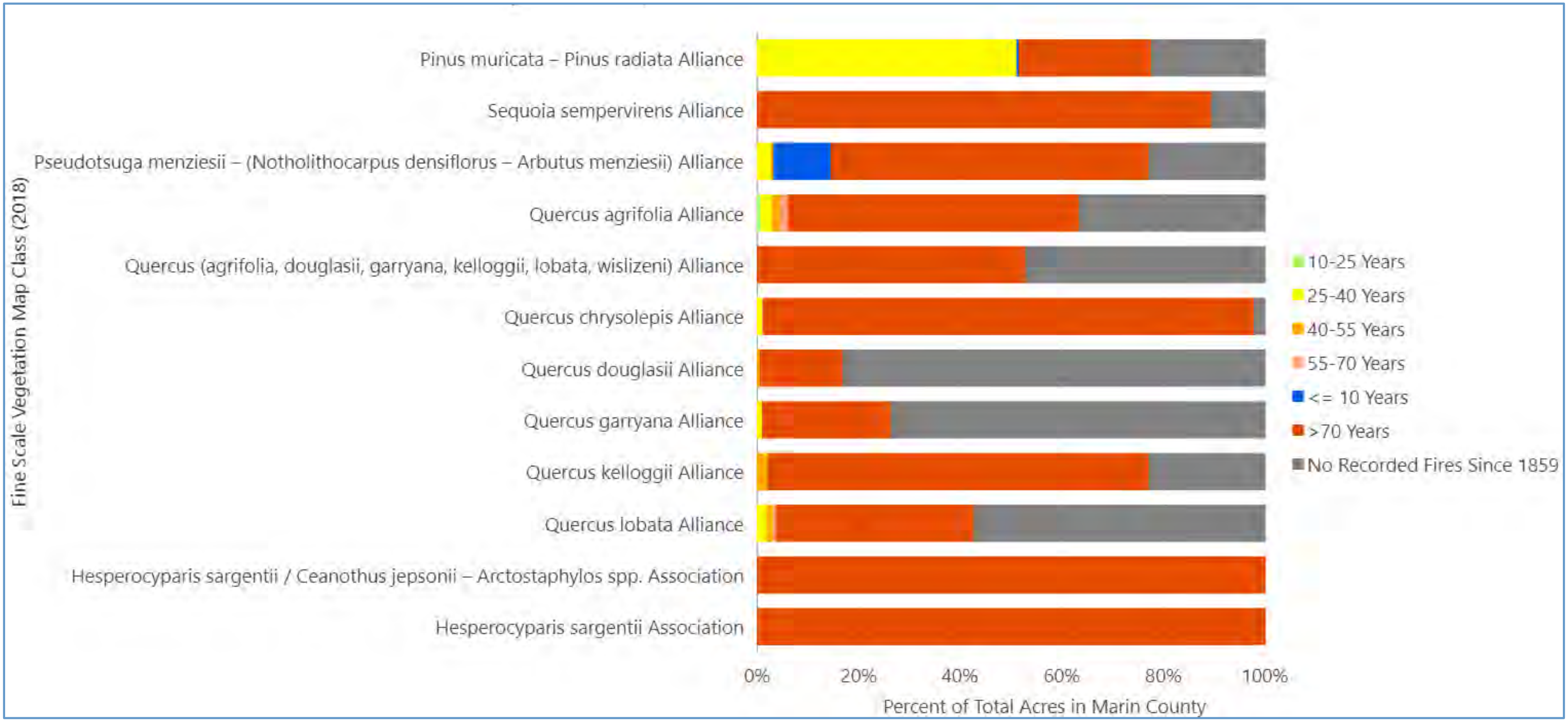


Figure 7.13. Classified time since last fire 1859-2020 (Dawson, 2021) by forest type, expressed as a percentage of the total countywide acres.



TARGET FOREST TYPE ASSESSMENT

Each target forest type is reviewed in the following sections. Metrics analysis is provided by acres and distribution, conifer-hardwood diversity for conifer forest types, stand structure, conversion to conifer forest for Open Canopy Oak Woodlands, canopy mortality dynamics, and fire history.

BISHOP PINE

Bishop Pine assessment metrics were acreage and distribution, conifer-hardwood diversity, stand structure, canopy mortality, canopy gap formation, canopy density change, and time since last fire. Chapter 5: Goals includes a brief Bishop Pine life history. A comprehensive Bishop Pine white paper can be found in Appendix A: Bishop Pine (Harvey & Agne, 2021), along with field study results for Bishop Pine forest health, fire behavior dynamics, and pitch canker impacts in Point Reyes National Seashore and Tomales Bay State Park (Harvey et al., 2022).

GOALS & ECOSYSTEM SERVICES

Goals identified for this forest type are maintaining Bishop Pine as a part of the mosaic of Marin forest types, including diverse seral states, retaining a diversity of pure and mixed conifer-hardwood stands at the landscape level, and protecting key ecosystem services of biodiversity and habitat. Other important ecosystem services include air quality, carbon sequestration, cultural values and recreation. Managing Bishop Pine to continue providing and strengthening these ecosystem services is an important goal for the One Tam agencies.

FOREST HEALTH ATTRIBUTES

Healthy attributes for Bishop Pine include age class diversity between stands, no/low incidence of pitch canker disease, and presence of snags. Native species diversity throughout the stands, fire as a part of the ecosystem, and healthy understory dynamics such as understory diversity, downed woody debris, seedling recruitment, and absorbent soil (sponge-like properties) are additional forest health attributes.

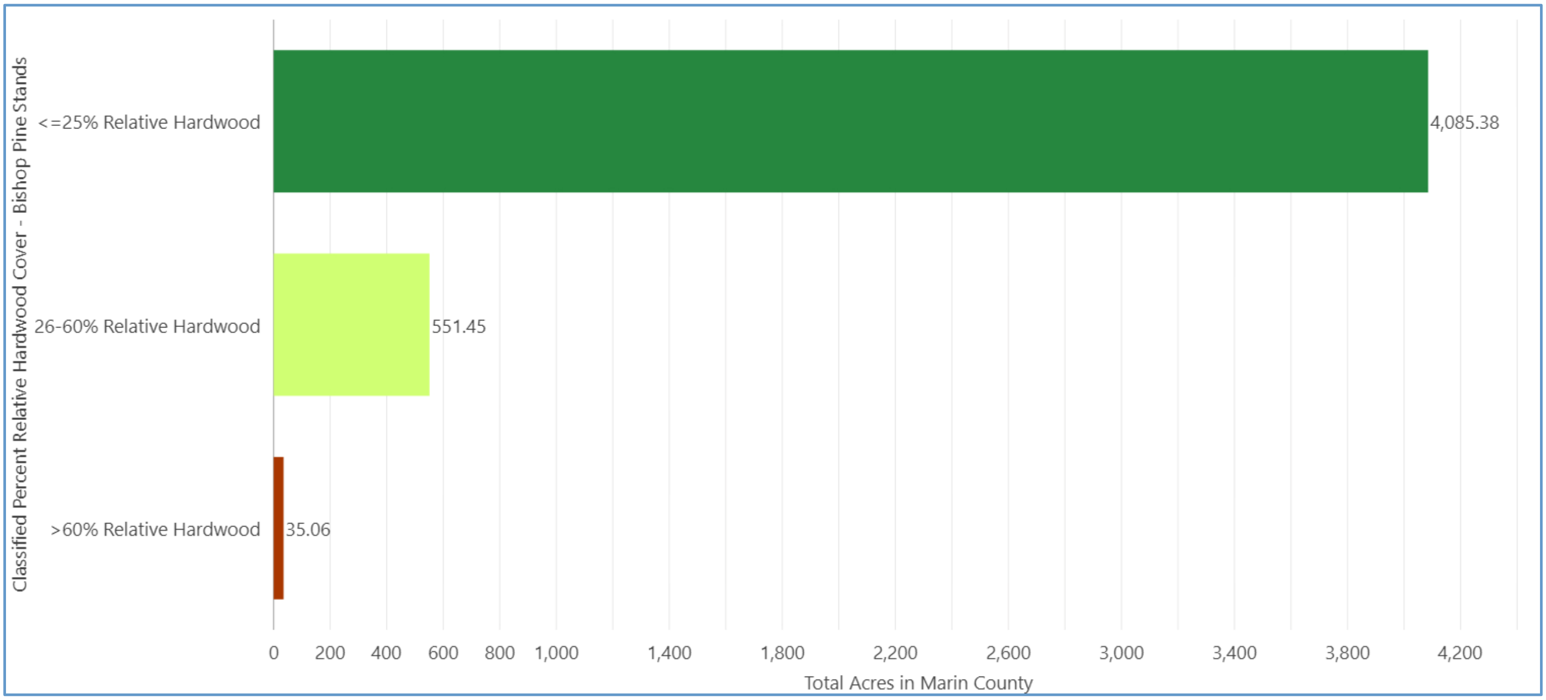
ACRES & DISTRIBUTION

The 2018 Fine Scale Vegetation Map tallied 4,668 acres of Bishop Pine forest (see Distribution in Chapter 5: Goals), mapped to the alliance level of the U.S. National Vegetation Classification (USNVC) and classified as *Pinus muricata – Pinus radiata* Alliance (Buck-Diaz et al., 2021). 89% of Bishop Pine forest in Marin County (4,152.36 acres) is on protected open space land, and 74% (3,090 acres) of the protected total is located on Point Reyes National Seashore. An additional 922 acres are located at Tomales Bay State Park (22% of protected acres). See Appendix 7A to this chapter for additional information about the distribution of Bishop Pine forest in Marin County. The total acres of Bishop Pine forest increased after high seedling recruitment following the 1995 Vision Fire (Harvey & Agne, 2021). The distribution of Bishop Pine stands can be seen in more detail in the Forest Health Web Map.

CONIFER-HARDWOOD DIVERSITY

Relative hardwood cover is used as a metric to understand variation both in the percent of hardwood in mixed Bishop Pine stands and in the presence and distribution of mixed stands. A similar pattern emerges for Bishop Pine, Douglas-fir and Coast Redwood forests in terms of prevalence of hardwood species in mixed conifer-hardwood stands. For Bishop Pine, 35 acres (less than 0.01%) had greater than 60% relative hardwood cover, 551 acres (12%) had 26-60% relative hardwood cover, and 4,085 acres (87%) had less than or equal to 25% relative hardwood cover (Figure 7.14).

Figure 7.14. Bishop Pine classified percent relative hardwood cover by acres.



STAND STRUCTURE

The Bishop Pine structural classification used the 2018 Fine Scale Vegetation Map, fire history, relative hardwood, and canopy gap and mortality attribution to differentiate stand conditions across Marin County. See Chapter 6: Metrics for details of the structural classification methodology.

- **Mid-seral stands represent the Bishop Pine cohort established after the 1995 Vision Fire.** Most (85% or 1,457 acres) mid-seral stands are in Point Reyes National Seashore (**Error! Reference source not found.**7.15, Table *7.4. Bishop Pine structural class by acres, with mean percent canopy mortality and mean percent canopy gaps formed between 2010 and 2019.*

Figure 7.5 **Bishop Pine Structural Classification**	**Total Acres in Marin County**	**Mean Percent Canopy Gap formed between 2010 and 2019**	**Mean Percent Canopy Mortality**
Late Seral, Mixed Hardwood	110	6.5%	7.4%
Late Seral, High Mortality	980	14.9%	17.7%
Late Seral, Open and Shrubby	683	6%	5.7%
Late Seral, Pure Bishop Pine	502	5%	6.4%
Mid Seral	1,715	2.9%	3.1%
Mid Seral, High Mortality	682	16.1%	14.4%

- *Table 7.*7.3).
- **It is unclear when the late-seral Bishop Pine cohort (or cohorts) were established, but according to Dawson (2021), four fires occurred in the general area of these stands between 1917 and 1934.** Additional reporting on those fires is currently not available.
- **A relatively higher proportion of late-seral stands (43%) were classified as high mortality compared to mid-seral stands (28%).** It is unclear how much (if any) mortality in late-seral stands is due to senescence versus pitch pine canker disease impacts, or what the interplay between the two stressors may be (**Error! Reference source not found.**7.15, 7.16, **Error! Reference source not found.**7.3).

Land Manager	**Mid-seral (acres)**		**Late-seral (acres)**			
	Mid-seral	**High mortality**	**Pure Bishop Pine**	**Open & shrubby**	**Mixed hardwood**	**High mortality**
Point Reyes National Seashore	1,457	598	305	412	14	305
Tomales Bay State Park	92	27	123	184	77	417
Other (public and private lands)	166	57	74	86	19	258

- **There were no mapped early-seral stands of Bishop Pine**; however, at least one Bishop Pine stand was confirmed to have burned in the 2020 Woodward Fire in Point Reyes National Seashore by National Park Service (NPS) ecologists. Future monitoring will confirm if a new cohort is established in these areas. (**Error! Reference source not**

Table 7.3. Bishop Pine structural classes by acres and land ownership.

found.7.15).

Figure 7.15. Bishop Pine structural classification with 1995 Vision Fire and 2020 Woodward Fire Perimeters, Point Reyes peninsula.

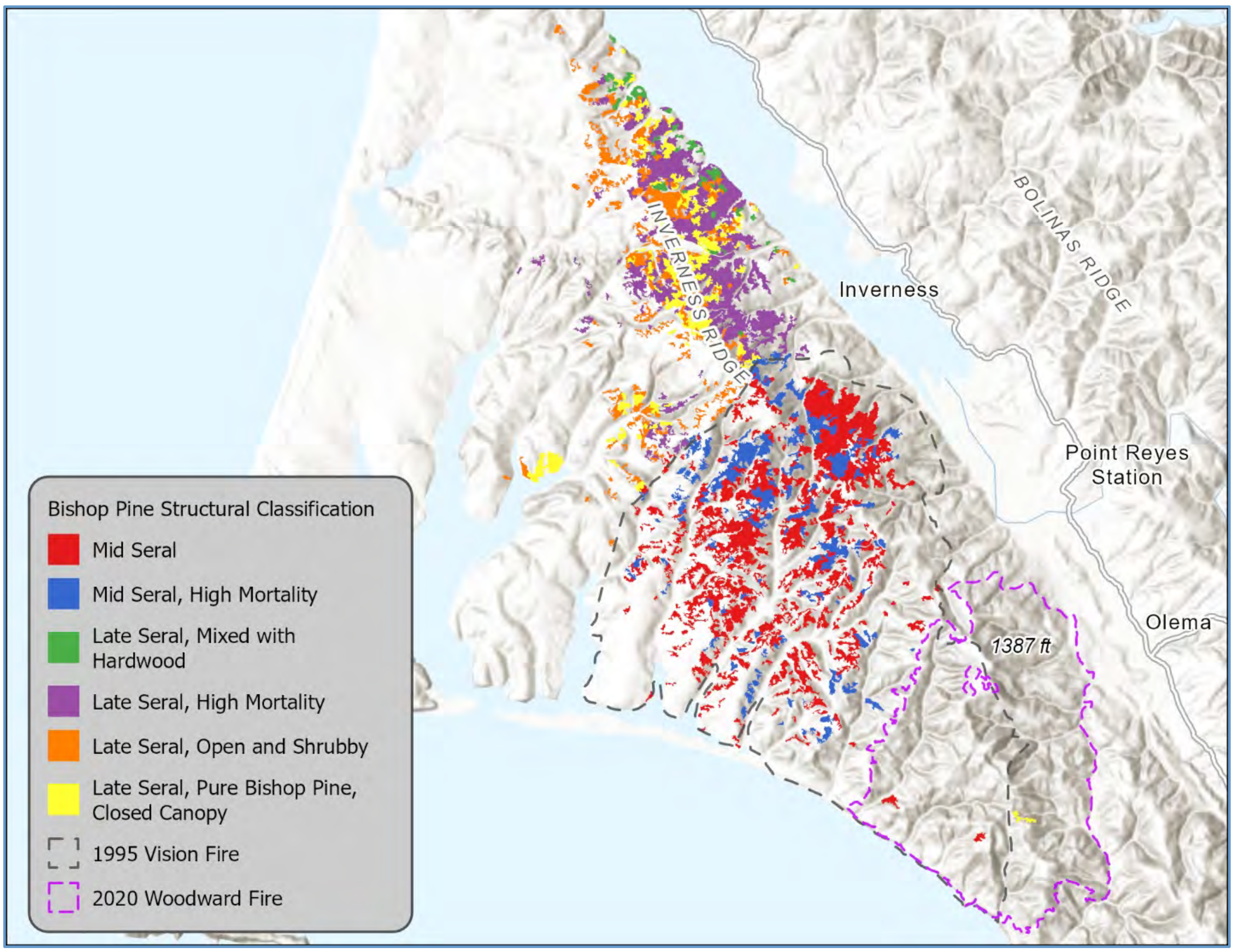
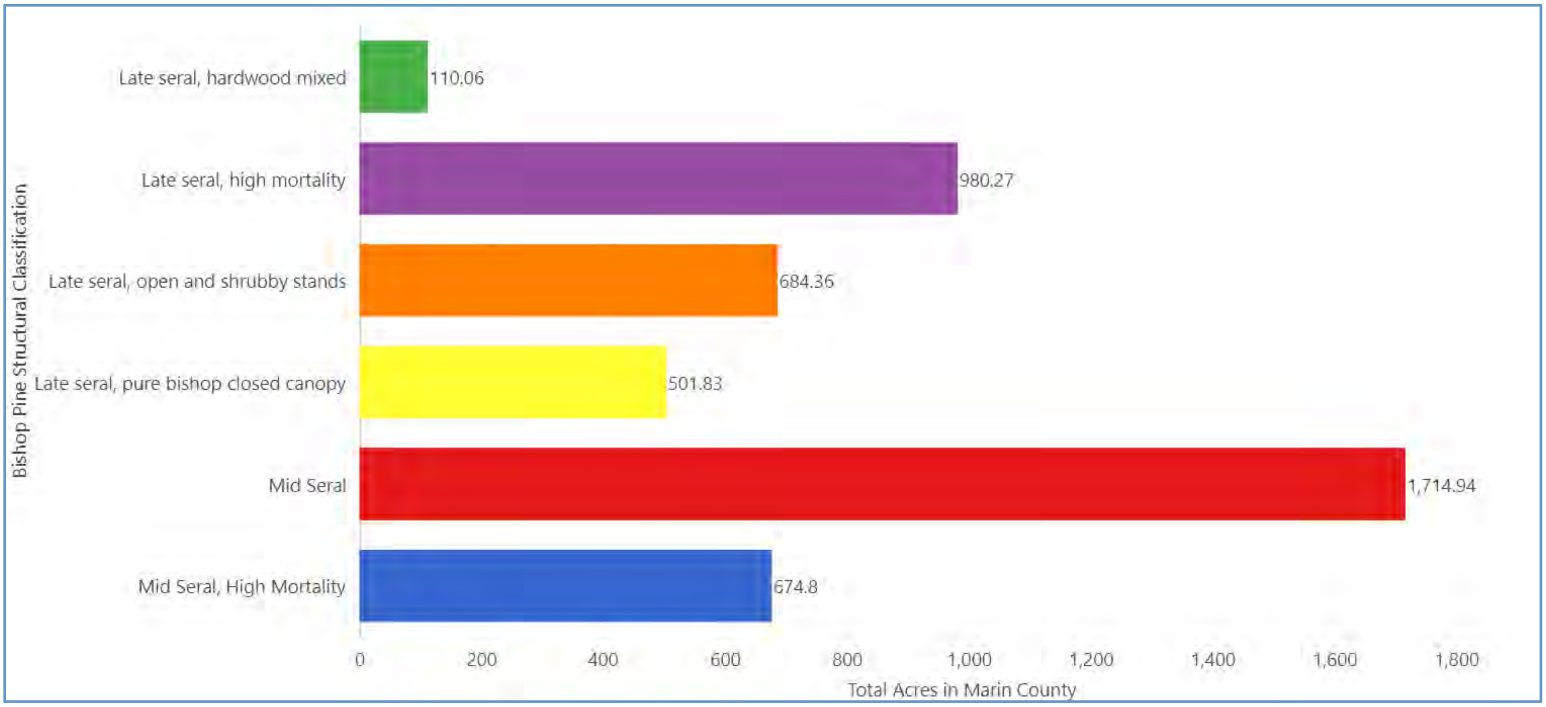


Figure 7.16. Bishop Pine structural classification by acres.



CANOPY MORTALITY & DYNAMICS

Field study on the Point Reyes Peninsula showed that nearly all sampled Bishop pine trees exhibited some pitch canker disease symptoms, although impacts are unlikely to result in local population loss (Harvey et al., 2022). Percent canopy mortality and canopy gaps metrics can be used to assess impacts of pitch canker, western gall rust, and other stressors in relationship to classified seral stage, relative percent hardwood, or other environmental and geographic variables. Table 7.4 compares results of the canopy mortality (percent standing dead) and canopy gap 2010-2019 metrics by Bishop Pine structural class.

Table 7.4. Bishop Pine structural class by acres, with mean percent canopy mortality and mean percent canopy gaps formed between 2010 and 2019.

Bishop Pine Structural Classification	Total Acres in Marin County	Mean Percent Canopy Gap Formed Between 2010 and 2019	Mean Percent Canopy Mortality
Late-seral, Mixed Hardwood	110	6.5%	7.4%
Late-seral, High Mortality	980	14.9%	17.7%
Late-seral, Open and Shrubby	683	6%	5.7%
Late-seral, Pure Bishop Pine	502	5%	6.4%
Mid-seral	1,715	2.9%	3.1%
Mid-seral, High Mortality	682	16.1%	14.4%

- **Taken together, percent canopy mortality and percent canopy gap formed 2010-2019 data illustrate the full cycle of pathogen impacts and tree decline in affected Bishop Pine stands**. Sixty-six percent (2,350 acres) of Bishop Pine forest in the highest canopy mortality class (greater than 2.5% of canopy) was mapped with greater than 5.5% canopy gap formed between 2010 and 2019, compared to only 24% (110 acres) with greater than 5.5% canopy gap formed in stands with less than 0.5% or no canopy mortality (Figure 7.17). Due to the clear relationship between canopy mortality and gap formation in Bishop Pine forest, it made sense to combine these metrics and include in the Bishop pine structural classification (see Chapter 6: Metrics for additional information).
- **Late-seral, mixed hardwood stands do not show lower incidence of canopy mortality or gap formation.** Mortality and gap information is not species-specific. However, late-seral mixed-hardwood Bishop Pine stands have similar canopy mortality and gap indices as both pure Bishop Pine and open and shrubby Bishop Pine stands, which suggests that there is not an obvious link between mixed-hardwood Bishop Pine stands and a lower incidence of pathogen impacts.
- **Bishop Pine forests show a relatively high proportion of canopy gaps[4] formed between 2010 and 2019 and percent canopy mortality (Table 7.4) compared to other native forests in Marin County**. The mean percent canopy mortality for all other native forests in Marin County (excluding Bishop Pine) is 0.23% (median equals 0, standard deviation equals 1.05%), and the mean percent canopy gaps formed between 2010-2019 for all other native forests in Marin County (excluding Bishop Pine) is 3.8% (median 3%, standard deviation equals 4.24%).
- **Bishop pine structural classes with the highest canopy mortality experienced more canopy density loss relative to other structural classes with less canopy mortality** (Figure 7.18). Nineteen percent (183 acres) of Bishop Pine stands in the late-seral, high-mortality structural class experienced canopy density loss greater than 10% between 2010 and 2019. Similarly, 59% (404 acres) of the mid-seral, high-mortality class showed greater than 10% canopy density loss between 2010-2019. While canopy density differencing cannot distinguish between species within a given stand, these results seem to support that late-seral stands with high mortality are in general decline, potentially due to a combination of pathogen impacts and senescence. Density loss in mid-seral, high-mortality stands could be driven by a combination of natural self-thinning (as part of stand progression) and pathogen impacts.

[4] Although remote sensing data cannot distinguish the causes of canopy gaps, NPS vegetation ecologists note that, anecdotally, all the canopy gaps in the Vision Fire footprint are caused by pitch canker. Sudden oak death appeared in the hardwood components in the same area in the early 2000s, pitch canker began to impact young Bishop pine approximately 5 years afterward, and Western gall rust is also impacting large Bishop pine individuals in Tomales Bay State Park (A. Forrestel, Chief of Natural Resources and Science, GGNRA, personal communication, 2022).

Figure 7.17. Bishop Pine classified percent canopy mortality (standing dead) with classified percent canopy gaps formed 2010-2019, expressed as a percentage of countywide acres.

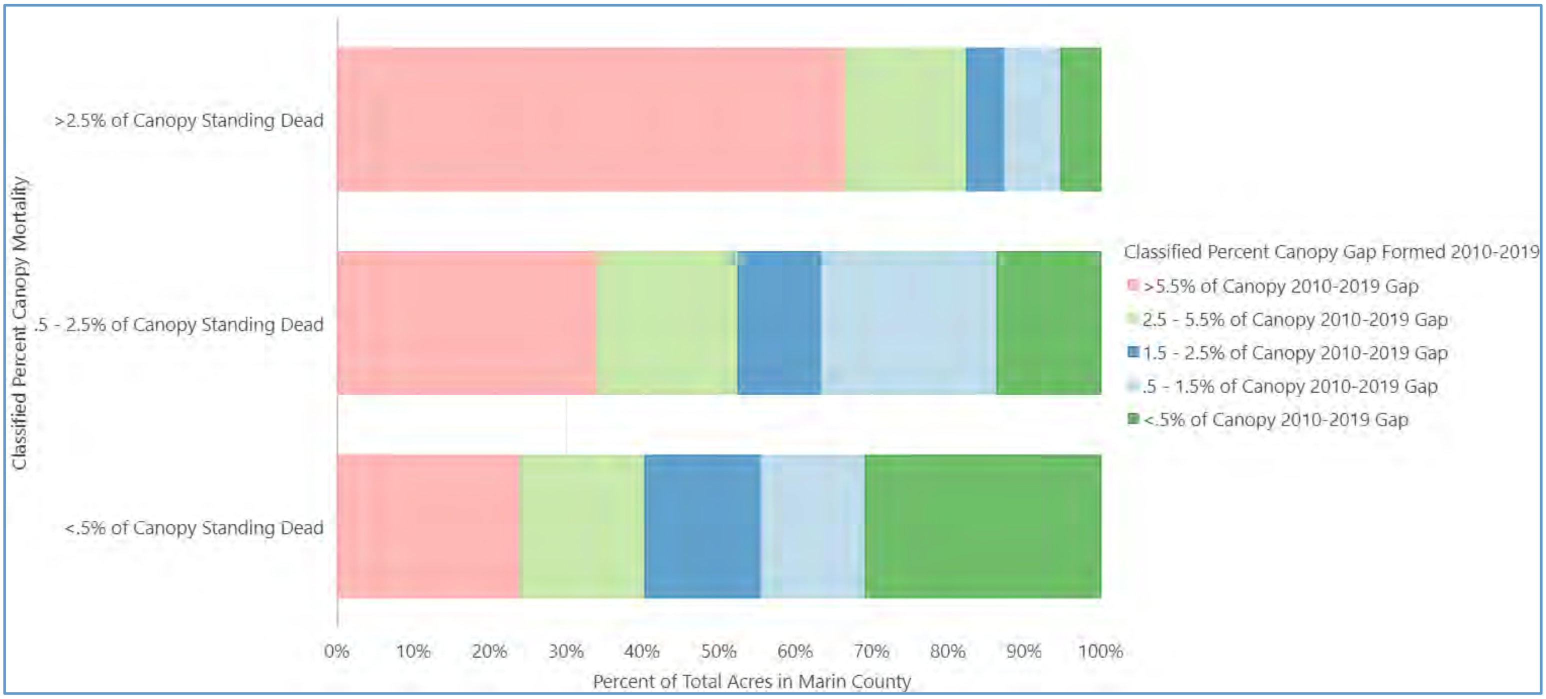
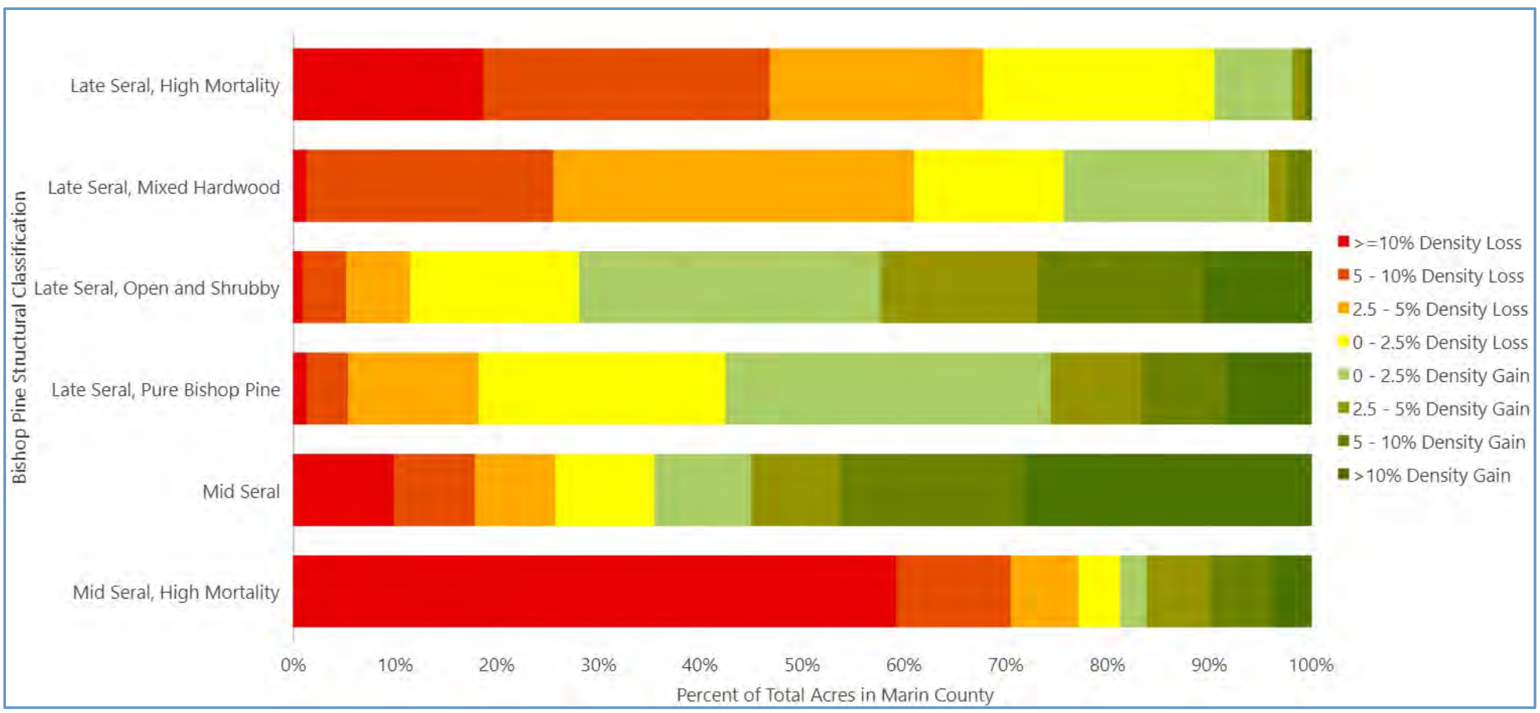


Figure 7.18. Bishop Pine structural classification with classified canopy density change 2010-2019, expressed as a percentage of total countywide acres.



FIRE HISTORY DYNAMICS

- **All mid-seral Bishop Pine stands in Marin County are part of the cohort established after the 1995 Vision Fire (**Figure 7.15, above). Notably, a few Bishop Pine stands appear to have burned in the 2020 Woodward Fire. Point Reyes National Seashore will be monitoring these areas to assess fire effects and determine if new, early-seral Bishop Pine stands are developing as a result.
- **All late-seral stands have not experienced a fire greater than 160 acres in size in 80 years or more** (Dawson, 2021). Fires were recorded in the vicinity of Inverness Ridge and Shafter Ranch between 1917 and 1934; however, additional information corroborating spatial extent and ignition date is lacking at this time (Dawson, 2021).

BISHOP PINE SUMMARY

Bishop Pine forests are an important component of the mosaic of forest types in Marin County. Available data supports the consensus among land managers and researchers that *Fusarium circinatum*, the fungal pathogen that causes pitch canker disease, is impacting this forest type, but that the pathogen alone is unlikely to threaten long-term persistence of Bishop Pine (Harvey et al., 2021). Additional field study may be able to explore relationships between pathogen impacts and mortality related to senescence in late-seral stands or self-thinning in mid-seral stands. Fire exclusion could threaten Bishop Pine in Marin County since stand-replacing fires are typically required for the establishment of new age cohorts; however, treatments designed to foster Bishop pine regeneration in late-seral stands may be effective. Demonstration projects could explore forest health treatment prescriptions that both advance mid-seral stands towards later seral conditions and may strategically alter fire behavior in priority areas.

COAST REDWOOD

Coast Redwood assessment metrics were acreage and distribution, conifer-hardwood diversity, stand structure, canopy mortality, canopy gap formation, canopy density change, and time since last fire. Chapter 5: Goals includes a brief Coast Redwood life history.

GOALS & ECOSYSTEM SERVICES

Less than 5% of the original old-growth Coast Redwood forests remain across its range, although second-growth forests have persisted over much of their historical distribution (Fox, 1989). Since most Coast Redwood in Marin County is second growth, the future desired condition is accelerating mature second-growth stands towards old-growth stand conditions.

Priority ecosystem services provided by Coast Redwood include carbon sequestration, recreation, and hydrologic function. Coast Redwood provides air quality, cultural values, habitat and biodiversity. Managing Coast Redwood stands to continue providing and strengthening these ecosystem services, as well as promoting old-growth conditions including reduced stem density, increased number of large-diameter trees, complex species composition, and multi-aged/storied stand structure is an important goal for One Tam agencies.

FOREST HEALTH ATTRIBUTES

Healthy Coast Redwood stands contain large-diameter trees of greater than 100 centimeters diameter at breast height (DBH), standing snags, and a density of 50-100 overstory trees/hectare (20-40 trees/acre). They are also multi-layered and multi-aged with a well-developed mid-canopy including tanoak (*Notholithocarpus densiflorus*), bay laurel (*Umbellularia californica*), and Douglas-fir, and host a healthy understory with shrub and herbaceous components (Lorimer et al., 2009; Van Pelt et al., 2016). Native species diversity and presence of indicator species such as northern spotted owl (*Strix occidentalis caurina*), Coho salmon (*Oncorhynchus kisutch*), and steelhead trout (*O. mykiss*) are additional important forest health attributes along with absorbent soil, healthy riparian and alluvial systems, and fire within the natural range of variation.

ACRES & DISTRIBUTION

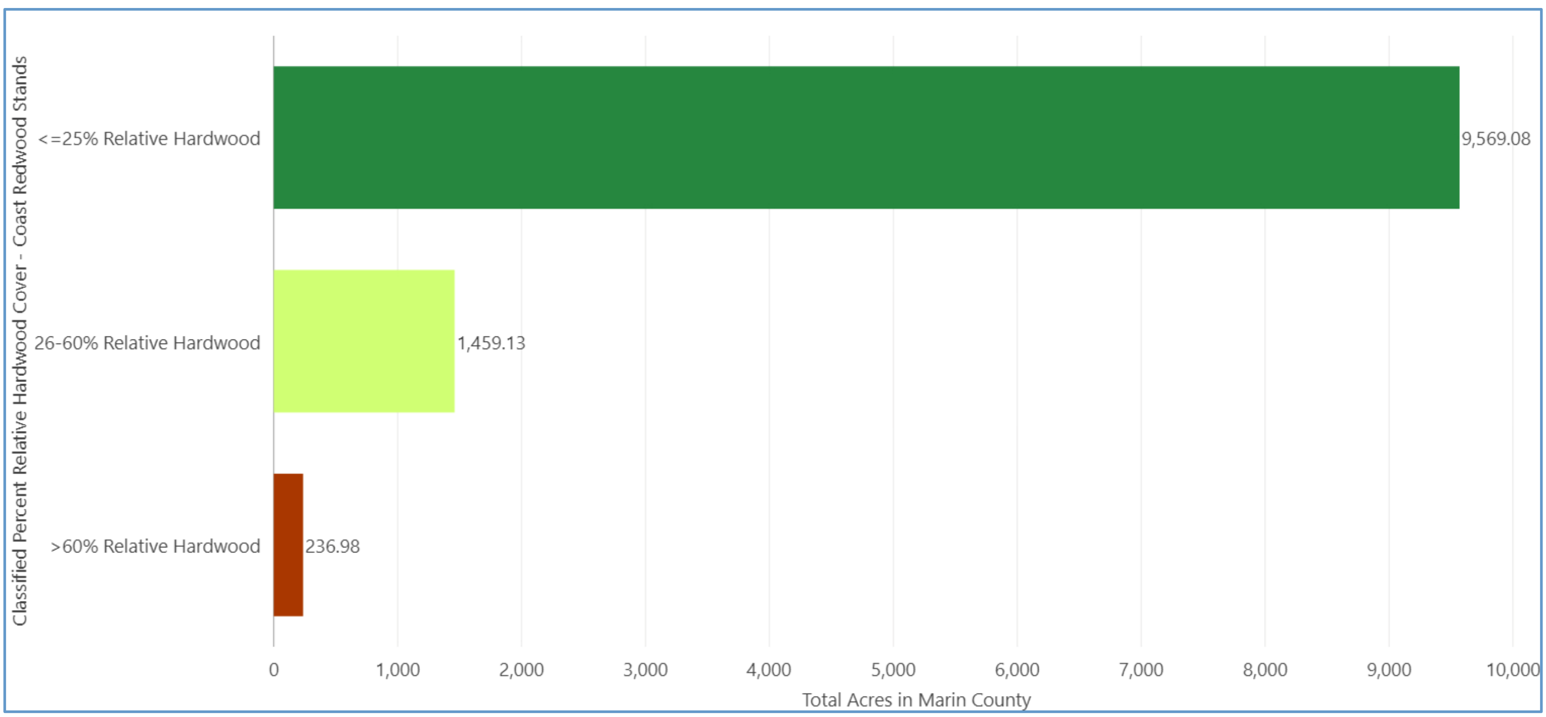
The 2018 Fine Scale Vegetation Map identified 11,265 acres of Coast Redwood forest in Marin County. Of that total, 72% (8,142 acres) are on protected open space lands. Marin Municipal Water District manages 50% (4,108) of all protected Coast Redwood forest in Marin County, followed by the Golden Gate National Recreation Area which manages 1,803 acres or 22% of the protected countywide total, including the iconic old growth stands of Muir Woods National Monument. See Appendix 7A for additional details on the distribution of Coast Redwood stands, see distribution map in Chapter 5: Goals, and explore in more detail via the Forest Health Web Map.

CONIFER-HARDWOOD DIVERSITY

Relative hardwood cover is used as a metric to understand variation in the presence and distribution of mixed coast redwood-hardwood stands.

- **Like other conifer forest types in Marin County, the vast majority of Coast Redwood forest have less than or equal to 25% relative hardwood cover (85 % or 9,569 acres),** see Figure 7.19. While the presence of mid-canopy hardwood species such as tanoak or bay laurel are considered an attribute of healthy Coast Redwood stands, low relative hardwood cover according to this mapping methodology should not be interpreted as direct evidence of absence for this attribute in Coast Redwood forests. This metric relies on mapping visible canopy using aerial imagery and is not intended to be an estimate of midstory or understory characteristics.
- **There appears to be a positive relationship between higher relative hardwood cover and shorter Coast Redwood stands.** Forty-six percent of Coast Redwood forest with greater than 60% relative hardwood cover is classified as having a mean lidar-derived stand height of 60 feet or less, while 36% of short Coast Redwood stands (less than 60 feet mean stand height) had 26-60% relative hardwood, and only 12% of pure Coast Redwood forest (less than or equal to 25% relative hardwood) were in the shortest structural class (Figure 7.21). While this relationship could simply reflect variation in stand height, soil type, moisture regime, or other environmental characteristics, land managers may be able to use this information to track forest type transitions and/or Coast Redwood climate exposure, especially in short, dense Coast Redwood stands.

Figure 7.19. Coast Redwood classified percent relative hardwood cover by acres.



STAND STRUCTURE

This metric classified each Coast Redwood stand in Marin County, assigning it to one of five structural classes that represents tree height and vertical structure (Figure 7.20). Tree height is represented first in the classification as “Small”, “Medium to Large”, or “Largest”. Vertical structure is represented second, as “LESS” or “MORE”. The "Largest Stands" category includes all stands of over 140 feet mean height. See Chapter 6: Metrics for details on the structural classification methodology.

- **Coast Redwood classified as largest stands (greater than 140 feet mean height) are highly correlated to areas known to contain old-growth Coast Redwood stands.** This includes Muir Woods National Monument, Mount Tamalpais State Park, Samuel P. Taylor State Park, and Roy’s Redwoods Open Space Preserve (Figure 7.22). Coast Redwood stands in this structural class generally correspond to areas of significant natural resource value, which can help managers prioritize forest health and conservation measures aimed at promoting the long-term resilience of these stands.
- **Most Coast Redwood stands (73% or 8,253 acres) in Marin County are in the medium to large, more vertical structure class** (Figure 7.20 and 7.22)**.** While this structural class is a reasonable proxy for identifying second-growth areas, there are notable areas understood to support old growth (i.e., never logged) that fall within this structural class, such as Steep Ravine Canyon in Mount Tamalpais State Park. This suggests that additional analysis and field data collection is likely needed to differentiate between some second-growth and old-growth stands. In addition, this shows that many previously logged, second-growth Coast Redwood stands share structural similarities with groves of old-growth trees, indicating opportunities to encourage late-seral conditions through active management in a variety of areas.
- **Regardless of classified stand height, most (91% or 10,244 acres) Coast Redwood stands were mapped as having more vertical structure or a higher coefficient of variation (CV[5])**. Future work could evaluate the relationship of less vertical structure or low CV to certain on-the-ground conditions; however, at the countywide scale, no spatial pattern could be detected in the distribution of Coast Redwood stands with less vertical structure.

[5] Coefficient of variation (CV) is calculated as the standard deviation of mean lidar-derived stand height divided by mean lidar-derived stand height. Managers should note that while the CV is a reasonable proxy for understanding variation in tree heights for a given stand, this metric can be influenced by a variety of environmental factors and may be more useful at local rather than landscape scales.

Figure 7.20. Coast Redwood structural classification by acres.

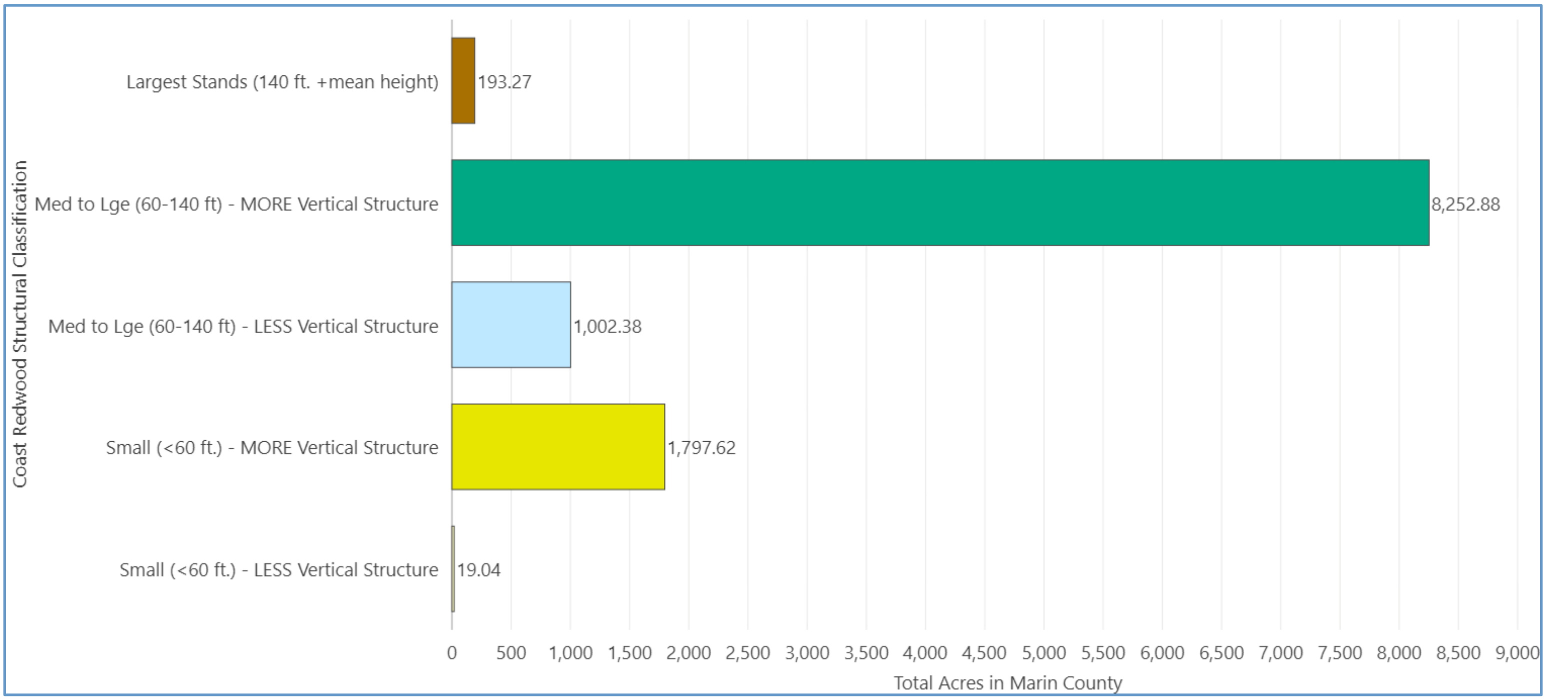


Figure 7.21. Coast Redwood structural classification with classified percent relative hardwood expressed as a percentage of total countywide acres.

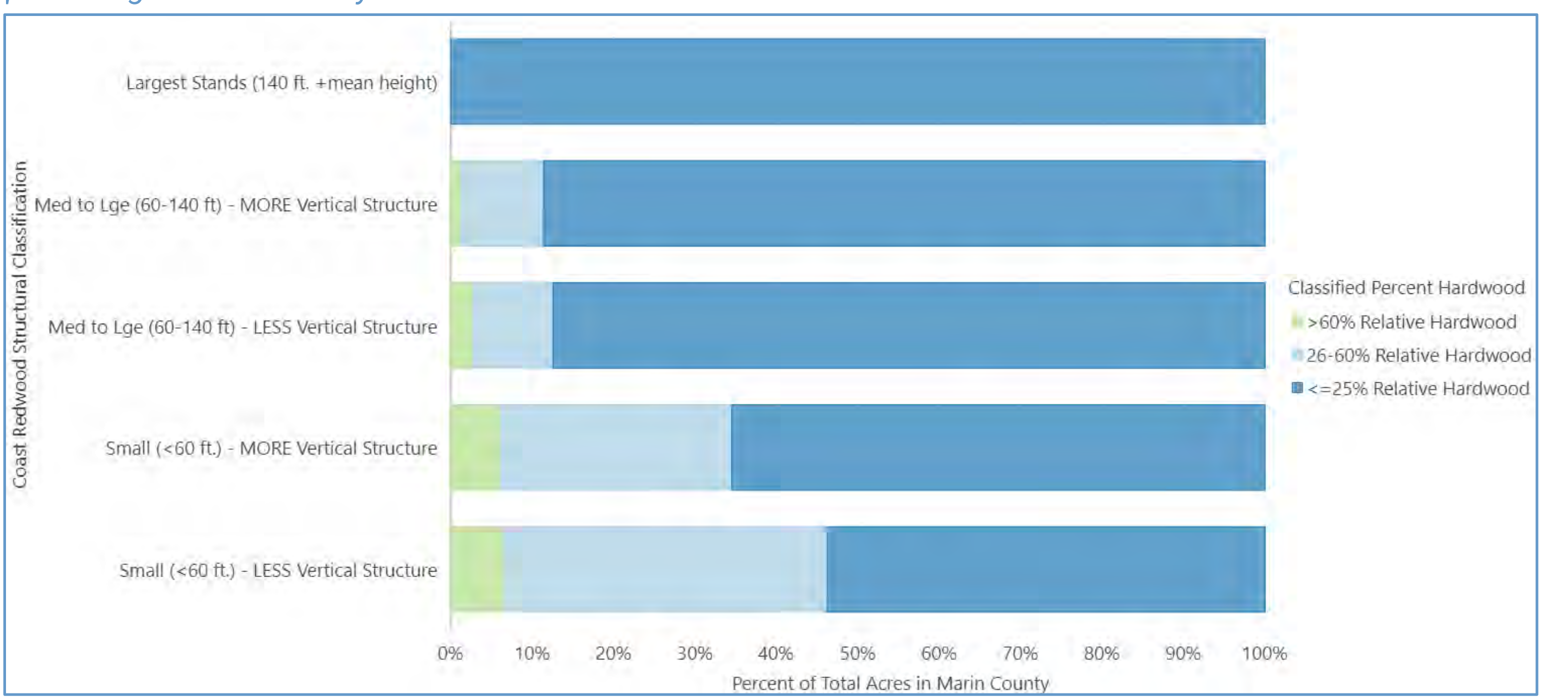
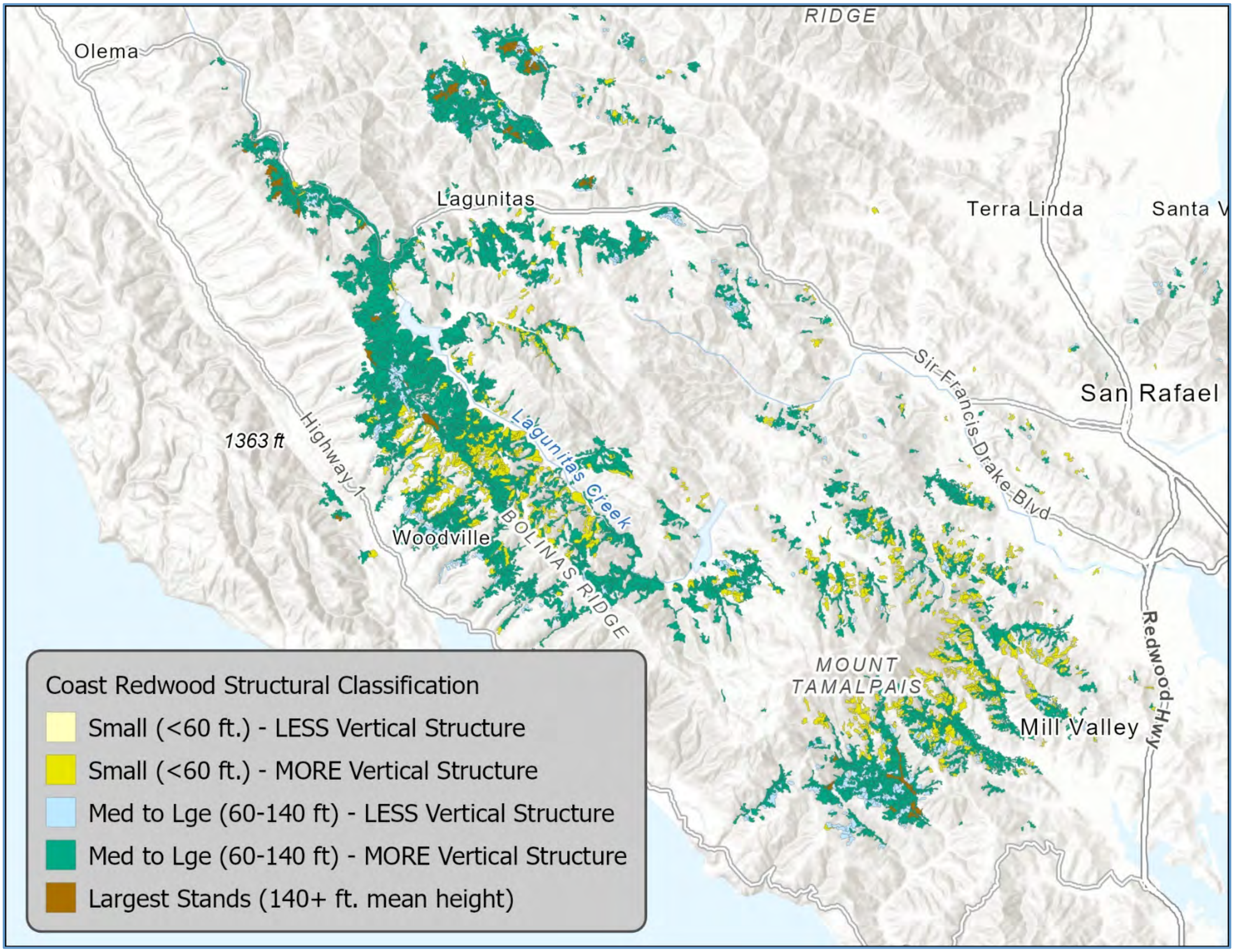


Figure 7.22. Coast Redwood structural classification, Mount Tamalpais, Bolinas Ridge, and San Geronimo Valley Areas.



CANOPY MORTALITY & DYNAMICS

Canopy mortality (percent standing dead) in Coast Redwood forests is likely caused by pathogen impacts (e.g., sudden oak death) to hardwood associates such as tanoak or Pacific madrone (*Arbutus menziesii*). In addition, *Phytophthora cinnamomi* has been detected on Marin Water's Tamalpais Watershed lands and could be contributing to mapped canopy mortality in some Coast Redwood forests.

- While canopy mortality in Coast Redwood forests is not as pronounced as in Bishop Pine areas, **significant canopy mortality is present in Marin's Coast Redwood forests.** Nineteen percent (2,182 acres) of Coast Redwood forests have detectible mortality in the canopy between 0.5 and 2.5%, and an additional 2% (186 acres) showed greater than 2.5% canopy mortality in 2018 (Figure 7.23).

- Analysis of canopy gaps formed between 2010 and 2019 in Coast Redwood forests reveals a similar trend to Bishop Pine: **a higher percentage of canopy gaps formed in Coast Redwood stands with higher classified canopy mortality** (Figure 7.24). In Coast Redwood areas classified with greater than 2.5% canopy mortality, 87% (161 acres) showed greater than 5.5% canopy gaps formed between 2010 and 2019. Many of these stands are located on the eastern side of Bolinas Ridge, on Tamalpais Watershed lands known to be affected by sudden oak death. It is important to note that canopy gaps form naturally as part of healthy Coast Redwood forest dynamics and play a role in forest regeneration. Therefore, tracking effects of pathogens (and other stressors) should use canopy gaps and canopy mortality metrics in conjunction to locate impacted areas, which also captures the temporal aspects of the disease cycle more fully.
- **Canopy mortality is greater in Coast Redwood forests that have higher classified relative percent hardwood cover** (Figure 7.25)**.** Eleven percent of Coast Redwood forests with greater than 60% relative hardwood cover have greater than 2.5% canopy mortality, compared to 1% canopy mortality for stands with less than 25% relative hardwood cover. Managers should note that mortality was mapped across all Coast Redwood forests regardless of hardwood cover. This result is likely confirmation that pathogen impacts largely effect the hardwood species associated with Coast Redwood.
- **The greatest proportion of canopy density loss in Coast Redwood forests came from areas mapped with higher relative hardwood cover** (Figure 7.28). This indicates that at least some loss in canopy density in Coast Redwood forests is likely attributable to pathogen impacts to evergreen hardwoods such as tanoak or madrone. Managers should note that the canopy density change metric will be less reliable for areas with deciduous species due to differences in phenology and the timing of lidar collection in 2010 (late-spring) versus 2019 (mid-winter).
- **Canopy mortality is relatively higher in Coast Redwood stands in the smaller structural classes** (Figure 7.26). Although canopy mortality was detected across all Coast Redwood structural classes, proportionally mortality was higher in Coast Redwood forests in the shorter structural classifications. In assessing all Coast Redwood forest with a mean lidar-derived stand height less than 60 feet, 32% (520 acres) had between 0.5 and 2.5% mortality in the canopy, and an additional 3% (60 acres) of these shorter Coast Redwood forests had greater than 2.5% canopy mortality. Future analysis could explore a possible relationship between a higher CV (more vertical structure) and higher canopy mortality to see how pathogen impacts influence lidar-based measurements of stand structure.
- **Analysis of canopy density change for Coast Redwood forests between 2010 and 2019 shows that most areas have increased in canopy density** (Figure 7.27). Eighty-three percent (9,405 acres) showed at least some increase in canopy density between 2010 and 2019.

Figure 7.23. Coast Redwood classified percent canopy mortality (standing dead).

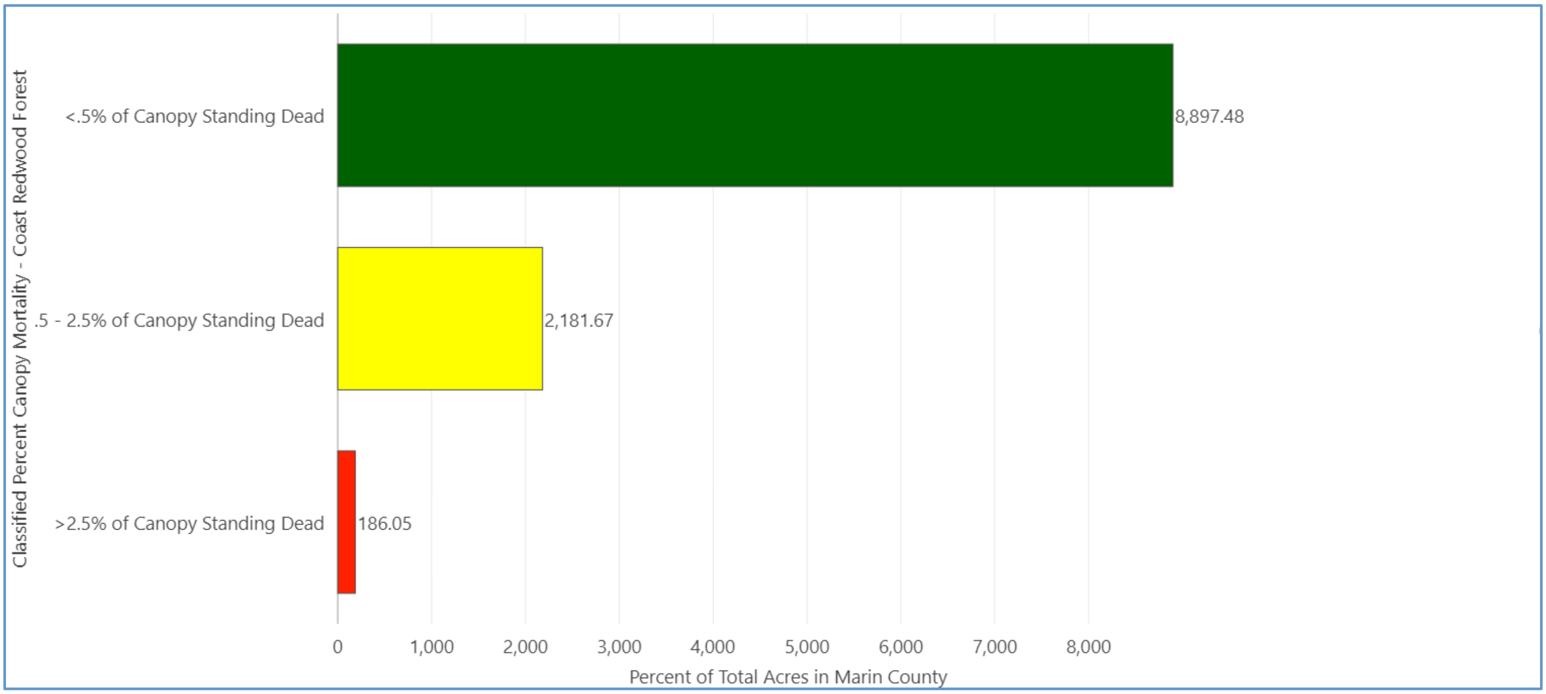


Figure 7.24. Coast Redwood classified percent canopy mortality (standing dead) with classified percent canopy gaps formed 2010-2019, expressed as a percentage of countywide acres.

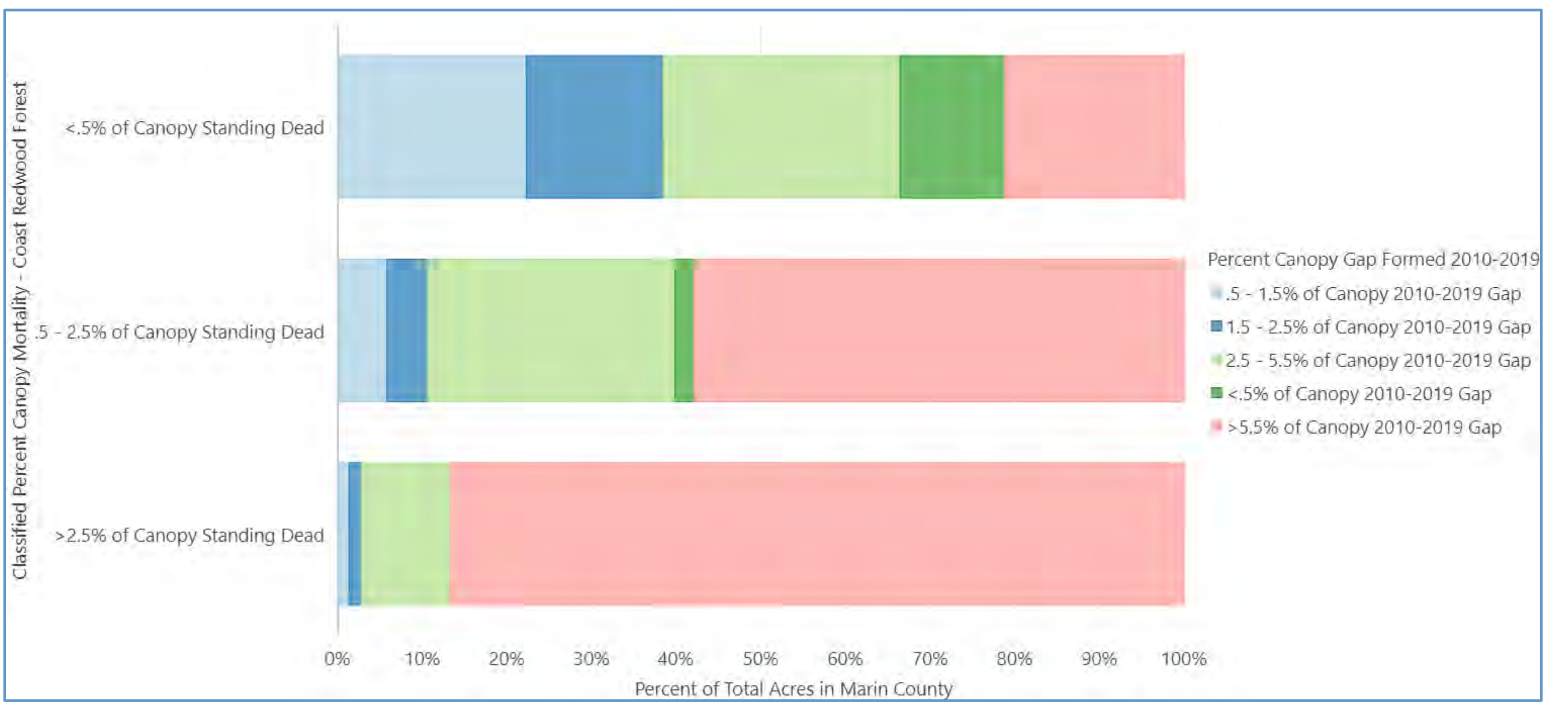


Figure 7.25. Coast Redwood classified percent relative hardwood with classified percent canopy mortality (standing dead), expressed as a percentage of the total countywide acres.

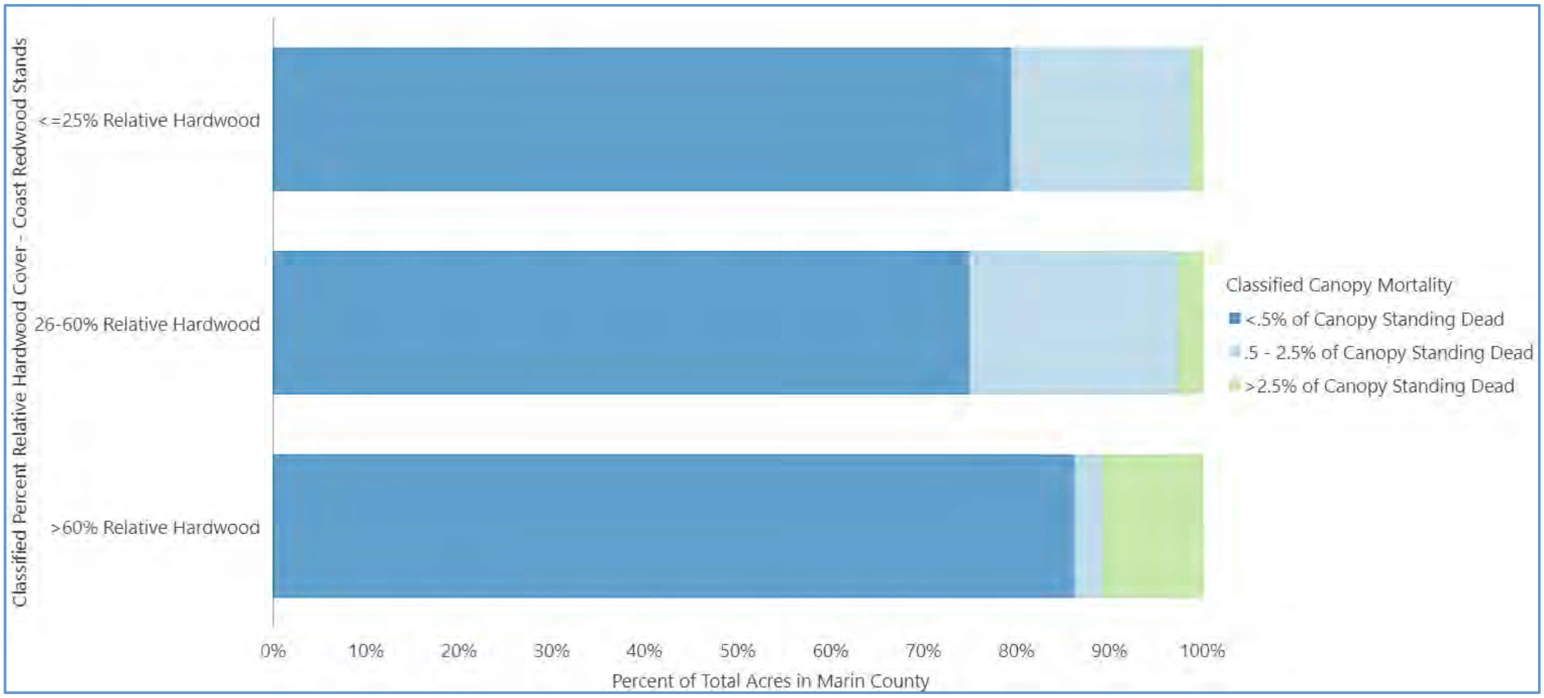


Figure 7.26. Coast Redwood structural classification with classified percent canopy mortality (standing dead), expressed as a percentage of the total countywide acres.

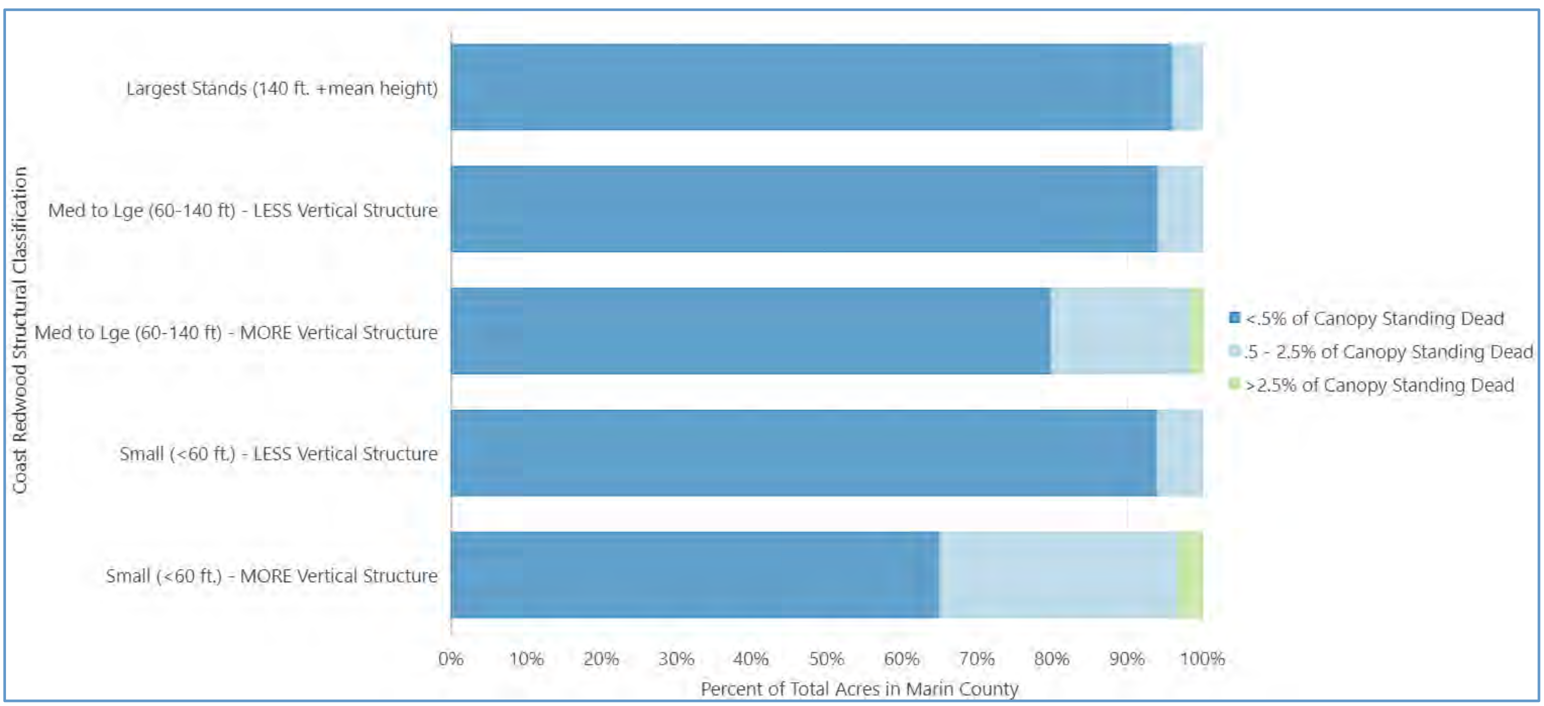


Figure 7.27. Coast Redwood classified canopy density change between 2010 and 2019 by acres.

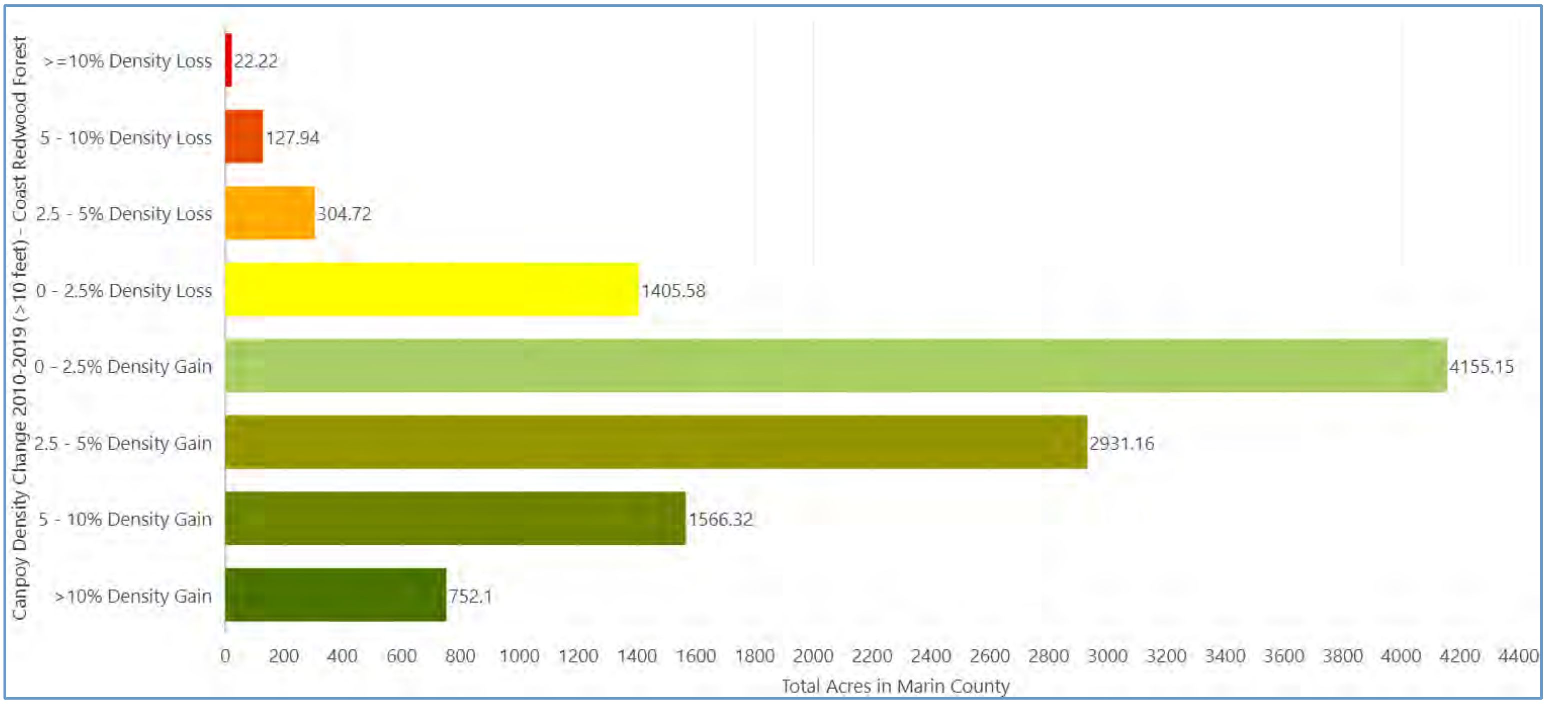
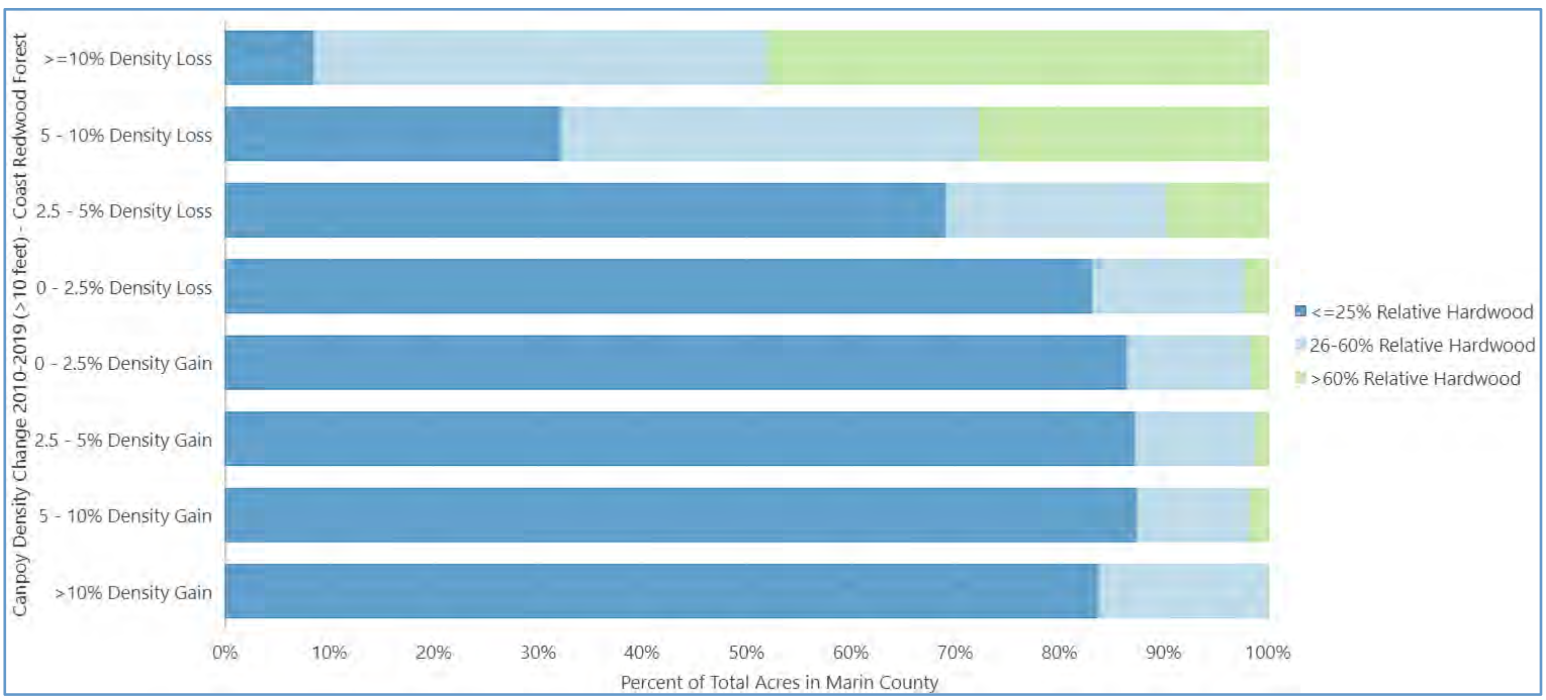


Figure 7.28. Coast Redwood classified canopy density change 2010-2019 with classified percent relative hardwood, expressed as a percentage of the total countywide acres.



FIRE HISTORY DYNAMICS

Coast Redwood forest is a fire-adapted ecosystem with a wide range in fire return intervals across its geographic range that are highly dependent on localized variables such as latitude, topography, and moisture regime. Several studies specific to Marin County have documented return intervals at various sites ranging from approximately 5 to 45 years (see Coast Redwood, Chapter 5: Goals). However, it should be noted that fire return intervals prior to colonization and EuroAmerican record-keeping were highly variable, and while some areas may have experienced fire more frequently as a result of Coast Miwok burning, return intervals of several hundred years have been documented, particularly in mesic areas. Therefore, management based solely on a departure from estimated mean or median historic fire return intervals may not be appropriate (Jones & Russell, 2015). Fire exclusion produces changes in the fuel structure, forest structure, and floristic composition (e.g., shift to more shade-tolerant species) of Coast Redwood forests (Arno, 2000; Brown et al., 1999; Brown & Baxter, 2003; Lorimer et al., 2009; Norman et al., 2009; Ramage et al., 2010).

- **According to data from the Marin Wildfire History Mapping Project** (Dawson, 2021), **79% (8,917 acres) of Coast Redwood forest had a fire return interval of 5 – 45 years** (Figure 7.29)**.** A significant percentage (49% or 5,543 acres) of Coast Redwood forest expirenced fire every 15-30 years, including forests on Bolinas Ridge and portions of Mount Tamalpais.
- **Much Coast Redwood forest in Marin County (41% or 4,643 acres) has not experienced a fire greater than 160 acres in size in the 76 years since the 1945 Mill/Carson Canyon Fire** (Dawson, 2021)**.** Significant Coast Redwood acreage has not burned in 100 years or more (Figure 7.30).

Figure 7.29. Coast Redwood classified fire return interval between 1859 and 1940 by acres.

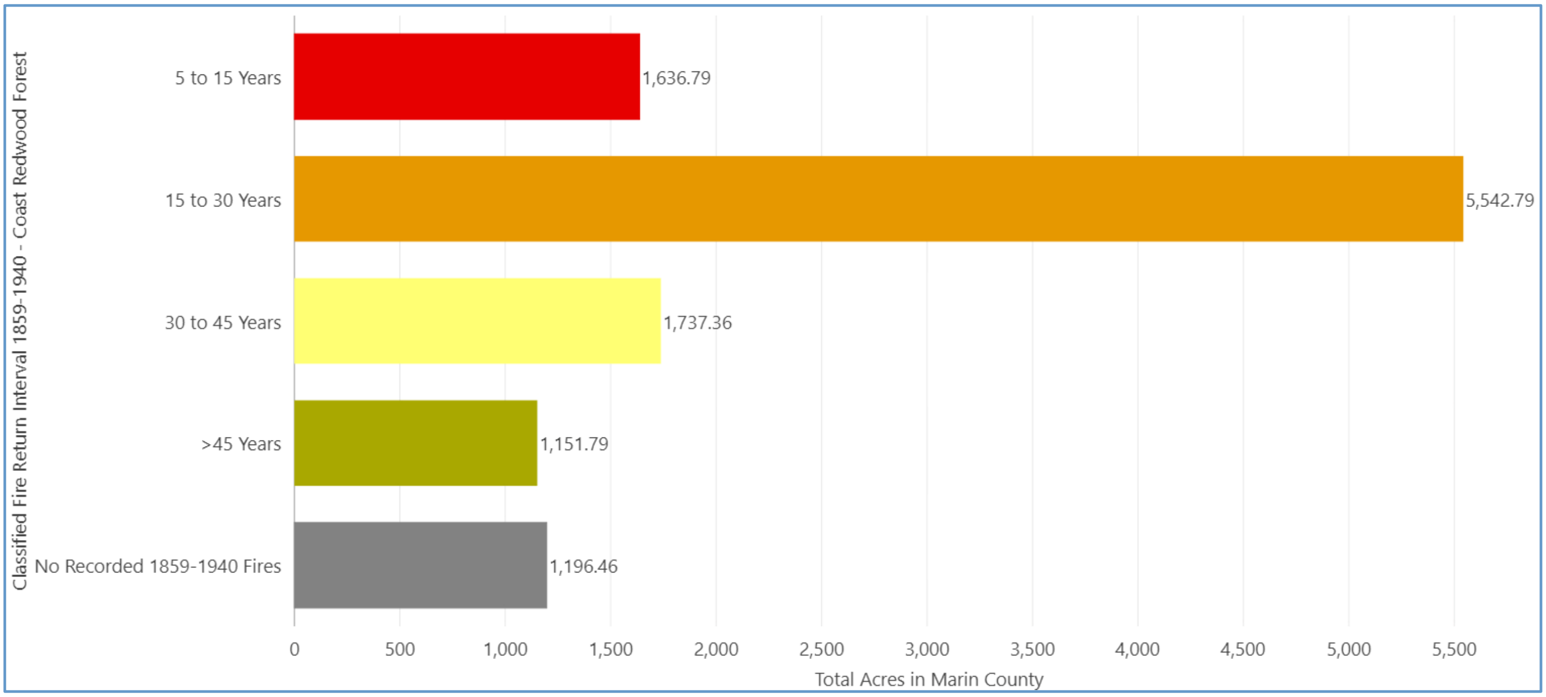
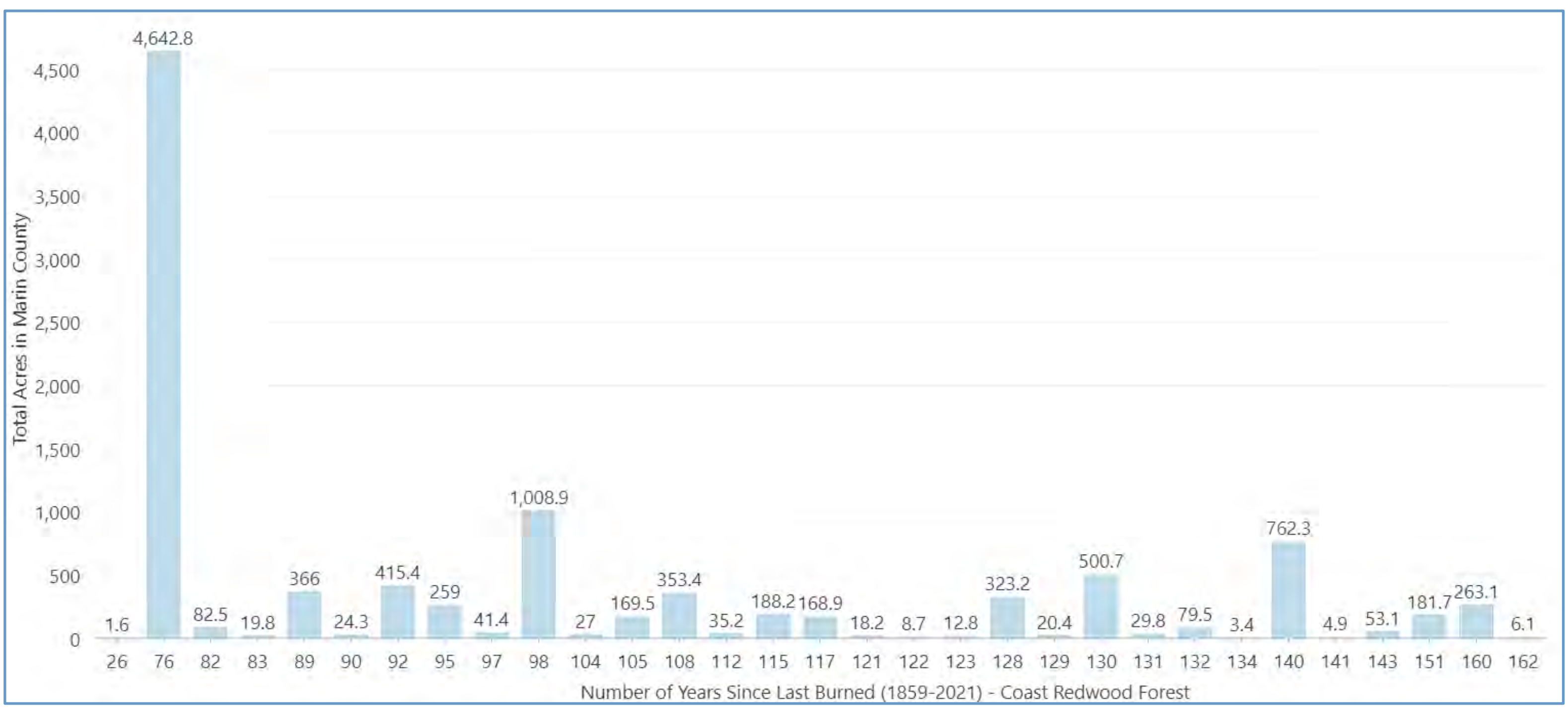


Figure 7.30. Coast Redwood number of years since last fire by acres.



COAST REDWOOD SUMMARY

Overall, Coast Redwood stands are a stable part of the Marin County forest mosaic. However, ongoing work aims to assess the vulnerability of these iconic trees to anticipated changes in climate. Structural indices show that many second-growth stands and previously unlogged stands have some similar characteristics, indicating there are opportunities to advance management approaches that could help accelerate a transition to old-growth conditions in key areas. Canopy mortality and other metrics used to quantify pathogen and disease impacts show that in some areas important evergreen hardwood associates of Coast Redwood forests, such as tanoak and Pacific madrone, are in decline. Fire exclusion continues to alter Coast Redwood ecosystem dynamics and reduce biological diversity of understory species.

DOUGLAS-FIR

Douglas-fir assessment metrics were acreage and distribution, conifer-hardwood diversity, stand structure, canopy mortality, canopy gap formation, canopy density change, and time since last fire. Chapter 5: Goals includes a brief Douglas-fir life history. Depending on location and vegetation, Douglas-fir can be challenging to assess since it is both a vital forest type and a threat to the persistence of other habitats. The role of Douglas-fir as a threat to biodiversity is linked to fire exclusion, which can lead to type conversion in Open Canopy Oak Woodlands, chaparral, and grassland areas.

GOALS & ECOSYSTEM SERVICES

Landscape-level goals for Douglas-fir forest are to retain it as part of the mosaic of forest types in Marin County and to increase the resilience of stands by addressing pathogen impacts, non-native invasive species cover, and changes in composition and biodiversity stemming from fire exclusion. Key ecosystem services discussed in Chapter 5: Goals include carbon sequestration, air quality, biodiversity, habitat, hydrologic function, and recreation. Managing Douglas-fir to continue providing and strengthening these ecosystem services is an important goal for the One Tam agencies.

FOREST HEALTH ATTRIBUTES

Healthy stands of Douglas-fir maintain structural diversity, snags, diverse understory vegetation, absorbent soil, and resistance to invasion, pests, and disease. Native species diversity and presence of indicator species such as northern spotted owl and Coho salmon are also important forest health attributes.

ACRES & DISTRIBUTION

The 2018 Fine Scale Vegetation Map identified 26,245 acres of Douglas-fir forest, and of that total 80% are on protected open space land. Point Reyes National Seashore manages 48% (10,148 acres) of protected Douglas-fir forest in Marin County, followed by Marin Water (3,968 acres), California State Parks (3,075 acres), and Golden Gate National Recreation Area (2,671 acres). More information on the distribution of Douglas-fir stands can be found Chapter 5: Goals and in Appendix 7A, and explored in more detail via the Forest Health Web Map.

CONIFER-HARDWOOD DIVERSITY

Relative hardwood cover is used as a metric to understand variation in the presence and distribution of mixed Douglas-fir-hardwood stands.

- **Like other native conifer types in Marin County, Douglas-fir stands had relatively low hardwood cover** (Figure 7.31)**.** Eighty-two percent (21,541 acres) of Douglas-fir stands were mapped with less than 25% relative hardwood cover. **However, Douglas-fir had the highest percentage of mixed conifer-hardwood acres of any native conifer type in Marin County**, with 15% (3,901 acres) mapped as having 26-60% relative hardwood, and an additional 3% (803 acres) mapped with greater than 60% relative hardwood. Mixed Douglas-fir-hardwood stands are scattered throughout Marin County and represent an important habitat type regionally and throughout northern California. This habitat is characterized floristically by a complex relationship between Douglas-fir (*Pseudotsuga* *menziesii*) and hardwoods, and is defined by the mixtures of co-dominant species (Buck-Diaz et al., 2021, p. 84). Mixed Douglas-fir-hardwood associations found in Marin County include *Pseudotsuga menziesii – Quercus chrysolepis* Association, *Pseudotsuga menziesii – Notholithocarpus densiflorus* Association, Pseudotsuga menziesii – (Umbellularia californica) / Frangula californica, *Pseudotsuga menziesii – Arbutus menziesii* Association, *Pseudotsuga menziesii – Quercus agrifolia* Association, and others (Buck-Diaz et al., 2021, p. 86).

- **Relative hardwood cover is generally higher in shorter Douglas-fir forested stands** (see structural classes below)**, a potential indicator of hardwood areas that have recently undergone succession to Douglas-fir forest** (Figure 7.32)**.** Due to the lack of fires over the last century, Douglas-fir is encroaching on grasslands, coastal scrub, and Open Canopy Oak Woodlands, a pattern that has been well documented throughout coastal California (Hsu et al. 2012; Startin, 2022; Cocking et al., 2015. See Douglas-fir in Chapter 5: Goals for further discussion of Douglas-fir expansion related to fire exclusion.

Figure 7.31. Douglas-fir classified relative percent hardwood by acres.

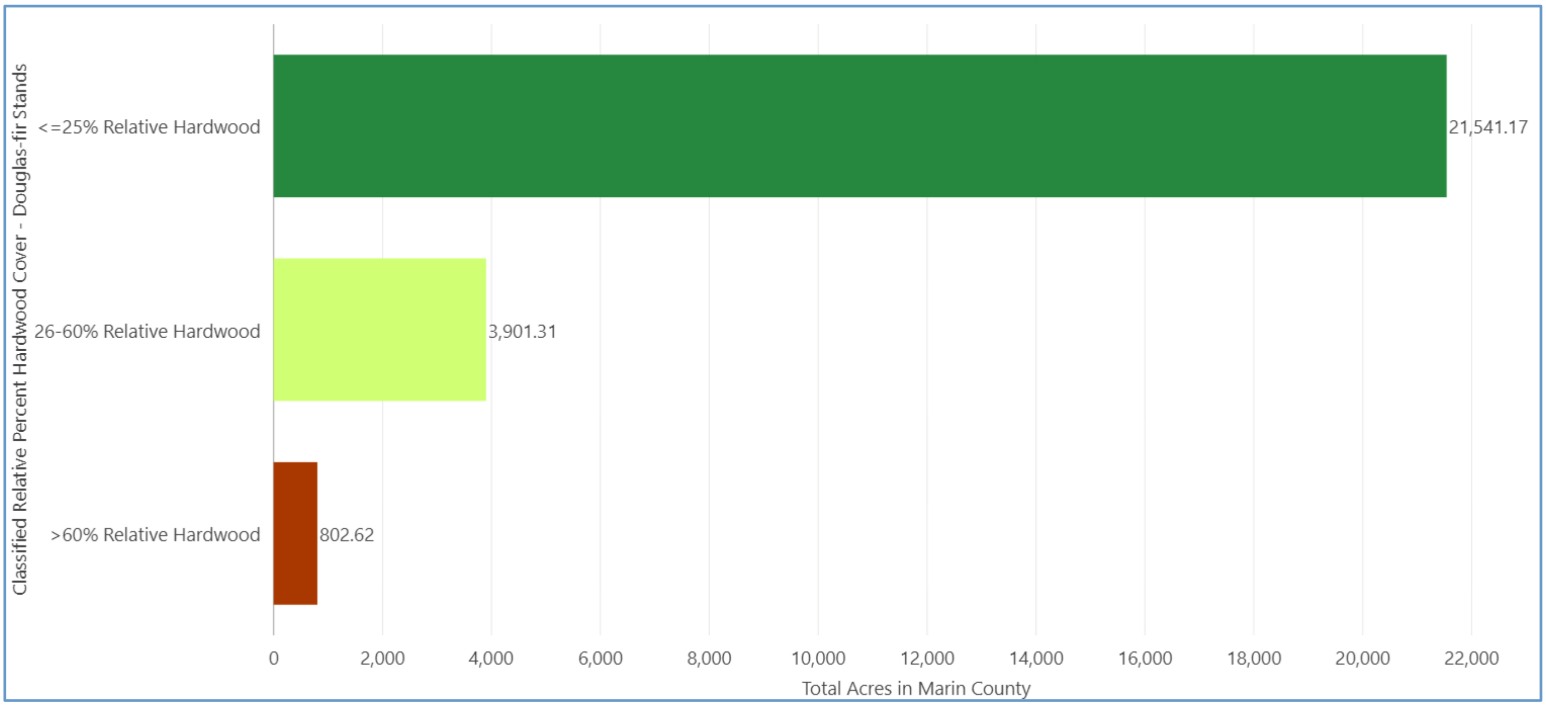
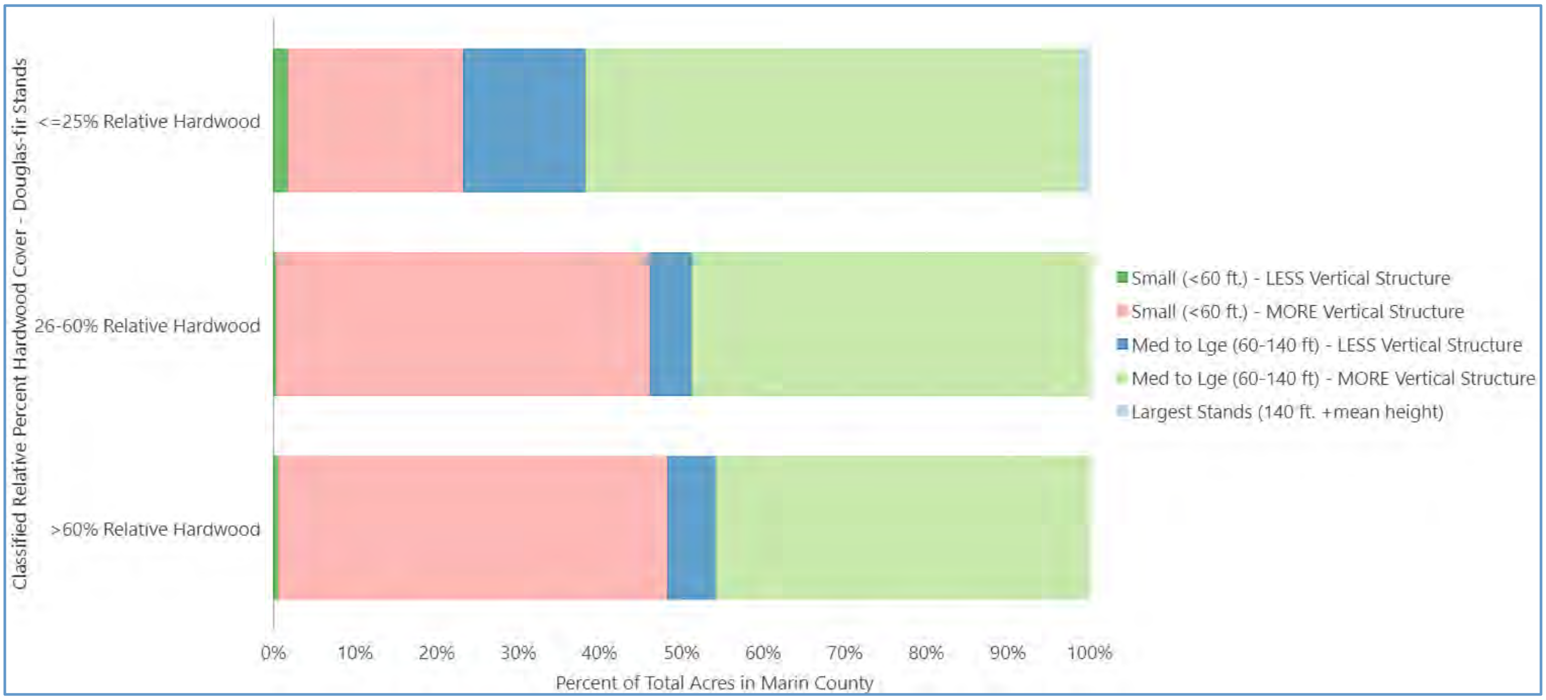


Figure 7.32. Douglas-fir classified percent relative hardwood with structural class, expressed as a percentage of the total countywide acres.



STAND STRUCTURE

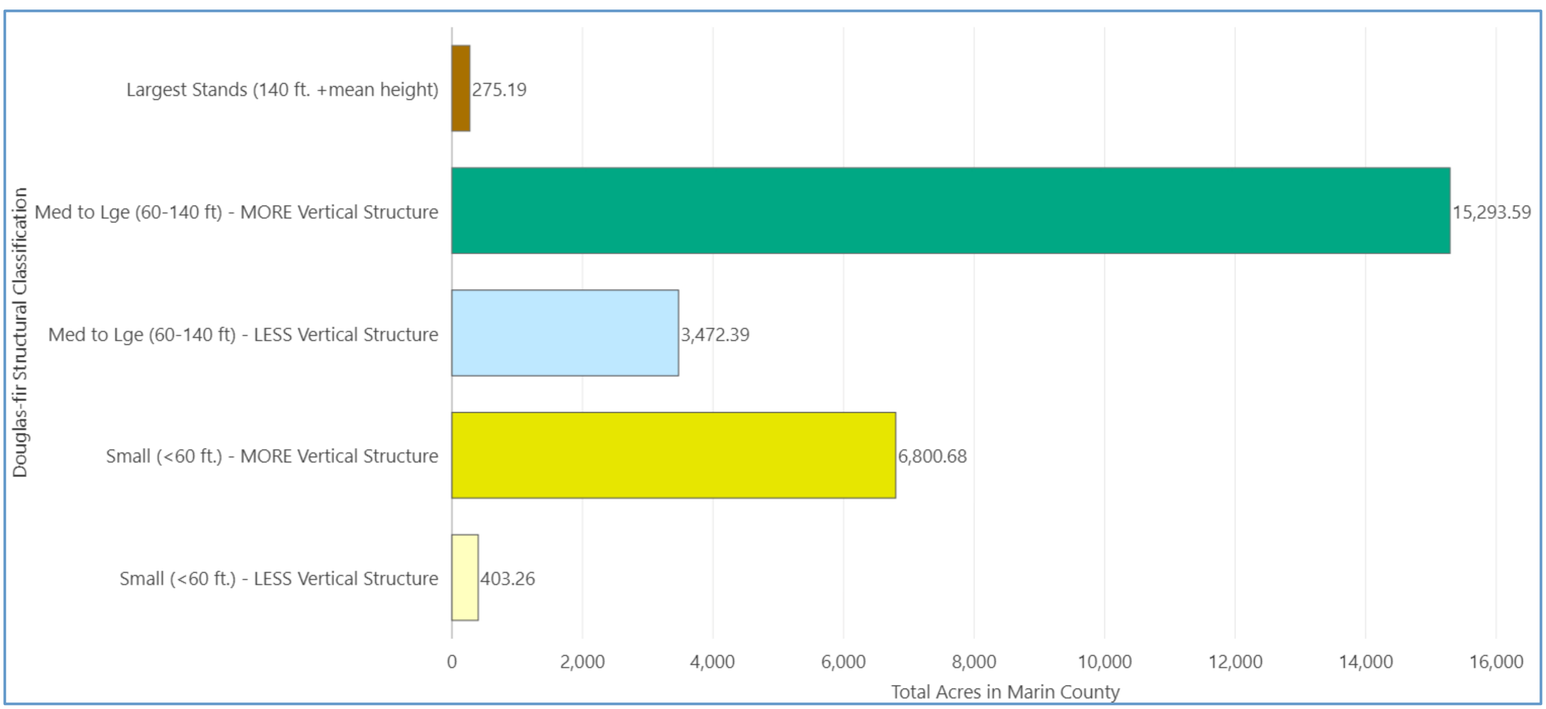
The Douglas-fir stand structure metric follows the same methodology as for Coast Redwood, however interpretations of the data can vary for each forest type. This metric classified each Douglas-fir stand in Marin County, assigning it to one of five structural classes that represents tree height and vertical structure (Figure 7.33). Tree height is represented first in the classification as “Small”, “Medium to Large”, or “Largest”. Vertical structure is represented second, as “LESS” or “MORE”.[6] The "Largest Stands" category includes all stands of over 140 feet mean height. See Chapter 6: Metrics for more details.

- **Only a small amount of Douglas-fir forest was classified as largest stands (1% or 275 acres).** Many of these stands are located west of Five Brooks Ranch between Woodville and Olema (Figure 7.34). The parameters used to define the largest stands structural class were informed by conditions in Marin County Douglas-fir stands understood to have never been logged. The unlogged stands were identified by National Park Service ecologists based on their understanding of the location of unlogged stands on the Point Reyes Peninsula.

[6] Coefficient of Variation (CV) is used to quantify vertical structure, calculated as the standard deviation of mean lidar-derived stand height divided by mean lidar-derived stand height. Managers should note that while the CV is a reasonable proxy for understanding variation in tree heights for a given stand, this metric can be influenced by a variety of environmental factors and may be more useful at local rather than landscape scales.

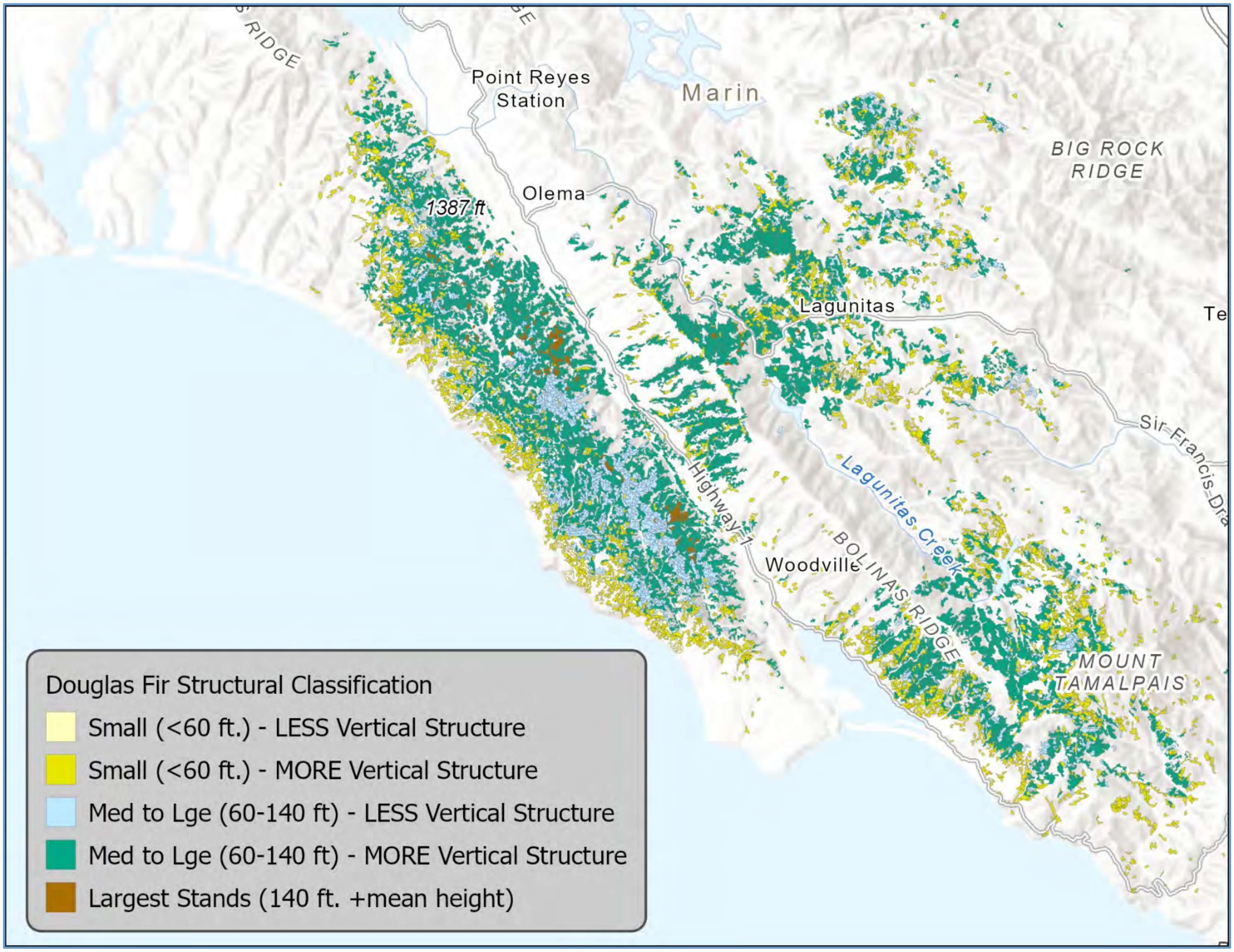
- **Most (58% or 15,294 acres) Douglas-fir forest is structurally classified as medium to large with more vertical structure** (**Error! Reference source not found.** 7.33). As with the Coast Redwood structural classification, the medium to large Douglas-fir structural class most likely corresponds to second-growth Douglas-fir stands. However, previously unlogged stands may be included in this class and are simply shorter than the largest unlogged stands due to environmental variables such as soil type and moisture regime.
- **Stands in the smallest structural classes** (mean lidar-derived stand height less than 60 feet) **showed a distinct spatial distribution pattern, occurring along the western edge of Douglas-fir forests on the Point Reyes peninsula,**[7] **and in other parts of Marin County, that correspond to known areas of Douglas-fir expansion into coastal scrub, chapparal, grasslands, and oak woodlands (Figure 7.34).** In addition, analysis of vegetation community change near Bolinas Ridge using 1952 historical imagery found that shrublands and grasslands had decreased by 62% and 51%, while woodlands increased by 307%, and that Douglas-fir accounted for the majority of that habitat type conversion ([Startin, 2022]() p.10). Comparison of lidar-derived Douglas-fir structural classification for the Bolinas Ridge study area shows that the smallest classes (less than 60 feet mean stand height) correspond to Startin's mapped successional areas ([Startin, 2022]()). See an illustration of this succession in Figure 6.14, Chapter 6: Metrics. Therefore, where preventing or reversing habitat loss due to fire exclusion and Douglas-fir encroachment is a priority, managers can use the Douglas-fir structural classification to identify potential treatment areas (see Chapter 8: Prioritization Framework and Implementation Analysis).

Figure 7.33. Douglas-fir structural classification by acres.



[7] In the 1930s much of this area was grazed grassland, with no trees (A. Forrestel, personal communication, 2022).

Figure 7.34. Douglas-fir structural classification, Point Reyes Peninsula, San Geronimo Valley, and Mount Tamalpais areas.



CANOPY MORTALITY & DYNAMICS

Douglas-fir trees in Marin County are easily infected when exposed to *Fusarium circinatum*, the pathogen that causes pitch canker disease. However, research shows that Douglas-fir do not typically show signs of significant damage (Gordon et al., 2006, p.6). Mapped canopy mortality in Douglas-fir forests is most likely capturing pathogen impacts to hardwood associates of Douglas-fir that are susceptible to *Phytophthora* species known to be present in Marin County (sudden oak death caused by *P. ramorum*, for example). Potentially impacted hardwood species include tanoak, Pacific madrone, and coast live oak (*Quercus agrifolia*).

- **Most Douglas-fir forest (91% or 23,823) has less than 0.5% canopy mortality,** however a significant area (2,250 acres or 9% of all Douglas-fir forest) was mapped with detectable mortality in the canopy (canopy standing dead) between 0.5% and 2.5%, with an additional 173 acres mapped with greater than 2.5% (Figure 7.35)
- Like Bishop Pine and Coast Redwood, **Douglas-fir forested stands with greater canopy mortality showed a higher relative percentage of canopy gaps formed between 2010 and 2019** (Figure 7.36). Fifty-three percent of Douglas-fir forest in the highest canopy mortality class (greater than 2.5% canopy standing dead) experienced greater than 5.5% canopy gap formation between 2010-2019, compared to only 16% of Douglas-fir forest with less than 0.5% canopy mortality. This is likely capturing the temporal aspects of pathogen induced decline in hardwood associates of Douglas-fir, as standing dead trees fall and create gaps.
- **Douglas-fir forests have the lowest relative percentage canopy mortality of all native conifer forest types in Marin County** (Figure 7.35), however there are still a significant number of acres of Douglas-fir forest with canopy mortality countywide. A total of 9% (2,422 acres) of all Douglas-fir forests had detectable canopy mortality in 2018 (greater than 0.5% standing dead), versus 21% (2,368 acres) of Coast Redwood forests, 28% of Sargent Cypress woodlands[8] (107 acres), and 90% of Bishop Pine stands (4,209 acres).
- **Douglas-fir forests with higher relative hardwood cover had a moderately higher level of canopy mortality (**Figure 7.37). Mortality was detected across all relative hardwood classes, however 10% of the Douglas-fir forest acres mapped with greater than 60% relative hardwood cover had detectible mortality in the canopy greater than 0.5%, versus 8% of Douglas-fir mapped with less than or equal to 25% relative hardwood. This data seems to support the theory that pathogen-induced mortality and decline tends to impact susceptible hardwood associates in Douglas-fir stands, such as tanoak, madrone, and coast live oak.
- **Canopy mortality was mapped across all structural classes of Douglas-fir but was proportionally slightly higher in shorter stands** (small structural class with less than 60 feet mean lidar-derived stand height) (Figure 7.38). Thirteen percent (904 acres) of Douglas-fir in the small with more vertical structure class had detectible mortality in the

[8] Includes values for both the *Hesperocyparis sargentii / Ceanothus jepsonii – Arctostaphylos spp*. Association and *Hesperocyparis sargentii* Association.

canopy greater than 0.5%, compared to only 2% of total acres in the largest structural class. Future analysis could explore a possible relationship between a higher CV (more vertical structure) and higher canopy mortality to see how pathogen impacts influence lidar-based measurements of stand structure

- Analysis of canopy density change between 2010 and 2019 show that **the greatest density gains in Douglas-fir forests occurred in stands classified as small** (less than 60 feet mean lidar derived stand height) **with more vertical structure** (Figure 7.39). Ninety-four percent (2,146 acres) of all Douglas-fir forest with greater than 10% canopy density gain between 2010 and 2019 occurred in structurally smaller stands (Figure 7.39). This data combined with a spatial analysis supports the conclusion that trees in Douglas-fir expansion areas, such as on the western edge of the Point Reyes peninsula, are increasing in size and vigor (Figure 7.40).
- **Canopy density loss in Douglas-fir forest occurred across all structural, relative hardwood, and canopy mortality classes but was comparatively higher in areas with greater hardwood cover and higher canopy mortality.** Thirty-five percent of Douglas-fir forest classified with greater than 10% canopy density loss had relative hardwood cover greater than 26% (Figure 7.41). Forty-four percent of Douglas-fir with greater than 10% canopy density loss had detectable canopy mortality above 2.5% (Figure 7.42). These metrics can be used to identify Douglas-fir stands that may contain associate hardwood species being impacted by pathogens or other stressors. However, managers should keep in mind that canopy density change detection may be influenced by other factors such as deciduous species phenology, tree clearing associated with development or infrastructure (e.g., under powerlines), or other forestry work.

Figure 7.35. Douglas-fir classified percent canopy mortality (standing dead) by acres.

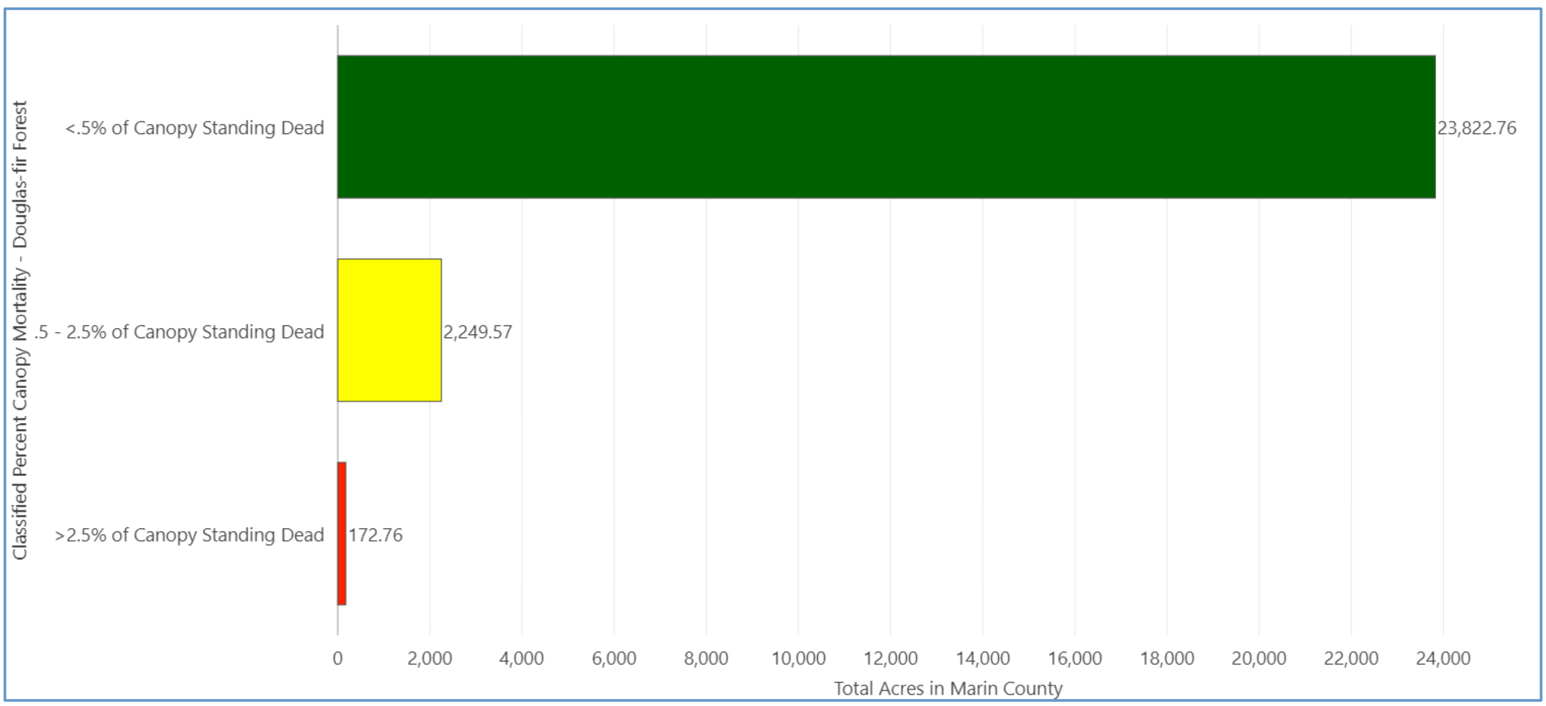


Figure 7.36. Douglas-fir classified percent canopy mortality (standing dead) with classified percent canopy gaps formed 2010-2019, expressed as a percentage of countywide acres.

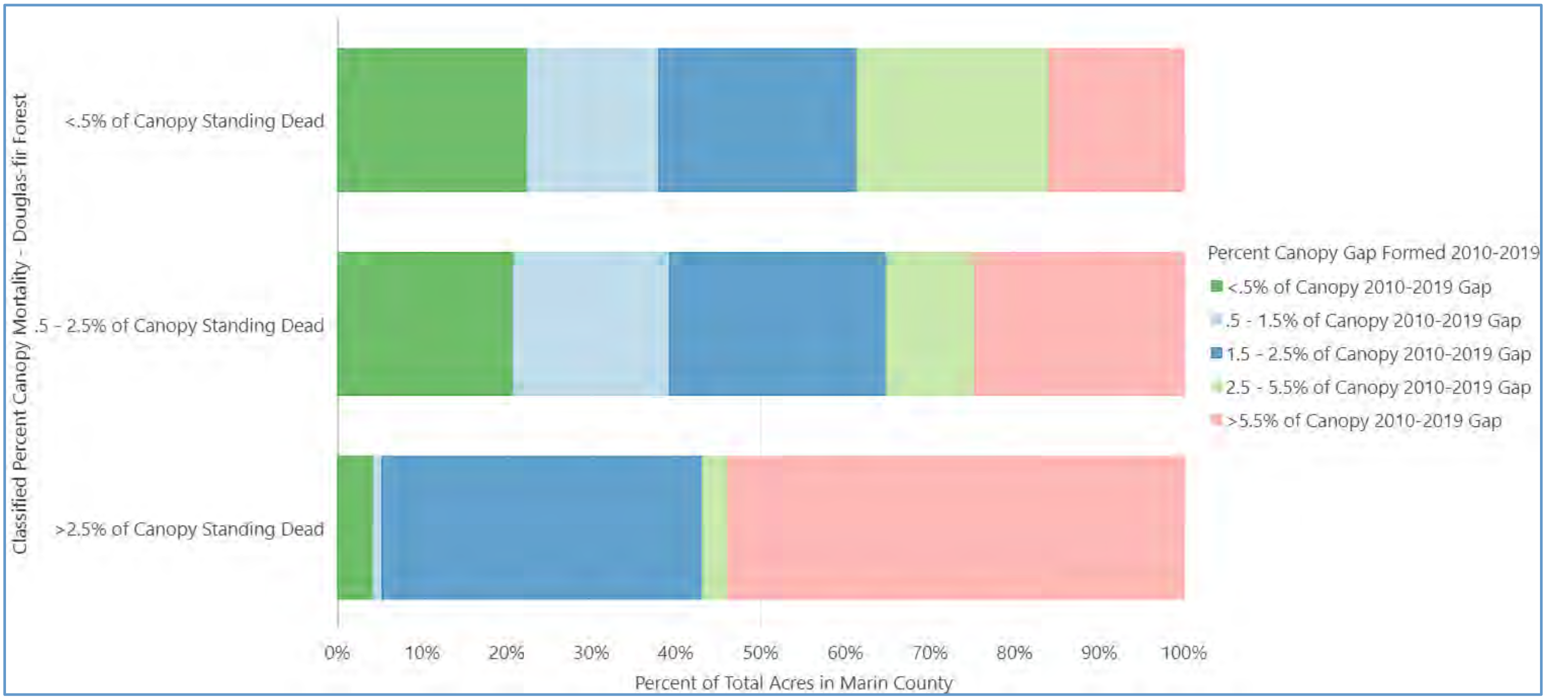


Figure 7.37. Douglas-fir classified percent relative hardwood with classified canopy mortality (standing dead), expressed as a percentage of countywide acres.

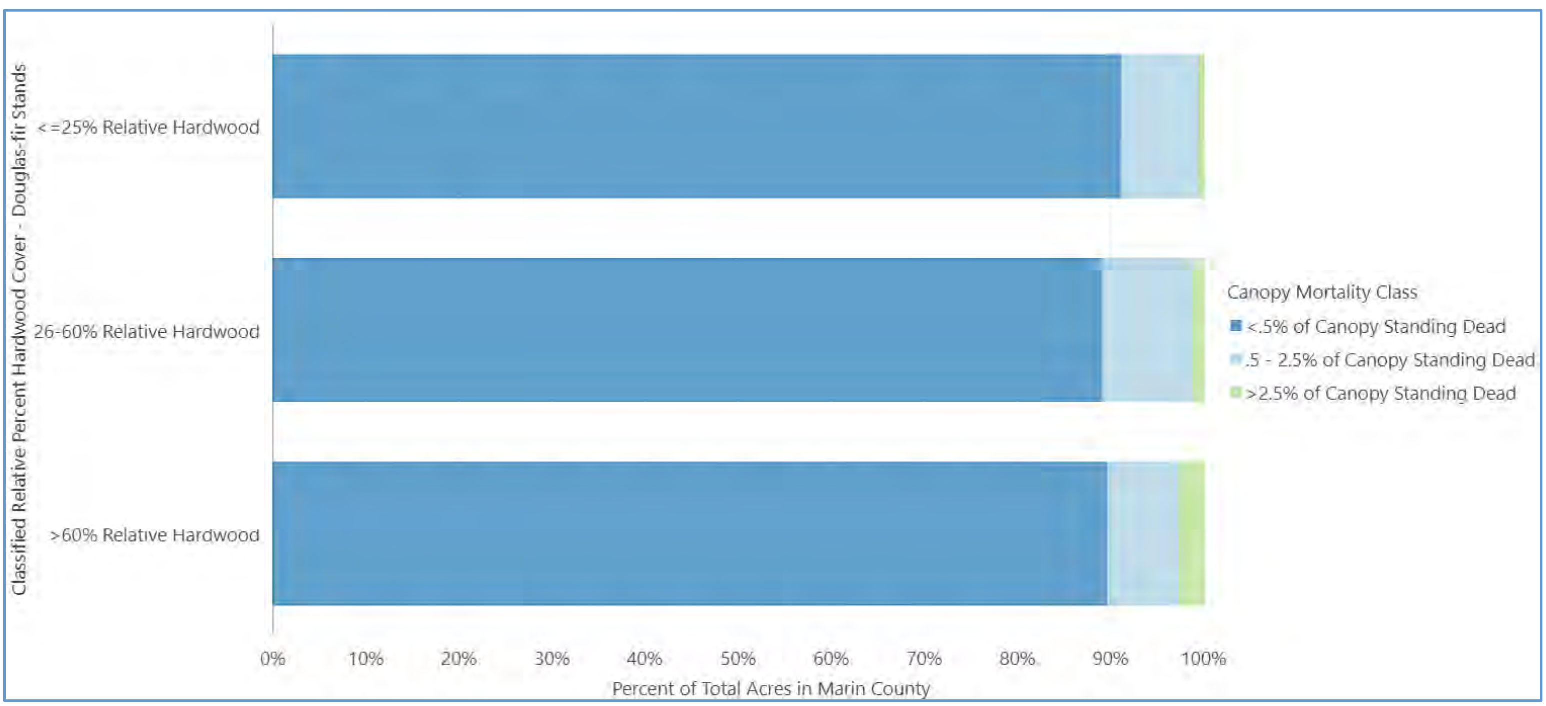


Figure 7.38. Douglas-fir structural classification with classified percent canopy mortality (standing dead), expressed as a percentage of the total countywide acres.

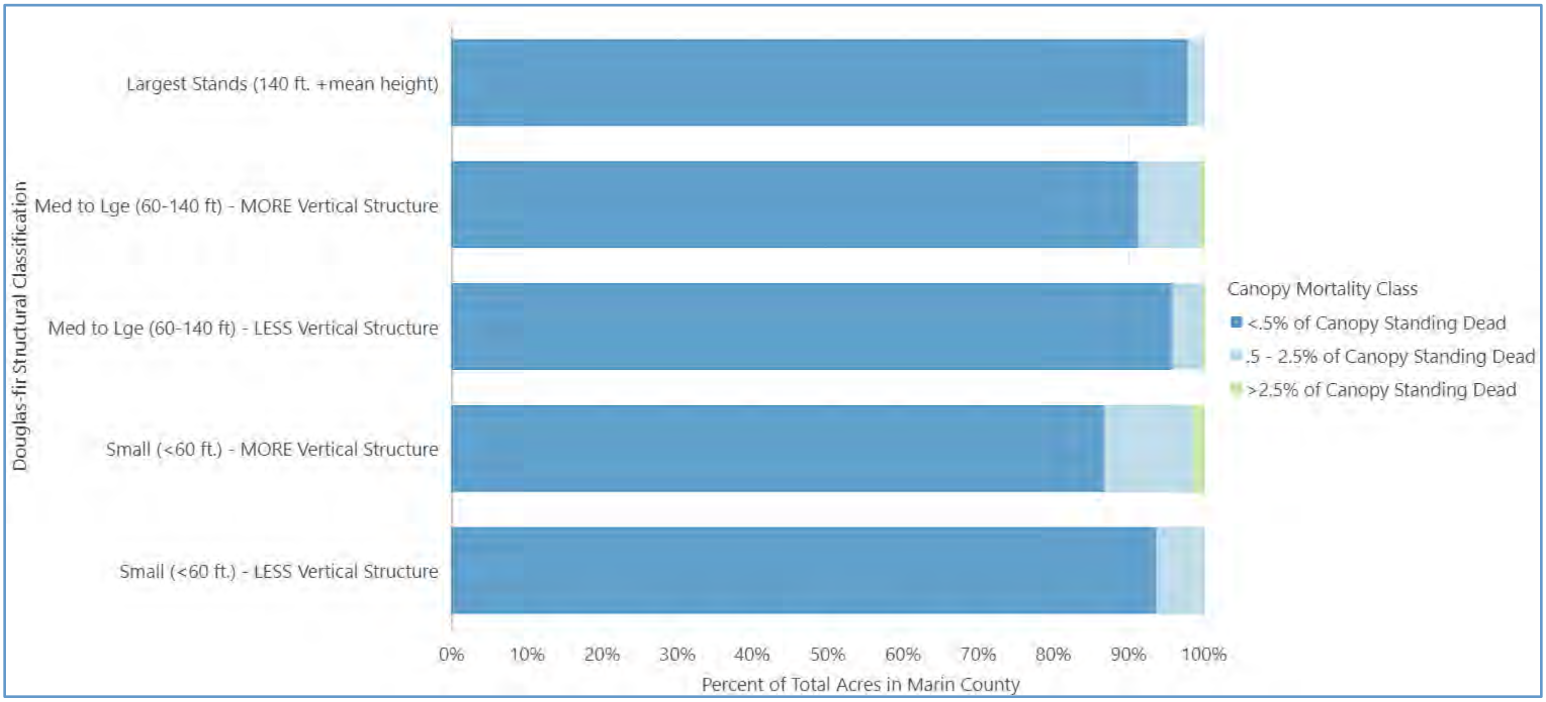


Figure 7.39. Douglas-fir classified canopy density change 2010-2019 with structural classification, expressed as a percentage of the total countywide acres.

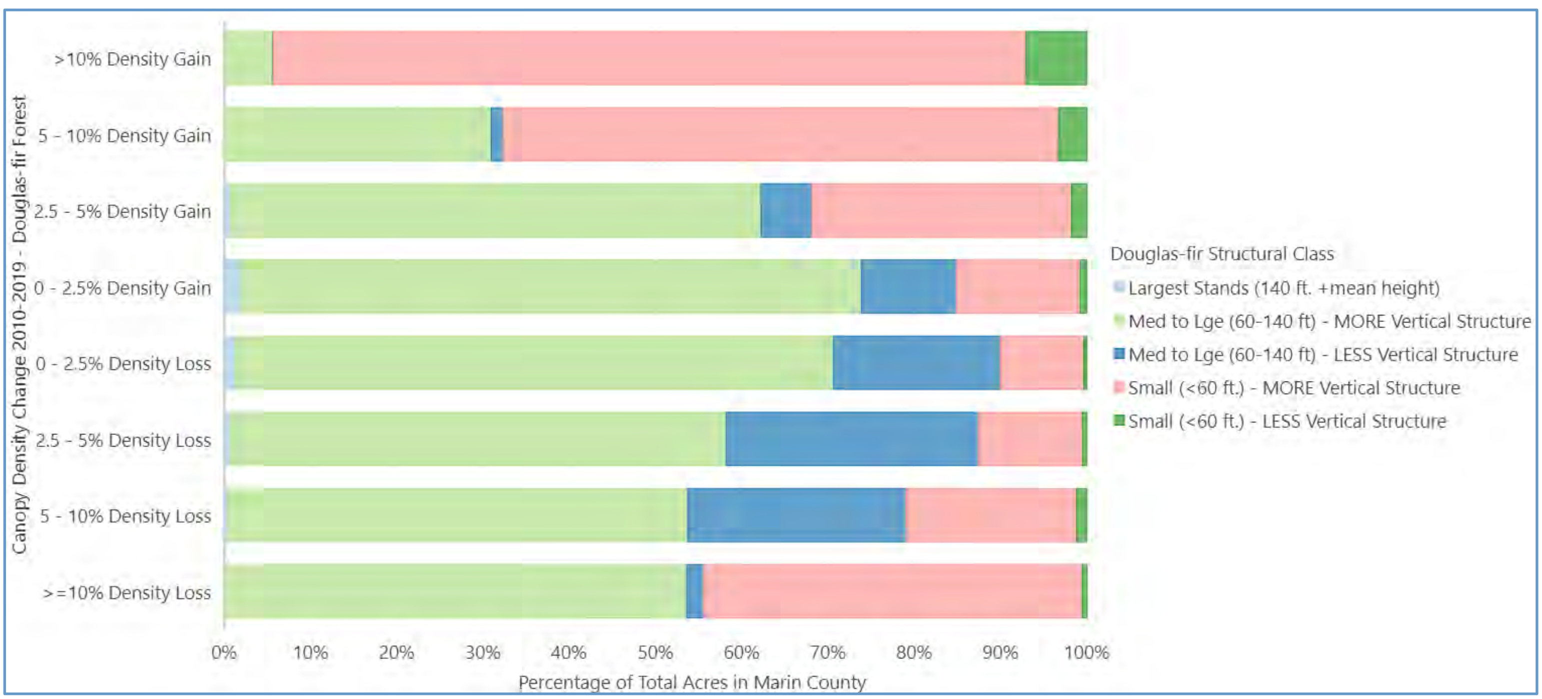


Figure 7.40. Douglas-fir classified percent canopy density change 2010-2019, Point Reyes Peninsula, Olema Valley, and surrounding area.

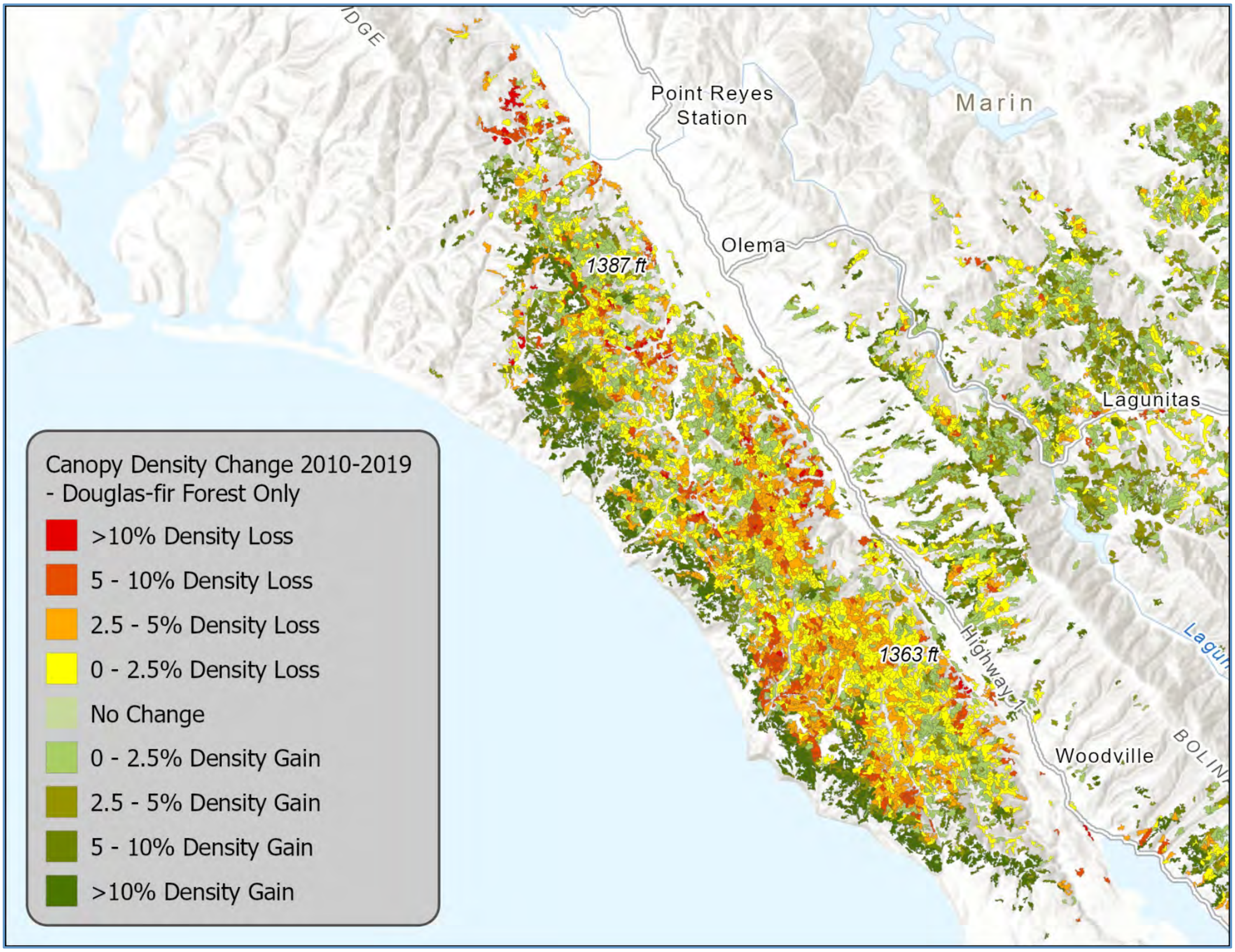


Figure 7.41. Douglas-fir classified percent canopy density change with classified percent relative hardwood cover, expressed as a percentage of countywide acres.

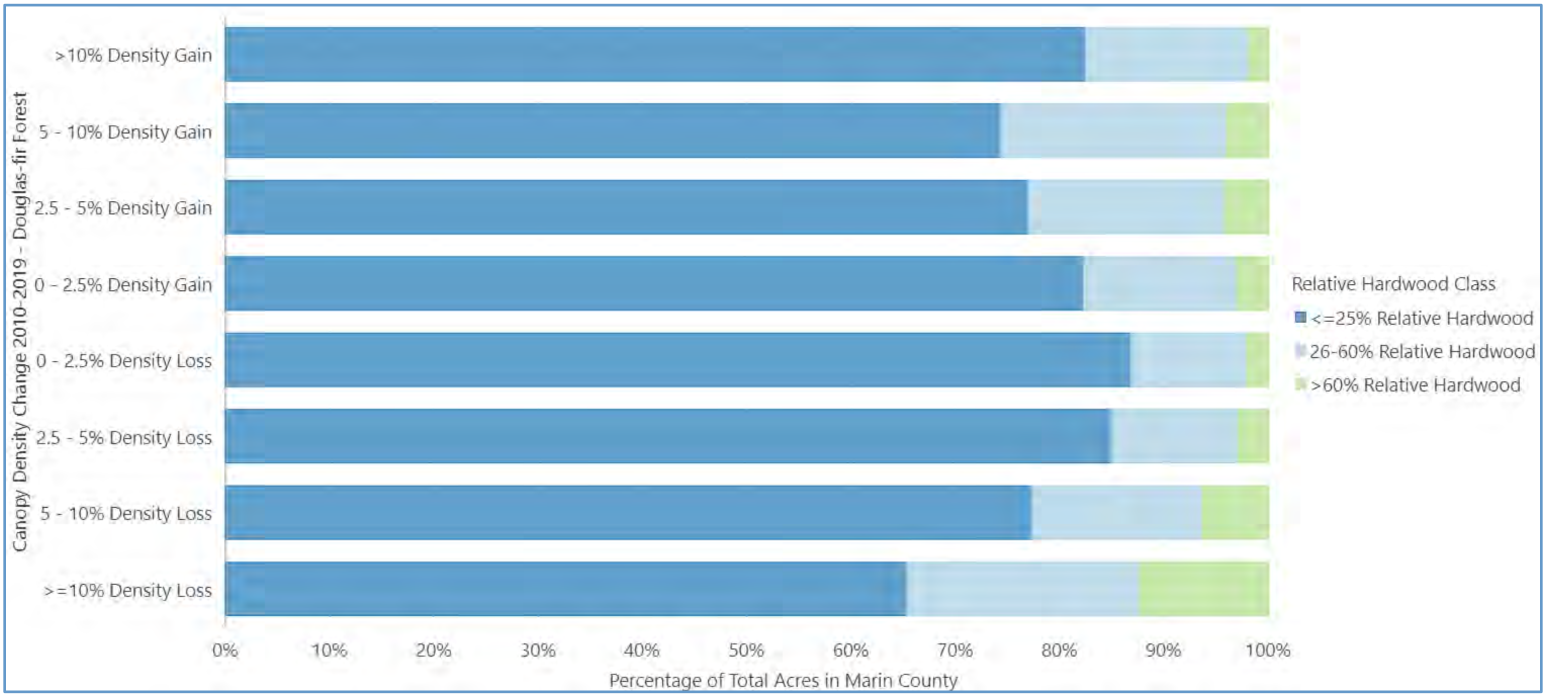
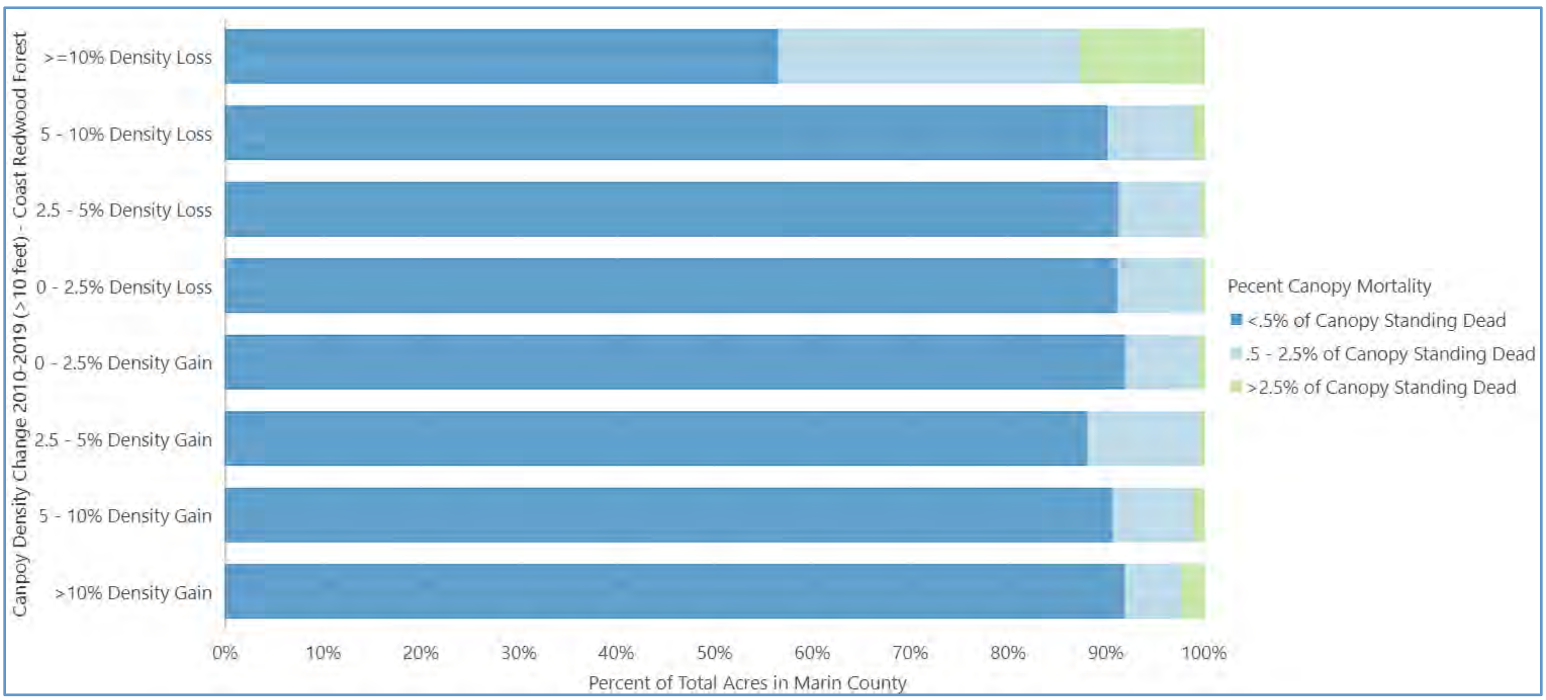


Figure 7.42. Douglas-fir classified percent canopy density change 2010-2019 with classified percent canopy mortality (standing dead), expressed as a percentage of countywide acres.



FIRE HISTORY DYNAMICS

Like Coast Redwood, Douglas-fir fire regimes vary widely across their range. However, in parts of the southern range, including northern California, Douglas-fir forests are likely to have experienced frequent low- and moderate-intensity and infrequent stand replacing fires (Brown et al. 1999; Lavender & Hermann, 2014, p. 293). It is important to note that Douglas-fir is generally more fire-sensitive than coast redwood (*Sequoia sempervirens*) or hardwood tree species, and that damage and tree mortality in Douglas-fir largely depends on tree age and fire intensity, i.e., younger trees are more vulnerable to fire, and high-intensity crown fires are likely to cause mortality in mature trees (Lavender & Hermann, 2014, p. 295). Trees become more resistant to fire as the bark thickens with age (Cocking et al., 2012; Engber et al., 2011). Douglas-fir stands may progress towards a more fire resilient old-growth state with a higher likelihood of surviving low to moderate-severity fires; however, any Douglas-fir stand is vulnerable to high-severity fire (Uchytil, 1991). Fire exclusion, which includes both fire suppression and the interruption of Tribal cultural burning after colonization (see Chapter 3: Stewardship and Partnership with the Federated Indians of Graton Rancheria), is likely contributing to unnatural fuel arrangements in Douglas-fir forest which could threaten the resilience of mature trees by increasing fire severity in some areas. However, it should be noted that research into recent wildfires in California indicates that weather plays an equally important role in the destructive potential of wildfires (Keeley & Syphard, 2019; Syphard & Keeley, 2019).

Fire exclusion, coupled with changes in land use and other disturbance regimes such as grazing, is enabling Douglas-fir expansion into grasslands, shrublands, and Open Canopy Oak Woodlands. This expansions results in loss of habitat, biological diversity, and threatens the persistence of rare chaparral species, including Mason's ceanothus (*Ceanothus masonii*) and Marin manzanita (*Arctostaphylos virgata*) (Point Reyes National Seashore, 2004).

- **Between 1859 and 1940, prior to the modern suppression era in Marin County, 42% (10,878 acres) of Douglas-fir forest experienced fire every 5-45 years** (Dawson, 2021) (Figure 7.43)**.** An additional 21% (5,550 acres) had a fire return interval (FRI) between 1859 and 1940 greater than 45 years, and 37% (9,778) had no recorded fires greater than 160 acres during that period (Dawson, 2021). Spatially, Douglas-fir forests had a shorter fire return interval around Mount Tamalpais, with generally less frequent or no recorded fires greater than 160 acres between 1859 and 1940 in the western, more mesic portions of Marin County, including Point Reyes peninsula (Figure 7.45).
- **Nearly two-thirds (63% or 16,425 acres) of Douglas-fir forest has not experienced fire in more than 70 years** (Figure 7.44). This includes many of the more xeric portions of Marin County that had a shorter FRI between 1859 and 1940 (Figure 7.45 and 7.46). The 1945 Mill/Carson Canyon Fire likely burned in patches through many of the Douglas-fir forested areas on the north side of Mount Tamalpais, however much of the Douglas-fir forest on the south side of the mountain has not burned in 140 years or more (Dawson, 2021).

DOUGLAS-FIR SUMMARY

Douglas-fir is currently a stable part of the mosaic of forest types in Marin County, and is potentially increasing in some areas of Marin. Except for California bay woodlands *(Umbellularia californica* Forest & Woodland Alliance), Douglas-fir is the most widespread forest type in the county, providing important ecosystem services including habitat for key species such as Northern Spotted Owl, Coho salmon, and steelhead trout. Climate change may influence the distribution and composition of Douglas-fir forests; for example, extended periods of drought may already be impacting evergreen hardwood components of mixed stands. Similarly, pathogen impacts to susceptible evergreen hardwood associates of Douglas-fir such as tanoak, madrone, and coast live oak are contributing to a cycle of disease-induced canopy mortality and gap formation in affected areas. Fire exclusion, coupled with changes in land use, both enables Douglas-fir expansion into grasslands, shrublands, and oak woodlands and also could threaten Douglas-fir resilience by increasing fire severity.

Figure 7.43. Douglas-fir classified fire return interval 1859-1940 by acres.

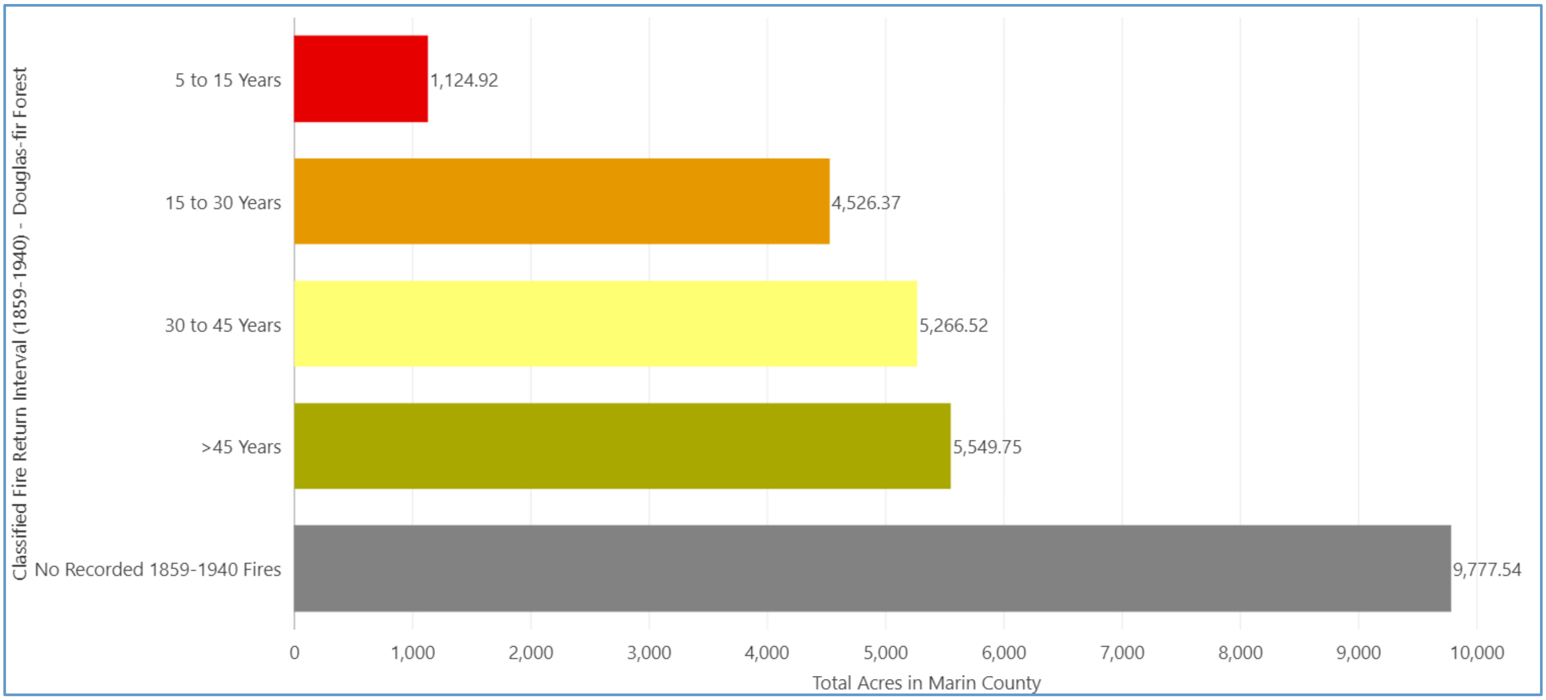


Figure 7.44. Douglas-fir classified number of years since last fire by acres.

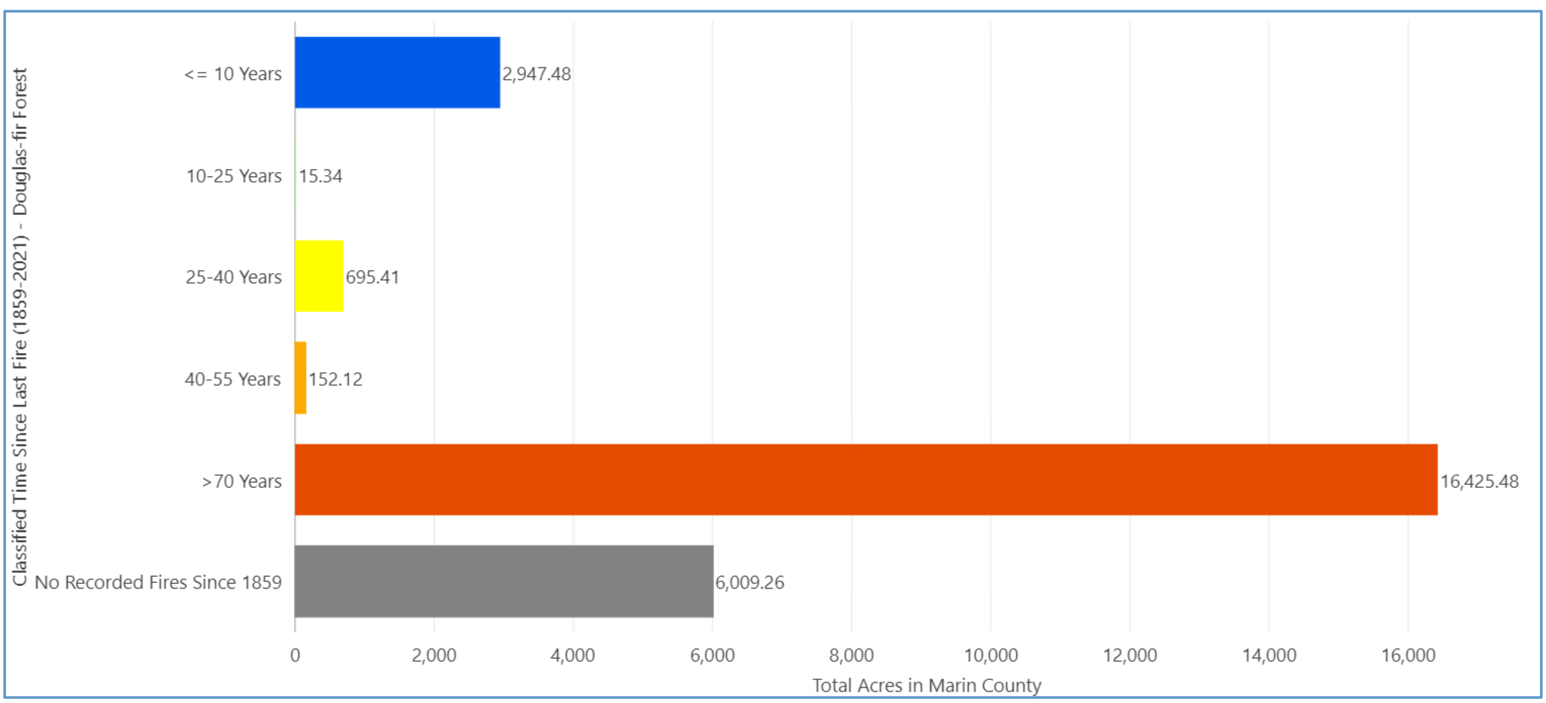


Figure 7.45. Douglas-fir classified fire return interval 1859-1940, Point Reyes Peninsula, Olema Valley, and Surrounding Area.

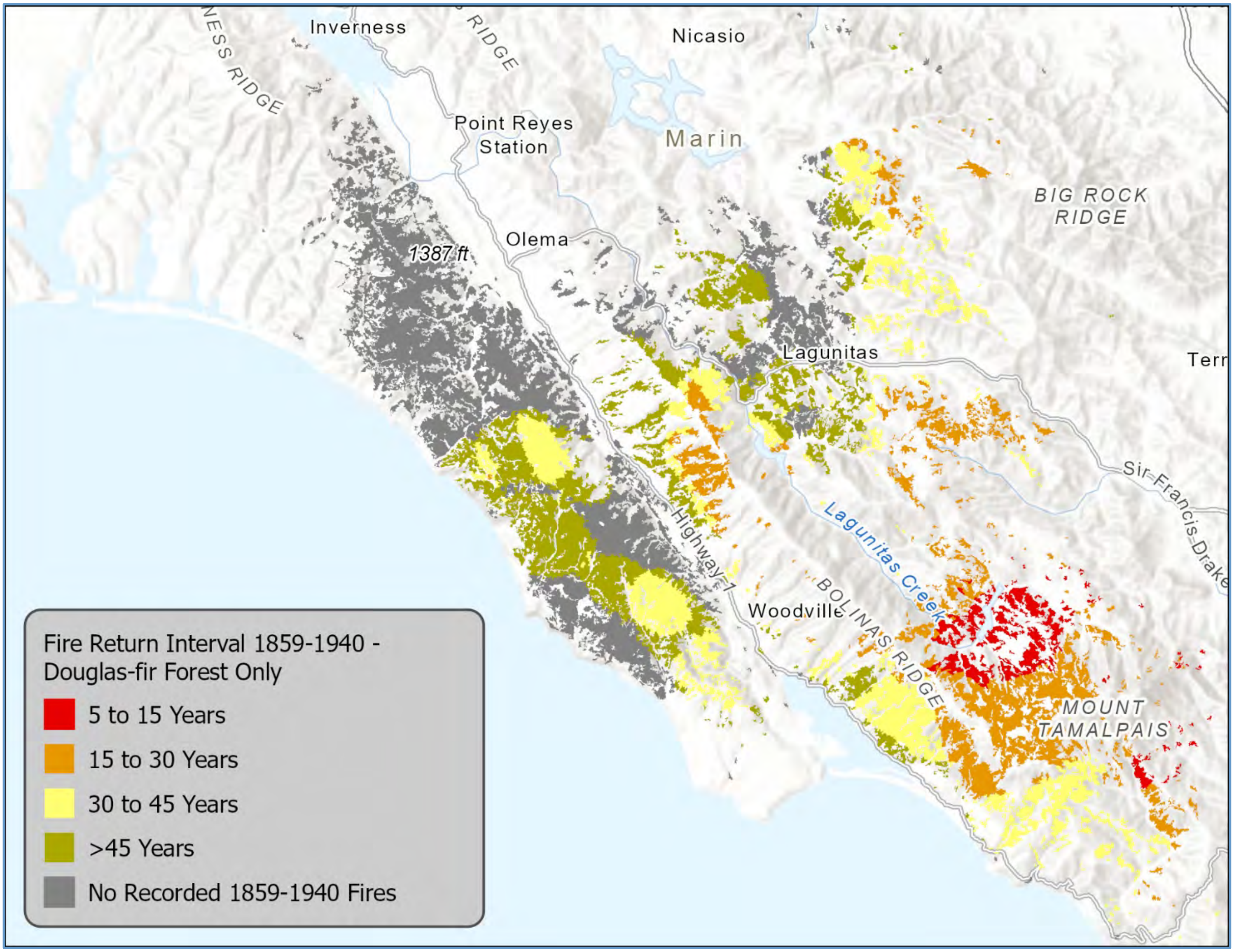
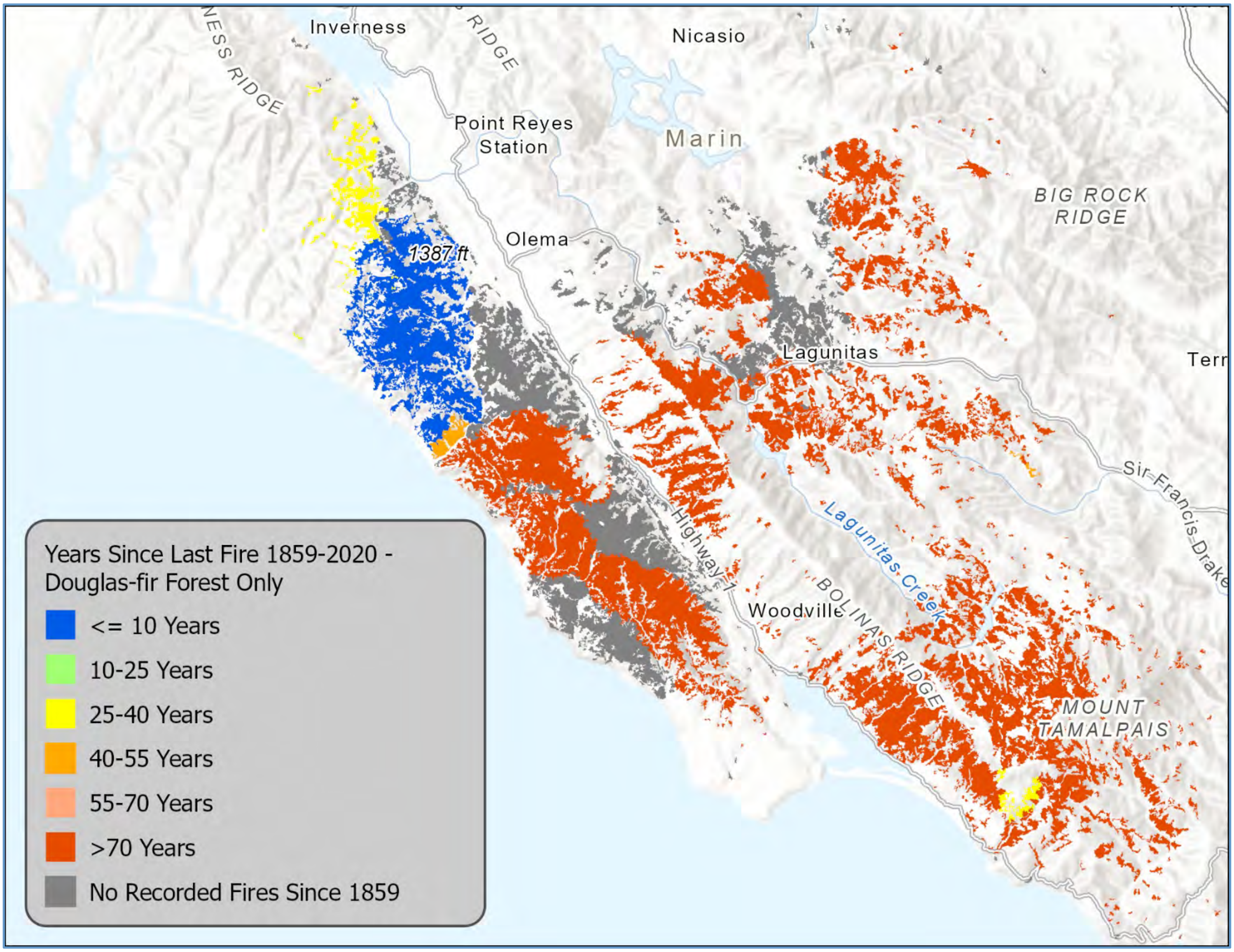


Figure 7.46. Douglas-fir classified years since last fire, Point Reyes Peninsula, Olema Valley, and Surrounding Area.



OPEN CANOPY OAK WOODLANDS

Open Canopy Oak Woodlands assessment metrics were acreage and distribution, stand structure and composition dynamics, canopy mortality, canopy gap formation, canopy density change, and fire history. Chapter 5: Goals includes a summary of Open Canopy Oak Woodland life history.

GOALS & ECOSYSTEM SERVICES

Open Canopy Oak Woodlands provide the priority ecosystem services of biodiversity and cultural values, in addition to air quality, carbon sequestration, habitat, hydrologic function, and recreation. Managing Open Canopy Oak Woodlands to continue providing and strengthening these ecosystem services is an important goal for the One Tam agencies.

Oak woodlands are of special significance to the Tribe and represent a key opportunity for collaborative approaches to stewardship with the Tribe. Additional discussion of Traditional Ecological Knowledge and significance of Open Canopy Oak Woodlands can be found in Chapter 3: Stewardship and Partnership with the Federated Indians of Graton Rancheria.

One Tam agencies will work together to protect and maintain Open Canopy Oak Woodlands resilience, including the persistence of a discontinuous canopy dominated by key *Quercus* spp. trees, a discontinuous shrub layer, and an herbaceous layer dominated by native species.

FOREST HEALTH ATTRIBUTES

Healthy stands of Open Canopy Oak Woodlands are characterized at landscape scale by abundance, oak tree species diversity, and stand integrity. Additional attributes associated with healthy Open Canopy Oak Woodland stands include understory diversity in both the shrub and herbaceous layer, soil absorption, healthy soil microbiota, and fire resilience with fire as a regular part of the ecosystem. Threats to Open Canopy Oak Woodland resilience are non-native invasive species, pests, pathogens, fire exclusion, and related conifer encroachment in the absence of fire.

ACRES & DISTRIBUTION

The 2018 Fine Scale Vegetation Map shows that the combined total acreage of all Open Canopy Oak Woodland types[9] is 20,649 acres, below only California bay (48,451 acres) and Douglas-fir (26,245 acres) in terms of native forest type abundance in Marin County (Table 7.5). However, unlike Douglas-fir, only 37% (7,575 acres) of Open Canopy Oak Woodlands are on protected open space land. Notably, Marin County Parks and Open Space District (MCOSD) manages 42% of the protected acres (3,154 acres) of Open Canopy Oak Woodlands in Marin County, presenting MCOSD with significant opportunity to protect and enhance the resilience of this key forest type. See Appendix 7A for additional information on the distribution of Open Canopy Oak Woodlands and explore details via the [Forest Health Web Map].

[9] The Open Canopy Oak Woodland acreage includes the following Quercus alliances: *Q. agrifolia, Q. chrysolepis, Q. douglasii, Q. garryana, Q. kelloggii, Q. lobata*, and *Q.* (*agrifolia/douglasii/garryana/kelloggii/lobata/wislizeni*).

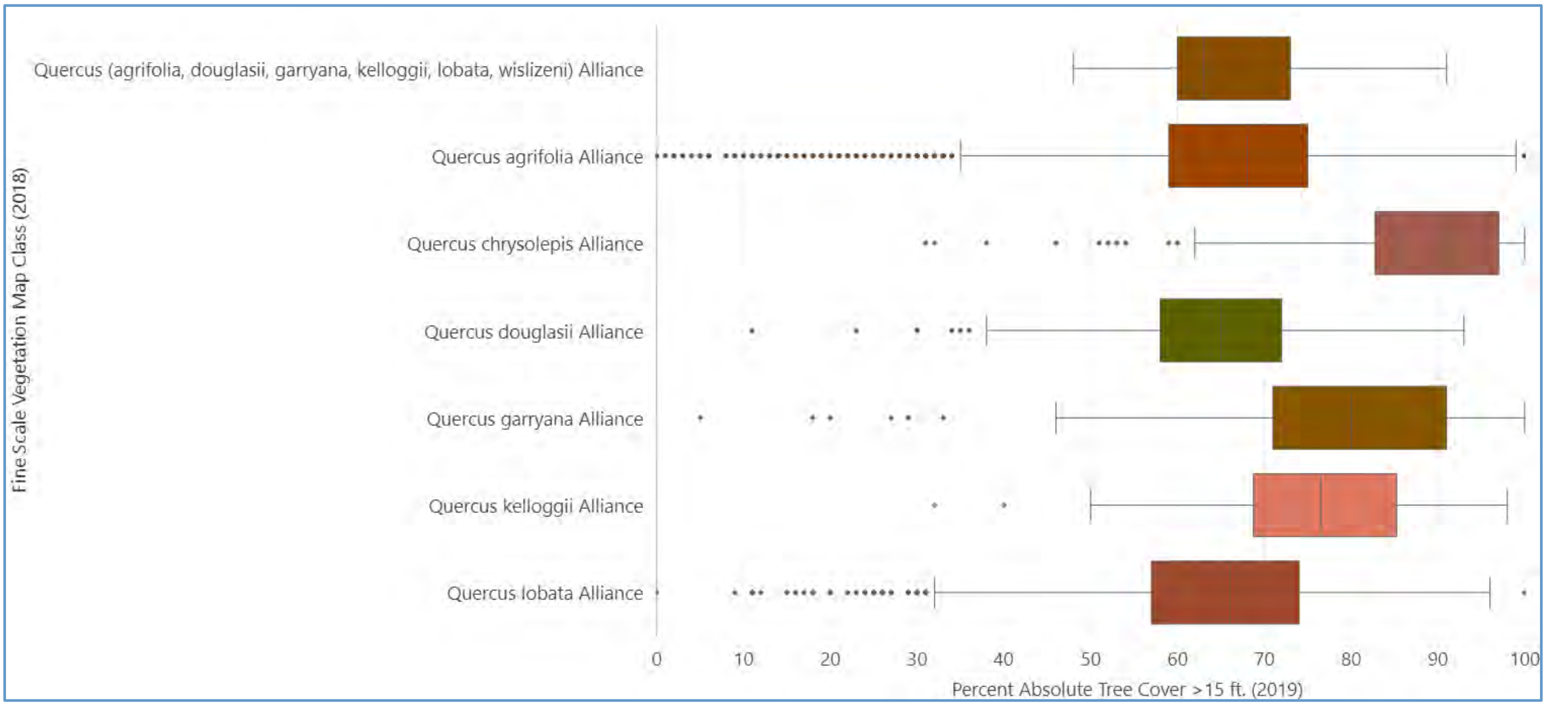
OPEN CANOPY OAK WOODLAND DIVERSITY

In California, Open Canopy Oak Woodlands are typically defined as stands with oak cover ranging between 10 and 60% (Sawyer et al., 2009). Analysis of this forest type in *Measuring the Health of a Mountain: A Report on Mount Tamalpais' Natural Resources (2016 Peak Health Report)* (Edson et al., 2016) focused on stands on Mount Tamalpais with dominant species that included coast live oak (*Q. agrifolia*), valley oak (*Q. lobata*), Oregon white oak (*Q. garryana* var. *garryana*), and California black oak (*Q. kelloggii*). Because the *Forest Health Strategy* includes forest types from all of Marin County (rather than exclusively types that occur on Mount Tamalpais), the definition of Open Canopy Oak Woodland species here includes *Q. douglasii* (blue oak). Additionally, by using lidar to develop the 2018 Fine Scale Vegetation Map, stands of *Q. chrysolepis* (canyon live oak) were distinguished in the classification from shorter shrub-like stands (*Quercus wislizeni – Quercus chrysolepis* (shrub) Alliance) and therefore also included in the broad definition of Open Canopy Oak Woodlands used in the *Forest Health Strategy* (Table 7.5). While *Q. chrysolepis* does tend to be more closed-canopy relative to some of the other types included in the Open Canopy Oak Woodland group, analysis of the natural range in variability of absolute canopy cover for *Q. chrysolepis* in Marin County demonstrates that this type can form more open habitat in some areas and have similar percent absolute tree cover to other Open Canopy Oak Woodland classes (Figure 7.47).

Table 7.5. Open Canopy Oak Woodland 2018 Fine Scale Vegetation Map classes by acres with percent absolute tree cover.

Forest Type	2018 Fine Scale Vegetation Map Classes	Common Name	Total Acres in Marin County	Percent Absolute Tree Cover >15 feet (2019)		
				Mean	Median	Std. Dev.
Open Canopy Oak Woodlands	*Quercus (agrifolia, douglasii, garryana, kelloggii, lobata, wislizeni)* Alliance	N/A mixed alliance	38.91	66.4	63	10.7
	Quercus agrifolia Alliance	Coast live oak	14,379.22	66.2	68	14.3
	Quercus chrysolepis Alliance	Canyon live oak	875.61	87.5	91	12.4
	Quercus douglasii Alliance	Blue oak	839.05	64.5	65	12.1
	Quercus garryana Alliance	Oregon white oak	1,404.65	79.2	80	13.3
	Quercus kelloggii Alliance	California black oak	219.36	76.4	76.5	12.3
	Quercus lobata Alliance	Valley oak	2,892.21	63.8	66	14.2

Figure 7.47. Distribution of percent absolute tree cover by Open Canopy Oak Woodland 2018 Fine Scale Vegetation Map class.



STAND STRUCTURE & CONIFER CONVERSION

Fire exclusion resulting from both suppression and interruption of Indigenous stewardship (see Chapter 3: Stewardship and Partnership with the Federated Indians of Graton Rancheria) has allowed conifers, especially Douglas-fir, to expand into oak woodlands. Conifer encroachment can change the structure and composition of oak woodland stands and eventually lead to forest type conversion. In order to assess this threat, the Open Canopy Oak Woodland stands "threatened with" or "actively converting to conifer forest" metric was developed. This metric uses relative conifer cover and proximity to conifer stands data from the 2018 Fine Scale Vegetation Map to create two classes, "actively converting to conifer forest" or "threatened with conversion to conifer forest". See Chapter 6: Metrics for details on the classification methodology.

- **Forty-three percent (6,245 acres) of coast live oak woodlands (*Q. agrifolia*), the most abundant and widespread Open Canopy Oak Woodland type in Marin County, are threatened with conifer conversion. An additional 8% (1,115 acres) are actively converting to conifer** (Figure 7.48).
- **All Canyon live oak (*Q. chrysolepis*) woodlands are classified as either threatened (73% or 635 acres) or actively converting (27% or 238 acres) to Douglas-fir** (Figure 7.48). Notably, most (83%) of canyon live oak woodlands are on protected open space lands. Of the protected total acres, Marin Water manages 63% (465 acres) and Point Reyes

National Seashore manages 26% (189 acres), both land managers also have significant acres of Douglas-fir forest (see Appendix 7A).

- **Stands of blue oak (*Q. douglasii*), Oregon white oak (*Q. garryana*), California black oak (*Q. kelloggii*), and valley oak (Q. *lobata*) woodland not threatened or converting to conifer forest are concentrated in the northern and eastern portions of Marin County, including on protected open space lands, away from large areas of Douglas-fir forest.** (Figure 7.49). Stands of these Open Canopy Oak Woodland types in areas such as Cascade Canyon Open Space Preserve (OSP), Terra Linda/Sleepy Hollow Divide OSP, Loma Verde OSP, Rush Creek OSP, Mount Burdell OSP and Olompali State Historic Park, could be prioritized for forest resilience-focused management based on the currently relatively low incidence of conifer encroachment.

Figure 7.48. Open Canopy Oak Woodland 2018 Fine Scale Vegetation Map class by conifer conversion class, expressed as a percentage of total countywide acres.

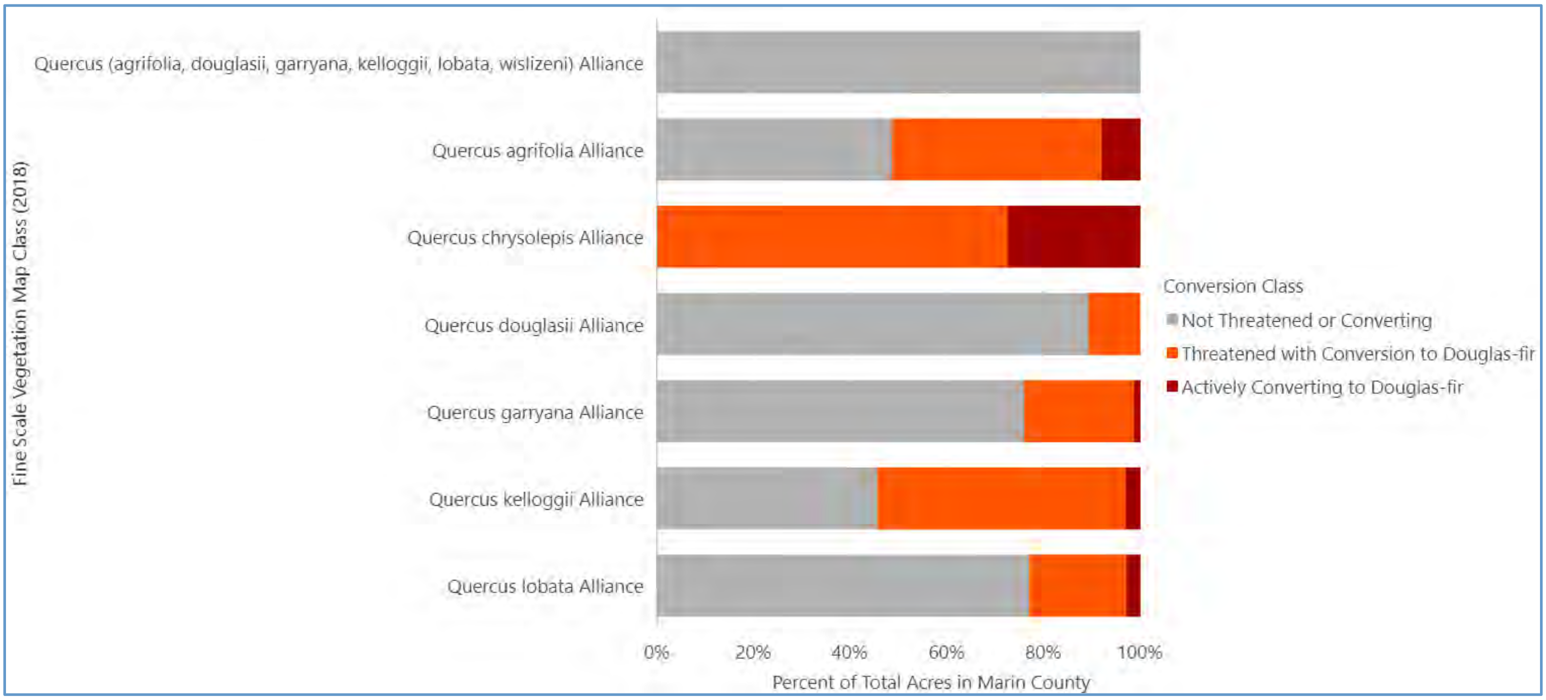
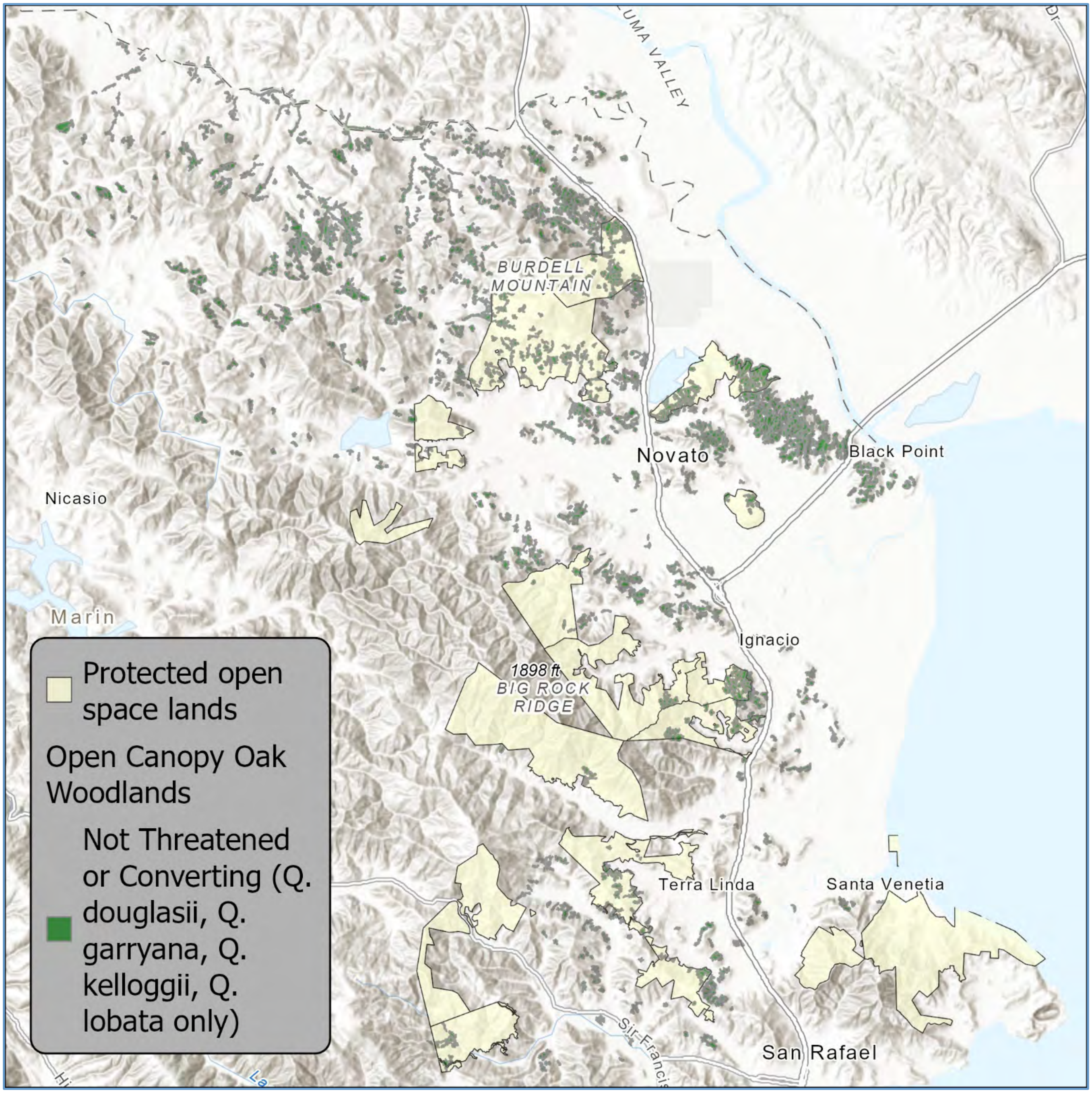


Figure 7.49. Open Canopy Oak Woodlands classified as not threatened with conifer conversion with adjacent protected open space units, northeastern Marin County.



CANOPY MORTALITY & DYNAMICS

Phytophthora ramorum, the pathogen that causes sudden oak death, is understood to impact several Open Canopy Oak Woodland species including coast live oak (*Quercus agrifolia*), California black oak (*Q. kelloggii*), and canyon live oak (*Q. chrysolepis*) (Garbelotto et al., 2003; Murphy & Rizzo, 2003; Rizzo et al., 2002). Other species associated with Open Canopy Oak Woodlands, such as tanoak and madrone, are also susceptible to *Phytophthora*, and documented mortality in oak woodlands may include these species. Although sudden oak death is the most widespread and well documented *Phytophthora*-linked oak disease in Marin County, mortality in Open Canopy Oak Woodland species could be caused by other species of *Phytophthora* (e.g., *P. cinnamomi*), as well as other pathogens, pests, drought stress, or a combination of stressors. Managers should note when interpreting the results of canopy mortality metric analysis that remote sensing methods used do not diagnose the cause of canopy mortality or canopy gap formation. Site-specific analysis, including soil or host testing, is needed to determine the presence/absence of pathogens, including *Phytophthora* species.

- **Canopy mortality was detected in all Open Canopy Oak Woodland classes in the 2018 Fine Scale Vegetation Map, except for the mixed alliance which was seldom mapped** (only 38 total acres in the county were mapped) (Figure 7.50).
- **Incidence of canopy mortality was greater in stands dominated by oak woodland species known to be affected by sudden oak death** (Figure 7.50)**.** Sixteen percent (2,336 acres) of *Q. agrifolia* woodland had detectible mortality in the canopy greater than 0.5%, with an additional 2% (304 acres) mapped with greater than 2.5% mortality. Incidence of mortality was proportionally the highest in *Q. chrysolepis* woodlands, with 25% (218 acres) of mapped canopy mortality greater than 0.5% and 4% (38 acres) with canopy mortality greater than 2.5%. In *Q. kelloggii* woodlands, 19% (41 acres) were mapped with detectable canopy mortality between 0.5 and 2.5%.
- Managers should note that **stands mapped as *Q. douglasii*, *Q. garryana*, and *Q. lobata* woodlands can also contain other tree species known to be affected by sudden oak death**. For example, *Q. agrifolia* is commonly associated with each of these woodland types in Marin County (Buck-Diaz et al., 2021).
- **Canopy gap formation in Open Canopy Oak Woodlands between 2010 and 2019 is high, and widespread across all classes** (Figure 7.51). Unlike canopy gap formation mapped in Bishop Pine, Coast Redwood, and Douglas-fir, gap formation in Open Canopy Oak Woodlands does not appear to be correlated with higher incidence of canopy mortality. Open Canopy Oak Woodland types that had relatively low canopy mortality, such as *Q. lobata,* still had relatively high canopy gaps formed between 2010-2019. These results suggest that gap formation in Open Canopy Oak Woodlands may be related to other factors. Managers should note that the canopy gaps formed between 2010-2019 metric cannot distinguish the cause of gaps; for example, gaps may be caused by stress-induced stand decline, natural forest dynamics, or as the result of vegetation clearing around development or infrastructure (e.g., power lines). Field-based assessments are useful to confirm incidence of gaps and their relation to stand conditions.

- **Canopy density change analysis for evergreen Open Canopy Oak Woodland classes (Q. agrifolia and Q. chrysolepis) shows an overall pattern of canopy density loss** (Figure 7.52). Note that because the 2010 to 2019 canopy density change analysis relied on lidar collected during different seasons (late-spring in 2010 vs. mid-winter 2019 winter), a loss in canopy density in deciduous open canopy oak species may be driven by leaf phenology, and not meaningful changes in stand vigor. In total 65% (9,377 acres) of *Q. agrifolia* woodlands had greater than 2.5% canopy density loss, including 6% (895 acres) classified with greater than 10% canopy density loss. Overall, 36% (315 acres) of Q. chrysolepis woodlands had greater than 2.5% canopy density loss, with 7% (60 acres) classified as experiencing greater than 10% canopy density loss between 2010 and 2019. This pattern suggests that drought, pathogens, and/or other stressors, e.g., non-native invasive species in the understory such as French broom (*Genista monspessulana*), are having an impact on tree vigor in at least some Open Canopy Oak Woodlands. Anecdotally managers in Marin County have observed loss of tree vigor in stands of other evergreen hardwood species such as Pacific madrone, which may corroborate these findings.

Figure 7.50. Open Canopy Oak Woodland 2018 Fine Scale Vegetation Map class with classified canopy mortality (standing dead), expressed as a percentage of the total countywide acres.

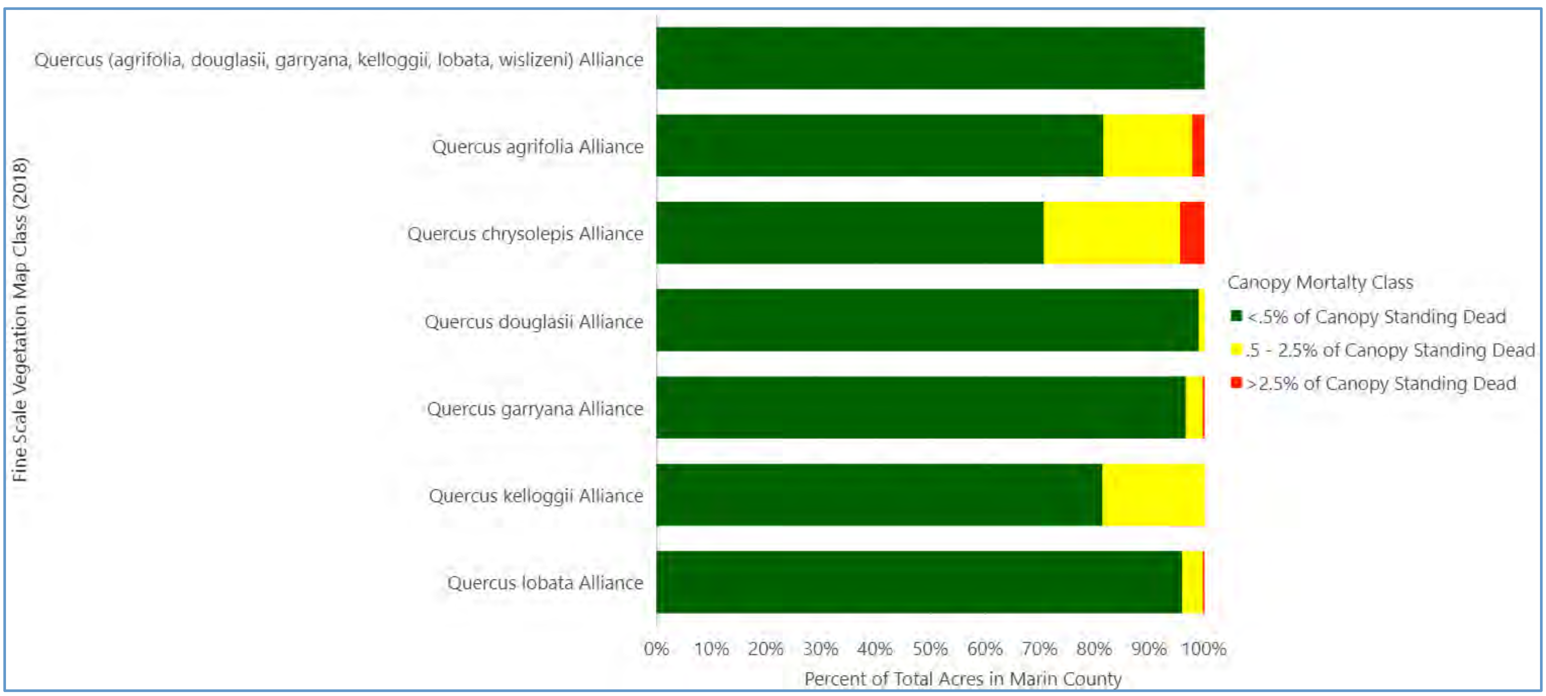


Figure 7.51. Open Canopy Oak Woodland 2018 Fine Scale Map class with classified percent canopy gaps formed between 2010-2019, expressed as a percentage of the total countywide acres.

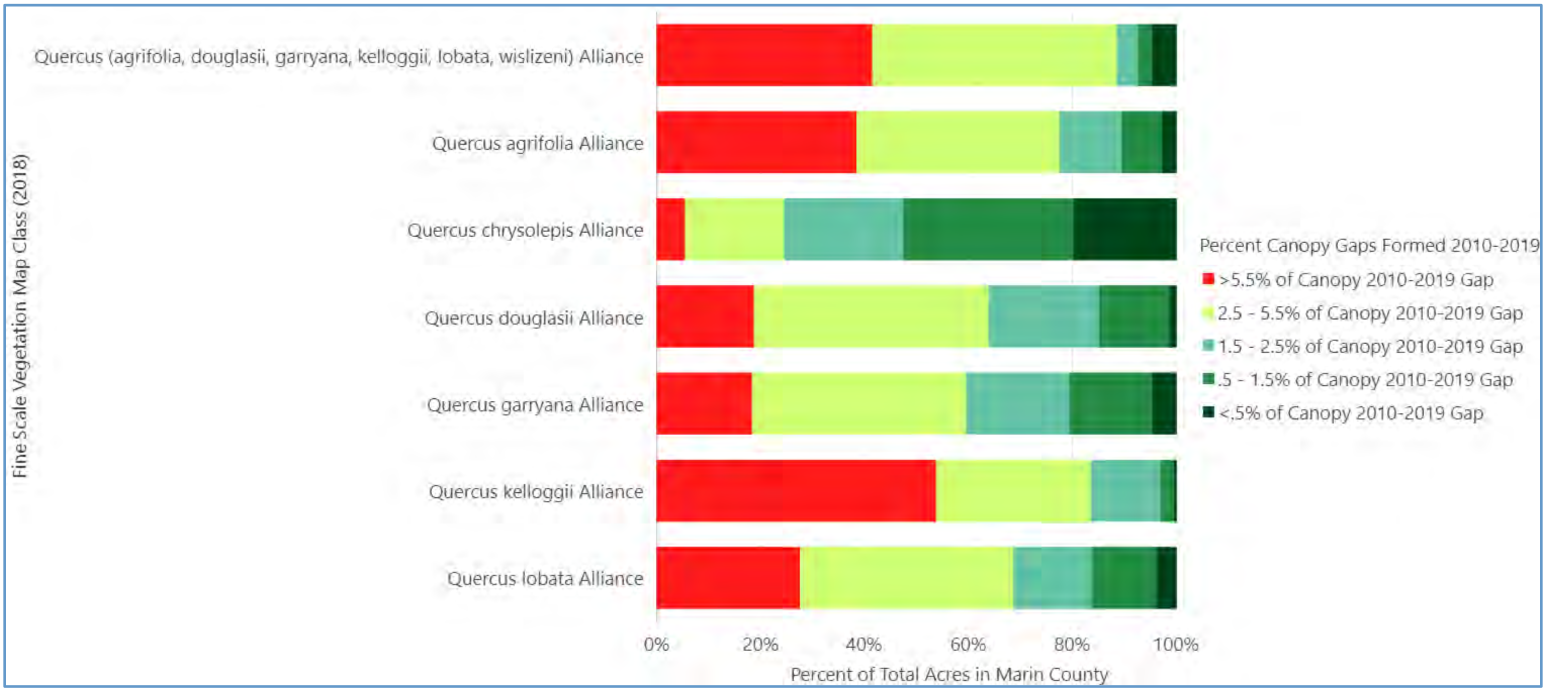
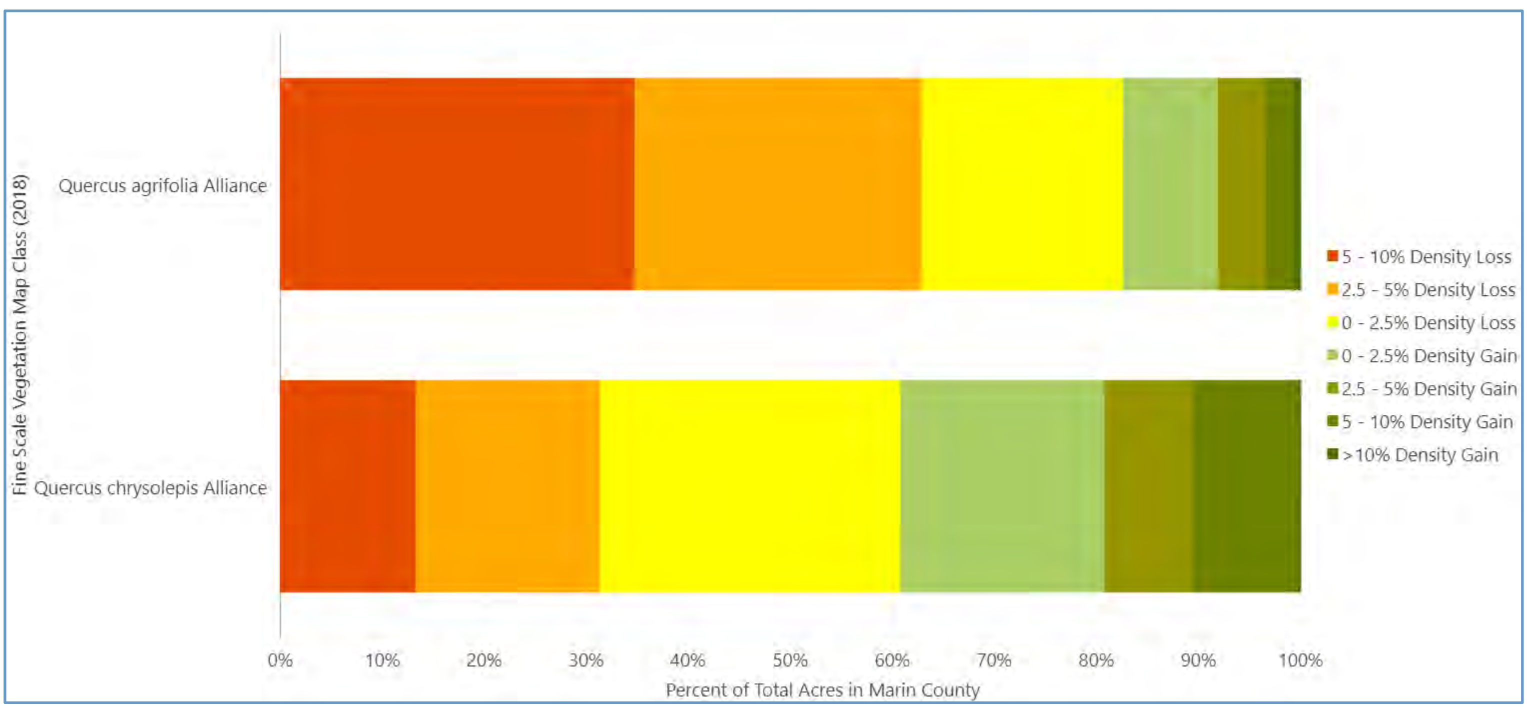


Figure 7.52. Evergreen Open Canopy Oak Woodland 2018 Fine Scale Vegetation Map class with classified canopy density change 2010-2019, expressed as a percentage of the total countywide acres.



FIRE HISTORY DYNAMICS

Fire exclusion, including both fire suppression and the removal of Coast Miwok people from their land and the interruption of cultural burning following colonization, has impacted Open Canopy Oak Woodland health across the region in a variety of complex ways including changes in regeneration, seedling production, understory species composition, stand structure, and others (see Open Canopy Oak Woodlands in Chapter 5: Goals). Coast Miwok tending and stewardship of specific oaks included the use of fire to increase acorn production, generate shoots for specific uses, or facilitate gathering (see Chapter 3: Stewardship and Partnership with the Federated Indians of Graton Rancheria). Analysis of available fire history data and post-1850 spatial patterns of fire occurrence in Marin County provides only a limited view into the complex dynamics at play with respect to fire in Open Canopy Oak Woodlands (for a pre-1850 fire timeline see the *Marin County Wildfire History Mapping Project* in Appendix B: Wildfire History). However, the overall trend of decreasing fire extent and increasing fire return interval is widely considered a threat to Open Canopy Oak Woodland health.

- **Between 1859 and 1940, prior to the modern fire suppression era in Marin County, fire return intervals in Open Canopy Oak Woodlands mostly ranged from every 20 to 70 years (**mean 45.7, median 40.5, std. dev. 24.3**), however 45% (9,208 acres) had no recorded fires greater than 160 acres during that period** (Figure 7.53) (Dawson, 2021).
- **All Open Canopy Oak Woodland stands within the shortest classified fire return interval (every 5-15 years) between 1859 and 1940 are within the frequent burn zone around Mount Tamalpais** (Dawson, 2021 pg. 13)**. The largest concentration of Open Canopy Oak Woodlands with no record of burning between 1859 and 1940 are in the northern and eastern portions of Marin, in rare burn zones with no documented fires** (Dawson, 2021) (Figure 7.55). Owing to this geographic difference in fire frequency, fire return intervals between 1859 and 1940 varied for each Open Canopy Oak Woodland species, with 98% (855 acres) of *Q. chrysolepis* woodlands (common in the Mount Tamalpais area) experiencing fire at least once within that time frame, compared to just 16% (137 acres) of *Q. douglasii* woodlands (predominantly in the northeast portion of Marin) (Figure 7.55).
- **Except for a relatively small percentage, most Open Canopy Oak Woodlands have either not experienced fire greater than 160 acres in more than 70 years (53% or 10,887 acres) or have no recorded fires since 1859 (42% or 8,744 acres)** (Figure 7.56)**.** The extent of fire exclusion at the countywide scale (Figure 7.54) is contributing to conifer encroachment, loss of biological diversity in the understory, and atypical fuel arrangements in Open Canopy Oak Woodlands, and could also be impacting regeneration and seedling recruitment based on the existing scientific literature (see Open Canopy Oak Woodland in Chapter 5: Goals).

OPEN CANOPY OAK WOODLANDS SUMMARY

Overall, Open Canopy Oak Woodlands are a stable part of the mosaic of forest types in Marin County; however, stressors including disease, drought, and fire exclusion are having a measurable negative impact across the region. Canopy mortality and gap formation data analysis shows significant acres of susceptible Open Canopy Oak Woodland species affected by pathogens, most likely *Phytophthora ramorum*. Canopy density changes between 2010-2019 indicate that drought stress may be causing reduced tree vigor in evergreen oak species. Fire exclusion is facilitating conifer encroachment, most commonly Douglas-fir, into Open Canopy Oak Woodlands resulting in widespread risk of type conversion and loss of biological diversity, and is also likely affecting seedling establishment and regeneration. Managers should look for ways to increase and protect Open Canopy Oak Woodland resilience given that only approximately one-third of Open Canopy Oak Woodlands are on protected open space lands. Finally, the special significance of oak woodlands to the Tribe represents an opportunity for land managers to partner with the Tribe to protect and steward this forest type.

Figure 7.53. Open Canopy Oak Woodland 2018 Fine Scale Vegetation Map class with classified fire return interval between 1859-1940, expressed as a percentage of the total countywide acres.

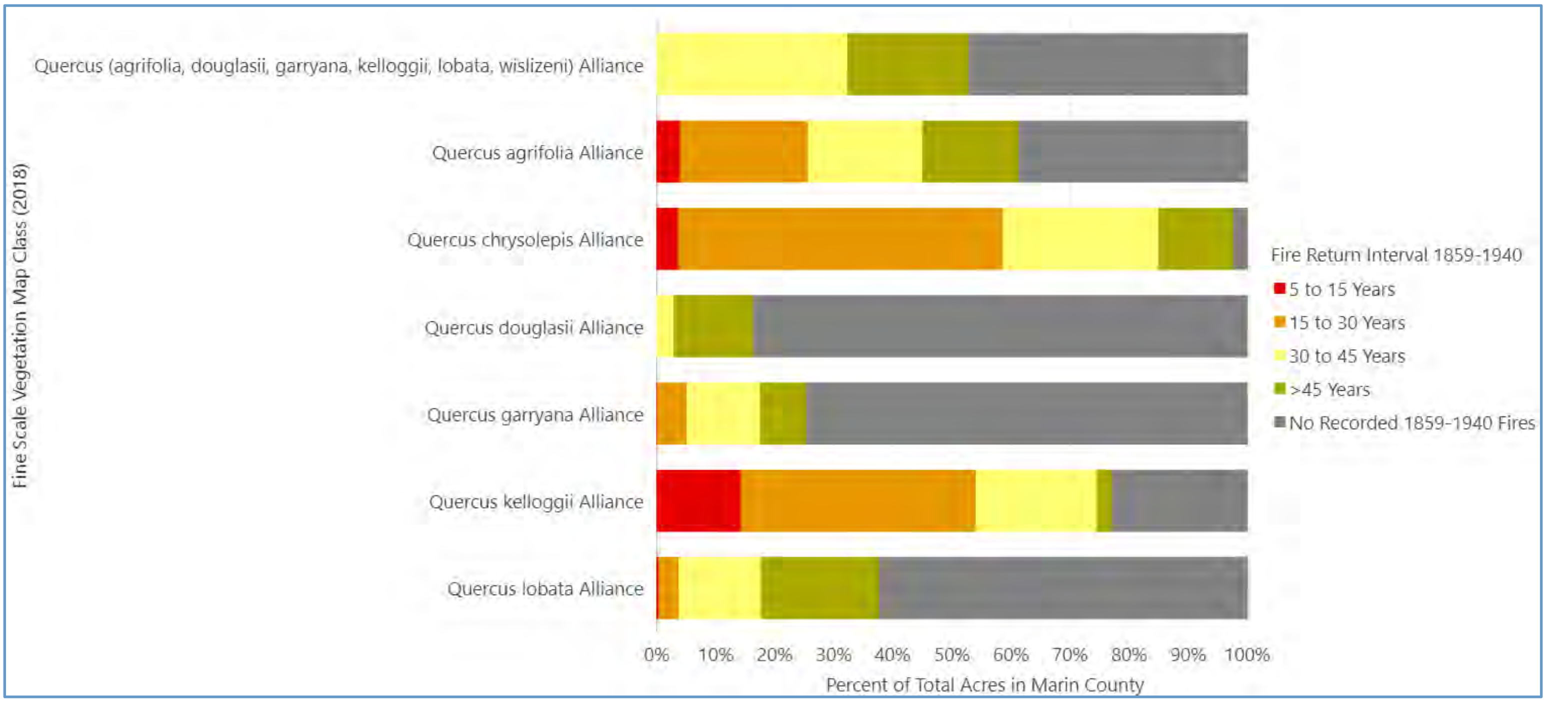


Figure 7.54. Open Canopy Oak Woodland 2018 Fine Scale Vegetation Map class with classified number of years since last fire, expressed as a percentage of the total countywide acres.

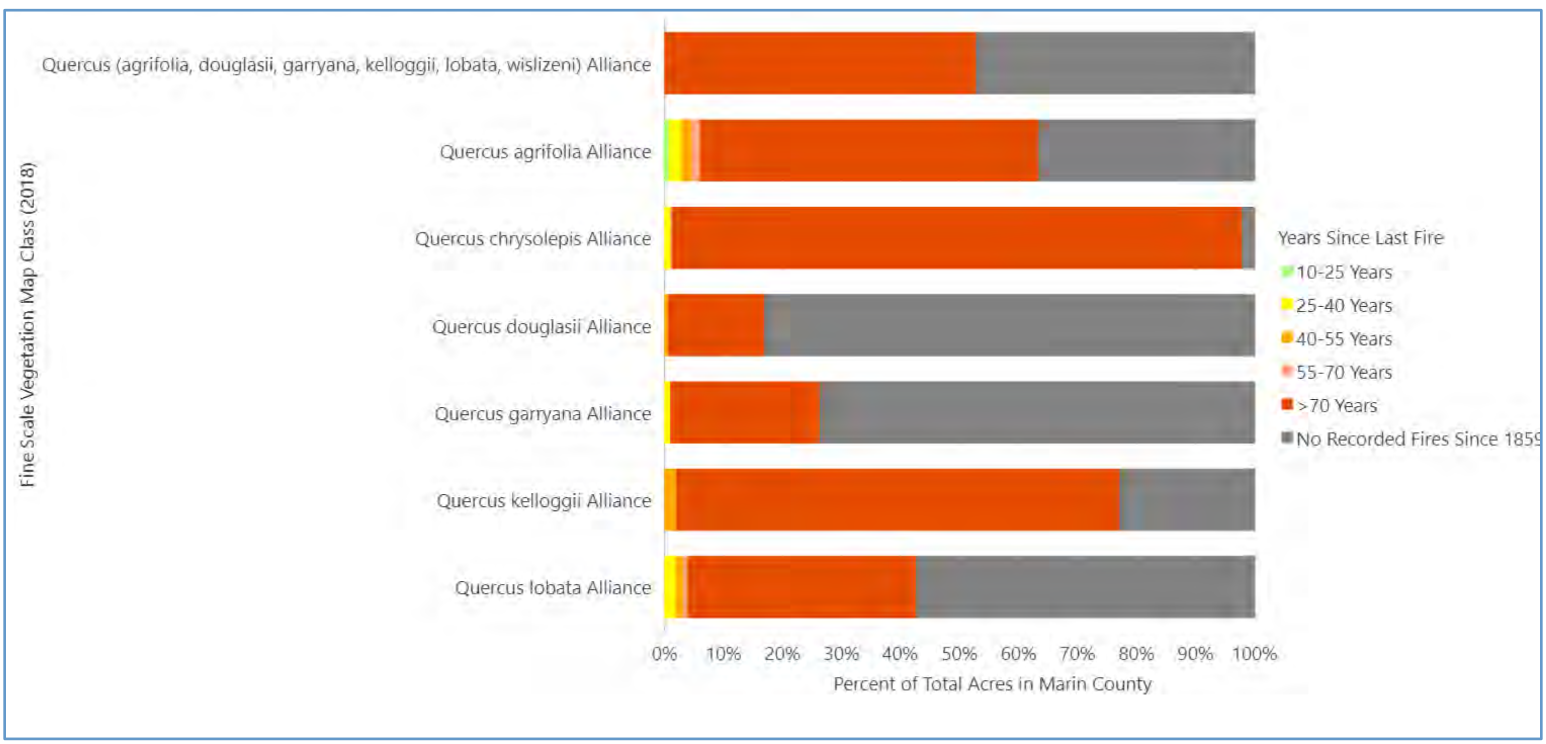


Figure 7.55. Open Canopy Oak Woodlands classified fire return interval 1859-1940.

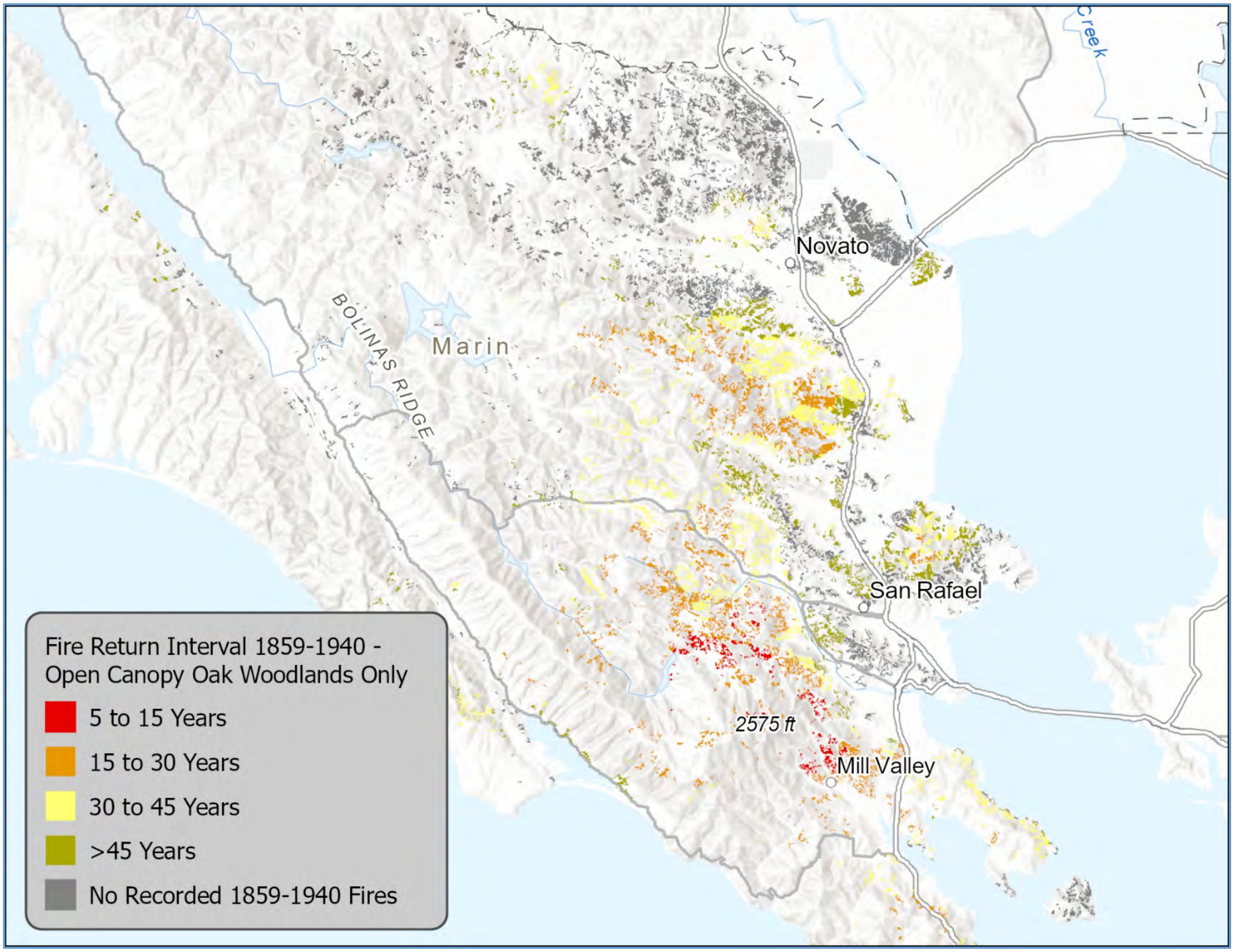
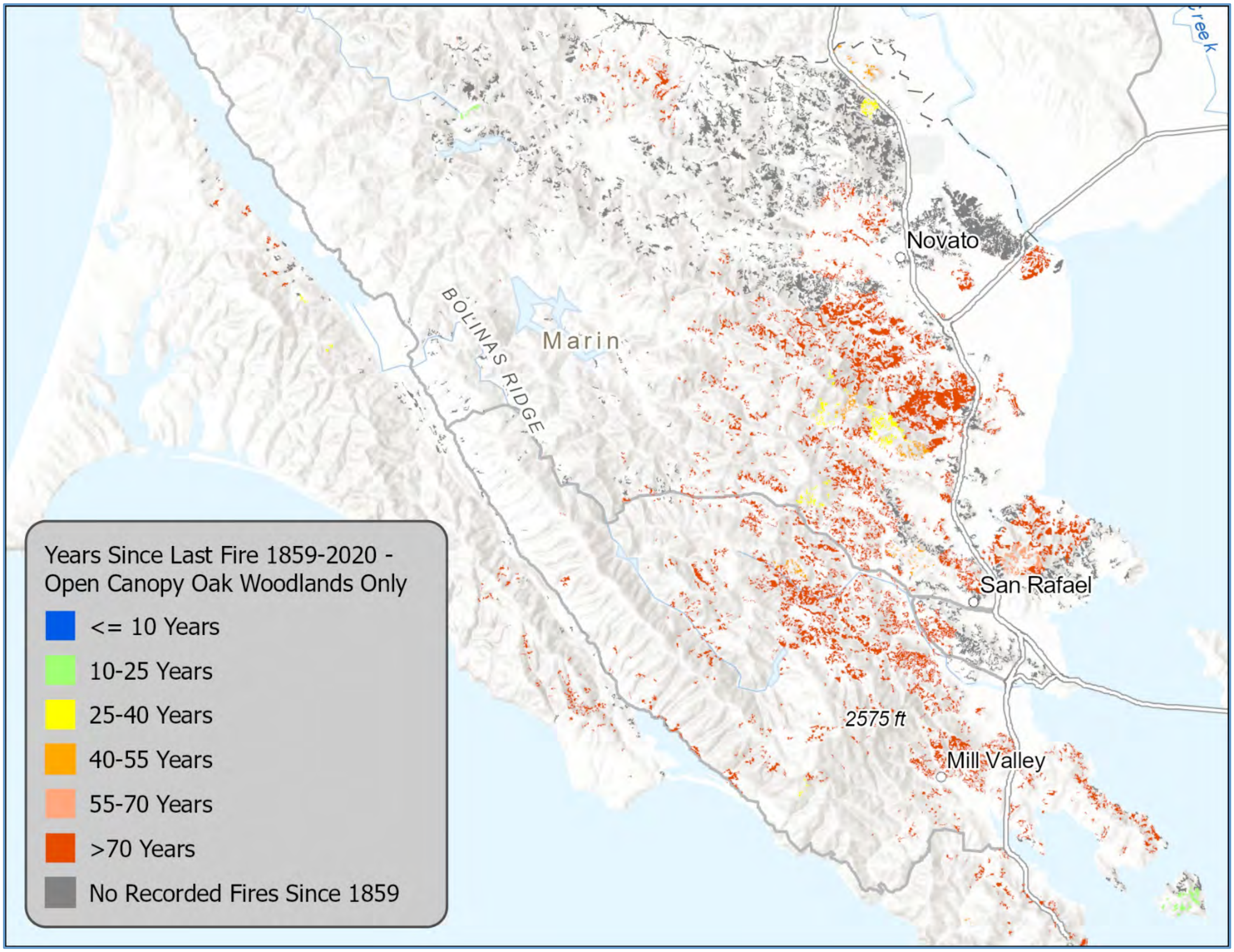


Figure 7.56. Open Canopy Oak Woodlands classified number of years since last fire.



SARGENT CYPRESS

Sargent cypress (*Hesperocyparis sargentii*) is a fire-adapted, fire-dependent tree species with serotinous cones. There is limited information on the lifespan of Sargent cypress; best estimates for trees in coastal areas is up to 300 years (Callahan, 2013, p. 21). Cones are produced on five- to seven-year-old trees and need approximately two years to mature, and can persist unopened on trees for 8 years or more (Edson et al., 2016; Little, 1975; Vogl et al., 1977). Data is sparse, but there are indications some cones may open in the absence of fire creating multi-age diversity within existing stands, however germination rates could be lower (M. Hoshovsky, California Department of Fish and Wildlife (retired), personal communication, 2021). The age of Sargent Cypress stands in Marin County is not currently well known, however approximately three-quarters of stands appear to have been within the 1945 Mill/Carson Canyon Fire perimeter (see Fire History Dynamics section below).

Metrics used to assess Sargent Cypress forest conditions were acreage and distribution, stand structure, canopy mortality, canopy gap formation, density change 2010 to 2019, and fire history. Chapter 5: Goals includes additional life history information for Sargent Cypress.

GOALS & ECOSYSTEM SERVICES

One Tam partners will work together to promote Sargent Cypress forest health and resilience in Marin County and look for opportunities to use beneficial fire to stimulate regeneration of this serotinous species. Biodiversity is the priority ecosystem service provided by Sargent Cypress forests, both in terms of its presence as part of the overall mosaic of forest types in Marin County as well as the unique composition of the Sargent Cypress forest community and associate species, particularly in serpentine areas. The *Hesperocyparis (sargentii, macnabiana)* Woodland Alliance is a California sensitive natural community (S3[10]), and the *Hesperocyparis sargentii / Ceanothus jepsonii – Arctostaphylos* spp. Association found in Marin County is even more rare (S1.2[11]) (Buck-Diaz et al., 2021). Like other forest types, Sargent Cypress also provides the ecosystem services of air quality, carbon sequestration, habitat, hydrologic function, and recreation. Managing Sargent Cypress forests to continue providing and strengthening these ecosystem services is an important goal for One Tam agencies.

FOREST HEALTH ATTRIBUTES

Characteristics of healthy Sargent Cypress stands include low non-native invasive species cover, understory diversity, seedling recruitment, and absorbent soil. Age-class diversity is another important health attribute for Sargent Cypress, which requires fire for regeneration recruitment. For continued persistence of this forest type across its range in Marin County,

[10] S3 = Vulnerable in the state due to a restricted range, relatively few populations (often 80 or fewer), recent and widespread declines, or other factors making it vulnerable to extirpation from the state.
[11] S1 = Critically imperiled in the state because of extreme rarity (often 5 or fewer populations) or because of factor(s) such as very steep declines making it especially vulnerable to extirpation from the state (California Department of Fish and Wildlife, n.d.)

some combination of early-, mid-, and late-seral cohorts is needed, with new trees propagating at least at replacement level following fire events (Edson et al., 2016, p. 58).

ACRES & DISTRIBUTION

The 2018 Fine Scale Vegetation Map and corresponding floristic classification report mapped a total of 451 acres of Sargent Cypress forest and described two associations in Marin County: *Hesperocyparis sargentii / Ceanothus jepsonii – Arctostaphylos spp*. Association (345 acres) and *Hesperocyparis sargentii* Association (106 acres). Notably, 100% of Sargent Cypress forests in Marin County are on protected open space lands, roughly 75% on Marin Water's Tamalpais Watershed lands and 25% on MCOSD lands in Gary Giacomini Open Space Preserve. See Appendix 7A and Chapter 5: Goals for additional information on the distribution of Sargent Cypress stands, or explore in detail via the Forest Health Web Map.

STAND STRUCTURE

The use of fire history data to inform the structural classification of Sargent Cypress was explored given that new cohorts are established after wildfire event; however, soil type and mean lidar-derived stand height proved to be a better metric for describing the current structural patterns and distribution of Sargent Cypress stands in Marin County. See Chapter 6: Metrics for details on the structural classification methodology. In general, stands are shorter (mean lidar-derived stand height less than or equal to 20 feet) on serpentine soils than on non-serpentine soils, however there is considerable overlap in stand height across soil types and floristic associations (Figure 7.57).

- **Eighty-nine percent (400 acres) of Sargent Cypress in Marin County occur in/adjacent to areas with serpentine soils** (SSURGO taxonomic class of Clayey-skeletal, serpentinitic, thermic Lithic Argixerolls[12]) (Figure 7.59). Both Sargent Cypress associations are found in this area. Mean lidar-derived height varied across stands of each association, which could be an indication of multiple age cohorts or variation in site-specific conditions such as soil, aspect, or water availability. Of the 400 acres on serpentine soils, 37% (149 acres) are in the shortest structural class, most likely corresponding to areas of pygmy Sargent Cypress forest (Figure 7.58)
- **The remaining 11% (51 acres) of Sargent Cypress are in non-serpentine areas; they are generally taller, with 80% (41 acres) classified as having a mean lidar-derived stand height greater than 20 feet** (Figure 7.60)**.** Notably, all shorter stands in this area are classified floristically as *Hesperocyparis sargentii / Ceanothus jepsonii – Arctostaphylos* spp. Association, and their presence could be an indication that pockets of serpentine exist in these locations (Figure 7.61).

[12] Soil Survey Geographic Database (SSURGO) | Natural Resources Conservation Service (usda.gov)

Figure 7.57. Sargent Cypress 2018 Fine Scale Vegetation Map class with distribution of mean stand height by structural class.

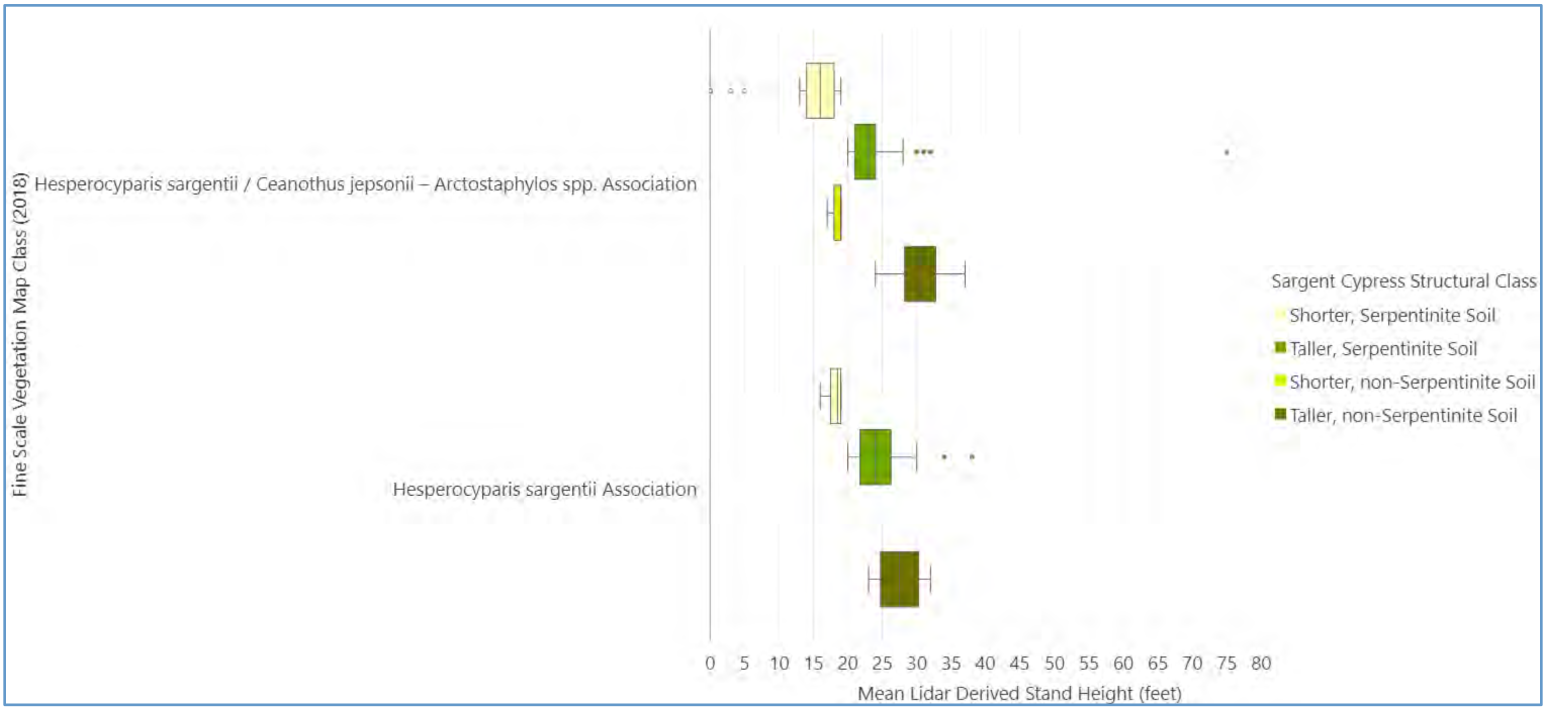


Figure 7.58. Sargent Cypress 2018 Fine Scale Vegetation Map class by acres with structural classification, serpentine areas only.

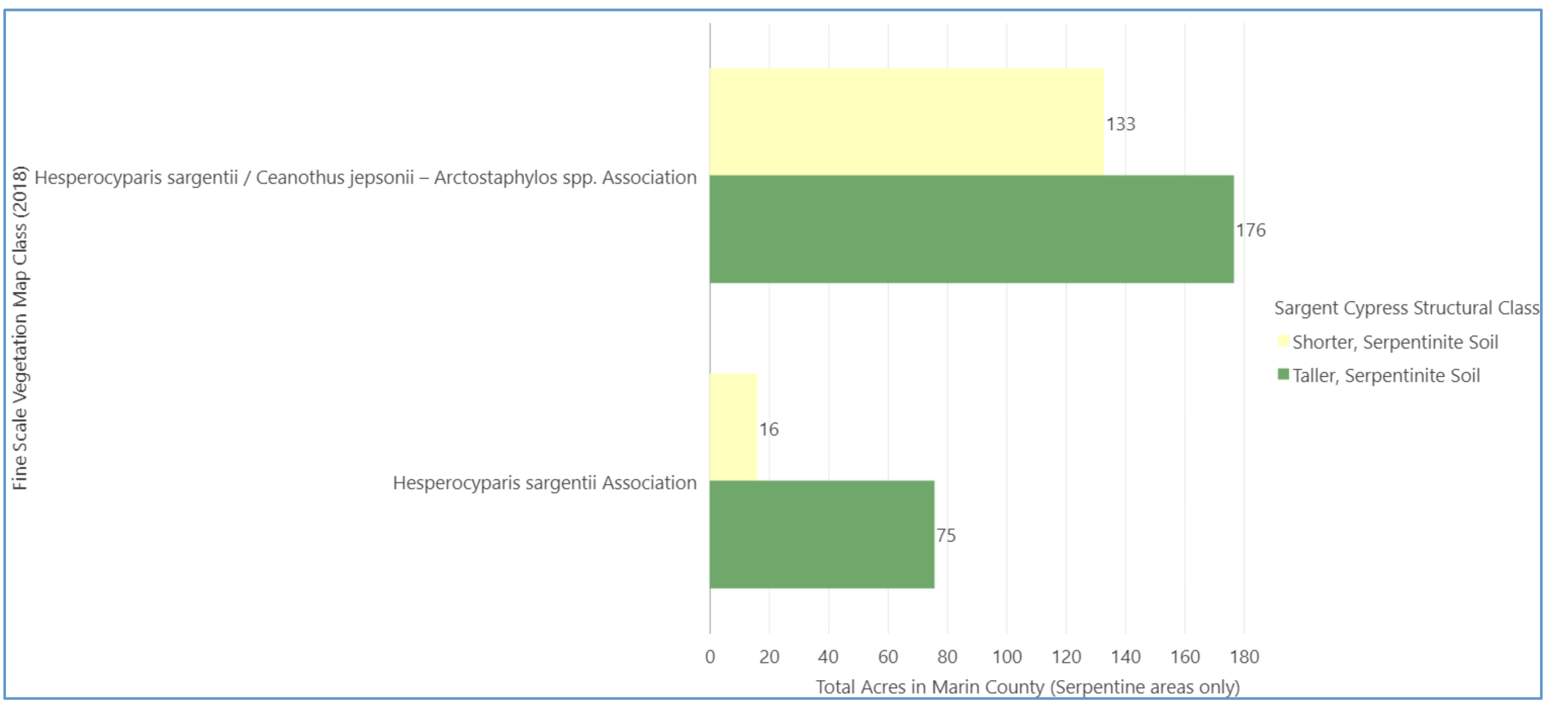


Figure 7.59. Sargent Cypress structural classification in serpentine areas, San Geronimo Ridge and surrounding areas.

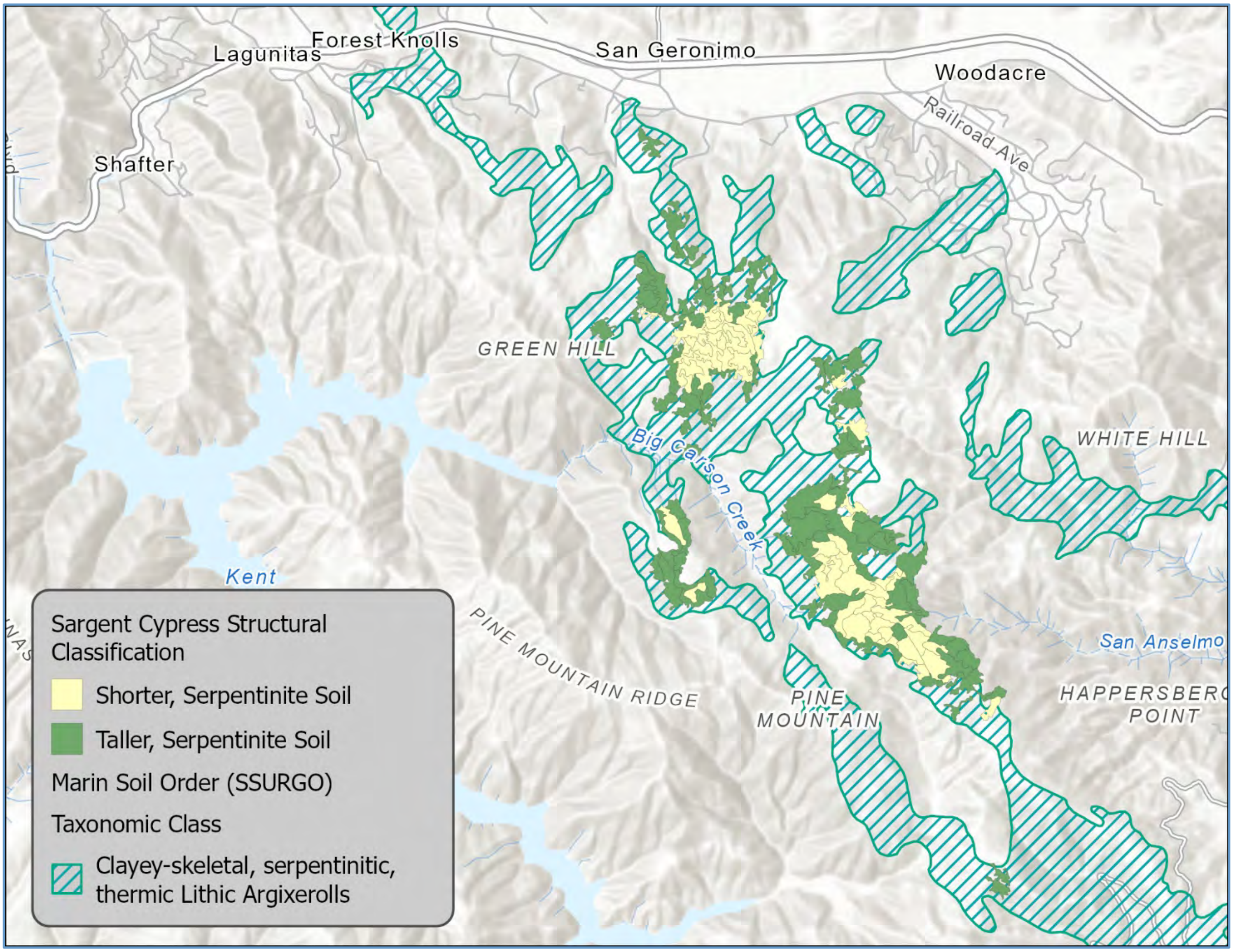


Figure 7.60. Sargent Cypress structural classification in non-serpentine areas, Mount Tamalpais area.

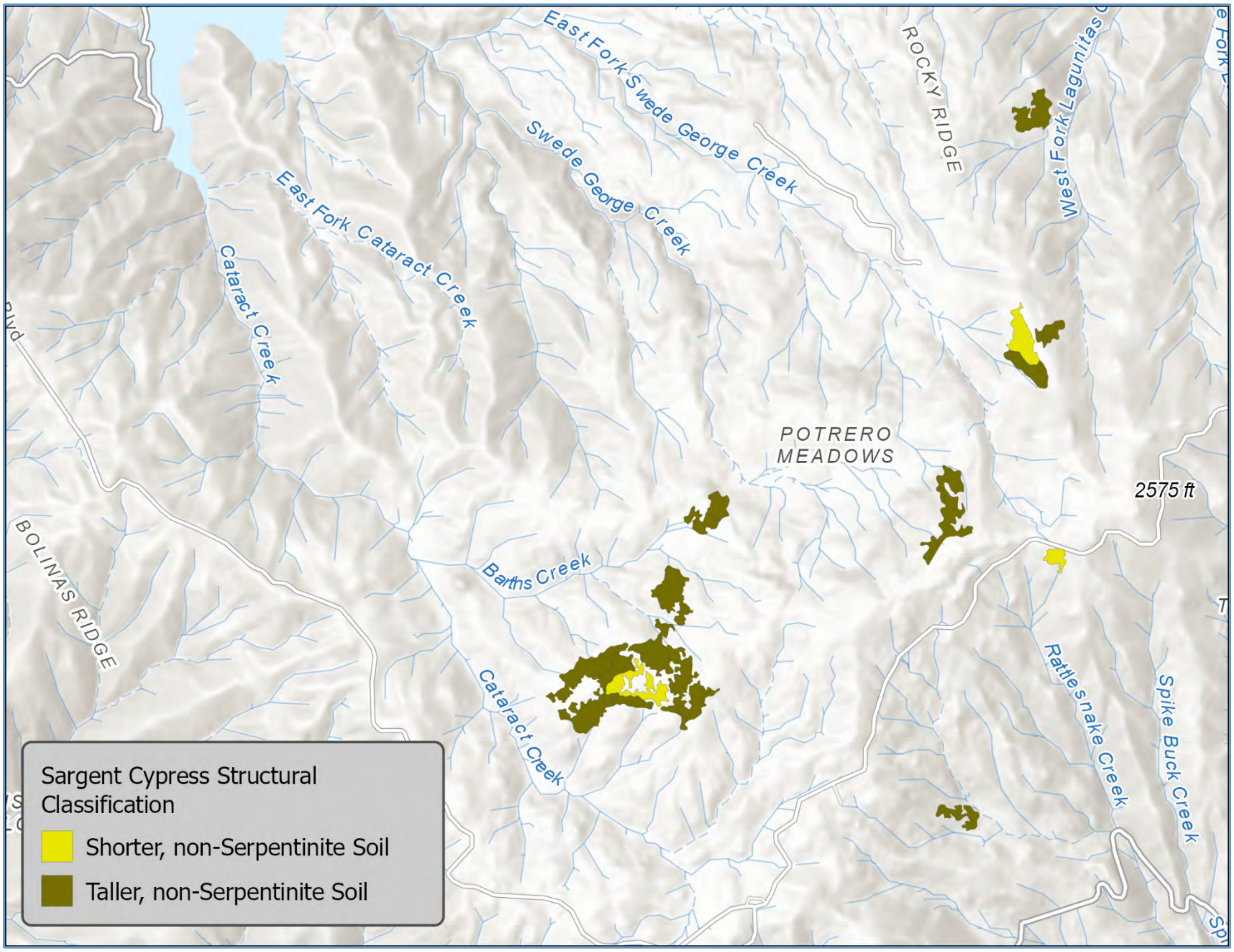
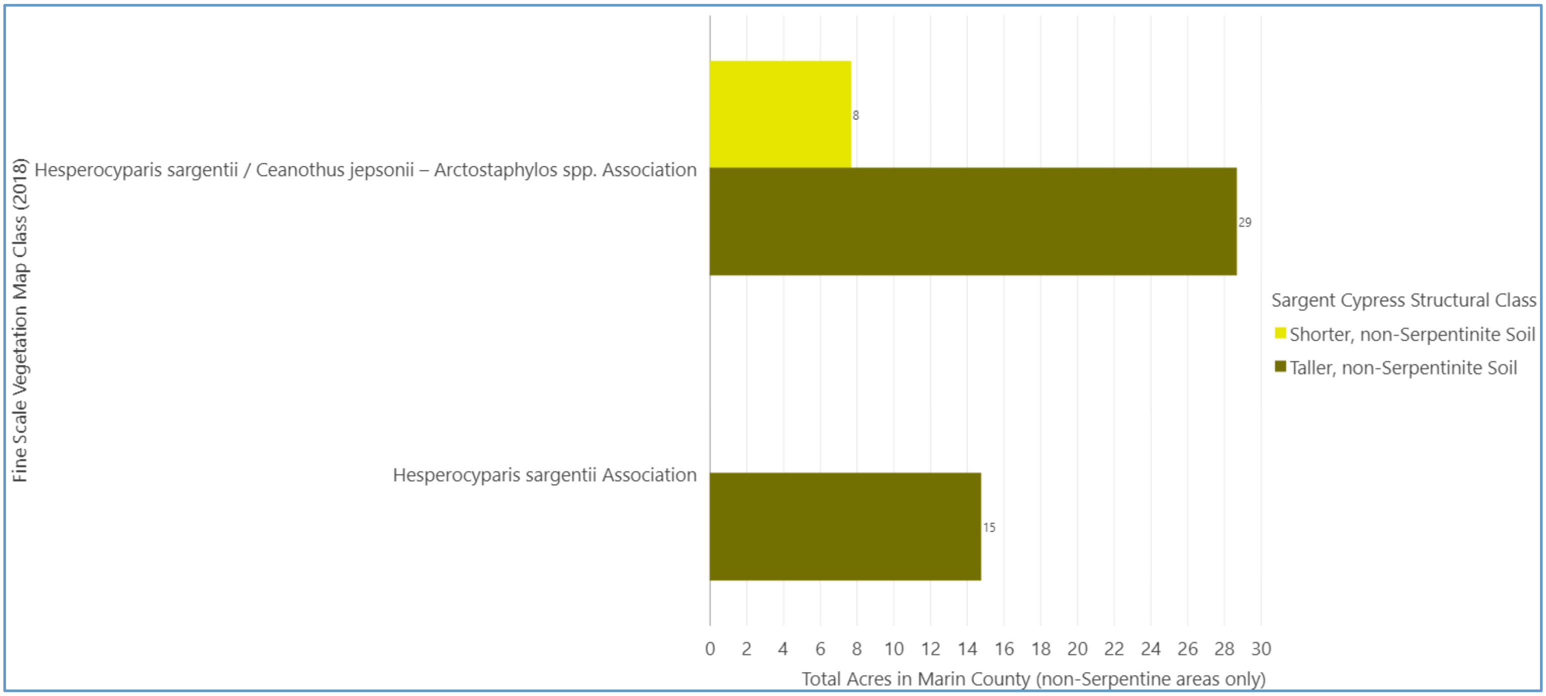


Figure 7.61. Sargent Cypress 2018 Fine Scale Vegetation Map class by acres with structural classification, non-serpentine areas only.



CANOPY MORTALITY & DYNAMICS

According to the *2016 Peak Health Report*, Sargent cypress in Marin County currently appear to be relatively free of disease (Edson et al., 2016, p. 56). However, Sargent cypress are susceptible to the pathogen *Seiridium cardinale* (formerly *Coryneum cardinale*), which can cause cypress canker disease and has been identified on MacNab cypress (*Cupressus macnabiana*) in California (Esser, 1994, Della Rocca et al., 2017). Mistletoe (*Phoradendron bolleanum*) has been previously documented on Sargent cypress trees in Marin and is present on Mount Tamalpais, but it is unclear whether mistletoe has negative effects (Calflora, n.d.; Edson et al., 2016; Esser, 1994).

Canopy mortality was detected in Sargent Cypress stands across associations and structural classes. Managers should note this metric does not distinguish the species of affected vegetation, which may be species other than Sargent cypress. For example, Douglas-fir mortality has been observed in Sargent Cypress stands on serpentine soils. Additional field study may be able to determine if tree age and senescence could be a factor contributing to canopy mortality or decadence due to lack of fire disturbance and regeneration in Sargent Cypress forests.

- **The majority of Sargent Cypress forest in Marin County had no detectable canopy mortality. However, a significant number of acres (effectively 25% of Sargent Cypress forests) had at least some canopy mortality detected, in both associations** (Figure

7.62). This suggests that additional field surveys and study to investigate mortality in Sargent Cypress forests is warranted.

- **In total (across both associations) a relatively small proportion (3% or 12 acres) of Sargent Cypress forest had greater than 2.5% canopy gaps formed between 2010-2019** (Figure 7.63). This result supports the conclusion that although Sargent Cypress forest may be affected by senescence or other stressors, they are not experiencing significant decline sufficient to cause downed trees.
- **Thirty-nine percent (174 acres) of Sargent Cypress forest experienced from 2.5% to 10% canopy density loss between 2010 and 2019** (Figure 7.64). Notably, nearly all (96% or 99 acres) of the Sargent Cypress forest mapped with 0.5% or greater canopy mortality also showed a loss in canopy density (Figure 7.65). This analysis shows there is likely a relationship between canopy mortality and decreased vigor (canopy density) in Sargent Cypress forests, which together could be an indicator of impacts from senescence or other stressors.

Figure 7.62. Sargent Cypress 2018 Fine Scale Vegetation Map class by acres with classified canopy mortality (standing dead).

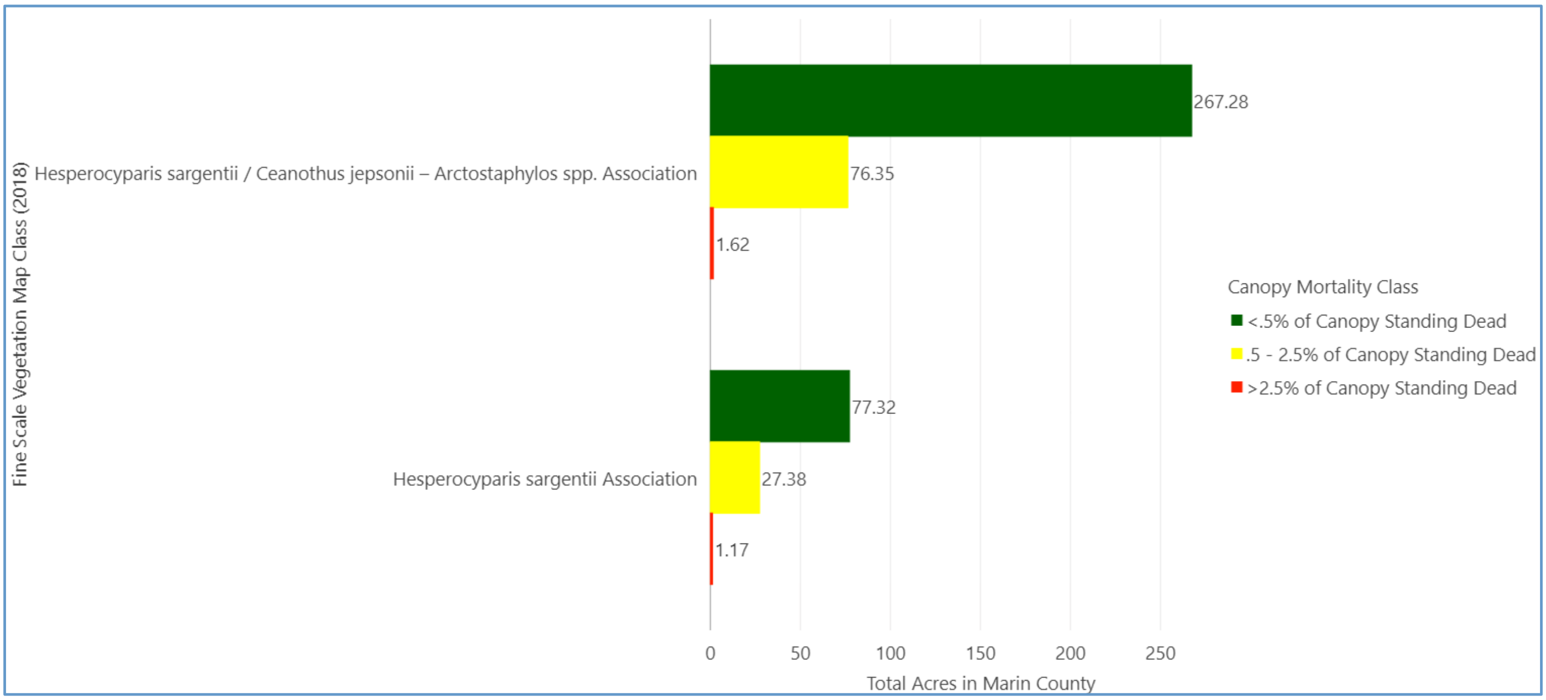


Figure 7.63. Sargent Cypress 2018 Fine Scale Vegetation Map class with classified percent canopy gap formed between 2010-2019, expressed as a percentage of the total countywide acres.

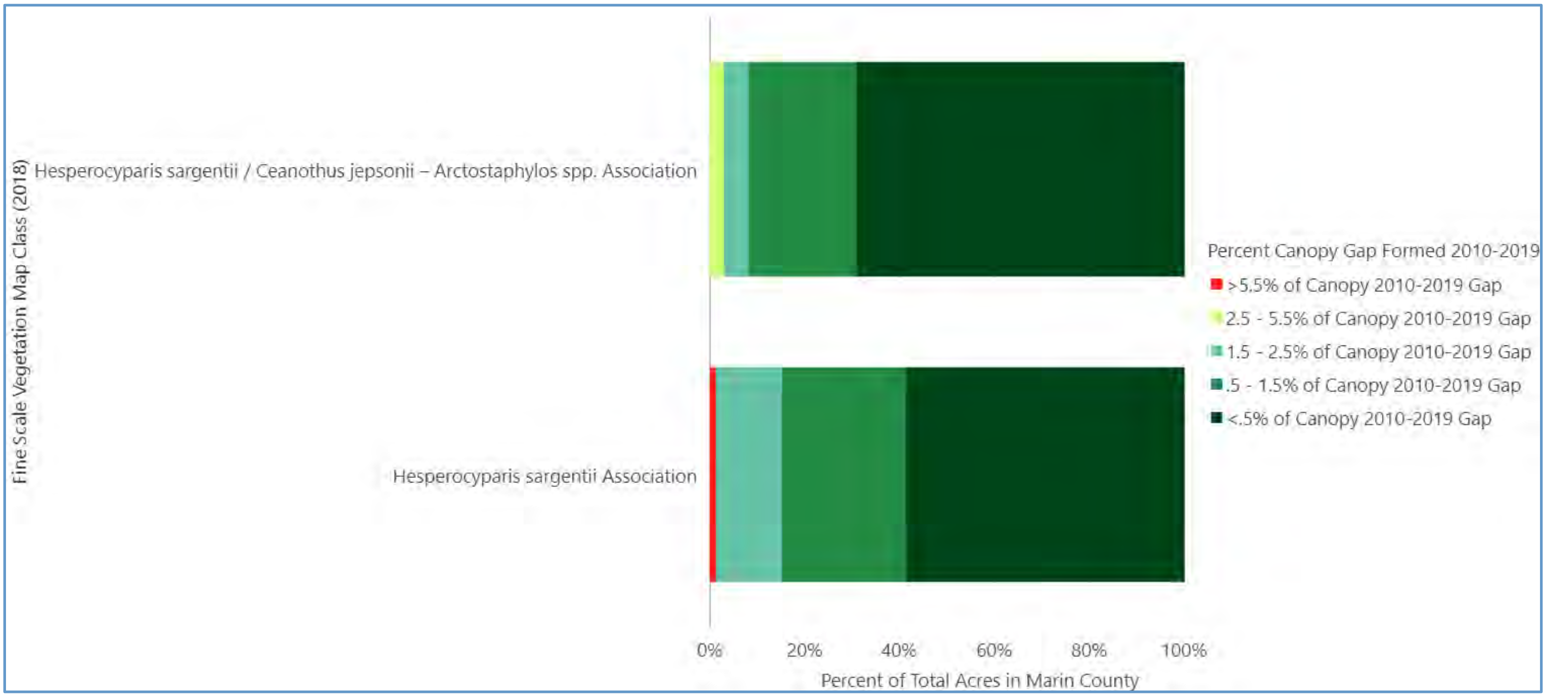


Figure 7.64. Sargent Cypress classified canopy density change 2010-2019 by acres.

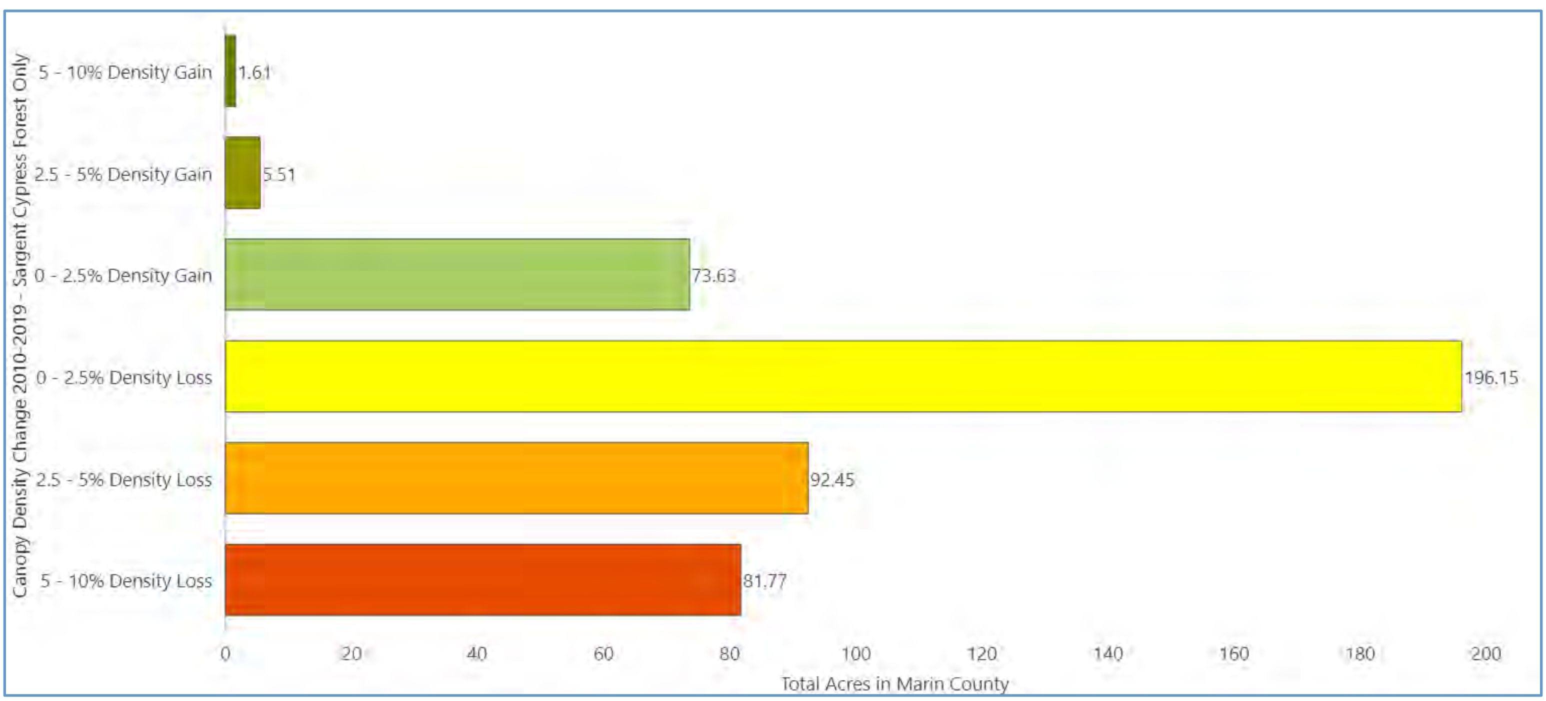
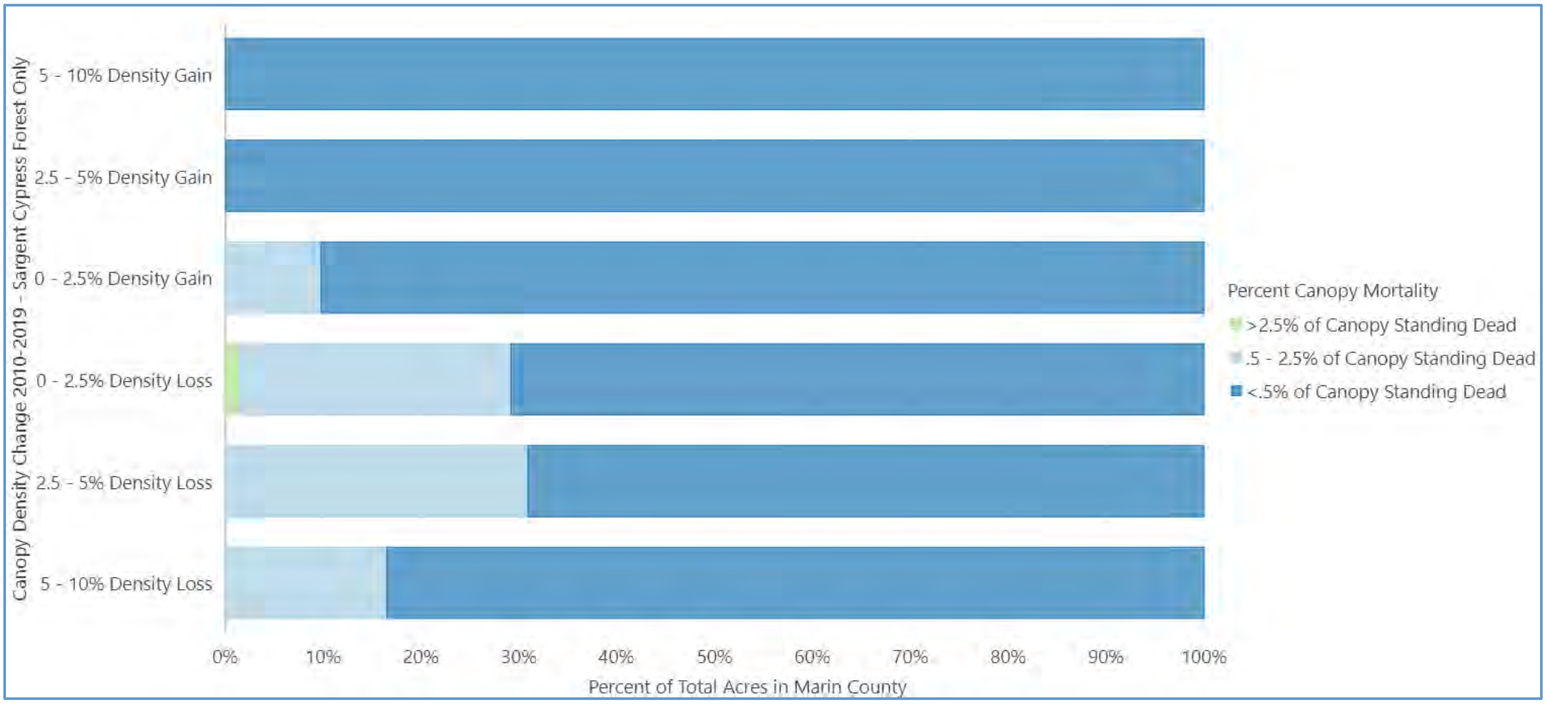


Figure 7.65. Sargent Cypress classified canopy density change 2010-2019 with classified canopy mortality (standing dead), expressed as a percentage of the total countywide acres.



FIRE HISTORY DYNAMICS

The typical fire return interval for Sargent Cypress stands is not well understood, but is thought to be variable and multi-decadal (Edson et al., 2016; M. Hoshovsky, personal communication, 2021). Trees require years to reach maturity and produce viable cones; fire recurring too frequently can be problematic for the establishment of new cohorts, and too long of an interval may pose a threat to resilience due to senescence. For further discussion of Sargent Cypress immaturity and senescence risk, see Sargent Cypress in Chapter 5: Goals.

- **According to spatial data provided by the *Marin County Wildfire History Mapping Project*, 90% (406 acres) of Sargent Cypress forest in Marin had a fire return interval of 15-30 years between 1859 and 1940** (Figure 7.66). Fires were recorded within the general area of existing Sargent Cypress stands in 1859, 1861, 1868, 1881, 1891, 1904, 1923, and 1931 (Dawson, 2021)
- **Seventy-seven percent (348 acres) of Sargent Cypress forest in Marin County last experienced fire during the 1945 Mill/Carson Canyon Fire, however 23% (101 acres) has not seen fire in 100 years or more** (Figure 7.67). This includes 52 acres in serpentine areas near San Geronimo Ridge that have not burned since the 1923 Ignacio Fire, and 36 acres in non-serpentine areas near Mount Tamalpais that have not seen fire since the 1904 Bolinas Ridge Fire (Figure 7.68).

Figure 7.66. Sargent Cypress classified fire return interval 1859-1940 by acres.

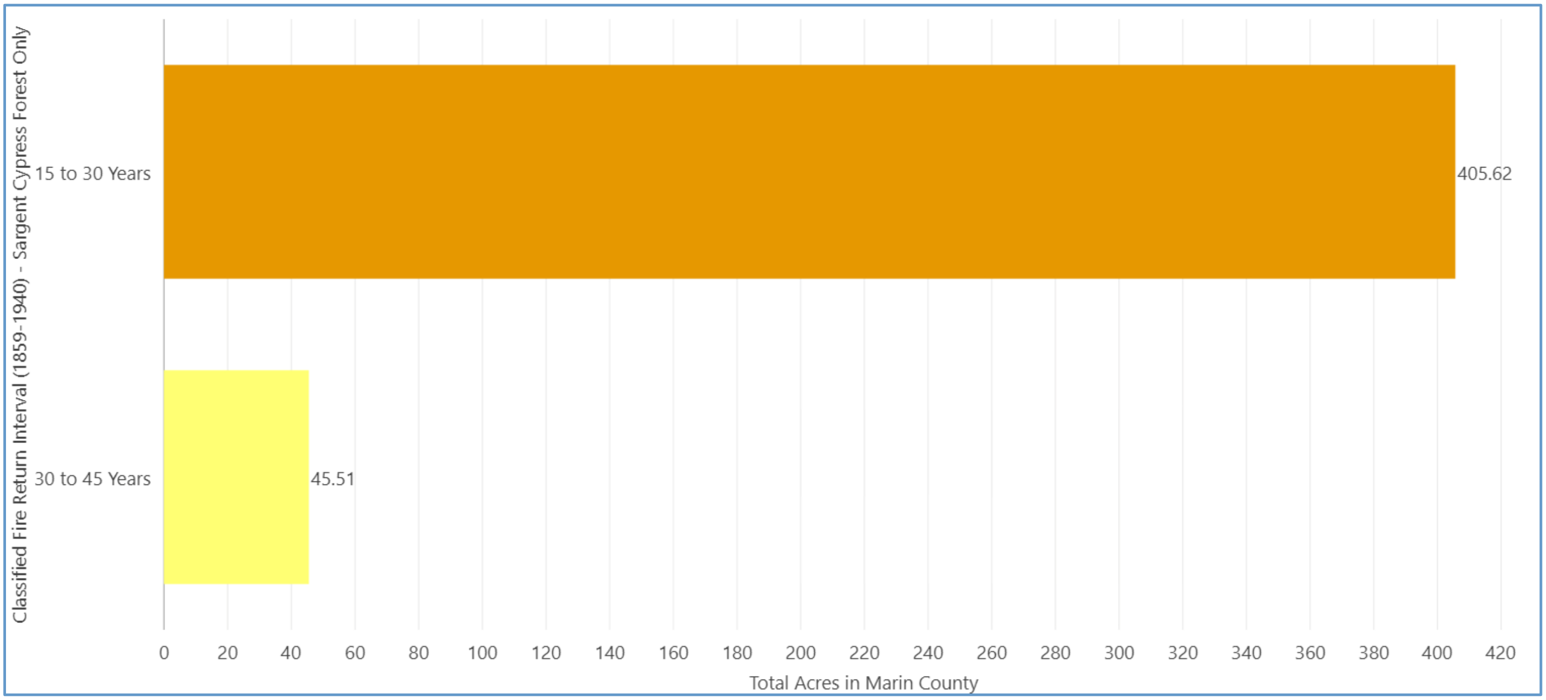


Figure 7.67. Sargent Cypress year of last fire by acres.

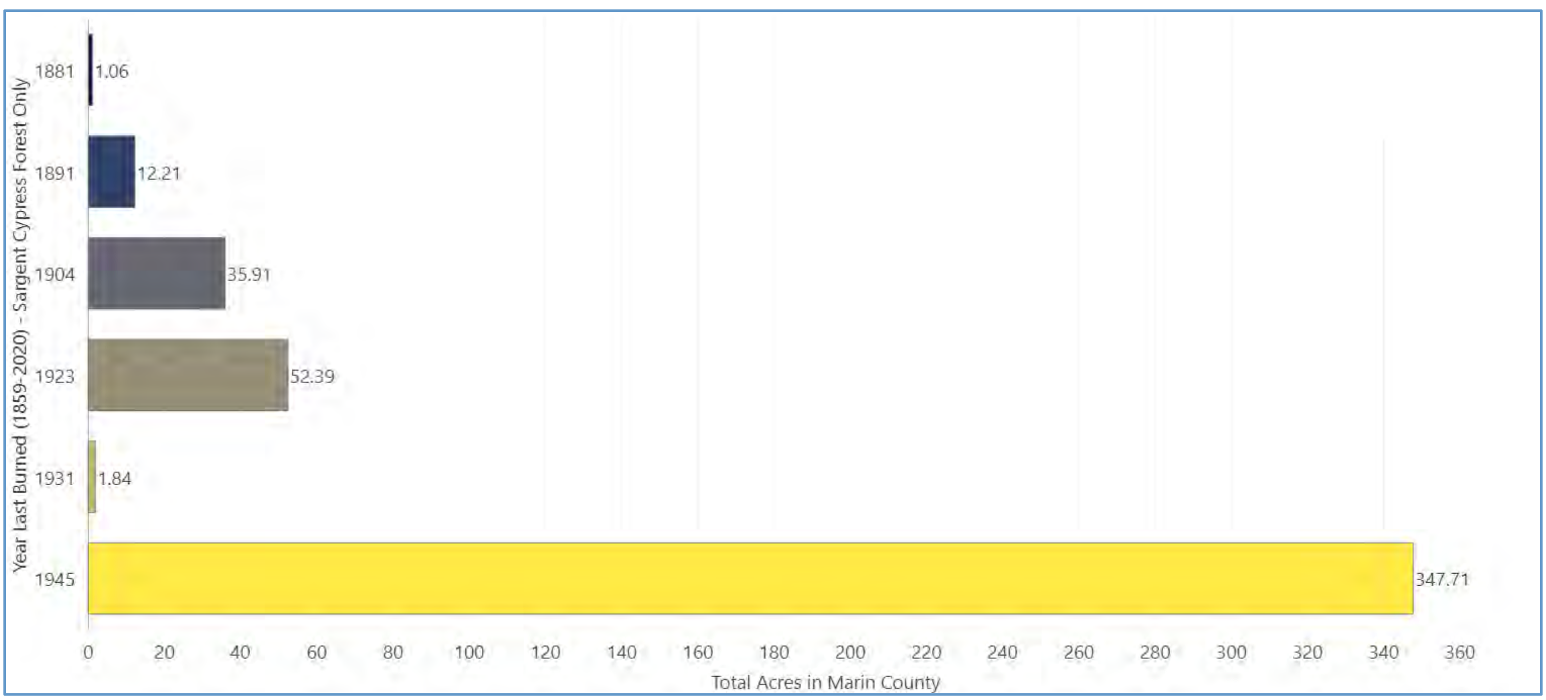
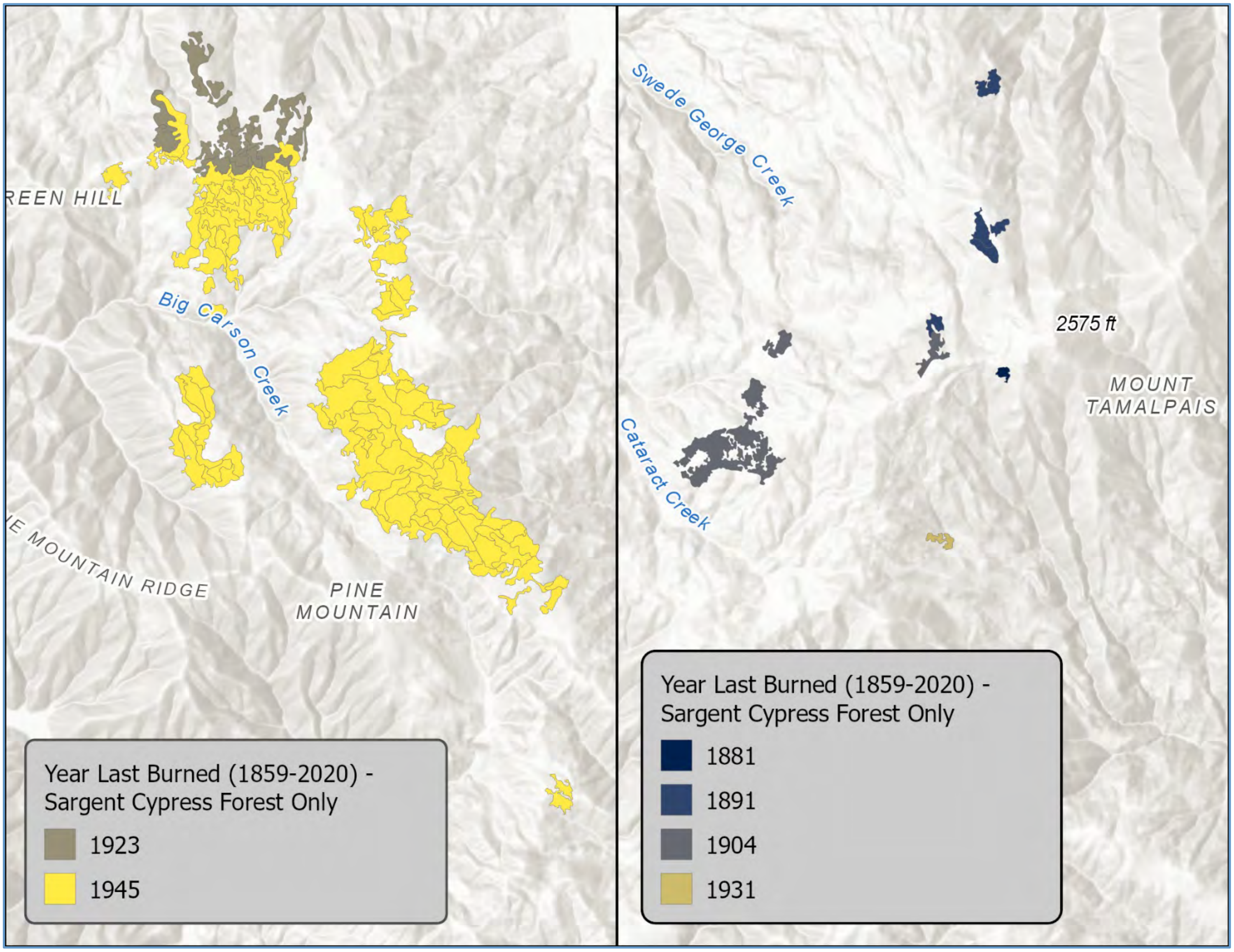


Figure 7.68. Sargent Cypress year last burned, in serpentine areas (left) and non-serpentine areas (right).



SARGENT CYPRESS SUMMARY

Overall, the presence of Sargent Cypress forests as part of the mosaic of forest types in Marin County appears stable. Canopy mortality and density analysis indicates that some areas are being impacted by senescence or other stressors and field-based investigations could be used to better understand the extent and drivers of these impacts. While existing trees may still be within the normal lifespan range, fire exclusion poses a significant threat to the long-term resilience of Sargent Cypress in Marin County and has the potential to reduce the extent of this important species.

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APPENDIX 7A. FOREST HEALTH STRATEGY TARGET FOREST TYPE ACRES AND DISTRIBUTION AMONGST PUBLIC LAND MANAGEMENT AGENCIES.

Forest Type	2018 Fine Scale Vegetation Map Classes	Total Acres in Marin County	Total Acres by Land Manager		Percent of Countywide Total	Percent of Protected Total
Bishop Pine	*Pinus muricata – Pinus radiata* Alliance	**4,668.36**	California State Parks	921.72	19.74%	22.20%
			Marin County Parks[1]	6.39	0.14%	0.15%
			Marin Municipal Water District	31.46	0.67%	0.76%
			National Park Service, GGNRA[2]	24.15	0.52%	0.58%
			National Park Service, PRNS	3,090.42	66.20%	74.43%
			Other protected lands[3]	78.22	1.68%	1.88%
			Total	**4,152.36**	**88.95%**	N/A
Coast Redwood	*Sequoia sempervirens* Alliance	**11,264.19**	California State Parks	952.17	8.45%	11.69%
			Marin County Parks[1]	849.86	7.54%	10.44%
			Marin Municipal Water District	4,107.60	36.47%	50.45%
			National Park Service, GGNRA[2]	1,802.52	16.00%	22.14%
			National Park Service, PRNS	58.38	0.52%	0.72%
			Other protected lands[3]	371.23	3.30%	4.56%
			Total	**8,141.75**	**72.28%**	N/A
Douglas-fir	*Pseudotsuga menziesii – (Notholithocarpus densiflorus – Arbutus menziesii)* Alliance	**26,245.10**	California State Parks	3,074.64	11.72%	14.56%
			Marin County Parks[1]	865.76	3.30%	4.10%
			Marin Municipal Water District	3,968.35	15.12%	18.79%
			National Park Service, GGNRA[2]	2,670.76	10.18%	12.64%
			National Park Service, PRNS	10,148.29	38.67%	48.04%
			Other protected lands[3]	394.68	1.50%	1.87%
			Total	**21,122.48**	**80.48%**	N/A

Open Canopy Oak Woodlands	*Quercus* (*agrifolia, douglasii, garryana, kelloggii, lobata, wislizeni*) Alliance	**38.91**	California State Parks	6.56	16.87%	53.15%
			Marin County Parks[1]	3.21	8.25%	25.98%
			Marin Municipal Water District	0	0.00%	0.00%
			National Park Service, GGNRA[2]	0	0.00%	0.00%
			National Park Service, PRNS	0	0.00%	0.00%
			Other protected lands[3]	2.58	6.62%	20.87%
			Total	**12.35**	**31.74%**	N/A
	Quercus agrifolia Alliance	**14,379.22**	California State Parks	771.38	5.36%	13.90%
			Marin County Parks[1]	2,403.38	16.71%	43.31%
			Marin Municipal Water District	908.26	6.32%	16.37%
			National Park Service, GGNRA[2]	331.63	2.31%	5.98%
			National Park Service, PRNS	82.67	0.57%	1.49%
			Other protected lands[3]	1,052.37	7.32%	18.96%
			Total	**5,549.69**	**38.60%**	N/A
	Quercus chrysolepis Alliance	**875.61**	California State Parks	69.31	7.92%	9.44%
			Marin County Parks[1]	1.45	0.17%	0.20%
			Marin Municipal Water District	465.18	53.13%	63.33%
			National Park Service, GGNRA[2]	9.54	1.09%	1.30%
			National Park Service, PRNS	189.07	21.59%	25.74%
			Other protected lands[3]	0	0.00%	0.00%
			Total	**734.55**	**83.89%**	N/A
	Quercus douglasii Alliance	**839.05**	California State Parks	0.62	0.07%	0.24%
			Marin County Parks[1]	189.52	22.59%	72.03%
			Marin Municipal Water District	0	0.00%	0.00%
			National Park Service, GGNRA[2]	0	0.00%	0.00%
			National Park Service, PRNS	0	0.00%	0.00%
			Other protected lands[3]	72.97	8.70%	27.73%
			Total	**263.11**	**31.36%**	N/A

	Quercus garryana Alliance	**1,404.65**	California State Parks	94.51	6.73%	37.90%
			Marin County Parks[1]	83.32	5.93%	33.41%
			Marin Municipal Water District	14.16	1.01%	5.68%
			National Park Service, GGNRA[2]	0	0.00%	0.00%
			National Park Service, PRNS	0	0.00%	0.00%
			Other protected lands[3]	57.38	4.09%	23.01%
			Total	**249.37**	**17.75%**	N/A
	Quercus kelloggii Alliance	**219.36**	California State Parks	2.87	1.31%	2.11%
			Marin County Parks[1]	60.15	27.42%	44.27%
			Marin Municipal Water District	63.07	28.75%	46.41%
			National Park Service, GGNRA[2]	0	0.00%	0.00%
			National Park Service, PRNS	0	0.00%	0.00%
			Other protected lands[3]	9.79	4.46%	7.21%
			Total	**135.89**	**61.95%**	N/A
	Quercus lobata Alliance	**2,892.21**	California State Parks	66.81	2.31%	10.65%
			Marin County Parks[1]	412.25	14.25%	65.73%
			Marin Municipal Water District	22.63	0.78%	3.61%
			National Park Service, GGNRA[2]	0	0.00%	0.00%
			National Park Service, PRNS	0	0.00%	0.00%
			Other protected lands[3]	125.51	4.34%	20.01%
			Total	**627.19**	**21.69%**	N/A
Sargent Cypress	*Hesperocyparis sargentii / Ceanothus jepsonii – Arctostaphylos spp.* Association	**345.25**	California State Parks	0.06	0.02%	0.02%
			Marin County Parks[1]	88.16	25.54%	25.80%
			Marin Municipal Water District	253.48	73.42%	74.18%
			National Park Service, GGNRA[2]	0	0.00%	0.00%
			National Park Service, PRNS	0	0.00%	0.00%
			Other protected lands[3]	0	0.00%	0.00%
			Total	**341.71**	**98.97%**	N/A

	Hesperocyparis sargentii Association	**105.87**	California State Parks	0.00	0.00%	0.00%
			Marin County Parks[1]	28.34	26.77%	26.77%
			Marin Municipal Water District	77.53	73.23%	73.23%
			National Park Service, GGNRA[2]	0	0.00%	0.00%
			National Park Service, PRNS	0	0.00%	0.00%
			Other protected lands[3]	0	0.00%	0.00%
			Total	**105.87**	**100.00%**	N/A

[1] Includes both Marin County Open Space District and Marin County Parks lands. Does not include conservation easements.

[2] Includes Muir Woods National Monument.

[3] Other protected lands in Marin County include lands managed by: Audubon Canyon Ranch, Bel Marin Keys Community Services District, City of Belvedere, Bolinas Community Public Utility District, California Department of Fish and Wildlife, California Department of Transportation, California State Coastal Conservancy, California State Lands Commission, Town of Corte Madera, Town of Fairfax, City of Larkspur, Las Gallinas Valley Sanitary District, Marin Audubon Society, Marin Conservation League, Marin Public Works Dept/Flood Control, County of Marin, Marinwood Community Service District, City of Mill Valley, National Audubon Society, North Marin Water District, Novato Sanitary District, City of Novato, Town of Ross, City of San Anselmo, City of San Rafael, City of Sausalito, Sonoma-Marin Area Rail Transit, Strawberry Recreation District, Tamalpais Community Services District, The Nature Conservancy, Town of Tiburon, Tomales Village Community Services District, Trust for Public Land, United States Bureau of Land Management, United States Coast Guard, United States Fish and Wildlife Service (California Protected Areas Database, 2022. Green Info Network. https://www.calands.org)

CHAPTER 8: PRIORITIZATION FRAMEWORK & IMPLEMENTATION ANALYSIS

One Tam partners approach land management through the lens of stewardship and science. Thus, the prioritization framework advanced by the *Marin Regional Forest Health Strategy* (*Forest Health Strategy*) centers on improving or conserving overall forest ecosystem health and resilience while also considering the potential benefits that treatments can have to other values at risk, for example, this could include restoring cultural resources and practices as defined by the Federated Indians of Graton Rancheria (the Tribe; see Chapter 3: Stewardship and Partnership with the Federated Indians of Graton Rancheria), protecting critical infrastructure, and enhancing community safety.

Building on metrics analysis in Chapter 7: Condition Assessment, the prioritization framework and multi-benefit treatment implementation analysis presented here defines multiple-benefit treatments for the *Forest Health Strategy*. It also provides a framework and spatial tools for identifying opportunities to restore or enhance ecological health and resilience in forested areas that considers both wildfire hazard and proximity to community, where applicable. This chapter presents the results of the implementation analysis as areas that can be prioritized from a multi-benefit treatment perspective for each One Tam land management agency. While this chapter identifies specific multi-benefit project areas primarily for One Tam agencies, the GIS layers developed to support prioritization are for all of Marin County. This information can be accessed via the One Tam Marin Forest Health Web Map and used by other land managers, agencies, and decision-makers seeking to advance additional multi-benefit treatment opportunities focused on other areas of Marin.

MULTIPLE BENEFIT DEFINITION

The *Forest Health Strategy* defines multiple-benefit treatments as:

Forest management actions that are designed to improve or protect the ecological health and resilience of forests in Marin County while simultaneously addressing one or more additional drivers for active management, including:

- **Conservation or restoration of cultural resources and practices as defined by the Tribe**
- **Natural resource protection/restoration[1]**
- **Climate change adaptation**
- **Water quality/fisheries**

[1] Includes wildlife considerations e.g., protecting Northern Spotted Owl habitat, increasing resilience of large diameter trees important to salmonid-bearing streams, etc.

- **Wildfire resilience**[2]
- **Safety for communities and critical infrastructure.**

An important component of the *Forest Health Strategy's* multiple-benefit treatment definition includes restoring ecosystem function and processes. Implicit in the definition are treatments that maximize carbon sequestration and improve resilience to climate change and other stressors. Increased wildfire resilience for forests, habitats, communities, and critical infrastructure will be an important benefit in many cases.

The key features of multi-benefit treatments areas include:

- **Protection**—healthy, unique, or otherwise significant forest areas where active treatment could maintain or improve forest health and resilience.
- **Enhancement**—forest stands that have departed from the desired condition and where active treatment could improve ecosystem function, forest health, and resilience.
- **Tribal use**—forests, which are Tribal Cultural Resources (TCRs) and have special value to the Tribe, where treatments could improve or protect those values as defined by the Tribe or restore practices as identified by the Tribe. These are uses specific to the Tribe and are distinct from other cultural uses that may also be important.
- **Public safety**—forest near communities or the wildland-urban interface and built infrastructure focused on protecting people and property, but treatments could improve and enhance ecosystem services.

Important considerations for multi-benefit treatments include:

- Implicit in the definition of multiple benefit presented here is that there is considerable overlap between the key features of protection, enhancement, Tribal use, and public safety. For example, Tribal use should not be seen as separate objective from resource protection or public safety, but rather as unique facet of an overall approach to management that centers the idea that a treatment should seek to advance multiple objectives.
- Maintenance of the treatments is needed to uphold benefits (e.g., ensure management does not inadvertently promote dispersal of non-native invasive species).
- Treatment approaches are based on intentional outcomes and future desired conditions. Developing quantifiable metrics to measure management outcomes that are relevant across projects at multiple scales is critical for measuring success, reporting to the public and other stakeholders, creating feedback loops to inform future treatment design, engage with Marin's communities, and advance scientific understanding.
- Multi-benefit treatments must have a scientific evidence base to be successful.

[2] Includes improved wildfire response, limiting suppression damage, increasing the use of beneficial fire, and strategic hazardous fuel reduction near communities and infrastructure.

- Land managers may consider how proposed actions will impact non-target values, then weigh goals and impacts to make decisions according to agreed priorities.

MULTIPLE BENEFIT LITERATURE REVIEW

A challenge for defining and understanding the term multiple benefit, or multi-benefit, is that it is used in conjunction with many different types of projects. Despite frequent use, multi-benefit is often not explicitly defined. Multiple-benefit restoration or treatment refers to projects achieving several ecological and socioeconomic goals simultaneously. The term is may be used synonymously, whether in error or not, with other terms such as triple-bottom-line, sustainable, nature-based solutions, resilient, and integrated restoration.

CONSERVATION & RESTORATION

Gardali et al. (2021) provide a recent and thoughtful definition for multiple-benefit conservation: "…conservation efforts designed to simultaneously benefit local communities of people, enhance ecological function, and improve habitat quality for fish and wildlife (p.1)." Projects addressing several goals and identifying these goals at the project outset are critical features of the definition. Each goal can be defined by metrics, e.g., human health vs. carbon sequestration vs. the number of wildlife species (Gardali et al., 2021).

Gregory Andrew, former fisheries program manager at Marin Water, edited a multi-benefit-focused issue of SERCAL's *Ecesis* magazine. The issue outlines multi-benefit projects with ecological restoration as one of the objectives and defines the term as "A multi-benefit project is planned, designed, implemented, and maintained with the intended purpose of providing two or more benefits; they can also effectively minimize the potential impacts from other project elements…" (Andrew, 2014, p.1).

The United Nations Environment Programme launched the decade on ecosystem restoration in 2020, and languages include understanding multiple benefits of successful ecosystem restoration (UNEP, 2020). The International Union for the Conservation of Nature states that conserving and restoring forest landscapes is not only a cost-effective way to mitigate climate change, but it also means that many other benefits are provided to local communities and broader society that include filtering pollutants from rainwater, protecting drinking water and aquatic habitats, sequester carbon, and protect biodiversity. (IUCN, 2019).

Nature-based solutions for conservation often describe projects with multiple benefits. For example, the Naturally Resilient Communities website states that nature-based solutions provide multiple benefits, giving communities high returns on their investments in flood risk reduction strategies. Another paper refines this definition by adding locally appropriate solutions: "Solutions are locally appropriate, adaptive actions to protect, sustainably manage or restore natural or modified ecosystems to address targeted societal challenge(s)-such as climate change mitigation-while simultaneously enhancing human well-being and providing biodiversity benefits." (Reise et al., 2022, p.10).

WATER & RESTORATION

Multiple-benefit conservation and restoration projects are frequently cited in the water use and conservation arenas, typically integrating water and people (Everard & McInnes, 2013). For example, green infrastructure projects such as the Transbay Transit Center rooftop garden in

San Francisco offer multiple benefits by reducing stormwater runoff, improving water quality, and providing habitat and public green space (Diringer et al., 2019). The same authors present a multi-benefit framework that includes water, energy, risk & resilience, land and environment, and people and communities. The Los Angeles River restoration project cites multi-benefit projects that support flood resilience, housing affordability, ecological function, arts, education, and culture (Henson & Hanna, 2021).

In recent years the concept of addressing multiple goals simultaneously has become widespread in California water conservation and management. In 2019 the California Department of Water Resources created a division of multi-benefit initiatives focusing on flood control and floodplain restoration. Their Central Valley Flood Protection Plan defines multi-benefit projects as achieving objectives for flood safety, ecosystem restoration, and economic development (Nemeth et al., 2022). The plan includes additional benefits such as sustaining agricultural production, improving water quality and water supply reliability, increasing groundwater recharge, supporting commercial fisheries, and providing public recreation and educational opportunities. The North Coast Resource Partnership (NCRP) Plan for the Department of Water Resources calls for multi-benefit projects that augment water supply, identify areas of concern, enhance water quality, reduce flooding, and create environmental and community benefits (NCRP, 2019).

Integrated Regional Water Management Plans are multi-benefit focused and started in 2002 with the Regional Water Management Planning act (SB 1672; California Department of Water Resources, n.d.). Senate Bill 155 provides funding to the California Natural Resources Agency "To support programs and activities that advance multi-benefit and nature-based solutions." Senate Bill 170 provides funding to restore Central Valley riparian habitat, emphasizing multi-benefit and climate resilience projects.

The San Francisco Bay Area Integrated Regional Watershed Management Plan Objective 1.2 is to "Encourage implementation of integrated, multi-benefit projects (San Francisco Bay Area IRWMP, 2019, p. 3-7)."It describes implementing "…multi-benefit projects that incorporate ecosystem components… (p. 16-50)" for water supply, treatment, and flood management projects as well as developing "…innovative multi-benefit projects… (p. 4-29)" related to the integration of flood control, tidal marsh enhancement, and habitat restoration (San Francisco Bay Area IRWMP, 2019,).

The North Bay Watershed Association cites multi-benefit projects related to water and restoration or ecosystem function at nbwatershed.org. The Association endorses an integrated multi-benefit water management project policy within the same plan and encourages member agencies to adopt a similar approach. Marin Water and North Marin Water District adopted the policy. Marin Water's policy, as included in the San Francisco Bay Area Integrated Regional Watershed Management Plan (IRWMP), states:

> It is the policy of the Marin Municipal Water District to achieve multiple benefits in the planning and implementation of its water management projects, where appropriate, and to coordinate these projects with other agencies, to realize the maximum number of benefits from a project. It is the intent of this policy to

encourage collaboration within and among MMWD and other agencies to conduct integrated water management planning and achieve multiple benefits on water management projects that provide appropriate opportunities. (San Francisco Bay Area IRWMP, 2019, p. 5-3).

FEDERAL & STATE POLICY

The idea of multi-benefit projects is increasingly used in government policy. At the federal level, President Biden administered an Executive Order in 2022 to strengthen America's forests, boost wildfire resilience, and combat global deforestation, and called for projects that can be defined as multi-benefit. One Tam was identified as a regional leader in this arena (The White House, 2022).

The California Department of Conservation defines multi-benefit as projects or activities that provide direct benefits to meeting objectives at the local to federal objective levels (California Department of Conservation, 2022). California's Regional Forest and Fire Capacity Program is invested in planning and implementing multi-benefit forest health projects (California Department of Conservation, n.d.), and their guidelines deepen the definition of multi-benefit wildfire and forest resilience projects to describe projects which impact socioeconomic outcomes, protect tribal resources and practices, and enhance water security, forest resilience, biodiversity, workforce development, recreation, and carbon sequestration through their implementation.

The *California Wildfire and Forest Resilience Action Plan* calls for facilitating multi-benefit and multi-jurisdictional projects (California Forest Management Task Force, 2021). The plan orders state agencies to "Advance multi-benefit, voluntary and cooperative approaches that protect and restore biodiversity while stewarding natural and working lands, building climate resilience, and supporting economic sustainability (p. 68)."

FOREST RESTORATION

Reforestation projects often achieve multiple goals, such as reducing carbon emissions, conserving species, providing economic benefits to local communities, and delivering ecosystem services, e.g., stable water systems (Brewer, 2021). At the international scale, the reduced emissions from the United Nations Deforestation and Forest Degradation Program (REDD+) expanded from a focus on greenhouse gas mitigation to include additional benefits, such as water quality (Richards & Panfil, 2011). Beneficial fire may be a successful means of changing the scale and benefits of fuel treatments for fire-dependent forest ecosystems to achieve multiple ecological and economic benefits, such as reducing density-dependent mortality and wildfire risk (North et al., 2012, 2022).

The North Coast Resource Partnership's *Regional Forest and Fire Capacity Plan* aims to improve forest health, increase wildfire resilience, address drinking water quality, increase biodiversity, improve recreational amenities, maintain watershed health, maintain wastewater needs, and help adapt to climate change (NCRP, n.d.). The North Coast Resource Partnership healthy forest initiative includes resilient, fire-adapted forests, community health & safety, biodiversity, conservation, climate change action, and vibrant economies.

MARIN COUNTY

Moving back to the local context, a search for a multi-benefit definition from the One Tam partners did not produce a definition; however, vegetation management plans for One Tam partners describe forest and fuel treatments using a multi-benefit framework.

- Marin Water's *Biodiversity, Fire, and Fuels Integrated Plan* (*BBFIP*) notes that multi-benefit projects designed to improve wildfire resilience, re-establish desired stand structure, and enhance ecosystem function are essential components of broadcast burns associated with oak woodland and grassland habitat projects (Marin Water, 2019a).
- Marin County Parks and Marin County Open Space District's *Vegetation and Biodiversity Management Plan* (MCP & MCOSD, 2015) outlines a "comprehensive approach" to vegetation management which focuses on protecting resources and public safety by addressing threats such as invasive species, pathogens, and unnatural fire events (MCP & MCOSD, 2015, p. 4-1).
- The 2004 Point Reyes National Seashore (PRNS) Fire Management Plan (FMP) recognizes that 150 years of fire suppression has dramatically changed native ecosystems and created a dangerous accumulation of fuels (PRNS, 2004). Fuels accumulation equates to a higher wildfire risk to residences and businesses adjacent to the parks. Subsequently, the seven goals outlined in the plan include protecting human life, infrastructure, cultural resources, and improving natural resource conditions. Public and firefighter safety is mentioned in both parks as the most important goal of the FMP.
- The Golden Gate National Recreation Area (GGNRA) FMP Final Environmental Impact Statement (FEIS) executive summary published in 2005 mentions restoring the role of fire in vegetation communities, reducing fuel loading and the threat of catastrophic wildfire, and studying fire effects in old-growth Coast Redwood forest through prescribed fire and mechanical thinning in the Muir Woods fire management unit (GGNRA, 2005). The preferred alternative in the FEIS clearly describes management approaches that would achieve fire management and resource objectives to both reduce fuel loading near developed areas and assist with restoration and maintenance of the park's natural and cultural resources (GGNRA, 2005, p. viii)

OPPORTUNITIES & CONSTRAINTS

A conceptual model diagram was developed to illustrate the process used in the *Forest Health Strategy* to identify multi-benefit treatment opportunities and show how implemented treatments and monitoring feed into achieving forest resilience goals (Figure 8.1). Multi-benefit treatment opportunities stem from the forest conditions assessment completed for each forest type profiled in the *Forest Health Strategy* and detailed in Chapter 7: Condition Assessment. Treatment drivers and available metrics feed into the multi-benefit treatment implementation analysis. Priority projects areas are implemented and maintained, leading to forest health and resilience outcomes (see Chapter 5: Goals). These outcomes are measured through monitoring, tied into adaptation and learning, and influence and inform management approaches (see Chapter 10: Monitoring). Opportunities and constraints are a characteristic of any given proposed forest health project and will be considered by land managers and project partners as part of the implementation process.

CONSTRAINTS

While multi-benefit projects are designed to advance more than one goal or address multiple challenges, there are constraints inherent to every proposed effort. Trade-offs and challenges for potential forest resilience treatments are an intrinsic part of the planning and decision-making process for land managers, agencies, and project stakeholders. Some considerations include:

- In some instances, especially within the wildland urban interface (WUI) or within defensible space buffers, wildfire risk reduction may influence treatment approaches and constrain forest resilience benefits. Tensions between desirable ecological processes and public safety my arise at times, for example the use beneficial fire may not be possible in developed areas due to infrastructure protection concerns (Downing et al., 2022). Natural resource managers will continue to work collaboratively with the Marin Wildfire Prevention Authority and other fire agencies to develop and advance treatment approaches that are, to the greatest extent possible, ecologically beneficial.
- Forest resilience projects may need to balance carbon sequestration benefits with wildlife considerations. For example, study of forest restoration efforts in central California showed highest levels of carbon storage in the densest riparian forest stands, however these same areas had lower bird diversity and abundance (Dybala et al., 2019; Gardali et al., 2021).
- State and regional policies or initiatives to increase carbon sequestration and biomass stocks may need to be adjusted to reflect that climate change can alter vegetation community type and structure, and in some cases forest resilience treatments and activities may lead to biomass stock reductions in conflict with climate mitigation goals (Bernal et al., 2022).
- Managing for multiple benefits may require thinking about the cumulative benefit of separate treatments across the landscape. Due to competing values and interests, individual treatment may prioritize one benefit over another, but in other areas the

balance can be reversed. For example, in WUI areas reducing native shrub cover may be needed to address fire risk, but wildland areas can be managed to benefit biological diversity including shrublands, chaparral, and grasslands.

OPPORTUNITIES

An advantage of the multi-benefit approach to forest resilience projects is that, by design, there are opportunities to address more than one value and achieve success on multiple levels while. Notable facets include:

- Multi-benefit conservation approaches can seek to improve ecosystem services but are not strictly focused on benefit to humans. This approach has the advantage of advantage of being constructive, inclusive of multiple perspectives, easily conveyed, solutions-oriented, and persuasive (Gardali et al., 2021).
- By working through cultural resources staff at land managing agencies to collaborate and share decision-making authority with the Federated Indians of Graton Rancheria, forest resilience projects can benefit from Traditional Ecological Knowledge, integrate the Tribe's values into all aspects of a project, improve forest health, and seek to address historical social inequalities (see Chapter 3: Stewardship and Partnership with the Federated Indians of Graton Rancheria). [3]
- By integrating datasets developed by the *Forest Health Strategy*, the 2018 Marin Countywide Fine Scale Vegetation Map (2018 Fine Scale Vegetation Map), One Tam Peak Health Report (Edson et al., 2016), partnering with researchers, or participating in studies, multi-benefit forest health and resilience treatments can both leverage the impact of collective knowledge and advance scientific understanding of forest ecosystems (see Appendix E: Opportunities for Additional Study).
- The *Forest Health Strategy's* multi-benefit treatment approach facilitates continued collaboration between natural resource managers, environmental scientists, and fire professionals within or across agencies and jurisdictions to advance projects that increase wildfire resilience and forest health. One Tam and other land managing agencies regularly coordinate with the Marin Wildfire Prevention Authority through established connections to facilitate project-level coordination (Figure 8.2).

[3] Spatial data denoting special oak trees, forest areas of concern, archaeological resources, location of important plants or vegetation communities, and other Tribal assets and values is sensitive and not provided in the *Forest Health Strategy*. Through coordination with cultural resource staff, agencies can collaborate with the Federated Indians of Graton Rancheria on a project-by-project basis to identify and integrate Tribal priorities and protect sensitive cultural resources.

Figure 8.1. Conceptual workflow diagram outlining process for identifying multi-benefit treatment opportunities and treatment implementation.

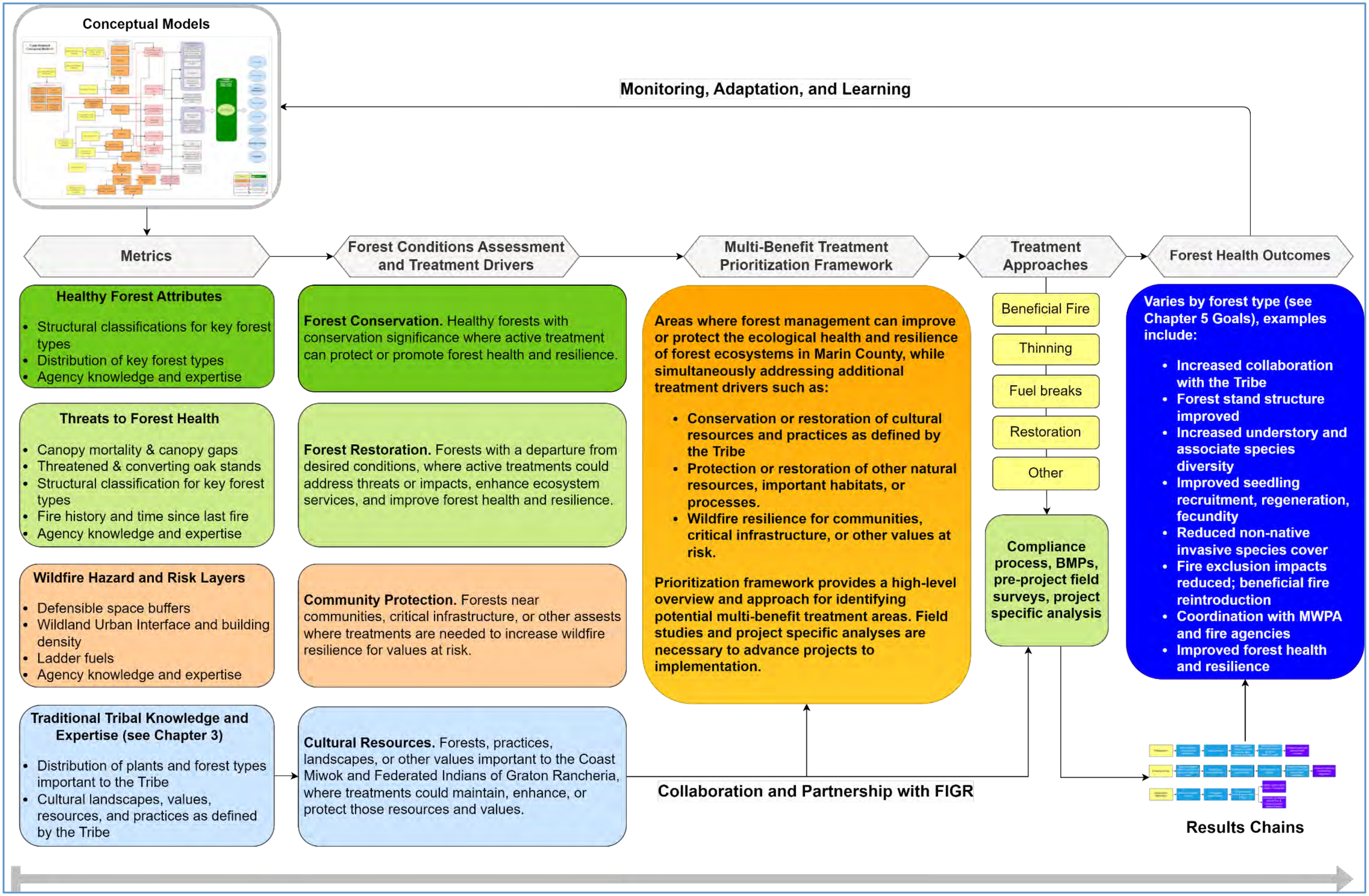
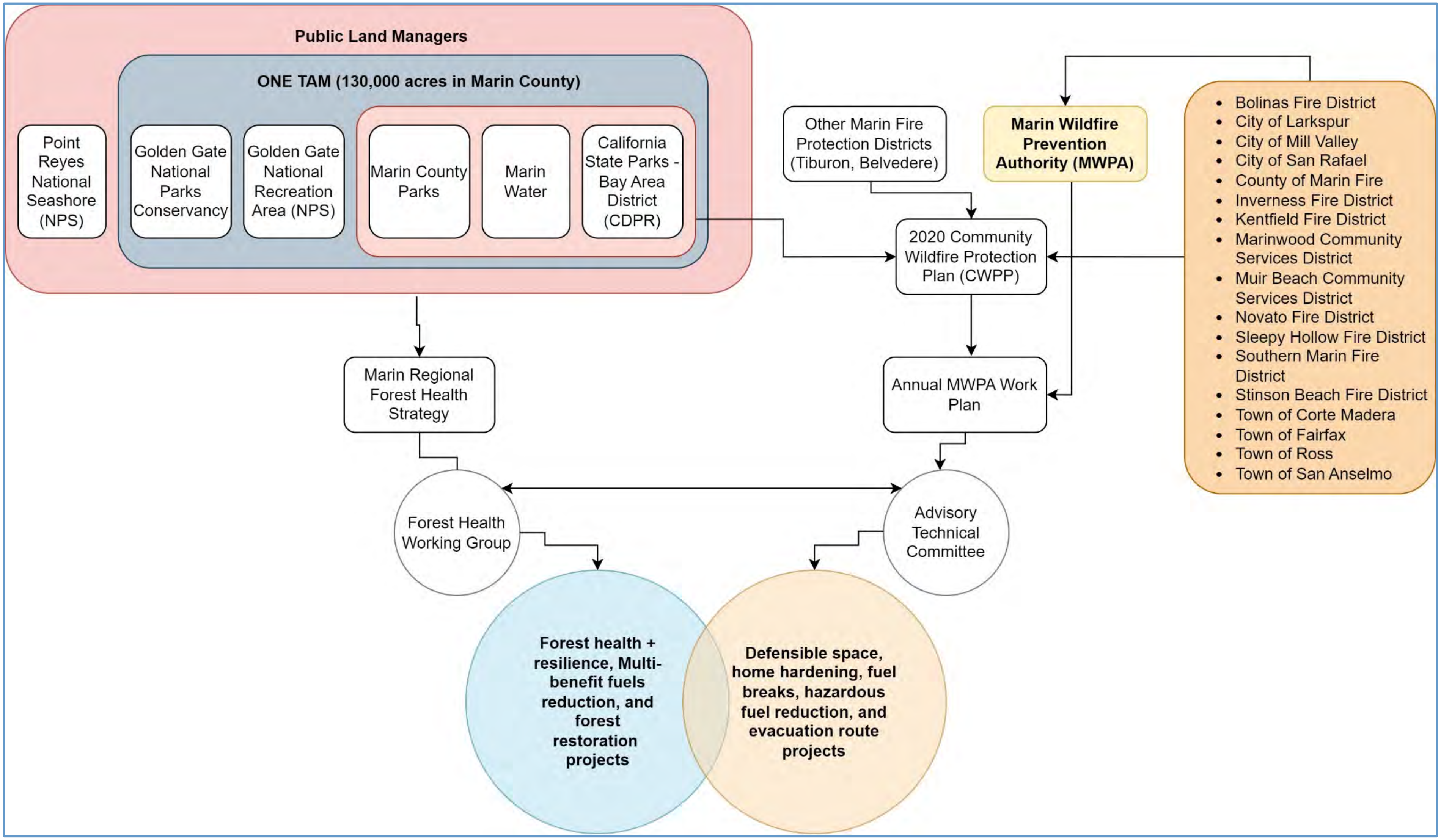


Figure 8.2. Existing connection points and pathways used by One Tam, public land managers, fire agencies, and the Marin Wildfire Prevention Authority to advance multi-benefit forest health and wildfire resilience projects.



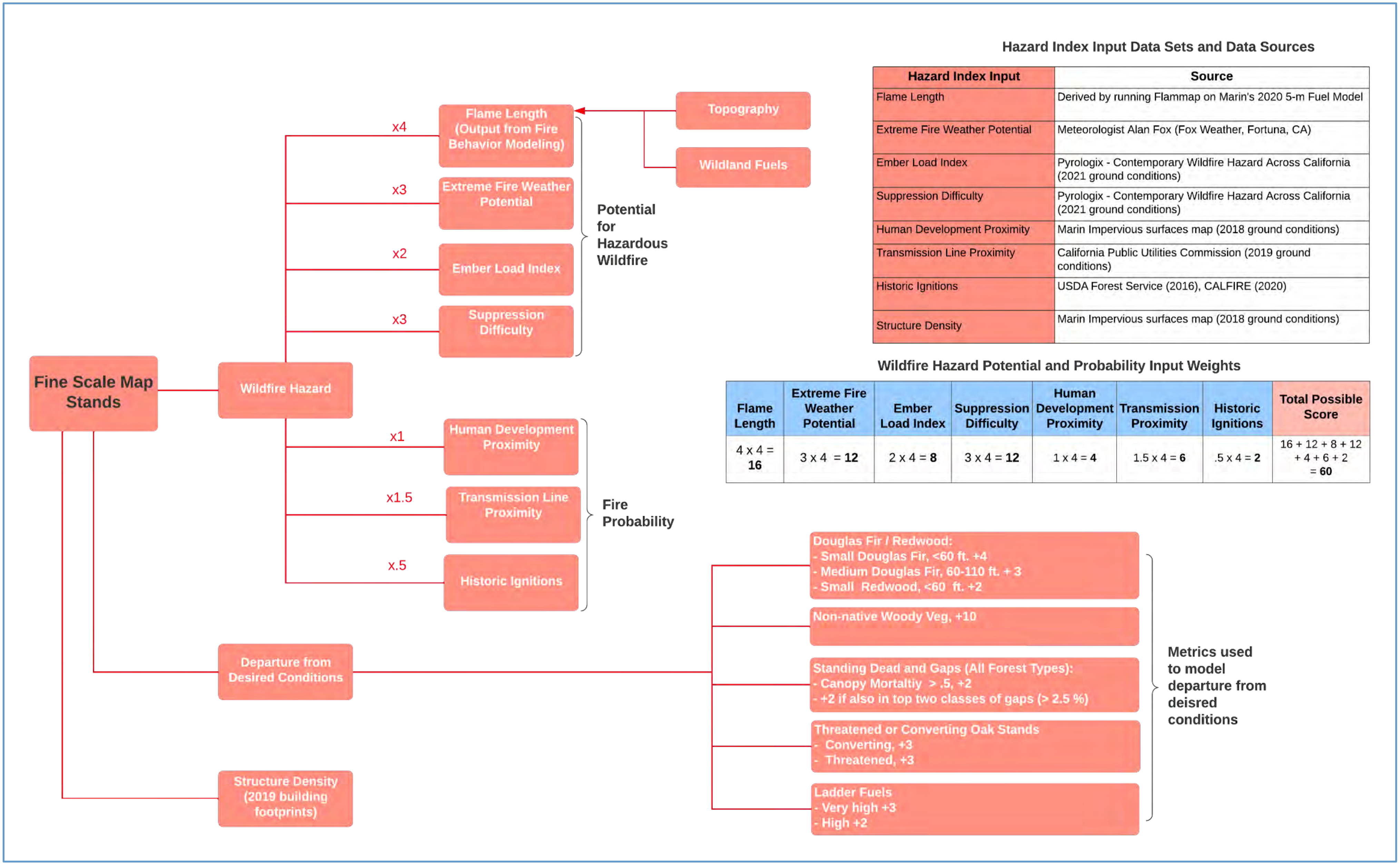
MULTI-BENEFIT TREATMENT OPPORTUNITY ANALYSIS

As with other remote sensing-based approaches to modeling and characterizing forest conditions elsewhere in the *Forest Health Strategy,* the prioritization framework and multi-benefit treatment implementation analysis is intended to be a tool for managers conducting landscape-scale planning and prioritization work. The modeling framework does not replace the need for ground-truthing and site-specific analysis to define project boundaries, identity treatment approaches, and confirm the location of sensitive resources. In many cases additional project specific analysis and compliance will be required to implement projects (see Appendix C: Regulatory Compliance).

The prioritization framework and multi-benefit treatment implementation analysis provided draws upon the best available vegetation and landcover spatial data to provide a reliable summary of how modeled forest conditions overlap with key vegetation communities, wildlife habitat, wildfire hazards, or other layers to identify multi-benefit, high-priority treatment opportunities. The spatial models developed as part of this analysis, such as the departure from desired conditions index, can be used as a stand-alone prioritization tool for land managers and decision-makers or can be combined with wildfire hazard, conservation targets, or other spatial layers to design and prioritize treatments that will have multiple benefits. Priority areas for active management can be further refined using the developed mechanical treatment feasibility spatial layer, which classifies the landscape by constraints related to conditions such as slope, access, and proximity to riparian areas.

The logic model for modeling departure from desired conditions, wildfire hazard, and building density is shown in Figure 8.3. This conceptual framework was designed to develop three new attributes for each polygon (stand) in the 2018 Fine Scale Vegetation Map: departure from desired conditions index (native forest, non-native forest, and non-native shrubland classes only), wildfire hazard, and building density. Methods for developing each attribute, along with examples of the outputs, are discussed below.

Figure 8.3. Logic model for mapping departure from desired conditions, wildfire hazard, and building density.



Hazard Index Input Data Sets and Data Sources

Hazard Index Input	Source
Flame Length	Derived by running Flammap on Marin's 2020 5-m Fuel Model
Extreme Fire Weather Potential	Meteorologist Alan Fox (Fox Weather, Fortuna, CA)
Ember Load Index	Pyrologix - Contemporary Wildfire Hazard Across California (2021 ground conditions)
Suppression Difficulty	Pyrologix - Contemporary Wildfire Hazard Across California (2021 ground conditions)
Human Development Proximity	Marin Impervious surfaces map (2018 ground conditions)
Transmission Line Proximity	California Public Utilities Commission (2019 ground conditions)
Historic Ignitions	USDA Forest Service (2016), CALFIRE (2020)
Structure Density	Marin Impervious surfaces map (2018 ground conditions)

Wildfire Hazard Potential and Probability Input Weights

Flame Length	Extreme Fire Weather Potential	Ember Load Index	Suppression Difficulty	Human Development Proximity	Transmission Proximity	Historic Ignitions	Total Possible Score
4 x 4 = **16**	3 x 4 = **12**	2 x 4 = **8**	3 x 4 = **12**	1 x 4 = **4**	1.5 x 4 = **6**	.5 x 4 = **2**	16 + 12 + 8 + 12 + 4 + 6 + 2 = **60**

DEPARTURE FROM DESIRED CONDITIONS INDEX

The goal of this analysis was to synthesize the metrics developed as part of the *Forest Health Strategy* (see Chapter 6: Metrics) and discussed in the Forest Conditions Assessment (Chapter 7: Condition Assessment) in a way that summarizes where forested areas across Marin County may have departed from desired conditions. Consideration was given to how each metric might be an indicator of departure from desired conditions, and weighting was assigned based on input from the Marin Forest Health Working Group. Using forested stands (polygons) in the 2018 Countywide Fine Scale Vegetation Map as the basic unit of analysis, selected forest health metrics (Table 8.1) were summarized into a single raw point total for each polygon. Raw point totals were then classed into 6 bins ranging from 1 (least departed) to 6 (most departed) (Table 8.2). The distribution of departure from desired conditions classes by acres is shown in Figure 8.4. Of the 123,046 acres of native forest, non-native forest, and non-native shrubland included in the departure from desired conditions analysis, 39,111 acres (32%) are included in the top three classifications.

As with other *Forest Health Strategy* metrics developed using remotely sensed data, the departure from desired conditions index has inherent limitations that users should consider when interpreting results. For example, due to lack of consistent countywide spatial data, the departure index does not reflect presence/absence of non-native invasive herbaceous plants or understory species composition. For similar reasons (lack of consistent available data at the countywide scale) the departure index does not consider other important indicators of forest health such as wildlife occupancy dynamics, soil microbiology, and lichen abundance. Furthermore, the departure index does not consider that, in many cases, the desired state of forest ecosystems is dynamic and highly correlated to forest type, such as in the case of serotinous species wherein a desirable condition at scale would include multiple age classes (cohorts) to ensure long term resilience of the species within the mosaic of forest types in Marin County (see Chapter 2: Resilience).

Despite these limitations, the departure from desired conditions index summarizes valuable information about the structure of forest stands, mortality dynamics, non-native invasive shrub/tree presence, and impacts from fire exclusion, in a way that is helpful for locating and prioritizing multi-benefit treatment opportunities across forest types at the countywide scale. Managers and users of the data may choose to further analyze the results of individual underlying metrics for a given area, and in some areas may elect to prioritize management of areas that are *less* (rather than more) departed from desired conditions. In all cases, additional information from field reconnaissance is required to determine the final work boundaries, appropriate forestry prescriptions, complete environmental review, conduct surveys for sensitive species, and to coordinate cultural resource protections with the Federated Indians of Graton Rancheria.

Table 8.1. Metrics used to develop the Departure from Desired Conditions Index and corresponding weights.

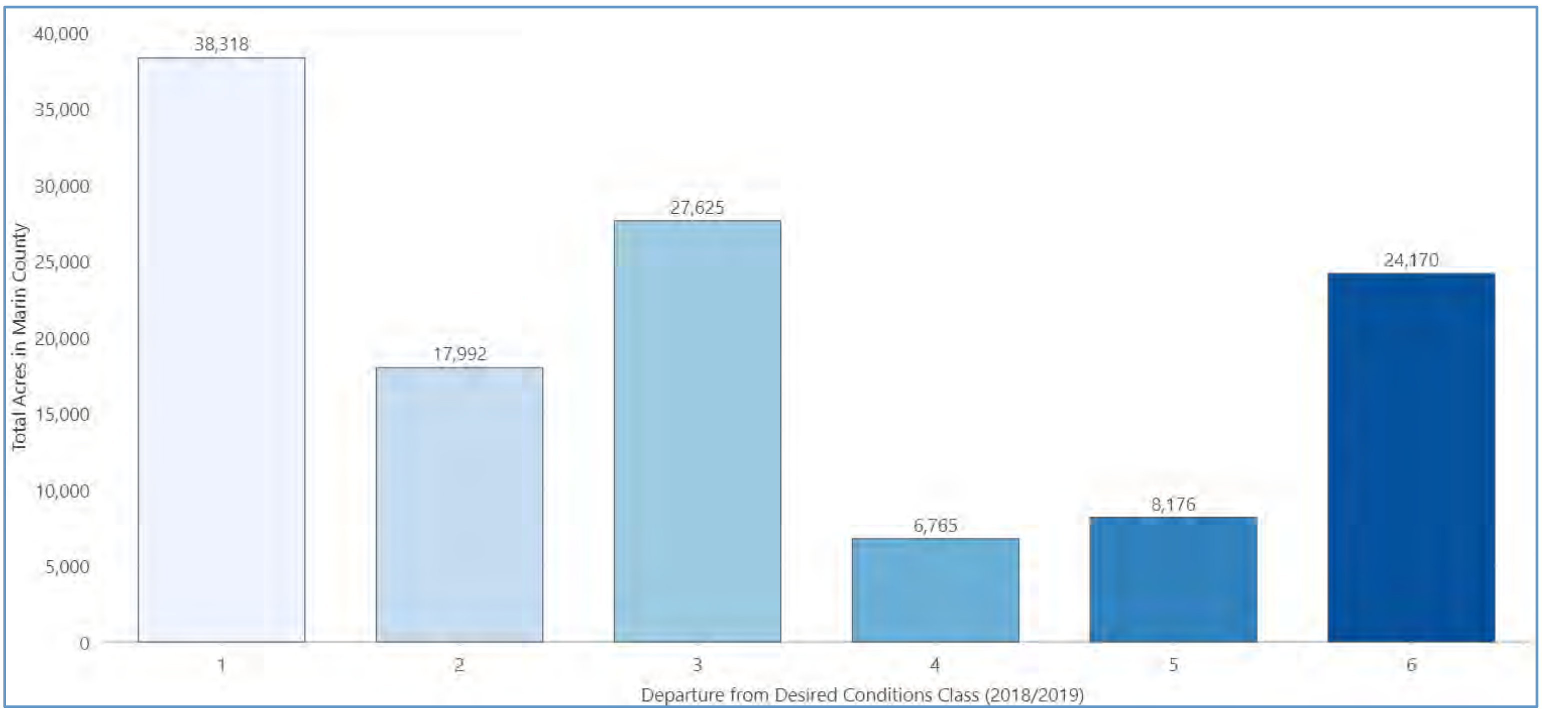
Departure from Desired Conditions Index		
Category	**Metric**	**Weight**
Forest Structure	Short Douglas-fir (<60 feet)	4
	Medium Douglas-fir (60-110 feet[4])	3
	Short Coast Redwood (<60 feet)	2
Invasive Species	Non-Native Forest and Shrublands[5]	10
Mortality Dynamics	Percent Mortality >0.5	2
	Percent Forest Gaps Formed 2010-2019 greater than 2.5%[6]	2
Open Canopy Oak Woodland Biodiversity	Converting Oak Stands	3
	Threatened Oak Stands	3
Classified Ladder Fuels	Very High	3
	High	2
Canopy Density Change[7]	>10% Canopy Density Loss	2
	5-10% Canopy Density Loss	1

[4] The Douglas-fir structural classification described in Chapter 6: Metrics and Chapter 7: Condition Assessment used mean lidar-derived stand height (and coefficient of variation) used three height bins to classify stand structure: <60 feet, 60-140 feet, and >140 feet. Since development, the authors determined that an intermediate height class (60-110 feet) would be useful in some instances to detect conditions that could precipitate planning for active Douglas-fir management, with the goal of identifying younger PSME stands expanding into grassland, oak woodland, and/or maritime chapparal habitats in the absence of a natural fire regime. This more detailed structural class is available via the Forest Health Web Map.
[5] Species included: *Acacia spp. – Grevillea spp. – Leptospermum laevigatum* Semi-Natural Alliance, *Eucalyptus* (*globulus, camaldulensis*) Provisional Semi-Natural Association, *Pinus radiata* Plantation Provisional Semi-Natural Association, *Cotoneaster* (*lacteus, pannosus*) Provisional Semi-Natural Association, *Cytisus scoparius* Provisional Semi-Natural Association, *Genista monspessulana* Semi-Natural Association, *Rubus armeniacus* Semi-Natural Association, *Ulex europaeus* Provisional Semi-Natural Association.
[6] To remove the potential for gaps caused by building development and other activities not associated with disease-induced forest decline, points were only assigned to stands that also showed canopy mortality above the <0.5% trace threshold.
[7] To reduce the possibility of false positives resulting from the difference in seasonality for 2010 and 2019 lidar acquisition, Canopy Density Loss is limited to evergreen hardwood and native conifer stands only. See Chapter 6: Metrics for additional information.

Table 8.2. Raw departure from desired conditions point total and corresponding class.

Raw Score	Classified Departure from Desired Conditions
0-1	1 (least)
2	2
3	3
4	4
5	5
6 and above	6 (greatest)

Figure 8.4. Total acres in Marin County by departure from desired conditions class (native forest, non-native forest, and non-native shrublands only).



EXAMPLE APPLICATION

Demonstration project work on Marin Water's Tamalpais Watershed lands was initiated in 2020 in the area surrounding Potrero Meadows (Figure 8.5, left), as a component of the *Forest Health Strategy*. Selected forestry management areas met prioritization criteria outlined in Marin Water's *Biodiversity, Fire, and Fuels Integrated Plan* (Marin Water, 2019a) and field assessments by Marin Water resource staff. Overall goals of work in this area were to advance forestry work within sudden oak death (SOD) impacted areas to disrupt the disease cycle through removal of dead and diseased tanoak trees (*Notholithocarpus densiflorus*), to restore healthy forest stands, remove competition form non-native invasive species, improve native forest resilience, and reduce accumulated fuels associated with fire exclusion and pathogen impacts. Results of departure from desired conditions mapping within the Potrero Meadows forestry management areas show general agreement between the modeled departure and the field assessment of Marin Water land managers (Figure 8.5, right). Seventy-three percent of the approximately 70-acre treatment area is within the top three departed conditions classes (Figure 8.6)

Figure 8.5. 2020 Potrero Meadows forestry management area (left) and corresponding classified restoration potential (right).

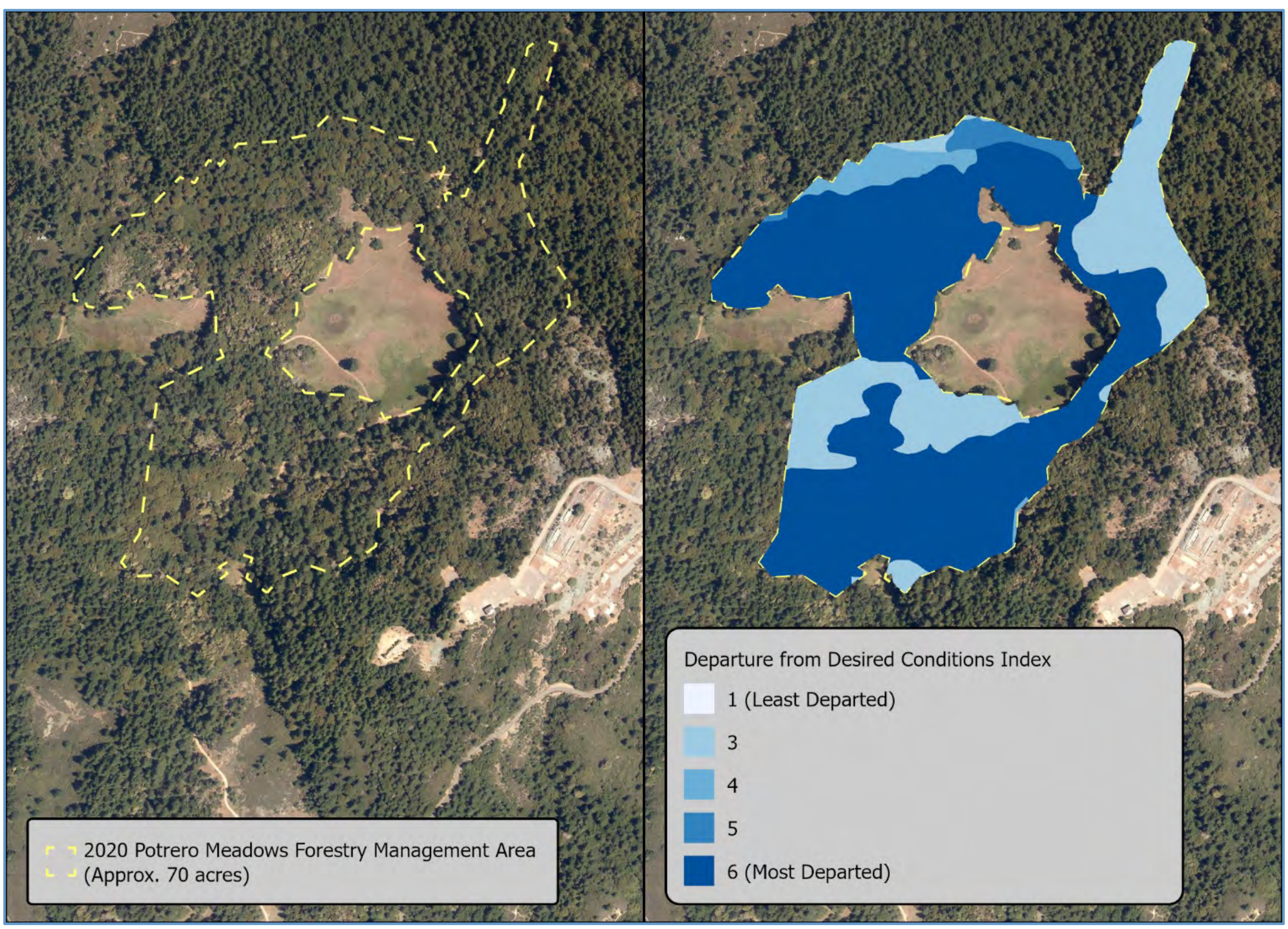
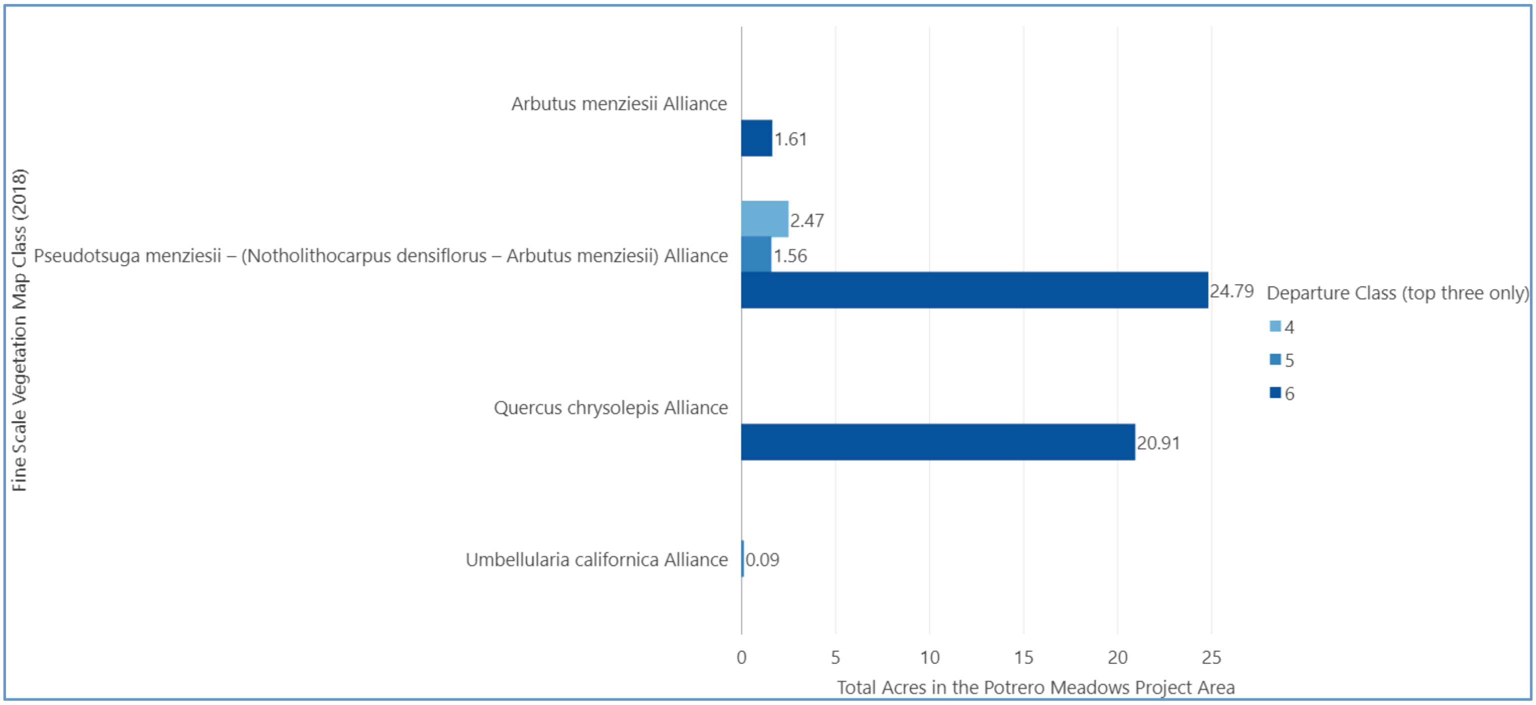


Figure 8.6. Potrero Forestry Areas broken down by forest type (2018 Fine Scale Vegetation Map alliance) and departure from desired conditions class.



While the departure from desired conditions classification does not account for other drivers of forest management, for example non-native invasive species in the understory, it does reflect the value managers placed on prioritizing forestry areas impacted by sudden oak death, protecting valued oak woodland habitat, addressing impacts from fire exclusion, and reducing accumulated ladder fuels associated with sudden oak death affected tanoak mortality. Post-implementation analysis of the Potrero Meadows demonstration project showed lower modelled fire behavior including overall shorter flame length, slower rate of fire spread, and less torching (See Appendix 8A: Potrero Meadows Fuel Model Changes). While study is ongoing, initial analysis of the benefits of similar restoration focused treatments elsewhere on Marin Water's Tamalpais Watershed lands suggests improvements to long term carbon sequestration, water yield, and sudden oak death impacts are likely (Cobb et al., 2017, pp. 9-10).

At the countywide scale, output of the departure from desired conditions index showed a broad distribution of forest areas that could benefit from a restorative approach to active management. Several areas emerge at this scale, including the west side of Tomales Bay State Park, Bolinas Ridge near Kent Lake on Marin Water and adjacent GGNRA lands, and large stands of eucalyptus and other non-native forest and shrublands in southern Marin County near Tamalpais Valley and Sausalito (Figure 8.7). For Tomales Bay State Park, primary drivers for departure from desired conditions include a combination of high mortality and canopy gaps formed between 2010-2019 related to *Fusarium circinatum* impacts and an aging Bishop pine (*Pinus muricata*) cohort. For Bolinas Ridge areas, high departure from desired conditions drivers are *Phytophthora ramorum* impacts, and several conditions resulting from fire exclusion including high ladder fuels, adjacent threatened or converting oak woodlands, and/or short (early seral) Douglas-fir stands[8]. Note that the presence of high ladder fuels alone does not result in a stand being designated as having a high departure from desired conditions classification.

The departure from desired conditions index is intended to be a useful way for managers to quickly visualize where forest conditions might precipitate further investigation and consideration for active management (Figure 8.6). Areas mapped as departed from desired conditions will have other values such as wildlife habitat and understory species that are not included in this model but will certainly be considered by land managers when evaluating prioritization for management. Where conditions are flagged as having departed from the desired state, managers can explore the underlying layers such as mortality/canopy gap indices, structural classifications, ladder fuel classifications, and oak woodland conversion risk via the Forest Health Web Map to further understand what metrics may be driving less than desired conditions for a given area. Figures 8.8 through 8.10 provide a summary of acres by 2018 Fine Scale Vegetation Map class in each of the top three (classes 4-6) departure from desired conditions classes. In general, forested stands require two or more weighted metrics to achieve a modeled departure class of four or above.

[8] While not included in the departure from desired conditions index, shrinking habitat for rare fire-dependent species endemic to Bolinas Ridge including Marin manzanita (*Arctostaphylos virgata*) and Mason's ceanothus (*Ceanothus masonii*) is also a result of fire exclusion.

Figure 8.7. Countywide results of departure from desired conditions index model. The Point Reyes peninsula (top), Bolinas Ridge (middle), and WUI areas in Southern Marin (bottom) each contain areas with a high departure from desired conditions classification.

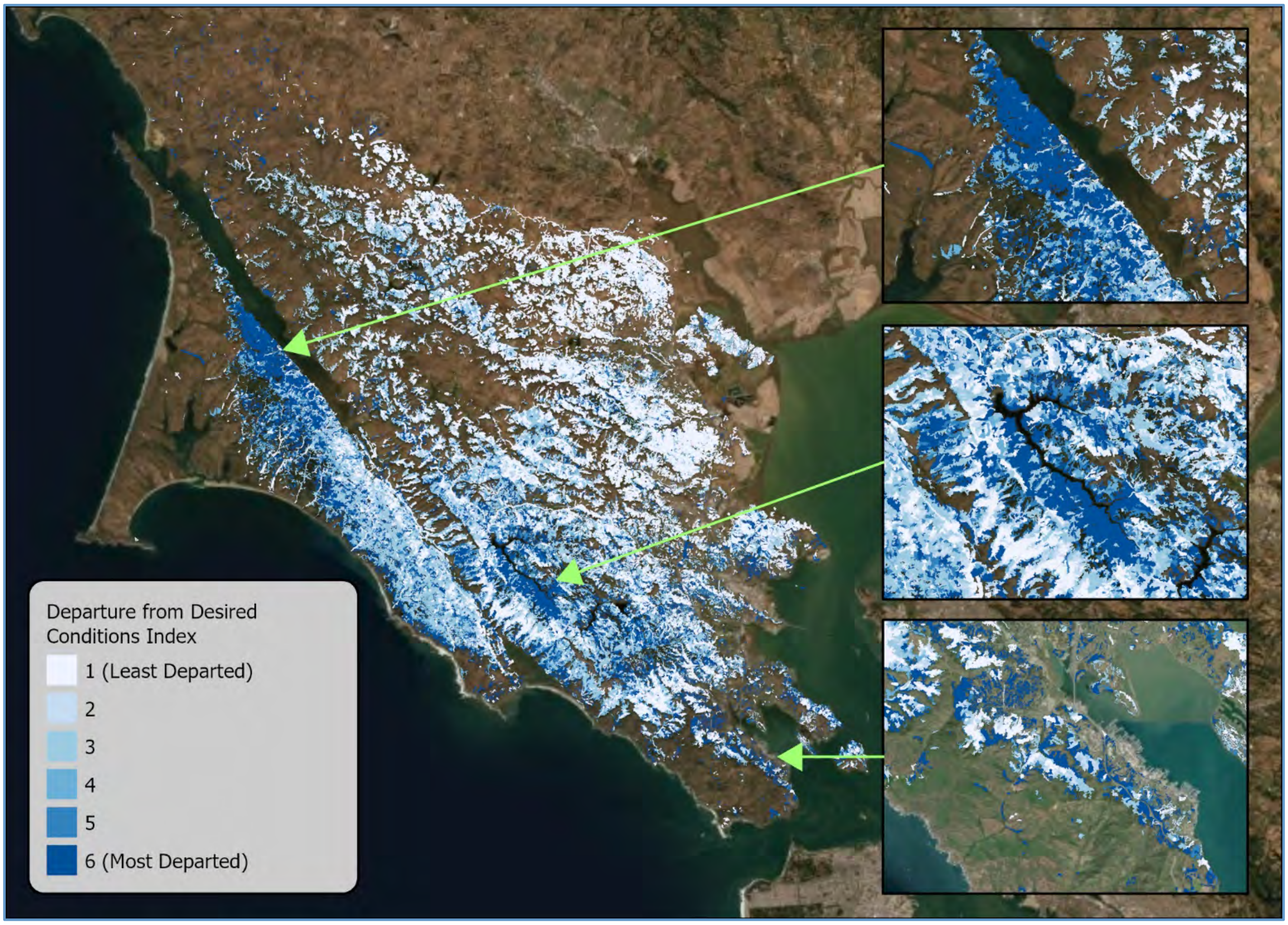


Figure 8.8. Countywide acres by 2018 Fine Scale Vegetation Map class and departure from desired conditions class 6 (highest or most departed).

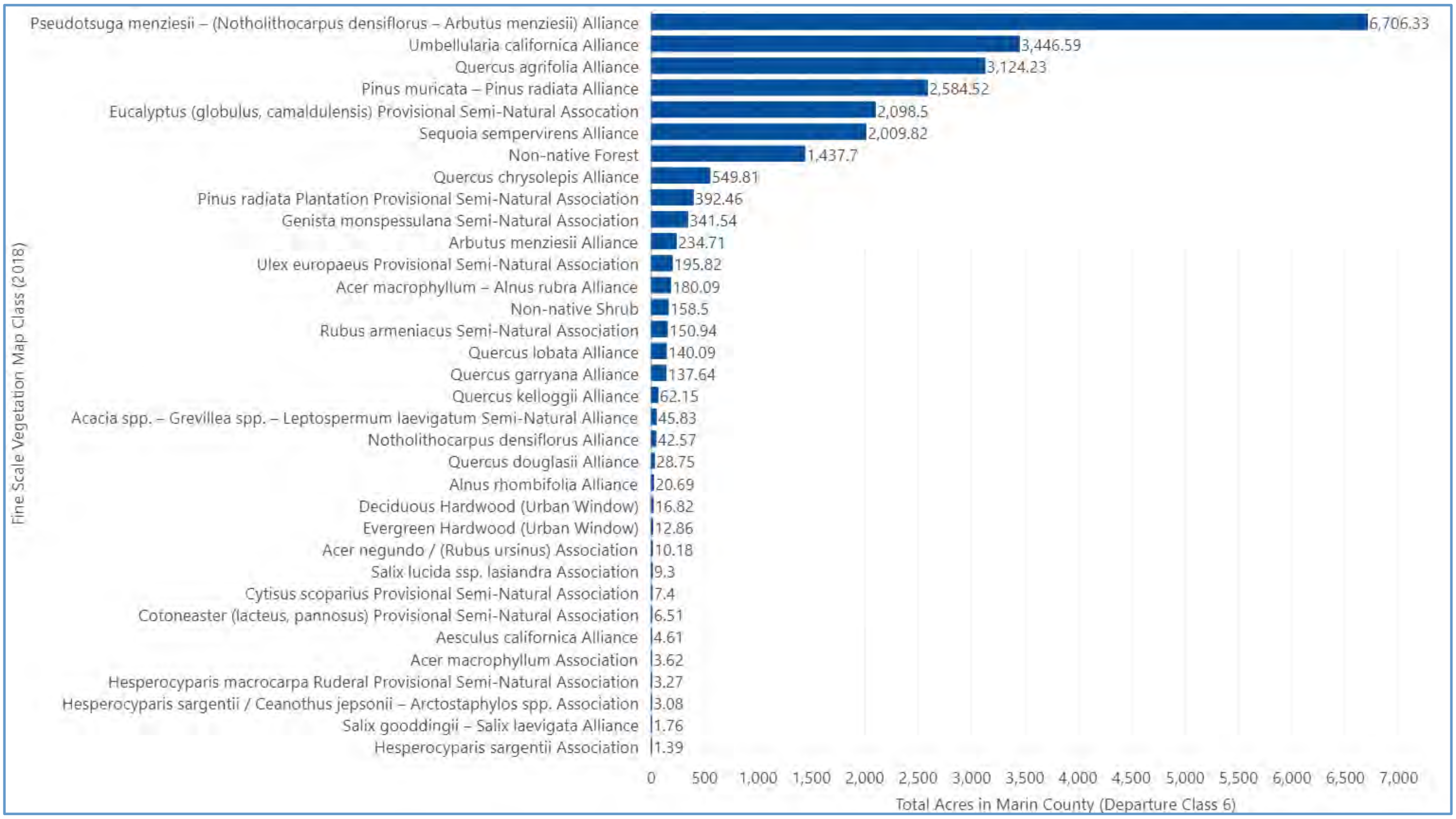


Figure 8.9. Countywide acres by 2018 Fine Scale Vegetation Map class and departure from desired conditions class 5.

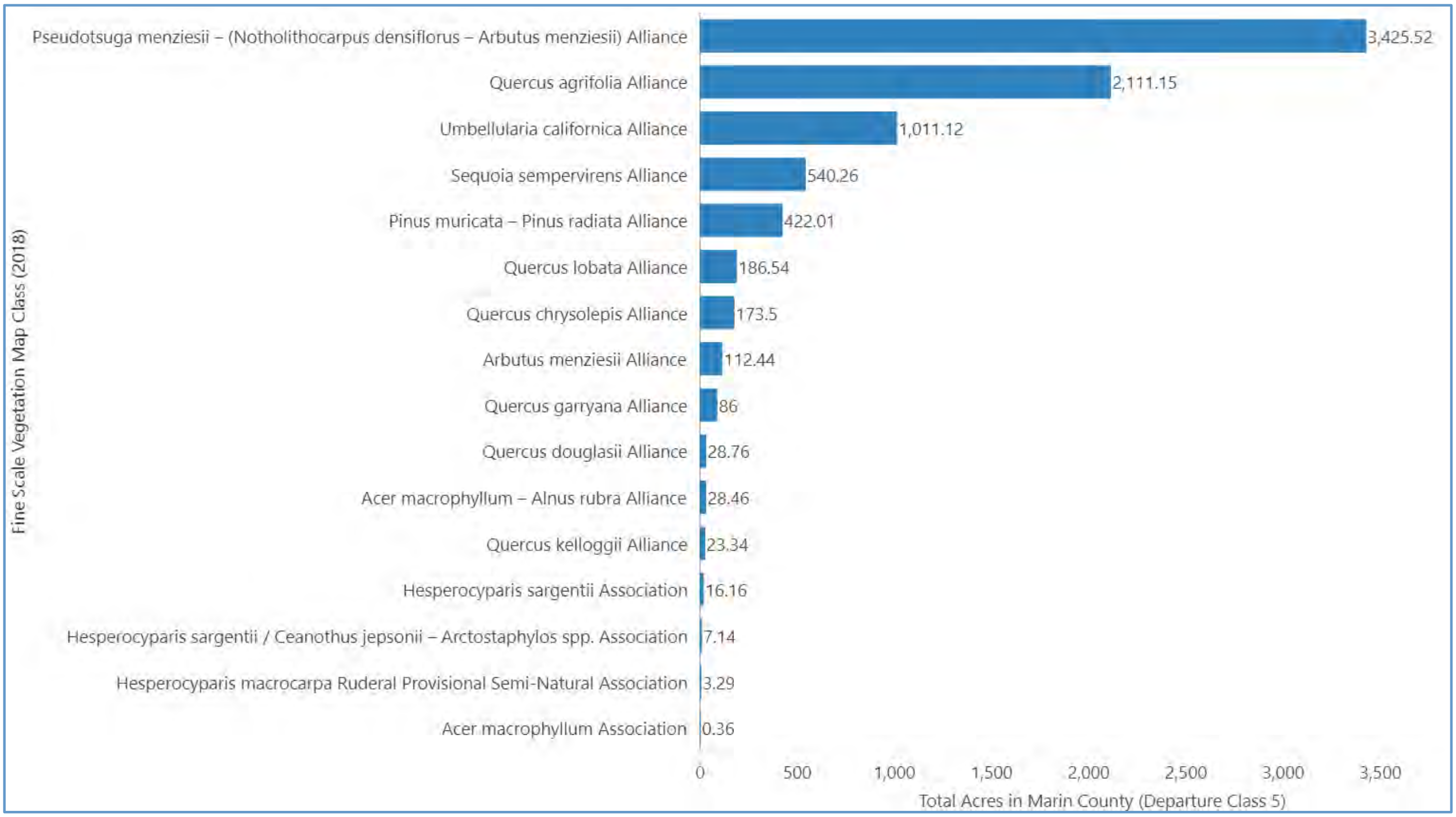
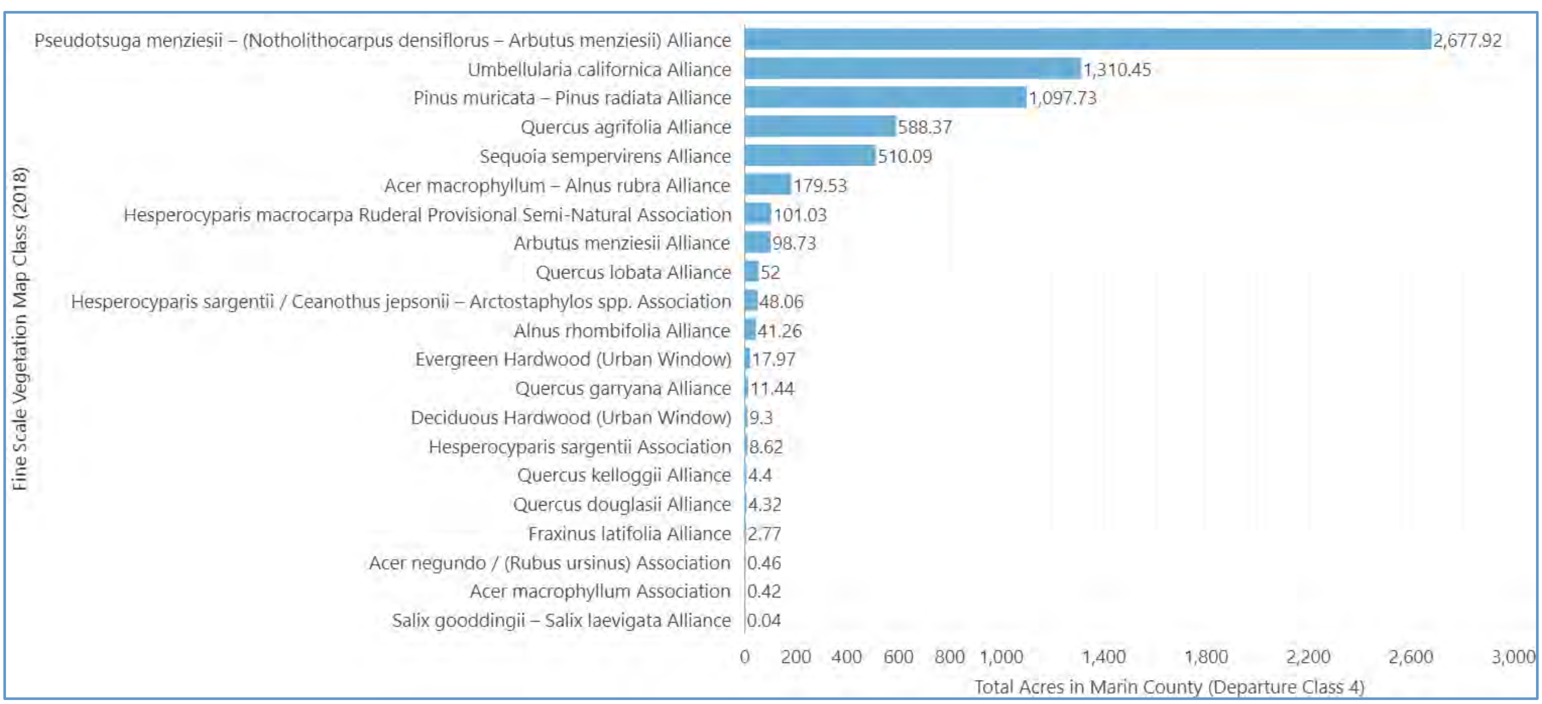


Figure 8.10. Countywide acres by 2018 Fine Scale Vegetation Map class and departure from desired conditions class 4.



MARIN WILDFIRE HAZARD INDEX

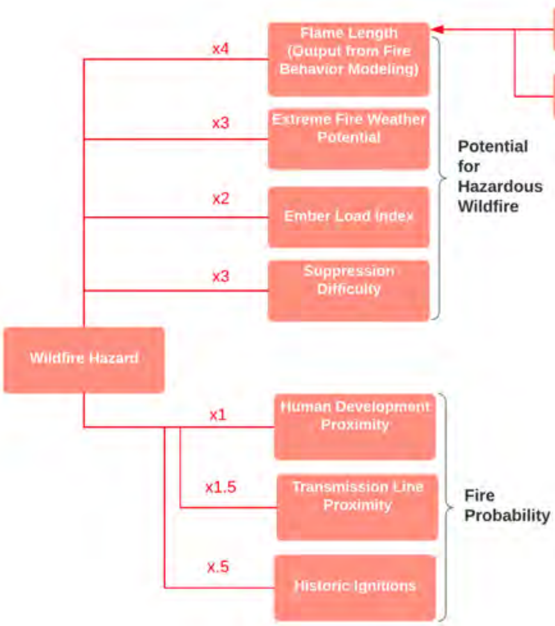
The Marin Wildfire Hazard Index was developed to provide land managers and decision-makers with the ability to evaluate potential forestry work areas in relationship to the potential for hazardous (i.e., difficult to control) wildfire. Existing wildfire hazard models, such as the California Department of Forestry and Fire Protection (CAL FIRE) Fire Hazard Severity Zones (FHSZ), are at a state-wide scale that limits utility for planning at the local level (Office of the State Fire Marshal, n.d.). Other models such as the Contemporary Wildfire Hazard Across California published jointly by Pyrologix and the US Forest Service (Tukman, 2022; Vogler et al., 2021) and recently completed First Street Foundation Wildfire Model (First Street Foundation, n.d., 2022) rely on surface fuel modeling from LANDFIRE (U.S. Department of Agriculture Forest Service and U.S. Department of the Interior) developed at the 30m resolution and intended for use at the regional, state, or even national scale.

While the CAL FIRE Fire and Resource Assessment Program (FRAP) has recently updated the FHSZ mapping, FRAP has acknowledged that locally driven wildfire hazard maps play an important complementary (rather than duplicative) role in informing managers about the potential for hazardous wildfire within the limits of available modeling methodology (D. Sapsis, Fire Scientist, California Department of Forestry and Fire Protection, Fire and Resource Assessment Program, personal communication, March, 2022). To that end CAL FIRE has used Wildfire Prevention Grant Program funding to develop locally driven wildfire hazard Index mapping projects in San Mateo, Santa Cruz, Santa Clara, Alameda, and Contra Costa counties (Green, 2021). The Marin Wildfire Hazard Index uses methods, weighting, and source data consistent with these other regional efforts, which also includes neighboring Sonoma County (County of Sonoma, 2021).

The Marin Wildfire Hazard Index is a model that predicts relative wildfire hazard on the landscape. Higher index values represent a higher relative hazard. Figure 8.11 shows the hazard model inputs and weights applied to each as well as sources for inputs. As the logic model shows, the Wildfire Hazard Index is calculated by combining the output of two broad categories of data inputs:

1. The expected distribution of intensity of a modeled wildfire (potential for hazardous wildfire inputs).
2. The probability of a fire occurring at a specific point during a specified time (fire probability inputs).

Figure 8.11. Logic model and data sources for Marin Wildfire Hazard Index.



Hazard Index Input Data Sets and Data Sources

Hazard Index Input	Source
Flame Length	Derived by running Flammap on Marin's 2020 5-m Fuel Model
Extreme Fire Weather Potential	Meteorologist Alan Fox (Fox Weather, Fortuna, CA)
Ember Load Index	Pyrologix - Contemporary Wildfire Hazard Across California (2021 ground conditions)
Suppression Difficulty	Pyrologix - Contemporary Wildfire Hazard Across California (2021 ground conditions)
Human Development Proximity	Marin Impervious surfaces map (2018 ground conditions)
Transmission Line Proximity	California Public Utilities Commission (2019 ground conditions)
Historic Ignitions	USDA Forest Service (2016), CALFIRE (2020)

Wildfire Hazard Potential and Probability Input Weights

Flame Length	Extreme Fire Weather Potential	Ember Load Index	Suppression Difficulty	Human Development Proximity	Transmission Proximity	Historic Ignitions	Total Possible Score
4 x 4 = **16**	3 x 4 = **12**	2 x 4 = **8**	3 x 4 = **12**	1 x 4 = **4**	1.5 x 4 = **6**	.5 x 4 = **2**	16 + 12 + 8 + 12 + 4 + 6 + 2 = **60**

HAZARD POTENTIAL INPUTS

The Hazard Potential Inputs section provides background on the selected model inputs, how they combine to create the index, and relevant figures.

Flame Length

To derive flame length during a modeled wildfire event the Marin Wildfire Hazard Index used the Landscape (.LCP) file and associated 5m surface fuel model developed by Sonoma Technologies Inc. for Marin County Fire Department as part of the 2020 Community Wildfire Protection Plan (CWPP) update. While the 2020 5-meter fuel model has some errors and limitations, it is currently the best available surface fuel model in Marin County (see Appendix 8B: 2020 Marin County 5-meter Fuel Model Review). Fire behavior simulation was performed using FLAMMAP software designed to simulate potential fire behavior characteristics, fire growth, spread, and conditional burn probabilities under constant environmental conditions (weather and fuel moisture). While FLAMMAP outputs include spread rate, flame length, fireline intensity, and others, the Wildfire Hazard Index uses the flame length output. The scenario used to derive flame length for the Hazard Index included the inputs is shown in Table 8.3. In general, the wind speed, direction, and foliar moisture content, and other characteristics are sufficient to generate substantial fire behavior within the constraints of the modeling software. The inputs are slightly more moderate than 97th percentile fire weather, but not much, and are consistent with parameters used by CAL FIRE in their statewide analyses.[9] Flame Length, which has the highest weighting and therefore influence on modeled wildfire hazard outputs, is classed into five bins (Table 8.4) that correspond to wildland firefighter hauling charts (Andrews & Rothermel, 1982) shown in Table 8.5.

Table 8.3. FLAMMAP inputs used to simulate fire behavior and derived flame length used in the Wildfire Hazard Index.

Landscape File	Fuel Moisture File	Initial Wind Speed	Initial Wind Direction	Uphill Setting	Foliar Moisture Content	Crown Fire Calc Method
LCP_Nov2020.lcp (from 2020 Marin CWPP)	3-4-5-70-70.fms	20mph	NE (45 deg)	YES	80%	Scott/Reinhardt

Table 8.4. Flame length output ranges and corresponding wildfire index classification, based on wildland firefighter hauling charts shown in Table 8.5.

Range (feet)	Flame Length Class
0	0
0 - 4 Feet	1
4 - 8 Feet	2
8 - 11 Feet	3
> 11 Feet	4

[8]FLAMMAP values used match those used for CAL FIRE's fire hazard severity zone mapping. This allows for comparison with other locations, and match those used in Sonoma, San Mateo, Santa Cruz, and Santa Clara counties for recent assessments. Ninety-seventh percentile varies by weather station and would be different across Marin County, therefore using statewide values is suitable for analysis at the countywide scale.

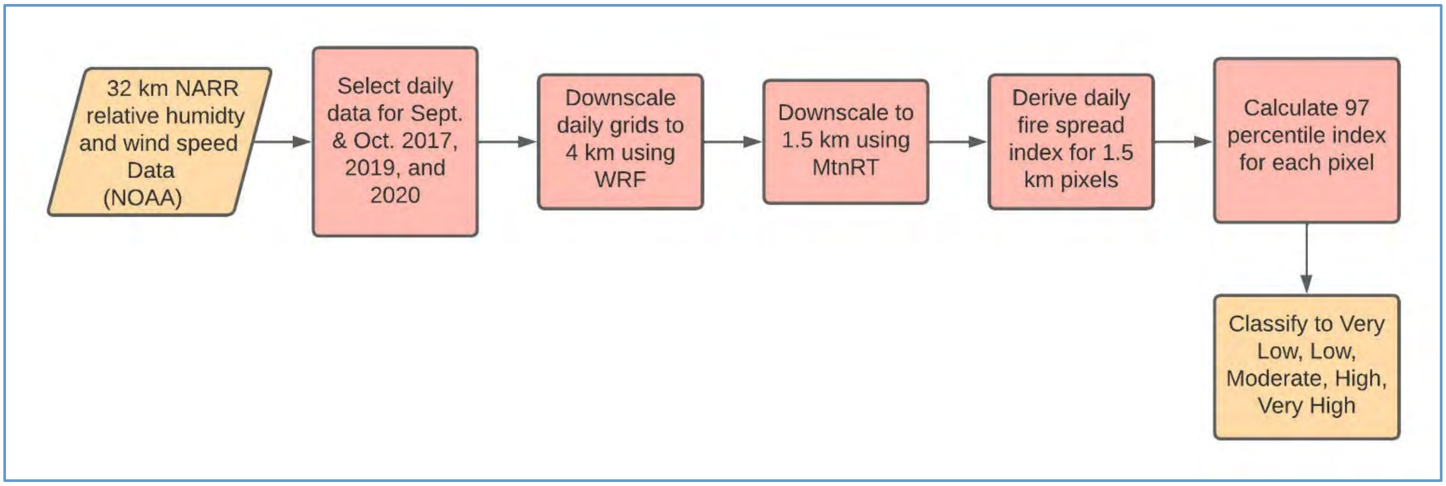
Table 8.5. Wildland firefighter hauling charts (Andrews & Rothermel, 1982).

Flame length	Fireline intensity	Interpretation
Feet	*Btu/ft/s*	
< 4	< 100	Fire can generally be attacked at the head or flanks by persons using handtools. Handline should hold the fire.
4-8	100-500	Fires are too intense for direct attack on the head by persons using handtools. Handline cannot be relied on to hold fire. Equipment such as plows, dozers, pumpers, and retardant aircraft can be effective.
8-11	500-1,000	Fires may present serious control problems—torching out, crowning, and spotting. Control efforts at the fire head will probably be ineffective.
> 11	> 1,000	Crowning, spotting, and major fire runs are probable. Control efforts at head of fire are ineffective.

Extreme Fire Weather Potential

Given the significant role that weather plays in driving fire behavior in the region, extreme fire weather potential is an important input to the Marin Wildfire Hazard Index. Potential for extreme fire weather was calculated in collaboration with Alan Fox (Fox Weather, LLC) and Tukman Geospatial and represents the relative potential across the County for very windy, very dry weather. The fire weather potential layer was created using a fire spread index that includes relative humidity and wind speed (Nelson, 1964, pp. 26-34). Maximum daily index values were calculated for each pixel in a 1.5-kilometer countywide raster for each day of September and October of 2017, 2019, and 2020. For each pixel, the 97th percentile index value was found for these 180 days. The resulting data was then classified into 5 classes - Very Low (0), Low (1), Moderate (2), High (3), and Very High (4) Extreme Fire Weather potential. The raw data for this analysis is from National Oceanic and Atmospheric Administration’s North American Regional Reanalysis (NARR). Fox Weather processed the NARR data (32 km resolution) using the Weather Research and Forecasting Model (WRF) to downscale it to 4 km resolution. The 4 km data from WRF was then downscaled to 1.5 km using Fox Weather's proprietary MtnRT software (Figure 8.12).

Figure 8.12. Extreme fire weather potential index workflow.



Ember Load & Suppression Difficulty Indices

The Ember Load Index and Suppression Difficulty inputs were developed jointly by Pyrologix and the US Forest Service and methodologies for each are detailed in the corresponding report, *Contemporary Wildfire Hazard Across California* (Vogler et al., 2021). Importantly for Marin County, these raster datasets were updated post-2020 fire season and therefore account for the Woodward Fire that occurred in August 2020 on the Point Reyes Peninsula. Ember Load Index represents the relative ember load at a given pixel, and Suppression Difficulty represents the relative difficulty in performing fire control work based on factors such as topography and accessibility (distance from roads/trails).

Fire Probability Inputs

Fire probability inputs for the Marin Wildfire Hazard Index include Human Development Proximity, Historic Ignitions, and Electrical Transmission Line proximity.

Proximity to Human Development

Recognizing there is a historical relationship between wildfire ignitions and human activity (Keeley & Syphard, 2018), Human Development Proximity was calculated using 2018 Marin impervious surfaces mapping of paved, dirt, and gravel roads along with building footprints and other paved/unpaved surfaces such as parking-lots and driveways (Golden Gate National Parks Conservancy et al., 2021). Human Development Proximity was classified according to distance from impervious feature (Table 8.6).

Table 8.6. Classification used to develop Human Proximity Index.

Distance from Impervious Feature	Class	Assigned Value
<= 50 feet	Very High	4
>50 & <=200 feet	High	3
>200 & <=500 feet	Moderate	2
>500 & <=1000 feet	Low	1
>1000 feet	Very Low	0

Historic Ignitions & Electrical Transmission Lines

Historic ignitions are another reliable indicator of fire probability, and both the CAL FIRE (through 2020) and USDA Forest Service databases of past ignitions were used to calculate this input. Keeley and Syphard (2018) found that although ignition sources overall have declined in recent decades, one notable exception is powerline ignitions. Recent preliminary data from the California State Fire Marshalls Office about powerline associated ignitions resulting in wildland fires indicated that distribution line related starts accounted for over 95% of all powerline related ignitions (R. Sampson, Division Chief, Resource Management, CAL FIRE, San Mateo - Santa Cruz Unit, personal communication, May, 2022). Unfortunately, Pacific Gas and Electric Company (PG&E) has not made electrical distribution line spatial data publicly available, which prevented it from being used for this analysis.[10] Transmission Line Proximity was calculated using spatial data from the California Public Utility Commission dataset, and lines less than 100 kV were included in the model (California Energy Commission, n.d.).

CALCULATING WILDFIRE HAZARD

Relative wildfire hazard was calculated by weighting each of the inputs, multiplying by a factor of four, and then totaling the result. Weights were assigned based on iteration and feedback from CAL FIRE Fire and Resource Assessment Program (FRAP) and consultation with fire

Table 8.7 - Theoretical maximum pixel value for the wildfire hazard index.

Flame Length	Extreme Fire Weather Potential	Ember Load Index	Suppression Difficulty	Human Development Proximity	Transmission Proximity	Historic Ignitions	Total Possible Score
4 x 4 = **16**	3 x 4 = **12**	2 x 4 = **8**	3 x 4 = **12**	1 x 4 = **4**	1.5 x 4 = **6**	.5 x 4 = **2**	16 + 12 + 8 + 12 + 4 + 6 + 2 = **60**

[10] Although not provided in time to include in the Marin County wildfire hazard analysis, PG&E has since made distribution line spatial data available (PG&E, n.d.).

behavior modeling consultants including Carol Rice (Wildland Res. Mgt) and Esther Madeno (Digital Mapping Solutions). Flame length was assigned a weight of four, extreme fire weather potential assigned a weight of three, ember load index was assigned a weight of two, suppression difficulty was assigned a weight of three, human development proximity was assigned a weight of 1, transmission proximity a weight of 1.5, and historic ignitions 0.5. The highest possible index value was 60. Table 8.7 shows how a theoretical pixel value of 60 would be assigned if all inputs had a 'Very High' (4) classification.

The resulting Marin Wildfire Hazard Index (Figure 8.13) is a geospatial raster dataset in which each pixel represents a 20m x 20m square on the landscape, with possible raw pixel values from 0 to 60. Each pixel was binned into 6 classes, with class 1 representing the lowest relative hazard and class 6 the highest. Table 8.8 shows how the reclassification occurred. The Hazard Index is made relative within Marin County's geography using an equal area slice, so there are roughly an equal number of pixels within each hazard class, excluding class 1 which represents the non-burnable areas such as waterbodies and tidal marshlands.

Figure 8.13. Marin Wildfire Hazard Index Raster. Manager can interact with this layer in the Forest Health Web Map.

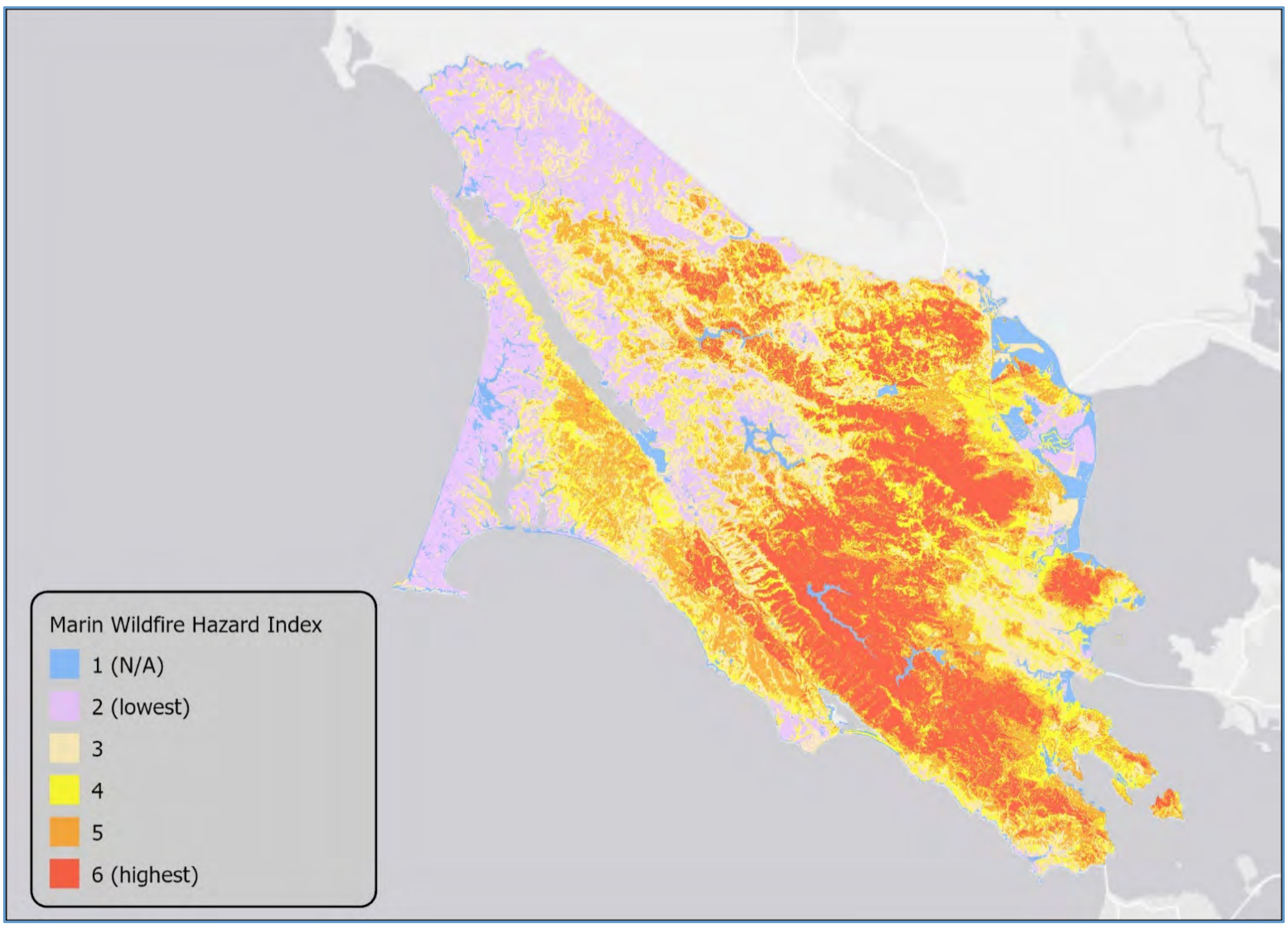


Table 8.8. Classification of the 0-60 hazard index into 6 classes.

Raw Score	Classified Description	Classified Index Value
0	'Non burnable' (water, salt marsh, pavement, etc.)	1
0-16	Very Low Relative Hazard	2
16-24.5	Low Relative Hazard	3
24.5-32	Moderate Relative Hazard	4
32-40.5	High Relative Hazard	5
40.5+	Very High Relative Hazard	6

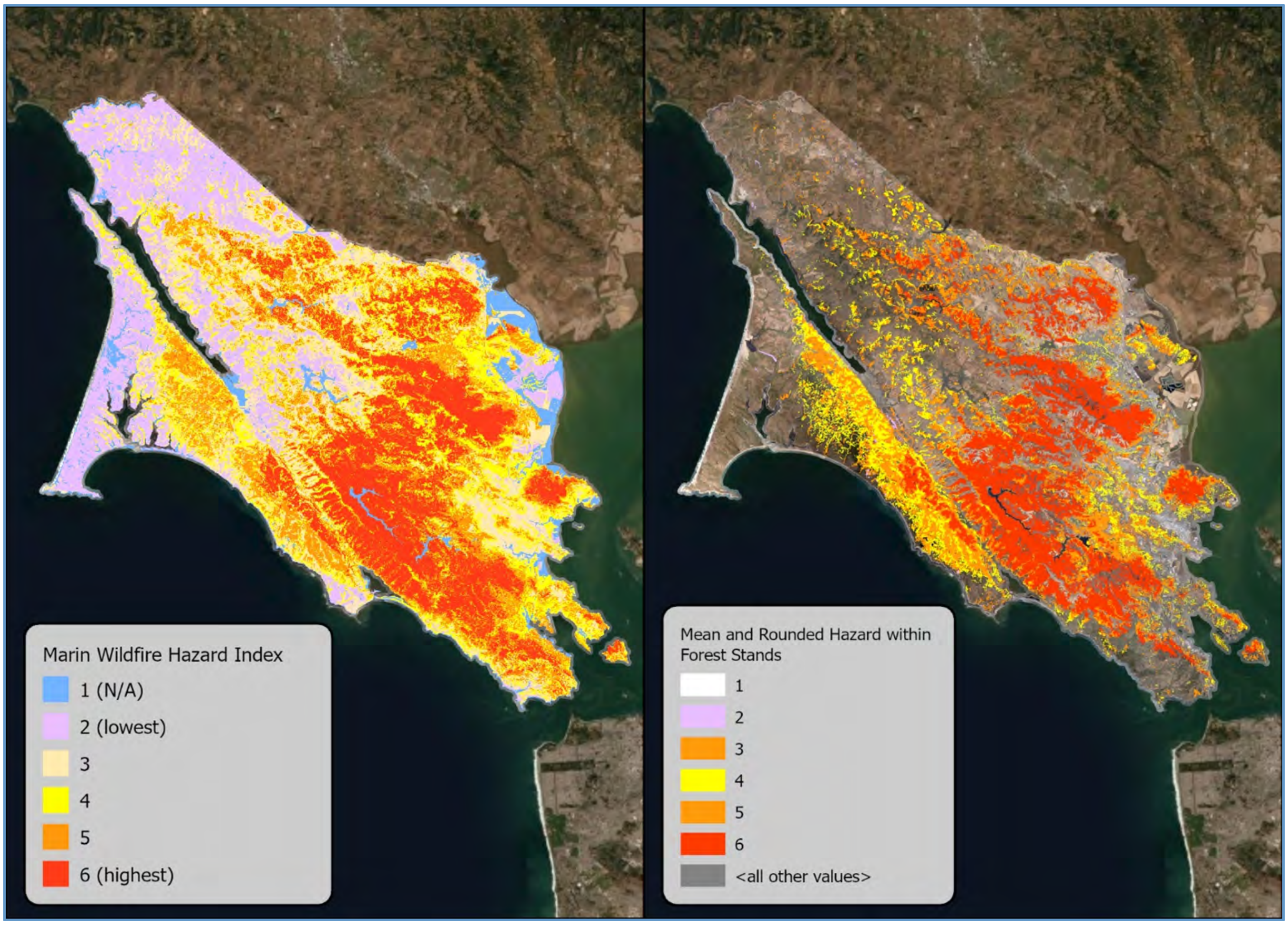
USING DEPARTURE FROM DESIRED CONDITIONS & WILDFIRE HAZARD TO EVALUATE MULTI-BENEFIT TREATMENT OPPORTUNITIES

Having mapped departure from desired conditions for forested areas and modeled wildfire hazard across Marin County, it becomes possible to look at the spatial distribution of and relationships between these two datasets to identify potential locations for treatments that can both improve forest conditions and address the potential for hazardous wildfire. Building density data can also be layered into this analysis to inform treatment planning near developed areas that may be at risk from potentially hazardous wildfire.

CALCULATING WILDFIRE HAZARD WITHIN A STAND

Using stands in the 2018 Fine Scale Vegetation Map as the basic unit of analysis, the value of each 20x20 meter pixel in the Marin Wildfire Hazard Index was then used to calculate the mean wildfire hazard within each polygon. Values were then rounded to the nearest integer. Figure 8.14 illustrates how values in the Wildfire Hazard Index raster were used to attribute mean wildfire hazard within 2018 Fine Scale Vegetation Map polygons.

Figure 8.14. Marin Wildfire Hazard Index raster (left) and 2018 Fine Scale Vegetation Map forested stands (vector polygons) attributed with mean wildfire hazard index.



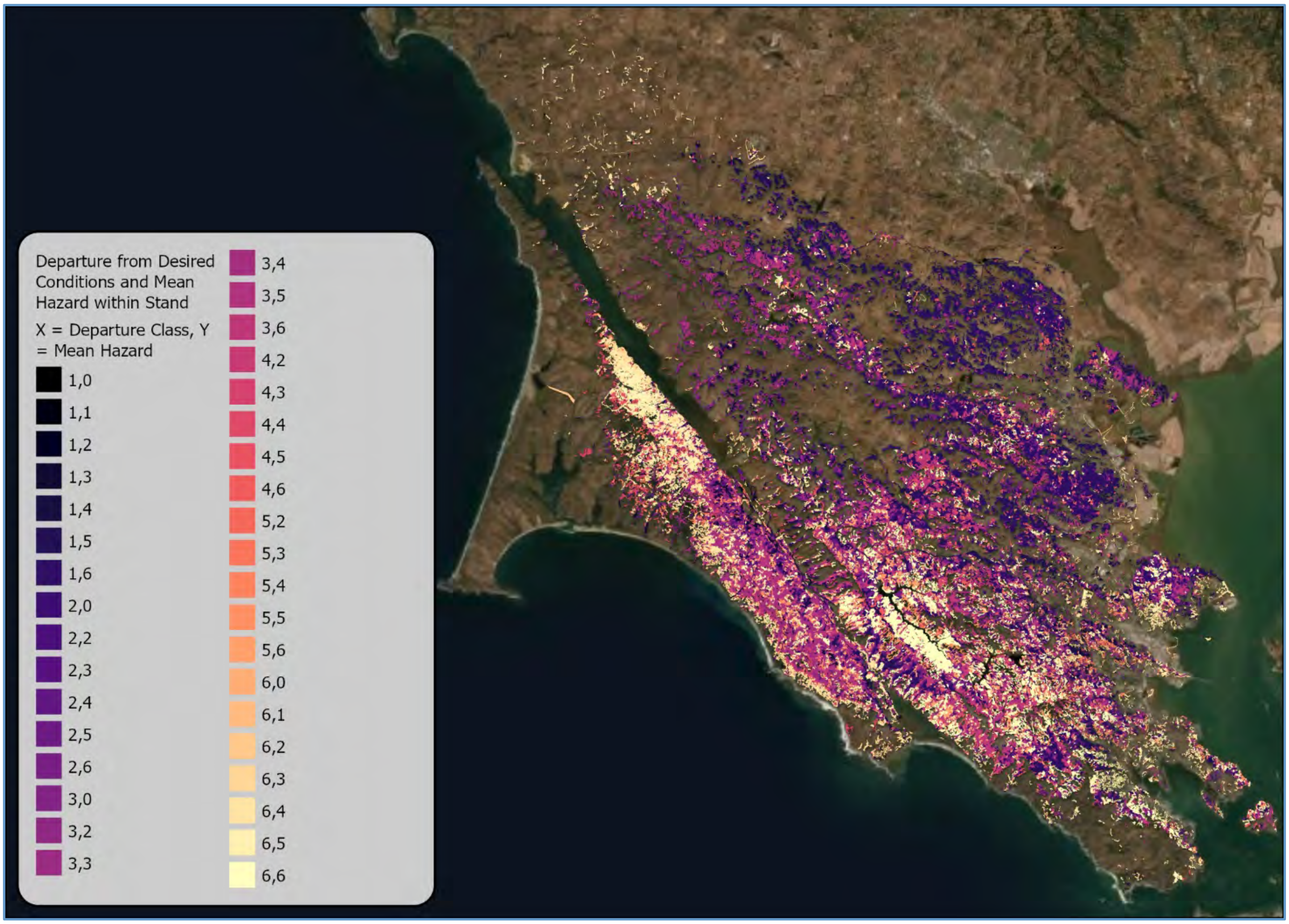
INTEGRATING DEPARTURE FROM DESIRED CONDITIONS WITH WILDFIRE HAZARD

With mean wildfire hazard attributed to each 2018 Fine Scale Vegetation Map polygon, managers can explore quantitative relationships between the departure from desired conditions index and mean wildfire hazard within forested stands. The XY values in the bivariate map (Figure 8.15) correspond to departure from desired conditions (X) and mean wildfire hazard (Y) within non-native forest, non-native shrub, and native forest polygon in the 2018 Fine Scale Vegetation Map. In general, the lighter the color, the greater both the departure from desired conditions and wildfire hazard.

Example Application

Analysis of both departure from desired conditions and wildfire hazard mapping provides a useful decision support tool for managers planning forestry projects that will advance multi-benefit treatment approaches to both improve forest health and reduce hazardous fuels adjacent to values at risk, such as important natural resources or public infrastructure. As with other spatial analyses in the *Forest Health Strategy*, this work relies on remote sensed data and other landscape scale information that will require ground-truthing to further develop project boundaries, work approach, anticipated benefits, and environmental constraints. Nevertheless, as the examples below illustrate, these layers can be used to locate and design multiple benefit projects.

Figure 8.15. Bivariate map showing departure from desired conditions (X) and mean wildfire hazard within stand (Y).



Lake Lagunitas, Tamalpais Watershed Lands

In 2021 Marin Water initiated approximately 360 acres of forest management adjacent to Lake Lagunitas and Bon Tempe Water Treatment Plant on Tamalpais Watershed Lands, with the goal of both improving forest health and increasing wildfire resilience for this critical water storage and delivery infrastructure. Treatments were designed to address impacts on native tanoak trees affected by *Phytophthora ramorum* (sudden oak death) and Pacific madrone (*Arbutus menziesii*) forest stands degraded by *Phytophthora cinnamomi*. Forest management prescriptions in the area sought to emulate the effects of a low-moderate intensity wildfire by thinning small-diameter Douglas-fir *(Pseudotsuga menziesii)*, especially where encroaching on native oak woodland and hardwood stands, and targeted removal of accumulated ladder fuels where appropriate.

Analysis of restoration potential and wildfire hazard mapping for this area demonstrates the utility of these spatial tools in locating forest stands that meet both wildfire resilience and forest health management objectives. Of the 325 acres of forest stands within the Lake Lagunitas-Bon Tempe Treatment Plant management area, 100% are within the top 3 classes of wildfire hazard (4-6). Sixty-eight percent (220 acres) of these forest stands are in a departure from desired conditions class of greater than or equal to three (≥3), with 36% (116 acres) in the most departed classification (Figure 8.16).

Figure 8.16. Acres by departure from desired conditions class and mean wildfire hazard, 2021 Marin Water treatment areas.

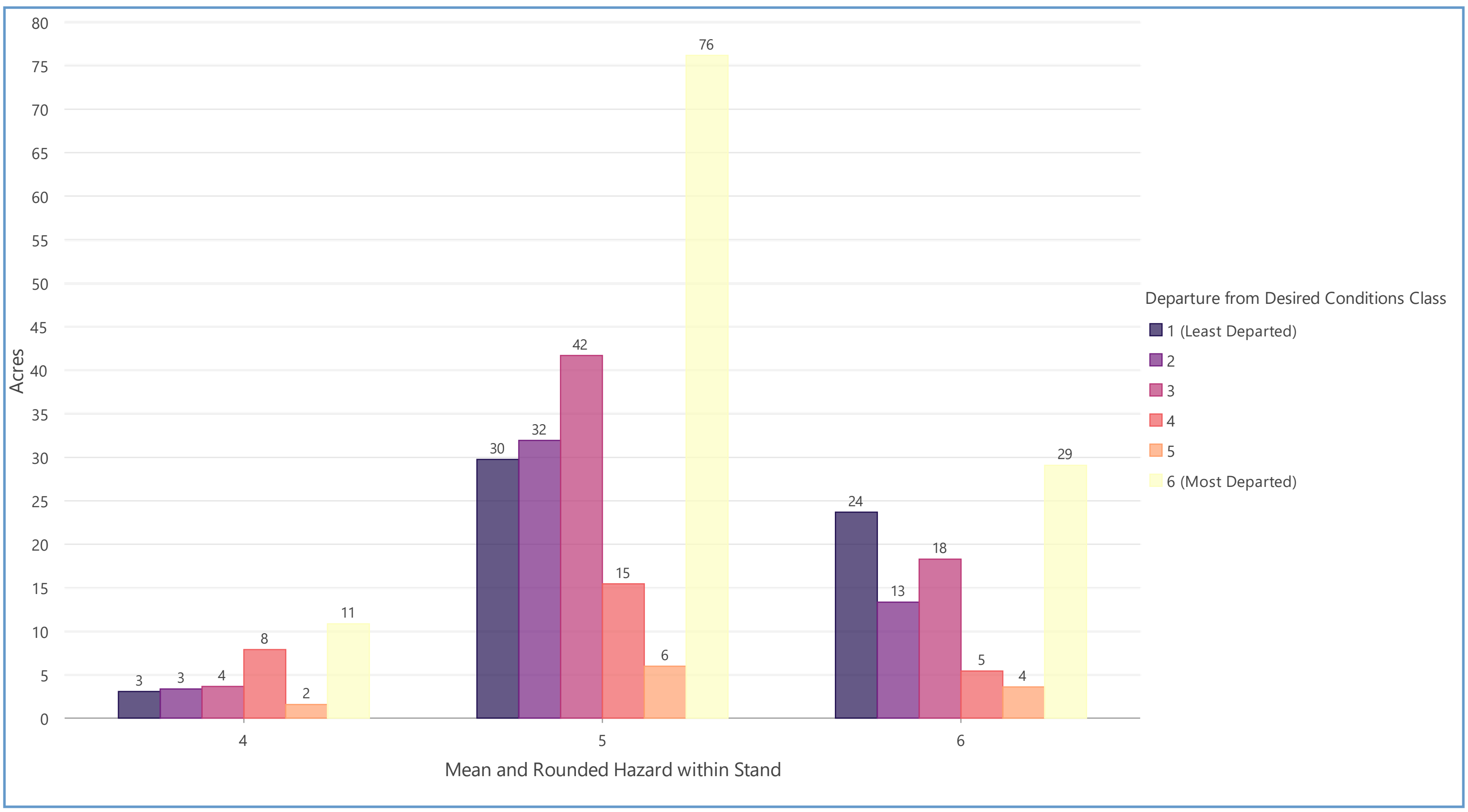
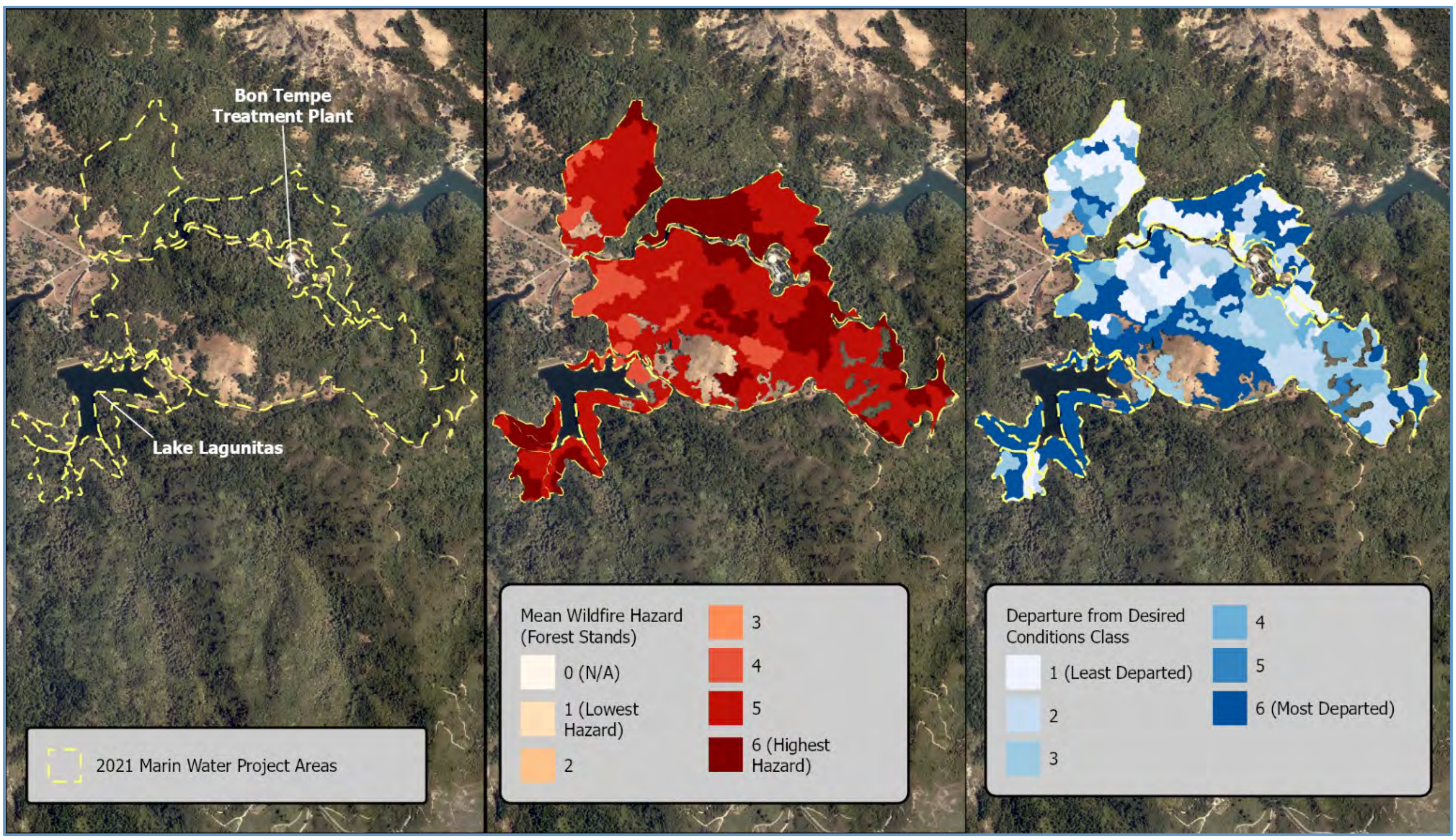


Figure 8.17 identifies the 2021 project area selected by Marin Water natural resource program staff located near Lake Lagunitas and Bon Tempe Treatment Plant (left). These areas include oak woodland, madrone, and tanoak dominated forest as well as Douglas-fir stands, classified with mean wildfire hazard within each stand (center). The corresponding departure from desired conditions index (right) shows significant opportunity to improve forest conditions while improving wildfire resilience for critical water infrastructure. This example in Figure 8.16 illustrates the utility of analyzing wildfire hazard and departure from desired conditions mapping concurrently as a means of identifying multi-benefit treatment opportunities, either by using bivariate symbology or displaying each spatial layer individually.

Figure 8.17. 2021 Marin Water project areas near Lake Lagunitas and Bon Tempe Treatment Plant (left). Treatments were designed to both address wildfire risk to water storage and delivery infrastructure (center) and to improve forest health (right).



USING DEPARTURE FROM DESIRED CONDITIONS, WILDFIRE HAZARD, & BUILDING DENSITY TO EVALUATE MULTI-BENEFIT TREATMENT OPPORTUNITIES

Wildfire hazardous fuel reduction projects are generally designed to reduce risk to adjacent homes, communities, evacuation routes, and important infrastructure by selectively removing or treating vegetation to remove accumulated fuels, break-up the horizontal and vertical structure of vegetation, and create defensible space for fire suppression efforts. By developing wildfire hazard, building density, and departure from desired conditions spatial layers, the *Forest Health Strategy* provides managers with tools to identify potential locations for multi-benefit projects that can reduce risk to communities, improve overall forest health, increase forest resilience, and restore healthy forests attributes.

The Marin Wildfire Prevention Authority (MWPA), whose stakeholders include fire protection districts and departments in Marin County, works to establish fuel reduction priorities based on the 2020 Marin Community Wildfire Protection Plan (CWPP) and advance projects through their annual work planning process. Beyond the CWPP, MWPA has several studies currently underway that will likely result in additional multi-benefit treatment opportunities including evacuation planning, home inspection data analysis, and shaded fuel break efficacy modeling (Anne Crealock, MWPA Planning and Program Manager, personal communication, March 28, 2023). Projects proposed by MWPA, individual fire departments, or land managing agencies, can be analyzed using these layers to help identify overlap between risk reduction and forest health goals so that agencies can work together to achieve multiple benefits.

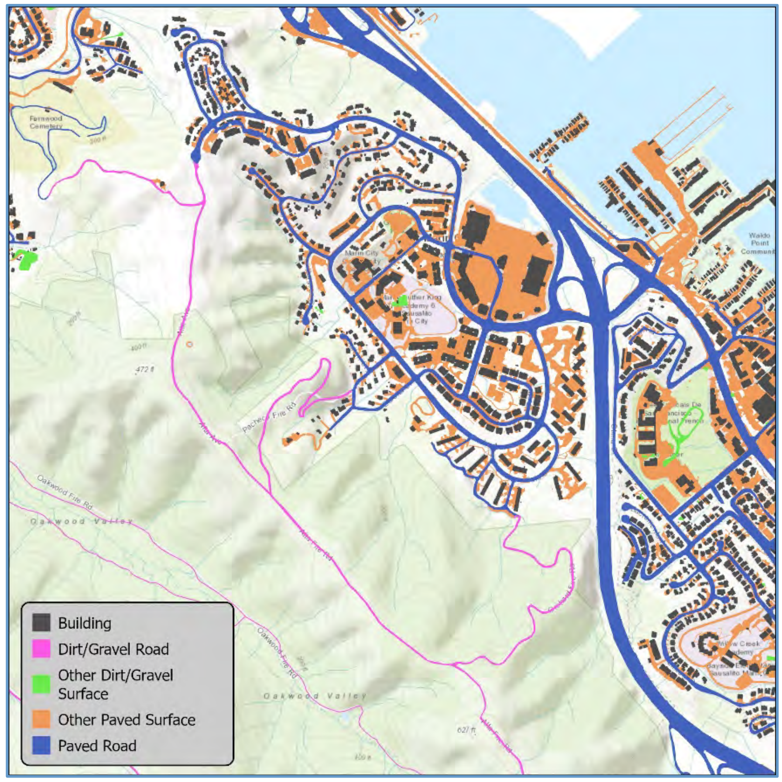
The goal of providing a framework to overlay restoration potential with wildfire hazard and building density mapping is to highlight where forest stewardship opportunities and wildfire risk to communities overlap. However, not every fuel reduction project will have forest health benefits. Due diligence should be exercised to limit the potential for risk reduction-focused vegetation management to negatively impact adjacent forests by spreading non-native invasive weeds and pathogens or degrading sensitive natural communities.[11] Additional work, including on-the-ground reconnaissance, is required to design approaches and advance projects that will meet both risk reduction and forest revitalization objectives. Follow-up maintenance is critical for ensuring long-term benefits.

[11] On June 16th, 2022, the MWPA Board voted unanimously to accept the *Ecologically Sound Practices for Vegetation Management* document (version June 9, 2022; ESP Partnership, 2022) as non-binding guidance for MWPA activities.

CALCULATING BUILDING DENSITY

As a component of the Marin Countywide Fine Scale Vegetation Map and Landscape Database Project, One Tam coordinated mapping of impervious surfaces in Marin County, including paved roads, dirt/gravel roads, other paved surfaces (e.g., sidewalks), other dirt/gravel surfaces (e.g., parking-lots), and building footprints (Figure 8.18). The building footprints were mapped with Object Based Image Analysis methods, using 6-inch, 4-band high-resolution aerial imagery collected in June 2018.[12] The 2018 building footprints are treated as a proxy for buildings or structures, and used to calculate building density. Limitations of this data include possible errors of omission, inclusion of non-building features (commission), absence of information on building use, occupancy status, or structural composition. However, this dataset represents the best available spatial layer depicting structures in Marin County.

Figure 8.18. 2018 Marin impervious surfaces mapping, including building footprints, near Marin City-Sausalito, GGNRA.



To calculate building density for each polygon in the 2018 Fine Scale Vegetation Map, analysts calculated the number of structures (2018 building footprints) per acre within each polygon. Classes were then assigned using the breakpoints identified in Table 8.9, which are based on (but not identical to) recently developed National Institute of Standards and Technology Wildland Urban Interface (WUI) definitions (Maranghides et al., 2022). The classified structures per acre value was then assigned to each polygon in the 2018 Fine Scale Vegetation Map. A second variable, number of structures per acre within ½ mile of each stand was also calculated, classified using the same breakpoints shown in Table 8.9, and attributed to each stand in the 2018 Fine Scale Vegetation Map.

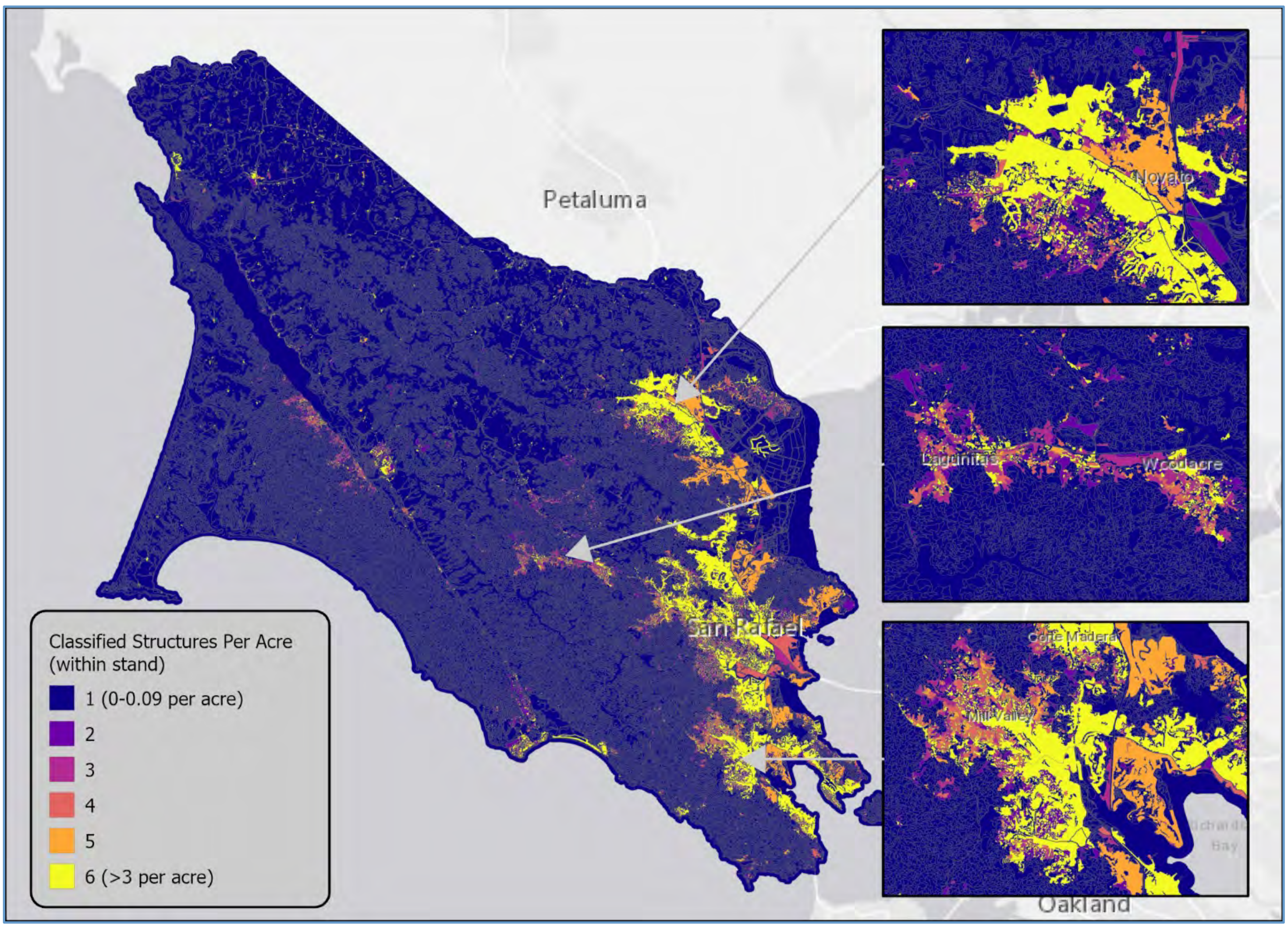
[12] For more information on methods or to access this data visit https://vegmap.press/marin_impervious_datasheet

Table 8.9. Structure (from 2018 building footprints) density classification.

Structure per Acre	Class
0-0.09 Structures per Acre	1
0.1-0.4 Structures per Acre	2
0.5-0.9 Structures per Acre	3
1-1.9 Structures per Acre	4
2-2.9 Structures per Acre	5
≥3 Structures per Acre	6

Classified building density attributed to stands (polygons) in the 2018 Fine Scale Vegetation Map provides insight into the distribution and density of structures in Marin County in relationship to other data points such as vegetation type, forest health metrics, the departure from desired conditions index, wildfire hazard, and the wealth of additional attribution within

Figure 8.19. Classified Structures per acre (within stand) attributed to each 2018 Fine Scale Vegetation Map polygon. Managers can explore this layer via the [Forest Health Web Map](#).



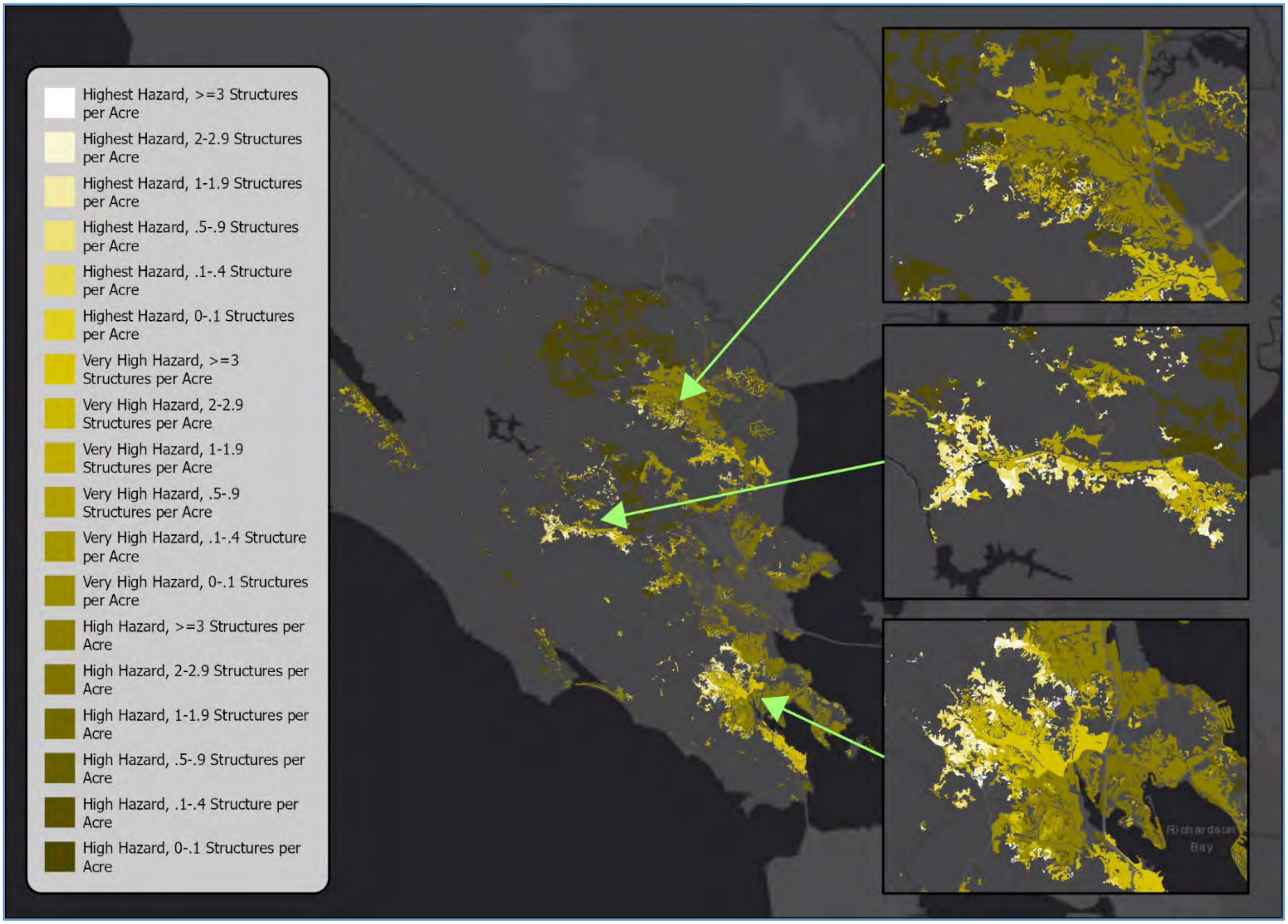
the 2018 Fine Scale Vegetation Map GIS dataset. This layer is spatially analogous to Marin County's available wildland urban interface (WUI) mapping; however, it is at a finer scale (Figure 8.19).

INTEGRATING BUILDING DENSITY WITH WILDFIRE HAZARD

The work of the *Forest Health Strategy* is centered on identifying opportunities to increase forest health and resilience, and to leverage individual One Tam agency forest management and fuel reduction programs and projects to address threats to forest health and protect forest ecosystem function. However, understanding how forest health treatment opportunities intersect with the goals of the MWPA and fire agencies in Marin County is a critical step for advancing multi-benefit projects at the regional and countywide scale. By integrating building density and wildfire hazard layers, the *Forest Health Strategy* can further serve as a decision support tool for identifying and advancing projects that meet desired outcomes for both land managers and fire protection agencies.

With both mean wildfire hazard and classified building density attributed to each stand (polygon) in the 2018 Fine Scale Vegetation Map, bivariate symbology was used to highlight areas that have both high relative wildfire hazard and building density. The XY values in Figure 8.20 represent the mean wildfire hazard value for each pixel within a given 2018 Fine Scale Vegetation Map polygon rounded to the nearest integer (X), and classified building density within the same polygon (Y). In this map, areas of significance are highlighted by displaying only wildfire hazard values greater than four (X>4) and building density classification of greater than 0.1 structures per acre (i.e., polygons with 0 structures per acre are not displayed). Managers can interact with this layer on the Forest Health Web Map.

Figure 8.20. Bivariate map display highlighting areas in Marin County with relatively high classified wildfire hazard within stand (X value) and classified building density within stand (Y value). Managers can interact with this data layer via the [Forest Health Web Map](#).



ASSESSING RESTORATION POTENTIAL IN RELATIONSHIP TO WILDFIRE HAZARD & BUILDING DENSITY

Modeled departure from desired conditions, wildfire hazard, and building density can be analyzed in relation to one another to develop and prioritize project areas and design treatment approaches that will achieve desired multi-benefit outcomes. Priority projects advanced as part of the Regional Forest Health Strategy or initiated by individual land managers, Federated Indians of Graton Rancheria, MWPA, individual fire protection districts, and others, can be assessed using this framework provided in the *Forest Health Strategy* to evaluate potential multi-benefit opportunities and design appropriate approaches to vegetation management.

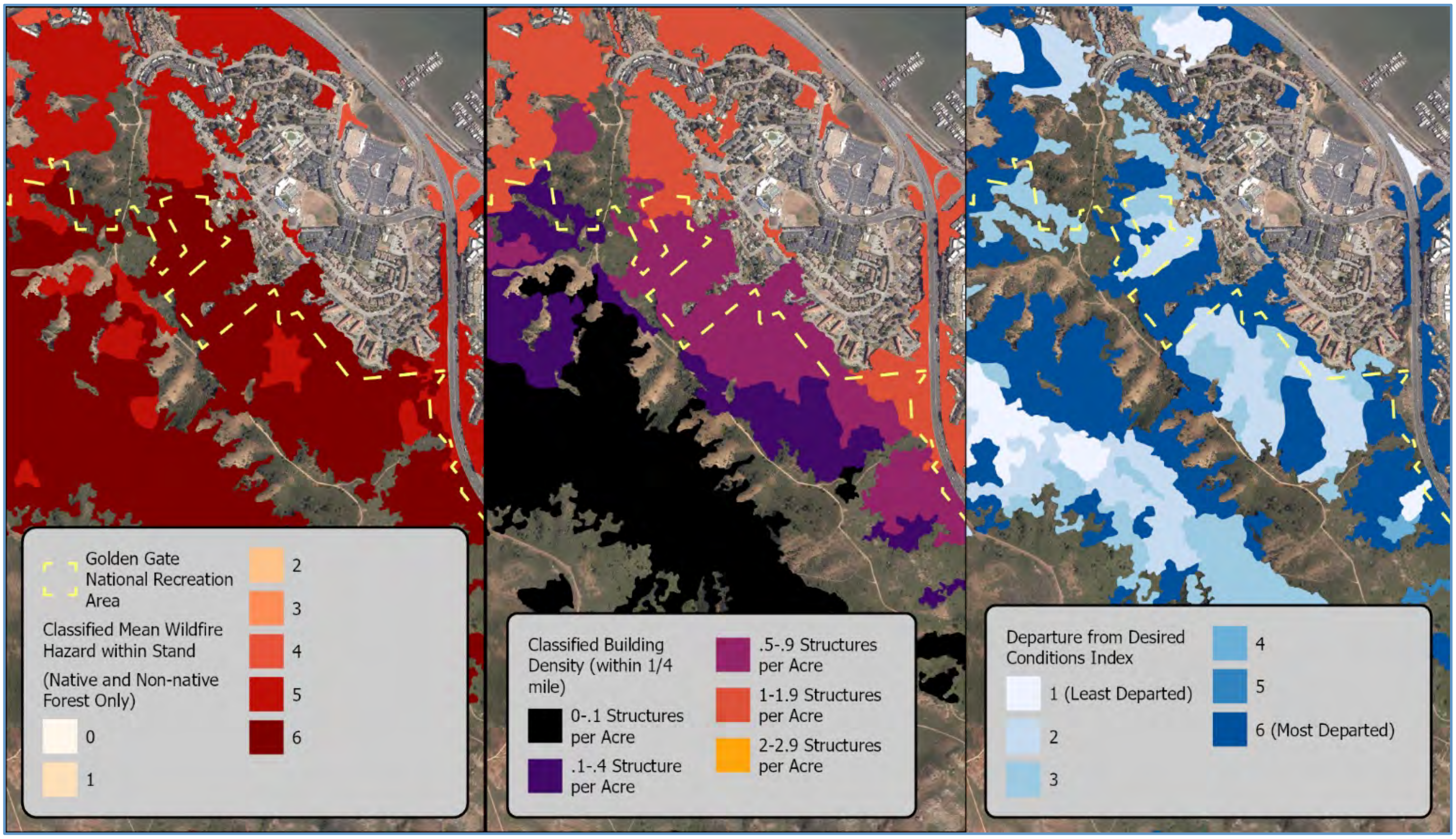
Example Application

The community of Marin City is adjacent to over 8,000 acres of national parklands in the Golden Gate National Recreation Area (GGNRA). Marin City is one of the most diverse communities in Marin, and 55% of people in this census tract are living below twice the federal poverty level, higher than 87% of the census tracts in California (CalEnviroScreen version 4.0). Dense vegetation and weeds are prevalent in parklands adjacent to Marin City, making the area less inviting to residents and creating the unnatural fuel arrangements that currently exist along the community boundary with the GGNRA. Both the National Park Service (NPS) and MWPA have indicated a desire to accomplish work in this area (Figure 8.21).

Spatial layers developed for the *Forest Health Strategy* multi-benefit treatment opportunity analysis can support the need to perform vegetation management to reduce risk to the community of Marin City and show how this work can improve forest health. Figure 8.22 (left) shows that much of the forested area adjacent to Marin City in high wildfire hazard classification, with significant building densities within a ¼ mile buffered distance (Figure 8.22, center). Substantial departure from desired conditions also exists in within this same area (Figure 8.22, right), driven by the prevalence of non-native trees and shrubs, high ladder fuels, as well as threatened valuable oak woodland habitat.

Figure 8.21. MWPA proposed project area near Marin City and adjacent GGNRA lands.

Figure 8.22. (left) The Marin City area is classified as relatively high wildfire hazard and has significant building density within 1/4 mile (center). This is also an area with considerable forest areas classified as departing from desired conditions (right).



MECHANICAL-MANUAL TREATMENT FEASIBILITY

To further support project planning and prioritization, a 5-meter resolution Mechanical/Manual treatment feasibility raster was developed. This spatial layer provides information about the feasibility of mechanized or manual vegetation management by classifying the landscape to show where management could potentially be challenging due to several constraints. The Marin mechanical-manual treatment feasibility layer was based on a similar analysis by North et. al (2015) for mechanized treatment feasibility across National Forests in the Sierra Nevada, and further refined by the Forest Health Working Group. The mechanical/manual treatment feasibility GIS layer is a model depicting treatment feasibility and constraints based on the following set of criteria: slope, proximity to riparian areas, and distance to roads/trails, and presence of serpentine soils. (Figure 8.23).

This is intentionally a coarse model of treatment feasibility based on available topographic and landcover datasets designed to support high-level planning. Additional opportunities and constraints for potential forestry treatments will emerge as part of required environmental compliance, including project and site-specific analysis and consultation related to cultural landscapes, Tribal resources, protected plant and animal species, sensitive natural communities, property ownership, and other constraints. This spatial data will not be used to confirm suitability or appropriateness of any projects or management actions subject to environmental review under NEPA, CEQA, or any other applicable laws and regulations.

Figure 8.23. Logic model used to create the Marin County treatment feasibility layer.

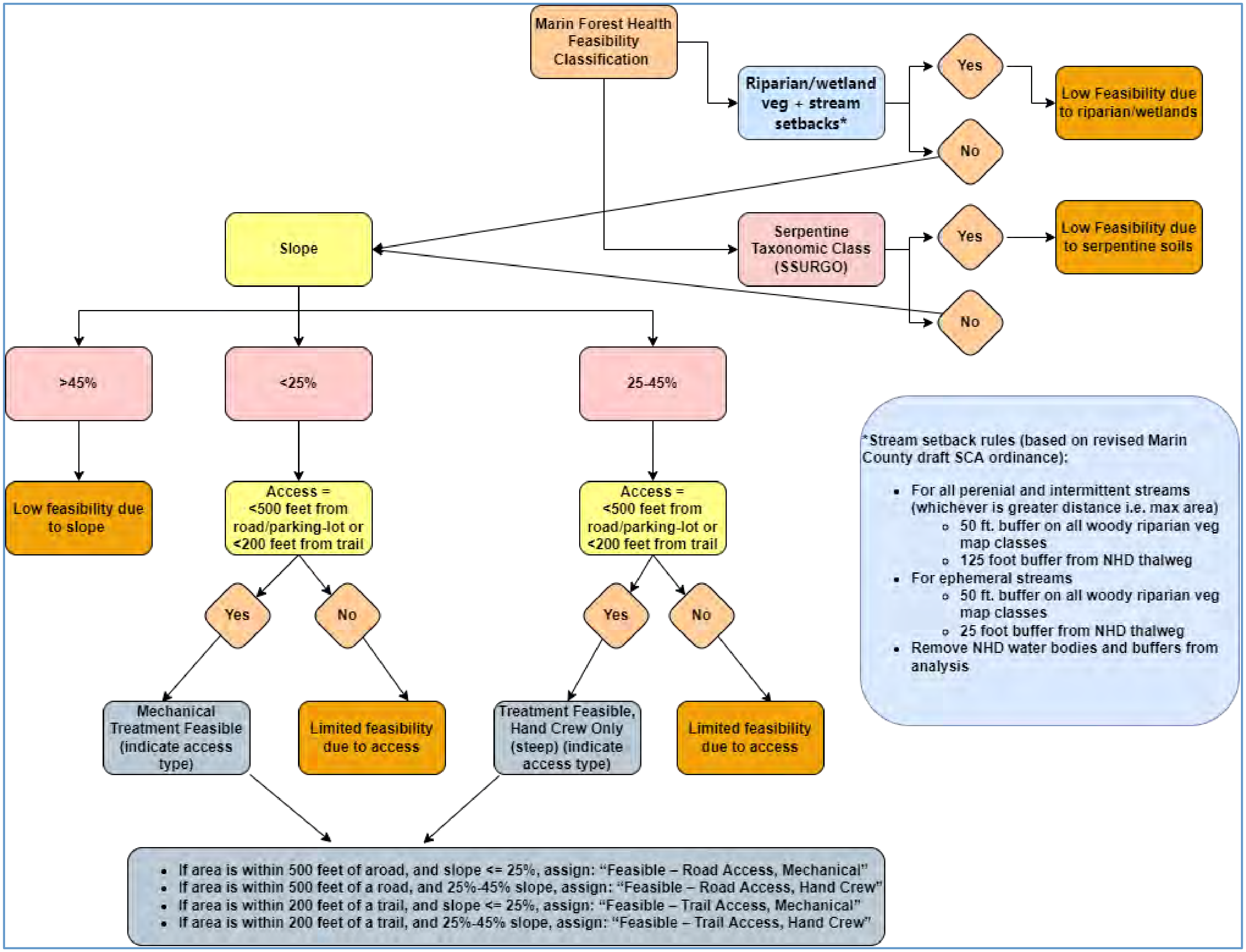


Table 8.10 provides additional information on each geospatial dataset used to develop the feasibility layer, including data source, constraint on treatment of vegetation, and processing steps performed on the geospatial data to create the raster. The far-right column also shows what label is applied to an area if a constraint is met. Note that constraints were applied working from the top of the table down. For example, if an area included both riparian and serpentine vegetation, it was assigned the class "Low Feasibility - Near Stream or Riparian Veg/Wetland/Water," because that constraint is applied first. In addition, if an area is both within 500 feet of a road and 200 feet of a trail, it would be assigned the class "Road Access" since road access would likely be preferred over trail access where available.

Table 8.10. Feasibility constraint data sources and processing rules used to assign classification.

Mechanical Treatment Constraint	Constraint Description	Source	Processing Rules/Label (assigned in order from top to bottom)
Riparian and Wetland	Mechanized treatment of vegetation is constrained in riparian corridors, wetlands, and areas covered by water.	Marin Countywide Fine Scale Veg Map (2018) 2019 Marin lidar-derived National Hydrography Dataset (NHD) Marin County Stream Conservation Ordinance (proposed; County of Marin, n.d.)	If area is mapped in the vegetation map as riparian vegetation (buffered by 50 feet), wetland, water, or is within 125 feet of a perennial/intermittent stream, or 25 feet of an ephemeral stream, assign: "**Low Feasibility - Near Stream or Riparian Veg/Wetland/Water**"
Serpentine	Serpentine areas are not feasible for mechanical treatments.	SSURGO Soil Survey (downloaded from ESRI Living Atlas, Summer 2021)	If area is in the following taxonomic classes: • Clayey-skeletal, serpentinitic, thermic Lithic Argixerolls; or • Loamy, serpentinitic, thermic Lithic Haploxerolls assign: "**Low Feasibility - Serpentine**"

Steepness	Areas with steep terrain are difficult to access with vehicles and make it difficult for humans to perform mechanical-manual treatment activities.	Slope derived from countywide lidar (2019)	If >=45% slope: "**Limited Feasibility - Steep**"
Access	Mechanical treatment requires road or trail access. Areas not road or trail-accessible have low feasibility for mechanical treatment.	Marin County Impervious Surfaces Map (2018)	If area is >= 500 feet from a road or paved parking lot or >= 200 feet from a trail, with no other constraints, assign: "**Limited Feasibility - Poor Access**"
NONE	Areas that do not have any of the above constraints	N/A	If area is within 500 feet of a road, and slope <= 25%, assign: **"Feasible – Road Access, Mechanical"** If area is within 500 feet of a road, and 25%-45% slope, assign: **"Feasible – Road Access, Hand Crew"** If area is within 200 feet of a trail, and slope <= 25%, assign: **"Feasible – Trail Access, Mechanical"** If area is within 200 feet of a trail, and 25%-45% slope, assign: **"Feasible – Trail Access, Hand Crew"**

Results of the feasibility analysis show that of the 365,994 acres analyzed in the layer, 32% (117,434 acres) are classified as feasible for mechanical or hand-crew vegetation management (Figure 8.24). When focused on the 123,128 acres of forested lands in Marin County, the feasible class acres are reduced to just 23% (28,066 acres) of the landscape (Figure 8.25). While this analysis is based on remote-sensed data and cannot be used exclusively to assess treatment opportunities or define project boundaries, it does underscore that much of the forested landscape may be prohibitively difficult to manage using manual or mechanical methods.

Figure 8.24. Acres by treatment feasibility classification, forested lands in Marin County.

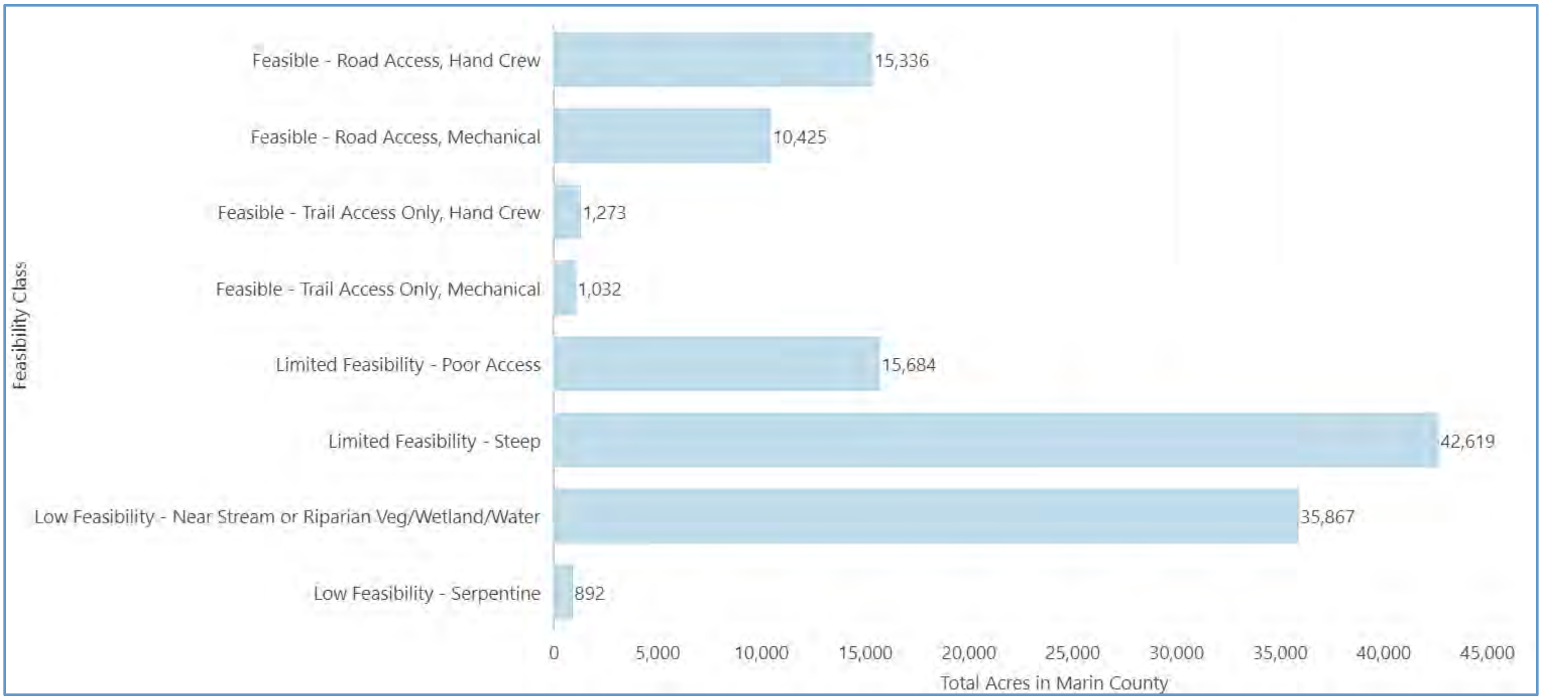
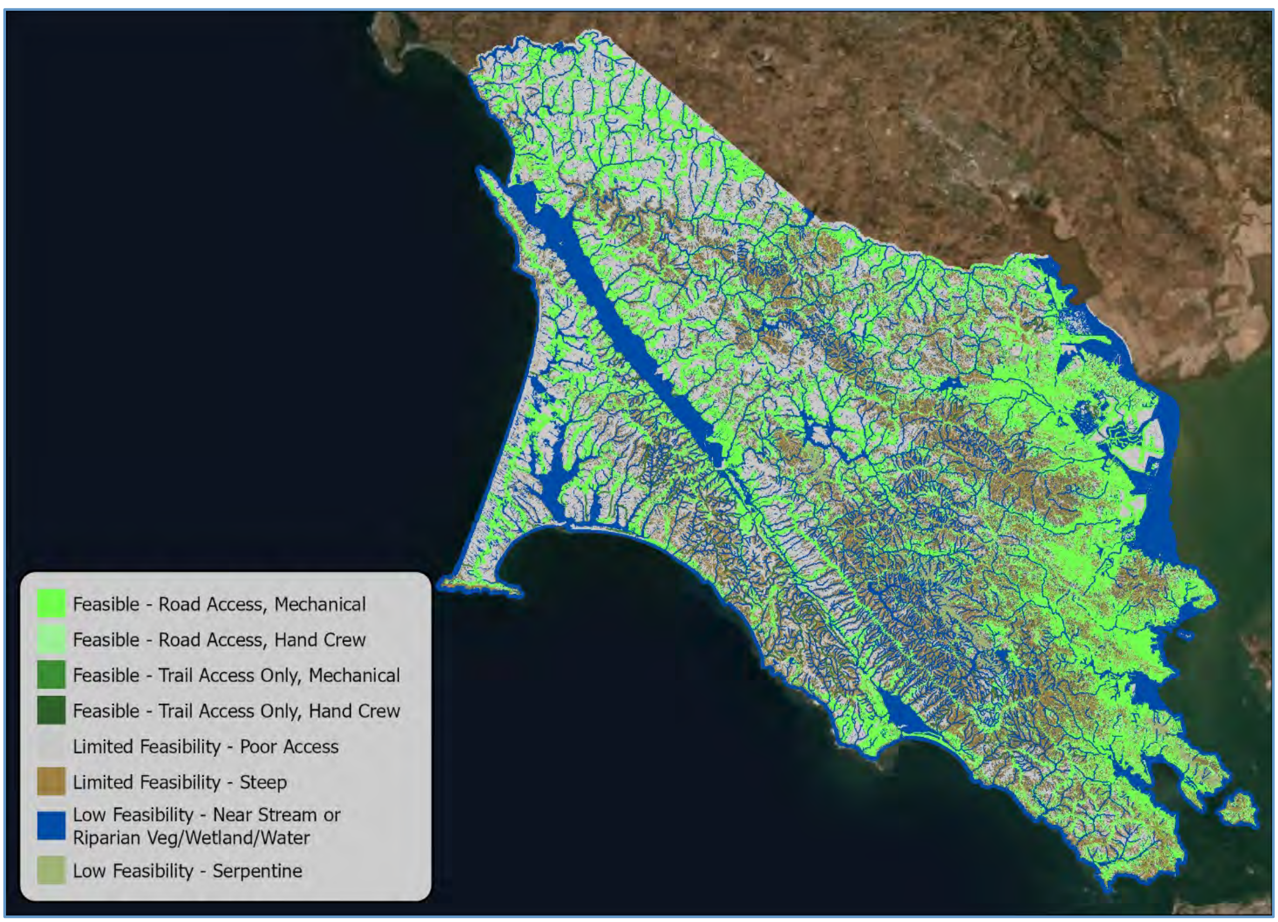


Figure 8.25. Countywide feasibility raster, also available on the [Forest Health Web Map.]



PRIORITY PROJECT AREAS & MULTI-BENEFIT TREATMENT OPPORTUNITIES

The priority project areas and multi-benefit treatment opportunities described below were developed using a combination of the analysis described in this chapter as well as expertise and knowledge from Marin's land managers regarding forests and natural resources on public lands in Marin County. Where applicable and relevant for a given location, project descriptions include information about geographical setting, relevant fire history, distribution of forest community types, wildlife or other natural resources, results of relevant analyses such as departure from desired conditions, wildfire hazard, proximity to community or critical infrastructure, building density, goals, multi-benefit treatment approaches, and feasibility constraints.

It is emphasized that each of these project areas will require additional project specific analysis prior to project implementation such as field-based surveys to confirm work area boundaries, identification of sensitive natural resources, avoidance areas, ingress/egress routes, staging areas, and treatment prescriptions to be implemented. **In addition, based on the guidance in Chapter 3: Stewardship and Partnership with the Federated Indians of Graton Rancheria and requirements under applicable regulatory compliance, land managers will conduct consultations with the Federated Indians of Graton Rancheria to share project goals and objectives, provide opportunity for Tribal input, identify sensitive cultural resources within the proposed project area, and integrate Traditional Ecological Knowledge (TEK) into treatment approaches if deemed appropriate by the Tribe**.

Marin's public land managers, including the National Park Service, Marin County Parks, California State Parks, and Marin Water, are responsible for stewarding a wide range of forest and woodland communities and many other important natural resources. Each land management agency operates within the mandate of their respective organization, and each has a nuanced set of opportunities and constraints within which active forestry management can be undertaken. Table 8.11 below highlights some of the key nuances related to forest management for each land managing agency.

Table 8.11. Forest management objective by partner.

Agency	Forest Management Objectives
Marin Water	• Focus on reducing wildfire risk to critical water storage, treatment, and delivery infrastructure on Tamalpais Watershed lands. Implement Biodiversity Fire and Fuels Integrated Plan. • Protect natural resources and improve ecological function; address impacts from sudden oak death, invasive species, and other threats to forest health.
National Park Service (including Golden Gate National Recreation Area and Point Reyes National Seashore)	• Prioritize fuel treatments that are most effective from a wildfire behavior perspective; focus on designing those treatments to be ecologically neutral or beneficial. • Center forest health projects on re-introduction of beneficial fire, addressing mortality in post-1995 Vision Fire stands at Point Reyes, and increasing climate resilience for key forest types. • Address impacts of fire exclusion and protect/restore biological diversity in key areas. • Restore areas dominated by non-native forests and shrublands to promote biodiversity and reduce wildfire hazard.
Marin County Parks	• Leverage work advanced by Marin Wildfire Prevention Authority (MWPA) and other fire agencies to improve degraded forest conditions and protect/enhance biodiversity. • Emphasis on understanding/improving forest ecosystem function and opportunities to advance cross-jurisdictional work in collaboration with other land managers.
California State Parks	• Increase forest health and resilience for key forest types across Marin County, using treatments designed to protect/enhance habitat. • Promote wildfire and climate resilience in forests that provide habitat for sensitive wildlife species. • Work with MWPA and other fire agencies to support strategic fuels reduction work while maintaining/improving ecological function.

MARIN WATER PRIORITY TREATMENT AREAS

Marin Water (previously Marin Municipal Water District, MMWD) owns 22,000 acres of land in Marin County and manages seven water supply reservoirs providing drinking water to 191,000 community members (Marin Water, n.d.b.). Mount Tamalpais is both the iconic heart of and highest peak in Marin County, at over 2,575 feet in elevation, and Marin Water manages nearly 19,000 acres of land adjacent to the mountain, the majority of which lies to to the north of the peak in the Kent Lake-Lagunitas Creek Watershed (Figure 8.26). Collectively referred to as Mount Tamalpais Watershed lands, these lands were recognized as one of the original thirteen protected areas designated part of the Golden Gate Biosphere Reserve in 1988, recognizing the global significance of its biological diversity (UNESCO, n.d.).

Marin Water lands contribute significantly to the total protected forested lands in Marin County including 4,108 acres of Coast Redwood (50% of all protected acres), 74% of protected Sargent Cypress forest (331 acres), 63% of Marin's canyon live oak (*Quercus chrysolepis*) woodlands (465 acres), and 46% of all protected California black oak (*Q. kelloggii*) woodlands (63 acres). Mount Tamalpais Watershed lands include significant acres of other valuable habitat types and vegetation communties including decidious and evergreen hardwood forests, riparian habitats, grasslands (including serpentine areas and wet meadows), chaparral, mixed-conifer forests, and others (Figure 8.27). These wildlands are important habitat for many wildlife species of interest including Northern Spotted Owls (*Strix occidentalis caurina*), Osprey (*Pandion haliaetus)*, western pond turtles (*Actinemys marmorata*), foothill yellow-legged frogs (*Rana boylii*), and the Lagunitas Creek run of Coho salmon (*Oncorhynchus kisutch*) and steelhead trout (*Oncorhynchus mykiss irideus*)[13] (Marin Water, 2019a, pp. 2-16).

Over 25,000 structures, housing approximately 45,000 residents, are within two miles of Marin Water's Mt. Tamalpais Watershed lands along the WUI that CAL FIRE characterizes as High to Very High Fire Hazard Severity Zones (Marin Water, 2019a, pp. 2-6). Marin Water recognized that complex interactions between wildfire hazard and ecological threats such as climate change, prolonged drought, invasive species, and forest pathogens, have the potential to degrade forests and watershed functions which can in turn reduce water quality, water supply infrastructure, and impact neighboring communities. To support management actions to address these challenges Marin Water adopted the *Biodiversity, Fire, and Fuels Integrated Plan* (*BFFIP*) in October 2019 (Marin Water, n.d.a., 2019a) following review of the Environmental Impact Report (EIR), which provides environmental assessment and clearance for vegetation management work on watershed lands (Marin Water, 2019b).

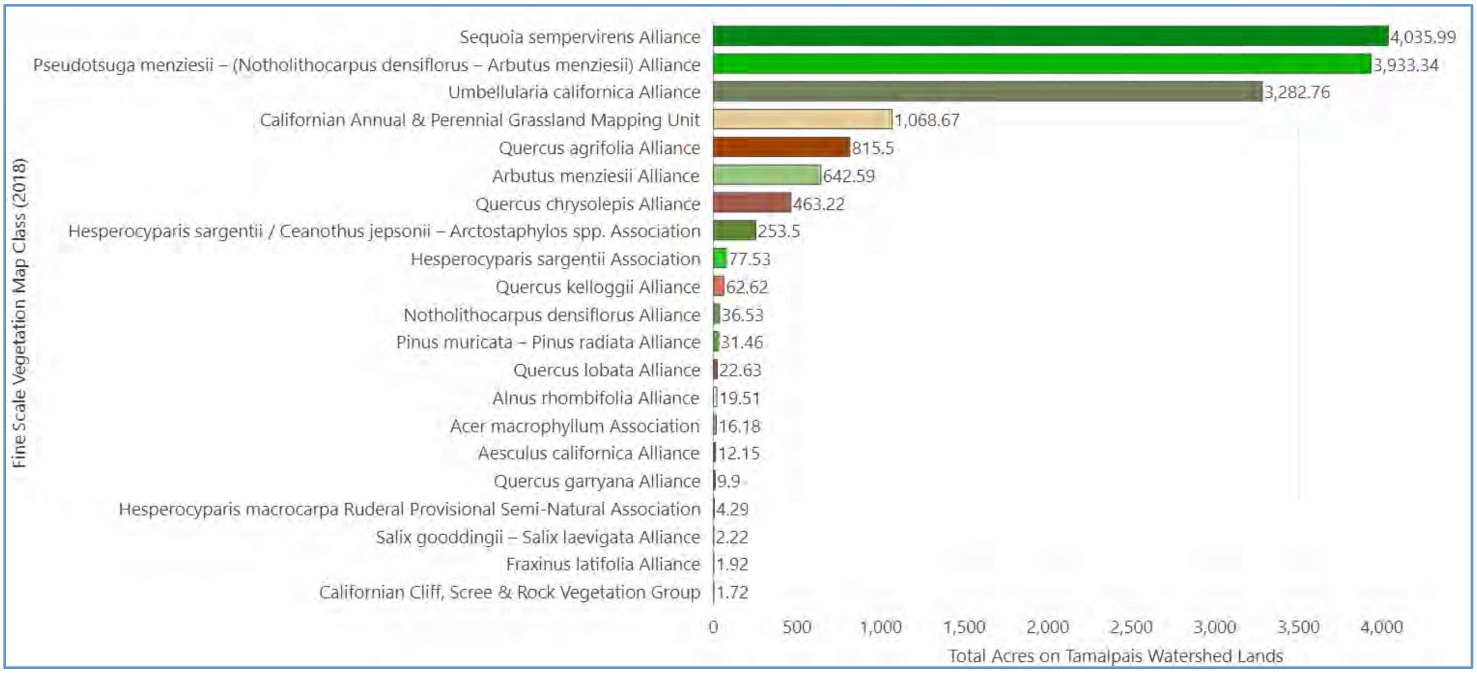
Under the *BFFIP*, Marin Water is implementing vegetation management projects to minimize fire hazard and maximize ecological health on its watershed lands. Analysis of potential

[13] Marin Water's *Biodiversity, Fire and Fuels Integrated Plan* (*BFFIP*) includes appendices detailing existing data and a reference list for research on District lands and biological resources (*BFFIP* Appendix C), as well as an inventory of Special-Status Plants Known to Occur or with Potential to Occur on Marin Water Lands (*BFFIP* Appendix D).

project areas and multi-benefit treatment opportunities for Marin Water lands described in this chapter will highlight places where active management, including the potental use of beneficial fire, can improve or restore forest health and the departure from desired conditions brought about by fire exclusion.

Figure 8.26. Mt. Tamalpais Watershed lands (approximately 19,000 acres) managed by Marin Water, Marin County, CA.

Figure 8.27. Native forest, shrubland, and herbaceous vegetation community acres, Marin Water, Tamalpais Watershed.



Prior to the modern fire suppression era, Marin Water's Tamalpais Watershed lands were some of the areas which most frequently experienced fire in Marin County. According to the *Marin County Wildfire History Mapping Project* (Dawson, 2021; Appendix B: Wildfire History) the upper slopes of Mount Tamalpais experienced fires greater than 160 acres in size between 7 and 11 times between 1852 and 1945 (Dawson, 2021, p. 13). Available spatial data shows that between 1859 and 1940 the average fire return interval for 63% of forests on Tamalpais Watershed lands (8,659 acres) was 15 to 30 years (Figure 8.28). Despite this history of relatively frequent fire, the last major fire in the area was the Mill/Carson Canyon Fire in 1945, thus nearly all of the forests (99.84% or 13,786 acres) on Tamalpais Watershed have not experienced a fire greater than 160 acres in more than 78 years (Dawson, 2021) (Figure 8.29).

Over multiple decades, fuel load and forest conditions have been impacted by the spread of sudden oak death (SOD), caused by the pathogen *Phytophthora ramorum*, and non-native invasive plants, such as French broom (*Genista monspessulana*) (Marin Water, 2019a). In some areas fire exclusion, which includes both the impacts of modern fire suppression and the removal of Coast Miwok people and tending practices from their lands, has resulted in a combination of fuel arrangements outside of historical norms. It has also lead to a departure from desired ecological conditions for many habitat types on Marin Water lands, including forest types profiled in the *Forest Health Strategy*.

As part of the *BFFIP*, Marin Water is conducting a series of actions to construct and maintain fuel breaks, control the spread of non-native invasive species, thin and remove Douglas-fir trees encroaching into sensitive habitats such as grasslands and oak woodlands, and manage forests impacted by sudden oak death. In many areas, Marin Water would like to follow-up on manual/mechanical thinning treatments with beneficial fire to improve biodiversity and forest ecosystem function. The *BFFIP* allows for prescribed burning on an annual basis, with individual burn projects ranging from 20 to 100 acres in size depending on habitat type (Marin Water, 2019a, p. 130).

The project areas and multi-benefit treatment opportunities described in this section are representative of Marin Water's future project goals and are greatly influenced by the treatment feasibility analysis and accessibility. However, final treatment areas prioritized for implementation will be influenced by additional ongoing fire behavior and treatment efficacy modeling, field reconnaissance, compliance surveys, and review by Marin Water resource staff.

Figure 8.28. Classified fire return interval between 1859 and 1940 by acres, Tamalpais Watershed (Dawson, 2021).

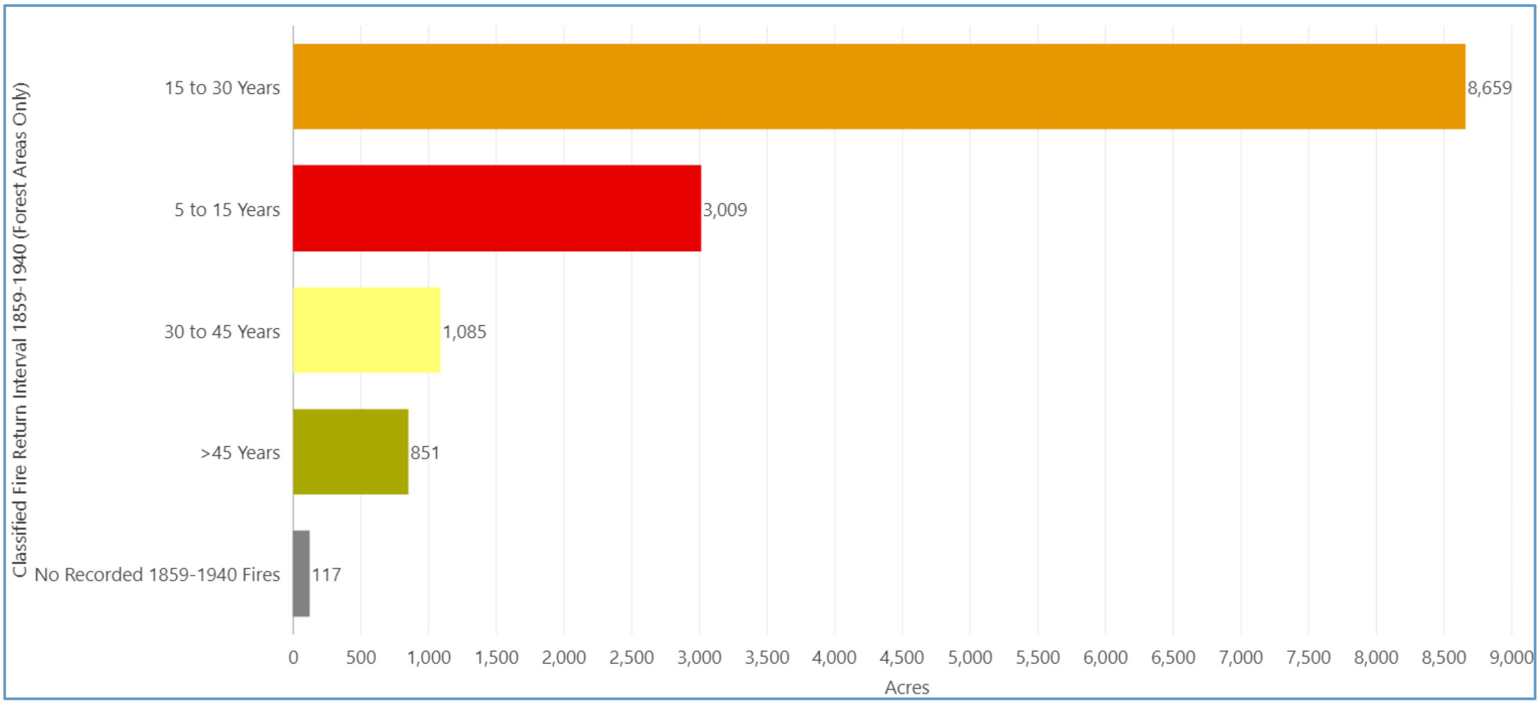
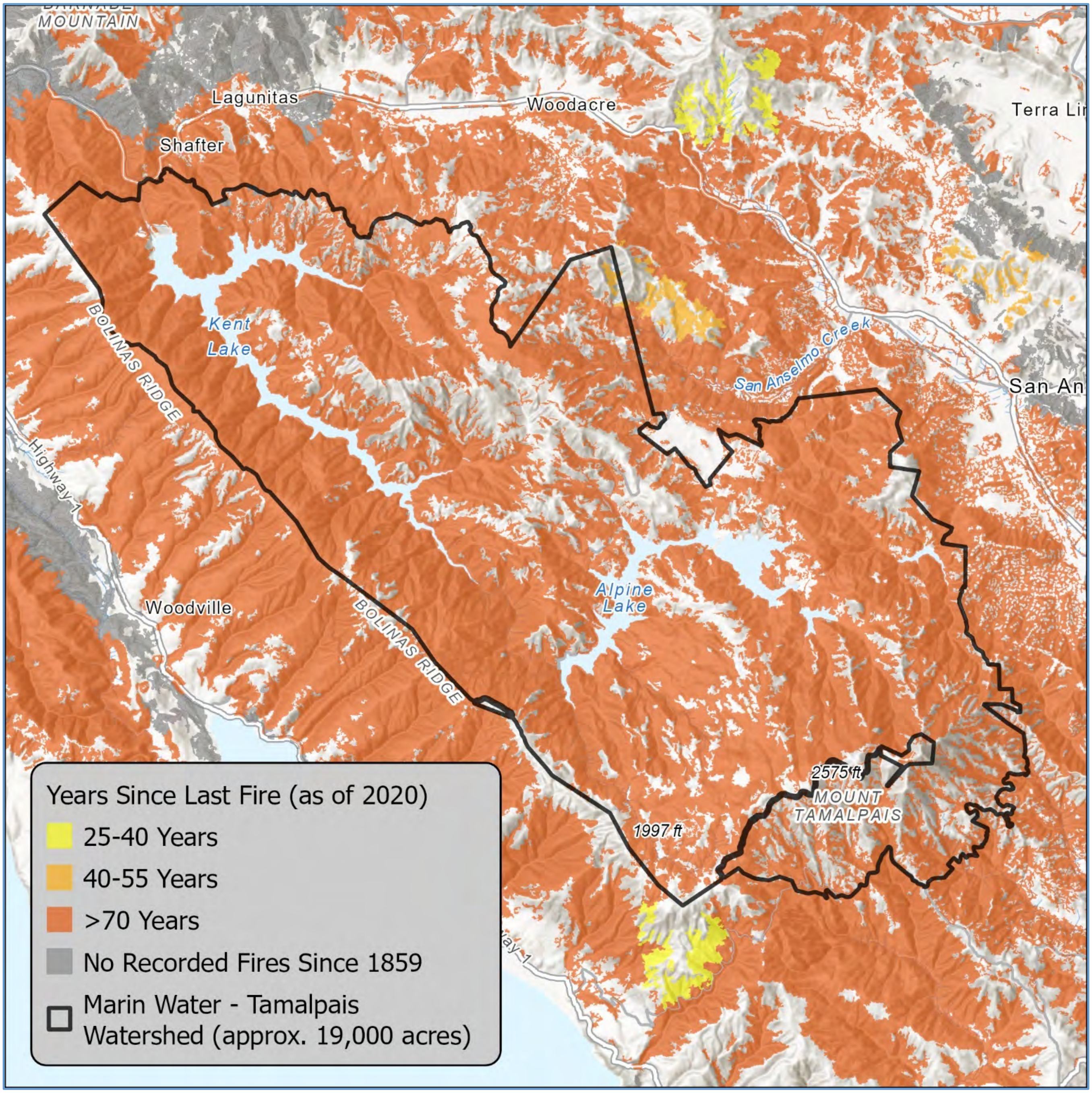


Figure 8.29. Classified years since last fire (forest areas only), Marin Water, Tamalpais Watershed (Dawson, 2021).



To prioritize and frame vegetation management approaches, the Marin Water *BFFIP* subdivides Tamalpais Watershed lands into two broad conceptual categories: Infrastructure Zones and Natural Areas Zones (Marin Water, 2019a, pp. 3-25). Infrastructure Zones comprise roughly 7% of watershed lands and include a maintained fuelbreak system around buildings, water supply infrastructure, and facilities (Marin Water, 2019a). Vegetation management approaches in these areas are oriented towards maintaining safety and accessibility for these assets, which can sometimes result in alteration of the natural plant community structure. Conversely, Natural Areas Zones, which encompass the remaining 93% of watershed lands, are characterized by the their relatively intact ecosystems and presence of predominantly native vegetation species (Marin Water, 2019a, pp. 3-40).

The *BFFIP* details threats and trends affecting Natural Areas Zones and, for prioritization purposes, futher segements them into units that correspond to differing conditions – Ecosystem Preservation Zone, Ecosystem Restoration Zone, Ecosystem Restoration/Wide Area Fuel Reduction Zone, and Ecosystem and Fuels Deferred Action Areas – and provides an overview of management drivers and approaches for each zone (Figure 8.30). The potential project areas and multi-benefit treatment opportunities on Marin Water lands described in this section (Figure 8.31) will reference corresponding infrastructure or natural area zones in order to connect them to the management opportunities and constraints outlined in the Marin Water *BFFIP*.

Figure 8.30. Management Zones identified in the 2019 Marin Water Biodiversity Fire and Fuels Integrated Plan (BFFIP) (left), and subdivision of Natural Areas Zones based on management objectives outlined in the BFFIP (Marin Water, 2019a, pp. 3-40 – 3-41) (right).

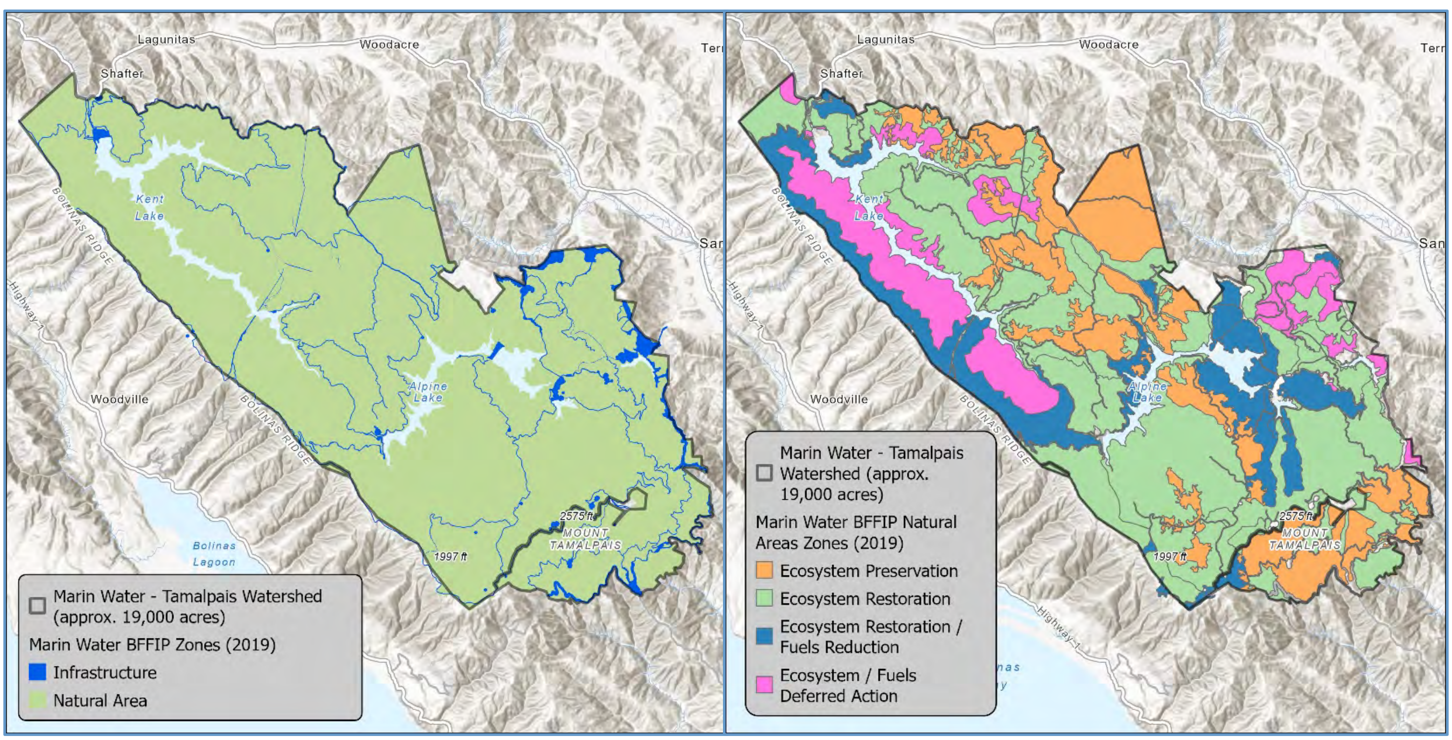
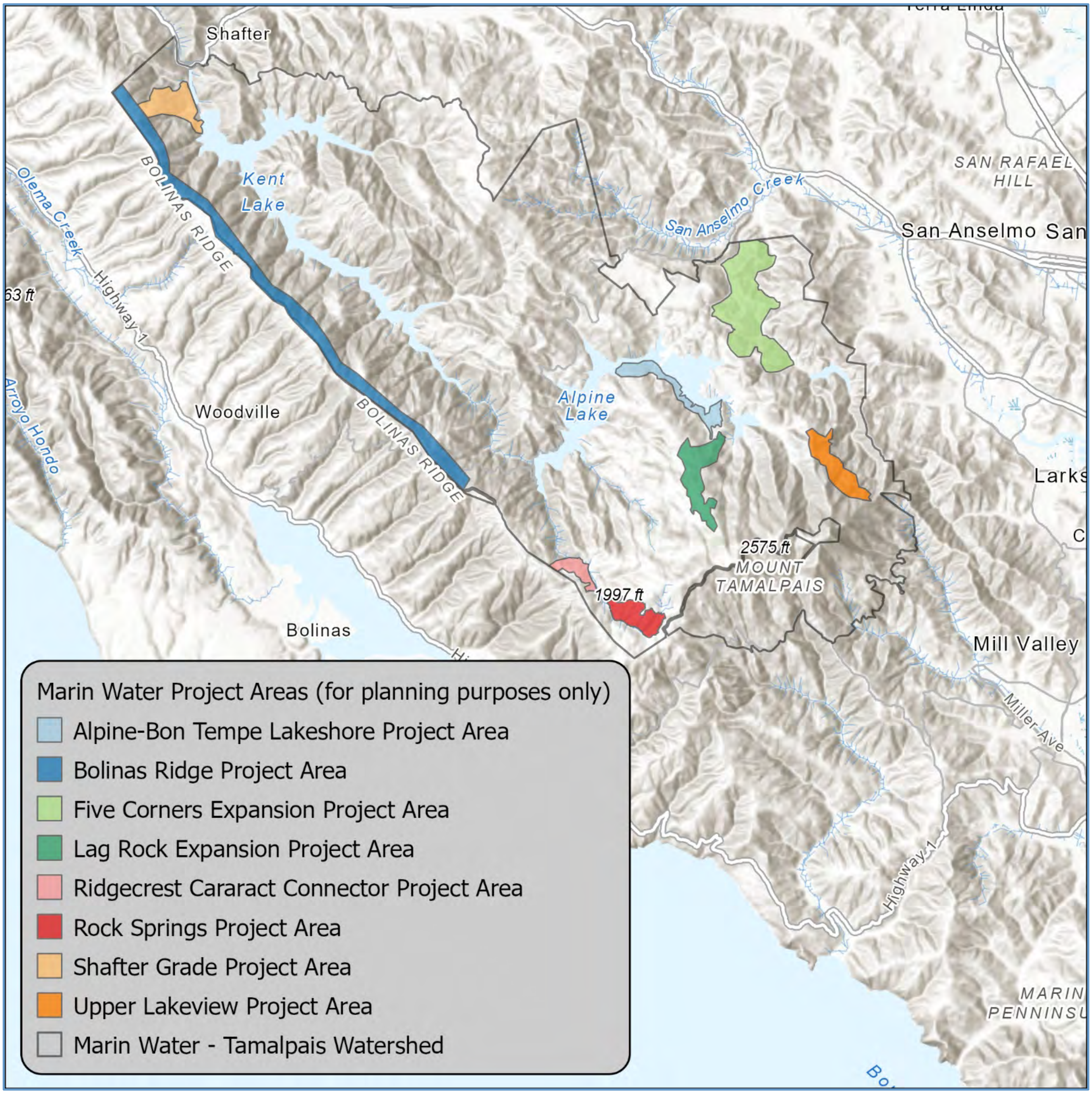


Figure 8.31. Overview of potential future priority project areas analyzed in this section, Marin Water, Tamalpais Watershed.



BOLINAS RIDGE & SHAFTER GRADE PROJECT AREAS

The Bolinas Ridge and Shafter Grade project areas are located near the western boundary of Tamalpais Watershed, adjacent to other protected open space lands including Golden Gate National Recreation Area – Northern District Lands (managed by PRNS) and Audubon Canyon Ranch's Martin Griffin Preserve (Figure 8.32). Most of the Bolinas Ridge and Shafter Grade project areas are located within the *BFFIP*-designated Ecosystem Restoration/ Wide Area Fuel Reduction Natural Area Zone, which corresponds to management goals centered around proximity to existing infrastructure and natural resources at risk of significant damage in the event of a high intensity wildfire (Marin Water, 2019a, p. 3-41). Therefore, the overall goals of active management in these areas are wildfire risk reduction and improvements to ecological health via invasive species removal and forest management.

Vegetation communities present in the Bolinas Ridge and Shafter Grade project areas include mixed-conifer hardwood forests, chaparral and shrublands, and evergreen hardwood stands of California bay (*Umbellularia californica*) and tanoak. Approximately 85% of the project areas are dominated by key forest types profiled in the *Forest Health Strategy*, including 483 acres of Coast Redwood forest and 73 acres of Douglas-fir forest (Figure 8.33).

Starting in 2015, Marin Water, in coordination with the US Forest Service, University of California Davis, and California Polytechnic State University, has conducted research on forest resilience at multiple sites along Bolinas Ridge (Cobb et al., 2017). This research focused on the vegetation response to mechanical thinning in Coast Redwood stands heavily impacted by sudden oak death. Continued long-term monitoring of stand conditions, including local hydrology, will continue to provide data to inform current and proposed forestry projects in the Bolinas Ridge area and more broadly across the watershed.

Figure 8.32. Bolinas Ridge and Shafter Grade Project Areas, Marin Water, Tamalpais Watershed.

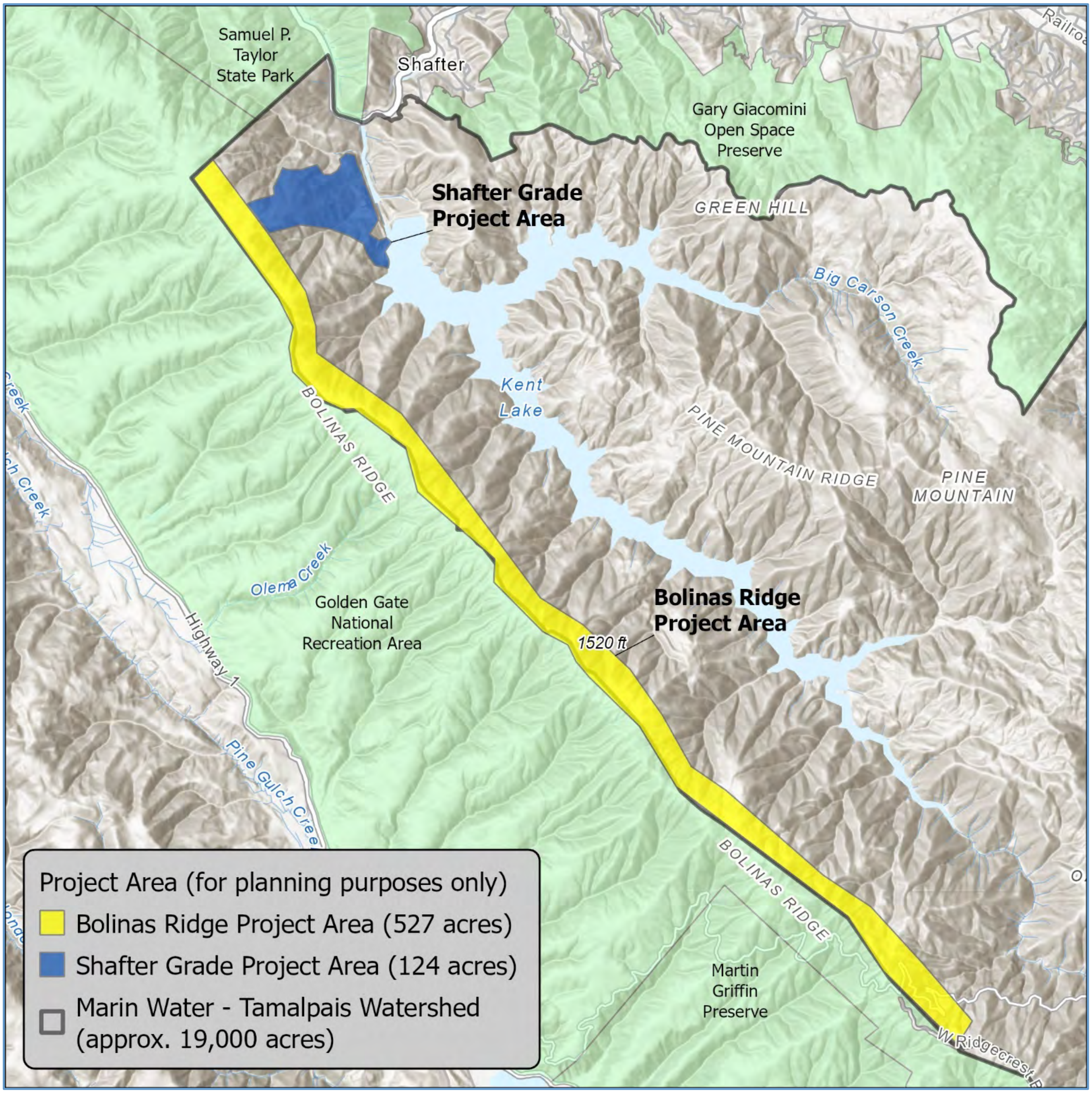
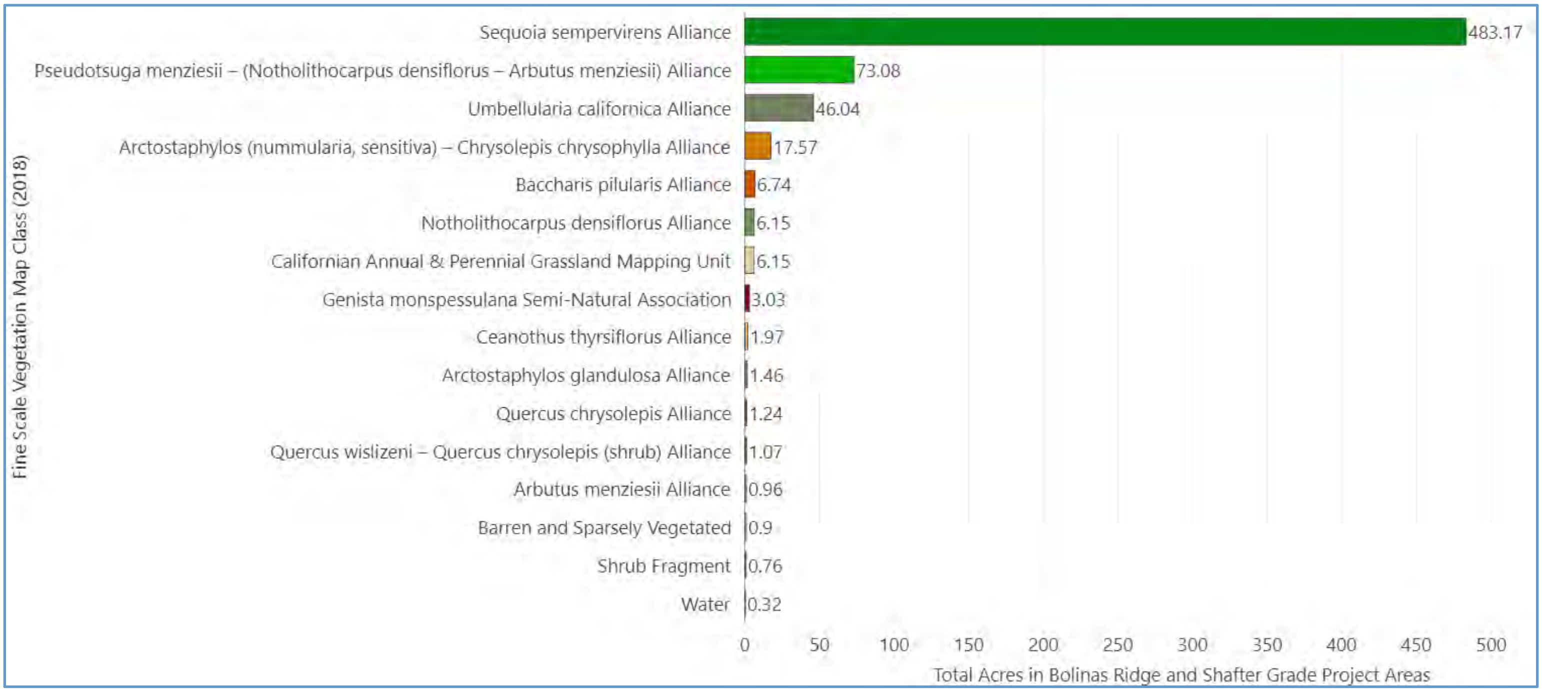


Figure 8.33. 2018 Fine Scale Vegetation Map vegetation community by acres within the Bolinas Ridge and Shafter Grade Project Areas.



Fire exclusion, coupled with impacts from sudden oak death, are driving a departure from desired conditions in the Bolinas Ridge and Shafter Grade project areas. Of the 610 acres of forest within these two project areas, 54% are classified as having relatively very high (188 acres) or high (141 acres) ladder fuels. Analysis of canopy mortality in these project areas shows 162 acres with 0.5 – 2.5 percent canopy mortality, with an additional 23 acres of forest with greater than 2.5 percent canopy mortality. The departure from desired conditions index for these project areas indicates significant opportunity to improve Coast Redwood forest health and resilience, with 164 acres in the top three departure classes (Figure 8.34). Notably, the project areas also include approximately 3 acres of French broom (*Genista monspessulana*). Treatment approaches could include thinning to strategically reduce ladder fuels, removal of dead dying biomass to address pathogen impacts (most likely sudden oak death), reduction of non-native species cover, and eventually reintroduction of beneficial fire. Treatments will focus on stands with a departure from desired conditions class greater than 4 and which are accessible via existing roads and trails. (Figure 8.35).

Figure 8.34. 2018 Fine Scale Vegetation Map class acres by departure from desired conditions indices (top three classes only), Bolinas Ridge and Shafter Grade Project Areas, Marin Water, Tamalpais Watershed.

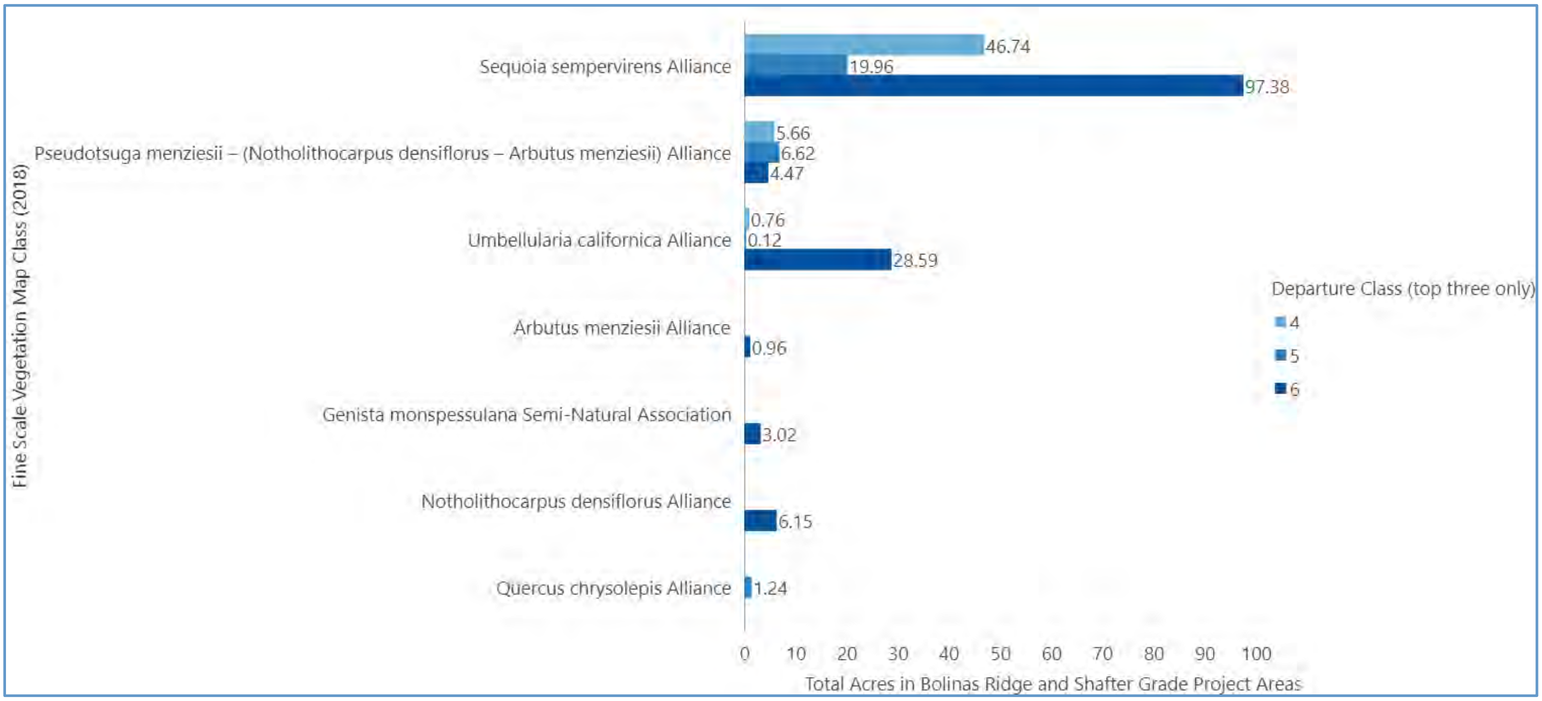
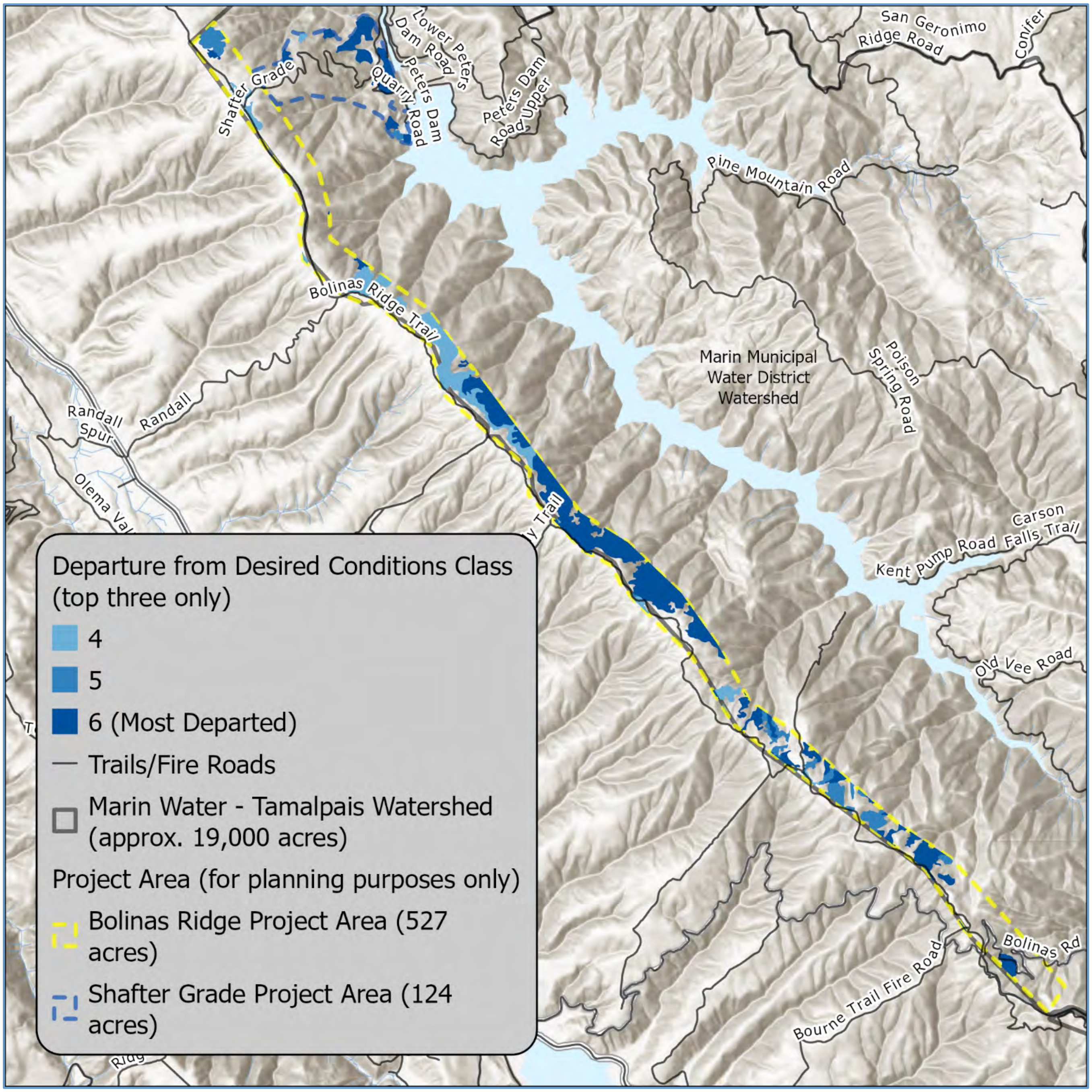


Figure 8.35. Bolinas Ridge and Shafter Grade Project Areas, departure from desired conditions (top three classes only) and nearby fire roads/trails.



ROCK SPRINGS & RIDGECREST-CATARACT CONNECTOR PROJECT AREAS

Marin Water's Rock Springs and Ridgecrest-Cataract Connector project areas are located in the southwestern corner of Tamalpais Watershed lands near Ridgecrest Blvd. and adjacent to Mount Tamalpais State Park (Figure 8.36). These project areas are primarly located in the Ecosystem Restoration Natural Areas Zones identified in the *BFFIP*, which are described as predominatly native species habitats impacted by pathogens, fire exclusion, and non-native invasive species. The overall management goals for Ecosystem Restoration Natural Areas Zones are focused on habitat improvements through invasive plant management and forestry work designed to protect or enhance biological diversity and ecosystem function (Marin Water 2019a, p. 3-40).

Work in the Rock Springs and Ridgecrest-Cataract Connector project areas will eventually tie into the Potrero Meadows forest restoration work that was completed in 2020 and builds off an existing wide area fuelbreak in place along Lagunitas Rock Springs Fire Rd. Additionally, the proposed treatment units builds off a smaller forestry project near the Mountain Theater in the vicinity of Rock Springs that was completed in 2021. Note also that this work aligns with the CWPP; Rock Springs Parking Lot and meadow are potential Temporary Refuge Areas (TRAs) for visitors during a wildfire (M. Brown, MWPA Executive Director, personal communication, March 7, 2023).

Marin Water is in the process of planning and implementing a prescribed burn adjacent to the proposed Rock Springs project area, which will likely be implemented within a 5-year timeframe. When completed, these treatments will collectively improve the ecological health and enhance the wildfire resilience for this portion of Tamalpais Watershed. Vegetation within these two project areas is dominated by Douglas-fir forest (74 % or 111 acres), 95% of which (105 acres) has less than 25% relative hardwood cover. Figure 8.37 shows the number of acres by 2018 Fine Scale Vegetation Map class for the Rock Springs and Ridgecrest-Cataract Connector project areas.

Figure 8.36. Rock Springs and Ridgecrest-Cataract Connector Project Areas, Marin Water, Tamalpais Watershed.

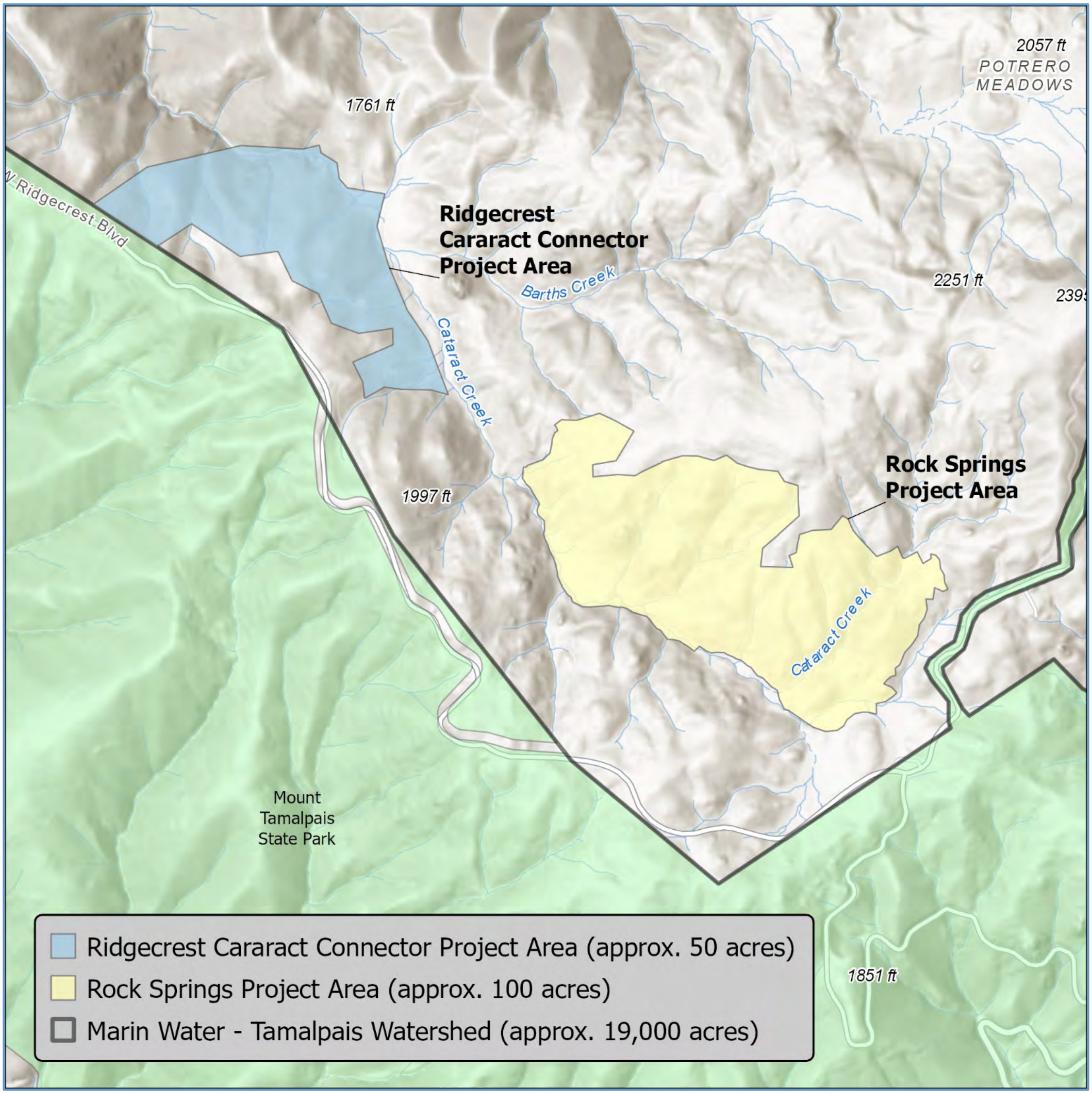
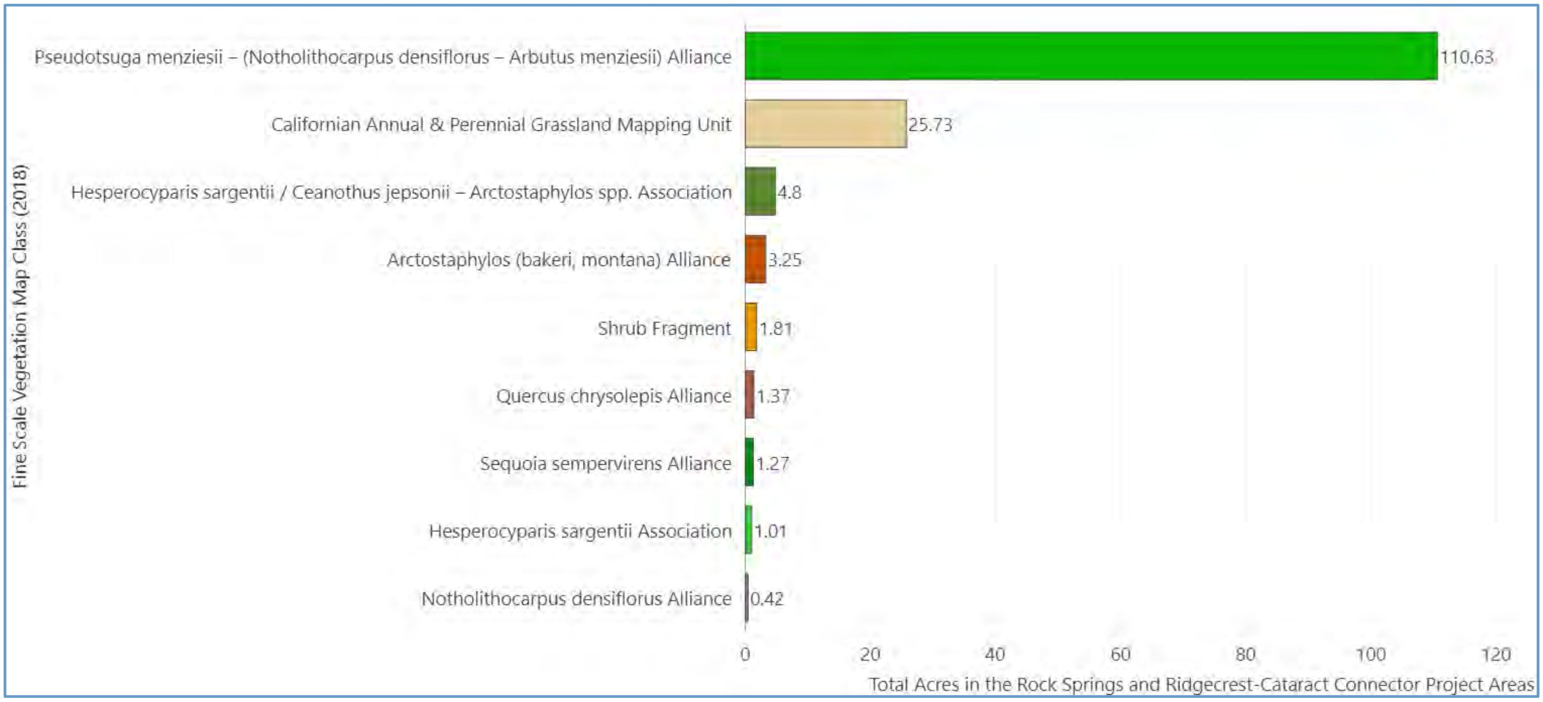


Figure 8.37. 2018 Fine Scale Vegetation Map vegetation communities by acres within Rock Springs and Ridgecrest-Cataract Connector Project Areas.



Fire exclusion and pathogen impacts are driving departure from desired conditions in the Rock Springs and Ridgecrest-Cataract Connector project areas. This includes significant areas of Douglas-fir forest with detectable canopy mortality (46 acres) and relatively high canopy gaps formed between 2010 and 2019 (67 acres with greater than 2.5% gaps formed). The project areas include 20 acres of short, early seral Douglas-fir stands with less 60 feet mean lidar-derived stand height, which are likely encroaching on nearby grassland and/or other habitats in the absence of fire. Analysis of the departure from desired conditions index shows that a majority (51%) of the forest stands in the project area are in the top three departure classes, including 40 acres in the most departed class, indicating significant opportunity to improve forest health in this area (Figure 8.38). Many stands mapped with a departure from desired condition class of 4 or greater are located near trails, making active management relatively feasible (Figure 8.39).

Over the last decade, Marin Water has conducted extensive removal of Douglas-fir encroaching on grasslands in the Ridgecrest area. Continued treatment approaches, focused on stands within the top three departure classes, will include forest thinning to emulate the effects of low intensity fire, non-native invasive species management, removal of dead and dying vegetation impacted by pathogens (most likely sudden oak death). The use of beneficial fire is also being evaluated, which would benefit long-term forest health within both the Ridgecrest and Rock Springs project areas.

Figure 8.38. 2018 Fine Scale Vegetation Map class acres by departure from desired conditions indices (top three classes only), Rock Springs and Ridgecrest-Cataract Connector project areas, Marin Water, Tamalpais Watershed.

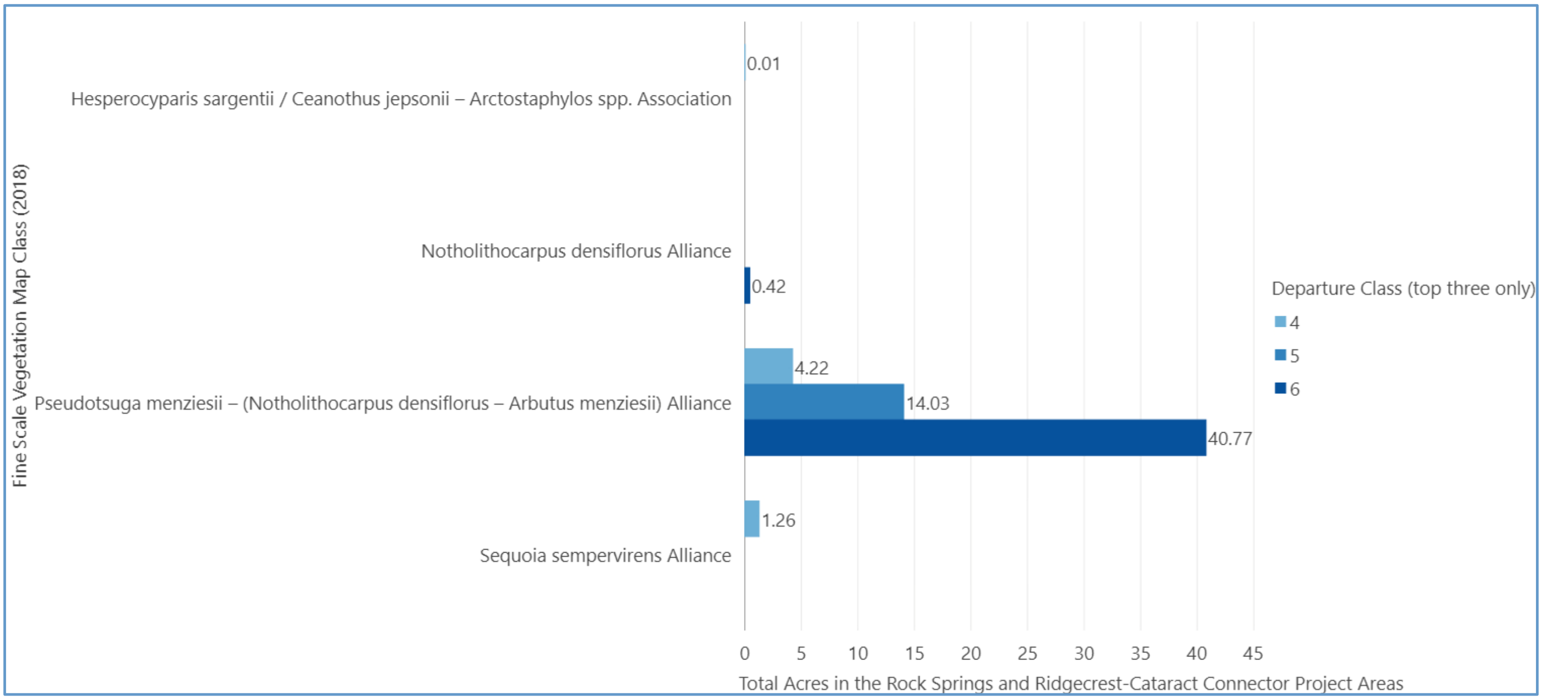
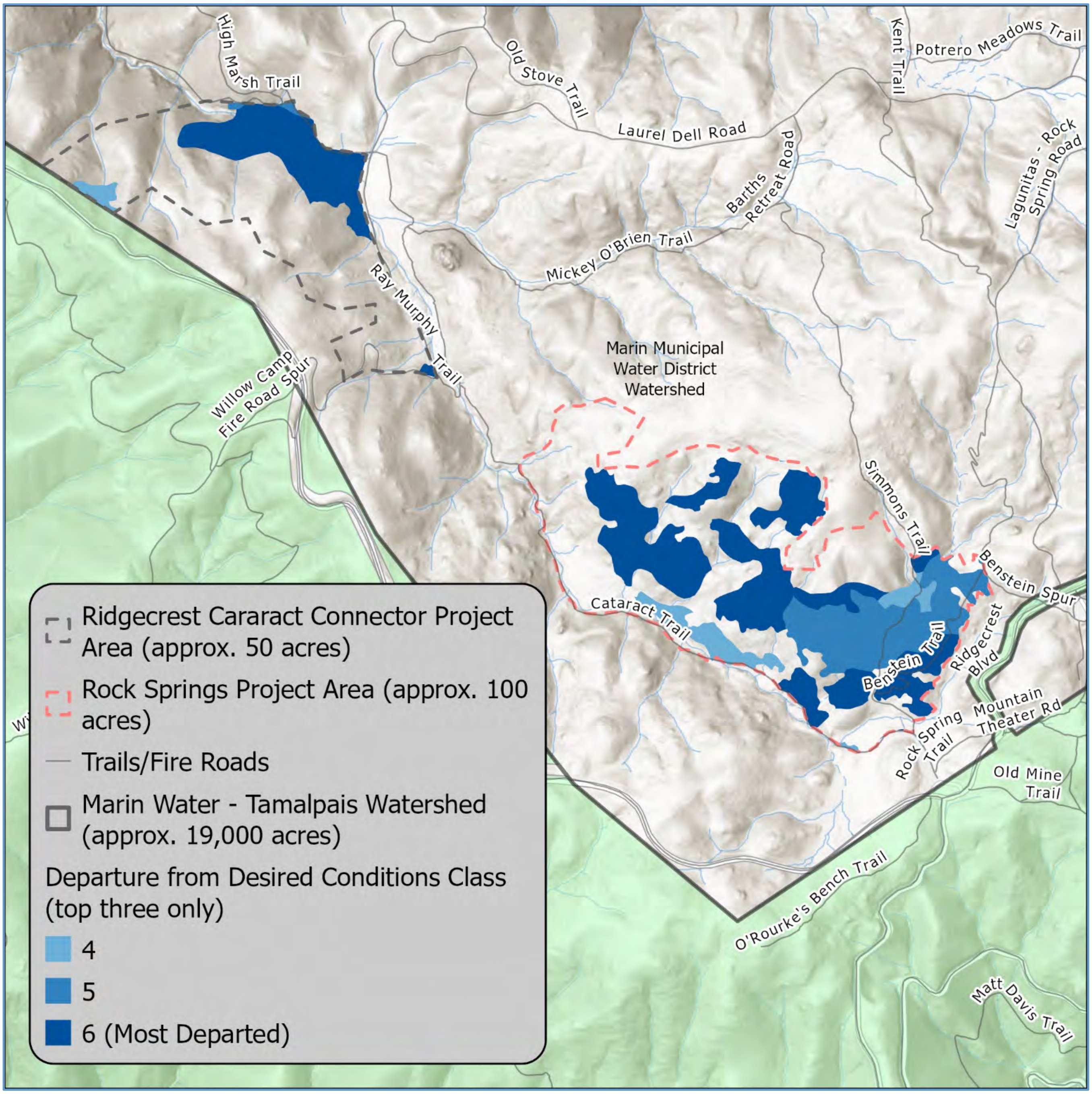


Figure 8.39. Rock Springs and Ridgecrest-Cataract Connector Project Areas, departure from desired conditions (top three classes only) and nearby fire roads/trails, Marin Water, Tamalpais Watershed.



ALPINE-BON TEMPE LAKESHORE & LAG ROCK EXPANSION PROJECT AREAS

The Alpine-Bon Tempe Lakeshore and Lag Rock Expansion project areas are situated on the north facing slopes and ridges of Tamalpais Watershed, adjacent to and above the Lake Lagunitas, Bon Tempe, and Alpine Lake reservoirs (Figure 8.40). Most of these two project areas are located within the *BFFIP*-designated Ecosystem Restoration / Wide Area Fuel Reduction Natural Area Zone which, like the Ecosystem Restoration zone emphasizes management designed to enhance biological diversity and function, but includes the need to break up the horizontal and vertical continuity of fuels in order to reduce wildfire risk to existing infrastructure and natural resources that could be damaged in a high intensity wildfire (Marin Water, 2019a, p. 3-41).

The overarching goals of forestry and vegetation management work in these project areas are to reduce wildfire risk and improve ecosystem health by controlling non-native invasive species and improving the fuel profile. Key forest communities present include Douglas-fir (157 acres), Coast Redwood (30 acres), Sargent Cypress (2 acres), and a relatively small number of Open Canopy Oak Woodland stands in the Alpine-Bon Tempe Lakeshore project area including coast live oak (*Quercus agrifolia*, 4 acres), California white oak (*Q. lobata*, 3 acres), and California black oak (*Q. kelloggii*, 1 acre) (Figure 8.41).

Pathogen impacts, likely sudden oak death caused by *Phytophthora ramorum*, are contributing to a departure from desired conditions in the Alpine-Bon Tempe Lakeshore and Lag Rock Expansion project areas. Eighteen percent (29 acres) of Douglas-fir forest have detectable canopy mortality combined with 25 acres of stands with greater than 2.5% canopy gaps formed between 2010 and 2019. Thirty-eight percent (14 acres) of Coast Redwood forest within the project area had visible canopy mortality in 2018, and 24 acres (80%) had gaps greater than 2.5% formed between 2010 and 2019.

Fire exclusion is also impacting these project areas and adding to a departure from desired conditions. Sixty-five percent (103 acres) of Douglas-fir forest within the Alpine-Bon Tempe Lakeshore and Lag Rock Expansion project areas is classified as small (mean lidar-derived stand height less than 60 feet), which is an indication of dense stands with “dog hair” thickets of small-diameter trees. Thirteen acres (43%) of Coast Redwood forest within these project areas is in a similar structural class (less than 60 feet mean stand height). Fire exclusion is also contributing to relatively high fuel loads, with 34% of all forests within the project areas (74 acres) classified as having high or very high ladder fuels. In total 127 acres (59%) of native forests within the project areas are in the top three departure from desired conditions classes (Figure 8.42).

These projects will focus on forest stands within the top three departure from desired conditions classes. Treatments designed to emulate the effects of low to moderate intensity fire could be used in these project areas, including selective thinning and removal of small-diameter Douglas-fir (particularly in areas where they are encroaching into adjacent chaparral communities hosting numerous rare plant species), breaking up the vertical and horizontal structure of fuels, removal of dead and dying vegetation, and eventually beneficial fire. Improved water quality is an additional anticipated benefit from treatments along the shorelines of Alpine Lake and Bon Tempe Lake reservoirs. Many of the stands with a departure from desired conditions index greater than three are adjacent to existing fire roads or trails, making manual/mechanical treatments feasible in the Alpine-Bon Tempe Lakeshore and Lag Rock Expansion project areas (Figure 8.43).

Figure 8.40. Alpine-Bon Tempe Lakeshore and Lag Rock Expansion Project Areas, Marin Water, Tamalpais Watershed.

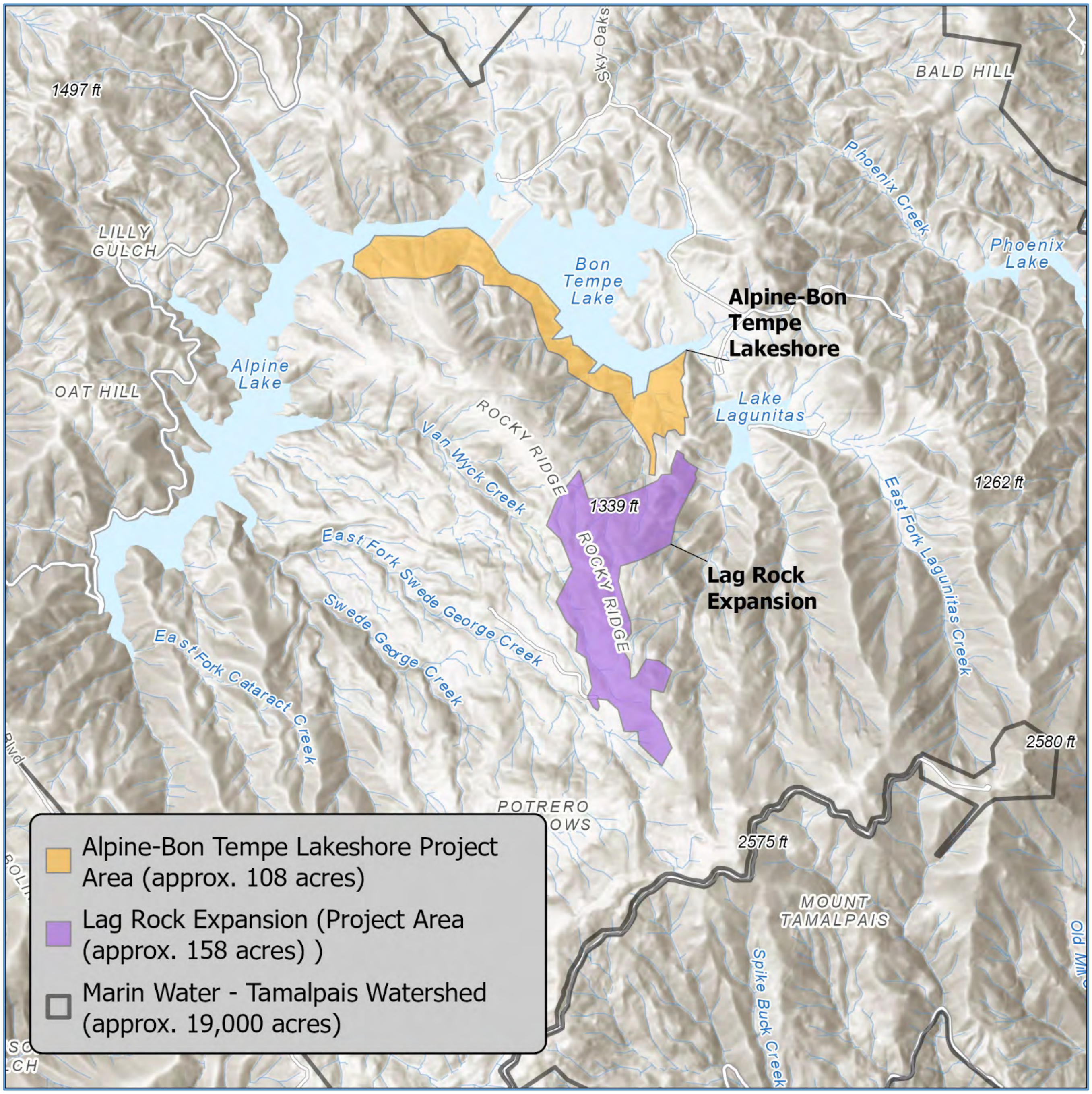


Figure 8.41. 2018 Fine Scale Vegetation Map vegetation communities by acres within Alpine-Bon Tempe Lakeshore and Lag Rock Expansion Project Areas.

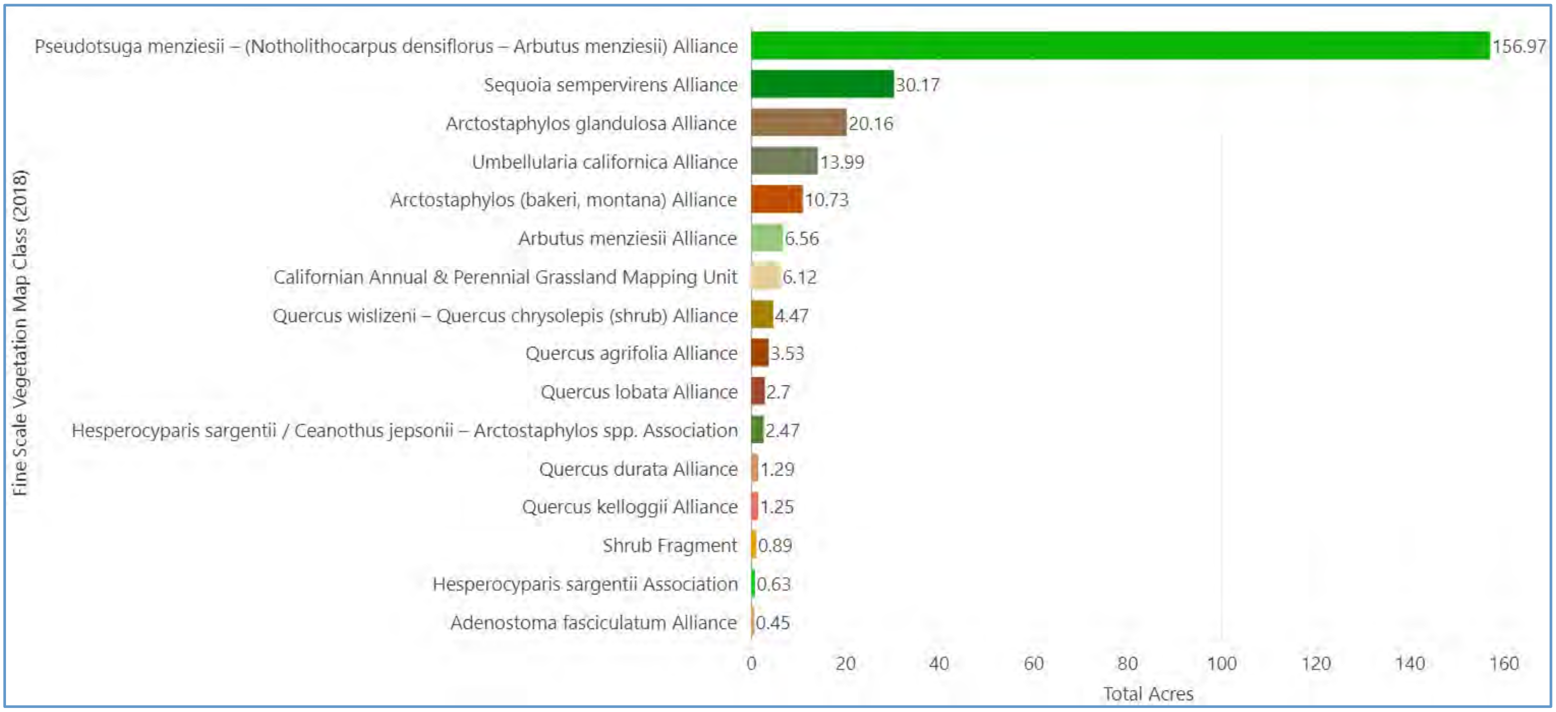


Figure 8.42. 2018 Fine Scale Vegetation Map class acres by departure from desired conditions indices (top three classes only), Alpine-Bon Tempe Lakeshore and Lag Rock Expansion Project Areas, Marin Water, Tamalpais Watershed.

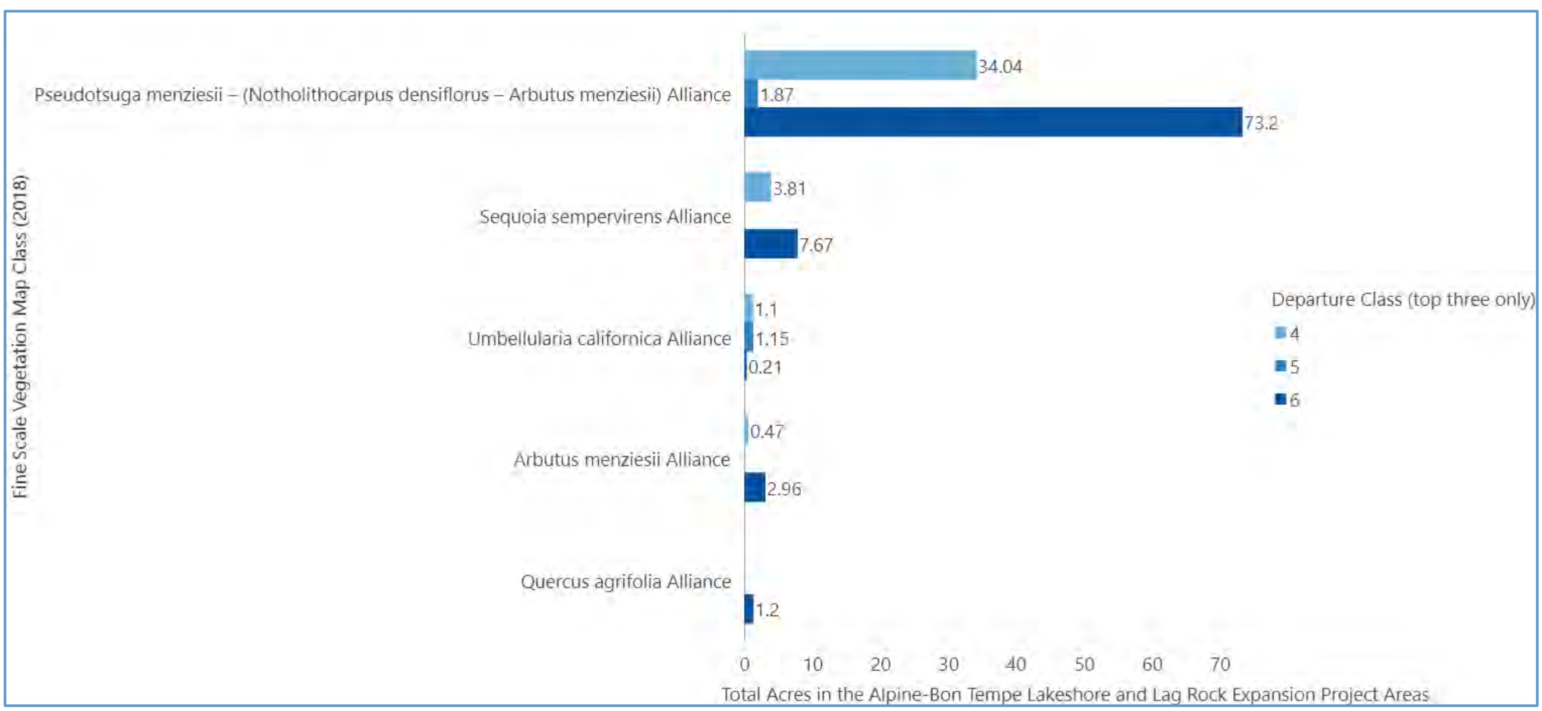
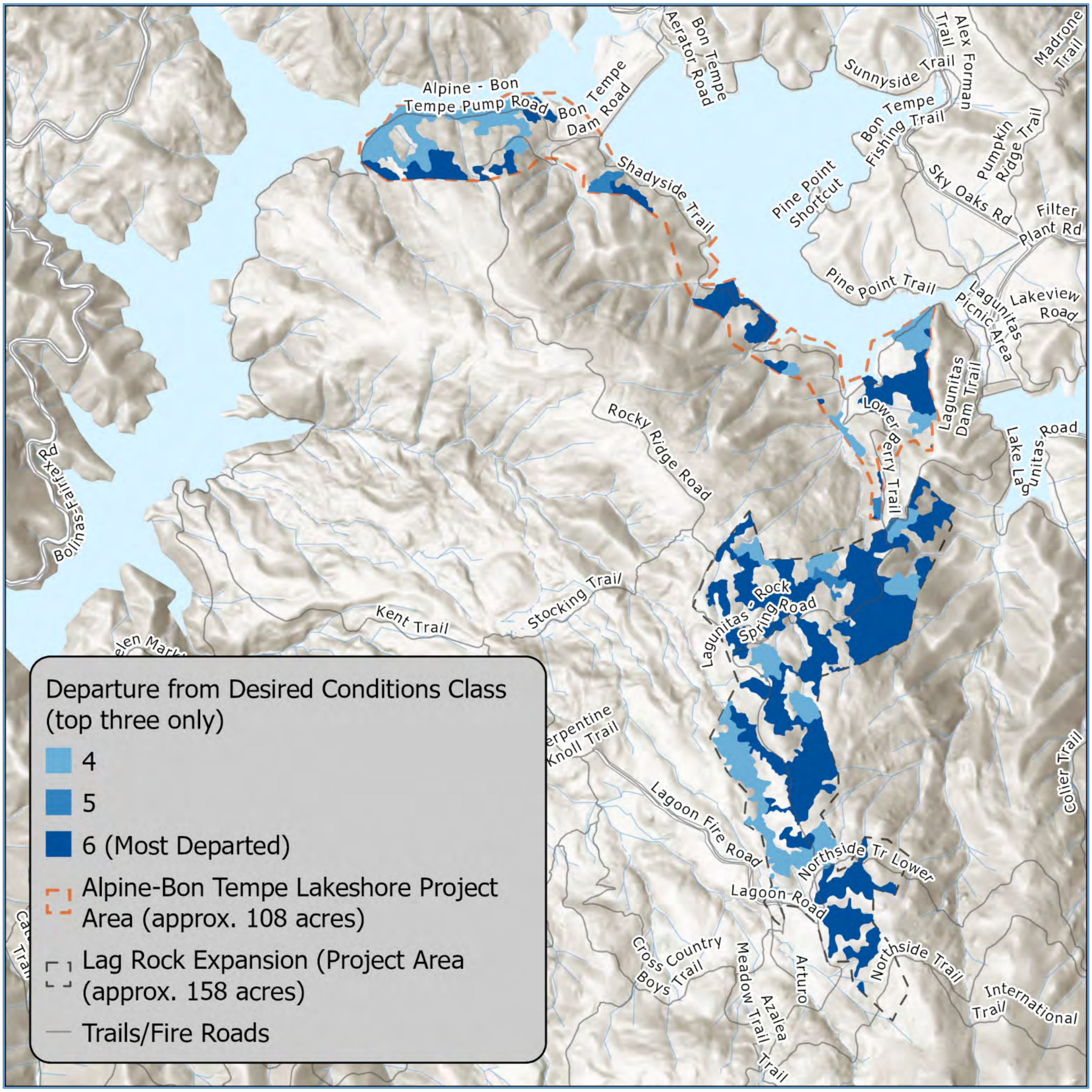


Figure 8.43. Alpine-Bon Tempe Lakeshore and Lag Rock Expansion Project Areas, departure from desired conditions (top three classes only) and nearby fire roads/trails, Marin Water, Tamalpais Watershed.



UPPER LAKEVIEW PROJECT AREA

The Upper Lakeview project area is located on the eastern side of Marin Water's Tamalpais Watershed lands, below the east peak of the Mount Tamalpais and above both the Lake Lagunitas and Phoenix Lake reservoirs (Figure 8.44). Virtually all of the Upper Lakeview project area is located within the Ecosystem Restoration Natural Areas Zone identified in the 2019 *BFFIP*, and designated as ecosystems predominatly comprised of native vegetation but negativly impacted by diseases such as sudden oak death, non-native invasive species, and altered conditions due to fire exclusion. The overall management goals for Ecosystem Restoration Natural Areas Zones are improvements to the ecological function and biodiversity through increased invasive plant removal and treatments that will promote forest health and resilence (Marin Water, 2019a, p. 3-40). Vegetation communties within the Upper Lakeview project area are varied; forest communities in the project area include a mix of Coast Redwood (40 acres) and evergreen hardwoods such as Pacific madrone (30 acres) and California bay (15 acres), along with significant acres of various chaparral species (Figure 8.45).

Indications of pathogen impacts, drought stress, and fire exclusion are driving departure from desired conditions in the Upper Lakeview project area. Of the 46 acres of evergreen hardwood stands (*Arbutus menziesii*, *Quercus chrysolepis*, and *Umbellularia californica*) in the project area 57% (26 acres) have detectable mortality in the canopy, 17% (8 acres) of which shows greater than 2.5% mortality. The evergreen hardwood stands also show an additional 7 acres (15%) as having greater than 2.5% canopy gaps formed between 2010 and 2019. Canopy density differencing in the evergreen hardwoods shows 29 acres (63%) have experienced greater than 5% canopy loss between 2010 and 2019. In conifer dominated portions of the project area (*Sequoia sempervirens* and *Pseudotsuga menziesii*), 12 of the 46 acres (26%) have detectable canopy mortality. Notably 100% of Douglas-fir (6.5 acres) and 60% (24 acres) Coast Redwood forest within the project area are in the shortest structural class (less than 60 feet mean lidar-derived stand height), an indication of small dense stands. Ladder fuels are high across forest types in the project area with 50% (63 acres) classified as very high, including 29 acres of Pacific madrone, 15 acres of Coast Redwood, 15 acres of California bay, and 3 acres of Douglas-fir forest all in the highest ladder fuel class. Cumulative results of the departure from desired conditions index for native forests in the Upper Lakeview project shows that 59% (54 acres) are in the top three departure classes (Figure 8.46).

Treatment approaches for this project area are oriented towards increasing forest health and resilience by thinning to remove small-diameter Douglas-fir and coast redwood trees, removal of dead and dying vegetation impacted by pathogens, invasive species management, and selective vegetation removals to break up the vertical and horizontal continuity of fuels emulating the effects of a low to moderate intensity fire. In areas where forks of Lagunitas Creek drain into Lake Lagunitas, increased water quality is also an expected benefit of active management. Work within the Upper Lakeview project areas ties directly into previous forest health and fuels reduction work surrounding Pilot Knob, further protecting the critical Bon Tempe Treatment Plant. Forestry work is feasible in the project area, including stands in the top three departure classes, given relatively good access from adjacent trails/fire roads (Figure 8.47).

Figure 8.44. Upper Lakeview Project Area, Marin Water, Tamalpais Watershed.

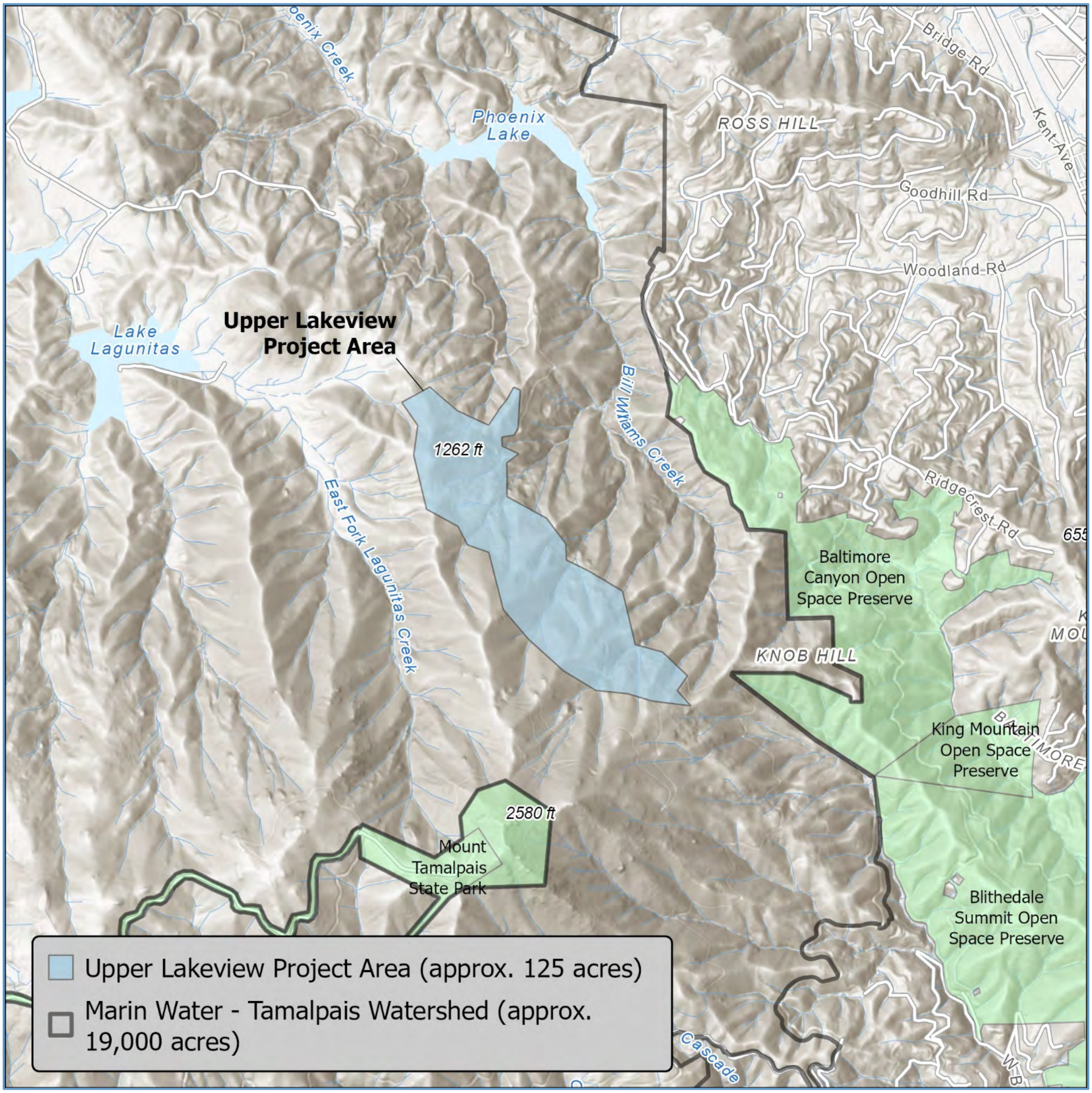


Figure 8.45. 2018 Fine Scale Vegetation Map vegetation communities by acres within the Upper Lakeview Project Area.

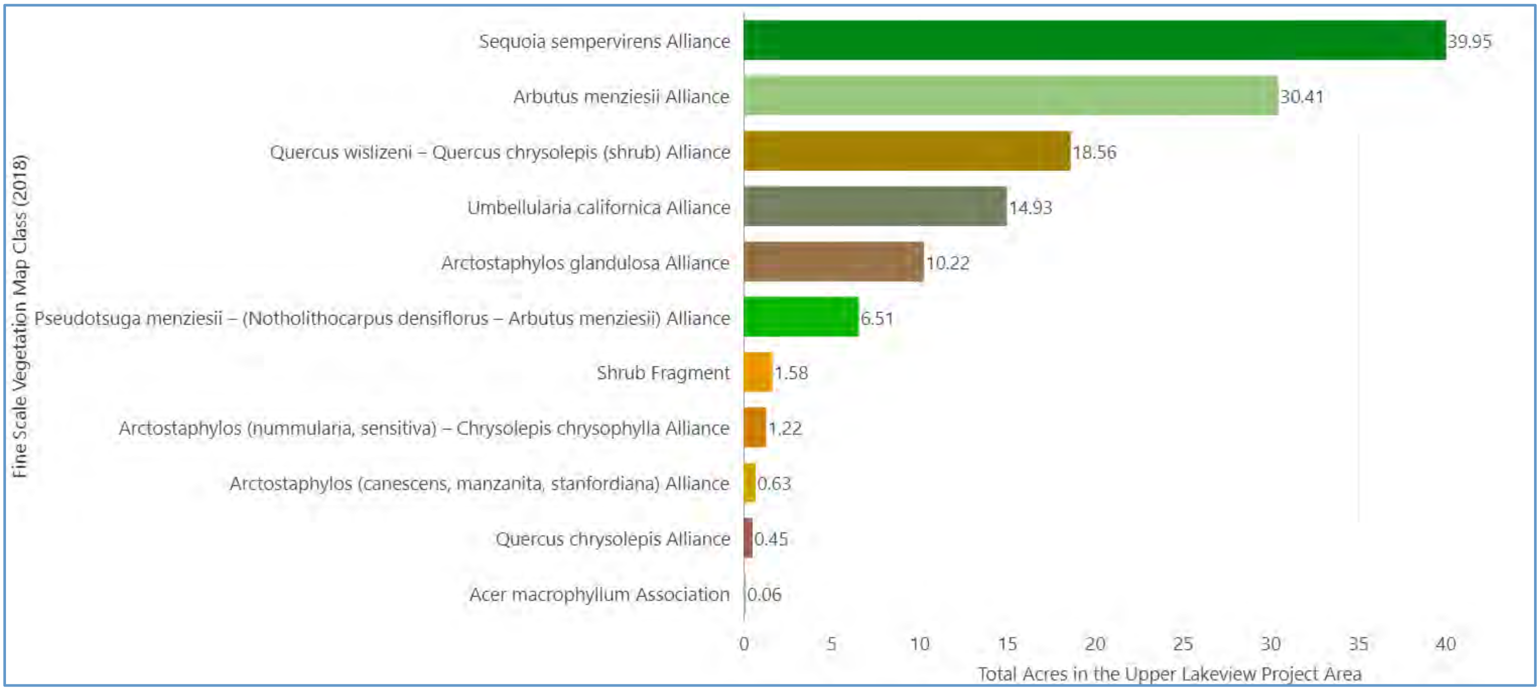


Figure 8.46. Upper Lakeview Project Area, departure from desired conditions (top three classes only) and nearby fire roads/trails, Marin Water, Tamalpais Watershed.

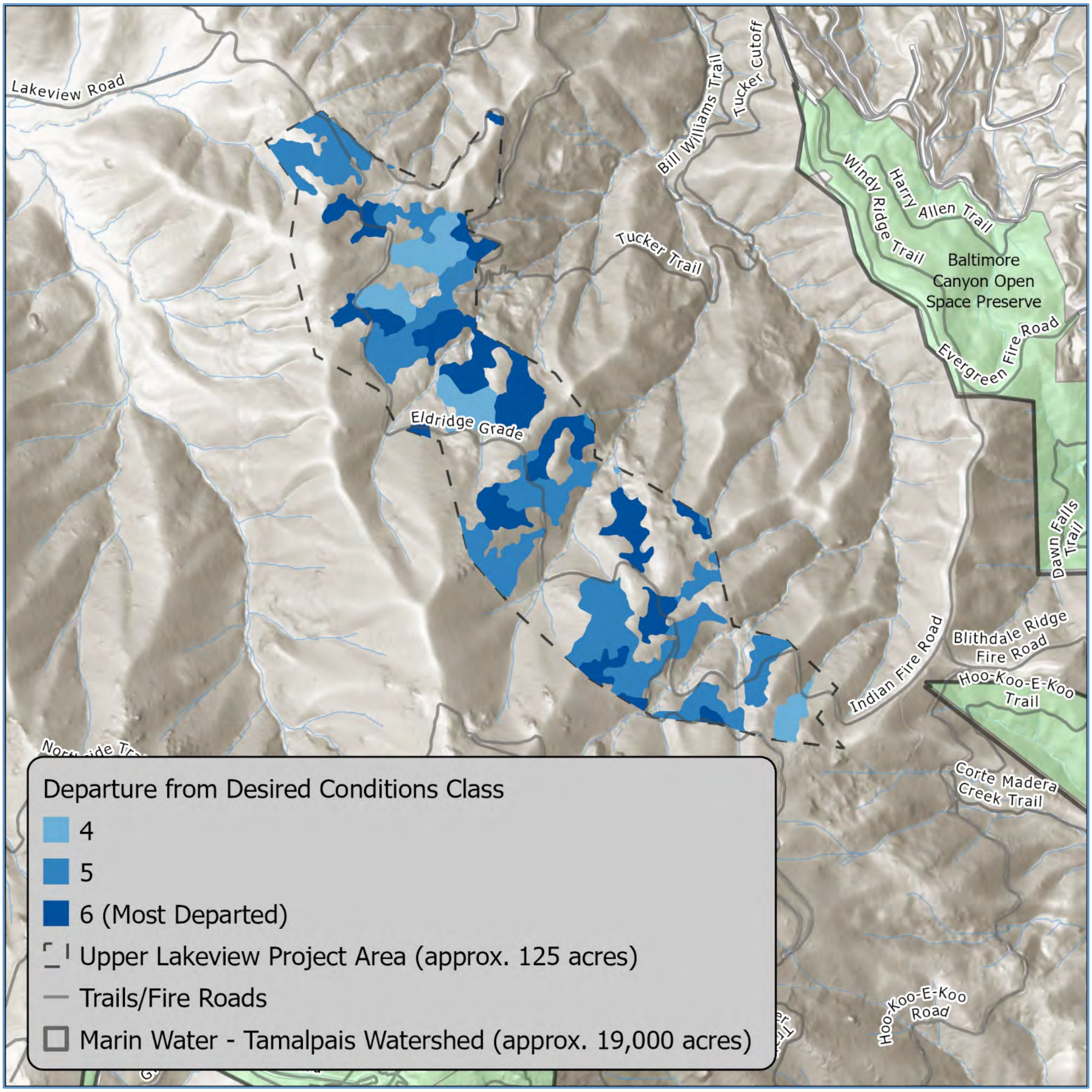
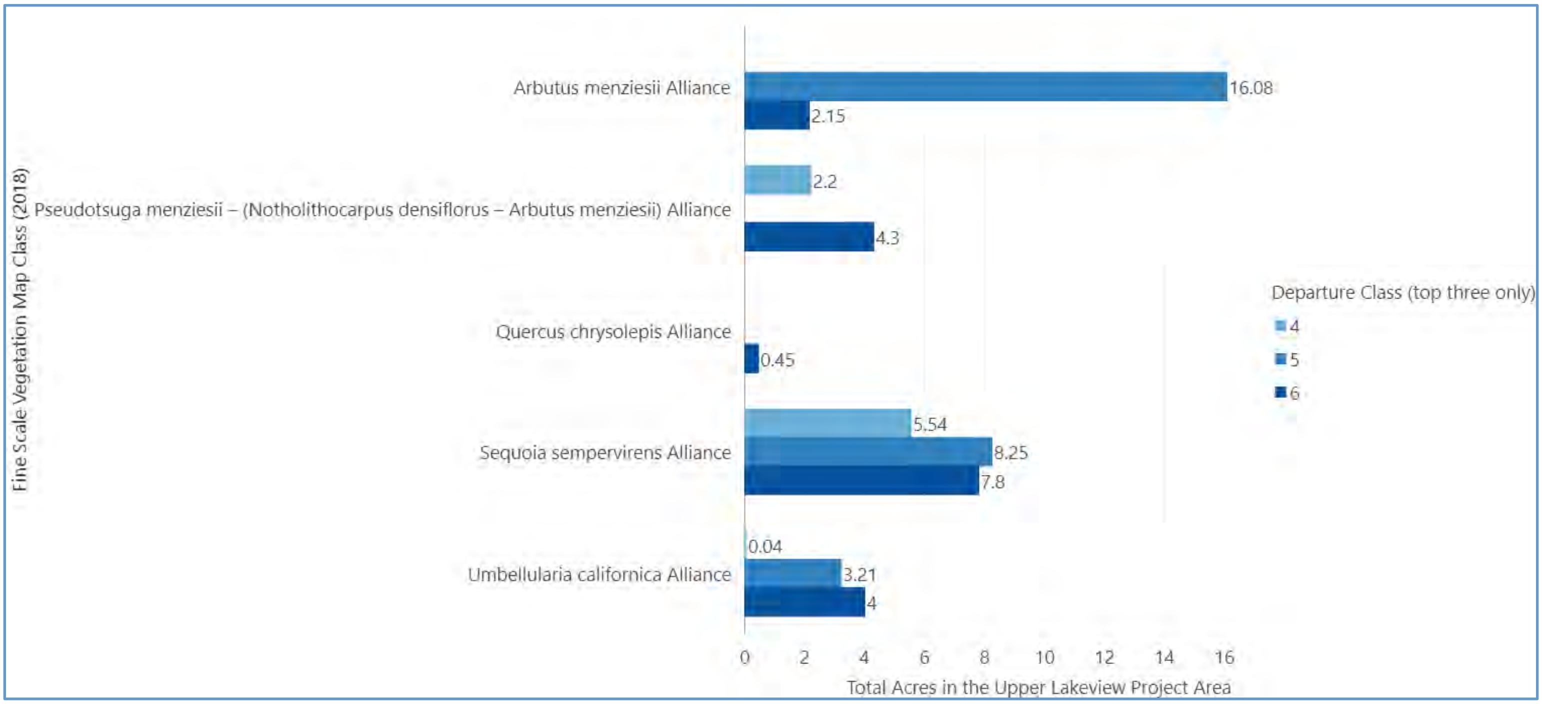


Figure 8.47. 2018 Fine Scale Vegetation Map class acres by departure from desired conditions indices (top three classes only), Upper Lakeview Project Area, Marin Water, Tamalpais Watershed.



FIVE CORNERS EXPANSION PROJECT AREA

The Five Corners Expansion project area is located on the eastern portion of Marin Water's Tamalpais Watershed lands, north of the Phoenix Lake and Bon Tempe Lake reservoirs, and near the watershed boundary with the Town of Fairfax. This project intersects with the Greater Ross Valley Shaded Fuel Break sponsored by the MWPA (Figure 8.48). Marin Water and MWPA will work together to implement vegetation management where projects intersect.

The Five Corners Expansion project area is within the Ecosystem Restoration Natural Areas Zone charictarized by the *BFFIP* as having an abundance of native vegetation species, yet also being demonstrably impacted by fire exclusion, plant pathogens, and/or non-native invasive species infestations (Marin Water, 2019a, p. 3-40). Per guidance in the *BFFIP*, conditions within Ecosystem Restoration Natural Areas Zones such as the Five Corners Expansion project area are conducive to sucessful long-term ecological improvement through management of weeds and treatment prescriptions designed to improve the health and resilence of native forests (Marin Water, 2019a). For more than two decades, Marin Water has conducted targeted mechanical broom removals within pockets of meadow habitat, as well as along roads and trails within the Five Corners Expansion project area.

Forest communties in the area include significant acres of evergreen hardwoods such as California bay (209 acres or 52% of the project area) and Pacific madrone (40 acres or 10% of the project area) (Figure 8.49). Several Open Canopy Oak Woodland types are also present within the Five Corners Expansion project area including 71 acres (18% of the project area) of coast live oak forest (also an evergreen hardwood) as well as stands of decidious open canopy oak species. Notably, the 15 acres of California black oak (*Q. kelloggii*) within this project area represent nearly a quarter of all black oak woodland on Marin Water lands (63 acres) and roughly 10% of the total protected acres in Marin County.

Analysis of departure from desired conditions indices within the Five Corners Expansion project area shows Open Canopy Oak Woodland and other hardwood stands could benefit from forestry prescriptions designed to address threats to forest health and resilience including pathogen impacts, drought stress, and fire exclusion.

Thirty-two percent (23 acres) of coast live oak stands have detectable canopy mortality (between 0.5 and 2.5%), along with 21 (10%) acres of California bay and 4 acres (10%) of Pacific madrone. Notably, 53% (8 acres) of California black oak within the project area also has visible mortality in the canopy. Analysis of canopy gaps formed between 2010 and 2019 shows a similar pattern: eighty-five percent (60 acres) of coast live oak, 20% (42) acres of California bay, and 48% (19 acres) of Pacific madrone stands exhibit greater than 5.5% gaps formed. In California black oak stands 11 of the 15 acres (73%) had greater than 5.5% canopy gaps formed between 2010 and 2019. Available data indicates that many of the evergreen hardwood and Open Canopy Oak Woodland types in the Five Corners Expansion area experienced a 5-10% decrease in canopy density between 2010 and 2019, including 35 acres (49%) of coast live oak, 52 acres (25%) of California bay, and 10 acres (25%) of Pacific madrone woodlands.

Fire exclusion is contributing to the threat of conifer conversion for Open Canopy Oak Woodland types within the project area; 66 acres (93%) of coast live oak within the project area were flagged as threatened with type conversion, with an additional 3 acres classed as actively converting. In addition, 10 acres (66%) of California black oak and 4 acres (100%) of California white oak are also threatened with conifer conversion. Fire exclusion has also contributed to unnatural fuel arrangements across forest types within the project area, with 267 acres (67%) classed with relatively high or very high lidar-derived ladder fuels. Significant acres of very high ladder fuels were mapped in California bay (100 acres), coast live oak (42 acres), Pacific madrone (21 acres) and California black oak (14 acres) woodlands. Overall, of the 400 acres of native forests within the Five Corners Expansion project area, 109 acres (27%) have a departure from desired conditions index value in the top three classes (Figure 8.50).

Treatment prescriptions for this project area will likely be designed to emulate the effects of a low to moderate intensity wildfire and will include removal of dead and dying vegetation impacted by pathogens and conifers encroaching on Open Canopy Oak Woodlands and other hardwood stands. Management will also focus on reducing invasive plant cover and selective vegetation thinning to break up the vertical and horizontal structure of fuels to reduce wildfire hazard and increase forest health and resilience. Access to and treatment of stands in the top three departure classes is supported by the proximity of trails and fire roads in the project area (Figure 8.51).

Figure 8.48. Five Corners Expansion Project Area, Marin Water, Tamalpais Watershed.

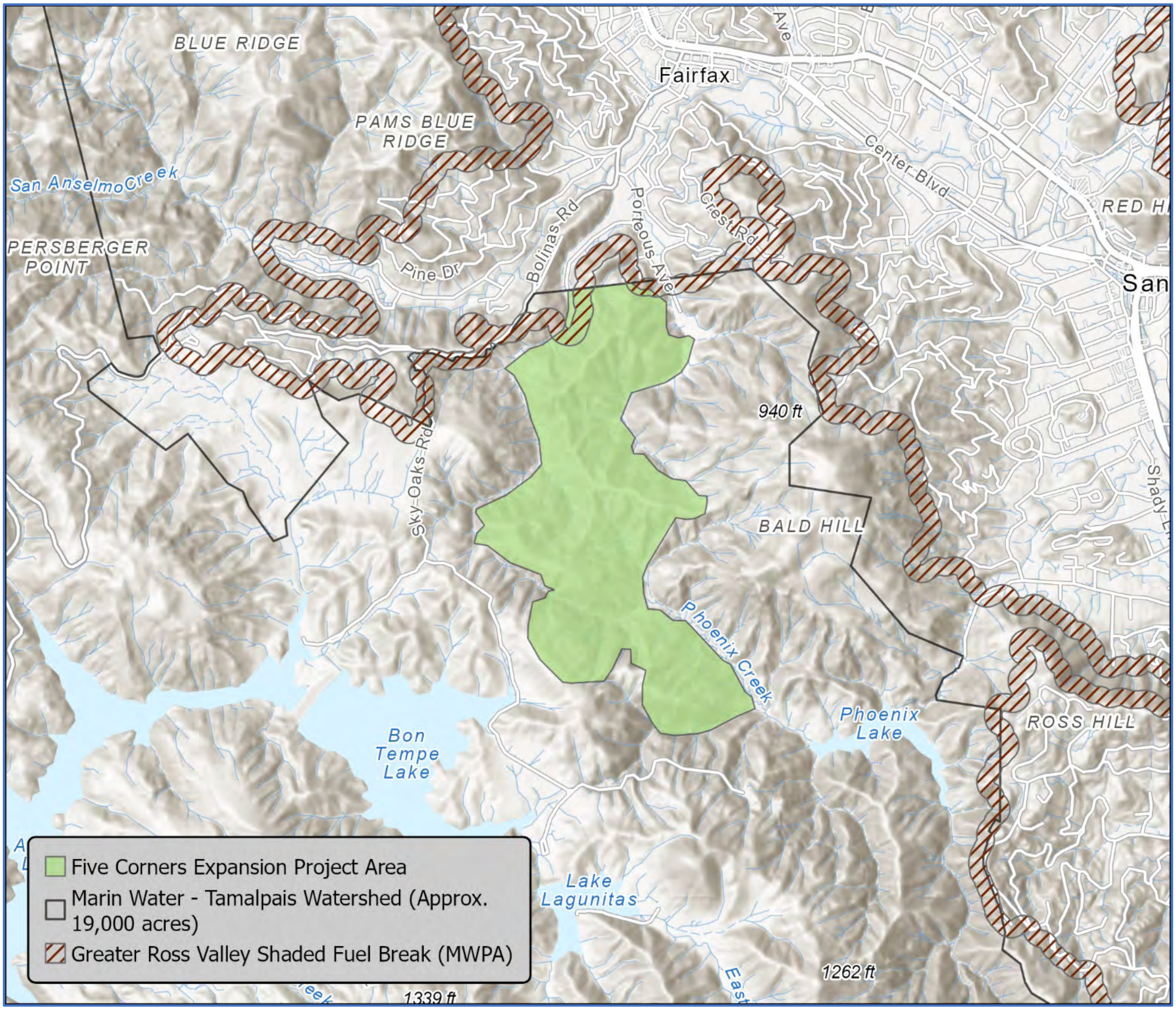


Figure 8.49. 2018 Fine Scale Vegetation Map vegetation communities by acres within the Five Corners Expansion Project Area.

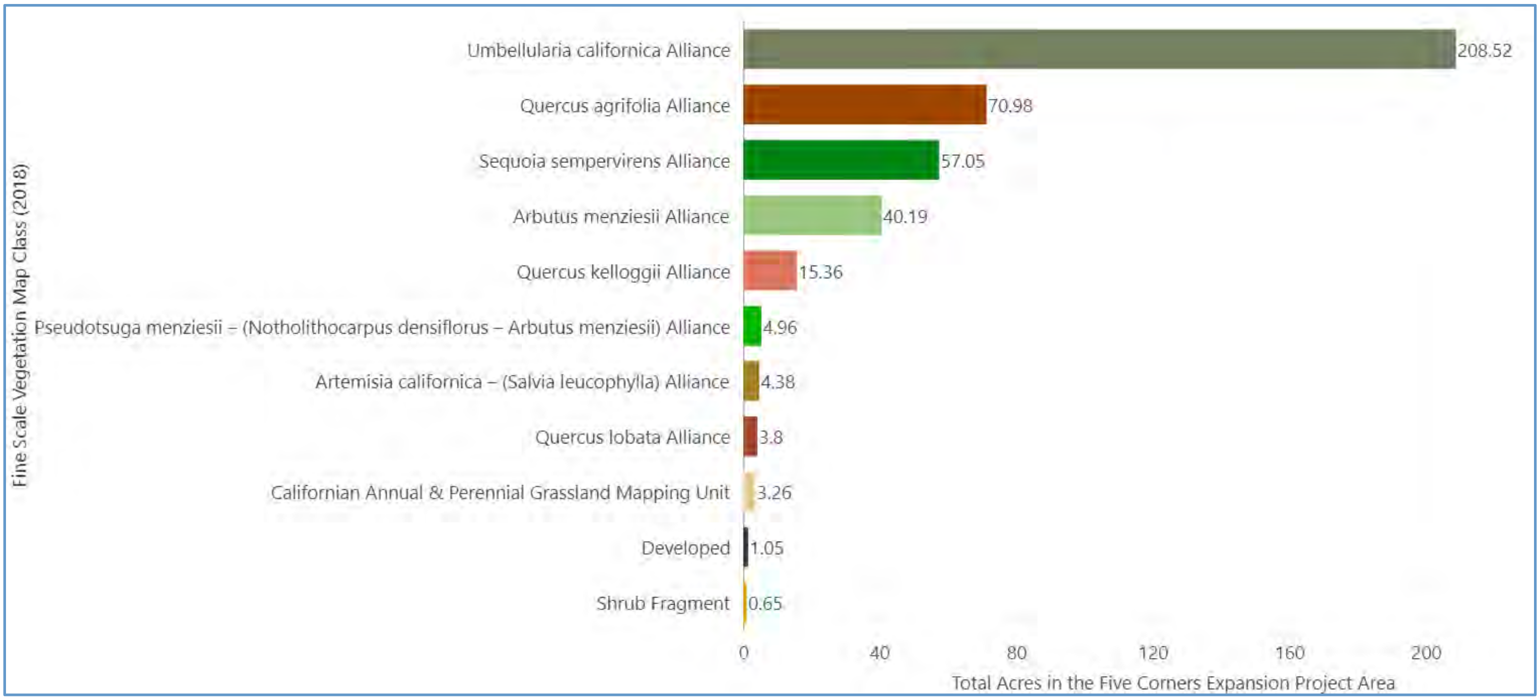


Figure 8.50. 2018 Fine Scale Vegetation Map class acres by departure from desired conditions indices (top three classes only), Five Corners Expansion Project Area, Marin Water, Tamalpais Watershed.

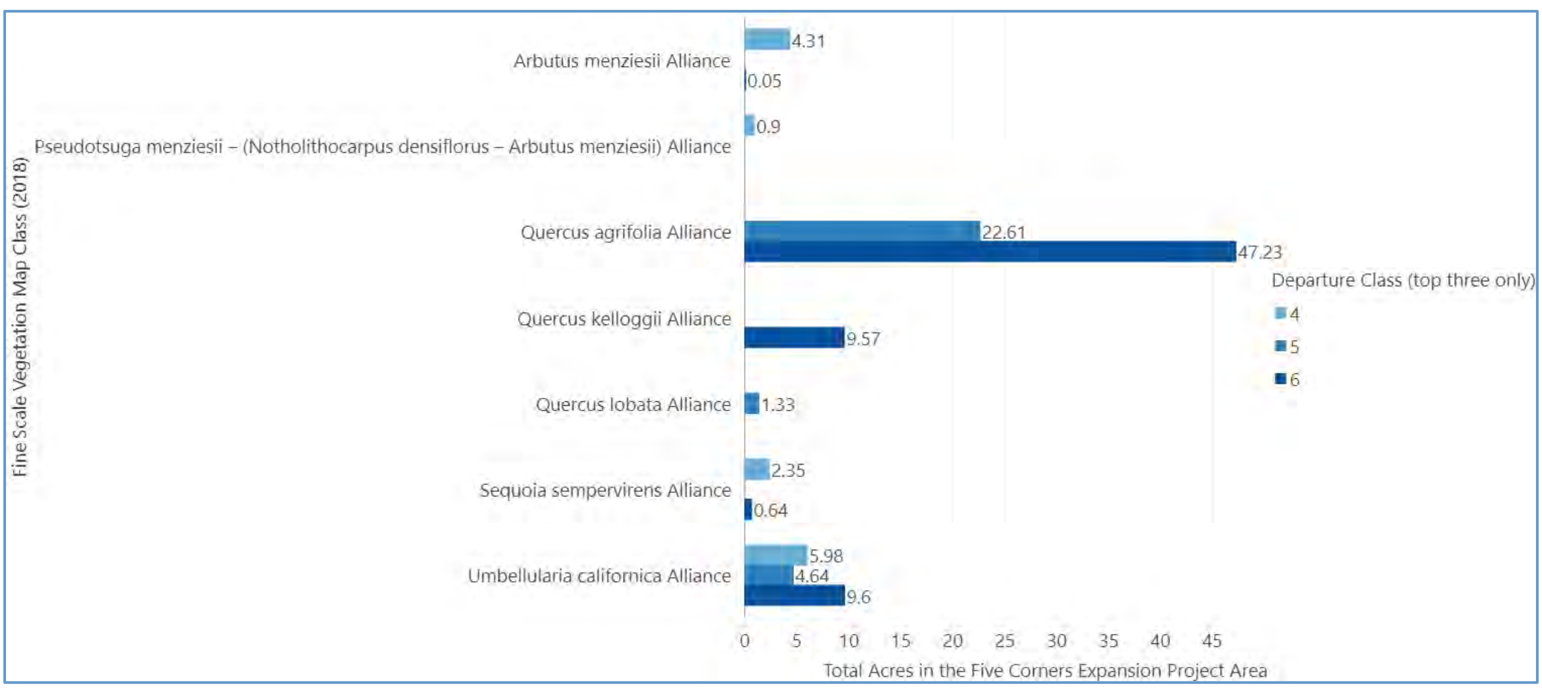
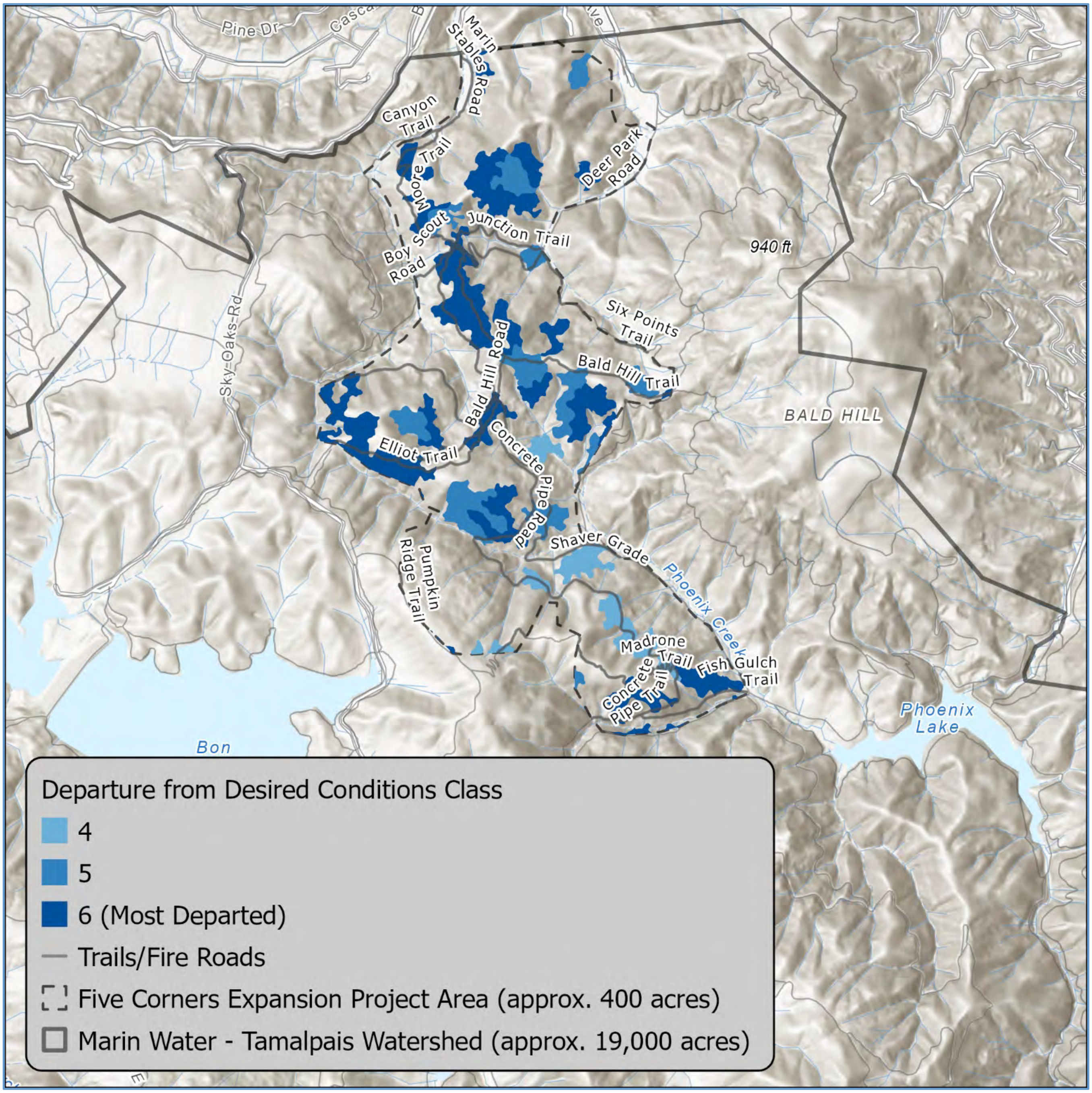


Figure 8.51. Five Corners Expansion Project Area, departure from desired conditions (top three classes only) and nearby fire roads/trails, Marin Water, Tamalpais Watershed.



CALIFORNIA STATE PARKS BAY AREA DISTRICT PRIORITY AREAS

The California Department of Parks and Recreation Bay Area District (CDPR or State Parks) manages more than 14,000 acres of protected open space in Marin County across seven units including Tomales Bay State Park, Samuel P. Taylor State Park, Mount Tamalpais State Park, Olompali State Historic Park, China Camp State Park, and Angel Island State Park. It is the mission of State Parks to “provide for the health, inspiration and education of the people of California by helping to preserve the state's extraordinary biological diversity, protecting its most valued natural and cultural resources, and creating opportunities for high-quality outdoor recreation” (CDPR, n.d.a.).

State Parks conducts vegetation management across the Bay Area District park units in accordance with policies, guidelines, and plans at the state and local level, including defensible space work to reduce wildfire risk to park structures and facilities. The priority project areas described below are a representative sample of the forest management priorities in the district, are distinguished from defensible space work conducted on State Parks lands, and are focused on increasing forest health, conserving valuable natural and cultural resources, protecting biodiversity, and increasing forest resilience to climate change and other stressors.

TOMALES BAY STATE PARK FOREST HEALTH & WILDFIRE RESILIENCE PROJECT

Tomales Bay State Park (TBSP) in Marin County encompasses over 2,400 acres along the western and eastern shores of Tomales Bay (Figure 8.52). Vegetation communities within TBSP include conifer forests dominated by Bishop pine, evergreen hardwood types such as California bay and coast live oak, and mixed hardwood-conifer areas (Figure 8.53). Notably, the more than 920 acres of Bishop Pine forest in Tomales Bay State Park represent 20% of all protected acres in Marin County, and approximately 44% (802 acres) of all protected late-seral Bishop Pine stands (see Chapter 7: Condition Assessment). This includes one of the finest remaining groves of Bishop Pine in California, the Jepson Memorial Grove. The TBSP General Plan identifies management guidelines for Bishop Pine forests which are to:

> Preserve and enhance the forest structure and age classes of the Jepson Grove/Bishop pine forest and forest growth by improving *Pinus muricata* growth. Investigate the use of both low-intensity prescribed fire and mechanical means to create openings allowing for natural seedling establishment. Create more open views through the forest floor from the trails to enhance aesthetic qualities. (CDPR, 2004, p.167)

The Bishop Pine stands at TBSP are declining and at risk due to multiple stressors including stand age, pitch pine canker disease caused by the fungus *Fusarium circinatum,* western gall rust caused by the native pathogen *Endocronartium harknessii*, and the lack of fire required for regeneration (see Chapter 5: Goals, Bishop Pine). Bishop Pine stands in the Park are reaching the end of their approximately 80–100-year life span and are senescing with little to no regeneration. State Parks is planning to conduct vegetation treatments to protect this unique habitat type and improve Bishop pine regeneration and resilience, consistent with the management directive. Treatment goals include facilitating Bishop pine regeneration and maintaining a dynamic mosaic of vegetation types and age classes in the park, with secondary benefits of reducing fire fuels. Also, MWPA anticipates future work in the WUI near TBSP (M. Brown, personal communication, March 7, 2023).

Figure 8.52. Tomales Bay State Park, Marin County.

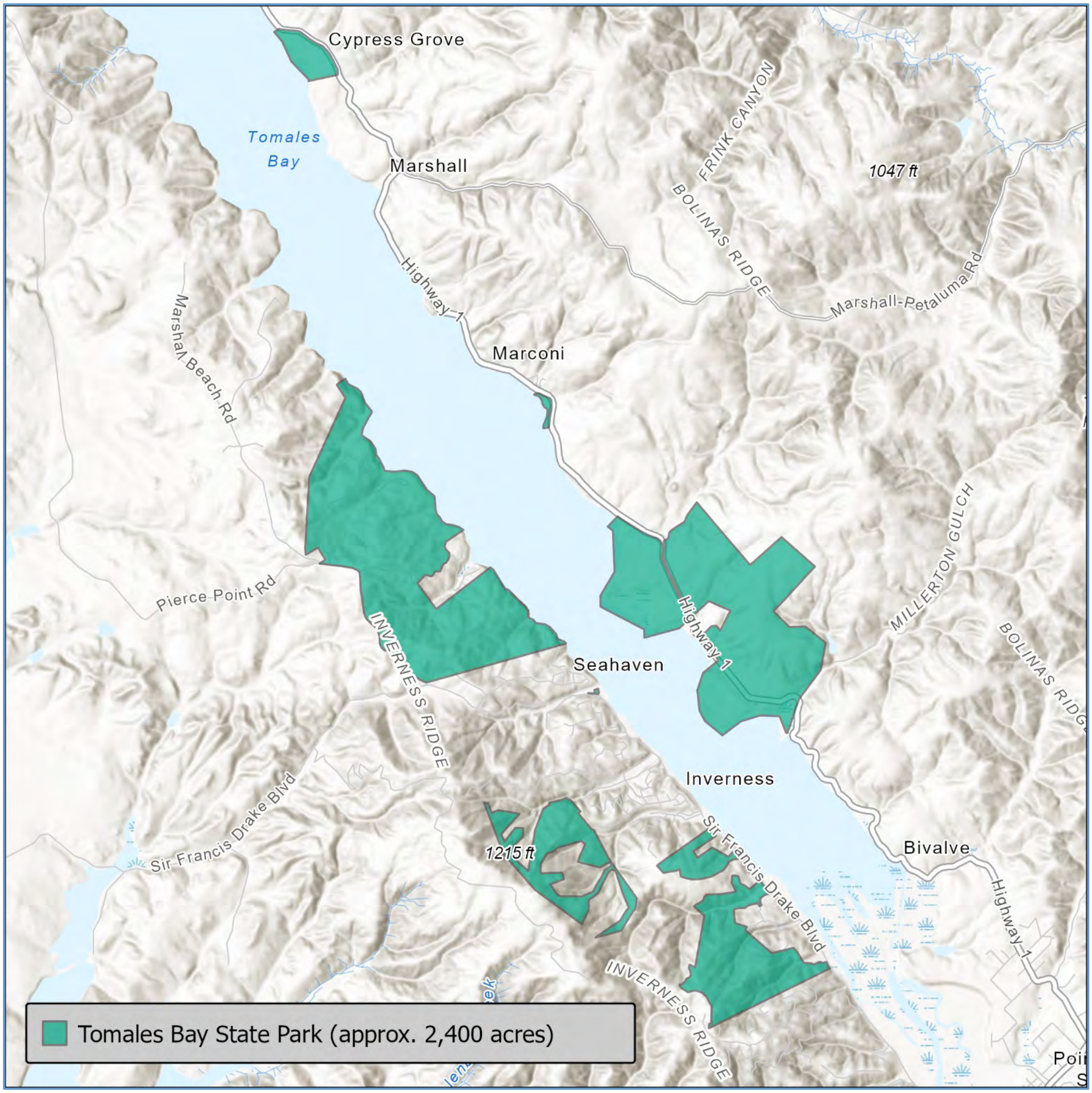
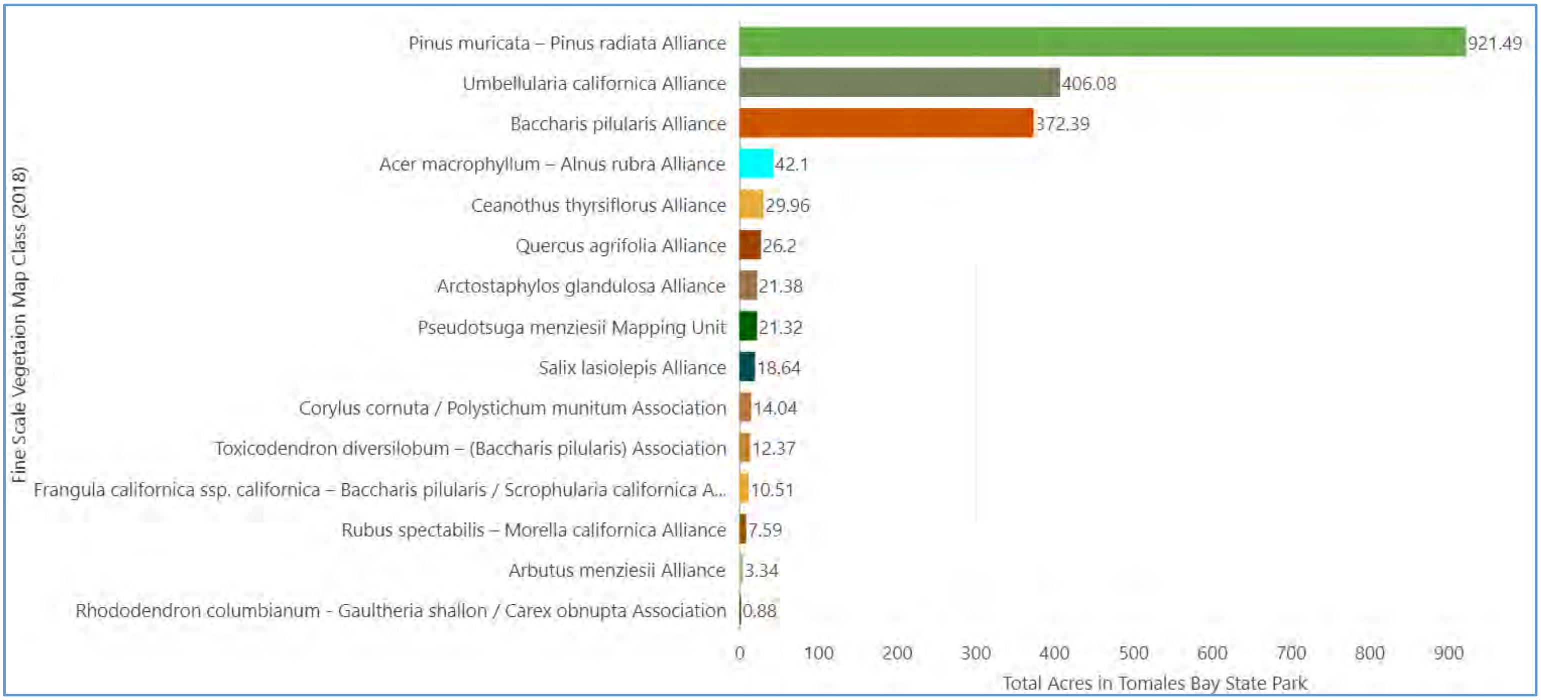


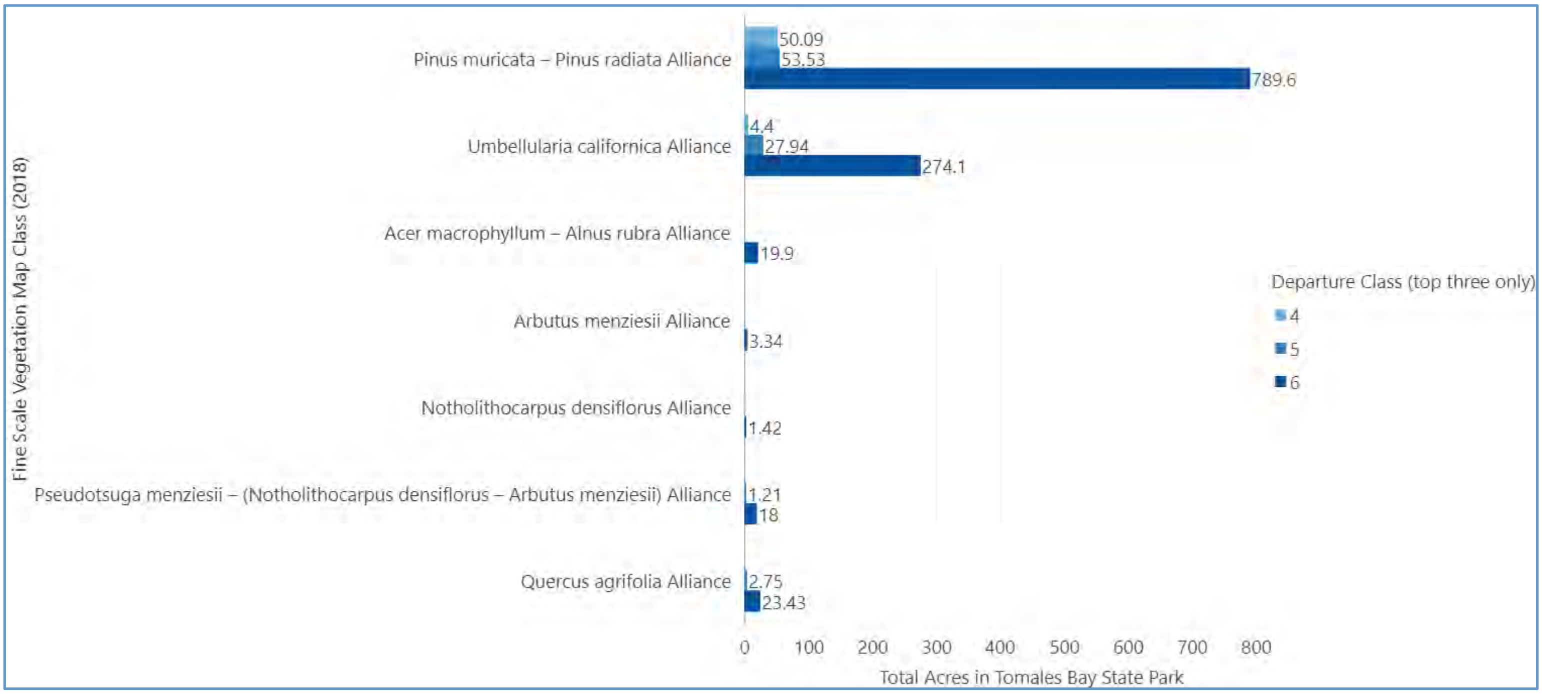
Figure 8.53. 2018 Fine Scale Vegetation Map native forest and shrubland communities in Tomales Bay State Park.



Bishop pine-mixed hardwood forest habitat within TBSP includes 233 acres with 26-60% relative hardwood cover and an additional 18 acres with greater than 60% cover. This unique mixed conifer-hardwood assemblage (27% of all Bishop Pine forest in TBSP) is in decline due to the absence of regenerative fire and impacts from pathogens primarily *Phytophthora ramorum*, the pathogen that causes sudden oak death. This contributes to the relatively high density of canopy mortality, standing and downed dead trees in TBSP. Ninety-one percent (840 acres) of Bishop Pine forest, 46% (217 acres) of California bay, and 58% (16 acres) of coast live oak woodlands have detectable canopy mortality greater than 2.5%, with a mean percent canopy mortality of 8% across all native forests within the park. Canopy mortality in mixed hardwood forest has also facilitated growth of understory woody plants resulting in dense understory brush, inhibiting the regeneration of hardwoods (Gaman, 2019). State Parks is planning to conduct vegetation management within this habitat type to improve its resilience, preserve biological and habitat diversity, with the secondary benefit of reducing ladder fuels.

Figure 8.54 summarizes the results of departure from desired conditions analysis for native forest types in Tomales Bay State Park. Eighty percent (1,141 acres) of these forest types were classified as having the highest departure from desired conditions (class 6). This is largely driven by pathogen impacts (canopy mortality and percent canopy gaps formed between 2010-2019), oak stands at risk of conversion to conifer due to fire exclusion, and relatively high ladder fuels. Treatment approaches will vary depending on habitat type, desired site conditions, access, Tribal input, and other considerations, but will include a combination of selective mechanical and manual removal of dead trees, biomass management, beneficial fire such as pile burning in adherence to a prescription documented in a burn plan, and other actions to promote Bishop pine regeneration and improve hardwood forest resiliency.

Figure 8.54. Native forest vegetation community acres by departure from desired conditions indices (top three only), Tomales Bay State Park.

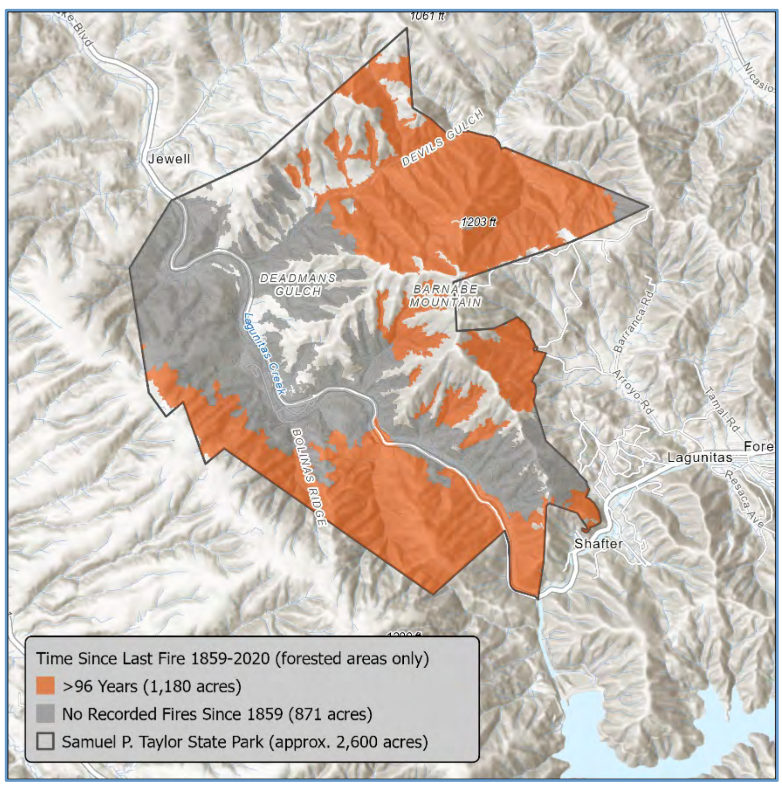


SAMUEL P. TAYLOR STATE PARK FOREST RESILIENCE PROJECT

Samuel P. Taylor State Park, established as a park in 1946, is located near the western edge of San Geronimo Valley within the Lagunitas Creek Watershed, neighboring other protected open space lands including Marin Water – Tamalpais Watershed, Golden Gate National Recreation Area, and Gary Giacomini Open Space Preserve (Figure 8.56). Archaeological evidence indicates that the Coast Miwok people have inhabited this region for at least 3000-4000 years prior to European colonization (CDPR, n.d.c.). Forests in Samuel P. Taylor State Park contain some of the largest Coast Redwood stands in Marin County and provide habitat for federally threatened Northern Spotted Owl, and cooling shade for special-status salmonids Coho salmon and steelhead trout in Lagunitas Creek. Fifty-nine percent of the park's 2,600 acres are dominated by conifer forests including Douglas-fir (1,066 acres) and Coast Redwood (420 acres) (Figure 8.57).

Analysis of available fire history data shows little to no recent fire activity within Samuel P. Taylor State Park, with only five fires greater than 160 acres documented in the general area (1870, 1890, 1904, 1906, and 1926). Of those, only the latter 1926 Devil's Gulch Fire appears to have burned substantial acres within the park (Dawson, 2021; Appendix B: Wildfire History). According to available data for the period of 1859-2021, there have been no recorded fires greater than 160 acres in 42% (871 acres) of the forested portions of Samuel P. Taylor State Park. The remaining 1,180 acres of forest have not experienced fire in 96 years or longer (Figure 8.55). While there is significant variability in the fire regime for Coast Redwood forests, fire return intervals such as those observed in the available data for Samuel P. Taylor State Park are generally outside those described in other Coast Redwood forests in Marin County (see Chapter 5: Goals, Coast Redwood Fire Regime).

Figure 8.55. Time since last fire in the forested portions of Samuel P. Taylor State Park (Dawson, 2021)



Given the importance of Coast Redwood forest for wildlife habitat, carbon sequestration, and cultural values, State Parks seeks to advance forest management that will increase the health and resilience of this iconic species and forest type. This could include treatment prescriptions that reduce ladder fuels to increase wildfire resilience for stands of large coast redwood trees while also selectively thinning stands of medium/small coast redwood trees to promote old-growth like conditions (Figure 8.58). State Parks treatments will be complimented by MWPA treatments and home hardening on adjacent private lands (M. Brown, personal communication, March 7, 2023).

Figure 8.56. Samuel P. Taylor State Park and adjacent protected open space lands, Marin County.

Figure 8.57. 2018 Fine Scale Vegetation Map native forest communities in Samuel P. Taylor State Park.

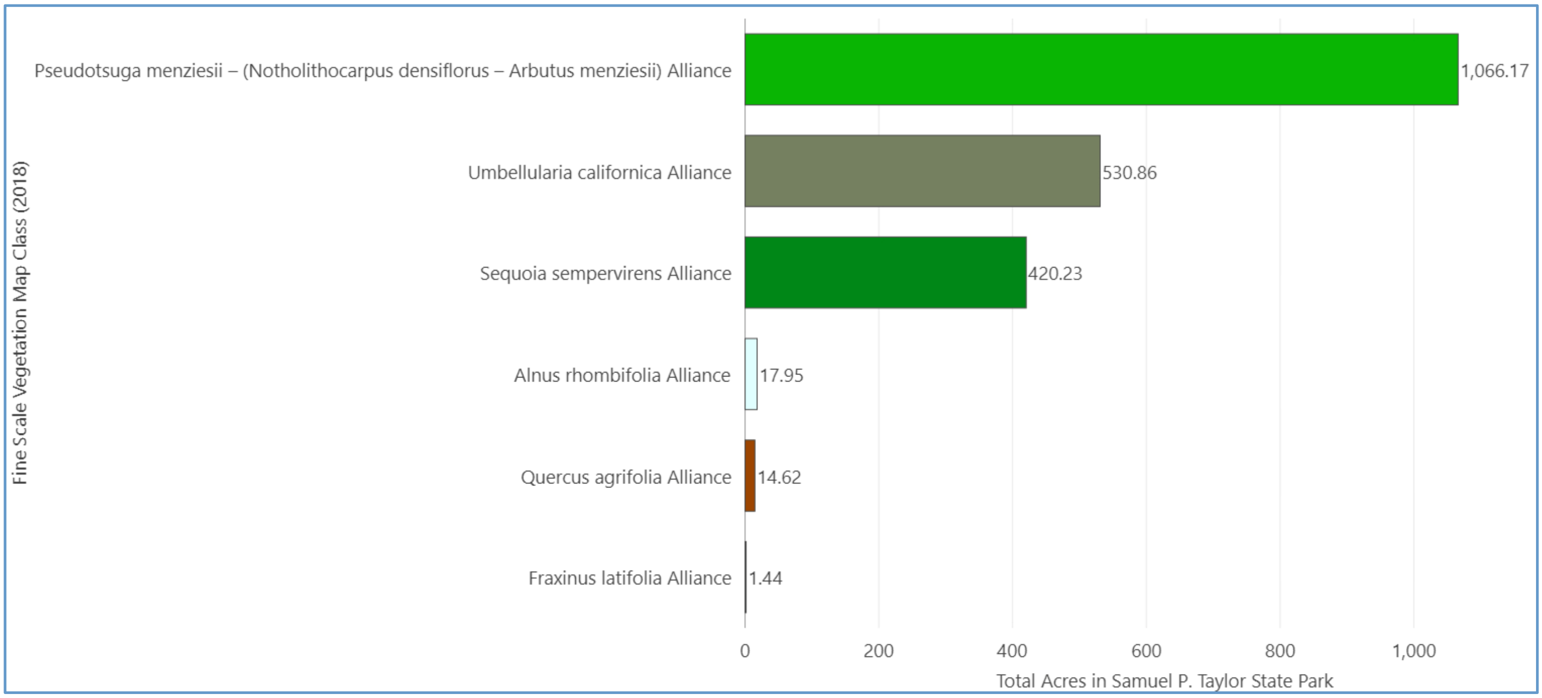
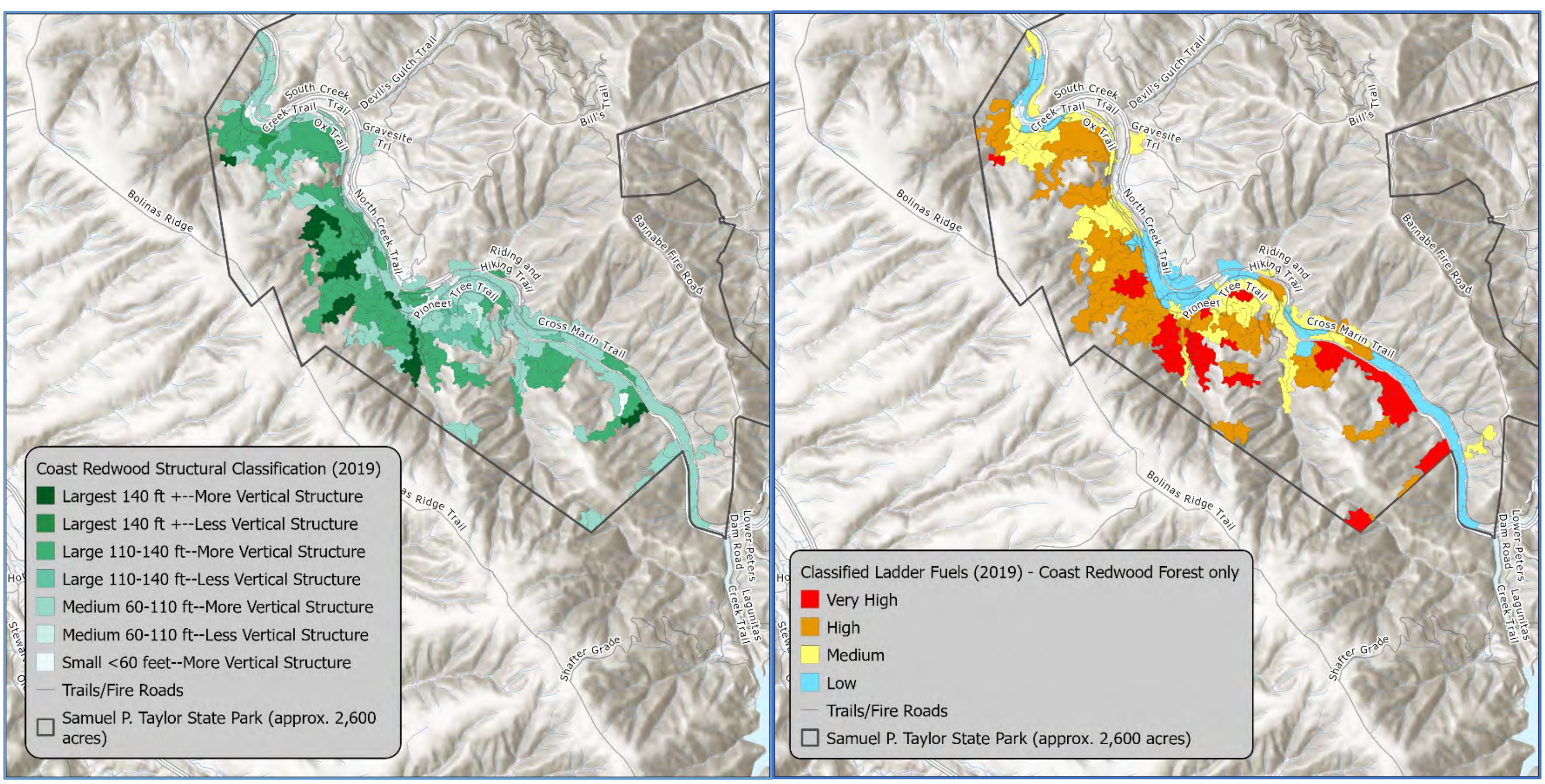


Figure 8.58. Coast Redwood structural classification (left), and classified ladder fuels (right) in Coast Redwood forests, Samuel P. Taylor State Park.



MOUNT TAMALPAIS STATE PARK FOREST HEALTH & RESILIENCE

Roughly two-thirds of Mount Tamalpais State Park is included in the Redwood Creek Watershed, it extends from the East Peak of Mount Tamalpais to the Pacific Ocean, sharing boundaries with Marin Water and the Golden Gate National Recreation Area (National Park Service), including nearly all the land surrounding Muir Woods National Monument (Figure 8.60). This area contains rich biological diversity including grasslands, coastal chaparral, mixed hardwood forests, old-growth Coast Redwood stands, seasonal wetlands, and riparian assemblages. Key forest types within the Mount Tamalpais State Park include Douglas-fir forest (1,987 acres), Coast Redwood (516 acres), and coast live oak (50 acres) (Figure 8.59). Mount Tamalpais State Park also provides habitat for several sensitive species including Coho salmon, steelhead trout, Northern Spotted Owl, and the California red-legged frog (*Rana aurora draytonii*).

State Parks environmental scientists are interested in advancing opportunities to increase Coast Redwood forest resilience in Redwood Creek Watershed portions of Mount Tamalpais State Park (see Chapter 5: Goals, Coast Redwood). Of the 427 acres of Coast Redwood forest on Mount Tamalpais SP Redwood Creek Watershed lands, 8% (36 acres) were classified as short (less than 60 feet mean lidar-derived stand height), with an additional 13% (55 acres) structurally classified as medium height (60-110 feet) with less vertical structure (Figure 8.59). Forestry prescriptions could be developed and implemented to promote old-growth conditions in shorter, less structurally complex Coast Redwood stands, and where applicable work could include management of ladder fuels to increase climate and wildfire resilience (Figure 8.61).

Figure 8.59. Coast Redwood structural class (2019) by acres, Redwood Creek Watershed, Mount Tamalpais State Park.

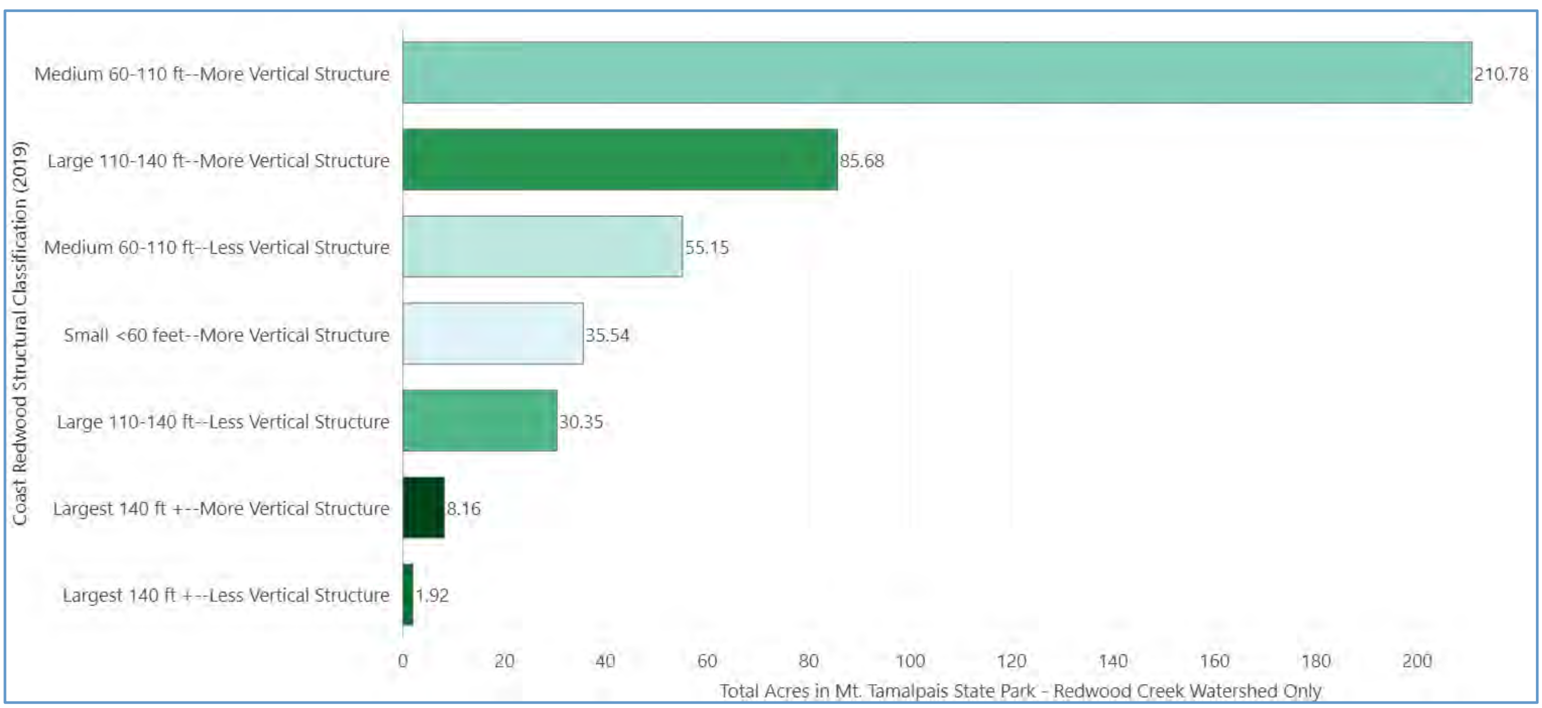
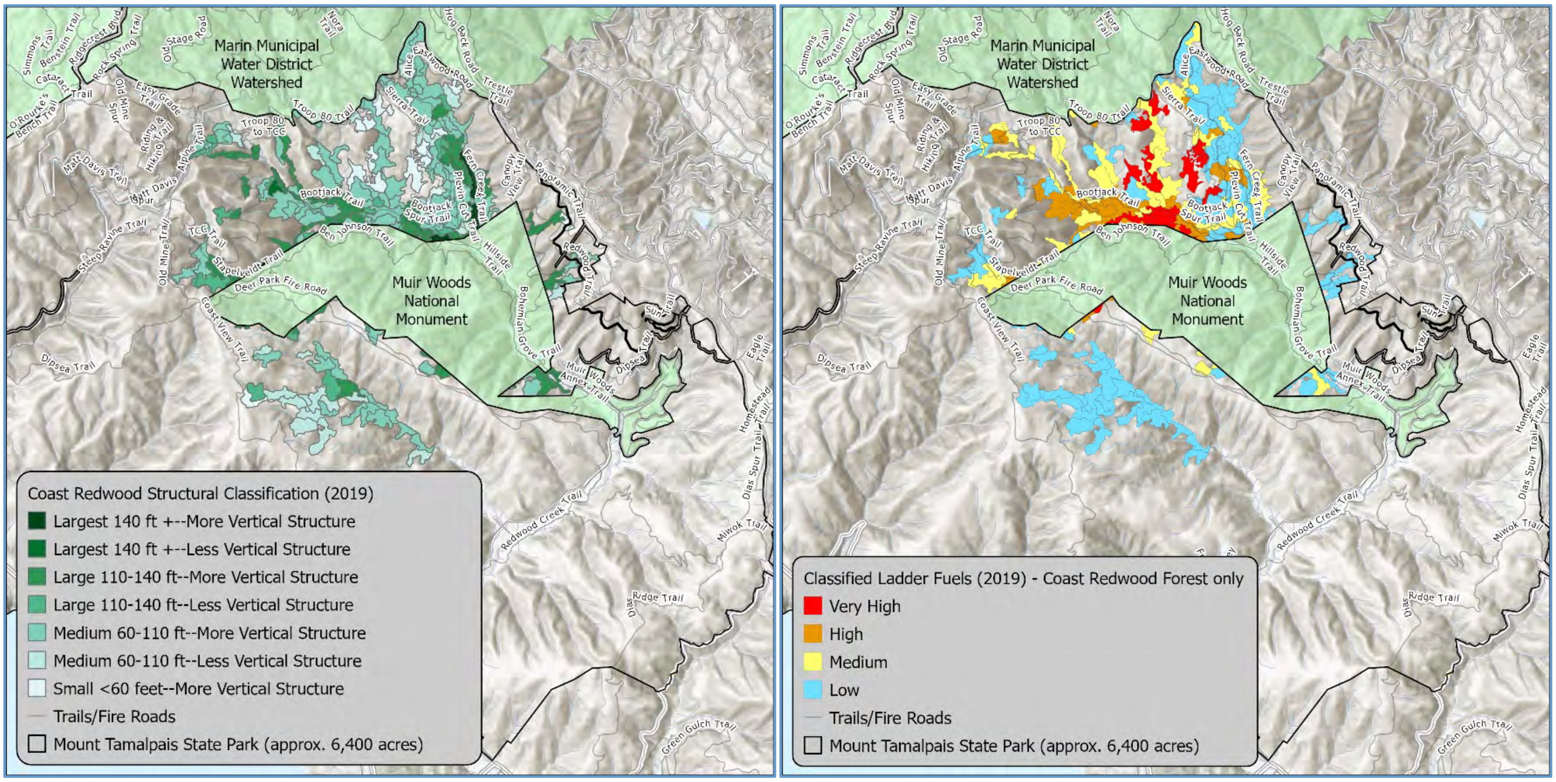


Figure 8.60. Mount Tamalpais State Park and surrounding protected open space areas, including Golden Gate National Recreation Area and Marin Water, Tamalpais Watershed.

Figure 8.61. Coast Redwood structural classification (left), and classified ladder fuels (right) in Coast Redwood forests, Redwood Creek Watershed, Mount Tamalpais State Park.



Forest management at Mount Tamalpais State Park includes creating defensible space to reduce wildfire risk to park facilities, including the Mountain Theater and Bootjack Campground. Work could be expanded to the surrounding area to advance overall forest health and resilience and move priority stands towards more desirable conditions (Figure 8.62). Opportunities to advance multi-benefit work in these areas could include management of structurally short, dense Douglas-fir stands, threatened or actively converting oak stand, and/or removal of dead and dying vegetation likely impacted by sudden oak death (Figure 8.63). Work in this area would also complement similar management on adjacent Marin Water lands in the Rock Springs, Ridgecrest, and Potrero Meadows areas (see Marin Water Priority Treatment Areas above).

Figure 8.63. Departure from desired conditions class (top three only) in the Mountain Theatre and Bootjack Campground areas, Mount Tamalpais State Park.

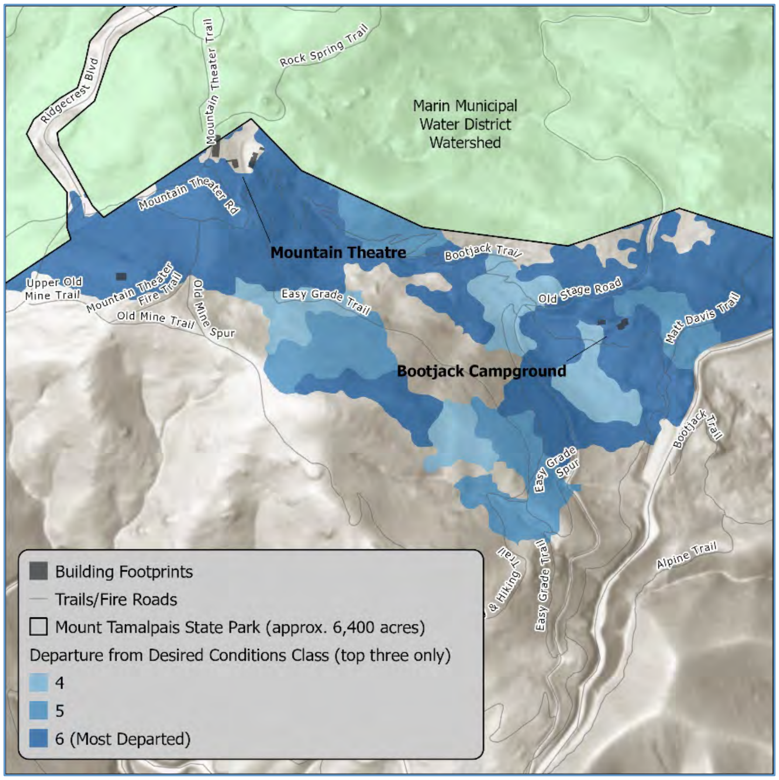
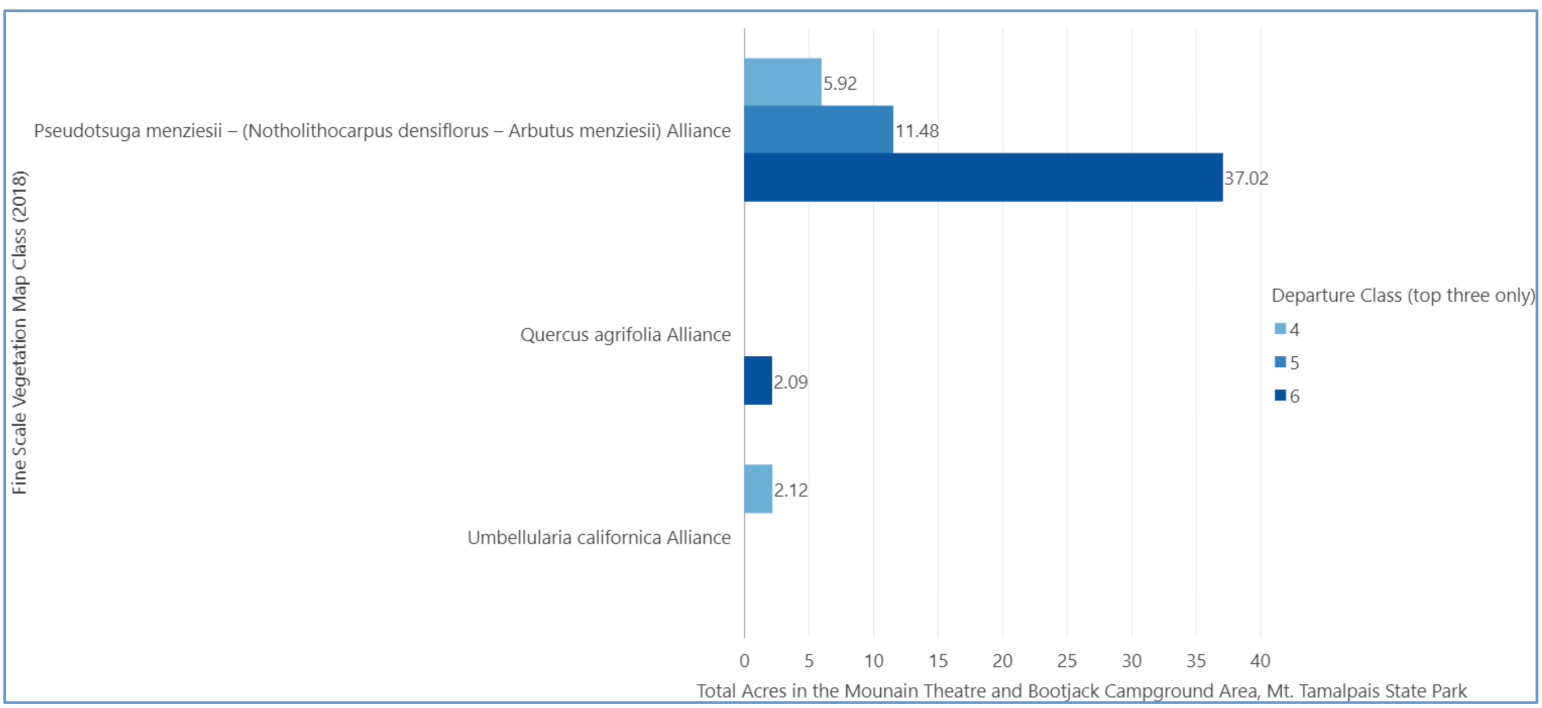


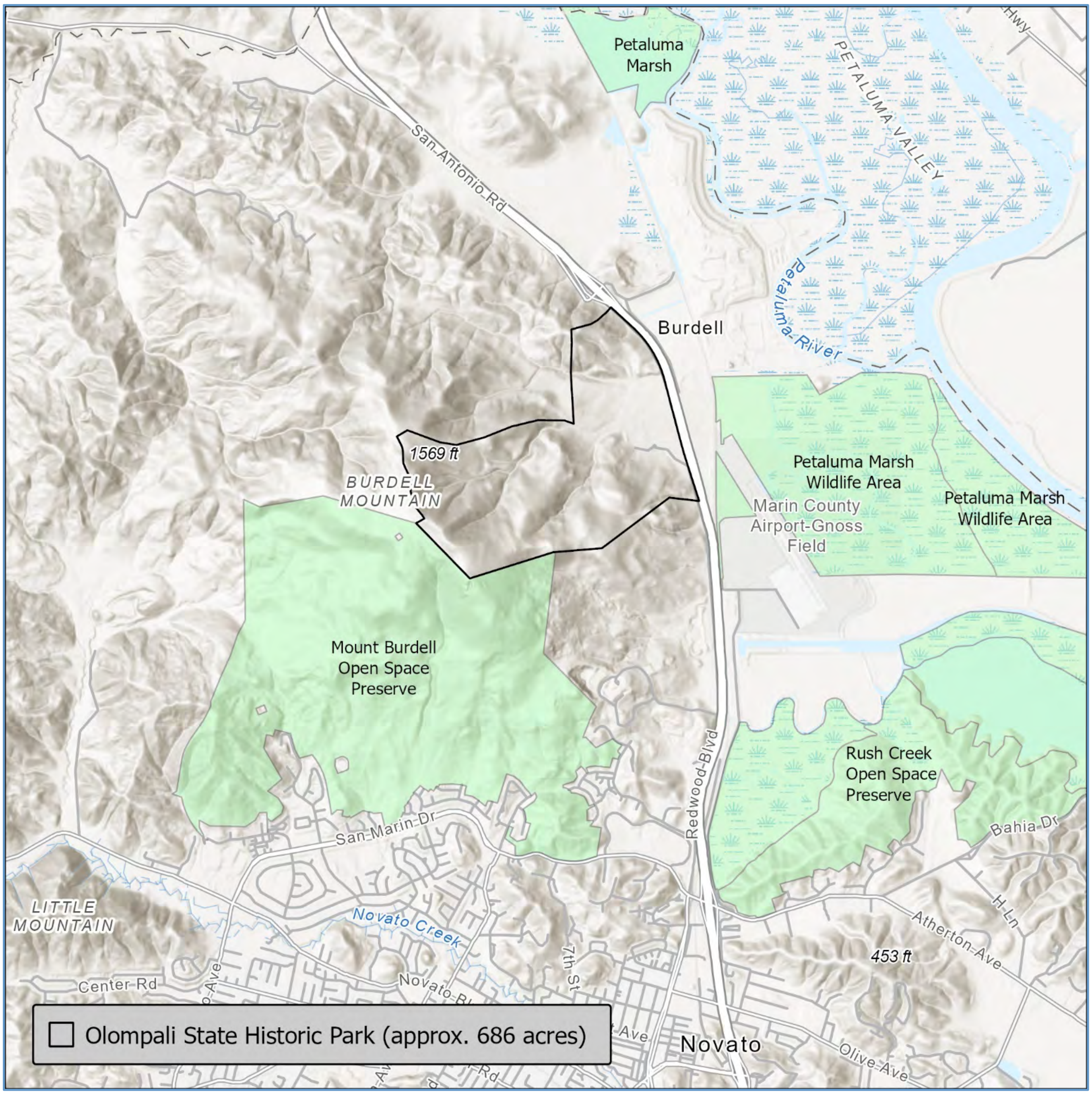
Figure 8.62. 2018 Fine Scale Vegetation Map class by departure from desired conditions indices (top three only), Mountain Theatre and Bootjack Campground areas, Mount Tamalpais State Park.



OLOMPALI STATE HISTORIC PARK FOREST HEALTH & RESILIENCE

Olompali State Historic Park is located north of the City of Novato, on the east facing slopes of Burdell Mountain (Figure 8.64). The first part of the expression "Olompali" seems to derive from the Coast Miwok word for "south" and there is evidence to suggest that the land in this portion of what is now known as Marin County was once one of the largest Coast Miwok polities in the area (Dr. Peter Nelson, Personal Communication). The approximate 686-acre State Historic Park is notable for its significance as a Coast Miwok village from as early as 6,000 BCE and Native American ownership that spans the period of missionization and

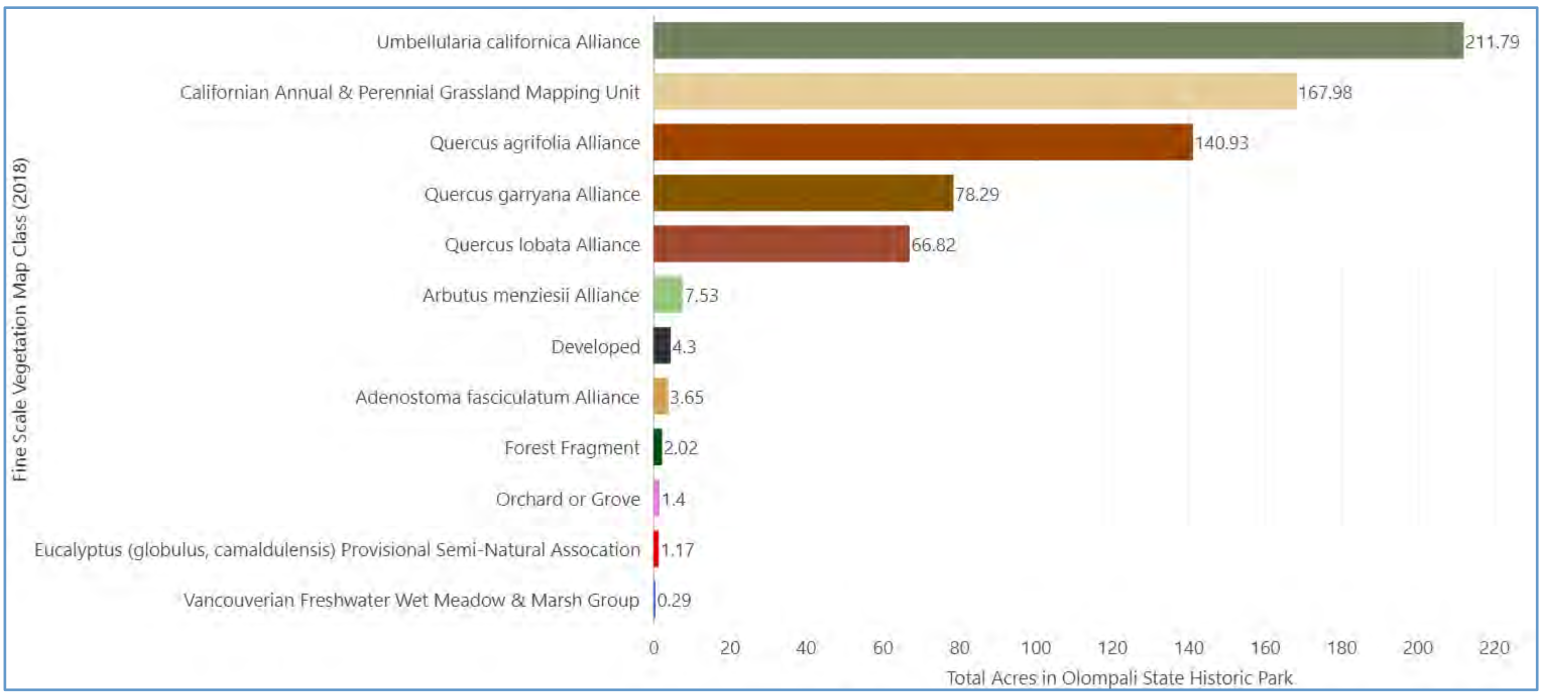
Figure 8.64. Olompali State Historic Park and surrounding area, Marin County.



California land grant era until the early 1850s, with numerous archeological and historic features that persist today (CDPR, 2011).

The open grasslands, mixed chaparral, and oak woodlands within Olompali State Historic Park provide habitat for numerous wildlife species including bird species such as Screech Owls (*Megascops kennicottii*), Western Bluebirds (*Sialia mexicana*), White-breasted Nuthatches (*Sitta carolinensis*), Acorn Woodpeckers (*Melanerpes formicivorus*), and more (CDPR, 2011). Notably eight unique bat species are found within the park, including pallid bats (*Antrozous pallidus*), Townsend's big-eared bats (*Corynorhinus townsendii)*, Mexican free-tail bats (*Tadarida brasiliensis*), California myotis (*Myotis californicus*), big brown bats (*Eptesicus fuscus*), hoary bats (*Lasiurus cinereus*), western red bats (*Lasiurus blossevillii*), and Yuma myotis (*Myotis yumanensis*) (CDPR, 2011). The 2018 Fine Scale Vegetation Map shows significant acres of several key Open Canopy Oak Woodland forest types within Olompali State Historic Park including 141 acres of coast live oak (*Quercus agrifolia*), 78 acres of Oregon white oak (*Q. garryana*), and 67 acres of valley oak (*Q. lobata*) (Figure 8.65).

Figure 8.65. 2018 Fine Scale Vegetation Map class by acres, Olompali State Historic Park.



According to data generated as part of the *Marin County Wildfire History Mapping Project*, the area within and around Olompali State Historic Park lies within a rare burn zone, with no documented fires greater than 160 acres since before 1859 (Dawson, 2021, see Appendix B: Wildfire History) (Figure 8.66). The absence of documented fire at Olompali State Historic Park represents a significant departure from desired conditions given the important role of fire in Open Canopy Oak Woodland regeneration and forest health, in which Coast Miwok oak stewardship and cultural burning played an integral part (see Chapter 3: Stewardship and

Partnership with the Federated Indians of Graton Rancheria). It is worth noting that State Parks conducted an approximately 40-acre prescribed burn at Olompali in the 1990s (R. Schneider, CDPR Senior Environmental Scientist-Specialist, personal communication, March 20, 2023).

California State Parks environmental scientists and archeologists seek to advance project work in Olompali State Historic Park that will address impacts from fire exclusion by strategically reducing unnatural fuel arrangements and addressing other stressors to increase oak woodland forest health and resilience. A significant percentage of oak woodland acres in Olompali State Historic Park are classified with very high or high ladder fuels, including 59% (46 acres) of *Quercus garryana* and 22% (31 acres) of *Quercus agrifolia* woodlands (Figure 8.67 and 8.68). Outreach and engagement with the Federated Indians of Graton Rancheria will be a key component of successful project planning and implementation.

Figure 8.66. Years since last fire, Olompali State Historic Park and surrounding area (Dawson, 2021).

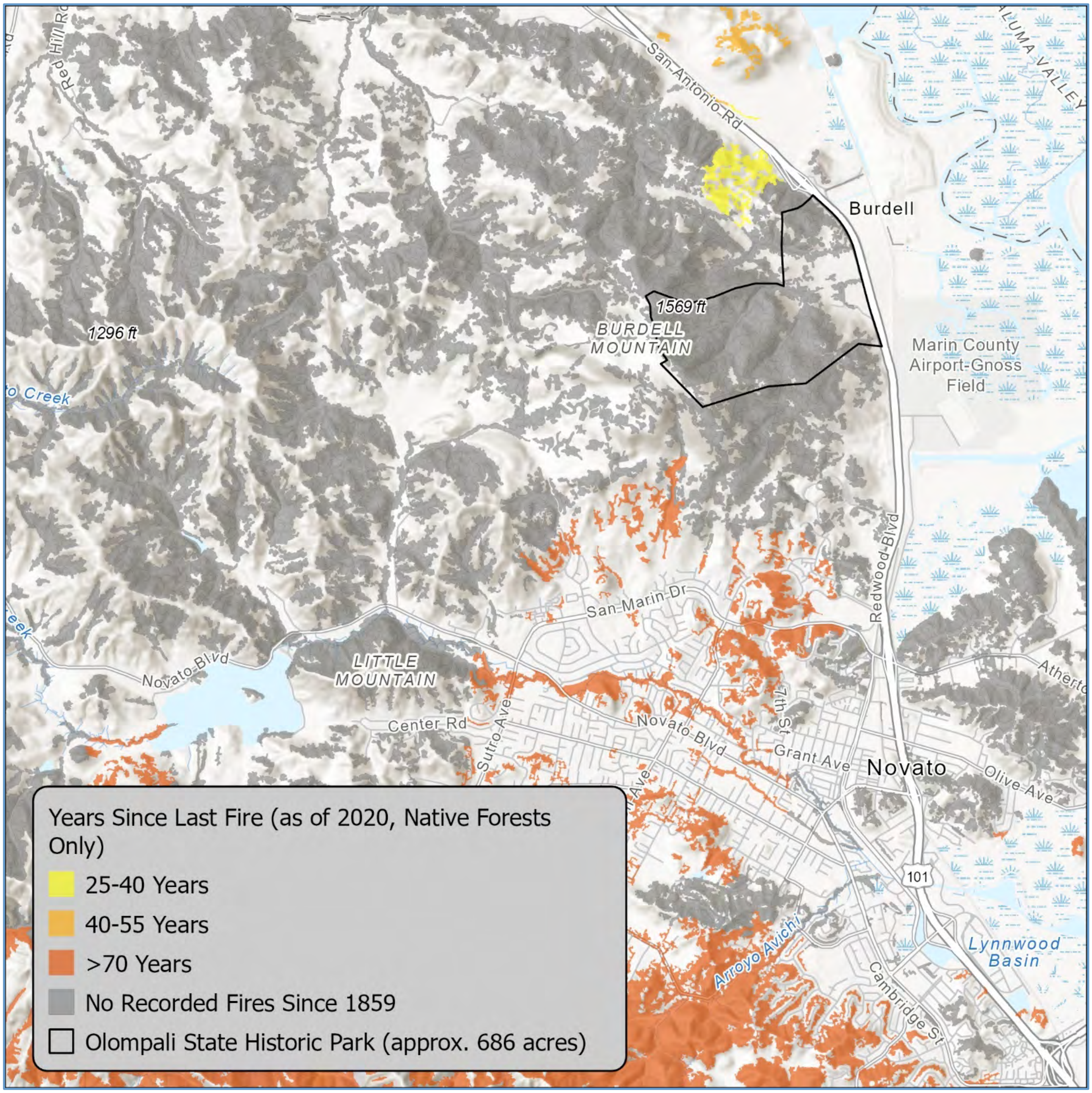


Figure 8.67. 2018 Fine Scale Vegetation Map class by classified ladder fuels, expressed as a percentage of total acres in Olompali State Historic Park.

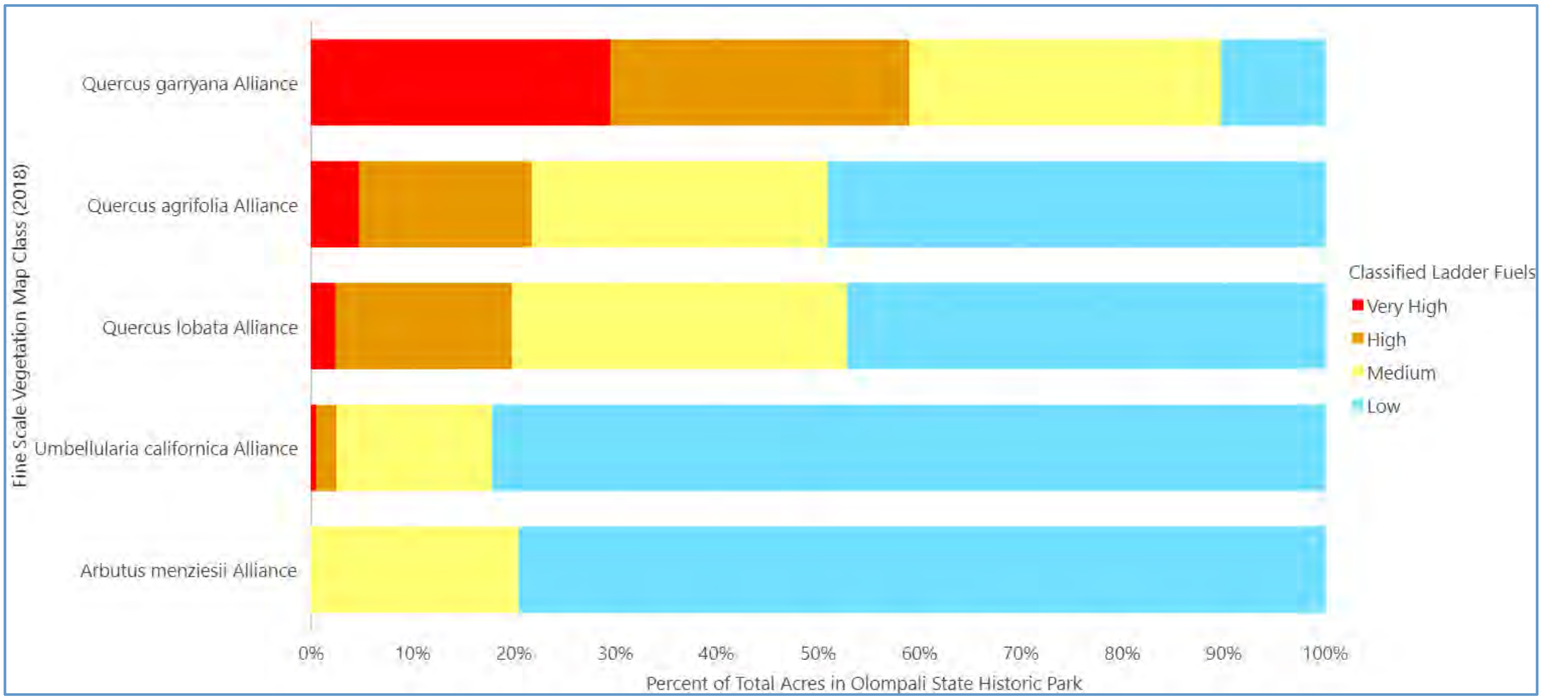
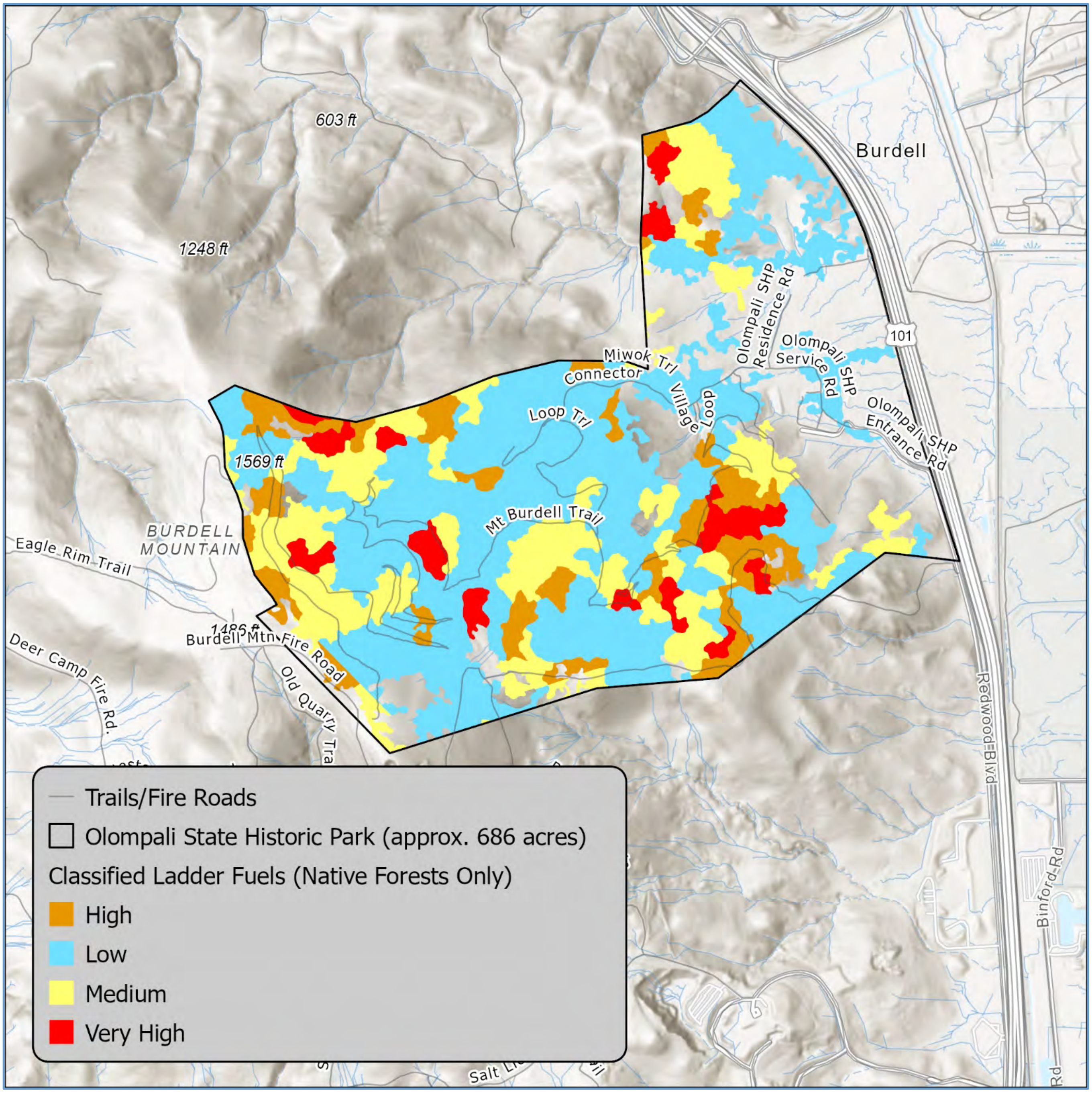


Figure 8.68. Classified ladder fuels and adjacent trails/roads, Olompali State Historic Park.



CHINA CAMP STATE PARK FOREST HEALTH & RESILIENCE

China Camp State Park is located along the shores of San Pablo Bay and northeast facing slopes of San Pedro Mountain in Marin County (Figure 8.69). Designated a state park in 1978, the history of the area that comprises China Camp State Park begins with the Coast Miwok people, and after European colonization, missionization, and Spanish land grant era, includes a period during the 1880s as a shrimp fishing village inhabited by Chinese immigrants seeking work after completion of the transcontinental railroad (CDPR, 2015). It should also be noted that Coast Miwok peoples continued to engage with this area into the colonial period (Schneider 2015), and Tribal engagements with these places persist through the present day, including the Tribe's current government-to-government relationship with California State Parks. This California State Parks unit includes a diversity of habitats, including tidal and freshwater marshes that are part of the San Francisco Bay National Estuarine Research Reserve system. China Camp State Park is heavily wooded, with nearly 70% (1,059 acres) of the land covered by native forests comprised of predominantly hardwoods, including California bay (*Umbellularia californica*), coast live oak (*Quercus agrifolia*), and Pacific madrone (*Arbutus menziesii*) (Figure 8.70).

Fire exclusion is likely contributing to a departure from desired conditions in China Camp State Park. Research conducted as part of the *Marin County Wildfire History Mapping Project* shows several fires were recorded in the general area of China Camp State Park between 1917 and 1935 by Edwin B. Gardner, Fire Warden & Superintendent of the Tamalpais Forest Fire District (Dawson, 2021; see Appendix B: Wildfire History). Since that period, no fires greater than 160 acres have been recorded, indicating much of the park has not experienced fire in approximately 89 years or more (Figure 8.71). It is worth noting that State Parks conducted approximately 200 acres of broadcast burns at China Camp in the 1990s (R. Schneider, personal communication, March 20, 2023).

Fire exclusion can result in unnatural fuel arrangements, and impact regeneration and fecundity in oak woodlands. Impacts from other forest health stressors, including non-native invasive species such as Scotch broom (*Cytisus scoparius*) and eucalyptus, as well as canopy mortality and sudden oak death, are also driving a departure from desired conditions at China Camp State Park (Figure 8.72 and 8.73). Environmental scientists are seeking to address these impacts to forest health and resilience at key areas in China Camp State Park by advancing projects to reduce non-native invasive species cover, strategically reduce accumulated fuels, and reintroduce beneficial fire.

Figure 8.69. China Camp State Park and surrounding area, Marin County.

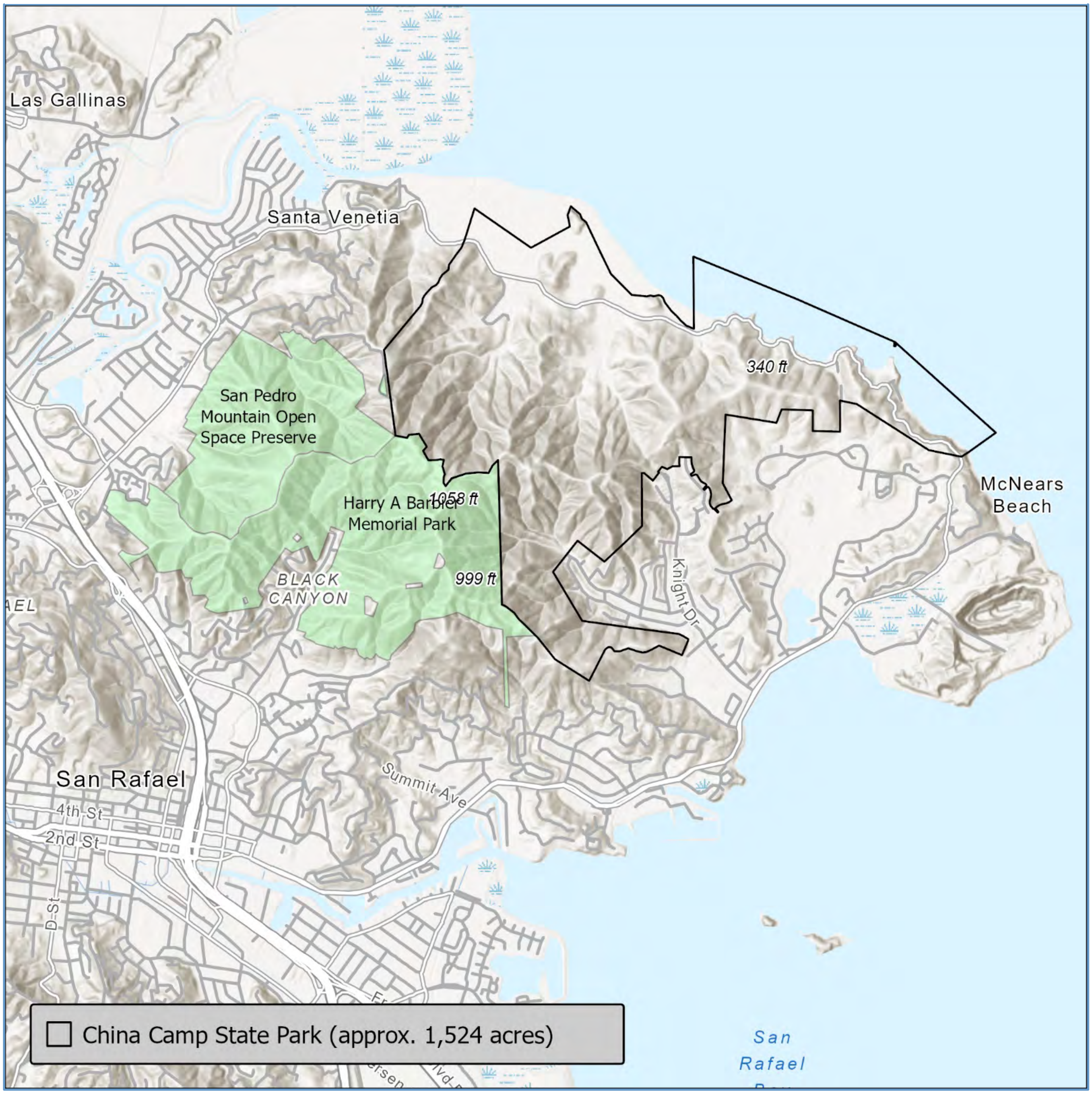


Figure 8.70. 2018 Fine Scale Vegetation Map native forests community by acres, China Camp State Park.

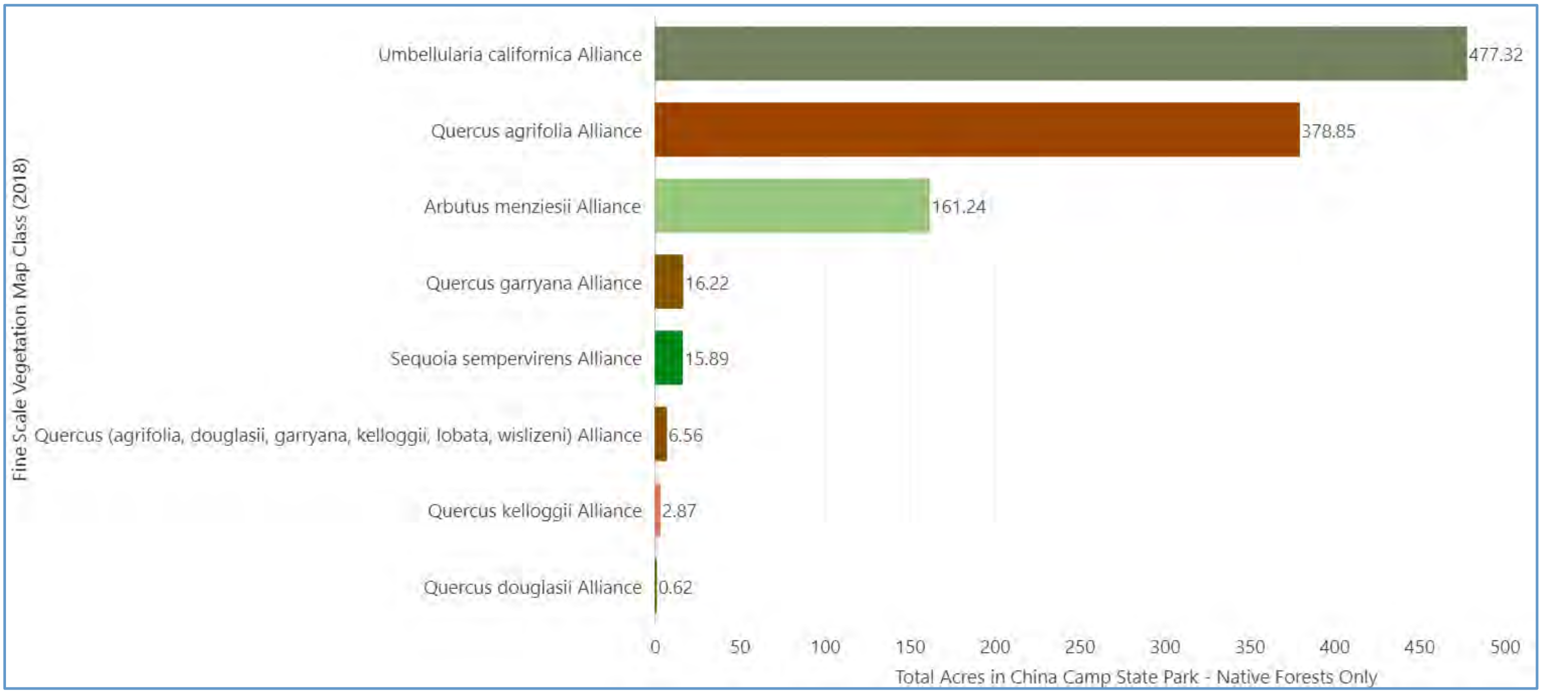


Figure 8.71. Years since last fire, China Camp State Park and surrounding area (Dawson, 2021).

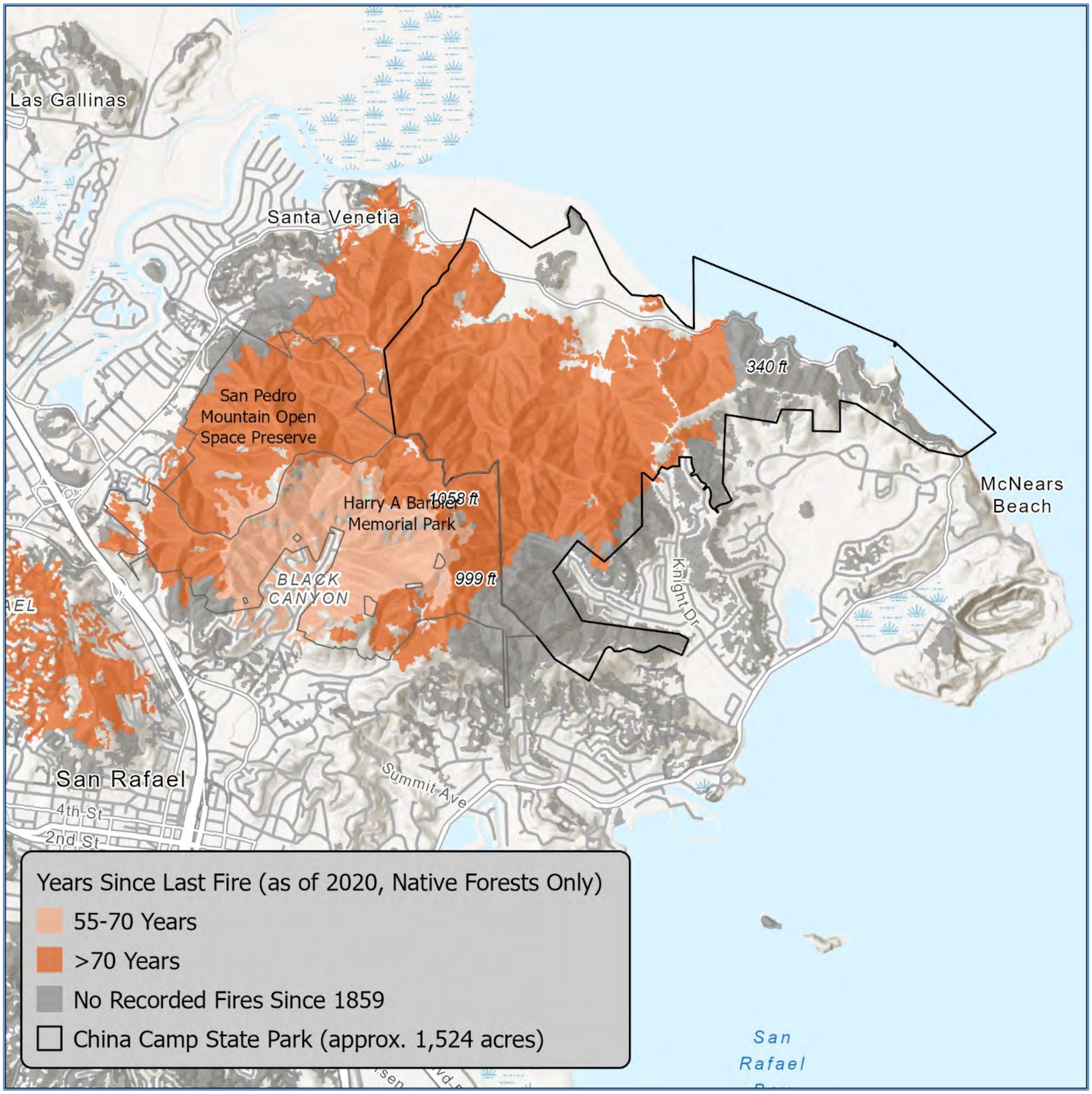


Figure 8.72. 2018 Fine Scale Vegetation Map class acres by departure from desired conditions indices (top three only), China Camp State Park.

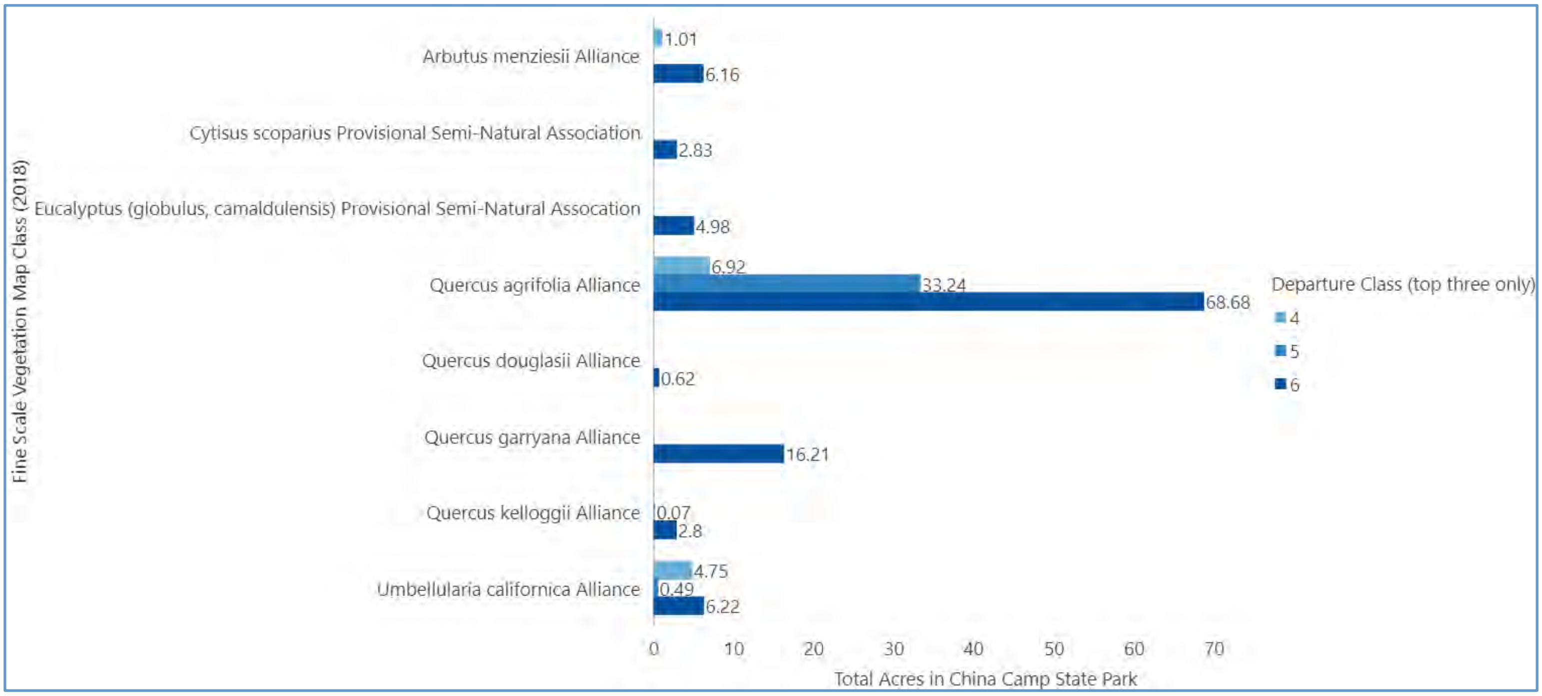
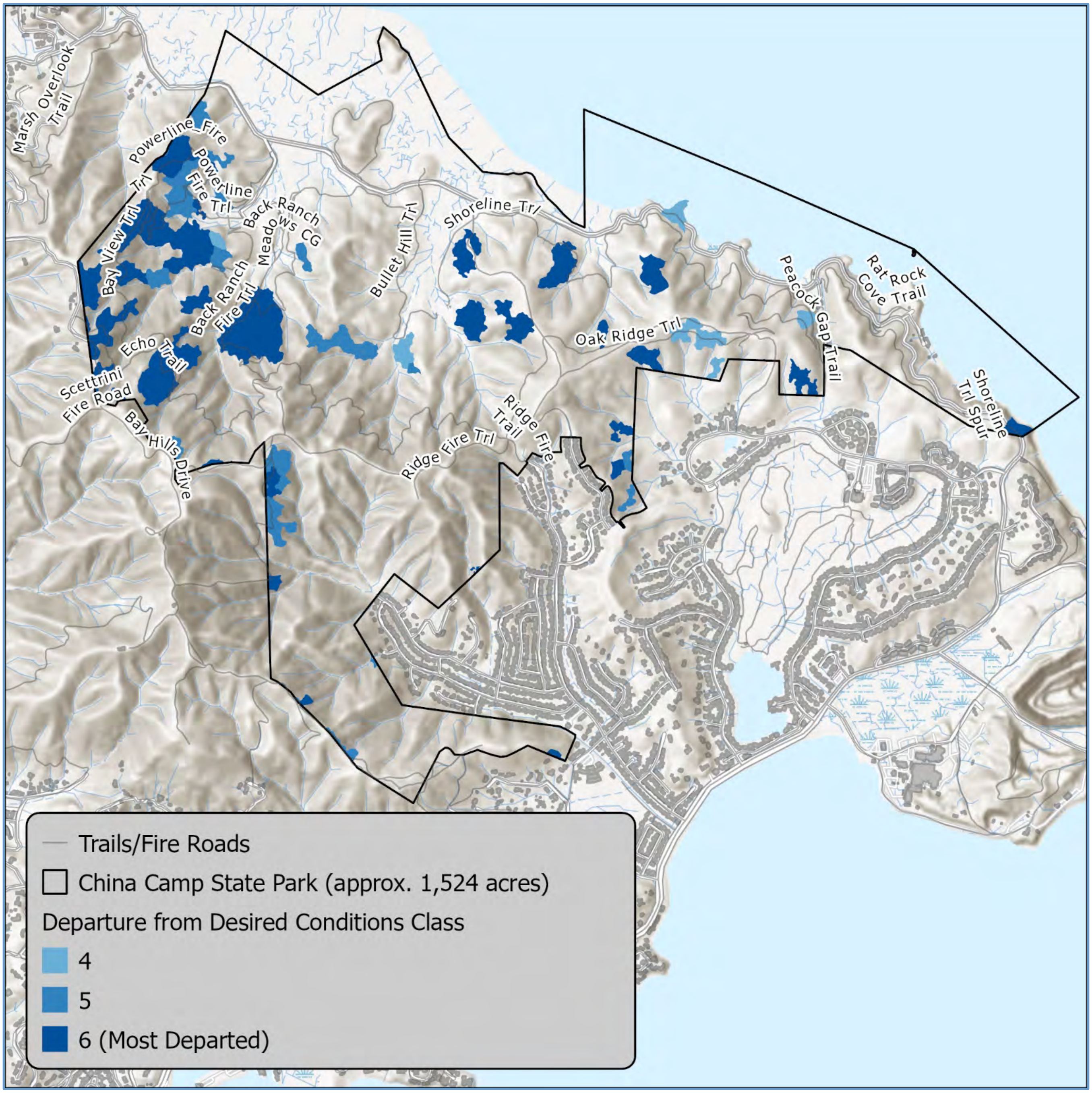


Figure 8.73. China Camp State Park, departure from desired conditions (top three classes only) and adjacent trails/roads.



ANGEL ISLAND STATE PARK FOREST HEALTH & RESILIENCE

The largest natural island in the San Francisco Bay, Angel Island is located off the tip of the Tiburon Peninsula in Marin County, separated approximately a mile from the mainland by the Raccoon Strait; the entire island is included in Angel Island State Park (Figure 8.74). A California Historical Landmark, the island was first used by the Coast Miwok as a fishing and hunting camp, and following the forced removal of Native peoples and land theft perpetrated by settler colonists, the area was used primarily in the economic, social, and political pursuits of colonists, such as cattle ranching, military installations, and as a quarantine station through the 1940s (CDPR, n.d.b.; CDPR Office of Historic Preservation, n.d.). The shift to a California State Park began in 1954 with Ayala Cove on the western side of the island and, following the departure of the military in the 1960s, eventually included the whole island (CDPR, n.d.b.).

Angel Island provides habitat for numerous wildlife species including waterfowl and other bird species, with seals and sea lions often found along the shoreline (CDPR, n.d.b.). Native vegetation communities in Angel Island State Park include grasslands, coastal shrublands, and hardwood forests, however a variety of non-native invasive woody plant species were also introduced to the island during the military era (Ripley, 1980; Wheeler, n.d.). The 2018 Fine Scale Vegetation Map depicts 344 acres of native forest in Angel Island State Park, including 181 acres of California bay (*Umbellularia californica*) and 160 acres coast live oak (*Quercus agrifolia*) dominated woodlands (Figure 8.75). Also mapped were 47 acres of non-native invasive forest including eucalyptus, Monterey cypress (*Hesperocyparis macrocarpa*), and Monterey pine (*Pinus radiata*).

Coast Miwok stewardship, including tending with fire to expand grassland and other favored habitats or conditions took place at Angel Island prior to colonization (Wheeler, n.d.). Between 1859 and 2020, the only documented fire greater than 160 acres occurred in October 2008; it eventually burned 303 acres on the island's south-facing slopes before being extinguished (Figure 8.76). Vegetation communities within the 2008 fire footprint mapped in the 2018 Fine Scale Vegetation Map include 165 acres of coyote brush (*Baccharis pilularis*) shrubland, 73 acres of coast live oak (*Quercus agrifolia*) woodland, and 29 acres of grassland. It is also worth noting that State Parks conducted at least 50 acres of broadcast burning at Angel Island in the 1990s (R. Schneider, personal communication, March 20, 2023).

Impacts from non-native invasive species, coupled with detectable canopy mortality and relatively high ladder fuels in some areas, are driving a departure from desired conditions in Angel Island State Park (Figure 8.77). Thirty-three percent (53 acres) of coast live oak woodlands have a departure class of 4 or greater, along with 49% of California bay forest. Notably, most hardwood forests with a departure from desired conditions of 4 or greater are outside of the 2008 Angel Island Fire perimeter (Figure 8.78). The proximity of many of the most departed stands to roads and trails indicates that treatment will be feasible in numerous areas.

Figure 8.74. Angel Island State Park, Marin County.

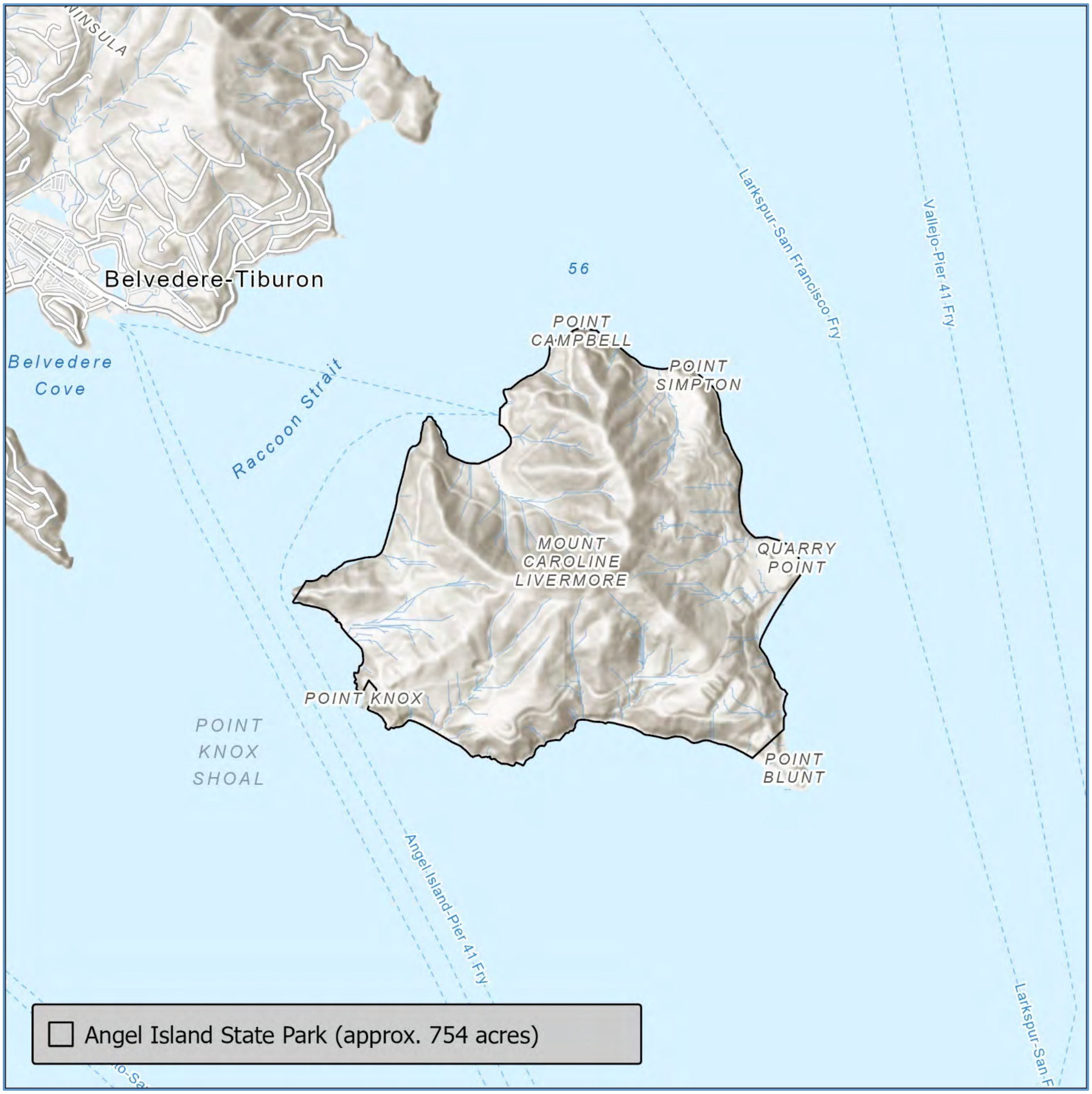


Figure 8.75. 2018 countywide fine scale vegetation map native forests communities by acres, Angel Island State Park.

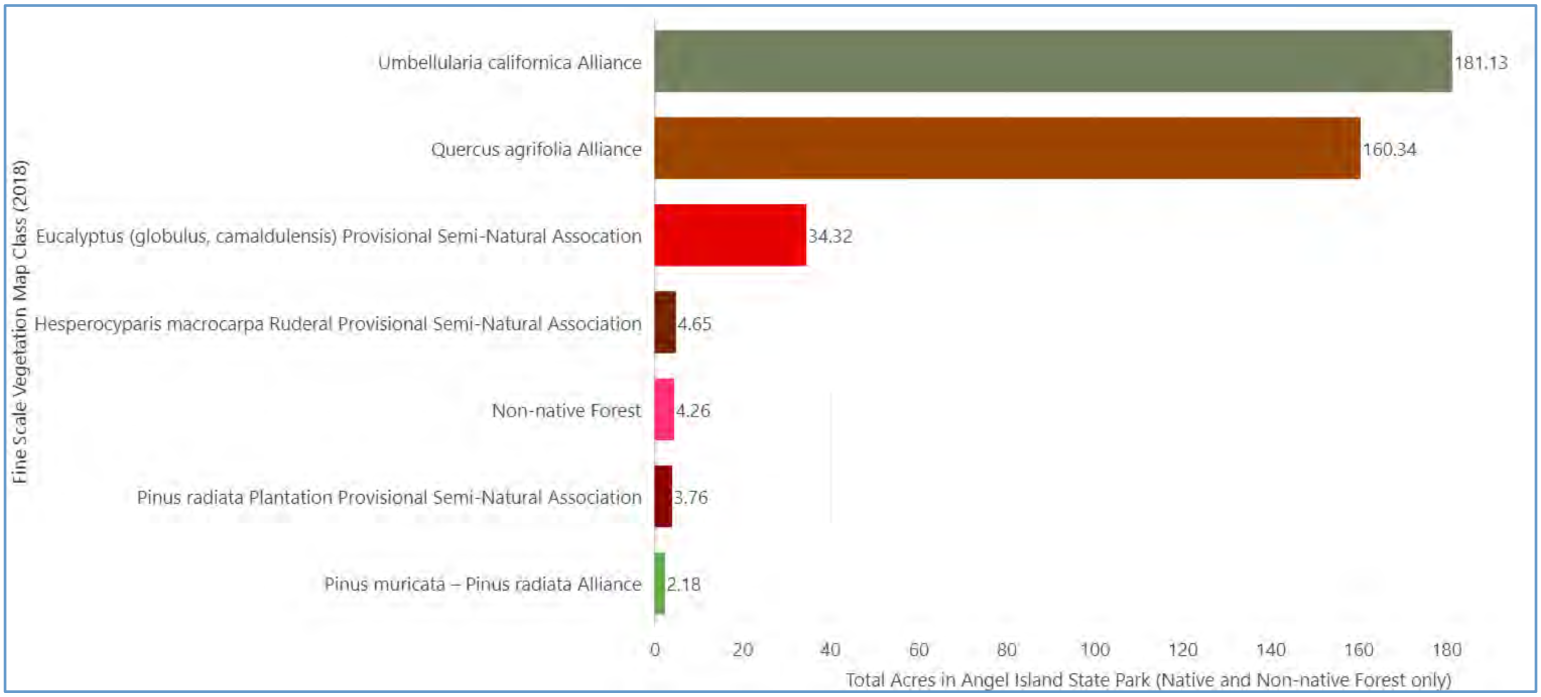


Figure 8.76. 2008 Angel Island Fire Perimeter, Angel Island State Park (Dawson, 2021).

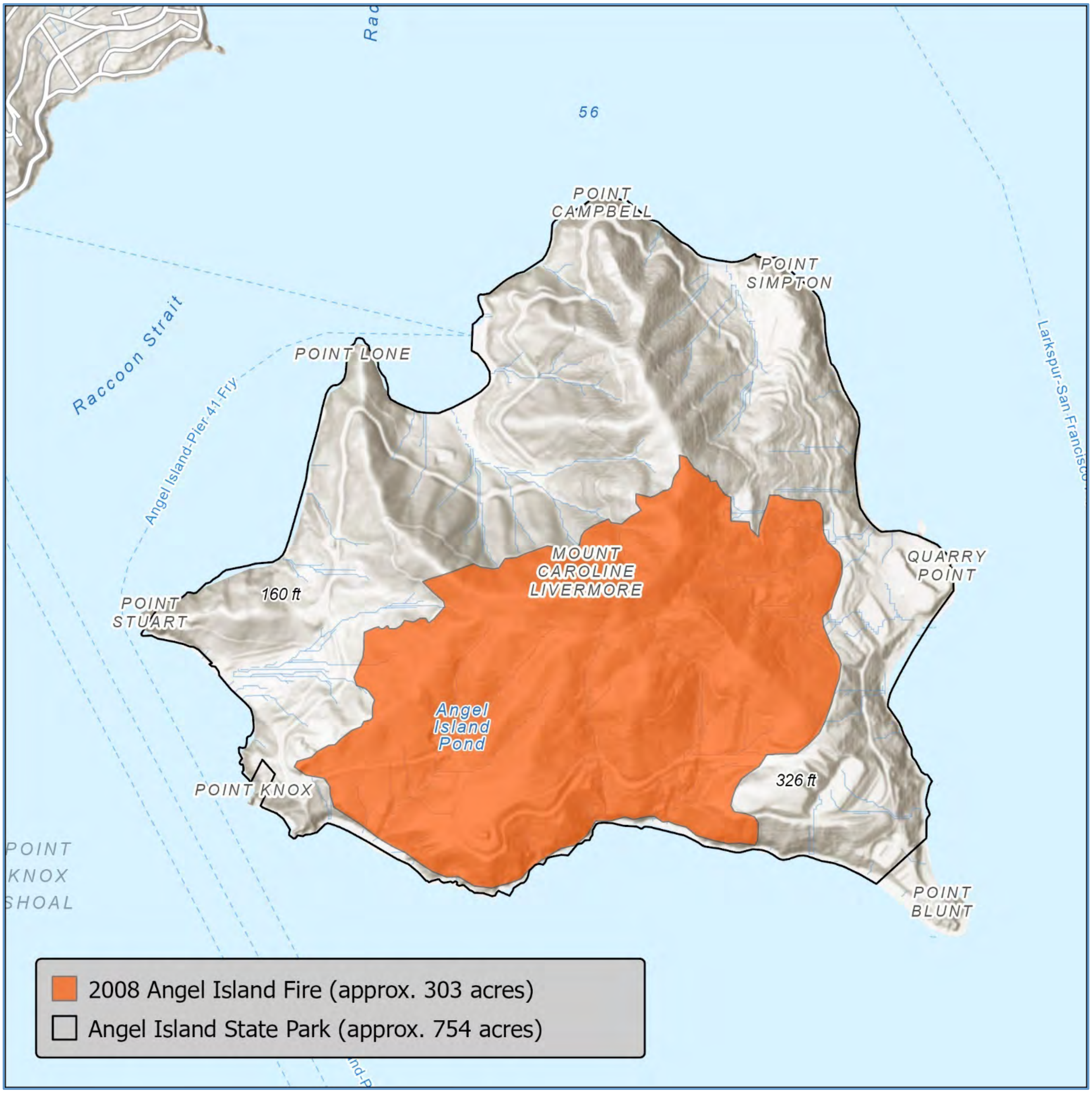


Figure 8.77. 2018 Fine Scale Vegetation Map class acres by departure from desired conditions indices (top three only), Angel Island State Park.

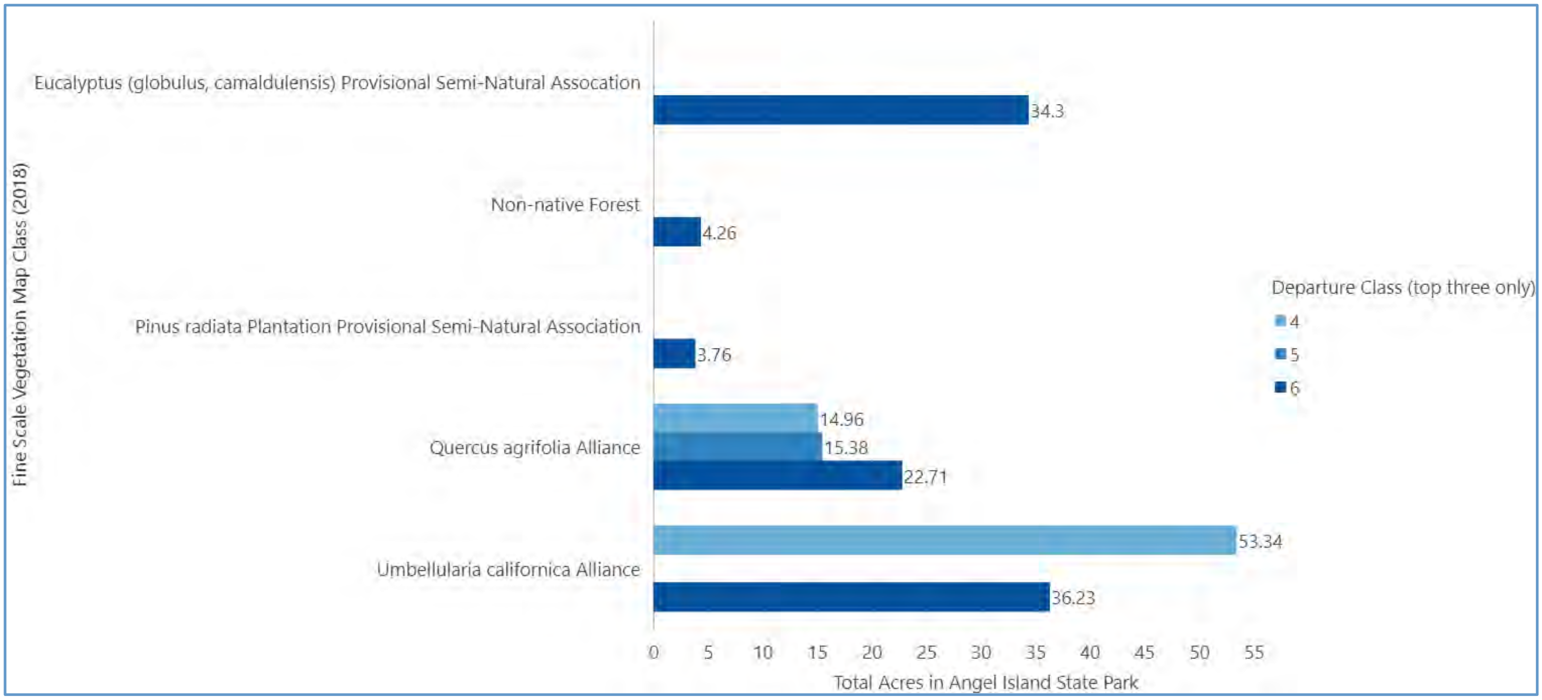
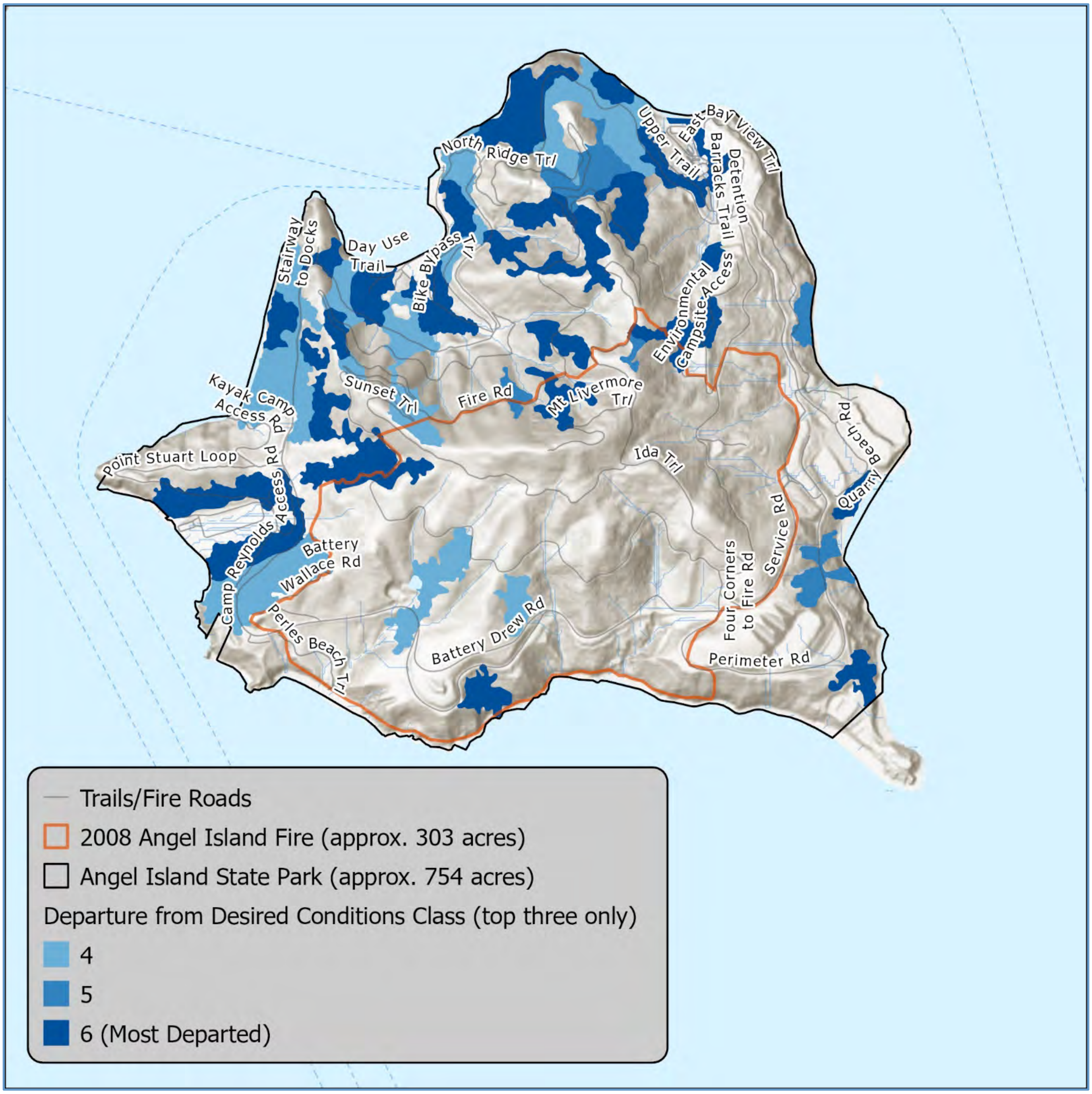


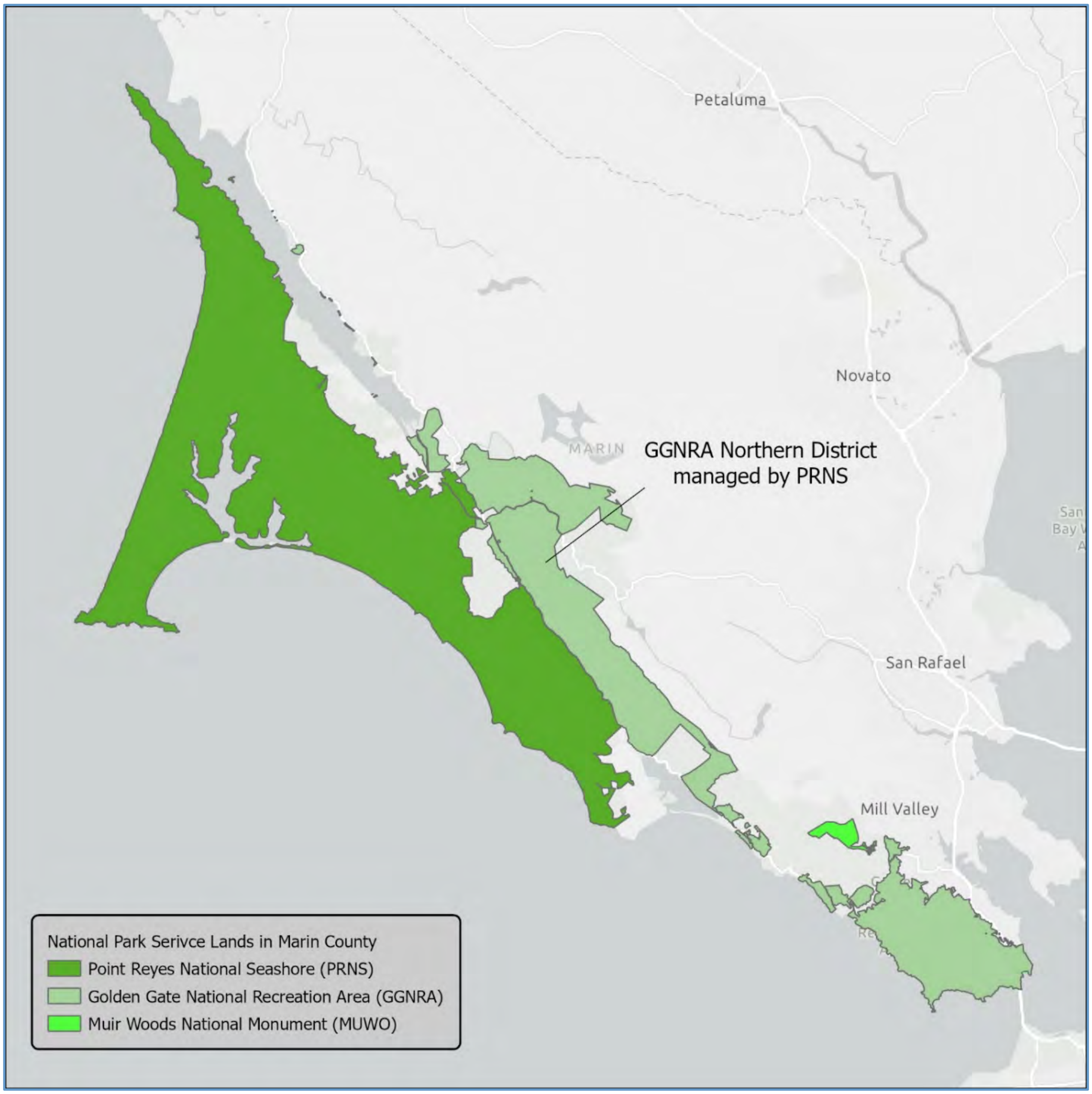
Figure 8.78. 2018 Fine Scale Vegetation Map class acres by departure from desired conditions class (top three only), Angel Island State Park.



NATIONAL PARK SERVICE PRIORITY TREATMENT AREAS

The National Park Service (NPS) manages more than 80,000 acres of land in Marin County, including Point Reyes National Seashore (PRNS or the Seashore), the 554-acre Muir Woods National Monument (MUWO or Muir Woods), and the Golden Gate National Recreation Area (GGNRA) (Figure 8.79). The Northern District of GGNRA, which includes approximately 14,500 acres of grasslands, coastal scrub, Douglas-fir, and Coast Redwood forests near Bolinas Ridge, is managed by PRNS under an agreement between the units. Together these federal parklands contain an exceptionally diverse variety of habitat types for dozens of rare, threatened, or endangered flora and fauna, Tribal Cultural Resources – including forests, plants, animals, other elements of the environment, storied places, and sites where people lived, worked, and played before and after colonization –historic landmarks and ranches, and one-of-a-kind recreational opportunities for millions of visitors each year.

Figure 8.79. National Park Service managed lands in Marin County.

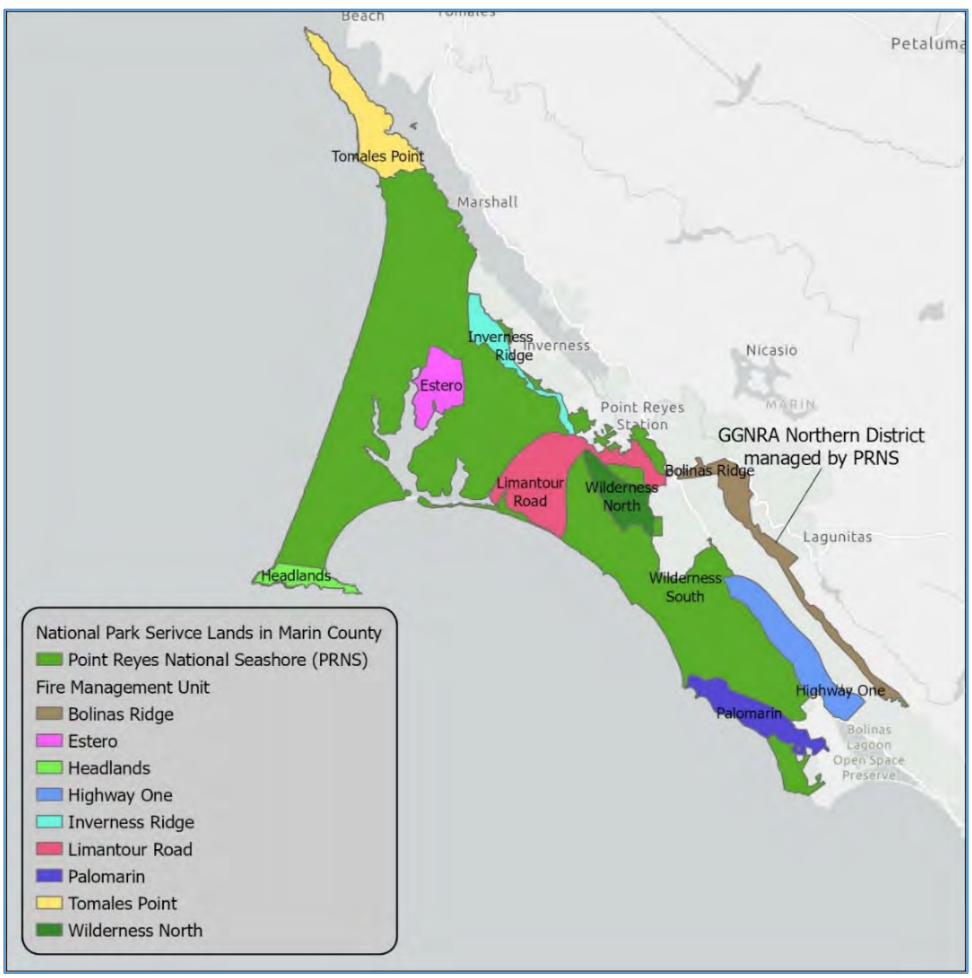


POINT REYES NATIONAL SEASHORE FOCUS AREAS

In 2004, Point Reyes National Seashore adopted the Fire Management Plan (FMP) Final Environmental Impact Statement (FEIS) for PRNS and North District GGNRA (PRNS, 2004). Under the preferred alternative in the FMP FEIS, the Seashore committed to a combination of mechanical and prescribed fire management approaches that prioritize the health of natural resources by increasing the abundance and distribution of threatened and endangered species, reducing infestations of invasive, non-native plants, and increasing native plant cover. Under the preferred alternative, the Seashore can mechanically treat up to 1,500 acres per year and conduct prescribed burning on up to 2,000 acres per year. For planning purposes, the PRNS FMP established 11 Fire Management Units (FMUs) based on landcover, geography, and associated opportunities and constraints within different regions of the Seashore (Figure 8.80). FMUs are referenced where applicable.

In the FMP, burning was identified as a tool for restoring cultural landscapes through opening vegetation in areas identified as having culturally significant viewsheds, improving habitat in key areas, and promote regeneration of rare species dependent on fire. Pilot projects with research components are emphasized where additional information would be helpful in

Figure 8.80. Fire Management Units identified and described in the Point Reyes National Seashore Fire Management Plan.

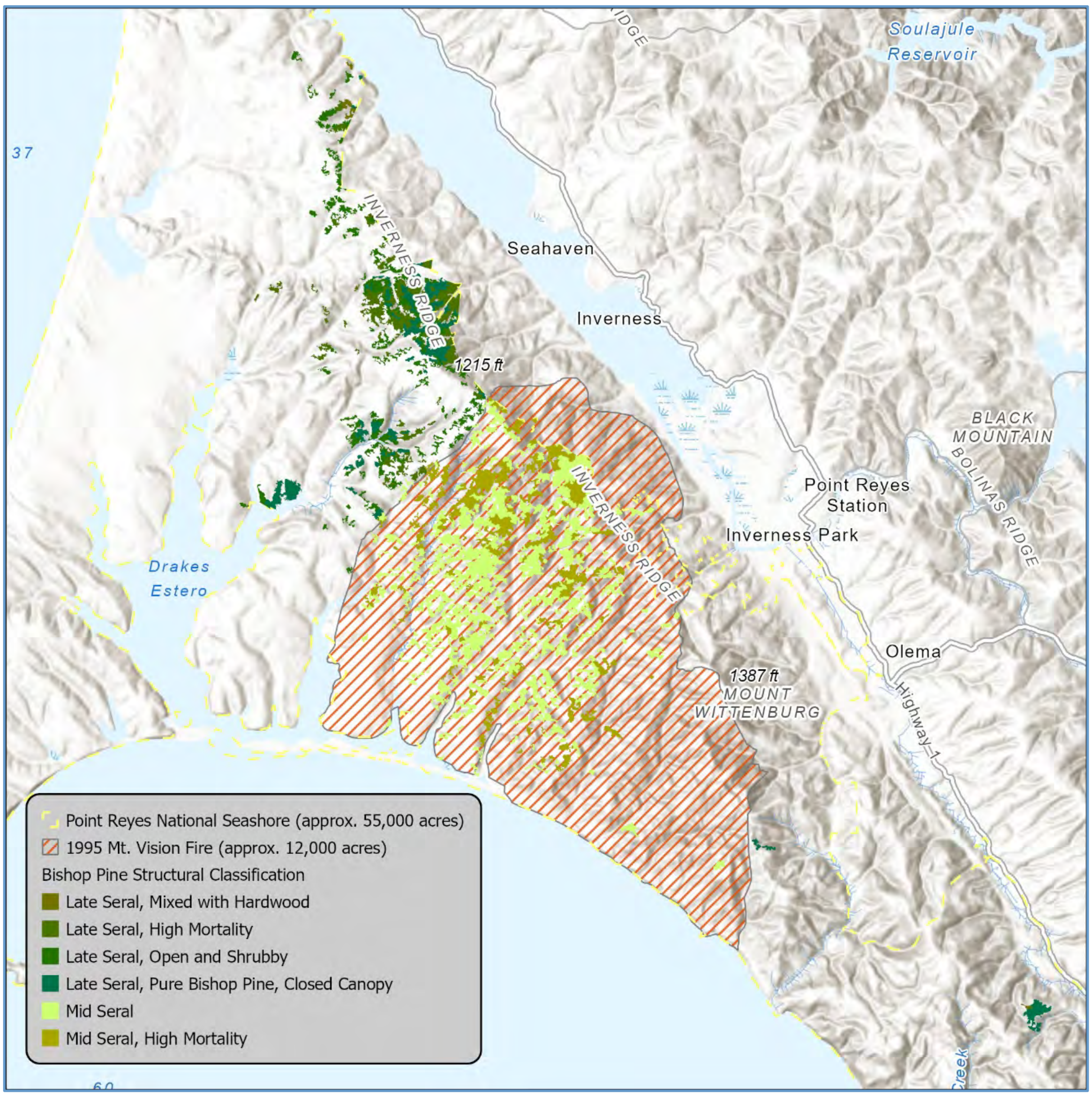


adaptively refining treatment approaches for different locations and habitat types. The FMP also calls for expanded hazardous fuel reduction in high priority areas (e.g., along road corridors and around structures) to reduce the risk that wildland fire poses to lives and property. The PRNS FMP foresees coupling hazardous fuel reduction with monitoring of fire effects on vegetation of interest (i.e., both rare and invasive species) to refine fire management practices.

Point Reyes National Seashore Bishop Pine Forest Health & Resilience

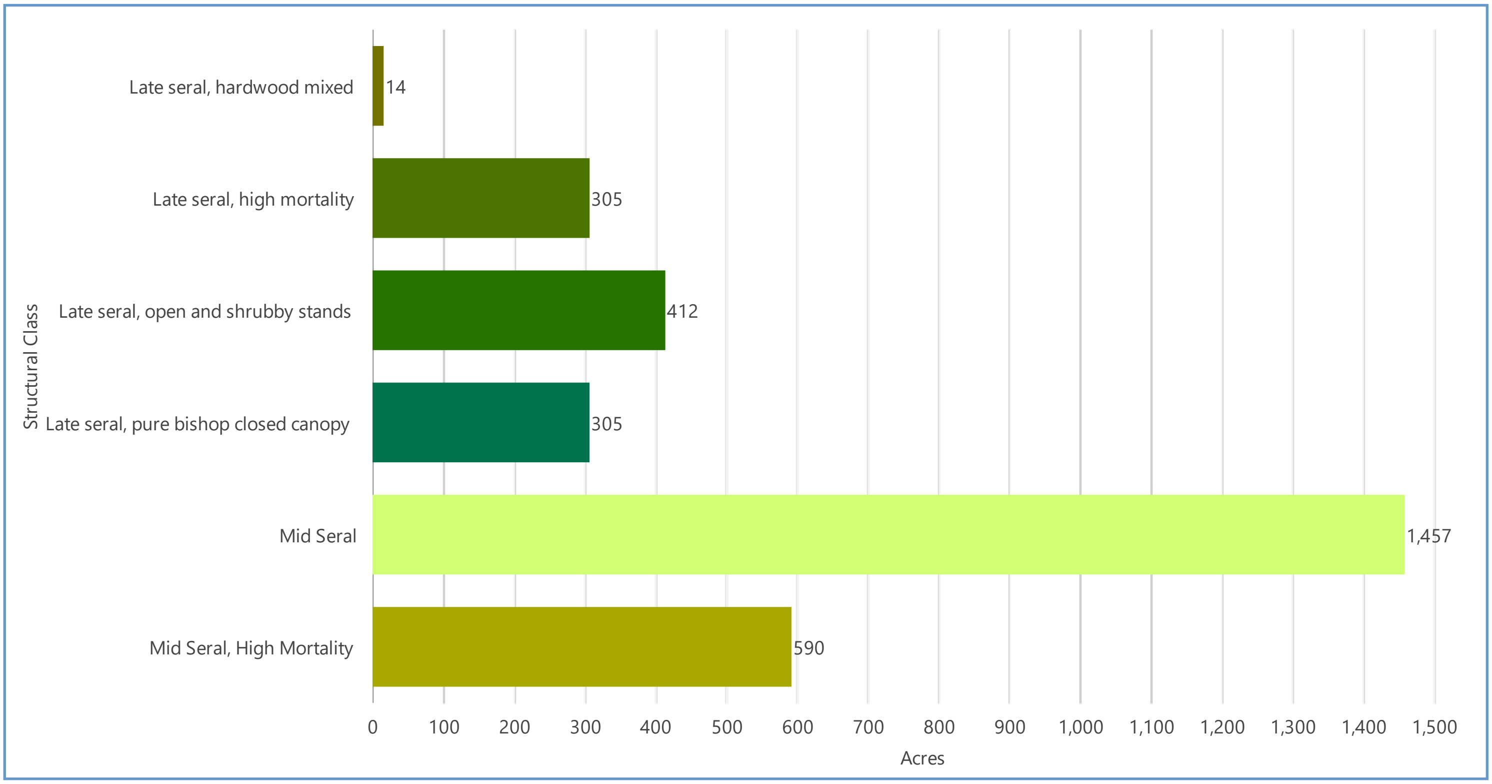
In October 1995, the Vision Fire burned approximately 12,000 acres and destroyed 45 structures on Inverness Ridge. According to the 2018 Fine Scale Vegetation Map, of the 3,083 acres of Bishop Pine forest on PRNS lands approximately 66% (2,047 acres) are within the Vision Fire perimeter – much of which includes an expanded footprint of post-fire regeneration Bishop Pine. Since 1995, the Bishop Pine forest within the Vision Fire footprint has been

Figure 8.81. Bishop Pine forest distribution on Point Reyes National Seashore by structural class.



severely affected by pine pitch canker disease (PPCD) (see Appendix A: Bishop Pine). The Bishop Pine structural classification developed as part of the *Forest Health Strategy* (see Chapter 6: Metrics) differentiates the younger mid-seral Bishop Pine forests of the Vision Fire cohort from late-seral stands, and further classifies each seral state based on the extent of canopy mortality and other characteristics (Figure 8.81). Of the 2,047 acres of mid-seral Bishop Pine, approximately 29% (590 acres) are classified as high mortality stands with greater than 15% canopy mortality (Figure 8.82).

Figure 8.82. Bishop Pine acres by structural class, Point Reyes National Seashore.



Bishop Pine forests within the Vision Fire footprint have been the subject of multiple studies by NPS and researchers interested in fire ecology and serotinous species. PPCD was detected in PRNS in 2006, and monitoring plots were established in post-Vision Fire stands as part of a 2011 study. As part of the *Forest Health Strategy* , monitoring plots were revisited by researchers from the Harvey Lab at the University of Washington, and subsequent analysis of data collected from revisited 2011 plots and compared with data from late-seral Bishop Pine stands provides meaningful insight into management approaches (see Appendix A: Bishop Pine; Harvey & Agne, 2021; Harvey et al., 2022). Importantly, this analysis suggests that key forest health indicators showed overall persistence of Bishop Pine forest in the Seashore, despite impacts from PPCD. Additionally, while coarse fuel loads associated with higher fire hazard were greater in stands with elevated mortality, they did not exceed levels observed in late-seral stands.

PRNS is interested in advancing demonstration project work at sites along Inverness Ridge. These projects will test multi-benefit treatment approaches aimed at reducing fuel loads and decreasing competition among mid-seral trees to improve resistance to disease and accelerate stands toward structurally complex old-growth conditions. Demonstration work and monitoring will inform approaches for scaling up treatments in high-priority Bishop Pine management areas on PRNS. In addition, MWPA anticipates future work in the WUI near PRNS (M. Brown, personal communication, March 7, 2023).

Palomarin Wildfire Risk Reduction & Habitat Restoration Project

Since their original 1965 founding on the Point Reyes Peninsula, Point Blue Conservation Science (Point Blue; founded as Point Reyes Bird Observatory) has been conducting data collection, training, public outreach, and other programs in the region. They are focused on the study of birds and their habitat, and the importance of avian species as indicators of overall ecosystem health and function (Ralph & Geupel, 2019). The Palomarin Field Station & Nature Center has been operating year-round since 1966 through a partnership between Point Blue and the Point Reyes National Seashore (PRNS). In the five decades since its inception it has amassed a uniquely rich and multi-faceted long-term dataset that provides insight into the ecological responses of landbirds to natural and human caused changes, including climate change and habitat succession (Point Blue, n.d.; Porzig et al., 2011).

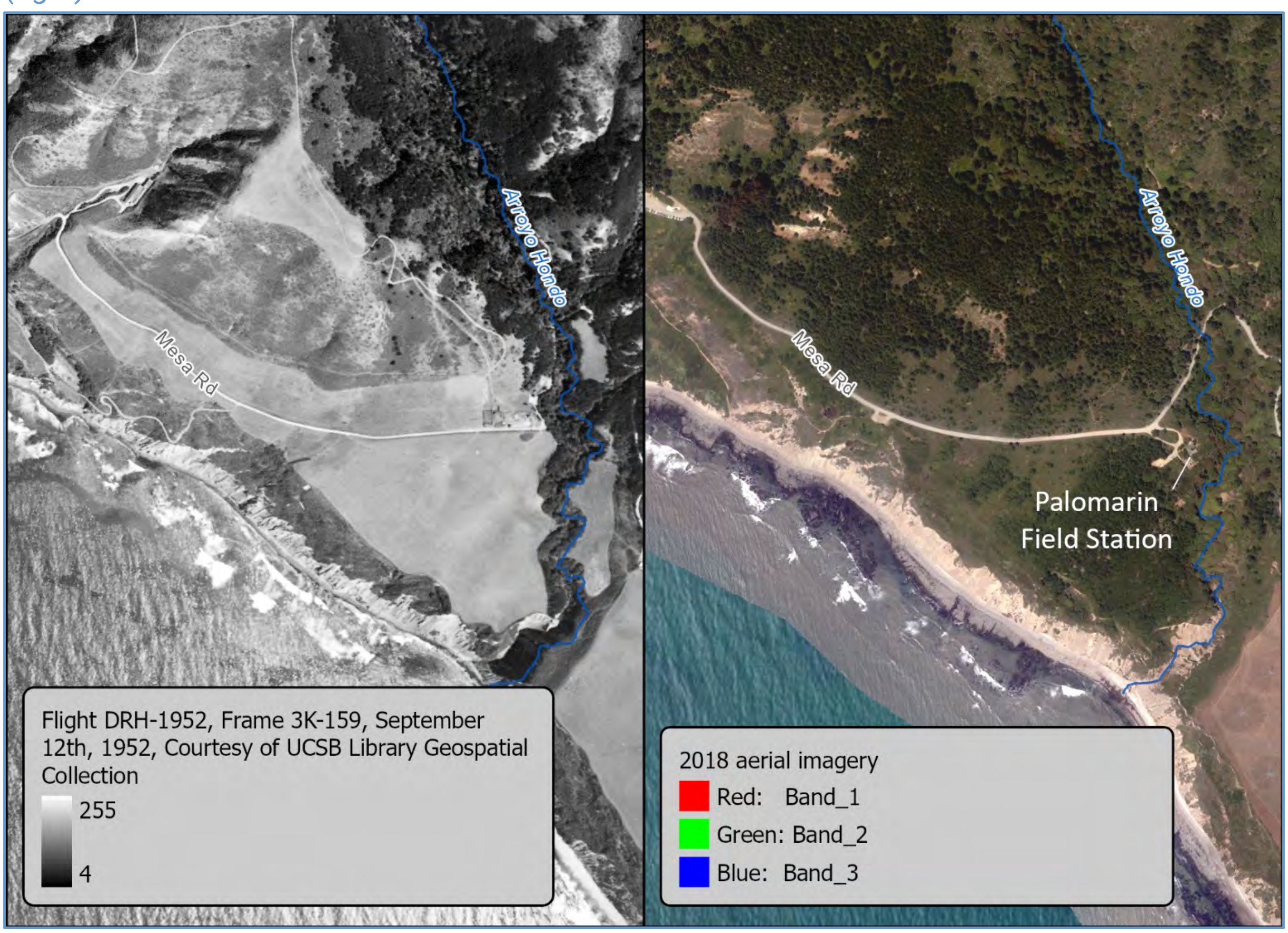
Since 1965, Point Blue has observed and recorded changes in the population dynamics of the bird community near the Palomarin Field Station in response to the succession of open coastal scrub and prairie to Douglas-fir forest in the absence of disturbance. The combination of well-established baseline data depicting habitat changes, bird occupancy, and trends, and conversion dynamics represents a unique opportunity to advance project work that will both restore native habitat using a combination of mechanical treatments and beneficial fire and document the corresponding ecosystem response (K. Dybala, Principal Ecologist, Point Blue Conservation Science, personal communication, 2022). Demonstration work within the approximately 100-acre Palomarin Field Station Project Area, and within the PRNS Palomarin Fire Management Unit (FMU; Figure 8.83), will provide NPS, other land managers, and the public invaluable scientific information about the impact of fire exclusion —which includes impacts of both modern fire suppression and the removal of Coast Miwok people from their lands and related cessation of cultural burning — and the role of ecological disturbance and associated bird community responses. The project will also inform approaches to Douglas-fir forest management and coastal vegetation restoration throughout the region. Importantly, this work will also reduce wildfire risk to the Palomarin Field Station and potential loss of structures (PRNS, 2004, p. 431).

Figure 8.83. Point Reyes Bird Observatory Project Area within Palomarin Fire Management Unit, Point Reyes National Seashore.

The 2004 PRNS FMP FEIS highlights the need to address Douglas-fir encroachment into coastal scrub and grassland communities around the Palomarin Field Station to protect and enhance the mosaic of vegetation in the area and improve bird habitat through a combination of manual/mechanical and beneficial fire treatments (PRNS, 2004, p. 44). The FMP stipulated that the initial phase of work would likely include removal of Douglas-fir trees less than 10 inches DBH (diameter at breast height) prior to the reintroduction of beneficial fire to improve fire control and to increase biodiversity (PRNS, 2004, p. 285). The efficacy of treatment approaches would be assessed from a plant biodiversity perspective and associated response from bird populations in collaboration with Point Blue (PRNS, 2004, p. 46). Initial planning must involve consultation with the Federated Indians of Graton Rancheria because the project area is within the Tribe's territory and has the potential to impact TCRs – a designation that holistically includes both environmental and cultural resources as significant Tribal Cultural Resources (PRNS, 2004, p. 154). Point Blue and NPS are open to collaboration with the Tribe regarding the scope of the overall proposed project.

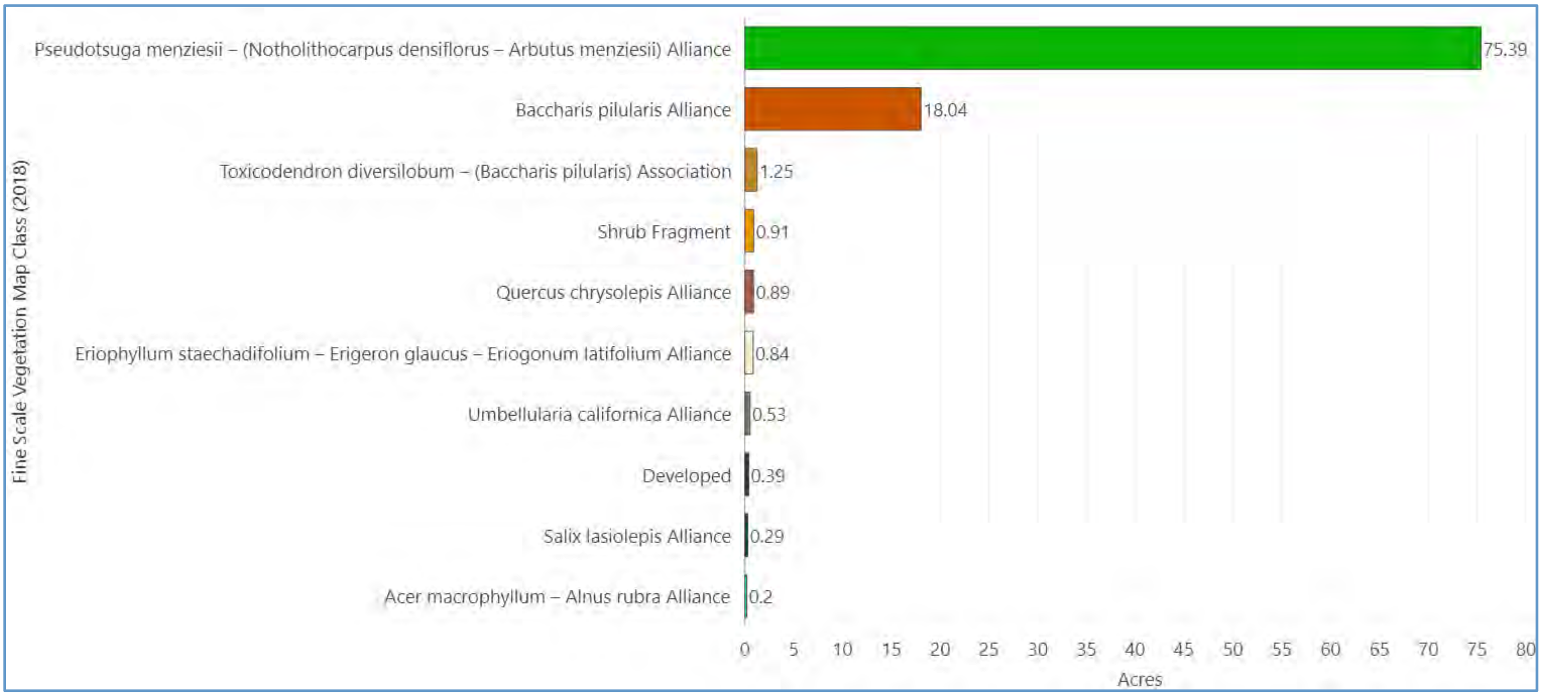
In addition to reducing wildfire risk for the Palomarin Field Station, restoring coastal habitat, and measuring the corresponding bird community response, conducting the Palomarin Wildfire Risk Reduction and Habitat Restoration Project adjacent to Palomarin's publicly-accessible bird banding laboratory and nature center presents a unique opportunity to demonstrate the impact of the *Forest Health Strategy*, the role and value of ecological disturbance, and build trust with those who might be unfamiliar or uncomfortable with active forest management including the use of beneficial fire. As recent as 1952, much of the project area adjacent to Palomarin Field Station was almost exclusively coastal prairie and shrubland (Figure 8.84, left),

Figure 8.84. Palomarin Field Station and surrounding area in 1952 (Flight DRH-1952, Frame 3K-159, September 12th, 1952, Courtesy of U.C. Santa Barbara Library Geospatial Collection, UCSB, n.d.) (left). The extent of Douglas-fir expansion resulting from fire exclusion, captured in 2018 (right).



however recent fire exclusion combined with other potential contributing factors has resulted in a significant shift towards Douglas-fir forest (Figure 8.84, right). According to the 2018 Fine Scale Vegetation Map, 75 acres of the approximately 100-acre project area are classified as

Figure 8.85. 2018 Fine Scale Vegetation Map Class by acres, Palomarin Wildfire Risk Reduction and Habitat Restoration Project Area.



Douglas-fir forest (Figure 8.85).

The Douglas-fir structural classification for this project area corresponds to early seral conditions that are closely aligned with forest expansion resulting from fire exclusion and habitat loss in other areas of Marin County (Figure 8.86). Approximately 95% (72 acres) of the Douglas-fir mapped within the project area has a mean lidar-derived stand height less than 60 feet (Figure 8.87). These conditions resemble Douglas-fir forest structure mapped on Bolinas Ridge in an area studied by Startin in 2022, who found that between 1952 and 2018 overall herbaceous plant community cover and shrubland cover decreased by 62% and 51%, respectively, while woodland increased by 307% (Startin, 2022, p. 10).

By using the *Forest Health Strategy* and partnering with Point Blue Conservation Science to develop and implement restoration and forest management actions, and study of the ecosystem response, the PRNS Palomarin Wildfire Risk Reduction and Habitat Restoration Project can serve as a reference to promote the adoption and application of best practices and lessons learned in other parts of Marin County and throughout coastal California.

Figure 8.86. Douglas-fir lidar-derived structural classification (2019) for Palomarin Wildfire Risk Reduction and Habitat Restoration Project Area.

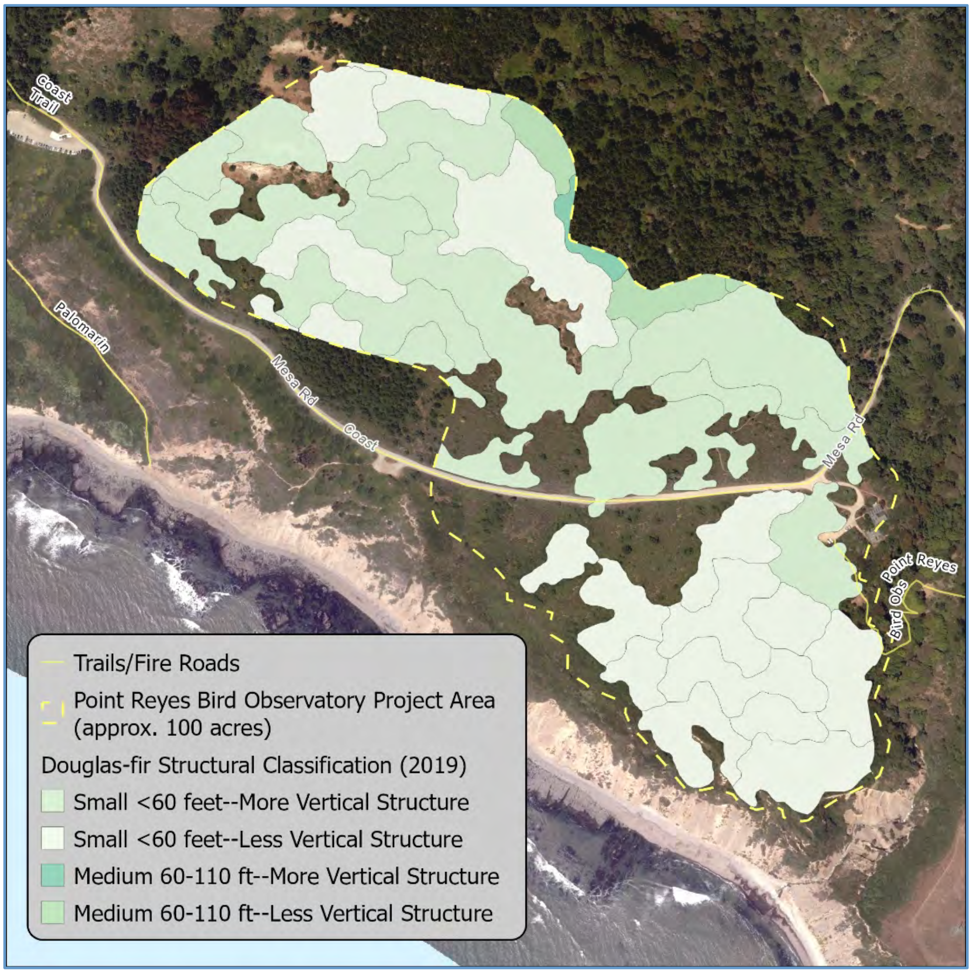
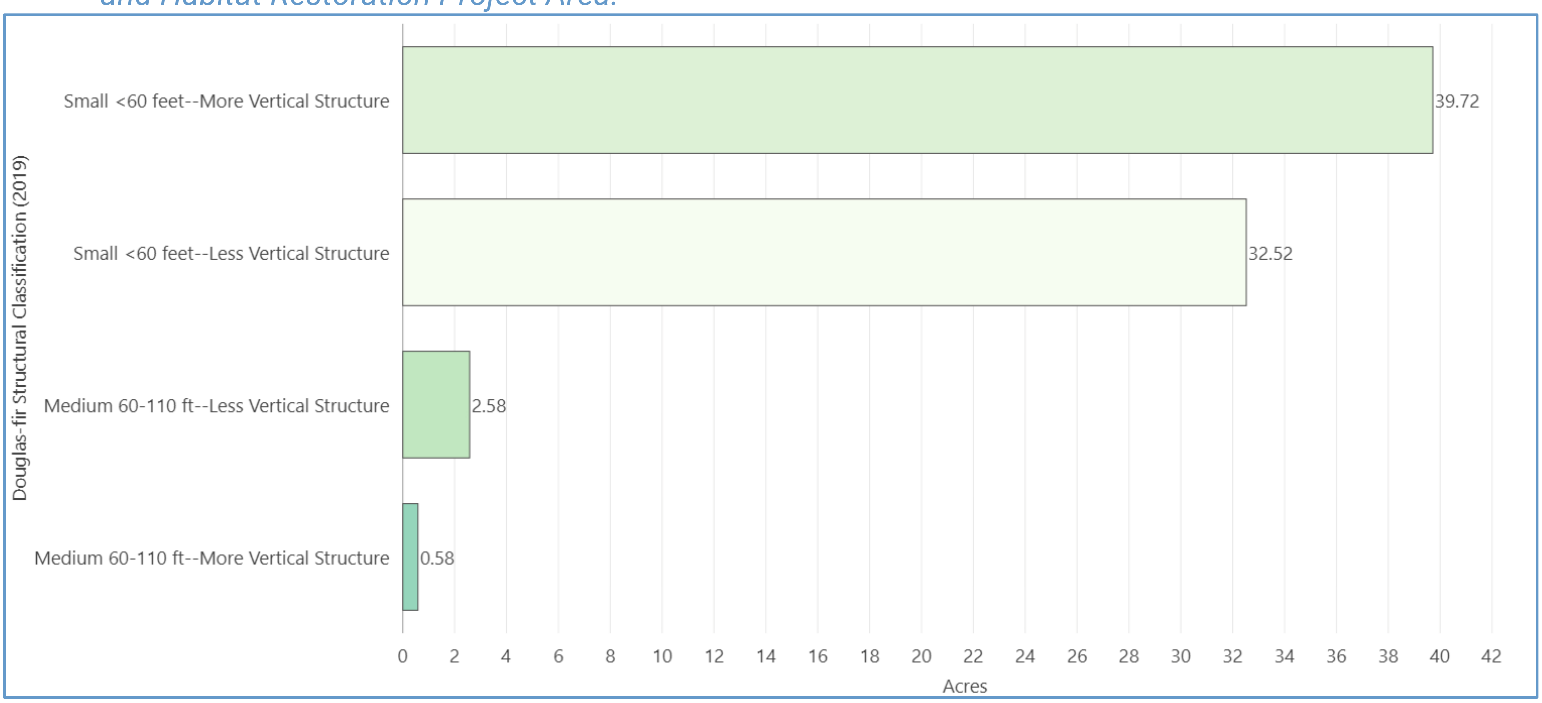


Figure 8.87. Douglas-fir structural classes by acres within the Palomarin Wildfire Risk Reduction and Habitat Restoration Project Area.



Bolinas Ridge Forest Resilience & Biodiversity

Bolinas Ridge, in southwest Marin County, runs north-south for approximately 12 miles, ranging from 400 feet in elevation near Olema to 1,800 feet on West Ridgecrest Boulevard. Much of the ridge is protected open space—with east facing slopes managed by Marin Water, drier west facing slopes managed by PRNS on behalf of GGNRA and transitioning to Mount Tamalpais State Park lands above Stinson Beach. Audubon Canyon Ranch manages the Martin Griffin Preserve directly adjacent to NPS lands (Figure 8.88). PRNS-managed lands on Bolinas Ridge are primarily grasslands (2,459 acres), with large swaths of Coyote Bush (*Baccharis pilularis*) dominated shrublands, Douglas-fir, California bay, Coast Redwood, manzanita (*Arctostaphylos sp*.), and coast live oak (*Quercus agrifolia*) stands (Figure 8.89).

Adjacent to Point Reyes, Finney (1990) found mean fire return intervals between 1850 and 1900 that ranged from 6 to 33 years, with a mean of 14 years in Coast Redwood stands on Bolinas Ridge (PRNS, 2004, p. 87). Dawson (2021) (Appendix B: Wildfire History) found that fire return intervals on Bolinas Ridge between 1859 and 1940 ranged from 15 to 45 years (Figure 8.90, left) and that the last fire to burn in this area was the Mill/Carson Canyon Fire in 1945. Thus, this area has not experienced fire in more than 77 years (Figure 8.90, right). In addition to unnatural fuel accumulations, fire exclusion has eliminated or altered habitat for two fire-dependent shrub species endemic to Marin County: Marin Manzanita (*Arctostaphylos virgata*) and Mason's Ceanothus (*Ceanothus masonii*). Both species are listed as threatened by the State of California (Rarity Rank 1B.2).

Figure 8.88. 2018 Fine Scale Vegetation Map forest communities on NPS-managed portions of Bolinas Ridge.

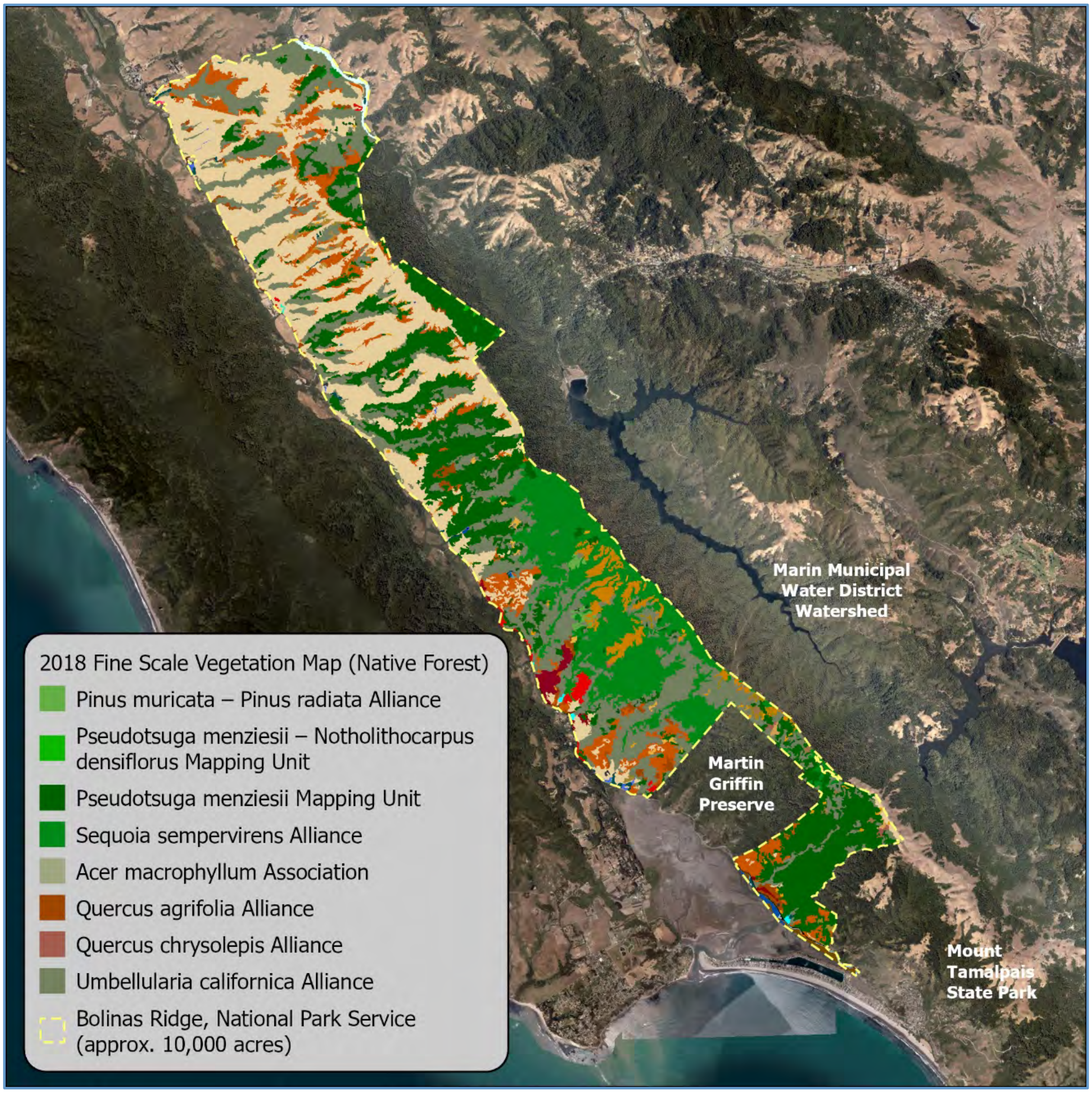


Figure 8.89. 2018 Fine Scale Vegetation Map class by acres on NPS portions of Bolinas Ridge (native forest and shrub types only).

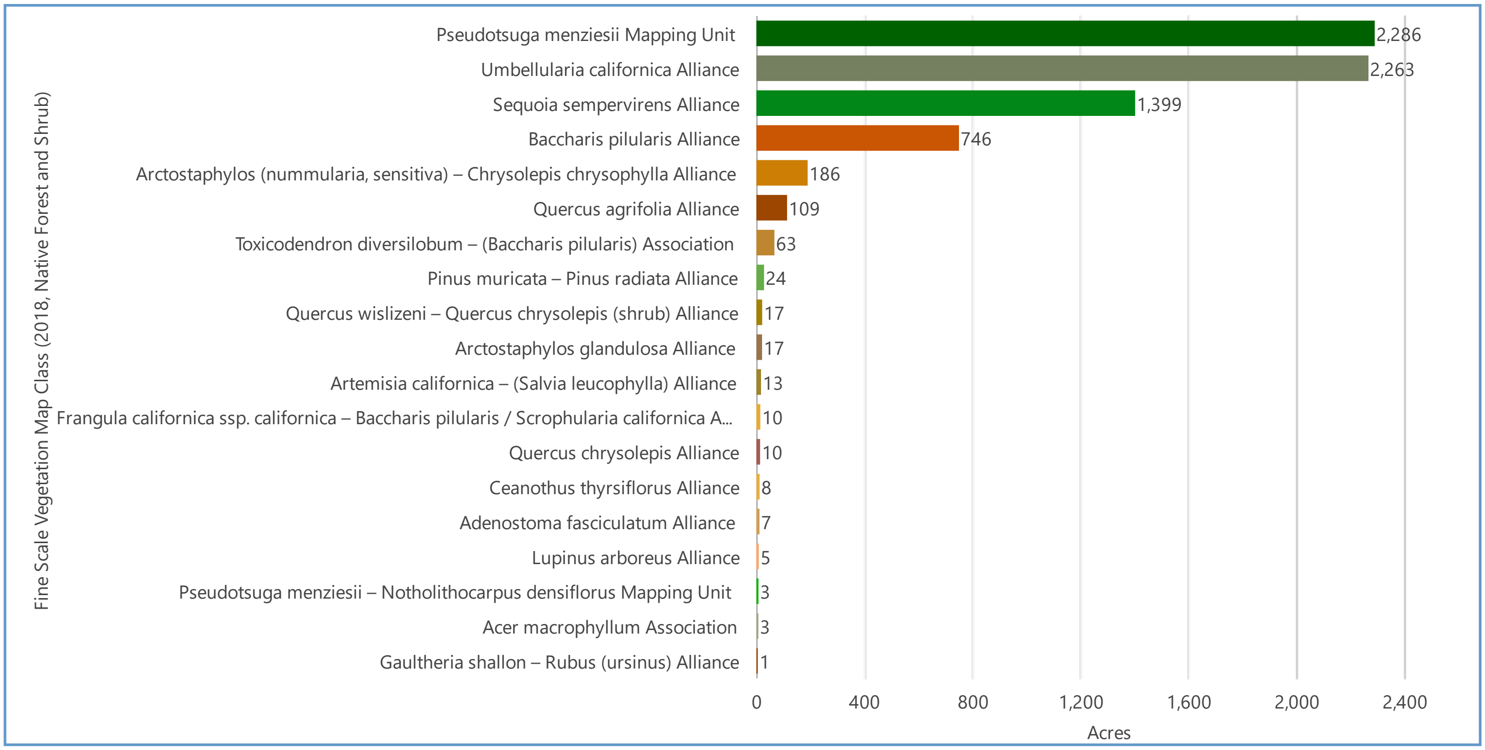
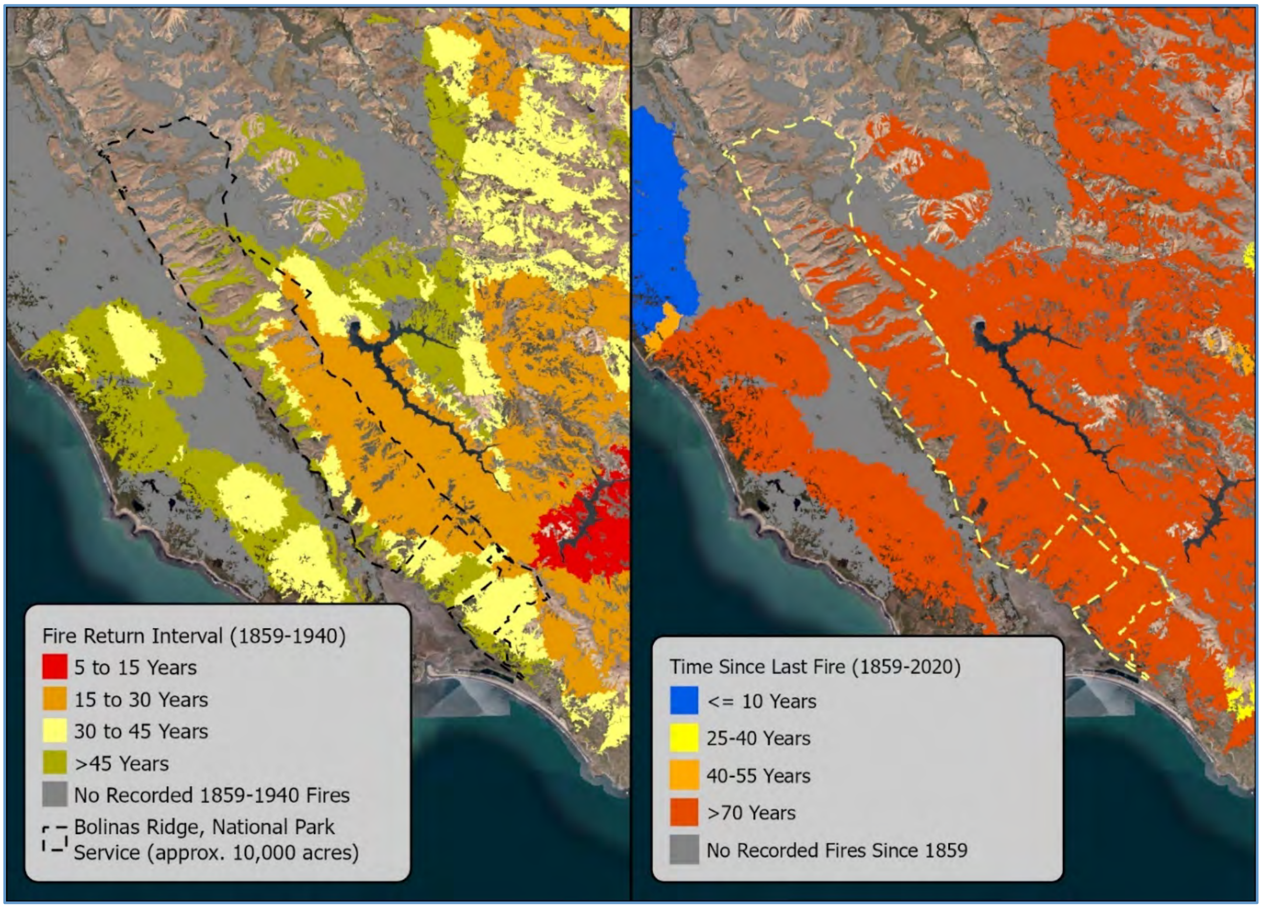


Figure. 8.90. Bolinas Ridge fire return interval between 1859 and 1940 (left), and time since last fire (right).



Fire exclusion, coupled with high canopy mortality likely related to sudden oak death impacts, is driving a departure from desired conditions on Bolinas Ridge (Figure 8.91). Analysis shows a total of 2,418 acres in the top three classes of the departure from desired conditions index, driven by a combination of abundant short dense stands of Douglas-fir, pathogen impacts, threatened and converting Open Canopy Oak Woodlands, and relatively high ladder fuels (Figure 8.92).

Point Reyes National Seashore seeks to build capacity to support the reintroduction of beneficial fire on Bolinas Ridge through development of burn plans and pre-treatment of priority areas. The PRNS FMP allows for burns in the southernmost portion of Bolinas Ridge FMU and along Bolinas Ridge Fire Road. Burns would be conducted in cooperation with Marin Water, Audubon Canyon Ranch, and GGNRA and be focused on reducing fuels and stimulating reproduction in the rare, fire-adapted species Marin manzanita and Mason's ceanothus (PRNS, 2004, pp. 81, 285). Effects of prescribed burning on native plant species richness would be monitored to inform scaling up approaches to other areas of the park (PRNS, 2004, p. 289). GGNRA managed lands south of Bolinas-Fairfax road share many of the same opportunities, and implementation of beneficial fire on the southernmost portion of Bolinas Ridge may be carried out through joint staffing and/or funding of projects to meet these shared objectives and goals (PRNS, 2004, p. 24).

Figure 8.91. Bolinas Ridge departure from desired conditions index, National Park Service lands.

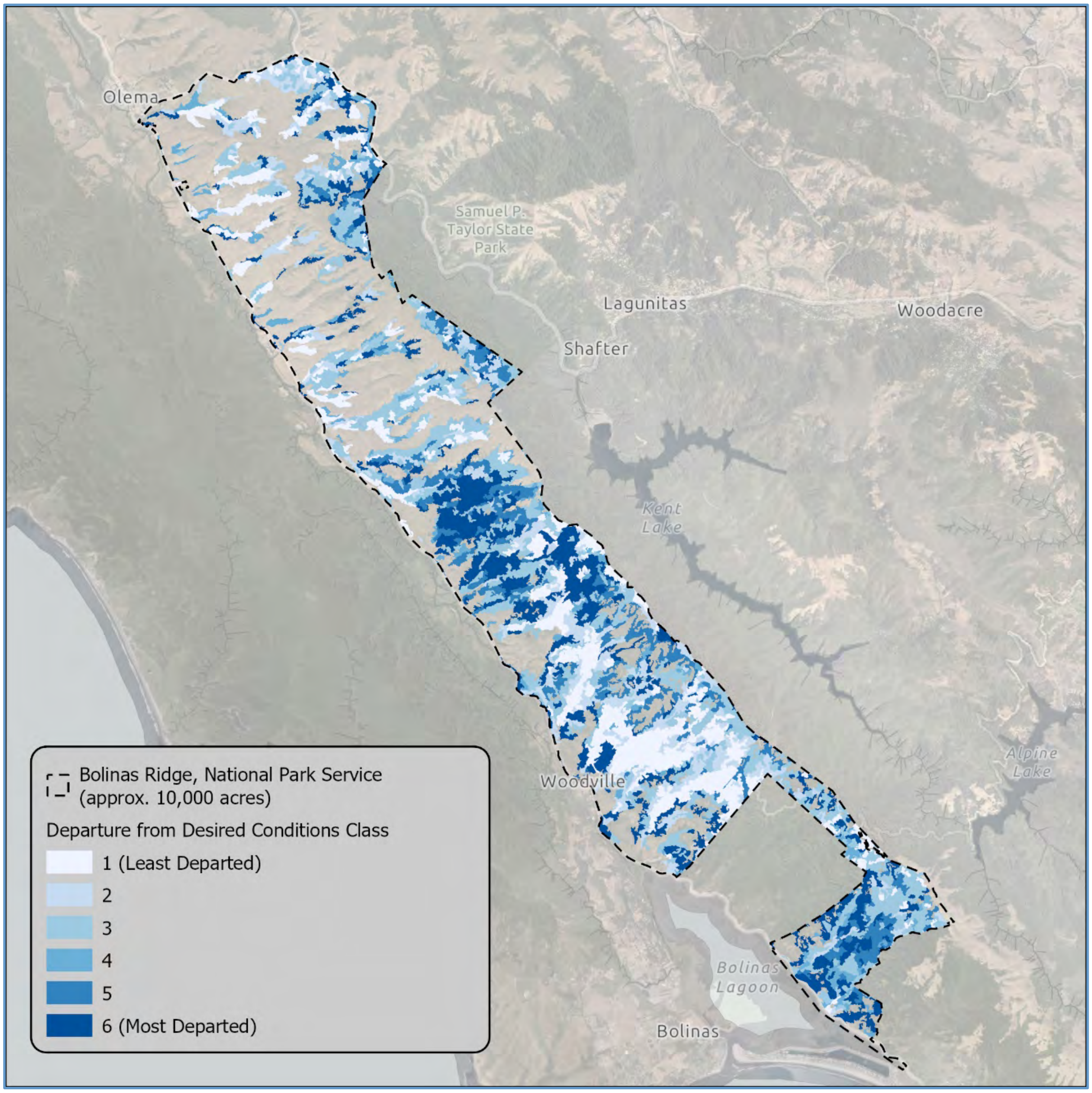
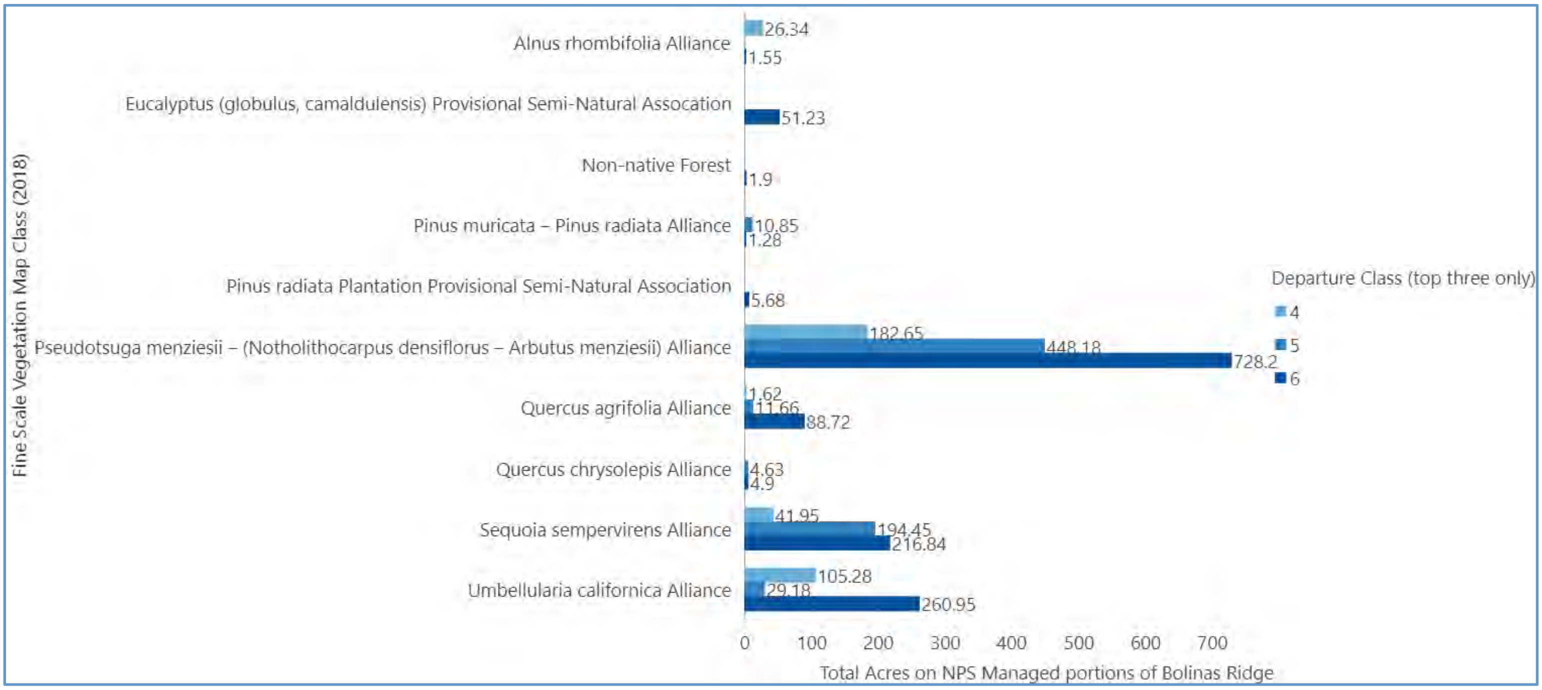


Figure 8.92. 2018 Fine Scale Vegetation Map class acres by departure from desired conditions indices (top three only), Bolinas Ridge, National Park Service lands.

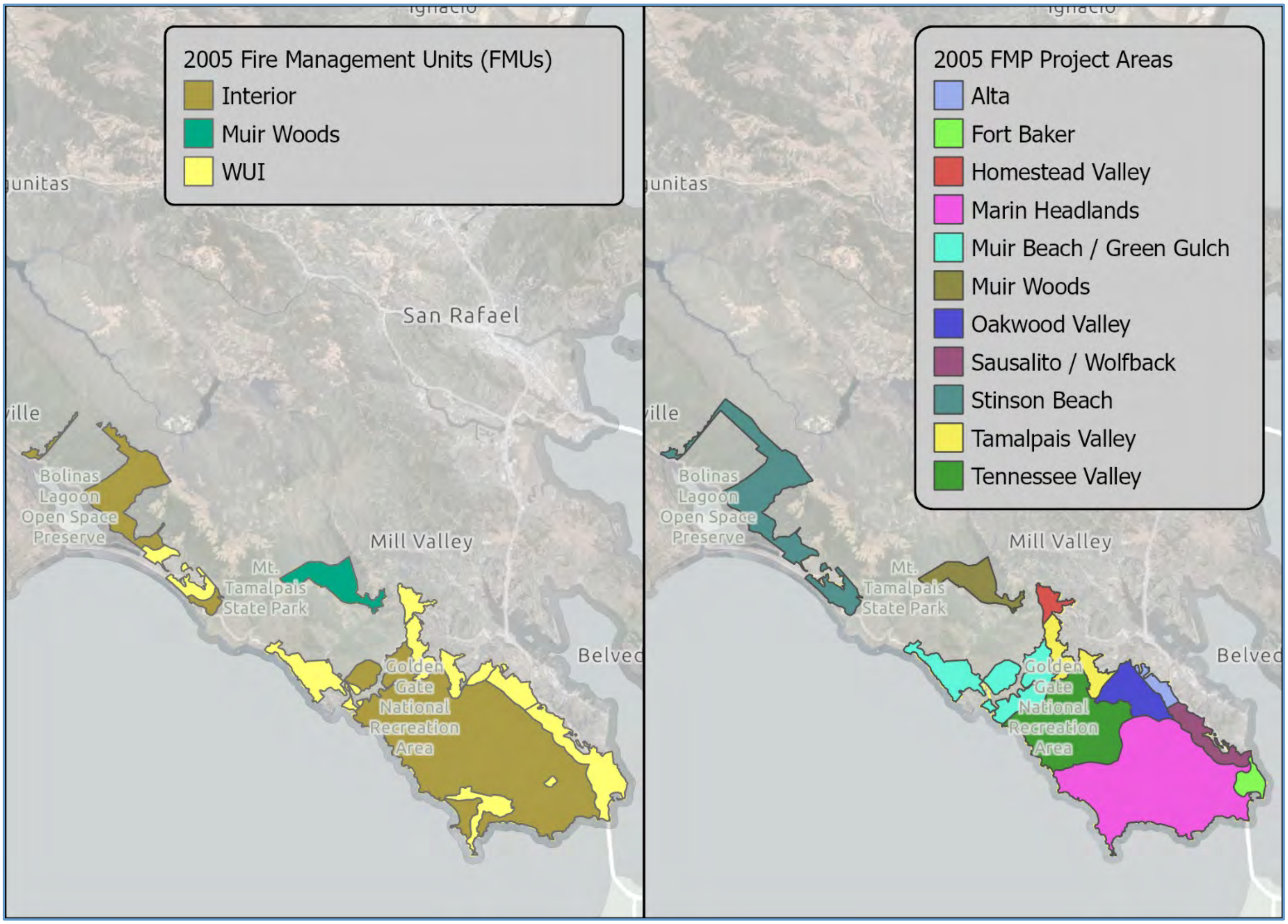


GOLDEN GATE NATIONAL RECREATION AREA FOCUS AREAS

The Golden Gate National Recreation Area (GGNRA) 2005 Fire Management Plan (FMP) Environmental Impact Statement (EIS) covers approximately 11,000 acres of National Park Service (NPS) lands directly managed by GGNRA in Marin County and allows for the implementation of vegetation treatment on up to 510 of these acres per year using mechanical treatments and beneficial fire (GGNRA, 2005). The GGNRA FMP EIS also addresses ecosystem changes evidenced by the spread of flammable non-native plant species, dense single-aged second-growth forests, conversion of shrublands to forest, forest and shrubland encroachment on grasslands, and decadence and decline of fire-adapted species (GGNRA, 2005, p. 10).

The GGNRA FMP divides the landscape into three Fire Management Units (FMUs): the Wildland Urban Interface or WUI FMU covering areas near communities or developed areas, the Park Interior FMU encompassing wildland portions of the Park, and a special FMU for Muir Woods National Monument (Muir Woods FMU) due to the recreational value and ecological significance of Muir Woods (GGNRA, 2005, p. 79) (Figure 8.93, left). The FMP then further divided these FMUs into project areas to provide for more detailed analysis of resources, values, plant communities, treatment drivers, and goals for each area (GGNRA, 2005, p. 79). A total of 11 project areas were identified for GGNRA lands in Marin County (pp. 92-94) (Figure 8.93, right). Where applicable, NPS GGNRA priority treatment areas identified in this section of the *Forest Health Strategy* will reference corresponding FMUs and project areas from the 2005 FMP to provide additional context and build consistency between these documents.

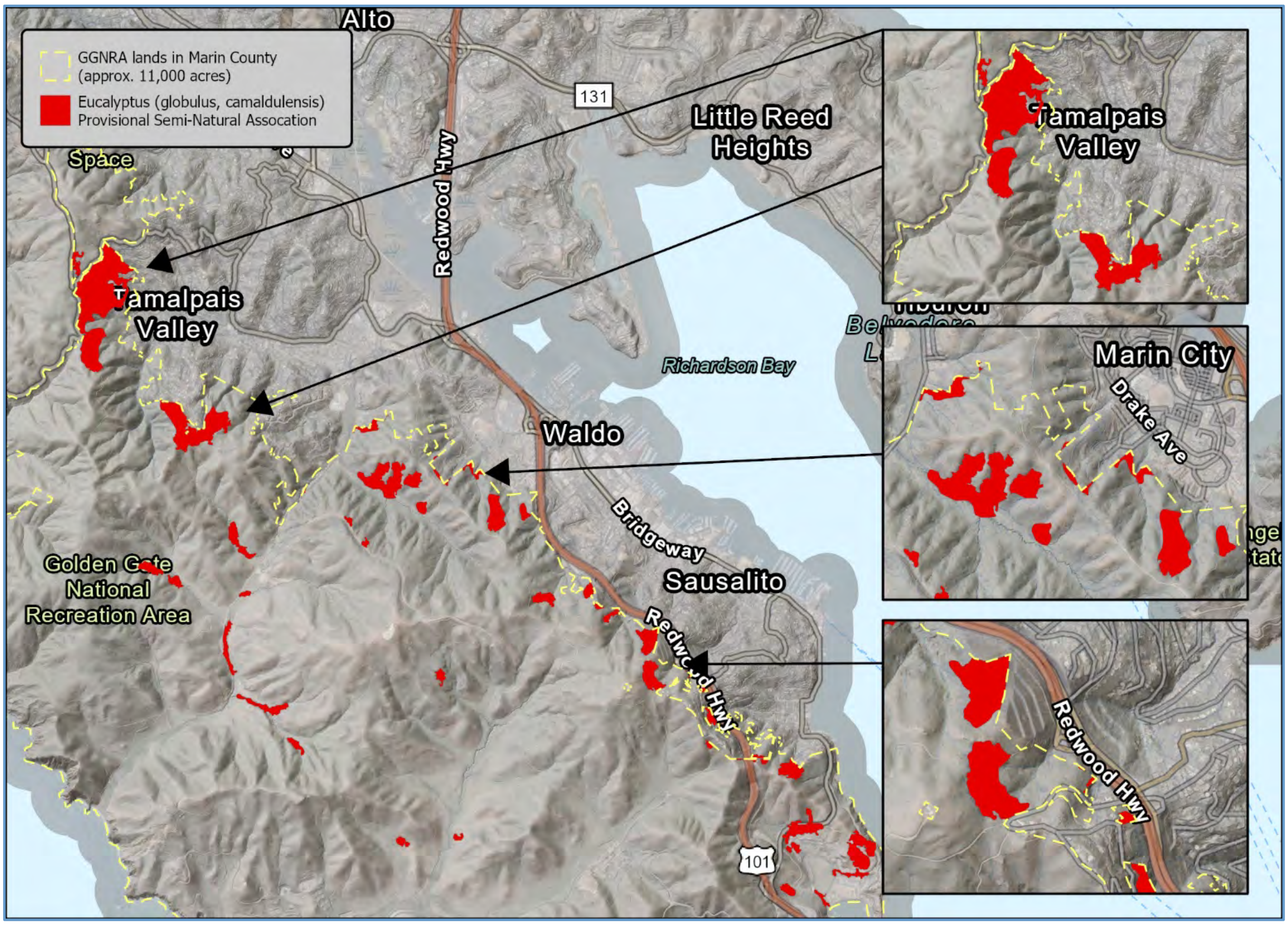
Figure 8.93. Marin County Fire Management Units (FMUs) and Project Areas identified in the 2005 Fire Management Plan, Golden Gate National Recreation Area.



GGNRA Eucalyptus Removal & Native Plant Restoration in the WUI

The southern Marin portion of the GGNRA borders several communities including Tamalpais Valley, Marin City, and Sausalito. These parklands are entirely within the Wildland Urban Interface FMU and contain over 300 acres of eucalyptus (both *E. globulus* and *E. camaldulensis*), a high fire risk invasive tree species, much of it concentrated near developed areas (Figure 8.94). GGNRA seeks to advance multi-benefit eucalyptus removal and native plant restoration projects in areas adjacent to these communities. These areas are already actively managed by GGNRA for non-native invasive species to preserve and enhance native plant habitat including coastal scrub, hardwood forests, and oak woodlands.

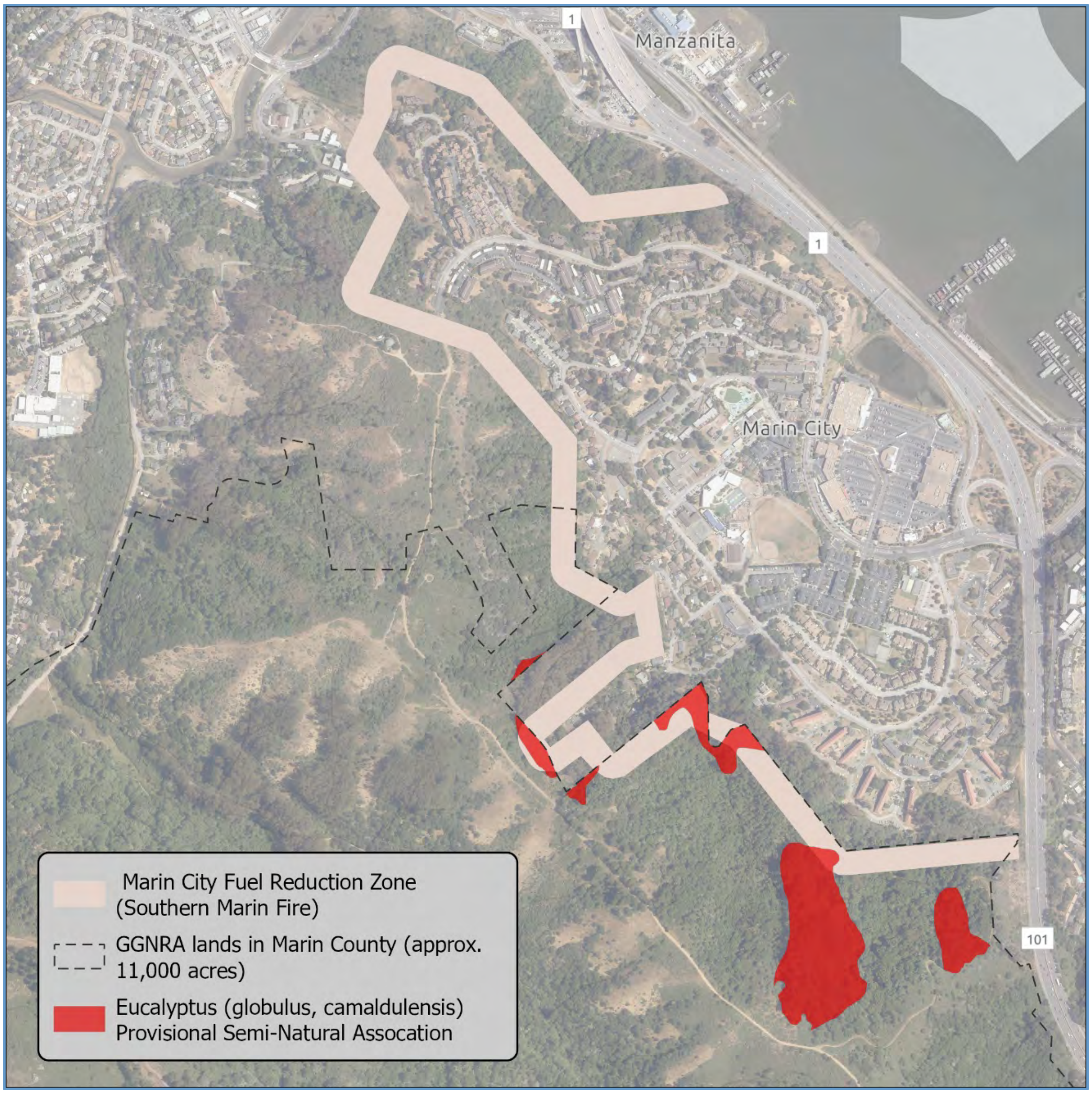
Figure 8.94. Priority eucalyptus removal areas within the WUI FMU, Golden Gate National Recreation Area, including (but not limited to) Tamalpais Valley, Marin City, and Sausalito areas.



Work proposed at each of these prospective project sites has the potential to reduce wildfire risk to communities, enhance native plant habitat and biodiversity, and increase resilience for native forests. The GGNRA FMP EIS allows for the implementation of mechanical vegetation treatment on up to 130 acres per year within the WUI FMU in Marin County, including the removal of nonnative evergreen (e.g., eucalyptus) trees to achieve fire management objectives and restoration and expansion of native plant communities (GGNRA, 2005, p. 119).

Eucalyptus removal and restoration work on NPS lands is consistent with the goals of fire agencies in the region. Priority NPS projects in Tamalpais Valley would complement planned efforts by the Marin Wildfire Prevention Authority (MWPA) and Southern Marin Fire Protection District (SMFPD) to construct and establish a fuel break and defensible space zone along the perimeter of Tamalpais Valley, which includes thinning and removal of eucalyptus and other non-native species approximately 100 feet from structures (MWPA, n.d.b.). Similarly, in their recent Strategic Fire Plan, Marin County Fire Department (MCFD) prioritized non-native species removal and fuel reduction work near Wolfback Ridge, Tennessee Valley, and Marin City (MCFD, 2022). The Marin City Fuel Reduction Zone project is included in the approved 2022-2023 MWPA Work Plan (MWPA, 2022, p. 180), and seeks to reduce hazardous fuels, including non-native trees, within 100-150 feet of structures along a two mile buffer around Marin City, including on adjacent NPS lands (Figure 8.95).

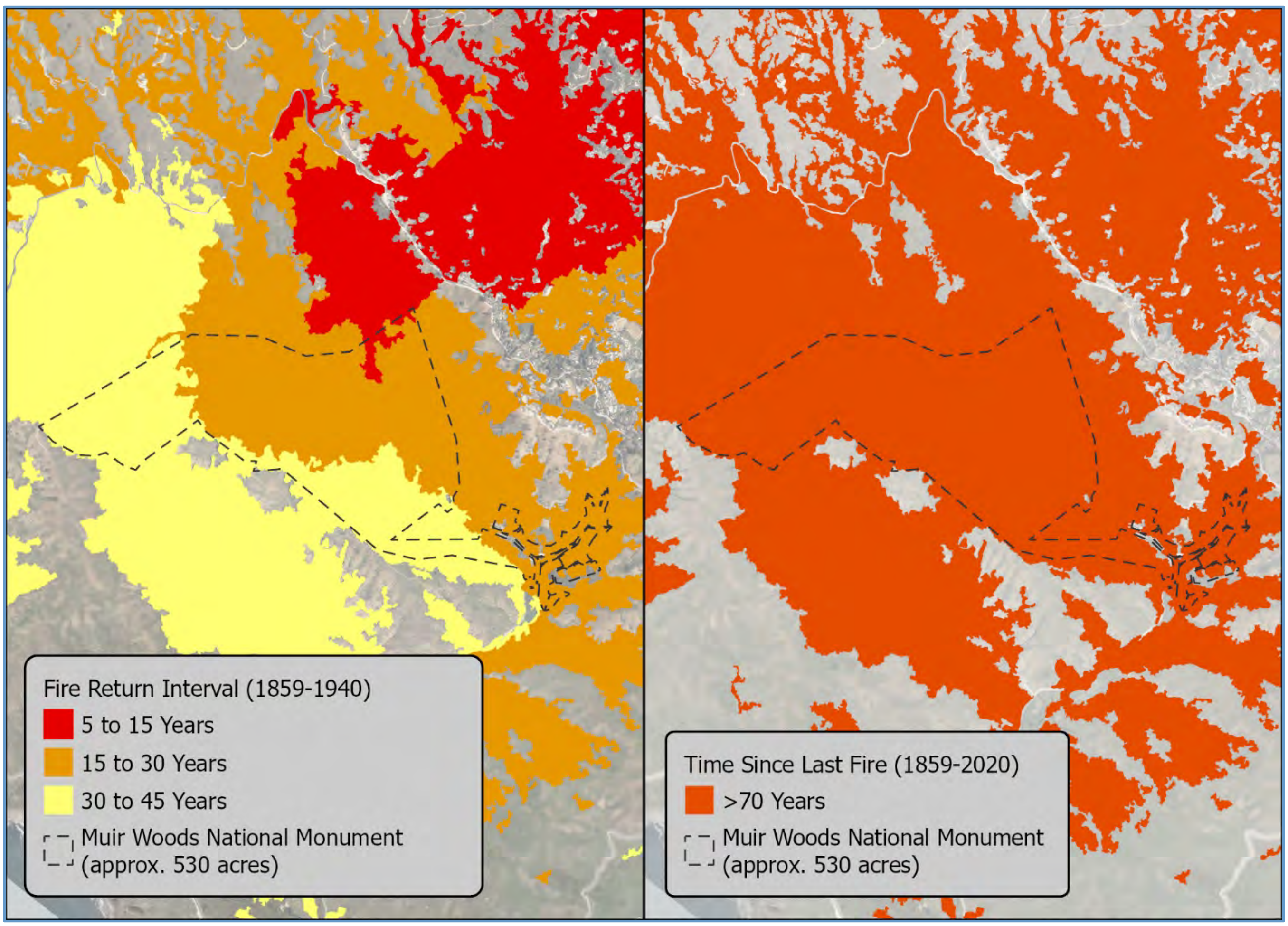
Figure 8.95. Marin City Fuel Reduction Zone proposed by Southern Marin Fire Department and adjacent eucalyptus on NPS lands.



Coast Redwood Forest Health & Resilience in Muir Woods National Monument

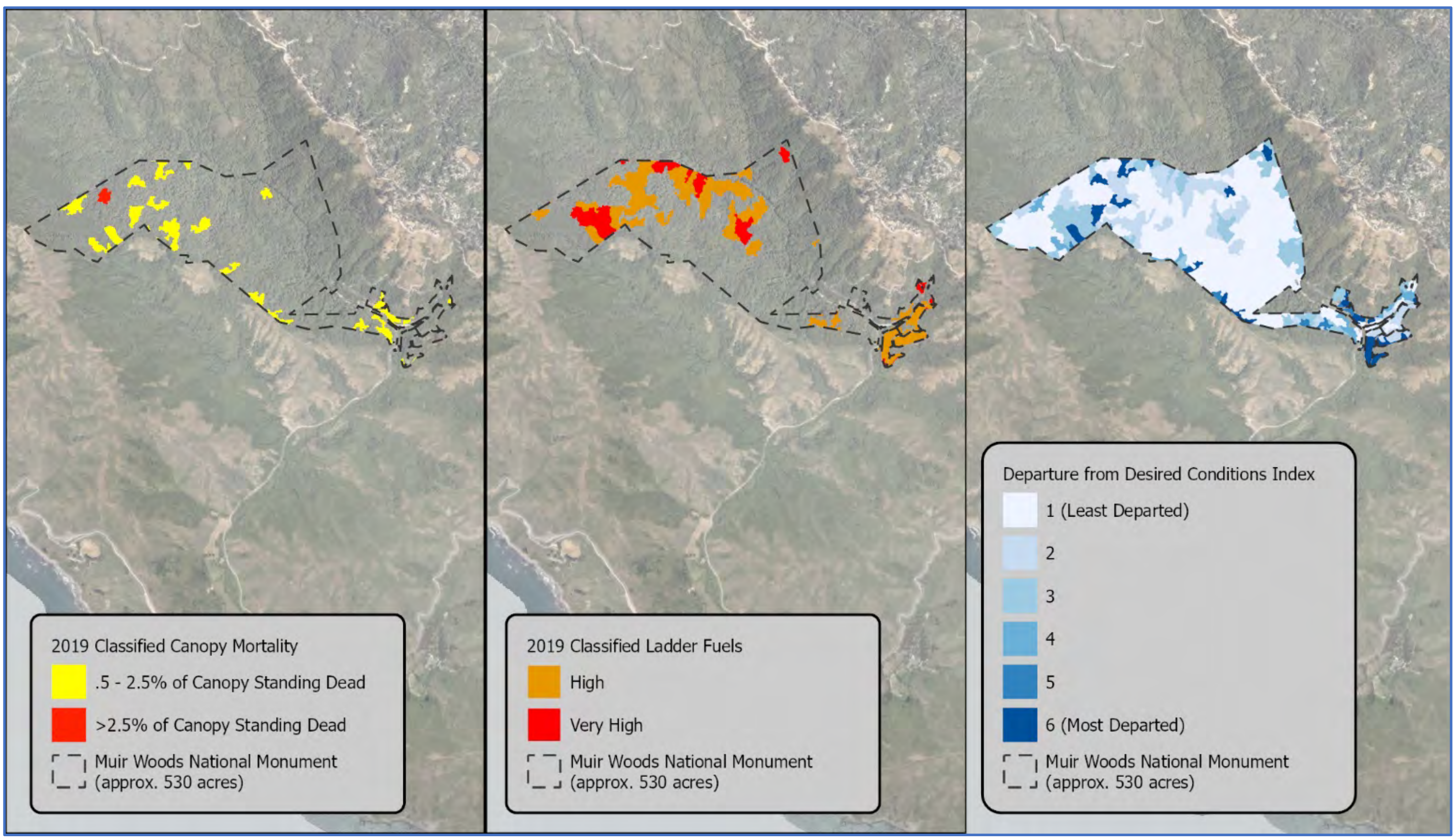
Conservation of the iconic Coast Redwood forests and biodiverse habitat found in Muir Woods National Monument (Muir Woods or the Monument) is a management priority for the National Park Service and discussed in detail in the 2005 FMP EIS (p. 102). Analysis of Coast Redwood forest fire scar data in Marin showed a fire return interval for this forest type of 21.7 to 27.3 years (McBride & Jacobs, 1978), however except for three prescribed burns executed in Muir Woods in the late 1990s totaling less than 100 acres (p. 103), most of the Monument has not experienced fire in more than 70 years (Dawson, 2021; Appendix B: Wildfire History) (Figure 8.96, right). Fire history mapping undertaken as part of the *Forest Health Strategy* (Dawson, 2021; Appendix B: Wildfire History) shows that between 1859 and 1940, large portions of Muir Woods experienced fire on average every 15-45 years (Figure 8.96, left). On average, fires decreased significantly in size after the Mt. Tamalpais fire lookout was established in 1920 (Dawson, 2021 p.14).

Figure 8.96. Fire return interval between 1859-1940 (left) and time since last fire (right), Muir Woods National Monument.



GGNRA seeks to restore the role of beneficial fire within the Muir Woods which, coupled with small targeted mechanical treatment in priority areas, will benefit the diverse vegetation communities of the Monument including Coast Redwood forests, and reduce unnatural fuel arrangements that contribute to the threat of high-intensity wildfire. The GGNRA FMP EIS allows for up to 50 acres of beneficial fire and 5 acres of mechanical treatments per year within the Muir Woods FMU (GGNRA, 2005, p. 139). The GGNRA FMP emphasizes the importance of further study of fire effects in old-growth Coast Redwood forests, as well as monitoring to investigate relationships between fire and sudden oak death recovery, as well as fire a potential tool for managing non-native invasive species (GGNRA, 2005, p. 104). While most of the Monument is structurally large and complex old-growth forest, departure from desired conditions analysis highlights pockets of forest with overlapping canopy mortality and with relatively high ladder fuels, which may be useful in prioritizing project areas within the FMU (Figure 8.97).

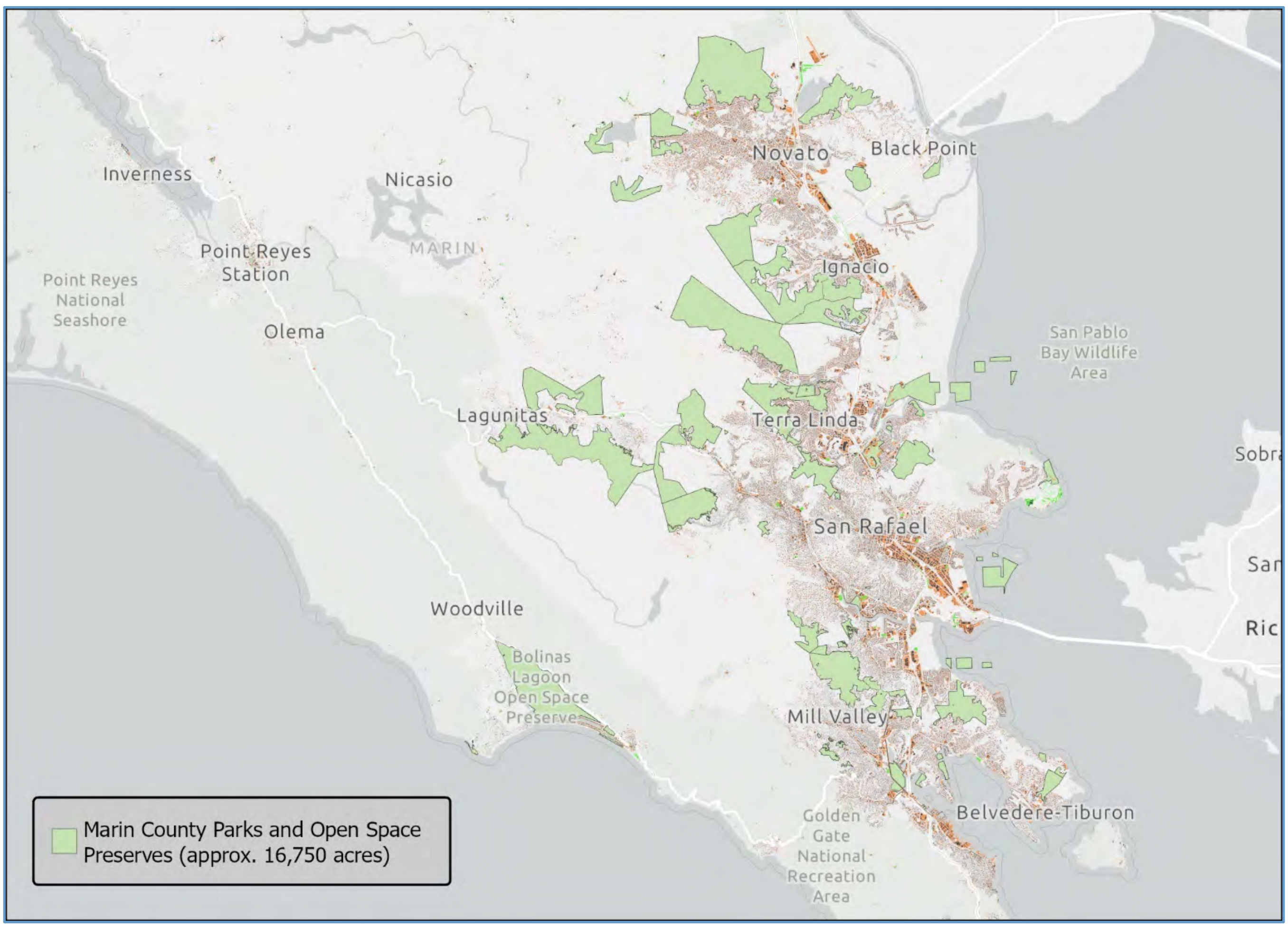
Figure 8.97. Forest stands with detectable canopy mortality (left), relatively high ladder fuels (center), and departure from desired condition index (right) for Muir Woods National Monument.



MARIN COUNTY PARKS PRIORITY TREATMENT AREAS

Marin County Parks (MCP) and Marin County Open Space District (MCOSD) lands encompass roughly 17,000 acres of protected lands in Marin County, including 39 parks and 34 open space preserves (Marin County Parks, n.d.b.). Much of MCP managed lands are adjacent to urban and suburban areas in Marin County, providing exceptional recreational value for county residents and visitors and protecting important vegetation communities and wildlife habitat in the region (Figure 8.98). The adjacency of many of MCP's preserves to developed areas in the county also presents management challenges, which prompted MCP to develop their *Vegetation and Biodiversity Management Plan* (MCP & MCOSD, 2015), which serves as an overall guiding document for vegetation work on MCP lands. The *Vegetation and Biodiversity Management Plan* highlights the difficulty in balancing the ecological health and resilience of MCP managed forested lands with the need to provide safe recreational opportunities for residents and address fire safety for adjacent communities with unnatural fuel loads resulting from fire exclusion (MCP & MCOSD, 2015, p. 99). MCP priority project areas identified in the *Forest Health Strategy* seek to address multiple challenges identified in the *Vegetation and Biodiversity Management Plan* such as sudden oak death and forest pathogen impacts, fire exclusion, forest type conversion, and public safety (MCP & MCOSD, 2015, pp. 96-99).

Figure 8.98. Distribution of Marin County Parks and Open Space Preserves, Marin County.



GARY GIACOMINI OPEN SPACE PRESERVE FOREST HEALTH & RESILIENCE

Gary Giacomini Open Space Preserve is in the San Geronimo Creek-Lagunitas Creek Watershed and borders the northern edge of Marin Water's Watershed lands above Kent Lake, connecting the forested slopes south of San Geronimo Valley to Mount Tamalpais (Figure 8.99). The preserve is comprised of more than 1,500 acres of wilderness, providing habitat for several special-status plant species including serpentine endemics such as *Arctostaphylos montana ssp. montana* (Mt. Tamalpais manzanita), *Cirsium hydrophilum var. vaseyi* (Mt. Tamalpais thistle), *Hesperolinon congestum* (Marin dwarf flax), and others. The forests and woodlands of Gary Giacomini Open Space Preserve also provide habitat for several special status wildlife species including Northern Spotted Owl and salmonids central California coast steelhead and Coho salmon (MCP & MCOSD, 2015. p. 39). The preserve includes significant acres of several key forest types including Coast Redwood (407 acres), Douglas-fir (550 acres), and Sargent Cypress (28 acres) (Figure 8.100).

Figure 8.99. Gary Giacomini Open Space Preserve (left), and 2018 Fine Scale Vegetation Map classes (right).

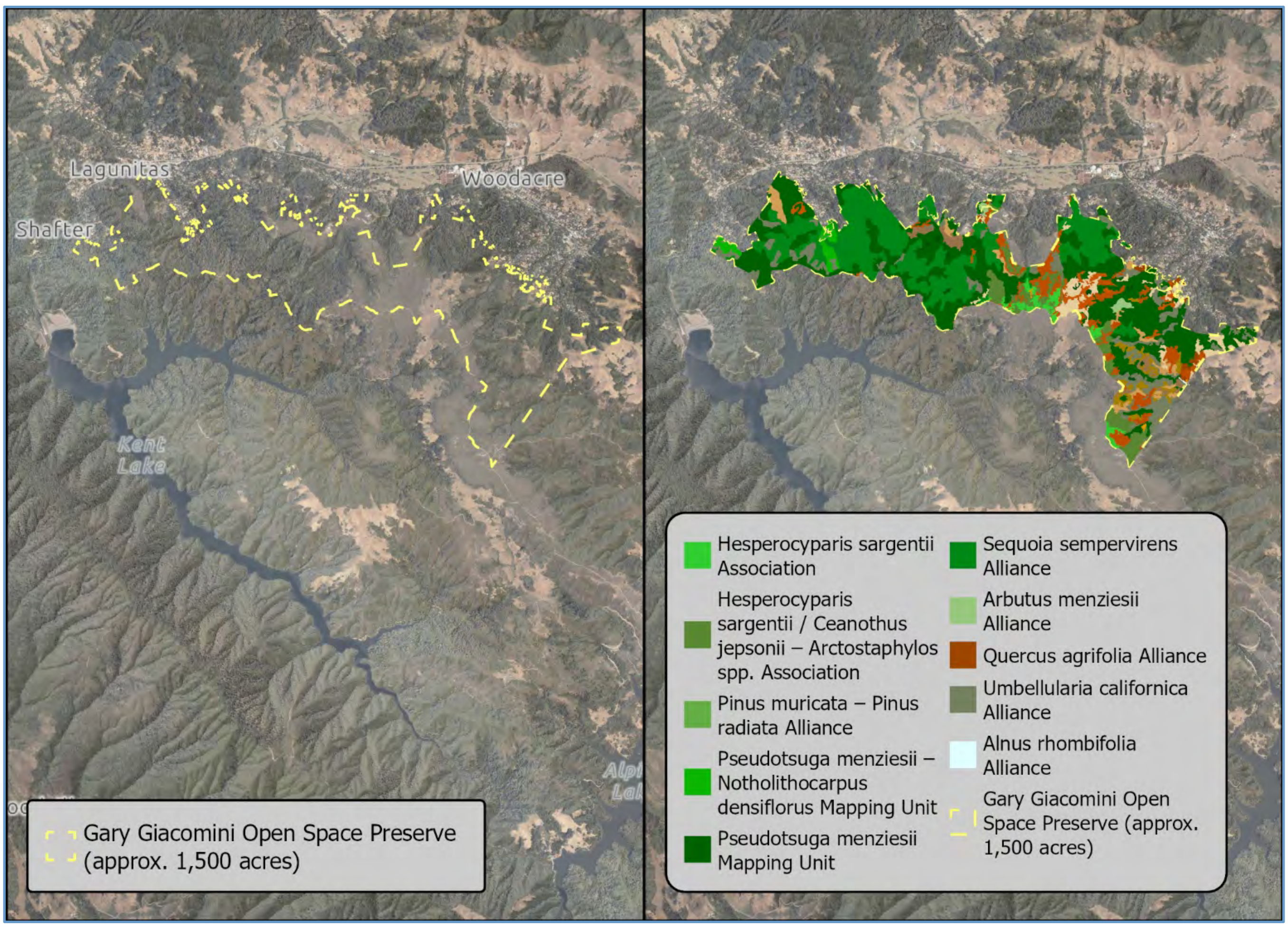
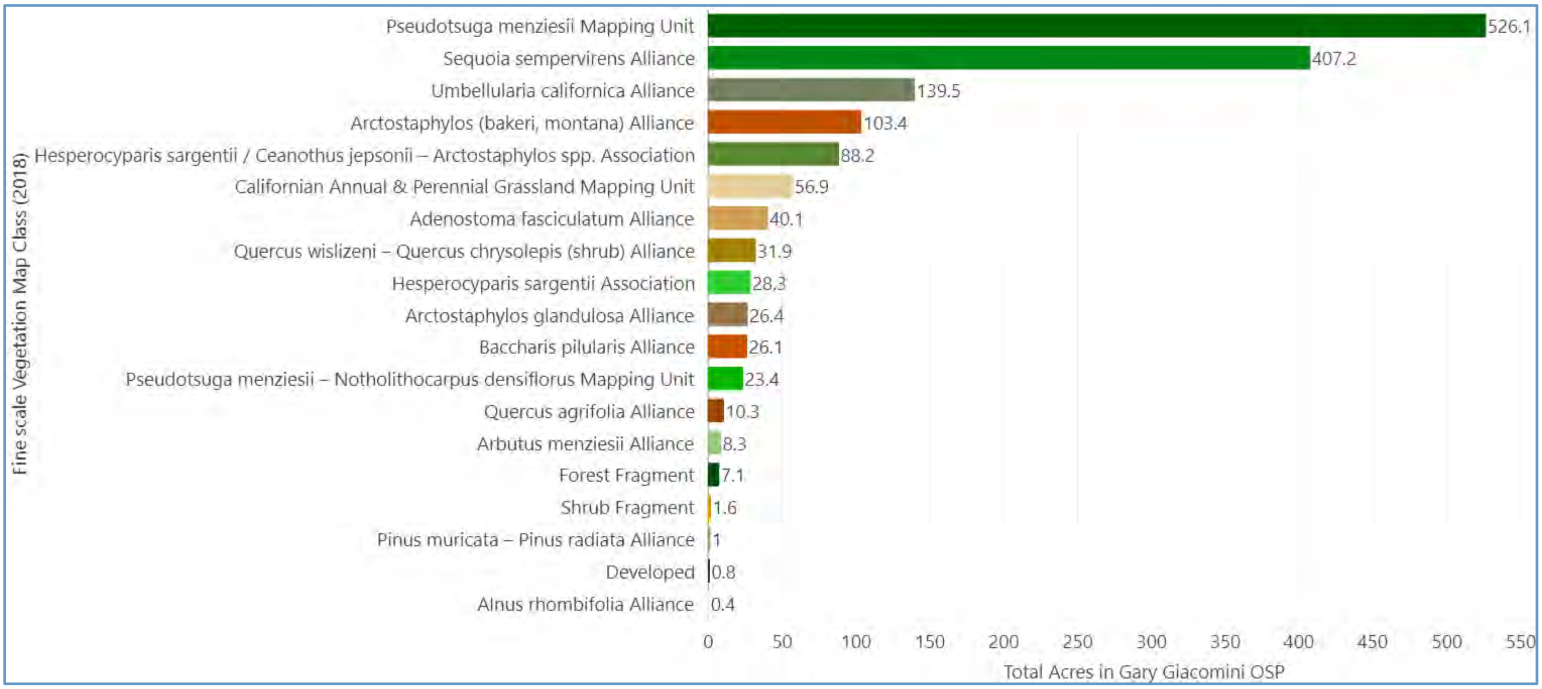


Figure 8.100. 2018 Fine Scale Vegetation Map vegetation communities by acres, Gary Giacomini Open Space Preserve.



Analysis of available fire history data for Gary Giacomini Open Space Preserve shows a trend of decreasing fire extent and frequency (Dawson, 2021; Appendix B: Wildfire History). Between 1859 and 1900, Dawson documented four fires in the vicinity of the preserve (Figure 8.101, top left). Between 1901 and 1940, just one fire (1923) was documented in the western two-thirds of the preserve (Figure 8.101, top right), and the 1945 Mill/Carson Canyon Fire did not appear to burn significant portions of Gary Giacomini Open Space Preserve (Figure 8.101, bottom left). While the fire history mapping was limited to fires greater than or equal to 160 acres, no fires were documented by Dawson in the area between 1981 and 2020 (Figure 8.101, bottom right). Recognizing that mapped fire perimeter boundaries have variable confidence levels, this analysis suggests that most of Gary Giacomini Open Space Preserve has not seen fire in 70 to 100 years, with potentially more than 150 years since last fire for eastern portions of the preserve.

While there is a high degree of variability in the fire regime for Coast Redwood forests, fire return intervals such as those observed in the available data for Gary Giacomini Open Space Preserve are generally outside those documented in other Coast Redwood forests in Marin County (see Chapter 5: Goals, Coast Redwood Fire Regime). Forest health and resilience treatments in the preserve's Coast Redwood forests will focus on restoration of beneficial fire and/or manual/mechanical treatments designed to mimic the effects of low to moderate intensity fire (see Chapter 9: Treatment Descriptions). Where feasible, treatments will focus on Coast Redwood stands impacted by sudden oak death with corresponding elevated levels of canopy mortality, canopy gaps formed between 2010-2019, and relatively high or very ladder fuels. (Figure 8.102).

Figure 8.101. Fire history mapping results near Gary Giacomini Open Space Preserve. Recorded fires 1859-1900 (top left), 1901-1940 (top right), 1941-1980 (bottom left), with no fires recorded between 1981-2021 (bottom right) (Dawson, 2021).

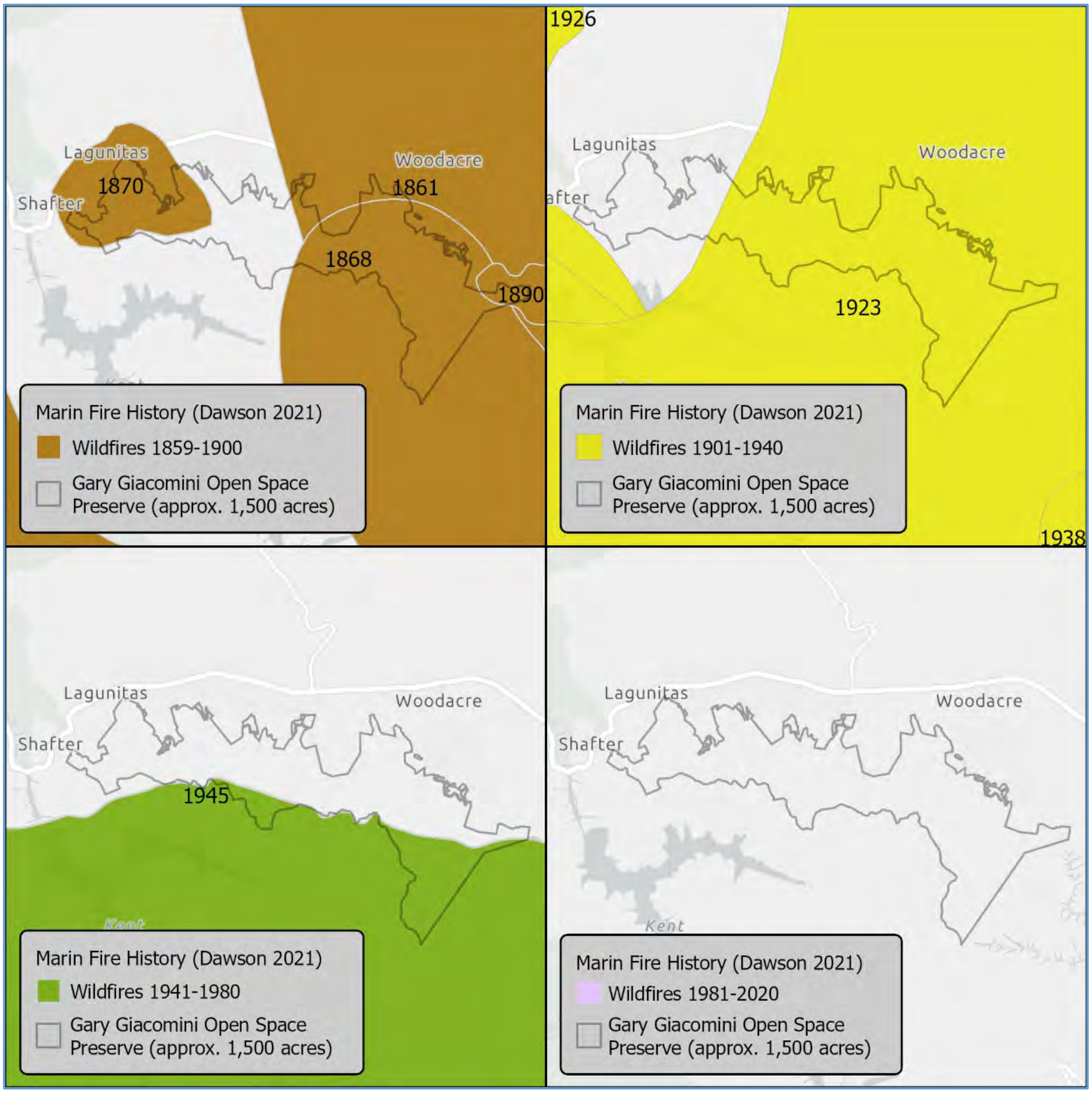
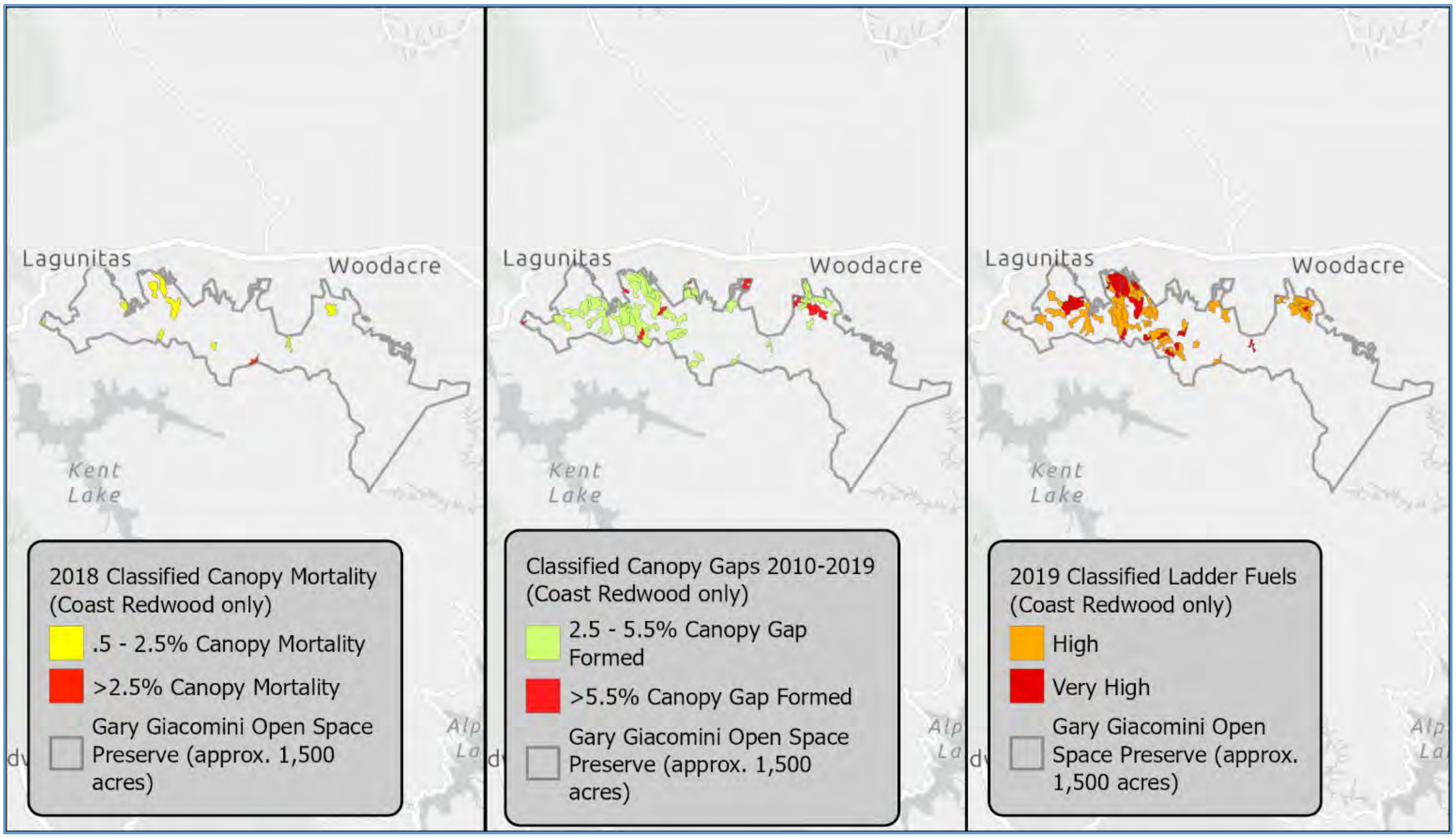


Figure 8.102. For Coast Redwood stands in Gary Giacomini Open Space Preserve: 2018 classified percent canopy mortality (left), classified canopy gaps formed between 2010-2019 (center), and 2019 classified ladder fuels (right).



Building density analysis could help Marin County Parks refine Coast Redwood and Douglas-fir multi-benefit forest health and resilience treatment areas that will leverage and support the county's fire prevention goals and ongoing defensible space improvements in/adjacent to the Gary Giacomini Open Space Preserve (Figure 8.103) (MCFD, 2022, p. 90).

Fire exclusion contributes to both a departure from desired conditions in Douglas-fir forest and expansion of Douglas-fir into Open Canopy Oak Woodlands, shrublands, and grassland communities in Gary Giacomini OSP, and future management would complement 2022 MCP forest health and fuel reduction efforts within the preserve on San Geronimo Ridge. This could include removal of small Douglas-fir trees in Open Canopy Oak Woodland stands threatened with or actively converting to conifer forest (Figure 8.104).

Targeted thinning within existing stands of Douglas-fir, including removal of small-diameter trees, dead and dying vegetation, and non-native species in key areas can address sudden oak death impacts and unnatural fuel arrangements, increasing the resilience of Douglas-fir forest (see Chapter 5: Goals, Douglas-fir) (Figure 8.105). Additionally, given the abundance of serpentine soils in this area, removal of small, early successional Douglas-fir in smaller structural classes (see Chapter 6: Metrics, Douglas-fir Structural Classification) can prevent habitat loss for associated special status plant species and protect biodiversity and habitat for key serpentinitic vegetation communities (Figure 8.106). Known special status and locally rare species in the preserve include *Arctostaphylos montana* (Mt. Tamalpais manzanita), *Calochortus umbellatus* (Oakland star-tulip), *Cirsium hydrophilum var. vaseyi* (Mt. Tamalpais thistle), *Hesperolinon congestum* (Marin dwarf flax), *Lessingia micradenia var. micradenia* (Mt. Tamalpais lessingia), *Navarretia rosulata* (Marin County navarettia), *Stebbinsoseris decipiens* (Santa Cruz microseris), and *Streptanthus batrachopus* (Mt. Tamalpais jewelflower) (MCP & MCOSD, 2015, p. 39). Similar analysis could be performed using these GIS layers (available in the One Tam Forest Health Web Map) to identify priority areas for Douglas-fir management in nearby French Ranch Open Space Preserve.

Figure 8.103. Forested areas in Gary Giacomini Open Space Preserve with 2019 classified building density within a quarter-mile buffer.

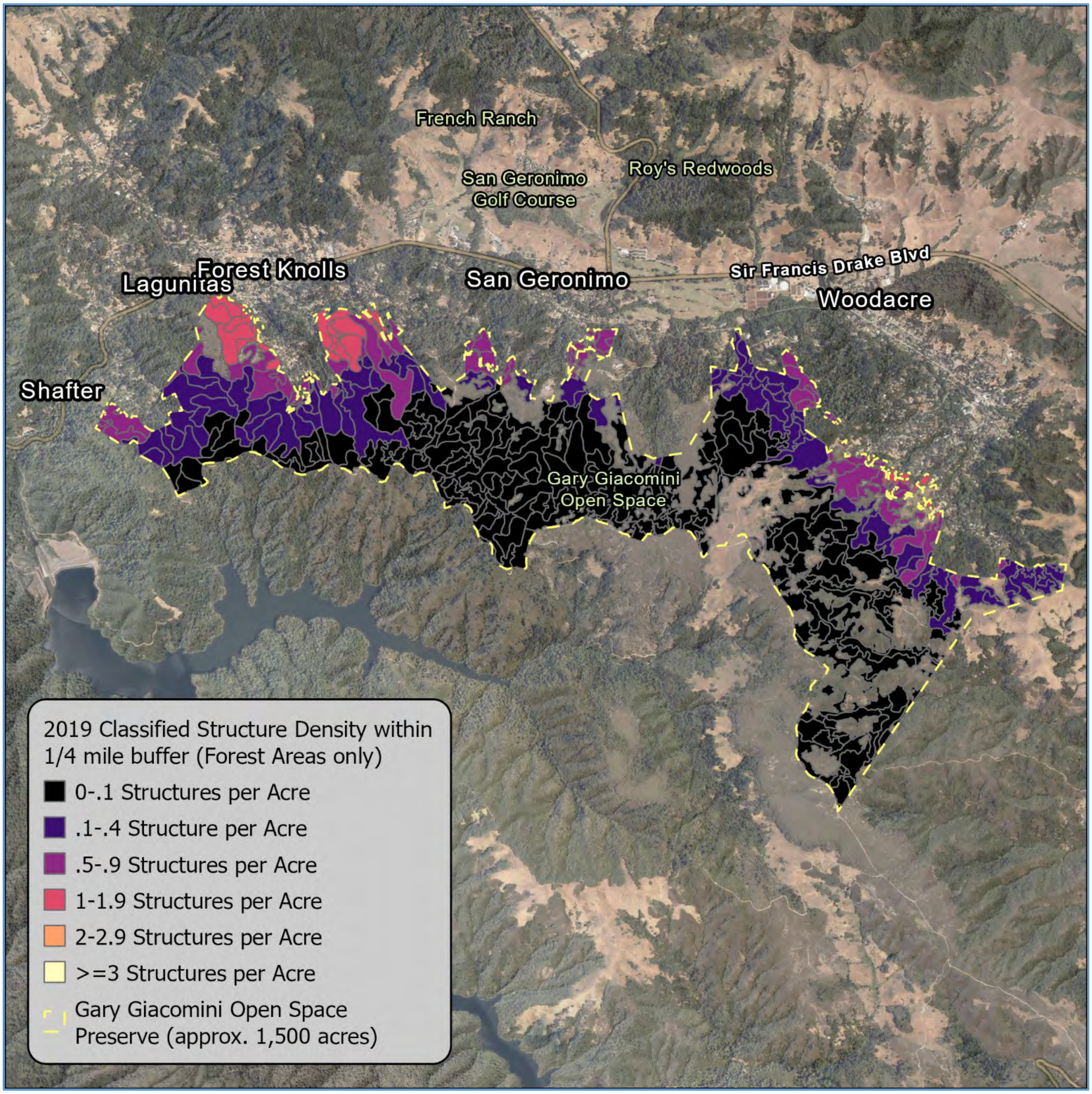


Figure 8.104. Open Canopy Oak Woodland stands threated with or actively converting to Douglas-fir forest, Gary Giacomini Open Space Preserve.

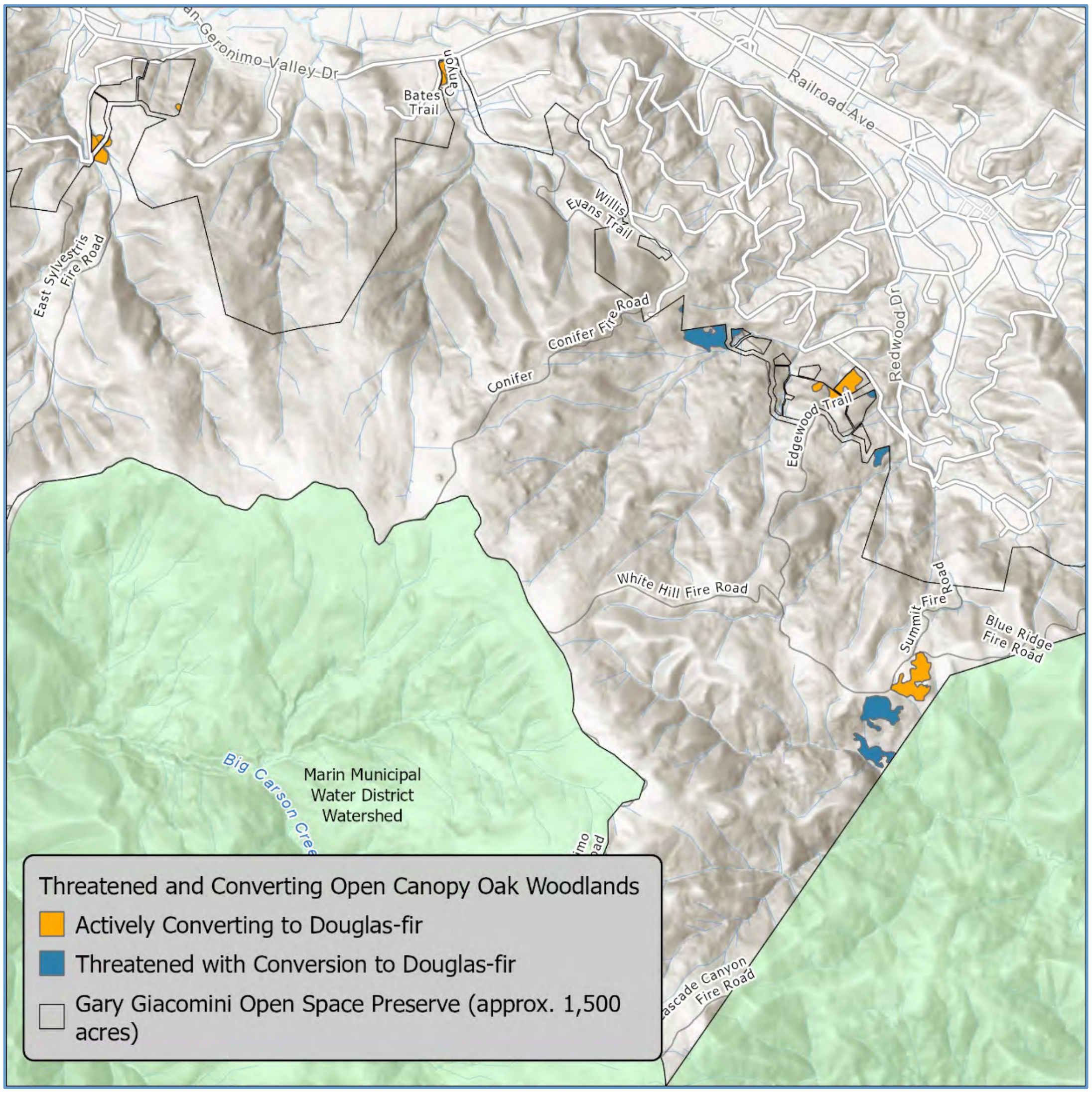


Figure 8.105. Douglas-fir forest 2019 classified canopy mortality (left), classified canopy gaps formed between 2010 and 2019 (center), 2019 classified ladder fuels (right), Gary Giacomini Open Space Preserve.

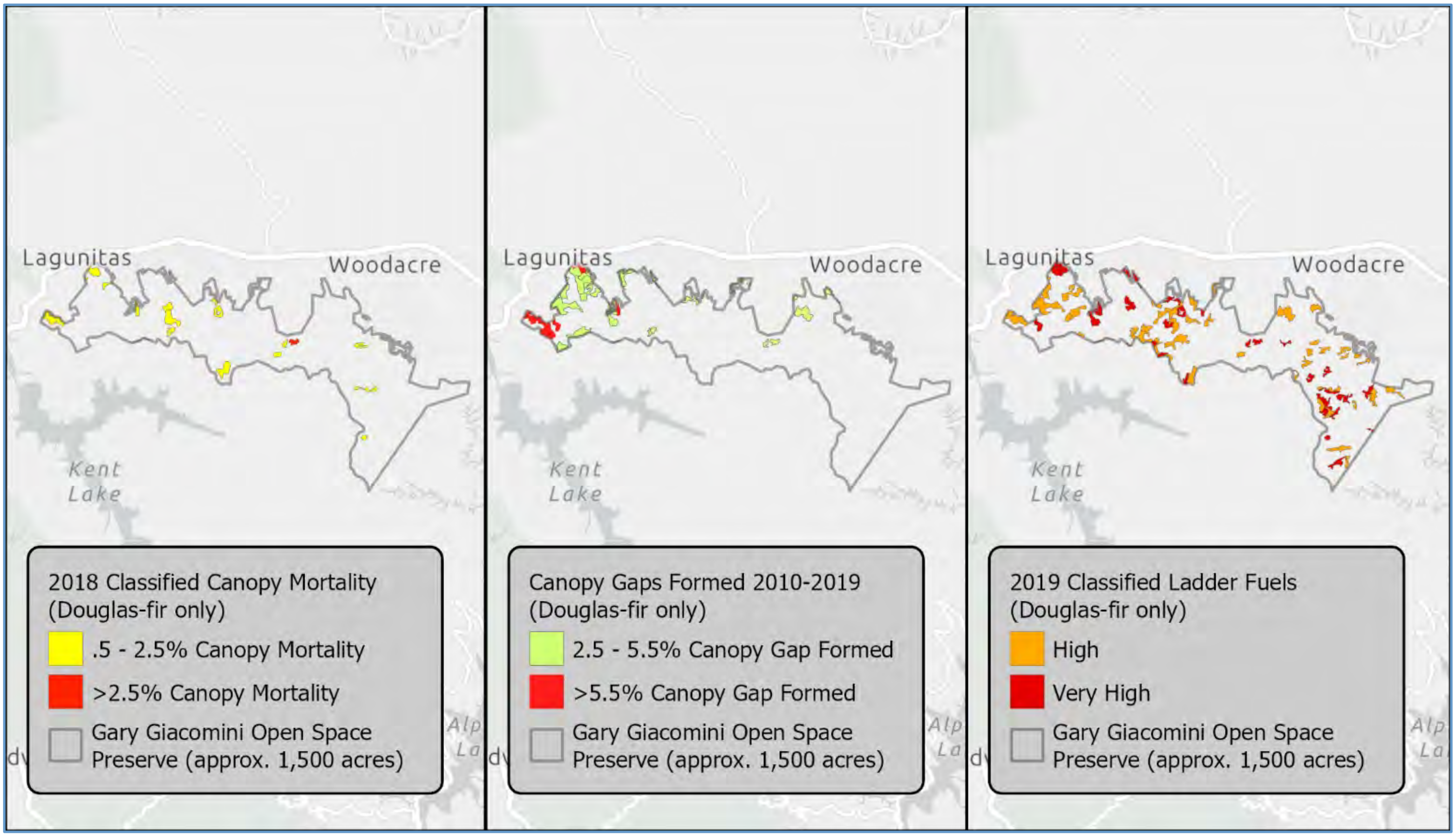
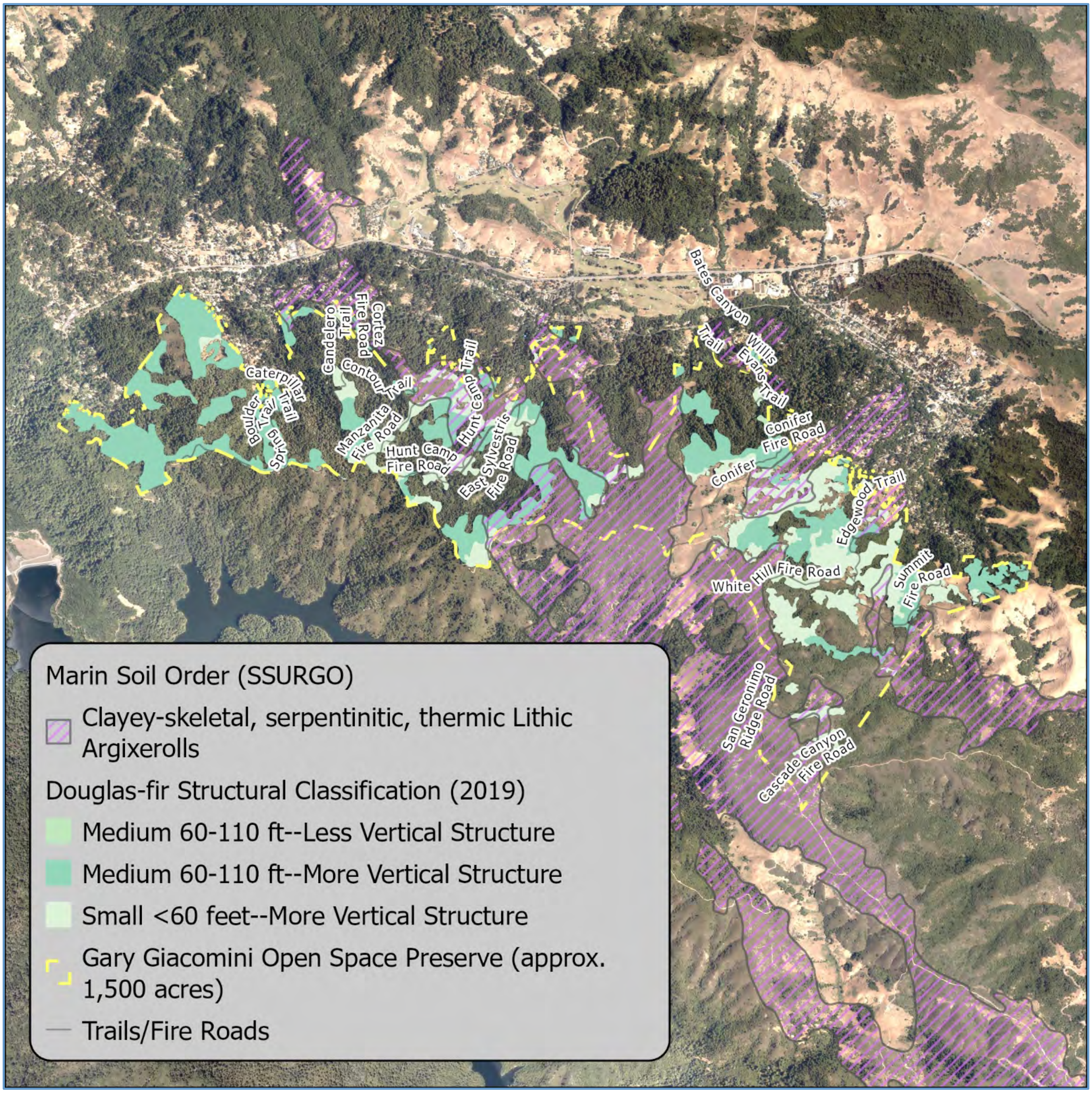


Figure 8.106. Serpentine soils and 2019 Douglas-fir structural classification, Gary Giacomini Open Space Preserve.



ROY'S REDWOODS OPEN SPACE PRESERVE RESTORATION PROJECT

Roy's Redwoods Open Space Preserve (OSP) is a 293-acre preserve managed by Marin County Parks (Figure 8.107). The preserve is entirely within the San Geronimo Creek Watershed, a tributary to Lagunitas Creek. Larsen Creek flows through an alluvial valley within Roy's Redwoods which supports several forest stands containing old-growth coast redwood trees, some measuring as much as 145-inches in diameter (MCP & One Tam, 2018, p. 3). Other native forest stands at the preserve include Douglas-fir, madrone, coast live oak, and California bay (Figure 8.108). Roy's Redwoods OSP also provides habitat for numerous important wildlife species, including potential nesting and foraging habitat for the federally endangered Northern Spotted Owl (MCP & One Tam, 2018, p. 14). A visitor use survey completed in 2017 underscored the recreational significance of the relatively easily accessible large-diameter old-growth coast redwood trees for families, hikers, and other visitors (MCP & One Tam, 2018, p. 6).

Figure 8.107. Roy's Redwood Open Space Preserve (left) and distribution of 2018 Fine Scale Vegetation Map native forest stands (right).

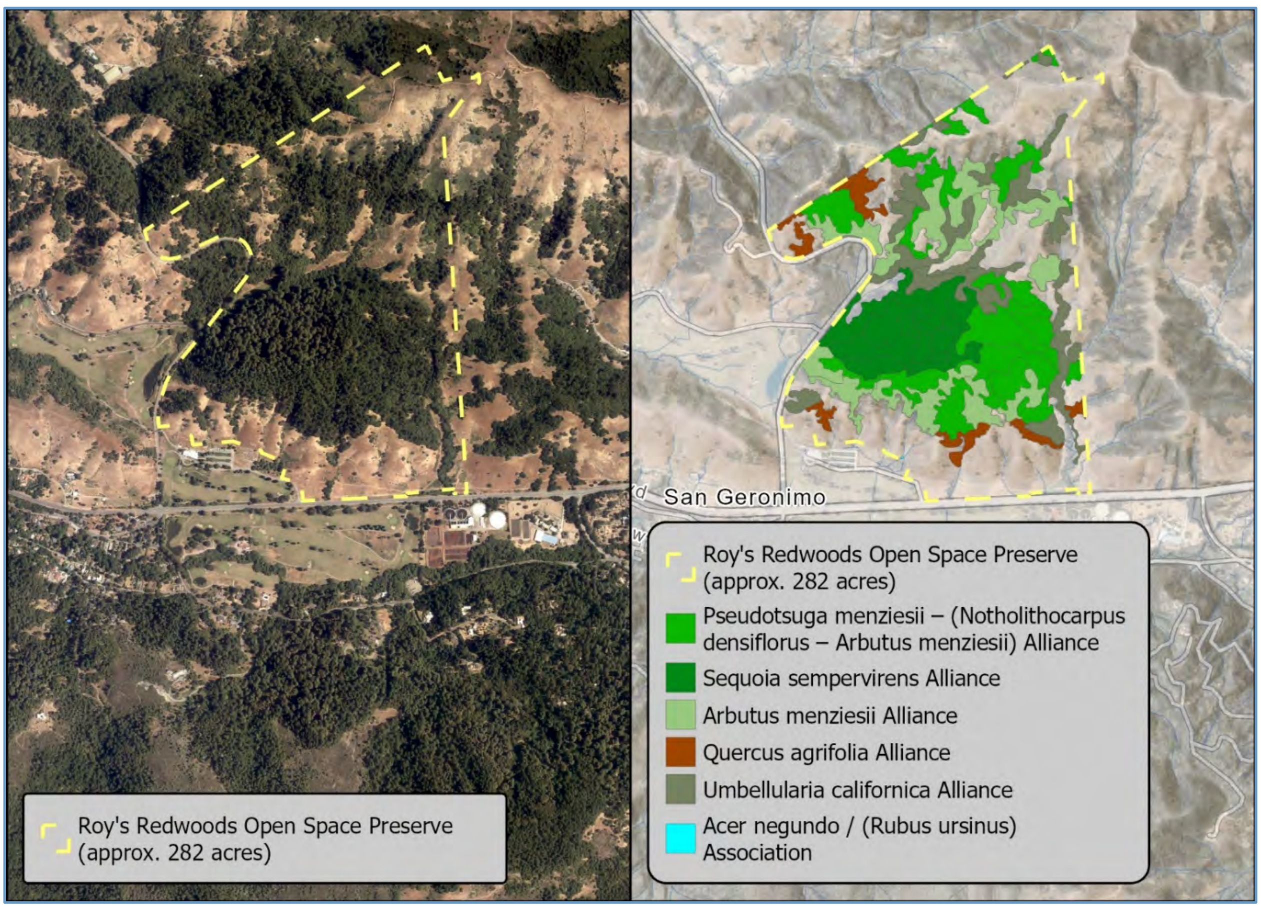
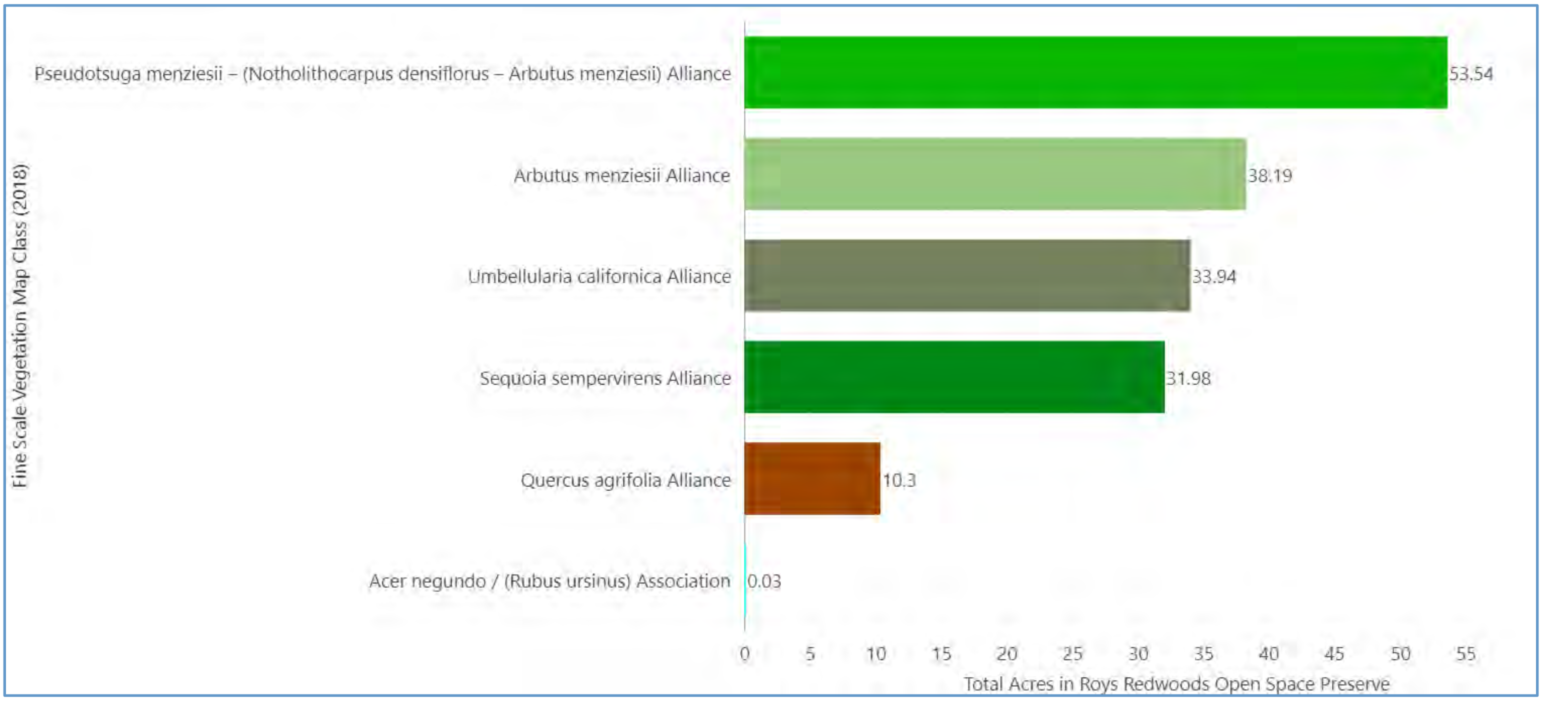


Figure 8.108. 2018 Fine Scale Vegetation Map native forest communities by acres in Roy's Redwoods Open Space Preserve.



Limited access planning has resulted in an extensive network of social trails within the preserve and across the alluvial floodplain in areas that support old-growth coast redwood trees and has contributed significantly to loss of plant biodiversity in the understory and damaged hydrologic function (p. 3). Marin County Parks and the One Tam collaborative have embarked on a project planning and design process for Roy's Redwoods OSP that will protect the diverse biological resources on-site, improve hydrologic function, and provide access for preserve visitors to enjoy the redwoods and surrounding area for generations to come (One Tam, n.d.; Stromberg & Roth, 2020).

Analysis of data generated as part of the *Forest Health Strategy* underscores the unique value of the redwood stands within Roy's Redwood Open Space Preserve and bolsters the need for the planned hydrological restoration and trail improvement project. Results of the countywide Coast Redwood structural classification indicate that stands within the preserve are predominantly in the large to largest structural classes (see Chapter 6: Metrics), an indicator of old-growth redwood conditions (Figure 8.109). Furthermore, Coast Redwood stands within Roy's Redwoods OSP have maximum lidar-derived stand heights indicating that some trees within the preserve are amongst the tallest coast redwoods in Marin County (Figure 8.110).

Figure 8.109. Coast Redwood structural classification for stands within Roy's Redwoods Open Space Preserve. The maximum lidar-derived individual tree height (in feet) for each stand is shown in white.

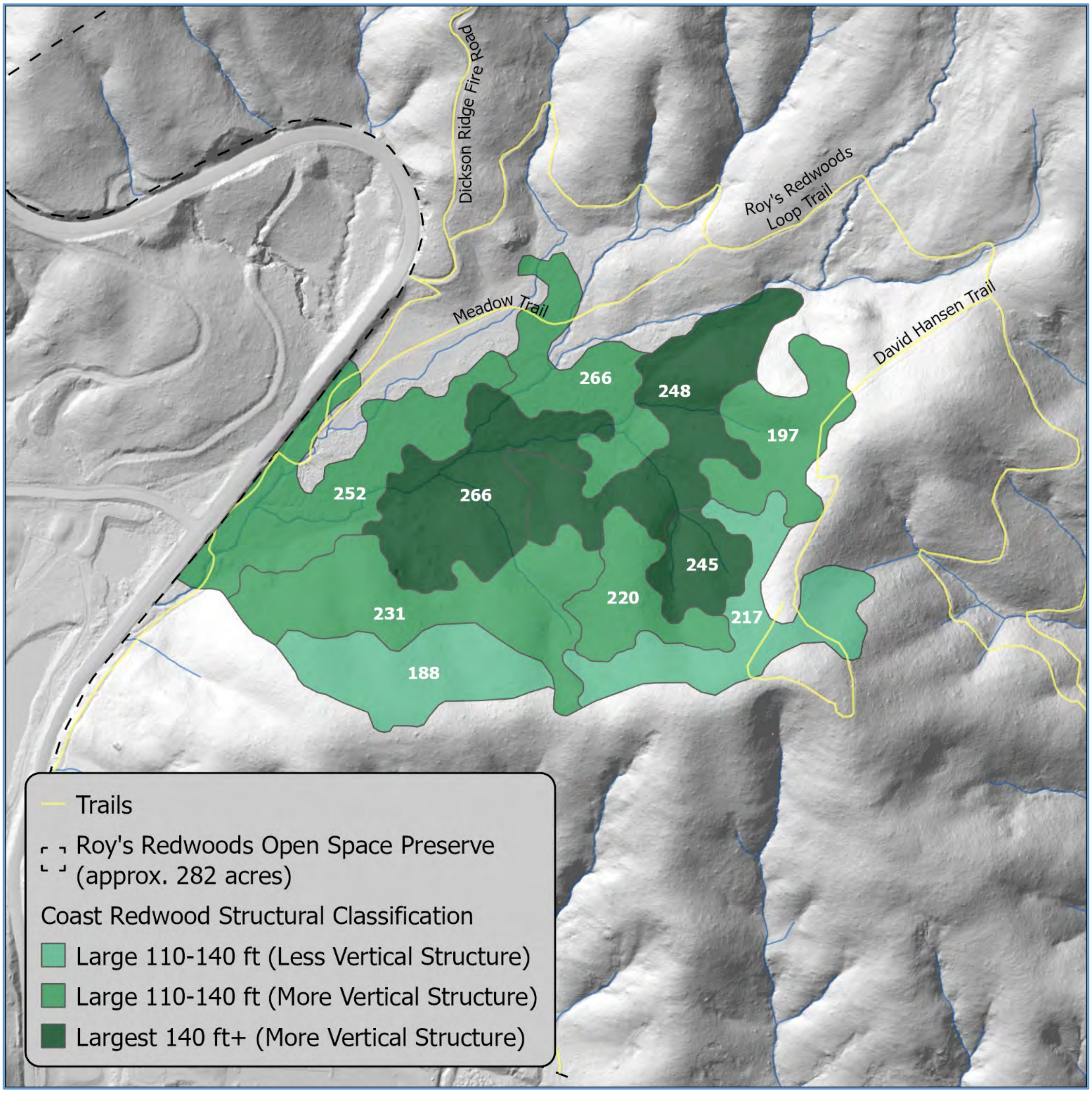
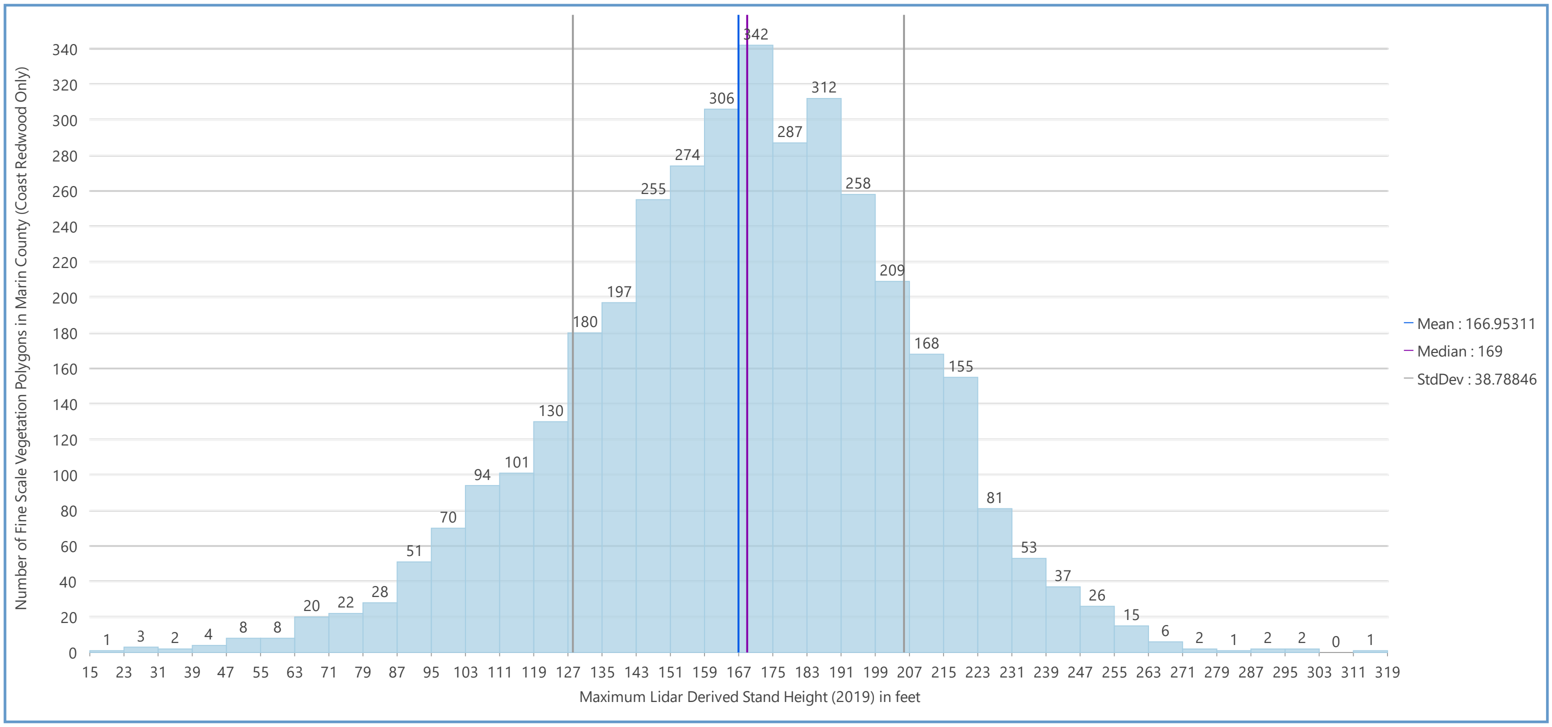
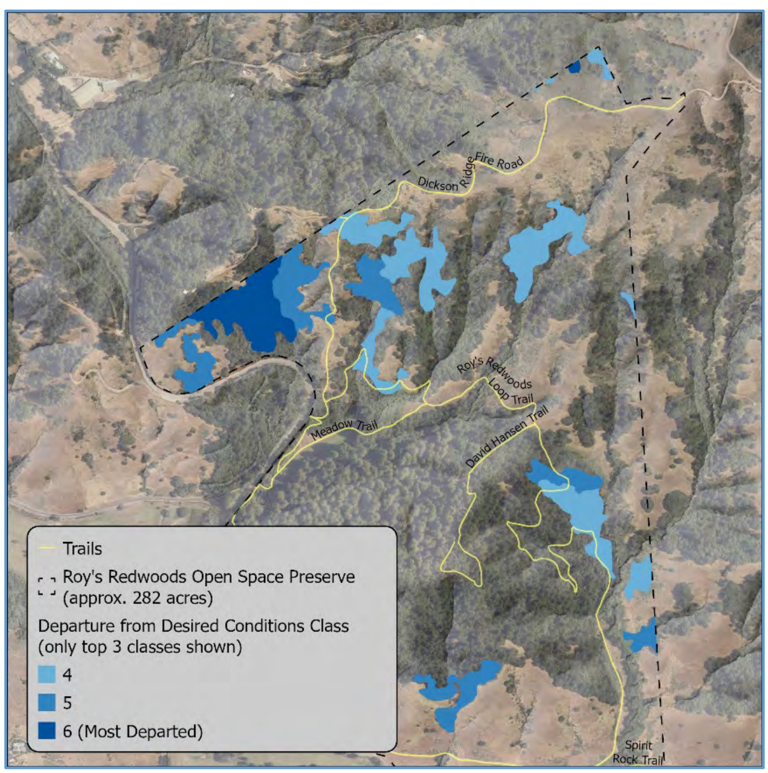


Figure 8.110. Distribution of maximum lidar-derived stand height (in feet) for Coast Redwood in Marin County (2019).



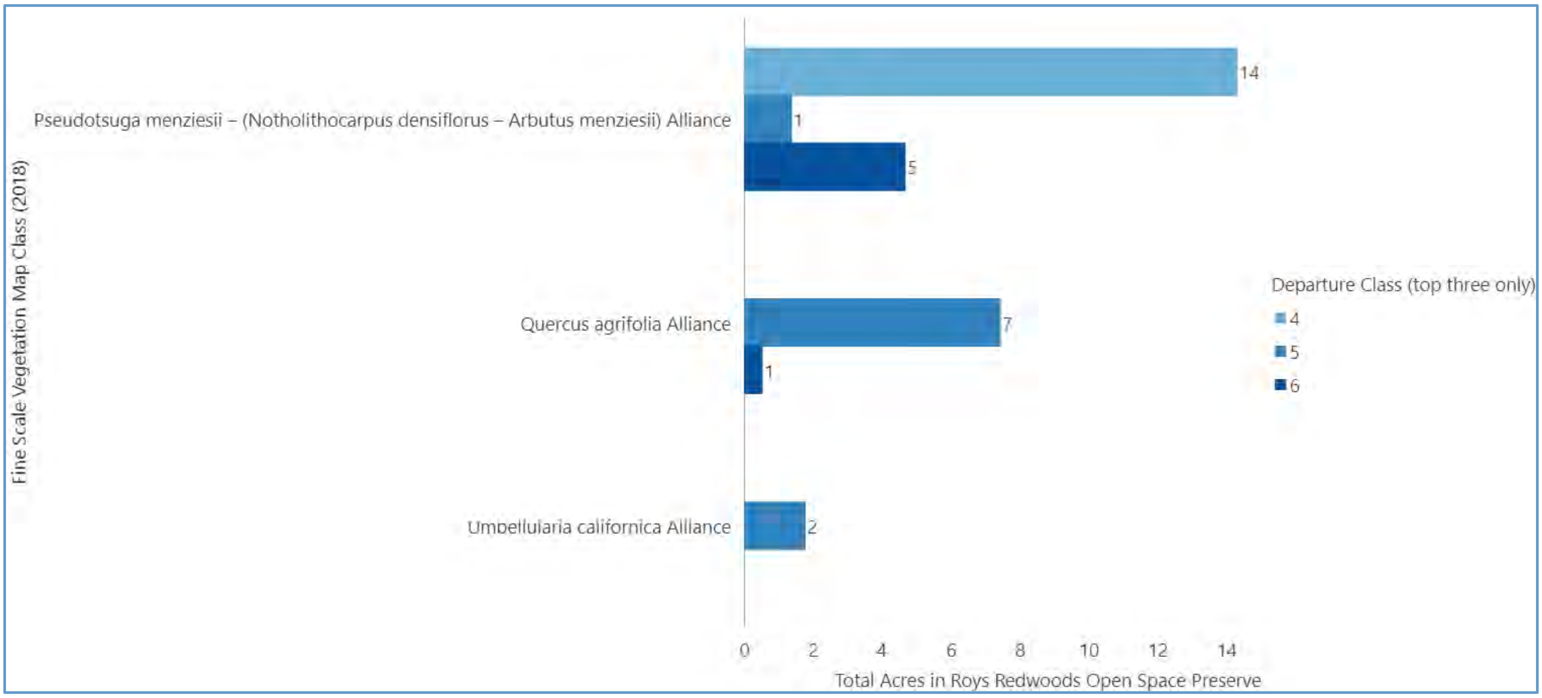
While focus of the current restoration work being planned for Roy's Redwoods Open Space Preserve is to protect Coast Redwood habitat through access planning and hydrological restoration (see Chapter 5: Goals, Coast Redwood), future phases of work at the preserve could improve the ecological health and resilience of other forest types. Departure from desired conditions analysis for Roy's Redwoods OSP shows some Douglas-fir stands around the perimeter of the preserve in the smaller structural classes, indicating shorter dense stands, and medium to high ladder fuels in some of the same areas (Figure 8.111). In addition, the last large fire (greater than 160 acres) mapped in this area was the Ignacio Fire in 1923 (Dawson, 2021; Appendix B: Wildfire History) which, when combined with the prevalence of

Figure 8.111. Roy's Redwoods Open Space Preserve departure from desired conditions index (only the top 3 classes).



Douglas-fir in and around the preserve, likely contributes to the roughly 8 acres of coast live oak (*Quercus agrifolia*) woodland mapped as either threatened with or actively converting to conifer forest and thus in an elevated departure class (Figure 8.112). Analysis of forest conditions in nearby French Ranch Open Space Preserve show similar trends and opportunities to address threatened and converting oak stands.

Figure 8.112. 2018 Fine Scale Vegetation Map class acres by departure from desired conditions class (top three only), Roy's Redwoods Open Space Preserve.



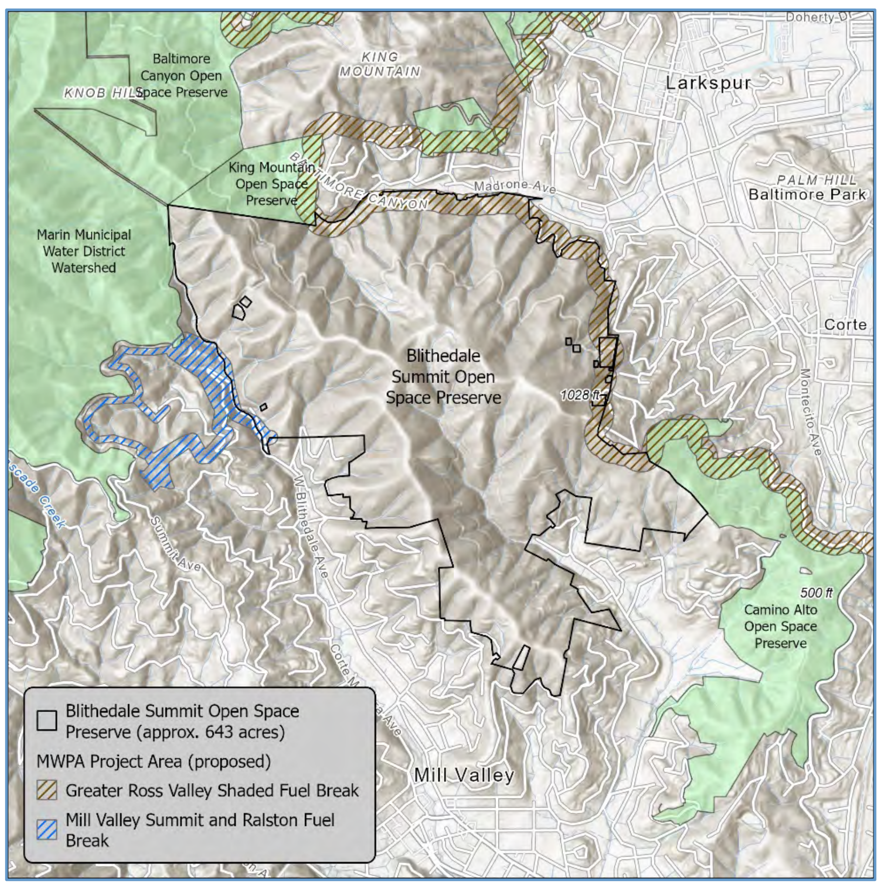
MARIN COUNTY PARKS OPEN CANOPY OAK WOODLAND FOREST HEALTH & RESILIENCE PROJECTS

Owing to the number and spatial distribution of many of their preserves in xeric environments, Marin County Parks manages a significant proportion of all protected Open Canopy Oak Woodland forests in the county. For example, *Quercus agrifolia* (coast live oak) is the most common Open Canopy Oak Woodland forest type in Marin County (14,379 acres), but only 38% (5,550 acres) is on protected open space lands, and of that protected total Marin County Parks manages 43% (2,403 acres) (2018 Fine Scale Vegetation Map, Golden Gate National Parks Conservancy et al., 2021). Similarly, **of the total 20,649 acres of Open Canopy Oak Woodland forest in Marin County, only 36% (7,572 acres) are on protected open space lands, 42% (3,153 acres) of which is managed by Marin County Parks.** Therefore, among land managing agencies in Marin County, MCP is uniquely positioned to advance projects that can improve the health and resilience of Open Canopy Oak Woodland forests and habitat. Project areas described in this section are intended to highlight the range of multi-benefit treatment opportunities for the health and resilience of key forest types including Open Canopy Oak Woodlands on MCP lands generally in the eastern portions of Marin County but are not intended to be an exhaustive list of potential treatment areas. Additional discussion, field reconnaissance, and analysis of opportunities and constraints will be needed before further advancing priority projects.

BLITHEDALE SUMMIT & ADJACENT OPEN SPACE PRESERVES

Blithedale Summit Open Space Preserve (Blithedale OSP), located along the eastern slopes of Mount Tamalpais, is the largest (approximately 640 acres) in a string of Marin County Parks units that follow the north ridge of the mountain (Marin County Parks, n.d.a.) including Camino Alto, King Mountain, and Baltimore Canyon Open Space Preserves. Blithedale OSP shares a boundary with Marin Water's Tamalpais Watershed lands along the western edge of the preserve and abuts several communities including Mill Valley to the south and Larkspur to the northeast (Figure 8.113). Due to its proximity to these and other neighborhoods, Blithedale OSP

Figure 8.113. Blithedale Summit Open Space Preserve and surrounding areas, including proposed MWPA project locations.

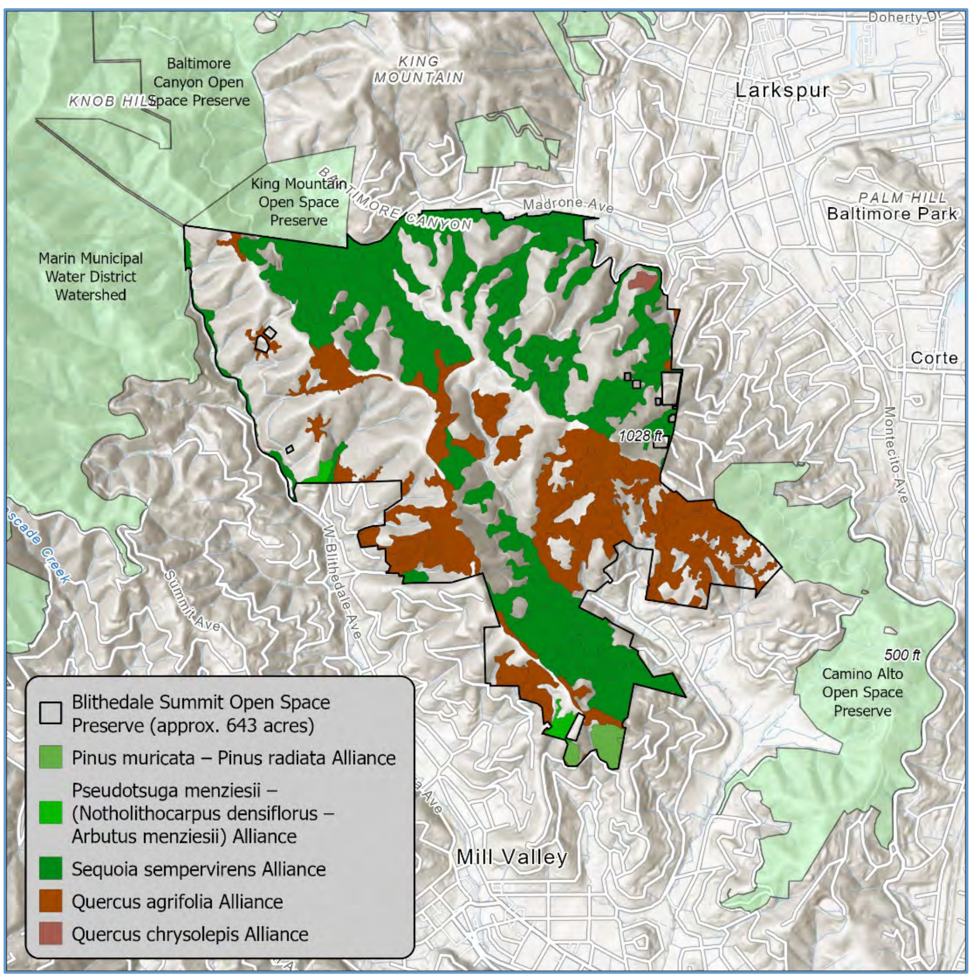


contains multiple maintained fire roads and fuel breaks which are also heavily impacted by French broom and other non-native invasive species and require significant follow-up and management (MCP & MCOSD, 2015, p. 33).

The Marin Wildfire Prevention Authority (MWPA) member agencies are advancing vegetation management projects in/adjacent to Blithedale OSP and surrounding MCP lands, including the Mill Valley Summit and Ralston Fuel Break and Greater Ross Valley Shaded Fuel Break projects (MWPA, 2022, pp. 211, 230). Where feasible and appropriate Marin County Parks is working with MWPA to design treatment approaches to be ecologically neutral or beneficial. Analysis provided by the *Forest Health Strategy* could be used to support multi-benefit treatment design efforts.

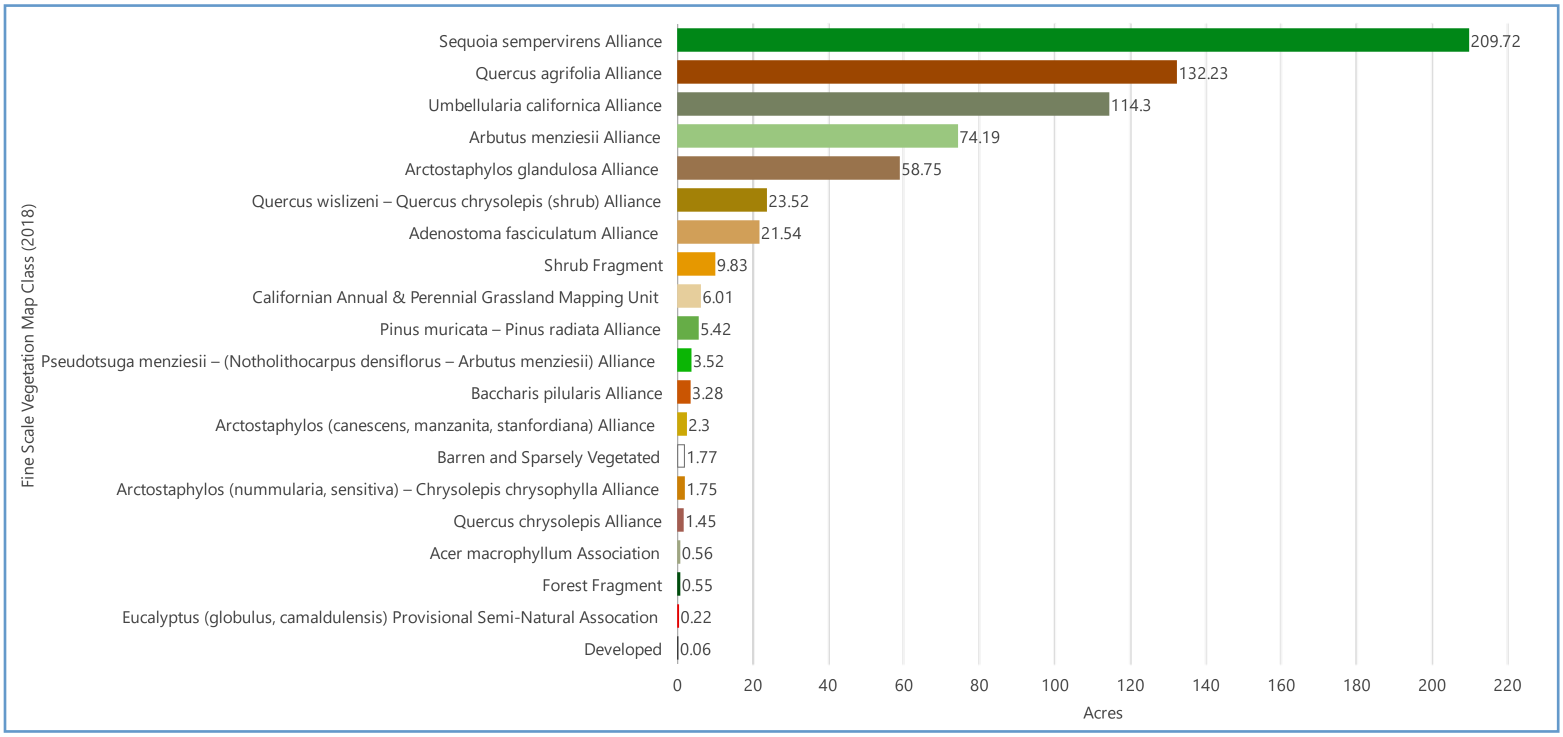
Blithedale Summit Open Space Preserve is dominated by forest and chaparral vegetation communities, including significant acreages of key types profiled as part of the *Forest Health Strategy* such as Coast Redwood forest, coast live oak woodland (*Quercus agrifolia*) (Figure 8.114). Other widespread vegetation communities within the preserve include Pacific madrone (*Arbutus menziesii*), California bay (*Umbellularia californica*), and Eastwood's manzanita (*Arctostaphylos glandulosa*) (Figure 8.115). These vegetation communities provide habitat for

Figure 8.114. 2018 Fine Scale Vegetation Map key forest communities within Blithedale Summit Open Space Preserve.



several special status wildlife species including Northern Spotted Owl, and rare plant species such as California false indigo (*Amorpha californica*) (MCP & MCOSD, 2015, p. 33).

Figure 8.115. 2018 Fine Scale Vegetation Map class by acres, Blithedale Summit Open Space Preserve.



Fire history mapping shows roughly two-thirds of Blithedale OSP had a fire return interval between 1859 and 1940 of 5-15 years, with the remaining one-third of the area mapped with fire every 15-30 years (Dawson, 2021; Appendix B: Wildfire History). Despite this evidence of a relatively frequent fire regime, most of Blithedale OSP has not experienced fire in more than 100 years, with the last documented wildfire (greater than 160 acres) in the preserve dated July 2013 (Dawson, 2021) (see Chapter 5: Goals for more information on historic fire return intervals for key forest types). Fire exclusion and other stressors within Blithedale OSP have contributed to a departure from desired conditions, including relatively high ladder fuels and canopy mortality (most likely sudden oak death impacted hardwoods in the understory) in structurally smaller stands of Coast Redwood forest, and coast live oak stands that show canopy mortality and are flagged as threatened with or actively converting to conifer forests (Figure 8.116). Many forest and woodland stands with a departure from desired conditions index class of three or greater are located near existing roads or trails, making access to conduct multi-benefit treatments more feasible (Figure 8.117).

Similar conditions are present in coast live oak woodlands to the south in Camino Alto Open Space Preserve, and to the north in Baltimore Canyon Open Space Preserve where fire exclusion, unnatural fuel accumulations, and Douglas-fir encroachment are driving a departure from desired conditions in several key forest types (Figure 8.118). Many of these areas are adjacent to existing roads and trails, as well as the proposed Greater Ross Valley Shaded Fuel Break (MWPA, 2022, p. 58), indicating additional opportunities to advance multi-benefit treatments (Figure 18.119).

Figure 8.116. 2018 Fine Scale Vegetation Map class acres by departure from desired conditions indices (top three only), Blithedale Summit Open Space Preserve.

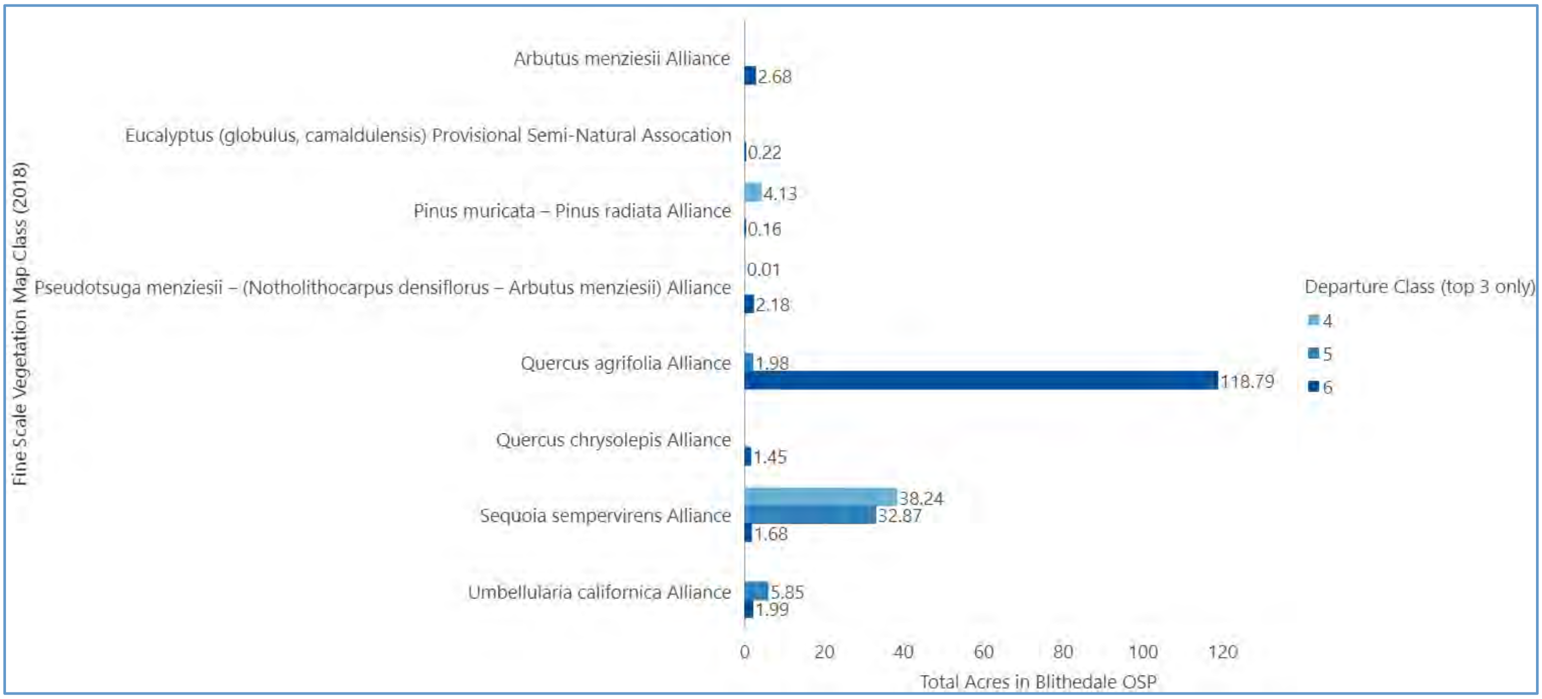


Figure 8.117. Blithedale Summit Open Space Preserve departure from desired conditions (top three classes only).

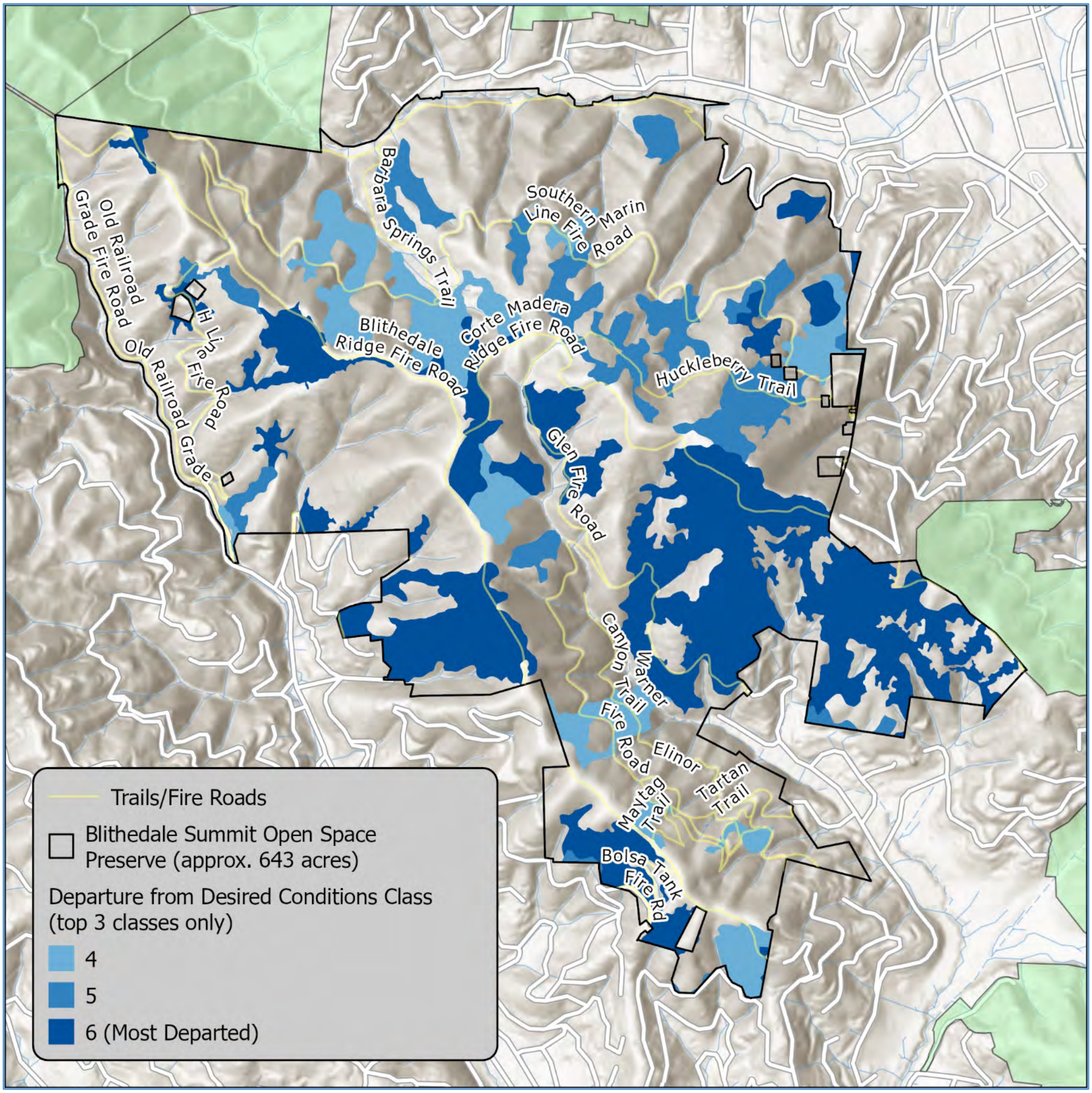


Figure 8.118. 2018 Fine Scale Vegetation Map class acres by departure from desired conditions indices (top three only), Baltimore Canyon Open Space Preserve.

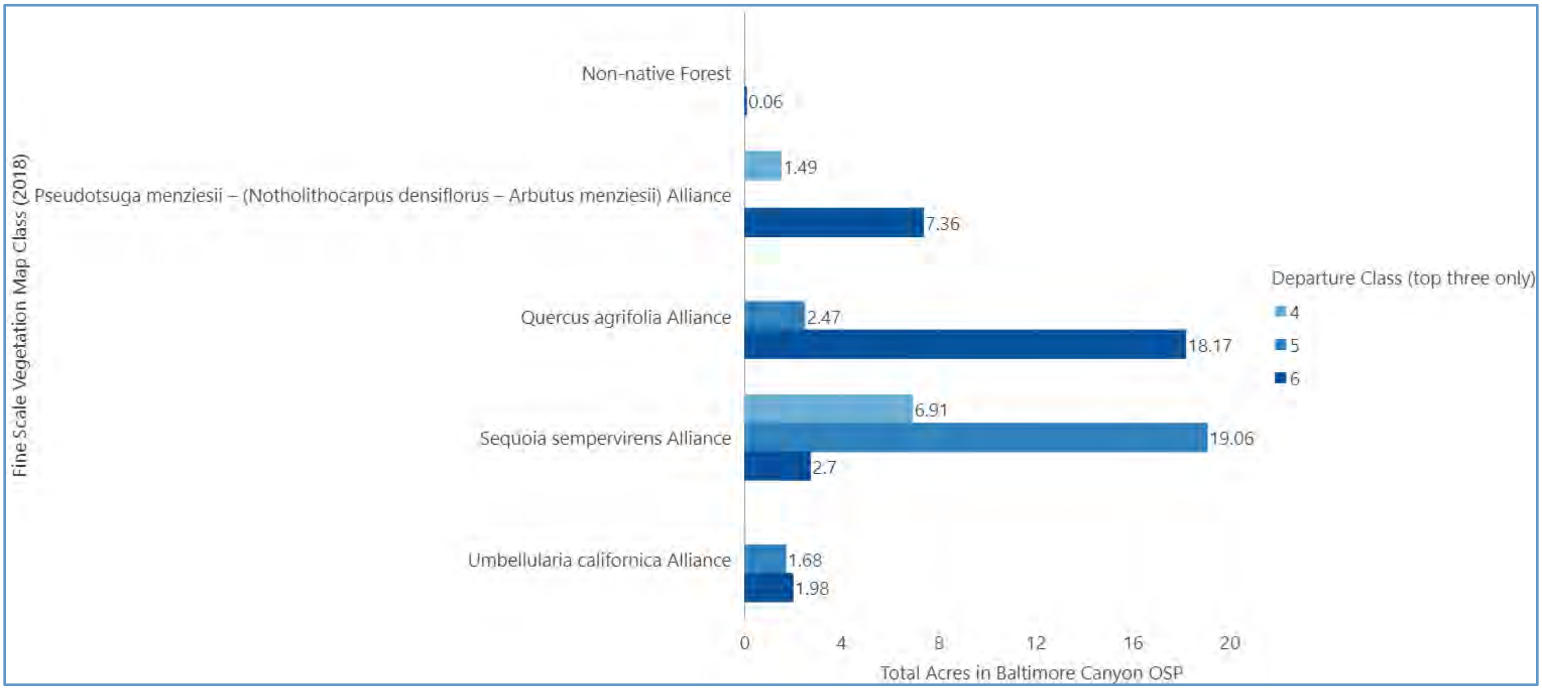
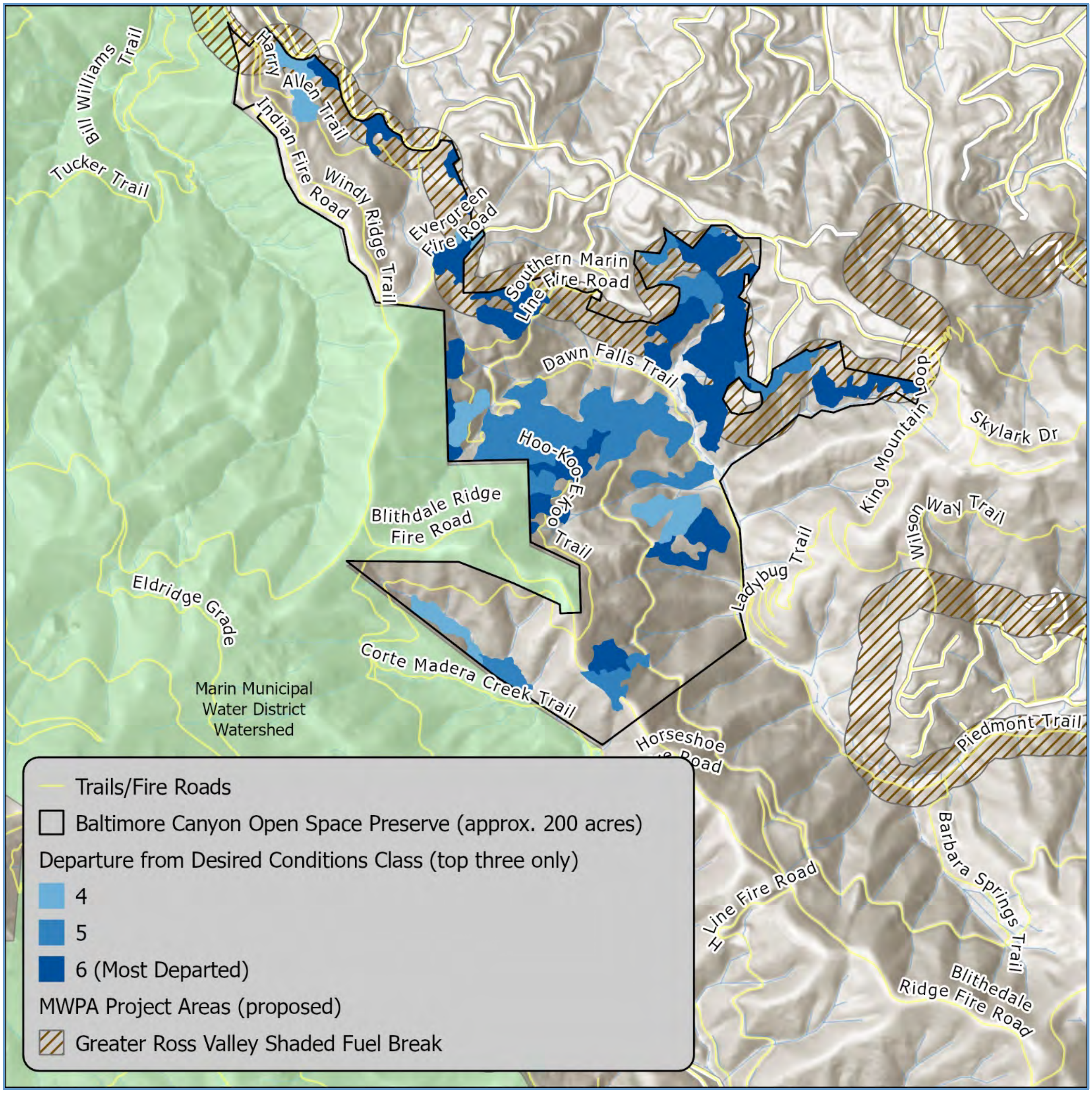


Figure 8.119. Baltimore Canyon Open Space Preserve departure from desired conditions (top three classes only).

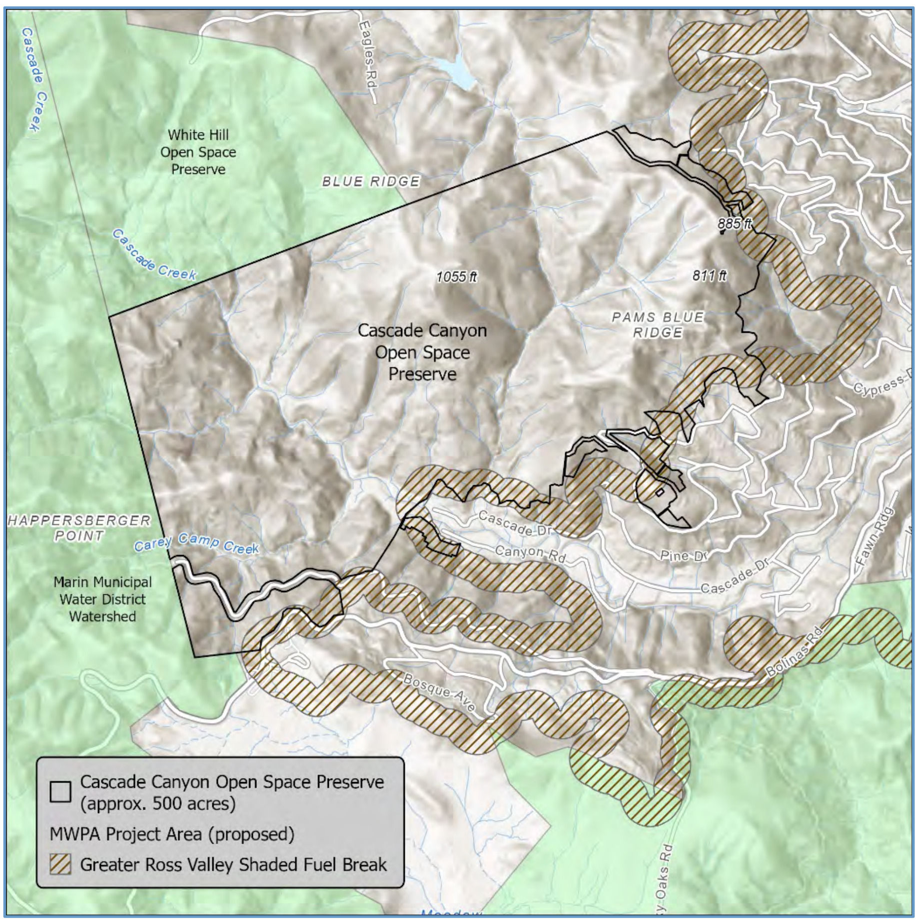


CASCADE CANYON OPEN SPACE PRESERVE

Cascade Canyon Open Space Preserve (Cascade Canyon OSP) is located within the Corte Madera Creek Watershed, west of the Town of Fairfax, and shares a border with White Hill Open Space Preserve and Marin Water's Tamalpais Watershed lands. Three streams within the preserve – Carey Camp Creek, San Anselmo Creek, and Cascade Creek – converge just west of Cascade Drive to form the larger San Anselmo Creek. While typically hosting rainbow trout, in November 2021 MCP documented presence of Chinook salmon (*Oncorhynchus tshawytscha)* in San Anselmo Creek (M. Martin, Chief of Natural Resources, Marin County Parks, personal communication, 2022). The creek is also home to the candidate for federally and state-listed foothill yellow-legged frog. In 2021 Marin County Parks released plans for a series of trail improvements and bridges designed to improve visitor access and reduce sediment deposition that could be negatively affecting downstream aquatic habitat (Marin County Open Space District, 2021).

Upland portions of Cascade Canyon OSP provide habitat for Northern Spotted Owl, eleven bat species, and several other avian special status species (MCP & MCOSD, 2015, p. 37). Some areas of the preserve support serpentine endemic chaparral species including Mount Tamalpais manzanita (*Arctostaphylos montana*) and herbaceous species such as Mount Tamalpais jewelflower (*Streptanthus glandulosus ssp. Pulchellus*) and others (MCP & MCOSD, 2015). Non-native invasive species including French, Scotch, and Spanish broom (*Genista monspessulana*, *Cytisus scoparius*, *Spartium junceum*) are present within the preserve near existing fire roads and fuel breaks (MCP & MCOSD, 2015). Portions of Cascade Canyon OSP are in and adjacent to the proposed extent of the Greater Ross Valley Shaded Fuel Break (MWPA, 2022, pp. 58, 230) (Figure 8.120)

Figure 8.120. Cascade Canyon Open Space Preserve and Marin Wildfire Prevention Authority's (proposed) Greater Ross Valley Shaded Fuel Break.



Cascade Canyon OSP is dominated by hardwood forests and woodland vegetation communities, including California bay (*Umbellularia californica*), coast live oak (*Quercus agrifolia*), and Pacific madrone (*Arbutus menziesii*) (Figure 8.121). In addition to coast live oak stands, Cascade Canyon OSP contains significant acres of other Open Canopy Oak Woodlands including valley oak (*Quercus lobata*) and Oregon white oak (*Quercus garryana*), the latter of which has relatively limited distribution (249 total acres) on protected open space lands in Marin County (Golden Gate National Parks Conservancy, 2021). The 44 acres of Oregon white oak woodland in Cascade Canyon OSP represents 17% of all protected stands in the County, and more than half (52%) of the total acres of this forest type on Marin County Parks managed lands. A small amount of Douglas-fir forest (*Pseudotsuga menziesii – Notholithocarpus densiflorus – Arbutus menziesii*) is also located within the preserve (Figure 8.122), which is identified in the 2015 *Vegetation and Biodiversity Management Plan* as a threat to the long-term persistence of oak woodlands and chaparral habitats due to the risk of habitat conversion stemming from fire suppression and the removal of Coast Miwok people from the land (MCP & MCOSD, 2015).

Figure 8.121. 2018 Fine Scale Vegetation Map class by acres, Cascade Canyon Open Space Preserve.

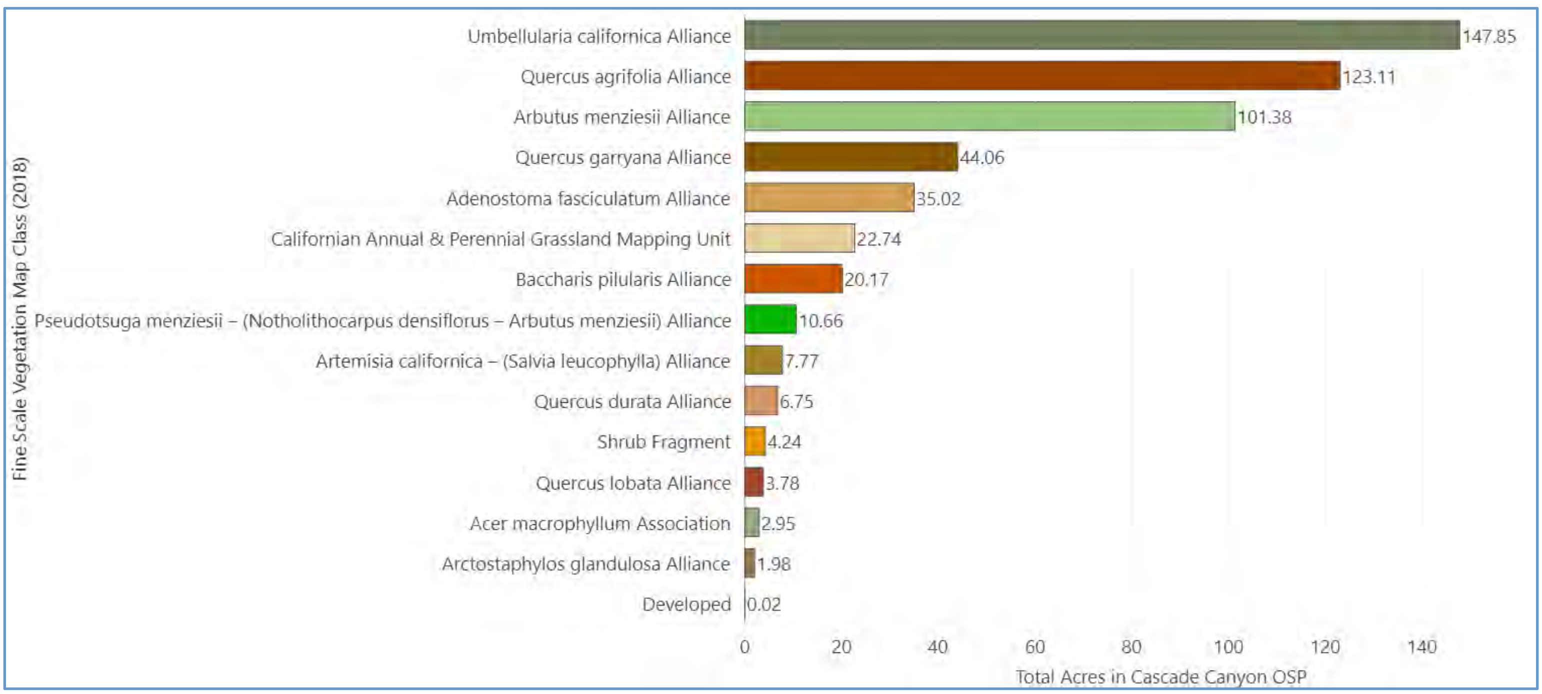
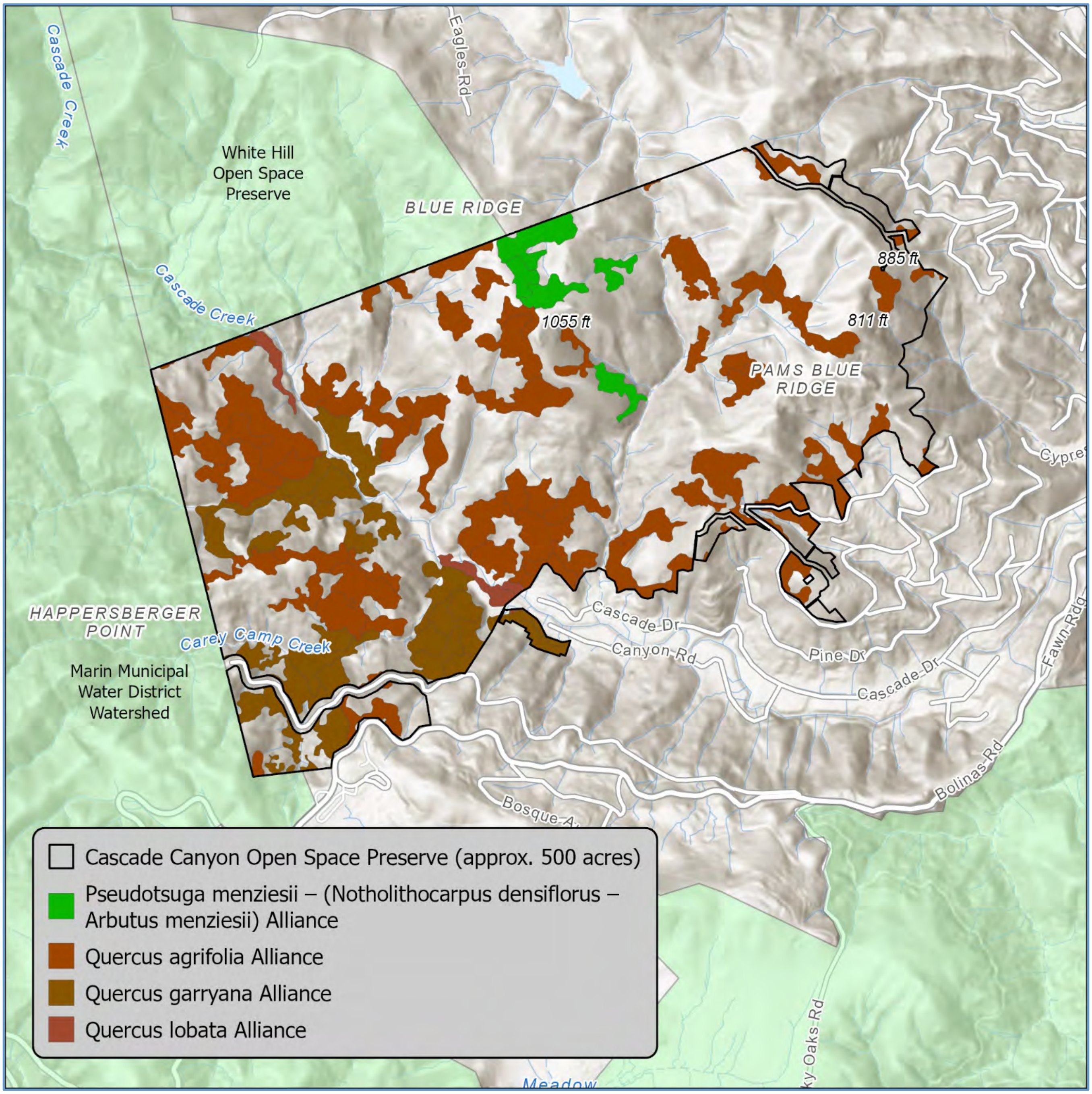


Figure 8.122. Forest Health Strategy key forest types in Cascade Canyon Open Space Preserve, per 2018 Fine Scale Vegetation Map.



Fire history mapping in Cascade Canyon Open Space Preserve shows a fire return interval of 15-45 years between 1859 and 1940, with the last significant wildfire (greater than 160 acres) dated 1945 (Mill/Carson Canyon Fire) (Dawson, 2021; Appendix B: Wildfire History). The 1973 Tamarancho Fire appears to have mostly burned in White Hill Open Space Preserve to the north, but a small portion may have also burned into Cascade Canyon OSP (Dawson, 2021). Interestingly, a small 10-acre fire was reported in 2016 near Camp Tamarancho, likely in the same vicinity as the 1973 fire which burned 200 acres (Weeks, 2016). Fire exclusion, which facilitates Douglas-fir encroachment in Cascade Canyon OSP's hardwood forests and contributes to relatively high ladder fuels, coupled with pockets of canopy mortality, results in a departure from desired conditions for several key forest types within the preserve (Figure 8.123). Notably, nearly all (87%) of the 10.66 acres of Douglas-fir within Cascade Canyon OSP has a mean lidar-derived stand height of less than 60 feet, indicating that these are expansion stands that are threatening or actively converting Open Canopy Oak Woodland forests within the preserve and could be prioritized for management. Many forest and woodland stands with an elevated departure from desired conditions classification (greater than or equal to 4) are located near roads and trails within the preserve which could facilitate prioritization for active management (Figure 8.124). Multi-benefit treatments could also be planned in nearby White Hill Open Space Preserve in areas where similar conditions exist.

Figure 8.123. 2018 Fine Scale Vegetation Map class acres by departure from desired conditions indices (top three classes only), Cascade Canyon Open Space Preserve.

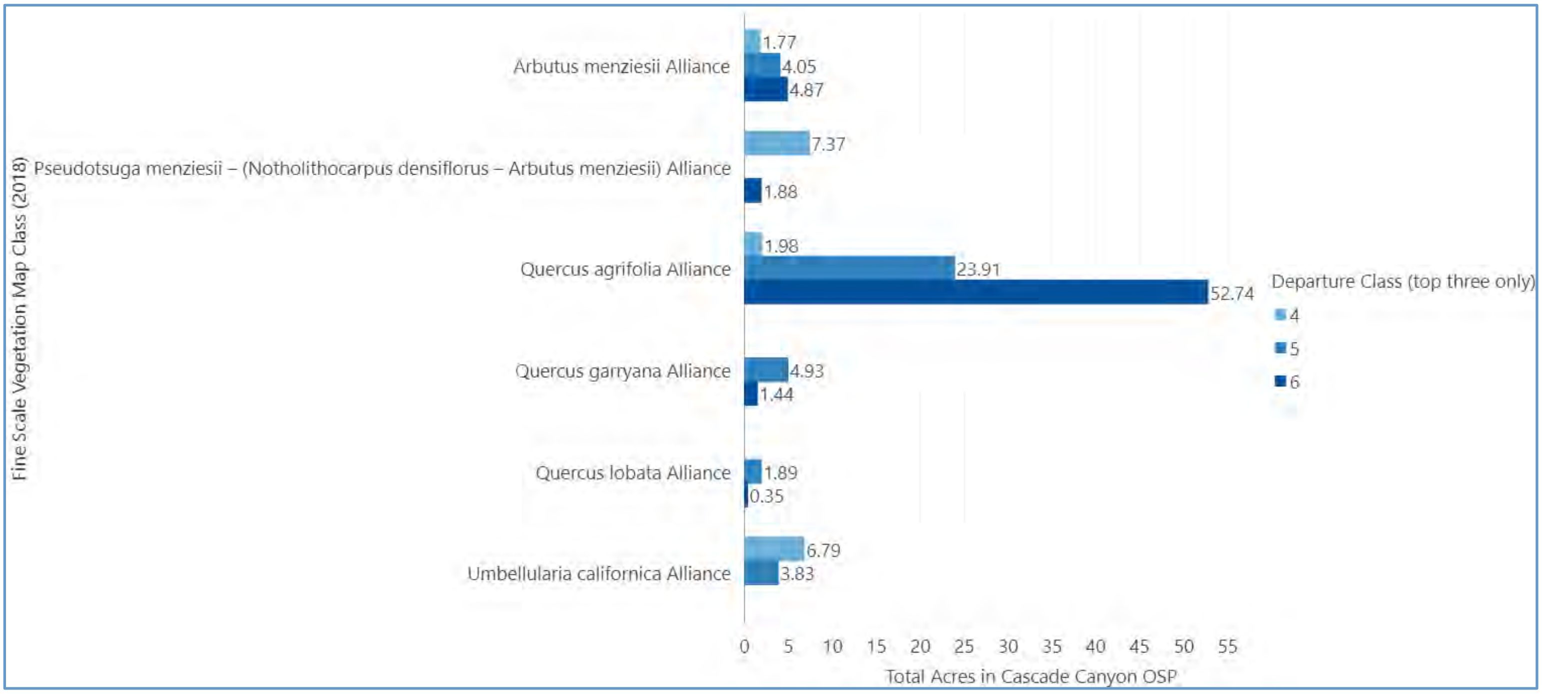
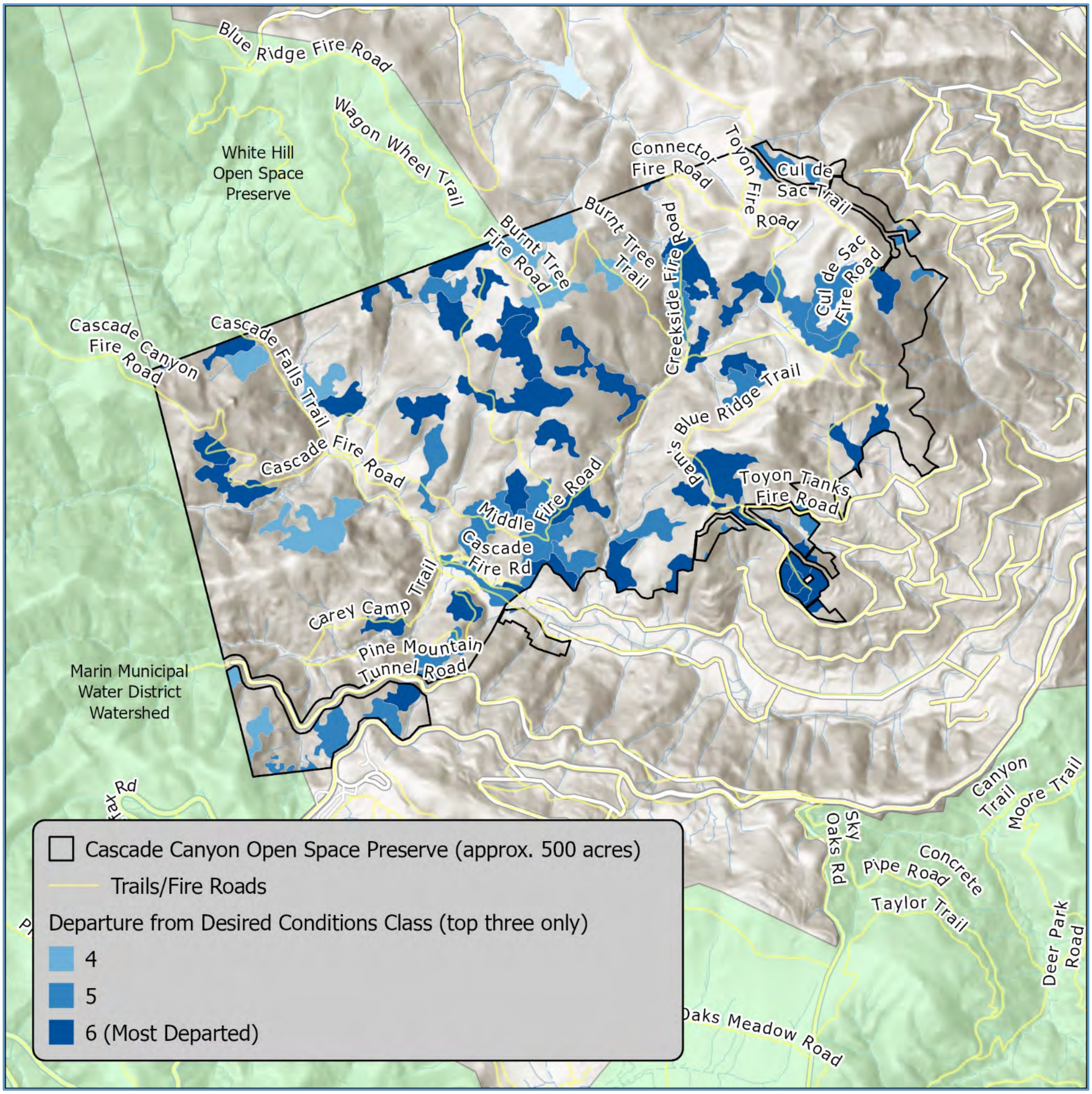


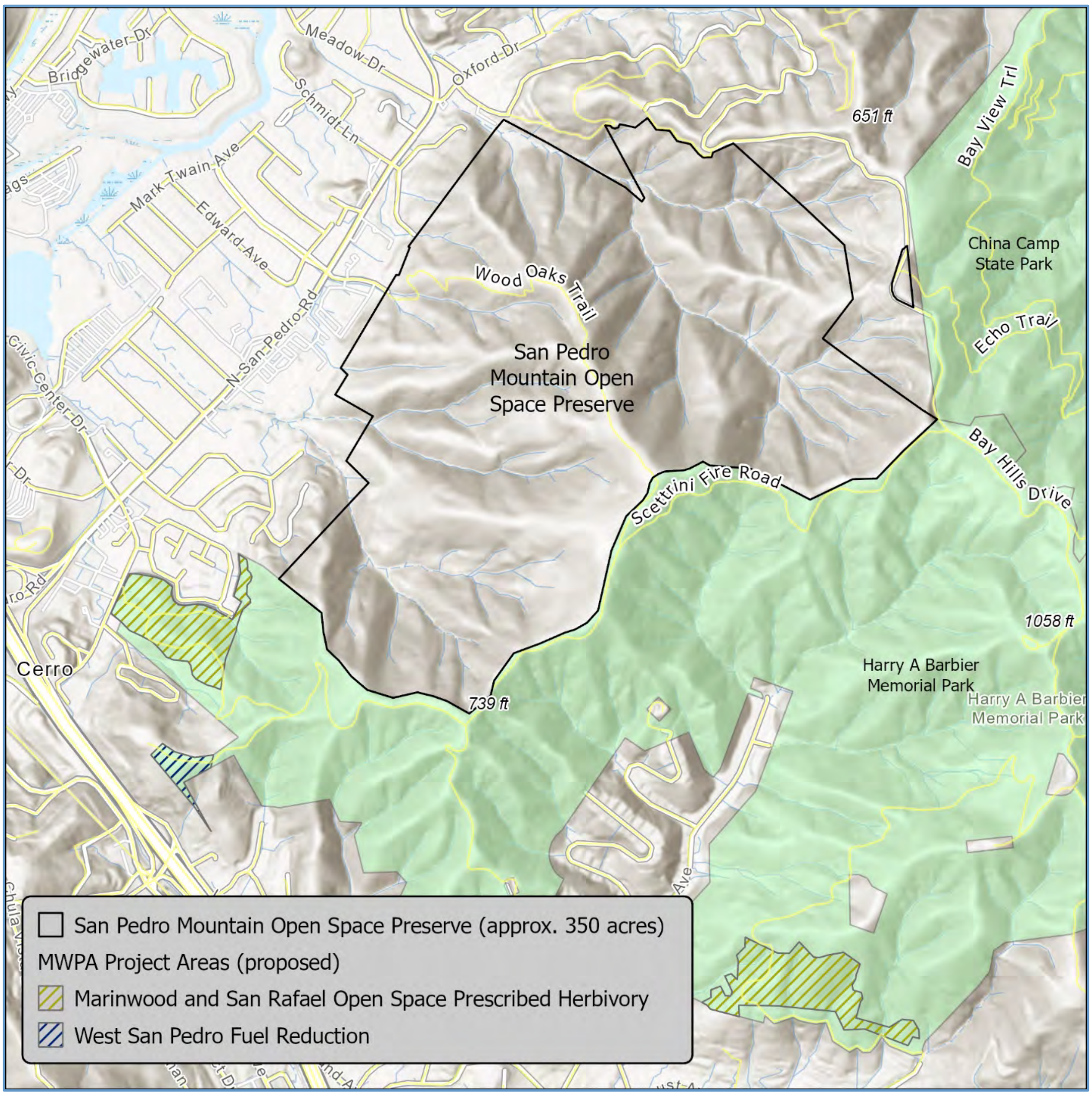
Figure 8.124. Cascade Canyon Open Space Preserve departure from desired conditions (top three classes only).



SAN PEDRO MOUNTAIN OPEN SPACE PRESERVE

San Pedro Mountain Open Space Preserve (San Pedro Mountain OSP) is located north of San Rafael in central Marin County east of highway 101, in Miller Creek's frontal watershed which drains to San Pablo Bay Estuary. To the south, the San Pedro Mountain OSP borders Harry A. Barbier Memorial Park managed by the City of San Rafael, and to the east is China Camp State Park. The preserve is roughly bisected north to south by the Wood Oaks Trail, which meets Scettrini Fire Road running west to east along the southern preserve boundary. The Marin Wildfire Prevention Authority (MWPA) has proposed fuels reduction projects in adjacent Harry A. Barbier Memorial Park (MWPA, n.d.a.), one of which (West San Pedro Fuel Reduction) involves management of non-native eucalyptus (Figure 8.125).

Figure 8.125. San Pedro Mountain Open Space Preserve and surrounding area, including nearby (proposed) MWPA project locations.



The ridges and valleys of San Pedro Mountain OSP are dominated by hardwood stands including California bay (*Umbellularia californica*), Pacific madrone (*Arbutus menziesii*), and coast live oak (*Quercus agrifolia*) woodlands (Figure 8.126). In addition to Open Canopy Oak Woodlands, the other key forest type in the preserve includes a handful of Coast Redwood stands, generally clustered near the top of and along steep seasonal stream drainages. (Figure 8.127). According to the 2015 draft *Vegetation and Biodiversity Management Plan*, Marin County Parks staff had previously confirmed a Golden Eagle (*Aquila chrysaetos*) nest site within the preserve (MCP & MCOSD, 2015, p. 51).

Figure 8.126. 2018 Fine Scale Vegetation Map Class by acres, San Pedro Mountain Open Space Preserve.

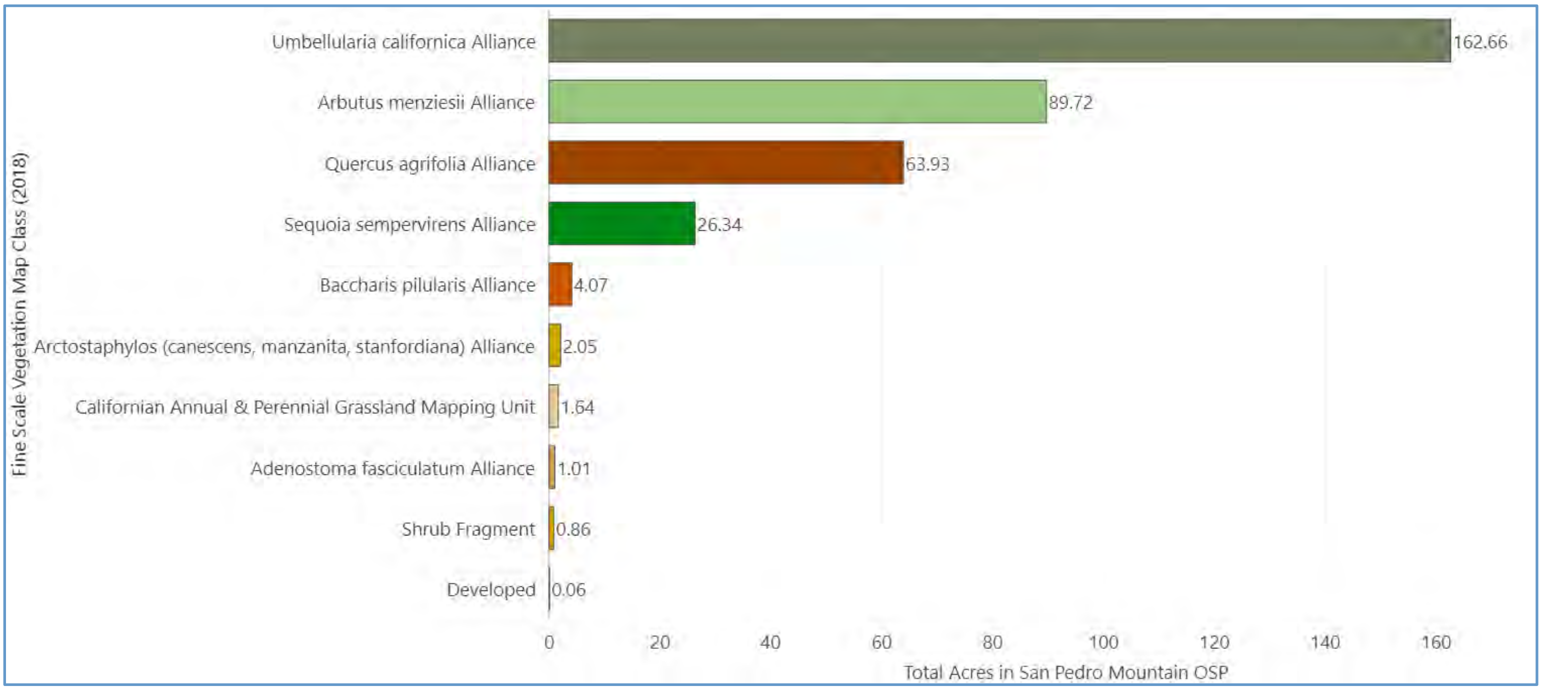
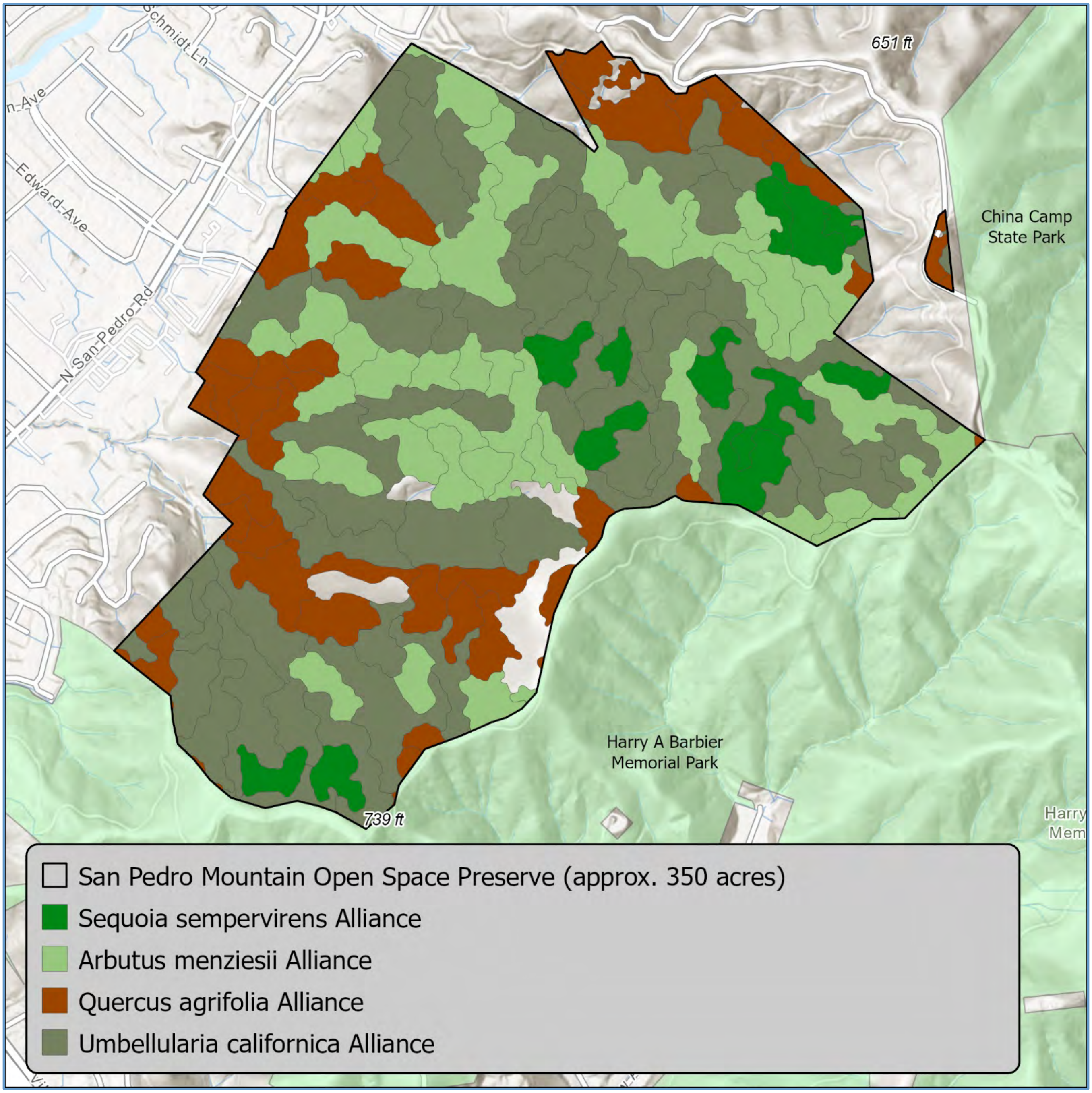


Figure 8.127. Forest Health Strategy key forest types in San Pedro Open Space Preserve, per 2018 Fine Scale Vegetation Map.



Fire history information is scarce for this area of Marin County. A series of fires appear to have occurred within or adjacent to San Pedro Mountain OSP between 1917 and 1938 according to one account but could not be corroborated by other sources (Dawson, 2021; Appendix B: Wildfire History). The last known fire in this area was documented to have occurred in 1958, most likely in Barbier Memorial Park, suggesting that San Pedro Mountain Open Space Preserve has not seen fire in at least 85 years (Dawson, 2021). Fire exclusion almost certainly contributes to the relatively high ladder fuels mapped in some areas and vegetation communities within the preserve, for example 41% (26 acres) of coast live oak stands were classified as high ladder fuels, with the remaining 59% (38 acres) classified as very high. Pacific madrone stands also showed relatively elevated ladder fuels, including 57% (52 acres) classified as high, with an additional 17% (15 acres) classified as very high (see Chapter 6: Metrics and Forest Health Web Map). Conversely, California bay woodlands within San Pedro OSP had relatively fewer acres (23 total) of high or very high ladder fuels (13%). While there are not many stands of Douglas-fir nearby, over time, fire exclusion in San Pedro Mountain OSP could facilitate conversion of evergreen hardwood forested stands to conifer in the absence of management or beneficial fire.

Canopy mortality is also contributing to a departure from desired conditions in San Pedro Mountain OSP, and although not widespread, is present in some evergreen hardwood stands. In Pacific madrone woodlands, 21% (19 acres) had between 0.5% and 2.5% canopy mortality, with an additional 3 acres (3% of stands) greater than 2.5% canopy mortality. 10% (7 acres) of coast live oak forests within the preserve also had greater than 2.5% canopy mortality. While the cause of the canopy dieback cannot be determined from this analysis, causes could include pathogen impacts and/or drought stress. Indeed, 30% of Pacific madrone stands and 70% of coast live oak stands had between 5% and 10% canopy density loss between 2010 and 2019, which could be an indicator of drought impacts. Analysis of the departure from desired conditions index for San Pedro Mountain OSP illustrates the impacts of these combined stressors on key forest types within the preserve (Figure 8.128). Where feasible given access and slope constraints, multi-benefit treatments could be advanced to remove non-native invasive species present, improve hardwood forest health and resilience, and strategically reduce unnatural fuel accumulations near communities (Figure 8.129).

Figure 8.128. 2018 Fine Scale Vegetation Map class acres by departure from desired conditions indices (top three classes only), San Pedro Mountain Open Space Preserve.

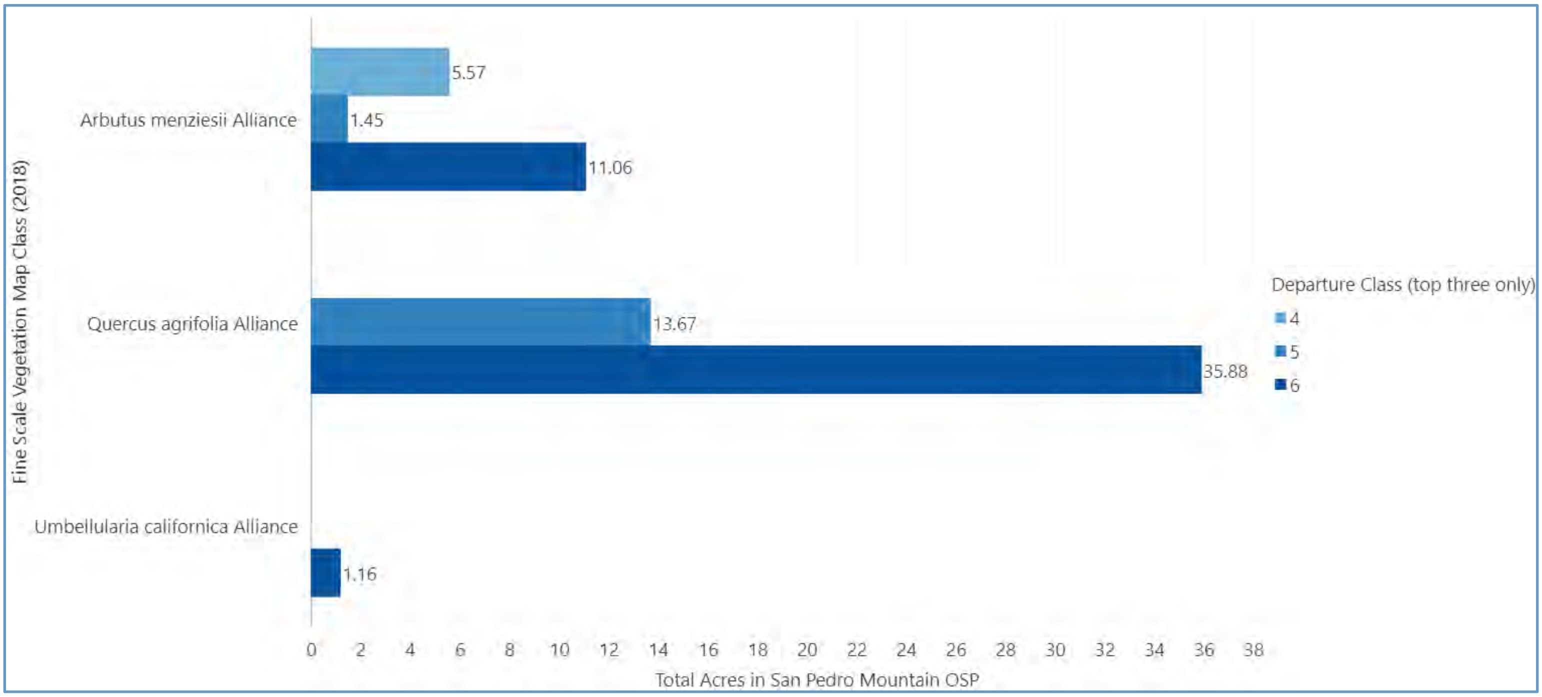
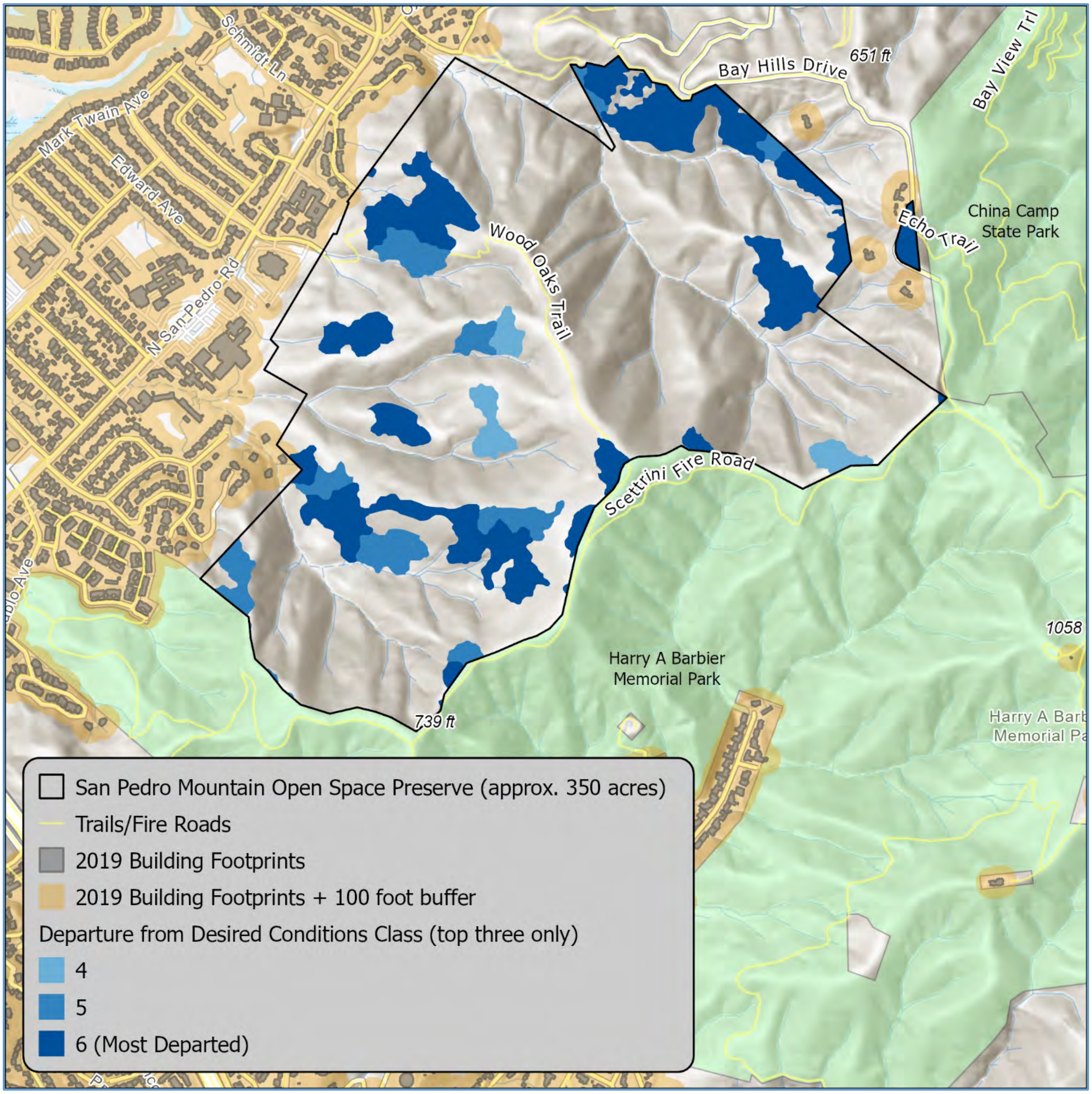


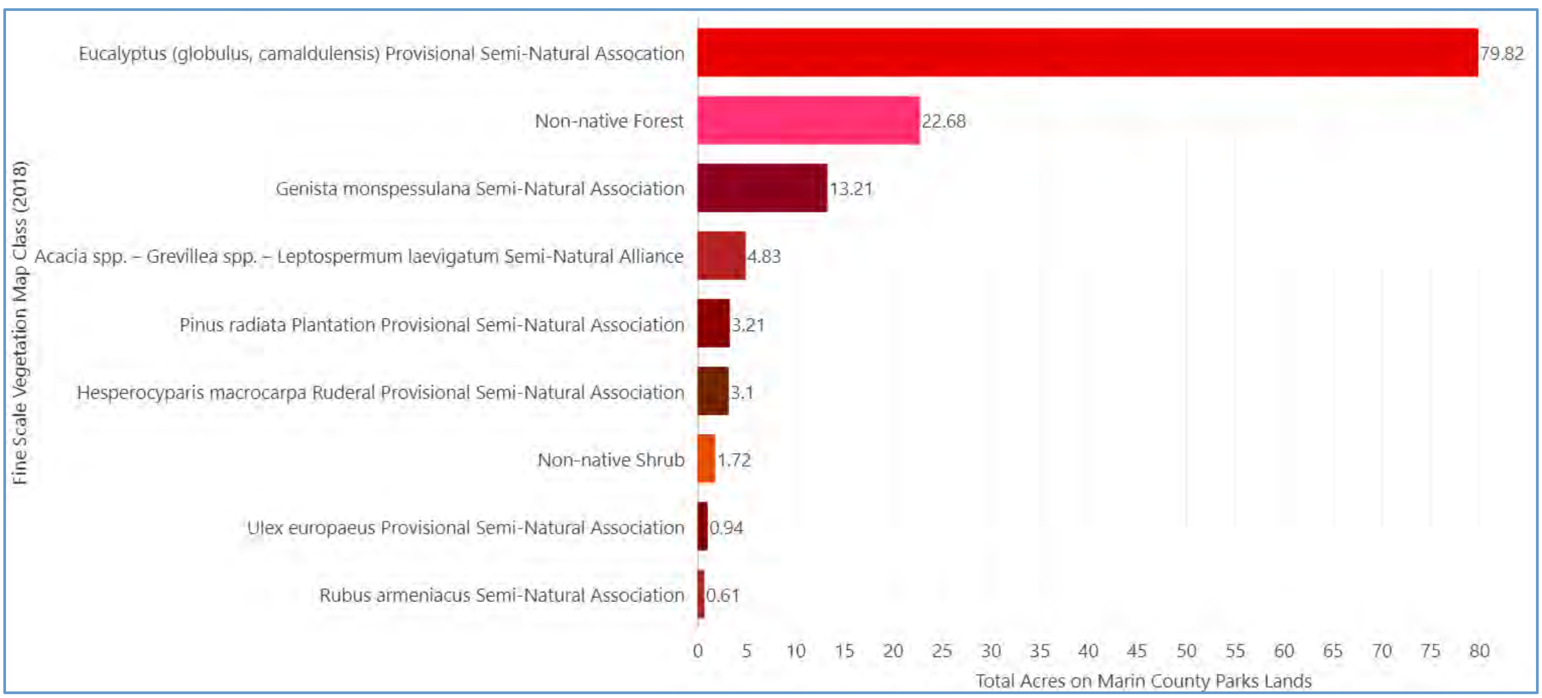
Figure 8.129. San Pedro Mountain Open Space Preserve departure from desired conditions (top three classes only). Includes 2019 building footprints with 100-foot buffers.



MARIN COUNTY PARKS NON-NATIVE INVASIVE FOREST & SHRUB MANAGEMENT & WILDFIRE HAZARD REDUCTION

Non-native invasive trees and shrubs pose a threat to biodiversity and can contribute to wildfire hazard in some areas of the wildland urban interface. On Marin County Parks managed preserves, these species are displacing native vegetation and are spreading into wildland areas (MCP & MCOSD, 2015, p. 160). Problematic species include acacia (*Acacia decurrens*, *A. melanoxylon*, and other *Acacia* spp.), blue gum eucalyptus (*Eucalyptus globulus*), Monterey cypress (*Hesperocyparis macrocarpa*), Monterey pine (*Pinus radiata*), cotoneaster (*Cotoneaster* spp.), French broom (*Genista monspessulana),* Himalayan blackberry (*Rubus armeniacus*), pride of Madeira (*Echium candicans*), Scotch broom (*Cytisus scoparius*), Spanish broom (*Spartium junceum)* (MCP & MCOSD, 2015). The 2018 Fine Scale Vegetation Map identifies a total of 130 acres dominated by non-native invasive species on Marin County Parks managed lands (Figure 8.130). While helpful for establishing landscape scale baseline conditions, this number surely underestimates the extent of non-native invasive species cover on MCP lands due to limitations such as minimum mapping units (1/4 to 1-acre) and the inability to map understory species composition.

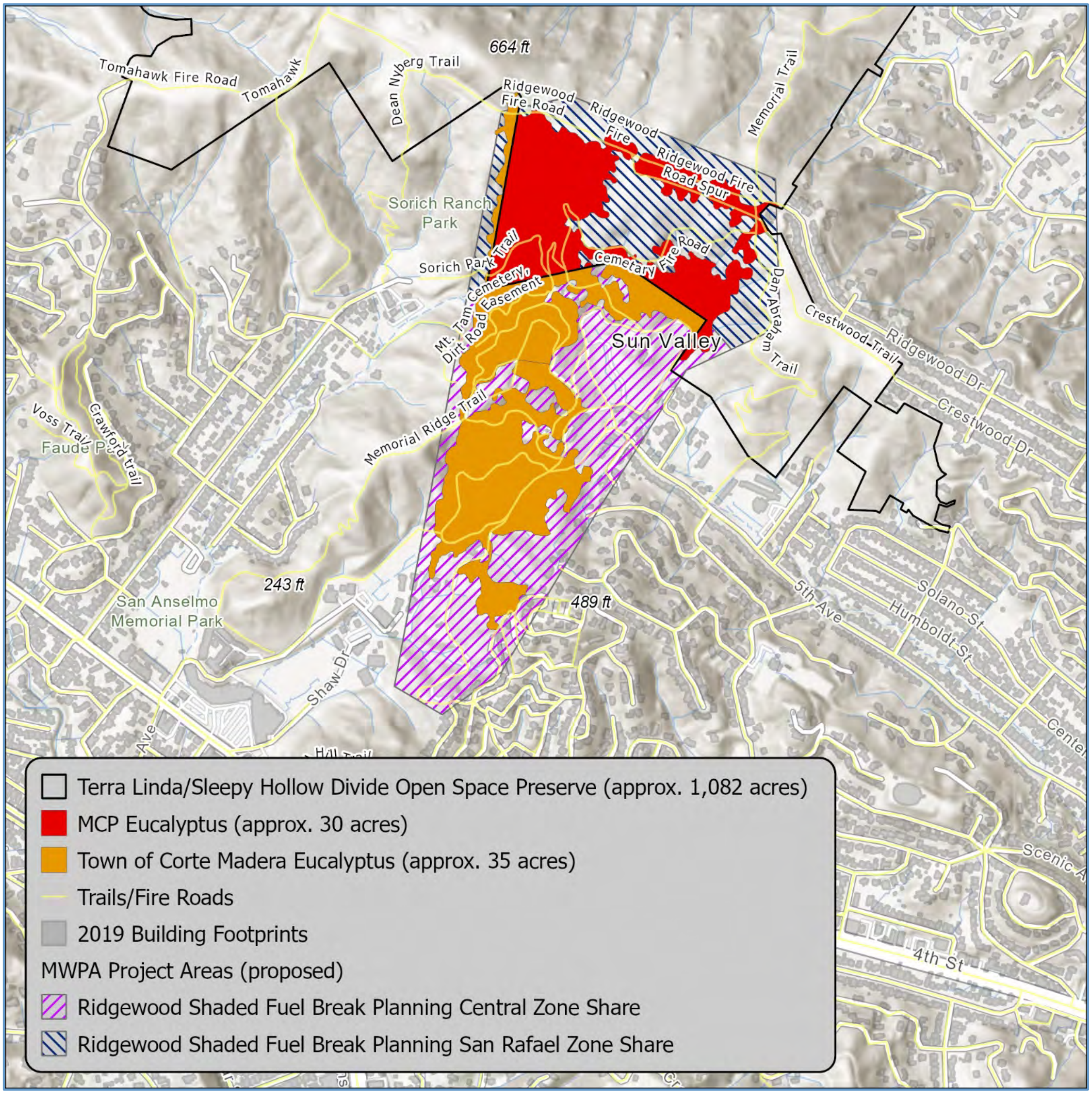
Figure 8.130. Non-native invasive tree and shrub species by acres, Marin County Parks managed lands only.



The Marin Wildfire Prevention Authority also recognizes the significance of high fire risk invasive species and has proposed Invasive Vegetation Treatment Programs in the WUI and along evacuation routes in Fairfax, San Anselmo, Ross, Kentfield, Larkspur, Corte Madera, and others (MWPA, 2022, p. 221). Eucalyptus is particularly problematic from a fire risk perspective because stands accumulate large amounts of dead, dry material because of persistent bark-shedding, can act as an ember catch during a wildfire event, and contain oils which can create more intense fire behavior (M. Swezy, Vegetation Management Program Manager, Novato Fire Protection District, personal communication, November 15, 2022). In Novato, MWPA's Valley Memorial Park Eucalyptus Removal Project included full removal of 1.4 acres of eucalyptus to reduce wildfire hazard for nearby homes and restore riparian native plant habitat near Rush Creek Open Space Preserve (MPWA, n.d.c. MWPA, 2022, p. 103). Similarly, the proposed Greater Ross Valley Shaded Fuel Break intersects with stands of non-native invasive species on Marin County Parks managed lands including in Ring Mountain, Alto Bowl, and King Mountain Open Space Preserves, which presents a significant opportunity to advance multi-benefit treatment approaches that will both improve biodiversity and reduce wildfire risk.

An additional opportunity is present in Terra Linda/Sleep Hollow Divide Open Space Preserve, where eucalyptus have been thinned since 2001 (MCP & MCOSD, 2015, p. 211). Eucalyptus stands in this area, which includes 30 acres on Marin County Parks land, have also been prioritized by MWPA for additional planning and active management as part of the Ridgewood Shaded Fuel due to decades of fuel accumulation, increasing tree density, and history of ignitions and wildland fire in this eucalyptus stand (MWPA, 2022 p. 139) (Figure 8.131). This area represents a unique chance to plan and implement work that will have multiple benefits including invasive plant removal, fire risk reduction, restoration, and establishment of a sustainable fuel break. The area currently dominated by eucalyptus could be restored to a combination of grassland, coastal scrub, and Open Canopy Oak Woodland habitat to increase native plant habitat and reduced fire risk (MCP & MCOSD, 2015 p. 211).

Figure 8.131. Eucalyptus stands on Marin County Parks and adjacent Town of Corte Madera lands, and associated MWPA proposed planning project boundaries.



CONCLUSION

The comprehensive analysis presented in this chapter provides a framework for identifying areas where there are opportunities to implement projects that will increase forest health and wildfire resilience at landscape scale in Marin County. Because this analysis is based on countywide spatial data, its utility as a decision-making and project development tool can be applied across Marin, both within and beyond the wildland urban interface. These spatial datasets are made available to all via the Forest Health Web Map, and can assist wildfire risk reduction efforts by the Marin Wildfire Prevention Authority (MWPA) and partner fire agencies by helping design and implement approaches that can be ecologically beneficial. As noted, many priority treatment areas identified in this chapter intersect with published MWPA work plans or priority areas identified in the 2020 Community Wildfire Protection Plan, and continued collaboration between One Tam and MWPA will ensure that cross-agency multiple benefit projects are advanced wherever possible. At the same time, the One Tam partners will continue to use this foundational analysis to advance opportunities to fundraise for, plan, develop, and implement projects and programs to address threats to forest health, increase wildfire resilience for forests and communities, and protect key ecosystem services provided by Marin's forests and woodlands.

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APPENDIX 8A: POTRERO MEADOWS FUEL MODEL CHANGES

Potrero Meadows Fuel Model Changes

Report Prepared for:

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Date: Thursday, February 16, 2023

All photos courtesy of Carol L. Rice.

Abstract

This report documents the update of fuel model assignments where recent fuel treatments have been completed in the Potrero Meadows Post-Forest Health and Fuels Reduction Demonstration Treatment Area. This update offers a way to demonstrate the benefits of work done in the six identified areas. This report details the post-treatment conditions found in those six work areas in and surrounding Potrero Meadows on Marin Municipal Water District's (Marin Water) lands. Our team conducted two separate field visits to record on-the-ground conditions. We gathered pre-treatment fuel conditions from the 2020 fuel model published by Marin County Fire and their consultant, Sonoma Technologies Inc. (STI) and associated fire behavior prediction landscape file. Based on the field visits, we altered the 2020 Fuel Model layer for the treated area. We then created a new landscape file and used fire behavior prediction software to determine likely fire characteristics. We then compare pre- and post-treatment fire behavior predictions to gauge the predicted effectiveness of each treatment type. Based on our modeling, we found that treatments dramatically improved (lowered) the predicted fire behavior in all metrics measured. Resulting flame length shifted to less than 2 feet in almost all treated locations. Rates of fire spread shifted to slower than 4 feet per minute and torching was nearly eliminated. All these indicate the value of fuel treatments.

Introduction and Methods

Marin Water serves more than 191,000 people in central and southern Marin. About 75 percent of their water supply comes from reservoirs on Mt. Tamalpais and in west Marin. One of Marin Water's top priorities is ensuring their 22,000 acres of watershed land on Mt. Tamalpais and in west Marin support healthy reservoirs and provide a clean and lasting resource for their community. Their stewardship centers on sustainable practices and responsible vegetation management that reduces invasive species, while preserving native species and natural habitats for wildlife. Guided by an extensive land management plan, they conduct numerous treatments throughout their lands (see Biodiversity Fire and Fuels Integrated Plan (BFFIP), 2019).

This report analyzes changes in predicted fire behavior from vegetation management work performed on lands surrounding Potrero Meadows in 2020. We do this by comparing on-the-ground conditions after treatment with pre-treatment conditions as they were recorded in the 2020 fuel model[1] developed by Sonoma Technology, Inc. (STI) for the Marin County Community Wildfire Protection Plan (CWPP).

Deliverables for this project include:

• New surface fuel model for the treated acres (approx. 70 acres) based on field reconnaissance, and

• Raster results of new fire behavior simulations showing changes in flame length, rate of fire spread and crown fire activity post demonstration project work, and

• This report documenting methods and results with figures, field pictures, description of methods, logic, etc.

The area analyzed in this report includes the 6 work areas as depicted in Figure 1. These areas are located on the western portion of Mount Tamalpais, south of Rocky Ridge (and Bon Tempe and Alpine Lake), and east of Bolinas Ridge. They are accessed from Ridgecrest Blvd and Rock Springs Lagunitas Rd (gated).

Table 1. Potrero Meadows work area names and sizes (by acres).

Name	Acres
Work Area 1	15.9
Work Area 2	6.9
Work Area 3	3.1
Work Area 4	18.2
Demo Area 1	14.7
Demo Area 2	10.2

In 2020, each work area received an understory treatment that included small diameter tree removal (thinning), tree limbing, removal of sudden oak death (SOD) impacted tanoak, targeted mastication, and scattering and/or piling of generated debris. Treatment types are discussed in Marin Water's BFFIP and were also described during a field visit with

[1] Fuel Model: A stylized set of fuel bed characteristics used as input for a variety of predictive wildfire modeling applications.

the Marin Wildfire Prevention Authority (MWPA), the Golden Gate National Parks Conservancy, and One Tam agency partners natural resource staff on June 30, 2021.

Details for each type of treatment conducted in each work area are discussed in the Field Notes section of this document.

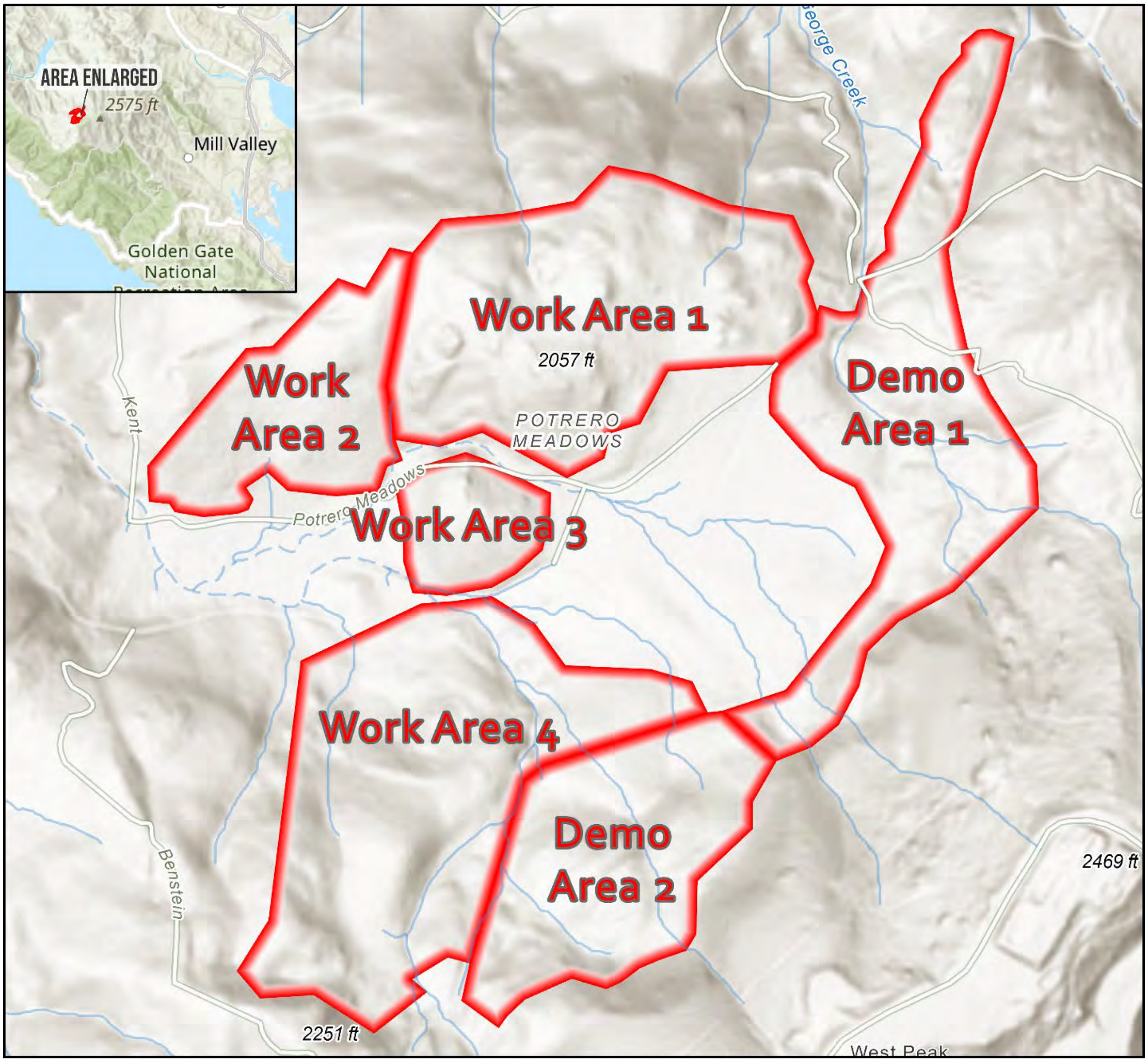

Figure 1. Location of Potrero Meadows work areas analyzed in this report.

Field Notes by Work Area

We conducted two field visits in the work areas of Potrero Meadows. Our first visit was on August 17th, 2021, and the second was November 3rd, 2021. Our aim during these site visits was to determine existing fuel characteristics and the corresponding fuel model(s) for each work area.

During the visits, we recorded our location, acquired photos, evaluated the accuracy of the 2020 pre-treatment fuel model, and assigned a post-treatment fuel model based on our assessment of how Marin Water's forestry work altered the fuel structure based on our observations. Each area we visited was given a field point number. We have organized this section by work area and then by field point number.

Work Area 1

Work Area 1 is north of Potrero Meadows. It includes stands of Douglas fir mixed with madrone and California bay as well as mixed stands of canyon live oak. There is also a small stand of madrone along the south-facing flank adjacent to Potrero Meadow.

The treatment on this site concentrated on hand-removal of understory saplings and select shrub material such as manzanita and diseased tanoak. Many hand piles were left on-site for later burning.

Figure 2. Aerial map of Work Area 1.

Work Area 1 – CID 1 (Field Point 12)

Figure 3. Field point #12 visited on 11/03/2021.

DATA SHEET

ID:	**Work Area 1 CID 1**		Elevation:	**629.372 m**	Slope:	**0%**	Azimuth: **300 deg**
	Latitude: **37.926911**	Longitude:	**-122.607579**		Date:	**11/3/2021**	

Area Description:

Overstory: Canyon live oak (with black acorns!), bay laurel, and madrone. Spacing between trees is 35 to 50 feet with clumps of mature madrone. There is one 8" diameter Douglas fir in vicinity of transect.

Understory: Diverse and numerous ground cover with lots of bay nuts, madrone seeds, and black acorns. Very productive site. Tree lichen is up to 3" on tree boles. Ground cover includes Douglas iris and snowberry.

Fuel Loading Description:

Best match is found in PNW 105 2-HD-2 (page 32 of https://www.fs.fed.us/pnw/pubs/pnw_gtr105.pdf).

Some logs next to base of madrones in piles of 10 logs or more each would cause localized high fire intensity. Logs are 6 feet long and arranged parallel to each other (to aid in decomposition?). Litter is closely compacted with most small sticks in piles (fuel has been moved into piles). Duff depth is much lower (compared to other transects) for a total of about 4" in total with 1-2" added from treatment.

Average Canopy Cover:	**73**	(percent)	STI FM:	**TL9**
Average Canopy Base Height:	**34**	feet	Current FM:	**TL2 with piles**

Expected Fire Behavior and Suppression Difficulty:

Expected rate of spread should be low along with a low flame length with low resistance to control. Likelihood of torching is also low except where piles are located. Fire behavior will be intense at piles but affects will be localized. Arranged piles will cause severe increase to residence time. Ideal conditions for prescribed fire in winter when it will be easy to control (area bounded by meadow and road).

Work Area 1 – CID 2 (Field Point 13)

Figure 4. Field point #13 visited on 11/03/2021.

DATA SHEET

ID: **Work Area 1 CID 2** Elevation: **636.796 m** Slope: **10%** Azimuth: **155**

Latitude: **37.926923** Longitude: **-122.608824** Date: **11/3/2021**

Area Description:

Overstory: Canopy cover is high and dense; 50% canyon live oak and 50% Douglas fir. Douglas fir is now over-topping the mature canyon live oak. Canopy did not get reduced with treatment - should create range of canopy density with gaps in canopy cover.

Understory: Found Douglas iris and moss-covered rocks. With some bunchgrasses. Meadow is trying to expand into hardwood stand (or hardwood stand has encroached into meadow). There is some young canopy live oak and bay laurel. Young canyon live oak is on edge of meadow (should be removed in order to expand meadow extent).

Fuel Loading Description:

Fewer big logs along this transect but does have piles of fines (fuels moved to piles at edge of meadow, 10' from oak canopy). Leaf litter will still carry a fire.

Best match is found in PNW 105 2-HD-2 (page 32 of https://www.fs.fed.us/pnw/pubs/pnw_gtr105.pdf).

Average Canopy Cover: **92** (percent) STI FM: **TL9**

Average Canopy Base Height: **13** feet Current FM: **TL2 with piles**

Expected Fire Behavior and Suppression Difficulty:

Because of low fuel load and flat terrain, expected rate of spread should be low along with a low flame length with low resistance to control. Likelihood of torching is also low. Pockets of intense fire behavior can be expected on/around piles. Be sure to not place piles under tree canopy or base of trees. A fire through here would *not* kill trees (to restore meadow and open overstory) due to low volume of fuels and compactness of fuels.

Work Area 1 – CID 2 (Field Point 14)

Figure 5. Field point #14 visited on 11/03/2021.

DATA SHEET

ID:	**Work Area 1 CID 3**			Elevation:	**639.114 m**	Slope:	**0%**	Azimuth:	**0**
	Latitude:	**37.926673**	Longitude:	**-122.609876**		Date:	**11/3/2021**		

Area Description:

Overstory: 70% Douglas fir (12 - 24" dbh) and 30% canyon live oak (mature and over 8" dbh). A few young bay laurels.

Understory: Occasional tanoak, patches of grass. Previously, there had been manzanita.

Fuel Loading Description:

Fuels have been re-arranged, but not placed in piles. Finer fuels have been scattered with some accumulations of 1-3 inches fuel classes up to 1' in height.

Best match is found in PNW 105 2-HD-2 (page 32 of https://www.fs.fed.us/pnw/pubs/pnw_gtr105.pdf) but with greater volume.

Average Canopy Cover:	**60**	(percent)	STI FM:	**TL6**
Average Canopy Base Height:	**13**	feet	Current FM:	**TL4**

Expected Fire Behavior and Suppression Difficulty:

Expected rate of spread should be low along with a low flame length (up to 4') with moderate resistance to control. Likelihood of torching is also low with pockets of greater intensity because of greater fuel volume where fuel bed depth is 1ft high (versus 6" in depth for CID 1 & 2 in this work area).

Work Area 2

Figure 6. Aerial map of Work Area 2.

Work Area 2 is north of Potrero Meadows and west of Work Area 1. It includes a stand of Douglas fir mixed with madrone and California bay with a substantial number of dead standing boles. In addition, there is a canyon live oak stand that extends into this work area from the adjacent work area in the canyon live oak stand, which has a shrubby understory.

The treatment on this site concentrated on hand-removal of understory saplings and shrub material such as manzanita and SOD impacted tanoak. Many hand piles were left on-site for later burning.

Work Area 2 – CID 1 (Field Point 6)

Figure 7. Field point #6 visited on 08/17/2021.

DATA SHEET							
ID:	**Work Area 2 CID 1**	Elevation:	**610.287 m**	Slope:	**10%**	Azimuth:	**40 deg**
	Latitude: **37.925743**	Longitude:	**-122.611443**	Date:	**8/17/2021**		

Area Description:

Overstory:

Canyon live oak overstory with occasional big madrones. 20% of overstory trees are dead, so snags remaining.

Understory:

Lots of tanoak sprouts. No other herbs/forbs. Off of transect, there is some perennial grass and thistle.

Fuel Loading Description:

Lots of elevated fine fuels from branches with a mix of size classes. The largest logs are 12" in diameter. Fuels consist of a mix of chips, bark, oak leaves, and twigs. Coarse fuels (size class 10 to 100 hr fuels) exist in 6" deep pockets throughout the treatment areas.

Best match is found in PNW 105 4-DFHD-4 (page 24 of https://www.fs.fed.us/pnw/pubs/pnw_gtr105.pdf) with less live fuel (though it will be more in 5 years). Total T/A = 13.7.

Average Canopy Cover:	**49**	(percent)	STI FM:	**TL9**
Average Canopy Base Height:	**9**	feet	Current FM:	**TL6 or TL4**

Expected Fire Behavior and Suppression Difficulty:

Expected rate of spread should be low moderate along with moderate flame lengths with some resistance to control. Likelihood of torching is also moderate or high, especially where piles are located. Create much better piles! The scattered fine fuels will increase rate of spread and flame lengths. Snags will burn hot and vertically. Expect 4' flame lengths and greater along transect, though flame length will be lower in open areas. Residence time is a concern, especially in 4" depth of 10 to 100 hr fuels.

Work Area 2 – CID 2 (Field Point 7)

Figure 8. Field point #7 visited on 08/17/2021.

DATA SHEET

ID: **Work Area 2 CID 2** Elevation: **626.844 m** Slope: **5%** Azimuth:
Latitude: **37.926475** Longitude: **-122.611426** Date: **8/17/2021**

Area Description:

Overstory: Large canyon live oak, also near transect is a mix of Douglas fir and canyon live oak. Roughly 50% DF/CLO. Manzanita in openings. However, treatment did not create additional openings in canopy cover.

Understory: Piles are common. Nothing living on ground. Away from transect in openings, there is some fern and tanoak sprouts.

Manzanita creates lots of little stems/acre.

Fuel Loading Description:

In this area, oak leaf litter will carry the fire. Piles will increase intensity dramatically in pockets.

Best match is found in PNW 105 1-HD-2 (page 30 of https://www.fs.fed.us/pnw/pubs/pnw_gtr105.pdf) with the addition of piles. Total T/A = 2.4 (plus the piles).

Average Canopy Cover:	**77**	(percent)	STI FM:	**TL9**
Average Canopy Base Height:	**13**	feet	Current FM:	**TL2 with piles**

Expected Fire Behavior and Suppression Difficulty:

Expected rate of spread should be low along with a low flame length with low resistance to control. Likelihood of torching is also low except where piles are located. A forest fire at this location may not burn into nearby chaparral. However, there may be soil damage from the numerous piles. Oak leaf litter will carry the fire into larger material.

Work Area 3

Work Area 3 is in between Work Area 1 and Work Area 4, west of Potrero Meadows. It encompasses a stand of Canyon live oak on a small knoll.

The treatment on this site concentrated on hand-removal of understory saplings and shrub material such as manzanita and SOD impacted tanoak. Many hand piles were left on-site for later burning.

From field observations, fuel characteristics were similar to Field Points #12 and #13 in Work Area 1.

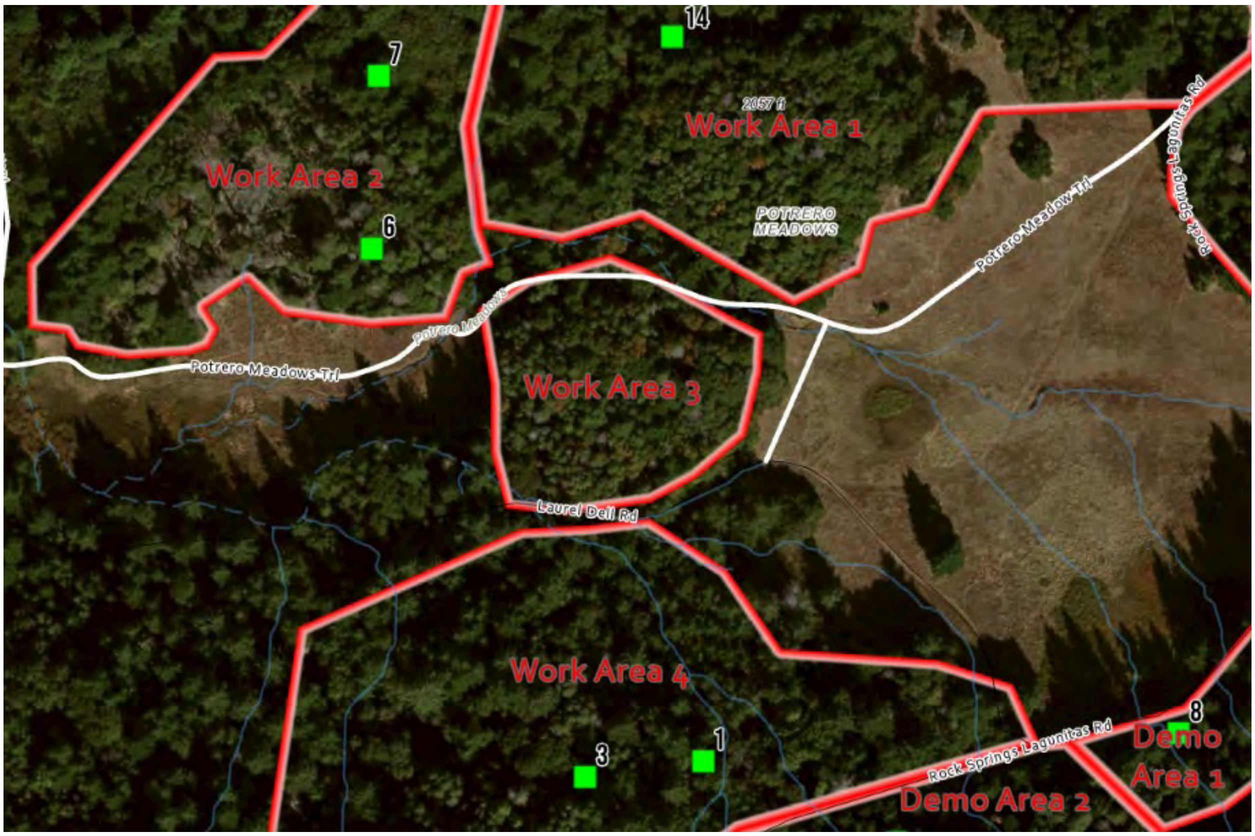

Figure 9. Aerial map of Work Area 3.

No photo points were established in Work Area 3.

Work Area 4

Work Area 4 is southwest of Potrero Meadows. It includes stands of Douglas fir mixed with madrone and California bay as well as mixed stands of canyon live oak.

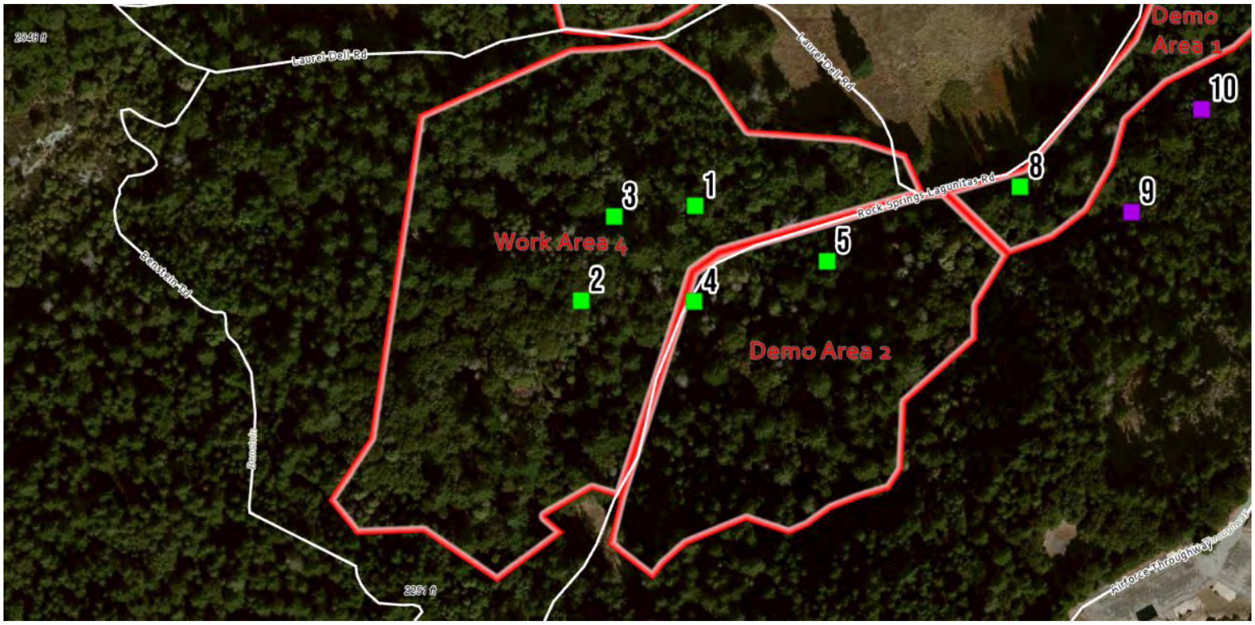

Figure 10. Aerial map of Work Area 4.

The treatment on this site consisted of mastication plus intentional placement of logs as erosion control features and for habitat enhancement. Widely spaced burn piles were constructed by hand and left on-site for later burning.

Work Area 4 – CID1 (Field Point 1)

Figure 11. Field point #1 visited on 08/17/2021.

DATA SHEET

ID:	**Work Area 4 CID 1**	Elevation:	**630.394**	Slope:	**28%**	Azimuth:	**162 deg**
Latitude:	**37.923606**	Longitude:	**-122.609608**	Date:	**8/17/2021**		

Area Description:

Overstory: Douglas fir and California bay

Understory: Mostly canyon live oak with some madrone, snowberry, *carex* and some tanoak sprouts. Mostly litter. 80% dead debris, 20% live material. Sprouts are less than 1' in height.

Fuel Loading Description:

Variable depth of debris, from 1" up to 6" in depressions. Lots of stacked 100hr+ wood.

Currently, best match is found in PNW 105 2-DFHD-3 (page 12 of https://www.fs.fed.us/pnw/pubs/pnw_gtr105.pdf). Total T/A = 10.1 (could be less). In 5 years time, when understory grows, 3-DFHD-3 might be a better fit.

Average Canopy Cover:	**85**	(percent)	STI FM:	**TL9**
Average Canopy Base Height:	**21**	feet	Current FM:	**TL3**

Expected Fire Behavior and Suppression Difficulty:

Expected rate of spread should be low along with a low flame length with a moderate resistance to control. Likelihood of torching is also low except where piles are located. While low flame lengths are expected, there may be high burn severity because of long residence time due to chips. Logs placed next to base of trees will cause damage to overstory trees on uphill side. Logs will increase suppression difficulty. Okay to prescribe burn in winter. Consider feeding the fire rather pre-stack piles.

Work Area 4 – CID 2 (Field Point 2)

Figure 12. Field point #2 visited on 08/17/2021. Photo courtesy of Carol L. Rice.

DATA SHEET

ID:	**Work Area 4 CID 2**		Elevation:	**647.435 m**	Slope:	**12%**	Azimuth: **240 deg**
	Latitude: **37.923008**	Longitude:	**-122.610497**		Date:	**8/17/2021**	

Area Description:

Overstory: Mostly California bay and madrone, only 1 Douglas fir in the immediate vicinity.

Understory: Sprouting tanoak, possible different pre-treatment vegetation type, there used to be a lot more tanoak.

Treatment changed canopy cover and took out tanoak midstory (dead and dying too). This was a hardwood stand with canyon live oak.

Fuel Loading Description:

Madrone leaf litter will carry the fire. Duff depth around 1". Very few large logs, what logs are on site are about 3-6" maximum dbh.

Best match is found in PNW 105 1-DFHD-3 (page 10 of https://www.fs.fed.us/pnw/pubs/pnw_gtr105.pdf). Total T/A = 3.3.

Average Canopy Cover:	**76**	(percent)	STI FM:	**TL9**
Average Canopy Base Height:	**71**	feet	Current FM:	**TL2**

Expected Fire Behavior and Suppression Difficulty:

Expected rate of spread should be low along with a low flame length with low resistance to control. Likelihood of torching is also low. Okay to prescribe burn now. In 5 years time, tanoak sprouts may limit ability to burn. If sprouts increase over 3', may cause torching, but could also be a heat sink. Possibly in 10 years time, the tanoak will become a dead ladder fuel.

Work Area 4 – CID 3 (Field Point 3)

Figure 13. Field point #3 visited on 08/17/2021.

DATA SHEET

ID:	**Work Area 4 CID 3**		Elevation:	**633.778 m**	Slope:	**5%**	Azimuth:	**76 deg**
	Latitude: **37.923533**	Longitude:	**-122.610252**		Date:	**8/17/2021**		

Area Description:

Overstory: 100 % Canyon Live Oak

Understory: Vaccinium sprouts in openings, 80m canopy live oak and tanoak. Understory is less than 10% of total area.

Fuel Loading Description:

Best match is found in PNW 105 2-HD-2 (page 32 of https://www.fs.fed.us/pnw/pubs/pnw_gtr105.pdf). Total T/A = 8.0.

Average Canopy Cover:	**81**	(percent)	STI FM:	**TL6**
Average Canopy Base Height:	**50**	feet	Current FM:	**TL2 or TL6**

Expected Fire Behavior and Suppression Difficulty:

Expected rate of spread should be low along with a low flame length with low resistance to control. Likelihood of torching is also low. Duff depth is less than 1" (inches). Much less T/A than total in photo series.

Demo Area 1

Demo Area 1 is east and south of Potrero Meadows. It includes stands of Douglas fir mixed with madrone and California bay as well as mixed stands of Canyon live oak. Two field point (numbers 9 and 10) were incorrectly located outside the treatment areas. However, we include the data from these field points here to illustrate pre-work conditions.

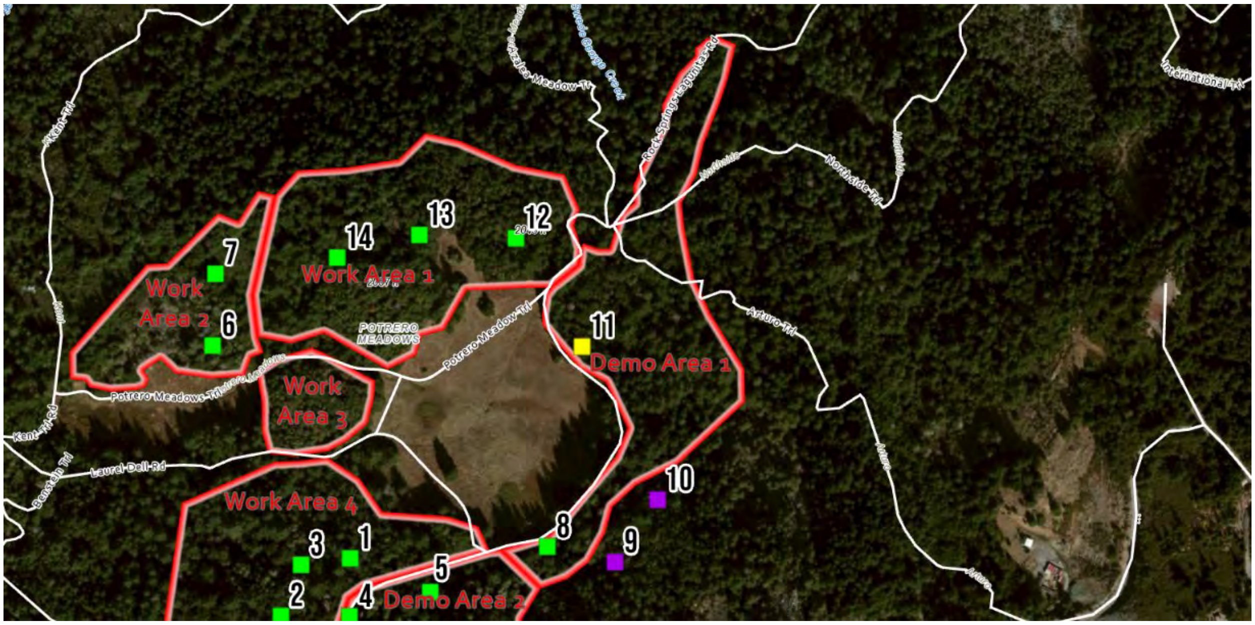

Figure 14. Aerial map of Demo Area 1.

As in Work Area 4, the area was treated with a mechanical masticator to remove small diameter trees and shrubs such as manzanita and diseased tanoak, combined with hand crews limbing lower branches of trees. However, few, if any, hand piles were left on-site for later burning.

Demo Area 1 – CID 1 (Field Point 8)

Figure 15. Field point #8 visited on 11/03/2021.

DATA SHEET

ID:	**Demo Area 1 CID 1**		Elevation:	**637.257**	Slope:	**20%**	Azimuth:	**90 deg**
Latitude:	**37.92377**	Longitude:	**-122.607073**		Date:	**11/3/2021**		

Area Description:

Overstory: Douglas fir in overstory with canyon live oak in midstory, 24-30" dbh

Understory: None. Tough getting through litter. Some bay laurel, tan oak, and canopy live oak seedlings about 1' tall.

Fuel Loading Description:

Suggest a broadcast burn in winter to expand meadow on east side of fire trail.

Best match is found in PNW 105 3-DFHD-4 (page 22 of https://www.fs.fed.us/pnw/pubs/pnw_gtr105.pdf).
Total T/A = 12.9

Average Canopy Cover:	**30**	(percent)	STI FM:	**TL9**
Average Canopy Base Height:	**41**	feet	Current FM:	**TL4**

Expected Fire Behavior and Suppression Difficulty:
Expected rate of spread should be low along with a low flame length with some resistance to control. Likelihood of torching is also low. Duff depth is 6" to 1 ft. Logs on ground up to 6-8" in diameter and up to 4' long. While flame length expected to be low but burn severity would be high due to long residence time. No logs against tree bases. Piles in unit to north of transect line. Piles are constructed with heavy 3' tall and 6" diameter material. Would not pose a bad situation in terms of resistance to control but line building could be a challenge.

Demo Area 1 – CID 2 (Field Point 9)

Figure 16. Field point #9 visited on 11/03/2021.

DATA SHEET

ID:	**Demo Area 1 CID 2**	Elevation:	**664.329 m**	Slope:	**30%**	Azimuth:	**20 deg**
Latitude:	**37.923628**	Longitude:	**-122.606195**	Date:	**11/3/2021**		

Area Description:

Overstory: Douglas fir and canyon live oak mixture with some madrone. 80% canopy cover in total; 50% Douglas fir and 50% hardwoods.

Understory: Tanoak sprouts and seedlings, cover is 50 to 80% tanoak live sprouts. No other species. Midstory is dead tanoak about 20' tall.

Fuel Loading Description:

Not as much dead, abundant live fuel, Douglas fir the dominant species. Tanoak understory create abundant ladder fuels.

Best match is found in PNW 105 2-DFHD-4 (page 20 of https://www.fs.fed.us/pnw/pubs/pnw_gtr105.pdf).
Total T/A = 6.4 (dead)

Average Canopy Cover:	**86**	(percent)	STI FM:	**TL9**
Average Canopy Base Height:	**8**	feet	Current FM:	**TU5**

Expected Fire Behavior and Suppression Difficulty:
Expected rate of spread could be high with relatively high flame length. Resistance to control could be moderate to high. Likelihood of torching is low. Steepness of slope and continuous fuels will create long (tall) flame lengths. However, the separation between tanoak and tree crowns of the upper trees would create a buffer and torching is not expected. Rate of spread would be fairly fast with less than obvious tree mortality. Dead tanoak in midstory will advance fire and increase flame length. Resistance to control is increased due to shrubs, and steep slope. Okay for mechanical control.

Demo Area 1 – CID 3 (Field Point 10)

Figure 17. Field point #10 visited on 11/03/2021.

DATA SHEET

ID:	**Demo Area 1 CID 3**		Elevation:	**665.693**	Slope:	**45%**	Azimuth: **180 deg**
	Latitude: **37.924274**	Longitude:	**-122.605666**		Date:	**11/3/2021**	

Area Description:

Overstory:

Canyon live oak with only scattered Douglas fir. Estimated 80 to 100% canopy cover.

Understory:

Only 1 Douglas fir seedling in vicinity of transect line. Lichen/fern could cause fire to creep up tree boles. Lichen is up to 2-3" long.

Fuel Loading Description:

Leaf litter will carry the fire, some logs 1 to 3" long, but not significant.

Best match is found in PNW 105 1-HD-2 (page 30 of https://www.fs.fed.us/pnw/pubs/pnw_gtr105.pdf).
Total T/A = 2.4 (dead)

Average Canopy Cover:	**90**	(percent)	STI FM:	**TL9**
Average Canopy Base Height:	**18**	feet	Current FM:	**TL2**

Expected Fire Behavior and Suppression Difficulty:

Expected rate of spread should be low along with a low flame length with a moderate resistance to control. Likelihood of torching is also low. Resistance to control is low due to low amounts of fuel. However, steep slope makes the resistance to control a bit higher.

Demo Area 1 – CID 4 (Field Point 11)

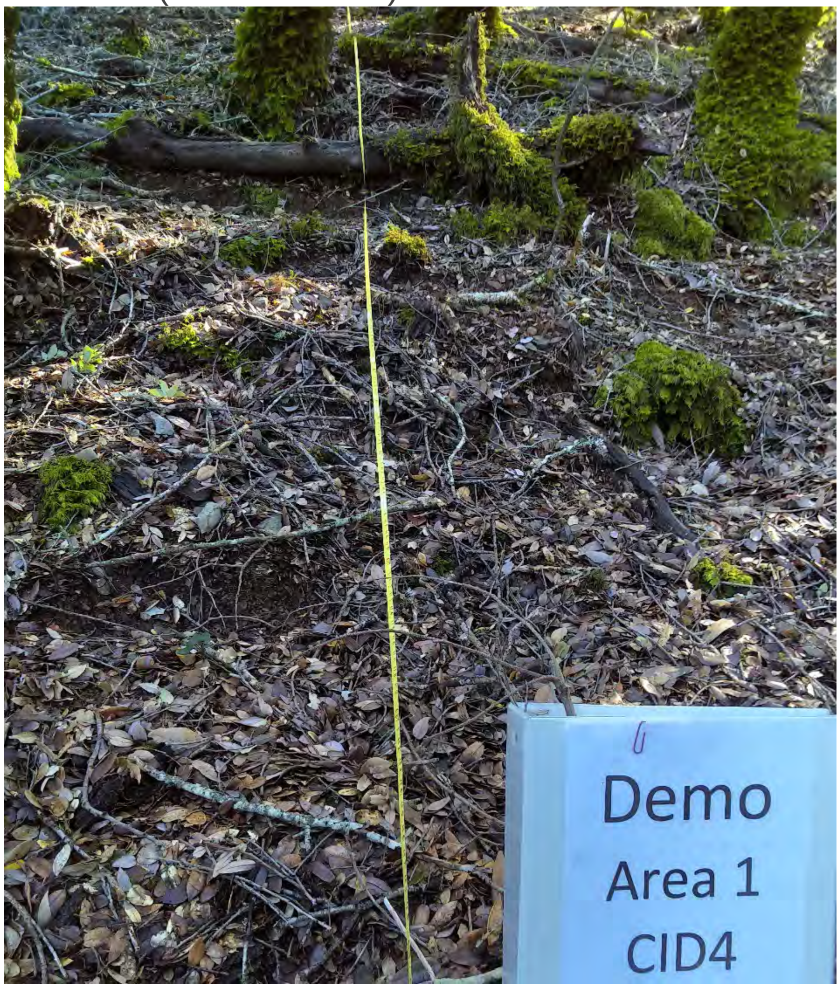

Figure 18. Field point #11 visited on 11/03/2021.

DATA SHEET							
ID:	**Demo Area 1 CID 4**		Elevation:	**625.708 m**	Slope:		Azimuth:
Latitude:	**37.925818**	Longitude:	**-122.607566**		Date:	**11/3/2021**	

Area Description:

Overstory:

No data collected

Understory:

Fuel Loading Description:

Average Canopy Cover:	(percent)	STI FM:	**TL9**
Average Canopy Base Height:	feet	Current FM:	**TL2**

Expected Fire Behavior and Suppression Difficulty:

Expected rate of spread should be low along with a low flame length with low resistance to control. Likelihood of torching is also low.

Demo Area 2

Demo Area 2 is south of Potrero Meadows. It includes stands of Douglas fir mixed with madrone and California bay as well as mixed stands of Canyon live oak.

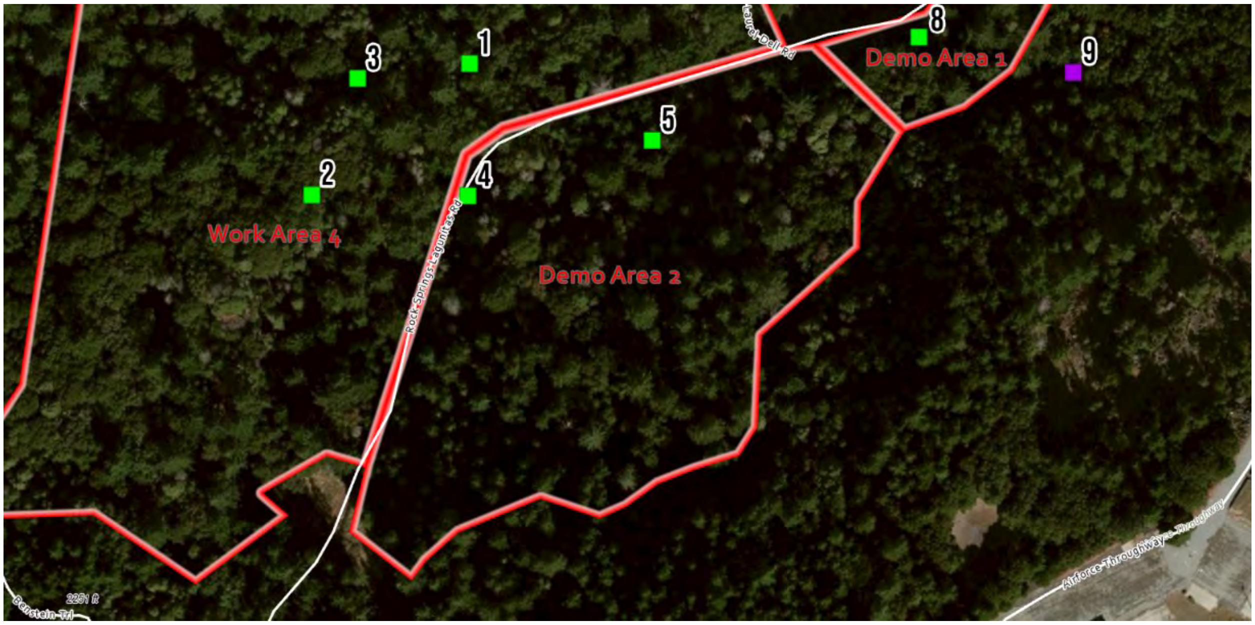

Figure 19. Aerial map of Demo Area 2.

Demo Area 2 was treated with a combination of masticator and hand crews to thin trees and shrubs such as manzanita and SOD impacted tanoak, and to limb lower tree branches. Logs were intentionally placed to provide for habitat, and infrequent, widely spaced piles were left on-site for later burning.

Demo Area 2 – CID 1 (Field Point 4)

DATA SHEET								
ID:	**Demo Area 2 CID 1**		Elevation:	**640.859 m**	Slope:	**20%**	Azimuth:	**90 deg**
	Latitude: **37.923019**	Longitude:	**-122.609614**		Date:	**8/17/2021**		

Area Description:

Overstory: Mostly bay laurel with some large canyon live oak. Patches of Vaccinium (huckleberry).

Understory: Mostly woody debris, but some sprouting tan oak and canyon live oak. 15% vegetative cover in understory.

Fuel Loading Description:

Duff depth is patchy, but deeper than other transects with an average of 4" duff depth. Lots of 100 hr fuels plus leaf litter. Many large rotten logs that are 10" or more in diameter.

Best match is found in PNW 105 4-DFHD-4 (page 24 of https://www.fs.fed.us/pnw/pubs/pnw_gtr105.pdf) without live fuel component. Total T/A = 13.7.

Average Canopy Cover:	**30**	(percent)	STI FM:	**GR4**
Average Canopy Base Height:	**49**	feet	Current FM:	**TL4**

Expected Fire Behavior and Suppression Difficulty:

Expected rate of spread should be low to moderate along with a low to moderate flame length with a low resistance to control. Likelihood of torching is also low. Long residence time due to churned up 1hr to 1000hr fuels (mixed with soil). Jackpot fuels will increase flame length and rate of spread.

Demo Area 2 – CID 2 (Field Point 5)

DATA SHEET							
ID:	**Demo Area 2 CID 2**		Elevation:	**641.966 m**	Slope:	**5%**	Azimuth: **213 deg**
	Latitude: **37.923286**	Longitude:	**-122.60858**		Date:	**8/17/2021**	

Area Description:

Overstory: Douglas fir

Understory: Very little in the understory. Lots of litter and debris, some grass near road and bay seedlings less than 6" in height.

Fuel Loading Description:

Lots of heavy fuels in the 10 to 100 hr size class. Logs that are less than 10" in diameter are sound. Even proportional 100 hr and 1000 hr fuels with just enough 1 hr fuels to ignite it.

Best match is found in PNW 105 2-DFHD-3 (page 12 of https://www.fs.fed.us/pnw/pubs/pnw_gtr105.pdf). Total T/A = 10.1 but with more 100 hr and 1000 hr fuels.

Average Canopy Cover:	**82**	(percent)	STI FM:	**TL9**
Average Canopy Base Height:	**67**	feet	Current FM:	**TL4**

Expected Fire Behavior and Suppression Difficulty:

Expected rate of spread is low with less than 2' flame lengths on all treatment areas. However, long residence time due to 10 hr and 100 hr and 1000 hr fuels. Definitely enough Douglas fir twigs to ignite larger diameter material. Resistance to control is moderate with the likelihood of torching is low.

Changes to Fuel Models

Based on the data gathered during our field visit, we changed the fuel model assignments within the work areas as outlined in the table below. We also increased the height of the canopy base height, as that was an observable difference from untreated areas. However, the observed canopy cover did not seem to change enough to warrant changing the canopy cover layer of the landscape file provided by STI.

photo pt	work location	field visit date	latitude	longitude	elevation	aspect	slope of transect (percent)
1	Work Area 4	8/17/2021	37.923606	-122.609608	630.394	NE	28%
2	Work Area 4	8/17/2021	37.923003	-122.610484	647.435	NE	12%
3	Work Area 4	8/17/2021	37.923528	-122.610239	633.778	NW	5%
4	Demo Area 2	8/17/2021	37.923014	-122.609601	640.859	N	20%
5	Demo Area 2	8/17/2021	37.923281	-122.608567	641.966	NE	5%
6	Work Area 2	8/17/2021	37.925743	-122.611443	610.287	S	10%
7	Work Area 2	8/17/2021	37.926475	-122.611426	626.844	SW	5%
8	Demo Area 1	11/3/2021	37.92377	-122.607073	637.257	NW	20%
9	**(out)**	11/3/2021	37.923628	-122.606195	664.399	NW	30%
10	**(out)**	11/3/2021	37.924274	-122.605666	665.693	N	45%
11	Demo Area 1	11/3/2021	37.925818	-122.606683	625.708	NW	n/a
12	Work Area 1	11/3/2021	37.926906	-122.607566	629.372	E	0%
13	Work Area 1	11/3/2021	37.926918	-122.608811	636.796	S	10%
14	Work Area 1	11/3/2021	37.926668	-122.609863	639.114	SE	0%

photo pt	STI fuel model	observed fuel model	STI canopy cover	observed canopy cover	STI crown base height (m)	observed crown base height (m)	observed ground fuel load (t/a)
1	TL9	TL3	90%	85%	3.0	6.4	10.1
2	TL9	TL2	91%	76%	3.0	21.6	3.3
3	TL6	TL2	88%	81%	3.0	15.2	8.0
4	GR4	TL4	39%	30%	3.0	14.9	13.7
5	TL9	TL4	94%	82%	3.0	20.4	10.1
6	TL9	TL4	91%	49%	2.1	2.7	13.7
7	TL9	TL2 with piles	88%	77%	2.1	4.0	2.4
8	TL9	TL4	92%	30%	3.0	12.5	12.9
9	TL9	TU5	92%	86%	3.0	2.4	6.4
10	TL9	TL2	85%	90%	2.1	5.5	2.4
11	TL9	TL2	76%	n/a	3.0	n/a	n/a
12	TL9	TL2 with piles	76%	73%	3.0	10.4	8.0
13	TL9	TL2 with piles	83%	92%	2.1	4.0	8.0
14	TL6	TL2 with piles	90%	60%	2.1	4.0	8.0

Point points 1, 4, 5, 6, and 8 were in a Douglas fir – Tanoak – Madrone Alliance with the remainder in canyon live oak.

Pre-Treatment Fuel Model

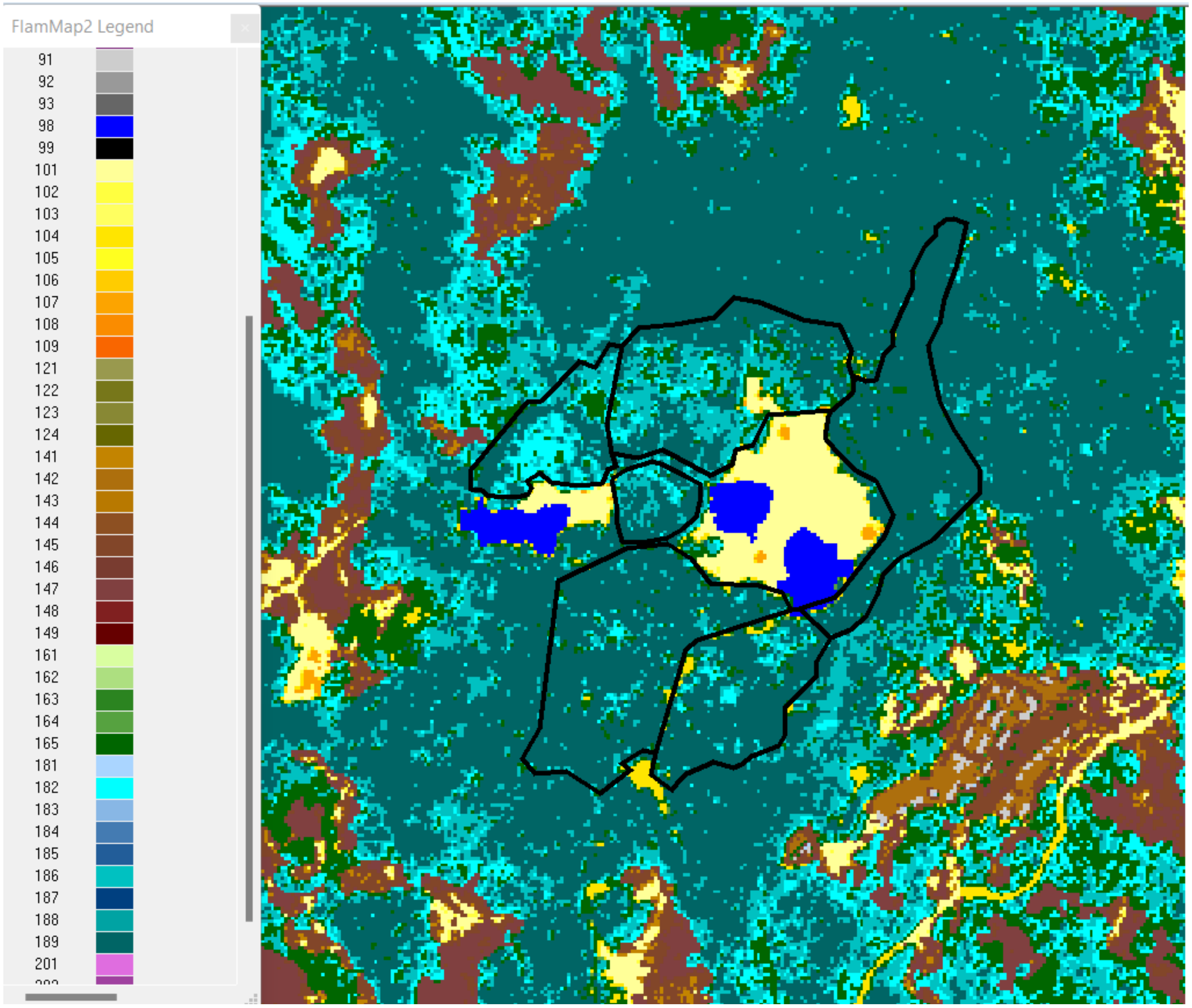

Figure 20. Fuel model assignments for the area within and surrounding Potrero Meadows (STI, 2020).

The map above shows the pre-treatment fuel model assignments.

Table 2. Acres table of pre-treatment fuel models within the Potrero work areas (STI, 2020).

Fuel Model	Description	Acres	Percent
98	NB8 Open Water	0.1	0.2%
101	GR1 Short, Sparse Dry Climate Grass	0.4	0.6%
102	GR2 Low Load, Dry Climate Grass	0.02	0.03%
104	GR4 Moderate Load, Dry Climate Grass	0.5	0.8%
107	GR7 High Load, Dry Climate Grass	0.05	0.1%
164	TU4 Dwarf Conifer with Understory	0.1	0.1%
165	TU5 Very High Load, Dry Climate Timber-Shrub	5.1	7.4%
182	TL2 Low Load Broadleaf Litter	4.2	6.1%
186	TL6 Moderate Load Broadleaf Litter	11.0	15.9%
189	TL9 Very High Load Broadleaf Litter	47.6	68.8%

Post-Treatment Fuel Model

The pretreatment 2020 fuel model was adjusted to reflect post treatment conditions using a set of decision rules. Canopy base heights were also updated to reflect post-treatment conditions. The rules are as follows.

- For areas with conifer as the dominate tree species:
  - Set post treatment Fuel Model = 184 (TL4) IF 2020 Fuel Model = (189) (TL9)
  - Set post treatment Fuel Model = 161 (TU1) IF 2020 Fuel Model = (165) (TU5)
  - Set post treatment Canopy Base Height = 37 (feet) (average of conifer-based photo points)
- For areas with hardwood as the dominate tree species:
  - Set post treatment Fuel Model = 182 (TL2) IF 2020 Fuel Model = (189) (TL9)
  - Set post treatment Fuel Model = 161 (TU1) IF 2020 Fuel Model = (165) (TU5)
  - Set post treatment Canopy Base Height = 28 (feet) (average of hardwood-based photo points)

Rule	Target Theme	Rule Description	Test Rule	Apply Rule	Delete Rule
1	Fuel Model	Set Fuel Model = 184 IF Fuel Model = (189) AND Landscape intersects Potrero_Work_Areas AND Landscape intersects Conifer	Test	Apply	Delete
2	Fuel Model	Set Fuel Model = 161 IF Fuel Model = (165) AND Landscape intersects Potrero_Work_Areas	Test	Apply	Delete
3	Fuel Model	Set Fuel Model = 182 IF Fuel Model = (189) AND Landscape intersects Potrero_Work_Areas AND Landscape intersects Hardwood	Test	Apply	Delete
4	Canopy Base Height	Set Canopy Base Height = 37 IF Landscape intersects Potrero_Work_Areas AND Landscape intersects Conifer	Test	Apply	Delete
5	Canopy Base Height	Set Canopy Base Height = 28 IF Landscape intersects Potrero_Work_Areas AND Landscape intersects Hardwood	Test	Apply	Delete

Figure 21. Rule set to change landscape to reflect post-treatment conditions.

Note the piles observed in the field would affect overall fire behavior and burn severity. However, burn piles are not represented in the fire behavior prediction software. Additionally, the five-meter resolution of the fuel model mapping does not capture the piles, since all piles are smaller than five meters. Lastly, the piles are intended to be ephemeral, with no anticipated long-term impact to fuel characteristics.

Table 3. Acres table of post-treatment fuel models within the Potrero work areas (DMS, 2022).

Fuel Model	Description	Acres	Percent
98	NB8 Open Water	0.1	0.2%
101	GR1 Short, Sparse Dry Climate Grass	0.4	0.6%
102	GR2 Low Load, Dry Climate Grass	0.02	0.03%
104	GR4 Moderate Load, Dry Climate Grass	0.5	0.8%
107	GR7 High Load, Dry Climate Grass	0.05	0.1%
161	TU1 Low Load Dry Climate Timber-Grass-Shrub	5.1	7.3%
164	TU4 Dwarf Conifer with Understory	0.1	0.1%
165	TU5 Very High Load, Dry Climate Timber-Shrub	0.05	0.1%
182	TL2 Low Load Broadleaf Litter	19.3	28.0%
184	TL4 Small downed logs	32.1	46.4%
186	TL6 Moderate Load Broadleaf Litter	11.0	15.9%
189	TL9 Very High Load Broadleaf Litter	0.4	0.5%

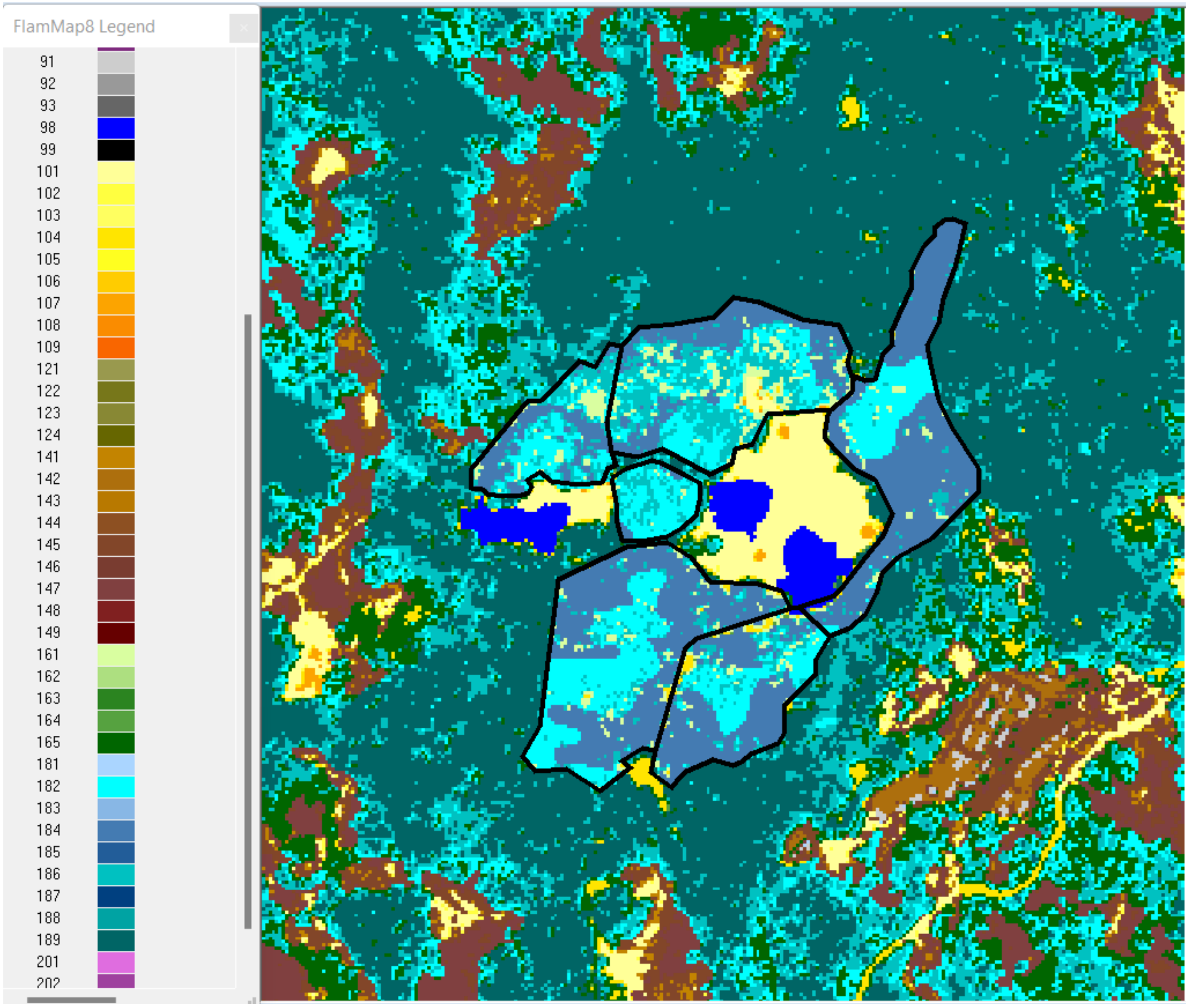

Figure 22. Fuel model assignment changes for the area within Potrero Meadows (DMS, 2022).

The largest difference is in the amount of TL9 (189) which went from 48 acres to less than half an acre, most of which was converted to TL4 (184) or TL2 (182). TU5 (165) also saw a significant decrease from 5 acres to less than a fraction of an acre, all of which was converted to TU1 (161).

Fire Behavior Prediction Comparison

Fire behavior prediction software was used to gauge the difference in expected fire behavior characteristics for both pre- and post-treatment fuel conditions. Several fire behavior prediction software applications have been developed by the U.S. Forest Service. These include a wide variety of applications designed to specifically meet firefighting or fire prevention needs. For this analysis, we used FlamMap version 6.1.

FlamMap is a fire behavior mapping and analysis program that computes potential fire behavior characteristics (spread rate, flame length, fireline intensity, etc.). The FlamMap fire mapping and analysis system calculates fire behavior for each pixel within the landscape file independently. It is designed for use by users familiar with fuels, weather, topography, wildfire situations and the associated terminology. Outputs are well-suited for landscape level comparisons of fuel treatment effectiveness because fuel is the only variable that changes. Outputs and comparisons can be used to identify combinations of hazardous fuel and topography, aiding in prioritizing fuel treatments[2].

Inputs

A standard fuel moisture regime was chosen for both scenarios. This includes using statewide parameters developed by CAL FIRE for fire predictions based on worst-case conditions augmented by local weather station analysis.

Table 4. Fuel moistures used for fire behavior predications.

Fuel Model	1hr time lag class	10hr time lag class	100 hr time lag class	Live herbaceous fuel moisture	Live woody fuel moisture
All models	4	5	10	40	60

The inputs into the FlamMap scenarios, both for the pre- and post-treatment landscapes, are summarized in the figures on the next page.

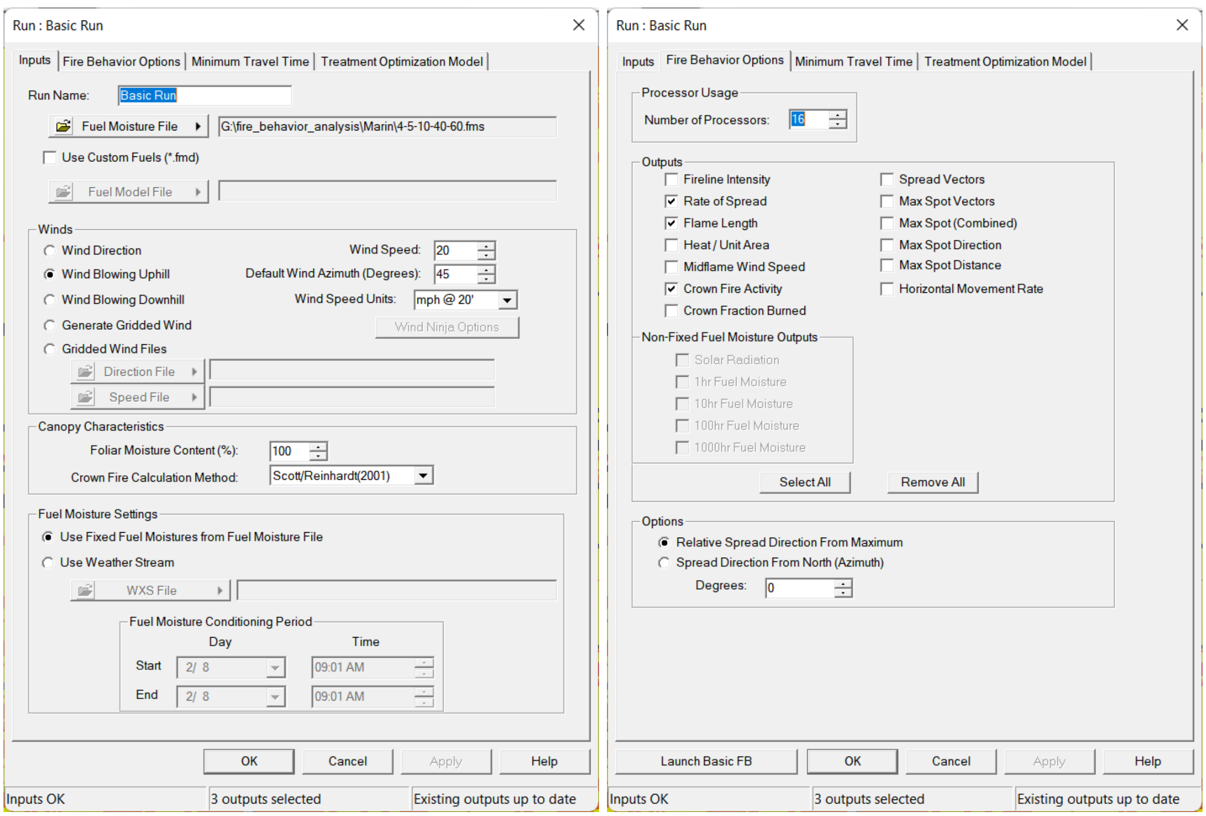

Figure 23. FlamMap input parameters used.

[2] Source: https://www.fs.usda.gov/rmrs/tools/flammap (accessed on 7/26/2021).

Outputs

In this section, we present three (3) fire behavior predictive factors, **flame length**, **rate of spread**, and **crown fire activity**, derived from the 2020 fuel model landscape file (representing pre-treatment conditions) and our altered landscape file (reflecting post-treatment conditions).

Flame Length

Flame length is an indicator of fire intensity. It is the distance between the flame tip and the midpoint of the flame depth at the base of the flame (generally the ground surface). In this scenario, flame length is predicted to range from 0 feet to over 20 feet throughout our modeled area in both pre-treatment and post-treatment conditions.

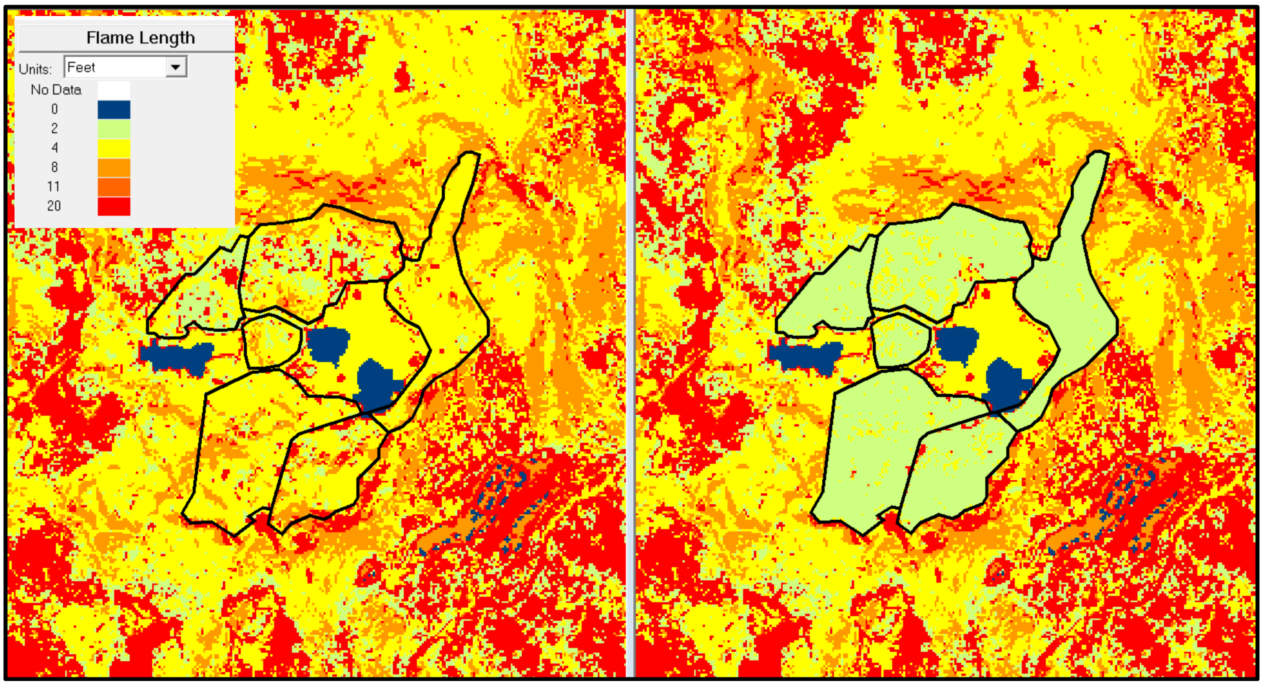

Figure 24. Pre-treatment (on left) and post-treatment (on right) flame length fire behavior prediction. Work areas shown with black outline.

In the maps above, the left map shows the flame length predictions for the pre-treatment landscape and the map on the right shows the predicted flame length predictions for the post-treatment landscape. There is a marked difference in the 2-4 feet category of flame lengths, which was reduced by 37.2 acres, likely moved into the 'less than 2-feet' category. All the other higher flame lengths were also reduced, resulting in an overall increase of 51.7 acres for the less than 2 feet category.

Table 5. Difference in acres by flame length categories for the pre- and post-treatment scenarios in the work areas only.

Flame Length Category	Pre-Treatment Acres	Post-Treatment Acres	Difference
No predicted fire	0.1	0.1	0.0
< 2 feet	10.4	62.1	51.7
2 – 4 feet	43.0	5.9	-37.2
4 – 8 feet	8.8	0.3	-8.6

8 – 11 feet	0.3	0.1	-0.2
11-20 feet	3.3	0.4	-2.9
> 20 feet	3.2	0.2	-3.0
Total Acres	69.2	69.2	

Rate of Spread

Rate of spread is a measure of the speed with which a fire moves in a horizontal direction across the landscape, usually expressed in chains per hour or feet per minute. Rate of spread ranges from 0 to 88 feet per minute. In our predictive models, for both pre- and post-treatment conditions, rate of spread is highest in the grass and shrub fuel models, and lowest in the timber models (as expected).

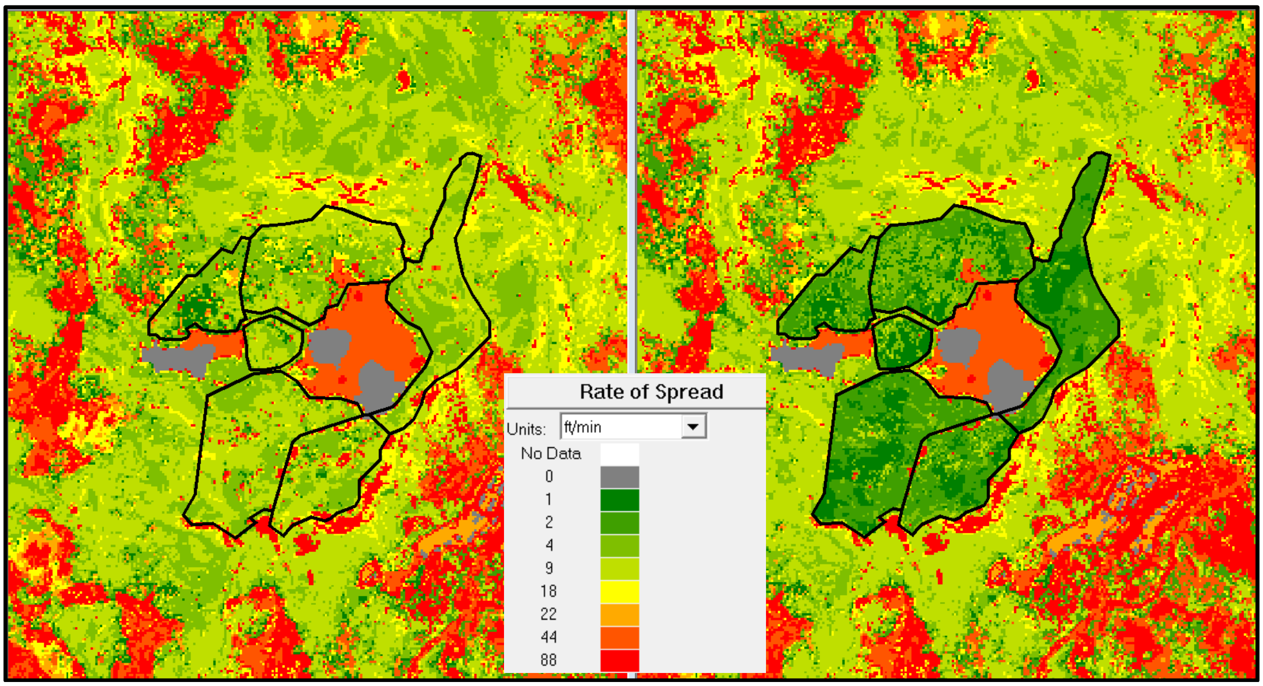

Figure 25. Pre-treatment (on left) and post-treatment (on right) rate of spread fire behavior prediction. Work areas shown with black outline.

In the maps above, the left map shows the rate of spread predictions for the pre-treatment landscape and the map on the right shows the rate of spread predictions for the post-treatment landscape.

Table 6. Difference in acres by rate of spread categories for the pre- and post-treatment scenarios in the work areas only.

Rate of Spread Category	Pre-Treatment Acres	Post-Treatment Acres	Difference
No predicted fire	0.1	0.1	0.0
< 1 foot/minute	3.2	18.0	14.8
1 – 2 ft/min	1.0	32.2	31.2
2 – 4 ft/min	18.0	15.7	-2.3
4 – 9 ft/min	38.9	1.8	-37.1
9 – 18 ft/min	3.3	0.2	-3.1
18 – 22 ft/min	0.7	0.0	-0.7

22 – 44 ft/min	1.2	0.4	-0.8
44 – 88 ft/min	0.7	0.2	-0.5
> 88 ft/min	1.9	0.5	-1.4
Total Acres	69.2	69.2	

Again, there is a shift in acres from the higher rate of spread categories to the lowest rate of spread categories. The less than 1 foot/minute category increased by almost 15 acres and the 1-2 ft/min category increased by 31 acres. Both account for 46 acres or 70 percent of the work areas.

Crown Fire Activity

Crown fire activity is a measure of the type of fire that involves the tree canopy that can be expected at any given location. On the maps following, a fire type of 1 (or yellow) indicates only a surface fire is predicted. A fire type of 2 (or orange) indicates a passive or torching fire. And a fire type of 3 (or red) indicates an active crown fire (when the fire propagates through the crowns of trees independent of a surface fire).

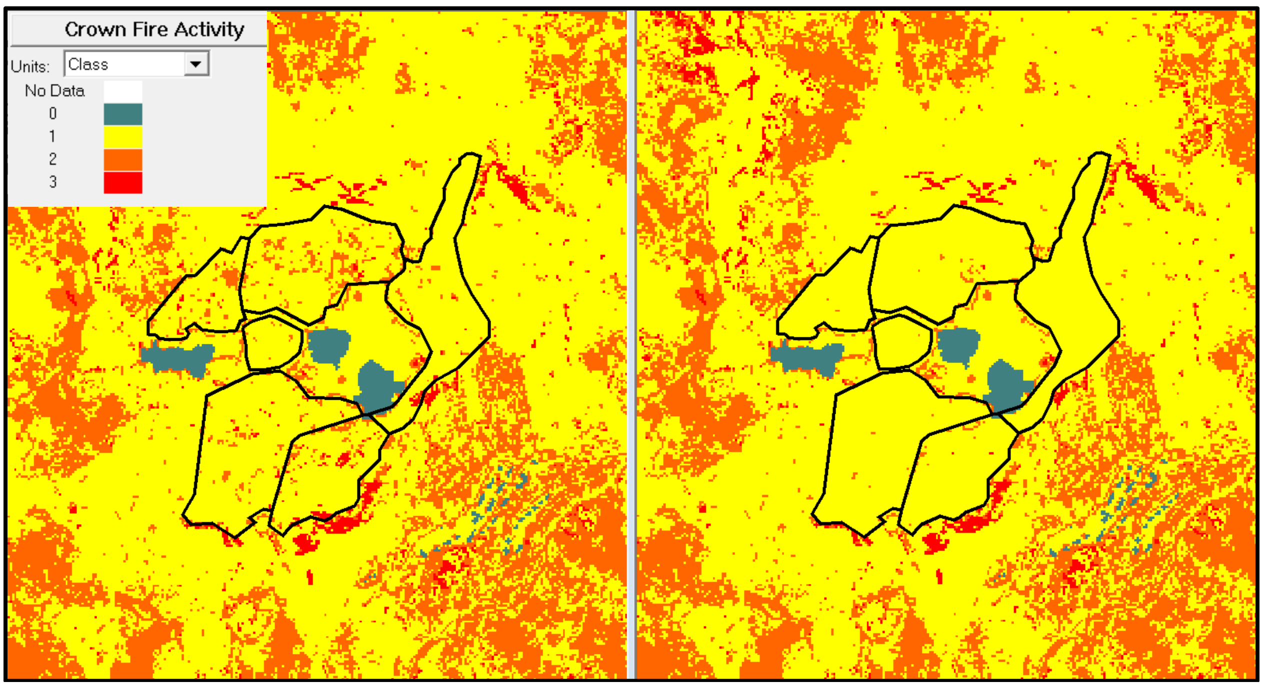

Figure 26. Pre-treatment (on left) and post-treatment (on right) crown fire activity fire behavior prediction. Work areas shown with black outline.

In the predicted results fire in pre-treatment conditions, there is a small band of crown fire predicted just south of the work areas along a ridgeline. There are also small pockets of predicted crown fire in Demo Area 2. A torching fire is predicted for scattered areas throughout the work areas in pre-treatment conditions. However, post-treatment conditions show a decrease in predicted crown fire within the work areas.

Table 7. Difference in acres by crown fire activity categories for the pre- and post-treatment scenarios in the work areas only.

Crown Fire Activity Category	Pre-Treatment Acres	Post-Treatment Acres	Difference

No predicted fire	0.1	0.1	0.0
Surface fire (1)	62.3	68.3	6.0
Torching fire (2)	5.3	0.7	-4.6
Active crown fire (3)	1.48	0.05	-1.4
Total Acres	69.2	69.2	

Discussion

Treatments changed the fuel volume by size class, shifted live to dead fuels, and changed the fuel arrangement; the combination of these characteristics lowered the predicted fire behavior in the Potrero Meadows area. The treatment methodology may have differed across each work area and vegetation type, but the resulting crown base height and ground fuels, led to the same post fire fuel model assignment.

The biggest change in fuel characteristics was in the re-distribution of fuels, from live shrubby fuels and low branches to dead, compact chips. Thus, while the total fuel volume has not been reduced, the compact nature of the fuels (whether in low, masticated areas, areas of lop and scatter treatment or in concentrated piles of fuel), results in a more benign predicted fire behavior. Thus, the surface fuel model changed to one that in more consistent with successful fire containment and reduced environmental impacts.

In addition, the crown base height was increased, leading to less crown fire activity – as would be expected given the targeted understory thinning of all treatments.

Within the treatment areas field observations noted variability of fuel characteristics such as fuel bed depth, abundance of large rotten logs and density of piles. This unevenness will affect resulting fire behavior, creating greater variability than can be portrayed by the software. Notes from the field observations can inform future work specifications.

With current fuel conditions, broadcast burning could easily be done in mid-winter (late January to early February) when the grass is green but dead fuels are dry. This period also has more frequent days of high smoke dispersal and avoids nesting and blooming seasons.

Fuel treatments can also restore meadows and natural stand density. In order to achieve these ecological goals, additional treatment will be needed to further reduce canopy cover (and possibly to create openings or gaps) or expand Potrero meadow by removing encroaching trees along the meadow edges.

Localized impacts from pile burning can be expected due to long residence time and soil heating. Similarly, where greater volume of fuel is concentrated in a shallow depth (i.e., where fuels are deep in areas of lop and scatter or mastication) residence time and resulting ecological impacts may be higher. Piles placed under trees may cause localized torching not captured by predictive fire behavior software. To reduce such potential impacts, these piles could be burned prior to a prescribed fire (broadcast burn) activity to reduce the potential for crowning or soil damage.

Conclusions

With the caveat that the effects of the addition of burn piles on the landscape are not captured in our fire behavior modeling predictions, treatments dramatically improved the predicted fire behavior in all metrics measured. Resulting flame length shifted to less than 2 feet in almost all treated locations. Rates of fire spread shifted to slower than 4 feet per minute and torching was nearly eliminated. All these indicate the value of fuel treatments.

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APPENDIX 8B: REVIEW OF THE 2020 MARIN COUNTY 5 METER FUEL MODEL

REVIEW OF THE 2020 MARIN COUNTY FUEL MODEL

Report/Data Reviewed:

- Categorizing Surface Fuel Models in Marin County, California by Christopher A. Dicus, PhD, August 31, 2020.
- 2020 5m Fuel Model (developed by Sonoma Technology, Inc. for Marin County Fire as part of the 2020 CWPP update)

Reviewed for:

Tamalpais Lands Collaborative (One Tam)

Reviewed by:

Petronila Esther Mandeno and Carol L Rice

Digital Mapping Solutions and Wildland Res Mgt

Date: Thursday, February 16, 2023

Abstract

Digital Mapping Solutions and Wildland Res Mgt, under a subcontract with Tukman Geospatial, were tasked with review of the Marin County 2020 5-m Fuel Model data layer updated for the 2020 Marin County CWPP.

We found irregularities in the 2020 fuel model that could not be explained by reviewing the vegetation-to-fuel-model crosswalk documentation. After several site visits, we were unable to arrive at the same fuel model assignment using the logic presented in the layer's documentation (*Categorizing surface fuel models in Marin County, California* by Christopher A. Dicus). It appears that the 2020 fuel model assignments were partially based on information in the Dicus report, but also included expert input from Marin County Fire. Unfortunately, sufficient metadata and documentation necessary to evaluate final fuel model assignments more thoroughly was not available, and therefore we could not propose systemic changes or improvements to the logic in the surface fuel model crosswalk.

Based on guidance from project stakeholders, we therefore shifted our focus to comparing the updated 2020 Fuel Model layer to the 2016 Fuel Model layer. Both are 5-m in resolution, relied on LiDAR data, and are widely used in Marin County. Our discussion includes considerations for end-users of the 2 existing 5-m surface fuel models in Marin County and recommendations for further study.

Introduction

In 2020, Sonoma Technology, Inc. (STI) produced an updated assigned surface **fuel model**[1] data layer for Marin County. This work was prompted by an update of the county's Community Wildfire Protection Plan (CWPP) in 2020 and supported by a **LiDAR**[2] acquisition managed by One Tam in 2019 as part of the collaborative's countywide fine scale vegetation map and landscape database project.

Previously, STI created county-wide fuel model assignments based on 2010 LiDAR, existing fine scale vegetation maps for Marin Water and County Park lands, and CalVeg vegetation type (Meyer & Laudenslayer 1988, Huang 2016). These were the assignments that were updated by Christopher A. Dicus in 2020 using the updated LiDAR data. Their methodology for creating those updated surface fuel model assignments was documented in *Categorizing surface fuel models in Marin County, California* (Dicus 2020).

The Dicus paper is the focus of this review, however we will also compare the Dicus fuel model assignments to the previous 2016 fuel model assignments. In addition, using FLAMMAP (Finney, 2006), we will compare the wildfire behavior predictions for both the 2020 and 2016 fuel model assignments.

For this review, we also conducted two field visits to document on-the-ground conditions spatially and photographically. This field verification highlights the places where over- or under- predicting may occur in the latest fuel model assignments.

We will then discuss our findings and report our conclusions.

Methodology

The basis of most surface fuel model assignments made across large areas are generally derived from using vegetation type and characteristics to assign a surface fuel model. These assignments are generally presented as a crosswalk. For both the older and newer versions of the Marin County surface fuel model assignments, LiDAR informed vegetation classifications were the starting point. Other vegetation characteristics and data were used to refine the fuel model assignments.

In this section, our review will go through Dicus' assignments in detail. We will then take a wider look at the county and compare the statistics for the Dicus assignments and

[1] Fuel Model: A stylized set of fuel bed characteristics used as input for a variety of predictive wildfire modeling applications.
[2] LiDAR: Light detection and ranging; a method for determining variable distances (ranges) by targeting an object with a laser and measuring the time for the reflected light to return to the receiver.

LANDFIRE's assignments. A basic statistical comparison can often illuminate fuel model assignments that may be over- or under-represented.

Designated Fuel Types

2020 Fuel Model Summary

In January 2020, One Tam provided Marin County Fire and STI a draft vegetation lifeform map developed as part of their countywide fine-scale vegetation mapping project. STI used the lifeform maps as the basis for their fuel model assignments.

The lifeform map, a 27-class was created using "expert systems" rulesets in Trimble Ecognition[3]. These rulesets combine automated image segmentation (stand delineation) with object-based image classification techniques. After it was produced using eCognition, the preliminary lifeform map product was manually edited by photo interpreters (see the lifeform datasheet online at: https://vegmap.press/marin_lifeform_datasheet).

Figure 1 (next page) shows the lifeform vegetation map that was an input into the 2020 Marin County fuel model assignments.

[3] eCognition software is used by GIS professionals, remote sensing experts & data scientists to automate geospatial data analytics. Users can design feature extraction solutions to transform geo-data into geo-information (https://geospatial.trimble.com/what-is-ecognition).

Figure 1. Lifeform vegetation map from the Marin County Vegetation Map (December 2019).

The Upland Forb & Grass lifeform, which represents grasslands, accounts for 29% of Marin County. These are large expanses of rangeland that exists in the north, central, and western part of Marin County. Coupled with Non-native Herbaceous (1%), grasslands make up 30% of the county.

Forest & Woodland is the next largest lifeform category, covering 34% of the county. These forested stands are found mainly in the south-central part of the county and scattered along the edges of grasslands. Shrubs (14%) make up the next largest (in terms of acres covered) lifeforms Shrubs are found throughout the county but tend to occupy the transition between grassland and forest.

Table 1. Lifeform acres based on the Marin County Vegetation Map (December 2019).

Lifeform	Acres	Percent
Annual Cropland	141.56	0.04%
Aquaculture	79.98	0.02%
Bare Soil	2,898.08	0.8%
Developed	26,024.10	7.1%
Eel Grass	1,545.28	0.4%
Forest & Woodland	122,767.17	33.5%
Freshwater Wetland	5,787.26	1.6%
Intensively Managed Hayfield	1,986.67	0.5%
Irrigated Pasture	228.06	0.06%
Major Roads	1,549.75	0.4%
Non-native Forest & Woodland	3,997.85	1.1%
Non-native Herbaceous	1,721.61	0.5%
Non-native Shrub	820.46	0.2%
Nursery or Ornamental Horticulture Area	9.58	0.003%
Orchard or Grove	107.44	0.03%
Perennial Cropland	0.97	0.000%
Shrub	52,801.72	14.4%
Tidal Marsh	5,593.62	1.5%
Tidal Mud Flat	3,614.22	1.0%
Upland Forb & Grass	107,845.88	29.4%
Vineyard	188.23	0.05%
Water	26,599.24	7.3%

The general fuel model assignments are presented in the first table in Dicus' report. A copy is provided on the next page for easy reference.

Acres	Lifeform Class	Description	Fuel Type	Fuel-Model
26024	Developed	Manmade developed areas greater than 0.2 acres	Nonburnable	NB1
1550	Major Roads	Area is a major road	Nonburnable	NB1
26599	Water	Water covers the area	Nonburnable	NB8
5787	Freshwater Wetland	Areas that are depressional, wet all year long, and exhibit obvious herbaceous wetland vegetation	Nonburnable	NB8
5594	Tidal Marsh	Area that has salt-water tolerant wetland species within the tidal zone	Nonburnable	NB8
3614	Tidal Mud Flat	Areas in the intertidal zone that are unvegetated and exposed during low tide	Nonburnable	NB8
1545	Eel Grass	Areas where eel grass is dominant	Nonburnable	NB8
80	Aquaculture	Area where aquaculture is present (e.g., oyster beds)	Nonburnable	NB8
2898	Bare Soil	Areas where shrub, forest, and herbaceous cover are each less than 10% absolute cover and the area is best characterized as bare land	Nonburnable	NB9
188	Vineyard	Area is a vineyard	Agriculture	GR1
142	Annual Cropland	Area is an irrigated annual cropland (e.g., vegetable crops)	Agriculture	GR1
107	Orchard or Grove	Area is an orchard or grove of fruit or nut trees	Agriculture	GR1
10	Nursery or Ornamental Horticulture Area	Nursery or horticultural area	Agriculture	GR1
107846	Upland Forb & Grass	Area where herbaceous vegetation is at least 10% absolute cover and is not overtopped by woody vegetation of equal or higher cover	Grass	Varies by breakpoints
1987	Intensively Managed Hayfield	Area is an intensively managed hayfield that is mechanically turned over every year	Grass	Varies by breakpoints
1722	Non-native Herbaceous	Area where non-native herbaceous vegetation is at least 10% absolute cover and is not overtopped by woody vegetation of equal or higher cover	Grass	Varies by breakpoints
228	Irrigated Pasture	Area is an irrigated pasture	Grass	Varies by breakpoints
52802	Shrub	Area where native woody shrubs are at least 10% absolute cover	Shrub	Varies by breakpoints
820	Non-native Shrub	Area where non-native, ornamental, or landscaping woody shrubs are at least 10% absolute cover	Shrub	Varies by breakpoints
1	Perennial Cropland	Area is a perennial cropland (e.g., lavender, berries, Christmas trees, rhododendron)	Shrub	Varies by breakpoints
122767	Forest & Woodland	Areas where native woody vegetation >15 feet is at least 10% absolute cover	Forest	Varies by breakpoints
3998	Non-native Forest & Woodland	Area where non-native, ornamental, or landscaping trees dominate the tree stratum	Forest	Varies by breakpoints

Figure 2. Copy of crosswalk table from Dicus report.

Essentially, the majority of the lifeforms were cross walked to fuel models that closely matched their basic fuel type (i.e. grass, shrub, or forest litter). However, assignments were made "across" lifeforms to better characterize the fuel types that would carry a fire through any given lifeform.

For example, oak savanna often has a grassy understory with very little else to carry a fire. In addition, the base of the oak canopy is high and broad. In this case, a grass fuel model would be assigned to the oak savanna lifeform based on canopy cover and canopy height assumptions or what Dicus called "breakpoints".

A copy of the breakpoints used is provided below in Figure 3.

	Cover	Height	Fuel Model
Grass	<20%	<1'	GR1
		1'	GR1
		2'	GR1
		3'+	GR1
	21%-50%	<1'	GR1
		1'	GR2
		2'	GR2
		3'+	GR4
	51%-80%	<1'	GR1
		1'	GR2
		2'	GR4
		3'+	GR7
	81%-100%	<1'	GR1
		1'	GR4
		2'	GR7
		3'+	GR7

	Cover	Height	Fuel Model
Shrubs	<20%	<1	GR1
		1-5	GS1
		>5	GS1
	21%-50%	<1	GS1
		1-5	GS2
		>5	SH5
	51%-80%	<1	SH1
		1-5	SH5
		>5	SH7
	81%-100%	<1	SH2
		1-5	SH5
		>5	SH7

	Cover	Height	Fuel Model
Timber (Broadleaf)	<20%	<25'	GR4
		25'-50'	GR4
		>50'	GR4
	21%-50%	<25'	GR4
		25'-50'	TU4
		>50'	TU5
	51%-80%	<25'	TU5
		25'-50'	TU5
		>50'	TL9
	81%-100%	<25'	TL2
		25'-50'	TL6
		>50'	TL9

	Cover	Height	Fuel Model
Timber (Conifer)	<20%	<25'	GR4
		25'-50'	GR4
		>50'	GR4
	21%-50%	<25'	GR4
		25'-50'	TU4
		>50'	TU5
	51%-80%	<25'	TL3
		25'-50'	TL5
		>50'	TL5
	81%-100%	<25'	TL5
		25'-50'	TL5
		>50'	TL5

Figure 3. Breakpoints of vegetative cover and height for fuel model assignments (Dicus, 2020).

The 2020 fuel model assignments were used to create a landscape file. A landscape file contains several data layers needed to predict wildland fire. In addition to surface fuel models (discussed in the Dicus paper), these data layers include elevation, slope, aspect, canopy cover, canopy height, canopy base height, and canopy bulk density. The Dicus paper does not discuss how elevation, slope, aspect, canopy cover, canopy height, canopy base height, or canopy bulk density were derived.

Below we present the metadata for the Dicus landscape file. The landscape file covers the entirety of Marin County (at roughly 365,787 acres) and is in the UTM Zone 10, NAD83, meters projection.

Table 2. Metadata for landscape file using the Discus assigned fuel models.

Latitude:	38		
Cell Resolution X	5.00	**Cell Resolution Y**	5.00
Num Cells East	10,647	**Num Cells North**	11,203
UTM North	4,241,425	**UTM South**	4,185,410
UTM East	551,141	**UTM West**	497,906

Table 3. Acres and percentages of assigned fuel models in the 2020 Discus landscape file.

Fuel Model	Description	Acres	Percent
91	NB1 Urban/Developed	6,954	2%
98	NB8 Open Water	37,381	10%
99	NB9 Bare Ground	2,894	1%
101	GR1 Short, Sparse Dry Climate Grass	129,379	35%
102	GR2 Low Load, Dry Climate Grass	4,874	1%
104	GR4 Moderate Load, Dry Climate Grass	7,798	2%
107	GR7 High Load, Dry Climate Grass	6,927	2%
121	GS1 Low Load, Dry Climate Grass-Shrub	1,613	0.4%
122	GS2 Moderate Load, Dry Climate Grass-Shrub	72	0.02%
141	SH1 Low Load Dry Climate Shrub	5,057	1%
142	SH2 Moderate Load Dry Climate Shrub	2,536	1%
145	SH5 High Load, Dry Climate Shrub	22,455	6%
147	SH7 Very High Load, Dry Climate Shrub	10,265	3%
161	TU1 Low Load Dry Climate Timber-Grass-Shrub	237	0.1%
162	TU2 Moderate Load, Humid Climate Timber-Shrub	82	0.02%
163	TU3 Moderate Load, Humid Climate Timber-Grass-Shrub	433	0.1%
164	TU4 Dwarf Conifer with Understory	518	0.1%
165	TU5 Very High Load, Dry Climate Timber-Shrub	39,508	11%
181	TL1 Low Load Compact Conifer Litter	2,056	1%
182	TL2 Low Load Broadleaf Litter	14,330	4%
186	TL6 Moderate Load Broadleaf Litter	28,413	8%
189	TL9 Very High Load Broadleaf Litter	42,005	11%

Table 3 shows fuel models found in the fuel model data layer along with their acreages for the entire county. Note that the fuel model highlighted in dark red are not found in the breakpoint assignments and presumably these were assigned based on some other logic not explained in the Dicus report or from on-the-ground observations. Together, these unaccounted-for fuel model assignments account for less than 3% of the area in Marin County.

Discounting the non-burnable fuel models (NB1, NB8, and NB9), the fuel model assigned most often is GR1 Short, Sparse Dry Climate Grass (35%). This occurs throughout the county, but mostly in the northern and western portions of the county where grazed grasslands are prominent.

The next fuel model assigned to the most area is TL9 Very High Load Broadleaf Litter (11% of the county). This corresponds with the dense Redwood and Douglas-fir forests located in the south, central, and western portion of the county (dark cyan shown in Figure 5).

Fuel model TU5 Very High Load, Dry Climate Timber-Shrub was also assigned to 11% of the county. This is shown in the map as darkest green and corresponds to areas that are at the transition between forest and shrubs located in the eastern portion of the county nearest population centers as well as in the western portion of the county at the southern end of Tomales Bay.

The next two most assigned fuel models are TL6 Moderate Load Broadleaf Litter (at 8%) and SH5 High Load, Dry Climate Shrub (at 6%). TL6 is mostly associated with areas mapped as Forest and Woodland. Together with SH7 Very High Load, Dry Climate Shrub, SH7 accounts for most of the Native Shrub lifeform.

TL2 Low Load Broadleaf Litter was often assigned to both conifer and hardwood lifeforms, though presumably the crosswalk was unable to distinguish between those basic forest types.

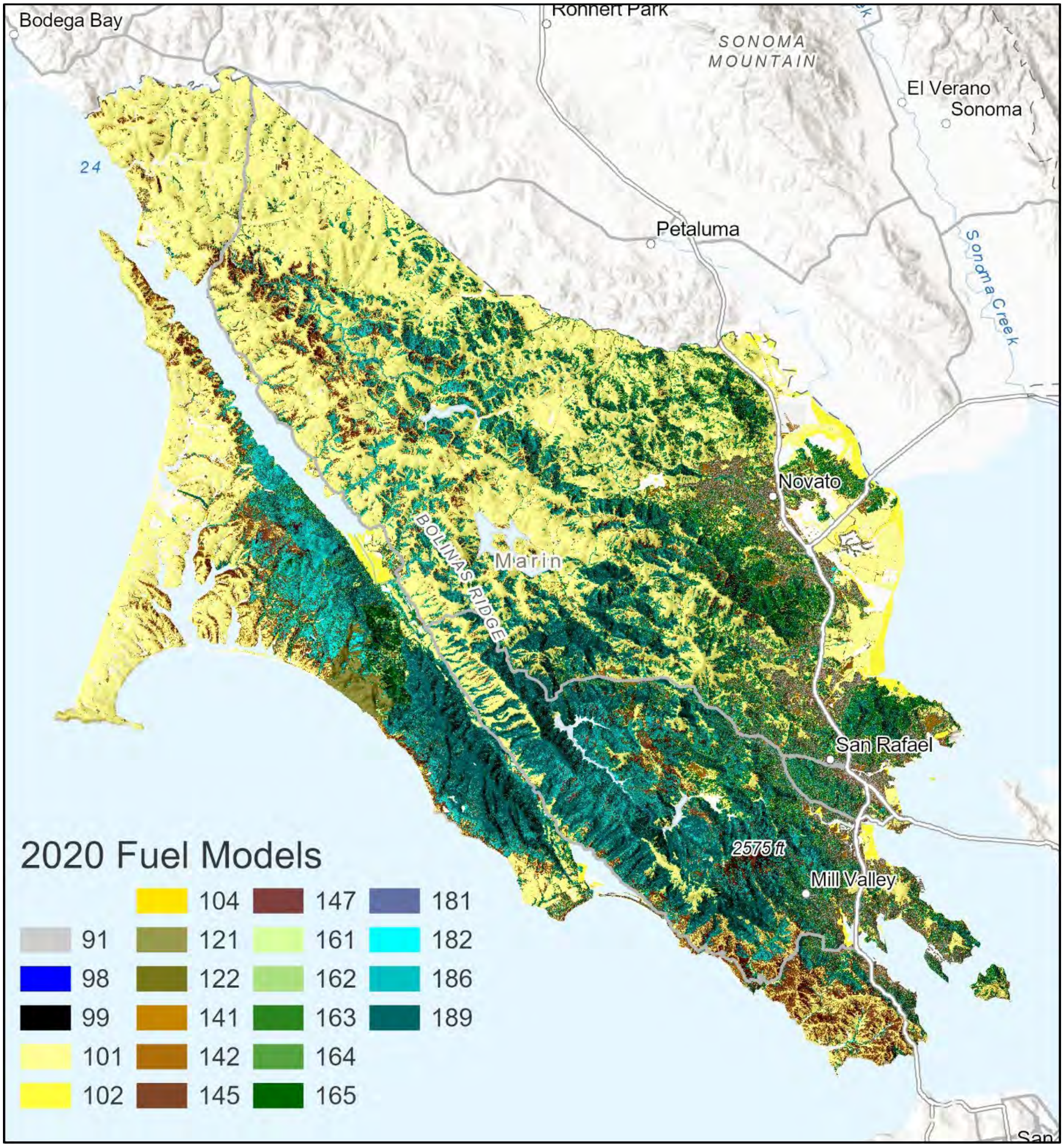

Figure 4. Map of Discus fuel model assignments for Marin County (2020).

2015/2016 Fuel Model Summary

Fuel model assignments in the 2015 fuel model were derived from a vegetation layer compiled by Sonoma Technology, Inc. (STI) by combining several of the best data sources available at the time (Huang, et.al., 2015). The data were derived from available LiDAR and aerial imagery as well as datasets reflecting vegetation types and the presence of structures, roads, and water bodies to refine the then coarse vegetation data available for the entire county. Their aim in doing this work was to develop a fuel model map that was "better" than the 30-meter-resolution data available through LANDFIRE[4].

STI used three available vegetation datasets to provide information about vegetation types for portions of Marin County: (1) the 2008 Marin County Open Space District (MCOSD) vegetation dataset obtained from the California Department of Fish and Wildlife (CDFW) GIS Clearinghouse, (2) the 2009 Marin Municipal Water District (MMWD) vegetation dataset obtained from the CDFW GIS Clearinghouse, and (3) the Existing Vegetation Classification and Assessment with LANDSAT of Visible Ecological Groupings (CALVEG) dataset, mostly based on 2007 imagery, published by the USDA Forest Service Pacific Southwest Region Remote Sensing Lab. STI also included building footprint, water body, and road network vector data obtained from MarinMap (http://www.marinmap.org) to refine vegetation information for Marin County.

From these data layers along with other characteristics derived from LiDAR data, the STI team developed a custom fuel model map for Marin County. Figure 5 below shows the process used.

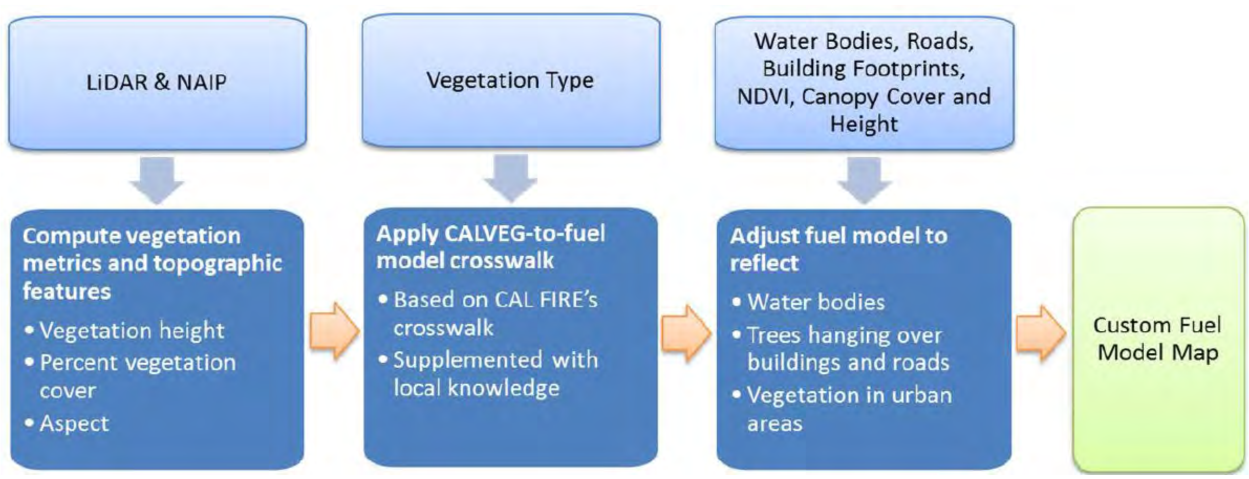

Figure 5. STI process used to create the 2015 Marin County fuel model map (Huang, 2016).

Below we present the metadata for the 2016 landscape file. The landscape file covers the entirety of Marin County (at roughly 365,787 acres) and is in the UTM Zone 10, NAD83, meters projection.

[4] https://landfire.gov/about.php

Table 4. Metadata for landscape file using the 2016 STI assigned fuel models.

Latitude:	38		
Cell Resolution X	5.00	**Cell Resolution Y**	5.00
Num Cells East	10800	**Num Cells North**	12000
UTM North	4,206,000	**UTM South**	4,184,000
UTM East	508,300	**UTM West**	497,500

Table 5. Acres and percentages of assigned fuel models in the 2016 STI landscape file.

Fuel Model	Description	Acres	Percent
91	NB1 Urban/Developed	15,957	4%
98	NB8 Open Water	5,725	2%
99	NB9 Bare Ground	25,616	7%
101	GR1 Short, Sparse Dry Climate Grass	62,036	17%
102	GR2 Low Load, Dry Climate Grass	2,177	1%
103	GR3 Low Load, Very Coarse, Humid Climate Grass	6,206	2%
104	GR4 Moderate Load, Dry Climate Grass	78,934	22%
108	GR8 High Load, Very Coarse, Humid Climate Grass	4	0.001%
121	GS1 Low Load, Dry Climate Grass-Shrub	2	0.001%
122	GS2 Moderate Load, Dry Climate Grass-Shrub	1,496	0.4%
141	SH1 Low Load Dry Climate Shrub	269	0.1%
142	SH2 Moderate Load Dry Climate Shrub	8,030	2%
144	SH4 Low Load, Humid Climate Timber-Shrub	29,769	8%
145	SH5 High Load, Dry Climate Shrub	24,573	7%
147	SH7 Very High Load, Dry Climate Shrub	6,516	2%
161	TU1 Low Load Dry Climate Timber-Grass-Shrub	92	0.03%
162	TU2 Moderate Load, Humid Climate Timber-Shrub	244	0.1%
163	TU3 Moderate Load, Humid Climate Timber-Grass-Shrub	2,308	1%
165	TU5 Very High Load, Dry Climate Timber-Shrub	29,780	8%
181	TL1 Low Load Compact Conifer Litter	7,300	2%
182	TL2 Low Load Broadleaf Litter	141	0.04%
183	TL3 Moderate Load Conifer Litter	438	0.1%
186	TL6 Moderate Load Broadleaf Litter	1,559	0.4%
188	TL8 Long-Needle Litter	27	0.01%
189	TL9 Very High Load Broadleaf Litter	49,756	14%

Table 5 shows fuel models found in the 2015 fuel model data layer along with their acreages for the entire county. Discounting the non-burnable fuel models (NB1, NB8, and NB9), the fuel model assigned most often is GR4 Moderate Load, Dry Climate Grass (22%). This occurs throughout the county, but mostly in the northern and western portions of the county where grasslands are prominent. The next most assigned fuel model is GR1 Short, Sparse Dry Climate Grass (17%).

The next fuel model assigned to the most area is TL9 Very High Load Broadleaf Litter (14% of the county). This corresponds with the dense Redwood and Douglas-fir forests located in the south, central, and western portion of the county (dark cyan shown in Figure 6).

Fuel model TU5 Very High Load, Dry Climate Timber-Shrub was assigned to 8% of the county. This is shown in the map as darkest green and corresponds to areas with a high volume to live woody vegetation under the forest canopy located in the eastern portion of the county nearest population centers as well as in the western portion of the county at the southern end of Tomales Bay.

The next two most assigned fuel models are SH4 Low Load, Humid Climate Timber-Shrub (8%) and SH5 High Load, Dry Climate Shrub (at 7%).

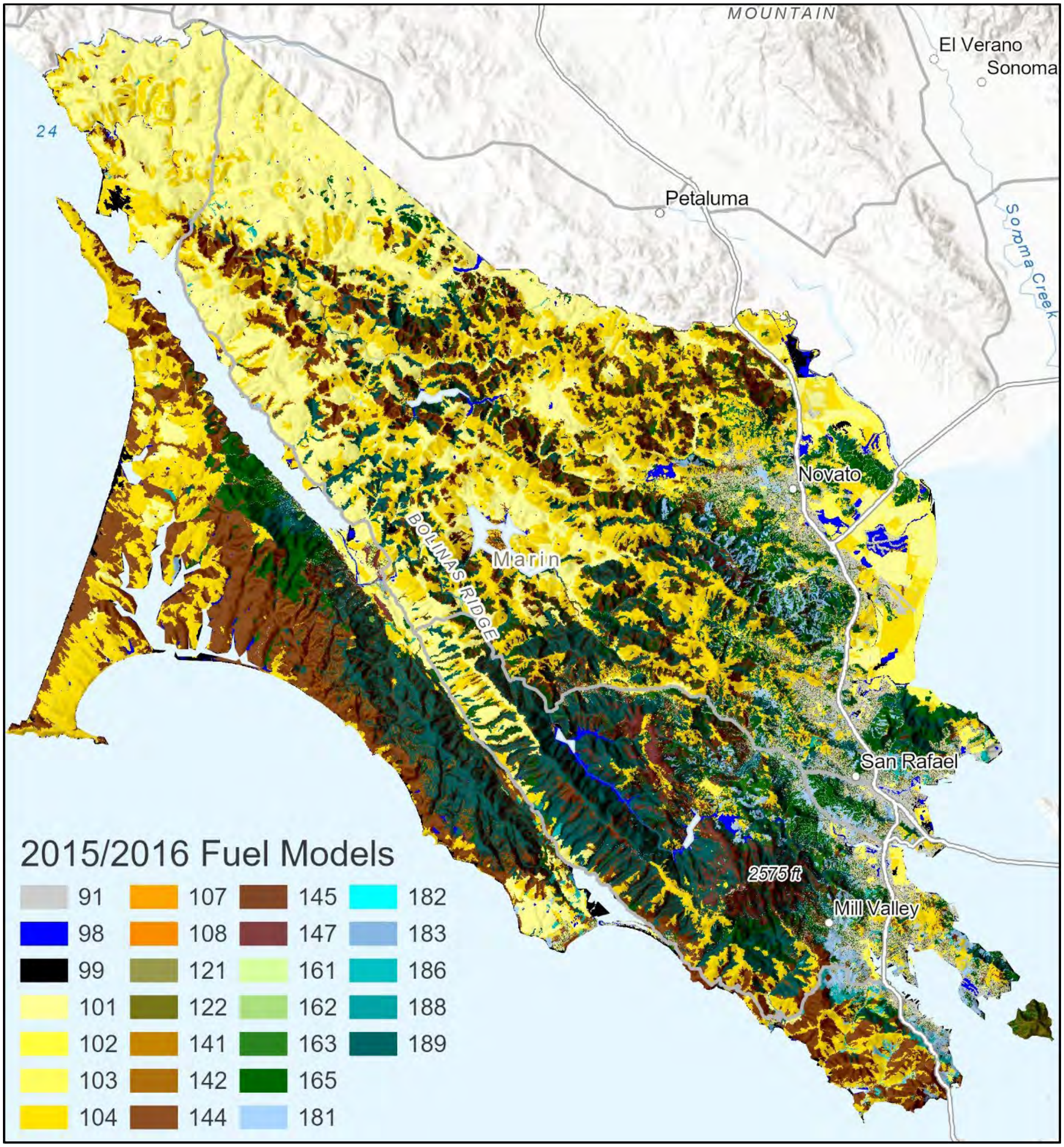

Figure 6. Map of 2015/2016 STI fuel model assignments for Marin County. Data in UTM Zone 10 WGS84 projection.

Highlighted Similarities and Differences

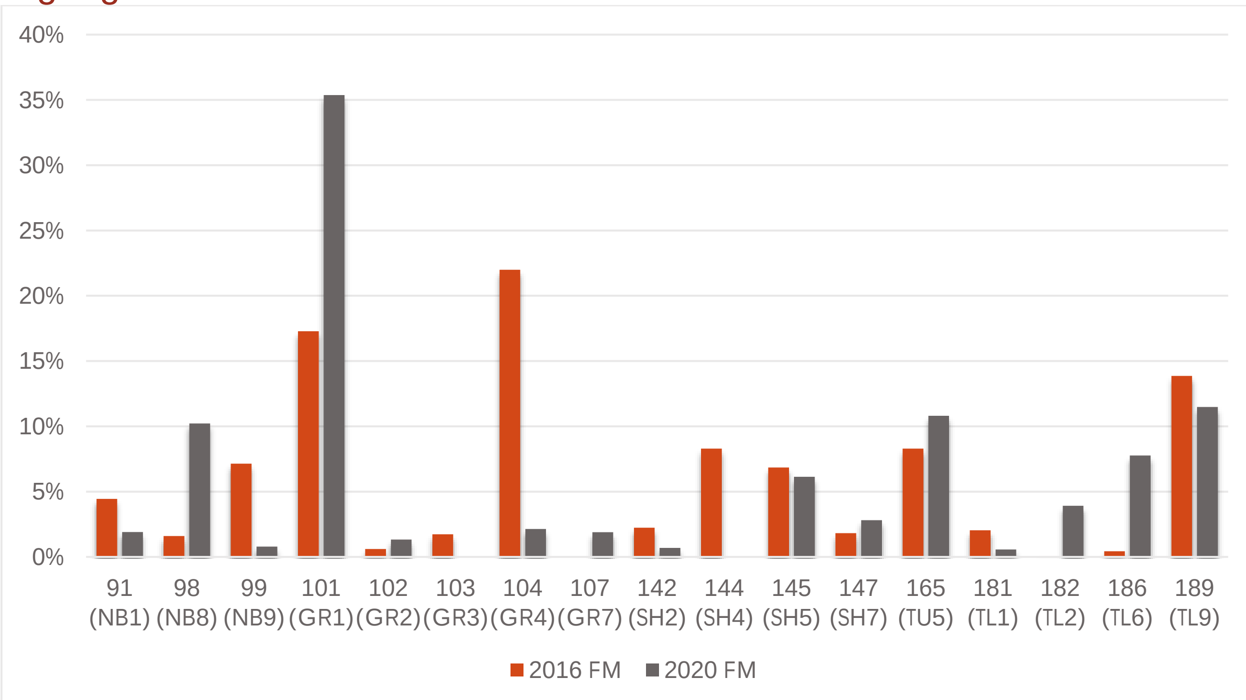

Figure 7. Proportion of Marin County assigned to each 40 Scott and Burgan fire behavior fuel model. All models representing less than 1% of Marin have been omitted for clarity.

The most significant change between the 2015/2016 fuel model version and the 2020 fuel model version is in the assignment of fuel model 104 (GR4). This was reduced significantly in the 2020 version. While 101 (GR1) was increased significantly. Presumably, this change from a moderate fuel load model to a lower fuel load model was to capture the fact that much of the grasslands in Marin County are grazed.

Another notable change is an increase to the assignment of 182 (TL2) and 186 (TL6). Both represent broadleaf litter (at both low and moderate fuel loading). The older fuel model version had very little to none assigned to these fuel models. The new assignments of 182 and 186 capture the fuel characteristics of the evergreen and deciduous hardwoods in Marin County.

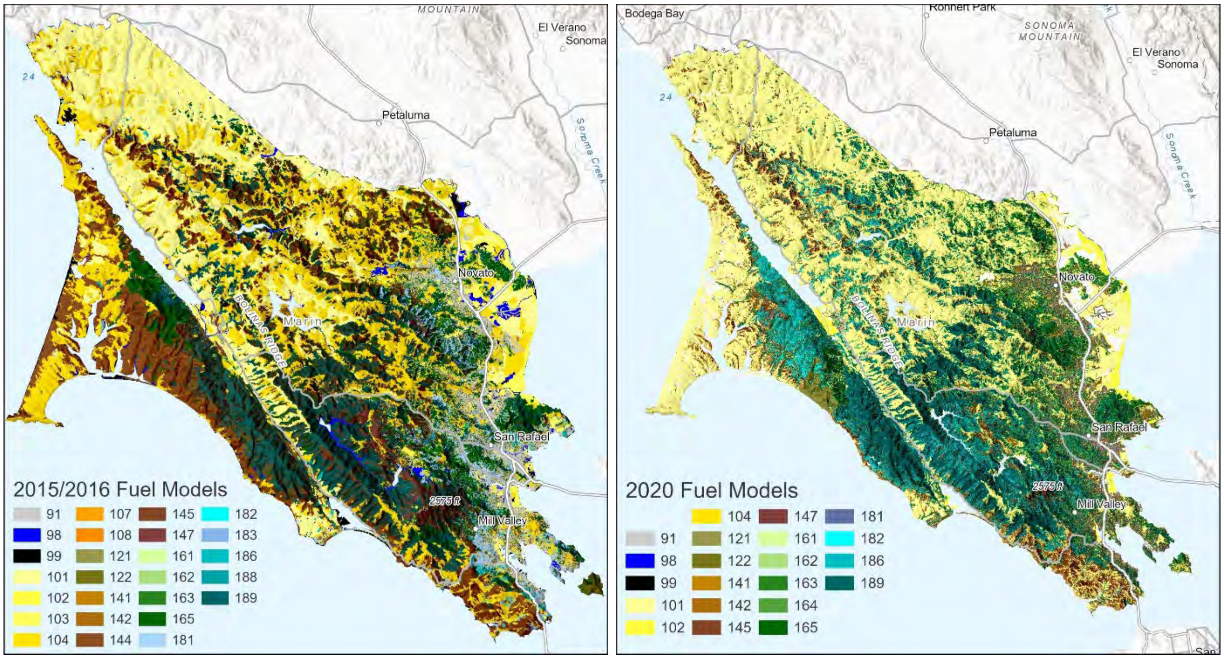

Figure 8. Side-by-side comparison of 2015 fuel model layer (on the left) and the updated 2020 fuel model layer (on the right) (STI, 2016/2020).

Another notable change is the elimination of 144 (SH4) from the 2020 fuel model layer. SH4 is a shrub model that represents a Low Load, Humid Climate Timber-Shrub fuel model scenario. This model is often used for areas in the eastern part of the United States to represent areas where the primary carrier of fire is woody shrubs and shrub litter. Low to moderate shrub and litter load, possibly with pine overstory, fuel bed depth about 3 feet. While the overall fuel characteristics may apply to the areas mapped, SH4 also includes a higher dead fuel moisture extinction. This fuel model could lead to an overall under-predicting of fire behavior.

SH4 was previously mapped mostly in the western part of Marin County along Point Reyes National Seashore. These areas are now mapped with a combination of 101 (GR1), 141 (SH1), 145 (SH5), 147 (SH7), 165 (TU5), 182 (TL2), and 186 (TL6).

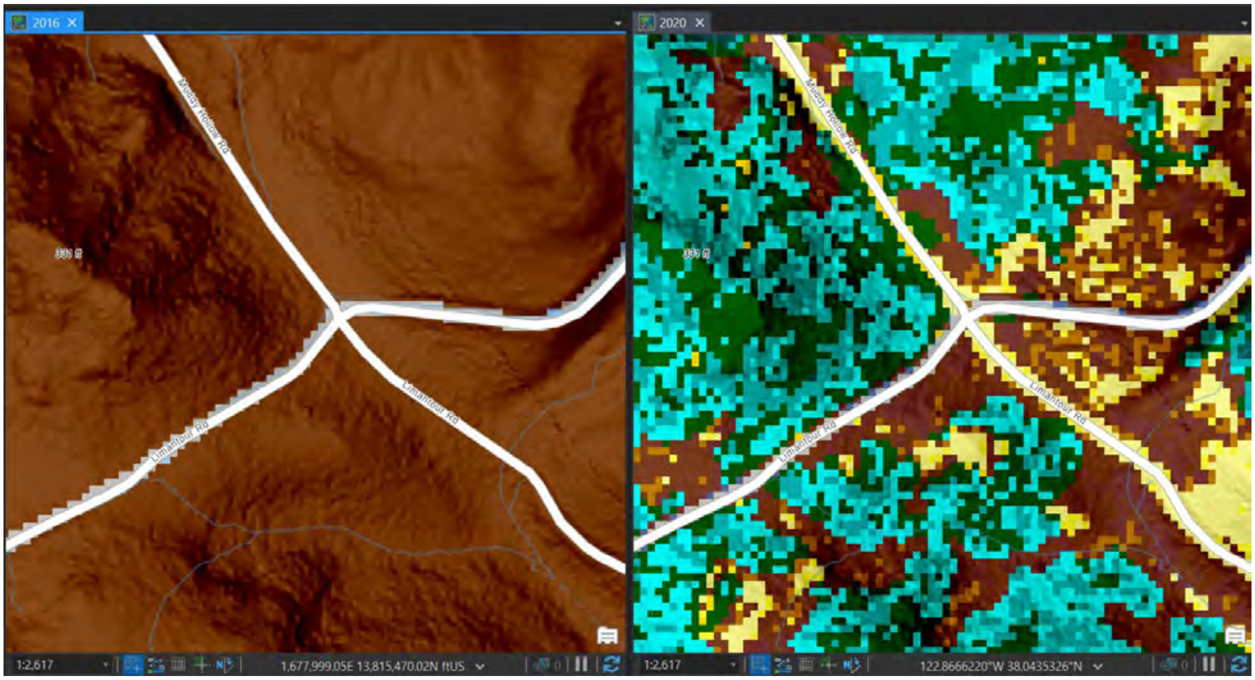

Figure 9. Close up of the intersection of Limantour Rd and Muddy Hollow Rd where previously mapped fuel model 144 (SH4) was re-assigned to several different fuel models (2016 data shown on the left, 2020 data shown on the right).

In the next section, we show how those changes affect the predicted fire behavior in Marin County.

Fire Behavior Prediction Comparison

Several fire behavior prediction software applications have been developed by the U.S. Forest Service. These include a wide variety of applications designed to specifically meet firefighting or fire prevention needs. For this analysis, we used FlamMap version 6.1.

FlamMap is a fire behavior mapping and analysis program that computes potential fire behavior characteristics (spread rate, flame length, fireline intensity, etc.). The FlamMap fire mapping and analysis system calculates fire behavior for each pixel within the landscape file independently. It is designed for use by users familiar with fuels, weather, topography, wildfire situations and the associated terminology. Outputs are well-suited for landscape level comparisons of fuel treatment effectiveness because fuel is the only variable that changes. Outputs and comparisons can be used to identify combinations of hazardous fuel and topography, aiding in prioritizing fuel treatments[5].

A standard fuel moisture regime was chosen for both scenarios. This includes using statewide parameters developed by CAL FIRE for fire predictions based on worst-case conditions augmented by local weather station analysis.

Table 6. Fuel moistures used for fire behavior predications.

Fuel Model	1hr time lag class	10hr time lag class	100 hr time lag class	Live herbaceous fuel moisture	Live woody fuel moisture
All models	4	5	10	40	60

The inputs into the FlamMap scenarios, both for the 2015/2016 and 2020 fuel model datasets, are summarized in the table below.

Table 7. Model parameters used for scenarios in FlamMap.

Parameter:	***Description/File:***
Landscape File:	Scenario 1: 2015/2016 landscape file (Marin_5m_scaled.lcp) Scenario 2: 2020 landscape file (LCP_Nov2020.lcp)
Custom Fuel Model File:	n/a
Fuel Moisture File:	4-5-10-40-60.fms
Winds:	10 mph at 45 degrees azimuth
Fuel Moisture Settings:	Not used
Condition Period:	Not used
Foliar Moisture Content:	100%
Crown Fire Calc Method:	Scott/Reinhardt(2001)
Outputs:	Flame Length, Rate of Spread, and Crown Fire Activity

[5] Source: https://www.fs.usda.gov/rmrs/tools/flammap (accessed on 7/26/2021).

2020 LCP Results

The following maps and brief description show the range of predicted fire behavior in Marin County using the 2020 landscape file (that includes the 2020 fuel model data described in previous sections of this document).

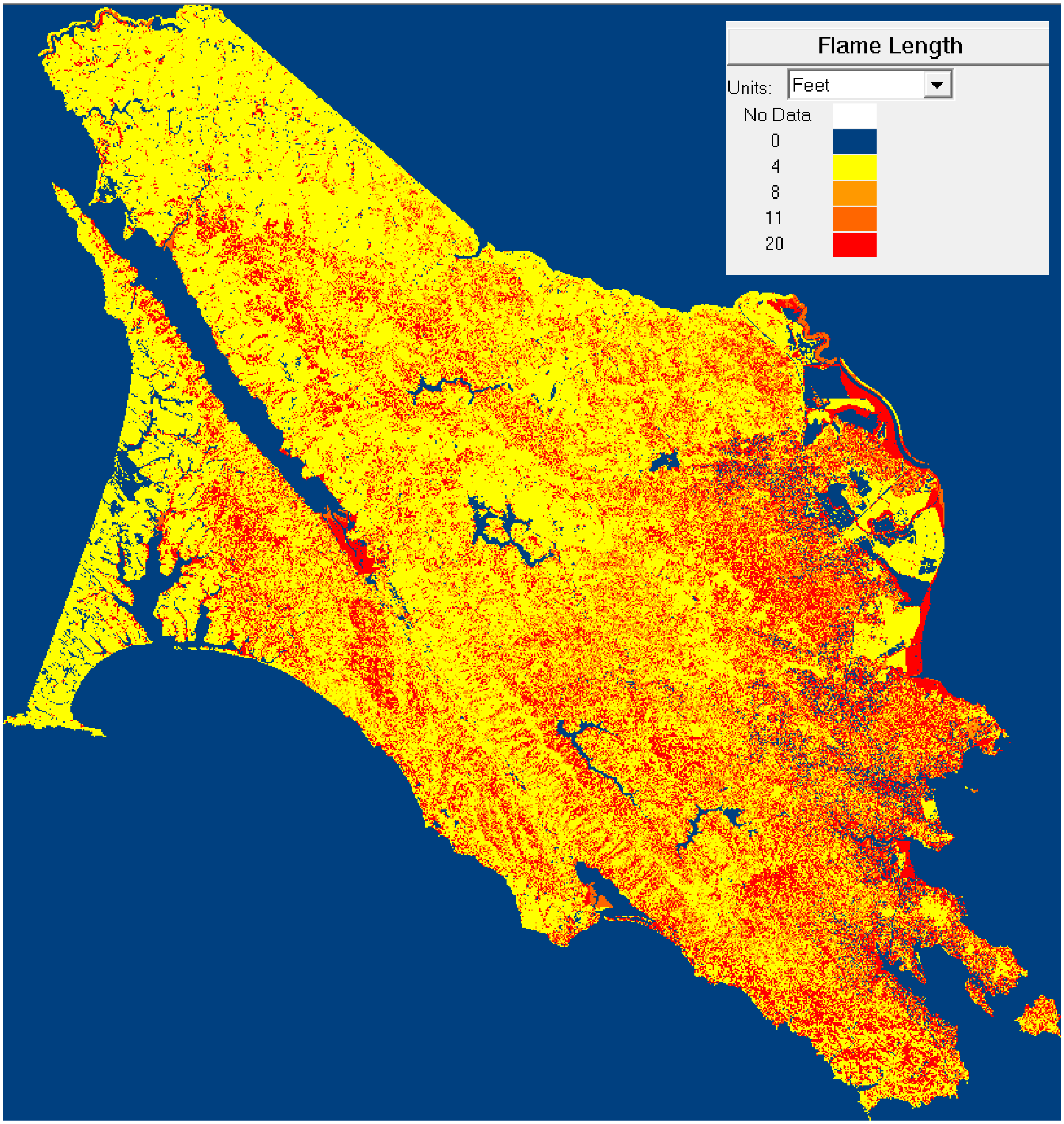

Figure 10. Predicted flame length based on the 2020 fuel model landscape file (STI, 2020).

Flame length is an indicator of fire intensity. It is the distance between the flame tip and the midpoint of the flame depth at the base of the flame (generally the ground surface). In this scenario, flame length is predicted to range from 2 feet to over 20 feet in pockets throughout the county, primarily in locations where dense canopy cover and shrubs exist. Less fire intensity is predicted in the norther part of the county and where grasslands prevail.

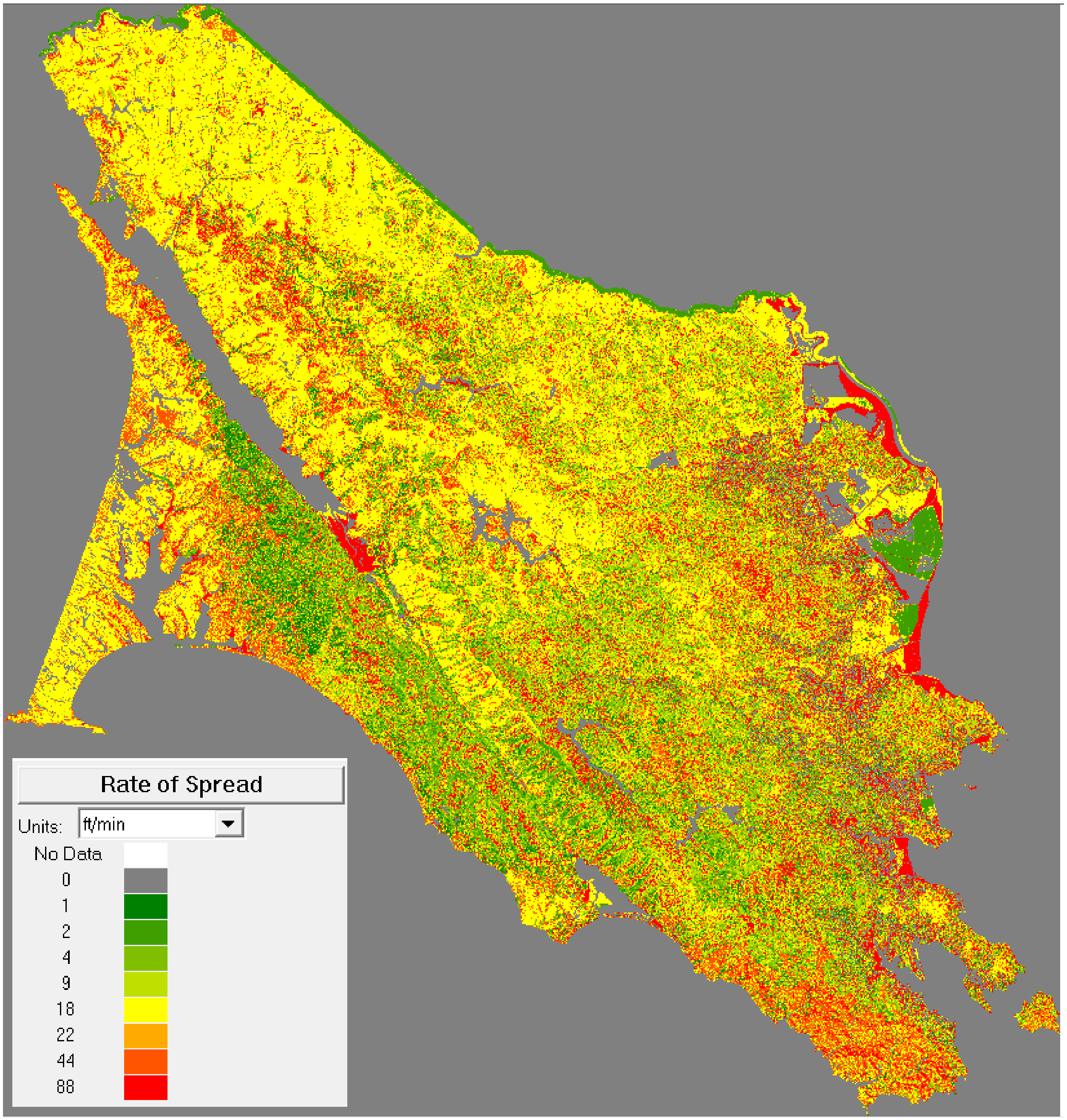

Figure 11. Predicted rate of spread based on the 2020 fuel model landscape file (STI, 2020).

Rate of spread is a measure of the speed with which a fire moves in a horizontal direction across the landscape, usually expressed in chains per hour or feet per minute. Rate of spread ranges from 1 to 88 feet per minute in a pattern across the county that follow where there is tree canopy rate of spread is slower and where there is dense shrubs rate of spread is highest. Grasslands have a moderate rate of spread.

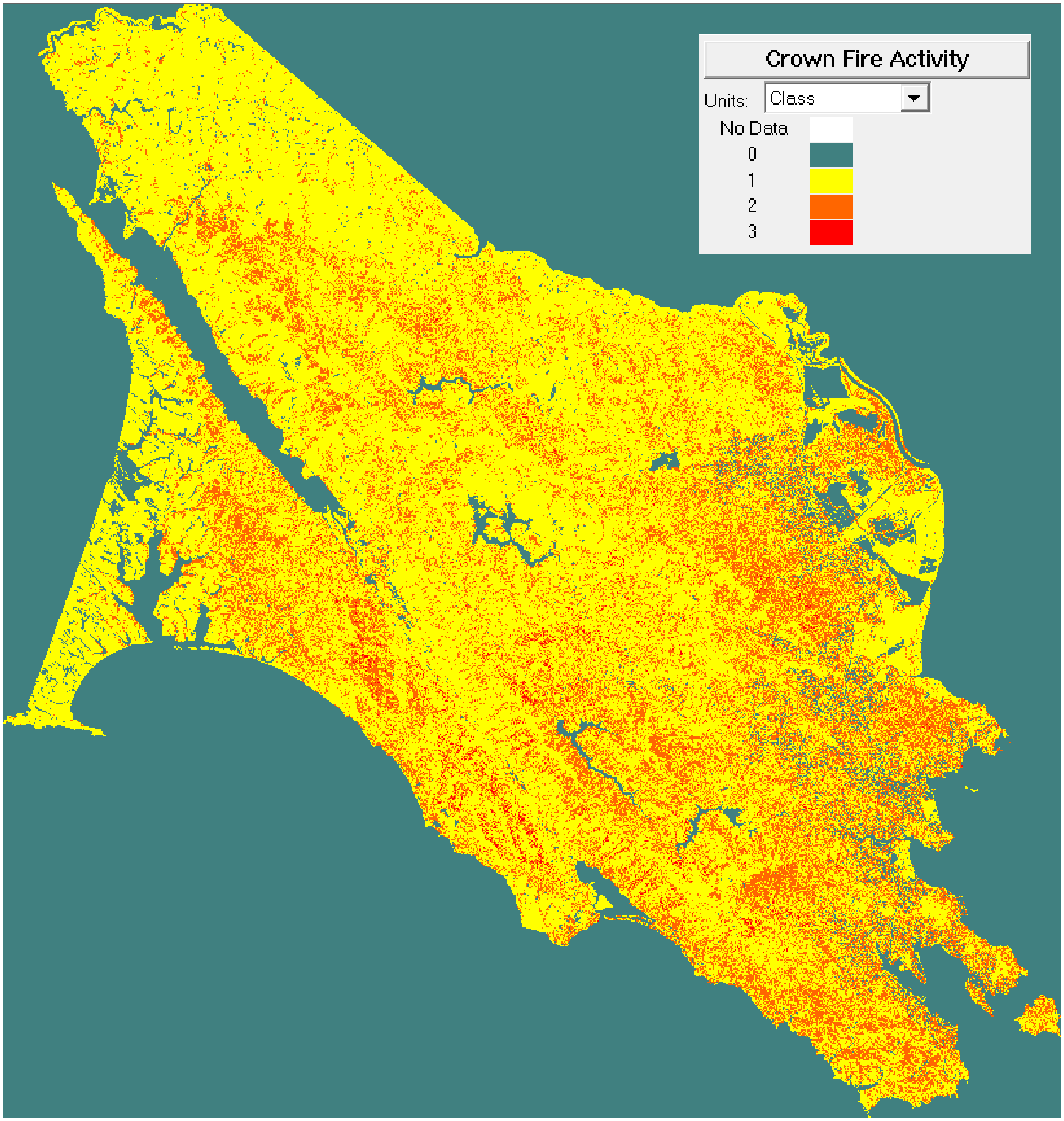

Figure 12. Predicted crown fire activity based on the 2020 fuel model landscape file (STI, 2020).

Crown fire activity is a measure of the type of wind driven crown fire can be expected at any given location in Marin County. On the map above, a fire type of 1 (or yellow) indicates only a surface fire is predicted. A fire type of 2 (or orange) indicates a passive or torching fire. And a fire type of 3 (or red) indicates an active crown fire (when the fire propagates through the crowns of trees independent of a surface fire).

An active crown fire is very rare and has not been documented in Marin County.

In the predicted results above, there are scattered areas throughout Marin County where torching is predicted, with some crown fire activity in limited areas.

2015/2016 LCP Results

The following maps and brief description show the range of predicted fire behavior in Marin County using the 2015/2016 landscape file (that includes the 2015/2016 fuel model data described in previous sections of this document).

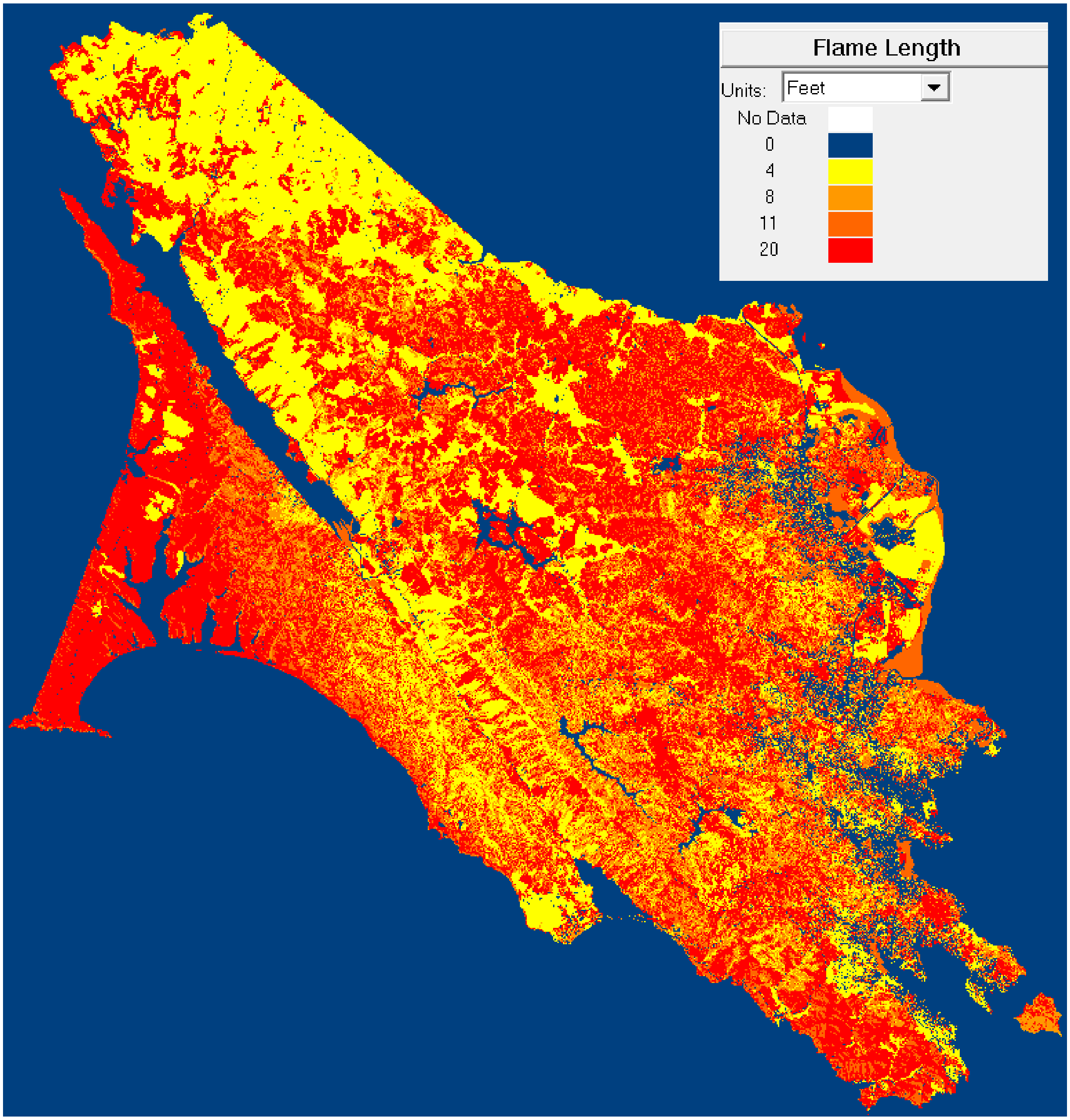

Figure 13. Predicted flame length based on the 2015/2016 fuel model landscape file (Huang, 2016).

In this scenario, flame length is predicted to be very high (over 20 feet) for much of Marin County. Less fire intensity is predicted in the norther part of the county where grassland prevail.

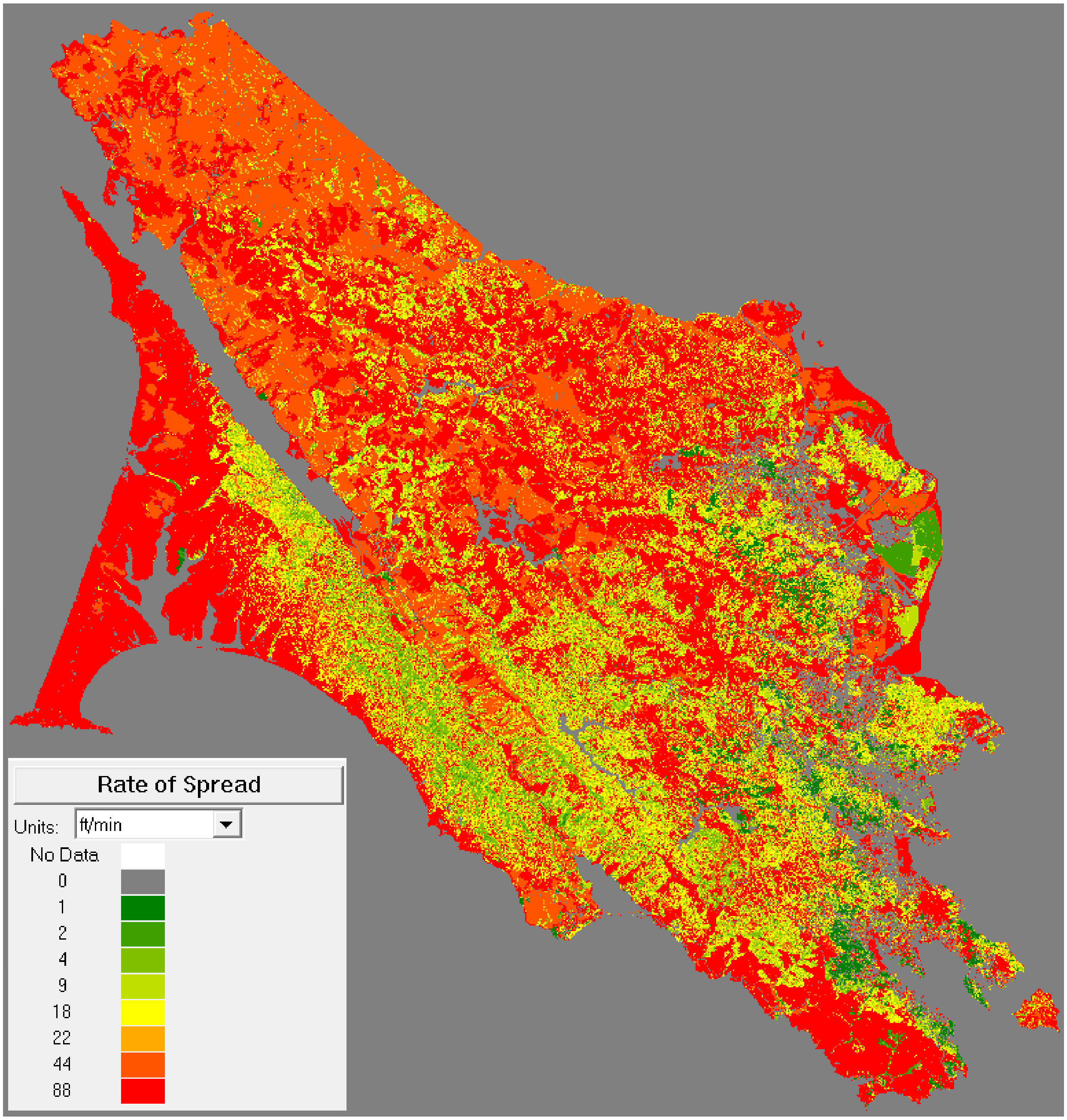

Figure 14. Predicted rate of spread based on the 2015/2016 fuel model landscape file (Huang, 2016).

Rate of spread is very high (over 88 feet per minute) in areas along the Point Reyes National Seashore, at the very southern tip of Marin County, and throughout the county where shrubs and grass persist. Lower rates of spread are predicted in the heavily treed areas west of the San Andreas Fault.

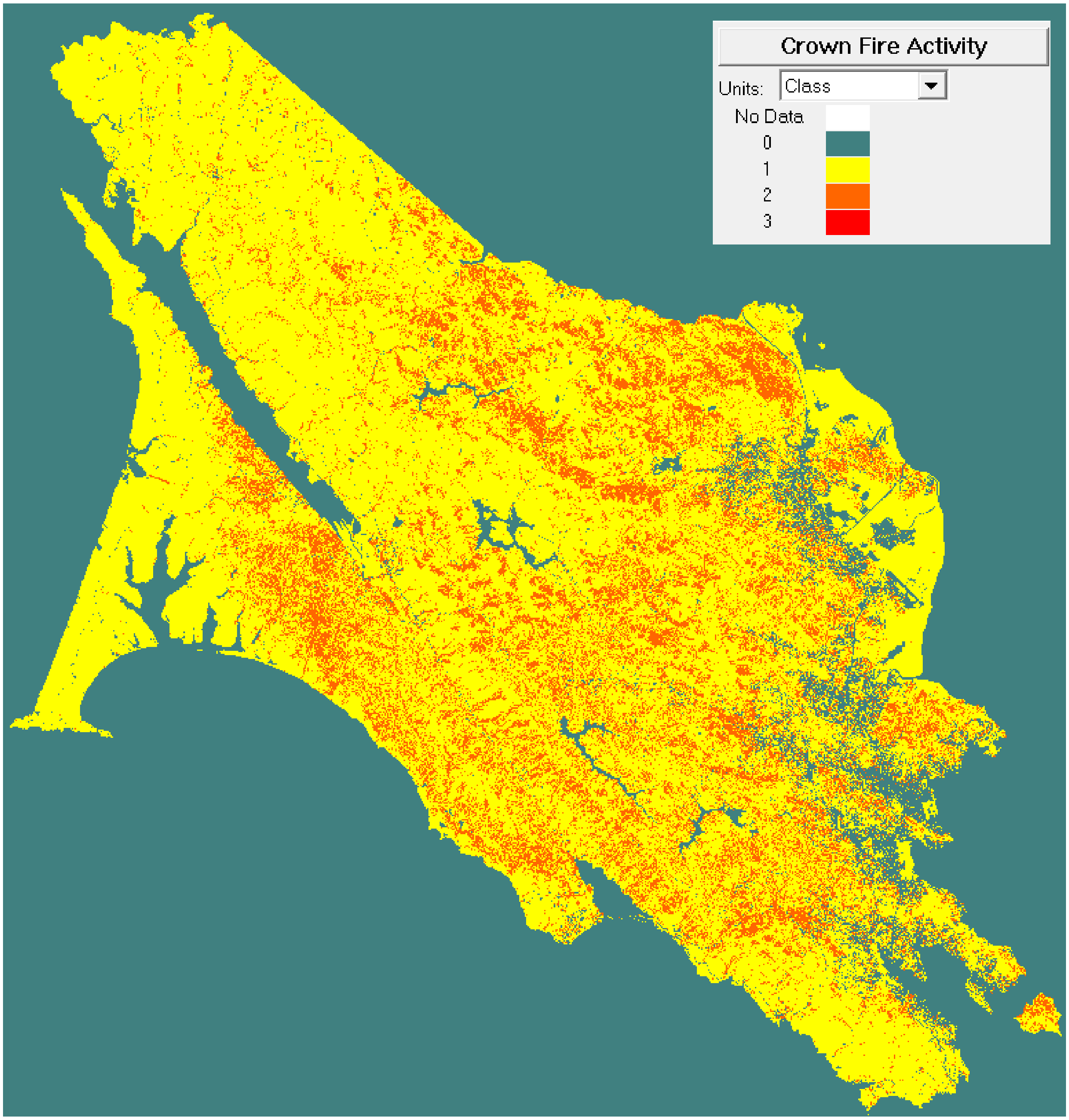

Figure 15. Predicted crown fire activity based on the 2015/2016 fuel model landscape file (Huang, 2016).

In the predicted results above, there are scattered areas throughout Marin County where torching is predicted, but no crown fire activity. This is likely due to a faulty or inaccurate crown base height layer in the landscape file.

Field Verification

We conducted two field visits into areas of Marin County with extensive wildland fuels. Our first visit was on August 4th, 2021 and the second was August 10th, 2021. Our aim was to target forested areas, particularly Oak Woodlands and Cypress/Monterey pine. However, we did not exclude other vegetation types.

During the visits, we recorded our location, acquired photos, and evaluated the application of the assigned fuel model and suggested changes to the **2020** fuel model assignment based on our observations, if any. Each area we visited was given a field point number. We have organized this section by those numbers.

Field Point 1

Figure 16. Field point #1 visited on 08/04/2021. Photo courtesy of Carol L. Rice.

Location:	**37.973468, -122.599325**
Mapped Vegetation (2020):	*Quercus agrifolia* (Coast live oak)
2015 Fuel Model Assignment:	165 (TU5) and 189 (TL9)
2020 Fuel Model Assignment:	165 (TU5)
Observations:	Field point 1 is located along Bolinas Road just south of Fairfax. The primary carry of fire would be the persistent grass throughout the immediate area surrounding this field point. Grass exists beneath tree canopies and in the open areas. GR2 should be applied to all vegetation types that within this area.
Suggested Fuel Model Assignment:	102 (GR2)

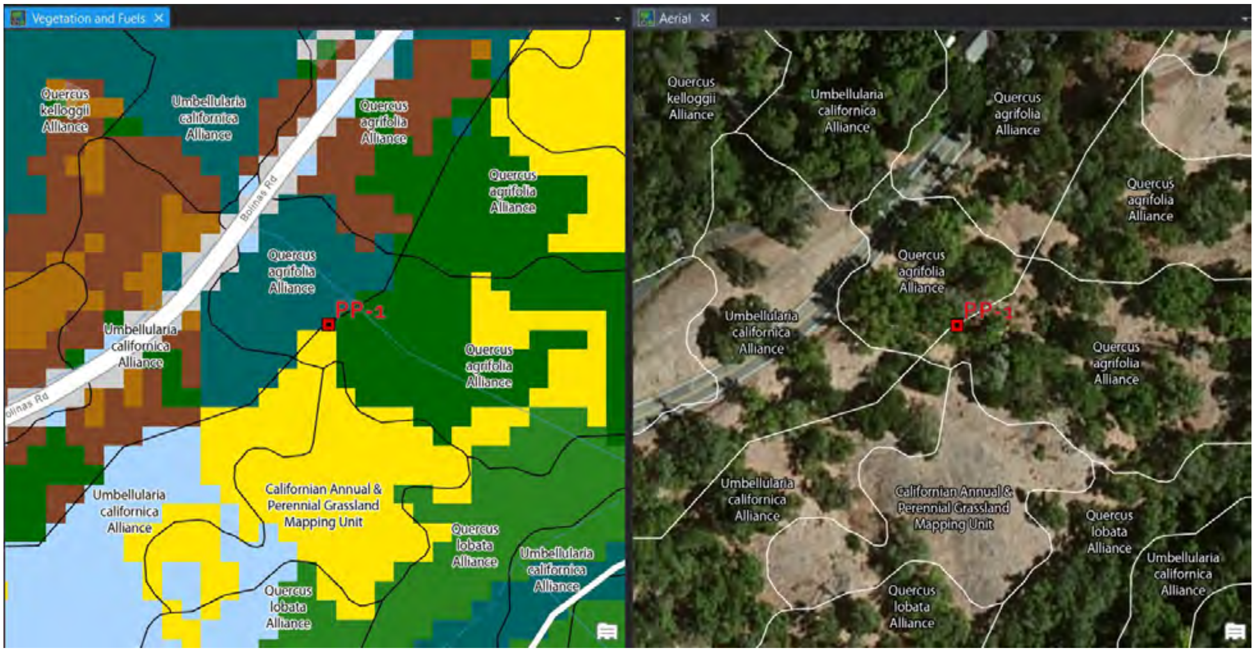

Figure 17. At field point 1, 2015 fuel model assignments shown next to 2019 aerial image (for comparison purposes only). 2018 fine-scale vegetation polygons shown in black/white outlines on both maps for reference only.

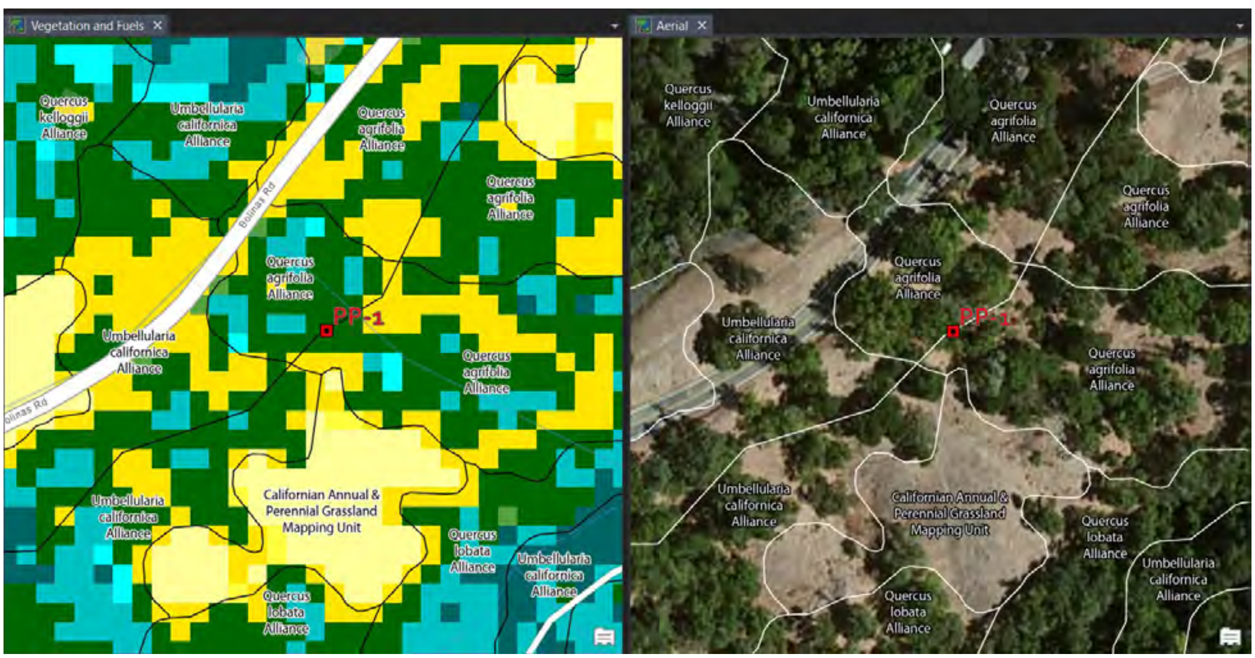

Figure 18. At field point 1, 2020 fuel model assignments shown next to 2019 aerial image (for comparison purposes only). 2018 fine-scale vegetation polygons shown in black/white outlines on both maps for reference only.

Field point 2

Figure 19. Field point #2 visited on 08/04/2021. Photo courtesy of Carol L. Rice.

Location:	**37.96033, -122.611212**
Mapped Vegetation (2020):	*Quercus kelloggii* (California black oak)
2015 Fuel Model Assignment:	181 (TL1)
2020 Fuel Model Assignment:	165 (TU5) and 189 (TL9)
Observations:	Field point 2 is located within Marin Municipal Water District lands next to Bull Frog Rd off Bon Temple Rd. This site has seen extensive fuel treatments which have occurred within the past 5 years. The primary carry of fire would compact litter and sporadic grasses. The 2020 fuel model assignments will grossly over-predict fire behavior in this stand. The 2015 fuel model assignment will most closely match expected fire behavior; however, this fuel model is usually applied to conifers (less litter compaction) rather than hardwoods.
Suggested Fuel Model Assignment:	182 (TL2) or 161 (TU1)

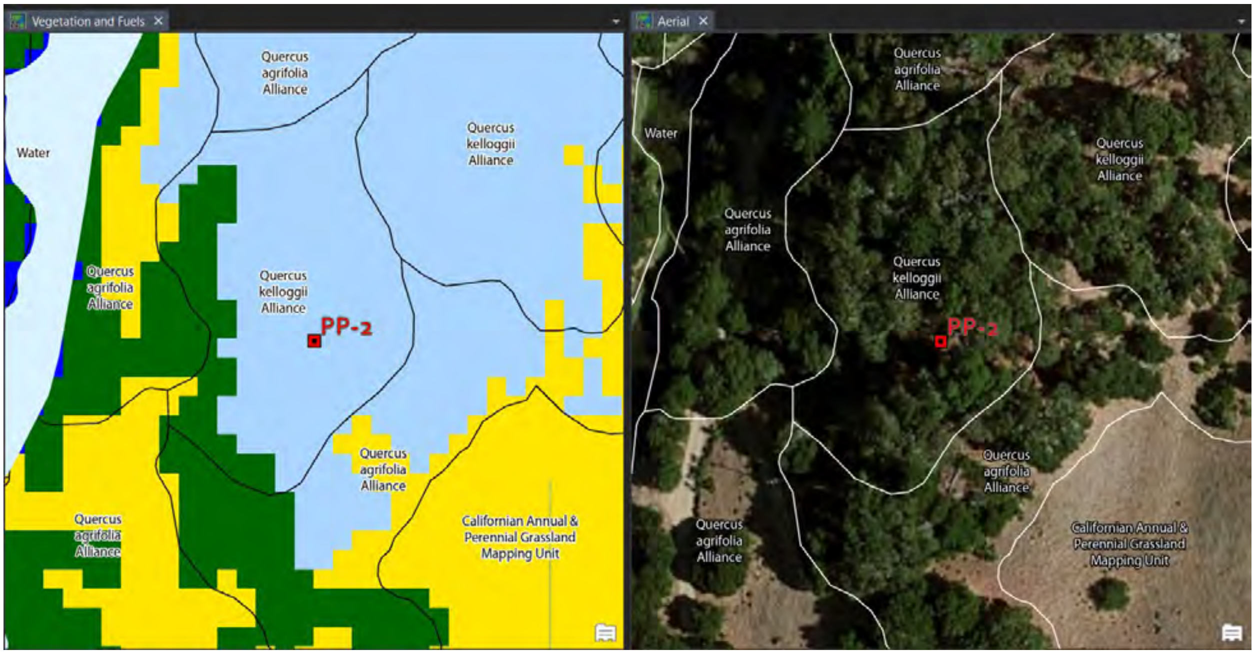

Figure 20. At field point 2, 2015 fuel model assignments shown next to 2019 aerial image (for comparison purposes only). 2018 fine-scale vegetation polygons shown in black/white outlines on both maps for reference only.

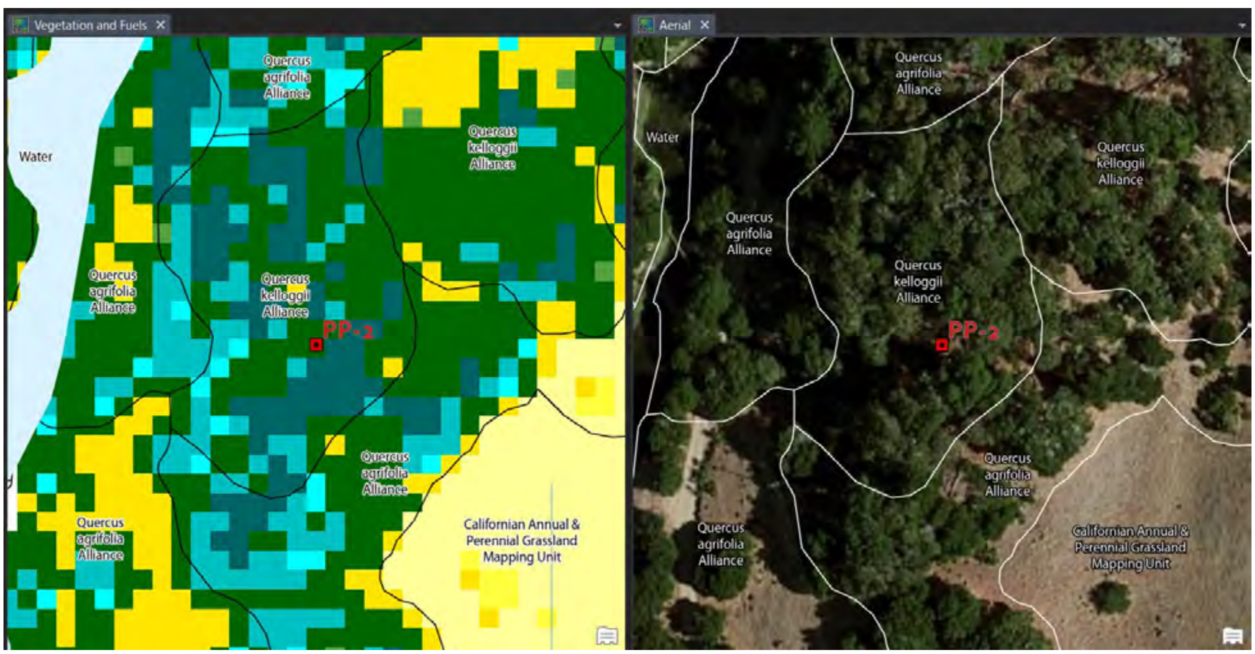

Figure 21. At field point 2, 2020 fuel model assignments shown next to 2019 aerial image (for comparison purposes only). 2018 fine-scale vegetation polygons shown in black/white outlines on both maps for reference only.

Field point 3

Figure 22. Field point #3 visited on 08/04/2021. Photo courtesy of Carol L. Rice.

Location:	**37.014592, -122.636926**
Mapped Vegetation (2020):	*Sequoia sempervirens* (Redwood)
2015 Fuel Model Assignment:	165 (TU5)
2020 Fuel Model Assignment:	189 (TL9)
Observations:	Field point 3 is located immediately south along San Geronimo Valley Dr (south of Sir Francis Drake Blvd). The field point's immediate location and surrounding area is dominated by tall redwoods. The understory varies from dense to open. Both the 2015 and 2020 fuel model assignments will likely over-predict fire behavior in this stand.
Suggested Fuel Model Assignment:	183 (TL3), 185 (TL5), or 188 (TL8) depending on canopy cover and presence of understory, fuel loading, or time since last fire.

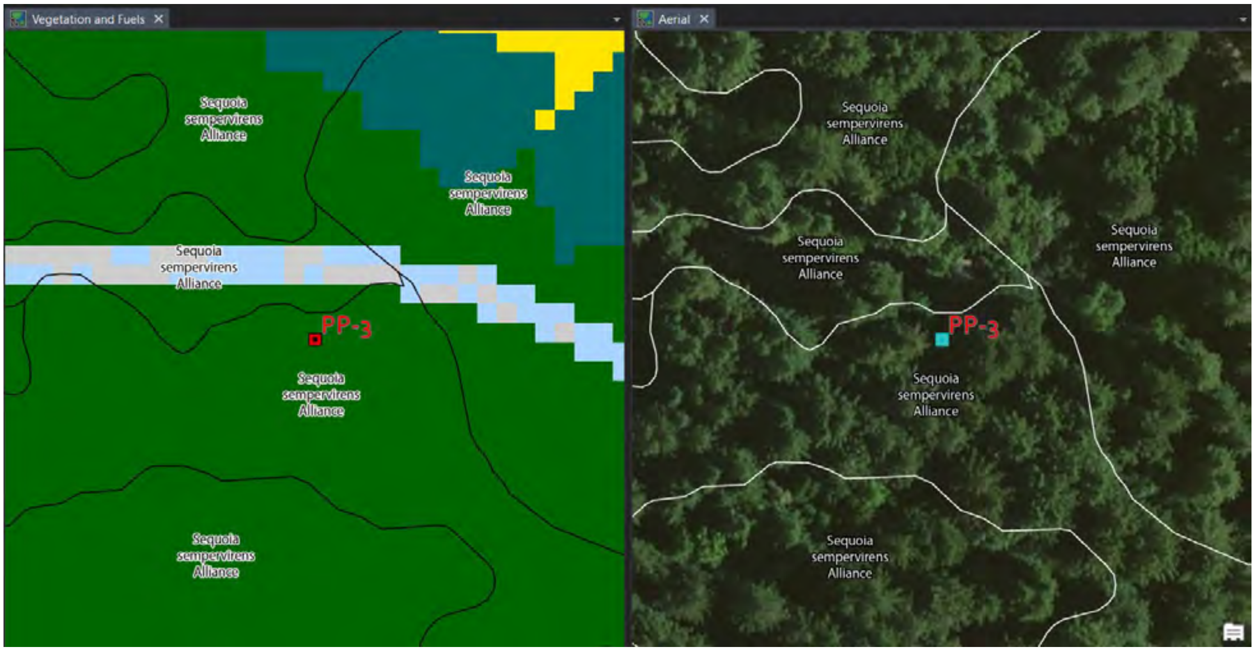

Figure 23. At field point 3, 2015 fuel model assignments shown next to 2019 aerial image (for comparison purposes only). 2018 fine-scale vegetation polygons shown in black/white outlines on both maps for reference only.

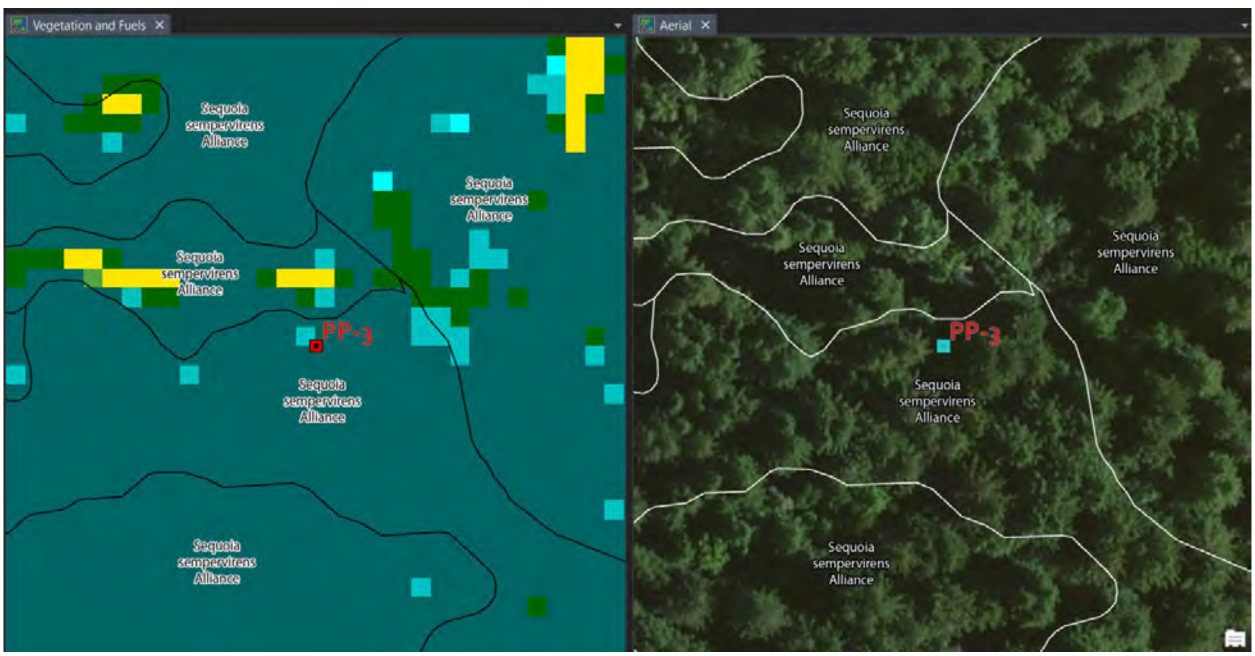

Figure 24. At field point 3, 2020 fuel model assignments shown next to 2019 aerial image (for comparison purposes only). 2018 fine-scale vegetation polygons shown in black/white outlines on both maps for reference only.

Field point 4

Figure 25. Field point #4 visited on 08/04/2021. Photo courtesy of Carol L. Rice.

Location:	**37.016534, -122.661197**
Mapped Vegetation (2020):	California Annual & Perennial Grassland
2015 Fuel Model Assignment:	104 (GR4)
2020 Fuel Model Assignment:	101 (GR1)
Observations:	Field point 4 is located within county park land next to a parking lot (see aerial on next page), just off Sir Francis Drake Blvd. The field point's immediate location and surrounding area is dominated by grasslands transitioning into mixed-hardwood forests.
Suggested Fuel Model Assignment:	102 (GR2) for ungrazed areas; 101 (GR1) for grazed areas. Note: Developed area (parking lot) is mapped in the 2015 fuel model area as unburnable, however, in the 2020 fuel model it is mapped as 165 (TU5) and various shrub models (SH#).

Figure 26. At field point 4, 2015 fuel model assignments shown next to 2019 aerial image (for comparison purposes only). 2018 fine-scale vegetation polygons shown in black/white outlines on both maps for reference only.

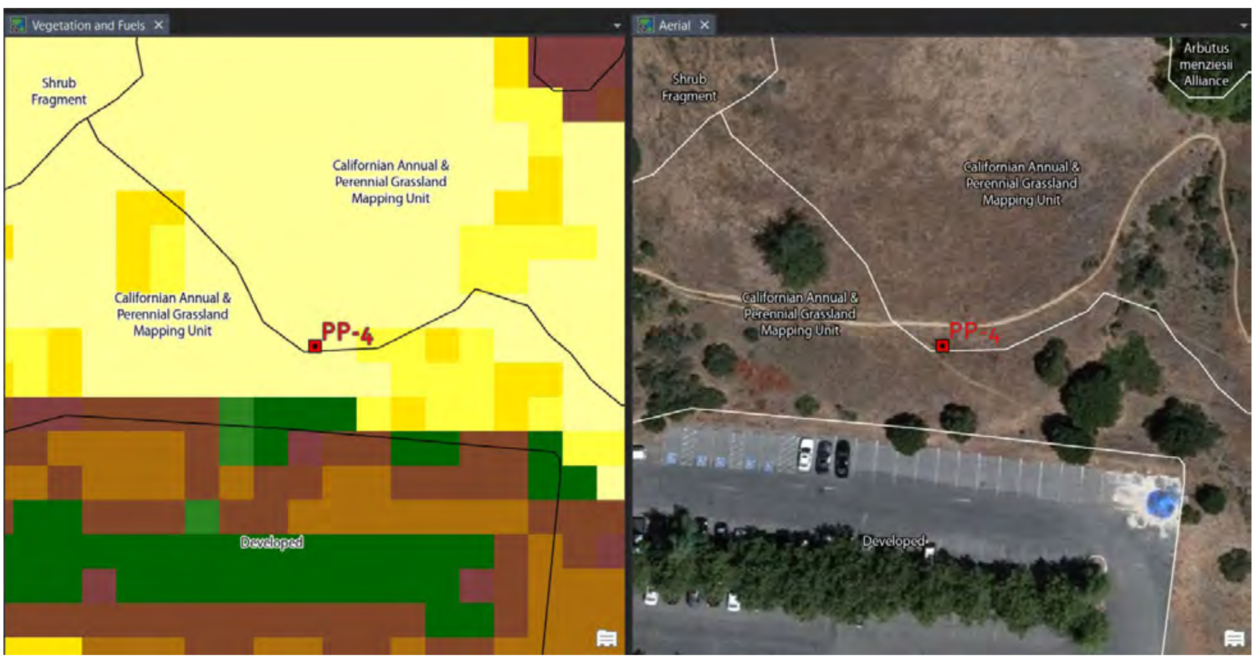

Figure 27. At field point 4, 2020 fuel model assignments shown next to 2019 aerial image (for comparison purposes only). 2018 fine-scale vegetation polygons shown in black/white outlines on both maps for reference only.

Field point 5

Figure 28. Field point #5 visited on 08/04/2021. Photo courtesy of Carol L. Rice.

Location:	37.02059, -122.660412
Mapped Vegetation (2020):	*Sequoia sempervirens* (Redwood)
2015 Fuel Model Assignment:	189 (TL9)
2020 Fuel Model Assignment:	189 (TL9)
Observations:	Field point 5 is located east of Nicasio Valley Rd near Sir Francis Drake Blvd. The field point's immediately location and surrounding area is dominated by tall redwoods with signs of relatively recent fire scars (within the last 10 to 15 years). The understory varies from dense to open. Both the 2015 and 2020 fuel model assignment will likely over-predict fire behavior in this stand.
Suggested Fuel Model Assignment:	183 (TL3), 185 (TL5), or 188 (TL8) depending on canopy cover and presence of understory, fuel loading, or time since last fire.

Figure 29. At field point 5, 2015 fuel model assignments shown next to 2019 aerial image (for comparison purposes only). 2018 fine-scale vegetation polygons shown in black/white outlines on both maps for reference only.

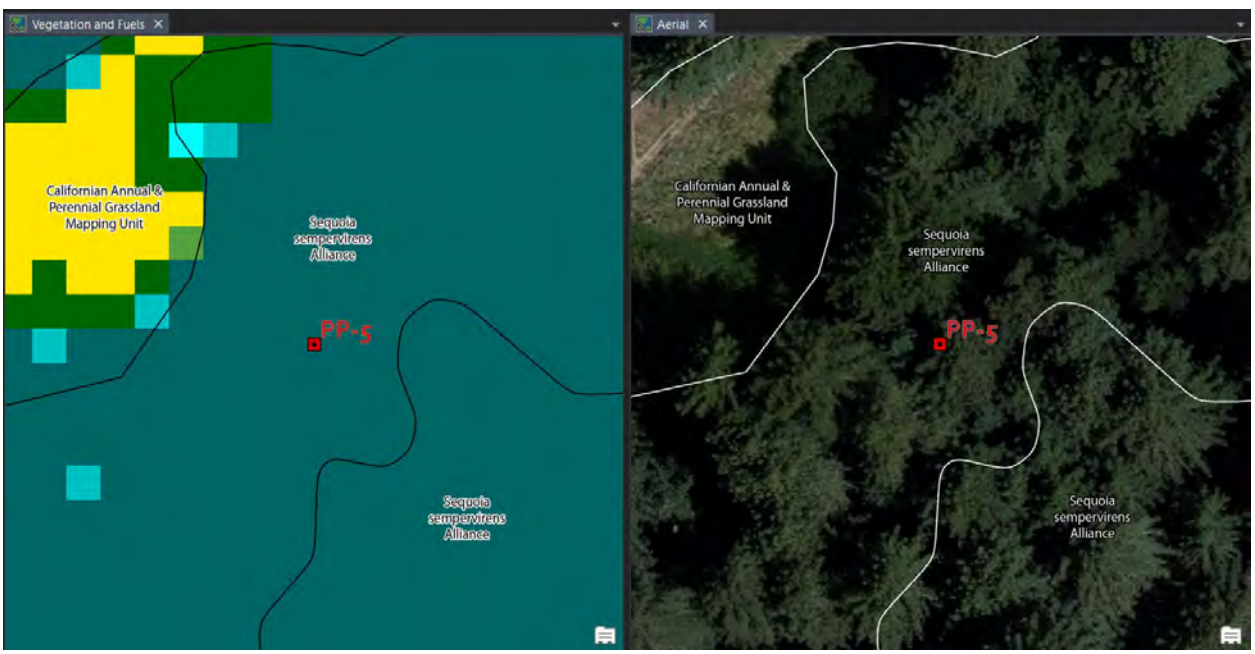

Figure 30. At field point 5, 2020 fuel model assignments shown next to 2019 aerial image (for comparison purposes only). 2018 fine-scale vegetation polygons shown in black/white outlines on both maps for reference only.

Field point 6

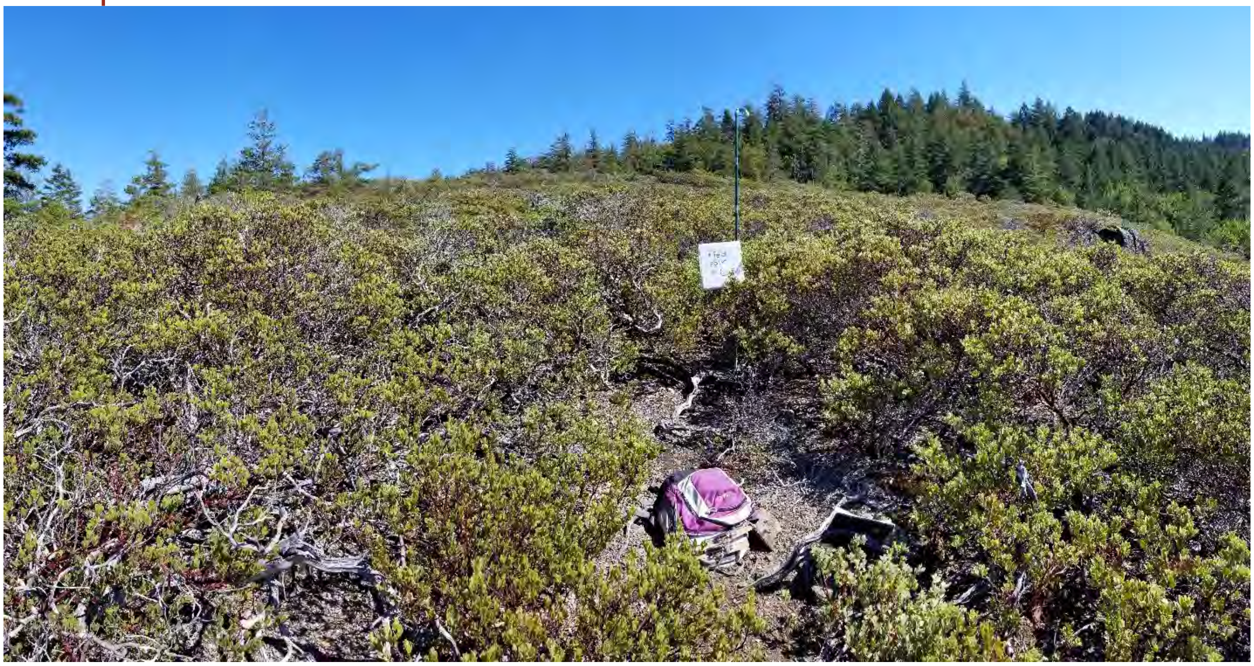

Figure 31. Field point #6 visited on 08/04/2021. Photo courtesy of Carol L. Rice.

Location:	**37.009576, -122.665326**
Mapped Vegetation (2020):	*Arctostaphylos (bakeri, montana)* (manzanita)
2015 Fuel Model Assignment:	147 (SH7)
2020 Fuel Model Assignment:	141 (SH1) and 145 (SH5)
Observations:	Field point 6 is located south of San Geronimo within the Marin Municipal Water District lands (accessible by foot). The field point's immediate location and surrounding area is dominated by waist to chest high shrubs with very little grass.
Suggested Fuel Model Assignment:	No suggestion

Figure 32. At field point 6, 2015 fuel model assignments shown next to 2019 aerial image (for comparison purposes only). 2018 fine-scale vegetation polygons shown in black/white outlines on both maps for reference only.

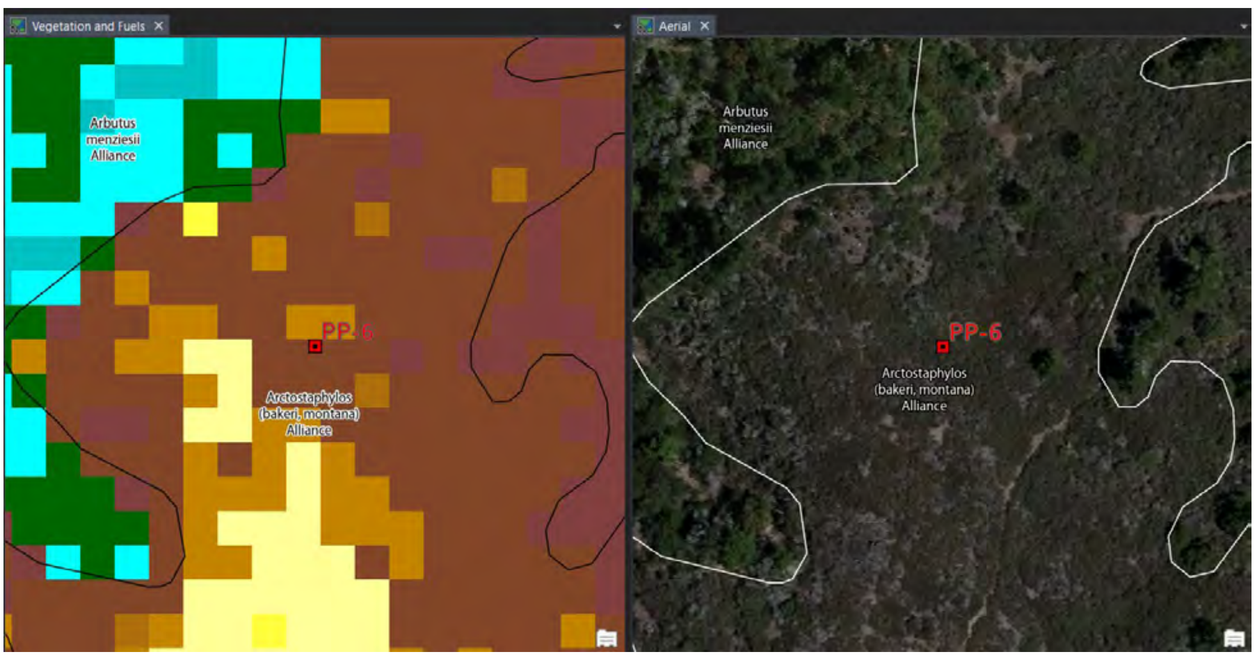

Figure 33. At field point 6, 2020 fuel model assignments shown next to 2019 aerial image (for comparison purposes only). 2018 fine-scale vegetation polygons shown in black/white outlines on both maps for reference only.

Field point 7

Figure 34. Field point #7 visited on 08/10/2021. Photo courtesy of Carol L. Rice.

Location:	**37.004087, -122.615424**
Mapped Vegetation (2020):	California Annual & Perennial Grassland
2015 Fuel Model Assignment:	165 (TU5)
2020 Fuel Model Assignment:	165 (TU5)
Observations:	Field point 7 is located on private land just west of Sir Francis Drake Blvd near Fairfax. The field point's immediate location and surrounding area is dominated by hardwood forest with a shrub and grass understory.
Suggested Fuel Model Assignment:	No suggestion

Figure 35. At field point 7, 2015 fuel model assignments shown next to 2019 aerial image (for comparison purposes only). 2018 fine-scale vegetation polygons shown in black/white outlines on both maps for reference only.

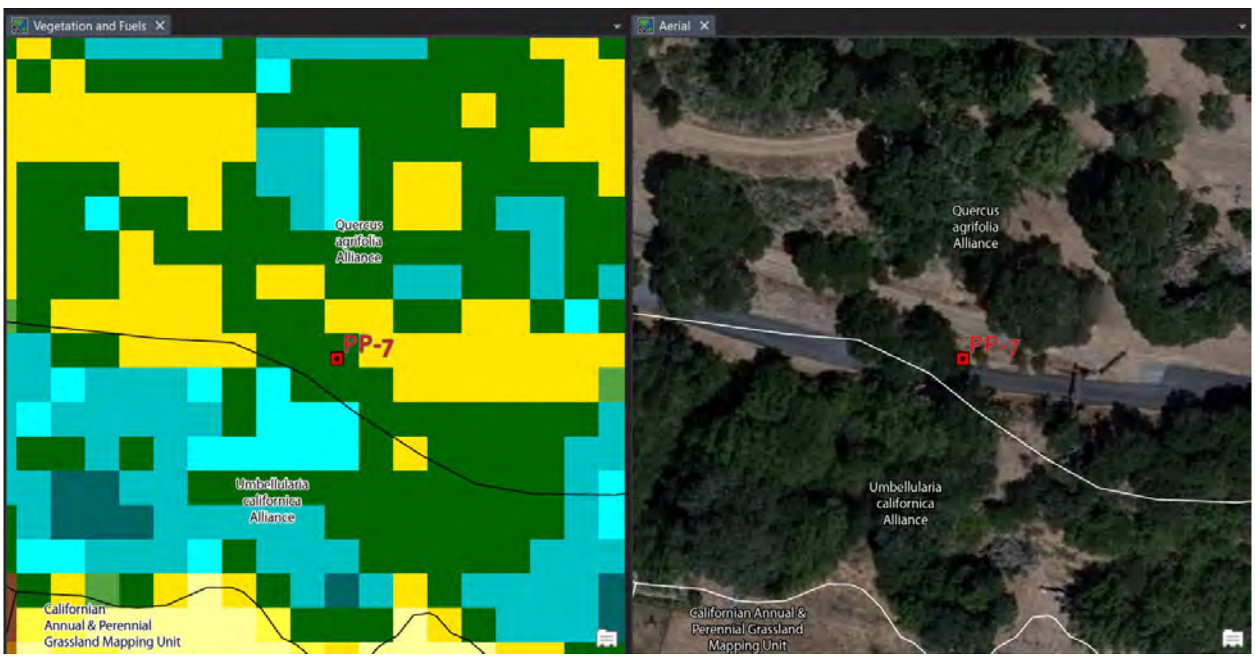

Figure 36. At field point 7, 2020 fuel model assignments shown next to 2019 aerial image (for comparison purposes only). 2018 fine-scale vegetation polygons shown in black/white outlines on both maps for reference only.

Field point 8

Figure 37. Field point #8 visited on 08/10/2021. Photo courtesy of Carol L. Rice.

Location:	**37.016139, -122.638414**
Mapped Vegetation (2020):	California Annual & Perennial Grassland
2015 Fuel Model Assignment:	101 (GR1)
2020 Fuel Model Assignment:	101 (GR1)
Observations:	Field point 8 is located just off Sir Francis Drake Blvd. The field point's immediate location and surrounding area is dominated by grasslands transitioning into mixed-hardwood forests. Overall, a GR1 assignment will under-predict fire behavior in areas that are ungrazed.
Suggested Fuel Model Assignment:	102 (GR2) for ungrazed areas; 101 (GR1) for grazed areas. Note: area immediately surround lone trees was assigned a taller grass model (GR2 and GR4), however, grass actually gets shorter immediately beneath the tree canopy.

Figure 38. At field point 8, 2015 fuel model assignments shown next to 2019 aerial image (for comparison purposes only). 2018 fine-scale vegetation polygons shown in black/white outlines on both maps for reference only.

Figure 39. At field point 8, 2020 fuel model assignments shown next to 2019 aerial image (for comparison purposes only). 2018 fine-scale vegetation polygons shown in black/white outlines on both maps for reference only.

Field point 9

Figure 40. Field point #9 visited on 08/10/2021. Photo courtesy of Carol L. Rice.

Location:	**37.014868, -122.655624**
Mapped Vegetation (2020):	California Annual & Perennial Grassland
2015 Fuel Model Assignment:	102 (GR2) and 104 (GR4)
2020 Fuel Model Assignment:	101 (GR1)
Observations:	Field point 9 is also located just off Sir Francis Drake Blvd. The field point's immediate location and surrounding area is dominated by grasslands transitioning into mixed-hardwood forests. Overall, a GR1 assignment will under-predict fire behavior in areas that are ungrazed. The 2015 assignments may better represent the fuels where it is ungrazed.
Suggested Fuel Model Assignment:	102 (GR2) for ungrazed areas; 101 (GR1) for grazed areas.

Figure 41. At field point 9, 2015 fuel model assignments shown next to 2019 aerial image (for comparison purposes only). 2018 fine-scale vegetation polygons shown in black/white outlines on both maps for reference only.

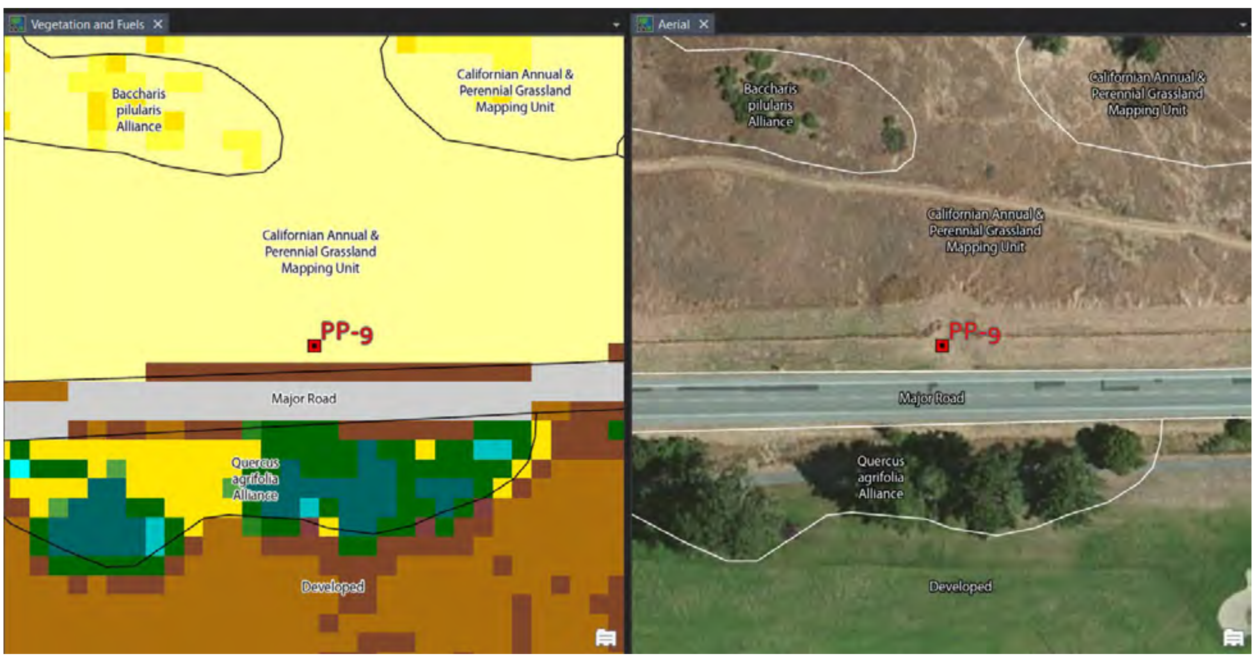

Figure 42. At field point 9, 2020 fuel model assignments shown next to 2019 aerial image (for comparison purposes only). 2018 fine-scale vegetation polygons shown in black/white outlines on both maps for reference only.

Field point 10

Figure 43. Field point #10 visited on 08/10/2021. Photo courtesy of Carol L. Rice.

Location:	**37.030515, -122.739589**
Mapped Vegetation (2020):	*Pseudotsuga menziesii – (Notholithocarpus densiflorus – Arbutus menziesii)* (Douglas fir with tanoak and madrone)
2015 Fuel Model Assignment:	142 (SH2), 145 (SH5), and 189 (TL9)
2020 Fuel Model Assignment:	186 (TL6) and 189 (TL9)
Observations:	Field point 10 is again located just off Sir Francis Drake Blvd. The field point's immediate location and surrounding area is dominated a mixed conifer/hardwood forest with dense understory transitioning to more open areas. Some fuel modification work may have occurred nearby (across the street).
Suggested Fuel Model Assignment:	2020 fuel model assignment are more aligned with the forested location. However, a TU1 or TU5 assignment might better characterize the live fuel component present at this site.

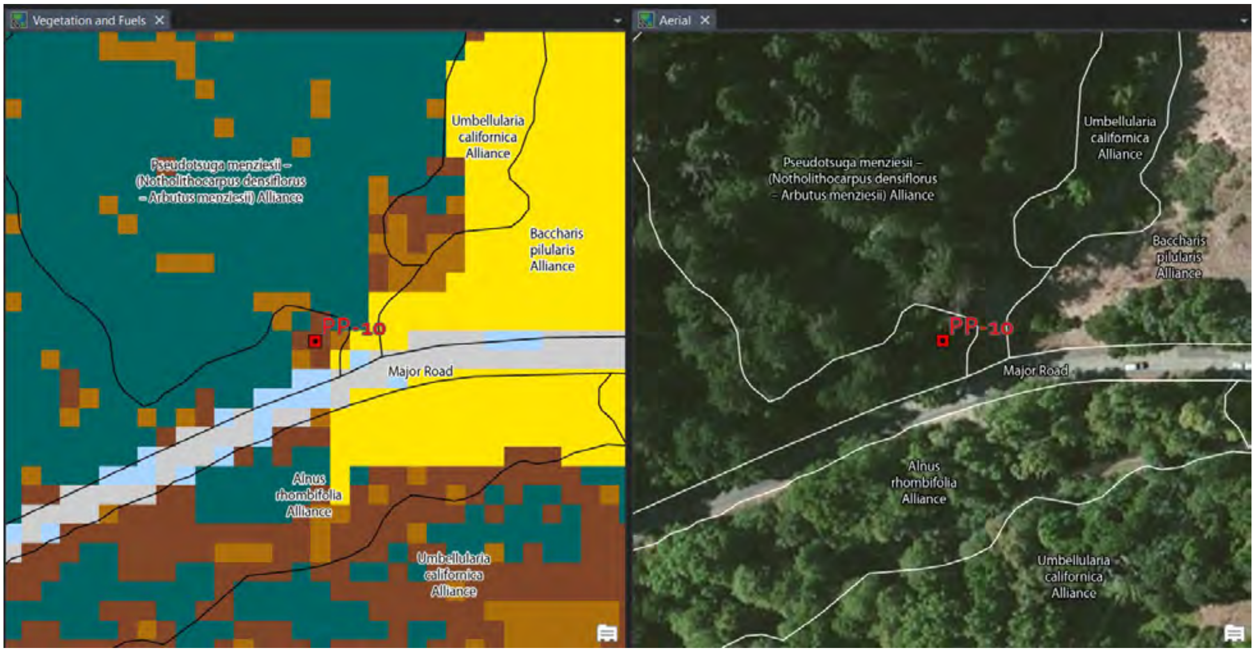

Figure 44. At field point 10, 2015 fuel model assignments shown next to 2019 aerial image (for comparison purposes only). 2018 fine-scale vegetation polygons shown in black/white outlines on both maps for reference only.

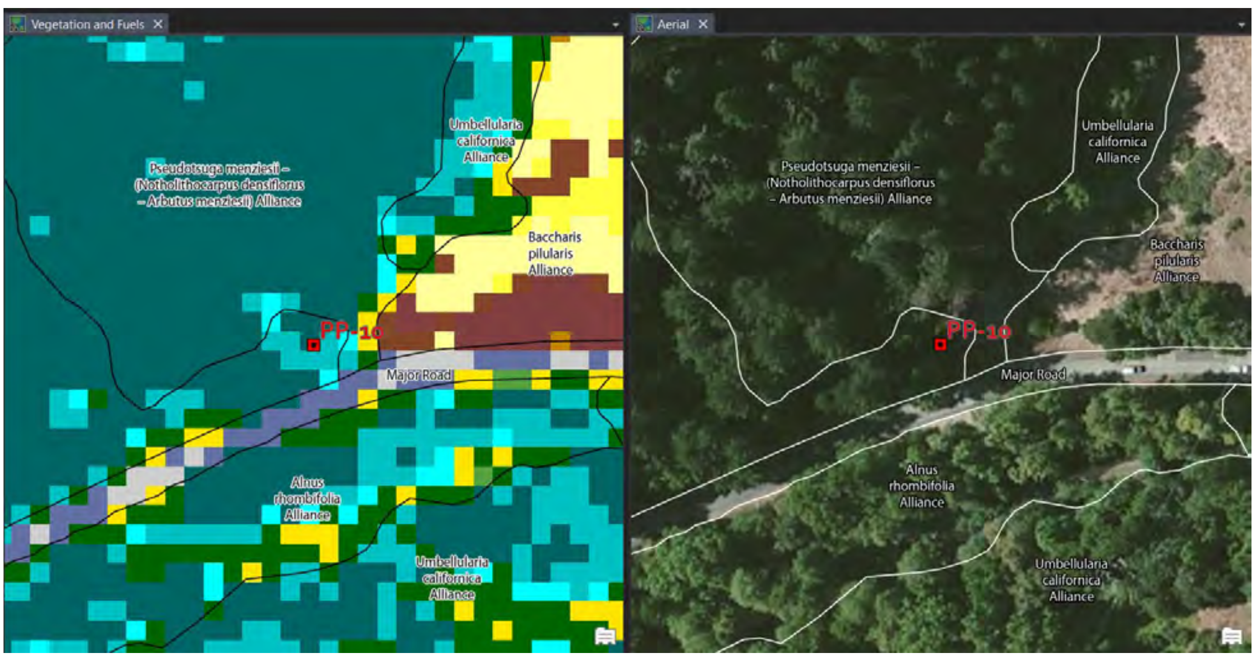

Figure 45. At field point 10, 2020 fuel model assignments shown next to 2019 aerial image (for comparison purposes only). 2018 fine-scale vegetation polygons shown in black/white outlines on both maps for reference only.

Field point 11

Figure 46. Field point #11 visited on 08/10/2021. Photo courtesy of Carol L. Rice.

Location:	**37.052551, -122.812757**
Mapped Vegetation (2020):	*Umbellularia californica* (California bay)
2015 Fuel Model Assignment:	145 (SH5)
2020 Fuel Model Assignment:	165 (TU5) and 189 (TL9)
Observations:	Field point 11 is located just off Limantour Rd within the Point Reyes National Seashore. The field point's immediate location and surrounding area is heavily treed. Recent fuel management activity was noted, and a relatively recent prescribed fire was conducted across the road (to the west, not in the direction photo was taken). The 2015 fuel model assignment is not correct. The 2020 fuel model assignments do not take the recent fuel work into consideration.
Suggested Fuel Model Assignment:	Though this area was mapped as California bay, it is currently primarily a conifer forest with little live understory. Litter would carry the fire in this area. Suggest TL3 or TL5.

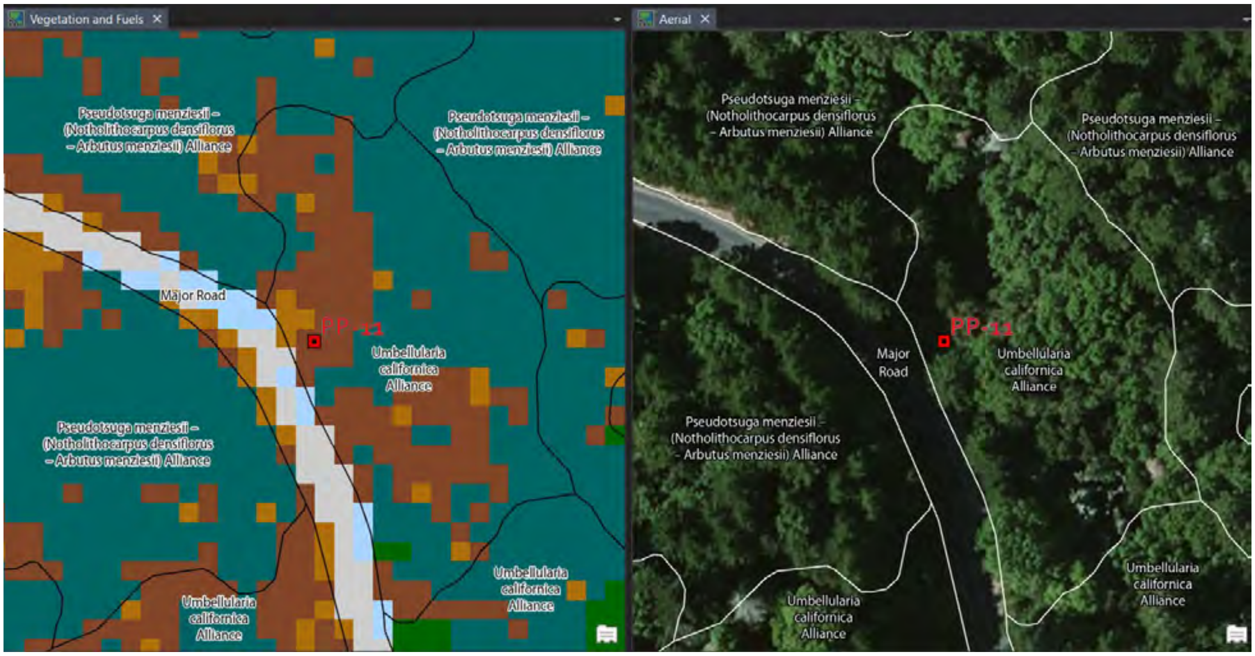

Figure 47. At field point 11, 2015 fuel model assignments shown next to 2019 aerial image (for comparison purposes only). 2018 fine-scale vegetation polygons shown in black/white outlines on both maps for reference only.

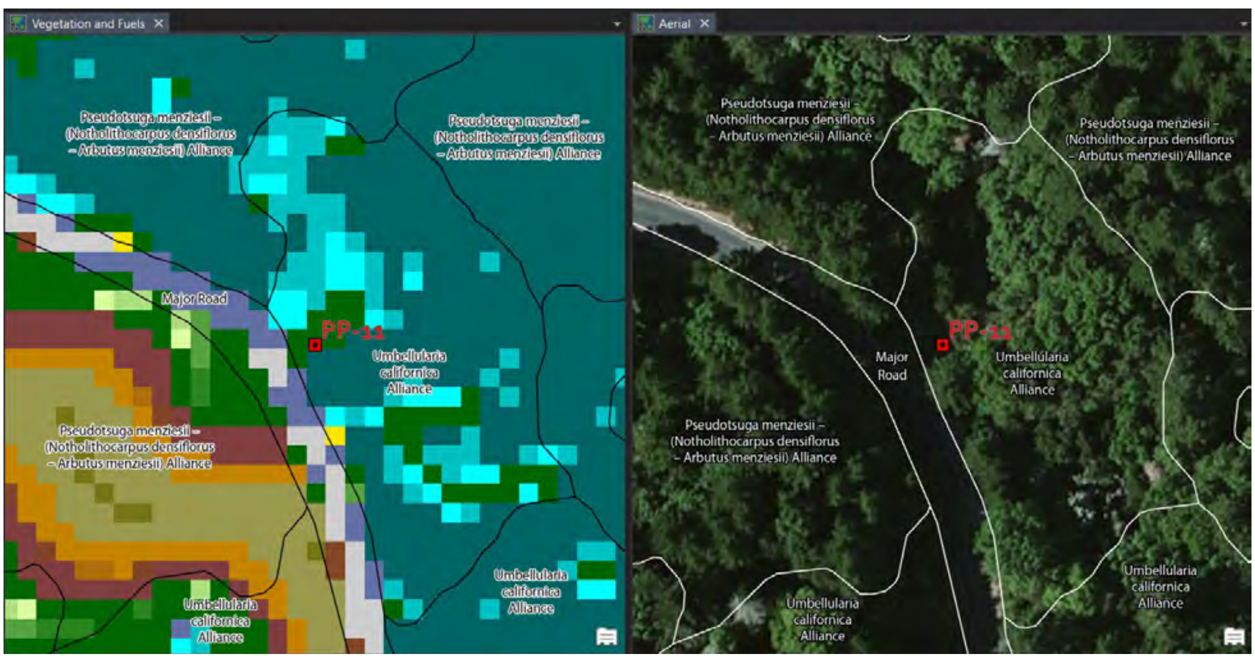

Figure 48. At field point 11, 2020 fuel model assignments shown next to 2019 aerial image (for comparison purposes only). 2018 fine-scale vegetation polygons shown in black/white outlines on both maps for reference only.

Field point 12

Figure 49. Field point #12 visited on 08/10/2021. Photo courtesy of Carol L. Rice.

Location:	**37.058966, -122.844648**
Mapped Vegetation (2020):	*Pinus muricata – Pinus radiata* (Bishop and Monterey pine)
2015 Fuel Model Assignment:	145 (SH5)
2020 Fuel Model Assignment:	104 (GR4), 165 (TU5), 182 (TL2), and 186 (TL6)
Observations:	Field point 12 is also located just off Limantour Rd within the Point Reyes National Seashore. The field point's immediate location and surrounding area is a complicated mix of shrub-filled open areas where the pine overstory has experienced heavy mortality. The 2015 fuel model assigned SH5, a shrub model that might well characterize the open areas, but it does not adequately capture the forested areas. Alternatively, the models assigned in the 2020 fuel model layer does not capture the heavy fuel load.
Suggested Fuel Model Assignment:	Because of the extensive downed fuels, we suggest an activity fuel model such as 202 (SB2) or 203 (SB3).

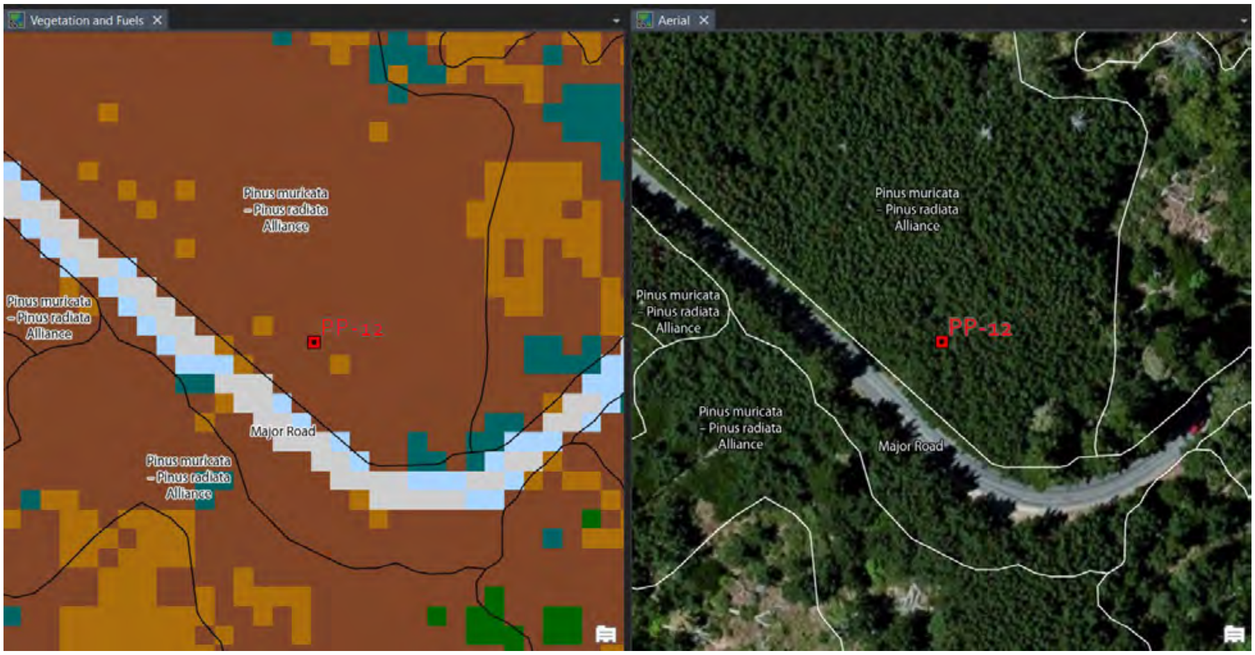

Figure 50. At field point 12, 2015 fuel model assignments shown next to 2019 aerial image (for comparison purposes only). 2018 fine-scale vegetation polygons shown in black/white outlines on both maps for reference only.

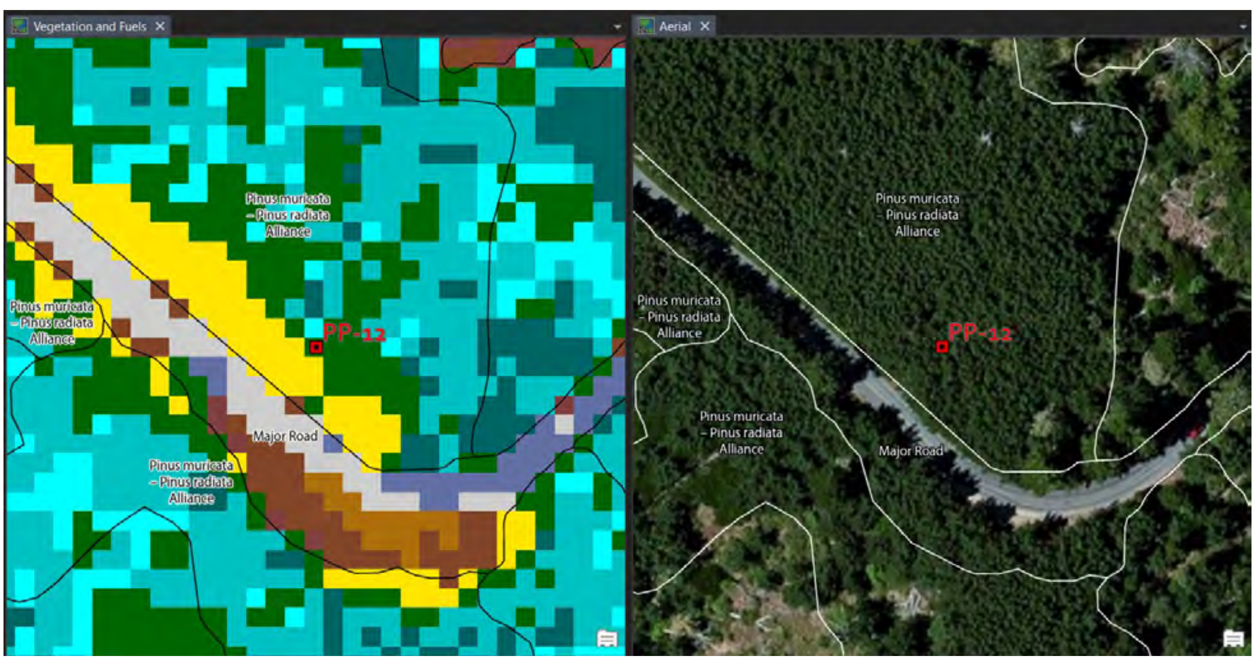

Figure 51. At field point 12, 2020 fuel model assignments shown next to 2019 aerial image (for comparison purposes only). 2018 fine-scale vegetation polygons shown in black/white outlines on both maps for reference only.

Field point 13

Figure 52. Field point #13 visited on 08/10/2021. Photo courtesy of Carol L. Rice.

Location:	**37.060043, -122.849633**
Mapped Vegetation (2020):	*Pinus muricata – Pinus radiata* (Bishop and Monterey pine)
2015 Fuel Model Assignment:	145 (SH5)
2020 Fuel Model Assignment:	182 (TL2) and 186 (TL6)
Observations:	Field point 13 is also located off Limantour Rd within the Point Reyes National Seashore. The field point's immediate location and surrounding area is a complicated mix of shrub-filled open areas where the pine overstory has experienced some mortality. The 2015 fuel model assigned SH5, a shrub model that might well characterize the open areas, but it does not adequately capture the forested areas. Alternatively, the models assigned in the 2020 fuel model layer does not capture the heavy fuel load.
Suggested Fuel Model Assignment:	Because of the extensive downed fuels, we suggest an activity fuel model such as 201 (SB1).

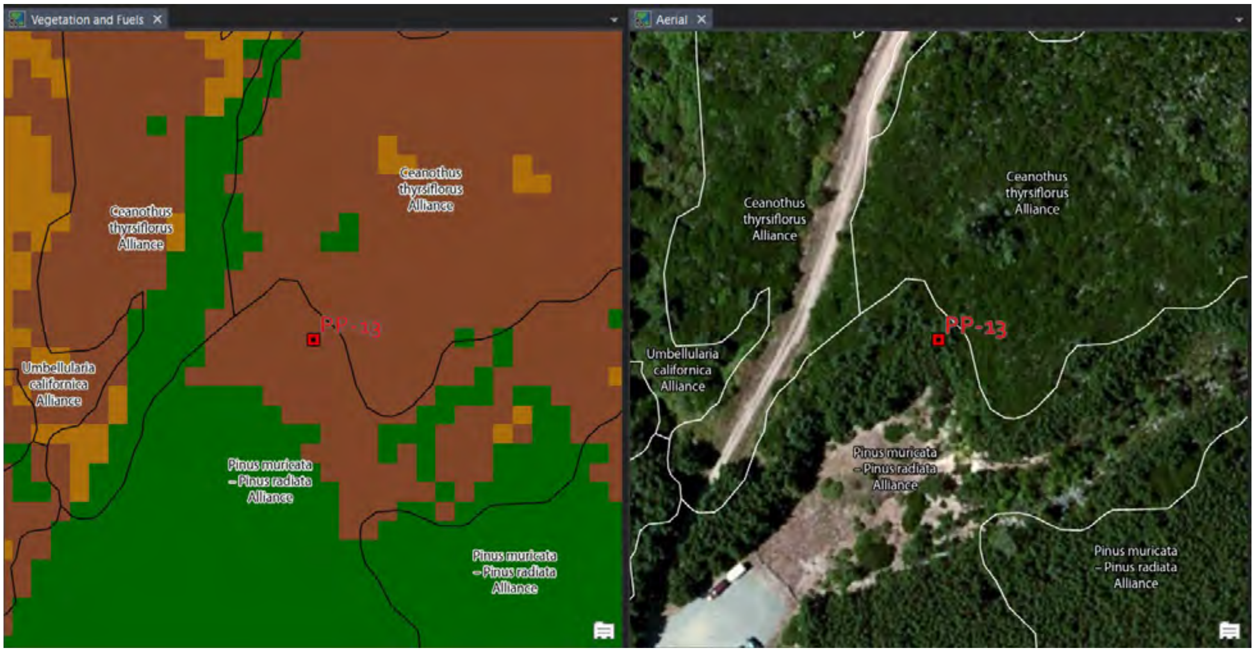

Figure 53. At field point 13, 2015 fuel model assignments shown next to 2019 aerial image (for comparison purposes only). 2018 fine-scale vegetation polygons shown in black/white outlines on both maps for reference only.

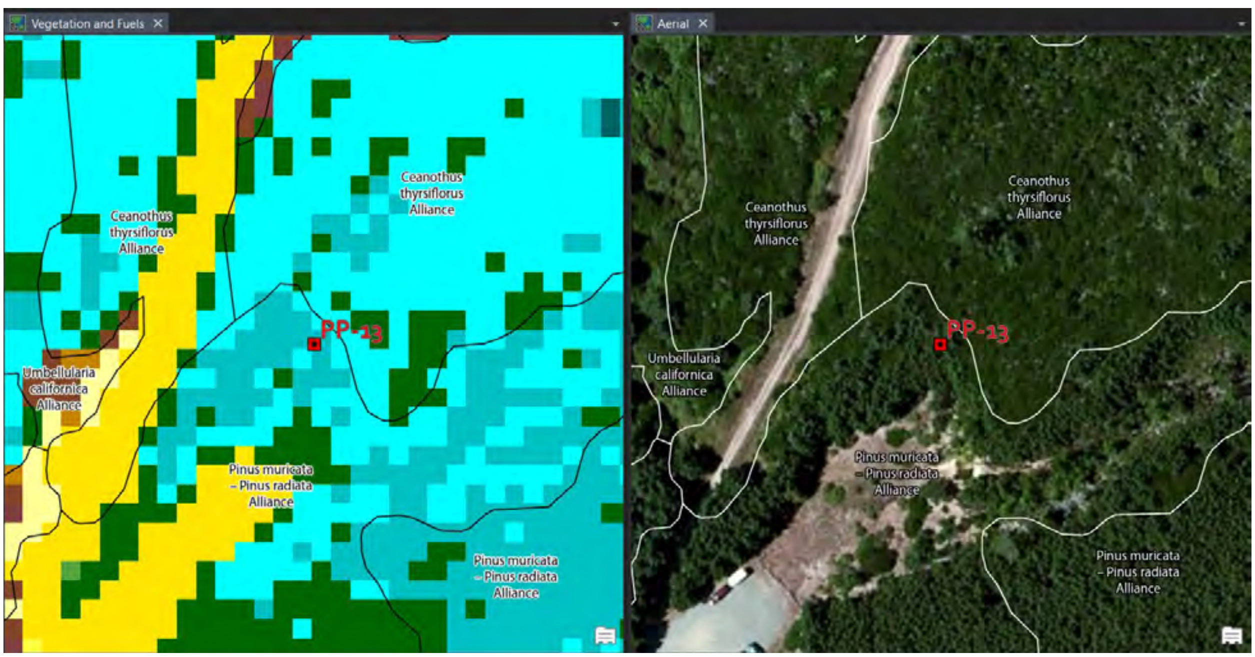

Figure 54. At field point 13, 2020 fuel model assignments shown next to 2019 aerial image (for comparison purposes only). 2018 fine-scale vegetation polygons shown in black/white outlines on both maps for reference only.

Field point 14

Figure 55. Field point #14 visited on 08/10/2021. Photo courtesy of Carol L. Rice.

Location:	37.101951, -122.896286
Mapped Vegetation (2020):	*Pinus muricata – Pinus radiata* (Bishop and Monterey pine)
2015 Fuel Model Assignment:	165 (TU5)
2020 Fuel Model Assignment:	165 (TU5)
Observations:	Field point 14 is located off Mt Vision Rd within the Point Reyes National Seashore. The field point's immediate location and surrounding area is an open pine forest with an extensive, but low-lying shrub understory. Both the 2015 and 2020 fuel model assignment may overpredict fire behavior in this area.
Suggested Fuel Model Assignment:	Where canopy cover is low and the fuel ladder ratio is low, suggest changing the fuel model to TU1.

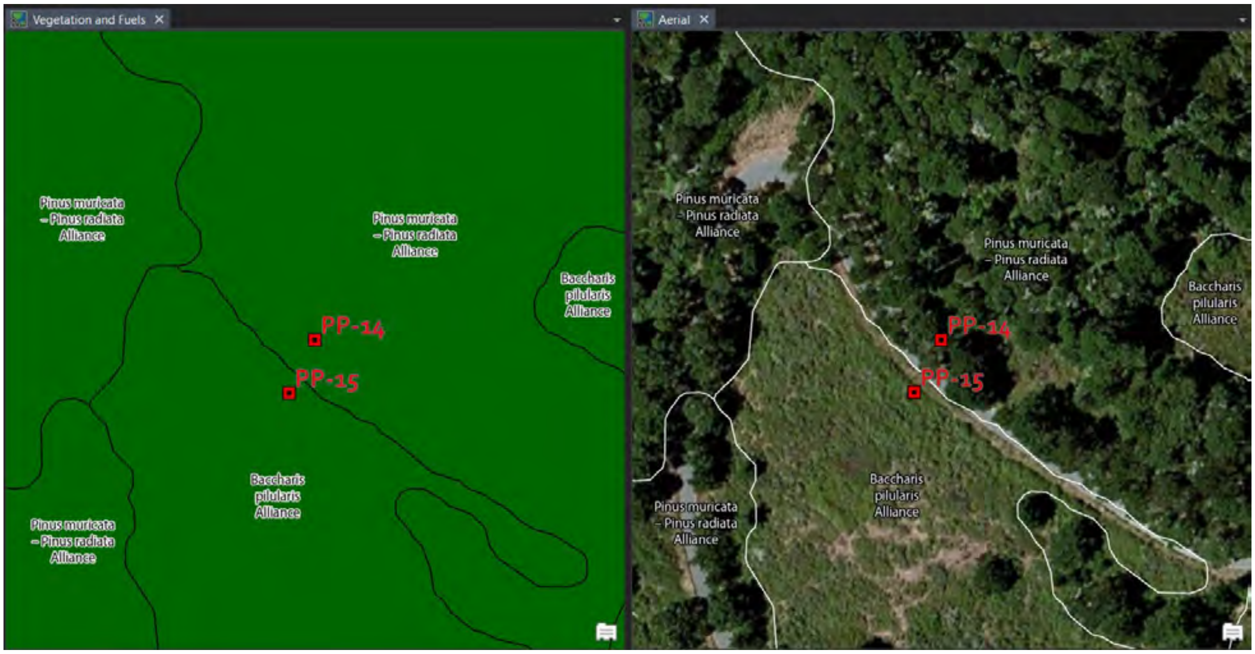

Figure 56. At field point 14, 2015 fuel model assignments shown next to 2019 aerial image (for comparison purposes only). 2018 fine-scale vegetation polygons shown in black/white outlines on both maps for reference only.

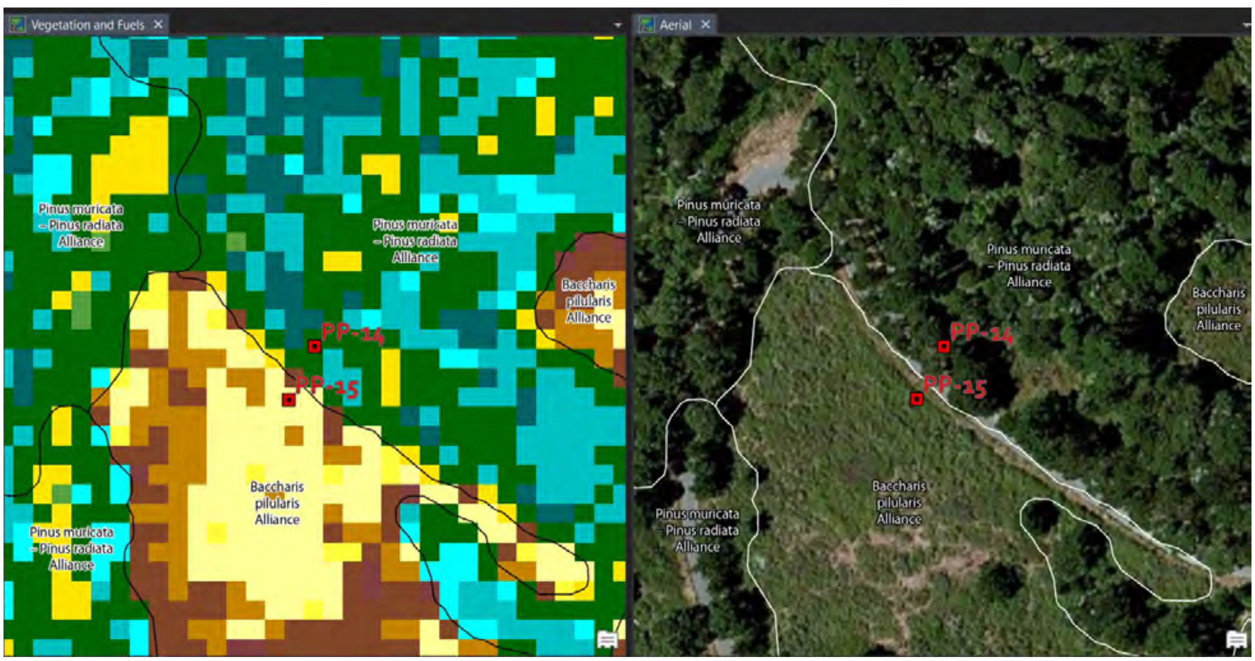

Figure 57. At field point 14, 2020 fuel model assignments shown next to 2019 aerial image (for comparison purposes only). 2018 fine-scale vegetation polygons shown in black/white outlines on both maps for reference only.

Field point 15

Figure 58. Field point #15 visited on 08/10/2021. Photo courtesy of Carol L. Rice.

Location:	**37.101827, -122.896362**
Mapped Vegetation (2020):	*Baccharis pilularis* (Coyote brush)
2015 Fuel Model Assignment:	165 (TU5)
2020 Fuel Model Assignment:	101 (GR1)
Observations:	Field point 15 represents a field of coyote brush that extends west. The field point's immediate location and surrounding area is dominated by shrubs with little to no grass. Unless there was a forest here before, the original 2015 assignment is incorrect. Similarly, the 2020 fuel model assignment of short grass is incorrect. Neither characterizes the fuels found.
Suggested Fuel Model Assignment:	Any of the SH models depending on coverage and stand height.

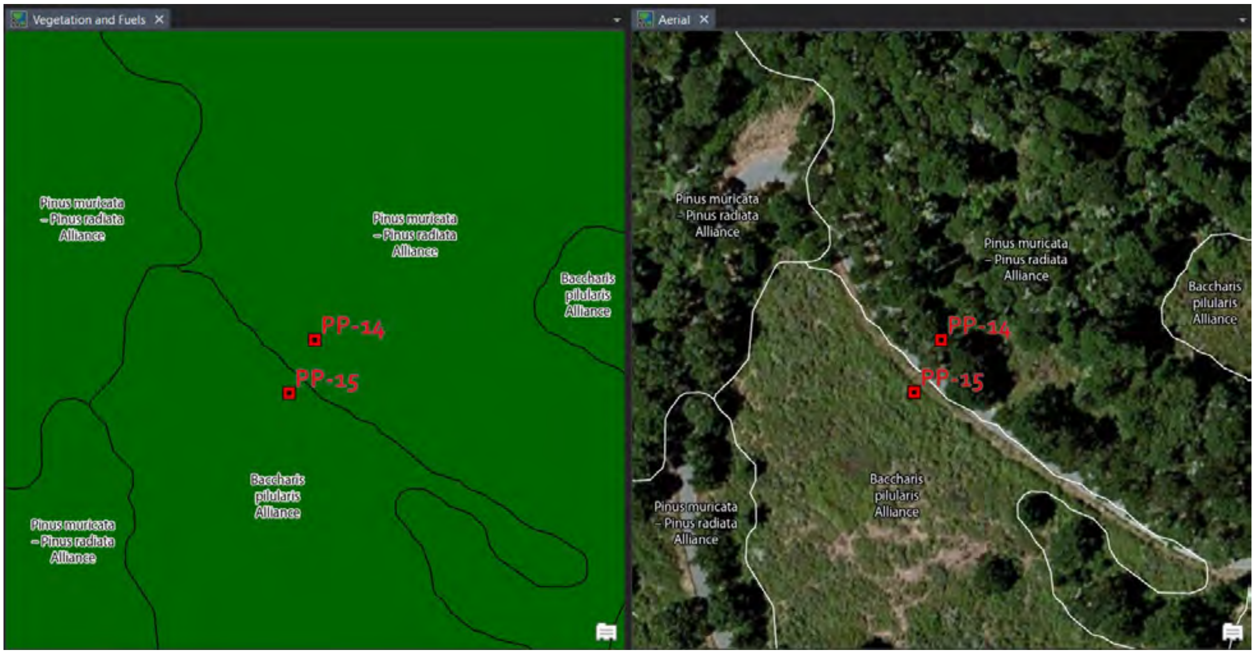

Figure 59. At field point 15, 2015 fuel model assignments shown next to 2019 aerial image (for comparison purposes only). 2018 fine-scale vegetation polygons shown in black/white outlines on both maps for reference only.

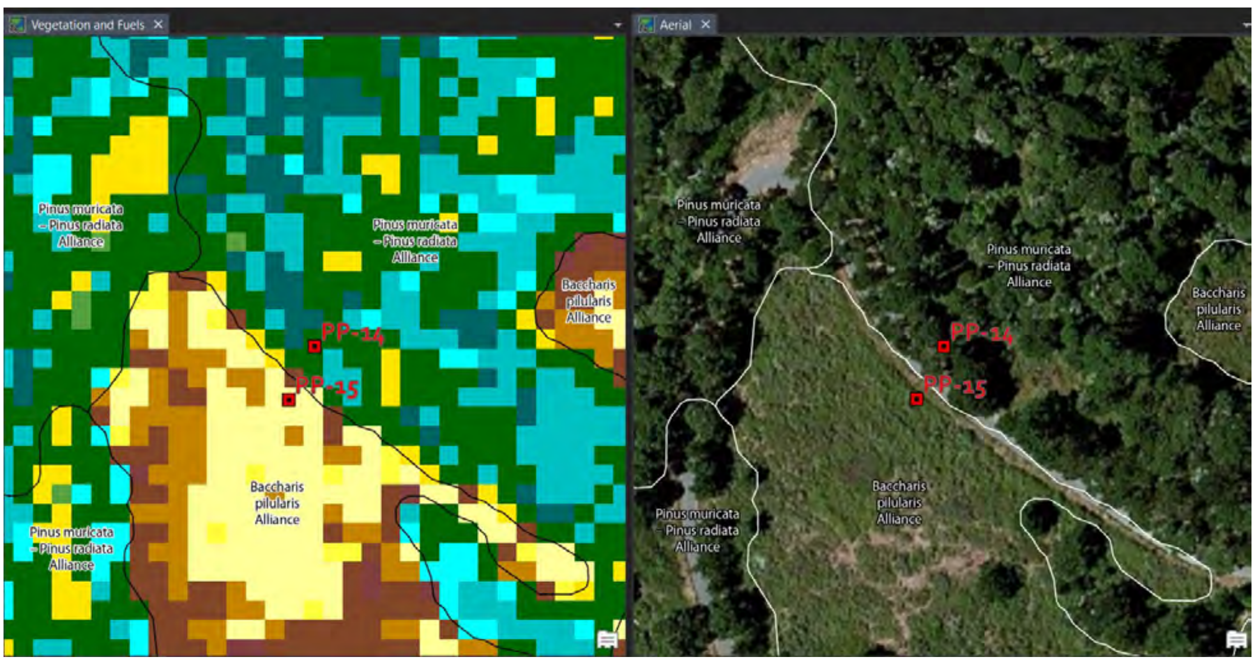

Figure 60. At field point 15, 2020 fuel model assignments shown next to 2019 aerial image (for comparison purposes only). 2018 fine-scale vegetation polygons shown in black/white outlines on both maps for reference only.

Results

Fuel Model Distribution: Comparing the two fuel models, there are larger patches of fuel types in the 2016 fuel model, compared to the 2020 fuel model. Page 17 of this report illustrates the difference in patch size, showing how fuels are uniformly classified in an area in the 2016 fuel model whereas the 2020 fuel model contains a range of fuel models as a fine-grained, pixelated spatial distribution. Not surprisingly, the patch size affects the distribution of predicted flame lengths and rates of fire spread.

While the total acres of fuel models are similar, the difference between distribution of these fuel types is greater than the table on Page 15 portrays. The side-by-side comparison on Page 17 best illustrates the difference.

In addition, fuel model assignments varied greatly between the two fuel models. For example, in 2015 both shrub-based fuel types and forested fuel types were assigned to most of Pt Reyes in large patches. In contrast, the 2020 fuel model categorized the same area as grass with forested fuel types, in smaller pixelated patches. Field observations (specifically, Field Point 14) showed that the assignment of shrub-based fuel models was correct. Other plots noted several discrepancies between the fuel models observed and those assigned. The predicted fire behavior of the 2016 and 2020 fuel model was quite different.

Flame Length: The 2016 fuel model predicted far more of the county would burn with flames longer than 20 ft, and in larger patches, due to the larger contiguous areas of similar fuel assigned to the landscape.

In the 2020 fuel model, more of a 'salt and pepper' pattern of varying flame lengths was observed, with roughly half as much of the area burning with flames longer than 11 feet, compared to the 2016 fuel model.

Rate of Fire Spread: There was quite a range of fire spread rates in the 2020 fuel model. The 2016 fuel model resulted in a very fast (greater than 88 ft/min) predicted spread rate, for most of the county.

The difference was most stark in the Pt. Reyes National Seashore. Using the 2016 fuel model, all of this area is predicted to burn with rates of spread greater than 88 ft/min, whereas with the 2020 fuel model fires are expected to burn at a rate of 18 ft/min with pockets of higher spread rates. This is likely because grasslands were predicted to spread fast in the 2016 fuel mode, but not the 2020 fuel model because the 2020 fuel model assigned most of the grass-based fuel types as GR1 (101) which has the least volume of fuel and slowest fire spread rate. In contrast, the 2016 fuel model assigned more than half of the grass-based fuel types as GR4 (104), which has among the highest fuel volume and greatest fire spread rate.

It is interesting to note that even though predicted flame lengths and fire spread rates are different between the 2016 and 2020 fuel models, the predicted crown fire activity is nearly identical, with slightly more torching predicted to occur in the 2020 fuel model. We postulate that this may be because the crown base height layer is not particularly accurate, however, because documentation did not include a robust discussion on how crown base height was derived or assigned, we cannot confidently determine why there is no difference in predicted crown fire activity.

Discussion

The 2020 fuel model was limited by the sole use of the lifeform map as the means of classifying fuel types, which precludes the more nuanced distinction in fuel characteristics with detailed alliance-level vegetation map data, which were available at the time for portions of Marin County.

STI's documentation was sparse and as a result, it is difficult to recommend strategies to refine or improve on their existing fuel model assignments and/or to understand the rationale for their assignments. While we could not obtain information about all the inputs to the 2020 fuel model, the 2020 fuel model did *not* take advantage of the best available data. For example, the use of a Ladder Fuel Index could improve the assignment of fuel types. Instead, the STI report used LiDAR to set crown base height in the landscape file but did not consider it in classifications of fuel models.

The documentation reviewed does not mention any field work conducted to verify the fuel model assignments. A personal discussion with the author of the documentation for the 2020 fuel model indicated that the scope of work did not include field visits. Though we do know that some areas were assigned fuel models based on local expert knowledge.

Conclusions

There are several tradeoffs between the updated 2020 fuel model and the 2016 fuel model for Marin County. The main advantage of the 2020 fuel model is the fine-grained nature of the data and resulting distribution of fuel types. This is a better representation of the conditions in the field, in that fuel types are rarely large expanses across the landscape. Instead, fuel types can vary within a short distance.

However, the misclassification of fuel types limits the 2020 fuel model’s utility. The differences between assigned and observed fuel types were stark, with obvious discrepancies.

There appear to be five choices of approaches for predicting fire behavior in Marin County.

1. Continue using the 2020 fuel model, acknowledging the error in fuel type classification, and taking advantage of the greater fine-grained pixelated and small patch size in the model.
2. Revert to the use of the 2016 fuel model, relying on the potentially more accurate fuel type assignment, but recognizing the false uniformity of fuel types within larger patch sizes.
3. Use LANDFIRE, a nation-wide data set with a 30-meter resolution. This dataset avoids areas of development and has issues with some assignment of fuel types.
4. Update the County's fuel model using the best available information (including the fine-scale Alliance-level vegetation data, the 2019 LiDAR data, and the ladder fuel index) and build consistency with fuel models in Sonoma, Napa, San Mateo, Santa Clara, and Santa Cruz counties.
5. Update the county's 5-meter fuelscape to include LiDAR derived Canopy Base Height and potentially Canopy Bulk Density using best available methods (Kelly et al.).

We recommend the fourth option, to both improve fuel type assignments and build upon the more granular mapping featured in the 2020 fuel model. While we recommend the fourth option, we also recognize that some end-users may need to work with the currently available data. Therefore, we conclude that, while the 2020 fuel model has documented issues, it is currently the best available product for understanding current fuel load conditions in Marin County.

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APPENDIX 8C: ACRES OF NATIVE FOREST BY TREATMENT FEASABILITY CLASS FOR MARIN PUBLIC LAND MANAGEMENT AGENCIES.

Agency Name	Feasibility Class	Acres	Percent of Total Native Forests[1] (by agency)
California Department of Parks and Recreation	Feasible - Road Access, Hand Crew	924	10%
	Feasible - Road Access, Mechanical	501	6%
	Feasible - Trail Access, Hand Crew	205	2%
	Feasible - Trail Access, Mechanical	118	1%
	Limited Feasibility - Poor Access	1,097	12%
	Limited Feasibility - Steep	3,520	40%
	Low Feasibility - Near Stream or Riparian Veg/Wetland	2,515	28%
	Low Feasibility - Serpentine	8	0.1%
	Total	8,888	100%
Marin County Parks[2]	Feasible - Road Access, Hand Crew	1,494	16%
	Feasible - Road Access, Mechanical	587	6%
	Feasible - Trail Access, Hand Crew	99	1%
	Feasible - Trail Access, Mechanical	46	1%
	Limited Feasibility - Poor Access	661	7%
	Limited Feasibility - Steep	3,942	43%
	Low Feasibility - Near Stream or Riparian Veg/Wetland	2,015	22%
	Low Feasibility - Serpentine	254	3%
	Total	9,098	100%

Marin Water	Feasible - Road Access, Hand Crew	1,071	7%
	Feasible - Road Access, Mechanical	610	4%
	Feasible - Trail Access, Hand Crew	186	1%
	Feasible - Trail Access, Mechanical	99	1%
	Limited Feasibility - Poor Access	1,317	9%
	Limited Feasibility - Steep	5,205	36%
	Low Feasibility - Near Stream or Riparian Veg/Wetland	5,457	38%
	Low Feasibility - Serpentine	399	3%
	Total	14,344	100%
National Park Service - GGNRA Managed[3]	Feasible - Road Access, Hand Crew	243	11%
	Feasible - Road Access, Mechanical	100	4%
	Feasible - Trail Access, Hand Crew	24	1%
	Feasible - Trail Access, Mechanical	9	0.4%
	Limited Feasibility - Poor Access	296	13%
	Limited Feasibility - Steep	847	38%
	Low Feasibility - Near Stream or Riparian Veg/Wetland	710	32%
	Low Feasibility - Serpentine	0	0%
	Total	2,229	100%
National Park Service - PRNS Managed	Feasible - Road Access, Hand Crew	1,616	6%
	Feasible - Road Access, Mechanical	1,452	6%
	Feasible - Trail Access, Hand Crew	689	3%
	Feasible - Trail Access, Mechanical	728	3%
	Limited Feasibility - Poor Access	6,028	24%
	Limited Feasibility - Steep	7,243	28%
	Low Feasibility - Near Stream or Riparian Veg/Wetland	7,815	31%
	Low Feasibility - Serpentine	3	0%
	Total	25,574	100%

Other Protected Lands[4]	Feasible - Road Access, Hand Crew	660	17%
	Feasible - Road Access, Mechanical	339	9%
	Feasible - Trail Access, Hand Crew	39	1%
	Feasible - Trail Access, Mechanical	13	0.3%
	Limited Feasibility - Poor Access	233	6%
	Limited Feasibility - Steep	1,626	42%
	Low Feasibility - Near Stream or Riparian Veg/Wetland	983	25%
	Low Feasibility - Serpentine	4	0%
	Total	3,897	100%

[1] Source: 2018 Marin Countywide Fine Scale Vegetation Map, Native Forest Lifeform Class

[2] Includes both Marin County Open Space Preserves and Marin County Parks units. Does not include conservation easements.

[3] Includes Muir Woods National Monument. Does **not includ**e GGNRA Northern District lands managed by PRNS.

[4] Other protected lands in Marin County include: Audubon Canyon Ranch, Bel Marin Keys Community Services District, City of Belvedere, Bolinas Community Public Utility District, California Department of Fish and Wildlife, California Department of Transportation, California State Coastal Conservancy, California State Lands Commission, Town of Corte Madera, Town of Fairfax, City of Larkspur, Las Gallinas Valley Sanitary District, Marin Audubon Society, Marin Conservation League, Marin Public Works Dept/Flood Control, County of Marin, Marinwood Community Service District, City of Mill Valley, National Audubon Society, North Marin Water District, Novato Sanitary District, City of Novato, Town of Ross, City of San Anselmo, City of San Rafael, City of Sausalito, Sonoma-Marin Area Rail Transit, Strawberry Recreation District, Tamalpais Community Services District, The Nature Conservancy, Town of Tiburon, Tomales Village Community Services District, Trust for Public Land, United States Bureau of Land Management, United States Coast Guard, United States Fish and Wildlife Service
(California Protected Areas Database, 2022.Green Info Network. https://www.calands.org)

CHAPTER 9: TREATMENT DESCRIPTIONS

The following Treatment Descriptions provide information about forest health treatment methods included in the results chains in Chapter 5: Goals. The descriptions are treatment overviews to provide a context and framework for land managers to consider when weighing treatment options.

In Chapter 5: Goals, conceptual models of ecological function for each forest type were presented. Results chains developed from the conceptual models then show the specific pathway associated with each forest health attribute, threat, and one or more treatments or actions to reduce the impact of the threat (see Glossary for definition of conceptual model and results chain). The results chains describe treatments that can be applied to achieve landscape-level goals by taking steps and meeting interim goals along a goal pathway. This chapter provides information for treatment methods included in the results chains:

- Beneficial Fire
- Thinning
- Restoration (including non-native invasive species control and revegetation)
- Pests and Pathogen Management

It also includes treatment descriptions for related actions:

- Fuelbreaks
- Biomass Management

The information in the Treatment Descriptions is intended to provide context for understanding the purpose, uses, benefits and constraints for different treatment approaches and to be a first step in planning forest health treatment projects. This chapter provides reference material and general concepts for consideration rather than detailed treatment prescriptions. Each prospective project location is unique and requires site-specific analysis and logistical planning. Field investigation and consultation with experienced professionals is needed to develop detailed project methods, timelines, and costs. In addition, though it is not included as a treatment, initial field data collection and on-going monitoring are important to plan and implement successful projects, evaluate outcomes, develop adaptive management, and improve the effectiveness of future projects.

The different treatments described below will most likely be used in combination to achieve multiple benefits; for example, land managers may plan a project that uses thinning, followed by beneficial fire, to improve forest health and reduce fire fuels. Researchers have found that this combined treatment is most effective for reducing fire severity (Collins et al., 2014; Prichard et al., 2020). This initial treatment may then be followed by restoration actions such as non-native invasive species control, erosion control, or revegetation to further improve site conditions and restore ecosystem functions.

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BENEFICIAL FIRE TREATMENT DESCRIPTION

Wildfires are increasing in size, severity, frequency, and duration due to long-term fire exclusion, climate change, and increased lightning strikes (Millar et al., 2007; Miller et al., 2012; Prichard et al., 2020; Safford et al., 2022; Westerling, 2016). Fire exclusion leads to a higher density of small trees and understory vegetation, a slower carbon sequestration rate, and forests prone to tree mortality and related carbon loss through high-severity fire (Hurteau et al., 2019). Beneficial fire is increasingly being utilized as a land management tool to improve forest health after decades of fire exclusion, and to increase forest resilience to climate change (Little, 2018; Norgaard, 2019).

Beneficial fire is a term which collectively refers to prescribed fire, cultural burning, and managed fire (California Wildfire and Resilience Task Force, 2022). According to *California's Strategic Plan for Expanding the Use of Beneficial Fire*, these terms integrate beneficial fire activities deployed to meet forest health objectives (California Wildfire and Resilience Task Force, 2022). All forms of beneficial fire have the goal of promoting resilience in California's forests and restoring fire to the landscape.

This treatment description outlines different types of beneficial fire, explores the benefits and challenges of beneficial fire as a forest health treatment tool, gives examples of current use, as well as different approaches and considerations for planning and implementation. Communication methods, collaborative strategies, resource protection, and best management practices are also discussed.

BACKGROUND

The Marin County *Community Wildfire Protection Plan (CWPP)* , Golden Gate National Recreation Area *Fire Management Plan*, Point Reyes National Seashore *Fire Management Plan*, Marin Water *Biodiversity Fire and Fuels Integrated Plan (BFFIP)*, various California Department of Parks and Recreation (CDPR) General and Management Plans, and the Marin County Parks and Open Space District *Vegetation and Biodiversity Management Plan* all recommend using prescribed fire to reduce fuels and restore healthy ecosystems in Marin County (CDPR, n.d.; GGNRA, 2005; Lavezzo et al., 2020; MCOSD, 2015; Marin Water, 2019a; PRNS, 2004a). Positive outcomes from the use of beneficial fire include reducing unnatural fuel accumulation, decreasing future fire severity (and future carbon emissions), recycling nutrients, temporarily reducing pests and pathogens, selecting for species or conditions identified and valued by the Federated Indians of Graton Rancheria (the Tribe), improved biological diversity, and restoration of plant community compositions associated with healthy forests. Beneficial fire is a useful tool, but there are some limitations associated with its use. Beneficial fire still creates carbon emissions, although generally at a much lower level than wildfires, is not appropriate for all forest types, and does not prevent wildfires, though it may reduce burn severity, particularly at the local scale. In addition, implementing beneficial fire can be arduous, expensive, difficult to permit, require significant personnel and resources, and a potential community engagement challenge for agencies.

RESULTS CHAIN RECOMMENDATIONS

Beneficial fire is included as a treatment method in the results chains for all target forest types of the *Marin Regional Forest Health Strategy* (*Forest Health Strategy*). The anticipated benefits vary by forest type, but generally aim to reduce unnatural fuel arrangements, decrease competition for resources, and increase native herbaceous and shrub seedling recruitment. In addition, there is potential for beneficial fire to increase seedling recruitment and regeneration in stands of target serotinous species Bishop pine and Sargent cypress and may play a role in seedling establishment for some species associated with Open Canopy Oak Woodland. The use of cultural burning, which is included in the broad definition of beneficial fire, would require collaboration and consultation with the Federated Indians of Graton Rancheria.

See Chapter 5: Goals for more information on each target forest type's forest health goals and results chains used to illustrate how treatments, including beneficial fire, can be used to achieve landscape-level resilience goals.

DESCRIPTION

This section provides definitions of different types of fire, a brief history of fire frequency before and during the 20th century, followed by detailed descriptions of the 3 types of beneficial fire.

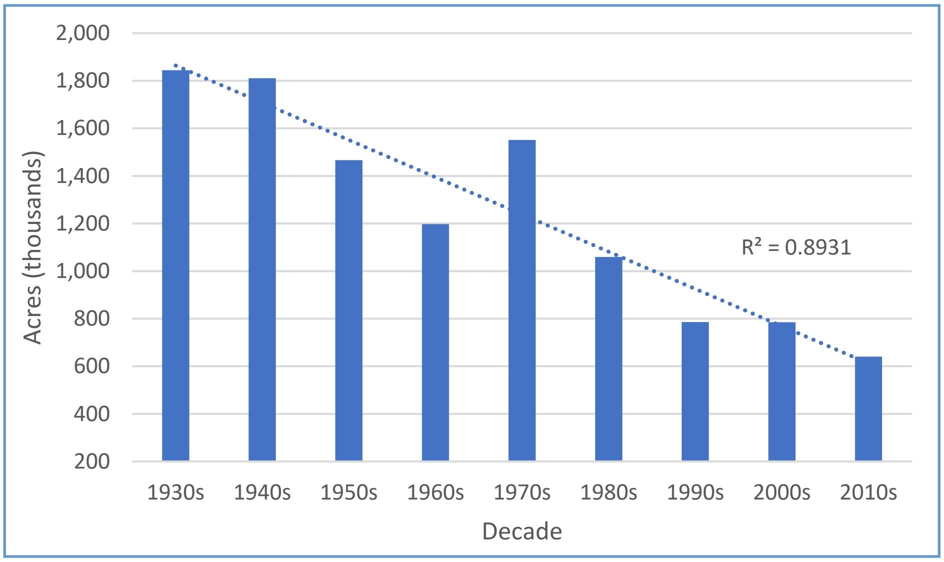
The following definitions are used throughout this and other chapters:

- **Managed wildfire**. An unintentionally caused fire that is allowed to burn within the parameters determined by forest managers and fire protection personnel (Ryan et al., 2013). Managed wildfire is also known as managed fire or fire managed for resource benefit (Wildfire and Resilience Task Force, 2022). The U.S. Forest Service has been advancing Potential Operational Delineations (PODs) as a tool for strategically managing wildfires to achieve benefits such as ecological restoration, watershed health, reduced risk of catastrophic wildfire, and reduced future fire suppression costs (Dunn et al., 2017).
- **Cultural burn.** Burning by Indigenous peoples to enhance the health and productivity of the land and its people. Practices include burning for community safety, food and fiber tending, wildlife, disease prevention and control, and ceremonial practices (Anderson, 2019; Firesticks Alliance Indigenous Corporation, n.d.; and see Chapter 3: Stewardship and Partnership with the Federated Indians of Graton Rancheria).
- **Prescribed fire**. A planned application of fire to achieve specific land management objectives — also known as a controlled, prescribed, or broadcast burn. The prescription is a set of conditions considering public safety, weather, terrain, smoke plan, burn objectives, and other key burn factors (NPS, 2020).
- **Wildfire**. Uncontrolled and unplanned fire started in wild vegetation (Tedim & Leone, 2020). Wildfires can be from natural causes, e.g., lightning, or human-caused, e.g., arson, or accidental ignition. Wildfires burn in wildlands and wildland-urban interfaces.

FIRE HISTORY

Fire was a common occurrence in wildlands in the United States before the early 20th century, with exclusion and suppression greatly increasing after World War II (Figure 9.1). From 1930 until 1945, the average number of acres burning in the United States was just under 34 million acres per year. After World War II, annual burn acreages decreased to 5.7 million, with many years below 2 million (NIFC, 2019). Thus, the United States built a significant "fire deficit" (Ryan et al., 2013). Increasing lightning strikes, temperatures, drought, and subsequent moisture deficits due to climate change, combined with fire exclusion and suppression, have recently led to more frequent and severe wildfires across the western United States (Miller et al., 2012, Romps et al., 2014, Safford et al., 2012). During the past 40 years, the area burned by wildfires in California has steadily increased, with a clear uptick in fires from 2010-2020 in northern California (Safford et al., 2022).

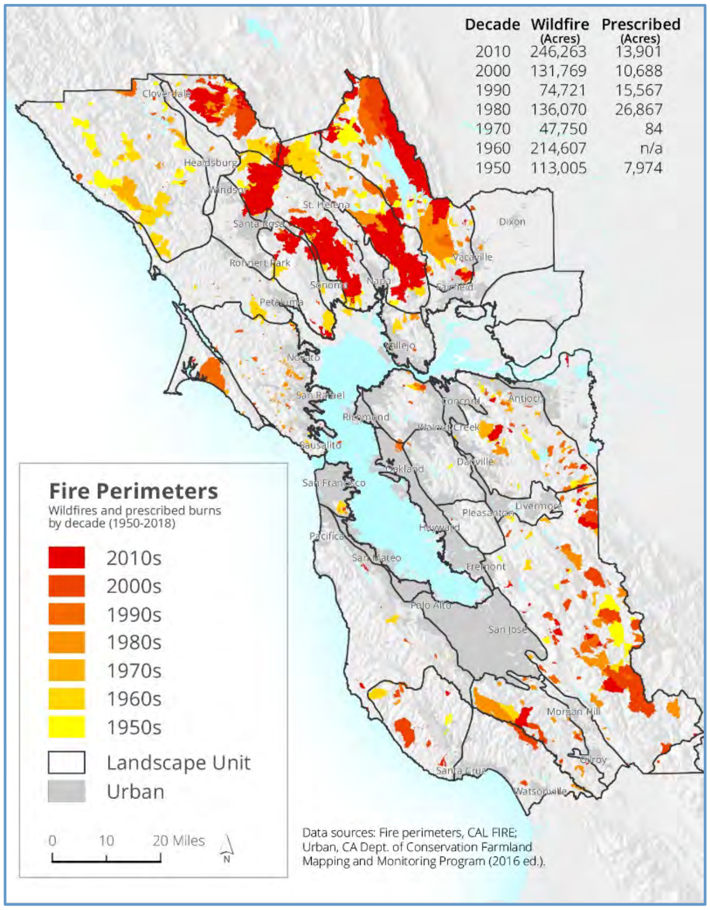
Figure 9.1. Acres burned (thousands) from 1930-2019 in the United States (NIFC, 2019). Note: data retrieved in 2019. Current NIFC data only officially reports from 1983.



Fires deliberately ignited by Indigenous communities have been common in California for thousands of years (Stephens et al., 2007). Before human populations increased during the Mid- to Late Holocene, lightning was the most common source of fire ignition (Keeley, 2005). Stephens et al. (2007) estimated that prior to fire exclusion and suppression after World War II, 4.4 - 11.8 million acres of California burned each year, much of this from frequent fires ignited by Indigenous Peoples. See Chapter 3: Stewardship and Partnership with the Federated Indians of Graton Rancheria for additional information and regional context.

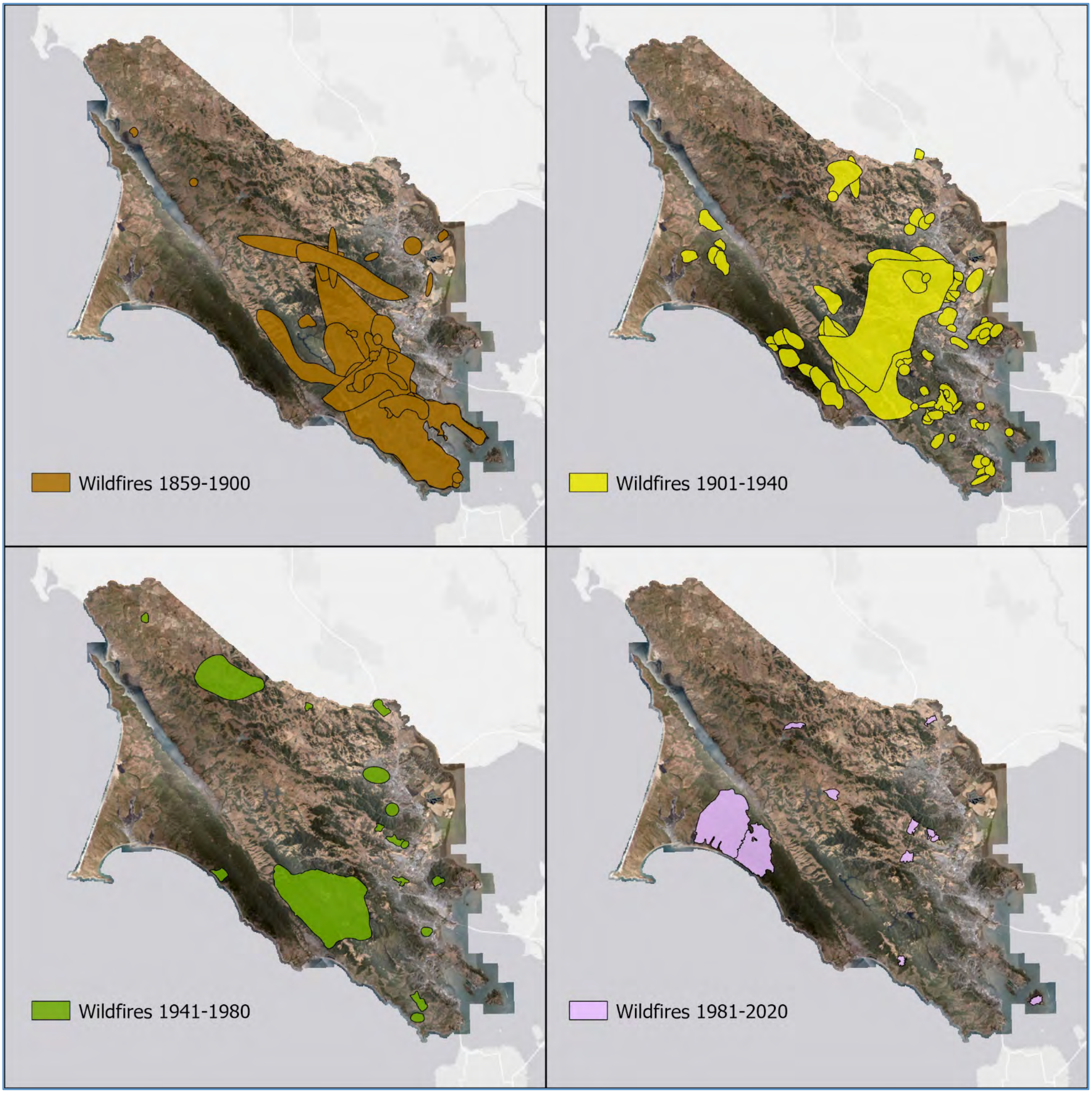
The Conservation Lands Network (CLN) 2.0 Report ([Bay Area Open Space Council, 2019](#)) developed a fire history map using existing data from California Department of Forestry and Fire Protection (CAL FIRE) Fire and Resource Protection Program (FRAP) and other sources, which shows the number of wildfire acres versus prescribed fire acres during the 1950s and 2010s. (Figure 9.2). The Bay Area Open Space Council's analysis showed that 18% of the Bay Area burned at least once, with many areas, notably the 1964 Handly Fire and 2017 Tubbs Fire in Sonoma County, burning multiple times since 1950 ([Bay Area Open Space Council 2019](#), p. 17). This report highlights that many parts of the Bay Area have fire prone landscapes, and that beneficial fire can be used to recover the ecological benefits of fire while mitigating the risk that wildfire poses to communities and infrastructure.

Figure 9.2. Bay Area prescribed burn and wildfire history map (Bay Area Open Space Council, 2019).



A deeper understanding of Marin County's wildfire history and trends was developed from the *Marin County Wildfire History Mapping Project* (Dawson, 2021). This Project created or updated historic wildfire perimeters by performing an archival search dating back to 1850. Using this enhanced historical understanding, the report provided valuable insight into fire return intervals, number of times burned, and time since last fire for Marin County. Figure 9.3 shows the extent of documented fire perimeters in Marin County greater than 160 acres between 1859 and 2020. The *Marin County Wildfire History Mapping Project* found an overall trend of decreasing wildfire extent (acres) and increasing fire return interval (years).

Figure 9.3. Marin County fire perimeter maps, top left: Fire perimeters from 1859-1900, top right: Wildfires from 1901-1940, bottom left: wildfires 1941 to 1980, and bottom right: 1981 to 2020 (Dawson, 2021).

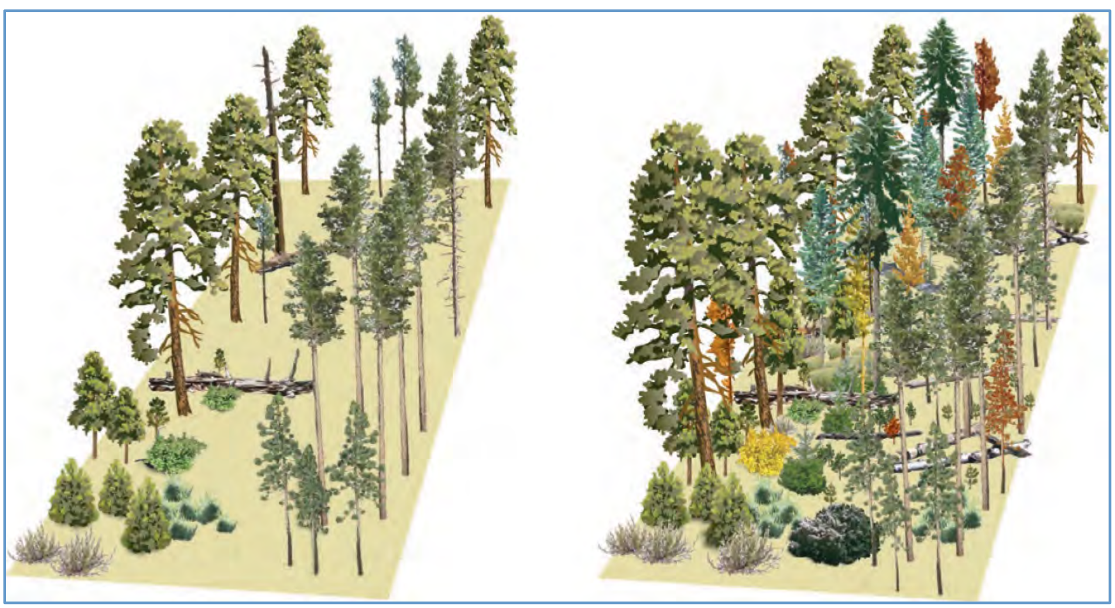


See a detailed discussion of the impacts of fire exclusion and altered fire regimes in Marin County in Chapter 4: Climate Change and Other Forest Health Stressors. Find more on Marin County's fire history in Chapter 7: Condition Assessment, Appendix B: Wildfire History, and in the One Tam Marin Forest Health Web Map.

PRESCRIBED FIRE

Prescribed fire is a component of beneficial fire in which fire is intentionally planned and applied to meet specific land management goals (Wildfire and Resilience Task Force, 2022) It attempts to reverse the legacy of fire exclusion and to return fire to the landscape as an ecological process (Figure 9.4). According to the California Air Resources Board (CARB), approximately 125,000 wildland acres in California are treated annually using prescribed burns (CARB, n.d.), increasing from less than 100,000 acres/year before the 1990s (Stephens et al., 2007). In contrast, the much smaller state of Florida burns 2.1 million acres annually on both public and private lands, with an average burn size of 24 acres (Roughton, 2019).

Figure 9.4. Simplified graphic depicting structural changes in fire-adapted forests resulting from fire exclusion. The figure on the left shows a generic forest that experienced periodic low-intensity fire. The figure on the right shows the same forest after decades of fire exclusion. For the forest on the right there is increased competition and risk for a high intensity fire, and reduced tree vigor and wildlife habitat value for some species in terms of forage and large healthy trees. (Strong & Bevis, 2016).



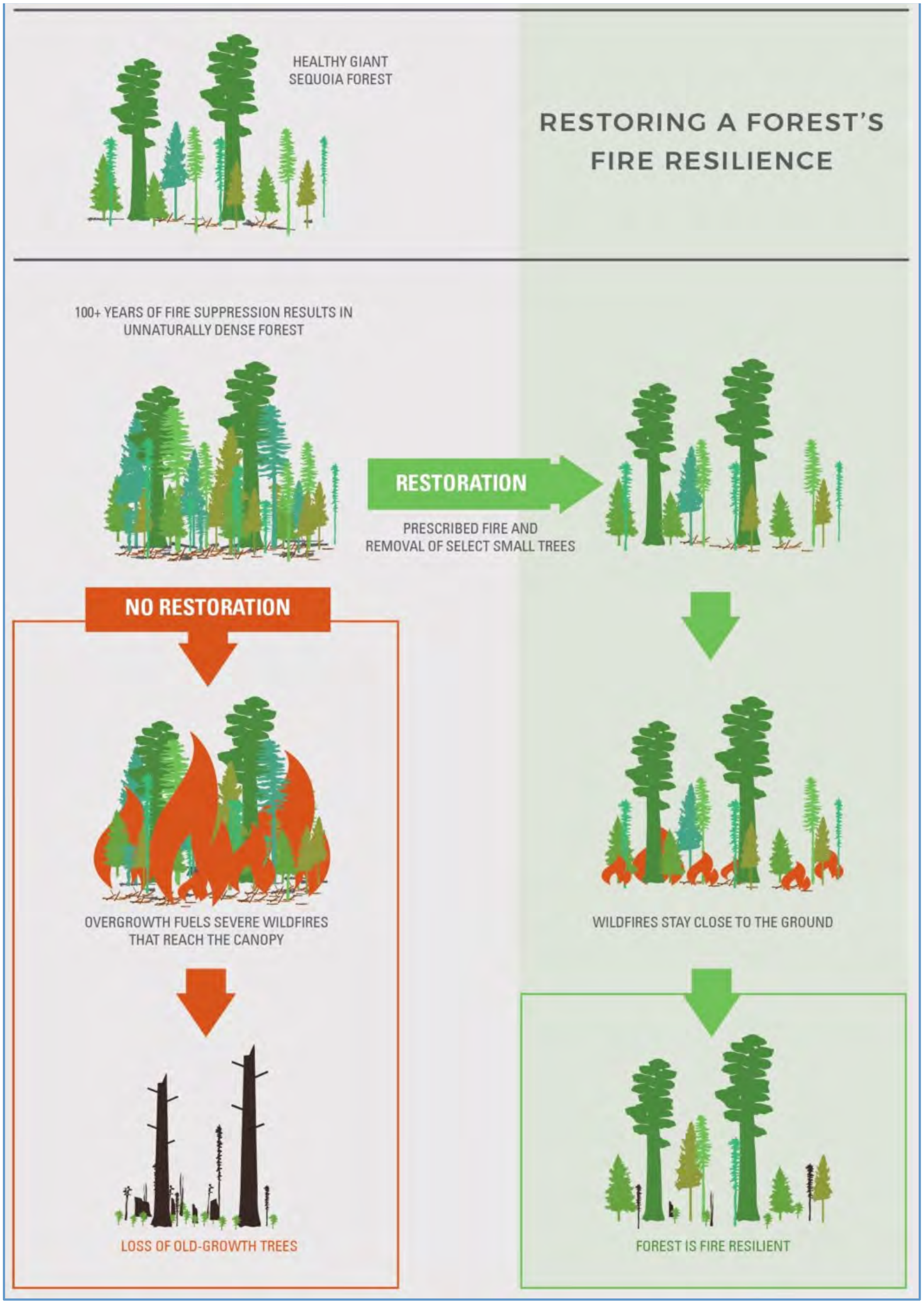
Prescribed fire is an important tool that can be used to manage forest health, and it is being increasingly used as the impacts from fire exclusion are recognized and managers seek to return fire to the landscape as an ecological process. Fires are important to recycle nutrients back to soil, open gaps to allow new understory vegetation to grow, and facilitate regeneration of closed-cone conifers and other native species. Managers may also choose prescribed fire because in some cases it can help reduce the cover of some invasive species, address pathogen impacts, improve biological diversity, and reduce unnatural fuel arrangements. Some considerations for prescribed fire planning:

- In some cases, prescribed fire may be effective as a large-scale treatment approach, especially in areas where mechanical and hand-thinning treatments may be infeasible due to slope or access constraints. However, prescribed burns typically involve significant amounts of planning, preparation, personnel, and equipment.
- Prescribed burning is best implemented in locations with moderate or low tree densities (e.g., grasslands), in areas with low ladder fuels, or areas that have been pre-treated to allow for effective fire control.
- Planning and implementing prescribed burns requires experienced personnel, such as a State Certified Prescribed Fire Burn Boss (Office of the State Fire Marshal, n.d.). Timing, frequency ,vegetation type, safety, air quality, communications, and other factors are typically included in burn plans. Constructing control lines using mechanical treatments is often necessary to ensure prescribed fires are implemented safely. A Smoke Management Plan (SMP) may be required depending upon the type, size, or location of your burn.
- Planning should also include developing clear criteria for monitoring to evaluate whether objectives are met.

Increasing the use of prescribed fire in Marin County will require funding, training, planning, compliance, implementation, and monitoring (Miller et al., 2020; Schultz et al., 2019). Although the conventional wisdom is that air quality regulation, environmental policies, and public resistance are the main barriers to prescribed fire, other impediments such as funding, capacity, liability concerns, and open burn windows may be more important to managers on the ground (Schultz et al., 2018; Weir et al. 2019).

In general, accelerating forest stands towards old-growth conditions could be a useful restoration goal to reduce burn severity and increase forest resilience, and one method for accelerating stands to old-growth conditions is prescribed burning (Figure 9.5). Douglas-fir (*Pseudotsuga menziesii*) is generally more fire-sensitive than coast redwood (*Sequoia sempervirens*) or hardwood tree species. Damage and tree mortality in Douglas-fir largely depends on tree age and fire intensity, i.e., younger, and less mature trees are more vulnerable to fire, and high intensity crown fires are likely to cause mortality in mature trees (Lavender & Hermann, 2014, p. 295). Trees become more resistant to fire as the bark thickens with age (Cocking et al., 2012; Engber et al., 2011). Douglas-fir stands may progress towards a more fire resilient old-growth state even with low to moderate severity fires; however, any Douglas-fir stand is vulnerable to high-severity fire (Uchytil, 1991).

Figure 9.5. Simplified diagram illustrating unnatural fuel arrangements resulting from a century of fire suppression. In some areas, these conditions can contribute to severe fire behavior that can imperil naturally fire-resilient trees such as giant sequoia and coast redwood ([Save the Redwoods League, 2021](#)).



CULTURAL BURNING

Indigenous peoples used burning for centuries to tend the landscape for food and fiber, disease reduction, game abundance, spiritual practices, and fire risk reduction (Anderson, 2019; Marks-Block & Tripp, 2021; see Chapter 3: Stewardship and Partnership with the Federated Indians of Graton Rancheria). Burning practices were banned, outlawed, and violently suppressed starting in the 19th century. Stolen lands and displacement interrupted land-tending practices, food and economic security, and traditional fire knowledge. They often led to resource quality and quantity declines across many forests in western and northern California (Long & Lake, 2018).

Like prescribed fire, cultural burning practices were applied to meet specific objectives, such as increased seed or fruit production (Hankins, 2021). Cultural burning manipulated vegetation to encourage desired plants with fires at different times of the year and at different intensities (Klamathmedia, 2012). For instance, sticks from California hazelnut (*Corylus cornuta* ssp. *Californica*) is used for basket weaving (Marks-Block et al., 2021). When hazel is burned in the spring, it creates straight shoots useful for weaving (ibid.). If the hazel is not burned, it produces crooked side shoots that cannot easily be woven (ibid). In another example, cultural burns in tanoak (*Notholithocarpus densiflorus*) stands kill young Douglas-fir trees, protect fire-sensitive tanoak, and produce an abundance of acorns (Klamathmedia, 2012). Fires also interrupt weevil life cycles that negatively impact acorn production (Klamathmedia, 2012). In addition, tribal communities used fires to thin young and diseased trees, and create habitat for desired species such as California hazelnut , evergreen huckleberry (*Vaccinium ovatum*), sword fern (*Polystichum munitum*), and redwood sorrel (*Oxalis oregana*) (Anderson, 2005; Lightfoot & Parrish, 2009, Hankins, 2021, Marks-Block et al., 2021) .

From the beginnings of human settlement, frequent burning of grasslands and oak woodlands maintained oaks across California during unsuitable climate conditions, such as wetter or cooler periods in geologic time (Hankins, 2021). Burns were also critical to maintain diverse understory vegetation; both the timing and location of burns were important and required in-depth knowledge and experience of germination patterns and species' response to fire at different life stages (Anderson, 2005, 2009).

Evidence of frequent fires from fire scar and tree-dating studies in Douglas-fir and Coast Redwood stands indicate centuries of intensive management by the Yurok Tribe (Norman et al., 2009). Coast Redwood growth-ring studies indicate fire-return intervals ranging from 10-18 years (Stephens & Fry, 2005; Stephens et al., 2018).

Tanoaks are an important food source for Native peoples in California, and cultural burning has traditionally been used in tanoak tending (see Chapter 3: Stewardship and Partnership with the Federated Indians of Graton Rancheria). Approaches other than mechanical removal are needed for tanoak tending and management in areas impacted or threatened by sudden oak death (SOD). Bowcutt (2013) advocates for a collaborative process with Tribal leadership to identify areas with mature tanoaks where traditional Indigenous burning practices can be tested in combination with best management practices informed by western science. Cobb et al. (2017) point out SOD-resilient forest stands, including tanoak stands, managed by Yurok

Tribe members and tended through thinning and burning practices as another approach using Traditional Ecological Knowledge.

Landscape-scale management necessitates an increased understanding of cultural burning and Traditional Ecological Knowledge (TEK) for various vegetation communities (Huffman, 2013; Long et al., 2015; Ray et al., 2012;). TEK can inform and guide fuels and fire management to perpetuate culturally important resources to Tribes (Lake et al., 2017). Integrating TEK into fire prescriptions will require building trust and cross-jurisdictional collaboration over time to share knowledge, recognize different perspectives, and gain support for using fire to achieve multiple land management objectives (Lake et al., 2017). Combining TEK with western knowledge can create more comprehensive fire management to reintroduce fire as an ecosystem process and maintain cultural landscapes while also reducing overall fire risk (Huffman 2013; Lake et al., 2017; Mason et al., 2012, Tripp, 2015).

MANAGED FIRE

Managed fire, also known as fire managed for resource benefit, is a strategic choice to address unplanned ignitions and achieve forest restoration or hazard reduction objectives by allowing unplanned fire to burn (California Wildfire and Forest Resilience Task Force, 2022). Managed fire is not appropriate near urban areas. It is most often deployed in wilderness areas, national parks, or remote national forests under specific conditions with a low risk of fire becoming a threat to natural and urban resources.

Managed fires, as with other beneficial fires, are used to meet specific goals and objectives (Sequoia National Forest, n.d.) Managers must plan and be actively involved in managed fire utilization. Fire Management Plans need to be in place in advance of utilizing managed fire for resource benefit. Planning tasks include assessing risk, determining acceptable fire extent or maximum manageable areas (MMAs), and defining fire trigger points or situations that would require actions to protect public safety and property (Sequoia National Forest, n.d.).

Managed fire is most often used on federal lands. The U.S. Forest Service (USFS) has been integrating the concept of Potential Operational Delineations (PODs) into wildfire planning efforts to facilitate the use of unplanned wildfire to achieve resource objectives. The PODs approach combines cross-jurisdictional risk management with local expertise to pre-identify potential control points for a hypothetical wildfire, which not only aids in planning fire suppression efforts but also improves the possibility of allowing fire to burn in areas to achieve ecological objectives (USFS, 2021). The PODs concept follows 2009 Federal Wildland Fire Policy put in place to support a consistent approach to managing wildfire and allows for fire to be managed for resource benefit in one area while actively suppressing it in another area in which safety or property are threatened. However, some state and local jurisdictions may be required to provide wildfire suppression and therefore may find it difficult to implement managed fire for resource benefit (Berger et al., 2018).

In recent years, managed fire has been used in California's National Parks and National Forests. For example, the Central Sierra Environmental Resource Center (CSERC) reports that in 2017 the McCormick Fire was managed for resource benefits in Stanislaus National Forest and the South Fork Fire and Empire Fire were managed in Yosemite National Park (CSERC, 2017). Over time, the use of managed fire has proven to be beneficial for Yosemite. In 1973, Yosemite adopted a strategy to manage wildfires with minimal suppression. University of California, Berkeley researchers completed a follow-up assessment to this approach and concluded that the strategy led to a landscape which is more resistant to fire, has more diverse vegetation and forest structure, and stores more water on the land (Sanders, 2016).

BENEFICIAL FIRE APPROACHES

This section explores important factors to consider in implementing any type of beneficial fire.

Figure 9.6. Broadcast burning training as part of Audubon Canyon Ranch's Fire Forward Program. (Photo from Audubon Canyon Ranch, n.d.b.)

TECHNICAL CONSIDERATIONS

All types of beneficial fire require advanced planning, experienced personnel, and considerations for crew and public safety.

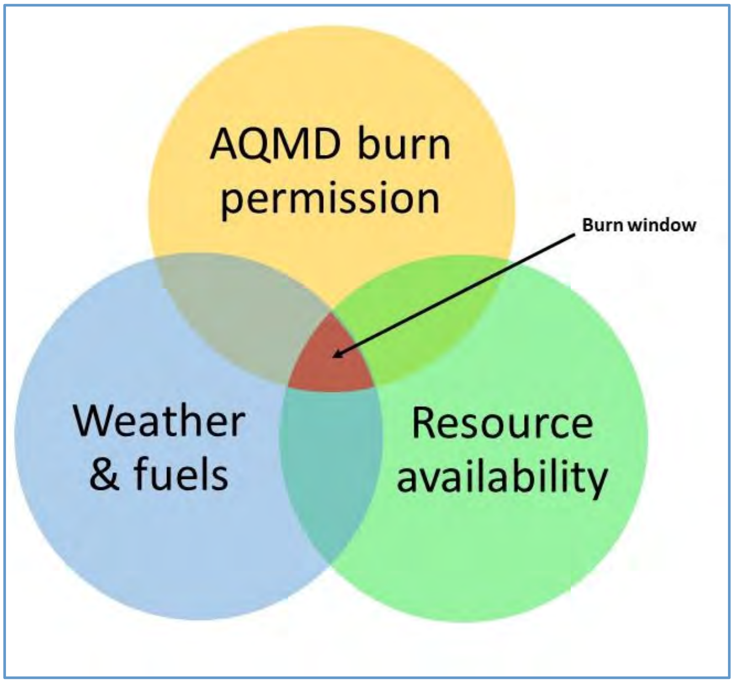
Applying beneficial fire may include the following components:

- Pre-fire mechanical vegetation treatment. Thinning to reduce fuel load and control fire behavior prior to a broadcast burn.
- Pile and burn. Thinning, creating piles from thinned vegetation, allowing the piles to season, and then burning them on site.
- Broadcast burning. Controlled burning to reduce fuels over a large area or restore fire resiliency in target fire-adapted plant communities, conducted under specific conditions related to fuels, vegetation, weather, and topography. Figure 9.6 shows a prescribed fire training underway as part of Audubon Canyon Ranch's Fire Forward Program.

Many burns are timed for late fall or winter when wetter, cooler weather allows for more control and greater safety. Burns may also be conducted at night to increase burn windows. At least three basic factors must be in place to support burn window conditions: weather and fuel conditions, resource availability (such as trained fire crews), and permission from the local Air Quality Management District (AQMD) (Figure 9.7). A downside of winter burning can be negative impacts on fruiting species that are adversely affected by burns during their reproductive period.

Prescribed burns typically occur over 1-7 days, with an average number of 45 workers on site (California Board of Forestry and Fire Protection, 2019b). Equipment can include multiple fire engines, bulldozers, masticators or track chippers, and water trucks. Brush rigs, McCleod shovels, rakes, water pumps, and fol-da tanks can also be used for fire control. Drip torches and fusees (e.g., safety flares or forest fire torches) are used to ignite fires. Sometimes flare launchers and ping-pong balls filled with napalm or gelling agents, such as Alumagel, are used to ignite fires, often from aircraft. See the CAL FIRE *Fuels Reduction Guide* for pictures of tools and techniques for prescribed fire (CAL FIRE, 2021b).

Figure 9.7. Venn diagram of supporting burn window conditions (adapted from California Fire Science Consortium, 2021).



COMMUNICATIONS

It will be important for managers, public information officers, and others to distinguish between beneficial and unplanned fires in public communications. Working with the local community is one of the crucial factors in burn planning; members of the public are likely to be concerned about unexpected fires and could call emergency services as soon as smoke is spotted. Outreach to the community from the early planning stages through implementation is essential for a successful beneficial fire project. These communication efforts will likely result in public interest and support for beneficial fire and could be an important capacity-building tool for fire implementation.

There are many tools and references available for beneficial fire communications. For example, the Put Fire to Work website is a prescribed fire outreach toolkit for practitioners with simple graphics showing how fire might be applied at various scales (Figure 9.5). The All Hands All Lands e-booklet is another example of an effective communications tool created for Washington state forests and communities. It describes collaborative approaches to forest and fire management and includes a substantial section on prescribed fire, fire training, and prescribed fire partnerships.

Figure 9.8. Example of free communications graphics available on Put Fire to Work website.

Pushing the boundaries on public communications, the Sagehen Creek Field Station started collaborating with artists to increase public outreach and understanding of fire. Their burn program added an inventive twist to involving artists by offering prescribed fire training to artists and scientists. The effort deepens artist engagement by helping them obtain an Incident Qualifications Card (Red Card) so they can take part in prescribed burns. The artists incorporated their training and fire management experiences in their work, blogs, and other outreach and communications efforts. Sagehen went a step further in connecting to fire by creating a community ritual in which "fire sprites" or carved wooden tokens are burned by community members. An in-person and virtual exhibit combining science and art to increase public awareness of forest health is also being created (Sagehen Creek Field Station, n.d.).

California Air Resources Board (CARB) released the California Smoke Spotter application (app) in May, 2021. This tool will support beneficial fire practitioners in streamlining communications. The app shows alerts and the local air quality index at locations throughout the state. In addition to allowing practitioners to enter upcoming planned fires, the app shows prescribed fires planned and in process. It also includes smoke forecasts related to prescribed fires which covers the current and next-day forecasts and allows animated viewing of the smoke forecast models (CARB, 2021).

COLLABORATIONS

Many organizations, agencies, and individual landowners are coming together to utilize beneficial fire. Given the skills and resources needed to plan and implement beneficial fire, collaborative efforts are important to grow the pace and scale of application successfully and safely.

The Cultural Fire Management Council is a community-based organization furthering fire use and cultural resource management with the aim of healthier ecosystems, fire protection, and a platform for Yurok hunting and gathering activities in Northern California. Also in Northern California, the Yurok-Hoopa-Karuk partners used indigenous planning processes to develop a fire year cultural burning and learning plan (Halpern, 2016). They are connecting with many other Tribes in Northern California to do the same. The Indigenous Peoples Burning Network (IPBN) is a collaboration among Native American communities that are revitalizing their traditional fire practices in a contemporary context. The IPBN began in Northern California and has since expanded to support beneficial fire use in many regions of the United States.

The California Prescribed Burn Association (PBA) is a collaborative statewide community effort to return fire to the landscape on private lands. There are many PBAs throughout California which focus on supporting landowners in their region. The cooperative nature of the PBA reduces the risk to single landowners when planning and implementing burns. Through the Good Fire Alliance, a California PBA, a network of landowners in Sonoma and Marin Counties are cooperatively conducting burns to manage vegetation.

In the San Francisco North Bay, Audubon Canyon Ranch is leading the Fire Forward program, which combines science-based program design and community and Tribal collaboration to create fire-adapted communities tending fire-adapted landscapes. More details on the Fire Forward Project are in the next section.

Fire Training Exchanges (TREX) are sponsored frequently by beneficial fire collaboratives throughout California These trainings are designed to support the growth of prescribed fire as a management tool by increasing the number of qualified, experienced burners. In the North Bay, Audubon Canyon Ranch (ACR) regularly hosts prescribed fire training exchanges (ACR, n.d.).

BENEFICIAL FIRE USE IN CALIFORNIA

California's Strategic Plan for Expanding the Use of Beneficial Fire was released in March 2022, providing a roadmap for increasing the pace and scale of beneficial fire throughout California (Wildfire and Resilience Task Force, 2022). The plan will help build a culture of beneficial fire to guide forest management in the coming decades. It sets out clear targets, including 400,000 acres of beneficial fire deployed by 2025.

A consortium of 37 state and federal land and resource management agencies, environmental groups, and regional prescribed fire councils joined the Fire MOU Partnership to pledge their commitment to advancing the use of fire for ecological benefits and improved fire management in California (Fire MOU Partnership, 2021). The partnership has been significant in influencing prescribed fire policy at the state level, reducing the barriers to implementation, and coordinating prescribed efforts across multiple entities in California.

PRESCRIBED FIRE IN MARIN AND SONOMA COUNTIES

Prescribed fire is already being used by landowners and public land managers in Marin and Sonoma counties, including One Tam agencies.

According to the *Biodiversity, Fire, and Fuels Integrated Plan* (*BFFIP*) (Marin Water, 2019a), Marin Water recognizes the importance of prescribed fire for managing watershed lands to achieve predetermined resource management objectives, such as controlling non-native invasive species, maintaining specific vegetation types (e.g., meadows, open woodlands), and reducing hazardous fuels. According to the *BFFIP*, each prescribed fire will be conducted based on a detailed plan that considers air quality, health effects, and regulatory and resource management objectives. Currently, Marin Water is in the process of drafting burn plans that will make it possible for this work to move forward.

The Golden Gate National Recreation Area (GGNRA) Fire Management Plan EIS (2005) examines the opportunities to use prescribed fire and mechanical fuel treatments to achieve fire risk reduction and resource protection objectives. The GGNRA Record of Decision (ROD; GGRNA, 2006) Fire Management Plan EIR Alternative C permits up to 595 acres to be treated per year using mechanical treatments and prescribed fire as well as mechanical treatments complemented by fire.

The Point Reyes National Seashore ROD EIS Fire Management Plan includes up to 3,500 acres treated per year using prescribed fire and mechanical treatments. The Fire Management Plan includes research to determine the effects of fire on rare and non-native species and determine the effectiveness of various treatments for fuel reduction.

California State Parks (CSP) has a decades-long history of using prescribed fire as a management tool. In State Parks in Marin and Sonoma Counties hundreds of acres were treated with prescribed fire during the 1990s and 2000s. The Bay Area District is currently rebuilding its capacity to use prescribed fire. In Fall 2020 and Fall 2022, broadcast burns were conducted at Jack London State Historic Park (Sonoma County) in grassland and woodland habitats. Planning is ongoing for future burns in Marin County (R. Schneider, CSP Senior Environmental Scientist-Specialist, and B. Hardcastle, CSP Environmental Scientist, personal communication, March 21, 2023).

Pepperwood Preserve's Strategic Plan for 2020-2025 has a major component focused on building climate and fire resilience throughout the Preserve and the region (Pepperwood Preserve, 2020). Pepperwood Preserve has used prescribed fire in recent years to improve forest health and reduce risk from wildfire. In 2022 Pepperwood Preserve worked with various partners to conduct prescribed burns in grassland and forest understory (Pepperwood Preserve, n.d.).

Audubon Canyon Ranch's Fire Forward program supports prescribed burns on public and private lands in Sonoma and Marin Counties using a science-based approach and cooperative burning across jurisdictions to reduce fire deficits and create fire-adapted landscapes. Audubon Canyon Ranch is working with the Federated Indians of Graton Rancheria (the Tribe) to integrate cultural/ecological burns into the program and strengthen collaboration with the Tribe.

Work at Audubon Canyon Ranch's Martin Griffin Preserve has included thinning and prescribed fire to remove encroaching or canopy-piercing Douglas-fir in coastal prairie and oak woodland habitats (Coy, 2019). Conducting burns in forests is quite different than in grasslands. Audubon Canyon Ranch started with grassland burns and then moved to more complicated and larger burns as crews and leadership were trained and gained knowledge and confidence in working with different vegetation types. Starting from grassland burns, they moved to pile burns, and then graduated to small broadcast burns in forested stands. In recent years they have expanded to medium-size broadcast burns in forested stands (Bland, 2022).

Recently Audubon Canyon Ranch expanded their beneficial fire program to include Coast Redwood. They started burning in second-growth Coast Redwood stands during winter 2020-21 to reduce excessive accumulation of duff and leaf litter under trees. Redwood burns were started after Audubon Canyon Ranch staff noted high mortality following wildfire in second-growth stands with a high accumulation of duff/litter, possibly caused by drier conditions not allowing materials to decompose as quickly, and potentially linked to climate change.

BENEFICIAL FIRE IN THE KLAMATH REGION

Several organizations, agencies, and collaborative programs are working together to use beneficial fire to improve forest health in the Klamath region of Northern California. The Mid Klamath Watershed Council's Fire and Forestry Program, working in collaboration with the Karuk Tribe, US Forest Service, CAL FIRE and others, uses prescribed fire to create resilient forests and enhance cultural resources and supports a Klamath fire training exchange program (KTREX).

The Western Klamath Restoration Partnership is an example of combining western and traditional knowledge. The Partnership works with the Karuk and Yurok Tribes to identify management methods that support traditional food and fiber collection, reduce wildfire risk, and restore forest health in Northwestern California.

Burning in the Klamath region by Yurok and Karuk Tribe members during the past 20 years has had several goals, including fuel reduction, improving ecosystem function, wildlife management, hardwood/oak selection, and reinstatement of ceremonial burning practices. Norgaard et al. (2016) analyzed the vulnerabilities of traditional foods and cultural-use species for the Karuk Climate Vulnerability Assessment. This Assessment found that food, fiber, and water are essential resources for the Karuk people and that TEK and beneficia fire play an important role in maintaining species and systems (Table 9.1). The importance of cultural burning in food and fiber production for Native people is being recognized more broadly and incorporated into fire and forest restoration plans such as Western Klamath Restoration Partnership Plan (Harling & Tripp, 2014).

Partnership between the Yurok and Karuk Tribes and agencies is increasing. For example, the U.S. Forest Service now conducts more prescribed burns with Tribal burn crews and ecologists to promote forest health and reduce fire risk. The National Park Service incorporates TEK into prescribed burning at Redwoods National and State Parks (Klamathmedia, 2012).

Redwood National and State Parks 2021 Fire Management Plan calls for fire to be used to restore natural and cultural processes, reduce invasive species, limit conifer encroachment into oak woodland and prairie habitat, and educate visitors about the important role of fire in the ecosystem (Redwood National and State Parks, 2022). One of their focal areas is the Bald Hills, where fire is used to control conifer invasions into grasslands and oak woodlands (van

Mantgem et al., 2021). Late-season burns at the Bald Hills oak woodlands allow grassland regrowth and benefit elk. Redwood National and State Parks have been using beneficial fire since the early 1980s, but managers have noted centuries-old fire scars from repeated burns in oak woodlands (Klamathmedia, 2012).

Table 9.1. Effects of Karuk cultural burning on tanoak forest and riparian systems across time, from Karuk Climate Adaptation Plan (Norgaard & Tripp, 2019.)

Effects of Karuk Cultural Burning on Low Elevation Tanoak Forests Across Time

Immediate	2-Year	Long-Term
• Kills encroaching smaller diameter younger conifers • Reduces brush and understory fuel loaing • Promotes grove and acorn health by periodically reducing predatory insect populations • Releases nutrients to system	• Healthy tanoak groves sustained by low intensity fires sustain other culturally vital species and ecosystem health • Increase deer and elk forage quality for understory shrubs, forbs, grasses and ferns.	• Resource patch mosaic leads to food security • Frequent burning prevents high severity fires
Sources: Karuk DNR 2010	Sources: Bowcutt 2013	Sources: Bowcutt 2013

Effects of Karuk Cultural Burning On Riparian Systems Across Time

Immediate	2-Year	Long-Term
• Reduced vegetative evapotranspiration increases stream flow to riparian system • Rejuvenate flood/disturbance adapted plants between flooding episodes. • Increase human and animal access to forage/post-fire growth.	• Gravel and wood debris enters aquatic systems following fire and enriching habitat for some species • Increased system productivity as fire releases nutrients into the food chain • Reduction of vigorous vegetative growth can provide more water in riparian system	• Water balance of riparian areas benefits from burning in surrounding forest • Frequent low intensity fire prevents negative impacts of high severity fire • Rejuvenate flood/disturbance adapted plants between flooding episodes. • Increase human and animal access to forage/post-fire growth.
Sources: Soto 2016, Lake 2007	Sources: Soto 2016	Sources: Dwire and Kauffman 2003

BENEFITS & CONSTRAINTS

Prescribed fire has many benefits to ecosystem function, but managers find numerous challenges in implementing burns related to costs, capacity, regulations, and public perception. A summary of the benefits and constraints can be found in Table 9.2.

Table 9.2. Summary of the benefits and constraints of beneficial fire treatments. From Bond & Keeley, 2005; Quinn-Davidson & Varner, 2012; Schultz et al., 2018.

Benefits	Constraints
• Reduces accumulated fuels. • Reduces fire severity and frequency. • Consumes vegetation & recycles nutrients in the soil. • Alters community composition, assembly, biomes, selects for fire-adapted species, increases pyrodiversity, and acts as an evolutionary agent. • By reducing fire severity, prescribed fire can increase resilience for habitats more sensitive to high-severity fire. • Creates diversity of forest stand structure in fire-adapted ecosystems. • Creates local job opportunities. • Though it causes carbon emissions, these may be lower emissions than unplanned high-intensity wildfires. • Cultural burning can help select species valued by indigenous communities. • Can be implemented at varying scales, including large-scale efforts. • Reduces pests and pathogens. • Creates landscape-level vegetation heterogeneity.	• May not prevent or mitigate wildfires, particularly wind/weather driven events. • Disturbance may temporarily have negative impacts on some species or forest systems. • Can be difficult to permit. • Can be costly to implement. • Difficult to implement within narrow burn windows. • Periodic retreatment is necessary. • Does not apply to all forest types and locations. Consultation with experienced practitioners is needed to ensure beneficial fire is used appropriately. • Not appropriate to use in the wildland urban interface (WUI). • May not create the burn mosaic of a wildfire. • Difficult to implement in areas with high fuel loads, requiring mechanical vegetation removal as a pre-fire treatment. • Public fear of fire, or not distinguishing between good fire/bad fire, risk of escaped fire, and liability. • Produces carbon emissions. • Qualified personnel are increasingly in demand for the longer/more severe fire season and training needed for fuel crews to plan and manage fires.

BENEFITS

Existing agency documents including Marin Water's *Biodiversity Fire and Fuels Integrated Plan* (*BFFIP*), Point Reyes National Seashore *Fire Management Plan*, Golden Gate National Recreation Area *Fire Management Plan*, and the Marin County *Community Wildfire Protection Plan* (*CWPP*), include discussions on the benefits of prescribed fire (GGNRA, 2005; Lavezzo et al., 2020; Marin Water, 2019a; PRNS, 2004a). Benefits include reducing hazardous fuel loads, protecting communities from catastrophic fire, reducing the spread of plant and tree diseases and invasive species, encouraging the health of fire-dependent native vegetation and animal species, encouraging palatable and nutritious forage for domestic livestock in timbered and open range, enhancing aesthetic value by increasing occurrence and visibility of flowering annuals and biennials, and improving access to areas previously inaccessible because of thickets or dead and downed wood (Lavezzo et al., 2020, p.92). The CWPP and other agency documents describe beneficial fire as an effective tool for hazard mitigation and ecosystem restoration.

In California's disturbance and fire adapted ecosystems, such as chapparal communities, beneficial fire can be a critical tool for restoring processes necessary for retaining biological diversity (Potts & Wirka, 2018). The rise of fire suppression following colonization coupled with policies that prevent Indigenous stewardship with fire alters the floristic composition of many vegetation communities in the region to the detriment of biodiversity, and provides a clear rational for restoring the use of fire as a management tool in key areas (Cocking et al., 2015; Hessburg et al., 2021).

Researchers in mixed-conifer forests in the Sierra Nevada and southern Cascades confirmed that prescribed fire does reduce wildfire risk, finding that thinning followed by prescribed fire, or prescribed fire alone, effectively reduces wildfire severity while minimizing ecological impacts (Winford et al., 2015). A chamise chaparral-focused study near Hopland Research Station recorded a finding related to prescribed fires and non-native weeds (Potts & Stephens, 2009). Comparing invasive and native species responses to shrubland fuel reduction, the authors found that cold season (winter/spring) prescribed fire treatments were the most resistant to non-native species invasions.

CONSTRAINTS

Some of the main concerns around beneficial fire risk include the potential for fires to spread outside of intended areas, air quality impacts, and carbon emissions. The risk of fire escapes from prescribed burning is exceptionally low. Reviews have found landowner prescribed burns without incident at 99% on private lands and burns without incident on public lands at 99.2%, or 14 escapes out of 16,600 prescribed fires (Weir et al., 2015; Wildland Fire Lessons Learned Center (WFLLC), 2013). In addition, damages and suppression costs for escapes are considerably less than for wildfire ignition and spread (Yoder, 2008). This lower cost should not be surprising, given that prescribed burns are typically conducted under favorable weather conditions dissimilar to those that spread large, destructive fires and are usually conducted at much smaller scales (Twidwell et al., 2015).

Air quality can be a significant barrier to conducting prescribed burns, especially in areas with poor air quality and high populations. As a result, air quality districts are often reluctant to issue permits unless conditions are close to perfect. However, researchers have found that emissions from prescribed fire are balanced by lower emissions and reduced carbon loss from reduced wildfire frequency and severity (Volkova et al., 2021). With this new perspective, CARB and air quality districts are changing their stance on prescribed burns. For instance, the Bay Area Air Quality Management District (BAAQMD) has changed its burn permit applications and encourages entities to burn during favorable conditions, as managed and smaller emissions from prescribed fires are preferred over uncontrolled large emissions from wildfire (BAAMQD, 2019).

Although it is often presumed that air quality permitting and NEPA/CEQA compliance were significant barriers to prescribed fire implementation on public lands, a recent study conducted throughout the Western United States found that lack of capacity and funding were more significant challenges to increasing prescribed fire implementation (Schultz et al., 2018). Other ongoing challenges include resources diverted from prescribed fire programs to wildfire suppression, disincentives for prescribed burns (less pay for prescribed fire vs. fighting wildfire, liability risk to burn bosses), and conflicting land-use priorities. Other secondary limitations included limited incentives to burn, narrow burn windows, planning limitations, and other conservation priorities, e.g., sage grouse conservation, that limit or supplant burning (Schultz, 2020).

A northern California survey (including Marin County) of land managers to identify constraints to implementing fire found that 66% of managers indicated were not satisfied with current levels of prescribed fire activity. The highest-ranked impediments were narrow burn windows, laws/regulations, and a lack of adequately trained personnel (Quinn-Davidson & Varner, 2012).

COSTS

Cobb et al. (2017) found treatment costs that included piling, prescribed fire, and mastication in high-density stands on steep slopes in Marin and Klamath counties to reach up to $10,000/acre. Cost per acre is difficult to summarize for prescribed fire treatments, as it can vary by an order of magnitude depending on burn unit preparation that is needed, the complexity of the burn, size of the burn, compliance and surveys, staffing model, rehabilitation required, and whether the treatment is an initial or subsequent entry. Implementation costs could potentially range from $1,000 acre to $10,000-15,000 per acre. Other cost factors include development of burn plans, pre-fire vegetation management, staffing qualified personnel, emergency response, and control resources. CAL FIRE Forest Health Grants and similar funding sources typically cover fire reintroduction and prescribe fire activities.

RESOURCE PROTECTION

Resource protection for beneficial burns focuses on training, education, safety, fuels and ignition reduction, and habitat and species protection. There are many useful documents which includes best management practices (BMPs) to use before, during, and post-fire to protect resources. The *California Vegetation Treatment Program* (Cal VTP) Mitigation Monitoring and Reporting Program has a thorough list of BMPs (California Board of Forestry and Fire Protection, 2019a). These BMPs must be followed for projects completing compliance under the Cal VTP Programmatic Environmental Impact Report (EIR). Agencies may be working under compliance documentation particular to their jurisdiction which includes specific BMPs. For example, Marin Water's *BFFIP EIR* includes a Mitigation, Monitoring, and Reporting Program with resource protection BMPs (Marin Water, 2019b) and the GGNRA's *Fire Management Plan Environmental Impact Statement* (FMP EIS) includes BMPs as part of the General FMP Mitigation Measures included in the Record of Decision (ROD) (GGNRA, 2006). In addition, the Marin Wildfire Prevention Authority (MWPA) worked with the Ecologically Sound Practices Partnership (ESP Partnership) to develop BMPs to be used by the MWPA for fire management actions in Marin County. The *Ecologically Sound Practices for Vegetation Management* document compiles BMPs from a variety of sources (ESP Partnership, 2022).

Some important BMPs for use of beneficial fire in Marin County focus on following burn safety procedures, creating a burn plan that reduces risks from burning, coordinating traffic control with public agencies, and working to ensure there is no net loss of listed species from fire treatments.

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THINNING TREATMENT DESCRIPTION

A century of fire exclusion and logging practices have left many forests in California with densely-packed small trees, which lowers heterogeneity and variability, can degrade habitat and biological diversity, and can contribute to uncharacteristically intense fires (Collins et al., 2011; Lydersen et al., 2013; Steel et al., 2015). While there are important ecological and fire behavior differences between Sierran forest systems and coastal forests, such as those in Marin County, forest health impacts from altered fire regimes, stand structure, and past/present land can be observed in Marin as in the Sierran forests (see Chapter 7: Condition Assessment). Although forest management may not be able to reduce the total area burned by wildfires, strategic vegetation management can help decrease fire intensity and severity at the local scale in key areas, and improve forest resilience to fire, insects, and drought (Halofsky et al., 2020).

This treatment description offers considerations for managers for utilizing thinning to improve forest health and resilience in appropriate forest stands in Marin County. This treatment description does not intend to address or inform thinning approaches for timber production/harvest, for-profit forest extraction, or other means and methods used for commercial production, which are not considered applicable to protected open spaces in Marin County. The treatment description outlines different approaches to thinning, including strategies for *Marin Regional Forest Health Strategy* (*Forest Health Strategy*) target forest types; explores the benefits and challenges of thinning as a forest health treatment tool; and discusses resource protection. Where possible, it highlights Marin County and California Coast Range examples and, where instructive, includes forest thinning treatment descriptions outside these areas.

BACKGROUND

Thinning is one of several forest management approaches that has the potential to both influence fire behavior and improve forest health and resilience. Thinning can be used independently, or in combination with other treatments such as beneficial fire, and these two treatments are often considered together for large-scale forest health and wildfire resilience, with the goal of creating heterogeneity in managed areas (Odland et al., 2021). *California's Wildfire and Forest Resilience Action Plan* describes "ecologically appropriate forest thinning and prescribed fire" treatments as being important to decrease forest density, support larger tree growth, and improve forest resilience to climate change and wildfire (California Forest Management Task Force, 2021, p.36).

Thinning can have multiple ecological benefits that emulate the effects of a low to moderate intensity wildfire, such as reducing stand density, decreasing competition for light and water resources, and increasing vigor and resilience for remaining trees (North et al. 2022; O'Hara et al., 2010). However, thinning does not offer all the same benefits as fire. For example, beneficial fire triggers the germination of many fire-adapted species, and thinning treatments likely will not replace this important function.

RESULTS CHAIN RECOMMENDATIONS

Thinning is included as a treatment method in the results chains for four of the target forest types of the *Forest Health Strategy*: Coast Redwood, Douglas-fir, Open Canopy Oak Woodland, and Bishop Pine. In Bishop Pine forest, thinning is part of the beneficial fire surrogate results chain. For Coast Redwood, Douglas-fir, and Open Canopy Oak Woodland, thinning can be used to mimic the effects of a low to mid-intensity fire and/or to prepare an area for beneficial fire and is recommended to create fire-resilient stands with more natural fuel arrangements. Thinning can be used to manage pest and pathogen-impacted vegetation, control Douglas-fir encroachment, and can act as a fire surrogate by removing small diameter trees and accelerating stands towards old-growth conditions. In addition, thinning can support the growth of a diverse understory and shrub layer.

For Bishop Pine forests, thinning can be used as a precursor to the use of beneficial fire. Thinning could also be used in conjunction with beneficial fire to find a controlled means to increase Bishop Pine forest regeneration.

For Sargent Cypress, thinning is not generally considered necessary. However, thinning or removal of Douglas-fir trees encroaching on Sargent Cypress stands is included as a potential treatment to meet forest health goals.

See Chapter 5: Goals for more information on each target forest type's forest health goals and results chains.

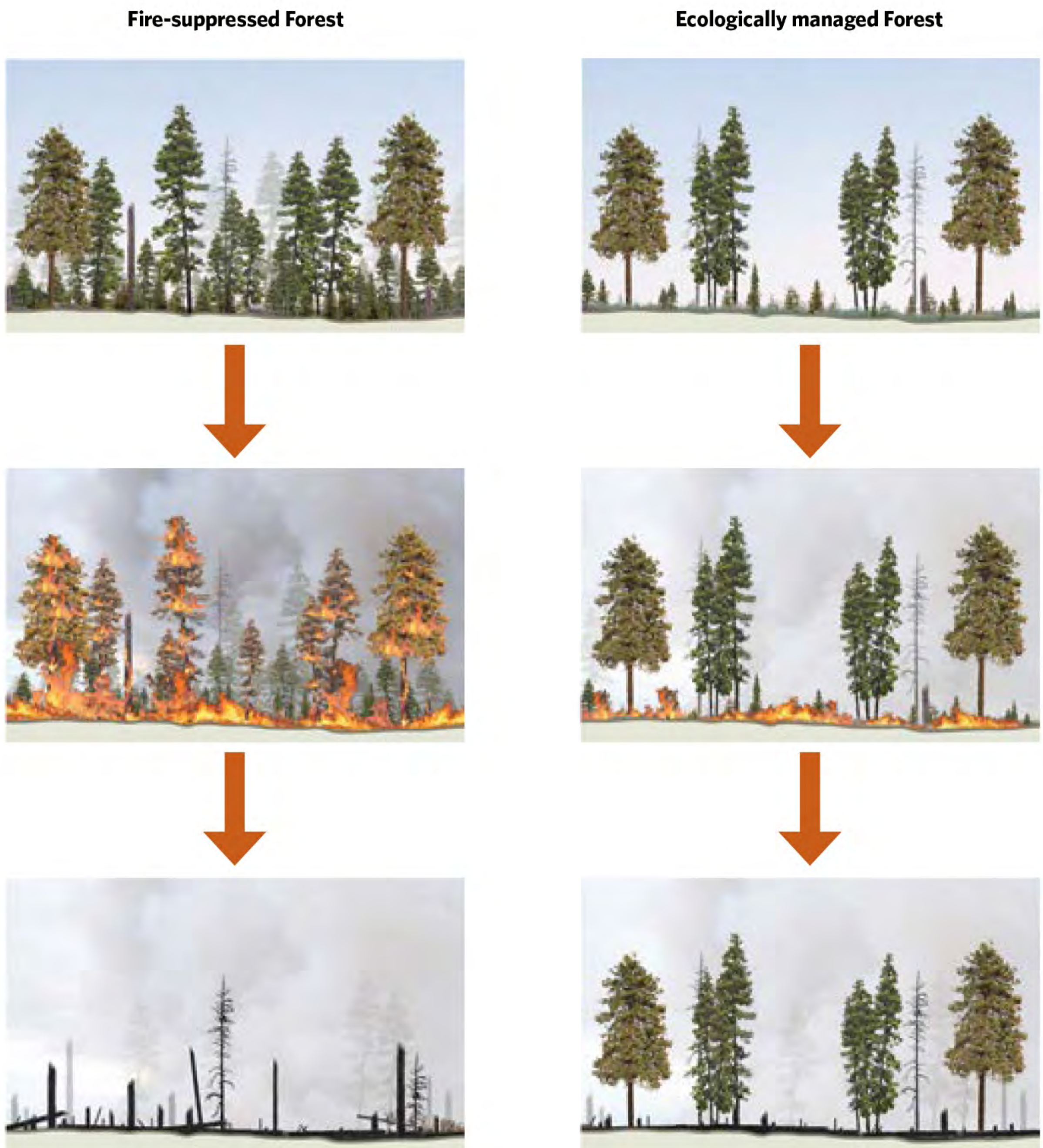
DESCRIPTION

The term "thinning" generally refers to manual or mechanical approaches to managing forest stands with a focus on restoring natural conditions with respect to tree density, tree species distribution, tree age distribution and natural gaps in the canopy (Westover, 2021). Ecological or restoration thinning involves the selective management of forest stands to restore heterogeneity and other ecologically desirable stand structure characteristics and processes (Dwyer et al., 2010; Knapp et al., 2020; North & Manley, 2012). Figure 9.9 provides a visual representation of anticipated benefits from ecological thinning.

Treatment prescriptions that involve a thinning component can and should be site and forest type specific, however they generally include elements such as removal of smaller-diameter trees growing in dense stands, management of pathogen-impacted vegetation, and/or reduction of fuel loads to increase wildfire resilience or facilitate beneficial fire use. In California's Coast Range, the Yurok Tribe has practiced thinning in north coast forests to reduce fuels and increase access to and availability of culturally important plants and animals (Cobb et al., 2017). Appropriate management of cut vegetation is an important component of thinning treatments, see the Biomass Management Treatment Description for information.

My Sierra Woods produced a series of three videos on thinning, with a focus on reducing fire risk; the third video provides a simulation of thinning treatments in a forest (My Sierra Woods, 2020). Figure 9.10 shows a mixed-conifer forest in Marin County before and after ecological thinning treatments. These photos show the Pilot Knob area on Marin Water lands; the before photo shows dense understory vegetation, including vegetation impacted by sudden oak death (SOD). The after-treatment photo shows mature trees and coast redwood retained, along with ferns and other desired understory species, with cut material staged into piles for subsequent burning.

Figure 9.9. Simplified graphic demonstrating the role of selective thinning in improving wildfire resilience for forests impacted by fire exclusion ([Kelsey, 2019](#)).



Forests that have not experienced fire in many decades, that are dense with thickets of young trees and shrubs in the understory, are prone to high-severity fires that travel up into the canopy, burn very hot and can kill most of the trees, even the large, fire-resistant trees. © The Nature Conservancy

By carefully thinning the understory of some forests to reduce overall fuel load and open the forest up, we can safely reintroduce fire as a restorative process that will over time maintain healthy forests. © The Nature Conservancy

Figure 9.10. Pilot Knob Project Area. Top, pre-treatment. Bottom, immediately post-treatment, cut material has been piled for burning. Photo from Loren Jenkins, Project Coordinator, Marin Water.

THINNING APPROACHES

There are many variables to consider when planning a thinning treatment. The appropriate prescription for a project site will be developed by land managers and depend on several factors, including site access, topography, climatic conditions, cost to implement, project size, anticipated environmental resource values, and any sensitive resources in the area. Some common thinning approaches are summarized in Table 9.3. The California Department of Forest and Fire Protection (CAL FIRE) *Fuels Reduction Guide* provides descriptions and pictures of many of the thinning practices and equipment described here (CAL FIRE, 2021).

There are many different scenarios in which thinning could be used independently or in conjunction with other treatments to improve forest health. For example, thinning as a precursor to beneficial fire is common practice. Thinning objectives could include removing smaller vegetation to reduce resource competition and promote old-growth forest conditions, removing pest or pathogen-impacted vegetation to reduce spread, removing vegetation that could act as ladder fuels in a fire, or some combination of these. Determining objectives for a particular stand is important in determining the appropriate thinning approach.

Thinning, as with other vegetation management actions, requires ongoing maintenance. Periodic retreatment of thinned trees is often required, depending on local site conditions, regrowth, and management objectives, and monitoring and management for invasive species, erosion, and other changes to site conditions should be included in plans and budgets.

Table 9.3. Summary of thinning treatment approaches.

Thinning approach	Description	Mechanical	Manual
Feller-buncher	Self-propelled machine with a bladed head that cuts, holds, and places stems on the ground but does not have processing capabilities (U.S. Forest Service, n.d.).	X	
Cable yarder	Cabled system that winches logs from cut stumps to landing (U.S. Forest Service, n.d.).	X	
Harvester	Self-propelled machine with a cutting head attachment capable of felling and processing stems (U.S. Forest Service, n.d.).	X	
Mastication	Mechanized unit that grinds, shreds, or chops noncommercial sized trees or shrubs into small chunks or pieces using various attachments to equipment such as a skid steer or excavator with mastication attachment (Jain et al., 2018).	X	

Chainsaw	Portable powered saw with a loop of chain driven around a bar at high speed (U.S. Forest Service, n.d.).	X	X
Prune	Branch or limb removal from trees using hand tools such as a lopper.	X	X
Pile/ Pile & Burn	Logs and slash stacked during thinning operations, then seasoned and burned on-site or removed off-site.	X	X
Lop & Scatter	Cut vegetation is scattered on site to decompose.	X	X
Grazing/ Livestock	Livestock use, typically goats, to reduce understory fuels in various vegetation types.		X

MECHANICAL VS. MANUAL THINNING

Thinning methodology is divided into two main categories: mechanical treatments and manual or hand treatments. Mechanical treatment involves using motorized equipment, such as wheeled tractors, crawler-type tractors, or specially designed vehicles with attached implements designed to cut, uproot, crush/compact, or chop target vegetation (California Board of Forestry and Fire Protection, 2019b). Manual treatments incorporate hand tools and hand-operated power tools to cut, clear, or prune herbaceous and woody species. Manual restoration activities could include use of chainsaws, lopping/pruning, pulling out root systems, or strategically placing mulch (California Board of Forestry and Fire Protection, 2019b).

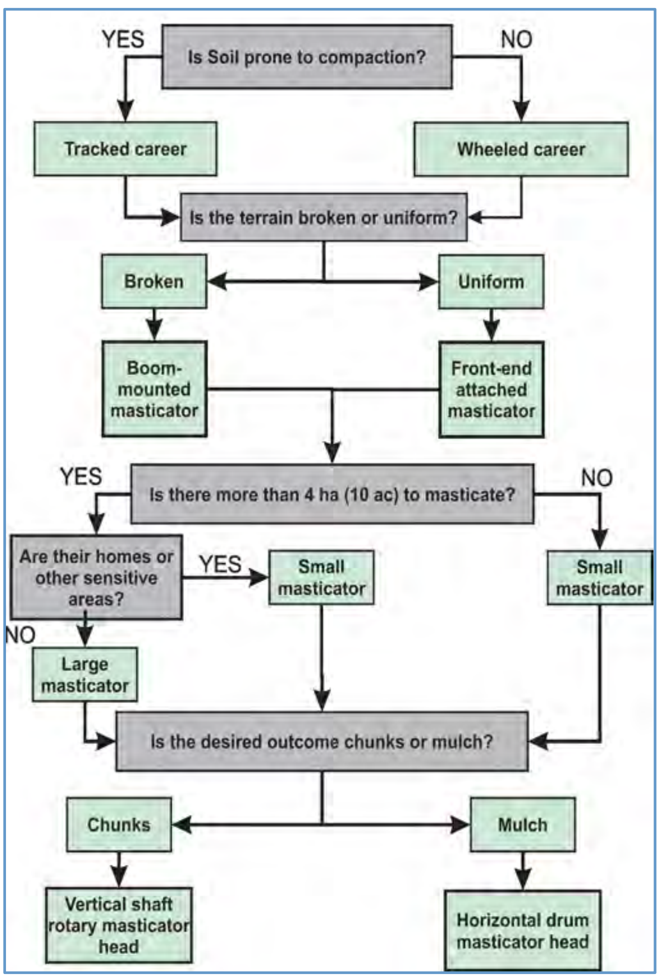
Biomass management is an important consideration for any thinning treatment, see the Biomass Management and Utilization Treatment Description for more information. Hand treatments may use lop and scatter, in which vegetation is cut and scattered on the soil surface, or piling cut vegetation, which can then be removed or burned on site. Pile burning can also be used to manage biomass created by mechanical treatments (Windell & Bradshaw, 2000). Mechanical or manual treatments can also be used before applications of beneficial fire as a pre-treatment when fuel loading is high, which is an ideal method to manage biomass (De Lasaux & Kocher, 2006).

When deciding whether to use manual or mechanical treatment, managers should consider project size, site access and topography, vegetation type, natural and cultural resource protection, and choosing the appropriately sized machinery or crews to efficiently complete the project. Mechanical treatment is more cost-effective and can treat larger areas during limited work windows. It is, therefore, the more efficient choice for sites that can be accessed by larger equipment. However, manual thinning may be the only option for sites with limited access, such as locations away from roads or in steeper areas. In addition, manual treatments may be useful in sensitive resource areas where equipment could damage resources and hand crews can work more carefully.

Using mechanized treatments on slopes greater than 35% is not usually feasible (North et al., 2015), although cable yarding systems, helicopters, and some types of feller-bunchers can be used in steeper terrain. However, costs increase directly with slope increase, and helicopter thinning is often not feasible due to cost, availability, or carbon emissions variables. In general, manual/hand crews are favored for steep terrain where there is still good road or trail access.

Choosing which thinning approach is appropriate can be difficult and may require trials and adaptive management to ultimately be successful. Jain et al. (2018) developed a guide to treating forest vegetation with a review of equipment choices, impacts on soil and vegetation, and costs. To help with deciding what type of thinning and tools to use, Jain et al. (2018) also offer several useful decision trees, including one that provides site specific components that

Figure 9.11. Mastication tool decision tree (Jain et al., 2018).



may help identify the appropriate masticator and head configuration for a given project (Figure 9.11). The same guide also examines vegetation response to mastication.

Marin Water has extensive experience implementing both mechanical and manual thinning treatments. A complete forest thinning prescription on Marin Water property often occurs in multiple phases. Where terrain accommodates, tracked equipment using a combination of flail, disc, and mulching attachments often makes the first pass through a stand, reducing ground and ladder fuels under 10 inches diameter at breast height (DBH). Once the understory has been cleared of smaller diameter fuels, hand crews may access and then fell select small-diameter trees. Slash is often piled for later burning or mastication. The resulting boles are usually left whole and in good ground contact to aid in decomposition (C. Sanders, Natural Resources Program Manager, Marin Water, personal communication, 2021).

Marin Water's *Biodiversity, Fire, and Fuels Integrated Plan* (*BFFIP*) (Marin Water, 2019a) provides useful guidance on thinning treatment methodology. Marin Water uses a combination of excavators, skid steers with different mulch heads, and hand crews with chainsaws and brushcutters to thin vegetation on slopes generally less than 30% grade. Mulch is redistributed on site to suppress weeds and retain soil moisture.

GRAZING

On specific sites, livestock can be used for thinning but are generally most effective at removing or reducing underbrush, smaller-diameter stems, and some invasive weed species. Moveable electric fencing can be employed to concentrate livestock in priority areas. There is evidence that goats and sheep can reduce fire hazards in certain stands and conditions and, with the right intensity and timing, can effectively keep invasive species at bay (Davies et al., 2022; U.C. Agriculture and Natural Resources, n.d.). A downside is they can often import invasives and require different management costs than hiring crews or using machinery. One grazing resource, Livestock for Landscapes, has produced a guide for using goats in fuel reduction. Another, California Grazing Exchange's Match.Graze, connects livestock producers and landowners throughout the state of California.

TREE DENSITY & MARKING

Thinning may have several different objectives, such as removing pathogen-impacted vegetation, small-diameter trees, or trees of a particular species which are encroaching into sensitive habitat. Developing a thinning treatment prescription requires managers to consider specific objectives for a particular site, including the intended tree density and stand structure at completion.

Tree marking identifies trees to be removed or retained. Marking a stand for thinning is based on local conditions and will differ based on the project's overall goals. Tree or stand marking for thinning is widely variable and can be an art as much as a science (California Forest Stewardship Program, 2011). Different marking protocols can be used to create greater heterogeneity in treated stands, but more complex protocols are not always easy to apply (O'Hara et al., 2012). Under the individual, clumps, and opening method (see Churchill et al., 2016) that aims to create spatial heterogeneity in stands, marking may need to be completed by crews with different specialists. Utilizing biologists, silviculturists, fire ecologists, botanists, and others to gain consensus on tree retention and removal across a stand may be more expensive but lead to more healthy stands.

North et al. (2022) argue that increasing forest resilience requires increasing tree vigor by returning to the very low densities and reduced resource competition seen in forests with frequent fire. Their examination of low historical stand density values suggests that thinning for restoring forest resilience may need to be more intensive than current fuels reduction approaches (North et al., 2022). However, others note that for some forest types shady, mesic conditions are important for fire resilience (Steel et al., 2015). Treatment prescriptions will vary greatly by forest type, current conditions of forest stand, objectives for treating a particular stand, proximity to sensitive natural and cultural resources, and proximity to infrastructure.

See Chapter 5: Goals for an overview of desired density and other structural conditions for key forest types. While the information in the *Forest Health Strategy* provides a useful framework for advancing landscape level goals to improve forest health and resilience across the region, all tree density and stand structure goals guiding forestry management are site- and forest type-specific, and managers will ultimately develop these goals on a site- and project-specific basis.

THINNING USE IN DIFFERENT FOREST TYPES

Thinning goals, methods, and considerations vary between forest types. This section explores the use of thinning treatments in target forest types in Marin. In the literature, studies of thinning impacts on forest health are strongly biased towards western coniferous forests, especially those in the Sierra Nevada. Research and citations are focused on local Marin species and forests, but where that information was unavailable, Coast Range forests are discussed.

TARGET FOREST TYPES

This section provides more information on thinning objectives, considerations, and methods for the five target forest types in the *Forest Health Strategy.* Thinning can be used for a variety of purposes including management of pest and pathogen-impacted vegetation, addressing impacts from fire exclusion such as control of Douglas-fir encroachment, to increase wildfire resilience, and to accelerate stands towards old-growth conditions. In addition to improving overstory forest stand health and resilience, thinning can support the growth of a diverse understory and shrub layer.

Bishop Pine

In general, thinning in Bishop Pine forest is considered a precursor to the use of beneficial fire, and could be used in conjunction with pile burning as a controlled means to encourage Bishop pine germination. Targeted thinning in mid-seral Bishop Pine stands could accelerate transition to lower density late-seral conditions, and may be necessary in some key areas to promote hardwood resilience in mixed stands or to address pathogen impacts. More information on Bishop Pine seral stages and management recommendations can be found in Appendix A: Bishop Pine.

Coast Redwood

In second-growth Coast Redwood stands, thinning of young, small-diameter trees can be used to promote old-growth characteristics while maintaining the forest canopy; thinning is often done in stages to avoid introducing too much sunlight that can shock trees (California Forest Stewardship Program, 2011). In Coast Redwood forest, wind blowdown is one of the most common disturbances and managers should consider future impacts of wind on treated stands (California Forest Stewardship Program, 2011). Redwood National and State Parks (RNSP) utilized thinning in second-growth Coast Redwood stands to restore forest structure. They remove mostly young redwood trees to mimic tree densities found in old-growth stands (RNSP, 2021). Without treatment, managers have found that second-growth forests continue to grow as thickets and do not accelerate towards old growth. The RNSP Second-growth Forests and Restoration Thinning website (RNSP, 2021) shows several before and after restoration thinning photos for Douglas-fir and Coast Redwood forests.

Thinning objectives and prescriptions in Coast Redwood stands may differ from thinning treatments in other forest types due to coast redwoods high shade tolerance. Coast redwoods can regenerate in shade and can therefore develop multi-age stands and establish complex canopies and understories without significant disturbance (Sillett et al. 2020). Treatments to promote old-growth attributes will vary greatly depending on current forest conditions, site characteristics, and larger landscape context.

Thinning in Coast Redwood stands may be focused on cutting select understory vegetation rather than young coast redwood trees. In stands experiencing or in danger of infestation by sudden oak death (SOD), thinning can be used to reduce surface fuels and potentially limit the spread of the pathogen. For example, Cobb et al. 2017 completed thinning treatments in Coast Redwood and Douglas-fir stands on Marin Water lands which have been impacted by sudden oak death (SOD), and in Humboldt County, in stands in danger of being invaded by *Phytophthora ramorum*, the pathogen which causes sudden oak death. Thinning treatments focused on removing understory vegetation such as tanoak (*Notholithocarpus densiflorus*) impacted by sudden oak death or pathogen hosts such as California bay (*Umbellularia californica*). They found that both thinning treatments reduced the density of sporulation hosts while minimizing effects on basal stand area. They then compared the Humboldt County treatments to reference stands on Yurok and Hoopa tribal lands. In the tribal lands, decades of thinning and prescribed fire have created park-like Coast Redwood and Douglas-fir stands and reduced the incidence of sudden oak death. In this case, a long-term commitment to forest management contributed to multiple land management goals (Cobb et al., 2017).

While thinning tanoak can be a useful tool, it does not address the importance of tanoak conservation. Approaches other than removal are needed for tanoak management in areas threatened by sudden oak death. Cobb et al. (2017) noted that long-term management on Yurok land, using both thinning and beneficial fire, resulted in forest stands, including tanoak stands, with greater sudden oak death resilience.

Some research suggests additional consideration for thinning treatments in Coast Redwood stands. Lazzeri-Aerts and Russell (2014) note that thinning of smaller redwoods may initially reduce fire hazard, but over time increased numbers of small stems from basal sprouts may increase ladder fuels. They offer that thinning in Coast Redwood stands could concentrate on associated tree or understory species. Jacobson and Dicus (2006) noted that slash left on site as part of lop and scatter treatments in Coast Redwood stands can increase surface fuels in the first year after treatment. Managers in Marin could address this potential issue by removing the biomass from the site, using pile burning when possible, and/or ensuring that slash left on site is in full contact with the soil surface to hasten decomposition and reduce air flow.

Douglas-fir

Thinning of Douglas-fir can be an important tool to address impacts from fire exclusion including Douglas-fir encroachment into grasslands, shrublands, and Open Canopy Oak Woodlands which can decrease heterogeneity and biological diversity throughout the region (Cocking et al., 2012; Engber et al., 2011; Startin, 2022). Prior to the interruption of Coast Miwok tending following colonization and modern fire suppression, periodic Tribal cultural burning would limit Douglas-fir expansion (see Chapter 3: Stewardship and Partnership with the Federated Indians of Graton Rancheria). Thinning treatments can mimic low to moderate-severity fire by removing small-diameter Douglas-fir, and thereby protect habitat diversity at a landscape scale. See more in the Open Canopy Oak Woodlands section below.

Douglas-fir stands may be managed to promote growth of larger, more wildfire resilient trees, and increase stand structural complexity and heterogeneity. For example, the Midpeninsula Regional Open Space District (Midpen) *Wildland Fire Resiliency Program* describes methods to reduce the fuel load in dense Douglas-fir forests. It calls for removal of “smaller, mid-canopy trees” in areas with high tree density (Midpen, 2021, p. 4-32). Small trunks will be chipped, hauled, or pile burned, with large trunks left in place.

The Marin Water *BFFIP* describes multiple thinning approaches which depend on project actions and related goals such as fuelbreak construction and maintenance and/or conifer forest stand enhancement (Marin Water, 2019a, pp. 137-145). Implementation actions in the *BFFIP* to include manual and mechanical vegetation to remove pathogen-impacted vegetation and targeted understory brush, followed by masticating, mulching, and other actions.

As with Coast Redwood forest, sudden oak death (SOD) is having significant impacts on tanoak in Douglas-fir forest and could decrease wildfire resilience in some areas. Initial thinning and removal of pathogen-impacted trees followed by periodic maintenance, which could include treatment with beneficial fire, will likely be implemented in key areas throughout the region. In Douglas-fir-tanoak forests on the North Coast, surface fuels in untreated SOD-impacted stands increased over long periods (8–12 years) following initial *Phytophthora ramorum* infection (Valachovic et al., 2011), highlighting the need for on-going management in priority areas.

Open Canopy Oak Woodlands

Sudden oak death (SOD), the disease caused by *Phytophthora ramorum*, has severely impacted the region's Open Canopy Oak Woodlands and associated hardwood species. In oak woodlands, the result may be standing dead trees surrounded by resprouting tanoak or other vegetation. Thinning treatments to target sudden oak death-impacted vegetation may reduce competition, increase wildfire resilience, and improve overall stand vigor.

Thinning encroaching Douglas-fir in oak woodlands is increasingly needed due to fire exclusion. Midpeninsula Regional Open Space District (Midpen) removes target conifers below 12 inches DBH in oak stands and limbs to approximately 12 feet above ground to promote late-seral conditions (Midpen, 2021). Midpen retain snags and downed woody debris to promote wildlife habitat unless they pose a fire risk.

Sargent Cypress

For Sargent Cypress, thinning is not generally necessary, as stands in Marin tend to occur on serpentine soils that inhibit the growth of other tree species. However, thinning or removal of Douglas-fir trees encroaching on Sargent cypress stands may be beneficial in some areas to conserve this key forest type. Since Sargent cypress is largely dependent on fire for regeneration, monitoring of Sargent cypress stands in Marin County should be prioritized to ensure forests do not senesce before regenerating. Future management including thinning of dead trees and application of beneficial fire could be necessary to ensure Sargent cypress forest remains a part of the mosaic of forest types in Marin County. See Chapter 5: Goals for additional information.

THINNING IN RIPARIAN AREAS

Use of thinning as a forest health treatment in riparian areas requires additional forethought and planning. In general, management of riparian forest types, such as willow and alder, is not a landscape priority for land managers in Marin County, and these areas are generally avoided during forestry work due to the sensitive nature of these vegetation communities and habitats. The effects of potential mechanical thinning treatments in riparian areas are more complex than in dry, upland areas because of potential impacts to moist wetland soils, water quality, and sensitive species. The extent of impacts often depends on machinery being used and whether biomass is removed from the site (Dwire et al., 2016).

Riparian vegetation has regular access to groundwater or soil moisture and higher foliar moisture than upland plants. Therefore, riparian areas are more resistant to fire and may act as a functional barrier to the spread of wildfire (Lambert et al., 2010; Pettit & Naiman, 2007). As a result, forested riparian areas generally experience fire less frequently than upland forests, and fire impacts in riparian areas may be less severe. Green et al. (2020) found riparian and mesic vegetation types exhibited the least canopy damage from wildfires across the landscape in Sonoma County.

There is significant variation in fire frequency in riparian forests in California. In the Coast Range ecoregion, riparian areas experience fire infrequently and may have fire-return intervals in the 100s to 1,000s of years (Bendix & Commons, 2017). Fire frequency in North Coast Range riparian systems has been found to increase moving inland from the coast (Bendix & Commons, 2017).

Fire behavior in riparian areas depends on vegetation, terrain, topography, stream order, fuel abundance, cold air drainages, and microclimates that influence fire-return intervals in these systems. For example, Taylor and Skinner (1998) found frequent fires in Klamath Mountains riparian areas. This behavior was more pronounced in steep terrain with narrow stream valleys that serve as chimneys promoting updraft and convective heating, causing fire to carry upslope (Skinner, 2003). So-called wicking behavior is more likely to occur on south-facing aspects along small or intermittent streams in their middle to upper reaches (Dwire et al., 2016). In addition, regulatory protection of riparian areas may exacerbate fuel accumulation and, together with tree mortality and non-native invasive species, may compound wicking across an entire watershed, similar to conditions seen in the 2007 Angora and Moonlight fires (North, 2012).

A wide-ranging survey of fuels reduction treatments in riparian areas conducted with fire program managers and resource professionals in the Interior West and northern Great Plains showed a higher than expected number of treatments in riparian areas due in part to substantial concerns about fuel loads (Meyer et al., 2012). In many cases, riparian fuel treatments were part of larger, predominantly upland-focused fuel reduction projects. Usually, managers were concerned about high fuel loads in riparian areas and were reluctant to leave them untreated when upland areas were treated. In some cases, managers used fuel reduction treatments for upland and riparian restoration and invasive plant species control, possibly due to funding be more readily availability for fuel reduction, or for efficiency of equipment deployment costs (e.g., simultaneous riparian restoration with upland thinning lowers overall project costs). Despite the increased level of treatment in riparian areas, managers mentioned other constraints to fuel-reduction treatments such as threatened and endangered species, cultural resources, and administrative policies. Additional concerns were about treatment's unknown or unpredictable effects on riparian and aquatic habitats, such as soil compaction from mastication or other types of mechanical thinning. A study of U.S.D.A. Forest Service Fire Management Officers that included Pacific states in the West found similar results (Stone et al., 2010).

Given that riparian areas can be important barriers to fire, forest health treatments such as thinning and beneficial fire could be important to limit fire impacts, protect infrastructure, and could improve riparian forest conditions as well. If deemed beneficial, these treatments can be planned to minimize impacts to sensitive resources and incorporate restoration objectives such as invasive species control.

BENEFITS & CONSTRAINTS

Thinning has many benefits: it is widely recognized as an effective treatment to address unnatural fuel accumulations, particularly in forests impacted by long-term fire exclusion, and in unnaturally dense stands with small-diameter trees. Thinning is also an effective precursor to treating stands before reintroducing beneficial fire. There are also important constraints to assess. For example, although thinning can be a partial surrogate for fire in some areas and be designed to mimic the heterogeneity produced by fire, it lacks some of the benefits that fire provides, such as regeneration of chaparral species and other fire followers (Naumovich, 2018; Potts & Wirka, 2018). It can be costly or simply unfeasible, especially in steep terrain or areas with poor access. Lastly, while thinning for wildfire resilience may influence fire behavior at the local scale, it will not prevent wildfires and may not alter the overall size of a given wildfire. A summary of the benefits and constraints can be found in Table 9.4.

Table 9.4. Summary of the benefits and constraints of thinning treatments.

Benefits	Constraints
• Fuel reduction and wildfire resilience tool • Fire severity can be reduced at some scales. • Useful as a pre-treatment to reintroduce beneficial fire. • Can create desired stand structure without prescribed fire. • Provides local jobs in the woods. • Acts as a partial surrogate for prescribed fire. • Protects Open Canopy Oak Woodlands and other vegetation communities from degradation and habitat loss caused by type conversion. • Can facilitate non-native invasive species removal. • Can increase overstory tree vigor, growth, and productivity from reduced competition. • Can increases understory species richness and heterogeneity. • Increases carbon sequestration (long-term).	• May not prevent or mitigate wildfire impacts at landscape-scale. • Intense disturbance may have negative impacts on some species or forest systems. • Can be costly depending on the project size. • Not a replacement for fire; lack of understory vegetation benefits that fire provides. • Periodic retreatment is necessary. • Does not apply to all forest types and geographies. • Often not feasible on steep slopes >35% to 45%. • Short-term decrease in carbon sequestration and increase in emissions during implementation. • Could facilitate non-native invasive plant and/or pathogen species spread if not done properly.

BENEFITS

There are many benefits to thinning (Table 9.4). One of the most common objectives for thinning treatments is increasing wildfire resilience for forests, neighboring communities, and critical infrastructure. Results from Prichard et al. (2020) provide evidence that strategic placement of fuel reduction treatments in the Pacific Northwest can effectively reduce localized fire spread and severity even under severe fire weather.

In the absence of fire, live tree density and biomass accumulation lead to increased competition for growth resources and reduced tree vigor (North et al., 2022). Thinning alleviates the long-term stress created by increased competition and reduces density-dependent tree mortality from reduced vigor. Thinning treatments may be the most appropriate tool to restore forest overstory health (Collins et al., 2014). In select geographies, locations, and forest types, restoration thinning may accelerate carbon sequestration and hasten the development of old-growth characteristics in dense forest stands (Dwyer et al., 2010; Gorrod et al., 2017; Tappeiner et al., 1997). Stephens & Moghaddas (2005) conducted a replicated, controlled study in 2000-2005 in temperate coniferous forests in California, finding that thinning decreased tree density, basal area, and canopy cover and increased tree height. In some cases, thinning treatments can be used to create a desired stand structure and composition without having to use prescribed burning, and it can be used in areas where there are risks and uncertainties with prescribed burning (California Board of Forestry and Fire Protection, 2019b).

Thinning in forested landscapes can create and maintain desired forest floor conditions , including an increase in understory species richness (Graham et al., 2010; Stephens et al., 2012). There may be short-term impacts to soil, such as compaction or mineral soil exposure, but where mechanical thinning is carefully implemented these effects are contained to a small area and do not persist (Stephens et al., 2012). Manual thinning treatments can be used in sensitive habitats, such as riparian areas and wetlands, where mechanical thinning would compact soil and prescribed burning or herbicide application would not be appropriate (California Board of Forestry and Fire Protection, 2019b).

Restoration treatments that included thinning at Mt. Tamalpais on Marin Water lands dramatically changed stand structure and reduced key sporulation hosts for sudden oak death (Cobb et al., 2017). In the short term, the treatments had a negligible effect on above-ground carbon storage, with the authors hypothesizing that treatments would reduce fine carbon production (e.g., leaf litter, fine root production) in the short term. However, short-term carbon losses will likely be overcome by longer-term carbon sequestration from increases in overstory tree growth and productivity (Cobb et al., 2017).

Across California, thinning has benefits for local communities as well as for forest ecosystems. Small-diameter wood utilization from thinning operations sequesters carbon, provides green jobs in the woods, and provides sustainable economic livelihoods for communities (Sierra Forest Legacy, 2008).

The potential for woody biomass utilization resulting from an increase in vegetation management by the Marin Wildfire Prevention Authority is currently being studied by the Marin Resource Conservation District. Due to constraints such as lack of access, increased expense, and lower volumes of material being generated, it is not readily clear to what extent forest health and ecological resilience thinning treatments can contribute to biomass feedstocks (T. Mason, CEO, TSS Consultants, personal communication, 2022).

Thinning has been touted by academics and practitioners as a way to increase water yield in headwater basins, yet the results are often mixed, e.g., thinning increases or decreases yield, and the effects are highly variable, unpredictable, or of short duration (Goeking & Tarboton, 2020; Hibbert, 1967; Saksa et al., 2017; Troendle et al., 2010). Recent studies indicate that water yield variability is a characteristic of semiarid western watersheds, but this research focused on water yield following beetle mortality in the Sierra Nevada and Rocky Mountains and may not be applicable (Biederman et al., 2015; Pugh & Gordon, 2013).

There are several meta-analyses and compilations of results regarding the effects of thinning on different taxa, including species richness and abundance. For example, Williams et al. (2019) reviewed 14 studies comparing bird species richness and abundance in sites with thinning to unmanaged sites. Of these, one study found higher bird species richness in thinned forests and three found no differences, seven studies found bird abundance was higher for some or all species in thinned sites, and five studies found that abundance was similar or that there were fewer of some species on thinned sites (Williams et al., 2019). In a worldwide meta-analysis of thinning effects on understory vegetation, Agra et al. found that in 17 of 25 studies, thinning trees in forests increased the density and cover of understory plants (Agra et al., 2019). Seven studies in this analysis found no effect or mixed effects and one study found a decrease in the abundance of herbaceous species (Agra et al., 2019). In the same analysis, 13 of 19 studies found that understory species diversity increased in thinned stands (Agra et al., 2019).

These studies should be distinguished from analysis of thinning treatments designed to address habitat loss due to lack of disturbance and/or fire exclusion, such as thinning and removal of Douglas-fir encroaching on Open Canopy Oak Woodlands, coastal grasslands, and shrublands. Bird species associated with shrub and grasslands are likely susceptible to interruptions in historical disturbance regimes, and studies have repeatedly found that populations of bird species associated with these habitat types were declining faster than other groups (Brawn et al., 2001; Rosenberg et al., 2019). At the Palomarin Field Station in Point Reyes National Seashore, ecologists with Point Blue Conservation Science have observed a significant reduction in the number of White-crowned Sparrows since 1980, which can be correlated to Douglas-fir encroachment and loss of habitat (Chase et al., 2005).

Littlewood et al. (2020) reviewed twelve studies which examined the effects on mammals of thinning trees. Two studies focused on species richness following thinning, both showed similar mammal species richness in thinned and unthinned stands. Eight studies of mammal abundance following thinning had mixed results: six studies found that thinning led to greater numbers of small mammal species or greater numbers of some but not all species studied while two studies showed no increase in abundance. Four studies examined the behavior of larger mammal species in thinned forests: three of these studies found that thinning did not increase use by larger mammals, but one study showed that a thinned area was used more by white-tailed deer (*Odocoileus virginianus*). Littlewood et al. (2020) also reviewed effects of specific forest management approaches. In their review of retaining undisturbed patches during thinning, two studies showed small mammals used undisturbed patches more. One study showed an increase in small mammal abundance from leaving standing deadwood. Two of three studies found more abundance or diversity of small mammals from leaving coarse woody debris on site, and two studies found greater small mammal abundance or diversity from gathering woody debris into piles (Littlewood et al., 2020).

A replicated, paired-sites, and site comparison study of 11 pairs of forest stands and nine old-growth forests in the Oregon Coast range found that thinned tree stands had higher bat activity (of at least nine bat species) than unthinned tree stands, and there was no detectable difference in bat activity between thinned stands and old-growth forest stands (Humes et al., 1999).

Five studies (including four replicated or controlled studies) in the United States compared amphibians in thinned to unharvested forests (Smith et al., 2019). Two found mixed effects of thinning on abundance, depending on amphibian species and time since thinning treatment. One study found that amphibian abundance increased. One found an overall negative response in amphibians, and one found that thinning did not affect abundance. One study found that migrating amphibians used thinned forests similarly to unthinned forest (Smith et al., 2019).

Thinning impacts on wildlife and vegetation are not fully understood and vary depending on site conditions. It will require careful monitoring to measure forest health outcomes and impacts on species in each system.

CONSTRAINTS

Depending on approach, thinning can create significant disturbance from soil compaction during mechanized treatments. If used improperly, mechanical equipment can displace mineral soil and reduce organic content (Graham et al., 2010). Woodchip or litter increase on the forest floor may suppress desired understory plant growth, similar to the effect that mulching has on weeds in restoration sites (Wolk & Rocca, 2009).

Replacing fire with thinning has several drawbacks. Thinning treatments often fail to provide specific vegetation regeneration elements beneficial fire can provide (Collins et al. 2014). For instance, fire is an important trigger for releasing seeds from serotinous cones in several coniferous, understory, and chaparral species (Keeley & Fotheringham, 1998; Keeley & Swift, 1995). In addition, low-intensity fire modifies nutrient cycling by releasing nutrients from burned vegetation and forest floor litter (Neary et al., 1999).

Thinning treatments do reduce carbon storage, but this will likely even out over the longer-term when the impacts of wildfire are taken into account. In fact, some experts argue that fuel reduction treatments are needed to stabilize carbon stored in forests vulnerable to wildfire (Hurteau et al., 2019). James et al. (2018) found that prescribed fire impacted belowground carbon stocks more than thinning, whereas thinning and combined treatments of fire and thinning had higher impacts on above-ground pools. The same study (James et al., 2018) also found that the amount of carbon lost during treatment varied based on specific treatment methods, and Bartowitz et al. (2022) note that removing mature trees releases more carbon than wildfire. Thinning treatment prescriptions should take carbon storage into account and balance it with other ecosystem services provided by forest stands.

In addition to above-ground disturbance, thinning changes soil temperature, water content, respiration, and root density (Tang et al., 2005). Though some studies show increased plant cover and richness following thinning or mastication, these studies tend to be from western pinyon-juniper or dry mixed-conifer forests, not coastal forests (Jain et al., 2018; Knapp et al., 2013). A chaparral-focused study near Hopland Research Station in the Coast Range compared prescribed fire, mastication, and treatment season (Potts & Stephens, 2009). The authors found that mastication treatments had 34% higher non-native annual grass abundance than prescribed fire treatments and the highest number of non-native invasive plant species. However, mastication also produced the highest post-treatment abundance of native plants, and treatment effects from mastication lasted over longer periods when compared to controls. Similarly, Schwilk et al. (2009) note that while non-native invasive species increase with levels of treatment disturbance, overall understory richness also increases, though plants that are adapted to xeric forest floor conditions may benefit most.

Thinning also produces costs associated with routine maintenance of treated areas. There may be cost and additional agency-based challenges in planning treatments across fire-excluded landscapes (Collins et al., 2010). Challenges of operations at large spatial and temporal scales also can make thinning difficult (Agee & Skinner, 2005).

COSTS

Thinning treatment costs will vary based on ease of access, use of manual or mechanical methods, equipment used, biomass management method, and specific site conditions. Cobb (2017) found treatment costs that included piling, prescribed fire, and mastication in high-density stands on steep slopes in Marin County and Klamath counties to reach up to $10,000/acre. In contrast, hand-crew thinning, albeit for different treatments, costs an average of $1,000-3,000/acre. With higher demand for crews, inflation, and increased funding availability, the cost of thinning is rapidly rising.

Costs for mastication vary widely and again depend on local site conditions. Jain et al. (2018) found that mastication can be 2.5 - 3 times the cost of a hand-thinning crew with a lop-and-scatter treatment, but also noted that costs are comparable if chipping follows hand thinning, in which case costs are similar.

Marin Water has been implementing thinning treatments as described in their *BFFIP* (Marin Water, 2019a) and provided the costs of that work in the *BFFIP 2022 Fiscal Year Report* (Marin Water, 2022). Forest restoration and fuel reduction treatments were completed at Pilot Knob and Lake Lagunitas at an initial cost of $7,954 per acre. Maintenance costs in the same area were only $2,019 per acre. Marin Water also removed Douglas-fir encroaching on oak woodlands and grasslands at a cost of $4,504 per acre. It should be noted that these are costs for field implementation only, and do not include planning, compliance, monitoring, or communications and outreach costs, which are likely to be an additional 15 to 20% of implementation costs.

RESOURCE PROTECTION

Resource protection related to thinning includes training, education, safety, fuel reduction, ignition reduction, and habitat and species protection. Best management practices (BMPs) for resource protection are presented in a variety of compliance documents.

The *California Vegetation Treatment Program* (Cal VTP) Mitigation Monitoring and Reporting Program has a thorough list of BMPs (California Board of Forestry and Fire Protection, 2019a). These BMPs must be followed for projects completing compliance under the *Cal VTP Programmatic Environmental Impact Report* (EIR). Agencies may be working under compliance documentation particular to their jurisdiction which includes specific BMPs. For example, Marin Water's *BFFIP EIR* includes a Mitigation, Monitoring, and Reporting Program with resource protection BMPs (Marin Water, 2019b) and the Golden Gate National Recreation Area (GGNRA) *Fire Management Plan Environmental Impact Statement* (FMP EIS includes BMPs as part of the General FMP Mitigation Measures included in the Record of Decision (ROD) (GGNRA, 2006). In addition, the Marin Wildfire Prevention Authority (MWPA) worked with the Ecologically Sound Practices Partnership (ESP Partnership) to develop BMPs to be used by the MWPA for fire management actions in Marin County. The *Ecologically Sound Practices for Vegetation Management* document compiles BMPs from a variety of sources (ESP Partnership, 2022).

BMPs for thinning treatments in Marin County focus on protecting listed species, limiting impacts to wetlands and riparian areas, reducing spread of pests and pathogens, and following proper biomass processing procedures.

Thinning treatments should protect sensitive habitat and species through pre-treatment monitoring to document and identify environmentally sensitive areas to avoid during implementation; developing treatment prescriptions that protect habitat by leaving snags, roosting trees, and healthy native understory vegetation in place; training workers on resource protection, and having a biologist or biological monitor available to provide guidance during implementation.

Riparian and wetland BMPs include maintaining buffers around riparian areas and waterways and designing treatments to avoid loss or degradation of riparian habitat function. In addition, BMPs call for limiting soil disturbance and ensuring proper erosion control practices are followed, which is important for upland and wetland areas.

Unfortunately, vegetation management which is intended to control invasive species or pathogen-impacted vegetation can also unwittingly spread these pests and pathogens. BMPs should be used to reduce the spread of non-native invasive species and pathogens by cleaning invasive plant materials, propagules, and soil from all equipment, tools, vehicles, and footwear and sanitizing all tools and surfaces before entering a new work area or when moving between work areas. Following treatment, managers should monitor and control invasive plants in management areas. Planning treatment timing and access should take these important BMPs into account and reduce movement between sites to limit the amount of cleaning and sanitizing required.

As with other forest heath treatments and ground disturbing projects in Marin County, agency cultural resource staff can work with the Federated Indians of Graton Rancheria to identify any sensitive cultural resources that require protection during project implementation.

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RESTORATION TREATMENT DESCRIPTION

Restoration is an important component of improving forest health and can be used independently or in coordination with other treatments such as thinning and prescribed fire. Restoration actions are important for increasing resilience, maintaining ecosystem services, and preserving biodiversity. Restoration actions can reduce fire intensity by controlling highly flammable invasive species and increasing year-round moisture availability. The benefits of restoration actions are widely dependent on the system and practice employed, but often focus on increasing the health of native species and populations and returning ecosystem function to a natural range of variability. Constraints include cost, ongoing maintenance, and the rapidly changing threats posed by climate change, e.g., new species arriving or invading, or systems unable to cope with higher temperatures and altered precipitation patterns.

Thinning and prescribed fire can be components of restoration programs; however, for the purposes of the *Marin Regional Forest Health Strategy (Forest Health Strategy)*, these have been described in separate treatment descriptions. The restoration actions reviewed in this treatment description are removal and control of non-native invasive plant species (NNIS), revegetation with native species, reducing soil erosion and compaction, and restoring natural hydrologic and geomorphic processes. The treatment description also explores the concepts of passive and active restoration and considers new technologies that may assist in future efforts for Marin County's forest health. Resource protection best management practices (BMPs) are discussed at the end of the document.

BACKGROUND

Land management agencies in Marin County use a variety of restoration methods and approaches to protect and enhance ecosystem services such as habitat, biodiversity, and hydrologic function. Restoration actions may include on-going programs, such as long-term efforts to control non-native invasive plant species, and large-scale projects to restore stream habitat and function. In some cases, restoration actions may be combined with other work, such as fire fuel reduction or trail improvements. Volunteers and citizen scientists are often involved in restoration through non-native invasive plant species removal, planting native species, and monitoring efforts.

Restoration planning and implementation is a good opportunity to collaborate with the Federated Indians of Graton Rancheria (the Tribe) and integrate Traditional Ecological Knowledge (TEK) and cultural values into project goals (see Chapter 3: Stewardship and Partnership with the Federated Indians of Graton Rancheria).

RESULTS CHAIN RECOMMENDATIONS

Results chains for all target forest types in the *Forest Health Strategy* include restoration via non-native invasive plant species control, actions to protect soil and address hydrological modifications, climate change adaptations, and environmental education and collaboration. Revegetation is recommended under certain conditions for Open Canopy Oak Woodlands and Coast Redwood forests.

Non-native invasive species (NNIS) removal and control actions are recommended for all target forest types. non-native invasive species threaten native species diversity, may displace native vegetation which provides essential food and shelter for sensitive wildlife, and can contribute to unnatural fuel loads which increase fire hazard risks. Removal of non-native invasive plant species protects habitat and improves forest resilience.

Protecting soil health and absorption is recommended for all target forest types.
Soil compaction can be a threat to all forest types and lead to reduced understory vegetation and water infiltration, which in turn leads to erosion and increased sediment entering streams. Using soil protection BMPs during field work and creating thoughtfully designed trails and signage can reduce soil compaction, as well as reducing the spread of pathogens and non-native invasive plant species. Increased soil health will result in increased water filtration, seedling recruitment, tree vigor, and understory diversity.

Hydrologic function is important for all forest types, but different approaches are appropriate depending on location and forest type. Addressing hydrologic modification through restoration includes decommissioning or improving drainage on roads and trails as well as direct restoration of riparian corridors. Removing or down-sizing roads can restore natural drainage, reducing erosion and increasing water infiltration. Restoration of riparian corridors is especially important for Coast Redwood forest which often grows in these areas. Restoration can slow drainage out of watersheds, increase groundwater recharge, and increase water availability for redwoods and associated species to help accelerate second-growth stands to old-growth conditions. As climate change causes increased temperatures and longer drought periods, retaining water will become increasingly important.

Revegetation is recommended for Coast Redwood and Open Canopy Oak Woodland in some cases. In some areas heavily impacted by pathogens, the dieback of tanoak (*Notholithocarpus densiflorus*) and other hardwoods can create canopy gaps in or adjacent to Coast Redwood forests. Without management, these gaps may persist or in-fill with non-native invasive species and impact Coast Redwood forest resilience or lead to forest type conversion. For Open Canopy Oak Woodland, pathogens, fire exclusion, predation, drought, and climate change threaten oaks, managers may consider the role of targeted revegetation in conserving and maintaining healthy stands. Revegetation efforts could potentially replace pathogen- impacted vegetation with disease-resistant native oak and hardwood plantings, as well as select native understory species. Revegetation can focus on herbaceous and shrub species in areas where understory vegetation is damaged or on desirable tree species in areas where canopy gaps persist and are a threat to the forest type.

Incorporating the latest climate change information is critical for all restoration actions and could influence which areas or habitat types are the focus of restoration efforts, which non-native invasive plant species are highest priority, and which species are used in revegetation efforts. In addition, developing climate adaptation strategies by forest type can help guide managers in long-term adaptation efforts and protection of climate refugia.

Successful restoration requires support and collaboration across jurisdictions and throughout the community. Environmental education and collaboration is necessary to ensure all groups are working together to meet overarching goals for forest health and resilience, cultural use, recreation, and fire safety. See Chapter 5: Goals for more information on each target forest type's forest health goals and results chains.

DESCRIPTION

Ecological restoration is "the process of assisting the recovery of an ecosystem that has been degraded, damaged, or destroyed." (Society for Ecological Restoration (SER), n.d.). Many different concepts, methods, and approaches fit under this broad category. It is important to note that restoration occurs over time, with human assistance and actions acting as a support for the natural functioning of water, soil, microorganisms, plants, and wildlife. Long-term success monitoring is necessary to determine whether restoration meets ecosystem recovery goals.

ACTIVE VS. PASSIVE RESTORATION

Passive restoration is defined as unassisted or natural recovery or regeneration, whereas active restoration is a range of human interventions designed to accelerate the successional trajectory of recovery (Holl & Aide, 2011). Passive restoration may include actions such as removing infrastructure and allowing for natural revegetation or excluding livestock from an area. Active restoration may include actions such as removing non-native invasive plant species and planting native species. Determining when to use active vs. passive approaches to restoration and revegetation can be driven by pressures to return habitats or ecosystems to pre-disturbance states. Halting any activities harmful to ecosystems should be the first step in restoration (Kauffman et al., 1997). In addition to passive vs. active triggers for restoration, managers should weigh short-term vs. long-term restoration goals and considerations of spatial scale (National Research Council, 2002). In addition, a combination of active and passive methods can be used to achieve objective and use resources efficiently.

Passive restoration can sometimes be as effective as active approaches, cost less, require fewer permits, and achieve the same outcomes. Sampling 10 common tree genera on riparian restoration sites in Marin, Sonoma, and Mendocino Counties, Lennox (2007) found that 50% were positively affected by passive restoration techniques alone (livestock exclusion or limited grazing). Ninety percent of the genera were positively impacted by active restoration techniques or tree planting with bioengineered deflectors, baffles, or willow wattles.[1] A global review of active vs. passive forest restoration showed that degraded forests or formerly forested systems recover with minimal human intervention, though time to recovery depends on location and past land use (Meli et al., 2017). The authors suggested implementing passive restoration where initial recovery is deemed rapid (after degradation or threats cease), and passive restoration meets management goals. Active restoration methods then can then be used if recovery trajectory is not moving towards management goals (Meli et al., 2017).

[1] Small structures made to redirect stream courses, secure slopes or bare soil to reduce erosion, and introduce new vegetation into riparian and wetland restoration projects, often created with biodegradable materials. Willow wattles are made of intertwined willow branches that are staked to the toe of river banks.

Nevertheless, passive approaches may not always lead to desirable outcomes in forest systems, particularly those with altered fire regimes (Agee, 2002).

In many California Coast Range locations, historical information does not exist about native riparian vegetation, flow regimes, or loss of woody vegetation (Jackson et al., 2015). As a result, active riparian restoration projects depend on current conditions, or reference site conditions, and site objectives rather than reconstructing historical ecosystems (Higgs et al., 2014). Proven active restoration approaches, especially to protect or help the recovery of sensitive species and habitats, should be undertaken when other methods are insufficient.

In addition, passive riparian restoration may not create predictable plant assemblage trajectories, and key plants may need to be added to the plantings over time (Trowbridge, 2007). In an evaluation of riparian revegetation of North Coast ranches, including Marin County, active restoration methods accelerated the achievement of benefits associated with tree canopy cover and bank stability in the first ten years following restoration. Still, the benefits of both active and passive restoration converged after 10-15 years for most variables related to vegetation cover and aquatic habitat (Lennox et al., 2007; Lennox et al., 2011). In a complementary study in the same region, researchers documented lower native cover and richness with passive restoration compared to active restoration, and invasive species cover and richness were not significantly different across sites (Gornish et al., 2017). Gornish et al. (2017) concluded that project design should be guided by the site-specific potential for passive revegetation, and active methods should be used to enhance that potential to achieve vegetation goals.

REVEGETATION

Habitat revegetation is particularly critical following the loss of tree species from sudden oak death (SOD) outbreaks or after large-scale non-native invasive species removal projects. According to the Marin Water *Biodiversity, Fire, and Fuels Integrated Plan* (*BFFIP*; Marin Water, 2019a, pp. 6-18), “Revegetation efforts will be designed with an end goal of establishing new trees in areas where disease has resulted in a discontinuous canopy with gaps large enough to contribute to hotter, drier soil conditions and natural regeneration is insufficient.” Various species may be used for post-sudden oak death revegetation, including native oak species (*Quercus* spp.), coast redwood (*Sequoia sempervirens*), Douglas-fir (*Pseudotsuga menziesii*), and California nutmeg (*Torreya californica*). The Marin County Open Space District (MCOSD) *Vegetation and Biodiversity Management Plan* and the Marin Water *BFFIP* call for local collection of a diversity of genotypes from dry to mesic locations to address future climatic changes and possibly carry some genetic disease resistance (Marin Water, 2019a; MCOSD, 2015).

RIPARIAN/HYDROLOGICAL RESTORATION

Riparian forests provide high ecosystem service values for biodiversity, water quality, and carbon sequestration. Restoring degraded riparian areas and associated hydrological processes are critical for forest health. Such restoration increases year-round soil and vegetation moisture to reduce fire intensity and improve other habitat values.

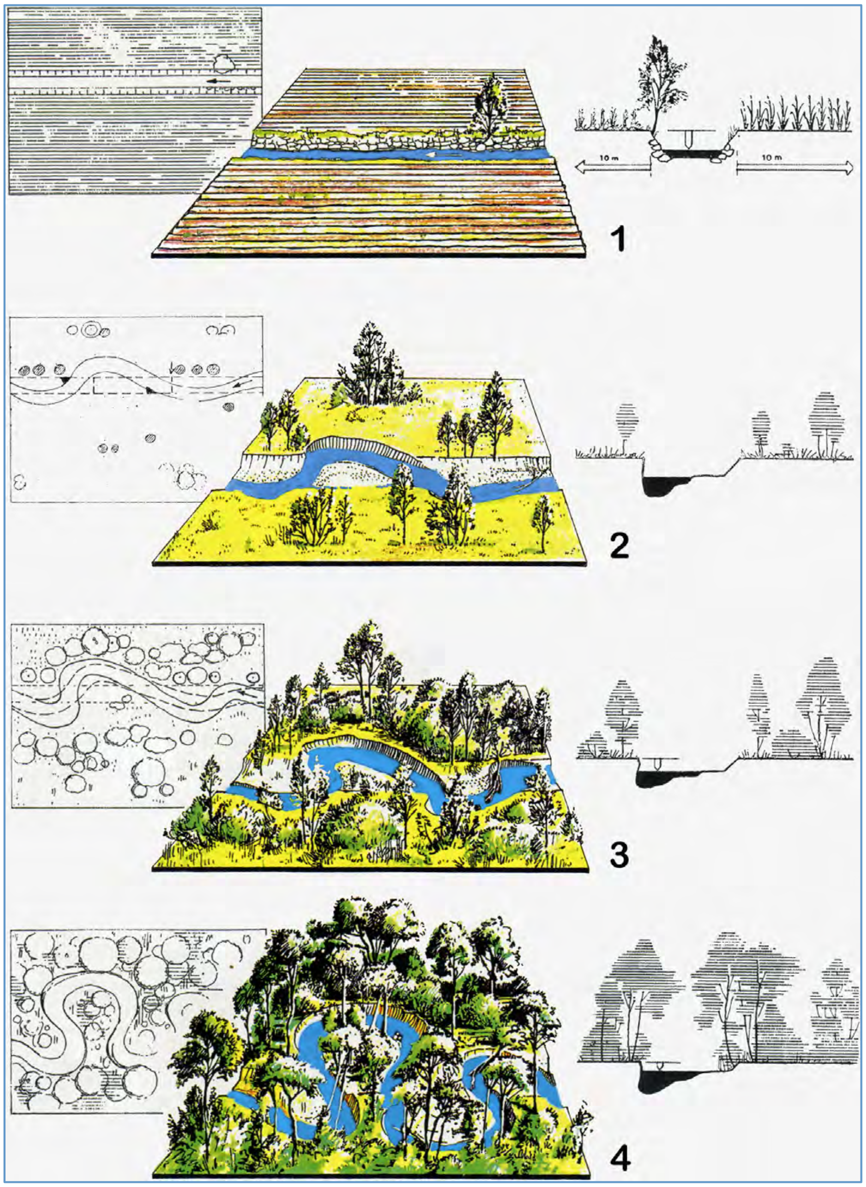
Riparian restoration must consider hydrology, geomorphology, vegetation, floodplain characteristics, and instream biogeochemistry. Extreme flow patterns characterize California coastal river systems, in which long reaches often dry up in rainless summer and fall, but then experience sudden floods during winter and spring rains (Moyle, 2014). These streams, which are often severely altered by human actions and non-native invasive plant species, typically support novel ecosystems dominated by new combinations of organisms in highly altered habitats (Moyle, 2014). As a result, restoration of degraded riparian areas is one of the foremost challenges facing land managers.

Given the capacity of riparian systems to recover, ending any practices preventing recovery, a form of passive restoration, may be all that is needed for restoration (Kauffman et al., 1997). However, in developed areas such as Marin County, the proximity of roads, buildings, and other infrastructure to riparian corridors may limit the use of passive restoration. Typically, impaired riparian systems are in straightened, channelized, or otherwise constrained streams managed to convey water out of a system as quickly as possible. As a result, they lack diverse hydrologic and geomorphic functions and species diversity (Dietrich, 2013; Table 9.5). To initiate the return of biologic, hydrologic, and geomorphic processes, levees or other infrastructure may be removed, large woody debris placed in the channel, areas graded for floodplain connection, rock or cobble added, check dams installed, gullies stuffed, and vegetation planted (Binder et al., 2015; Figure 9.12). In well-designed projects, restoration becomes more passive over time, and hydrologic processes drive change through disturbance and varied flooding regimes.

Table 9.5. Comparison of channelized or impaired stream channels vs. short- and long-term restoration approaches (adapted from Dietrich, 2013).

Process	Impairment (lack of, or reduced)	Short-term <10 years	Long-term >10 years
Geomorphic	• Sinuosity and flow path complexity • Water depth variation • Channel roughness	• Channel area and elevation variation • Riparian connectivity • Channel, riparian elevation	• Sediment and nutrient recruitment • Roughness
Hydrologic	• Bank length and riparian ecotone • Hyporheic exchange • Water table connectivity • Timing and magnitude of peak flows	• Water depth elevation changes • Retention time • Backchannels, wetlands • Flooding frequency and duration	• Primary production • Reconnected riparian/river zones
Vegetation	• Native species • Species diversity	• Weed vs. native species competition • Seedbank viability	• Habitat complexity • Species diversity

Figure 9.12. River restoration steps from channelized to meandering. Inputs are highest in steps 1 and 2, and decrease from 3 to 4 (Binder et al., 2015).



Riparian Fire Impacts

The impacts of wildfires on stream habitat can be mild to severe, and are usually short-lived disturbance pulses (Beyers et al., 2018; Detenbeck et al., 1992). Postfire landslides and runoff may renew streams through increased gravel recruitment and woody debris movement (Benda et al., 2003; Burton, 2005). However, runoff from roads and overwhelmed culverts, along with overland erosion, especially on steep slopes, can be a major postfire sediment problem (Beyers et al. 2018). Applying mitigation measures on roads in susceptible areas, such as rolling dips, upgraded culverts, and understory vegetation plantings, can reduce postfire risks. BMPs for erosion control postfire, such as staked revetment geotextiles and wattles made from weed-free straw or native grasses, can reduce sediment discharge. Particularly problematic roads in highly erosive areas can be decommissioned or removed (Weaver et al., 2015).

RESTORATION APPROACHES

Restoration approaches range from simple to complex, and the approach selected depend on management objectives, local site conditions, regulatory requirements and permitting, project costs, agency practices, and local implementation capacity. The following approaches offer options, selection criteria, and factors to consider when restoring woodland and riparian sites.

Revegetation and restoration efforts in forested areas face many challenges, including the cost of replanting high seedling mortality due to water stress, competing vegetation, and repeat fires (North et al., 2019). Active restoration is warranted when fire exclusion substantially alters forested ecosystems (Noss et al., 2006). Small-scale experimentation to avoid unintended consequences coupled and long-term monitoring regimes should be included in any revegetation/restoration approach.

Hessburg et al. (2015) offer several core restoration planning principles relevant to Marin County forested landscapes:

- Conduct planning and management at the regional scale.
- Use topography to guide successional and habitat patchwork restoration.
- Restore natural fire regimes and successional pattern variation to drive ecosystem processes and disturbance regimes.
- Move towards size distributions of historical successional patches and allow disturbance regimes to adapt to climate change.
- Retain relict trees, snags, and downed logs.
- Collaborate across land ownerships.

Additional factors to consider in planning a restoration project include ecosystem resilience, land-use history, and the surrounding landscape vegetation matrix (Holl & Aide, 2011). These should be balanced with socio-ecological factors of project goals, including the budget, timeframe, and capacity to complete projects. When planning forest health treatments, both hydrological system impacts and erosion control caused by treatments must also be considered.

NON-NATIVE INVASIVE SPECIES

Weed removal and management may be a primary goal for restoration, or it may be a secondary consideration to ensure success of native vegetation. Either way, all restoration projects must incorporate management of non-native invasive species (NNIS). Depending on the site, vegetation type, sensitive species present, permitting, and agency policy, weed control methods may include hand pulling, brushcutting, mowing, application of mulch or other cover, flaming, chemical treatment, prescribed fire, and grazing to allow native species to grow. Usually, intensive management at the outset of a project settles into less resource-intensive management over time. Ongoing monitoring at restoration sites and early detection, rapid response (EDRR) monitoring throughout wildlands are key components to non-native invasive species control. Restoration, construction, and maintenance projects, such as road and trail maintenance, can facilitate movement of non-native invasive species. Following BMPs to reduce the spread of weeds (and pests and pathogens) is an important management action for all field work. In addition, infrastructure such as roads, trails, and fuelbreaks act as non-native invasive species vectors. On-going monitoring and management of weeds along these corridors is generally needed to control non-native invasive species.

Marin land management agencies recognize non-native invasive species management as both a short-term need for active project sites and a long-term need for protecting ecosystem services on a landscape scale. Each of the Marin County public land management agencies has plans and programs in place to address non-native invasive plant species management, such as the MCOSD *Vegetation and Biodiversity Management Plan* (MCOSD, 2015). Efforts led by individual agency departments, such as the National Park Service San Francisco Network of Bay Area National Parks Inventory and Monitoring Program (SFAN I&M Network) or the One Tam Early Detection Rapid Response (EDRR) Program, provide critical information for managing non-native invasive species. Widespread use of CalFlora's Weed Manager system makes this a potentially effective tool for monitoring the distribution and treatment of weeds across jurisdictions. More information on weed management can be found on the California Native Plant Society (CNPS) and California Invasive Plant Council (Cal-IPC) websites.

Managing non-native invasive species in riparian areas can be particularly challenging, but critical for habitat and fire risk. Due to higher moisture availability and ecosystem impairment, riparian vegetation can be prone to non-native invasive species. Dense vegetation near water courses can wick flames through a watershed, particularly during drought (Dwire et al., 2016; Skinner, 2003). Non-native invasive species can intensify this behavior with flashy fine fuels, and alter the fire regime in riparian vegetation by making it more intense and frequent (Lambert et al., 2010). Specific non-native invasive species, such as eucalyptus, often grow in riparian areas. The introduction of eucalyptus into native plant areas alters the historic fire regime of the area, and, while live parts of trees may not themselves have high flammability, dry leaves, high volumes of shredded bark and branches, and potential for trees to cast embers long distances during a fire event contribute to overall high fire hazard for trees of this genus (National Park Service, 2006, Wolf & DiTomaso, 2016).

Livestock Grazing

Livestock grazing is practiced on public and private lands throughout the San Francisco Bay Area to control weeds and reduce fuels. Grazing may be more cost-effective than mowing and chemical use for non-native invasive species control in some locations, but timing and intensity need to be carefully considered by land managers as grazing can have negative impacts (Marin Water, 2018; Morris, 2021). Planted trees must be protected or large enough (e.g., oak saplings greater than 180 centimeters) to avoid damage in planted areas (Bernhardt & Swiecki, 2015). The introduction of livestock to some sites may assist non-native invasive weed introduction and spread, damage rare species, or could cause erosion or soil compaction if grazing is too intense.

Livestock is generally detrimental to wetland and stream habitats, even in fenced crossings, and should be kept out of riparian habitats (Kauffman et al., 2022). The exception to this rule is when riparian areas are overcome with non-native invasive weeds and can benefit from episodic, carefully controlled flash grazing that is short and of light intensity (Allen-Diaz et al., 2004; Sheley et al., 1995).

Costs for Non-Native Invasive Species Control

Costs for non-native invasive species control vary widely based on species, soil, topography, ease of access, removal or control methods, biomass management methods, and proximity to sensitive habitat or species and protection measures. Marin Water has calculated some of their weed control costs in the *BFFIP 2022 Fiscal Year Report* (Marin Water, 2022). They found that early detection rapid response work cost about $20,000 for the year; they surveyed 300 acres and identified 638 patches of weeds. Initial removal of broom (primarily *Genista monspessulana*) in grasslands and oak woodlands cost $2,167 per acre, while maintenance after initial removal was only $502 per acre. Barbed goatgrass control (*Aegilops triuncialis)* efforts were more expensive, at $4,092 per acre. An additional $742 per acre was spent on other priority weeds. Marin Water also experimented with grazing for weed management and found mixed outcomes in terms of efficacy for broom management and cost efficiencies. The grazing trials cost $2,115 per acre.

Erosion Control

Similar to non-native invasive species control, reducing erosion and runoff may be a primary goal of a restoration project, or it may be a BMP to protect soil health and water quality. Either way, erosion control must be a component of planning a restoration project. Erosion control objectives and methods will vary based on project objectives, location, topography, soil type, vegetation type, and proximity to a waterway. For restoration projects in upland areas erosion, sediment movement, and runoff are generally limited to the greatest extent feasible. For riparian restoration there is often a need to find a careful balance between allowing for natural geomorphic processes, which include some level of erosion, and ensuring that erosion is not excessive (Benda & Bigelow, 2014; Florsheim et al., 2008).

In upland areas, using rolled erosion control products (coir netting), fiber rolls (wattles), or mulch to reduce erosion and sediment runoff while vegetation establishes are common practices, as is maintaining undisturbed buffers around drainages (California Department of Transportation, n.d.). Compacted soils can be scarified and seeded to reduce runoff in areas devoid of vegetation or where vegetation removal creates bare ground. Incidentally, some bare ground surrounded by native vegetation can be a boon to biodiversity as it benefits ground-nesting bees and other native invertebrates (U.C. Davis, 2018).

When planning restoration in areas with high visitor use, managers should consider cordoning off restoration sites or rerouting trails to avoid sensitive or recently restored vegetation and reduce weed and pathogen reintroduction. High levels of recreation can increase erosion, especially when visitors leave the formal trail system and create social trails (MCOSD, 2014). Social trails are informal trails created by foot traffic; over time vegetation is trampled, soil is compacted, and erosion increases. Trail systems should be designed and upgraded to reduce trail grades, allow visitors to access desire points (such as viewpoints) on formal trails, and remove braided or social trails. Fencing, vegetation, and signage can be used to direct visitors to use formal trails (California Department of Parks and Recreation (CDPR), 2019).

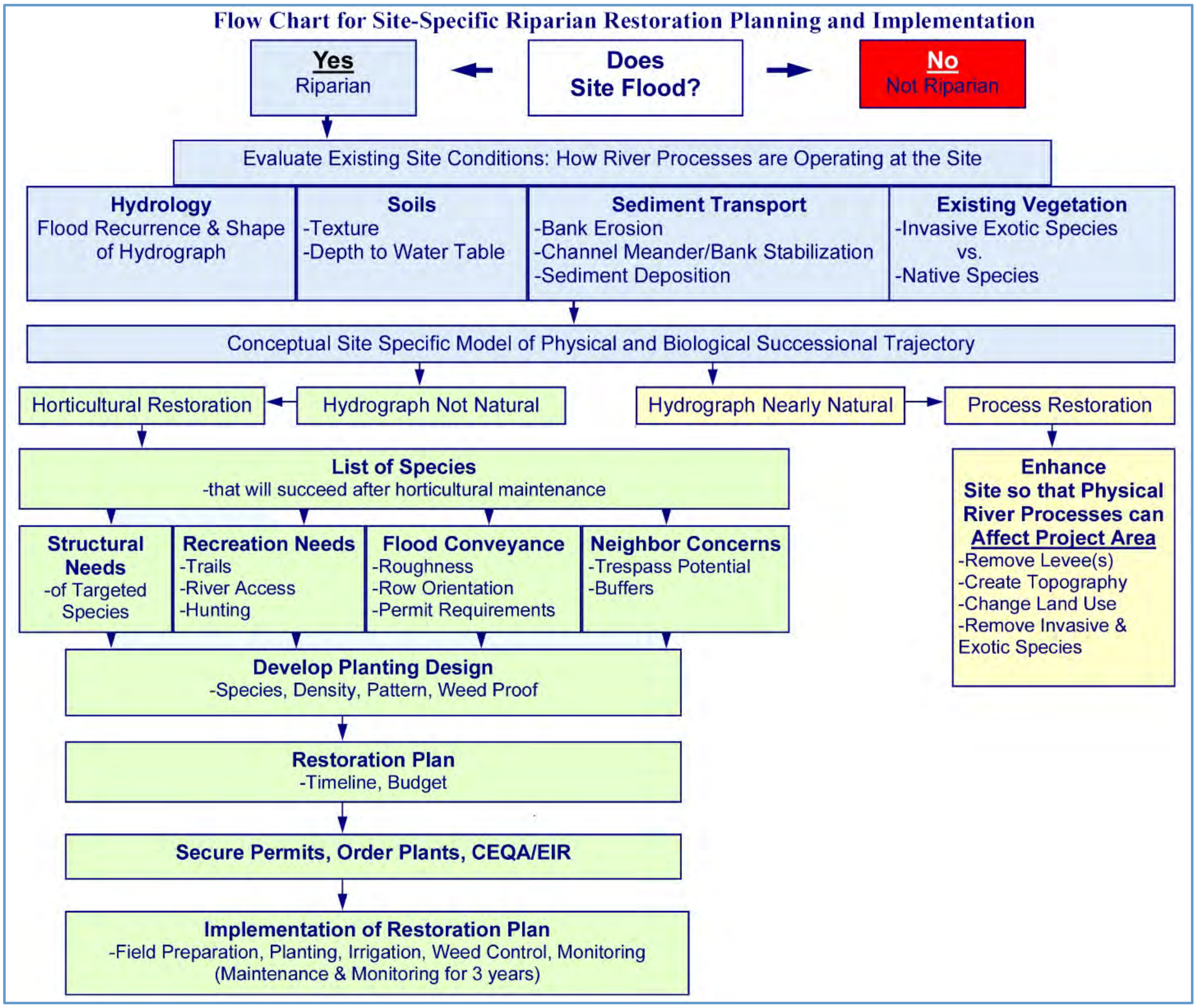
RIPARIAN

Riparian restoration is often a significant and complex undertaking, involving years of field study, planning, and compliance before implementation (Griggs, 2009). Depending on existing site conditions and management objectives, recontouring earth and adding large woody debris (LWD) may be needed to achieve the hydrologic connectivity and geomorphic complexity important for riparian habitat function. In coastal California, riparian corridors are often habitat for threatened and endangered aquatic species, and restoration design and implementation must take into account short and long-term impacts to those species.

A general decision tree for the geomorphic and ecological factors to consider in riparian restoration planning and implementation is shown in Figure 9.13. The implementation may be an iterative process between passive and active approaches but should be holistic in considering soils, sediment transport/recruitment, vegetation, and hydrology. Ideally, modeling flood and flow regimes post-restoration and over time should be factored into riparian restoration plans.

Riparian and upland forest restoration are often thought of as distinct processes that can be tackled separately. However, forests and riparian areas are interconnected and the exchange between the two is critical for ecosystem function of both. Therefore, when planning restoration work, upland forest and riparian ecosystems should be considered as linked entities that cannot be addressed or restored independently (Hjältén et al., 2016).

Figure 9.13. Riparian restoration options and factors (Griggs, 2009). Note the restoration plan may need alteration if the hydrology is functioning, but vegetation is degraded, or the vegetation is healthy, but the hydrology is altered.



Thinning & Prescribed Fire in Riparian Areas

Fuel reduction treatments using fire or thinning techniques are increasing, including in riparian and near-stream habitats (Dwire et al., 2016). The use of thinning or mastication equipment in riparian areas is not recommended due to soil compaction and potential to impact sensitive species, nor is it often allowed from a regulatory standpoint. Prescribed fire to reduce the intervention footprint in riparian areas with high fuel loads may be the best approach (Arkle & Pilliod, 2010; Beche et al., 2005).

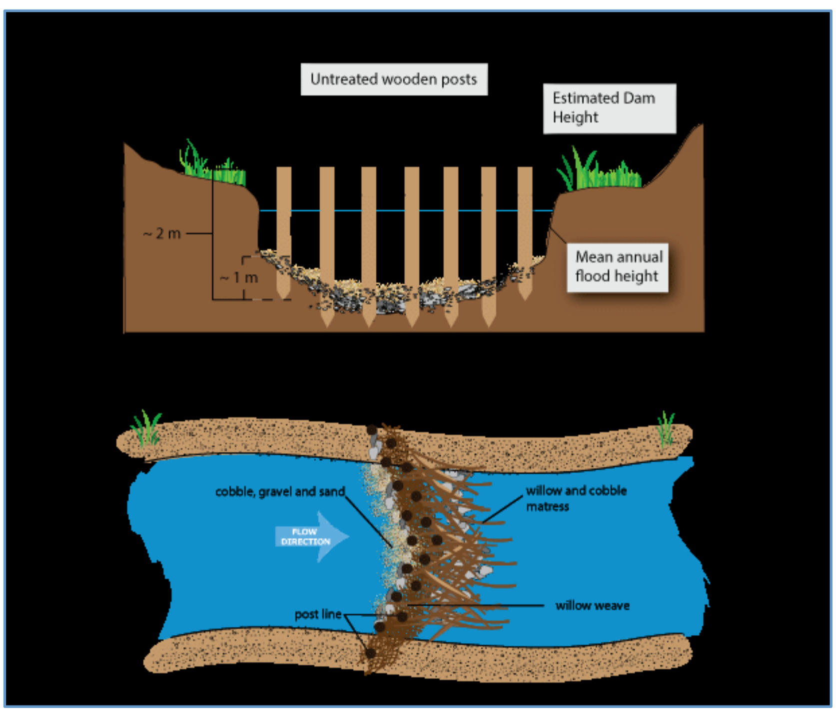
Erosion Control in Riparian Areas

While some level of erosion is necessary to sustain riparian and wetland habitat, many creeks in coastal California experience extreme bank erosion, channel incision, and downcutting of the creek bed (Leroy & Green, 2016). Addressing extreme erosion can be quite complex as there are many factors and drivers, including existing conditions and actions up and down stream. There are a variety of methods used to address creeks with head cutting or gully erosion, these methods generally seek to slow water flow, retain sediment, and reconnect the creek to the floodplain. Methods include installing stakes and branches, or slash woven across t-stakes; placing large woody debris within the channel; or utilizing large rock to rebuild the incised channel (Flosi et al., 2010; Roni et al., 2014) .Grading the adjacent floodplain to encourage overbank flow is another method that may allow for quicker habitat improvement. In smaller channels, less intensive measures may be utilized. For example, branches, stems, and slash can be secured to provide a strong countermeasure to s erosion. So-called gully stuffing can often be done with fuel-reduction projects that produce high amounts of slash (U.S. Department of Agriculture, 2021).

Beaver & Beaver Dam Analogs

The reintroduction of beaver (*Castor canadensis*) throughout riparian areas in the Western United States and Europe is gaining momentum to restore water systems and hydrological function. Where permitting and beaver reintroduction is difficult, beaver dam analogs (BDAs) composed of untreated wooden posts with cross-lattices of willow mattresses are used to restore riparian areas (Figure 9.14) and can restore deeply incised streams (Biohabitats, 2018). Beaver reintroduction and beaver dam analogs are often cheaper than other restoration techniques. Estimates for beaver/beaver analogs are at $10,000/stream mile vs. upwards of $1,000,000/stream mile for other types of riparian restoration projects. Utilizing the beaver dam analogs technique is possible in either urban or rural areas, and where dams are not a hindrance to migrating salmon (Pollock et al., 2015). More information on beavers and BDAs can be found at the U.S. Department of Agriculture Incised Stream Restoration in the Western U.S. website.

Figure 9.14. Cross-sectional and overhead view of a generic beaver dam analog (Shahverdian & Wheaton, 2017).



Road Removal

Poorly constructed or unmaintained roads are one of the greatest contributors to sediment and other pollution in riparian areas throughout the region. Turbidity and suspended sediments can lead to higher water treatment costs for domestic water supplies and negatively affect wildlife, particularly endangered fish species (Madrone, 2011). Reducing negative impacts to improve aquatic ecology should be a goal of road removal (Luce et al., 2001). Although relatively costly on an expense/mile basis, fines, poor water quality, and expenses related to maintenance and mitigation may be far greater over the long run when considering road removal projects.

Many public land management agencies are decommissioning roads to restore surrounding watershed. California State Parks and Redwood Community Action Agency, among others, have successfully removed unused roads throughout the California North Coast (Merrill & Cassady, 2001). Six Rivers National Forest on the North Coast has decommissioned 430 miles of forest roads since 1990. However, the decision-making process for determining whether and which roads to remove is controversial and involves many factors, including aquatic system health, but also various access needs, including access for fire suppression. (Luce et al., 2001).

Coast Redwood

Coast Redwood forest often is concentrated along riparian corridors. In this target forest type especially, riparian and forest function and restoration are intrinsically connected. Coast Redwood stands provide shade and create a cooler microclimate which is important for many sensitive aquatic species. At the same time, coastal creeks and connected floodplains provide moisture and fresh mineral deposits for redwood seedlings (Lorimer et al., 2009).

Hydrological restoration for Coast Redwood can include riparian restoration actions discussed above, thinning, and removing or decommissioning roads to improve hydrological function, promote old growth characteristics throughout stands, and increase water availability to help accelerate the second growth stands towards old growth. The Redwoods Rising project, a collaboration between the National Park Service, California State Parks, and Save the Redwoods League, is an example of restoration tied with hydrological function to accelerate Coast Redwood toward old-growth conditions.

REVEGETATION

Land managers can take many passive and active approaches to revegetate degraded lands or areas of high tree mortality. The MCOSD *Vegetation and Biodiversity Management Plan (VBMP)* (2015) recommends developing a planting palette for the targeted vegetation type slated for revegetation, basing species and percent relative cover on reference site conditions. Managers could also reference the Vegetation Descriptions in the California Native Plant Society (CNPS) report on *Vegetation Classification of Alliances and Associations in Marin County, California* (Buck-Diaz et al., 2021), which includes stand tables with species composition based on analysis of local field data. Adjustments can be made to plant pallets based on specific site conditions.

The *BFFIP* and *VBMP* recommend collecting plant material from diverse local phenotypes close to the restoration site (MCOSD, 2015; Marin Water, 2019a). Pre- and post-restoration photo monitoring, vegetation monitoring plots, and surveys to establish overall performance criteria are critical. Standardized monitoring protocols across landscapes are useful for comparing treatment success.

Direct Seeding

High mortality rates from disease, negative impacts from non-native invasive species, wildfire, off-trail trampling of understory vegetation, and increasing forest stress from climate change create a need for low-cost restoration treatments applied at scale. In one study, direct seeding of woody species was up to 29 times more cost-effective than planting container stock in the Coast Range of northern California (Palmerlee & Young, 2010).

However, there are some drawbacks to direct seeding. Direct seeding success rates vary by species, and there may be lower survivorship than for container plantings (Palma & Laurance, 2015). In addition, in areas where non-native invasive species are prevalent, native seeds may not compete well. Depending on species and project objectives, a large volume of seed may be required for a project. If land managers are using local seed only to protect local genetic stock, then it may not be possible to collect enough seed for direct seeding. Multiplying seed using native seed farms is an option, but requires advance planning and may be fairly resource intensive (Pedrini et al., 2020). In addition, container plantings are useful on sites where it is important to establish vegetation more quickly for erosion control, habitat, or aesthetics. Managers will need to think through the process for revegetation carefully to determine the best methods and may find a combination of container planting and direct seeding to be optimal.

Revegetation Following Wildfire

Postfire revegetation is a complicated task dependent on technical expertise and collaboration across stakeholders. The challenges of revegetation on a large scale are many. For example, plantings in drier sites without irrigation often fail. Focusing plantings on cooler, wetter microsites may help decrease mortality (Halofsky et al., 2020). Erosion can be a significant problem, as experienced in many areas across California following fires. Ensuring that erosion-control structures are in place prior to planting is critical to fire-recovery and restoration efforts (Vallejo & Alloza, 2015). Depending on the scale of fire impacts, it may be necessary to prioritize some sites to use limited resources effectively. Methods for evaluation and prioritization are discussed in the Technology section below.

The CNPS has a useful Fire Recovery Guide that includes erosion control recommendations, a decision flow chart, and tips for postfire tree care. University of California Agriculture and Natural Resources (UC ANR) offers a Recovering from Wildfire guide for forest landowners (Shive & Kocher, 2017). Sonoma Resource Conservation District (RCD) has a comprehensive fire prevention and postfire recovery webpage with particular attention to erosion control, resources for home and landowners, and multiple links to documents on erosion control and other practices that can restore vegetation and reduce erosion.

Revegetation of forested sites is highly dependent on location, slope, aspect, local climate, and species-specific climate adaptation factors. The U.S. Department of Agriculture Climate Hubs has gathered a variety of useful forest revegetation resources together on their California Reforestation Resources website.

An emerging postfire restoration approach is examining how arbuscular mycorrhizal fungi could play a role in ecosystem recovery (Washington, 2021). As researchers discover more about how these fungi assist tree communication and can be measures of soil health, this work may become important in future restoration efforts.

Climate Change Adaptation

Climate change impacts current and future vegetation virtually everywhere due to increased temperature and precipitation variability. With these changes comes increased invasions of non-native invasive species, movement north and uphill of some (but not all) native species, and phenological mismatches, all resulting in novel ecological communities (Jennings et al., 2018). When responding to climate change, managers may choose to plant species adapted to projected future climatic conditions or take a varied approach that considers resiliency, adaptation, and accepts uncertainty (Schurrman et al., 2020). The resist, accept, and direct framework adopted by the National Park Service (NPS) and other federal agencies is an attempt to update conservation management approaches to address these climate change uncertainties (NPS, 2021, 2022).

Restoration is not just returning sites to historic conditions; it can help position ecosystems to adapt to climate change (Hanberry et al., 2015). One starting point is the vulnerability assessment of California's terrestrial vegetation (Thorne et al., 2016). The authors consider exposure to climate change for each vegetation type in California and movement to and from areas no longer climatically suitable. The Climate Smart Restoration Tool calculates and maps seed transfer limits for plant species using genecological and climate variable inputs. The California Climate Adaptation Strategy also has broad guidance related to climate change adaptation, forests, and restoration.

Dobrowski et al. (2013) advocate for addressing and tracking climate velocity, or the rate and direction an organism must migrate to maintain an isocline of a given climate variable, or to stay within the same enveloped climate condition (Burrows et al., 2014). Climate velocity may be more relevant biologically than modeling future climate changes since it accounts for topographic heterogeneity and regional climate change and demonstrates how species may respond locally (Dobrowski et al., 2013; Bachelet et al., 2016). Climate velocity studies could be used to locate climate refugia, prioritize areas for protection, and support assisted migration planning. Portions of California may show lower rates of change in climate velocities compared to most of the rest of the country due to a higher diversity of physiographic features, microrefugia, and habitat niches (Dobrowski et al., 2013). This diversity may allow some species to adapt to climate change.

The Nature Conservancy's publication on nature-based climate solutions has an entire chapter focused on restoring California's forests for climate and other benefits. It includes reduced wildfire severity, post-fire revegetation, and riparian restoration discussions (Chamberlin et al., 2020).

More on climate change, adaptation, and other stressors impacting forest health can be found in Chapter 4: Climate Change and Other Forest Health Stressors.

Technology

New restoration approaches and tools are emerging continually. Collection methodologies using remote sensing (aerial imagery, lidar) and data analysis tools allow researchers and land managers to evaluate restoration on a landscape scale and prioritize resource use accordingly. In addition, rapidly expanding drone capabilities are providing quicker and less expensive ways to collect data (Robinson et al., 2022)

Spatial analyses, such as that provided in the *Forest Health Strategy*, can help provide insight into where restoration and revegetation may be needed and what measures could be used to evaluate the success of ongoing efforts (Churchill et al., 2013; Dobrowski et al., 2011; Kane et al., 2014). Other novel approaches using spatial data and algorithms to analyze multiple variables, including species, costs, climate change mitigation, and response to individual planning units to restoration, are evolving. For example, the Climate Change Vulnerability Assessment of California's Terrestrial Vegetation provides information on how ecosystems and vegetation may change under different climate scenarios and could guide vegetation management strategies (Thorne et al., 2016).

Spatial analyses can also help in preparing for post-fire restoration efforts (before or after a fire has occurred). Where fire severity is high, seed banks low, or other conditions that may complicate future tree and understory recruitment; spatial analyses can help to determine where to focus post-fire restoration efforts (North et al., 2019). See Chapter 6: Metrics, Chapter 7: Condition Assessment, and Chapter 8: Prioritization Framework and Implementation Analysis for data and evaluation methods to identify stands that may be prone to fire and help plan for postfire restoration.

A variety of tools are being developed to support postfire restoration efforts. For example, the Post-fire Reforestation Success Estimation Tool (PReSET) makes predictions of the effect of tree planting on mid-term (10-20 years post-fire) tree seedling densities (Young et al., n.d.). Steps to use the tool include: 1) choose spatial resolution, 2) upload severity raster, and 3) upload fire perimeter or focal area perimeter. Once data is entered, the tool calculates predicted outcomes. The Post-fire Restoration Prioritization (PreP) tool can be used to plan postfire restoration in shrublands (Underwood & Safford, 2021).

In another example of restoration prioritization methodology, Strassburg et al. (2019) divided the Brazilian Atlantic Forest into 1 km^2 units. They then used linear programming to identify solutions that included cost-benefit trade-offs under different restoration scenarios and variations on the scale of the response. The study examined solutions to both reduce extinction rates and sequester carbon. With increasingly powerful analysis tools and regular spatial data collection, this multifactorial analysis is becoming increasingly accessible to land managers to aid in their decision-making.

There is also new technology available to support implementation of restoration actions. Prototype tree-planting drones exist, although it is unlikely that the scale of revegetation/tree planting projects would currently warrant their cost (DroneSeed; Flash Forest; Robinson et al., 2022)Maintenance robots for weed removal, irrigation, and plant health assessment are not outside the realm of future possibility and are already being used in many sectors. Robots are starting to be used in forestry tasks as well (Oliveira et al., 2021).

BENEFITS & CONSTRAINTS

Restoration is highly variable according to system and scale. There are many assessment and monitoring concepts and techniques used to evaluate the ecological benefits of different types of restoration projects (Prach et al., 2019; Wortley et al., 2013). Ecological benefits can then be compared to initial and maintenance costs of restoration to evaluate the overall value of restoration projects and inform planning and investments in future restoration (Wainaina et al., 2020). This cost-benefit analysis model is being revised to include the larger value of ecosystem services which can be improved through restoration, such as improved air and water quality, decreased flooding, carbon sequestration, and recreation (De Groot et al., 2013; Elmqvist et al., 2015). See a summary of benefits and constraints in Table 9.6.

Restoration can be very expensive, and often is challenging to apply at larger scales. For riparian and wetland restoration, which may be costly even at small scales, a compelling case can be made for beaver reintroduction or beaver dam analogs to support climate change adaptation, ecological function and processes, with favorable costs and project scale (Pollock et al., 2015). Removing artificial obstructions (culverts, dams), gully stuffing, controlling road erosion, or decommissioning roads are other highly impactful and cost-effective approaches for restoring riparian areas and hydrological function (Roni et al., 2002; U.S. Department of Agriculture, 2021).

Riparian restoration is a complex undertaking with many constraints in addition to high costs. Though riparian restoration is critical, it also has the potential for negative short-term impacts to sensitive habitat and species. Compliance and permitting for work in creeks and floodplains is complex and time-intensive (Griggs, 2009). Personnel implementing riparian restoration projects require high levels of training and expertise to be successful, and labor-intensive pre-, during, and post-implementation monitoring is necessary for compliance and to measure project effectiveness (Roni et al., 2019).

For many forest health projects incorporating methods to address fire exclusion such as thinning and prescribed fire, riparian areas are simply avoided or excluded from treatment. Where avoidance is not desired or feasible, treatments can be modified to prevent negative impacts, such as compaction from machinery, to protect riparian ecosystem function.

As mentioned above, non-native invasive species control and managing erosion and runoff are essential for restoration projects, and both require ongoing monitoring and maintenance work. This type of ongoing restoration work can be an excellent opportunity to involve the community in caring for the land. There are many existing volunteer programs in Marin County that engage people in weed removal, native species planting, and monitoring efforts.

Table 9.6. Summary of the benefits and constraints of restoration treatments.

Benefits	Constraints
NNIS Control • Allows native species to flourish and provide food and habitat for wildlife. • Can address unnatural or hazardous fuels arrangements.	• Weed control is only one piece of restoration, alone may not fully restore ecosystem function. • Often requires long-term maintenance.
Grazing • Can be a useful tool for weed control and maintenance in specific cases. • Manure can add nutrients to the soil.	• Livestock may import weeds to the project area. • Livestock may negatively impact riparian areas and other sensitive habitats. • Grazing must be managed to ensure intensity and timing are appropriate. • May have unforeseen costs or additional management needs.
Erosion Control • Reduce runoff into river and wetland systems. • Reduces loss of topsoil, key to vegetation health and moisture retention. • Assist abiotic recovery, e.g., reduce or eliminate gully erosion.	• Can be costly and requires maintenance. • Surface erosion control does not prevent landslides or other major erosion events. • Can be challenging to plant or direct seed into erosion control materials.
Beaver and BDAs • Cost-effective tool for wetland and riparian restoration. • Restores natural hydrological and vegetative processes.	• May not work in certain settings and land ownerships. • Careful planning is needed to ensure that changed hydrology does not affect nearby infrastructure.

• Timing of hydrograph, water release can be beneficial over long-term, especially during drought.	• Compliance and permitting requirements may be complex. • On-going monitoring is needed.
Road Removal • For some roads, it is highly effective at removing major sediment source, and reducing erosion and runoff. • Aesthetic and recreation benefits.	• Overall costs can be high, especially in mountainous or steep terrain. • Erosion control measures can be extensive. • Compliance and permitting requirements may be complex. • On-going monitoring is needed.
Direct Seeding • May be more cost-effective than container stock. • Easier and quicker than planting container stock. • May not have same pathogen/ disease problems as container stock, but the pathogen which causes pitch canker can be carried on seeds (Zamora-Ballesteros et al., 2019).	• Often requires seed sourcing and amplification–can be time and cost-intensive. • Protection of emergent seedlings can be challenging. • Potential for low survivorship rate. • Slower establishment of soil cover and habitat.
Container Planting • Higher survivorship than direct seeding, thus requires less seed collection. • Quick establishment of soil cover and habitat. • Easier to monitor success than with direct seeding. • Easier to implement weed controls.	• Costly and time-consuming. • May require browse control for some species. • Nursery must follow pest and pathogen BMPs.

RESOURCE PROTECTION

Restoration, although focused on protecting or restoring ecosystem function, may have short-term negative impacts during implementation and BMPs are needed to ensure protection. In addition, it is recommended that restoration be planned in conjunction with fuel management to develop projects that have multiple benefits; use materials, crews, and equipment efficiently; and reduce the number of times an area experiences disturbance.

In general, key needs to reduce short-term impacts are protection of listed (threatened or endangered) species, mitigating erosion and runoff, and meeting NEPA/CEQA compliance and other permitting requirements. BMPs for reducing the spread of pests, pathogens, and non-native invasive species should also be followed.

BMPs for restoration projects are presented in a variety of existing compliance and planning documents completed by Marin County land management agencies (see Appendix C: Regulatory Compliance for more information). For example, Marin Water's *BFFIP EIR* includes a Mitigation, Monitoring, and Reporting Program with resource protection BMPs (Marin Water, 2019b) and MCOSD *Vegetation and Biodiversity Management Plan* includes a chapter on BMPs (MCOSD, 2015). BMPs include a variety of actions to protect both sensitive habitat and particular species. Examples for habitat protection include limiting fuels reduction in wetlands, maintaining riparian buffers, and limiting work footprints in sensitive resource areas.

BMPs for reducing erosion include installing erosion control and slope stability measures and suspending soil disturbance during precipitation. BMPs for protecting sensitive species include avoiding work during bird nesting season and during winter months when work around streams is most likely to impact aquatic species. Pre-implementation monitoring to identify and map locations of sensitive and listed species is often needed and allows sensitive areas to be demarcated and avoided during field work.

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PESTS & PATHOGENS MANAGEMENT TREATMENT DESCRIPTION

Pests and pathogens can cause significant damage and mortality in forest stands. In Marin County, two forest diseases, sudden oak death (SOD) and pitch canker, have significantly altered forest conditions and affected innumerable trees. Current treatment options are difficult to implement or limited in their effectiveness. The reduction of human-assisted spread is critical, which can be decreased by following best management practices (BMPs) for nursery stock procurement and during maintenance and construction activities.

This treatment description reviews the benefits and drawbacks of a variety of approaches and treatments related to managing pests and pathogens, with the general conclusion that, currently, the best approach is following existing BMPs to avoid the spread and contamination from infested to non-infested sites. Discussions of emerging pests and pathogens and new technologies for detection are included, as well as resources to support tracking pests and pathogens in California.

BACKGROUND

Since its discovery in Marin County in the 1990s, sudden oak death, the disease caused by the pathogen *Phytophthora ramorum*, is estimated to have killed more than 50 million trees in coastal California and Oregon (Cunniffe et al., 2016; Garbelotto, 2020). The disease can cause decline and mortality in tanoak (*Notholithocarpus densiflorus*), coast live oak (*Quercus agrifolia*), California black oak (*Q. kelloggi*), and canyon live oak (*Q. chrysolepis*) (Garbelotto et al., 2003; Murphy & Rizzo, 2003; Rizzo et al., 2002). The pathogen *P. ramorum* can affect over 100 species of plants, including popular ornamental plants (e.g., rhododendron and camellia) (Alexander & Swain, 2010; Garbelotto et al., 2001). This invasive, exotic pathogen is under federal and state quarantine (California Department of Food and Agriculture, n.d.). On Mount Tamalpais, the pathogen has caused stands formerly dominated by tanoak to convert to brush fields (Cobb. et al. 2017). Concerns include sudden oak death–caused decline in ecosystem function, changes in floristic composition of affected stands, loss of forage for wildlife (Metz et al., 2017; Rizzo & Garbelotto, 2003), and altered fire behavior and fuel loading patterns (Metz et al., 2017).

Pitch pine canker, a disease caused by *Fusarium circinatum*, can cause decline and mortality in Bishop pine (*Pinus muricata*), and is currently impacting stands at Point Reyes National Seashore and Tomales Bay State Park (Harvey & Agne, 2021; see Appendix A: Bishop Pine and Chapter 7: Condition Assessment). The pathogen was first detected in California in 1986 near Santa Cruz, damaging Monterey pine (*Pinus radiata*) (Swett & Gordon, 2013). It has subsequently caused mortality in vast numbers of pines, largely along the Central Coast (Camilli et al., 2013). The pathogen also contributes to the decline of the Monterey pine in Santa Cruz, Monterey, and San Luis Obispo Counties (Gordon et al., 2001; McCain, 1987). Degradation of Central Coast native Monterey pine stands, the genetic repository for *P. radiata* planted worldwide, is a significant concern.

Western gall rust, a disease caused by the native pathogen *Endocronartium harknessii*, is also a concern for Bishop pine in some areas. Older Bishop pine trees not exposed to fire may succumb to western gall rust and die without reproducing (Vogl et al., 1988).

RESULTS CHAIN RECOMMENDATIONS

Results chains for all target forest types of the *Marin Regional Forest Health Strategy* (*Forest Health Strategy*) include actions to control pests and pathogens. The first step in managing pests and pathogens is reducing their spread to new areas. BMPs, such as those developed by the California Oak Mortality Task Force (2014), can be used by staff and contractors to limit the spread of pests and pathogens from site to site, protect uninfected sites, and comply with environmental regulations. Ideally, BMPs should be coordinated amongst land managers and those doing vegetation management, including the Marin Wildfire Prevention Authority (MWPA) and fire agencies. Similarly, environmental education and collaboration can help inform park visitors and private landowners about the dangers of pests and pathogens. Increased education and signage about plant pathogens and related impacts can help prevent further spread. In addition, access planning and thoughtfully designed trails and signage encourage visitors to use designated trails, which reduces travel off trail and the spread of pests and pathogens.

See Chapter 5: Goals for more information on each target forest type's forest health goals and results chains.

DESCRIPTION

Introduced and native pests and pathogens can cause widespread damage to forested regions. Pests as discussed here refers to organisms which damage forest vegetation directly or are vectors for pathogens. Pathogens are organisms which cause disease, as *F. circinatum* is the pathogen which causes pitch canker disease. Pests and pathogens are considered together because their impacts are linked. For example, *F. circinatum* can be moved between trees by a variety of insects, including native insects (Camilli et al., 2013). This treatment description focuses on sudden oak death and pitch canker as two of the most impactful forest diseases in Marin County at this time.

In general, current treatments for sudden oak death are limited and may have undesirable impacts. Removal of California bay laurels (*Umbellularia californica*) adjacent to high-value oaks is effective but reduces stand diversity (Lee et al., 2010). Applications of phosphoric acid as a preventive may slow or prevent infection in high-value trees but is neither 100% effective nor scalable, and has some phytotoxicity (Garbelotto, et al., 2002). Federal and state quarantines (regulations) are in place to avoid human-assisted movement and introduction to new areas on nursery stock, firewood, and other plant materials (California Department of Food and Agriculture, n.d.).

Management for pitch pine canker relies primarily on prevention, but over time natural resistance increases, sustaining some survival and recovery in infected stands (Gordon et al., 2010; Swett & Gordon, 2013). Climatic conditions greatly influence disease spread and persistence; climate changes are expected to profoundly alter tree disease dynamics (Hennon et al., 2020). Fire and pests/pathogens interact in several ways, namely through increased fuels due to tree mortality. The relationship is complex, varying by pest/pathogen, temporal epidemiological trajectories, and local vegetation and climate (Neary et al., 2005; Forrestel et al., 2015; He et al., 2021).

SUDDEN OAK DEATH

Sudden oak death was first reported in Marin County in the mid-1990s (Rizzo & Garbelotto, 2003). The sudden oak death-causing pathogen aerially infects leaves or twigs of hosts and causes lethal bole infections on tanoaks, coast live oaks, and other hardwood species. The pathogen causes bole cankers, appearing as brown or black discolored outer bark on the lower trunk, which may seep dark red sap (Rizzo et al., 2002). Tanoak is more susceptible to *P. ramorum* than other species (Rizzo et al., 2002; Swiecki & Bernhardt, 2013). Various types of tanoak alliances on Marin Water lands declined between 51-100% between 2004 and 2014 due to sudden oak death (Marin Water, 2019a). The pathogen sporulates readily on California bay laurel but only causes leaf spots on the species. The pathogen does not sporulate on oaks, so most infection is caused by the movement of the pathogen from bay laurel to nearby oaks (Kozanitas et al., 2022). For more information on sudden oak death, visit the California Oak Mortality Task Force website.

Sudden Oak Death & Fire

Sudden oak death (SOD) tree mortality can affect fire behavior and hazards by altering fuel arrangements and distribution (Simler et al., 2018; Simler-Williamson et al., 2021; Swiecki & Bernhardt, 2013). In northern California coastal forests, surface fuels in SOD-infected tanoak - Douglas-fir stands increased over long periods from 8-12 years (Valachovic et al., 2011). Fire behavior in sudden oak death-infected stands may differ from that predicted by typical fire and fuels models. For example, sudden oak death can create canopy gaps that open the forest floor to more wind and light, creating hotter and drier conditions for fuel moistures and increased wind speeds in openings, both of which can potentially accelerate ignited fires (Swiecki & Bernhardt, 2013).[1] In addition, the progression of sudden oak death can result in standing dead trees with low foliar moisture content, which can result in higher potential for crown fire (Kuljian & Varner, 2010).

In several studies, sudden oak death was found to be less prevalent in forests stands that had burned since 1950, however the authors indicated this could be related to differences in forest structure and tree vigor in burned versus unburned areas, and that more study is needed to determine if prescribed fire is preventative against sudden oak death spread (Moritz & Odion, 2005; Simler-Williamson et al., 2021; Withgott, 2004).

[1] Changes in ground and aerial fuels due to sudden oak death can be found in Tables 3-5, 3-6, and 3-7, of *A Reference Manual for Managing Sudden Oak Death in California* (Swiecki & Bernhardt, 2013, pp. 103-108).

Lee (2009, p.1) conducted a literature review on sudden oak death and fire and noted the following key observations:

- Prescribed fires and large wildfires reduce *P. ramorum* inoculum but do not eliminate it from a given area.
- Results of surface- and crown-fuel studies in sudden oak death-infected stands show that predicted surface fire behavior in infected stands seems to conform to fuel models used for hardwood stands. However, the low moisture content of dead tanoak leaves may lead to more frequent crown ignitions even during fires of normal intensity.
- Fire effects in *P. ramorum*-infested forests vary depending on the stage of disease progression.
- Surface fuels from hardwoods killed by *P. ramorum* alter fire behavior; safety hazards from *P. ramorum*-killed trees present a concern for firefighters.
- Detailed maps of the distribution of hardwood mortality in sudden oak death-infected areas are helpful for more effective and safer firefighting.
- More studies of surface and crown fuel amounts and fire history are needed throughout the distribution of *P. ramorum* in California.

SUDDEN OAK DEATH IN TARGET FOREST TYPES

The following section reviews impacts of sudden oak death in the *Forest Health Strategy* key forest types.

Open Canopy Oak Woodlands

Several Open Canopy Oak Woodland species found in Marin County can be directly affected by *Phytophthora ramorum*, the pathogen that causes sudden oak death, including coast live oak (*Quercus agrifolia*), California black oak (*Q. kelloggi*), and canyon live oak (*Q. chrysolepis*) (Garbelotto et al., 2003; Murphy & Rizzo, 2003; Rizzo et al., 2002). Although Open Canopy Oak Woodlands share many of the same associates of mixed conifer-hardwood forests, for example tanoak, California bay laurel, and madrone (*Arbutus menziesii*), the generally lower tree density, canopy cover, and variability make them a unique habitat type (Buck-Diaz et al. 2021; Edson et al., 2016). Sudden oak death impacts in Open Canopy Oak Woodlands can affect both the dominant oak species (*Quercus* spp.) and understory associates (e.g. tanoak), changing the species composition and structure of affected stands. Sudden oak death impacts are widespread in Marin County; the pathogen is unlikely to be eradicated and is predicted to continue to spread into new areas in the future (Cunniffe et al. 2016).

Landscape-scale measurements of sudden oak death disease presence and impacts can be difficult to analyze using remote methods. However, according to data provided by the 2018 Marin Countywide Fine Scale Vegetation Map (2018 Fine Scale Vegetation Map; Golden Gate National Parks Conservancy et al., 2021) and analyzed as part of the *Forest Health Strategy*, 15% of all Open Canopy Oak Woodlands in Marin County (approximately 3,103 acres) have detectible mortality in the canopy, a key indicator of potential sudden oak death impacts. See Chapter 7: Condition Assessment for additional information.

Coast Redwood

Sudden oak death is most likely to affect susceptible associates of Coast Redwood forests such as tanoak (*Notholithocarpus densiflorus*), altering the floristic composition and structure of this key forest type. Coast redwood trees (*Sequoia sempervirens)* are susceptible to *P. ramorum,* but infections are not lethal (Goheen et al., 2006). Typically, damage is limited to die-back of sprouts or lower branch tips. However, sudden oak death may contribute to increased coast redwood mortality following wildfires (Metz et al., 2013; Simler-Williamson et al., 2021; Steel et al., 2015). On the California central coast, Metz et al. (2013) assessed tree mortality, sudden oak death, and wildfire associations. They found the presence of infected tanoak and bay laurel increased coast redwood mortality during wildfire by 200%. Increased fuel loads and decreased fuel moisture may have elevated fire intensities and subsequent coast redwood mortality. Forrestel et al. (2015) noted similar SOD and fuels interactions in Coast Redwood and Douglas-fir forests at Point Reyes National Seashore and Golden Gate National Recreation Area.

Analysis of data provided by the 2018 Fine Scale Vegetation Map as part of the *Forest Health Strategy* indicates that 21% of all Coast Redwood forests in Marin County (approximately 2,368 acres) have detectible canopy mortality, an indicator of potential sudden oak death impacts (Golden Gate National Parks Conservancy et al., 2021). See Chapter 7: Condition Assessment for additional information.

Douglas-fir

Similar to Coast Redwood, the greatest sudden oak death impacts to Douglas-fir forest result from the decline of associates such as tanoak, which changes the structure and species composition of affected stands. Douglas-fir is susceptible to *P. ramorum,* but it has been observed to be lethal only to seedlings or saplings less than three feet tall, although larger trees may show branch tip die-back (Davidson et al., 2002; Goheen et al., 2006). Surface fuels in sudden oak death-infected tanoak -Douglas-fir stands increase over long periods in oak and Douglas-fir - tanoak forests along the north coast (Valachovic et al., 2011). In mixed stands with tanoak and Douglas-fir, Valachovic et al. (2011) compared stand structure and fuel loading in Sonoma, Mendocino, and Humboldt Counties to assess whether *P. ramorum* alters surface fuel loading and fire behavior. The authors compared stands infected with sudden oak death disease with stands killed by herbicides. Results showed surface fuel loading in herbicide-treated plots was similar to sudden oak death-infected plots, and using fuel loading in herbicide-treated plots to assess long-term changes in fuels concluded that fuel loading in sudden oak death-infected plots will continue to increase relative to controls over a long time horizon.

Examination of data included in the 2018 Fine Scale Vegetation Map as part of the *Forest Health Strategy* shows 9% of all Douglas-fir forests in Marin County (approximately 2,422 acres) have detectible mortality in the canopy, an indicator of potential sudden oak death impacts (Golden Gate National Parks Conservancy et al., 2021). See Chapter 7: Condition Assessment for additional information.

PITCH CANKER DISEASE

In coastal California, pitch canker, caused by *Fusarium circinatum*, causes decline and mortality in Monterey pine (*Pinus radiata*), Bishop pine (*Pinus muricata*), and knobcone pine (*Pinus attenuata*)(Swett & Gordon, 2013). Infected trees excrete large amounts of pitch in response to lesions caused by the disease (Gordon et al., 2020; Storer et al., 2001; Wood et al., 2003). Infection and beetle activity may cause branch and crown die-back or whole tree mortality (Crowley et al., 2009; Erbilgin et al., 2008). The spores of *F. circinatum* require an opening in the tree bark to initiate infection; these can be created by weather, cultural practices such as pruning, and by insects (Camilli et al., 2013). Twig beetles (*Pityophthorus* spp.) can serve as vectors for the pitch canker pathogen, as can engraver (*Ips* spp.), cone (*Conophthorus radiatae*), and deathwatch beetles (*Ernobius punctulatus*) (Ergilbin et al., 2008; Sakamoto et al., 2007). The Pitch Canker Task Force website provides up-to-date information on the disease.

Likely introduced from either seed transport for reforestation projects or Christmas tree nursery stock, the disease spread rapidly from Central Coast Monterey pine (*Pinus radiata*) stands in 1986 (Gordon et al., 2001; McCain, 1987). In Marin County, pitch canker expanded from less than five hectares in Point Reyes National Seashore Bishop Pine stands in 2006 to infest most of the forest in the Seashore by 2016 (Crowley et al., 2009; Gordon, 2017; Harvey & Agne, 2021). See Appendix A: Bishop Pine for more information.

Despite the rapid rate of increase of pitch canker on the Monterey Peninsula in the 1990s, Gordon et al. (2020) found that disease severity leveled off in Monterey pine from 1996-2013, with severity stabilizing in areas of long residence for the disease. The evidence of disease remission in infected trees of Monterey pine suggests that trees may develop systemic induced resistance to the disease (Gordon et al., 2010). Along with the potential for acquired resistance, a reduction in frequency and duration of fog near the coast during this period may have reduced disease incidence (Gordon et al., 2020).

Pitch canker appears to be most severe in Bishop Pine forest during the mid-seral state or approximately 10-50 years post-fire (Harvey & Agne, 2021). Bishop Pine forests in Tomales Bay State Park are not as severely affected as stands in Point Reyes, possibly because they are located in areas featuring deeper soils and higher rainfall (Gaman, 2019). Douglas-fir is known to be a carrier of pitch canker, though less susceptible, and 16 other conifer species may also be susceptible (Camilli et al., 2013; U.C. Integrated Pest Management Program, 2007).

A new Point Reyes Peninsula field study showed that nearly all sampled Bishop pine trees exhibited some pine pitch canker disease symptoms (Harvey et al., 2022; see Appendix A: Bishop Pine). In 2021, mid-seral stands with greater pitch canker severity were associated with moderately higher coarse surface fuel loads, crown die-back and canopy openness, and greater plant community diversity and forb cover. However, other stand structure variables, such as live and dead tree size, basal area, density, and reproductive potential, were not different across stands with high or low severity pitch canker and overall did not suggest a major departure from expected stand structural developments. Study results indicate that pitch canker continues to impact Bishop Pine stands but is unlikely to result in loss of local populations in the near term as changes to stand structure are not outside the range of variability across seral stages. Harvey et al. (2022) recommend experimental treatments to reduce tree density in mid-seral stands to those that more closely resemble late-seral conditions, and to test approaches to modifying fuel arrangements to determine if any reduction in fire behavior can be achieved in a forest type that typically burns at high severity and has stand replacing events.

Climate is a critical determinant of plant disease development (Drenkhan et al., 2020; Sturrock et al., 2011). Like most fungal pathogens, temperature and moisture are two of the most important climatic factors governing the distribution and spread of *F. circinatum*. For example, lesion lengths induced on Monterey pine by *F. circinatum* were positively correlated with temperatures between 14 and 26 degrees Celsius; no lesions developed on Monterey pine (*Pinus radiata*) inoculated and maintained at 10 degrees Celsius (McDonald, 1994). Infection can occur in colder locations at temperatures between 0-10 degrees Celsius but tends to proceed very slowly. Fog and mist in coastal areas are the main reasons pitch canker develops more rapidly and is more severe in *P. radiata* stands closer to the coast than inland (Gordon et al., 2006; Gordon et al., 2020; Wikler et al., 2003). Increased spread in foggy areas is partly explained by sporulation being enhanced during warm, wet conditions and has thus limited spread along California's coasts to areas where moisture is available during warmer periods (Camilli et al., 2013).

Pitch Canker & Fire

Tree mortality in Bishop Pine forest can alter the fuel profile in affected stands and potentially influence fire behavior (Point Reyes National Seashore, 2022). There are several unanswered questions on interactions between fire behavior and pitch canker in coastal California. For instance, how long are fuel loads altered by tree mortality, and does this vary by forest type? See Appendix E: Opportunities for Additional Study for additional ideas for future research.

Fire can result in increasing levels of pitch canker. For pitch canker-impacted stands, biotic factors such as fire and water deficit increase the susceptibility of pine trees to beetle outbreaks (Fernández-Fernández et al., 2019). Increased colonization of some pine beetle species due to tree mortality and fire facilitates the beetles' ability to act as a vector for pitch canker disease. In European Mediterranean regions, post-fire colonization of pine stands by *Ips sexdentatus* and *Tomicus piniperda* may be associated with pitch canker spread when beetles move from infected to uninfected trees (Fernández-Fernández et al., 2019).

There is currently very little information available on the effects of pitch canker on fire behavior over time. Harvey & Agne (2021) theorize that conifer mortality from other causes could be used to understand the fire hazard impacts of pitch canker, and use research focused on the effects of bark beetles as a surrogate to describe likely fire behavior changes. They find that fuel loads will likely vary with time since infection, with the greatest increase in fuel loads occurring decades after tree mortality (Harvey & Agne, 2021).

PEST & PATHOGEN MANAGEMENT APPROACHES

In general, a combination of site- and species-specific forest management, along with monitoring, early detection, education, and outreach, are the best approaches to reducing the impacts of pests and pathogens. Despite advances in understanding diseases such as sudden oak death and pitch canker, management treatment options are limited. To date, there are no treatments for sudden oak death and pitch canker that can be applied at scale. Preventative treatments such as sanitizing equipment, limiting public access, and not transporting infested materials are generally considered the best approaches, as, for example, described in the Marin County Parks and Open Space District (MCOSD) *Vegetation and Biodiversity Management Plan* (MCOSD, 2015).

TRACKING PESTS & PATHOGENS

Many tools are available to aid in tracking sudden oak death, pine pitch canker, and other pathogens. The Pitch Canker Task Force website is a central repository for disease description, publication, management, legislation, and funding related to the disease. The California Oak Mortality Task Force coordinates the work of many agencies to track and research sudden oak death. The California Oak Disease and Arthropod Dataset or CODA is a compilation of agents that affect oaks in California and an especially useful resource for oak woodland disease and pest management.

More pest and pathogen information can be found on the California Forest Pest Council website, at the U.C. Integrated Pest Management (IPM) Program website for invasive and exotic pests, the U.S. Forest Service Pacific Southwest Research Station website, the U.S. Forest Service Detection Surveys website for insects and disease. However, many of these pages focus on the Sierra Nevada and threats to species with timber value, which is not applicable to forests in Marin County.

In many locations local volunteers have been involved in tracking pathogens through citizen science efforts. For example, SOD blitzes involve volunteers in disease detection and produce detailed disease distribution maps (U.C. Berkeley Forest Pathology and Mycology Lab, n.d.).

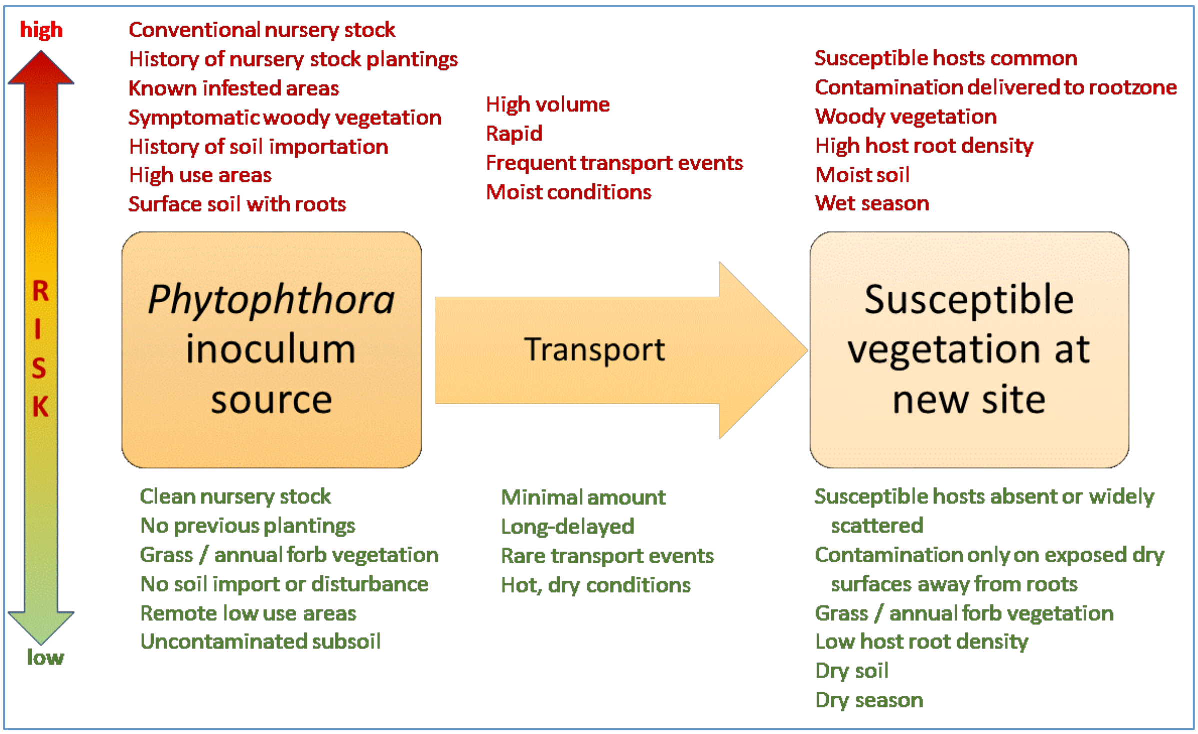
EARLY DETECTION OF PESTS & PATHOGENS

Early detection of diseases in trees or other plants is important to limit spread but can be difficult since infections may be latent and pests inside tree bark, or internal layers such as the cambium, may not be visible. For example, Douglas-fir may harbor *F. circinatum* with no signs of disease, even while airborne spores are being produced (U.C. Integrated Pest Management Program, 2007). Therefore, visual detection is generally not sufficient for early detection. Sampling of vegetation and soil and spore trapping can be used to monitor the early presence of diseases such as pitch canker and sudden oak death (Vainio et al., 2019; Swiecki & Bernhardt, 2013). Detection of *F. circinatum* DNA can be done using polymerase chain reactions either directly in plants or soil or by trapping airborne propagules (Zamora-Ballesteros et al., 2019). Detecting plant volatile organic compounds or spectral changes could provide a more accurate early detection and non-invasive methodology for pathogens, thus helping to limit spread (Sharifi & Ryu, 2018).

SUDDEN OAK DEATH

The most effective and efficient management method is to limit the spread of *Phytophthora sp.* into new areas. Many resources which provide useful preventative best management practices (BMPs) are listed below. In general, *Phytophthora* BMPs are not specific to *Phytophthora ramorum*, the species of water mold that causes sudden oak death, and instead focus on reducing the risk that a particular activity may have for potential introduction of any *Phytophthora* sp. inoculum. Generally, the greater the volume of plant or soil material, and/or the wetter the conditions, the greater the risk of *Phytophthora* introduction (Figure 9.15).

Figure 9.15. Diagram of the general risk model for introduction and spread of soil-borne Phytophthora species into uncontaminated sites ([Swiecki & Bernhardt, 2018](#)).



There are also several options to manage sudden oak death infested sites, and to reduce the spread from infested locations to new locations, but these may be expensive, labor-intensive, and have varying levels of efficacy.

The Sudden Oak Death Guidelines for Forestry from the California Oak Mortality Task Force offer straightforward and practical regulatory, diagnostic, and management recommendations for sudden oak death (California Oak Mortality Task Force, 2014). BMPs include:

- Avoid working in forests that are known or appear to be infested. If working in an infested forest, follow recommended sanitation practices.
- Avoid working in infested forests during wet, rainy, and cool times of the year. Avoid muddy conditions.

- Inform personnel working within a sudden oak death-infected area and use mitigation measures to prevent disease spread.
- Route equipment away from host plants and trees. Locate any landings or other equipment activity sites away from these areas and use paved or rocked roads/landings if possible. Inspect any equipment leaving a site for host plant debris and remove it if found.
- After working in an infested area, wash shoes, clothing, and equipment before exiting the site. Lysol or a bleach solution can be used with boots after cleaning.
- Remove bark from woody debris and allow it to dry on-site before moving elsewhere.
- Do not select sudden oak death-infected snags for wildlife benefit retention.

The California Oak Mortality Task Force website also includes a comprehensive list of sudden oak death best management practices for homeowners, recreational visitors, and other groups that may come into contact with sudden oak death infestations (California Oak Mortality Task Force, n.d.a.).

The U.S. Forest Service prepared a comprehensive reference manual for managing sudden oak death in California (Swiecki & Bernhardt, 2013). The manual describes the epidemiology of sudden oak death, advises managers on choosing the most appropriate strategies for managing it at a given location, and includes a detailed planning chapter for prioritized sudden oak death treatment and management.

The GGNRA developed BMPs for reducing the spread of soil-borne *Phytophthora* spp., described in the report *Best Management Practices for Preventing* Phytophthora *Introduction and Spread* (Swiecki & Bernhardt, 2018). The report includes project-specific BMPs for activities associated with trail construction and maintenance, heavy equipment construction, and soil for import. An extensive list of best management practices is offered for each section and includes assessment checklists and flowcharts to help land managers with decision-making.

The Marin County Parks and Open Space District (MCOSD) *Vegetation and Biodiversity Management Plan* (2015) outlines the following actions for managing sudden oak death:

- Sanitizing equipment, vehicles, and shoes with a mild bleach solution before leaving infected areas.
- Limiting public access to infected areas (e.g., temporarily closing trails or cordoning off areas) as needed to reduce any potential spread.
- Prohibiting the transport of leaf litter, soil, woody debris, firewood, or cut limbs from infestation areas and leaving woody debris at the infestation site.
- Removing or felling diseased oak and tanoak trees in place and removing surrounding California bay laurel.
- Containing the diseased trees (i.e., felling the tree and leaving it in place) and monitoring surrounding trees until the disease has run its course in the area.

The density and distribution of tanoaks and California bay laurel can be used as indicators for sudden oak death disease risk (Swiecki & Bernhardt, 2013). Tanoaks are very susceptible to sudden oak death, which can infect and kill all sizes and age classes of this tree. Bay laurel seems to be a significant source for inoculum and play a large role in spreading the disease (Alexander & Swain, 2010). Removal of one or both species is one option to reduce the impacts and spread of sudden oak death, but the vigorous resprouting of both species can complicate this control method.

Bay Laurel Removal

Bay laurel supports prolific pathogen sporulation, so removing them lowers inoculum loads and reduces the risk of infection to nearby oaks (Filipe et al., 2019). Swiecki and Bernhardt (2013) and Garbelotto (2020) found that removing bay trees within 5-10 meters of oak trees reduces their chance of becoming infected from sudden oak death. Valachovic et al. tested several control methods which included bay laurel removal, and found that rates of re-infection following treatments were lowest where bay laurel densities were lowest (Valachovic et al., 2017a).

Tanoak Thinning & Tending

As described in Chapter 3: Stewardship and Partnership with the Federated Indians of Graton Rancheria, tanoaks are highly valued by the Coast Miwok, and agencies should consider management approaches, including potential partnership with the Federated Indians of Graton Rancheria, that encourage conservation and restoration of tanoak as a species that has been an important Coast Miwok food source for millennia.

Thinning or changing species composition and structure for tanoaks is a sudden oak death management approach studied in several locations. However, widespread thinning of tanoaks could impact biodiversity and cultural uses of tanoak.

Cobb et al. (2017) compared mastication plus hand thinning of tanoak in Douglas-fir/tanoak and coast redwood/tanoak stands on Marin Water lands to tanoak thinning on Bureau of Land Management (BLM) lands in Humboldt County. Both treatments greatly reduced the density of key sporulation-supporting hosts with modest to minimal effects on stand basal area. The reduction in stand density treatment results was comparable to results from longer-term efforts by the Hoopa and Yurok tribes for the thinning treatments on BLM lands. They also found nominal differences in carbon sequestration since the basal area was conserved in the treatments. However, the authors noted that longer-term management would be required to reach the state documented on tribal lands (Cobb et al., 2017).

In some locations a long-term management program could be used to preserve tanoak. Bowcutt (2013) advocated for a collaborative approach with Tribal leadership to identify areas with mature tanoaks where cultural burning practices can be tested with best management practices to reduce sudden oak death infestations. Selective thinning could also be used in these forests, as it helps to minimize disease spread and possibly makes stands more resistant to initial invasion (Cobb et al., 2017).

Fire

Empirical and observational data indicate that prescribed fire temporarily reduces sudden oak death infestations but does not eradicate the pathogen. In a study by a multi-agency task force in Curry County, Oregon, infected tanoak stands were cut, then broadcast-burned in an attempt to eliminate sudden oak death (Goheen et al., 2017). The sites were monitored for *P. ramorum* periodically following treatment. Initial post-treatment results showed that *P. ramorum* presence was eliminated at some sites. Still, at others, the pathogen survived at low levels (present in 1.1% of trees surveyed), mainly on sprouts from infected tanoak stumps. Three years post-eradication stand surveys suggested that eradication efforts slowed the spread of *P. ramorum* as the number of infected trees each year decreased following treatment (Kanaskie et al. 2006). Researchers found that most newly infected trees were north of eradication sites due to spreading related to the prevailing wind and rain patterns (Hansen et al., 2019; Kanaskie et al., 2006). Valachovic et al. (2008, 2010, 2017b) reported similar results in Humboldt County following removing tanoak and bay laurel from experimental sites. After removal, half of the sites were underburned. Following removal, sampling found the infrequent recovery of *P. ramorum* from spore traps.

Information on controlling sudden oak death with burning is still limited. Burning may injure trees and make them more susceptible to infection. Experimental results and observations suggest that burning may be a valuable tool to remove infectious materials from affected sites, but the pathogen will persist at low levels following a fire (Beh et al., 2013). A single round of treatments will not eliminate the pathogen from a stand. For example, the Marin County Fire Department observed *P. ramorum* in trees following prescribed burns (Lee, 2009). In a presentation to the San Mateo Fire Safe Council, Garbelotto (2020) cautioned against using fire as a silver bullet to control sudden oak death since fire's reduction of *P. ramorum* inoculum is often short-lived (Valachovic et al. 2017b). Garbelotto indicated that beneficial fire could, however, be utilized as a part of a broader forest prescription for treating infested stands.

Genetic Resistance

One important path towards protecting tanoaks and other species susceptible to sudden oak death is increasing the frequency of genetic resistance to the disease (Showalter et al., 2018). Research on other tree diseases may be useful for better understanding different types of disease resistance and potential management strategies for sudden oak death. For example, a study focused on damage to two pine species (*Pinus monticola, P. lambertiana*) caused by white pine blister rust (*Cronartium ribicola*) found that resistance varies for each host species and in different environments (Sniezko et al., 2019).[2] The authors recommend increased use of field trials to ensure that resistance is effective for restoration and recovery against invasive pathogens.

[2] Sniezko et al. (2019) points out that major gene resistance (MGR) may have limited utility and the search for resistance should include all types of resistance, as quantitative disease resistance (QDR) appears to be more durable than MGR in the long term at many sites in the study. Durable, rather than stable, is more important for long-lived trees.

American chestnut blight, a disease caused by the introduced pathogen *Cryphonectria parasitica,* severely altered forests in the eastern U.S. (Forest Pathology, n.d.). A genetic resistance research effort is being undertaken to manage American chestnut blight. Researchers have tried to control the disease through breeding, genetic resistance selection, biocontrol, and biotechnology. Of these approaches, they found genetically engineered American chestnut trees (*Castanea dentata*) to be most resistant to chestnut blight that killed billions of wild trees in the past (Conrow, 2020).

For sudden oak death, researchers are experimenting with planting disease-resistant oaks on the North Coast of California to create more resilient oak stands. Another approach still under development is the deployment of genetically resistant seedlings. Initial research on selecting for sudden oak death resistance in tanoak is taking place in several locations (Conrad et al., 2020).

Cobb et al. (2019) surveyed tanoak resistance to *P. ramorum* on Hoopa and Yurok Tribal lands at sites with different management regimes, including thinning and prescribed fire. They found variation in resistance at all sites, with resistance tending to have random spatial distribution and not be associated with stand management. The study results suggest that a small portion of trees sampled across ecologically different sites had high resistance. However, they found no significant association between resistance and measured or manipulated stand variables, consistent with previous studies (Cobb et al. 2012). An unpublished study on tanoak resistance on Karuk, Hoopa, and Yurok Tribal lands showed similar results (Cannon and Sniezko, personal communications, 2021). Overall, researchers concluded that although partial resistance is unlikely to prevent losses of tanoak, it is a potential tool to combine with additional management actions (Cobb et al., 2019; Cunniffe et al., 2016).

The Midpeninsula Regional Open Space District (Midpen) has participated in resistance trials for tanoaks to *P. ramorum* since 2006 (Midpen, 2016). Researchers collected acorns and leaf samples from 35 tanoak trees throughout the Santa Cruz Mountains and other locations in California and Oregon, analyzed samples genetically, and then inoculated them with sudden oak death. A portion of the tanoak saplings were planted in a sudden oak death-infested forest in the Santa Lucia Preserve, Carmel Valley (Hayden et al., 2011). Key results included the following: some saplings show high tolerance to sudden oak death in the lab and field; genes responsible for increased SOD resistance were identified, and a laboratory assay method was developed to identify tanoaks with high disease tolerance (Hayden et al., 2013). Further research is ongoing in several locations to assess resistance beyond sapling age, determine if a resistance strategy can be developed, and refine the lab resistance assay (Søndreli et al., 2019; Hawkes, 2017).

Chemical Treatments

Another potential treatment is the use of chemicals, classified as fungicides, to prevent *P. ramorum* infection or slow disease progression. Systemic fungicides are likely most effective, but still need to be reapplied regularly (Swiecki & Bernhardt, 2013). Fungicides inhibit fungal growth, so this method works best when disease risk has been reduced through other management methods, such as removal of nearby bay laurel trees (Swiecki & Bernhardt, 2013).This method is not feasible for wide-scale use, but could be used in limited areas to protect high value trees, and may be useful to preserve tanoak. A recent study focused on preserving tanoak in California used a new modelling approach to evaluate bay laurel removal and chemical protection of tanoak, and found that a combination of these two treatments was needed to help preserve tanoak populations (Filipe et al., 2019).

PITCH CANKER

No direct methods of controlling pitch canker have been identified, although actions can be taken to slow the pathogen's spread (Storer et al., 2001). Current management methods focus on containment and limiting the spread of pitch canker, similar to sudden oak death management actions. BMPs should be used to ensure that timber, firewood, diseased trees, other woody material, and soil that may carry pitch canker are not transported to new locations, and sanitation methods should be used to clean tools and equipment used in pitch canker-infested areas (Pitch Canker Task Force, n.d.). The MCOSD *Vegetation and Biodiversity Management Plan* (2015) recommends containment to reduce spread.

Other pitch canker management approaches include planting disease-resistant trees, monitoring high-value or historical trees, and treating those with boles with beetle pesticides to prevent attack (Camilli et al., 2013). Fungicides that affect pine pitch canker are available, but no effective techniques for using them to control the disease effectively have been demonstrated (Swett & Gordon, 2013).

Finally, actions to reduce the number of insects emerging from diseased plants, such as removing diseased or insect-infested trees from areas near susceptible trees and debarking recently killed trees can be used to reduce disease spread. Harvey & Agne (2021) suggest avoiding thinning to mitigate pitch canker due to unintended consequences. These consequences may include increased pathogen severity in low-density stands and loss of the natural self-thinning process, which may impair individual selection for new traits. See Appendix A: Bishop Pine for more information.

Insect Vector Control

Insects play a key role in the spread of pitch canker since they act as wounding agents that provide a disease entry point as well as carrying the pathogen to new trees (Fernández-Fernández et al., 2019; Swett & Gordon, 2013). Controlling insects such as bark beetles could therefore control the disease. However, most of the approaches tried in this realm are production forestry-focused and are not as applicable or appropriate to wildlands. For instance, chemical control of insect forest pests can be effective for some species but often involves harmful insecticides, such as neonicotinoids, which have far-reaching negative environmental effects, including impacts on pollinators (Hladik et al., 2018; Pisa et al., 2015). Silvicultural practices that improve tree vigor have been successfully applied to reduce stand susceptibility to damage from bark and wood-boring insects, which often exploit low vigor trees (Fettig et al., 2014; Seybold & Paine, 2008).

Mechanical control to limit host availability to insects is increasingly used given the costs, permitting, and negative environmental impacts of insecticides. Strategies such as removing bark, from wood to be stored or transported, eliminating coarse woody debris colonized by insects before their emergence, and avoiding the storage of freshly cut logs in forests have been effective (Zamora-Ballesteros et al., 2019). Biological control using fungi, parasitoids, and nematodes is effective for some wood boring and bark beetle species (Fernández-Fernández et al., 2019). However, these controls are nearly always species-specific, take lengthy periods to develop and permit, and carry the risk that the biocontrol agent will not be effective in the field or wreak havoc in new ecosystems.

Pheromones can be used to monitor insect populations, and in conjunction with integrated pest management approaches can mitigate insect impacts (Augstin et al., 2012). Pheromones may also be useful in attracting insects to traps and reducing their populations. However, this approach has met with limited success (Zamora-Ballesteros et al., 2019).

Genetic Resistance

Traditional breeding, genetic selection for tolerance, or genetic engineering are possible long-term solutions for pitch canker. For example, some Monterey pine individuals exhibit higher resistance to the disease and have been used for propagation of disease-resistant stock; breeding for resistance is a possible option for control in the future (Martín-García et al., 2019).

Traditional breeding programs are expensive and only recommended for highly-susceptible or small populations which have high risk of disease exposure (Serra-Varela et al., 2017). Nevertheless, genetic resistance to pitch canker may be important for the longer-term health of conifer stands. As the disease progresses, researches are finding that individual trees have inherent genetic resistance, and other trees may develop disease resistance over time (Gordon et al., 2010; Gordon et al., 2020; Harvey & Agne, 2021).

NEW APPROACHES & TECHNOLOGIES FOR PEST & PATHOGEN MANAGEMENT

The mortality analysis completed for the *Marin Regional Forest Health Strategy* (*Forest Health Strategy*), which utilizes remote sensing data, is a useful tool for understanding impacts of pests and pathogens, and other stressors, on a landscape scale (See Chapter 7: Condition Assessment). This tool is not appropriate for early pest and pathogen detection or regular monitoring However. early detection through surveys and sampling, especially in areas identified as hotspots from the Condition Assessment, could be a useful approach for tracking newly infected areas.

Remote sensing technologies will likely become more important for detection, tracking, monitoring, and developing management strategies for pests and pathogens (Abd El-Ghany et al., 2020; Fraser & Congalton, 2021). As mentioned above in the Early Detection section, chemical or spectral analysis could be a future route for detection, possibly used in conjunction with drone mapping in priority or susceptible areas (Fang et al., 2021; Sharifi & Ryu, 2018). However, spectral analysis may be difficult to adapt to emerging pests and pathogens, is unproven, especially in wildland settings, and may be costly (Cheshkova, 2022).

Researchers are studying biological control methods for pitch canker and other diseases, which have the benefit of avoiding potentially harmful pesticides (Martín-García, et al., 2019). Approaches to using microbes such as fungi and bacteria as biological controls could include producing toxins, parasitizing disease-causing pathogens, or competing with pathogens at a nutritional niche level within trees (Blumenstein et al., 2015; Mondy & Corio-Costet, 2004). Mycorrhizal fungi are part of the microbiome as well, and it is conceivable that their relevance for pine health could be linked to defenses against pathogens and pests (Lehto & Zwiatek, 2011). Mycorrhizal colonization related to pine susceptibility to pitch canker has not been studied yet, but in other pathosystems, has been shown to suppress other diseases (Zamora-Ballesteros et al., 2019).

NEWLY EMERGING PESTS & PATHOGENS

Newly emerging pests and pathogens offer additional challenges to land managers. With globalization and climate change increasing, new pests and pathogens will continue to emerge in Marin County.

Tracking emerging pests and pathogens outside the region is critical to early detection and rapid response. For example, goldspotted oak borer, primarily affecting oak species in southern California, may move north after originally entering California from Arizona, likely carried by infested firewood. The infestation zone is currently in Los Angeles, Orange, San Bernardino, Riverside, and San Diego Counties (U.S. Forest Service, 2017). Mediterranean oak borer (*Xyleborus monographus*), which primarily infests valley oak (*Q. lobata*) and blue oak (*Q. douglasii*), was first collected in California in 2017 and is currently found in Sonoma, Lake, Sacramento, and Napa Counties. The beetle is native to Europe, and this is the first confirmed infestation of this species in North America (U.C. Agriculture and Natural Resources, 2020). Other important emerging pathogens and diseases include *Phytophthora* spp. other than *P. ramorum*, *Heterobasion* spp., *Armillaria* spp., dwarf mistletoe (*Arceuthobium* spp.), and black stain root disease (*Leptographium wageneri*) (Hawkins, 2020).

Phytophthora cinnamomi is known to cause widespread madrone mortality and also causes decline and death in many other native woody species, including oaks, bay, manzanita (*Arctostaphylos* spp.), and chinquapin (*Chrysolepis* spp.) (Elliott et al., 2012; Lee, 2019). Warm wet conditions favor its spread, and nursery-grown plants act as a transport vector (Garbelotto et al., 2018; Sena et al., 2018). *P. cinnamomi* has been detected on the lower slopes surrounding Lake Lagunitas on Marin Water land and, given that it has been common in nursery stock for many decades, is likely in other parts of Marin County (Swiecki & Bernhardt, 2021, p.180). *P. cinnamomi* is nearly impossible to eradicate, but limiting movement around wet dirt can prevent its spread (Garbelotto et al., 2018).

Field observation and sampling is important for identifying new diseases or known diseases in new locations or on new hosts. For example, recent research into drought stress impacting a wide variety of native and nonnative trees in the Bay Area revealed fungal pathogens in acacia trees (Simons, 2021). Following sampling, researchers found two pathogens, *Diaporthe foeniculina,* and *Dothiorella viticola,* in all sick acacia. Both pathogens are native to California, are generalists in their attack on host plants, and take advantage of stressors such as drought.

BENEFITS & CONSTRAINTS

A summary of current and promising approaches to reduce the spread of pests and pathogens and manage impacted sites is shown in Table 9.7. Currently, there are no known effective treatments for either sudden oak death or pitch canker, thus following BMPs that prevent the spread of spores outside of infected areas is critical. Empirical and observational data indicate that prescribed fire temporarily reduces sudden oak death infestations in southern Oregon and Marin County but does not eradicate the disease (Goheen et al., 2017; Lee, 2009). Other new approaches that are still being tested include genetic resistance, insect vector control, and biocontrol. It does appear that the trajectory of pitch canker is possibly on a downward trend in some geographies for Monterey pine, which could be due to genetic resistance or changes in environmental conditions (reduced summer fog) which are less favorable to pathogen spread (Gordon et al., 2010; Gordon et al., 2020). For emerging pests and pathogens, early detection and rapid response collaboration across agencies is the current approach to limit spread.

Table 9.7. Summary of the benefits and constraints of pest and pathogen treatment options. (EDRR = early detection rapid response)

Benefits	Constraints
EDRR and BMPs (All pests and pathogens) • Only known effective means to stop or slow disease spread. • Known practices across agencies. • Does not require permitting. • Relatively low cost for implementing most BMPs.	• Will not save infested forest stands. • Requires training and education. • Must be implemented consistently across all land jurisdictions. • EDRR slows but generally does not stop disease spread.
Host Plant Thinning and/or Removal • Can reduce pathogen and disease spread. • Useful around target oak or tanoak trees or stands. • Reduces stand density for improved forest health. • Reduces fuel loads.	• Significant costs and resources for removal. • Can be a serious disturbance and impact to ecosystem services. • Trees resprout and require retreatment. • Removal of trees can reduce shade and create a drier understory environment. • Host trees may have significant cultural value.
Prescribed fire (SOD) • Cost efficient. • Nearly eliminates disease upon initial application. • Most effective in small forest stands.	• Does not eliminate the disease over time.

Genetic resistance selection (All) • Effective over a longer time scale. • Could create future resistance to diseases. • Recommended for highly susceptible populations.	• Long time scale to implementation. • May not fully contain or eradicate the disease. • High cost and resources to implement. • Uncertainty is high.
Pheromones (Pitch canker) • Pheromone disruption or attractants could disrupt beetle cycles and contain disease spread.	• Some beetle species may be affected or attracted by pheromones; others may not be.
Chemical (Pitch canker) • Integrated pest management treatments may reduce beetle populations and diminish their role as a pitch canker vector.	• Insecticides used for bark beetles tend to be highly damaging pyrethroids and neonicotinoids. • Chemicals not used by most agencies, permitting difficult. • Forest application is difficult to impossible or costly (aerial or injecting tree stems).
Chemical (SOD) • Fungicides can protect individual or small blocks of high-value trees. • Can be used in combination with other treatment approaches to protect tanoak.	• Not feasible to implement on a larger scale. • Requires regular reapplication.
Biocontrol (All) • Avoids use of potentially harmful pesticides. • Less disturbance than removal of infected or host vegetation. • Could be a long-term control strategy.	• Time/ cost/ resources to develop appropriate methods. • Biological controls alone will likely not be sufficient to control disease.

RESOURCE PROTECTION & PREVENTATIVE BEST MANAGEMENT PRACTICES

This section describes preventative best management practices (BMPs) used to protect resources by reducing the spread of pests and pathogens. In addition, protection of natural and cultural resources should be integrated into planning for other approaches to disease management. For example, removal of host trees or diseased trees should follow guidelines for seasonality, bat protection, and avoiding impacts to sensitive habitats and rare species. Prescribed fire should be used during appropriate burn windows to limit fire hazards and impacts to sensitive species and air quality.

When working in areas with known or suspected disease, it is important to use BMPs to reduce spread from the work area. This includes sanitization BMPs, such as cleaning equipment, and BMPs around moving cut vegetation and soil. Sanitization BMPs require the use of chemicals to clean tools, equipment, shoes, and other surfaces that could carry pests and pathogens. Sanitizing tools and equipment should be done over buckets or pavement, and chemicals should be captured and disposed of properly.

According to a review of Marin Water pathogen BMPs by Swiecki and Bernhardt (2021, pp. 9-10, pp.188-189 in PDF), principles related to reducing pathogen spread, especially soil-borne *Phytophthora*, include:

1. Minimize risk-generating activities. Keep high risk activities to the minimum needed to accomplish the task, including minimizing the area of disturbance and amount of soil and roots moved.
2. Segment operations spatially across the site. Separate projects into smaller activity areas where possible to minimize long range spread or spread from infested areas to non-infested areas. This includes directional controls, i.e., working from non-infested toward infested areas.
3. Phase operations over time across the site. Separate project activities over time to minimize spread from infested areas to non-infested areas or avoid working in high-risk areas under wet conditions.
4. Use equipment and working practices that will minimize disturbance of the surface soil and movement of soil and debris from known or potentially-infested areas to non-infested areas within and beyond job site.
5. Decontaminate frequently to minimize transport of infested soil and debris. Especially when working in known infected areas, more frequent cleaning and sanitizing of tools and equipment may be needed. Note that some cleaning and decontamination is normally needed in conjunction with all of the above strategies.

Additional BMPs to reduce the spread of pests and pathogens are presented in a variety of compliance documents. The *California Vegetation Treatment Program* (Cal VTP) Mitigation Monitoring and Reporting Program has a thorough list of BMPs (California Board of Forestry and Fire Protection, 2019). These BMPs must be followed for projects completing compliance under the *Cal VTP Programmatic Environmental Impact Report* (EIR). Agencies may be working under compliance documentation particular to their jurisdiction which includes specific BMPs. For example, MCOSD's *Vegetation and Biodiversity Management Plan* (MCOSD, 2015) includes BMPs, Marin Water's *BFFIP EIR* includes a Mitigation, Monitoring, and Reporting Program with resource protection BMPs (Marin Water, 2019b), and the Golden Gate National Recreation Area (GGNRA) *Fire Management Plan Environmental Impact Statement* (FMP EIS) includes BMPs as part of the General FMP Mitigation Measures included in the Record of Decision (ROD) (GGNRA, 2006). Additional guidance and resources for reducing pathogen spread can be found on the California Oak Mortality Task Force, Resources webpage and on the Pitch Canker Task Force, Management webpage.

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FUELBREAKS TREATMENT DESCRIPTION

Strategically located fuelbreaks can reduce fire spread and severity. They can alter fire behavior in priority landscapes to meet specific management objectives and outcomes. Fuelbreaks slow the spread of wildfire, reduce potential for embers to spread, can reduce fire intensity along evacuation routes, and allow firefighting teams to access critical wildfire-prone areas (California Department of Forestry and Fire Protection (CAL FIRE), 2021). They are designed to work with other equipment and tactics such as fire engines, water tankers, and firefighting crews to suppress wildfires. From a forest health perspective, some fuelbreaks may come with a trade-off: altered habitat in exchange for reduced fire spread and severity. However, fuelbreaks can be designed to be ecologically neutral or even beneficial, and steps can be taken to reduce the potential for fuelbreaks to act as vectors for the spread of non-native invasive plant or pathogen species. Fuelbreaks are generally regarded as infrastructure and therefore require cost to are maintain, and, ultimately, are not a guarantee that communities and infrastructure will not be affected by wildfires.

This treatment description reviews several different types of fuelbreaks which vary in level of disturbance, habitat impact, and maintenance needs. Choosing lower-impact fuel break methods where appropriate can limit ecosystem disruptions and reduce required maintenance.

BACKGROUND

The wildland-urban interface (WUI) is where buildings and infrastructure meet wildland vegetation. In the U.S. the WUI has grown quickly, increasing the potential safety issues and property damage caused by wildfire (Radeloff et al., 2018). Fuelbreaks of different types are one method to reduce fire hazard risk and prepare staging areas to fight fire in the WUI or around critical infrastructure.

Land management agencies in Marin County commonly use fuelbreaks to support fire management and suppression activities. Information about fuelbreak design, implementation, and maintenance are often included in management plans and compliance documents, such as Marin Water's *Biodiversity, Fire, and Fuels Integrated Plan* (*BFFIP*; Marin Water, 2019a) and the Golden Gate National Recreation Area's *Fire Management Plan Environmental Impact Statement* (*FMP EIS*; GGNRA, 2005).

RESULTS CHAINS RECOMMENDATIONS

Fuelbreaks are not included in the result chains as a method to improve forest health. However, in key areas, land managers can use fuelbreaks strategically in conjunction with other treatments such as thinning, beneficial fire, and invasive plant management, to improve forest health and reduce fire hazards at a landscape scale (Palm, 2021).

DESCRIPTION

The term fuelbreak (also referred to as fuel break, fire break, or fire line) is commonly used for several related concepts in which changes to vegetation structure influences fire behavior and supports fire suppression actions. Fuelbreaks are strategically located to create zones of vegetation management and ongoing maintenance that support fire suppression by reducing the connectivity of fuels and providing responders with a staging area or access to a remote landscape for fire control actions (California Board of Forestry and Fire Protection, 2019a). CAL FIRE (2019, p.2) defines a fuelbreak as a "…wide strip of land on which vegetation has been modified so that a fire burning into it can be more readily controlled." Green (1977) states that fuelbreaks are a strategically located wide block, or strip, on which a cover of dense, heavy, or flammable vegetation has been permanently changed to one of lower fuel volume or reduced flammability. Fuelbreaks can also refer to vegetation modification near buildings, roads, and other infrastructure to protect lives, safety, and property.

Open space can be divided into different fuel management zones to meet varying fuel and fire management needs. For example, shaded fuelbreaks may be a good option along roads used for fire control access (Figure 9.16). Determining which type of fuelbreak to employ depends on topography, weather patterns, vegetation, and anthropogenic factors such as distance to buildings and roads and site fire history. The location and design of fuelbreaks can also be informed using computer applications that simulate fire behavior under modeled conditions (Novo et al., 2020; Yakubu et al., 2015). Using a combination of fuelbreak approaches will provide the best solution to fire management. Additional photos of fuelbreaks can be found in the CAL FIRE Fuels Reduction Guide (2021) and on the Marin Wildfire Prevention Authority (MWPA) website.

Figure 9.16. Greater Ross Valley Shaded Fuel Break; trees are thinned to ensure tree crowns do not touch, lower branches are pruned, and dead/downed woody debris is removed. Shaded fuelbreaks are often placed along roads, ridgetops, and near buildings. Photo from Andrea Salinas, GrizzlyCorps Fellow, Marin Wildfire Prevention Authority (MWPA).

FUELBREAK APPROACHES

Different fuelbreak approaches are appropriate for different fuel management zones and to meet differing fire suppression or fire behavior modification goals. For example, the fuel management approach used in areas immediately adjacent to buildings will differ from the approach used along roadways, which will in turn differ from more remote wildland settings. Some approaches used by land management agencies in Marin are described below.

Marin Water divides its fuelbreaks into the following categories: defensible space, primary fuelbreaks, secondary fuelbreaks, ingress/egress, and wide area fuel reduction zones (WAFRZ), with all categories except for WAFRZ part of their permanent fuelbreak system (Marin Water, 2019a). The agency uses the following characteristics to determine the vegetation management approach at each location: fuelbreak zoning, project location inside/outside the wildland-urban interface (WUI)[1], vegetation, topography, broom (invasive plant) presence, ownership, structure use, ignitability, and recommendations from fire departments (Marin Water, 2019a). Marin County Parks and Open Space District (MCOSD) uses the following categories of fuelbreaks: defensible space, ignition prevention zones, fuelbreaks, including primary and secondary fuelbreaks, wide-area fuelbreaks, and ingress/egress zones (MCOSD, 2015).

The National Park Service clears vegetation and debris from selected dirt and paved roads that provide routes for emergency evacuation and access for fire suppression activities or conducting prescribed burns, or that serve as control lines for prescribed fire projects (Point Reyes National Seashore (PRNS), 2004, p. ix). California Department of Parks and Recreation (CDPR) policy permits vegetation modification such as fuelbreaks and defensible space zones on California State Park lands.

More detailed descriptions of various fuelbreak approaches are described below. Unless otherwise cited, they are summarized from Marin public land agency vegetation management guidelines such as Marin Water's *BFFIP*, MCOSD's *Vegetation and Biodiversity Management Plan*, and PRNS's *Fire Management Plan* (Marin Water, 2019a; MCOSD, 2015; PRNS, 2004).

DEFENSIBLE SPACE

Defensible space is a fuel management zone established around buildings or structures, infrastructure such as power and communication lines, or high-use roads, where vegetation is modified and maintained to slow the rate of fire spread. California Public Resource Code (PL-4290 and 4291) dictates the parameters for structural safety in residential communities and specifies defensible space requirements for different areas and county fire code and various city fire codes also apply.

Marin land management agencies include guidelines for defensible space in their planning documents. Maintaining defensible space is considered an effective approach to reducing fire hazards because developed areas have the highest probability of ignition and these areas have

[1] The WUI is the area where structures and human development and wildland vegetation meet or intermingle, and where wildfire problems are most pronounced (Radeloff, 2018).

the greatest concentration of people and property to protect. In addition, creating defensible space allows fire departments to fight fires. Practices include eliminating vegetation that easily ignites or burns intensely, such as eucalyptus, pruning or limbing lower tree branches, removing dead wood, mowing, and other forms of creating discontinuous horizontal and vertical fuels.

The Marin Wildfire Prevention Authority (MWPA) is approaching defensible space by focusing residents on a house-out approach, mitigating fire risk to the home first (siding, gutters, vents) and then moving on to their yards. To support this approach, MWPA is developing a parcel-level fire risk model that will include all parcels in Marin County. MWPA also provides local inspectors to evaluate home hardening and defensible space measures and provides grants for residents to perform work. More information can be found on the MWPA website under Fire Resistant Homes.

FUELBREAKS

Fuelbreaks are areas in which vegetation has been managed to diminish the rate of fire spread, fire line intensity, ember casting, and flame length, and to improve access for firefighters. **Primary fuelbreaks** are usually 100-200 feet wide and are designed to control low-intensity fires, slow edges of high-intensity fires, and aid firefighter safety. **Secondary fuelbreaks** are typically 60-100 feet wide and are located next to roads to control lower-intensity fires and support firefighting actions (Marin Water, 2019a; MCOSD, 2015). Fuelbreaks are created using chainsaws or machinery to thin or remove vegetation that is piled, burned, or chipped. Fuelbreaks allow firefighters to plan their tactical response, offer a strategic location to prevent fire spread, and be used as anchor points during suppression efforts to contain or control wildfires.

IGNITION PREVENTION ZONE

Ignition prevention zones are areas designed to reduce the probability of fire ignition in key areas such as roads, trailheads, campgrounds, and utility lines by reducing vegetation volume. According to the MCOSD (2015, p.3-32), ignition prevention zones may be on either side of a road, path, or utility line or an identified point ignition source.

WIDE-AREA OR SHADED FUELBREAK

Wide area fuel reduction zones (WAFRZ) are implemented to combine fuel load reduction and habitat enhancement goals. Synonymous with fuel reduction zones or shaded fuelbreaks, WAFRZ cover larger land areas than traditional fuelbreaks, often in forested settings. They are constructed by thinning tree density, removing weeds, and managing ladder fuels to reduce the potential for a torching or crown fire. Beneficial fire may be used to manage understory vegetation in these areas, often after an initial round of treatment. The retained canopy provides shade, habitat, and conditions for native species regeneration, retains soil and understory vegetation moisture (further reducing fire risk), and can reduce erosion. No standard width for shaded fuelbreaks is established, but work generally creates wide bands or swaths of managed areas where weeds are removed, surface fuels are reduced, and fuel arrangements that could increase potential for crown fire are thinned (Agee et al., 1999).

The MWPA is currently implementing large-scale shaded fuelbreaks in several areas in Marin County (MWPA, n.d.b.). General shaded fuelbreak goals are to create and maintain a continuous reduced-fuel and forest-health-restoration zone around communities in Marin. The Greater Ross Valley Shaded Fuel Break Project is focused on communities in Central Marin and involves vegetation management activities on 1,379 acres to create an approximately 38-mile-long continuous shaded fuelbreak. The project, which is currently underway, will reduce excess and ladder fuels within a generally 200-foot-wide fuel break, which may increase up to 300 feet where appropriate. MWPA plans to restore forest health by enhancing native, fire-resilient plant communities, through invasive species removal (MWPA, 2022).

Similarly, the Greater Novato Shaded Fuel Break aims to create and maintain a continuous reduced-fuel and forest-health-restoration zone around the communities in the greater Novato area. The proposed project would create an approximately 60-mile-long continuous shaded fuel break within a 2,123-acre area. The MWPA plans to reduce excess and ladder fuels within a fuelbreak 200-300 feet wide and adjacent wildland areas. It would also restore forest health through invasive species removal, removing lower tree limbs, thinning small trees and shrubs, and removing dead and down woody debris (MWPA, 2023).

INGRESS/EGRESS

Ingress/egress zones are fuel management zones adjacent to fire roads which allow vehicle access during a fire. Vegetation management typically includes pruning, mowing, or other vegetation removal actions in a buffer on either side of access roads. Ingress/egress zones aid the movement of firefighting equipment and firefighters and evacuation for the public and emergency vehicles during a fire.

NON-NATIVE INVASIVE PLANT SPECIES

Forest management infrastructure such as roads, trails, and fuelbreaks act as non-native invasive species (NNIS) vectors. Non-native invasive species impact habitat and biodiversity, and they can also be a fire hazard. Implementing NNIS management in fuelbreaks is an important component of protecting forest health and reducing NNIS infestations, and can be critical for fuelbreaks to function as intended. Ongoing maintenance of fuelbreaks is generally included in agency plans and budgets.

SPATIAL PLANNING

With spatial data available to depict the location and condition of landcover variables such as ladder fuels, vegetation type, vegetation structure, and fuel type, treatments can be prioritized based on the relationship between modeled wildfire behavior and values at risk such as infrastructure, communities, structures, or sensitive natural resources. See Chapter 8: Prioritization Framework and Implementation Analysis for a detailed discussion. The 2020 *Marin County Wildfire Protection Plan* (CWPP) is an example of how fire agencies conduct spatial planning for wildfire hazard and risk in Marin County (Lavezzo et al., 2020).

BENEFITS & CONSTRAINTS

All fuelbreaks require maintenance and can be a vector for non-native invasive plant and pathogen species spread. A study across California found that fuelbreaks that expose bare soil promote non-native plant species invasions, with non-native plant cover 200% higher on fuelbreaks than in adjacent wildlands (Merriam et al. 2006). However, fuelbreaks in defensible space zones and along emergency access routes are relatively easy to reach for maintenance and they do not cause the same large-scale disturbance to intact vegetation as ridgetop fuelbreaks.

Fuelbreaks along ridgetops may help prevent fire spreading to other ridgetops and adjacent lands. However, their construction and maintenance can negatively impact biodiversity from habitat loss and non-native species spread. Fuelbreaks are often located in chaparral where brush removal may devastate bird populations (Newman et al., 2018). In addition, ridgetop fuelbreak construction can lead to erosion and worsen water quality problems from runoff at the highest elevations.

Shaded fuelbreaks are an alternative to primary and secondary fuelbreaks and have a lower impact on multiple ecosystem services while still altering fire behavior in fire-prone areas. This approach can be combined with other fuel reduction methods, such as invasive plant management, thinning, and beneficial fire, to reduce fire risks in a larger area while maintaining or improving ecosystem services.

Defensible space is considered a best management practice around buildings and other critical infrastructure. Regular maintenance is critical for all types of fuelbreaks to ensure they meet fire risk reduction objectives and do not become vectors for non-native invasive species. A summary of the benefits and drawbacks for each fuelbreak type is shown in Table 9.8.

Table 9.8. Breakdown of benefits and constraints by fuelbreak type.

Benefits	Constraints
Defensible Space • Helps protect buildings and infrastructure. • Can reduce undesirable weed species cover if maintained effectively. • Can decrease fuels near ignition sources. • Generally, easier to access for regular maintenance.	• Requires regular maintenance. • Weeds can take advantage of disturbance. • One size does not fit all; defensible space clearing must be tailored based on vegetation type. • May require surveys to reduce potential impacts to sensitive wildlife or plant species.
Ignition Prevention Zones • Reduce ignitions near critical infrastructure.	• Require regular maintenance. • Do not always prevent ignitions or fires.
Primary & Secondary Fuelbreaks • Reduces fuels and associated radiant and convective heat transfer during wildfires. • Reduces potential for flame contact with structures. • Provides staging for fire suppression activities and may reduce impact of suppression activities by decreasing fire activity in managed area. • Agency use familiarity. • Fire equipment accessibility. • If well planned, implemented, and maintained, can be leveraged to reduce undesirable weed cover or otherwise be adapted to be ecologically neutral/beneficial. •	• Can be expensive to construct and maintain. • Can become a vector for non-native invasive species if poorly managed/maintained. • Potentially highly erosive and may degrade water quality. • Can potentially alter or reduce habitat. • May prevent some species movement (may facilitate others). • Not a perfect solution: fires may jump or burn through a fuelbreak, especially in weather driven events. • Ridgetop fuelbreaks can create major disturbances to wildlife and resources.

Shaded Fuelbreak/ Wide-area Fuel Reduction Zones • Less costly to construct and maintain than primary and secondary fuelbreaks. • Lowers fire spread and intensity. • Cooler/mesic understory remains greener longer, helping to reduce fire risk. • If well planned, implemented, and maintained, can be leveraged to achieve multiple benefits including protecting or increasing forest health and resilience.	• Are still expensive to construct and maintain. • Fires may burn through the fuelbreak, especially in wind driven events. • Require more area than primary and secondary fuelbreaks; large area needed. • Requires regular maintenance; can become a vector for non-native invasive species if poorly managed/maintained. • May alter or reduce habitat for some species.
Ingress/Egress • Fire equipment accessibility. • Increase safety of evacuation routes.	• Limited effectiveness for evacuation and safe passage of firefighting equipment when in steep terrain, not adequately maintained, or during hazardous fire conditions. • Expensive to construct and maintain; can become a vector for non-native invasive species if poorly managed/maintained.

MAINTENANCE & COSTS

The *BFFIP* recommends performing fuelbreak maintenance every 1-5 years, depending on site conditions (Marin Water, 2019a). Marin Water has been constructing and maintaining fuelbreaks as described in their *BFFIP* and provided the costs of that work in the *BFFIP 2022 Fiscal Year Report* (Marin Water, 2022). In 2022, they constructed 10 new acres of fuelbreaks at a cost $5,748 per acre. Maintaining fuelbreaks is less expensive than new construction, but still significant: fuelbreak vegetation maintenance cost $2,567 per acre, removing NNIS (such as *Genista monspessulana*) from fuelbreaks cost $269 per acre, and mowing fine fuels cost $861 per acre. Defensible space maintenance and fine fuel reduction were performed at a cost of $853 per acre. It should be noted that these are costs for field implementation only, and do not include planning, compliance, monitoring, or communications and outreach costs, which are likely to be an additional 15 to 20% of implementation costs.

Midpeninsula Regional Open Space District's Wildland Fire Resiliency Program Draft Environmental Impact Report (Midpen DEIR) recommends periodic retreatment dependent on vegetation growth rates, colonization by non-native invasive species, the likelihood of ignition/fire spread, and building proximity (Midpen, 2021). They suggest annual treatment for higher-risk areas such as defensible spaces around structures with grassy fuels, ingress/egress road corridors, and areas with rapidly growing woody weeds.

RESOURCE PROTECTION

Resource protection related to fuelbreaks largely revolves around training, education, and habitat and species protection. Best management practices (BMPs) include a variety of measures for protecting sensitive habitats and species during vegetation removal actions. When planning for the use of fuelbreaks, the potential value for fire hazard reduction should be balanced with the potential impact to resources, considering sensitive habitat, species, the potential for erosion, and non-native invasive species spread. Fuelbreak objectives should be clear, and design and setting should be chosen to meet specific objectives, avoid impacts to natural and cultural resources, and accomplish multiple benefits wherever possible.

BMPs for fuelbreak construction and maintenance are presented in a variety of compliance documents. The *California Vegetation Treatment Program* (Cal VTP) Mitigation Monitoring and Reporting Program has a thorough list of BMPs (California Board of Forestry and Fire Protection, 2019b). These BMPs must be followed for projects completing compliance under the *Cal VTP Programmatic Environmental Impact Report* (EIR). Agencies may be working under compliance documentation particular to their jurisdiction which includes specific BMPs. For example, Marin Water's *BFFIP EIR* includes a Mitigation, Monitoring, and Reporting Program with resource protection BMPs (Marin Water, 2019b) and the Golden Gate National Recreation Area (GGNRA) *Fire Management Plan Environmental Impact Statement* (FMP EIS includes BMPs as part of the General FMP Mitigation Measures included in the Record of Decision (ROD) (GGNRA, 2006). In addition, the MWPA worked with the Ecologically Sound Practices Partnership (ESP Partnership) to develop BMPs to be used by the MWPA for fire management actions in Marin County. The *Ecologically Sound Practices for Vegetation Management* document compiles BMPs from a variety of sources (ESP Partnership, 2022). MWPA has also drafted Project Design and Implementation Features based on the ESP Partnership practices and BMPs from partner agencies; these are incorporated into projects wherever applicable (Anne Crealock, MWPA Planning and Program Manager, personal communication, March 28, 2023).

BMPs for fuelbreaks are generally similar to those for other vegetation management actions and focus on procedures to reduce impacts to threatened and endangered species; reduce spread of NNIS, pests, and pathogens; reduce soil disturbance, erosion, and compaction; and contain potential pollutants. Emergency fuelbreaks may be cut during fire incidents; in these situations, there is little time to plan for resource protection, but resource managers will work with fire personnel to choose locations and methods to protect sensitive habitat and species.

There is a lack of research on ecological impacts related to various types of fuelbreaks. Additional research is needed to answer key questions about where and how to construct fuelbreaks to minimize risks to natural systems while reducing wildfire risk to communities.

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BIOMASS MANAGEMENT TREATMENT DESCRIPTION

Thinning in fire-suppressed forests is an increasingly common practice to reduce wildfire risk, increase stand diversity, and reduce density-dependent stand mortality. Thinning or mastication treatments produce residual woody materials such as logs, chips, and sawdust, referred to generally as biomass. As active forest management increases, more biomass will be produced. Rather than treat biomass as a waste, it can be viewed as a resource to be utilized for carbon sequestration, producing soil amendments, generating heat and power, and creating wood products.

Biomass management and utilization benefits vary by approach, machinery used, site and access, proximity to infrastructure, and forest type . Leaving biomass scattered on-site and pile burning are the most cost-effective and low-impact methods from forest health and disturbance perspectives. However, leaving large amounts of biomass on a site can produce excessive accumulation, including short-term increases in surface fuel loads, and timing for pile burning can be complicated by dry winter weather and poor air quality. On the other hand, hauling biomass off-site can be costly, and there are currently few options for local utilization. This problem may be surmounted by converting biomass on-site, such as creating biochar. Finding the best balance between maximizing forest health, reducing emissions, and maintaining feasible treatment costs will benefit from quantification and careful consideration by land managers.

This treatment description offers considerations for managing biomass being generated by forest health and resilience improvement treatments in appropriate forest stands in Marin County. This treatment description does not intend to support creation of timber production/harvest or forest resource extraction in order to generate biomass. This treatment description reviews a variety of on-site and off-site approaches to managing and utilizing biomass, benefits and constraints of these approaches, and resource protection practices to consider when planning forest treatments.

BACKGROUND

Organizations and agencies in Marin County have been working on improving processes and increasing capacity for managing biowaste. Goals include reducing carbon emissions and landfill waste and finding ways to utilize biowaste locally. These efforts received significant support with funding of the Marin Biomass Project.

The Marin Biomass Project is one of five pilot projects selected in 2021 by the Governor's Office of Planning and Research (OPR) to identify solutions that overcome barriers to biomass feedstock utilization (Marin Resource Conservation District (RCD), n.d.). The Project is designed to foster cooperation among stakeholders in biomass utilization, particularly the public authorities who oversee and the private organizations that manage biomass management infrastructure and processes. The Marin Biomass Project was developed in response to increasing flows of biomass materials generated by wildfire prevention activities and landfill diversion efforts in Marin County. Materials range from woody biomass generated by woodland thinning and landscape trimmings to source-separated and mixed organic streams generated by collecting metropolitan wood debris, food scraps, yard materials, and agricultural biomass. The Marin Biomass Project includes a Biomass Utilization Study to assess biomass flows and opportunities for utilization in Marin. The Project, which began in 2022, will provide important information for determining methods to utilize biomass, transforming it from a waste product to a useful resource.

DESCRIPTION

Forest biomass is surplus material generated in forested areas as a byproduct of forest health and fuel reduction projects and includes wood chips, small-diameter trees, and dead trees and vegetation not retained for habitat (Sierra Business Council, 2019). As forest health and fuel reduction projects are increasingly funded and implemented throughout California, the amount of surplus biomass will increase. Biomass management, a critical component of forest health projects, balances the benefits and costs of managing biomass on-site or removing it from the site.

Biomass utilization recognizes biomass as a resource rather than a waste product, and uses residual solid material generated by agricultural or forestry activities to create value-added products, such as bioenergy and wood products (Sierra Business Council, 2019). Bioenergy is considered a key step to decarbonization and part of a diverse energy portfolio in the transition to clean and renewable energy sources (Clack et al., 2017). Another opportunity is to utilize woody biomass for construction materials and reduce dependence on conventional materials such as concrete and steel. For example, small-diameter trees can be used to produce engineered wood or mass timber building products which can be used for structural elements in place of steel or concrete (Winandy & Kamke, 2004; APA-The Engineered Wood Association, 2022). Other opportunities for biomass utilization are described below.

BIOMASS MANAGEMENT& UTILIZATION APPROACHES

Biomass management and utilization methods can generally be classified into two categories: on-site approaches such as mastication, mulching, chipping, or pile burning, or removal off-site for use as bioenergy, biochar, compost, or other wood products. In addition, new innovations in biomass management now allow bioenergy and biochar to be created near to, or even within, the forest setting. For example, portable kilns allow biochar to be created on site. Managers now have a wide array of options to consider in determining how best to balance forest health, carbon emissions, and costs for biomass management. Managers will need to consider impacts of leaving biomass materials on site, such as increased fire risk and suppression of undergrowth, and compare them to the costs and potential uses of biomass processed on site, or removed from site, in determining the best approach. Site-specific approaches and solutions will need to be developed which account for differing site access, stand structures, and species.

MarinCAN, a Marin County organization focused on climate change (formerly Drawdown: Marin) and Marin Wildfire Prevention Authority (MWPA) Ecologically Sound Practices Partnership (ESP Partnership) Carbon Resource Management Workgroup have proposed methods for managing biomass and lowering carbon emissions. The ESP Partnership outlined vegetation management guidelines accepted by the MWPA Board in June 2022, which included a series of recommended carbon management best practices designed to reduce greenhouse gas emissions and increase sequestration (ESP 2022 pp. 10-14).

BIOMASS MANAGEMENT ON-SITE

There are several approaches for managing biomass on-site, whether created through manual or mechanical treatments. If retained on-site, material can be lopped and scattered, masticated, chipped and dispersed, or piled on-site for later burning. Prescribed grazing is another option for managing biomass on-site, however appropriateness would need to be determined on a site-by-site basis. The range of biomass management options is often constrained by treatment logistics such as access, slope, budget, and schedule.

Mastication and lopping and scattering are typically recommended as cost-effective biomass management methods. In addition, biomass retained on site can be a resource: cut vegetation can be used as a mulch to suppress weeds, retain soil moisture, and/or help control surface erosion (Jacobson & Dicus, 2006). However, biomass left on site could also suppress native species; studies show the depth of biomass retained on the forest floor is important, and effects vary by forest type (Fornwalt et al., 2017; Wolk & Rocca, 2009).

Biomass left on site can potentially increase surface fuels and fire risks (Cram et al., 2006). To lessen fire risks, biomass should be in contact with soil to promote decomposition and reduce air flow in case of a fire. Material can be scattered discontinuously to create breaks in surface fuels. Jain et al. (2018) recommend leaving some material as downed logs rather than masticating or chipping to provide habitat and not contribute to fine surface fuels. Similarly, some cut materials can be left in larger pieces to reduce fine fuels.

Many Marin land managers currently manage biomass on site. For example, for treatments performed under the *Biodiversity, Fire, and Fuels Integrated Plan* (*BFFIP*), Marin Water often uses a combination of manual vegetation management followed by creation of piles staged for later burning, coupled with mechanical treatments using equipment to masticate material in place where feasible (Marin Water, 2019a). In some cases, material can be staged for later off-haul or chipped directly into a truck, but this requires nearby road access and can add significantly to project cost.

The California Department of Forestry and Fire Protection (CAL FIRE) *Fuels Reduction Guide* provides descriptions and pictures of many of the biomass management practices and equipment described below (CAL FIRE, 2021).

Lopping & Scattering

Lopping and scattering is a cost-effective biomass management approach, especially in remote or topographically challenging sites. This approach is used in manual thinning treatments in which vegetation is cut with hand tools. The approach has scale limitations due to the need for crews to conduct the lopping and scattering. However, this approach can be useful in sensitive resource areas where equipment could damage resources and hand crews can work more carefully.

Mastication & Chipping

Also referred to as mulching or chipping, mastication treatments involve machine processing of vegetation from thinning projects and grinding, shredding, or chopping it into small chips (Jain et al., 2018). In most mastication projects, the materials are left on site as mulch or ground cover. In some cases, such as drier sites with significant materials produced and high fire risk, the biomass can be piled and burned to avoid excessive fuel accumulation.

As a general rule, mechanized treatment such as mastication is undertaken on slopes less than or equal to 35%, but operability depends on access, the specific equipment, soil type, moisture levels, precipitation, topography, and safety factors (North et al. 2015). For example, rocky ground wears out masticator head teeth more quickly, makes head control difficult, may result in unevenly processed biomass, and poses a fire hazard from errant sparks (U.S. Forest Service Equipment Catalog, n.d.).

There are many types of mastication machine options and combinations available. The U.S. Forest Service *Understory Biomass Reduction Methods and Equipment Catalog* details approximately 118 machines and equipment used for thinning and biomass operations (Windell & Bradshaw, 2000). In *To Masticate or Not: Useful Tips for Treating Forest, Woodland, and Shrubland Vegetation* Jain et al. (2018) counted 79 tracked and 30 wheeled carrier machines used in mastication operations from one guide alone. Jain et al.'s report is one of the more useful resources for mastication equipment and practices with photos, costs, and management considerations, albeit from a more silvicultural perspective (Jain et al., 2018).

The size of cut vegetation created, or chip size, can vary by individual machine or across machines. Specifying the largest acceptable resulting fuel size when planning a mulching operation is critical to managing fuel loads, reducing impacts on understory vegetation, and controlling costs. For example, Marin Water recommends chips of size 2-4 inches when working in Douglas-fir forest and oak woodlands, and specifies chip depths of no more than 6 inches when working with a stationary chipper.

According to Fight and Barbour (2004), key items to consider that affect the cost of mastication include:

- **Volume treated**. Leave 3 inch and larger stems to provide coarse woody debris, do not use mulchers as felling machines, do not exceed 25 tons per acre, and specify the largest acceptable resulting fuel size.
- **Travel**. Avoid treating areas less than 66 feet in width, operations in dense stands of greater than 100 trees per acre, steep slopes of greater than 35 degrees, and broken terrain.
- **Access**. Provide adequate access for operations, fueling, cleaning, and maintenance.

Pile Burning

Pile burning is another common method to manage biomass on-site. This method reduces fire risks from surface fuels remaining on site and may provide better conditions for understory vegetation. However, using fire may not be feasible in some locations or during dry years, and smoke may be a concern.

Pile burning can be used with either manual or mechanical thinning treatments. Hand-cutting and creating piles can be used on steeper slopes that prohibit machinery due to mechanical, safety, or cost limitations. In more accessible locations, a tracked machine, such as a feller-buncher, may be used to cut or pile trees with equipment sized to the operation.

Piles are usually allowed to season over time and are then burned when conditions allow, e.g., when surrounding fuel moisture is too high to carry a ground fire away from the pile. Pile burning is a relatively low risk method of biomass treatment since the burn location can be controlled and fire escape risk is minimal (De Lasaux & Kocher, 2006).

According to Marin Water's *Biodiversity, Fire, and Fuels Integrated Plan* (*BFFI*P), piles vary in size, but can be up to 10 feet in diameter by 6 feet high, and pile burning should occur between November and May when conditions meet the Bay Area Air Quality Management District (BAAQMD) permit (Marin Water, 2019a, p.6-20). Piles should be located away from tree canopies, overhead power lines, and infrastructure to avoid risks during burning. Figure 9.17 shows a thinning treatment at the Pilot Knob area on Marin Water lands; the before photo shows dense understory vegetation, including vegetation impacted by sudden oak death (SOD). The after-photo shows cut material which has been gathered into piles for burning.

One downside of pile burning is that it emits relatively significant amounts of carbon monoxide, carbon dioxide, and particulate matter, 2.5 times more than a biomass facility (Sierra Business Council, 2019). Air curtain burners may be a way to reduce emissions on-site and produce biochar that can help with carbon sequestration (Lee & Han, 2017). There is an additional cost of using air curtain burners as well as considerations for access, both of which vary by type of machine used. However, they have the advantage of greater fire control and significant reduction of emissions (Lee & Han, 2017).

Figure 9.17 Pilot Knob project area. Top, pre-treatment. Bottom, post-treatment: cut material has been piled for later burning. Photo from Loren Jenkins, Project Coordinator, Marin Water.

BIOMASS MANAGEMENT OFF-SITE

This section describes biomass management approaches which typically involve removing biomass from the treatment area. However, as biomass management becomes increasingly critical, new tools and equipment are being developed to manage biomass at different scales and in closer proximity to treatment areas. For example, portable bioenergy processing facilities can be set up near forest treatment areas and air curtain burners and portable kilns can create biochar on site.

For biomass utilized to create a beneficial product, creating soil additives and amendments such as mulch or biochar, or firewood production, require the least amount of processing and cost to produce. Creating fuel for bioenergy plants requires only slightly more processing. Creating wood products such as lumber, particleboard, laminated veneer lumber, and oriented-strand board require more infrastructure, processing, and capacity to produce (Woody Biomass Utilization Group, n.d.a.).

Limited or unreliable feedstock supply is one of the primary constraints for wood utilization in California. In the fall of 2021, the OPR funded five pilot projects to assist in addressing feedstock supply issues throughout the state (Kollars, 2022). Through aggregation mechanisms and organizational innovation, pilot projects will develop regional strategies to establish reliable access to woody feedstock. The Marin Biomass Project was selected as a pilot and will assist public and private sector entities in collaborating on long-term, ecologically sounds solutions for managing biomass produced throughout Marin and developing value-added products to support the local economy. The funded Biomass Utilization Study is the first step in facilitating the emerging biomass utilization economy in Marin and will evaluate biomass sources across Marin County (Marin RCD, n.d.). The Study is one of seven local climate change solutions endorsed by MarinCAN (County of Marin, 2020). In addition, MarinCAN has contributed funds to support the Marin Biomass Project (MarinCAN, n.d.)

Led by the Marin Biomass Project Steering Committee, outcomes of the Biomass Utilization Study will include biomass feedstock amounts, identification of utilization pathways, economic analysis, carbon analysis, and recommended pathways, practices, and infrastructure for Marin. Development of a Marin Biomass Collaborative is underway to support implementation of Study recommendations (Marin RCD, n.d.).

Bioenergy

Bioenergy is electricity, fuel, or heat generated from converting food, yard, dairy, agricultural, wastewater, forest, or wood waste into energy through one of several conversion technologies (Bioenergy Association of California, 2014).Many technologies are available, including thermal conversion, pyrolysis, gasification, anaerobic decomposition, and direct firing plants (Sierra Business Council, 2019). Gasification converts biomass at high temperatures into gases such as hydrogen and anaerobic digestion produces methane. Both hydrogen and methane are considered renewable energy sources. Springsteen et al. (2011) found that converting biomass to energy using a conventional boiler is less carbon-intensive than the emissions generated by a wildfire or pile burning and reduces regulated pollutants such as particulate matter emissions by 98%, nitrogen oxides by 54%, carbon monoxide by 97%, and carbon dioxide equivalent by 17% compared to open pile burning. With more sophisticated systems, such as pyrolysis or gasification, the differences in emissions could be even greater.

Biomass generated from forest treatments can be converted to bioenergy, however this requires treatments to be adjacent to roads with good access. Thinned, masticated, or chipped material is removed from the site and transported to a biomass or bioenergy facility to process. The closest biomass facility to Marin County is Woodland Biomass Power in Woodland, CA, approximately 92 miles northeast of Olema, and Stockton Biomass Power in Stockton, CA, both run by DTE Energy (UCCE, 2021). Appropriate agricultural and forest biomass from Marin is currently trucked to the DTE biomass power plant in Stockton, more than 100 miles from Olema. Since a 30-mile radius from a forest to a bioenergy site is the marker for transportation cost feasibility, portable or modular systems could be considered (Northern Sonoma County Air Pollution Control District, 2021; Stewart et al., 2011).

Biochar

Biochar is the term used for a wide variety of carbonized biomass; it is produced by heating biomass in a low-oxygen environment (Sonoma Biochar Initiative, 2022). Biochar is created as a byproduct of bioenergy production or from burning biomass in controlled settings. Biochar is most commonly used as a soil amendment which also sequesters carbon in the soil (Sonoma Biochar Initiative, 2022). Research has shown that biochar has good negative emissions potential, though there are saturation limits to consider (Smith, 2016).

Biomass from forest treatments can be used to produce biochar, but large-scale production of biochar requires hauling materials to distant bioenergy processing plants. Biochar can also be produced at portable bioenergy production facilities, or produced on-site within an air curtain burner or portable kiln (Sonoma Ecology Center, 2020). Air curtain burners and flame-cap kilns reduce emissions, increase carbon sequestration through biochar production, and provide an in-situ alternative to pile burning (Lee & Han, 2017).

The Sonoma Ecology Center, with the North Coast Resource Partnership, recently completed a biochar production demonstration project using portable kilns (North Coast Resource Partnership, 2022). Sonoma Ecology Center prepared a storymap which illustrates how portable kilns can reduce carbon emissions from hazardous fuel reduction projects in the North Coast Region (Sonoma Ecology Center, 2022). The project tested using mobile flam-cap kilns to process slash material in a forestry setting. Lessons from the project include that they were able to successfully create biochar and have high levels of carbon storage, permitting difficulties may be a limiting factor for widespread use, and using portable kilns to convert biomass to biochar can be time and labor intensive. Nonetheless, they conclude that fuel reduction projects should be paired with biochar production where feasible to reduce carbon emissions.

Green Waste

Composting green waste may be another viable alternative for biomass management, particularly for smaller projects that produce biomass from invasive species removal or tree removal, provided road access is adjacent to the work area. Biomass can be removed from site and taken to a green waste or landfill facility. Some green wastes are chipped, composted, and then used as a soil amendment.

Wood Products & Firewood

Small-diameter trees can be used for dimensional lumber, engineered wood products, furniture, and firewood. Another important utilization pathway is chipping wood to create mulches for livestock and landscaping. The use of engineered or mass timber is being promoted to California architects and businesses as a sustainable construction alternative. For example, California's Mass Timber Competition challenged architects to use engineered timber and reduce the use of steel and concrete in construction (California Government Operations Agency, 2018). The Sonoma County Biomass Business Competition, or BioBiz, works to spur local small business innovation to create high-value wood products from biomass and help maintain healthy forest ecosystems (Northern Sonoma County Air Pollution District, n.d.). The CAL FIRE Wood Products and Bioenergy Team awards Workforce and Business Development Grant funds to organizations, agencies, and businesses improving the wood product industry across California (CAL FIRE, 2022).

There are not any mills close to Marin County, which can make processing wood products more challenging. According to the Wood Facility Database, the closest operating sawmills to Marin County are Big Creek Sawmill, about 90 miles south of Olema; Redwood Empire, about 70 miles north of Olema; and Berry's Sawmill, about 44 miles north (Woody Biomass Utilization Group, n.d.b.). A small mill in Marin could be instrumental in creating quality wood products which put cut wood materials to good use, sequester carbon, and provide local jobs. A nearby example of such a mill is the one run by A-Plus Tree Care on Mare Island which repurposes trees removed during urban tree care into furniture, including this large coast live oak (*Quercus agrifolia*) from Marin.

Given the high mortality of tanoak (*Notholithocarpus densiflorus*) due to sudden oak death (SOD), finding beneficial uses for woody biomass from large trees is of interest. For example, there have been proposals to process dead tanoak trees for lumber (Shelly, 2001), however much of the biomass generated by SOD-affected tanoaks are small diameter resprouts which would not be suitable for this use. Tanoak's common name comes from its high tannin content, which made it valuable for use in the leather tanning industry. However, the high tannin content of tanoak creates challenges in drying the wood for lumber (Evans, 2012; Niemiec, 1995; Shelly, 2001). Yet, others note that tanoak can be used in the same ways as other hardwoods, such as for furniture, flooring, and wood chips, if the correct milling and drying processes are used (Bowcutt, 2014; Niemiec, 1995).

Woody biomass can also be used as firewood. Local firewood production and use can reduce the problem of new pests and pathogens being transported in firewood bundles from other locations (California Firewood Task Force, 2017). In fact, in California firewood cannot be moved more than 50 miles to protect California forests from pests, making local sources of firewood important (Bokach et al., 2010). The Dead Tree Utilization Assessment completed for the Tree Mortality Task Force by The Beck Group identified firewood as a high-scoring opportunity to utilize biomass due to low capital costs, quick startup time, and mobility of required machinery (The Beck Group, 2017). The low volume of wood needed for a firewood operation could also be attractive given the size of thinning projects in the region. However, a significant downside to firewood use is emissions of carbon monoxide, particulate matter, and other harmful toxins during burning (U.S. EPA, n.d.).

NON-NATIVE INVASIVE SPECIES REMOVAL

Non-native invasive species (NNIS) removal generates considerable amounts of biomass which can be managed on site or off-site, as with biomass from forest treatments. For example, Marin Water either piles or scatters broom slash depending on site conditions. These piles typically decompose quickly and do not need to be burned. Depending on access, time, budget, and type of material, NNIS biomass can also be removed from site and composted. Generally, removal from site is only utilized when NNIS seed germination is a concern.

Removal methods for non-native trees, such as eucalyptus (*Eucalytpus spp*.), include lop and scatter (small material only), chipping, and removal to a landfill. Trees could be left in place in remote areas where native vegetation will not be adversely impacted. In front-country park settings, removed trees may be chipped and scattered, or wood chips may be used for landscaping or on-site mulch. Appropriate removed trees can also be used as in-channel woody debris for stream and floodplain restoration projects.

Eucalyptus wood can be used for some woodworking and furniture, but generally, it is not favored since it is heavy and cracks if not seasoned correctly or when using common milling practices of sawing lengthwise. Using an alternative cutting process in which seasoned logs are sawn radially there were no signs of cracking, but this sawing method is not economical (Kalshian, 1994). In the United States, eucalyptus is often used to make posts and poles. Eucalyptus is an excellent source of fuelwood, leaving little ash and producing good charcoal, and could be an addition to biochar and bioenergy wood fuel streams (Nati, 2021; Rockwood et al., 2020).

ADDITIONAL RESOURCES

California Biomass Collaborative

The California Biomass Collaborative is a statewide collaboration of government, industry, environmental groups, and educational institutions administered for the state by the University of California, Davis. It works to improve the sustainable management of biomass for production of renewable energy, biofuels, and wood products.

California’s Statewide Wood Energy Team

The California Statewide Wood Energy Team (SWET) works with wood energy businesses and community-led wood energy projects throughout the state providing technical assistance and grants.

CAL FIRE Wood Products and Bioenergy

CAL FIRE’s Wood Products and Bioenergy program focuses on the forest-sector workforce in California to promote healthy resilient forests by supporting business and workforce development projects.

MarinCAN,
MarinCan is a community-driven campaign to dramatically reduce greenhouse gas emissions, prepare for climate change impacts, and meaningfully address and integrate equity throughout Marin County. MarinCAN works with Marin County residents, businesses, organizations, agencies, and local governments to design and implement climate change solutions in six focus areas: renewable energy, transportation, buildings and infrastructure, local food and food waste, carbon sequestration, and climate resilient communities.

Marin Carbon Project
The Marin Carbon Project works with Marin landowners to support carbon farming, to sequester carbon and increase agricultural productivity. The use of compost is a key element of carbon farming plans, and biomass from forest treatments could contribute to locally produced compost.

Waste to Wisdom
Humboldt State University's Waste to Wisdom Biomass Research initiative examines feasible biomass facility deployment to convert biomass into bioenergy and bioproducts while exploring the environmental sustainability of each method.

Woody Biomass Utilization Group
The Woody Biomass Utilization Group is part of the University of California Division of Agriculture and Natural Resources. It is a collaborative which provides science, technical assistance, and funding information related to biomass use in California.

BENEFITS & CONSTRAINTS

Biomass can be retained on-site or removed, and there are benefits and constraints for each approach. Leaving materials on site has the advantage of low overall costs since it eliminates transport, and it also reduces emissions from transportation. Potential disadvantages of leaving biomass on-site include temporary surface fuel loading, potential suppression of desired native plants, and slow decomposition (especially in dry conditions). However, these concerns can be mitigated by careful selection of biomass size and placement, or by burning biomass. Gathering biomass into piles for burning reduces surface fuels and potential fire hazard.

Biomass removed from a site can be used for bioenergy, lumber, firewood, mulch or composted and used to improve soil, however options for off-haul may be limited and not feasible in many areas due to access constraints. Biomass off-haul increases costs and greenhouse gas emissions for transportation and processing off-site, can potentially increase soil compaction on-site, and depending on the amount and type of material removed, could alter soil carbon and nutrient levels by removing biological materials from the ecosystem (Stewart et al., 2011). From a cost feasibility standpoint, the recommended economic radius from site to processing facility is 30 miles (Stewart et al., 2011, p.27); currently, Marin County does not have the infrastructure available for this route to be feasible.

Additional benefits and constraints of biomass management approaches are summarized in Table 9.9.

Table 9.9. Summary of the benefits and constraints of biomass management options. From Brack, 2017; Cram et al., 2006; De Lasaux & Kocher, 2006; Janowiak et al., 2017; Springsteen et al. 2011; Stewart et al., 2011.

Benefits	Constraints
Mastication • Cost-efficient biomass disposal. • Avoids carbon emissions from off-haul. • Could host desirable organisms that break down chips and return nutrients to the soil over time. • The compacted nature of masticated fuel beds may reduce the rate of fire spread, flame length, and fireline intensity (Kane et al., 2009).	• Buildup of materials could potentially suppress native understory regeneration. • May temporarily increase surface fuels. • Produces some CO_2 emissions. • Alters physical properties of fuels (greater surface area/volume), potentially increasing combustibility and consumability on some sites (Kane et al., 2009).
Pile and burn • Efficient and cost-effective manner of managing biomass. • Safer than broadcast burning and allows control of burn location. • Nutrients released to soil/vegetation. • May encourage regeneration and native plant recruitment for some species/sites.	• Carbon emissions. • Smoke emissions. • Permitting requirements. • Limited burn windows. • Requires fire suppression/control resources.
Bioenergy • Lower emissions compared to the pile and burn approach. • Energy is generated on demand. • Greenhouse gas (GHG) emissions low when the plant is local. • Renewable energy source. • Biochar improves soil health and increases carbon sequestration.	• Requires road access to facilitate off-haul. • Transportation costs and carbon emissions. • No local biomass facilities. • High perceived cost/kilowatt-hour. • Difficult to permit and operate given state power purchase agreements and electricity pricing. • May not be carbon neutral.

Portable mill • Carbon sequestration. • Local wood products, supports economy. • Mill large woody materials on-site; reduces emissions from transporting materials elsewhere.	• Requires access to facilitate. • Processing costs may be expensive compared to chipping or mastication.
Firewood • Removes larger woody materials and avoids chipping them. • Local product, supports economy.	• Air quality concerns from burning. • Can act as pest and pathogen vectors if transported elsewhere.

BIOENERGY & GREENHOUSE GAS EMISSIONS

There is significant interest in using woody biomass as a fuel to create energy and heat, and to reduce emissions from pile burning (Forest Climate Action Team, 2018). Due to the complexity of forest ecosystems, there is considerable debate on whether bioenergy is beneficial compared to fossil fuels (Favero et al., 2020; IEA Bioenergy, 2019; Searchinger et al., 2009; Zanchi et al., 2012). The Chatham House report *Woody Biomass for Power and Heat* (Brack, 2017) succinctly outlines several key drawbacks to woody biomass utilization for power and heat, noting:

> For its supporters, it represents a relatively cheap and flexible way of supplying renewable energy, with benefits to the global climate and to forest industries. To its critics, it can release more greenhouse gas emissions into the atmosphere than the fossil fuels it replaces, and threatens the maintenance of natural forests and the biodiversity that depends on them. (Brack, 2017, p.2)

Bioenergy proponents argue that burning fossil fuels releases carbon locked up in the ground for millions of years and increases the amount of carbon in the atmosphere. In contrast, biomass burns biogenic carbon dioxide already cycling within the biosphere. Opponents to this notion argue that bioenergy still releases carbon into the atmosphere that may or may not be absorbed by future tree growth (Favero et al., 2020). But assessing whether biomass energy is carbon neutral can be complex. For example, a Buchholz et al. (2016) meta-analysis showed that the carbon payback period[1] in carbon accounting for bioenergy projects ranged from 0 to over 1,000 years.

A study by Springsteen et al. (2011) compared emission reductions from pile burning to bioenergy production in a biomass boiler. In this study, open pile burning produced 13,717 metric tons of carbon dioxide vs. 11,402 metric tons from the biomass boiler, or a 17% emissions reduction. The biomass boiler project included processing and transport of the

[1] The time required by the forest to recover equivalent amounts of carbon through sequestration compared to carbon emissions due to biomass combusted for energy.

biomass as part of the emissions calculations (Springsteen et al., 2011). Study results are from mixed conifer forest slash in the Sierra Nevada Foothills. Bioenergy generation facilities are able to reduce air pollution and emissions using pollution capture devices (Sierra Business Council, 2019). Protocols for comparing emissions from bioenergy, pile burning, and decomposition of masticated material can be useful tools to more fully understand the benefits and constraints of biomass management approaches (Placer County Air Pollution Control District, 2013).

FEEDSTOCK PIPELINE

A major constraint for biomass management from forest health, restoration, and other vegetation management activities is ensuring a steady supply of feedstock for processing. The Governor's Office of Planning and Research funded five pilot projects to address biomass feedstock barriers, one of which was awarded to the Marin Biomass Project (Marin Resource Conservation District (RCD), n.d.). The Marin Biomass Utilization Study, being completed as part of the Project, will cover urban, woodland, agricultural, and open space lands of the County, focusing on practices and infrastructure that can utilize woody biomass and organic materials from the built environment or agriculture.

RESOURCE PROTECTION

Best management practices (BMPs) related to biomass management generally focus on fire risk reduction, protecting wildlife and soil, and reducing air pollution. For example, biomass should be processed to reduce ignition risk by chipping material and laying it flat. Piles size should be limited, and piles spaced to reduce impacts during burning. Burn windows for pile burning is limited to reduce risk of fire spreading and impacts to nesting birds and air quality. Removal of biomass from the site requires more advanced planning, including a waste management plan that describes how materials will be utilized or disposed of off-site.

There are many factors to consider in moving biomass between sites or out of a project area. Removal of biomass from a site may have restrictions, a need for permits, or other compliance regulations. When moving biomass, managers should plan to mitigate the spread of invasive species, pests and pathogens, limit disruptions to birds and other animals that may use slash and thinning piles, protect soil and water quality when bringing equipment on-site, and follow BMPs for discharge or pollution prevention.

BMPs for resource protection are presented in a variety of compliance documents. The *California Vegetation Treatment Program* (Cal VTP) Mitigation Monitoring and Reporting Program has a thorough list of BMPs (California Board of Forestry and Fire Protection, 2019). These BMPs must be followed for projects completing compliance under the *Cal VTP Programmatic Environmental Impact Report* (EIR). Agencies may be working under compliance documentation particular to their jurisdiction which includes specific BMPs. For example, Marin Water's *BFFIP EIR* includes a Mitigation, Monitoring, and Reporting Program with resource protection BMPs (Marin Water, 2019b) and the Golden Gate National Recreation Area (GGNRA) *Fire Management Plan Environmental Impact Statement* (FMP EIS) includes BMPs as part of the General FMP Mitigation Measures included in the Record of Decision (ROD) (GGNRA, 2006). In addition, the MWPA worked with the ESP Partnership to develop BMPs to be used by the MWPA for fire management actions in Marin County. The *Ecologically Sound Practices for Vegetation Management* document compiles BMPs from a variety of sources (ESP Partnership, 2022).

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CHAPTER 10: MONITORING

This chapter outlines recommended field-based and geospatial monitoring approaches for forest resiliency treatments and change detection over time. The primary audience for monitoring information is the One Tam agencies, with secondary audiences including the Marin Wildfire Prevention Authority (MWPA), donors/funders of forest health projects, and the public. The purpose of the chapter is to describe the rationale for forest health monitoring, differentiate monitoring approaches and methodologies, demonstrate how monitoring can guide successful forest health treatments in the field, and provide monitoring recommendations for the One Tam agencies.

RATIONALE

Conceptual models outline a common understanding of how systems work; testing assumptions inherent in the project's conceptual models and collecting monitoring data for better-informed management decisions are critical components of project success. No project manager should assume that all restoration activities will be completely effective, and results may vary from those predicted at the project outset. Allowing for analysis, interpretation, and learning from project planning, implementation, and monitoring are critical, often ignored, components of the project cycle and adaptive management in general.

Data to evaluate management actions is not always available, however. The lack of consistent landscape and county data on past fuels reduction and forest resiliency treatments makes it difficult to assess their efficacy and impact over time. Managers should look for opportunities to leverage the baseline conditions established by the 2018 Marin Countywide Fine Scale Vegetation Map (2018 Fine Scale Vegetation Map, Golden Gate National Parks Conservancy et al., 2021) and the *Marin Regional Forest Health Strategy* (*Forest Health Strategy*) in their ongoing land management activities. Quantifying the impacts of treatments can be difficult, especially with many confounding factors interacting in each ecosystem. Treatments can be expensive financially; therefore, collecting data on their effectiveness is vital for ensuring long-term conservation impact and cost-efficiency. Collecting data over long periods is effective in quantifying ecosystem services and responding to uncertainty (Phillips & McGee, 2016).

MONITORING APPROACHES

Monitoring is the collection and analysis of repeated measurements to evaluate changes in conditions toward meeting conservation management objectives (Elzinga et al., 2001). Two approaches to natural resource management include trial-and-error and adaptive management. Trial-and-error is the process of experimenting with various treatments until finding the most successful method. Trial-and-error is not necessarily adaptive, but it is possibly one of the most frequently employed types of natural resource management. However, it is heavily fraught with cause-and-effect assumptions about interventions, lack of data over time, and high costs.

Adaptive management is a systematic approach for improving resource management decision-making by learning from doing, altering activities to reflect new information, and embracing uncertainty (Walters & Holling, 1990). Through this approach, management becomes a partner with science by designing questions that produce updated understanding and improved conservation outcomes. Limitations of adaptive management include lack of spatial scale and replication, time-treatment interactions, delays, sensitivity, and allowing experiments to fail (Walters & Holling, 1990; Walters et al., 1988). Cost, capacity, and time constraints are additional limitations.

Walters (1986) notes there are three ways to structure natural resource management as an adaptive process: trial-and-error, where initial approaches are haphazard then lead to improved approaches and outcomes; passive, where historical data construct the best management model; and active, where available data helps structure a range of alternative management models and a policy choice for implementation to help weigh short-term and long-term outcomes. Active adaptive management is considered the most robust of the three processes.

The *Forest Health Strategy* follows widely accepted management principles from the Conservation Measures Partnership. Having developed conceptual models, results chains, and metrics for each key forest type, the One Tam collaborative conducted a conditions assessment of each forest type and developed criteria for identifying priority treatment areas. The *Forest Health Strategy* generated a large amount of baseline data. Regular analysis, interpretation, and learning from these data will be critical for future forest health work in the County. Where possible, the *Forest Health Strategy* recommends that project partners collectively analyze results, learn from them to inform the design and scope of future forest health work, and communicate lessons with wider audiences. This should include partnership with the Tribe for cultural monitoring of Tribally defined metrics to assess project outcomes and landscape changes in the context of Tribal perspectives and values, and to create space for the Tribe to include Traditional Ecological Knowledge into adaptive management approaches.

FOREST HEALTH MONITORING METHODS

The *Forest Health Strategy* recommends that ongoing monitoring be prioritized to study changes in forest health (using forest health metrics) on the landscape level over time, as well as implementing project-specific monitoring for forest health treatment areas. As much as is feasible, forest health monitoring methods should be standardized across agencies and collected over long-term periods, and data/results shared across partners to support regular analysis and learning. Methods should be accurate, reliable, cost-effective, feasible, and appropriate.

EXISTING MONITORING PROGRAMS

Existing monitoring programs can be leveraged to support future forest health assessments and contribute to a broader Marin-wide understanding of forest conditions and changes over time.

COMPLIANCE MONITORING

Compliance monitoring generally refers to regulatory obligations such as those set out in NEPA and CEQA documents but also includes monitoring required by permits issued by regulatory agencies. Marin Water's *Biodiversity, Fire, and Fuels Integrated Plan* (Marin Water, 2019) and the Golden Gate National Recreation Area's *Fire Management Plan* (FMP; GGNRA, 2005) have examples of monitoring protocols and indicators associated with NEPA/CEQA documents. In many cases, the data generated from these efforts can inform future forest health assessments and help quantify the impacts and benefits of forest management. More details related to compliance can be found in Appendix C: Regulatory Compliance.

ENDANGERED, RARE, & PROTECTED SPECIES MONITORING

Numerous programs exist at federal and state agencies for tracking the presence and distribution of species of concern. Cross-jurisdiction and agency-specific monitoring for rare, protected, and endangered species is coordinated internally by land managing agencies, augmented by efforts of organizations such as the California Native Plant Society (CNPS), and supported by databases such as the California Department of Fish and Wildlife's California Natural Diversity Database and Calflora. Rare and sensitive species can be good indicators or overall ecosystem health, and this type of monitoring could be used to understand how forest health treatments impact sensitive species.

RESEARCHERS & ACADEMIC INSTITUTIONS

Researchers can play a vital role in helping managers assess forest health resiliency and the impacts of climate change, particularly to address unanswered ecological questions and test monitoring methods. Academic research, however, is usually not suited to practitioner-based monitoring owing to the more extended time frames of research projects or lack of congruence between research and monitoring goals. However, there may be opportunities to invest in longer-term research to answer key questions. Please see Appendix E: Opportunities for Additional Study for identified information gaps.

COMMUNITY-DRIVEN MONITORING & BIOBLITZES

Community science, or citizen science, is an excellent way to involve the public in conservation efforts and demystify science. The quality of community science crowdsourced data is increasing. For example, ebird.org hosts large datasets generated by community scientists, helping to advance ornithological science. Bioblitzes such as the SOD Blitz Project are helping managers gain a better understanding of disease distribution and spread. The California Academy of Sciences has a Citizen Science Toolkit designed to integrate science into classroom curricula and also runs iNaturalist with the National Geographic Society, which allows naturalists to record observations, share with fellow naturalists, and discuss findings. The iNaturalist application (app) can suggest species identifications using artificial intelligence, which when combined with other users' input, can facilitate accurate species identification. The app contributes to biodiversity science by increasing records to help scientists and resource managers understand where species occur.

In Marin County, many community science efforts are driven by One Tam programs and partnerships with other organizations. An example is the 2014 BioBlitz completed in the GGNRA in partnership with iNaturalist. Current community science efforts through One Tam, such as the Tamalpais Bee Lab and Marin Wildlife Watch, and other local programs such as California Academy of Sciences' City Nature Challenge, are just a few examples of how community members continue to contribute to ecological knowledge in Marin. Managers in Marin should continue to seek opportunities to work with community science efforts to fill in knowledge gaps, increase scientific understanding, and connect community members to the natural landscape.

Community-driven monitoring can also be helpful for monitoring changing conditions after a fire. In Point Reyes National Seashore, the Point Reyes National Seashore Association and National Park Service are working with Chronolog to complete photo-monitoring at 5 sites affected by the 2020 Woodward Fire. Photos taken by citizen scientists and posted to Chronolog will help track vegetation growth and habitat recovery (Chronolog, n.d.).

POST-WILDFIRE & PRESCRIBED FIRE MONITORING

Due to the high number of forestland acres in California and Marin County, understanding the landscape processes and conditions that drive fire impacts is critical for human safety and natural system conservation (Green et al., 2020). The same authors outline a process using high-resolution aerial imagery, mapping canopy conditions, and machine learning to determine the importance of landscape measures as predictors of woody canopy conditions in areas that burned during the 2017 Sonoma Complex Fires. They found that riparian and mesic vegetation types showed the least canopy damage, followed by upland hardwood forest types, whereas shrub and upland conifer types exhibited the most damage. High ladder fuel density and proximity to eucalyptus were among the variables found to lead to greater canopy damage. An important outcome of the study has been to share data and analysis methods and results with other conservation professionals and researchers (Green et al., 2020).

The National Park Service (NPS) has an established program for monitoring fire effects. (NPS, 2003). The Burned Area Emergency Response (BAER) storymap following the 2020 Woodward Fire in Point Reyes National Seashore highlights post-fire findings related to soils, vegetation, hazard tree monitoring, watershed response, wildlife (Northern Spotted Owl), cultural resources, and recreation (Johnson, n.d.). The fire burned in predominantly Douglas-fir stands and may cause the spread of jubata grass (*Cortaderia jubata)*, a non-native invasive species that the NPS is working to eliminate from the region.

In 2019 the California Native Plant Society (CNPS) developed and published the CNPS *Fire Recovery Guide* in partnership with dozens of topic experts, ecologists, agency staff, and others (CNPS, 2019). The statewide recovery guide includes:

- Frequently asked questions about wildfire in California.
- A post-fire checklist for property owners.
- A decision-flow diagram for post-fire conditions.
- Erosion control recommendations.

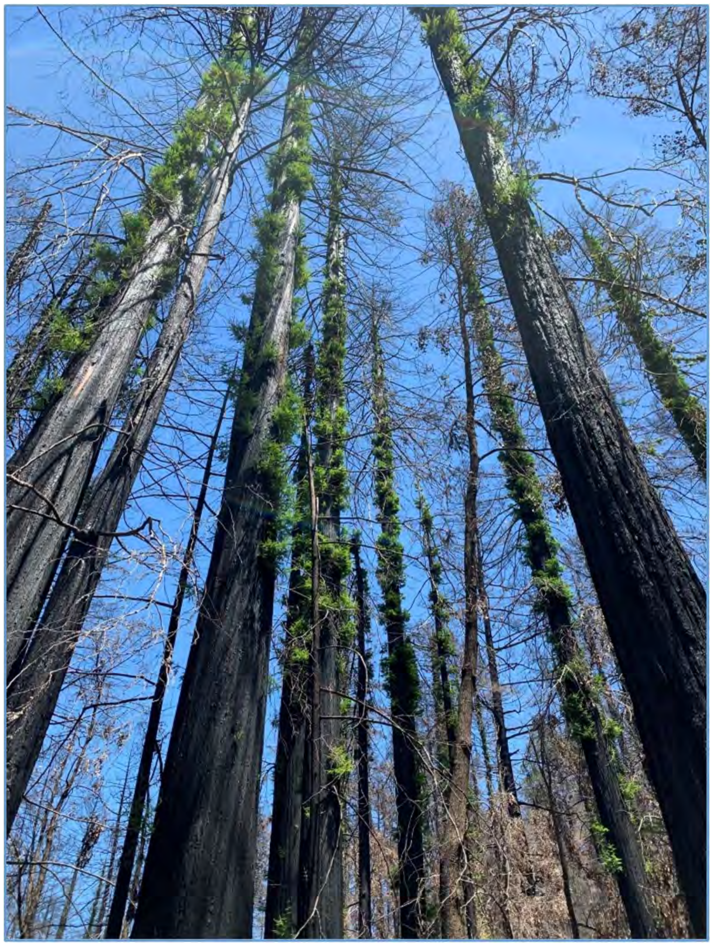
- Tips for tree care and landscaping after fire.
- Defensible space updates.
- An overview of California's most fire-prone habitats.

Following the 2020 CZU Lightning Complex Fire, the CNPS Vegetation Program and California Department of Fish and Wildlife Vegetation Classification and Mapping Program developed a modified version of the standard CNPS/CDFW Rapid Assessment/Relevé Protocol to evaluate immediate post-fire effects on natural and semi-natural stands of vegetation. This protocol could be useful for monitoring the effects of a future wildfire in Marin County (see Appendix 10A to this chapter).

A One Tam site visit to Big Basin State Park following the 2020 CZU Lightning Complex Fire generated valuable lessons learned and photos from throughout the burn (Figure 10.1). Key findings included the following:

- Large-diameter coast redwoods appear to tolerate high severity fires even in areas without active management. However, the long-term survivorship of coast redwoods following fire and timing for Coast Redwood forest recovery remains an area of active study (Gómez-Van Cortright, 2022).
- Redwoods respond with vigorous epicormic sprouting post-fire, and as a result, remote sensing imagery should be able to differentiate between trees with and without sprouting in a stand.
- Large-diameter Douglas-fir trees did not appear to survive this high-intensity fire.
- Documenting the location of chimney trees that retain fire, also known as fire storage, may allow resource managers to devise tree-retention strategies during post-fire recovery.
- Regularly updated infrastructure inventories could help prioritize post-fire projects and funding for replacement and restoration efforts.

Figure 10.1. Epicormic resprouts on coast redwood trees burned in the 2020 CZU Lightning Complex Fire, Big Basin State Park. Photo taken in June, 2021. Post-fire monitoring will answer key questions about redwood resilience and recovery from high intensity fire.



Elsewhere in the CZU Lightning Complex footprint, the Santa Cruz Mountains Stewardship Network, in partnership with California Department of Forestry and Fire Protection (CAL FIRE), is studying the relationships between post-fire damage and pre-fire land cover variables. This work is intended to support future planning for mitigating fire impacts, such as landslides and debris flows, and support sustainable fire recovery for future fire events through image acquisition, data analysis, and tool creation for land managers.

Audubon Canyon Ranch is conducting a prescribed fire research study (Peterson, 2021) to examine the effects of prescribed fire on acorn pests, phenology, and gathering efficiency. ACR also runs Fire Forward, a program that brings a unique blend of science-based program design and community organizing to create lasting models of fire-adapted communities tending fire-adapted landscapes. Working with other land managers who are grappling with forest and fire issues can help Marin agencies shape future treatment and monitoring methods, and lead to shared best management practices to build resiliency throughout the Bay Area.

ONGOING FIELD MONITORING

One Tam partners have numerous ongoing programmatic and project-specific field-based monitoring efforts which are already being leveraged to collect data and respond to questions about forest health and resiliency. In some cases, these efforts can be expanded to further support forest resiliency work.

NON-NATIVE INVASIVE SPECIES MONITORING

Early detection rapid response for non-native invasive weeds is an essential cross-agency cooperative effort to detect and remove invasive plants prior to the establishment of large, difficult to manage patches of undesirable weeds. Efforts led by individual agency departments, such as the National Park Service San Francisco Network of Bay Area National Parks Inventory and Monitoring Program (SFAN I&M Program) or the One Tam Early Detection Rapid Response (EDRR) Program, provide critical information for managing non-native invasive species. Widespread use of Calflora's Weed Manager system makes this a potentially effective tool for monitoring the distribution and treatment of weeds across the County.

The NPS I&M Program has an early detection program that is volunteer based. The outlined methodology is geared toward land managers and offers methods and guidance for where, how, when, and what types of data to gather (Williams et al., 2009). Early Detection Annual Reports contain survey results with maps from priority non-native invasive weed populations and all the survey areas (Wrubel & Graver, 2019).

Monitoring and early detection of non-native plants should be coordinated with forest resiliency treatments wherever possible. Existing programs, such as the One Tam EDRR program, could be leveraged or replicated, where financially feasible, to support future forest resiliency work. The One Tam *Early Detection of Invasive Plants Protocol* (Kesel et al., 2017) outlines cross-agency collaboration to prioritize and treat invasives at the most cost-effective stage. The Protocol describes monitoring and survey methods for early detection rapid response across the County, including data management and reporting procedures.

ESTABLISH MONITORING PLOTS

The establishment of permanent or long-term monitoring plots is useful for understanding changes in plant communities over time. For example, The National Park Service monitors the structure and composition of Coast Redwood and coastal scrub communities every four years at Bolinas Ridge, Muir Woods, and Green Gulch at permanent vegetation plots (Edson et al., 2016).

The monitoring plot type depends on monitoring objectives. For their *Long-term Forest Monitoring Plan* (Halbur et al., 2020), Pepperwood Preserve elected to use modified Forest Inventory and Analysis (FIA; U.S. Forest Service, n.d., 2005) plot design combined with wildlife monitoring. Pepperwood also worked with UC Berkeley to establish research plots using the following design:

> Fifty 20 x 20 m plots were established across topographic and hydrologic gradients throughout the preserve. Within each plot all saplings (>50 cm tall) and trees (> 1 cm

diameter at breast height) were permanently tagged, identified, mapped and measured. All seedlings (<10 cm tall) and juveniles (10-50 cm tall) were counted and identified. Micrometeorological monitoring was initiated and will be expanded in the future (Ackerly et al., 2013, p. i).

FOREST HEALTH MONITORING REGIMES

Several existing monitoring regimes are included in agency-specific documentation, such as Marin Water's *BFFIP* (2019) and Marin County Parks and Open Space District's *Vegetation and Biodiversity Management Plan* (2015). For comparison, Midpeninsula Regional Open Space District (2020a & 2020b) has established a monitoring program and monitoring protocols to evaluate parameters identified in their *Wildland Fire Resiliency Program*. The protocols include methods for avian, invertebrate, and mammalian populations and special status species protocols. It has a spatial section with available mapping data and considerations for using lidar and unmanned aerial vehicles (drones) for higher resolution spatial data. Rare plants, hydrology, forest health, non-native invasive species (early detection rapid response), and soils are considered.

Marin Water, working in collaboration with the U.S Forest Service, Cal Poly, and U.C. Davis, developed the Resilient Forest Study in 2015, which aimed to establish forestry treatments for sudden oak death impacted forests (Cobb et al., 2017). In 2020, Marin Water expanded the implementation of forestry projects on their lands based on the treatments designed as part of the Resilient Forest Study and the management actions outlined in the *BFFIP* (Marin Water, 2019). The Resilient Forest Study informed the design and approach to the Potrero Meadows Demonstration Project undertaken as part of the *Forest Health Strategy*. Demonstration project site monitoring consists of:

- Periodic photo-monitoring.
- Regular monitoring at established vegetation plots. Potential to pair plots with nearby Potrero Meadows grassland vegetation plots.
- Pre-project monitoring for rare plants, nesting birds, and bat roosts. Potential follow-up monitoring to record any changes from these baseline monitoring data.
- Periodic hydrological monitoring using water quality and flow metrics following pre-project baseline.
- Periodic non-native invasive species monitoring in treatment areas and adjacent footpaths.
- Fire fuel profiles developed from remote-sensed LiDAR, and landcover data could be re-analyzed by experts using a revised set of input variables to measure the reduction in fuel loads and associated fire behavior.

REMOTE SENSING-BASED MONITORING

Remote sensing-based monitoring, such as the Marin Countywide Fine Scale Vegetation Map, is a valuable tool for tracking changes at the countywide or landscape scale. These data provide valuable information about the composition and distribution of Marin's forests and their structural characteristics and current conditions. As new foundational data such as lidar and optical imagery become available, spatial databases can be updated to study change over time. New technologies allowing for automation of some data collection are rapidly evolving and decreasing in cost. Acoustic sensors, for example, now cost less than $100, and software that rapidly analyzes terabytes of sound and camera-sensing data are making tech-based wildlife surveys more feasible (Marin Wildlife Watch; Bat Monitoring). Google Earth users can examine historical satellite photos and analyze landscape-level changes over time. Managers should look for opportunities to coordinate acquiring new and existing foundational data at a landscape scale at least every 5-10 years. There may also be opportunities to use remote sensing for monitoring forest treatment projects.

The methods for spatial analysis used in the *Forest Health Strategy* are described in Chapter 6: Metrics. Metrics used in the forest health assessment are relative hardwood and conifer cover values, fire history, canopy density change between 2010-19, lidar derived stand structure, standing dead (canopy mortality), and canopy gaps formed between 2010-2019. Remote-sensed data by metric, including data required and suggested update frequency are shown in Table 10.1. Regular updates of the Marin Countywide Fine Scale Vegetation Map (Golden Gate National Parks Conservancy et al., 2021) are critical for tracking changes over time and making adjustments to forest health management methods and treatments.

Table 10.1. Summary of remote-sensed metrics, data, requirements, and suggested update frequency.

Metric	Foundational Data Required	Suggested Update Frequency
Fine scale vegetation map	Aerial imagery, lidar	5-10 years
Relative hardwood and conifer values for forest stands	Fine scale veg map, aerial imagery	5 years
Fire history	CAL FIRE Watershed Emergency Response Team (WERT) data, USGS Burned Area Emergency Response (BAER) data, etc.	As fire events occur
Canopy density change 2010-2019	Fine scale veg map, lidar	10 Years
Structure-based classification of forest stands	Fine scale veg map, lidar	10 years
Standing dead (canopy mortality) and canopy gaps	Fine scale veg map, imagery, lidar	5-10 years

One Tam partners have explored methods for real-time drought stress monitoring. This type of remote sensing-based monitoring could provide data on drought-stressed vegetation, to help land managers prioritize forest resiliency treatments or fuels reduction projects. Because the proposed methodology uses remote measurements of vegetation vigor and evapotranspiration, the analysis could provide land managers with rapid near-term identification of drought stress or other disturbances at locally relevant scales to support on-the-ground preparation and adaptation to accelerating changing climate in California's highly populated, fire-prone landscapes. It could also explore and quantify relationships between vegetation stress and resilience to drought by using machine learning to evaluate stress levels relative to a suite of landscape characteristics.

MONITORING RECOMMENDATIONS

Continued monitoring is needed on both the landscape level and the project level to assess changes in Marin forest ecosystems and the impacts of forest health treatments. Landscape-scale monitoring requires a coordinated tracking approach across all land ownerships; forest health monitoring methods should be standardized across agencies to the greatest extent possible, and data and lessons learned should be shared regularly to support continuous analysis and adaptive management. More specific recommendations for spatial data/remote sensing, field-based monitoring, and collaboration across agencies follow below.

COORDINATED TREATMENT TRACKING

As part of developing the *Forest Health Strategy*, agencies worked together to draft a coordinated spatial database to pilot standardized reporting protocols to track fuels reduction and other forest restoration treatments. The drafted treatment tracking protocol, based on CAL FIRE's CALMAPPER (2020) database, standardizes field collection methods for line, polygon, and photo point monitoring and how those data can be digitized in the office. In addition, a draft database schema defines field domains and relationships across fields and a workflow for creating schema in ArcGIS pro was drafted. A fuel treatment tracking web map that contains all feature layers outlined in the Conceptual Workflow, draft Database Schema, and the ability to add/update records are being developed.

The benefits of standardizing fuel and forest health treatment tracking across jurisdictional boundaries, including those carried out by One Tam agencies, the Marin Wildfire Prevention Authority (MWPA), other local fire departments, and other public land managers, should include the ability to quantify treatments by type across all of Marin County and would enable collaborators to study treatment impact and efficacy. Standardized spatial treatment tracking should be further developed and will help managers plan and coordinate future treatments to achieve maximum efficacy, avoid redundancy, and streamline both project reporting and communication with the broader public.

REMOTE SENSING-BASED MONITORING

Framework. Establish a programmatic framework, to include obtaining remote sensing-based data on a regular time interval, sharing data, and using new data for analysis.

Data Acquisition. Regularly obtain new high-resolution, 4-band aerial imagery and high-quality lidar data (minimum 8 pulses per square meter) for Marin County.

Update. Update countywide fine scale vegetation map, vegetation structure derivatives, and metrics developed for use in the *Forest Health* Strategy, *2016 One Tam Peak Health Report* (Edson et al., 2016), and other applicable studies.

Analyze. Work to study and analyze the results of updated or new information, understand the implications of changes detected, new patterns, and trends. Take the time necessary to establish a feedback loop with ongoing initiatives and programs and implement changes to work approaches based on acquired knowledge and learning.

Automation. Develop automated approaches to process data and run queries or geoprocessing tools as licenses and staff capacity permits. More specifically, pursue methods for automated remote sensing monitoring of drought stress in forests, with a focus on high temporal resolution (i.e., near real-time conditions). Encourage a further understanding of the connection between remote sensing, on-ground conditions, and monitoring proxies.

FIELD-BASED MONITORING

Existing Programs. Continue to invest in One Tam and individual agency-led monitoring programs such as field-based inventory, monitoring, and study of the key indicator and special status species, as well as programmatic efforts to detect and manage non-native invasive species in forests and woodlands.

Standardization. Use standardized methods to track forest management activities throughout Marin. Establish long-term vegetation monitoring plots across all jurisdictions using protocols consistent with other regional efforts such as long-term monitoring plots at Pepperwood Preserve (Halbur et al., 2020) or the USDA's FIA program U.S. Forest Service, 2005).

Carbon. Together with Marin County agencies and MarinCAN, a Marin County organization focused on climate change (formerly Drawdown: Marin), conduct a comprehensive countywide accounting of aboveground carbon and biomass, as well as soil carbon estimates, to establish baseline sequestration values and allow for change analysis and opportunities to protect/enhance carbon sinks. Participate in studies such as the Marin Biomass Project (Marin Resource Conservation District (RCD), n.d.) to understand how forest resilience treatments might be able to support regional biomass recovery goals and sustainable use initiatives. Through community engagement and monitoring, share information with key audiences about differences that exist between aboveground live carbon and biomass policy goals and climate projections that show future landscapes may support fewer trees, and that overstocked stands are less climate and wildfire resilient (Bernal et al., 2022; Liang et al., 2017).

Permanent plots. Ensure additional long-term monitoring plots are designed to detect changes to carbon, soil health, fungi, biodiversity, and other ecosystem services which are critical to understanding vegetation dynamics over time.

INTERAGENCY COORDINATION

State agencies. Coordinate information, analysis, and data sharing with California state agencies such as CDFW, Department of Conservation, CAL FIRE, and others.

Other land management agencies and NGOs. Maintain and develop information sharing with organizations doing similar work across the region including Audubon Canyon Ranch, Pepperwood Preserve, Santa Cruz Mountains Stewardship Network, and others.

Treatments. Continue to work towards a comprehensive countywide system for tracking forest resiliency and fuels reduction treatments, including MWPA and local/county fire agency led treatments, to facilitate and improve cross-jurisdictional collaboration and project coordination. This could include developing treatment tracking based on the CAL FIRE state-standard CalMAPPER (2020).

Communications and reporting. Share research and monitoring results via communications to identified audiences including local and state agencies and members of the Marin community. Create *Forest Health Strategy* briefs for the same audiences.

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APPENDIX 10A: CDFW-CNPS POST-FIRE RAPID ASSESSMENT/ RELEVÉ PROTOCOL AND FIELD FORM

CDFW-CNPS Protocol for the Combined Vegetation Rapid Assessment, Relevé and Post-Fire Severity Protocol

(V. 9 March 24, 2021)

Introduction

This protocol describes the methodology for combining the CDFW-CNPS Relevé and Rapid Assessment (RA) vegetation sampling techniques with a post-fire vegetation severity assessment as recorded in the Combined Vegetation Rapid Assessment/ Relevé and Post-fire Monitoring Field Form. This protocol and field form is designed to capture transient conditions existing immediately following a wildland fire. The most interpretable fire severity effects diminish rapidly following precipitation, wind, and processes of biological regeneration. The same environmental data are collected for both relevé and rapid assessment techniques. However, the relevé sample is a plot demarcated with a measuring tape, and each species in the plot is recorded along with its cover. The rapid assessment sample is not based on a taped plot, but is based on a visually estimated, usually circular area within a representative portion of the entire stand, with up to 20 of the dominant or characteristic species and their cover values recorded.

In general, collect rapid assessments in woody vegetation and relevés in herbaceous vegetation. When working in an area that has not been sampled before, RAs in woody vegetation may list more than 20 species. Therefore, there will generally be even less of a distinction between RA and relevé based on the listing of species. In post-fire conditions the list of identifiable species may be much shorter, but it is important to record age classes such as seedlings, re-sprouting individuals, and saplings of the same species.

Defining a Stand

A stand is the basic physical unit of vegetation in a landscape. It has no set size. Some vegetation stands are very small, such as a portion of a vernal pool, and some may be several square kilometers in size, such as some forest and desert scrub types. For CDFW-CNPS standard vegetation mapping projects all samples should be in stands that meet the minimum mapping unit of 1 acre for upland and 0.5 acre for special stands such as small wetlands, riparian and serpentine barrens. For classification and monitoring of naturally occurring small stands such as vernal pools and mountain meadows, smaller stands may be selected.

A stand is defined by two main unifying characteristics:

1) It has <u>compositional</u> integrity. Throughout the site, the combination of species is similar. The stand is differentiated from adjacent stands by a discernable boundary that may be abrupt or indistinct.
2) It has <u>structural</u> integrity. It has a similar history or environmental setting that affords relatively similar horizontal and vertical spacing of plant species. For example, a hillside forest originally dominated by the same species that burned on the upper part of the slopes but not the lower would be divided into two stands. Likewise, sparse woodland occupying a slope with very shallow rocky soils would be considered a different stand from an adjacent slope with deeper, moister soil and a denser woodland or forest of the same species.

The structural and compositional features of a stand are often combined into a term called <u>homogeneity</u>. For an area of vegetated ground to meet the requirements of a stand, it must be homogeneous (uniform in structure and composition throughout). Selecting recently burned stands may be confusing due to local-scale variable combustion and obliteration of the original structural and compositional components. An existing pre-fire monument, accurate GPS location, plot description, recent field photographs, detailed aerial images, or a combination of these may be used to assist locating the sample area.

Selecting a bounded plot (Relevé) or representative area (Rapid Assessment) to sample within a stand

Stands to be sampled may be selected by evaluation prior to a site visit (e.g., from aerial photos) or they may be selected on site during reconnaissance to determine extent and boundaries, location of other similar stands, etc.

Because many stands are large, it may be difficult to summarize the species composition, cover, and structure of an entire stand. A sample of vegetation is selected to be representative of the entire stand and should be conducted in a standardized way to ensure that it can be compared to samples of other stands. This means that you are not randomly selecting a plot; on the contrary, you are actively using your own best judgment to find a representative example of the stand.

Selecting a relevé plot or RA area requires that you see enough of the stand you are sampling to feel comfortable in choosing a representative plot location. Take a brief walk through the stand and look for variations in species composition and in stand structure. In hilly or mountainous terrain, look for a vantage point from which you can get a representative view of the whole stand. Variations in vegetation that are repeated throughout the stand should be included in your plot. Once you assess the variation within the stand, attempt to locate a sample area that captures the stand's common species composition and structural condition.

Selecting recently burned stands may be confusing due to local-scale variable combustion and obliteration of pre-fire vegetation structure and composition. Comparative information on pre-fire conditions is an important consideration. An existing pre-fire monument, accurate GPS location, plot description, recent field photographs, detailed pre- and post-fire aerial images, or a combination of these should be used to assist locating the post-fire sample area. To facilitate re-location of a permanent sample permanent markers, re-bar or pvc pipe segments with additional notes on specific location citing bearing trees should be used as appropriate, based on local land manager's requirements.

Tracking sampled vegetation types

For large projects, the number of samples should be tracked daily or weekly by field-assessed Alliance and Association type so that samples are distributed as evenly as possible over types and time is not wasted collecting excessive numbers of samples of certain types. When multiple teams are in the field in the same week, daily communication between teams about Alliances and Associations sampled can ensure even sampling*. Prior to selecting a stand to sample, determine if what you are going to sample is needed based on this tracking.*

Selecting samples to avoid spatial autocorrelation

In no case should you sample the same stand more than once in a given project. For large projects, select sample locations to limit spatial autocorrelation. When possible, do not sample adjacent stands. Do not take a sample within 1000 meters of a survey of the same vegetation type. Exceptions can be made due to limited access to private lands. For example, samples taken from different formations, subclasses, or classes (e.g., wetlands vs. uplands, lithomorphic vs. mesomorphic) adjacent to one-another have a lower probability of sharing a number of species and may be sampled within 1000 meters of each other. However, avoid sampling adjacent stands that tend to have more species overlap even if they are technically different formations, such as a grassland adjacent to an open woodland.

Plot Size

All relevés of the same type of vegetation need to be the same size if they are to be analyzed together. Plot shape and size are somewhat dependent on the type of vegetation under study. Therefore, general guidelines for plot sizes of tree, shrub, and herbaceous communities have been established. Sufficient work has been done in Californian vegetation to be confident the following conventions will capture species richness:

Herbaceous communities: 100 m^2 plot
Special herbaceous communities of small size, such as vernal pools, fens: 10 m^2 plot

Shrublands and riparian forest/woodlands: 400 m^2 plot
Open desert and other shrublands with widely dispersed but regularly occurring woody species: 1000 m^2 plot
Upland Forest and woodland communities: 1000 m^2 plot

In post-fire situations these general rules prevail. However, you may have to rely upon the dimensions of the pre-fire stand, or pre-fire sample. Since fewer species are recognizable just after a fire, it is possible to enlarge the post-fire survey without compromising the species search time taken to cover a larger area. We recommend a RA radius of from 10 m (for small stands or uniformly burned herbaceous communities), ranging up to 30 m for larger stands of woody vegetation. The most important point is to remain within what was (or may still be) a homogeneous stand.

Plot Shape

A relevé has no fixed shape, though plot shape should reflect the character of the stand and is either a square, rectangle, or circle. Adjust the orientation and dimensions of the plot to incorporate the best approximation of stand homogeneity. If the stand is about the same size as a relevé, the plot boundaries may be similar to that of the entire stand. If we are sampling streamside riparian or other linear communities, our plot dimensions should not go beyond the community's natural ecological boundaries. Thus, a relatively long, narrow plot capturing the vegetation within the stand, but not outside it, would be appropriate. Species present along the edges of the plot and are clearly part of the adjacent stand should be excluded. Accordingly, the post-fire assessment should adhere to these general rules of inclusion and exclusion. The post-fire assessment requires subdividing the sample into 4 equally sized quadrants. In most cases if the burned area is a stand > 10 m for its minimum dimension, a circular sample is most efficient. Herein, we describe the RA radius set-up method divided into quadrants oriented along ordinal bearings. However, under certain situations such as narrow, elongated riparian stands, it is possible to use a rectangular sample and divide it into quadrants. In this case the four subdivisions are determined by the general orientation of the stand.

Location of GPS Points

For square-to-rectangular relevés, one point will be considered the plot identifier (ID point) and should be in the SW corner of a rectangular or square plot, if possible, or in the center of a circular plot. If it is taken in another location, this should be noted in the Site History section. If a pre-fire sample was established with a reference point, relocate it or a best approximation of it as the main ID point.

Definitions of fields in the Field Form

I. LOCATIONAL/ENVIRONMENTAL DESCRIPTION

Relevé or RA: Circle the appropriate survey type.

Database #: This is the unique ID number for Relevés and Rapid Assessments, in the form of *PPPPxxxx*, where *PPPP* is the 4-character project code and *xxxx* is a unique 4-digit number (e.g. CZPO0001 for Santa Cruz Post-fire sample #1). If this is a long-term plot, a character from A to Z can be added to the unique ID for each re-sampling survey; so the first re-sample for CZPO0001 would be CZPO0001A.

Base points will not be collected for the post-fire protocol.

Photo Points: Occasionally, stand photos will be taken from a vantage point outside the stand, or in a place other than the survey point. The ID for this point is *PPPPxxxx*_P#, i.e. the first Photo Point for CZPO0001 will be CZPO0001_P1.

Date: Date of the sampling.

UID: The ID number of a reference point that this survey describes.

Name of recorder: The full name of the recorder should be provided for the first field form for the day. On successive forms, initials can be recorded.

Other Surveyors: The full names of each person assisting should be provided for the first field form for the day. On successive forms, initials of each person assisting can be recorded.

Location Name: The name of the property or park, or the location within large holdings (like USFS or BLM properties).

GPS name: The name/number assigned to each GPS unit. This can be the serial number if another number is not assigned.

Bearing°, left axis at ID point of Long / Short side: Fill this in for relevés or non-circular post-fire assessments only. For square or rectangular plots: from the ID Point, looking towards the plot, record the bearing of the axis to your left. If the plot is a rectangle, indicate whether the left side of the plot is the long or short side of the rectangle by circling "long" or "short" side (no need to circle anything for square plots). If there are no stand constraints, set up the plot with boundaries running in the cardinal directions and place the ID Point in the SW corner.

UTM coordinates: Easting (**UTME**) and northing (**UTMN**) location coordinates using the Universal Transverse Mercator (UTM) grid. Record the information from your GPS unit. These coordinates are always the base point of the survey. Soil samples and photos are taken from this point, and exposure, steepness, topography, etc. are measured here.

For Relevé plots, take the waypoint in the southwest corner of the plot whenever possible or in the center of a circular plot.

Zone: Universal Transverse Mercator zone. Zone 10 is for California west of the 120th longitude; zone 11 is for California east of 120th longitude (the straight portion of California's eastern boundary).

NAD83: This is the default GPS datum. If you use a different one, cross this out and write in the correct datum.

GPS error: ft./ m./ PDOP: Circle the appropriate unit of measure and record the error reading from the GPS unit.

Decimal degrees: *Use this only if your GPS unit will not record UTM coordinates.* Latitude–Longitude reading in decimal degrees. Record the information from your GPS unit. These coordinates are always the base point of the survey. Soil samples and photos are taken from this point, and exposure, steepness, topography, etc. are measured here.

For Relevé plots, take the waypoint in the southwest corner of the plot whenever possible or in the center of a circular plot.

Camera Name: Write the camera name or code as identified by the users.

Cardinal photos at ID point: Take four photos in the main cardinal directions (N, E, S, W) clockwise from the north, from the ID Point, and record the jpeg numbers here. Try to include the horizon in at least some of these photos. A digital camera with a minimum 10-megapixel resolution must be used.

Other photos: This may include cardinal photos at additional corners or other relevant photos. Notes regarding photo locations or subjects can go here. See above for photo naming conventions.

Stand Size: Estimate the size of the entire stand in which the sample is taken. As a measure, one acre is about 4,000 square meters (approximately 64 x 64 m), or 208 feet by 208 feet. One acre is similar in size to a football field.

Plot Area (m^2): If this is a relevé, circle "100" for a $100m^2$ plot, or record the plot size.

Plot Dimensions: Record the length and width of the Relevé plot in meters.

RA Radius: Enter the radius in meters of the visually estimated sample area for Rapid Assessments (should be a 10-meter radius at minimum). **This is the preferred sampling type for the Post-fire assessment.** It is relatively fast to set up and enables field teams to easily estimate both above ground and substrate fire effects. For a large stand, the **RA Radius** limits the area covered by the RA. If you can see and assess the entire stand, the length and width should be recorded. If it is a long, narrow stand, note the width of the stand at your location.

Setting up site using RA Radius: Establish center location and mark with a pin flag, flagging, or permanent marker and collect the GPS ID point. Take 4 bearings along N, E, S, and W cardinal directions correcting for Magnetic North declination. Use laser rangefinder to measure full distance to the edge along the 4 cardinal directions. Mark edges with flagging or pin flags. The site is now divided into 4 quadrants: NE, SE, SW, and NW (See Figure 1).

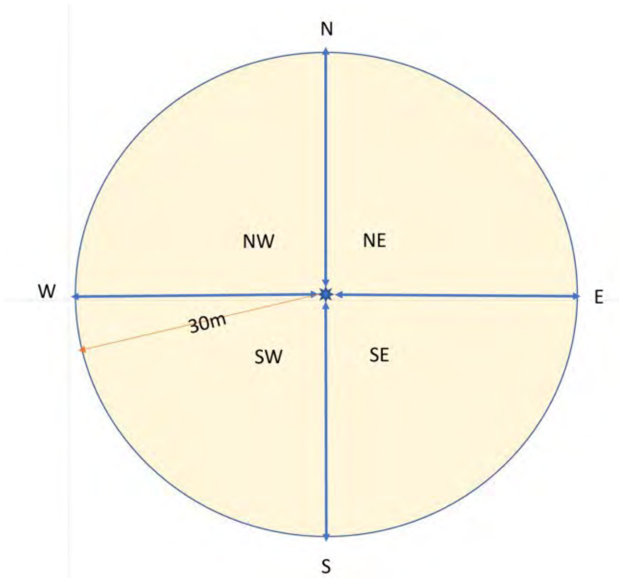


Figure 1: Example of 30 m radius RA plot oriented on cardinal directions showing 4 quadrants

Exposure: (Enter Actual º and circle general category): While facing in the general downhill direction, read degrees of the compass for the aspect or the direction you are standing, using degrees from north, adjusted for declination. Average the reading over the entire stand, even if you are sampling a relevé plot, since your plot is representative of the stand. If estimating the exposure, write "N/A" for the actual degrees, and circle the general category chosen. "Variable" may be selected if the same, homogenous stand of vegetation occurs across a varied range of slope exposures.

Steepness: (Enter Actual º and circle general category): Read degree slope from your compass/clinometer by following the manufacturer's directions for use. If estimating, write "N/A" for the actual degrees, and circle the general category chosen. Make sure to average the reading across the entire stand even if you are sampling in a relevé plot.

Topography: First assess the broad (**Macro**) topographic feature or general position of the stand relative to the immediately surrounding landscape. This attribute does not refer to the watershed as a whole, but to a cross section of the topography at the location of your stand. For instance, if your stand is located along a small creek in a narrow, v-shaped canyon, your position would be at the "Bottom," even if the canyon itself slopes downward. Since stands can occupy more than just a single slope position, **circle all the positions that apply**.

Then assess the local (**Micro**) topographic features or the lay of the area within the stand being sampled (e.g., surface is flat or concave). **Circle only *one* of the microtopographic descriptors**.

Geology code: Geological parent material of stand. If exact type is unknown, use a more general category (e.g., igneous, metamorphic, sedimentary). *See code list for types*.

Soil Texture code: Record soil texture that is characteristic of the plot (*e.g.,* coarse loamy sand, sandy clay loam). *See soil texture key for types.*

Upland or Wetland/Riparian: Indicate if the stand is in an upland or wetland/riparian setting. (wetland and riparian are one category.) Note that a site need not be officially delineated (as in the Army Corps of Engineer's wetland delineation protocols) as a wetland to qualify as such in this context (e.g., seasonally wet meadow).

% Surface cover: The non-living (abiotic and biotic) components of the surface of the ground. The total should sum to 100%. It is helpful to imagine "mowing off" all live vegetation at the base of the plants and removing it – you will be estimating what is left covering the surface. Note that non-vascular cover (lichens, mosses, cryptobiotic crusts), including "basal area" of ground attachment, is not estimated in this section.

H_2O:	Percent surface cover of running or standing water, ignoring the substrate below the water.
Snow:	if snow has fallen since the fire, estimate percent snow cover, otherwise skip
BA Stems:	Percent surface cover of the basal area of vascular plant stems at the ground surface. For most vegetation types, BA is 1-3% cover.
Litter:	Percent surface cover of litter, duff, or wood on the ground.
Ash/Char	Percent surface cover of consumed/partly consumed plant matter from fire
Bedrock:	Percent surface cover of bedrock, including outcrops.
Boulder:	Percent surface cover of rocks >60 cm in the longest dimension.
Stone:	Percent surface cover of rocks >25–60 cm in the longest dimension.
Cobble:	Percent surface cover of rocks >7.5–25 cm in the longest dimension.
Gravel:	Percent surface cover of rocks 2 mm–7.5 cm in the longest dimension.
Fines:	Percent surface cover of bare ground and fine sediment <2 mm in the longest dimension (*e.g.,* dirt, sand).

% Current year bioturbation: Estimate the percent of the plot exhibiting soil disturbance by any organism that lives underground. Do not include disturbance by native ungulates. Note that this is a separate estimation from surface cover. Bioturbation is often much more visible with the removal of litter and duff following surface fires.

Past bioturbation present? Circle Yes if there is evidence of bioturbation from previous years in the plot. This field gets at the long-term effects of bioturbation on a given vegetation stand.

% Hoof punch: Note the percent of the plot surface that has been punched down by hooves (cattle or native grazers) in wet soil. Depressions must be >2 cm deep.

Fire Evidence: Circle Yes if there is visible evidence of fire within the stand, and note the type of evidence in the **Fire and research history**

Fire and research history, comments: Include known date(s) of fire(s), past sampling events (reference project and curator), photography (curator), summary of fire effects including those on main vegetation strata, special status plants, and rationale for sample selection and location. You may also record more general historic information such as ownership, past human activity and natural disturbance that may have affected this stand. In addition to fire this may include landslides, avalanching, drought, flood, animal burrowing, or pest outbreak. Also, try to estimate date(s) or frequency of disturbance. Examples of land use: grazing, timber harvest, or mining. Examples of other site factors: exposed rocks, soil with fine-textured sediments, high litter/duff build-up, multi-storied vegetation structure, recent gullying, erosion, or other stand dynamics.

Human-mediated disturbance code / Intensity (L,M,H): List codes for potential or existing impacts on the stability of the plant community. See code list for impacts and definitions of levels of disturbance. Characterize each impact each as L (=Light), M (=Moderate), or H (=Heavy). Disturbance is evaluated on a stand basis.

II. HABITAT DESCRIPTION

California Wildlife Habitat Relationships (CWHR)

For CWHR, identify the size/height class of the plot using the following tree, shrub, and/or herbaceous categories. These categories are based on functional life forms of live plants. **If the majority of plants appear dead as a result of recent fire, only estimate living component of each lifeform.** Any pre-fire structure of recently killed strata is summarized in **Fire and research history, comments.**

Tree DBH: Circle one of the tree size classes provided when the tree canopy closure exceeds 10% of the total cover, or if young tree density indicates imminent tree dominance. Size class is based on the average diameter at breast height (dbh) of each trunk (standard breast height is 4.5ft or 137cm). When marking the main size class, make sure to estimate the mean diameter of all trees over the entire stand, and weight the mean toward the larger tree dbh's. The "**T6 multi-layered**" dbh size class signifies a multi-layered tree canopy (with a size class T3 and/or T4 layer growing under a T5 layer and a distinct height separation between the classes) exceeding 60% total cover. Stands in the T6 class need also to contain at least 10% cover of size class 5 (>24" dbh) trees growing over a distinct layer with at least 10% combined cover of trees in size classes 3 (>6-11" dbh) or 4 (>11-24" dbh).

Shrub: Circle one of the shrub size classes provided when shrub canopy closure exceeds 10% (except in desert types) by recording which class is predominant in the survey. Shrub size class is based on the average amount of crown decadence (dead standing vegetation on live shrubs when looking across the crowns of the shrubs).

Herbaceous: Circle one of the herb height classes when herbaceous cover exceeds 2% by recording the predominant class in the survey. Note*: This height class is based on the average plant height at maturity, not necessarily at the time of observation.*

III. INTERPRETATION OF STAND

Field-assessed vegetation Alliance name: Enter the name of the Alliance following the Manual of California Vegetation Online. Please use scientific nomenclature, *e.g., Quercus agrifolia* forest. An Alliance is based on the dominant or diagnostic species of the stand, and usually reflects the uppermost and/or dominant height stratum. A dominant species covers the greatest area. A diagnostic species is consistently found in some vegetation types but not others.

The field-assessed Alliance name may not exist in the present classification, in which case you can provide a new Alliance name in this field. If this is the case, also make sure to state that it is not in the MCV under "Explain" below.

Field-assessed Association name (optional): Enter the name of the species in the Alliance and additional dominant/diagnostic species from any strata. In following naming conventions, species in differing strata are separated with a slash, and species in the uppermost stratum are listed first (*e.g., Quercus douglasii / Toxicodendron diversilobum*)*.* Species in the same stratum are separated with a dash (*e.g., Quercus lobata – Quercus douglasii)*.

The field-assessed Association name may not exist in the present classification, in which you can provide a new Association name in this field.

Adjacent Alliances/direction: Identify other vegetation types that are directly adjacent to the stand being assessed by noting the dominant species (or known type). Also note the distance in meters from the GPS waypoint and the direction in degrees that the adjacent alliance is found (*e.g., Amsinckia tessellata* / 50m, 360° N or *Eriogonum fasciculatum* / 100m, 110°).

Confidence in Alliance identification: (L, M, H) With respect to the “Field-assessed Alliance name,” note whether you have L (=Low), M (=Moderate), or H (=High) confidence in the interpretation of this Alliance name.

Explain: Please elaborate if your “Confidence in Alliance identification” is low or moderate. Low confidence can occur from such things as a poor view of the stand, recent fire, an unusual mix of species that does not meet the criteria of any described Alliance, or a low confidence in your ability to identify species that are significant members of the stand.

Phenology: Indicate early (E), peak (P), or late (L) phenology for each of the strata. For herbs, this generally indicates if species are in flower and/or fruit and are therefore identifiable. For shrubs and trees, this attribute generally refers to cover, e.g., a tree that is fully leafed-out will be considered peak (P) even if it is not in flower. Phenology is useful for cover estimation and species identification issues and should be elaborated upon in the next field. If fire has obliterated a vegetation stratum record **N/A**

Other identification or mapping information: Discuss any further problems with the identification of the assessment or issues that may be of interest to mappers. Note if this sample represents a type that is likely too small to map.

IV: VEGETATION BURN PATTERN

Using the key to the 5 main vegetation fire severity conditions (described in Table 1 below: [Fire Monitoring Handbook - National Park Service www.nps.gov › orgs › upload › fire-effects-monitoring-h...](www.nps.gov)), estimate the proportion of the above-ground vegetated area affected by the different types of fire severity per quadrant (**not the percent ground cover**).

FMH-21

	Unburned (5)	Scorched (4)	Lightly Burned (3)	Moderately Burned (2)	Heavily Burned (1)
Substrate (S)	not burned	litter partially blackened; duff nearly unchanged; wood/leaf structures unchanged	litter charred to partially consumed; upper duff layer may be charred but the duff layer is not altered over the entire depth; surface appears black; woody debris is partially burned; logs are scorched or blackened but not charred; rotten wood is scorched to partially burned	litter mostly to entirely consumed, leaving coarse, light colored ash; duff deeply charred, but underlying mineral soil is not visibly altered; woody debris is mostly consumed; logs are deeply charred, burned-out stump holes are common	litter and duff completely consumed, leaving fine white ash; mineral soil visibly altered, often reddish; sound logs are deeply charred, and rotten logs are completely consumed. This code generally applies to less than 10% of natural or slash burned areas
Vegetation (V)	not burned	foliage scorched and attached to supporting twigs	foliage and smaller twigs partially to completely consumed; branches mostly intact	foliage, twigs, and small stems consumed; some branches still present	all plant parts consumed, leaving some or no major stems/trunks; any left are deeply charred

Table 1: Substrate and Vegetation Burn Severity Codes, FMH-21, USDI 2003

(each quadrant will add up to 100%). Enter mean estimated proportion of each fire severity type for the entire sample on the **Mean severity all quadrants** row (sum the proportions of fire severity types in quadrats, then divide by 4, see example Figure 2).

Note: The purpose of this part of the protocol is to report the relative importance of the five different fire severity effects for the plot quickly and efficiently. Depending on the complexity of the vegetation burn pattern and your increasing familiarity with the protocol, you may be able to quickly estimate the overall burn effects within the plot without summarizing them quadrant-by-quadrant Therefore you may be able to simply use the bottom summary row to denote the proportion of each severity type within the plot.

By Quadrant:
NW 65% heavily, 35% moderately burned
NE 45% heavily, 55% moderately burned
SE 60% heavily, 30% moderately, 10% lightly burned
SW 35% heavily, 65% moderately burned

Sum categories across quadrants:
205% heavily
185% moderately
10% lightly

400%

Plot Vegetation Burn Summary:

Heavily burned:	51.25%
Moderately burned:	46.25%
Lightly burned:	2.5%
	100.0%

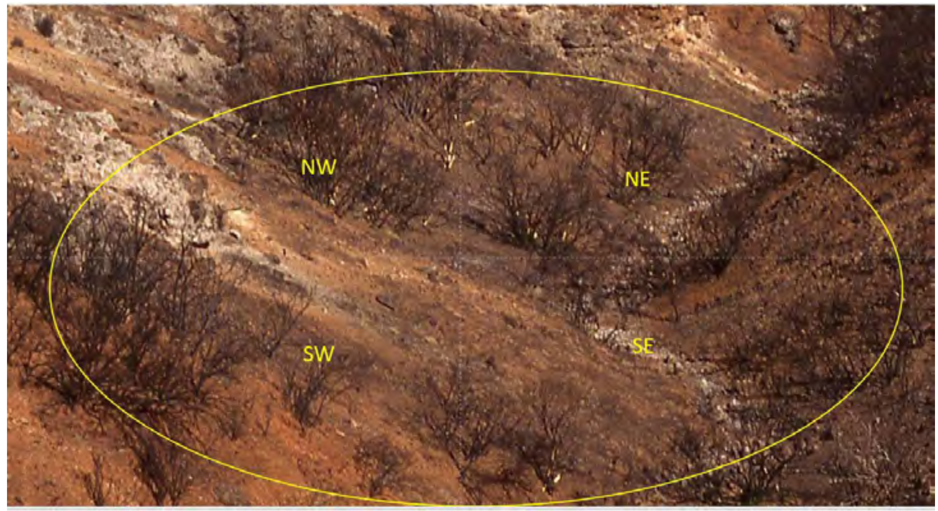
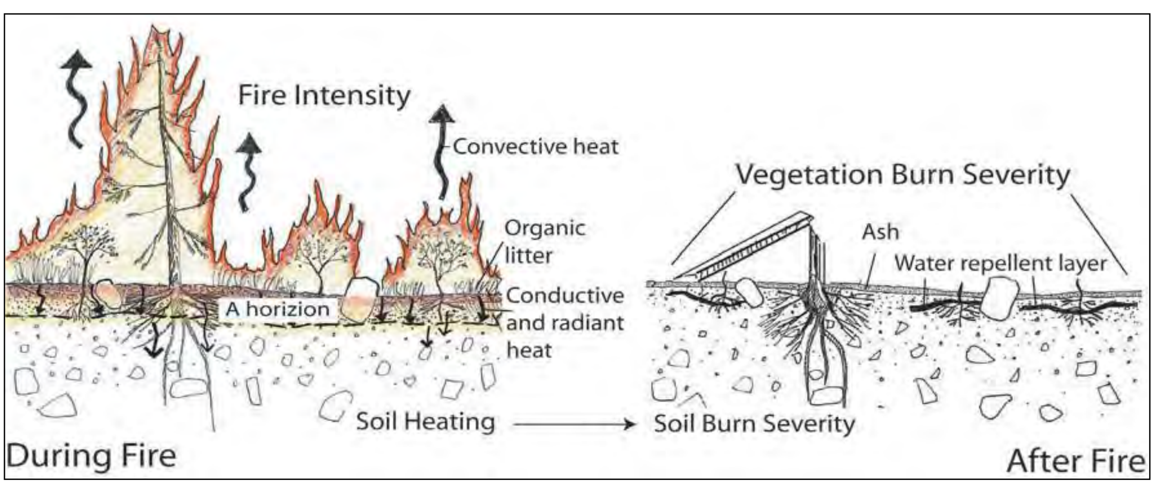


Figure 2: Example of assessment of RA radius within heavily to moderately burned *Quercus wislizeni* scrub stand

V. SUBSTRATE BURN ASSESMENT

This part of the protocol applies to ground-level effects. Instead of above-ground effects. we are looking at effects on litter (recently fallen and only partly decomposed foliage and small branches), duff (decomposing fragments of leaves and branches), sound and rotting logs, mineral soil, and their conversion to ash or structurally altered soil. All basic fire intensity conditions in the vegetation burn patterns are also mirrored in the substrate samples (Table 1).

The field form provides a key to each of the 5 fire severity substrate types using diagnostic characteristics. After looking within each of the quadrants use the key, to identify the substrate severity types and estimate their proportion affecting each quadrant (each quadrant will add up to 100%). Enter mean estimated proportion of each fire severity type for the entire sample on the **Mean severity all quadrants** row after summing the proportions of fire severity types in quadrats and dividing by 4. **Please refer to the "note" comments under section IV (vegetation burn pattern, above).** They also apply to the substrate burn assessment. You may be able to quickly estimate the substrate burn effects within the plot without summarizing them quadrant-by-quadrant. **Figure 3 (below)** depicts some of these concepts for vegetation and substrate during burn and post-fire conditions.



VI. VEGETATION DESCRIPTION

Database #: Copy the database # from Page 1.

Overall Cover of Vegetation

Provide an estimate of cover for the life-form categories below. Record a specific number for the total aerial cover or "bird's-eye view" looking from above for each category, **estimating cover for the living plants only**. In heavily and moderately burned vegetation the percent live cover will often be very low or non-existent. Litter/duff should not be included in these estimates.

The *porosity* of the vegetation should be taken into consideration when estimating percent foliar cover for all categories below: consider how much of the sky you can see when you are standing under the canopy of a tree, or how much light passes through the canopy of the shrub layer to help you estimate foliar cover.

% NonVasc cover: The total cover of all lichens, bryophytes (mosses, liverworts, hornworts), and cryptogamic crust on substrate surfaces including downed logs, rocks and soil, but not on standing or inclined trees or vertical rock surfaces.

Total % Vasc Veg cover: The total cover of all vascular vegetation taking into consideration the porosity, or the holes, in the vegetation, and disregarding overlap[1] of the various tree, shrub, and/or herbaceous layers and species.

% Cover by Layer

Conifer Tree /Hardwood Tree: The total foliar cover (considering porosity) of all live tree species, disregarding overlap[1] of individual trees. Estimate conifer and hardwood covers separately. **Please note:** These cover values should not include the coverage of regenerating tree species (i.e., tree seedlings and saplings).

Regenerating Tree: The total foliar cover of seedlings and saplings, disregarding overlap[1] of individual recruits. See seedling and sapling definitions below.

Shrub: The total foliar cover (considering porosity) of all live shrub species disregarding overlap[1] of individual shrubs.

Herbaceous: The total cover (considering porosity) of all herbaceous species, disregarding overlap[1] of individual herbs.

Height Class by Layer

Modal height for conifer tree / hardwood tree, regenerating tree, shrub, and herbaceous categories. Record an average height value for each category by estimating the mean height for each group. Please use the following height intervals to record a height class: 1 = <1/2 m, 2 = 1/2-1 m, 3 = 1-2 m, 4 = 2-5 m, 5 = 5-10 m, 6 = 10-15 m, 7 = 15-20 m, 8 = 20-35 m, 9 = 35-50 m, 10 => 50 m.

VII. SPECIES SHEET

Entries for this form are based on estimates applied to the variable radius assessment determined on accompanying RA/Relevé field form. The species sheet is used to assess the evidence of living or presumed living plant species. All identifiable species will be listed and treated on this form. Unlike the standard RA/Releve species list, this sheet includes additional species-specific post-fire-related effects and responses.

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[1] Porosity reduces the total cover of the canopy. Overlapping strata should not be included in the total cover percent; for instance, if a shrub is growing under a tree, only the cover of the tree will be added into the total; the cover of the shrub will be disregarded, except for the amount by which it fills in the porosity of the tree canopy.

Plant Species: Within the entire circular area enter plant species name (or taxon at finest level of resolution possible). For Santa Cruz County, use Neubauer's most recent Checklist of Vascular Plants of Santa Cruz County as authority. Use Jepson e-manual for uncertain taxa outside of county. Write out the genus and species of the plant. Do not abbreviate except for dominant species that do not have ambiguous codes. If you are unsure about duplicate codes, don't use a code. Do not search for seeds in soil seed bank, but otherwise attempt to list every species present, including recently (post-fire) shed seeds. If newly-shed seeds from trees or shrubs are visible enter "Y" in the seed column, otherwise enter "N". Newly-shed seeds include those from closed-coned conifers, shrubs with explosive capsules, etc. released following fire. Do not include other seeds that may have accumulated in soil or on substrate over 1 or more seasons prior to the fire.

Lifeform: Use the following abbreviations of lifeform descriptors: Multiple lifeforms can be applied to the same species listed in the first column (e.g., Tree, Sapling, Seedling, and Seed Rain)

- **T = Tree.** A woody perennial plant that has a single trunk.
- **S = Shrub.** A perennial, woody plant, that is multi-branched and doesn't die back to the ground every year.
- **H = Herb.** An annual or perennial that dies down to ground level every year.
- **E = SEedling**. A tree or shrub species clearly of a very young age that is < 1" dbh.
- **A = SApling**. 1" - <6" dbh and young in age, OR small trees that are < 1"diameter at breast height, are clearly of appreciable age, and kept short by repeated browsing, burning, or other disturbance.
- **N = Non-vascular**. Includes moss, lichen, liverworts, hornworts, cryptogammic crust, and algae.

Live Foliar Cover: Estimate in 1% increments when > 1%, use **+** if < 1%, use **"r"** if a single isolated occurrence well below 1%.

Regeneration: Report presence or absence after a survey in each quadrant, no estimation of numbers or distribution needed. 2 categories:

- **Seedlings and newly dispersed seeds**: **Y or N**. report in the row that pertains to the mature individuals of the species (either tree, shrub, or herbaceous)
- **Resprouting individuals: Y or N** based on recent new foliage on, or at base of fire-damaged individuals of species.

Sprout/Resprout Information:

Proportion of live re-sprouting woody species / all individuals per species: *record for woody species only***.** An estimate of the ratio of live resprouting plants of a given woody species (resprouts on any part of plant) to the total number of all individuals of the same species alive prior to the fire. **Report Categories: 0=** no sprouters apparent**, 1=** less than one-third have resprouts**, 2**= more than a third to 2/3 of individuals have resprouts**, 3=** more than 2/3 of all individuals have resprouts**.**

Estimate mean new sprout length: *record for all woody **and** non-woody species*. A categorical estimate of average length of individuals with sprouts, assuming assessment occurs within 12 months of fire [**1=** < 10 cm; **2**= 10-30cm, **3**) = > 30 cm]. "Sprout length" may be interpreted as basal or cauline sprouts with leaves from woody plants, or as individual leaf blades as in cespitose or rhizomatous leafy or graminoid herbaceous perennials.

Pre-fire multiple stems: *woody species only.* Assess pre-fire species growth habit using categorical coding of **0=** no evidence of multi-stems, **1**= 2-3 stems per plant, **2**= 4- 7 stems, **3**= > 7 stems per plant.

Scorch and char Information: (see Figure 4). Pertains to trees only. Please use the following height intervals to record a height class for the categories below except proportion crown volume scorched: **01** =< 1/2m, **02**=1/2-1m, **03** = 1-2 m, **04** = 2-5 m, **05** = 5-10 m, **06** = 10-15 m, **07** = 15-20 m, **08** = 20-35 m, **09** = 35-50 m, **10** => 50m.

Maximum scorch height: (Woody species only) Measure distance from ground to highest point in the crown where foliar death is evident using range-finder, within the assessment radius, Canopy may be trees or shrubs, but if trees were dominant, report trees.

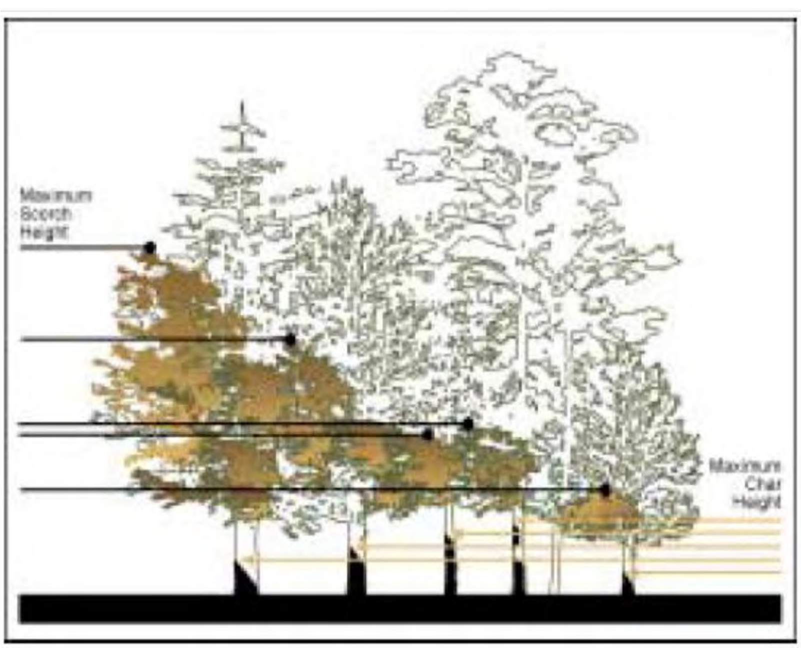
Mean scorch height: Estimate mean height category of scorch for this species

Percent crown volume scorched: (no height estimate, trees only) Estimate relative proportion of the crowns of this tree species that is scorched relative to the proportion that has living foliage (green or fall colors). Using the following 11 classes: **0=** 0%, **1 =** >0-10%; **2**= >10 –20%, **3** = >20-30%, **4**= >30-40%, **5**= >40 – 50%, **6** = >50-60% **7** = >60-70%., **8**=>70-80%, **9**=>80-90%, and **10**=>90-100%. This should be collected no longer than 4 months after the burn to limit needles lost to "cast". Recent "cast" foliage is recorded as litter (under **% Surface cover).**

Highest point of char: (Trees only) using range-finder estimate height class of the highest point on stem or trunk of tree where char exists (this may be isolated and not continuous charring)

Mean char height: (trees only) quickly survey the sample area and estimate the height class of the mean char height on stems/trunks of this species.

Figure 4: Diagram depicting concepts of mean and max scorch and char heights in 5 different tree species in a stand:



Note: Field forms are generally filled out in pencil, so that changes may be made easily while working in the plot or stand. Once out of the stand, however, entries on the field form should not be erased, but should be crossed out and corrected in a different-colored ink.

For Office Use:	**Final database #:**	**Final vegetation type:**	**Alliance**___ **Association**

I. LOCATIONAL/ENVIRONMENTAL DESCRIPTION — circle: **Relevé or RA**

Database #:	**Date:**	**Name of recorder:**
		Other surveyors: ☐
	UID:	**Location Name:** ☐

GPS name: ___ For Relevé only**: Bearing°,** left axis at ID point___**of Long / Short** side ☐

UTME ___ **UTMN** ___ **Zone: 11 NAD83** GPS error: **ft./ m./ PDOP** ___

Decimal degrees: **LAT** ___ . ___ **LONG** ___ . ___

Camera Name: **Cardinal photos at ID point:** ☐

Other photos:

Stand Size (acres): <1, 1-5, >5 | Plot Area (m²): 100 / ___ **| Plot Dimensions** ___**x**___**m | RA Radius**___**m** ☐

Exposure, Actual °: ___ **NE NW SE SW Flat Variable | Steepness, Actual °:** ___ **0° 1-5° > 5-25° > 25** ☐

Topography: Macro: top upper mid lower bottom | Micro: convex flat concave undulating ☐

Geology code: ___ **Soil Texture code:** ___ | **Upland** or **Wetland/Riparian** (circle one) ☐

% Surface cover:				(Incl. outcrops)	(>60cm diam)	(25-60cm)	(7.5-25cm)	(2mm-7.5cm)	(Incl sand, mud)	(burned organics)	
$H_2$0:	**Snow:**	**BA Stems:**	**Litter:**	**Bedrock:**	**Boulder:**	**Stone:**	**Cobble:**	**Gravel:**	**Fines:**	**Ash:**	**=100%**

☐

% Current year bioturbation ___ **Past bioturbation present? Yes / No | % Hoof punch** ___ ☐

Fire evidence: Yes / No (circle one) If yes, describe in Site history section, including date of fire, if known. ☐

Fire and research history. Include known date(s) of fire(s), past sampling events (reference project and curator), photography (curator), summary of fire effects including those on special status plants, and rationale for sample selection and location. ☐

Disturbance code / Intensity (L,M,H): ___/___ ___/___ ___/___ ___/___ ___/___ **"Other"** ___/___ ☐

II. HABITAT DESCRIPTION

Tree DBH : T1 (<1" dbh), **T2** (1-6" dbh), **T3** (6-11" dbh), **T4** (11-24" dbh), **T5** (>24" dbh), **T6** multi-layered (T3 or T4 layer under T5, >60% cover) **F/D** (fire-destroyed) ☐

Shrub: S1 seedling (<3 yr. old), **S2** young (<1% dead), **S3** mature (1-25% dead), **S4** decadent (>25% dead), **F/D** (fire-destroyed) ☐

Herbaceous: H1 (<12" plant ht.), **H2** (>12" ht.), **F/D** (fire-destroyed) ☐

III. INTERPRETATION OF STAND

Field-assessed vegetation Alliance name: ___ ☐

Field-assessed Association name (optional): ___ ☐

Adjacent Alliances/direction: ___/___, ___/___ ☐

Confidence in Alliance identification: L M H Explain: ___ ☐

Phenology (E,P,L): Herb Shrub Tree Other identification or mapping information: ☐

IV: VEGETATION BURN PATTERN Divide circular area into quadrants, use key to identify vegetation burn severity type. Estimate portion of severity type in each, then average column scores to determine proportion of severity per sample. With increased protocol familiarity, you may be able to skip quadrant summaries and report vegetation fire severity for the entire plot.

1. Above ground vegetation (including all strata; herbaceous, shrub, and tree) showing no recent evidence of fire, with green or otherwise living, un-singed, or unburned foliage from the current growing season ....**Unburned**

1'. Above-ground vegetation showing recent fire effects, including any combination of scorched foliage, charring, recent consumption of foliage, twigs, branches, stems, cones, etc.. **Go to 2**.

2. Foliage, small twigs, branches, and other plant structures still attached to plants with at least some part of plants in quadrant showing evidence of scorching (light tan to darker brown leaves and needles affected by heat of recent fire). If there is more than a few weeks since the fire, some of this scorched foliage may have fallen and littered the ground... **Scorched**

2'. Foliage and smaller twigs partly to completely consumed by recent fire, branches mostly intact; little-to-no remaining scorched foliage ….. **Go to 3**.

3. Foliage and smaller twigs partly-to-completely consumed (including non-woody grasses and herbs); branches of woody plants mostly intact.. **Lightly burned**

3'. Foliage, twigs, small stems consumed, some branches may be still present, or all plant parts may be completely consumed. Any parts remaining are charred.. **Go to 4.**

4. Foliage, twigs and small stems consumed, some branches still present .... **Moderately Burned**

4'. All plant parts are either consumed or the remaining parts composed of deeply charred stems, or trunks .... **Heavily burned**

% Vegetation severity type per quadrant	**Unburned**	**Scorched**	**Lightly burned**	**Moderately burned**	**Heavily burned**
NW					
NE					
SE					
SW					
% Vegetation Severity type per plot (mean severity all quadrants)					

V. SUBSTRATE ASSESSMENT

Use following key to identify the fire severity of the substrate of each quadrant. Focus on the presence and condition of down logs, branches, and woody debris, leaf litter, duff, and soil conditions. Summarize proportion occupied by each severity type, then average per quadrant in table below. With increased protocol familiarity, you may be able to skip quadrant summaries and report substrate fire severity for the entire plot.

1. No fire-related substrate change; litter, duff, and soil have no recent ash, charr, or heat-related changes in mineral soil .... **Not burned**

1'. Fire related recent changes to substrate present; including charring, consumption, and ash; fallen logs partly burned or consumed .... **Go to 2.**

2. Litter partly blackened, duff nearly unchanged wood and leaf structures unchanged .... **Scorched**

2'. Litter charred duff at least, partly charred, exposed mineral soil is at least black, woody material (large branches, logs) is at least partly burned, rotten wood at least partly burned .... **Go to 3**.

3. Litter charred to partly consumed; duff partly charred, not altered to the full depth, recently fallen scorched leaves may be present. Any exposed mineral soil is lightly charred (usually brown or black). Any rotten wood is scorched to partly burned. Shallow roots (1-3 inches down) are not changed (not burned or shriveled), and the canopy and understory strata are mostly alive .... **Lightly Burned**

3'. Litter mostly to entirely consumed, ash is present, from coarse gray to fine powdery white, mineral \soil may or may not be altered, woody debris is mostly to entirely consumed. Logs are deeply charred, and rotten logs may be consumed.
…........ **Go to 4.**

4. Litter mostly to entirely consumed leaving coarse mostly light colored (grayish) ash; duff is deeply charred, but underlying mineral soil is not visibly altered. Woody debris mostly consumed, logs deeply charred, and burned-out stump holes are common .... **Moderately Burned**

4'. Litter and duff is completely consumed, at least some ash is whitish. Mineral soil is visibly altered, often reddish orange, and vitrious (glassy, brittle texture). Sound logs are deeply charred, and many logs are completely consumed. This level of severity is usually patchy throughout a stand .... **Heavily Burned**

% Substrate severity type per quadrant	**Unburned**	**Scorched**	**Lightly burned**	**Moderately burned**	**Heavily burned**
NW					
NE					
SE					
SW					
% substrate severity type per plot (Mean soil severity all quadrants)					

VI. VEGETATION DESCRIPTION (living vegetation only; fire effects may severely reduce or eliminate prior cover and structure)

% NonVasc cover:____Total % Vasc Veg cover:_____ ☐

% Cover - **Conifer tree / Hardwood tree:** ____/____ **Regenerating Tree:** ____ **Shrub:** ____ **Herbaceous:** ____ ☐

Height Class - **Conifer tree / Hardwood tree:** ____/____ **Regenerating Tree:** ____ **Shrub:** ____ **Herbaceous:** ____ ☐

Height classes: 1=<1/2m, 2=1/2-1m, 3=1-2m, 4=2-5m, 5=5-10m, 6=10-15m, 7=15-20m, 8=20-35m, 9=35-50m, 10=>50m

% Cover Intervals for reference: r = trace, + = <1%, 1-5%, >5-15%, >15-25%, >25-50%, >50-75%, >75%

Combined Vegetation Rapid Assessment/ Relevé and Post-fire Monitoring Field Form

(Version 9: March 24, 2021)

Database #: __________

VII. SPECIES SHEET

Stratum categories: T=Tree, A = SApling, E = SEedling,, S = Shrub, H= Herb, N= Non-vascular	**Woody pre-fire stems: 0=** no evidence of multi-stems**, 1 =** 2-3 stems per plant**, 2 =** 4- 7 stems**,** **3 =** > 7 stems per woody plant.

Proportion Sprouters: 0= no sprouters**, 1 =** less than 1/3 w/ resprouts**, 2 =** >1/3 -2/3 w/ resprouts**, 3 =** > 2/3 w/ sprouts	**Sprout length: 1 = <10 cm; 2 = 10-30 cm, 3 = >30 cm**	**Scorched crown vol. classes: 0 = 0%, 1 => 0-10%; 2=>10 –20%, 3 = >20-30%, 4 = >30-40%, 5 = > 40 – 50%, 6 = > 50-60% 7 = >60-70%., 8=>70-80%, 9=>80-90%, and 10=>90-100%.**

Height classes: 1=<1/2m, 2=1/2-1m, 3=1-2m, 4=2-5m, 5=5-10m, 6=10-15m, 7=15-20m, 8=20-35m, 9=35-50m, 10=>50m

			Regeneration (all individuals)		Re-sprout Information			Scorch and Char Information (For Woody, Trees > 5 m)				
Species (verify acronym)	Stratum	% Live foliar cover	Newly-shed seeds (Y,N)	Resprout-ing indiv's (Y,N)	Proportion woody sprt / sprt+nonspr't indiv's.	Woody pre-fire stems	Mean sprout length (woody & non)	Scorch Max height	Scorch Mean height	% Crown volume scorch	Char Highest point	Char Mean height

GLOSSARY

Beneficial Fire: A term used to collectively refer to prescribed fire, cultural burning, and managed fire. See separate definitions for each term. (California Wildfire and Forest Resilience Task Force, 2022)

Collaboration: A continuum of involvement between two or more parties coming together to work on projects, ranging from legally-mandated (the least community-oriented) to fully community-based and participatory forms of collaborative work. Though there are different levels of involvement across this continuum, there may be specific goals, values, capacities, and needs that drive community decisions to engage on a more or less involved level of collaboration. At every level, partners should strive to center the goals and priorities of communities to engage in these collaborative processes.

Conceptual Model: A visual diagram representing the relationships between key factors identified in a situation analysis believed to impact or lead to one or more conservation targets. A good model should link the conservation targets to threats, opportunities, stakeholders, and key intervention points. Sometimes known as a situation model. (Conservation Measures Partnership, 2020)

Condition Goal: The desired, measurable state for each metric against which monitoring data are compared. (Edson et al., 2016)

Conservation Target: Elements of biodiversity at a project site, which can be a species, community, vegetation type, and/or habitat on which a project is focused. For the purposes of the Marin Forest Health project the proposed targets are Bishop Pine, Coast Redwood, Douglas Fir, Open Canopy Oak Woodland, and Sargent Cypress forest. (Conservation Measures Partnership, 2020)

Contributing Factor: The indirect threats and other important variables that influence direct threats; sometimes called a root cause or underlying cause. (Conservation Measures Partnership, 2020)

Cultural Burn: The intentional application of fire to land by California Native American tribes, Tribal organizations, or cultural fire practitioners to achieve cultural goals or objectives, including for subsistence, ceremonial activities, biodiversity, or other benefits. Cultural burning can differ from prescribed fire in terms of size, seasonality, timing, prepping/ planning, and post-fire treatment. See definition for Beneficial Fire. (California Wildfire and Forest Resilience Task Force, 2022).

Ecosystem Services: The benefits that humans and other species obtain from ecosystems. (International Union for Conservation of Nature (IUCN), n.d.)

Fire Exclusion: The exclusion of natural and indigenous fire ignitions and policies to suppress all fires. (University of California Agriculture and Natural Resources, n.d.)

Fire Suppression: Activities, procedures, and policies developed and deployed to contain, control, and extinguish wildfires. (Cernak, 1996)

Forest Health: A condition of ecosystem sustainability and attainment of management objectives for a given forest area; usually considered to include forests with green trees, snags, resilient stands growing at a moderate rate, and endemic levels of insects and disease. Natural processes still function or are duplicated through management intervention, resulting in a more fire-tolerant forest condition and the elimination of unnatural woody biomass accumulations that have resulted from past fire suppression. Forest composition, structure, and function are within the range of conditions expected under natural disturbance regimes. Perception and interpretation of forest health are influenced by individual and cultural viewpoints, land management objectives, spatial and temporal scales, the relative health in stands that comprise the forest, and the appearance of the forest at a point in time. (Forest Climate Action Team, 2018, p.7)

Forest Health Attributes: Dynamic biophysical factors, natural processes, and stand conditions, e.g., age class structure, fire return interval, disturbance, canopy, dominance, processes and/or composition, that collectively describe an ecologically functioning forested ecosystem. (As used in *Marin Regional Forest Health Strategy*)

Goal: A formal statement of the desired project or program impact. It is a long-term aim or purpose that may or may not be achieved during the life of a project, e.g., By 2040 a viable sturgeon population will exist on the Danube River.
(Conservation Measures Partnership, 2020)

Impact: The desired future state of a conservation target.
(Conservation Measures Partnership, 2020)

Indicator: The species, community, or physical process (e.g., stream flow/water quantity) that provides an essential ecological function, or are indicative of essential habitat conditions, and are measured as an indication of health; indicators are akin to human vital signs such as blood pressure and pulse: easily measured and strongly correlated with overall condition, sensitive to stressors, and an early warning of potential problems. (Edson et al., 2016)

Interim Result: If/then statements in a results chain indicating short term outcomes. When linked together they lead to the outcome objective.
(Conservation Measures Partnership, 2020)

Managed Fire: The strategic choice to manage unplanned ignitions to achieve management objectives, such as ecosystem restoration or hazard reduction. Fire managed for resource benefit is typically deployed in wilderness areas, national parks, and other areas in public ownership under specific conditions or circumstances.
(California Wildfire and Forest Resilience Task Force, 2022).

Managed Wildfire: An unintentionally caused fire that is allowed to burn within the parameters determined by forest managers and fire protection personnel.
(Ryan et al., 2013)

Metric: Measurable data points that can be used to assess the relative health or threats for a given forest area by type. Metrics can be monitored over time to understand the impact of treatments. (As used in *Marin Regional Forest Health Strategy*)

Natural Capital: The world's stock of renewable and non-renewable natural resources that combine to yield a flow of benefits to people, otherwise known as ecosystem services. (Natural Capitals Coalition, 2021)

Objective: An outcome that is specific, measurable, achievable, realistic, results oriented, and time bound contributing to an overall goal. For example, by 2008, at least 70% of the target population in 8 major European cities is supportive of existing laws to conserve Russian sturgeon.(Conservation Measures Partnership, 2020)

Outcome: The desired future state of a threat or opportunity factor. An objective is a formal statement of the desired outcome. (Conservation Measures Partnership, 2020)

Prescribed Fire: The intentional application of fire to land for wildland management goals, including the prevention of high intensity wildland fires, watershed management, range improvement, vegetation management, forest improvement, wildlife habitat improvement, restoring ecological integrity and resilience, community wildfire protection, carbon resilience, enhancement of culturally important resources, and maintenance of air quality. Prescribed fires undertaken for any of these reasons are considered "public purpose" burns pursuant to state law. (Public Resources Code § 4491(a).) Prescribed fires are typically conducted in compliance with a written prescribed fire plan that outlines the conditions necessary for the burn to be "within prescription." (California Wildfire and Forest Resilience Task Force, 2022).

Resilience: The capacity of systems to absorb or recover from disturbance while undergoing change to retain desired ecosystem services and functions within a mosaic of forest types. (As defined for the *Marin Regional Forest Health Strategy* in Chapter 2: Resilience)

Result: The desired future state of a target or factor. Includes impacts, outcomes, and outputs.(Conservation Measures Partnership, 2020)

Results Chain: A tool that maps how a particular treatment leads to desired results. Results chains are diagrams that link if/then statements between the treatment and desired outcome. (Conservation Measures Partnership, 2020)

Scope: Definition of the broad parameters or rough boundaries (geographic or thematic) for where or on what a project will focus.
(Conservation Measures Partnership, 2020)

Stresses: Attributes of a conservation target's ecology that are impaired directly or indirectly by human activities (e.g., reduced population size or fragmentation of forest habitat). A stress is not a threat in and of itself, but rather a degraded condition or "symptom" of the target that results from a direct threat. Stresses are synonymous with degraded key attributes. (Salafsky et al., 2008)

Stressor: (sometimes called "threat"). Things that challenge the integrity of ecosystems and the quality of the environment, which may be natural environmental factors, or may result from the activities of humans; some stressors exert a relatively local influence, while others are regional or global in their scope. (Edson et al., 2016)

Threat: (sometimes called "stressor"). An often human-caused condition or unsustainable use that degrades one or more conservation targets (e.g., non-native invasive species, fire suppression or urban development) (Conservation Measures Partnership, 2020).

Treatment: Any combination of practices or coordinated actions designed to reduce or mitigate the negative effects of threats and contributing factors to the conservation targets. (As used in *Marin Regional Forest Health Strategy*)

Wildfire: Uncontrolled and/or unplanned burn from natural, e.g., lightning, or human caused, e.g., arson, ignition in wildlands and/or wildland-urban interfaces. (Tedim & Leone, 2020)

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APPENDIX A: BISHOP PINE

Bishop pine (*Pinus muricata*) forest health

White paper prepared for the Golden Gate Parks Conservancy

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Executive Summary

Bishop pine (*Pinus muricata*) is endemic to coastal California and Baja California. With a limited geographic distribution and several threats to its persistence, bishop pine is characterized as a 'vulnerable.' Bishop pine forests are adapted to high severity fire via post-fire seed release from serotinous cones, proceeding through early seral, mid-seral, and old-growth successional stages within approximately 100 years post fire. The structure and composition of bishop pine forests is expected to be distinct within each of three seral stages. Early seral (0-10 years post-fire) stands are characterized by very high tree density and species diversity with low fuel loads and low bishop pine seed availability. Mid-seral stands (10-50 years post-fire) are characterized by high tree density, low species diversity, high fuel loads, and moderate bishop pine seed availability. Old-growth stands (50-100 years post-fire) are characterized by low tree density, moderate species diversity, moderate to high fuel loads, and high bishop pine seed availability.

Key threats to bishop pine health include a potentially changing fire regime, increasing temperature and drought, non-native invasive plants, and non-native pine pitch canker disease—all which may alter bishop pine successional pathways and regional distribution. The relative importance of threats varies with seral stage. Resilience to fire is high in mid-seral and old-growth stands with live, seed-producing trees, but low in early seral stands that lack a seedbank or very old stands where bishop pine has senesced. Increasing temperature and drought may affect all seral stages, but effects may be strongest immediately following fire, during the establishment of post-fire tree seedlings. Invasive plant species can strongly impact the early seral post-fire period if they establish and compete with native vegetation. Pine pitch canker disease causes dieback and mortality in all seral stages. Currently, severity is greatest in mid-seral stands, but the disease is unlikely to be at equilibrium, posing substantial uncertainties regarding its effects on other seral stages. In addition, pine pitch canker disease is likely to cause changes to fuel profiles, fire behavior, and fire management operations in all seral stages; effects on post-fire regeneration and fire severity are less known and potentially minor.

Important knowledge gaps exist for all threats. Given the dynamic nature of these threats and the high level of uncertainty regarding their potential effects on bishop pine, six metrics are recommended to measure and monitor bishop pine forest health, with seral-stage specific target ranges. Metrics include bishop pine density, native plant species diversity, fuel profiles, bishop pine reproductive capacity, large snag and coarse woody debris abundance, canopy structure and texture. A key management recommendation is the implementation of a monitoring protocol that has been developed around these six metrics to measure bishop pine forest health in Point Reyes National Seashore. Additional management recommendations include:

- minimizing unplanned fire in early seral stands and raising awareness of potentially extreme fire behavior in stands severely affected by pine pitch canker
- avoiding density reduction for pine pitch canker mitigation due to unintended consequences
- implement monitoring following fuel reduction treatments in mid-seral stands near the WUI
- identify individual bishop pines with inherent genetic resistance to pine pitch canker disease
- applied experiments testing acceleration of development of mid-seral stands to old-growth
- applied burning experiments in old-growth to regenerate bishop pine prior to senescence

Managing for the conservation of bishop pine forests in and around the Point Reyes Peninsula will be well served by a combination of monitoring, applied experiments, and application of best practices that can mitigate threats to forest health.

Bishop pine background and natural history

Bishop pine (*Pinus muricata*) forests are an iconic ecosystem endemic to the coastal region of the Californian Floristic Province (Millar 1986a). Fossil evidence suggests bishop pine, along with closely related Monterey pine (*Pinus radiata*) and knobcone pine (*Pinus attenuata*)—collectively referred to as the California closed-cone pines (Barbour et al. 2007)—was once more widespread as part of the Madro-Tertiary flora in western North America (Axelrod 1967). The present-day distribution of bishop pine is restricted to relatively cool and moist sites near the Pacific coast, in isolated populations spanning from southwest Oregon to southern California (USA), as well as Baja California (Mex.) and the Santa Rosa and Santa Cruz Channel Islands (Axelrod 1967, Barbour et al. 2007). Bishop pine populations are divided into two mainland varieties, the northern var. *borealis*, which occurs north of Monterey, CA and the southern var. *muricata*, which occurs south of Monterey, CA; an island variety (var. *stantonii*) occurs on the Channel Islands (Millar 1986b, Millar 1983). Due to the relatively limited distribution of bishop pine, coupled with several threats to the persistence of the species (detailed below), it is listed as "vulnerable" on the Red List for the International Union for Conservation of Nature (https://www.iucnredlist.org/species/34058/2841776).

Bishop pine is a medium sized (approximately 12 to 24 m tall) and short-lived (typical life span of 80 to 100 years) tree with traits that are generally associated with strong adaptations to severe fire (Stuart and Sawyer 2001). Bishop pine possesses moderately serotinous cones, an adaptive trait where mature seeds are retained inside tightly sealed cone scales until the heat of fire (or extremely warm days) melts the resin bonds. Cone scales from southern populations of bishop pine remained closed at temperatures of 30 deg C, but 50% of cone scales opened at temperatures between 80 deg C and 130 deg C – above which no additional scales opened (Ostoja and Klinger 1999). Seed germination can be 80% successful when exposed to temperatures as high as 95 deg C, but germination fails when seeds are exposed to temperatures exceeding 125 deg C (Linhart 1978). Seeds within serotinous cones at the time of fire are typically protected from such extreme temperatures. Serotiny varies across the distribution of bishop pine, generally increasing in warmer and drier environments where cone production is prolific and serotiny is extreme (Millar 1986a). Further, bishop pine is reproductively mature at a young age (approx. 5 years old, Holzman and Folger 2005), has relatively thin bark, and retains low foliage that can easily carry fire into the crown (Davis and Borchert 2006)—all traits that are associated with adaptations to reproduce after severe fire (as opposed to resisting or surviving fire).

The typical fire regime in bishop pine forests is best understood as a stand-replacement, or high-severity (near 100% mortality of pre-fire trees) regime (Stuart and Stephens 2006). Fires likely occurred historically in the late summer or early fall when dry periods coincided with warm, dry winds originating from the east (e.g., Diablo winds in Northern California) and an ignition source. Due to relatively low frequency of lightning ignitions on and around the California coast (Keeley and Syphard 2018), anthropogenic ignitions from Indigenous peoples were likely an important component of the fire regime throughout the Holocene (Keeley 2002, Keeley 2005). However, as much of the documented practices of cultural burning were focused on promoting grasslands, it is unknown if fires were intentionally set in bishop pine forests or if fire transferred from adjacent grasslands. Historically, fire sizes were likely at least several hundred hectares; however, the exact fire history of bishop pine is difficult to reconstruct because of two reasons.

First, in stand-replacing regimes, there are very few, if any, trees that survive fires and retain fire scars—the absence of which makes it near impossible to reconstruct multiple past fire events. Second, in stand-replacing regimes, age/cohort reconstruction is typically used to reconstruct past fire patches by mapping the contiguous extent of the cohort of trees established since the last fire (Romme 1982, Hemstrom and Franklin 1982)—but comprehensive information on bishop pine age cohorts is lacking throughout the distribution of bishop pine (Stuart and Stephens 2006).

The combination of bishop pine traits and the general fire regime throughout most of its range leads to a general pattern of even-aged stands that originated as a single cohort of pulsed regeneration following the most recent stand-replacing fire. These stand dynamics have been documented in northern (e.g., Millar 1986a, Harvey et al. 2014c) and southern (e.g., Urza et al. in review) mainland populations of bishop pine, where high-intensity fires (prescribed fire and wildfire) can lead to post-fire seedling densities that are several orders of magnitude greater than the pre-fire stand density. Although some evidence suggests that low-intensity fires can also result in even-age stands through killing of canopy trees and releasing seed from serotinous cones (Sugnet 1985), most accounts of prescribed fire in bishop pine forests result in high-intensity crown fires that cause near 100% above-ground vegetation mortality and initiate a post-fire cohort (Urza et al. in review).

In the absence of fire, regeneration is possible, though more idiosyncratic and sparse than following fire (Millar 1986a). Bishop pine has moderate to low shade tolerance (McCune 1988) and is a poor competitor with neighboring shrubs (Harvey and Holzman 2014)—hence the high establishment success after severe fire when growing space is available. However, if seeds are released from open cones, bishop pine seedlings can germinate and establish in open, rocky sites with poor soil and sparse vegetation—where competition is low from other woody vegetation (Sugnet 1985, Millar 1986a). Such establishment is evident along roadsides and trail breaks that abut older stands. Regeneration of bishop pine in the absence of fire has been documented in var. *stantonii* on Santa Cruz Island, where low-productivity and rocky sites can provide refugia from competition by other woody vegetation (Walter et al. 2005). However, the Santa Cruz Island populations of bishop pine are distinct subpopulations with different ecological dynamics than the mainland populations (Millar 1986b) and may therefore have a different evolutionarily relationship with fire (Linhart 1978). Recognizing these above exceptions, for purposes of this report and usefulness to managing for bishop pine forest health in Marin County, we focus hereafter primarily on the more general stand-replacing fire regime and even-age cohort stand dynamics of bishop pine forests.

Forest health attributes depend on seral stage

Similar to temperate and boreal forests elsewhere that are characterized by stand-replacing fire regimes, bishop pine forests proceed through generally consistent seral stages in the interval between stand-replacing fire events. Although these stages represent discrete points along a temporal continuum and there can be variability in forest structure and pathways at any point in time (Harvey et al. 2011, Harvey and Holzman 2014), it is nonetheless useful to organize stand dynamics into seral stages. Such concepts are applied in forests in other stand-replacing fire regimes such as subalpine forests in the Rocky Mountains, boreal forests in northern latitudes, and wet coastal forests in the Pacific Northwest (Donato et al. 2012, Franklin et al. 2018). As forest structure and function changes drastically among seral stages, this can provide a framework for understanding the range of variability of key structural and compositional attributes that are within the natural range of variability (NRV) and would be presumed to be 'healthy' and resilient to stressors. The early- to mid-seral stages are the stages for which there is the most published literature on bishop pine forest dynamics. Much research followed the 1995 Vision Fire in Point Reyes, which burned through 5000 ha, of which nearly 500 ha was old-growth bishop pine forest. However, data from several monitoring reports on nearby old-growth stands that have not burned in more than half a century provides insight into old-growth characteristics of the bishop pine conservation target.

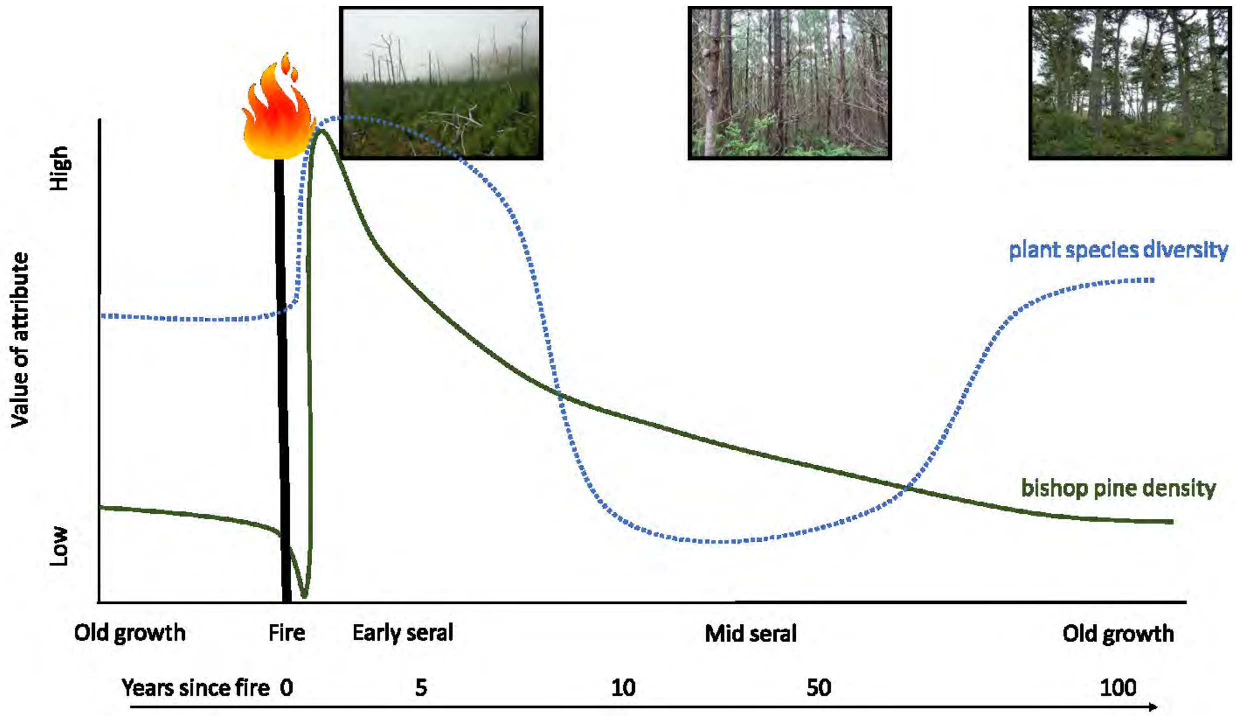

Figure 1. Generalized trends of key attributes of forest structure (Adopted from Franklin et al. 2018 and Harvey and Holzman 2014)

Disturbance and legacy creation stage

Severe (i.e., stand-replacing) fire that kills most or all of the above-ground vegetation is the characteristic disturbance that resets the sere, or creates early seral conditions. While such fires can be considered frequent on an absolute scale (e.g., 50-80 years apart) compared to other forests with infrequent, stand-replacing regimes (e.g., several centuries in subalpine forests), they are infrequent relative to the lifespan of bishop pine trees (approx. 80 to 100 years, Stuart and Sawyer 2001) and the pace of stand structural development. When fires occur, they leave myriad biological legacies—living or dead biologically derived structures that persist through disturbance (Franklin et al. 2000)—in the form of coarse woody debris, standing snags, and a range of reproductive structures (canopy seedbanks, soil seedbanks, underground root structures for re-sprouters).

Figure 2. Early seral bishop pine forest 4 years post-fire. Abundant bishop pine seedlings (approx. 100,000 ha^{-1} are beginning to dominate and shade out post-fire colonizing herbaceous plants. Standing snags are the pre-fire bishop pine trees that were killed in the fire event but released seed necessary for the post-fire cohort to establish. Photo location: Diablo Canyon, CA. Photo credit: B. Harvey

Early seral stage (approximately 0-10 years post-fire)

The early seral stage of bishop pine forest-stand development is characterized by high plant species diversity, very high density of small bishop pine seedlings, dense and short stature vegetation, and standing snags from fire-killed trees (Figure 1, 2). Within months following fire, tree, shrub, and herbaceous regeneration from seed and re-sprouting structures rapidly colonize and/or begin to reoccupy burned stands (Ornduff and Norris 1997). The fire-catalyzed synchronous release of the bishop pine canopy-seedbank leads to extremely high seedling density 1 year post-fire, which can average as great as 250,000 seedlings ha^{-1} (Holzman and Folger 2005). Species richness is high, mostly composed of disturbance adapted broad-leaf plants that have a range of adaptations to fire. Dominant plant forms (measured by percent cover) in the first year post fire are broadleaved herbaceous plants in the family Fabaceae (many of which have nitrogen-fixing symbioses with bacteria in their roots) and shrubs that sprout from fire-stimulated soil seedbanks (e.g., *Ceanothus thrysiflorus* and *Arctostaphylos* spp.) or resprout from roots (e.g., *Baccharis pilularis*). Re-sprouting trees (e.g., *Quercus agrifolia*, *Umbellularia Californica*, *Arbutus menziesii*, and *Notholithocarpus densiflorus*) are also present, but lower in percent-cover dominance in the early seral stage (Holzman and Folger 2005). Species richness typically peaks 2-yr post-fire and evenness is highest in the first year post-fire, before the dominant trees and shrubs crowd out smaller statured and shade intolerant plants toward the later end (e.g., 10-yr post-fire) of the early seral stage (Holzman and Folger 2005, Harvey and Holzman 2014, Harvey et al. 2014c). Species diversity and bishop pine density (dominance) are inversely related in the early seral stage; that is, species diversity is greatest in stands where bishop pine dominance is lower –likely due to the low light environment under a dense canopy of bishop pine saplings (Harvey and Holzman 2014). Vegetation height is mostly less than 1-m in the first year post-fire, but can reach heights of 2-4 m by 10-yr post-fire. The first several years post-fire are characterized by high densities of fire-killed standing snags (~ 100-1000 snags per ha), which have mostly fallen by the end of the early seral stage. Throughout the early seral stage, bishop pine trees grow and come to dominate aerial cover by 10 to 15 years post-fire as they go through an intense period of density-dependent thinning (Harvey et al. 2011, 2014c, Harvey and Holzman 2014). With very little bishop pine seedling establishment occurring in the absence of fire, density steadily decreases from ~250,000 ha^{-1} 1-yr post-fire to an average of ~5,000 ha^{-1} in the second decade after fire (Harvey and Holzman 2014).


Figure 3. Mid-seral bishop pine forest 14 years post-fire. Bishop pine density (approx. 50,000 ha^{-1}) and canopy dominance is very high, excluding most understory vegetation except for shade tolerant shrubs and ferns (*Vaccinium ovatum* pictured here). Photo location: Inverness Ridge, CA. Photo credit: B. Harvey

Mid-seral stage (approximately 10-50 years post-fire)

By approximately 10 years post-fire and persisting until approximately 50 years post-fire, bishop pine stands are in a mid-seral stage, characterized by comparatively low plant species diversity and moderately high density (approximately 1,000 to 50,000 stems ha^{-1}) of mature bishop pine trees (Figure 1, 3). Canopy closure resulting from bishop pine dominance leads to dark conditions inside stands. Understory vegetation is sparse and composed of shade-tolerant evergreen shrubs (e.g., *Vaccinium ovatum*, *Frangula californica*, *Gaultheria shallon*, *Rubus ursinus*) where bishop pine density and canopy cover are high. Canopy gaps where initial bishop pine dominance was low are often dominated by *Ceanothus thrysiflorus* and support slightly greater understory plant diversity (Harvey et al. 2014c, Harvey and Holzman 2014). Most fire-killed snags have fallen by ~15 years post-fire, and high moisture in coastal regions leads to rapid decomposition of logs once on the ground. Little research has tracked the transition from mid-seral to old-growth stages of bishop pine forest development, but at some point several decades after fire, bishop pine trees reach their maximum height (~25 m) and crown width, resulting in a cessation of density-dependent mortality. Mortality from processes other than competition with neighboring trees (e.g., insect, fungi, physical damage from wind) then starts to cause opening of the otherwise uniform and dominant bishop pine canopy.

Figure 4. Old-growth bishop pine forest in an area that has not burned for approx. 80 years. Bishop pine density (approx. 100 stems ha^{-1}) and canopy cover is low, leading to greater co-dominance by broadleaf trees and a wider range of understory shrubs. Photo location: Inverness Ridge, CA. Photo credit: B. Harvey

Old-growth stage (approximately 50-100 years post-fire)
A sparse canopy of bishop pine, co-dominance by broadleaf evergreen trees, and moderately high plant species diversity, characterizes the old-growth stage of bishop pine forest stand development (Figure 1, 4). Density of tall (~25 m) and large diameter (50-80 cm DBH) bishop pine trees is approximately 50-500 stems ha^{-1} and accounts for less than 20% of the canopy cover. However, these relatively sparse bishop pine trees account for half or more of the total tree basal area, which averages approx. 25 m^2 ha^{-1} (Gaman 2019). The forest canopy is not closed as it is in the mid-seral stage, but is instead characterized by gaps between crowns of bishop pine and co-dominant broadleaf trees (*Arbutus menziesii*, *Quercus agrifolua*, *Umbellularia californica*, *Notholithocarpus densiflorus*). Since these broadleaf tree species can regenerate in the absence of fire, with more time since fire they will dominate more of the canopy. When shrub and herbaceous cover is high, bishop pine regeneration is rare in the absence of fire, resulting in fewer than 5 seedlings ha^{-1} on average in old-growth stands (Gaman 2019), and limited to rocky and open sites near a seed source (Millar 1986a). With the opening of the canopy, increased light availability leads to understory plant species diversity that is greater than the mid-seral stage, but not as diverse as the early seral stage. In addition to

seedlings of broadleaf trees, the understory is dominated by evergreen shrubs and ferns (*Polystichum munitum, Pteridium aquilinum*), which collectively can total to 80% cover in the understory (Gaman 2019).

Bishop pine on Point Reyes Peninsula

The bishop pine forests on the Point Reyes Peninsula are primarily restricted to the eastern (inland) and western (coastal) slopes of Inverness Ridge. Bishop pine forests are the dominant plant community at higher elevations on Inverness Ridge, but sparse stands (i.e., woodlands) intermix with some dense stands continuing down to sea level at Tomales Bay and the Pacific Ocean. Isolated stands occur throughout other locations on and around the Point Reyes Peninsula and further inland in Marin County that are relicts of a once more widespread local distribution (Millar 1986a). Bishop pine in Point Reyes is the northern variety (*Pinus muricata* var. *borealis*) though they are intermediate in their trait characteristics between populations in Northern California and Southern California (Millar 1983).

The Point Reyes Peninsula has been occupied by people for most of the Holocene epoch (since approx. 10,000 years BP) and the influence of humans on the vegetation and fire regimes continues today. Coast Miwok people used fire as a land management tool to burn grasslands and charcoal evidence suggests that human-ignited fires were a major part of the local fire regime since approximately 3,500 years BP (Anderson 2005). Temporal data at high resolution (e.g., annual) are not available to reconstruct fire return intervals (FRIs) for the time when Coast Miwok people occupied the Point Reyes Peninsula prior to European colonization. However, wide ranging FRIs from 3 to 188 years in coast redwood forests in the Santa Cruz Mountains suggest pre-colonization anthropogenic influences on the fire regime that were variable in space and time (Jones and Russell 2015). Frequent fall burning approaching annual frequency occurred in grasslands along the coast to promote prairie habitat, and would have likely spread into forest areas occasionally (Sugnet 1985). In the mid- to late-1700s, Spanish colonizers settled in the San Francisco Bay and by the 1820s had heavily impacted Coast Miwok populations, changing human influence on the fire regime.

During the Spanish era, the primary land uses on the Point Reyes Peninsula were grazing and logging. Logging in the bishop pine forest would have been mostly for firewood, as opposed to harvesting of large Douglas-fir and coast redwood trees for dimensional lumber. Ranchers during the Spanish era intentionally set fires, but for the purpose of clearing shrubland and promoting grazing pasture (Sugnet 1985). Although anthropogenic fires were concentrated in the grasslands, fire scars on coast redwood and Douglas-fir trees demonstrate that fires also expanded into forested areas (Brown et al. 1999). Fire return intervals (FRIs) were 20 to 30 years in coast redwood (Brown et al. 1999), and likely at least some of these fires would have burned in bishop pine forests, resulting in a slightly longer FRI in bishop pine forests than in the adjacent coast redwood forests. Following the Spanish era, in the 1850s when California became a state, more than 30 dairies and cattle ranches occupied the peninsula, with larger ranches toward the north and east (Watt 2002). Several large fires in and around the peninsula are noted between the late 1880s through the 1940s, after which two small fires occurred in the mid-1950s and 1970 (Sugnet 1985, Brown et al. 1999). In 1962, the Point Reyes National Seashore (PRNS) was formed and further broad-scale active manipulation of vegetation within the unit boundaries was slowed.

The 1995 Vision Fire: summary of post-fire research on PIMU forests

The 1995 Vision Fire catalyzed research and understanding on the fire ecology, post-fire response, and general stand dynamics of bishop pine forests. In early October 1995, a wildfire ignited from an unattended campfire just outside the PRNS boundary on the east side of Mt. Vision. During a 4-day period of warm and dry easterly winds (Diablo Winds), the Vision Fire burned more than 5,000 hectares on the Point Reyes Peninsula, mostly within PRNS. Although initial concern was high regarding the capacity for the bishop pine forest to recover following fire, dense seedlings of bishop pine blanketed the burned area within months, and plant species diversity was higher than pre-fire in the bishop pine forest (Ornduff and Norris 1997, Ornduff 1998). Prior to the Vision Fire, bishop pine forest covered 756 ha; post-fire bishop pine expanded to cover 993 ha. Expansion within the burn perimeter, where the bishop pine forest extent nearly doubled in area (from 348 ha pre-fire to 584 ha post-fire) was concentrated primarily in areas that were pre-fire coastal scrub and grassland on the lower slopes of the Pacific side of Mt Vision (Forrestel et al. 2011).

Following the Vision Fire, several trends were characterized through research tracking succession and stand development (Harvey et al. 2014c). First, the Vision Fire demonstrated the interconnectedness of ectomycorrhizal fungi communities and bishop pine. Fire caused rapid turnover in the ectomycorrhizal fungi community (Baar et al. 1999, Grogan et al. 2000), and post-fire bishop pines colonized by *Rhizopogon* sp. fungi demonstrated enhanced growth compared to plants without ectomycorrhizal fungi (Kennedy and Peay 2007). Second, the bishop pine forest demonstrated tremendous resilience to fire. Bishop pine density and plant species diversity were extremely high in the first two years following fire (~250,000 seedlings per hectare and 34 plant species per plot, respectively) (Holzman and Folger 2005), and were immediately followed by a period of rapid successional change.

Over the next decade and a half, bishop pine sapling density decreased by >90% through intense and naturally occurring density-dependent thinning (to an average of ~15,000 stems per hectare), and plant species diversity decreased by nearly 40% (Harvey and Holzman 2014). The fire also served as a catalyst for bishop pine forest expansion, as the bishop pine forest extent nearly doubled (Forrestel et al. 2011) from a combination of expansion from the edge of existing pre-fire forest and new stand development from seeds provided by isolated pre-fire trees (Harvey et al. 2011). These newly established tree islands served as important locations for ectomycorrhizal fungi, where greater than 40 ectomycorrhizal fungi species were found on single isolated trees established post-fire (Peay et al. 2010). Finally, the bishop pine forest within the Vision Fire footprint has been one of the areas most severely affected by pine pitch canker disease (PPCD) in California, which has expanded from a few isolated stands in 2006 (Crowley et al. 2009) to most of the forest by 10 years later (Gordon 2017).

Current state of bishop pine and seral stage distribution

Currently, there are approximately 1,000 hectares of bishop pine forest on the Point Reyes Peninsula, which are primarily in two different stand development stages, depending on whether they were burned in the 1995 Vision Fire (Figure 5). Slightly more than half of the bishop pine forest on the Point Reyes Peninsula (578 ha) is in the mid-seral stage (25 years old), having originated immediately following the 1995 Vision Fire. Nearly all of the mid-seral bishop pine stands are located on the southwest slopes of Inverness Ridge, stretching from the crest of the ridge to the Pacific Ocean.

The remaining extent of bishop pine forest on the Point Reyes Peninsula (430 ha) is in the old-growth stage (exact stand age unknown, but approximately 80 years old or greater) likely having originated from fires in the 1940s or earlier. While records prior to the modern satellite era of fire databases (e.g., MTBS) are sparse, accounts exist for some fire events in the bishop pine forest on Point Reyes Peninsula between the late 1800s and the start of the satellite fire record in 1984. Newspaper reports note a large fire near Point Reyes in October 1887, though the spatial location within the peninsula is unclear (Sugnet 1985). In October 1927, a fire that was set to clear shrubs along the slopes of Inverness Ridge escaped into bishop pine stands on Mount Vision (Sugnet 1985). A 430 ha fire is mapped in Tomales Bay State Park with an unknown date between 1917 and 1934, which covered the approximate extent of bishop pine stands within the park (https://data-nifc.opendata.arcgis.com/). Smaller, isolated fires in bishop pine stands are recorded during the 1950s in and around Mt Vision, though perimeters are not known (Sugnet 1985). Nearly all of the old-growth bishop pine stands are located along the upper elevations of the west slope of Inverness Ridge (north of the Vision Fire perimeter) or on the northeast slopes of Inverness Ridge between the crest of the ridge and Tomales Bay.

Collectively, the fire history data and fire perimeters from Marin County Fire records suggest most of the old-growth forest in Point Reyes established following fires between the years 1917 and 1934, with some likely originating from the 1887 fire—though exact dates of some fires are unknown (Figure 5). Presumably, most or all of the historical fires were stand-replacing, high-severity fires, as even two accounts of low intensity prescribed surface fires in PRNS in the 1970s resulted in near 100% mortality of bishop pine (Sugnet 1985).

Currently there is no known bishop pine forest on the Point Reyes Peninsula in the early seral stage, because of no recent fires burning bishop pine stands since the 1995 Vision Fire. The Woodward Fire in 2020 burned southwest of the Vision Fire perimeter with a small area of overlap, however only a few isolated and very small stands of bishop pine were affected (Figure 5).

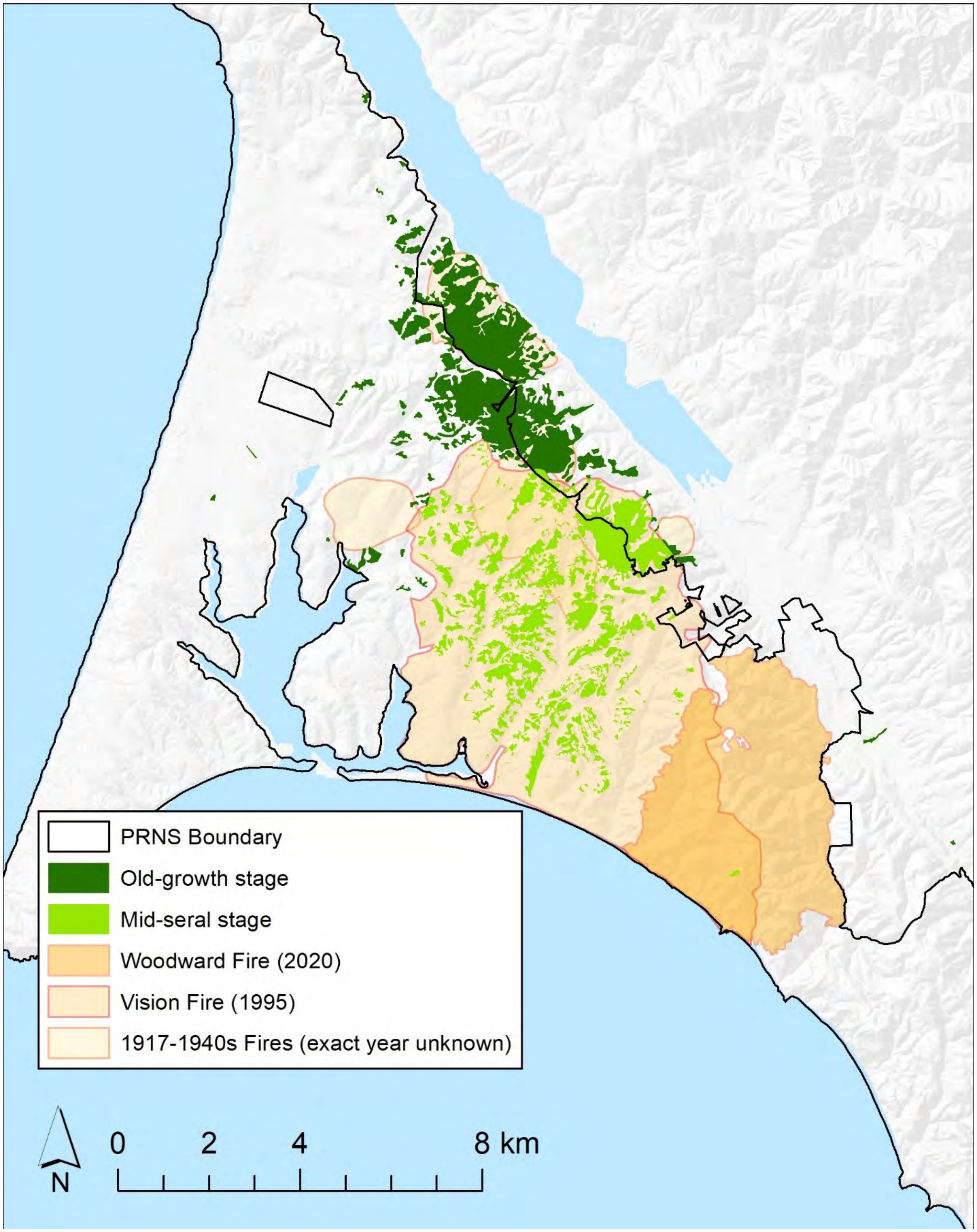

Figure 5. Bishop pine forest on the Point Reyes Peninsula by stand age, based on vegetation layers for GGNRA in 1995 and 2005 used in Forrestel et al. (2011). Fire perimeters are overlain with darker colors signifying more recent fires. Perimeters are from the National Interagency Fire Center (https://data-nifc.opendata.arcgis.com/).

Several key threats to bishop pine forest health are summarized in Table 1; although many relate to knowledge gaps where further research is needed (see later section). The primary threat is the likely severe, but currently unknown, impacts to the population, physical structure, and ecological function of the bishop pine forest from mortality associated with PPCD. The second threat is potentially altered fuel structure and fire hazard, which is driven by PPCD-associated mortality. The third threat is the direct effect of climate warming and associated changes in precipitation and moisture availability for bishop pine forests. The fourth threat is forest resilience to fire associated with potential alterations to the natural range of variability (NRV) in the fire regime in bishop pine forests. The fifth threat is the potential effects of non-native invasive species on the bishop pine forest. Each threat and associated knowledge gaps are discussed in detail in the following section.

Table 1. Threats to bishop pine forest health.

			
Threat	**Early seral** **(~0-10 years post-fire)**	**Mid-seral** **(~10-50 years post-fire)**	**Old-growth** **(~50-100 years post-fire)**
Pine Pitch Canker Disease (PPCD)	Unknown, as pitch canker was not introduced in PRNS until stands were mid-seral	Pitch canker incidence (~75% of trees) and severity (~50% canopy dieback) is greatest in mid-seral stands	Pitch canker incidence and severity is lower in old-growth stands, though less well surveyed
Fuel structure / fire hazard altered from PPCD	Fuels within the NRV are limiting to fire and would have a low likelihood of supporting stand-replacing crown fire. Threat is high if fuels are sufficient to carry fire prior to reproductive maturity of bishop pine.	Fuels within the NRV are sufficient to carry stand-replacing crown fire but not support high intensity fire that would burn important ecological legacies (e.g., seeds). Pitch canker disease may alter fuel profiles and fire hazard.	Fuels within the NRV are sufficient to carry stand-replacing crown fire but not support high intensity fire that would burn important ecological legacies (e.g., seeds). Pitch canker disease may alter fuel profiles and fire hazard.
Climate warming and associated drought stress	Potential increased mortality of post-fire tree seedlings, lowering establishment rates	Potential increased drought stress in dense stands, accelerating density dependent mortality	Potential increased drought stress and mortality for old trees, shortening longevity of old growth stage
Resilience to fire under altered fire regime	Short-interval reburn prior to seed/cone production on bishop pine trees can lower resilience	Resilience to fire would be expected to be high with sufficient canopy seedbank	Fire exclusion or suppression could lead to senescence risk (mortality before fire) / low resilience
Non-native and invasive plant species	Likely high risk from abundant available space, firefighting operations, re-seeding for erosion control, especially for disturbance adapted and shade intolerant spp. such as Australian fireweed.	Potentially high risk for shade-tolerant understory plants such as English Ivy. Potential for stands impacted by PPCD to be more susceptible to non-native and invasive plant species.	Potentially high risk for species such as Himalayan blackberry and English Ivy. Potential for stands impacted by PPCD to be more susceptible to non-native and invasive plant species.

Threats and contributing factors
Pine pitch canker disease (PPCD)

Pine pitch canker disease (PPCD) is a major threat to the health of bishop pine forest via direct and indirect effects. Direct effects include fundamentally altering the population, physical structure, and ecological function of bishop pine forests, while indirect effects are via changes to fuel structure and fire hazard. Pine pitch canker disease is caused by the fungal pathogen *Fusarium circinatum*, which is suggested to be native to Mexico and introduced to pine forests in coastal California in the mid-1980s (Gordon et al. 1997, Wikler and Gordon 2000). *Fusarium circinatum* affects multiple host trees in the genus *Pinus*, and has been most notable on Monterey and bishop pine populations near the California coast (Storer et al. 1997). Localized infections, often aided by wounds caused by penetration of tree bark from native beetles (Storer et al. 2004) result in cankers, which then girdle conductive tissue and lead to branch or crown dieback (Storer et al. 1997).

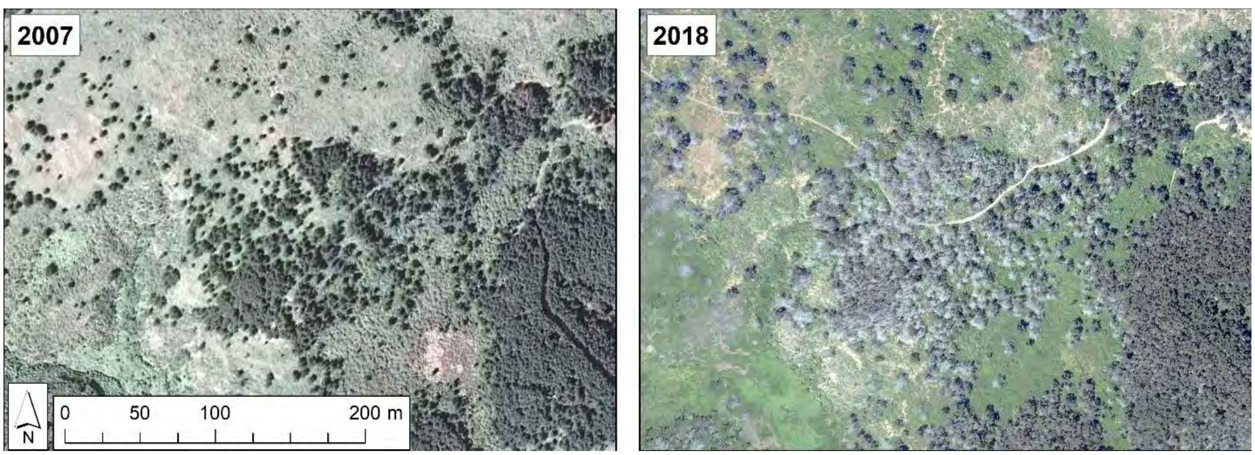

Figure 6. Progression of bishop pine mortality caused by PPCD along the Estero Trail north of Muddy Hollow in PRNS. In 2007, very few trees were infected (green crowns) and by 2018 mortality was near 100% (gray crowns) near the center of the aerial photograph (source: marinmap.org).

Across the Point Reyes Peninsula, the incidence (percentage of trees infected) and severity (degree of damage per tree summed across all trees in a plot) of PPCD has increased steadily since the early 2000s (Figure 6). First discovered in PRNS in 2006, in 2007, the aerial extent of PPCD in the PRNS bishop pine forest was less than approximately 5 ha, accounting for less than 1% of the bishop pine forest in PRNS (Crowley et al. 2009). Initial analyses of the spatial distribution of PPCD in 2007 indicated that PPCD presence was not strongly associated with topographic variables (e.g., elevation, slope, aspect, and distance from Drakes Bay). However, these analyses were from very early in pitch canker spread, and as the disease was far from equilibrium with the potential extent, inference for the eventual spatial distribution was limited (Crowley et al. 2009). Between 2011 and 2016, a series of 16 monitoring plots (each containing 20-30 bishop pine trees) distributed across the post-Vision-Fire bishop pine population were installed to track the progression of PPCD (Gordon 2017). Disease incidence and severity in 2011 were greater in low-density bishop pine stands, which tend to be lower elevation and in areas where the bishop pine forest expanded following the 1995 Vision Fire. In 2011, incidence and severity were 55% and 28%, respectively, in low-density stands, compared to 6% and 2% in high-density stands (Gordon 2017). The initially higher incidence and severity of PPCD in low-density stands at lower elevations could relate to proximity to a potential introduction site – a Monterey pine plantation near Home Bay in Drakes Estero. From 2011 to 2016, incidence and severity monotonically increased in every plot between each re-measurement interval, and by 2016, incidence and severity were 95% and 79%, respectively, in low-density stands, and 47% and 23% in high-density stands (Gordon 2017). By 2020, observations indicate that the disease continues to spread and has caused canopy dieback exceeding 50% across broad extents of bishop pine forest.

The effects of PPCD on bishop pine are most concentrated in mid-seral stands, and impacts to stands of other stages are either unknown or potentially less severe. The timing of the first discovery of PPCD on Point Reyes Peninsula coincided with the period in which most forest stands were transitioning from early seral to mid-seral; therefore impacts in early seral bishop pine forests are unknown. In populations of bishop pine near San Luis Obispo (CA), PPCD has been documented in early seral stands, though incidence and severity are much lower than observed in the mid-seral stands in PRNS (Urza et al, in review). In old-growth bishop pine stands on the Peninsula (i.e., those not burned in the 1995 Vision Fire), incidence and severity of PPCD is also low (Gaman 2019). However, old-growth stands further north in the bishop pine distribution (Mendocino and Sonoma Counties) are experiencing dieback with unknown proximal causes. Drought mortality is suspected, but PPCD has been observed on dead and dying bishop pine trees (Lee et al. 2019).

The effects of the drastic expansion of PPCD are a major threat to bishop pine forest health at PRNS, with many knowledge gaps. Such a widespread mortality event in the absence of fire could be detrimental to local bishop pine forest health for several reasons. First, the natural disturbance regime for bishop pine forests is characterized by population cycles that are driven by fire. Populations increase by several orders of magnitude following a stand-replacing fire and release of seed from serotinous cones, and then steadily decrease as stands thin out through density-dependent mortality (Harvey et al. 2014c, Harvey and Holzman 2014). This process results in the largest trees outcompeting their neighbors, with mortality restricted primarily to smaller trees—all resulting in relatively steady live tree basal area among stands that have full canopy closure (Harvey et al. 2011).

However, mortality caused by PPCD in mid-seral stands is occurring across all tree size classes, which represents a substantial departure from population dynamics within the natural disturbance regime with unknown consequences. Second, the widespread canopy dieback caused by PPCD likely causes important changes to the physical structure and microclimate with bishop pine forests. The increase in resource availability likely provides opportunities for compensatory growth in shrubs and herbs and may provide establishment opportunities for bishop pine if seed are released. However, the vegetation dynamics following severe PPCD-caused canopy dieback have not been documented. Finally, a key mechanism of resilience to fire for bishop pine is sufficient viable seed stored in the canopy seedbank when fire occurs. PPCD may influence the number of live reproductive individuals present in the canopy at the time of fire, producing unknown effects on seed availability. Further, whether seed in cones of trees impacted or killed by PPCD remain viable is unknown, but critically important.

In addition, there are still many unknowns about the dynamics of PPCD itself, which have important consequences for bishop pine forests in the future. Trends in fog cover and PPCD incidence and severity on Monterey pine forests on Central California suggest that duration of fog cover (and associated moisture) is a key requirement for *Fusarium circinatum*, and that warmer and drier conditions with less fog may halt the spread of PPCD, which declined with respect to new infections following substantial mortality (Gordon et al. 2020). If, as the climate warms, fog cover duration decreases in the Point Reyes Peninsula, PPCD incidence and severity may decrease. Alternatively, warmer and drier conditions with less fog cover have been linked to bishop pine stress and widespread mortality in Channel Islands populations (Baguskas et al. 2014, 2016, Fischer et al. 2016), and may offset the effects of fog reduction on PPCD. Interactions among stress from PPCD and drought stress associated with changes in fog regimes are also likely important, but are currently unknown.

There is evidence of variation in susceptibility of bishop pine to PPCD. Results from a single laboratory study suggest 27% of individuals inoculated with *F. circinatum* did not develop significant lesions, demonstrating inherent genetic resistance to PPCD (Schmale and Gordon 2003). Further, for trees that developed lesions, lesion size declined with multiple inoculations, suggesting that systemic induced resistance, or the ability for individual trees to develop disease resistance over time, is common in bishop pine. Studies have shown similar findings for *Pinus radiata* with respect to inherent genetic resistance (Gordon et al. 1998) and systemic induced resistance (Reynolds et al. 2016) to *F. circinatum* and PPCD. Recent findings from *P. radiata* indicate that individual trees that were infected became free of symptoms over a period of <15 years, with new infections also declining over that period (Gordon et al. 2020). These findings suggest that breeding programs could be initiated in the future to improve genetic resistance in these species (Wingfield et al. 2008), and that susceptibility may also vary temporally. Greenhouse trials suggest that exposure of *P. radiata* seeds to soil containing *F. circinatum* expressed greater resistance to disease than individuals that were not exposed (Swett and Gordon 2017). Furthermore, two fungal endophytes of several *Pinus* spp. have been identified for possible use as biological control agents, as they are associated with reduced disease severity in hosts (Martinez-Alvarez et al. 2016). However, operational feasibility of seed exposure or use of endophytes as biological controls have not been shown in the field.

Potentially altered fuel structure and fire hazard from PPCD
(contributing factor: PPCD)

Virtually no information exists on the potential effects of PPCD on fuel profiles or fire hazard, making this a critical knowledge gap. However, insights can be gained from much research in other conifer forest systems with similar fire regimes that have experienced widespread tree mortality from other agents. Bark beetles in the genus *Dendroctonus* have caused widespread mortality across large swaths of forest in North America (Raffa et al. 2008, Meddens et al. 2012), and much research has focused on the effects of beetle-caused tree mortality on subsequent fuel structure and fire hazard (Hicke et al. 2012). While key differences between tree mortality caused by beetle outbreaks and PPCD exist (and are explained in detail below), until there is more empirical study of the interactions of PPCD and fuels/fire, information from bark beetle outbreaks and fire likely serves as the best potential surrogate. Bark beetles and PPCD are both agents that cause mortality primarily via girdling of the bole and stem conductive tissue of the affected tree, leading to some probable similarities in how fuels are changed in affected stands. Further, the effects of PPCD on fuels and fire hazard, similar to those of bark beetle outbreaks, likely change over time since tree mortality.

Therefore, we describe potential effects using the stages developed for beetle outbreaks with stages that represent the post-outbreak structural trajectory characterized as "red," "gray," and "silver" (Simard et al. 2011, Hicke et al. 2012, Donato et al. 2013). The red stage occurs 0-2 years following tree mortality, when dead trees retain dead (red) needles. The gray stage occurs 3-10 years following tree mortality, as trees have shed needles and begin to shed smaller branches, but retain larger branches and remain standing as snags. The silver stage occurs 2-3 decades following tree mortality and characterizes the time when most dead trees remain standing as snags with few to no branches, or fall to the forest floor. We use these stages because as the disease impacts spread, all stages will be present on the landscape until the spread has completed and stages all go toward silver and later. One key difference between beetle outbreaks and PPCD is the time over which each causes tree mortality across a landscape. Beetle outbreaks typically result in relatively synchronous tree mortality (occurring over 2-3 years) among stands, whereas the effects of an introduced pathogen are more protracted (occurring over 3-10 years) among stands.

This section is organized into the following subsections, each with a temporal progression of how effects are likely to unfold as stands progress through stages of PPCD–caused mortality (e.g., red, gray, and silver stages): Fuels/fire hazard; potential changes to fire behavior; effects on fire severity (if fire were likely to occur); and post-fire forest recovery. For each section, a brief summary of the effects of bark beetle outbreaks is presented first, immediately followed by a discussion of likely similarities and differences with PPCD.

Changes to fuels driven by tree mortality

Red stage (0-2 years following tree mortality)

The red stage of post-beetle outbreak is characterized generally by changes to fine fuels in the canopy with correspondingly minor changes to other components of the fuel profile (e.g., live surface fuels or downed woody fuels) (Hicke et al. 2012, Jenkins et al. 2014). In the period following initial attack from beetles and leading up to tree death, needles immediately lose moisture and increase in flammability, with these changes greatest at the point when the tree is dead and needles turn from green to red (or yellow, depending on tree species) (Jolly et al. 2012). Counteracting the increased flammability of canopy fuels is the decrease in canopy fuel amount when foliage biomass decreases as dead needles drop from dead tree crowns, leading to a decrease in available canopy fuel load and canopy bulk density (Simard et al. 2011, Schoennagel et al. 2012, Donato et al. 2013, Jenkins et al. 2014). Changes to surface fuels in the red stage are minimal, with slight increases possible as needles fall and before they decompose (Jenkins et al. 2008, Simard et al. 2011, Schoennagel et al. 2012, Donato et al. 2013).

Effects of PPCD on fuel profiles in red-stage bishop pine forests likely follow similar trends as beetle outbreaks, with a few key differences. First, whereas beetle-caused tree mortality kills a tree over the course of one year (Amman and Cole 1983), PPCD-caused mortality is more protracted and can last multiple years (Gordon 2017). Therefore, the length of time that PPCD-affected stands remain in the red stage may be longer than following beetle outbreaks. However, the magnitude of this effect may be diminished if a lower proportion of the canopy is in the red stage at any given time. Second, the amount of pitch/resin exuded by bishop pine trees affected by PPCD is greater and covers more of the tree (e.g., main bole and branches) than pitch tubes on beetle-killed trees (just the main bole). While the contribution of resin/pitch as a fuel has yet to be quantified in beetle-killed trees, the contribution is likely greater in PPCD-killed trees due to the greater amount of resin material exuded. Finally, beetle outbreaks are a selective mortality agent, typically killing trees that are greater than 12-15 cm diameter (Raffa et al. 2008, Hart et al. 2014, Buonanduci et al. 2020), whereas PPCD can affect trees of all sizes (Wikler et al. 2003). Therefore, potential effects to canopy fuels can be greater where nearly all trees are affected (Hoffman et al. 2012), as opposed to only trees that are large enough in diameter for a selective agent like beetles to attack.

Gray stage (3-10 years following tree mortality)
The gray stage of post-beetle outbreak is characterized by modest decreases in canopy fuels from the red stage (as all needles have fallen and some branches begin to fall), with corresponding increases to dead surface fuels. In addition, increases occur in live surface fuels as graminoids, herbs, and shrubs respond to the increase in resource availability (Hicke et al. 2012, Jenkins et al. 2014). Canopy fuel loads reach their lowest point over the course of the outbreak as dead trees have lost their fine fuels and regeneration or other vegetation has yet to ascend to the canopy. While snags remain standing, there are little-to-no changes to dead coarse surface fuels, and changes to fine surface fuels from fallen needles and fine branches may be offset by decomposition, depending on site conditions (Klutsch et al. 2009, Simard et al. 2011, Schoennagel et al. 2012, Hicke et al. 2012, Donato et al. 2013, Jenkins et al. 2014). With increasing time since tree mortality (and more breakage of branches from snags), dead surface fuels continue to accumulate on the forest floor while the mass and height of live fuels (primarily herbs and shrubs) increases (Jenkins et al. 2008, Klutsch et al. 2009).

Effects of PPCD on fuel profiles in gray-stage bishop pine forests are likely to be similar to bark beetle outbreaks; however, the potential for increases in live and dead surface fuels are likely greater following PPCD for two reasons. First, because PPCD kills trees across diameter size classes, there is likely to be more fine (e.g., 10-hr and 100-hr) canopy fuel that accumulates on the forest floor from the combination of branches from larger dead trees and boles + branches from smaller dead trees. Second, woody shrubs compose more of the total woody biomass in bishop pine forests than in many of the forest types affected by *Dendroctonus* beetle outbreaks. Therefore, the capacity for the shrub component to respond via compensatory growth is likely greater in bishop pine forests affected by PPCD and may lead to greater live surface fuels in the gray stage.

Silver stage (decades following tree mortality)
The silver stage of post-beetle outbreak is characterized by substantial increases in coarse surface fuels as snags fall, advanced tree regeneration ascends to the canopy, and herbaceous/shrubby vegetation peaks in dominance (Hicke et al. 2012, Jenkins et al. 2014). Canopy fuels begin to increase in amount and connectivity again as surviving canopy trees, shrubs, and any advanced regeneration increase in foliar and fine branch biomass (Jenkins et al. 2008, Collins et al. 2012, Woolley et al. 2019). Coarse surface fuels (1000-hr fuels) reach their greatest mass over the time

since tree mortality, in some cases nearly doubling from background levels pre-outbreak (Donato et al. 2013). Depending on forest composition, increasing growth in advanced and post-outbreak tree regeneration can eventually outcompete shrubs and lead to increasing ladder fuels as regenerating trees link the understory live and dead fuels to the canopy fuels of trees that survived the outbreak (Jenkins et al. 2008).

Effects of PPCD on fuel profiles in silver-stage bishop pine forests likely differ in some important ways. First, because of high moisture and relatively rapid decomposition rates, coarse surface fuels likely persist for a shorter time than following beetle outbreaks that occur in more generally drier environments. Combined with the greater range in sizes of dead tree boles following PPCD-caused mortality, this may shift biomass more quickly from coarse woody debris to duff than post-beetle-outbreak. Second, similar to the gray stage, the increase in shrub woody biomass is likely to be greater than following beetle outbreaks, as shrubs make up a greater proportion of background biomass, and the capacity for shrubs to encroach from nearby chaparral patches is greater than in montane and subalpine forests where beetle outbreaks occur. Finally, in beetle outbreaks, many of the surviving canopy and advance regeneration trees are other conifer species, with fuel profiles that are similar in nature to the host pine or spruce trees killed in the outbreak. However, in bishop pine forests, the tree species not affected by PPCD are broadleaf trees (e.g., *Quercus agrifolia, Umbellularia californica*) with very different canopy architecture and fuel profiles.

Potential changes to fire behavior and resistance to control

Despite the changes to fuel profiles brought about by tree mortality events such as beetle outbreaks (and similarly PPCD), there is little evidence to suggest that fires are more likely to occur or are larger in beetle-affected forests than in unaffected areas. Several studies across a range of spatial scales in the western US have shown that the likelihood of fire occurring (Bebi et al. 2003, Kulakowski and Jarvis 2011, Meigs et al. 2016) and area burned (Kulakowski and Veblen 2007, Hart et al. 2015, Hart and Preston 2020) are not statistically related to insect outbreaks. In historically frequent low- and mixed-severity fire regimes of the Southern Sierra Nevada Mountains, recent fire activity has been reported to be unpredictable in stands where a large proportion of trees were killed by pre-fire drought, though current research is underway to quantify potential effects—and may differ from findings in high-severity fire regimes of the Rockies. In any case, when fires do burn in areas with high levels of dead trees (from beetle outbreaks or other causes), there are potential operational concerns regarding fire behavior and resistance to control (Jenkins et al. 2014, Moriarty et al. 2019).

Red stage (0-2 years following tree mortality)

Several metrics of modeled fire behavior and on-the-ground operational concerns can be affected by tree mortality caused by beetle outbreaks in the red stage. Crown fire potential can be greater while red needles are retained on tree (Jolly et al. 2012), but increased flammability is offset by a reduction of fine fuels in the canopy as needles are shed (Simard et al. 2011). Outbreak-caused increases in crown fire potential (Schoennagel et al. 2012) are likely a result of two key factors: the proportion of trees in the red stage simultaneously (Hoffman et al. 2012) and the pre-outbreak surface fuels complex (Hoffman et al. 2013). With greater synchrony in red-stage trees and pre-outbreak fuel loads, crown fire potential in the red stage increases. Surface fire potential is likely less affected by canopy tree mortality in the red stage as the addition of dead needles to the surface fuel profile represents a minor contribution to potential surface fire behavior. Operational concerns are primarily focused on the increased danger associated with numerous snags that are much more likely to fall than live trees when burned, as well as the potential for torching on snags that retain high levels of red needles (Page et al. 2013).

Effects of PPCD on potential changes to fire behavior and resistance to control in the red stage are likely similar. That is, fire is probably not more likely to occur or burn a larger area in PPCD-affected stands relative to unaffected stands, but when it does occur, crown fire potential may be greater when high levels of red needles are still retained in tree crowns. Further, safety and navigation through already dense stands of bishop pine may be more dangerous because of the increased potential for snag gall when dead bishop pine tree are burning.

Gray stage (3-10 years following tree mortality)
In the gray stage, crown fire potential is lower than unaffected stands due to the reduction in canopy fuels (canopy bulk density, available canopy fuel load) and less horizontal continuity (Jenkins et al. 2008, Klutsch et al. 2011, Hicke et al. 2012). Surface fire potential is modestly increased compared to unaffected stands, with the magnitude depending on the amount of fine and coarse fuels fallen from the canopy. As more canopy fuels fall to the forest floor in the form of branches and some snags, the potential for surface fire intensity and flame length increases (Jenkins et al. 2008, Klutsch et al. 2009). Operational concerns are elevated in the gray stage as standing snags are more likely to fall during a fire because of reduced structural integrity compared to the red stage (Page et al. 2013). In addition, standing snags with weakened branches can produce large firebrands with long burnout times, increasing potential for spot fires (Page et al. 2013). Effects of PPCD on potential changes to fire behavior and resistance to control in the gray stage are likely similar to those from beetle outbreaks.

Silver stage (decades following tree mortality)
Decades following tree mortality caused by beetle outbreaks, active crown fire potential remains low due to the sustained reduction in crown fuel amount and continuity, though surface fire potential and several operational concerns are at their highest levels. Fireline intensity, rate of spread, and flame lengths can be increased from the combination of high levels of coarse fuels and increased windspeeds with an open canopy (Jenkins et al. 2008, Klutsch et al. 2009). Operational concerns are primarily associated with extremely challenging navigation through forests as snag fall contributes to high loads of downed coarse woody debris and logs stacked on the forest floor, as well as increased resistance to control from high potential surface fire intensity and fireline intensity driven by high coarse surface fuel loads (Page et al. 2013)

Effects of PPCD on potential changes to fire behavior, operational concerns, and resistance to control, are likely similar to those from beetle outbreaks, with some potential differences. The higher dominance of shrubs in bishop pine stands compared to beetle-affected forests may lead to more of a mixing of downed coarse woody fuels and live surface fuels, with more fallen snags partially suspended above the ground (as opposed to flush on the forest floor). This may increase drying of coarse fuels and affect surface fire potential, as well as increase operational and navigational challenges through areas with high levels of mortality.

<u>Potential effects on fire severity</u>

From the mid-2000s to the mid-2010s, fires that burned through varying levels of pre-fire mortality from bark beetles led to many studies examining the effects of beetle outbreaks on subsequent fire severity—defined as the ecological effect of fire, often measured as fire-killed vegetation or fire-caused change (Keeley 2009).

Red stage (0-2 years following tree mortality)
Burn severity has been mostly similar between beetle-impacted and unaffected forests when fires have burned through the earliest outbreak phases. In the green-attack stage (when trees are attacked by beetles and in the process of dying, but before needles have turned red), some measures of burn severity increased modestly when weather conditions were moderate, but under extreme weather conditions (warm, dry, and windy), burn severity was mostly unaffected by beetle outbreaks (Harvey et al. 2014a). In the red stage, most measures of burn severity were unaffected by pre-fire beetle outbreaks under moderate or extreme weather conditions, with the exception of deep charring on trees that were dead pre-fire (Harvey et al. 2014b). Compared to the effects of topography and weather conditions, beetle outbreaks had relatively minor effects on burn severity in the green-attack and red stage (Harvey et al. 2014a, 2014b). Remotely sensed burn severity analyses of multiple fires throughout the Pacific Northwest and Northern Rockies have also found little effect of beetle or defoliator outbreaks on burn severity, and in some cases burn severity is decreased following outbreaks (Meigs et al. 2016). Effects of PPCD on burn severity in the red stage are likely similar to those of beetle outbreaks; that is, relatively minor compared to other drivers of burn severity (e.g., weather and topography).

Gray stage (3-10 years following tree mortality)
Effects of beetle outbreaks on burn severity in the gray stage have been more varied and depend on weather conditions at the time of fire. Several studies in a range of forest types and beetle outbreaks have found no effect of beetle outbreak severity on burn severity under extreme or moderate weather conditions (Harvey et al. 2013, Andrus et al. 2016, Agne et al. 2016). In gray stage mountain pine beetle outbreaks in the Northern Rockies, however, burn severity decreased with beetle outbreak severity under moderate weather conditions (Harvey et al. 2014a), but increased with beetle outbreak severity under extreme weather conditions (Harvey et al. 2014b). Under extreme weather conditions, when severe fire is expected in lodgepole pine forests, beetle-killed snags in the gray stage were more prone to deep charring and partial consumption of bole and branch mass than were live or red-stage trees (Harvey et al. 2014b, Talucci and Krawchuk 2019).

Effects of PPCD on burn severity in the gray stage are likely similar to those of beetle outbreaks, with a potential increase in effects of deep charring and partial-to-whole consumption of branches and boles. Such effects have been documented in Santa Cruz Island bishop pine stands that burned in the gray stage following drought-induced mortality (Walter et al. 2005). The smaller diameter branches and boles of bishop pine, especially in the mid-seral stages most severely impacted by PPCD, make combustion more likely during extreme weather conditions when fire potentials are high.

Silver stage (decades following tree mortality)
Not enough time has elapsed following recent beetle outbreaks in North America to have an opportunity to study the effects of silver-stage beetle outbreaks on subsequent burn severity.

Potential effects on post-fire recovery

Red stage (0-2 years following tree mortality)

In serotinous lodgepole pine forests that experienced beetle outbreaks followed by fire, post-fire regeneration has been unaffected by pre-fire beetle outbreak severity. That is, post-fire lodgepole pine seedling density was not statistically different between areas with severe beetle outbreaks pre-fire or areas where most trees were alive pre-fire (Harvey et al. 2014a, 2014b). Instead, post-fire tree regeneration was driven strongly by the pre-fire abundance of serotinous cones and burn severity. Seeds can remain viable inside serotinous cones of dead trees for more than a decade (Aoki et al. 2011, Teste et al. 2011). Further, cones from beetle-killed lodgepole pine open slower in a fire than cones on live lodgepole pine, potentially providing added protection to seeds from encountering lethal temperatures (Sharpe and Ryu 2015). Therefore, trees killed pre-fire that still retain closed cones in the canopy may contribute substantially to post-fire tree regeneration if cones are not consumed by fire. Effects of PPCD on post-fire bishop pine regeneration are expected to be similar if seeds contained in closed cones on trees killed by PPCD remain viable after tree death.

Gray stage (3-10 years following tree mortality)

Similar to the red stage, no effect of pre-fire beetle outbreaks has been detected on post-fire tree regeneration in lodgepole pine forests that burned in the gray stage post-outbreak (Harvey et al. 2014a, 2014b, Edwards et al. 2015, Agne et al. 2016, Talucci et al. 2019). Reasons for the lack of effect are interpreted as similar to those explained above for the red stage (i.e., viable seeds are still retained in closed cones on dead trees). Effects of PPCD on post-fire bishop pine regeneration are expected to be similar if seeds contained in closed cones on trees killed by PPCD remain viable after tree death.

Silver stage (decades following tree mortality)

Not enough time has elapsed following recent beetle outbreaks to have an opportunity to study the potential effects of beetle outbreaks on post-fire tree regeneration when fires burn through the silver stage. However, as beetle-killed trees fall, cones are moved to the forest floor where they are more likely to be consumed by fire, removing the potential seed source that could be provided by dead trees. Effects are expected to be similar in bishop pine forests, where dead and fallen trees (boles, branches, cones) are more susceptible to consumption in fire (Walter et al. 2005), or if not consumed, exposed to lethal temperatures greater than 125 deg C (Linhart 1978).

Summary of effects of PPCD on fuels, fire behavior, operational concerns, fire severity, and post-fire recovery

A key difference between bark beetle outbreaks and PPCD is that stand-level crown dieback and subsequent mortality occur within several years in bark beetle outbreaks but may develop over longer time spans for PPCD. Trees with PPCD are likely to experience partial crown dieback for years to a decade or more before dying. This suggests that at the aggregated scale of a stand, PPCD is unlikely to follow a progression of discrete phases (e.g., red, gray, and silver stages) and is more likely to contain trees in each phase at a single time.

Effects of PPCD on fuels will depend on the proportion of trees in each phase. Infected or dead trees with recent crown dieback (dead needles remain in the crown) may increase canopy flammability, but if substantial standing dead trees without needles exist in a stand, this effect could be counteracted due to decreased canopy fuel amount. In general, canopy fuels are expected to decline in areas with PPCD, except for in the early phases of symptom expression and decades following mortality where hardwood species have entered the canopy layer. Additionally, the contribution of pitch/resin may serve as an important fuel component in PPCD-affected stands, but this has yet to be quantified. Surface fuels are likely to be elevated in areas where PPCD-killed trees have lost their needles and/or fallen to the forest floor. Live surface fuels are likely to accumulate rapidly following crown dieback through compensatory growth of shrubs. Downed woody surface fuels may also be elevated, although rapid decomposition may counteract this effect when mortality occurs over a protracted time.

Fire is probably no more likely to occur or burn a larger area in PPCD-affected stands relative to unaffected stands. Potential changes to fire behavior following PPCD are likely to differ depending on the proportion of dead trees in various phases. Where PPCD-affected stands have high levels of red needles retained in tree crowns, crown fire potential may be increased. Where stands have many standing dead trees that have experienced branch loss and fallen dead trees, surface fire intensity and flame lengths are likely to increase. Where stands contain a mix of recently dead trees with red needles, standing dead and fallen trees, both surface fire intensity and crown fire potential are likely to increase.

Resistance to control and operational concerns vary with the proportion of trees in each phase. Where standing dead trees are abundant, navigation through dense bishop pine stands may be more dangerous because of the increased potential for snag fall, especially where trees have been dead for several years. Standing dead snags can also increase potential for spot fires. Where trees killed by PPCD have fallen, mixing of downed coarse woody fuels and live surface fuels from the shrub layer may increase navigational challenges through areas with high levels of mortality. However, rapid decomposition of coarse woody debris combined with asynchronous tree mortality may render these concerns minor in comparison with bark beetle-killed forests.

Effects of PPCD on burn severity are likely to be relatively minor compared to other drivers of burn severity (e.g., weather and topography), although deep charring and increased combustion of dead trees in the gray stage are likely. Post-fire recovery is unlikely to be affected by PPCD if seeds contained in closed cones on trees infected with or killed by PPCD remain viable after crown dieback and tree death. However, as the proportion of dead trees in the silver stage increases within a stand, post-fire bishop pine regeneration is expected to decrease as long dead cones may lack viable seed and are more susceptible to consumption by fire.

Climate warming and associated drought stress

In addition to acting as a contributing factor for other threats to bishop pine, direct effects of climate warming may threaten bishop pine. Direct effects of climate change on forests include the effects of changing temperatures and moisture availability on plant physiological function. Heatwaves and drought events are predicted to increase in many regions as the climate continues to warm and have been linked to widespread and severe forest die-off events (Williams et al. 2013, Allen et al. 2015). Further, reproductive capacity may be delayed and decreased as moisture stress on plants increases (Redmond et al. 2012, Enright et al. 2015). In California, the occurrence of drought events has been exacerbated by anthropogenic climate warming (Williams et al. 2015) and will become significantly more likely as climate warming continues to occur

(Diffenbaugh et al. 2015, Swain et al. 2016). For bishop pine, mortality caused by moisture stress is possible, especially as drought events become more frequent. Some old-growth bishop pine stands in Mendocino and Sonoma Counties are experiencing dieback attributed to drought (although PPCD may be involved). Further, fog drip is an important supplemental moisture source for bishop pine through summer drought (Fischer et al. 2016, Baguskas et al. 2016). If fog cover and duration decrease in tandem with increasing temperature and frequency of drought events, bishop pine mortality may increase, especially in small to moderate-size trees (Baguskas et al. 2014). Relatively small and late-developing canopy seedbanks may also result, leading to decreased reproductive capacity (Enright et al. 2015).

Resilience to fire under altered fire regime
(contributing factor: altered fire regime and interaction with warming climate)

Altered fire regimes threaten bishop pine forest persistence by potentially eroding their resilience to fire (defined as the capacity to experience fire and return to a bishop pine forest at some point following fire). As the primary regeneration opportunity for bishop pine forests is stand replacing fire, the forest stand condition at the time of fire, as well as the climatic conditions following fire are key factors affecting resilience.

If the fire regime changes such that the time between fires becomes anomalously short or long, the reproductive capacity of bishop pine stands may not be sufficient to regenerate a forest (Keeley et al. 1999, Buma et al. 2013, Enright et al. 2015). The typical fire return interval of bishop pine forests of approx. 40-70 years coincides with the time period where cone abundance is likely greatest. Although bishop pine trees as young as 5 years old can produce cones, stand level cone abundance likely remains below the point required to regenerate a stand if fire were to occur within the first decade or two post-fire. If fire were to occur at anomalously short intervals, bishop pine is at risk if “immaturity risk” (Keeley et al. 1999), and bishop pine may be replaced post-fire by other vegetation communities. Such dynamics have been documented in the Northern Rockies with serotinous lodgepole pine, where short-interval severe fires have led to drastic reductions in post-fire seedling density (Turner et al. 2019). Conversely, if fire return intervals approach or exceed the maximum lifespan of bishop pine (approx. 100 years), the canopy seedbank that is key to post-fire regeneration may deteriorate, and seed abundance may become insufficient to replace the stand if fire were to occur at anomalously long intervals (i.e., ‘senescence risk’). At every seral stage of bishop pine stand development, any factor such as PPCD that potentially reduces the abundance of viable seed may compound the effects of altered fire return intervals on bishop pine resilience to fire.

Further decreases in resilience to fire are likely if post-fire conditions are warm and dry during the first 1-3 post-fire years, when seedlings are particularly vulnerable to drought (Enright et al. 2015). Reductions of several orders of magnitude of post-fire seedling establishment have been observed when fires are followed by drought in the Rocky Mountains (Harvey et al. 2016), and in extreme cases have led to post-fire tree regeneration failure (Stevens-Rumann et al. 2018). In California, drought events have increased in recent decades and will become significantly more likely as climate warming continues to occur (Diffenbaugh et al. 2015, Swain et al. 2016). While average precipitation in California may remain similar, the window in which precipitation occurs is likely to become compressed, while extreme dry and wet years will become more common

(Swain et al. 2018). Both of these phenomena may have important implications for seedling establishment and survival. Furthermore, as the climate warms, trees will experience increased drought stress, even in the absence of changes in precipitation amount (Diffenbaugh et al. 2015). For bishop pine, impacts of drought more strongly negatively affect small trees in dry landscape positions (Baguskas et al. 2014), which may have important implications for post-fire seedling establishment. Fog drip is an important supplemental moisture source for bishop pine through summer drought and is particularly important for smaller seedlings and saplings (Fischer et al. 2016, Baguskas et al. 2016). If fog cover and duration decrease in addition to warmer and drier conditions following future fires, post-fire resilience of bishop pine may be further eroded.

Non-native and invasive plant species
(contributing factor: vectors of introduction)

Non-native invasive plant species are a threat to bishop pine forest health and likely interact with the previous threats. Following the Vision Fire, there was heightened concern about non-native Australian fireweed (*Erechtites minima*), which is an aggressive post-fire colonizing annual herb or sometimes perennial plant. Australian fireweed cover was as great as 20% in some post-fire plot locations, and aggressive removal along with succession toward shrub and tree cover reduced incidence through the early seral stage (Holzman and Folger 2005, Harvey and Holzman 2014). As Australian fireweed can produce a persistent seedbank that remains dormant in the soil, the long-term impacts of the post-fire cover following the Vision Fire are unknown. In the absence of fire, aggressive shade tolerant species such as English Ivy (*Hedera helix*) have been documented in the understory of the mid-seral bishop pine forest, particularly under tall fire-killed snags where birds may disperse seeds (personal observation, B. Harvey). Additional invasive plant species of concern in bishop pine forests include pampasgrass species (*Cortaderia spp.*), cotoneaster species (*Cotoneaster spp.*), panic veldtgrass (*Ehrharta erecta*), and English holly (*Ilex aquifolium*).

While non-native invasive plant species are not currently dominating bishop pine forests on the Point Reyes Peninsula, a key knowledge gap is how future fire or the current tree mortality caused by PPCD may affect establishment and spread of non-native species. Fire and disease-caused mortality of the dominant canopy trees (bishop pine) makes available light, water, and nutrient resources that may benefit non-native species.

Future desired conditions
The primary attribute of future desired conditions, based on input from GGPNC, CA State Parks, NPS, and One Tam Partnership, is to sustain local populations of bishop pine in Marin County in a mosaic that includes patches in each of the seral stages. As bishop pine is a fire-adapted species, fire is the key natural process that governs the distribution of seral stages across time and space. The natural range of variability in the abundance / proportion of seral stages is not known at this time, though the natural fire regime likely would have resulted in a shifting mosaic of stand ages across populations in Marin County. As each seral stage provides relatively unique conditions and functions, maintaining a diversity of seral stages is likely important for biodiversity as well as promoting resilience to disturbance and stressors.

Early seral stage**:** The presence of early seral bishop pine forests is strongly dependent on fire activity, which 'resets' stands to early seral conditions. It is currently unknown if there are surrogate disturbance processes (e.g., harvesting) that can create early seral conditions, and fire is likely to remain the primary driver of early seral stands. Desired conditions in the early seral stage are outlined in Table 2 below, but generally are characterized by extremely high bishop pine seedling density (though a wide range of seedling density is common), open forest canopy with large snags, low fuel loads, and high native plant species diversity.

Mid-seral stage**:** After approximately 10 years post-fire, early seral stands will transition to mid-seral, where desired conditions are high density of bishop pine trees proceeding through intense and naturally occurring density-dependent thinning, though density and the intensity of natural thinning are variable, depending on a wide range of initial post-fire bishop pine seedling densities. Currently, most bishop pine stands in Point Reyes are in this seral stage. Desired conditions in mid-seral stands are generally characterized by continuous canopy cover, low understory plant diversity, and a moderate to large canopy seedbank. High fuel loads are expected in this stage and it is uncertain whether treatments to reduce fuel loads would significantly reduce fire hazard, or what trade-offs with other measures of forest health might exist.

Old-growth stage**:** By approximately 50 years post-fire, bishop pine stands transition from mid-seral to old-growth. This transition occurs following a period of heavy density-dependent mortality, with desired conditions for density of old-growth stands 2-3 orders of magnitude lower than those of mid-seral stands. In general, desired conditions in old-growth stands include low density stands with canopy gaps that facilitate increased understory plant diversity, and a large canopy seedbank. As old-growth bishop pine stands meet or surpass 100 years since experiencing fire, trees may naturally (i.e., in the absence of pitch canker or other threats outside of the historical range of variability for this species) may begin to senesce. In the absence of fire, bishop pine is unlikely to persist in a stand after all mature trees senesce.

Condition and trends assessment

Six forest attributes are identified that can be used as potential metrics to assess and track forest health (Table 2). Each metric is described below and separated out by what would be expected within the NRV in each of the three key seral stages and is presented in context of how threats are likely to potentially affect metrics.

Table 2. Forest health attributes (metrics) and expected range of values under the NRV across each seral stage of bishop pine stand development. Values are ranked from 1-4 (and color-coded) where 1 = low (green), 2 = moderate (yellow), 3 = high (orange), 4 = extreme (red).

Forest Health Attribute (Metric)	**Early seral** (~0-10 years post-fire)	**Mid-seral** (~10-50 years post-fire)	**Old-growth** (~50-100 years post-fire)
Bishop pine live tree density (stems ha^{-1})	4. Extreme (~100,000 to 500,000) from post-fire, even-aged, cohort establishment.	3. High (~1,000 to 50,000) as stands proceed through a period of heavy density-dependent mortality.	1. Low (~100 to 500) as stands have occupied maximum growing space and mortality is not replaced by ingrowth.
Native plant species diversity and dominance of life forms	3. High (herb and shrub-dominated with small stature bishop pine seedlings). Native plant diversity a27pprox. 30 species per 100 m^2 and >90% cover.	1. Low (bishop pine dominated w/ few evergreen shrubs in understory). Native plant diversity a27pprox. 8 species per 100 m^2 and >99% cover.	2. Moderate (shrub and herb diversity increasing again in canopy gaps). Native plant diversity a27pprox. 15 species per 100 m^2 and >99% cover.
Fuel profiles and fire hazard	1. Low canopy fuel loads.	3. High canopy fuel load and continuity as soon as canopy closure occurs.	3. High canopy fuel load, but continuity likely lower than mid-seral stage.
	1. Low live surface fuels until substantial vegetation regrowth occurs.	2. Moderate live surface fuels are from shrubs.	3. High live surface fuels are from shrubs.
	1. Low dead surface fuels until fire-killed snags begin to fall and/or fragment.	3. High dead surface fuels that accumulate from density dependent thinning (fine) and fallen snags (coarse).	3. High dead surface fuels continue to accumulate from fallen branches and needles (fine) and snagfall (coarse).
Bishop pine reproductive capacity	1. Low as the canopy seedbank from pre-fire has been exhausted and young trees are just beginning to produce cones.	2-3. Moderate (increasing to high over the stage) as the canopy seedbank accumulates with time.	3-2. High (decreasing to moderate over the stage) as the canopy seedbank declines with time through eventual mortality of the canopy bishop pines.
Large snag and coarse woody debris abundance	3. High large snag abundance (from fire-killed cohort).	1. Low large snag abundance.	2. Moderate large snag abundance (increase in snags from density independent mortality).

	2. Moderate coarse woody debris from fallen snags.	1-2. Low (increasing to moderate over the stage) coarse woody debris (increase in small dead trees from density dependent mortality).	2. Moderate (gradually accumulating) coarse woody debris.
Canopy structure texture (LIDAR signature)	3. High fine grain (e.g., < 1m) variability with low (~2m) live canopy hei and standing snags (~10m).	1. Low variability at fine and moderate grain with continuous canopy cover (~3-20m).	3. High coarse grain (e.g., ~5m) variability with shrubs (~1m) and canopy trees (~20m).

Metric 1 – Bishop pine live tree density (stems ha^{-1}): stand dynamics that are in line with NRV and fire regime

Research on post-fire bishop pine stand dynamics outlined in the section above suggests general expectations for characterizing the condition and assessing trends in bishop pine population dynamics. Similar to other moderately or strongly serotinous fire-adapted conifers, bishop pine populations go through cycles of boom and bust. That is, fire catalyzes seed release and establishment of seedlings at the point in time where the population is greatest, after which the population monotonically declines over time through early-, mid- and old-stages, until the next fire occurs (Figure 1). Therefore, within stands, live bishop pine density in the range of several hundred thousand seedlings/saplings per hectare in early seral stages, several thousand to tens of thousands of medium sized trees per hectare in mid-seral stages, and several hundred old trees per hectare in old-growth stages would be considered healthy (Table 2). At any given stage, a wide range of density (and naturally occurring density-dependent mortality) is expected, driven primarily by initial post-fire seedling densities. As density-dependent mortality is the result of larger trees outcompeting smaller trees, mortality through the early- and mid-seral stages should be dominated by poorly competing trees with small diameter and height. Deviations from these patterns of stand dynamics expected under the NRV and fire regime may signify poor forest health. For example, especially in early- and mid-seral stages, mortality in a healthy bishop pine stand would be dominated in frequency by small-diameter and shorter trees. However, mortality across all sizes of trees (e.g., caused by PPCD) in early- and mid-seral stands would represent a deviation from ‘healthy’ stand dynamics undergoing competitive density-dependent mortality.

With specifics of the NRV for fire regime parameters (e.g., size, frequency) unknown, it is difficult to construct expectations for age/stage class diversity among stands. However, even though within-stand structure is relatively homogenous (e.g., single-age cohorts), heterogeneity in fire effects across any moderately sized landscape of bishop pine such as those on the Point Reyes Peninsula would create some heterogeneity among stands. That is, at any given point in time it would be normal to expect some mix of stands in early-, mid-, and old-stages across a landscape forested by bishop pine. Given the duration of each stage, the relative proportions at any time would likely be greater for old-growth and mid-seral stages, and less for early seral stages. As the threats to bishop pine forest health vary in nature and magnitude across seral stages, greater diversity in seral stages across a forested landscape would likely provide more resistance to stressors and disturbance.

Threats to bishop pine health pose several key questions regarding Metric 1. First, the impacts of PPCD have likely caused substantial deviation from stand dynamics within the NRV of bishop pine. The degree to which areas affected by PPCD are experiencing mortality patterns deviating from the expected density-dependent (e.g., mortality constrained to mostly smaller trees) remains an un-characterized, but important knowledge gap. Second, recent fire activity is likely the primary driver in variability in seral stages among stands. Prior to the 1995 Vision Fire, most of the bishop pine forest on the Point Reyes Peninsula was in the later mid-seral stage or the old-growth stage, with presumably relatively low among-stand diversity in seral stages. Currently, seral stage diversity is relatively evenly split between mid-seral (post-Vision Fire) and old-growth (unburned in the Vision Fire) stands, in proportions that are likely within the expected range given the fire regime. Despite heterogeneity in seral stages at the aggregate level, the spatial arrangement of seral stages is homogenous, as they are dictated by areas burned in the Vision Fire—within which most to all bishop pine stands were reset to early seral. Whether PPCD is potentially accelerating stand development from mid-seral to old-growth, reversing development from mid-seral to early seral, or sending stands on an alternative and novel trajectory is an important knowledge gap with implications for Metric 1.

Metric 2 – Native plant species diversity and dominance of life forms

Baseline information on trends in native plant species diversity and dominance suggest that over time, plant species diversity follows somewhat predictable trends (Figure 1 and Table 2). Diversity is highest in early seral stages (when herbs, shrubs, and small tree seedlings co-dominate) and native plant species richness is approx. 30 species per 0.01 ha with >90% cover. Diversity is lowest in mid-seral stages (when few evergreen shrubs are present) and native plant species richness is approx. 8 species per 0.01 ha with >99% cover. Diversity increases to moderate levels in old-growth stages (when shrub and herb diversity increases again as bishop pine canopy gaps open) and native plant species richness is approx. 15 species per 0.01 ha with >99% cover. Similar to (and related to) variability in bishop pine density, variability exists among stands at any seral stage, where the greater the canopy dominance by bishop pine, the lower the diversity of other plants (herbs, shrubs, and broadleaf trees).

Several threats to bishop pine health may potentially affect Metric 2 and pose important questions. First, the widespread and severe bishop pine mortality caused by PPCD in mid-seral stands is likely affecting the plant community in important, but unknown (i.e., yet to be documented) ways. The removal of dominant bishop pine trees in the canopy layer opens up light, water, and nutrient resources for other plants, which may increase plant diversity relative to what would otherwise be expected in mid-seral stages. However, depending on the native plant diversity nearby or in the understory, the canopy disturbance caused by PPCD and likely resulting effects on the understory microclimate may facilitate spread of non-native invasive species. If non-native / invasive species establish and/or spread in areas affected by PPCD, effects on native plant diversity could be negative. In sum, the effects of PPCD on the plant community, especially understory herbs and shrubs in bishop pine forests remains a critical knowledge gap with strong implications for Metric 2.

Metric 3 – Fuel profiles and fire hazard: values in line with NRV and fire regime

Fuel profiles and fire hazard in bishop pine forests change substantively over time (Agne et al. in review) (Table 2). In the early seral stage, fuels are not typically sufficient to support stand-replacing fire, as fine dead fuels consumed by the previous fire have yet to recover, and most fuels are large coarse fuels and live, small-statured vegetation. By the time stands enter mid-seral and old-growth stands, fuels within the NRV are typically sufficient to carry stand-replacing crown fire, but presumably at intensities that do not consume important biological legacies for post-fire regeneration (e.g., bishop pine canopy seedbank, soil seedbank, underground root structure for resprouting shrubs and broadleaf trees). Fire intensity that produces temperatures of ~130 deg C outside of cones, but does not expose seeds to sustained temperatures greater than 105 deg C would open most bishop pine cones without damaging seeds. However, temperatures greater than 130 deg C do not yield any additional benefit for cone opening, and temperatures of 125 deg C are lethal to bishop pine seeds.

The key threat to bishop pine health regarding metric 3 is the likely effects of PPCD on fuel profiles and potential effects on fire behavior (specifically heat duration and intensity). Measurements of fuel profiles in PPCD-impacted stands can be compared to measurements in stands unaffected by PPCD to assess if, and how far, deviated fuel profiles are from expectations under the NRV. In addition to fuel amount, unknowns about the quality of fuels on dead trees (e.g., effusive pitch streaming on PPCD-killed trees) are important considerations for potentially altered fire behavior in bishop pine stands. The effects of PPCD on fuel profiles and fire behavior remain a critical knowledge gap, as basic information on fuel profiles in bishop pine forests are not widely documented (but see Agne et al. in review), and to our knowledge, no information exists currently on the effects of PPCD on fuel profiles for any forest type.

Metric 4 – Bishop pine reproductive capacity: sufficiently high when fire occurs
Post-fire persistence of bishop pine populations requires the presence of an ample on-site seed source at the time of fire. Observations and research in progress (Agne et al. in prep) suggest that bishop pine reproductive capacity, measured as the abundance of closed serotinous cones in a live stand containing viable seed peaks somewhere toward the end of mid-seral stages or in the early old-growth stages. In early seral stands, reproductive capacity is low until the post-fire cohort of trees has been reproductively mature for several years or more, and the canopy seedbank is replenished. As stands age, the canopy seedbank likely peaks at some point around 40-50 years post-fire, after which a slow but gradual depletion of the canopy seedbank likely follows the gradual mortality of bishop pine trees through old-growth stages (Table 2).

Several threats to bishop pine health are likely to affect Metric 4. First, the effects of PPCD production and retention of viable seed in cones on infected or killed trees are unknown. If PPCD has negative effects on viable seed production and storage, reproductive capacity could be lessened across all stages of stand development. Second, if PPCD alters fuel profiles and/or fire behavior to increase heat intensity or duration, viable seeds in serotinous cones may be damaged or consumed by fire. In both cases, PPCD is likely to lessen reproductive capacity at the time of fire. Third, if fire return intervals that are either anomalously short or long and fire occur in early seral stands or in late old-growth stands, reproductive capacity is likely low from immaturity risk and senescence risk, respectively, and may lead to low post-fire recruitment. Finally, increasing temperatures and drought stress may lead to delayed reproductive maturity and decreased annual cone production, diminishing the overall reproductive capacity of bishop pine forests. Understanding how reproductive capacity is affected by any of these factors is an important knowledge gap.

Metric 5 – Large snag and coarse woody debris abundance
Large snags and coarse woody debris are important contributors to wildlife habitat and woody carbon storage in bishop pine forests and likely follow somewhat predicable patterns through seral stages. In early seral stages, large snag abundance is expected to be at its greatest level, since stand-replacing fire immediately creates snags from the pre-fire cohort of trees. The size of the snags will depend, in part, on the seral stage at the time of fire. Coarse woody debris is expected to be moderate, consisting primarily of pre-fire downed and burned logs until the fire-killed cohort of snags begins to fall. In mid-seral stages, large snag abundance is expected to be very low, as the fire-killed snags have mostly (or all) fallen, and dead trees from the post-fire cohort killed through competition are primarily small diameter. Coarse woody debris levels are low-to moderate as fire-killed snags fall and decompose, and little-to-no coarse woody debris is produced from small-diameter trees killed by density dependent mortality. In old-growth stages, large snag abundance is moderate, as density-independent mortality becomes the primary driver of bishop pine tree death. As snags fall, coarse woody debris levels correspondingly increase.

Several threats to bishop pine forest health have implications for Metric 5. First, widespread PPCD in mid-seral stands is decreasing capacity for large snag and coarse woody debris production by killing trees that would otherwise outcompete neighboring trees and become dominant canopy trees (i.e., large snags and coarse woody debris after death). Second, changes to fuel profiles or fire behavior resulting from PPCD that increases consumption of dead wood will likely drive reductions in post-fire snags and/or coarse woody debris in future early seral (post-fire) forests. Third, shortened FRIs can drastically reduce large snag and coarse woody debris abundance in serotinous lodgepole pine forests in the Rocky Mountains (Turner et al. 2019), and similar effects in bishop pine forests could occur with short-interval fires.

Metric 6 – Canopy structure texture: LIDAR signature
Canopy structure (height, roughness/rumple, and density) as measured by LiDAR (Kane et al. 2010) can aid in mapping expected characteristics for each seral stage (Table 2). In early seral stages, canopy surface texture would be expected to be highly variable (high rumple) at a fine spatial grain (e.g., <1m) with a low live canopy height (approx. 2m) as shrubs, herbs, and trees co-dominate a short-statured canopy. Standing snags (approx. 10-15m tall) would be expected to contribute to canopy roughness/rumple with peaked height signature separated by several meters horizontally. In mid-seral stages, canopy surface texture would be expected to have low variability (low rumple) at fine (e.g., <1m) and moderate (e.g., 2-4 m) spatial grain, as canopy cover would be fairly homogenous and dense at heights of approx. 3 to 20m (Figure 7, left image). Few snags may be present and would be sharp anomalies extending several meters above the continuous canopy. In old-growth stages, canopy texture would be expected to have high coarse grain (e.g., approx. 5m) variability (high rumple) with irregular patches of canopy heights dominated by widely-spaced canopy bishop pine trees (approx. 20m tall) interspersed with canopy heights dominated by shrubs (approx. 1m tall) (Figure 7, right image).

The primary threat to bishop pine forest health that has implications for Metric 6 is PPCD. Through canopy dieback and mortality, PPCD is expected to increase canopy surface roughness in any seral stage, but most notably in mid-seral stages where canopy surface roughness would otherwise be very low.

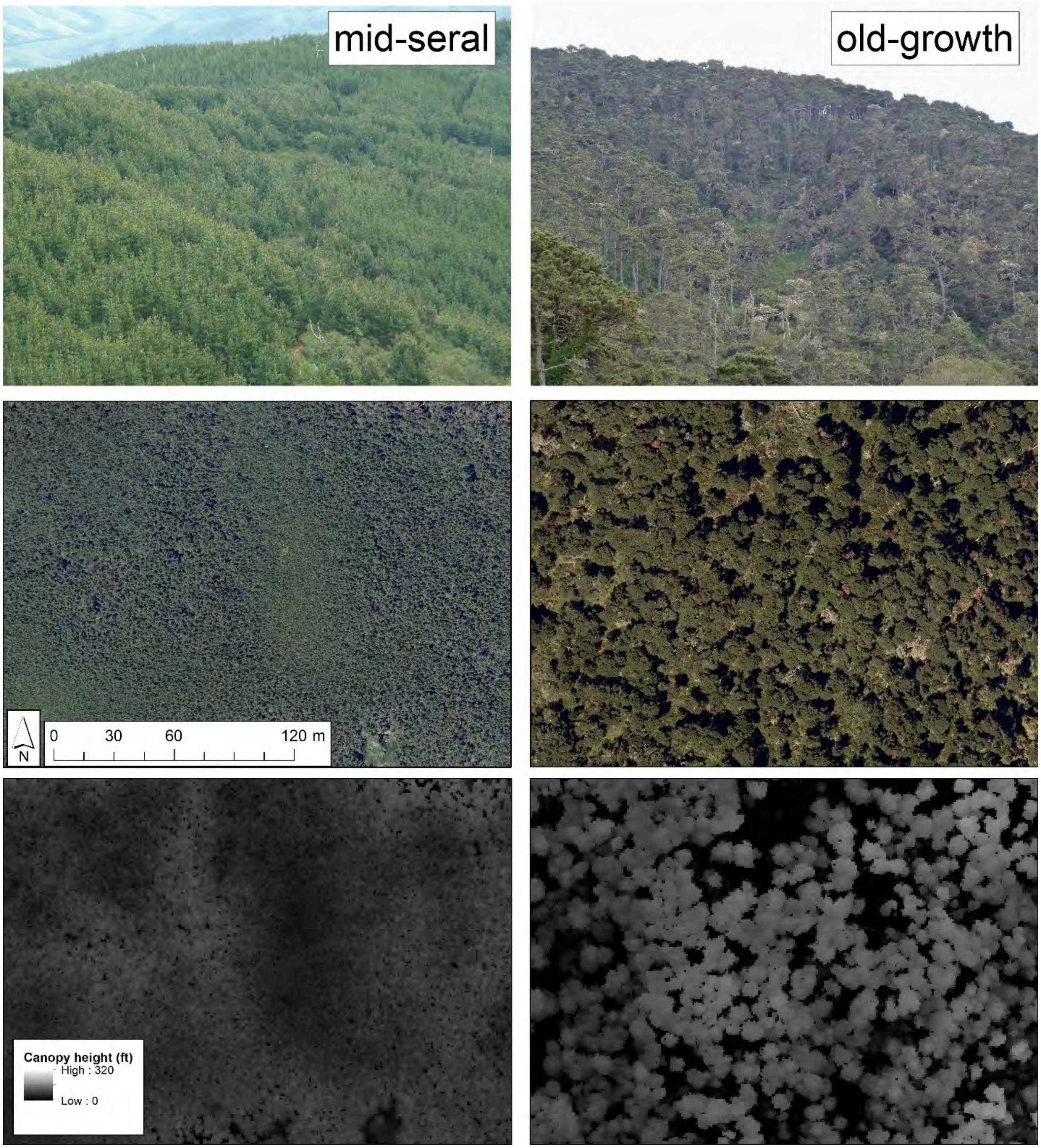

Figure 7. Visual difference in aerial canopy roughness (texture) between smooth and even texture in mid-seral stands (left) and rough texture with gaps between tree crowns in old-growth stands (right). Top row is an oblique photograph, middle row is an aerial photograph, and bottom row is LiDAR-derived canopy height at 1m pixel size. All images in each row are of the same location. (source: top row – B. Harvey; middle row – marinmap.org; bottom row – onetam.maps.arcgis.com).

Management recommendations and guidance on addressing knowledge gaps

Based on the information above, here we discuss potential treatment options in the bishop pine forest with objectives of reducing fire risk, reducing exposure to negative effects of PPCD, fostering ecological resilience and supporting desired future condition (e.g., addressing threats identified in Table 1). We break these out into recommendations for each seral stage, focusing on ideas for adaptive management and research for continued learning. While these recommendations are at present for the bishop pine forests on the Point Reyes Peninsula, they are likely to be applicable to other bishop pine forests in the region.

Early seral stands

Management actions

- Minimize unplanned fire in early seral stands, especially if bishop pine are reproductively immature. Unplanned fire can be limited by decreasing ignition sources from roads adjacent to early seral stands. Specific actions include avoiding parking heavy equipment on adjacent roads, eliminating brush cutter work during the dry season, trimming grasses on adjacent roadsides (both within and outside the defensible space rotation), and coordinating with PG&E to prioritize areas adjacent to early seral stands for power pole replacements and undergrounding or removal of power lines where possible.
- When fire occurs in early seral stands prior to reproductive maturity and continued bishop pine presence is desired, closed cones can be collected from nearby mature stands, opened in the oven to release seeds, and planted in recently burned stands. Note that this action is not strictly ecological restoration, and its feasibility may be limited if fire in early seral stands increases.

Knowledge gaps

- Characterization of seed dispersal distance and rate from unburned, reproductively mature stands, with implications for natural regeneration of burned early seral stands from an adjacent seed source if the on-site seed source is not present post-fire.

Mid-seral stands

Management actions

- Applied experiments with thinning could be considered in limited locations to accelerate succession toward old-growth conditions, mitigate PPCD, and/or alter fuel profiles. Ideally, experimental thinning should be conducted in areas that are planned to be thinned for other purposes, as several unintended consequences could arise including: increased PPCD severity in low density stands (as suggested by observations) and loss of the process of forest self-thinning, which may select for traits in ways that are not yet understood.
- Target density and basal area of a thinning to accelerate succession toward old-growth conditions can be developed from reference stands that are currently in old-growth seral stage (e.g., approx. 100 to 500 stems ha^{-1}). However, a somewhat higher retention density (e.g., the higher end of this range, or a gradient of densities far exceeding this target) could buffer against the possibility that a considerable number of retained individuals may be lost to PPCD following treatment. The exact number or proportion of stems to be removed would vary on initial pre-treatment density, as stands 23-years post-fire ranged

from approx. 2,000 to 30,000 live trees ha^{-1}. Timing of thinning should occur when stands have well exceeded the age of reproductive maturity for trees that are retained, to avoid substantial loss of the canopy seedbank and therefore potential eroded resilience to subsequent fire. Additional prescription details include avoiding wounding of retained (unharvested) trees as PPCD develops most readily through wounds, or otherwise creating conditions that could facilitate the spread of PPCD.

- Fuels treatments should be prioritized in the WUI vs. more remote areas, as fuel treatments that retain a significant component of bishop pine forest are unlikely to prevent the occurrence of high severity crown fire. Fuel breaks should be implemented around values at risk with the understanding that when these forests experience fire under extreme conditions, crown fire remains highly likely.

Knowledge gaps

- Identify individuals with inherent genetic resistance to PCCD in the field; longer term/larger effort could initiate seed collection for a resistance breeding program.

Old-growth stands

Management actions

- Applied experiments with prescribed burning or other fire surrogate (raking) to regenerate bishop pine prior to canopy senescence.
- Within treated areas, disperse seed from cones opened in the oven; seed dispersal from open cones on live trees within or adjacent to the plot could also provide a source of regeneration.

Knowledge gaps

- Effects of PPCD on old-growth bishop pine are observationally less severe than in mid-seral stands, monitoring is needed to ensure this is a true effect over time vs. delayed demonstration of symptoms in older trees.
- Potential for seeds that germinate in soil containing *F. circinatum* to demonstrate greater PPCD resistance as seedlings—monitoring of regeneration in areas where PPCD is present and absent (or if opening cones in the oven, could experiment with exposing them to inoculum in the lab before outplanting).

Proposed field measurements and forest health monitoring

A separate field plan has been drafted to install and augment existing field plots to measure current conditions and set up future monitoring to assess conditions related to several questions of forest health in the post-fire (Mt Vision) Fire cohort of bishop pine that has now been affected by non-native PPCD. Plots will be designed to answer the following research question:

1. How does the level of PPCD affect the following measures of forest health:
    a. Fuel profiles (e.g., surface and canopy fuel amount and configuration)?
    b. Vegetation dynamics (e.g., tree regeneration and understory vegetation community shifts)?
    c. Reproductive capacity in the event of a subsequent fire (e.g., viable PIMU seed abundance)?

Plots will be installed in stands that originated following stand-replacing fire in the 1995 Vision Fire (mid-seral stands composed of a ~25 year old cohort), as well as old-growth stands. Plots will be installed across a gradient of PPCD severity for each seral stage (ideally ranging from unaffected to nearly 100% overstory mortality, or as close to these extremes as exist in the study area). For logistical ease, plots will be given a quick field ID of an ocular estimate of PPCD severity (0-25%, 25-50%, 50-75%, and 75-100% canopy dieback) prior to plot establishment and an attempt will be made to sample 6-8 plots within each of the four categories in each seral stage (24-32 plots per seral stage). Plots will be installed in areas with near complete canopy closure (e.g., > 75% bishop pine canopy dominance) of bishop pine in the forests established after the 1995 Vision Fire (e.g., excluding more open scattered trees in coastal scrub and woodland areas).

For old-growth plots, the canopy may be more open due to the successional state of these stands, but bishop pine should be the dominant canopy species. For both seral stages, bishop pine canopy cover may be lower today because of mortality from PPCD, but would be reconstructed to the pre-PPCD canopy dominance of bishop pine. Plots will be stratified across a range of stand densities, across topographic positions, and at varying distance from the coast to capture a range of conditions that may influence disease severity.

The protocol is intended to be flexible enough to be implemented as additional stand structures and seral stages arise on the landscape including following wildfire to monitor recruitment and pitch canker effects on early seral stands or following the implementation of hazardous fuels reduction, Rx burning, or removal of infected trees. Potential areas for monitoring early seral stands established following the 2020 Woodward Fire are being scouted for inclusion in the initial monitoring efforts outlined in the field plan.

At this time, there is no recommendation to treat stands to mitigate effects of pitch canker. However, if treatments are implemented for other purposes or in the context of an experiment, this protocol can be implemented in such stands, ideally prior to treatment and following treatment.

The protocol will be modified from existing plot protocols (Alison Forrestel fuels plots) and similar plot design (Agne et al. in prep design has similar plots across a time since fire chronosequence in bishop pine and knobcone pine forests throughout CA and southern OR).

Conclusion

Bishop pine forests are an emblematic ecosystem endemic to the coastal region of the Californian Floristic Province. From a combination of introduced fungal pathogens, a warming climate, and potentially altered fire regimes, bishop pine forests face a number of threats and are a high priority for conservation throughout their distribution. This report can serve as a state of the condition, published research, identification of threats, and suggested management actions to aide in conserving bishop pine forests. Also identified are several key knowledge gaps that, if addressed, can provide critical information for augmenting management actions with the goal of fostering bishop pine forest health and resilience to stressors.

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FINAL REPORT

Bishop pine forest health and pitch canker disease field study: Point Reyes Peninsula, CA

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Executive Summary

This report presents work conducted in a field study to assess bishop pine (*Pinus muricata*) forest health and effects from continued progression of pine pitch canker disease (PPCD, caused by the fungal pathogen *Fusarium circinatum*) on the Point Reyes Peninsula, CA (USA). This work builds from a white paper produced in 2021 on bishop pine forest health (Harvey and Agne 2021) and is intended to (a) provide an assessment of forest conditions in 2021 across gradients of stand structure, and (b) describe changes in forest conditions between 2011 and 2021 in eight permanent monitoring plots that were re-measured ten years apart. In total, 11 plots were surveyed or installed as part of this work (eight were plots that were established in 2011 in mid-seral stands within the 1995 Vision Fire footprint and were re-measured in 2021, and three were newly established plots in late-seral / old growth stands outside the 1995 Vision Fire footprint). In 2021, mid-seral (26-yr old) stands ranged from 26 to 51 m^2 / ha live bishop pine basal area and from 805 to 3,178 live bishop pine trees / ha. Nearly all trees had some symptoms of infection from PPCD, though resultant visible crown dieback ranged from 1% to 34% on average across trees. Old-growth (approx. 60 to 100-yr old) stands in 2021 ranged from 25 to 39 m^2 / ha live bishop pine basal area and from 72 to 236 live bishop pine trees / ha. Visible crown dieback attributed to PPCD was less than in mid-seral stands, ranging from 2% to 10% on average across trees. In 2021, plots with greater severity of PPCD were on average associated with greater coarse surface fuel loads, greater crown dieback and resultant canopy openness, greater plant community diversity, and greater forb cover. Other variables of stand structure (live and dead tree size, basal area, and density) and reproductive potential (cone abundance on live trees) were not detectably different between stands with high or low severity of PPCD, and overall do not suggest major departures from expected stand structural development in mid-seral stands. In mid-seral plots that were measured in 2011 and re-measured in 2021, trends over 10-years were characterized by increases in coarse surface fuel loads, decreases in bishop pine live tree basal area and density, and increases in all measures of PPCD incidence and severity. Overall, findings from this field study suggest that PPCD continues to impact the bishop pine forest, but is unlikely to result in loss of local bishop pine populations in the near term as changes to stand structure are not widely outside the range of variability across seral stages for this ecosystem. Recommendations are discussed for potential experimental treatments in locations where alteration of stand structure and fuel loading / fire hazard may be desired in bishop pine forests affected by PPCD.

Introduction and Background

Bishop pine (*Pinus muricata*) forests are an iconic ecosystem endemic to the coastal region of the Californian Floristic Province (Millar 1986a,b). Due to the relatively limited distribution of bishop pine, coupled with several contemporary threats to the persistence of the species, it is listed as "vulnerable" on the Red List for the International Union for Conservation of Nature. The primary threat of concern is potential impacts to the population, physical structure, fire regime, and ecological function of the bishop pine forest from mortality associated with pine pitch canker disease (PPCD). Direct effects include fundamentally altering the population, physical structure, and ecological function of bishop pine forests, while indirect effects are from changes to fuel structure and associated fire hazard. Pine pitch canker disease is caused by the fungal pathogen *Fusarium circinatum*, which is suggested to be native to Mexico and introduced to pine forests in coastal California in the mid-1980s (Gordon et al. 1997, Wikler and Gordon 2000). Localized infections result in cankers, which then girdle conductive tissue and lead to branch or crown dieback (Storer et al. 1997).

This field study addresses several key knowledge gaps identified in a recent white paper on bishop pine forest health (Harvey and Agne 2021) regarding the effects of PPCD on forest health. Specifically, we (1) characterized several key attributes of forest structure and indicators of forest health across seral stages of bishop pine forest on the Point Reyes Peninsula, (2) assessed changes in stand structure and indicators of forest health in a series of permanently marked monitoring plots that were installed earlier in the PPCD progression, and (3) compared stand structure and indicators of forest health between stands that have low and high severity of PPCD in 2021.

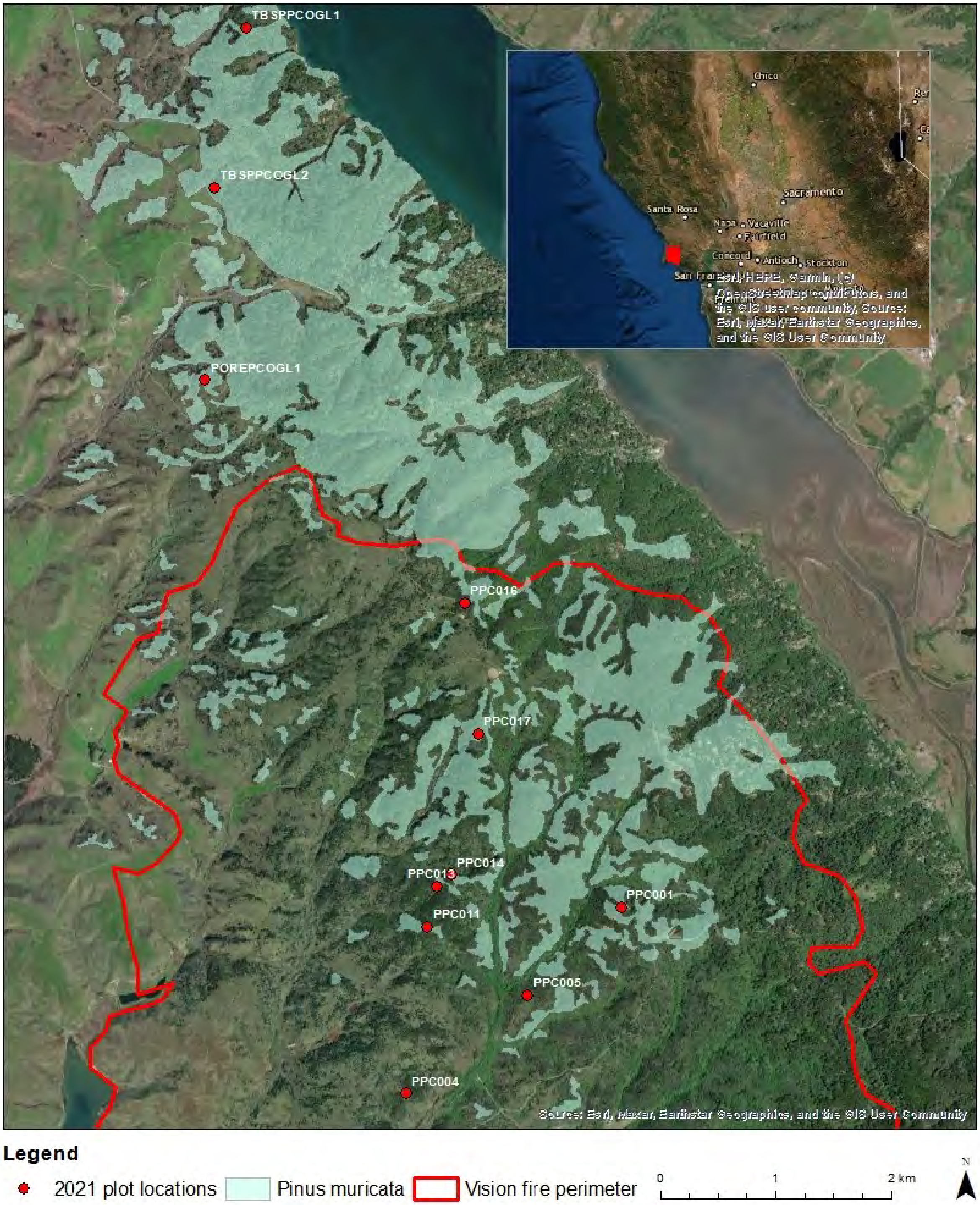
Approach and Methods

Study area

The focal study area for this field study is the bishop pine forest on the Point Reyes Peninsula, which is the dominant forest ecosystem on the northern half of the peninsula on the east and west slopes of Inverness Ridge. Bishop pine forests are distributed across the northern portions of Point Reyes National Seashore and throughout Tomales Bay State Park, and cover a range of seral stages that resulted from the most recent fire to occur in each location. The southernmost extensive stands of bishop pine forest are mid-seral stands that originated following the 1995 Vision Fire and were therefore 26 years old at the time of field sampling in 2021. Northern stands of bishop pine forest on the Point Reyes Peninsula are older, having not burned in the Vision Fire, and range in age from approximately 50-70 years old on the Northern slopes of Inverness Ridge to approaching or just exceeding 100 years old on lower slopes near Tomales Bay in Tomales Bay State Park (late-seral or old-growth). Older, late-seral stands are within the northern portions of Point Reyes National Seashore and throughout much of Tomales Bay State Park.

Plot selection and characteristics

Plots were installed in stands that originated following stand-replacing fire in the 1995 Vision Fire (mid-seral stands composed of a 26-year-old cohort), as well as in old-growth stands (Figure 1). Eight plots within mid-seral stands were initially installed in 2011 by NPS personnel. Four of these plots were in high-density areas that were bishop pine forest prior to the Vision Fire and four plots were in low-density forests that were not bishop pine forest prior to the Vision Fire (i.e., areas where the forest expanded into pre-fire grassland or coastal scrub as a result of the fire). These eight plots that were selected for resampling in 2021 were distributed across a gradient of PPCD, with four plots classified as low-severity / unaffected (<10% crown dieback and/or tree mortality) and four plots classified as high severity (>50% crown dieback and/or tree mortality) using 2018 aerial imagery classification provided by the Golden Gate Parks Conservancy. All plots were installed in areas with near complete canopy closure (e.g., > 75% bishop pine canopy dominance) of bishop pine in the forests established after the 1995 Vision Fire (e.g., excluding more open scattered single trees in coastal scrub and woodland areas). For old-growth plots installed in 2021, the canopy was often more open due to the successional stage of these stands; however, bishop pine was the dominant canopy tree species in all study plots.



Vision fire perimeter: Monitoring Trends in Burn Severity (MTBS) project jointly implemented by the USGS EROS and the USFS RSAC.
PIMU range: National Park Service. 2003. Geospatial data for the Vegetation Mapping Inventory Project of Point Reyes National Seashore, Golden Gate National Recreation Area, Muir Woods National Monument and Fort Point National Historic Site.
Basemap: ESRI.

Figure 1. Map of plot locations for this study. Plots with "PPC" at the beginning of the plot name are from the initial network of plots installed in 2011 and all other plots are newly established plots in 2021.

Sampling protocol

Plots were sampled using a combination of methods that blend two protocols; one is an existing protocol established by NPS personnel in 2011 and the other is modified from a protocol established by the authors for a study on California Closed Cone pine forest dynamics (see Agne et al. 2022). Blending these two protocols allowed for additional information to be collected in 2021 that was not part of the 2011 protocol, while retaining all variables in the 2011 protocol for comparison across time. The general variables measured per plot are summarized here; for a full description of all methods and procedures, see the full protocol in Appendix 1.

Each plot consisted of a 1,257 m^2 macroplot (circular plot with 20 m radius) and multiple subplots located within the main plot, including a 6.3 m radius central subplot (the main sample area for the 2011 plots and 2021 re-measures). In each plot, understory vegetation cover by species and life form, and ground cover was visually estimated in the 6.3 m radius central subplot using a modified Braun-Blanquet scale, and additional understory vegetation, shrub morphology, and canopy cover measurements were collected at the midpoints of each main plot radii (Appendix 1). Downed woody fuels in 1-, 10-, 100-, and 1000-hr time lag classes, as well as litter, duff, and fuel-bed depth were measured along each of the 4 plot radii along the cardinal directions following established protocols (Brown 1974). Tree regeneration was measured within variable-width belt transects along the four main plot radii, and seedlings for each species were measured for height class and presence / absence of pitch canker or defoliation.

Overstory trees were measured within the central circle plot and the radius was variable and determined to include approximately 50 live (or recently dead with cones) bishop pine trees that reached 1.4 m in height. Each tree was measured/recorded for species, status (live/dead), diameter at breast height (DBH, at 1.4 m above the ground surface), height, canopy base height, cones (open, closed, total), PPCD-associated crown dieback, PPCD severity on the bole and branches following a scale in Wikler et al. (2003). Decay class was recorded for all dead trees.

All variables used in this analysis were summed (e.g., basal area or density) or averaged (e.g., quadratic mean diameter, QMD) across trees or subplots to the level of the macroplot prior to analysis. Because of the sample size in the study, comparisons are made using means or medians where appropriate, as measures of central tendency, while also presenting the range of values.

Findings

Bishop pine forest stand conditions in 2021 across seral stages

Across the array of monitoring plots, forest stand conditions varied by seral stage, primarily as a function of whether they originated following the 1995 Vision Fire (26 year old mid-seral stands) or not (>50-70 and 90-100 year old late-seral old-growth stands) (Table 1). Mid-seral stands were characterized by median live bishop pine basal area of 40.6 m^2/ha (range: 26.1 to 51.1 m^2/ha), standing dead bishop pine basal area of 12.2 m^2/ha (range: 9.1 to 22.9 m^2/ha), live QMD of 18.4 cm (range: 12.8 to 21.7 cm), dead QMD of 12.0 cm (range: 6.1 to 16.7 cm). Live and dead bishop pine density were similar at approximately 1,500 stems / ha. Overall, more than 90% of all bishop pine trees in mid-seral stands exhibited some visible symptoms of PPCD, though crown dieback was lower and averaged 9.8% (range 1.4 to 33.5 %) of tree crown area across stands. Despite initial differences between dense mid-seral stands that were bishop pine forest prior to the Vision Fire and open stands that were not pre-fire forest (i.e., other pre-fire vegetation types where forest established post-fire), most mid-seral stand characteristics were similar across pre-fire stand histories by 2021 (Table 2). The main differences were that coarse surface fuels were nearly double the values in dense stands than in open stands (median 44.3 Mg/ha in dense stands compared to 27.0 Mg/ha in open stands), and total + closed bishop pine cones on live trees were marginally greater in abundance in dense stands (Table 2).

Old-growth stands were characterized by much lower live and dead tree density, and much greater average live tree and standing snag sizes than in mid-seral stands (Table 1). In general, the percentage of bishop pine trees exhibiting PPCD symptoms, as well as the percentage of average crown dieback associated with PPCD on bishop pine trees was lower in old-growth stands than in mid-seral stands. Coarse surface fuel loads, as well as live and dead standing bishop pine basal area were similar between mid-seral and old-growth plots (Table 1).

Table 1. Summary statistics for select variables across seral stages in 2021. Values for mid-seral stands are medians (min - max) and values for old growth stands are the plot-level value for each of the old growth stands. Old-growth stand 1 is approximately 50-70 years old and Old-growth stands 2 and 3 are approximately 87-104 years old (Dawson, 2021).

	Mid-seral	Old-growth 1	Old-growth 2	Old-growth 3
Coarse surface fuels (Mg/ha)	34.1 (13.2 - 65.7)	27.8	27.2	85.5
PIMU QMD live (cm)	18.4 (12.8 - 21.7)	42.0	49.7	46.4
PIMU QMD dead (cm)	12.0 (6.1 - 16.7)	27.1	46.4	67.0
PIMU basal area live (m2/ha)	40.6 (26.1 - 51.1)	32.8	24.9	38.8
PIMU basal area dead (m2/ha)	12.2 (9.1 - 22.9)	2.9	8.1	16.9
PIMU live trees / ha	1,553 (805 - 3,178)	236	128	72
PIMU dead trees / ha	1,469 (723 - 3,125)	51	48	48
Live PIMU trees exhibiting PPCD symptoms (%)	97.3 (90.0 - 100.0)	85.7	93.8	88.9
PIMU PPCD crown dieback (%)	9.8 (1.4 - 33.5)	1.7	10.2	5.5

Table 2. Summary statistics for select variables across levels of bishop pine density in 2021, as a result of being pre-Vision Fire bishop pine forest (dense) or pre-Vision Fire non-forest (open). Values are means (min - max).

	Dense (pre-Vision Fire forest)	Open (pre-Vision Fire non-forest)
Coarse surface fuels (Mg/ha)	44.3 (31.5 - 65.7)	27.0 (13.2 - 53.5)
PIMU QMD live (cm)	17.1 (12.8 - 21.7)	18.4 (16.0 - 20.7)
PIMU QMD dead (cm)	11.4 (6.1 - 16.7)	10.9 (6.5 - 13.3)
PIMU basal area live (m2/ha)	39.1 (29.7 - 50.3)	41.6 (26.1 - 51.1)
PIMU basal area dead (m2/ha)	14.3 (9.1 - 22.9)	12.8 (9.5 - 17.3)
PIMU live trees / ha	2,057 (805 - 3,178)	1,554 (1,299 - 1,811)
PIMU dead trees / ha	1,866 (723 - 3,125)	1,613 (818 - 2,842)
Canopy openness (%)	19.4 (10.6 - 26.0)	11.3 (8.3 - 12.5)
Shannon Diversity Index	0.95 (0.29 - 1.61)	0.72 (0.10 - 1.09)
Species Evenness	0.42 (0.18 - 0.55)	0.40 (0.06 - 0.61)
Shrub cover (%)	4.83 (0.03 - 10.00)	0.32 (0.00 - 1.25)
Graminoid cover (%)	0.01 (0.00 - 0.03)	0.00 (0.00 - 0.00)
Forb cover (%)	8.28 (0.30 - 17.78)	12.03 (1.00 - 27.50)
Live PIMU trees exhibiting PPCD symptoms (%)	92.5 (90.0 - 94.6)	100.0 (100.0 - 100.0)
PIMU PPCD crown dieback (%)	15.6 (1.4 - 33.5)	7.4 (3.7 - 10.1)
Total PIMU cones on live trees (cones / ha)	74,961 (24,781 - 117,174)	59,306 (35,809 - 88,177)
Closed PIMU cones on live trees (cones / ha)	25,750 (314 - 51,200)	11,912 (7,328 - 16,031)

Changes in mid-seral stands between 16 years (2011) and 26 years post-fire (2021)

Between 16 and 26 years post-fire, the primary changes to mid-seral stands that were re-measured in 2021 were associated with forest stand dynamics related to density-dependent thinning and effects from the continued progression of PPCD (Table 3). Over this 10-year period, stands were characterized by a 50% increase in live bishop pine QMD, a doubling of standing dead bishop pine QMD, and sharp reductions in live and dead bishop pine tree density - all trends that are expected in this seral stage. The percentage of live bishop pine trees exhibiting PPCD symptoms increased from a median of 75% in 2011 to 97% in 2021. Live bishop pine basal area decreased modestly and dead bishop pine basal area increased modestly in this period, which may be related to the increase in incidence of PPCD. The decrease in live basal area and potential opening of the canopy from combined PPCD crown dieback and subsequent tree blowdown could have been associated with documented increases in coarse surface fuels, as well as increased diversity and evenness in the plant community (Table 3).

Table 3. Summary statistics for select variables in mid-seral stands that were measure in 2011 (16 years post-fire) and again in 2021 (26 years post-fire). Values are medians (min - max).

	16 years post-fire (2011)	26 years post-fire (2021)
Coarse surface fuels (Mg/ha)	9.4 (0 - 168.4*)	34.1 (13.2 - 65.7)
PIMU QMD live (cm)	12.3 (6.6 - 15.3)	18.4 (12.8 - 21.7)
PIMU QMD dead (cm)	5.9 (3.6 - 10.8)	12.0 (6.1 - 16.7)
PIMU basal area live (m2/ha)	54.7 (29.5 - 69.3)	40.6 (26.1 - 51.1)
PIMU basal area dead (m2/ha)	7.3 (1.9 - 41.4)	12.2 (9.1 - 22.9)
PIMU live trees / ha	5,073 (3,266 - 14,525)	1,553 (805 - 3,178)
PIMU dead trees / ha	3,254 (1,061 - 7,227)	1,469 (723 - 3,125)
Shannon Diversity Index	0.51 (0.04 - 1.02)	0.84 (0.10 - 1.61)
Species Evenness	0.22 (0.03 - 0.44)	0.41 (0.06 - 0.61)
Live PIMU trees exhibiting PPCD symptoms (%)	74.7 (8.5 - 93.2)	97.3 (90.0 - 100.0)

* value is likely an error from the 2011 survey but we are unable to reconcile. Medians are less affected by such high outliers.

Differences among stands with high and low severity of PPCD in 2021

Despite the continued progression of PPCD since the early 2000s, most stand structure characteristics did not differ strongly between stands that were designated as high severity or low severity PPCD based on classified aerial photography. Live and dead bishop pine QMD, basal area, and density were similar among stands with high or low PPCD severity, as were total-cone and open-cone abundance for live bishop pine trees (Table 4). Not surprisingly, bishop pine crown dieback associated with PPCD was approximately 2x greater in high severity stands than in low severity stands, and correspondingly, canopy openness was 2x greater as well. Most plant community metrics were similar, though greater plant community diversity and forb cover in high-severity stands were likely in response to the opening of the canopy from PPCD-associated crown dieback. Coarse surface fuels were approximately 2x greater in high-severity stands, though still within the range of values associated with late-seral stands (Table 1). Importantly, most of the bishop pine demographic parameters of concern were not different between low and high severity PPCD stands. Live and dead bishop pine populations and tree sizes, as well as cone abundance on live trees were similar in 2021. Bishop pine seedling regeneration was not observed in any plots other than two high-severity PPCD plots in 2021 (139 and 764 stems / ha).

Table 4. Summary statistics for select variables in mid-seral stands across levels of PPCD severity in 2021. Values are means (min - max).

	High severity PPCD	Low severity PPCD
Coarse surface fuels (Mg/ha)	49.8 (36.8 - 65.7)	21.5 (13.2 - 31.5)
PIMU QMD live (cm)	18.8 (12.8 - 21.7)	16.7 (14.2 - 19.5)
PIMU QMD dead (cm)	12.9 (6.1 - 16.7)	9.4 (6.5 - 13.3)
PIMU basal area live (m2/ha)	38.2 (29.7 - 46.6)	42.5 (26.1 - 51.1)
PIMU basal area dead (m2/ha)	14.6 (9.1 - 22.9)	12.4 - (9.3 - 17.3)
PIMU live trees / ha	1,610 (805 - 3,040)	2,001 (1,299 - 3,178)
PIMU dead trees / ha	1,448 (723 - 3,125)	2,031 (980 - 2,842)
Canopy openness (%)	19.9 (12.6 - 26.0)	10.8 (8.3 - 12.3)
Shannon Diversity Index	1.03 (0.29 - 1.61)	0.65 (0.10 - 1.09)
Species Evenness	0.44 (0.18 - 0.55)	0.37 (0.06 - 0.61)
Shrub cover (%)	2.61 (0.03 - 7.53)	2.51 (0.00 - 10.00)
Graminoid cover (%)	0.01 (0.00 - 0.03)	0.00 (0.00 - 0.00)
Forb cover (%)	15.08 (2.25 - 27.50)	5.23 (0.30 - 12.25)
Live PIMU trees exhibiting PPCD symptoms (%)	93.8 (90.0 - 100.0)	98.6 (94.6 - 100.0)
PIMU PPCD crown dieback (%)	16.2 (3.7 - 33.5)	6.8 (1.4 - 10.1)
Total PIMU cones on live trees (cones/ha)	64,430 (24,781 - 98,465)	69,838 (35,809 - 117,174)
Closed PIMU cones on live trees (cones/ha)	18,642 (314 - 51,200)	19,020 (7,328 - 41,760)

Key insights and considerations for management

The findings of this field study provide insights on current conditions and forest health for bishop pine forests.

1. Although PPCD has continued to progress in the bishop pine forests on the Point Reyes Peninsula, several key measures of forest health remain at levels that suggest continued persistence of the bishop pine forest. First, the effects of PPCD were found to be strongest in mid-seral stands and weaker in late-seral / old growth stands. In mid-seral stands included in this study, there was no strong evidence indicative of PPCD converting bishop pine forests to a different vegetation type. In general, the effects of PPCD-associated canopy dieback and tree mortality have included opening of the canopy and increasing surface fuel loads - though not to levels that exceed those found in late-seral old-growth stands. The effects of PPCD, coupled with subsequent blowdown of dead trees (as a result of density dependent mortality or from PPCD) could modestly accelerate successional trajectories and stand development toward late-seral old growth conditions for some attributes. In two cases, high-severity PPCD mid-seral stands had sparse establishment of bishop pine seedlings in the absence of fire (seedlings were approximately 1-2 years old in 2021), which may buffer against canopy tree mortality and increase structural complexity in stands.

2. Surface fuel profiles and stand structure attributes that relate to fire hazard (live and dead tree density, canopy closure / openness) across all seral stages are within bounds of what is expected for a fire-prone serotinous forest ecosystem characterized by a stand-replacing fire regime. Fuel loads and attributes associated with potential fire hazard were greater in mid-seral stands that were forested prior to the Vision Fire (compared with mid-seral stands that were not forested prior to the Vision Fire) and mid-seral stands with greater PPCD severity (compared to mid-seral stands with lower PPCD severity). In addition, the effects of PPCD opening the canopy and increasing tree mortality can increase within-stand wind speeds, potentially affecting fire rate-of-spread if fire were to occur. However, values for fuel loads, canopy openness, and live and dead tree basal area were all within the range of values measured in old-growth stands, suggesting that any potential elevated fire hazard is not outside the bounds of this ecosystem.

3. While the effects of PPCD and current conditions for bishop pine forests on Point Reyes Peninsula suggest that broad-scale mitigation treatments may not be necessary from the standpoint of forest health or continued persistence of this ecosystem, they also suggest that experimental treatments aimed at reducing fuel loads / fire hazard or decreasing competition among mid-seral bishop pine trees to improve resistance to disease could be implemented to explore options for different treatments to accelerate conditions toward structurally complex older-seral conditions. Data from the old-growth stands that were

measured in this study could be used as an approximate target for structural characteristics (e.g., tree sizes, densities, fuel loads) to apply experimental treatments that aim to reduce negative impacts from PPCD and retain desirable characteristics for eventual late-seral bishop pine forests. For example, if thinning treatments were applied in mid-seral stands with the aim of reducing fuels and mitigating against PPCD, target densities could be set to be above those in old-growth stands assuming continued mortality and little-to-no bishop pine regeneration will occur in the absence of fire.

Potential experimental treatments

Incorporating the findings of this study into the broader context of bishop pine forest health outlined in the 2021 White Paper (Harvey and Agne, 2021) provides information for consideration of potential experimental treatments to achieve a range of objectives. These are explained below and are separated out within forests of different seral stages, as context and potential objectives vary.

Early-seral (~0 to 10 years post-fire)

This stand condition is not abundant on the Point Reyes Peninsula, aside from small areas of bishop pine forest that burned in the 2020 Woodward Fire. Therefore experimental treatments are not presented here, other than a recommendation for post-fire monitoring of bishop pine forests that were burned in 2020, where feasible. Following the 1995 Vision Fire, post-fire monitoring occurred at annual intervals initially, and then progressed to semi-decadal and decadal intervals as successional dynamics slowed (Harvey and Holzman 2014).

Mid-seral (~10 to 50 years post-fire)

This stand condition is abundant on the Point Reyes Peninsula, and is characteristic of areas burned in and regenerated from the 1995 Vision Fire. Mid-seral stands are heavily impacted by the spread of introduced pine pitch canker disease, and combined with naturally occurring density-dependent mortality, are where management concerns are greatest regarding bishop pine forest health and potential fire hazard. Three potential experimental treatments are outlined below, providing a range of options, depending on specific objectives.

Optimizing mitigation of fire hazard: Forest thinning and reduction of surface fuels

As bishop pine forests are characterized by a high-severity, stand-replacing fire regime, this treatment is not necessarily ecologically oriented, but instead is designed to maintain some bishop pine forest cover while mitigating fire hazard near roads and the wildland urban interface.

Actions would include thinning of mid-seral bishop pine forests from current densities of ~1,500 stems per ha to target densities of ~150 trees per hectare. This tree density is near the midpoint of late-seral / old-growth bishop pine stands, and with expected additional tree mortality over the next several decades, would result in open canopy conditions with reduced crown fuel loads and horizontal discontinuity among crowns. Treatments could target removal of dead snags, live trees of smaller diameter and height, and trees showing signs of more severe pitch canker disease. Coarse woody surface fuels would be pile burned and fine surface fuels would be treated with a masticator and pile burned. Target surface fuel loads would be < 10 Mg/ha, though specific targets would be part of the demonstration project study design. Broadcast burning is not recommended as this would likely stimulate vigorous understory shrub response through soil seed banks and resprouting.

Acceleration of late-seral structural complexity and mitigating pine pitch canker severity
Contrasting the treatment above, this treatment is ecologically oriented, but not intended to primarily address fire hazard (recognizing that stand-replacing severe fire is normal in this ecosystem). As it is not anticipated to *increase* fuel loads or fire hazard, this experiment could be opportunistically located in/near areas where other treatments are being applied for fire hazard reduction for operational feasibility.

Actions would include thinning of mid-seral bishop pine forests from current densities of ~1,500 stems per ha to target densities of ~300-500 stems per ha. This tree density is near the upper density of late-seral / old-growth bishop pine stands, and allows for some additional density-dependent mortality to occur over the next several decades as stands approach late-seral / old-growth stages. This treatment would result in reduced crown fuel loads, though to remaining crown fuel loads that are greater than the treatment above. Cut trees could be removed and pile burned if treatments are applied near the WUI, and treatments could retain larger dead snags for wildlife habitat. Treatments could target removal of live trees that are showing signs of more severe pitch canker disease, and then prioritize smaller trees as a second filter. Tree removal should be conducted with goals of increasing horizontal heterogeneity in stand structure (e.g., leaving live trees in complex spatial patterns of clumps and gaps) that is characteristic of such patterns in old-growth stands. Treatment of surface fuels would not be part of this design, as thinning of the canopy would be intended to stimulate advanced development of native shrubs in the understory.

NOTE:
With any of the above treatments, careful consideration should be given to unintended negative impacts. This includes

- *Introduction or favoring of non-native species.* Where non-native species (e.g., Himalayan blackberry) are already present in the understory, thinning the overstory bishop pine may stimulate growth of non-native and aggressive plants. In addition, treatment activities can be a vector for introduction of seeds of non-native species.

- *Inadvertent spread of Fusarium circinatum (the fungus that causes pitch canker disease).* To the degree possible, treatment activities should avoid wounding or limbing retained (unharvested) trees, as pine pitch canker develops most readily through wounds on trees.

- *Alteration of within-stand windspeeds through reduced friction.* Opening of the canopy in these treatments will alter wind friction within stands, and can potentially alter fire behavior through increasing wind speeds. As high-intensity crown fire is normal fire behavior in bishop pine forests, when any stand (treated or not) experiences fire under extreme conditions, crown fire and dangerous fire management operations are highly likely.

- *Thinning and unknown potential effects on population-level genetic resistance to pine pitch canker disease or other important traits.* Bishop pine forests characteristically go through a stand-development period of intense density-dependent thinning where young and mature post-fire trees are competing. This is a local population process of selection that has evolutionary consequences, and altering this process through management thinning may select for traits in ways that are not yet understood.

Old growth (~50 to 100+ years post-fire)

The effects of pine pitch canker disease have been less severe in late-seral / old-growth stands on the Point Reyes Peninsula, and fire hazard is normally high in these forests as well. Therefore, experimental treatments for fire hazard reduction and bishop pine forest health (with regard to pine pitch canker disease) are less relevant. However, in very old stands (>100 years) that are at risk of senescence (death of the canopy bishop pine trees before the next fire), if desired, experimental treatments could provide small scale surrogates for fire and regeneration opportunities for bishop pine.

Fostering bishop pine regeneration in old-growth forests

In locations where bishop pine forests are at risk of senescence (e.g., >80-120 years old), and bishop pine regeneration is desirable, prescribed burning at a very local scales and under very controlled conditions would likely be needed to create substrates available for seedling regeneration. Broadcast prescribed burning is highly not recommended due to risks of fire escape and natural fuel complexes in bishop pine forests that can easily support intense crown fire behavior that is challenging to control and manage. Removing coarse surface fuels via cutting and fine surface fuels via raking is highly important prior to prescribed burning. If prescribed burning cannot be conducted safely, experiments could include soil scarification and either planting seedlings or dropping seed from bishop pine cones that are opened up in an oven.

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Appendices

Appendix 1: Complete field data collection protocol

Appendix 2: Plot level data for field plots sampled in this study (see attached data file)

Appendix 3: GIS shapefile for field plot locations sample in this study (see attached shapefile)

Appendix 1: Complete field data collection protocol

PORE/TBSP bishop pine pitch canker and forest health field study

Objectives and research questions

Plots will be installed to measure current conditions and set up future monitoring to assess conditions related to multiple questions about forest health in bishop pine forest on the Point Reyes Peninsula. Plots will be designed to answer the following research question:

1. How does the level of pitch canker infection affect the following measures of forest health:
    a. Fuel profiles (e.g., surface and canopy fuel amount and configuration)?
    b. Vegetation dynamics (e.g., tree regeneration and understory vegetation community shifts)?
    c. Reproductive capacity in the event of a subsequent fire (e.g., viable PIMU seed abundance)?

The following protocol is intended to be flexible enough to be implemented as additional stand structures and seral stages arise on the landscape including:

- Following wildfire to monitor recruitment and pitch canker effects on early seral stands
- Following the implementation of hazardous fuels reduction, RX burning, or removal of infected trees

At this time, there is no recommendation to treat these stands to mitigate effects of pitch canker. However, if treatments are implemented for other purposes or in the context of an experiment, this protocol can be implemented in such stands, ideally prior to treatment and following treatment.

Plot location and arrangement

Initially, plots will be installed in stands that originated following stand-replacing fire in the 1995 Vision Fire (mid seral stands composed of a ~25 year old cohort), as well as in old growth stands. Plots will be installed in areas affected by pitch canker and (as much as possible) unaffected by pitch canker, within each seral stage. Recognizing that the gradient of pitch canker disease severity is continuous, for logistical ease, plots will be given a quick field ID of an ocular estimate of pitch canker severity prior to plot establishment, and will be classified as either low severity / unaffected (<10% crown dieback and/or tree mortality) or high severity (>50% crown dieback and/or tree mortality). We plan to sample 5 plots within each of these severity categories and across the following stand trajectories / seral stage: mid-seral stands that were bishop pine forest pre-Vision Fire; mid-seral stands that were areas where bishop pine expanded as a result of the Vision Fire; and old-growth stands that were not burned in the Vision Fire. With 5 plots per each of these 6 strata, we anticipate a total of 30 plots should there be sufficient area for sampling within each class. Plots will be installed in areas with near complete canopy closure (e.g., > 75% bishop pine canopy dominance) of bishop pine in the forests established after the 1995 Vision Fire (e.g., excluding more open scattered single trees in coastal scrub and woodland areas). For old growth plots, the canopy may be more open due to the successional state of these stands, but bishop pine should be the dominant canopy species. For both seral stages, bishop pine canopy cover may be lower today because of mortality from pitch canker, but would be reconstructed to the pre-pitch canker canopy dominance of bishop pine. Within each strata (seral stage x mortality class), plots will be distributed, though not intentionally stratified, across a range of stand densities, topographic positions, and distance from the coast to capture a range of conditions that may influence disease severity.

The protocol below is slightly modified from an existing protocol developed and used by Michelle Agne, who has been installing similar plots across a time since fire chronosequence in bishop pine and knobcone pine forests throughout CA and southern OR.

Timeline
The total estimated time for plot installation with a crew of 2 or 3 people is approximately 4 to 6 weeks, which depends on accessibility of plot locations. This is based off an estimated pace of 2 plots per day. We propose to sample in October and November 2021, depending on how COVID-19 restrictions unfold. Reconnaissance using google earth imagery and detailed vegetation maps have allowed plot selection prior to field work.

Plot measurement workflow
1. Arrive at plot, mark plot center with chaining pin
2. Follow protocol for plot size selection
3. Field crew member 1 marks GPS point, takes photos, slope, aspect while field crew member 2 runs a transect tape north and field crew member 3 runs a transect tape east (center person can help sight the azimuths)—all crew check to ensure compass declinations are correct*
4. Field crew member 2 runs the tape south, field crew member 3 runs the tape west while field crew member 1 records a list of all understory plant species visible from plot center
5. Measure downed woody fuels and depth along the transects
6. Tally tree regeneration (regen during the interfire period for mid-seral and old growth plots) < 1m in height by microsite in 2m width x 16m length belts beginning at 2 meters from plot center in each cardinal direction (increase size if <10 seedlings/belt, decrease size if >200 seedlings/belt)
7. Estimate canopy, understory vegetation and ground % cover at 8 total 1x 1m subplots at the middle and the end of each belt transect; within a 2m circle plot centered on the cover plots, count all shrubs, identified to species and take crown dimensions of each shrub
8. Set radius of central circular plot to capture approximately 50 standing bishop pine trees; flag border and measure every tree in the stand for DBH, L/D, count cones, assess for pitch canker
9. For subset of plots, collect three cones from three representative bishop pine trees.
10. Check data sheets to ensure all data have been recorded
11. Roll up tapes, collect chaining pins, take down flagging; check that all gear is accounted for
12. Mark plot center with permanent metal stake to be used for plot location for possible future remeasurements

Take care not to crush seedlings and fuels on the cardinal directions

***Compass Declinations at PORE – 13.3 degrees E**

Plot Design and Layout

All plots consist of the following elements:

- A central 6.3m radius plot for measurement of standing trees > 1m in height. The central radius can extend to 20m if the target of approximately 50 standing bishop pine is not reached within a 6.3m radius.
- 20 m length transects established in the 4 cardinal directions, beginning from plot center.
- 4 belt transects oriented to the right of each cardinal direction transect (when looking from plot center to the end of the transect) for counting regeneration < 1m in height. Beginning two meters from plot center, regeneration will be counted in a two meter width belt transect until the 20 meter mark. Note: This is the default, but we will vary this protocol by seedling density—if <10 seedlings per belt transect—we will sample the entire overstory plot, if >200 seedlings per belt transect—we will decrease the belt transect size to 1 x 18m. Note that we expect low densities of seedlings in mid-seral and old growth plots.

*Plot locations should be at least 50 m from any road or disturbance such as a clear-cut. Plots should also be located at least 50 m apart if they differ by aspect or pitch canker severity. If plots do not differ on such characteristics, they should be located at least 200 m apart.

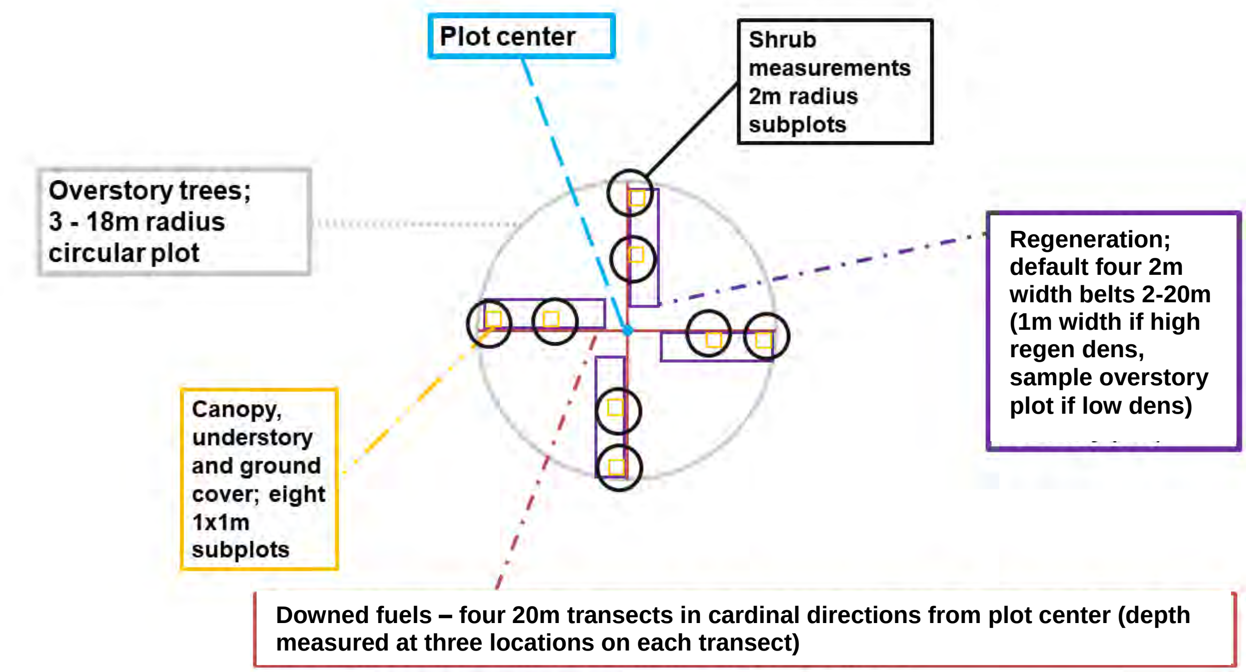


Figure 1. Plot layout diagram

Plot

Plot Center Installation

- After locating plot center place chaining pin (candy cane) in ground and hammer in until firmly in place, but with enough height to attach meter tapes for transect establishment.
    - Replace chaining pin with permanent plot center stake following plot measurement
- *Take care not to crush fuels and vegetation along transect lines before taking photographs and measuring fuels and vegetation transects.*

Record the following on **Plot** data sheet:

- SITE (PORE_PC_ and one of: DL, DH, OL, OH for dense/low mortality, dense/high mortality, open/low mortality, open/high mortality) if in post-Vision stands, OGL or OGH if in old growth stands
- PLOT# (1,2,3, etc)
- Date of plot measurement (Month/Day/Year)
- Personnel initials
- Aspect (measured in degrees using a compass at plot center)
- Elevation (meters)—from GPS unit
- Slope (average degrees slope of upslope and down slope measurements taken from plot center with laser rangefinder or clinometer)
- Physiographic details (convex or concave; low, mid, upper 1/3 of slope/flat/ridgetop)
- Overstory plot radius (measured in meters, determined to capture approximately 50 overstory trees)
- Regeneration plot dimensions (dimensions and locations of belt transects, or the radius of the entire plot if seedling density is low [see regeneration for decision criteria])
- GPS Coordinates (measured in Universal Transverse Mercator [UTM], WGS1984)
- Fire Year(s) = year of last fire at plot, if unknown record "UNK"
- Species list—list all species present in the plot
- Plot remarks (disturbance, slash, dense vegetation, sparse understory, details that could help relocate the plot in the future)

Photography

Photographs will be taken from plot center in the four cardinal directions (N, S, E, W) and a photo of the canopy facing directly up from plot center before plot is measured. From plot center take 1 plot scale photo along each fuel transect. Place plot ID card in foreground of photo prior to photo without the identification card. Attempt to capture ground fuels and distant overstory. Record photograph # from camera on **Plot** data sheet.

2011 Understory and Canopy Cover Remeasure

Within the 6.3m central subplot, record the following at the bottom of the **Understory and Canopy Cover** data sheet:

Total live vegetation and canopy cover (%) —visually estimated using the cover classes below

- %Canopy cover
- % Shrub cover
- % Herb cover

Ground cover (%) —visually estimated using the cover classes below

- % Litter/duff
- % Bare soil
- % Rock

Species cover — four letter species code, visually estimated using the cover classes below. The sum of species cover for each cover type should be within the range of the total cover %

- Tree
- Shrub
- Species — any species that is not a tree or shrub.

Cover classes (%):

0.25 (<0.5)	**0.75** (0.5-1)	**3** (1-5)	**15** (5-25)	**37.5** (25-50)	**62.5** (50-75)	**85** (75-95)	**97.5** (95-100)

Downed Woody Fuels

Transect Establishment

Starting from plot center 4 fuel transects will be established in the cardinal directions. Each transect will be 20 m in length & established using 50m tapes. Check the declination on your compass and have someone sight you from plot center as necessary. 50 m tapes will be fixed to the ground using candy cane chaining pins as low to the ground as fuels and vegetation allow.

Record the following on **Fuels** data sheet:

- SITE (PORE_PC_ and one of: DL, DH, OL, OH for dense/low mortality, dense/high mortality, open/low mortality, open/high mortality) if in post-Vision stands, OGL or OGH if in old growth stands
- PLOT # (1,2,3, etc)
- Month/Day/Year
- Initials of Personnel
- Plot remarks (disturbance, slash, dense vegetation, sparse understory, etc.)

Measurements

Along each 20 m transect (starting from transect end to plot center), the number of 1-hour, 10-hour, 100-hour, and 1,000-hour fuels are tallied. Fuel classes are defined and measured as:

- 1-hour – 0-0.64 cm diameter – **Tallied from 0-2 m** along transect
- 10-hour – 0.65-2.54 cm diameter – **Tallied from 0-5 m** along transect
- 100-hour – 2.55-7.62 cm diameter – **Tallied from 0-10 m** along transect
- 1000-hour – >7.62 cm diameter – Tallied and measured along **entire transect (0-20 m)**
    - For Fine Woody Debris (1-, 10-, and 100-hr fuels), tally by size class for each transect and record total for the transect under Count
    - For Coarse Woody Debris (1000-hour fuels), record Transect and for each piece:
        - Four letter Species code if known (if unknown, UNK)
        - Piece Count (most often this is 1)
        - Decay Class from 1 to 5 (Figure 1; Table 1)
        - Char Class (0 = no char, 1 = light char, 2 = deep char)
        - Diameter at intersection with transect (x.x cm)

Go-no-Go gauges will be used to classify 1, 10, and 100 hr fuels, and diameter measurements of 1,000 hr fuels will be done with large metal calipers.

Litter, duff, and fuel bed depth are measured along each Transect at the Distances 2m, 5m, and 10m. Use a trowel to create a clear soil profile and use a ruler to measure in cm (Figure 4):

- Litter depth = top of loose layer made up of dead plant material with individual pieces still identifiable to top of duff layer
- Duff depth = top of profile made up of decomposed unrecognizable litter, darker color than litter (under litter, above mineral soil which is lighter color than duff, sandy)
- Fuel bed depth is measured in cm with an avalanche probe in cm from the specified transect distances. Align the avalanche probe at a right angle and determine the tallest point of dead and downed fuel. Dead fuel depth is measured from the bottom of the litter layer to the top of the highest intercepted dead and downed particle (including litter and wood).

Regeneration

Plot Establishment
For typical post-fire regeneration densities, seedlings and saplings (<1m in height) will be measured within four 2m width belt transects beginning at 2m from plot center and extending to 20m (18m length per belt). Belts will be oriented in the cardinal directions, using the transects previously established for fuels measurement (the four 20m transects established in the N, E, S, and W directions). Belt transects are oriented to the clockwise side (right of each transect when facing plot edge--line transect is the belt transect's left border). Plot size varies by regeneration density. The default is four 2 x 18m belt transects.. If >200 seedlings per belt transect—decrease each belt transect to 1 x 18m. ***We expect low densities of seedlings in mid-seral and old growth plots, so sampling the entire overstory plot may be common during 2021 fall field work.***

Record the following plot-level information on **Regeneration Counts** data sheet:
- SITE (PORE_PC_ and one of: DL, DH, OL, OH for dense/low mortality, dense/high mortality, open/low mortality, open/high mortality) if in post-Vision stands, OGL or OGH if in old growth stands
- PLOT # (1,2,3, etc)
- Month/Day/Year
- Initials of Personnel
- Plot location notes (any comments that could help relocate the subplots in the future)

Record the following subplot-level information on the **Regeneration Counts** data sheet:
- Subplot (N, E, S, W for the transect it is on, or NE, SE, SW, NW for quadrant if sampling within overstory plot)
- Dimensions (Length x width [meters] of the belt transect or radius of quadrant if sampling within overstory plot)

Measurements
Regeneration counts are tallied by substrate, cover, year, and live/dead classification
- Species
- Height class = 0-15cm, 15-30cm, 30-60cm, 1-2m (DBH)
- PC = Y if tree has pitch cankers or defoliation, N if tree looks healthy

Understory and Canopy Cover

Plot Establishment

At the end and in the middle of each of the 4 belt transects canopy, understory vegetation and substrate cover will be visually assessed within a 1x1m quadrat (at 9 – 10 m along the length of the transect and half the width of the belt transect) for a total of 4 subplots per plot.

Record the following on **Understory and Canopy Cover** data sheet:

- SITE (PORE_PC_ and one of: DL, DH, OL, OH for dense/low mortality, dense/high mortality, open/low mortality, open/high mortality) if in post-Vision stands, OGL or OGH if in old growth stands
- PLOT # (1,2,3, etc)
- Month/Day/Year
- Initials of Personnel
- Plot comments (disturbance, slash, dense vegetation, sparse understory, etc.)

For each quadrat record:

- Subplot (direction of the transect on which the subplot is located, e.g., N, E, S, W)
- Location (distance along the transect at which the subplot is location e.g., 9-10)

Measurements

Ground cover (%)—visually estimated to the nearest 5% as a team within the quadrat—sum to 100% as a direct overhead view

- % Litter
- % Wood (including twigs, branches, and coarse wood)
- % Tree bole
- % Bare (soil, gravel)
- % Rock (boulders, exposed bedrock)

Live vegetation cover (%)—visually estimated to the nearest 5% as within the quadrat—can range from 0 to over 100% (0 would be no live vegetation within the plot, over 100% means there are multiple layers of canopy over at least part of the plot)

- % Shrub (woody non-tree species)
- % Graminoid (grasses, sedges, rushes)
- % Herb/Forb (non-woody, non-graminoids)
- % Tree (live tree canopy)

Invasive cover (%)—visually estimate to the nearest 5% the invasive species cover of each of the above life forms, estimated as a percentage of the total quadrat area (if no invasive species present for a life form, record 0)

Inv. spp. – record the four letter codes for all invasive species noted in the quadrat

Canopy openness—use densiometer (see Figure 7) at 9m markon each transect to estimate canopy cover

- Make four readings in each location, facing N E S and W—record number of intersections not occupied by canopy cover for each reading

Shrubs

Plot Establishment

Individual shrubs are measured using an avalanche probe to sweep in a circular 2m radius subplot centered on the 9m transect mark (corner of understory cover 1x1 plot). Record the following on **Shrubs** data sheet:

- SITE (PORE_PC_ and one of: DL, DH, OL, OH for dense/low mortality, dense/high mortality, open/low mortality, open/high mortality) if in post-Vision stands, OGL or OGH if in old growth stands
- PLOT # (1,2,3, etc)
- Month/Day/Year
- Initials of Personnel
- Plot comments (disturbance, slash, dense vegetation, sparse understory, etc.)

For each subplot record:

- Subplot (direction of the transect on which the subplot is located, e.g., N, E, S, W)
- Location (distance along the transect at which the subplot is location e.g., 9)

Measurements

For each individual shrub record each of the following:

- Species-- record four letter code for the shrub species (first two letters of genus, first two letters of species)
- Status—L (live, has green foliage, no skeleton from pre-fire individual), D (dead, recently dead, fine twigs and foliage still attached), S (skeleton, long dead, no foliage, bark or fine branches remain), R (resprouting, evidence that plant killed by fire is coming back vegetatively—charred skeleton with live foliage coming from same individual)
- Height (Ht) —maximum height of plant (cm) measured with avalanche probe
- Crown Width 1 (CW1), Crown Width 2 (CW2)—two perpendicular widths of the shrub crown (for live and resprouting shrubs) or the maximum extent of dead branches/foliage (for dead and skeleton shrubs)

NOTE: If the shrub can't be identified in the field—take photo and assign a code such as "Shrub A," write down photo number and attempt to keep consistent when the plant is next seen, collect a sample to press

Overstory Trees

Plot Establishment

Overstory trees and saplings > 1m in height will be measured within a central circle plot with a variable radius set to capture approximately 50 live (or recently dead with cones) bishop pine trees above breast height. Select the radius of the plot and flag the border. A maximum radius of 18m is expected to capture this number of trees, but if not, radius can be expanded. The minimum radius is 6m.

Record the following on **Overstory Trees** data sheet:

- SITE (PORE_PC_ and one of: DL, DH, OL, OH for dense/low mortality, dense/high mortality, open/low mortality, open/high mortality) if in post-Vision stands, OGL or OGH if in old growth stands
- PLOT # (1,2,3, etc)
- Month/Day/Year
- Initials of Personnel
- Plot radius (meters)
- Plot comments (disturbance, slash, dense vegetation, sparse understory, etc.)

Measurements

For each standing tree (including all conifers, bay laurel, madrone, coast live oak, tanoak) over 1 m record:

- Quadrant (NE, SE, SW, NW)
- Species (four letter code)
- Status (L for live trees, D for standing snags, B for broken snags)
- DBH (Diameter at breast height in cm recorded to nearest 0.1)

For the closest canopy-dominant and sub canopy bishop pine in each quadrant (8 trees/plot):

- Height (height to top of tree—tallest live OR dead height measured to nearest 0.1 meter using Laser rangefinder; Figure 3)
- Canopy base height (lowest live foliage measured to nearest 0.1 meter using rangefinder)
    - Note that heights may be difficult to measure in dense stands. In this case, measure trees that are visible with the rangefinder and use those heights to estimate heights of remaining trees in plot

For bishop pine only:

- Total cones (count)
- Closed cones (%)
- Squirrel cones (%)
- Open cones (%)
-
- Pitch Canker crown dieback (approximate percentage of tree crown exhibiting dieback, to nearest 5%)
- Wikler bole rating (0-2; 0 = no visible cankers, 1 = 1-3 visible cankers on bole and branches 2 = >3 visible cankers on bole and branches [Source: Wikler et al. 2003]
- Wikler branch rating (0-2; 0 = no visible top-down crown dieback, 1 = 1-7 visible terminal branches with dieback, 2 = >7 visible terminal branches with dieback) [Source: Wikler et al. 2003]. NOTE if there is evidence of resin bleeding on cones please make a note in the comments "Cone PC"

For dead trees (all species) only:

- Decay class (1-5) of standing snags using scale in Table 2, Figure 6

For old growth only:

- Record closed cone presence/absence (Y/N) only, do not count cones.

For each plot, once 50 trees have been measured, exclude cone counting (total cones and the closed/squirrel/open % ONLY) from the tree measurements in the following quadrant(s)

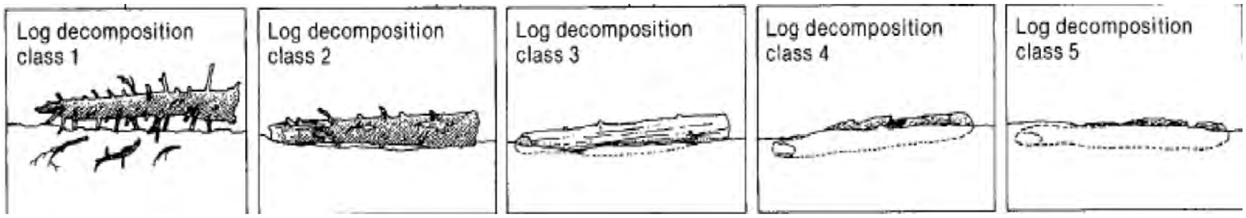
Cone sampling
Within three plots from each mortality (low vs high) by structural class (post-Vision Fire open, post-Vision Fire dense, old growth) combination (3 structural classes x 2 mortality classes x 3 plots each = 18 plots total), collect two closed cones from five live bishop pine trees within 5-20m outside of the overstory plot perimeter (18 plots x 3 trees each plot x 3 cones each tree = 162 cones). Select trees representative of the structure of most trees in the stand (i.e., codominant) that are representative of the pitch canker infection level consistent with most of the trees in the stand. Select cones that have been produced within the last several years (i.e., close to branch tips) with cone scales that are sealed and no obvious sign of damage from seed predators or insects. Store each individual cone within a brown paper lunch bag and record on the bag:

- SITE (PORE_PC_ and one of: DL, DH, OL, OH for dense/low mortality, dense/high mortality, open/low mortality, open/high mortality) if in post-Vision stands, OGL or OGH if in old growth stands
- PLOT # (1,2,3, etc)
- TREE # (Tree 1, Tree 2, or Tree 3)
- Tree DBH
- Wikler bole score
- Wikler branch score
- Month/Day/Year
- Initials of Personnel

The nine individually bagged cones from each site should be stored within a large paper grocery bag with the following on it:

- SITE (PORE_PC_ and one of: DL, DH, OL, OH for dense/low mortality, dense/high mortality, open/low mortality, open/high mortality) if in post-Vision stands, OGL or OGH if in old growth stands
- PLOT # (1,2,3, etc)
- Month/Day/Year

When transporting cones take care to store them in a cool place to prevent cone opening.



solid still solid Still pretty solid can start to kick apart
buried
Some bark some bark broken chunks
crumbly fine branches Few Fine branches

Figure 1. Coarse woody debris decay classes (1-5)

	Decay Class				
Characteristic	**1**	**2**	**3**	**4**	**5**
Bark	Intact	Mostly intact	Sloughing or absent	Detached or absent	Detached or absent
Structural Integrity	Sound, freshly fallen, intact logs	Sapwood somewhat decayed; heartwood mostly sound	Heartwood sound, supports own weight	Heartwood rotten; piece does not support its own weight, but maintains its shape, branch stubs pull out	None, piece no longer maintains its shape, it spreads out on ground
Branches and Twigs	If branches are present, fine twigs are still attached and have fine bark	Larger twigs are present, branch system entire	Large branches present, longer than log diameter, stubs will not pull out	Branch stubs present, shorter than diameter of log, stubs pull out	Absent, branch stubs and pitch pockets have rotted down
Texture of Rotten Portions	Intact, no rot; conks of decay absent	Mostly intact; sapwood partially soft (start of decay but cannot be pulled apart by hand)	Hard, large pieces; sapwood can be pulled apart by hand or sapwood absent	Soft, small blocky pieces; a metal pin can be pushed into heartwood	Soft; powdery when dry
Color of Wood	Original color	Original color	Reddish brown or original color	Reddish or light brown	Red-brown to dark brown
Invading Roots	Absent	Absent	Sapwood only	Throughout	Throughout
Vegetation	None	Mostly intact	Sloughing or absent	Detached or absent	Detached or absent

Table 1. Coarse woody debris decay classes (1-5)

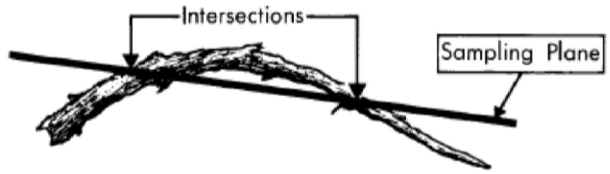
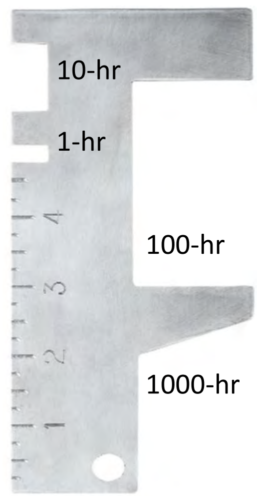
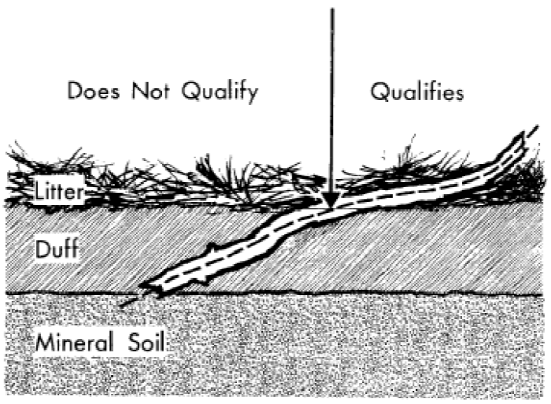


Figure 9.—Count both intersections for a curved piece.





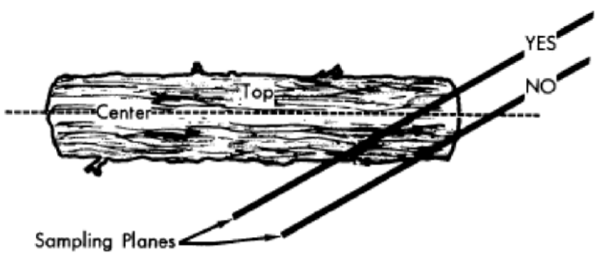


Figure 2. Additional rules for sampling downed woody debris.

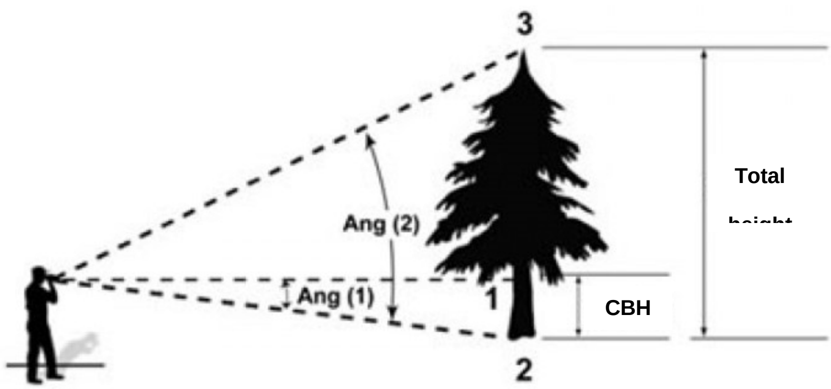


Figure 3. Diagram example of how to measure total tree height and canopy base height (CBH) using a laser rangefinder.

Yes= center of log is <u>in</u> duff layer or below.
No= center of log is <u>above</u> duff layer.

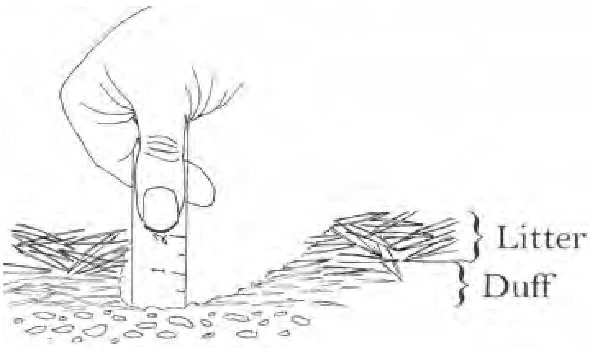


Figure 4. Rules for measuring litter and duff depths

Figure 5. From left to right: closed cone, open cone, squirrel cone

Table 2. Decay condition class for *snags*.

Code	Description
1	limbs and bark intact, heartwood decay minor, no sapwood decay, top breakage may be present
2	bark is 50% loose or missing, small limbs are missing, heartwood decay-none to advanced, sapwood decay-none to incipient, top breakage may be present, bole form is intact
3	bark is 75% missing, most limbs are missing, heartwood decay-incipient to advanced, sapwood decay-none to 25%, approximately 1/3 top breakage, bole is mostly intact
4	bark is 75% missing, most limbs are missing, heartwood decay-incipient to advanced, sapwood decay- > 25%, top breakage is 1/3 to 1/2, bole is losing form
5	bark is 75% missing, no limbs present, heartwood decay is advanced to crumbly, sapwood decay is 50% to advanced, top breakage is 1/2 or more, bole form is mostly lost

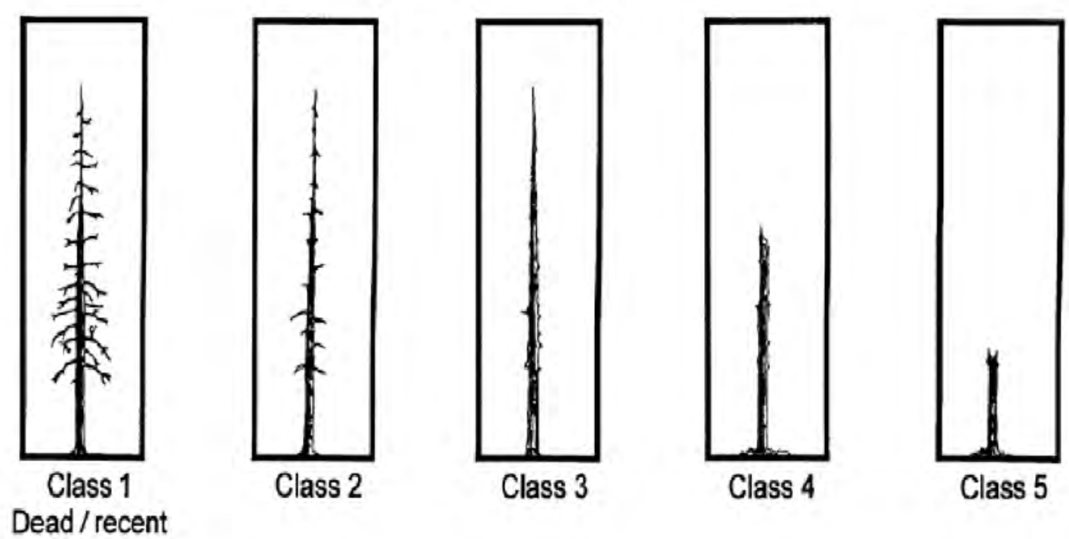


Figure 6. Decay class condition for snags

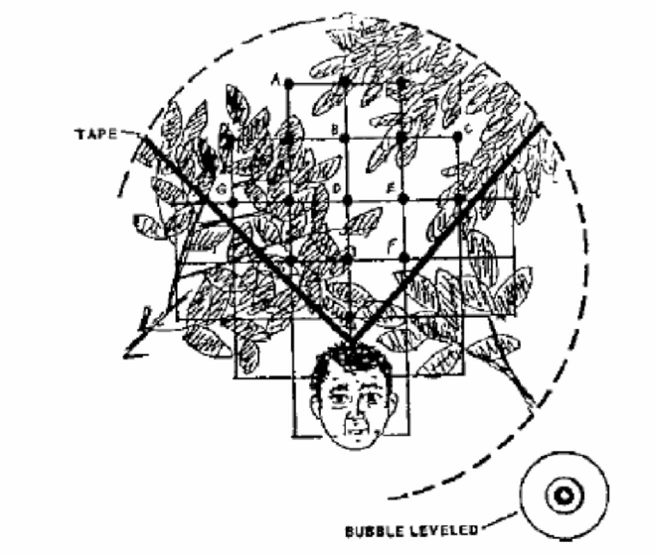
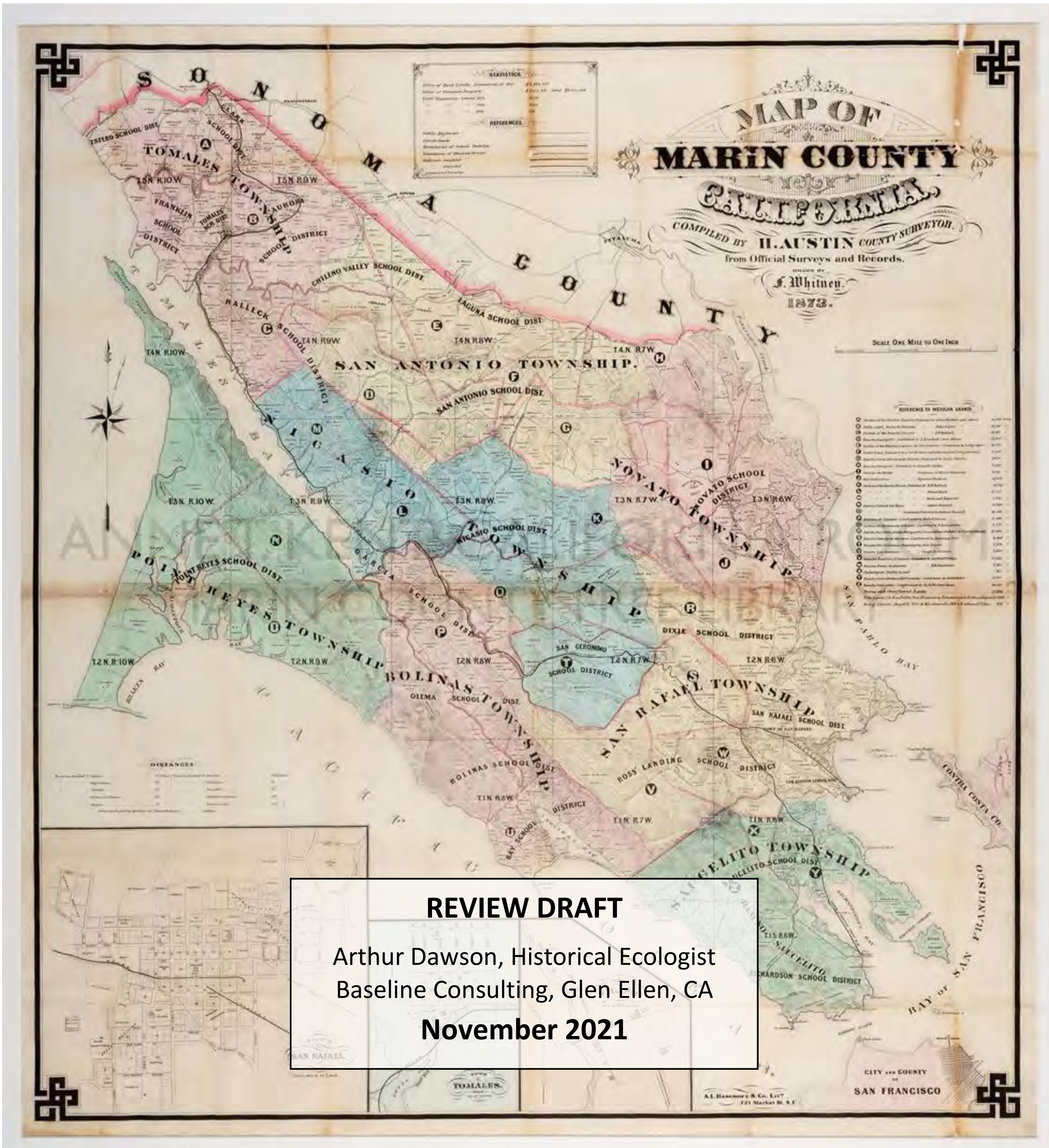


Figure 7. Modified convex densiometer for overstory cover measurement. Schematic of a modified convex densiometer (Strickler 1959) used for measuring overstory canopy cover. Note the proper positioning of the bubble level and the location of the head reflected at the apex of the "V".

Figure 8. Pitch canker symptoms – bleeding cankers/resin streaming (left [credit: Joey Hulbert] and middle [credit: Robert L. Anderson]), crown dieback (right; credit: Pitch Canker Task Force)

APPENDIX B: WILDFIRE HISTORY

MARIN COUNTY
WILDFIRE HISTORY MAPPING PROJECT



REVIEW DRAFT

Arthur Dawson, Historical Ecologist
Baseline Consulting, Glen Ellen, CA

November 2021

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Cover illustration: Austin, H. 1873. “Map of Marin County, California.” Compiled by H. Austin, County Surveyor. Drawn by F. Whitney.

BACKGROUND

Within the last five years, some of the largest and most destructive wildfires in California history have occurred in the North Bay counties of Lake, Napa, and Sonoma. Dozens perished in these fires, hundreds of thousands of people evacuated, and nearly 10,000 homes and structures were destroyed.

A recent study (Dawson 2019) of eleven square miles within the perimeter of the 2017 Nunns Fire (among those mentioned above), revealed that most of it had also burned in large fires in 1880, 1923, 1936, and 1964. In addition, a dozen smaller fires (< 1000 acres) were also recorded within the study area between 1871 and 2016. Some locations burned six times over that 145-year span. In contrast, on the eve of the 2017 fire, the CALFIRE record, spanning half that period (1945 – 2016), recorded just one large fire and four smaller ones within the same area.

Preliminary historical research into other recent wildfires in the North Bay, including the 2015 Valley Fire, the 2017 Atlas Fire, and the 2020 Wahlbridge Fire tell a similar story. Nevertheless, they took most people, including seasoned fire fighters, by surprise. While unprecedented in the loss of human lives and property, such burns, when placed within an historical context, fit into a long-term pattern.

These incidents point to the danger of taking the short-term as a guide. For example, most of the area visited by the 2017 Tubbs and Nunns Fires had not burned since 1964, placing the last fire outside the living memory of most citizens. Without a deep and spatially-detailed knowledge of our fire history, large fires are seen as 'chance' or 'unprecedented' events rather than recognized as part of a pattern. The fact that Marin County has escaped serious conflagrations in recent years encourages a similar mindset. But its history of large wildfires in the 19th and early 20th centuries suggests the likelihood of recurrence there as well.

OBJECTIVES

The recently released Marin Community Wildfire Protection Plan (CWPP; Dec. 2020, pg. 43) states, the "fire history for Marin is incomplete." This project, combining existing records with additional research, is intended to address this gap by documenting historical fires over a longer period and to a higher degree of spatial and temporal precision than has previously been undertaken. This detailed wildfire history for Marin County is intended to inform first responders, government agencies, decision-makers and the public about landscape-scale fire patterns and to support site-specific risk management.

TABLE 1: Source Comparison
*as individual fires were often documented from multiple sources, the sum of recorded fires from all sources is greater than 153

	# Recorded Fires > 160 acres	Ignition Date Known	Ignition Year Known
CALFIRE: 1917 – 2020	77	19 (25%)	40 (52%)
Newspapers: 1852 -1949	77	77 (100%)	77 (100%)
NPS 2011: 1852 – 1945	32	32 (100%)	32 (100%)
marinfirehistory.org: 1865 – 1972	23	22 (95%)	23 (100%)
Gaudinski 1990: 1859 – 1916	11	6 (55%)	11 (100%)
Marin Wildfire History Compilation (this study) 1852 – 2020	153*	116 (76%)	129 (84%)
Pre-1850 (see Appendix)	11	0	11 (100%)

TASKS & DELIVERABLES

All project **tasks** were successfully completed:

1) Documenting and mapping fires between the mid-19th century and 1917 (earliest CALFIRE data), with locations, estimated size, and perimeter where possible (threshold >160 acres);

2) Augmenting and enhancing early CALFIRE data between 1917 and 1966;

3) Developing a detailed wildfire timeline for the period 1850 to 2020;

4) Analyzing and identifying fire patterns (e.g. recurring locations, return intervals, seasonality etc.).

The associated **Deliverables**, incorporated into this report and related GIS files, are:

- Wildfire Timeline with citations, 1850 – 2020
- Map of known fires, 1850 – 2020, at best possible resolution
- Summary Report, 12 -25 pages
- All related electronic files, including images, text and GIS layers

METHODS

Wildfire data was compiled into a timeline (see Appendix) from a number of sources, including CALFIRE, the California Digital Newspaper Collection, the National Park Service, Marin County Fire Chief's Association, and "Fire History of the Marin Municipal Water District and Marin County Open Space District" (Gaudinski 1990). The lower limit for fire extent was 160 acres.

The earliest available wildfire perimeters were from CALFIRE, compiled by Edwin B. Gardner, Chief Fire Warden & Superintendent of the Tamalpais Forest Fire District from 1917 until his death in 1935. Documenting fires and fire perimeters before that date required extensive research into historical newspapers using the California Digital Newspaper Collection (CDNC) which contains material going back to the 1850s.

Various search phrases were used, including "wildfire," "grass fire," "brush fire," "forest fire" and others. False hits, most commonly structural fires, were discarded. The CDNC newspaper data was also used to augment and refine the CALFIRE record after 1917. As CALFIRE perimeters drawn for the 1917 to 1934 period do not have specific years attached to them, the newspaper data allowed us to assign dates for many of these fires.

Relevant search hits were digitally clipped, collected into a project archive, and relevant data filtered out to populate the columns in the timeline (Appendix B). Newspaper accounts included ignition dates, weather conditions, damage caused, extent in acres or miles, and specific locations (e.g. DeLong Ranch). Where only days of the week were mentioned (e.g. 'last Thursday'), it was translated into a date using historical calendars available online. In most cases, there was enough information to draw an estimated perimeter for each fire. Confidence levels were assigned as a rough assessment of the mapped accuracy of each fire's extent and location (Table 2).

Table 2. Confidence Levels for Accuracy of Mapped Historical Fire Perimeters

	Extent	Location
HIGH	Mapped at 85 – 120% of reported value	5 or more identified points OR CALFIRE data
MEDIUM	Mapped at 50 - 150% of reported value OR if unreported, has a rating of 'High' for location	1 point identified for fires ≤ 300 acres OR 2-4 points identified for fires > 300 acres OR Uncorroborated Gaudinski 1990 data
LOW	Mapped at <50 or >150% of reported value OR if unreported, has a rating of 'Medium' for location	1 point identified for fires > 300 acres

In about a dozen cases, there was only enough data to justify mapping a single point. In these cases, the descriptions (e.g. "much damage," "destroyed timber, houses and other property") were used to assess their relative size compared to better documented fires. These were later converted to small polygons.

Historical maps were essential to finding locations mentioned in the news reports, in particular official Marin County maps from 1873 and 1892, as well as historical USGS topo maps. Dewey Livingston's research on the ranches of Point Reyes (Livingston 1995) was also a valuable reference.

Once all the perimeters were drawn, fire intervals were calculated for each fire polygon using the clipping tool on a second copy of the shapefile. This provided dates for the most recent fire(s) within the polygon. For example, clipping the 1916 San Geronimo Fire (ProjectID 42) showed that fires in 1881 and 1859 had burned a portion of the area within the 1916 perimeter (and did not have identical footprints). Thus the fire return interval within the San Geronimo Fire perimeter was 35 and 57 years, or an average of 46 years. Where the 1926 Mount Tamalpais Fire (PROJECT1D 52) burned into the 1916 perimeter, that portion was given a return interval of 10 years. Areas with no known previous fires, were designated as "Unknown."

Using the 'Overlapping Features' tool allowed the number of fires at each location to be mapped. Finally, the ignition dates and extents were brought into an excel table to investigate changes in fire size and ignition dates.

RESULTS

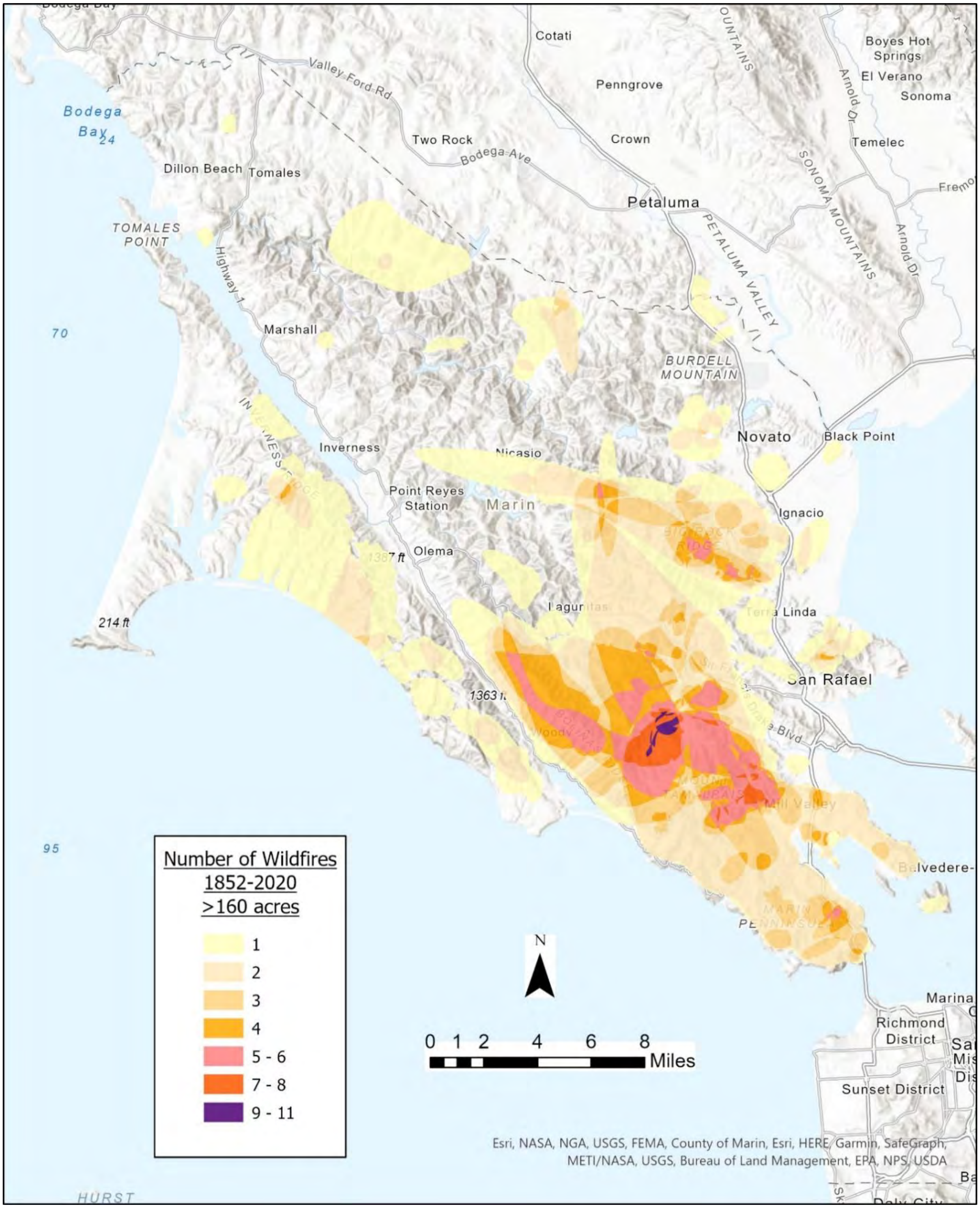

Figure 1. Number of Wildfires Mapped by Location

MARIN COUNTY WILDFIRE HISTORY MAPPING PROJECT
Baseline Consulting, Glen Ellen, CA

SEASONALITY

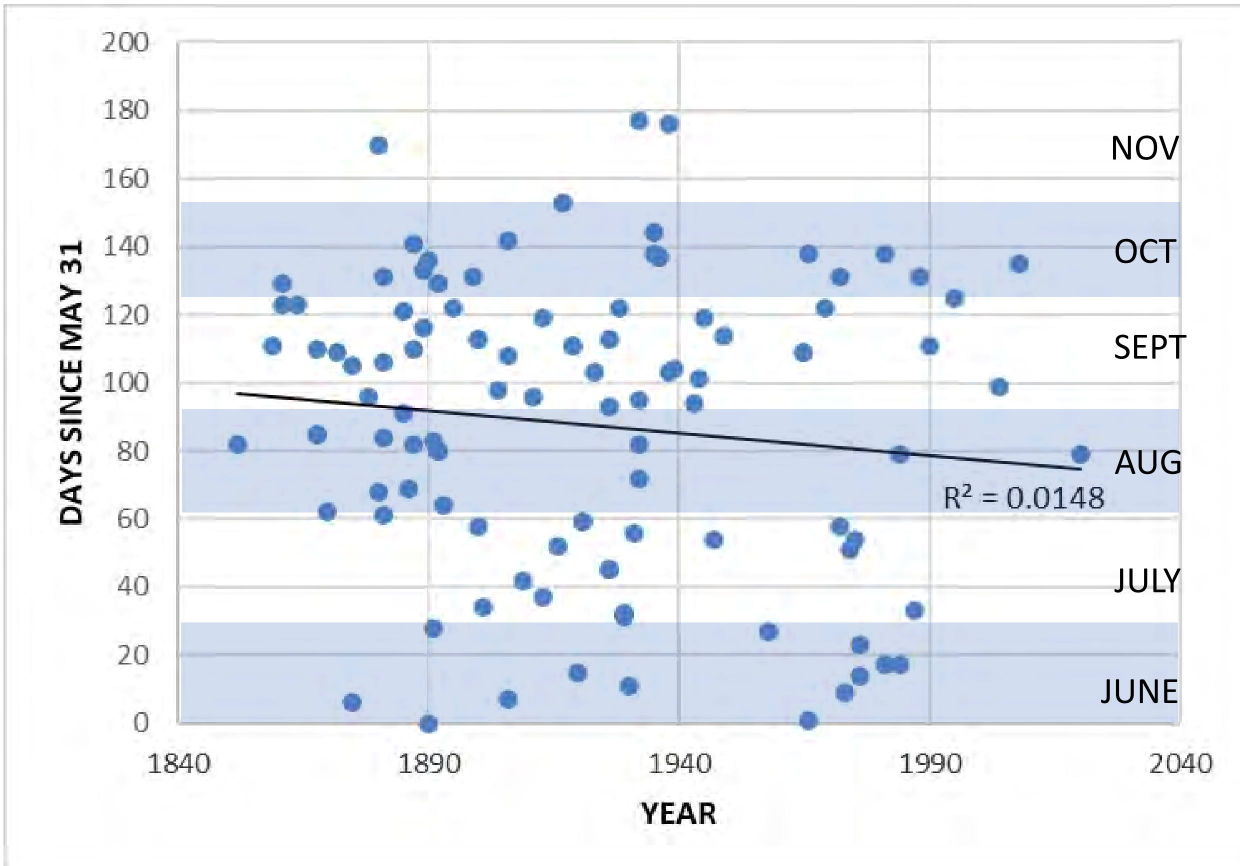

Figure 2. Ignition Dates, 1852 - 2021

MARIN COUNTY WILDFIRE HISTORY MAPPING PROJECT
Baseline Consulting, Glen Ellen, CA

Table 3. Ignition Date Comparison		
	Average Ignition Date	**Shift from Preceding Era**
Pre-CALFIRE Era 1852 – 1916	**September 2** SD = 35.5 days; median = Sept 6	NA
Early CALFIRE Era 1917 - 1970	**August 28** SD = 45.6 days; median = Sept 10	(midpoints = 1884 & 1944) **0.8 days earlier/decade**
Recent CALFIRE Era 1971 - 2020	**August 11** SD = 46.4 days; median= August 8	(midpoints = 1944 & 1995) **3.3 days earlier/decade**
Whole CALFIRE Era 1917 - 2020	**August 23** SD = 46.4 days; median= Sept 4	(midpoints = 1884 & 1969) **1.2 days/decade**
Whole Period 1852 - 2020	**August 26** SD = 42 days; median= Sept 5	NA

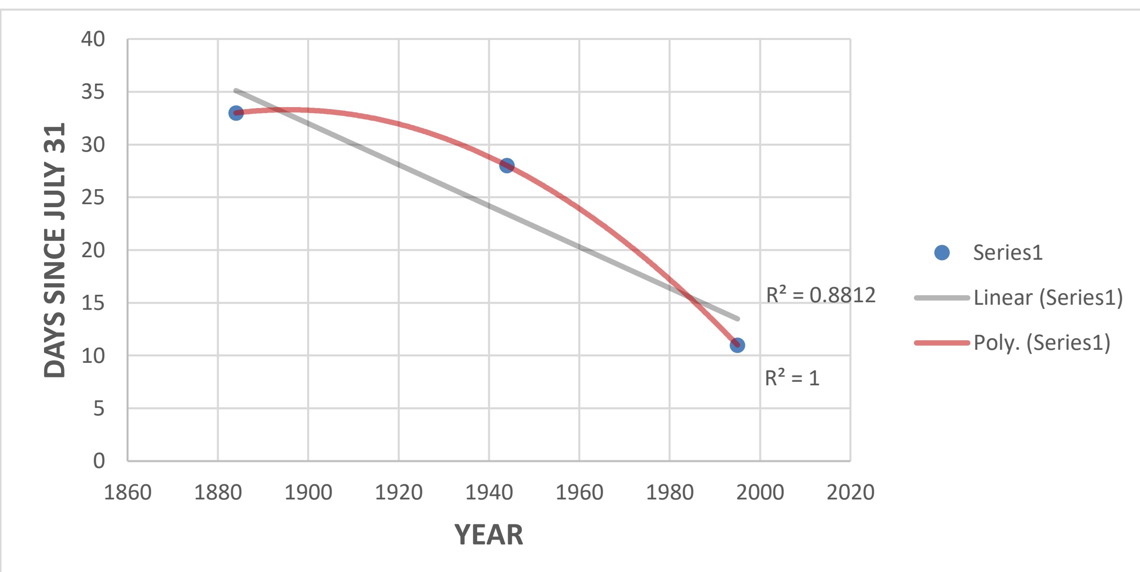

Figure 3. Average Ignition Dates
using Mid-point of Pre, Early and Recent CALFIRE Eras
1884, 1944, 1995

MARIN COUNTY WILDFIRE HISTORY MAPPING PROJECT
Baseline Consulting, Glen Ellen, CA

FIRE RETURN INTERVALS

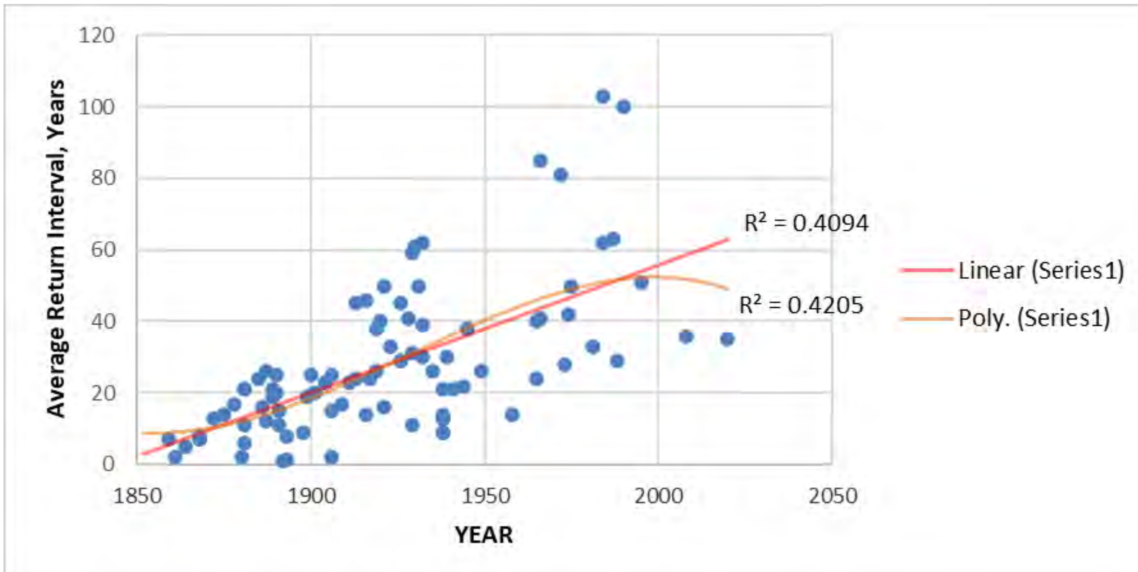

Figure 4. Average Fire Return Interval within Mapped Fire Perimeters 1852 - 2020

Table 4. Comparison of Fire Return Intervals within Mapped Fire Perimeters: 1852 – 2020 Marin County, current study		
	Average Return Interval	**Standard Deviation**
Early Pre-CALFIRE Era 1852 - 1884	**10.1 years**	6.1 years
Late Pre-CALFIRE Era 1884 - 1916	**18.8 years**	10.3 years
Pre-CALFIRE Era, all 1852 - 1916	**15.8 years**	10.1 years
Early CALFIRE Era 1917 - 1969	**32.3 years**	16.9 years
Recent CALFIRE Era 1971 - 2020	**38.5 years**	21.8 years
CALFIRE Era 1917 - 2020	**37.6 years**	21.5 years
Whole Period 1852 - 2020	**28.4 years**	20.6 years

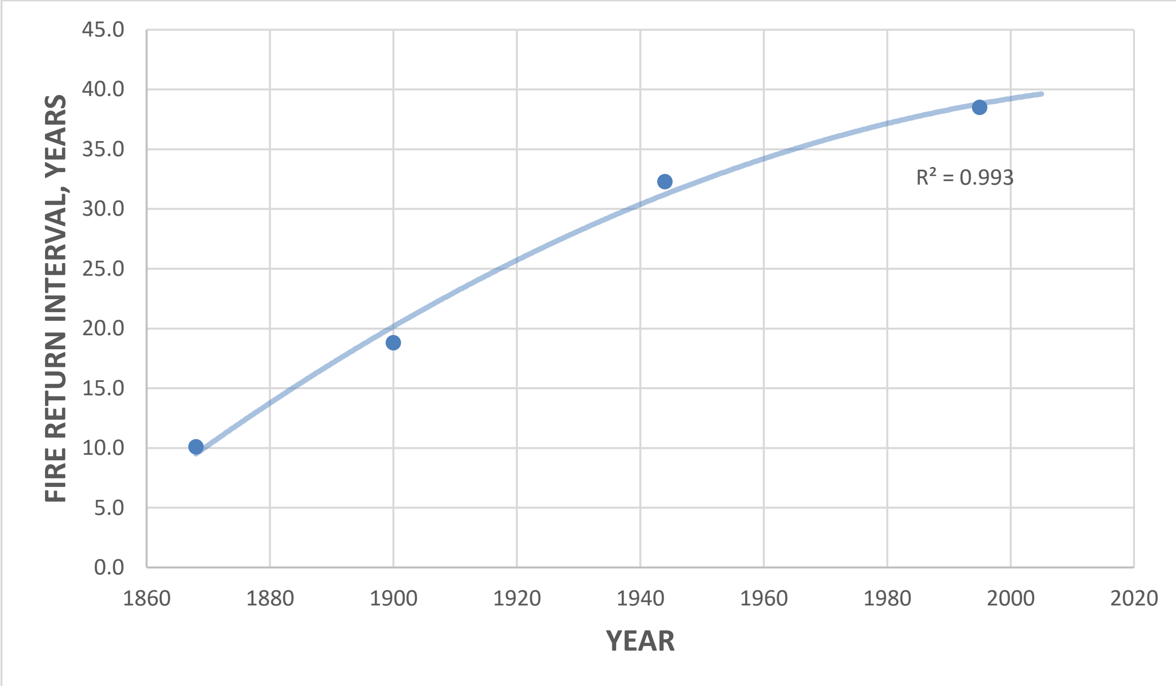

Figure 5. Average Fire Return Intervals using Mid-points of Early & Later Pre-CALFIRE, and Early & Recent CALFIRE Eras: 1868, 1900, 1944, 1995

Table 5. Fire Return Intervals (indigenous/pre-suppression era) c. 1450 – 1850 Specific Locations, Marin County, other studies		
(Brown et. al 1999):		**Standard Deviations**
All stands sampled back to 1700s	**7.7 – 8.5 years**	**Unknown**
Pine Gulch Creek, pre-1850	**8.1-12.0 years**	(full data sets not available)
(Finney 1990):		
Bolinas Ridge 1450 – 1850	**8-20 years**	
(Jacobs 1985):		
Old Mill Creek	**21.7 years**	
Alpine Dam	**27.3 years**	NOTE: different forest types may account for the difference between the average return intervals in Brown and Finney's data and that of Jacobs (10.7 vs. 24.5 years respectively).
Average	**16.2 years** (14.6 - 17.9 years)	

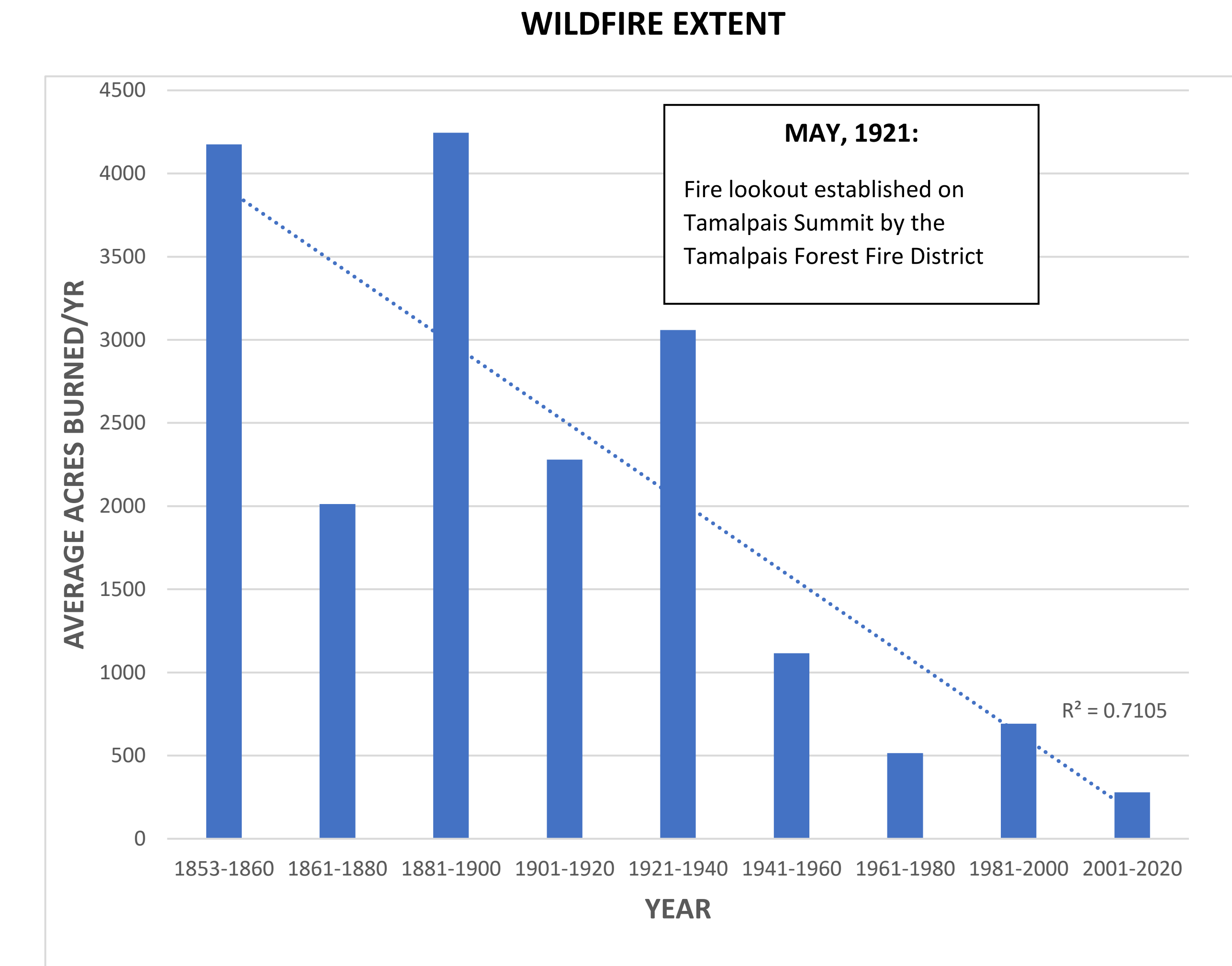

Figure 6. Average Acres Burned per Year in 20-year increments, 1852 - 2020

KEY FINDINGS

Rare Burn Zones (RBZ):

The majority of Marin County lies within a RBZ with no documented fires since before 1852. The area mapped within fire perimeters for this study covers 137,099 acres (areas within overlapping perimeters counted only once) or 214.2 square miles. This represents 41% of Marin County's total land area of 520 square miles. No documented wildfire record was found within the remainder of the county (59%).

Frequent Burn Zones (FBZ):

The upper slopes of Mt. Tamalpais burned 7-11 times between 1852 and 2020. Fire Return intervals for this area are between 17 and 28 years. Neighboring slopes and ridges burned between 5 and 8 times during that period, giving return intervals between 24 and 42 years.

A less intensive FBZ is centered on Big Rock Ridge on the north side of Lucas Valley. This area burned 4-6 times during the study period. Return intervals are 34 – 56 years.

Trend for Earlier Ignition Dates

Average ignition dates came 3 weeks (22 days) earlier in the Recent CALFIRE Era (1970 -2020) than in the pre-CALFIRE Era, shifting from September 2 to August 11. This represents a rate of 1.2 days earlier per decade over the full study period. This rate appears to have accelerated over the 20th and early 21st centuries to 3.3 days earlier per decade (figures calculated from the mid-points of each era).

Median dates showed an even greater shift.

(Note that this apparent trend is not supported by the very low R^2 value for the linear trendline in Figure 2. However, plotting the average ignition date for each era—pre, early and recent CALFIRE—as seen in Figure 3, gives a high R^2 value. The low R^2 value in Figure 2 may be from the "noisiness" of this data as is reflected in the high standard deviation values. More statistical analysis would be helpful to fully assess this apparent trend.)

Increasing Fire Return Intervals:

Fire Return intervals nearly quadrupled between the Early pre-CALFIRE Era and the Recent CALFIRE Era, growing from roughly 10 years to over 38 years (Table 4).

Fire scar data for more limited locations (collected in other studies, Table 5) goes back several hundred years to extensive cultural burning by indigenous people and well before modern fire suppression. While this data is quite limited, the average return interval is strikingly similar to the earliest historical data, with an overall value of 9.9 years compared to 10.1 years for the early pre-CALFIRE era. This suggests that the fire return interval did not change appreciably during the early settlement of Marin. It was only between 1880 and 1900 that the return interval begins to deviate from the pattern maintained by cultural burning prior to 1850.

Decreasing Wildfire Extent

This is particularly evident after 1940 (Figure 5). The average annual extent covered by wildfires between 1852 and 1900 was 3477 acres, or about 1% of Marin County's land area. The first decades of the 20th century, through 1940, saw this drop by nearly a quarter, to 2670 acres and 0.8% annually. After that, the annual acreage burned declined even more steeply.

Since 1960, only 495 acres have burned per year on average; this is just 14% of the 19th century average and only 0.1% of Marin's land area. If this level of suppression were maintained, the return interval for the county would be on the order of 1,000 years.

One factor that may partially explain this trend was the establishment of the fire lookout on top of Mt. Tam, which allowed fires to be spotted, located and suppressed quickly. Up until the lookout went in, in 1920, Marin's average annual area burned was over 3000 acres. In the century since then, it has been less than half that. This decline is not obvious in the graph until after 1940 because Marin's largest recorded wildfire occurred in 1923, and thus raises the average substantially during this period. Without the 1923 fire, the average annual acres burned between 1921 and 1940 would be just 1470.

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APPENDIX A: TIMELINE OF DOCUMENTED FIRES IN MARIN COUNTY 1852 – 2020

160 acres+; expanded citations under 'Sources' section of this report

PROJECTID	YEAR & NAME* & SOURCE(S) *bolded if given by CALFIRE or marinfirehistory.org	IGNITION DATE	EXTENT "direct quote" **Bold** = as mapped OBJECTID refers to original shapefile associated with the fire	CONFIDENCE LEVEL Extent & Location H = High; M = Medium; L = Low (Full rubric at end of table)	LOCATION(S) *=reported origin point **DAMAGE/INTENSITY/DURATION**	LAST FIRE(S) WITHIN PERIMETER	FIRE RETURN INTERVAL(S) Years
NA	1852 **MARIN COUNTY** Nevada County Journal, Aug 21 (NPS 2011)	8/21 (reported)	Described as significant Not mapped NO OBJECTID	NA	Many parts of the state. For Marin: "much damage" Destroyed "timber," "houses and other property" NOT ENOUGH DATA TO MAP	Unknown	Unknown
0001	1859 **MOUNT TAMALPAIS** Mill Valley FD Peter Martin, Greg Jennings, SF Chronicle (NPS 2011)	9/19	Estimated 30-70,000 acres **33,396 acres** POLYGON OBJECTID # 1	Extent: M Location: M	Burned for three months Perimeter drawn from later comparison to Sept 1881 fire [Marin Journal Sept 22, 1881] Gaudinski 1990 has a much smaller perimeter. However comparison to the 1881 fire suggests large perimeter likely	Unknown (1852?)	(7?)
0002	1861 Marin Journal, Oct 5	10/1	**23,518 acres** POLYGON OBJECTID # 3	Extent: M Location: H	*Wheelock's Ranch Butterfield, Creighton, White Ranches Dixon Mill Blythesdale Canyon	1859 Unknown	2 Unknown
NA	Marin Journal, Oct 12 (NPS 2011)	10/7	Not mapped; Possibly same fire as Oct. 1 above NO OBJECTID	NA	"Tamalpais ablaze from base to summit" "Considerable damage sustained by those having wood in the gulches" "1100 cords of wood burned" may be one mapped in Gaudinski 1990	Unknown	Unknown

PROJECTID	YEAR & NAME* & SOURCE(S) *bolded if given by CALFIRE or marinfirehistory.org	IGNITION DATE	EXTENT "direct quote" **Bold** = as mapped OBJECTID refers to original shapefile associated with the fire	CONFIDENCE LEVEL Extent & Location H = High; M = Medium; L = Low (Full rubric at end of table)	LOCATION(S) *=reported origin point **DAMAGE/INTENSITY/DURATION**	LAST FIRE(S) WITHIN PERIMETER	FIRE RETURN INTERVAL(S) Years
1001	1864 Marin Journal, Oct 8 SJ Mercury Journal (NPS 2011)	10/1	"large" Mapped as point POINT OBJECTID # 1	NA	"interior of County" "timbered land in Blythesdale Canyon" "terrible fire raging…destroying timber, pasturage and devastating the country"	1859	5
1002	1865 **BOLINAS BAY WOODS** Marinfirehistory.org	No data	Mapped as point POINT OBJECTID # 2	NA	"above Bolinas Bay" "burned for two weeks"	(1859 possible)	(6?)
1003	1868 Marin Journal, Aug 29	8/24	Mapped as point POINT OBJECTID # 3	NA	"Mt Tamalpais all ablaze" Raged for several days "Considerable damage"	1859	9
1004	Marin Journal, Aug 29	8/24	Mapped as point POINT OBJECTID # 4	NA	Bull Tail Valley, east of Nicasio	1861	7
0003	Daily Alta California, Sept 18 Barrett, 1935 Maine Daily Whig & Courier (NPS 2011)	9/18	"a tract 5-6 miles in extent" **9049 acres** POLYGON OBJECTID # 4	Extent: M Location: M	"woods on White Ranch and seaward side of Mt. Tamalpais are all ablaze" "woods near San Rafael"	1861 1859 Unknown	7 9 Unknown (>8 yr av)
000321	1870 Gaudinski 1990 Marin Journal, Aug 2 (NPS 2011)	8/1	640 acres	Extent: M Location: M	part of Shafter Ranch betw. the Lagunitas & White Ranches	Unknown	Unknown
0004	1872 Bancroft 'Scraps' MV Library (NPS 2011)	9/17	"200 acres" **228 acres** POLYGON OBJECTID # 6	Extent: H Location: H	"Saucelito Rancho" "severe fire" "extinguished by Mr. Gardner"	1859	13

PROJECTID	YEAR & NAME* & SOURCE(S) *bolded if given by CALFIRE or marinfirehistory.org	IGNITION DATE	EXTENT "direct quote" **Bold** = as mapped OBJECTID refers to original shapefile associated with the fire	CONFIDENCE LEVEL Extent & Location H = High; M = Medium; L = Low (Full rubric at end of table)	LOCATION(S) *=reported origin point DAMAGE/INTENSITY/DURATION	LAST FIRE(S) WITHIN PERIMETER	FIRE RETURN INTERVAL(S) Years
1006	1875 Marin Journal, June 10 Peter Martin SF Chronicle, June 12 (NPS 2011)	6/6	Mapped as point POINT OBJECTID # 8	NA	"Fires raged in the redwoods to the west of us on Sunday" "100 – 150,000 feet of logs and large amount of felled timber for cordwood consumed" belonging to Isaac Shaver Fire was in Antoine King Gulch	1868	7
1007	Marin Journal, Sept 16 SF Evening Bulletin (NPS 2011)	9/13	"extensive" Mapped as point POINT OBJECTID # 9	NA	"west slopes of hills above the Bolinas trail near San Rafael" "extensive fire raging in the woods on the western slope of the hills above the Bolinas Trail on Shafter Ranch, on Monday"	Unknown	Unknown
0005	1878 **NICASIO** Marin Journal, Sept 12 Marinfirehistory.org	9/4	"1200 - 1500 acres" **1443 acres** POLYGON OBJECTID # 7	Extent: H Location: H	"timber, chaparral and grass burned in Nicasio" Joyce, Pet, Murray Ranches. Whitmore on Joyce was 'heaviest loser.' Frank Rodgers place had "very narrow escape."	1861 Unknown	17 Unknown (>17 yr av)
0006	1880 Marin Journal, Aug 12	8/7	"200 acres" **205 acres** POLYGON OBJECTID # 8	Extent: H Location: H	"grass fire…on Charles Filippini's place" "last Saturday"	Unknown	Unknown
0007	Marin Journal, Nov 25	11/17	"5000-6000 acres" **5164 acres** POLYGON OBJECTID # 10	Extent: H Location: H	"Terrific fire raged in Nicasio" starting on the Claussen place and spreading to the Irwin and Murphy Ranches and spreading to the line of the Novato Ranch. Burned 5000 - 6000 acres. DeLong burned 1000 acres as a fire break (Marin Journal).	1878 Unknown	2 Unknown

PROJECTID	YEAR & NAME* & SOURCE(S) *bolded if given by CALFIRE or marinfirehistory.org	IGNITION DATE	EXTENT "direct quote" **Bold** = as mapped OBJECTID refers to original shapefile associated with the fire	CONFIDENCE LEVEL Extent & Location H = High; M = Medium; L = Low (Full rubric at end of table)	LOCATION(S) *=reported origin point **DAMAGE/INTENSITY/DURATION**	LAST FIRE(S) WITHIN PERIMETER	FIRE RETURN INTERVAL(S) Years
0008	**1881** **BILL WILLIAMS** Marin Journal, Aug 4 SF Bulletin, Aug 2 (NPS 2011)	7/31 To at least 8/11	"6000 acres" "10 miles long" **6205 acres** POLYGON OBJECTID # 11	Extent: H Location: H	*head of Bill Williams Gulch Spread south and easterly; To summit; Cushing Gulch Spur overlooking Blythedale Threatened Kent and Richardson residences, Ross Valley, Corte Madera. Burned western fence of Kent's Deer Park Threatened water works at Lagunitas, pipes carrying water to San Rafael were on the northern edge of the fire "Mt Tam—One Mass of Fire and Flame" "every available man pressed into service" 8/11: has "nearly spent itself" "Flames stayed from the Water Co. works" "Fires raged up to Monday last [8/8] "burning in the direction of Blythedale and the gulches on Sausalito Ranch" 8/4: "bulk of fire now in the big gulch back of Lagunitas Lake, working west and south, threatening Bon Tempe ranch, Kent's cabin, Liberty and Bolinas bridges. Also burning down the Bolinas side of the mountain	1868 1861 1859	13 20 22 (18 yr av)

PROJECTID	YEAR & NAME* & SOURCE(S) *bolded if given by CALFIRE or marinfirehistory.org	IGNITION DATE	EXTENT "direct quote" **Bold** = as mapped OBJECTID refers to original shapefile associated with the fire	CONFIDENCE LEVEL Extent & Location H = High; M = Medium; L = Low (Full rubric at end of table)	LOCATION(S) *=reported origin point **DAMAGE/INTENSITY/DURATION**	LAST FIRE(S) WITHIN PERIMETER	FIRE RETURN INTERVAL(S) Years
0009	Marin Journal, Sept 1 (Jan 20, 1916)	8/23	"1800 acres" **1783 acres** POLYGON OBJECTID # 25	Extent: H Location: M	Ranches of Ryan, Rodgers & Burdell in Novato Grass fire	1880 1878 1868 Unknown	1 3 13 (6 yr av)
0010	1881 **BLITHEDALE CANYON/ MILL VALLEY** Marin Journal, Sept 15 -22 Marinfirehistory.org SF Chronicle, Sept 15 – 19 SF Bulletin, Sept 20 (NPS 2011)	9/14	"50 - 65,000 acres" "12 miles long, 7 or 8 wide" **32,344 acres** POLYGON OBJECTID # 12	Extent: M Location: H	*Frank Pixley's wife's ranch" "slopes of Mt Tam back of Patrick King's place" "top most peak "redwoods on the Sausalito Ranch" "South slope of mountain" Fire spread S and W to Cushing place in Blithedale Reed, Throckmorton Ranches "schoolhouses were closely approached" by fire "flames crossed the road and swept through the gulches and over the hills toward the bay and southward along the line of the road" "train traveled a long way through flame and smoke" Throckmorton Ranch: "swept through many gulches on the south side of the mountain, which are full of virgin timber" "the larger part of the great Sausalito Ranch is being burned over" "burned for seven days" William Pixley died in the fire	1881, July 1875 (point) 1872 1868 (point 1864 (point) 1861 1859	0 6 9 13 17 20 (11 yr av)

PROJECTID	YEAR & NAME* & SOURCE(S) *bolded if given by CALFIRE or marinfirehistory.org	IGNITION DATE	EXTENT "direct quote" **Bold** = as mapped OBJECTID refers to original shapefile associated with the fire	CONFIDENCE LEVEL Extent & Location H = High; M = Medium; L = Low (Full rubric at end of table)	LOCATION(S) *=reported origin point **DAMAGE/INTENSITY/DURATION**	LAST FIRE(S) WITHIN PERIMETER	FIRE RETURN INTERVAL(S) Years
1008	Orig source unknown (NPS 2011)	10/9	Mapped as point POINT OBJECTID # 10	NA	* Baltimore Gulch Burned NE and SE	1861 1859	20 22 (21 yr av)
1009	**1885** Marin Journal, Sept 3 (NPS 2011)	8/30	Mapped as point POINT OBJECTID # 11	NA	*Land of Mailliard and Shafter Lagunitas Creek "raging" "forest fire" "on the banks of the Lagunitas"	Unknown	Unknown
0011	Sausalito News, Oct 1 (NPS 2011)	9/29	**328 acres** POLYGON OBJECTID # 15	Extent: L Location: M	"foothills of Mt Tamalpais back of Mr. Kent's deer park" "whole side of the hill was smoking" spread rapidly to the top of the ridges; brush fire "appeared as if the devastating fire of 1882[1881?] was repeating"	1861	24
0012	**1886** Sausalito News, Aug 12	8/9	"over 150 acres" **165 acres** POLYGON OBJECTID # 17	Extent: H Location: M	*Bluff Lime Point Grass fire	1881 1859 Unknown	5 27 (16 yr av)
0013	**1887** Sausalito News, Aug 25	8/21	"hundreds of acres" **327 acres** POLYGON OBJECTID # 18	Extent: M Location: M	"vicinity of tide gauge station "the Government Reservation" "government buildings" Grass fire, some fences burned	1886 1881 1859 Unknown	1 6 28 Unknown (12 yr av)
1010	Press Democrat, Sept 24 SF Examiner (NPS 2011)	9/18	"wide range" Mapped as point POINT OBJECTID # 12	NA	Chileno Valley Fire "of wide range" "doing a great deal of damage…fences & stock feed" "large gang of men fought it all night long"	Unknown	Unknown

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0014	Marin Journal, Oct 20 SF Chronicle, Oct 20 (NPS 2011)	10/19	"2000 acres+" **2484 acres** POLYGON OBJECTID # 21	Extent: M Location: M	"a few miles northwest of San Rafael" "fine grain land" Described as both a 'forest' fire and a 'brush' fire Austin Ranch, Brush Tract (former Sais Ranch)	1861 Unknown	26
0015	**1888** Gaudinski 1990	No data	**302 acres** POLYGON OBJECTID # 62	Extent: M Location: M	Traced from Gaudinski 1990. Attributes not available in 2021	1885 1861	3 27 (15 year av)
0016	**1889** Daily Alta California, Sept 28 marinfirehistory.org Peter Martin (NPS 2011)	9/24	"80 acres of timber" plus grasslands **144 acres** POLYGON OBJECTID # 22	Extent: M Location: M	*Corte Madera depot "spread and reached heavy timber "Mt Tam, Baltimore Canyon" (10/11 in NPS possibly separate fire) 80 acres of timber + grasslands	1881 1859 Unknown	8 30 (19 yr av)
0017	Gaudinski 1990 SF Call, Oct 11, pg. 8 Bancroft Scrapbook, p 71-2 (NPS 2011)	10/11 (may be report date)	**2803 acres** POLYGON OBJECTID # 64	Extent: M Location: M	Traced from Gaudinski 1990 polygon Mt. Tam fire, Baltimore Canyon, see San Francisco Call, p 8,	1881 (almost all) 1864 1859	8 (most) 25 30 (21 yr av, but see note above)

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0018	1890 **SAN RAFAEL TO BOLINAS** Daily Alta California, Oct 30; Nov 6 Marinfirehistory.org Morning Oregonian, Oct 24 San Jose Daily Mercury, Oct 26 SF Chronicle, Oct 28 San Diego Union, Oct 30 (NPS 2011)	10/14 10/31 contained	"8000 acres" **8435 acres** POLYGON OBJECTID # 26	Extent: H Location: H	Between San Rafael and Bolinas, 8 bridges burned West slope, Bolinas Ridge, threatened Taylorville, Olema "still raging in an eastern direction" [Oct 30] "90% Wilkins Ranch burned" Described as both brush fire and forest fire "Hundreds of acres of grazing land burned over" some overlap with Gaudinski 1990. Gaudinski leaves out Wilkins Ranch (90% burned). Possibly could extend polygon to include more of Gaudinski's.	1881 1868 1861 Unknown	9 22 29 (20 yr av)
0019	Gaudinski 1990	No data	**204 acres** POLYGON OBJECTID # 60	Extent: M Location: M	traced from Gaudinski 1990 map	1868 1861	22 29 (25 yrs av)

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0020	1891 **BILL WILLIAMS GULCH** Marin Journal, July1 SF Call, June 29 – July 4 Greg Jennings Peter Martin SF Chronicle, June 28 SF Examiner, June 29-July 5 San Luis Obispo Tribune, July 3 (NPS 2011)	6/28 (reported?)	"12,000 acres" **12,604 acres** POLYGON OBJECTID # 29	Extent: H Location: H	*Barber property Kittle property Bill Williams Gulch "swept the sides of the mountain" "Eldridge Grade burned N and S, northside of mountain" Kent property "tearing through Bolinas [Ridge] devouring all the chaparral and redwoods in its path" Lagunitas Lake Cushings Gulch Beach near Bolinas Porteous property Cascade Canyon; Ling [?] Canyon Above Larkspur & Tamalpais Depots	1890 1887 1885 1881 (point) 1875 (point) 1868 1861 1859 Unknown	1 4 6 10 16 23 30 32 Unknown (16 yr av)
0021	Marin Journal, Aug 27	8/22	**1902 acres** POLYGON OBJECTID # 30	Extent: M Location: H	*west side Fairfax grade" Behind Fairfax and San Anselmo to Foster Ranch near Seminary Brush Tract, Porteous, Woodward, Smith properties	1891, June 1887 1861	0.2 4 30 (11 yr av)
0022	1892 **BOLINAS ROAD** Marin Journal, Aug 25 Greg Jennings SF Bulletin, Aug 24 Peter Martin (NPS 2011)	8/19	**1234 acres** POLYGON OBJECTID # 31	Extent: L Location: M	*Bolinas Road Foot of Bolinas Grade, bridge over Lagunitas Creek, turned south toward Lake Lagunitas; Sweet George Creek Damage to water district structures	1891	1

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0023	Sausalito News, Aug 25	8/19	**398 acres** POLYGON OBJECTID # 32	Extent: L Location: M	Hans Nelson's Dairy, Ignacio A few hundred yards from St. Vincents; Pacheco estate 2 miles north of St. Vincents. Ferris reclaimed marsh property "grass fire" "feed destroyed"	Unknown	Unknown
0024	Sausalito News, Oct 14	10/7	"200 acres+" **210 acres** POLYGON OBJECTID # 33	Extent: H Location: H	Preston Point "grass fire"	Unknown	Unknown
0025	1893 **MILL VALLEY MT TAM** Marin Journal, Aug 10 Peter Martin Barrett, SF 1935 (NPS 2011)	8/3	"over 3000 acres" **2957 acres** POLYGON OBJECTID # 34	Extent: H Location: M	"forest fire raging in and around the base of Mount Tam" *Porteous, Lazzini & Johnston properties Did not reach Water District lands Valuable timber & grazing land	1892 1891	1 2 (1.5 yr av)
0026	Gaudinski 1990	No data	**177 acres** POLYGON OBJECTID # 63	Extent: M Location: M	Traced from Gaudinski 1990; no overlap with 1893 fire mapped from other sources	1889 1881	4 12 (8 yr av)
0027	1895 Marin Journal, Oct 3	9/30 est	**323 acres** POLYGON OBJECTID # 35	Extent: L Location: M	Southern edge of DeLong +Scown and Pachecho Damage slight	Unknown	Unknown
0028	1898 Gaudinski 1990	No data	**279 acres** POLYGON OBJECTID # 61	Extent: M Location: M	traced from Gaudinski 1990 map attributes not available in 2021	1891 1887	7 11 (9 yr av)

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0029	1899 **CORTE MADERA, MILL VALLEY & LARKSPUR** Marin Journal, Oct 12. 19 Marinfirehistory.org San Francisco Call, Oct 11 Fleck, Vol. 1 p. 287 (NPS 2011)	10/9 10/11 contained	**789 acres** POLYGON OBJECTID # 36	Extent: H Location: H NOTE: detailed description of locations suggests high accuracy for both extent and location	*Rosenquist property near the water tanks/ where summit trail crosses the RR tracks "spread Down Corte Madera Canyon, south and east into Blithedale and Warner canyons, and easterly over the Cascade ridge toward Larkspur the roundhouse, Southerly in Corte Madera Canyon, almost to the grounds of the Hotel Eastland, on both sides of the railroad track, the undergrowth was nothing but hot ashes and smoldering embers. In Warner's (or Boyle's) Canyon Ridge between Mill Valley and the other two towns Ridge separating Baltimore Canyon from valley Mile and a half flames sweeping down west side of ridge toward Baltimore Canyon $100,000 damage; including 2 houses owned by Geo. Marsh Woods above Corte Madera Ave	1891 1889 1881 1859	8 10 18 40 (19 yr av)
0030	1900 Marin Journal, Aug 2	7/28	"300 acres" **311 acres** POLYGON OBJECTID # 38	Extent: H Location: M	Black Point Little damage other than fencing and pasture	Unknown	Unknown

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Baseline Consulting, Glen Ellen, CA

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0031	Marin County Tocsin, Sept 29 Marin Journal, Sept 27	9/21	"several thousand acres" 9/24 contained **7238 acres** POLYGON OBJECTID # 39	Extent: M Location: H	*DeLong Ranch "In the northwest section" Almost to Nicasio and the ridge above the Poor Farm Taylor, Cabrelli, Powers, Pacheco, Miller, Freitas places; Big Rock; Mill Valley OK, but uncertain for a while Pasture, fencing and timber lost	1881 1880 1878 1861 Unknown	19 20 22 39 Unknown (25 yr av)
0032	Marin Journal, Sept 27	9/21	"1000+ acres" **954 acres** POLYGON OBJECTID # 42	Extent: H Location: M	*Novato Land Co Novato Land Company property "Back in the hills" Did not burn Burdell property Brush and grass fire	Unknown	Unknown
1011	1901 Marin Journal, July 11	7/4	"large area" Mapped as point POINT OBJECTID # 21	NA	Lake Lagunitas Damage comparatively light	1891	10

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0033	1904 **BOLINAS RIDGE FIRE** Marin Journal, Sept 15 Marin County Tocsin, Sept 10 Marinfirehistory.org Peter Martin (NPS 2011)	9/6	"15-20,000 acres" **16,549 acres** POLYGON OBJECTID # 43	Extent: H Location: H	*Bolinas Ridge *Wilkins Ranch and "spread rapidly southward" Hasbrouk property burned on 9/8 "flames rushed westward pushed by a northerly wind and reached the bay shore in 25 minutes" McCurdy, Wilkin's, Bourne Ranches; Weeks, Morse and Stinson places "whole watershed of Marin County Water was in danger" Timber tracts of Shafter and Howard Summit House; Jct of Big Carson & Lagunitas "almost to the Scenic Railroad" County Road from summit to Winkin's gate [Wilkins?]Houses, grass and timber lost Toward Camp Taylor, Pine Hill, into Cascade Canyon Overlaps much of Gaudinski 1990. Gaudinski perimeter includes Pine Hill (mtn). News reports this threatened but not necessarily burned	1893 1892 1891 1890 1885 (point) 1881 1870 (point) 1868 1865 1861	11 12 13 14 19 23 34 36 39 43 (24 yr av)
0034	1906 Marin Journal, June 7	6/7 reported	"big fire" **815 acres** POLYGON OBJECTID # 44	Extent: M Location: M	"from Mrs. Hasbrouck's place on Bolinas ridge" "rushed down Bolinas Way and then back as far as Lagunitas Creek"	1904	2

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0035	Sausalito News, Sept 22	9/16	"a few hundred acres" **575 acres** POLYGON OBJECTID # 46	Extent: H Location: H	*Gioli Ranch Fort Baker perimeter "ridge back of Sausalito and came down the hillsides" "low brush on the ridge above Wildwood Glen caught fire" "fire was checked several hundred feet away" from nearest residence "gum trees near Old Sausalito caught fire" Grazing land	1881	25
0036	Marin Journal, Oct 20	10/20	"thousands of acres" **6236 acres** POLYGON OBJECTID # 47	Extent: M Location: H	*big hill on the road on the Mucio Ranch between Olema and Bolinas Burned south toward Bolinas Bourne, McCurdy, Langley Ranches Tocaloma, Camp Taylor endangered South of there over to Big Carson, then Lagunitas toward Pine Hill Pedrina's "could not burn far south on Bolinas Ridge because it was burned two years ago."	1906, June 1904 1885 (point layer)* 1870 (point layer)* *possible, depends on undetermined perimeter	0.4 (4.5 months) 2 21 36 (15 yr av)
0037	**1909** **LARKSPUR** San Francisco Call, July 13 Marinfirehistory.org (NPS 2011)	7/12	**175 acres** POLYGON OBJECTID # 48	Extent: L Location: M	*Baltimore Canyon beyond end of road "ashen trail from valley bottom to ridge a half mile away" [ridge described as 'back of town'] Threatened Kent homestead	1893 1891	16 18 (17 yr av)

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0038	1911 Marin Journal, Sept 8	9/4 9/7 contained	**7288 acres** POLYGON OBJECTID # 53	Extent: M Location: H	*Bodkin Ranch near Ignacio, went W and S; Lucas Valley Ridge, threatened Poor Farm North to Scown Ranch at Novato High ridges back of Pacheco, Miller, Bodkin; Destroyed much pasture, timber and fencing	1900 1895 1870 or before est.	11 16 41+ (23 yr av)
0039	Press Democrat, Nov 7	9/6	**1418 acres** POLYGON OBJECTID # 66	Extent: L Location: H	Chileno Valley, *Bork [Bourke?] & Goatley Ranches. Dry grass, fencing and timber "Considerable damage"		
0040	1913 Marin Journal, July 24 Marinfirehistory.org (NPS 2011)	7/7 7/12 contained	**2025 acres** POLYGON OBJECTID # 50	Extent: M Location: H	*Fern Canyon South slope of Mt Tam, Muir Woods Areas of Larkspur, threatened Corte Madera, Baltimore Cyn "Flames swept down toward Blithedale and up the opposite side of the canyon; head of Baltimore Cyn Inn at Muir Woods lost 7000 fire fighters on hand [700?]	1909 1899 1893 1891 1881 1859	4 14 20 22 32 54 (24 yr av)
0041	San Anselmo Herald, Oct 1	9/27	"400 acres" **412 acres** POLYGON OBJECTID # 55	Extent: H Location: L	Grass fire " near Novato" burns pastureland "Considerable fencing but no buildings destroyed"	1870 (possible. See point layer)	45 (uncertain)

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0042	1916 SAN GERONIMO Marin Journal, July 27 Roof 1934	7/22 7/24 contained	**329 acres** POLYGON OBJECTID # 56	Extent: M Location: H	*within 200 yards of West Point Inn, then over ridge driven by west wind "Mile and a half long, half a mile wide"(500 acres) "burned whole ridge…burned trees in Spice Buck Canyon, Nora Canyon and elsewhere on the main ridge"	1881 1859	35 57 (46 yr av)
0043	Gaudinski 1990	No data	**153 acres** POLYGON OBJECTID # 65	Extent: M Location: M	Traced from Gaudinski polygon	1913 1891	3 25 (14 yr av)
	BEGINNING OF CALFIRE RECORD (incomplete 1917 – 1964)						
00441 **00442** **00443** **00444**	1917 **INVERNESS RIDGE** Marinfirehistory.org CALFIRE, Gardner	Unknown	2000 acres **2014 acres:** 303, 359, 619; 733 POLYGON OBJECTID#s 88, 89, 91, 146	Extent: H Location: M (due to uncertainty of combining polygons)	(no newspaper corroboration) Gardner map: OBJECTIDs: 88, 89,91,146	Unknown	Unknown
0045	PACHECHO GULCH Marin Journal, Nov 8 CALFIRE, Gardner	Est. 10/31 (week of 10-28)	**3573 acres** POLYGON OBJECTID # 107	Extent: H Location: H	"A forest fire in Pacheco Gulch NW of San Rafael burned for two or three days" "Controlled after slight material damage" Gardner map: OBJECTID 107	1911 1900 1895 1881 1880	6 17 22 36 37 (24 yr av)

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0046	1919 **MUIR WOODS & MT TAM** Mill Valley Record, Sept 20 Sausalito News, Sep 20 Marinfirehistory.org CALFIRE, Gardner (NPS 2011)	9/19	**517 acres** POLYGON OBJECTID # 139	Extent: H Location: H	Muir Woods Slopes of Mount Tam Ridge above Cascade Canyon 40 homes lost Gardner map: OBJECTID 139	1881	38
0047	**SAUSALITO HILLS** Mill Valley Record, Sept 20 Marinfirehistory.org CALFIRE, Gardner	9/19	**497 acres** POLYGON OBJECTID # 149	Extent: H Location: H	*Wildwood Glen Hurricane Gulch, South Sausalito, Fort Baker 12 homes, 5 businesses lost Gardner map: OBJECTID 149	1906 1881	13 38 (26 yr av)
0048	1921 Mill Valley Record, June 16	6/15	400 acres **397 acres** POLYGON OBJECTID # 175	Extent: M Location: M	Between Fort Baker and Fort Barry, a mile and a half long by a half mile wide. Wind drove fire toward 'tunnel hill' "grass fire" OBJECT ID 175	1881	40
0049	Mill Valley Record, July 30 CALFIRE, Gardner	7/29	>200 acres **237 acres** POLYGON OBJECTID # 113	Extent: H Location: H	*foothills of White's Hill "Burned in the direction of Sleepy Hollow Ranch" "grass fire" Gardner map: OBJECTID 113	1861	50
0050	Mill Valley Record, July 30 CALFIRE, Gardner	7/29	"Several hundred acres" **529 acres** POLYGON OBJECTID # 111	Extent: H Location: H	"near St. Vincents" "grass fire" "extinguished after several hours fighting" Gardner map: OBJECTID 111	1911 1900 No record	10 21 (16 yr av)

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0051	**1923** Mill Valley Record, Sept 22 Snta Barb Daily News, Snta Cruz News; NPS 2021b CALFIRE, Gardner (NPS 2011)	9/11; Flared up 9/17	"100 sq. mi" "1/3 of cnty" "40,000 acres" **31,774 acres** POLYGON OBJECTID # 119	Extent: H Location: H (Gardner likely more accurate than the media)	*Ignacio "entered Lucas Valley…threatened county farm and hospital" "much pine and redwood destroyed in Woodacre" Gardner map: OBJECTID 119	1911 1890 Unknown 1906 1887 1904 1881 1900 1878 1895 1870 1891 1868	12 33 Unknown 17 36 19 42 23 45 28 53 32 55 (33 year av)
00521 522	**1926** **MT TAMALPAIS** Marinfirehistory.org CALFIRE, Gardner (NPS 2011)	7/15	**256 acres** **261 acres** POLYGON OBJECTID#s 132, 134	Extent: H Location: H	"two days of firefighting on Mt. Tam" (No newspaper corroboration) Gardner map: OBJECTIDs 132 & 134	1916 1889 1913 1881 1893 1891	10 37 13 45 33 35 (29 year av)
0053	**DEVILS GULCH** Mill Valley Record July 17, 24 CALFIRE, Gardner	7/15	4000-8000 acres **1543 acres** POLYGON OBJECTID # 102	Extent: H Location: H (Gardner likely more accurate than the media)	*many origin points; Shafter Ranch "northwest part of the county" "Brush and timber fire"; "grazing lands" mentioned; mostly confined to an "uninhabited section of the county" July 16, started "afresh on second ridge beyond Bolinas Ridge" Gardner map: OBJECTID 102	Unknown	Unknown
0054	Mill Valley Record 4 Sept CALFIRE, Gardner	9/1	220 acres **207 acres** POLYGON OBJECTID # 141	Extent: H Location: H	"pasture land of the M.F. Silveria Ranch in the vicinity of the Island in Richardson Bay" Hill opposite Bartnett's Island Pasture land destroyed Gardner map: OBJECTID 141	1881	45
0055	Sausalito News Mill Valley Record 25 Sept (both) CALFIRE, Gardner	9/21	150- 500 acres **270 acres** POLYGON OBJECTID # 116	Extent: H Location: H	Bon Tempe Meadows Golf Links East wind carried it across Portuguese Flat and up Azalea Ridge Grass, brush and forest burned Gardner map: OBJECTID 116	1904 1891	22 35 (29 yr av)

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1012	**1928** Mill Valley Record 28 Sept	9/20	"extensive" Mapped as point POINT OBJECTID # 22	NA	"Fort Baker" "grass fire" "whole army was fighting it" OBJECTID 22 (point)	1887	41
0056	**1929** Mill Valley Record, 12 July	7/1	350 acres **334 acres** POLYGON OBJECTID # 176	Extent: H Location: M	Chileno Valley Pasture land of Bord Bros. and Martin Thompson Could be Thompson and Corda Brothers in Hicks Valley (Dewey Livingston, personal communication)	Unknown	Unknown
0057	**MILL VALLEY** Roof 1934 NPS 2021b City of Mill Valley 2013 CALFIRE, Gardner Peter Martin (NPS 2011)	7/2	**864 acres** POLYGON OBJECTID #6		*RR tracks near Double Bow Knot "swept down Blithedale Canyon" "south and east slopes of East Peak" "brush field above Kentfield-Ocean trail" ½ mile below Tavern of Tamalpais on Tamelpa trail, west of phone line; Middle Ridge neighborhood First creek west of BowKnot	1916 1913 1899 1891 1889 1881	13 16 30 38 40 48 (31 yr av)
0058	Mill Valley Record Feb 7 1930 CALFIRE, Gardner	7/2	**276 acres** POLYGON OBJECTID # 140		Fire lookout on Mt Tam called in three fires on July 2 within twenty minutes	1881 1859	48 70 (59 yr av)
0059	Mill Valley Record Feb 7 1930 CALFIRE, Gardner	7/2	**229 acres** POLYGON OBJECTID # 112		Fire lookout on Mt Tam called in three fires on July 2 within twenty minutes	1923 1921 1911 Unknown	6 8 18 Unknown (11+ yr av)

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0060	**1930** Mill Valley Record 13 June	6/11	**223 acres** POLYGON OBJECTID # 177	Extent: M Location: M	"the ranges of hills to the left of Lyford's Cove" blackened by grass fire "appeared dangerous until put out by volunteer fire fighters" (Not in CALFIRE, Gardner)	1881 1859	51 71 (61 yr av)
0061	**1931** Mill Valley Record 14 Aug Roof 1934	7/26	**175 acres** POLYGON OBJECTID # 179	Extent: M Location: M	"West and across the road from the Inn" "smaller burn" [compared to the 1916 San Geronimo and 1929 Mill Valley fires] (Not in CALFIRE, Gardner)	1904 1859	27 72 (50 yr av)
0062	**1932** Mill Valley Record 26 Aug CALFIRE, Gardner	8/11	**221 acres** POLYGON OBJECTID # 148		"Corte Madera Hill" Grass fire	1881 1859	51 73 (62 yr av)
0063	Mill Valley Record 26 Aug CALFIRE, Gardner	8/21	>200 acres **581 acres** POLYGON OBJECTID # 145		Outskirts of Sausalito Threatened Industrial Solvents Company plant Burned grass but destroyed no property	1906 1881	26 51 (39 yr av)
0064	**SHAFTER RANCH** Marinfirehistory.org CALFIRE, Gardner (NPS 2011)	9/3	800 acres **1061 acres** POLYGON OBJECTID # 90		*Mother Lane's Gulch Pierce Point (?) Shell Beach "On Tomales Bay between Inverness and Point Reyes" Pines, oaks, scrub timber, huckleberry vines and grazing lands destroyed Gardner map: OBJECTID 90	Unknown	Unknown

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0065	**THANKSGIVING DAY** Marinfirehistory.org CALFIRE, Gardner	11/24	200 acres **462 acres** POLYGON OBJECTID # 135		Gardner map: OBJECTID 135	1926 1913 1889 1881	6 19 43 51 (30 yr av)
	1917 – 1934 Unable to corroborate the following perimeters from other sources; # = ObjectID						
0066	CALFIRE, Gardner 93	1917 -1934	**280 acres**		Bear Valley South	Unknown	Unknown
0067	CALFIRE, Gardner 94	1917 -1934	**207 acres**		Millers Point	Unknown	Unknown
0068	CALFIRE, Gardner 96	1917 -1934	**993 acres**		Alamere Creek Headwaters	Unknown	Unknown
0069	CALFIRE, Gardner 97	1917 -1934	**1189 acres**		Alamere Creek	Unknown	Unknown
0070	CALFIRE, Gardner 98	1917 -1934	**992 acres**		Arroyo Hondo	Unknown	Unknown
0071	CALFIRE, Gardner 99	1917 -1934	**1732 acres**		Pablo Point	Unknown	Unknown
0072	CALFIRE, Gardner 108	1917 -1934	**180 acres**		Marin Country Club	1911	15 ± 8 yrs av
0073	CALFIRE, Gardner 109	1917 -1934	**270 acres**		Alameda del Prado Ridge	1911	15 ± 8 yrs av
0074	CALFIRE, Gardner 110	1917 -1934	**285 acres**		Alameda del Prado	1911; Unknown	15 ± 8 yrs av
0075	CALFIRE, Gardner 114	1917 -1934	**726 acres**		White Hill	1891,1890,1868,1861	16 ± 2 yrs av
0076	CALFIRE, Gardner 115	1917 -1934	**169 acres**		Happersberger Point	1904; 1868	29 ± 4 yrs. av
0077	CALFIRE, Gardner 118	1917 -1934	**350 acres**		Bald Hill	1893; 1891	18 ± 4 yrs av
0078	CALFIRE, Gardner 120	1917 -1934	**849 acres**		San Marin Drive	1915, Unknown	11 ± 9 yrs av
0079	CALFIRE, Gardner 121	1917 -1934	**1007 acres**		Freitas Ranch	Unknown	Unknown
0080	CALFIRE, Gardner 124	1917 -1934	**225 acres**		Northgate	Unknown	Unknown
0081	CALFIRE, Gardner 125	1917 -1934	**486 acres**		San Rafael Hill	Unknown	Unknown
0082	CALFIRE, Gardner 126	1917 -1934	**288 acres**		China Camp	Unknown	Unknown
0083	CALFIRE, Gardner 127	1917 -1934	**1184 acres**		Civic Center Ridge	Unknown	Unknown
0084	CALFIRE, Gardner 129	1917 -1934	**363 acres**		Barbier Park	Unknown	Unknown
0085	CALFIRE, Gardner 130	1917 -1934	**495 acres**		Peacock Gap	Unknown	Unknown
0086	CALFIRE, Gardner 144	1917 -1934	**303 acres**		County Line	Unknown	Unknown

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0087	CALFIRE, Gardner 150	1917 -1934	**186 acres**		Tamalpais Valley	1881	44 ± 8 yrs av
0088	CALFIRE, Gardner 153	1917 -1934	**466 acres**		Simmons Lane	Unknown	Unknown
0089	CALFIRE, Gardner 152	1935-1936	**1494 acres**		Big Rock Summit	1917 1911 1900	19.5 24.5 35.5 (27 yr av)
0090	1935 San Anselmo Herald 17 October	10/16	> 200 acres **497 acres** POLYGON OBJECTID # 180		Ridge west of Sausalito Threatened northern Sausalito Burned grazing land	1932 1919 1906 1881	3 16 29 54 (26 yr av)
0091	Sotoyome Scimitar, Oct 24 CALFIRE, Gardner 154 (1935–36)	10/22	5000 acres **2927 acres**		Hick-Chileno Valley; Lincoln School Fought by 500 volunteers "thousands of feet of fencing destroyed"	1911	24
0092	1936 **BOLINAS RIDGE** Marinfirehistory.org Santa Cruz Sentinel, Oct 16 CALFIRE, Gardner 147(1935-36)	Oct 15	"4000 acres" **1621 acres**		"southern side of the mountain near the Bolinas Schoolhouse spreading swiftly through dry grass"	Unknown	Unknown
NA	Santa Cruz Sentinel, Oct 16	Oct 15	"several hundred acres" Description too vague to map NO OBJECTID		Stopped at a ridge above Mill Valley "heavy timber and grass" "destroyed at least one building"	Not enough information to determine	Not enough information to determine
0093	1937 CALFIRE, Gardner 159	1937	**319 acres**		San Marin Drive	1917-1934	3-20 12 ± 8 yrs av
0094	CALFIRE, Gardner 157	1937	**175 acres**		Strawberry	1929	8
0095	CALFIRE, Gardner 158	1937	**1098 acres**		Hamilton Field	1892, Unknown	45, unknown

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0096	1938 San Anselmo Herald Sept 15	9/11	400 acres **399 acres** POLYGON OBJECTID # 186	Extent: H Location: M	*North Slope of Mountain "400 acres of brushland" "threatened the Meadow Club" Could be same fire as CALFIRE, Gardner 161 below	1938 1926	0 12 (6 or 12 yrs av—see location notes)
0097	Sausalito News, Dec 1 CALFIRE, Gardner 95	11/23	"large" **949 acres**		Vicinity of Firtop; Glen Ranch, west of Five Brooks "expected to burn itself out at the water's edge" "remained out of control for 24 hours" (year may be wrong)	1917-1934 Unknown	4-21; 13 ± 9 yrs av
0098	CALFIRE, Gardner 161	1938	**194 acres**		Azalea Hill—could be same fire as 9/11/1938 above	1938 1926	0 12 (6 or 12 yrs av—see location notes)
0099	CALFIRE, Gardner 162	1938	**318 acres**		Black Canyon	1917-1934	4-21; 13 ± 9 yrs av
0100	CALFIRE, Gardner 164	1938	**227 acres**		Big Rock Ridge	1923, 1917 - 1934	15,4-21; 14 ± 4 yrs av
0101	CALFIRE, Gardner 165	1938	**898 acres**		Inverness Ridge, Mt Vision	1917	21
0102	1939 Mill Valley Record Sept 15	9/12	**203 acres** POLYGON OBJECTID # 183	Extent: M Location: H	*Upland Drive Blithdale Ridge Warner Canyon; Elinor Fire Rd No homes lost	1929 1889	10 50 (30 yr av)
0103	1941 CALFIRE, Gardner? 61 (uncertain)	1941	**176 acres**		Chileno Valley	1887	54
0104	CALFIRE, Gardner 170	1941	**168 acres**		Gallinas Valley	1929 1921 1911 Unknown	12 20 30 Unknown 21 yr + av

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0105	Chief Gardner Map remapped to correct CALFIRE shapefile	1941	"400 acres" **388 acres** CALFIRE polygon seems too small POLYGON OBJECTID #193	Extent: H Location: H	Wolf Ridge, Marin Peninsula Unable to corroborate	1881	60
1015	1943 **BALD HILL** Marinfirehistory.org	9/2/1943	Unknown Mapped as point POINT OBJECTID #25	NA	"Fought by several hundred military and civilian personnel" Unable to corroborate in newspaper	1917-34	9-26 c. 17.5
(out of sequence; no #106) **0107**	1944 Mill Valley Record, Sept 21	9/9	1250 acres **1277 acres** POLYGON OBJECTID # 184	Extent: H Location: L	"grazing land west of Novato" "one of the largest grass fires in Marin history"	1917 – 1934 1917 – 1934 1915 1870	29 10 - 27 10 – 27 74 35 yr + av
0108	1945 **MILL/CARSON CYN** Mill Valley Record, Dec 6 Marin Cty Fire Chiefs Assoc. Peter Martin (NPS 2011)	9/27	20,000 acres **19,161 acres** POLYGON OBJECTID # 178	Extent: H Location: H	Perimeter mapped from map on Fire Chiefs Association website	1938 1893 1926 1892 1923 1891 1906 1890 1904 Unknown	7 52 19 53 22 54 39 55 41 Unknown 38 yr + av
0109	1947 **CORTE MADERA JUNCTION** Marinfirehistory.org Mill Valley Record, July 25	7/24	300 - 400 acres **315 acres** POLYGON OBJECTID # 188	Extent: H Location: M	Corte Madera Junction "between Larkspur and Highwy 101"	Unknown	Unknown
0110	1949 **IGNACIO TO BIG ROCK RIDGE** Mill Valley Record, Sept 23, 27 Marinfirehistory.org	9/22	3000 acres **507 acres** POLYGON OBJECTID # 185	Extent: L Location: L	*back of Ignacio, started in 4 spots "raging fire" on "straight up and down brush" "no homes were threatened" 2nd report incr. size to 500 acres "3000 acres" from marinfirehistory	1923	26

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0111	1958 **BLACK CANYON** Marinfirehistory.org	6/27	"300 acres" **318 acres** POLYGON OBJECTID # 190	Extent: H Location: M	Black Canyon Unable to corroborate	1917-34 (three times)	14 yr av
	CALFIRE RECORD more consistent, 1965 – 2020 (no sizeable fires reported in the press, 1959-1964)						
0112	1965 **ANDERSON** CALFIRE	9/17	**165 acres** POLYGON OBJECTID # 32	Extent: H Location: L		1917-34	31 – 48 + (median = 40+)
0113	**CHILENO VALLEY** Marinfirehistory.org (not in CALFIRE)	9/17	8000 acres **7197 acres** POLYGON OBJECTID # 192	Extent: H Location: L	Chileno Valley Unable to corroborate	1941 1935	24 30 27 yr av
0114	1966 **LES CORDA RANCH** CALFIRE	6/1	**588 acres** POLYGON OBJECTID # 41	Extent: H Location: L		1917-34 Unknown	32 – 49 + Unknown (median = 41+)
0115	1966 **MARINCELLO** CALFIRE	10/16	**568 acres** POLYGON OBJECTID # 42	Extent: H Location: L		1881	85
0116	1969 **S & T RANCH** CALFIRE	9/30	**210 acres** POLYGON OBJECTID # 36	Extent: H Location: L		Unknown	Unknown
1013	1972 **ANGEL ISLAND** Marinfirehistory.org (not in CALFIRE)	7/28	Unknown POINT OBJECTID # 24	NA	Unable to corroborate	Unknown	Unknown
1014	**KENT WOODLANDS** Marinfirehistory.org (not in CALFIRE)	10/9	Unknown POINT OBJECTID # 23	NA	Unable to corroborate	1891	81

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0117	**1973** **TAMARANCHO** CALFIRE	6/9	**202 acres** POLYGON OBJECTID # 10	Extent: H Location: L		1945	28
0118	**1974** **MARINWOOD** CALFIRE	7/21	**423 acres** POLYGON OBJECTID # 7	Extent: H Location: L		1941 1923 1921	33 41 53 42 yr av
0119	**1975** **CAT CREEK** CALFIRE	7/24	**185 acres** POLYGON OBJECTID # 46	Extent: H Location: L		1917-34	41-58 (median = 50)
0120	**1976** **SORICH PARK** CALFIRE	6/14	**285 acres** POLYGON OBJECTID # 52	Extent: H Location: L		Unknown (western edge may have burned in 1861 and/or 1887)	Unknown
0121	**KELHAM** CALFIRE	6/23	**479 acres** POLYGON OBJECTID # 51	Extent: H Location: L		Unknown	Unknown
0122	**1981** **OLOMPALI** CALFIRE	6/17	**212 acres** POLYGON OBJECTID # 3	Extent: H Location: L		Unknown	Unknown
0123	**VOGELSANE** CALFIRE	10/16	**179 acres** POLYGON OBJECTID # 4	Extent: H Location: L		1974 1923	7 58 33 yr av.
0124	**1984** **TROJAN POINT** CALFIRE	6/17	**226 acres** POLYGON OBJECTID # 67	Extent: H Location: L		1904 1859	80 125 103 yr av

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0125	**WHITE'S HILL** CALFIRE	8/18	**411 acres** POLYGON OBJECTID # 66	Extent: H Location: L		1923 1921	61 63 62 yr av
0126	**1987** **BIG ROCK** CALFIRE	7/3	**407 acres** POLYGON OBJECTID # 21	Extent: H Location: L		1917 – 1934 1923	53 – 70 (med = 62) 64 63 yr av
0127	**1988** **RUBICON** CALFIRE	10/9	**207 acres** POLYGON OBJECTID # 11	Extent: H Location: L		1981 1974 1923	7 14 65 29 yr av
0128	**1990** **LA FRANCHI** CALFIRE	9/19	**395 acres** POLYGON OBJECTID # 72	Extent: H Location: L		1900 1880 Unknown	90 110 Unknown 100 yr av +
0129	**1995** **VISION** CALFIRE	10/3	**11796 acres** POLYGON OBJECTID # 76	Extent: H Location: L		1976 1938 1917 Unknown	19 57 78 Unknown 51 yr av +
0130	**2004** **DOLCINI** CALFIRE	9/7	**365 acres** POLYGON OBJECTID # 71	Extent: H Location: L		Unknown	Unknown
0131	**2008** **ANGEL ISLAND** CALFIRE	10/13	**303 acres** POLYGON OBJECTID # 77	Extent: H Location: L		1972	36

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0132	**2020** **WOODWARD** CALFIRE	8/18 To 11/20	**4902 acres** POLYGON OBJECTID # 21765	Extent: H Location: L	Lightning	1995 1976 Unknown	25 44 Unknown 35 yr av +

APPENDIX C: REGULATORY COMPLIANCE

ASCENT
ENVIRONMENTAL

Regulatory Compliance Guidance for the Marin Regional Forest Health Strategy

SUBMITTED TO:

ONE TAM

AND

GOLDEN GATE NATIONAL PARKS CONSERVANCY

JANUARY 28, 2022

Regulatory Compliance Guidance for the

Marin Regional Forest Health Strategy

Prepared for:

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January 2022

LIST OF ABBREVIATIONS

AB	Assembly Bill
Air District	Bay Area Air Quality Management District
BFFIP	Biodiversity, Fire, and Fuels Integrated Plan
BIA	Bureau of Indian Affairs
BMP	best management practice
CalVTP	California Vegetation Treatment Program
CDFW	California Department of Fish and Wildlife
CE	categorical exclusion
CEQ	Council of Environmental Quality
CEQA	California Environmental Quality Act
EA	Environmental Assessment
EIR	Environmental Impact Report
EIS	Environmental Impact Statements
FIGR	Federated Indians of Graton Rancheria
guidance document	Regulatory Compliance Guidance document
Handbook	2015 NPS NEPA Handbook
LRA	Local Responsibility Area
LSAA	Lake and Streambed Alteration Agreement
Marin Forest Health Strategy	Marin Regional Forest Health Strategy for Public Lands
MND	Mitigated Negative Declaration
NAHC	Native American Heritage Commission
ND	Negative Declaration
NEPA	National Environmental Policy Act
NGO	nongovernmental organization
NOAA	National Oceanic and Atmospheric Administration
NOE	Notice of Exemption
NPS	National Park Service
NWIC	Northwest Information Center
One Tam	Tamalpais Lands Collaborative
Plan	Biodiversity, Fire, and Fuels Integrated Plan
PRC	Public Resources Code
PRNS	Point Reyes National Seashore
PSA	project-specific analysis
RCD	Resource Conservation Districts
RWQCB	Regional Water Quality Control Board
SRA	State Responsibility Area
Strategy	Marin Regional Forest Health Strategy for Public Lands
USFWS	U.S. Fish and Wildlife Service

1 INTRODUCTION AND CONTEXT

The Tamalpais Lands Collaborative (One Tam) is developing the Marin Regional Forest Health Strategy for Public Lands (Marin Forest Health Strategy or Strategy) with support from the California Natural Resources Agency's Regional Forest and Fire Capacity Program and the California State Coastal Conservancy, and in collaboration with other Marin land managing agencies. Both Point Reyes National Seashore (PRNS) and the Federated Indians of Graton Rancheria (FIGR), while not currently official members of One Tam, have participated in development of the Regional Forest Health Strategy (collaborators). The One Tam partners and collaborators acknowledge that the lands in Marin County are the traditional territory and ancestral homeland of the Federated Indians of Graton Rancheria.

The Strategy will include a health assessment of key forest types in Marin County, and will provide managers with a data-driven framework identifying priority treatment areas with the objective of maintaining and restoring biodiversity and forest health while increasing fire resiliency. The stakeholders, as identified in Section 1.2, are responding to the urgent need to protect forests, reduce wildfire risk, and help forests maintain their natural resiliency. The Strategy will provide a series of informed vegetation treatment methods to improve the ecology of Marin forests. These approaches will improve forest habitat quality and protect biodiversity, while also strategically managing vegetation to reduce fire fuels, such as dry brush, dense ladder fuel, and diseased or dying trees.

This Regulatory Compliance Guidance document (guidance document) has been prepared to assist the stakeholders with understanding the various environmental regulatory compliance approaches that could be used to implement treatment approaches identified in the Strategy. The purpose of this guidance document is to identify opportunities for an expeditious and effective California Environmental Quality Act (CEQA) and National Environmental Policy Act (NEPA) environmental review process and for integrated compliance with other regulatory processes for forest restoration and wildfire fuel reduction treatments. The guidance document identifies compliance pathways for multi-agency treatment projects. These include application of CEQA statutory and categorical exemptions and NEPA exclusions, use of existing CEQA or NEPA documents (e.g., the Program Environmental Impact Report [EIR] for the California Vegetation Treatment Program [CalVTP] and completed Environmental Impact Statements [EIS] for fire fuel management plans on NPS land in Marin County), or preparation of a separate CEQA and/or NEPA document. Additionally, this guidance document describes approaches for compliance with existing regulations, such as general strategies to avoid adverse effects to endangered and threatened species and historical and tribal cultural resources during treatment implementation.

1.1 FOREST HEALTH STRATEGY GOALS AND OBJECTIVES

The Strategy covers all public lands in Marin County (Strategy Area) and is intended to be a regional, multi-benefit forest health strategy that will foster partnerships between public land management agencies, the Marin Wildfire Prevention Authority, FIGR, and other groups to advance forestry projects that will restore and enhance ecosystem functions while increasing wildfire resiliency for forests and communities. The Strategy aims to identify, coordinate, and demonstrate successful approaches to forestry assessment and active management at a landscape scale and contribute to California's statewide efforts to achieve climate resilience, ecosystem restoration, wildfire fuel reduction, and wildfire risk mitigation goals.

1.2 STAKEHOLDERS

As described under "Introduction and Context" above, One Tam partners and their collaborators (National Park Service [NPS] PRNS and FIGR) are developing the Strategy. Together, the One Tam partners and collaborators are the stakeholders for this effort. Marin County Parks, State Parks, and Marin Water, as public agencies, could serve in the role of CEQA lead agency for individual projects. NPS could serve in the role of NEPA lead agency for individual projects. FIGR could potentially partner with the Bureau of Indian Affairs (BIA) to plan vegetation treatment projects, with the BIA as the NEPA lead agency if BIA provides federal funding or an approval. The Parks Conservancy is supporting the other stakeholders with development and implementation of the Strategy. Other entities, such as nongovernmental organizations (NGOs), may also be involved in future project development and implementation and will be identified as the Strategy evolves in collaboration with the stakeholders.

1.3 EXISTING ENVIRONMENTAL INFORMATION

There is a wealth of existing information that can be leveraged by the stakeholders to maximize efficiency when planning treatment projects and preparing environmental documents, including previously prepared CEQA and NEPA documents, resource-specific databases, and existing regulatory approvals (e.g., Biological Opinions). This information may help inform what compliance pathway is best suited for a specific project and help to prepare the necessary resource-specific environmental analysis in CEQA and NEPA documents. The list below includes and summarizes relevant existing environmental information that may be helpful to the stakeholders, including links to databases and resource information, relevant example documents, and previously prepared environmental documents and permits.

Existing CEQA/NEPA Documents and Biological Opinions Available for Stakeholder Use in the Strategy Area

- California Board of Forestry and Fire Protection 2019. *CalVTP Program EIR*: https://bof.fire.ca.gov/projects-and-programs/calvtp/calvtp-program-eir/.
- Marin Municipal Water District 2019. *Biodiversity, Fire and Fuels Integrated Plan EIR*: https://www.marinwater.org/vegetation.
- Golden Gate National Recreation Area 2015. *General Management Plan*: https://parkplanning.nps.gov/documentsList.cfm?parkID=303&projectID=15075.
- Golden Gate National Recreation Area 2005. *Fire Management Plan EIS*: https://parkplanning.nps.gov/documentsList.cfm?parkID=303&projectID=13822.
    - U.S. Fish and Wildlife Service 2005. *Biological Opinion on the Fire Management Plan*: https://parkplanning.nps.gov/document.cfm?parkID=303&projectID=13822&documentID=13599#content.
    - National Oceanic and Atmospheric Administration National Marine Fisheries Service (NOAA Fisheries) 2006. *Programmatic Biological Opinion on the Fire Management Plan*.
- Point Reyes National Seashore and North District of Golden Gate National Recreation Area 2004. *Fire Management Plan EIS*: https://www.nps.gov/pore/getinvolved/planning_fmp.htm.
    - U.S. Fish and Wildlife Service. 2004. *Biological Opinion on the Fire Management Plan*: https://www.nps.gov/pore/getinvolved/planning_fmp.htm.

CalVTP PSA Examples and Tools

- CalVTP Implementation Database and PSA Template: https://bof.fire.ca.gov/projects-and-programs/calvtp/calvtp-implementation-database/ (contains links to a Project-Specific Analysis (PSA) template for use by any PSA preparer and an online viewer of planned, approved, and completed projects using the CalVTP Program EIR).
- ArcGIS CalVTP Treatable Landscape Viewer: https://calfire-forestry.maps.arcgis.com/apps/webappviewer/index.html?id=78782787ae4d459e8cb313141a5c41be (online viewer of the CalVTP treatable landscape).
- CalVTP PSA and PSA/Addendum Examples:
    - https://bof.fire.ca.gov/projects-and-programs/calvtp/how-to-use-the-calvtp/ (refer to “Example PSA Documents” on the webpage, including the following).

        - *Bear Creek Redwoods Open Space Preserve Vegetation Treatment Project PSA* (an example PSA; project involves ecological restoration treatments within a preserve, treatment in special-status species habitat).
        - *Grouse Ridge Vegetation Treatment Project PSA/Addendum* (an example PSA/Addendum; the Addendum provides CEQA coverage for portions of proposed treatment areas that extend outside the CalVTP treatable landscape).
    - https://bof.fire.ca.gov/projects-and-programs/calvtp/approved-projects-environmental-documentation/ (view completed PSAs and PSA/Addenda from throughout the state under "Approved Project-Specific Analyses & Supporting Documents" on the webpage, including the following).
        - 2020-9 (Yuba Foothills Healthy Forest Projects) PSA/Addendum (a PSA/Addendum; the Addendum provides CEQA coverage for portions of the proposed treatment areas that extend outside the CalVTP treatable landscape; this PSA/Addendum includes multiple private landowners)
- Identification of Coastal Zone Boundary: https://www.coastal.ca.gov/maps/czb/.
- Local Coastal Program. County of Marin 2021. Local Coastal Program (LCP) Amendments: https://www.marincounty.org/depts/cd/divisions/planning/local-coastal-program (refer to Section 5.2, "Coastal Act Compliance," below for additional information).
- Public Works Plans for Coastal Act Compliance using the CalVTP Program EIR: https://bof.fire.ca.gov/projects-and-programs/calvtp/how-to-use-the-calvtp/ (view completed plans under "Additional Regulatory Streamlining Options" on the webpage, including the following).
    - *San Mateo County Forest Health and Fire Resilience Public Works Plan* (PWP).
    - *Santa Cruz County Forest Health and Fire Resilience Public Works Plan* (PWP).
    - *Upper Salinas-Las Tablas Resource Conservation District Forest Health and Fire Resilience Public Works Plan* (PWP).

Existing Information and Databases Useful for CEQA and PSA Preparation

The information linked below is resource specific and will be helpful when preparing CEQA documents, including PSAs under the CalVTP. Each link can provide useful information about resources present within a treatment area (e.g., presence of state scenic highways, important farmland, special-status plants), or the resource-specific context/general information within a treatment area (e.g., wildfire risk, culturally affiliated Native American tribes, prescribed burning regulations). For additional guidance regarding CEQA compliance for several resources (e.g., biological resources, cultural resources, tribal cultural resources), refer to Section 5, "Other Regulatory Compliance."

- CAL FIRE Hazard Severity Zones: https://egis.fire.ca.gov/FHSZ/.
- Caltrans State Scenic Highways Map: https://www.arcgis.com/apps/webappviewer/index.html?id=2e921695c43643b1aaf7000dfcc19983.
- California Department of Conservation Farmland Mapping & Monitoring Program, California Important Farmland Finder: https://maps.conservation.ca.gov/DLRP/CIFF/.
- Information and resources on prescribed burning: https://ww2.arb.ca.gov/our-work/programs/prescribed-burning.
- Occurrences of rare plants and animals in California: https://wildlife.ca.gov/Data/CNDDB.
- Occurrences of rare plants in California from California Native Plant Society: https://www.cnps.org/rare-plants/cnps-inventory-of-rare-plants.
- Potential for federally listed species from the Planning and Consultation website (U.S. Fish and Wildlife Service): https://ecos.fws.gov/ipac/.
- Marin County Fine Scale Vegetation Map: https://vegmap.press/marin_vegmap_datasheet.

- Marin County Forest Health Webmap: https://parksconservancy.maps.arcgis.com/apps/mapviewer/index.html?webmap=cb923f0647c1455fbb6e7451776841fa.
- National Wetlands Inventory (U.S. Fish and Wildlife Service): https://fws.gov/wetlands/.
- National Hydrography Dataset (NHD) National Map from U.S. Geological Survey (USGS): https://hydro.nationalmap.gov/arcgis/rest/services/nhd/MapServer.
- Biological data from California Department of Fish and Wildlife on Biogeographic Information and Observation System (BIOS): https://wildlife.ca.gov/Data/BIOS.
- Cultural Records from the California Historical Resources Information System (CHRIS): https://ohp.parks.ca.gov/?page_id=28066.
- Tribal Consultation List Request and Sacred Lands File Search: http://nahc.ca.gov/resources/forms/.
- Geology/Soil Characteristics: https://websoilsurvey.sc.egov.usda.gov/App/HomePage.htm.
- Cortese List Sites (Hazmat):
  - SWRCB's GeoTracker: https://geotracker.waterboards.ca.gov/map/.
  - Cortese List Sites, DTSC's EnviroStor: https://www.envirostor.dtsc.ca.gov/public/map/.

1.4 TREATMENT PROJECT PLANNING

In most circumstances, treatment projects can be designed to avoid and/or minimize adverse environmental effects and maintain wildfire risk reduction and forest health benefits, thereby providing opportunities to streamline environmental compliance. Recommended approaches to employ during treatment project planning are listed here and described in more detail below.

- Review existing environmental information in the vicinity of the treatment area.
- Coordinate with agencies having knowledge of or jurisdiction over resources affected by the project (if needed).
- Design the project description of treatment to include standard requirements that avoid impacts to known resources (e.g., cultural, biological) and integrate best management practices (BMPs) to avoid impacts where feasible.
- Define the CEQA/NEPA compliance approaches to take advantage of streamlining tools that avoid redundant environmental reviews.

Existing information that can be reviewed when designing treatments projects is summarized above in Section 1.3, "Existing Environmental Information." Reviewing existing environmental information during treatment design would allow the stakeholders to design treatments to avoid known sensitive resources, as feasible. In addition, it would provide awareness of the extent of potential environmental impacts and associated level of CEQA or NEPA documentation and potential permits/approvals that may be required.

If a treatment project is located within multiple jurisdictions, early outreach and communication with those agencies with jurisdiction over parts of a project (e.g., lands, resources) and other interested parties will be key to the success of a project. Refer to Section 4, "Multi-Jurisdiction Projects," below for more detailed guidance on how to approach compliance for multi-jurisdictional projects. The general public, concerned neighborhood groups, and environmental advocacy organizations, as well as other NGOs are often interested in projects occurring in Marin County. These interested groups and individuals can provide valuable information about proposed project activities and resources potentially present that can benefit a project's outcome; however, if opposition to a proposed project cannot be resolved, parties may litigate following the decision on the environmental review process, causing or adding to delays and inefficiencies. An in-depth collaboration effort for implementation of the Strategy would afford an opportunity to gather and address input from interested groups and individuals early and throughout the process to best address concerns when still in the treatment design phase.

To achieve "downstream" acceleration of project approval and implementation, it is important to incorporate features "upstream" in the process to avoid significant environmental effects. Because the underlying goals of the Strategy focus on improving and enhancing ecosystem functions, many of the environmental protection features would be inherent in project development. An iterative approach is typically needed, which consists of preparation of an initial or draft project description, preliminary environmental analysis and feedback to treatment designers, and refinement of project description with environmental protection features incorporated. Refer to Chapter 5, "Other Regulatory Compliance," below and Section 8, "Treatment Descriptions," of the Strategy for more information on specific treatment recommendations, strategies for avoidance, and tools for identifying environmental protection measures.

Lastly, it is important to define the anticipated CEQA or NEPA approach early so the level of initial scoping, document detail and content, and review and approval processes are understood. Stakeholders may include components in a forest health project that are not vegetation treatment (e.g., trail improvements, access road maintenance, culvert replacement). For a forest health project that is not within the scope of an existing EIR or EIS (refer to Section 2.4 and 3.3 below), an initial step is determining whether components of a project have independent utility, or have an accessory use. Under the concept of independent utility, related projects can be evaluated separately if each has substantial utility irrespective of the other's approval. As it applies to vegetation treatment, the consideration would be whether the project component has a use that is accessory to the objective of vegetation treatment. For example, trail improvements may be contemplated as part of a forest health project that is seeking to use the CalVTP Program EIR to streamline CEQA compliance. Although trail improvements are not within the scope of the CalVTP Program EIR, in this hypothetical example, recreational use facilitated by the trail improvement could also be an accessory use of a shaded or non-shaded fuel break that can serve as access to treat vegetation and for firefighters in the event of a fire, and for trail users otherwise. In this case, the trail is not a new facility; rather, it is an accessory use of a fuel break that provides access; fuel breaks are a covered treatment type under the CalVTP Program EIR.

If it is determined that the trail improvement is a new facility that is more than an accessory use of the vegetation treatment (e.g., possibly for a paved trail), the trail improvement would be reviewed to determine the appropriate environmental document. An illustration of this decision process is presented in Figure 1.

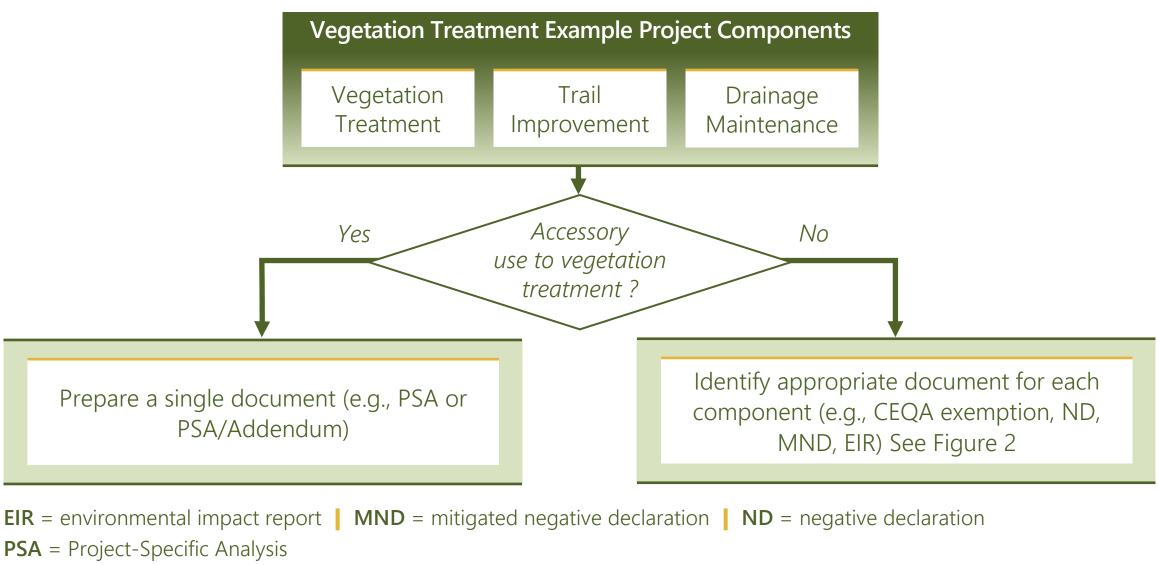


Figure 1 Determining the Appropriate CEQA Compliance Route for Projects with Accessory Uses

2 CALIFORNIA ENVIRONMENTAL QUALITY ACT COMPLIANCE

2.1 CEQA PRINCIPLES FOR VEGETATION TREATMENT

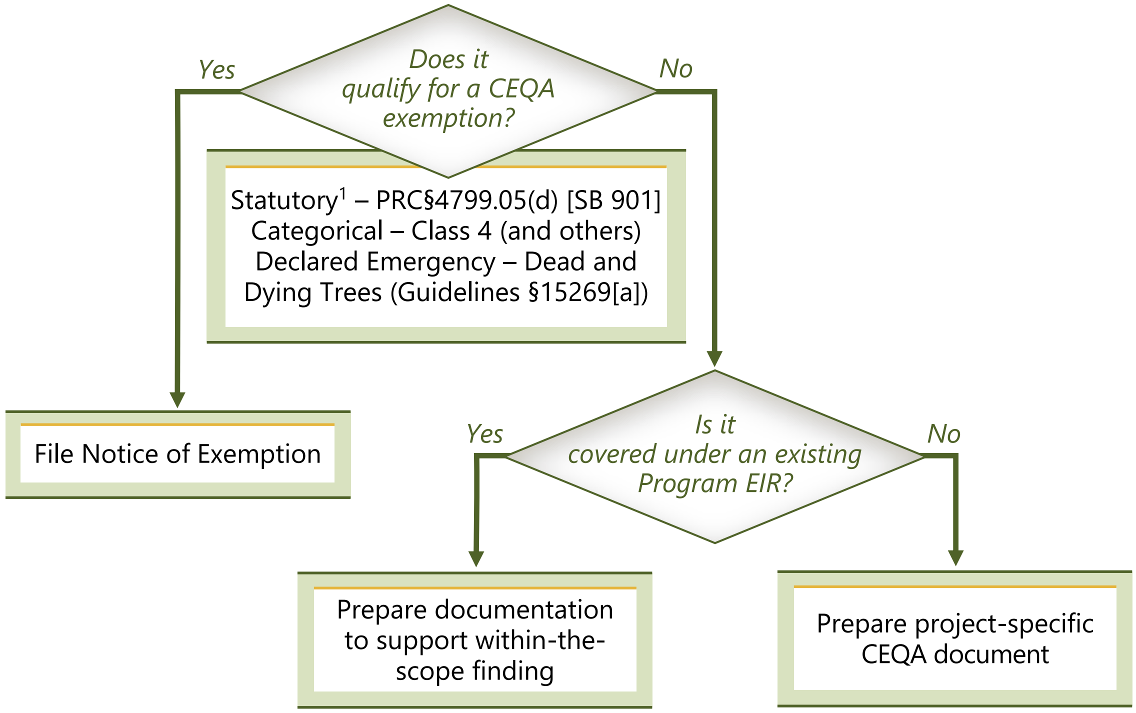
CEQA applies to all state, regional, and local government agencies in California that carry out or approve an action that qualifies as a "project" under the statute and guidelines. When the legislature enacted CEQA and the Natural Resources Agency adopted the State CEQA Guidelines, they both recognized that some projects are carried out or approved by more than one agency. Therefore, both CEQA and the State CEQA Guidelines define several different categories of agencies and give differing roles and responsibilities to each. The lead agency is the public agency with the primary responsibility for project approval. One key to successful CEQA compliance is for the various agencies involved in a project to figure out their respective roles at the beginning of a project. This is particularly important because for most projects only one CEQA document is prepared by the lead agency, and it must be used by all of the agencies carrying out or approving the project (called "responsible agencies" under CEQA).

State CEQA Guidelines Section 15378 defines a project under CEQA to be "the whole of an action, which has a potential for resulting in either a direct physical change in the environment, or a reasonably foreseeable indirect physical change in the environment." It further describes a project to be an activity undertaken by a public agency, such as clearing or grading of land, improvements to existing public structures, and public works construction; an activity undertaken by a person which is supported through public agency contacts, grants, subsidies, loans, or other forms of assistance from one or more public agencies; or an activity involving the issuance of a lease, permit, license, certificate, or other entitlement for use by a public agency. Vegetation treatment projects that require a discretionary approval, funding approval, or environmental permitting by a state, regional, or local agency would result in physical changes and, therefore, qualify as a project under CEQA. As vegetation treatment projects are developed under the Strategy, they should undergo a stepwise evaluation to identify the appropriate environmental document:

1. confirm whether environmental regulations even apply (e.g., whether it is a "project" pursuant to State CEQA Guidelines Section 15378);
2. if CEQA requirements are applicable, determine what level of review is required, what document(s) should be prepared, and whether any streamlining tools apply (e.g., application of an exemption, use of the CalVTP Program EIR); and
3. identify and execute necessary technical studies to support completion of the environmental document(s).

The various CEQA approaches that could be used for vegetation treatment projects proposed under the Strategy are detailed below in Section 2.3 through 2.5. Figure 1 illustrates decision points for different document types and the process for each.

A CEQA lead agency is the public agency that has principal responsibility for approving or carrying out a project (CEQA Guidelines Section 15367), which may include providing funding. Where two or more public agencies are involved with a project, as will likely be the case with Strategy projects, the public agency that will be carrying out the project should be the lead agency for the purposes of CEQA, even if the project is located within the jurisdiction of another public agency. If the project would be carried out by a nongovernmental entity, then the lead agency should be the public agency with the greatest responsibility for supervising or approving the project as a whole. State Parks, Marin County Parks, or Marin Water would be appropriate lead agencies for Strategy projects carried out in their respective jurisdictions.



[1]**Considerations:**
The statutory exemption in PRC § 4799.05(d) requires annual certification by CNRA Secretary and becomes inoperative January 1, 2023.

Under proposed Assembly Bill 267 it would become inoperative January 1, 2026.

Bill Text - AB-267 California Environmental Quality Act: exemption: prescribed fire, thinning, and fuel reduction projects.

Source: Ascent Environmental Inc.

Figure 2 Determining the Most Expeditious Route to CEQA Compliance

A responsible agency under CEQA is a public agency with some discretionary authority over a project or a portion of it, but which has not been designated the lead agency (State CEQA Guidelines Section 15381.) If a project involves discretionary actions by more than one agency, one may be selected as the lead agency pursuant to State CEQA Guidelines Section 15051, and the others would become responsible agencies. State agencies may have permit approval authority over actions implemented under the Strategy, such as California Department of Fish and Wildlife (CDFW) and the San Francisco Bay or North Coast Regional Water Quality Control Board (RWQCB), depending on the project and resources involved. CDFW and the RWQCB both have approval authorities related to specific resources (streambeds and state listed species for CDFW, and water quality for the RWQCB) and may be responsible agencies during CEQA review.

A trustee agency is a State agency having jurisdiction by law over natural resources that are held in trust for the people of California, and which may be affected by a project (State CEQA Guidelines Section 15386). The trustee agencies with resources in Marin County are CDFW, California State Parks, University of California, and California State Lands Commission. A trustee agency may also be a responsible agency if it has discretionary authority over a project. For example, CDFW is a trustee agency for projects that involve or could have an effect on the fish and wildlife resources of the State, including designated rare or endangered native plants, game refuges, ecological reserves, and other areas it administers, and may also be a responsible agency for a project.

2.2 CUMULATIVE IMPACT CONSIDERATIONS

Section 15355 of the State CEQA Guidelines defines a cumulative impact as the condition under which "two or more individual effects which, when considered together, are considerable or which compound or increase other environmental impacts. The cumulative impact from several projects is the change in the environment which results from the incremental impact of the project when added to other closely related past, present, and reasonably foreseeable probable future projects. Cumulative impacts can result from individually minor but collectively significant projects taking place over a period of time" (State CEQA Guidelines Section 15355). In other words, a project that is being evaluated within a certain area may contribute to a larger impact/effect to certain resources if you look at other projects that are also affecting that resource in that same area. The evaluation of cumulative impacts needs to be considered when preparing any of the following:

- Program EIR or Project EIR
- Mitigated Negative Declaration (MND) or Negative Declaration (ND)
- Notice of Exemption (NOE)

The need to evaluate cumulative impacts in connection with NOEs is limited to categorical exemptions, as stated within Section 15300.2 of the State CEQA Guidelines. Statutory exemptions do not need to consider cumulative impacts, unless this qualification is explicitly included in the exempting statute. NOEs relying on categorical exemptions are required to determine whether the cumulative impacts of successive projects of the same type and place over time are significant; if there is such an impact and there is substantial evidence the project would actually contribute to that impact, the project could not use a categorical exemption. Because cumulative impacts are evaluated during preparation of a Program EIR, projects that are within the scope of an existing Program EIR do not need further cumulative impact analysis.

2.3 EXEMPTIONS

Two types of CEQA exemptions, statutory and categorical, can eliminate the need to prepare an ND, MND, or EIR for qualifying forest health projects. Both of these types of CEQA exemptions are described in more detail below. Once it is determined that a proposed project is exempt (statutory or categorical) a Notice of Exemption [NOE] is normally filed with the California State Clearinghouse. Although CEQA does not require a lead agency to file a NOE, it is a good practice to file a NOE for all exempt projects which then reduces the statute of limitations (the period of time in which a decision can be challenged) from 180 to 35 days.

2.3.1 Statutory Exemptions

Statutory exemptions are commonly used for projects involving fire control, repairs to prevent immediate injury or death, and actions or repairs necessary as a result of a Governor-declared emergency (CAL FIRE 2010:4). Currently, there are two statutory exemptions that could be used for Strategy projects, each are summarized below.

Senate Bill (SB) 901, Wildfires (Public Resources Code §4799.05(d)(1)). This exemption was approved by the California legislature in the 2018 session and enacted by the Governor. SB 901 provides that, until January 1, 2023, under specified conditions, CEQA would not apply to "prescribed fire, thinning, or fuel reduction projects" undertaken on federal lands to reduce the risk of high-severity wildfire that have been reviewed under NEPA and where the role of the state is limited to providing funding, staff, and Good Neighbor Authority stewardship support. In the Strategy Area, this would apply to qualifying projects implemented on NPS land that are covered by a NEPA document and are receiving funding from state grants (e.g., CAL FIRE, California Coastal Conservancy). This exemption also provides that CEQA would not apply to the issuance of a permit or other project approval by a state or local agency on such projects (e.g., 401 certifications, Section 1602 connected with state funding action, etc.). The relevant provisions of SB 901 are included in Section 23 of the bill, which amends Public Resources Code Section 4799.05. This exemption must be recertified by the Secretary of the California Natural Resources Agency each year.

Declared Emergency (State CEQA Guidelines §15269[a]). This exemption stems from the 2015 emergency declaration for tree mortality and associated wildfire risk, which was reinforced by Executive Order B-42-17. It applies to removal of dead and dying trees that threaten power lines, roads, structures, and critical infrastructure in designated high hazard areas. While removal of hazard trees can be a component of a vegetation treatment program, when it occurs in conjunction with a broader array of treatment activities, the broader project would not qualify for use of the exemption for emergency actions, so this path is not discussed further here.

2.3.2 Categorical Exemptions

Categorical exemptions allow for entire classes of projects to avoid the need to comply with CEQA because the state has determined that these categories of activities do not have a significant effect on the environment (CEQA Guidelines Section 15300). However, where the potential exists for environmental impacts because of location, scenic highways, hazardous materials sites, unusual circumstances, or cumulative effects, the exemptions cannot apply.

The categorical exemption that most commonly applies to fire fuel treatments like the Strategy projects is the Class 4 Exemption: "Minor Alterations to Land" (State CEQA Guidelines Section 15304). This class "consists of minor public or private alterations in the condition of land, water, and/or vegetation which do not involve removal of healthy, mature, scenic trees except for forestry or agricultural purposes." The list of examples of qualifying activities includes vegetation removal generally occurring for defensible space, as provided in CEQA Guidelines Section 15304(i) and below:

> Fuel management activities within 30 feet of structures to reduce the volume of flammable vegetation, provided that the activities will not result in the taking of endangered, rare, or threatened plant or animal species or significant erosion and sedimentation of surface waters. This exemption shall apply to fuel management activities within 100 feet of a structure if the public agency having fire protection responsibility for the area has determined that 100 feet of fuel clearance is required due to extra hazardous fire conditions.

Fuel management activities in a larger area than what is described for defensible space in the example may also use a Class 4 exemption if it qualifies as "minor alteration of vegetation" and significant impacts would not occur. The Sierra Nevada Conservancy, California Tahoe Conservancy, State Parks, and other agencies have applied this exemption to fuel management activities beyond 100 feet from a structure for defensible space. When applying this exemption, it is critical for the Strategy stakeholders to clearly document its reason for proceeding with the exemption and why none of the exceptions to the exemption apply.

Some of the other existing classes of projects could apply to small-scale projects implemented under the Strategy. For example, Class 1 (CEQA Guidelines Section 15301), the existing facilities class, could be used for grading of existing roads. Class 3 (CEQA Guidelines Section 15303), the new construction or conversion class, could be used for new, minor roads. Also, Classes 7, 8, and 33 (CEQA Guidelines Sections 15307, 15308, and 15333) apply to qualifying regulatory actions for the maintenance, restoration, or enhancement of the environment or to implementation of qualifying activity that constitutes a small habitat restoration project (with a maximum size of 5 acres).

2.4 USE OF EXISTING PROGRAM ENVIRONMENTAL IMPACT REPORT

2.4.1 California Vegetation Treatment Program Program EIR

The CalVTP Program EIR is a powerful CEQA streamlining tool for fire fuel vegetation treatment throughout California, including in Marin County. It is specially designed for use by many agencies to expedite delivery of qualifying vegetation treatment projects in the State Responsibility Area (SRA) of California. It is a cornerstone in the state's response to the wildfire crisis, and improving regulatory efficiency by enhancing CalVTP implementation was identified as a key action in *California's Wildfire and Forest Resilience Action Plan*: *A Comprehensive Strategy of* the Governor's Forest Management Task Force, which was released in January 2021.

The geographic scope of the CalVTP Program EIR is called the SRA "treatable landscape," which comprises 20.3 million acres of grass, shrub, and tree vegetation communities. The treatable landscape was modeled by CAL FIRE's Fire Resource Assessment Program by dividing the SRA into vegetation types from the California Wildlife Habitat Relationship system and excluding those vegetation types with negligible wildfire risks (e.g., wet meadow, estuarine, agriculture). This process resulted in a highly pixelated treatable landscape layer that appears as a checkerboard in some areas. Within Marin County, there are 129,971 acres within the digitally mapped treatable landscape (Figure 3).

The CalVTP Program EIR can be used to streamline CEQA compliance of vegetation treatment projects wholly within the treatable landscape, as well as projects extending partially outside of the treatable landscape into the Local Responsibility Area (LRA) or Federal Responsibility Area, using a project-specific analysis (PSA), PSA/CEQA Addendum, or other focused CEQA document, as described in the following sections.

Specifically, the CalVTP includes the following treatment types to strategically modify portions of the landscape to reduce losses from and improve resiliency to wildfire:

- Wildland-Urban Interface (WUI) Fuel Reduction: Located in WUI-designated areas, fuel reduction would generally consist of strategic removal of vegetation to prevent or slow the spread of non-wind driven wildfire between structures and wildlands, and vice versa.
- Fuel Breaks: In strategic locations, fuel breaks create zones of vegetation removal and ongoing maintenance, often in a linear layout, that support fire suppression by providing responders with a staging area or access to a remote landscape for fire control actions. While fuel breaks can passively interrupt the path of a fire or halt or slow its progress, this is not the primary goal of constructing fuel breaks.
- Ecological Restoration: Generally, outside of the WUI in areas that have departed from the natural fire regime as a result of fire exclusion, ecological restoration would focus on restoring ecosystem processes, conditions, and resiliency by moderating uncharacteristic wildland fuel conditions to reflect historic vegetative composition, structure, and habitat values.

The following treatment activities could be used in various combinations to implement the treatment types:

- Manual methods of vegetation management include hand pulling and grabbing, thinning, pruning, hand piling, lop and scatter, and hand planting.
- Mechanical methods of vegetation management include masticating, chipping, brush raking, tilling, mowing, roller chopping, chaining, skidding and removal, and piling with motorized equipment.
- Prescribed burning includes broadcast and pile burning.
- Prescribed herbivory includes grazing or browsing by cows, goats, or sheep.
- Herbicide application includes ground-level application only (i.e., no aerial spraying is allowed), such as paint-on stems, backpack hand-application, hypo-hatchet tree injection, or hand placement of pellets.

Sources: Data downloaded from Marin GeoHub in 2021; adapted by Ascent Environmental in 2021

Figure 3 CalVTP Treatable Landscape in Marin County

PROJECT-SPECIFIC ANALYSIS

The CalVTP includes a project-specific implementation checklist for streamlining CEQA review of later site-specific vegetation treatment projects consistent with the Program EIR, in accordance with procedures described in State CEQA Guidelines Section 15168 for later activities consistent with a program EIR. With its broad suite of treatment types and activities, comprehensive impact analysis, adaptable and agency-vetted mitigation measures, and PSA checklist template, the CalVTP was designed to maximize the ability for agencies to make the finding that later vegetation treatment projects are "within the scope" of the CalVTP and the Program EIR (i.e., fully covered by the Program EIR and consistent with the requirements of the program), thereby facilitating an increase in the pace and scale of project approvals while maintaining environmental protection.

The first step in determining whether a project may be "within the scope" of the CalVTP Program EIR is to determine the extent of the treatment area's overlap with the treatable landscape. A link to the treatable landscape online viewer is provided in Section 1.3 and also available on the Strategy webmap. To make a "within the scope" finding, the stakeholders can use the PSA checklist to evaluate proposed vegetation treatment projects to determine whether the proposed treatments have been covered in the Program EIR. Such evaluations must ascertain whether vegetation treatment projects are consistent with the treatment activities and treatment types of the CalVTP and would have effects that were analyzed in the Program EIR. If this evaluation determines that the impacts were covered in the Program EIR, that no new or substantially more severe significant effects could occur and that no new mitigation measures would be required, the project qualifies as within the scope of the Program EIR. In this circumstance, no additional CEQA documentation would need to be prepared or publicly circulated (State CEQA Guidelines Section 15168[c][2] and [4]). The CEQA lead agency may approve the proposed treatment project using the PSA and the Program EIR for CEQA compliance purposes. If the project is approved, a notice of determination would be filed with the California State Clearinghouse. Refer to Section 1.3, "Existing Environmental Information," for links to example PSAs.

PSA / ADDENDUM

An Addendum to an EIR is appropriate where a previously certified EIR has been prepared and some changes or revisions to the project are proposed, or the circumstances surrounding the project have changed, but none of the changes or revisions would result in new or substantially more severe significant environmental impacts, consistent with CEQA Section 21166 and State CEQA Guidelines Sections 15162, 15163, 15164, and 15168. In the case of a treatment project extending outside of the treatable landscape, for example into a LRA, the change is the inclusion of areas outside of the treatable landscape analyzed in the CalVTP Program EIR in a proposed vegetation treatment project. If the vegetation treatment activities are covered by the Program EIR and the landscape and resource conditions of the LRA portion are similar to the SRA treatable landscape portion, no new or substantially more severe significant impacts would be expected. This situation would qualify for an Addendum.

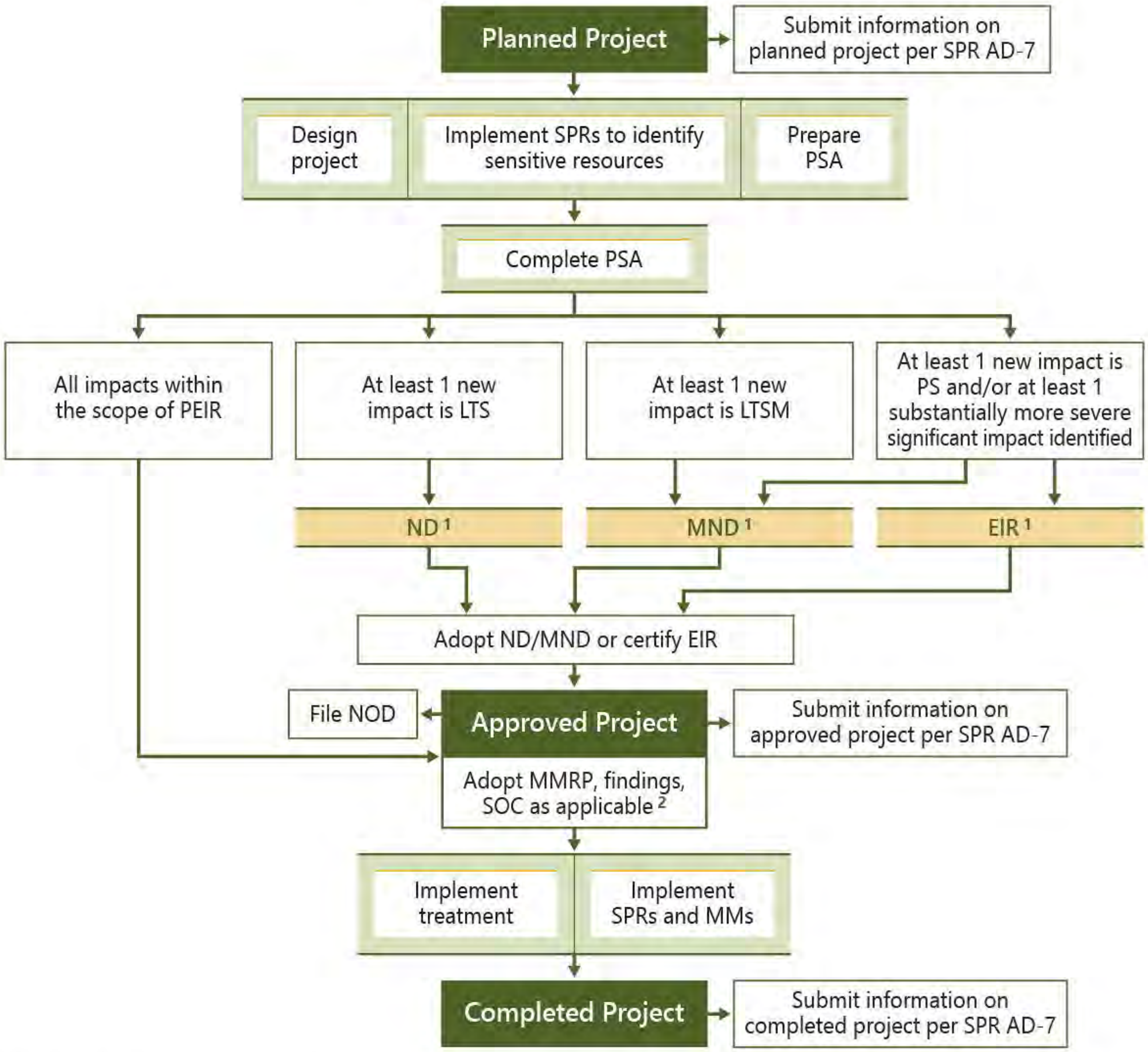
The PSA checklist template includes the criteria to support an Addendum to the CalVTP Program EIR for the inclusion of areas outside the CalVTP treatable landscape. The template evaluates each resource in terms of whether the later treatment project, including the "changed condition" (e.g., of additional geographic area), would result in significant impacts that would be substantially more severe than those covered in the Program EIR and/or would result in any new impacts that were not covered in the Program EIR. Like a PSA, a PSA/Addendum does not need to be circulated for public review and, in the case of a legal challenge, is evaluated against the substantial evidence standard of review, which is deferential to the lead agency. If the project is approved, a notice of determination would be filed with the California State Clearinghouse.

This approach has been successfully applied in the preparation of the Grouse Ridge Vegetation Treatment Project PSA/Addendum, for which 406 of the 1,134 acres were outside of the treatable landscape, and the Yuba Foothills Healthy Forest Project PSA/Addendum, for which 1,500 of the 4,055 acres were outside of the treatable landscape. Refer to Section 1.3, "Existing Environmental Information," for links to the PSA/Addendum for each project.

An Addendum to the CalVTP Program EIR could be appropriate for projects generally consistent with the CalVTP Program EIR with changes other than the expansion of the geographic area outside the treatable landscape. For example, the use of an herbicide compound that was not included in the Program EIR analysis could be a change to the Program that may be appropriate for a PSA/Addendum if none of the changes would result in new or substantially more severe significant environmental impacts and meets the other requirements listed in State CEQA Guidelines Section 15164.

FOCUSED ND, MND, OR EIR USING THE CALVTP

If a proposed project is not within the scope of the CalVTP Program EIR, then the stakeholders could prepare additional CEQA documentation that accompanies the Program EIR for CEQA compliance, narrowed to cover only those impacts or topics outside the scope of the Program EIR. Additional CEQA documentation could be needed if a vegetation treatment project is proposed completely outside of, but adjacent to, the CalVTP treatable landscape, or if a project proposes an action that was not evaluated in the CalVTP Program EIR (e.g., access or trail improvements) that is not exempt or covered under an Addendum (refer to additional information in Section 1.4). Pursuant to State CEQA Guidelines Section 15168(d), a later ND could be prepared if the new impact(s) would be less than significant, or an MND could be prepared if the new impact(s) could be clearly mitigated to less than significant. The ND or MND would be focused on the new impact(s). If a new or substantially more severe significant impact(s) could not be clearly mitigated to less than significant, an EIR would need to be prepared that could focus on the new or substantially more severe significant impact(s). In these cases, the PSA checklist would function as the IS to identify the new or substantially more severe significant impact(s) and document the remainder of the impact(s) as being within the scope of the CalVTP Program EIR. These documents would need to be publicly circulated before project approval, consistent with State CEQA Guidelines Section 15073 and 15087. Refer to the CalVTP PSA Process Flow Chart included as Figure 4 for an illustrative view of the various pathways to implement vegetation treatment projects under the CalVTP.



[1] The CEQA document will be limited to impact(s) not within the scope of PEIR. Impacts within the scope of PEIR will be documented in PSA. PSA will function as an Initial Study for new impacts.

[2] Findings are required for any LTSM or SU impacts identified in an EIR, including impacts within the scope of PEIR. SOC is required for any SU impact identified, including impacts within the scope of PEIR. MMRP is required if any SPRs or MMs are identified as applicable in the PSA or CEQA document.

Note: This figure illustrates the process to implement later vegetation treatment projects under the CalVTP. It may not identify every detail of the steps required for CEQA compliance. Please refer to the relevant sections of the PSA and PEIR for additional information.

EIR: environmental impact report
LTS: less than significant
LTSM: less than significant with mitigation incorporated
MM: mitigation measure
MMRP: mitigation monitoring and reporting program
MND: mitigated negative declaration
ND: negative declaration
PEIR: Program EIR
PS: potentially significant
PSA: Project-specific Analysis
SOC: statement of overriding considerations
SPR: Standard Project Requirement

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Source: Ascent Environmental Inc.

Figure 4 CalVTP CEQA Process Flow Chart

2.4.2 Marin Municipal Water District Program EIR

The Program EIR for the Biodiversity, Fire, and Fuels Integrated Plan (BFFIP or Plan) was prepared by Marin Water in 2019 to protect the integrity of the Mount Tamalpais watershed by maintaining natural conditions on watershed lands. It covers the Mount Tamalpais Watershed, and Marin Water-owned lands around Nicasio Reservoir and Soulajule Reservoir. The purpose of the BFFIP is to identify the tools and actions Marin Water can take to reduce fuel loads and fire risks and improve ecosystem health. The Plan includes the management of vegetation to maintain existing fuel breaks to their design specifications, creation of new fuel breaks for added protection, and treatment of forest areas to reduce the number of diseased and dying trees and facilitate forest health, diversity, and resiliency. These actions are intended to reduce fire risks across the Plan area, improve ecosystem health, and help Marin Water effectively manage water quality and supply. The BFFIP identifies strategies for different vegetation types and areas within the Plan area, which include:

- Fuel break construction and maintenance in grasslands, shrublands, oak woodlands and mixed hardwood forests, and coniferous forests;
- Hazard tree removal in the infrastructure zone;
- Conifer and mixed hardwood forest stand enhancement (including sudden oak death research and treatment);
- Control of invasive species; and
- Habitat restoration.

Manual and mechanical treatment methods and prescribed burning are evaluated in the Program EIR to manage vegetation under the Plan, and are described as follows:

- Prescribed burning would include broadcast and pile burning.
- Propane flaming would remove weeds by wilting plants but ignition would not occur.
- Manual methods of vegetation management include tree girdling, removal or pruning; mulching; plastic cover application (solarization); weed pulling by hand or using hand tools such as shovels to remove plants; competitive planting.
- Mechanical methods of vegetation management include cutting and mowing with heavy equipment, cutting plants with powered hand equipment, scalping, mowing, masticating, and pulling large plants with heavy equipment.
- Grazing would include the use of livestock (sheep, goats, or cattle) to reduce fuel load, suppress weeks, and enhance habitat.

The BFFIP Program EIR requires the implementation of numerous mitigation measures to reduce adverse impacts from vegetation management activities. Mitigation measures include avoidance of special-status species, smoke management planning, water quality protection, a training program to teach workers how to recognize and avoid cultural resources, and tribal consultation.

Vegetation treatment projects under the Strategy could be covered by the BFFIP Program EIR to the extent they are within the Plan area, are consistent with the vegetation treatment activities included in the BFFIP, are within the acreage allocations for identified management areas, and have effects that were analyzed in the Program EIR. To determine if the activity is "within the scope" of the BFFIP Program EIR, Marin Water would conduct a project-specific review of the proposed treatments using the tools described in Appendix A, "Project Specific Review," of the Final BFFIP Program EIR. Several management actions were analyzed at a project level in the Program EIR and may be implemented without further analysis. For actions that were analyzed at a program level, Marin Water would use the Project Environmental Checklist to evaluate proposed treatment projects to determine whether the proposed treatments have been covered in the Program EIR. If this evaluation determines that the impacts were analyzed in the Program EIR, that no new or substantially more severe significant effects could occur and that no new mitigation measures would be required, the project falls within the scope of the Program EIR. If the evaluation determines that the project is not within the scope of the Program EIR (e.g., if acres exceed the allocations for identified management areas), Marin Water would determine whether additional CEQA documentation is needed using the criteria described in CEQA Guidelines Sections 15162, 15163, and 15164.

Marin Water could also use the CalVTP Program EIR instead of or in addition to the BFFIP consistency analysis for compliance with projects that do not fall within the scope of the BFFIP, such as treatment activities not covered by the BFFIP or which result in impacts that are not evaluated in the BFFIP. Examples include implementation of a treatment (e.g., prescribed burning) that would benefit special-status plant populations overall, even though loss of an individual listed or special-status plants may occur. For instance, the CalVTP PSA for the Bear Creek Redwoods Open Space Preserve Vegetation Treatment Project included substantial evidence that a rare plant species would benefit from vegetation treatment, even though individual plants may be lost (refer to Section 1.3, "Existing Environmental Information," for a link to this PSA and to the BFFIP Program EIR).

2.5 OTHER CEQA DOCUMENTS

It is conceivable that a stand-alone CEQA document could be required for Strategy projects not covered by other EIRs and not qualifying for exemptions. This could occur if a project proposed under the Strategy does not fall under any CEQA exemptions, is far removed from the CalVTP treatable landscape and the Plan area of the BFFIP, and includes activities outside of the scope of what was evaluated in the CalVTP Program EIR and BFFIP Program EIR. An ND could be prepared if all of the potential impacts of the project would be less than significant, and an MND could be prepared if the potential impacts could be clearly mitigated to less than significant. An EIR would be required if there are significant impacts that cannot be mitigated to a less-than-significant level. Preparing an EIR can also be beneficial for controversial projects with threats of litigation. If a project is subject to legal challenge, the adequacy of an EIR is assessed by the court against the substantial evidence standard of review, which is deferential to the lead agency determinations supported by evidence. In contrast, the "fair argument" standard applies to NDs and MNDs, which is deferential to opponents who raise a fair argument based on evidence that a significant impact may occur.

If the stakeholders find that often there are non-vegetation treatment components (e.g., trails or other public access or recreational features) integrated into projects such that these components are outside of the scope of existing CEQA documents, another option is to prepare a new program EIR or a Supplement to the CalVTP Program EIR that includes vegetation treatment and these other project components.

3 NATIONAL ENVIRONMENTAL POLICY ACT COMPLIANCE

3.1 NEPA PRINCIPLES FOR VEGETATION TREATMENT

NEPA compliance is required for major federal actions, which are defined, in relevant part, as those entirely or partly financed, assisted, conducted, regulated, or approved by a federal agency. Under NEPA, the roles of a federal agency designated as the lead agency and any other agency with jurisdictional responsibility over a project (known as Cooperating Agencies under NEPA) are similar to those of lead and responsible or trustee agencies, respectively, under CEQA (refer to Section 2.1, "CEQA Principles for Vegetation Treatment above). Differences exist regarding the role of public agencies under CEQA and NEPA. For example, under NEPA, multiple public agencies, including state or local agencies, may act as joint lead agencies along with at least one federal agency (40 Code of Federal Registry CFR 1501.5(b)), whereas under CEQA, a single lead agency must be designated.

3.2 CATEGORICAL EXCLUSIONS

The Council of Environmental Quality (CEQ) regulations provide for NEPA categorical exclusions (CEs) to implement NEPA for the purpose of reducing delay and paperwork. CEQ regulations allow federal agencies to exclude from documentation in an Environmental Assessment (EA) or EIS categories of actions that do not individually or cumulatively have a significant effect on the human environment. The responsible official of a federal agency can conclude that if the action fits within an identified category and analysis shows there are no extraordinary circumstances, then the action would not have significant effects.

According to the 2015 NPS NEPA Handbook (Handbook), there are several NEPA CEs available, some require supporting documentation and others do not. NEPA CEs that do not require supporting documentation are limited to actions that would have little to no potential for environmental impacts of any kind, such as stabilization of disturbed areas by planting native plant species and day-to-day resource management and research activities. This type of CE would not apply to many Strategy projects. However, a variety of CEs exist for actions that generally result in some level of environmental impact but that do not have the potential to cause significant adverse impacts under normal circumstances. For such actions, documentation is required indicating that the action fits within a CE and that no extraordinary circumstances exist. Available CEs that may be applicable to Strategy projects include:

- CE for actions related to development (e.g., road maintenance, reconstruction, or rehabilitation; minor trail relocation, trail maintenance, and repair).
- CE for actions related to resource management and protection (e.g., restoration of native species and elimination of exotic species).
- CE for actions related to hazardous fuels reduction and post-fire rehabilitation (e.g., tree planting, habitat restoration, heritage site restoration, repair of roads and trails).

The categorical exclusion applicable to hazardous fuel management (43 CFR 46.210 (l)) covers post-fire rehabilitation activities under 4,200 acres to repair or improve lands unlikely to recover to a management-approved condition from wildland fire damage, or to repair or replace minor facilities damaged by fire. It expressly prohibits the use of pesticides and the construction of new permanent roads or other infrastructure and must be completed within 3 years following a wildland fire. This CE would only help the stakeholders with post-wildfire hazardous fuel reduction projects.

The U.S. Department of Interior NEPA regulations include an additional CE for hazardous fuels reduction activities (43 CFR 46.210 (k)) that is not listed in the Handbook. It includes hazardous fuels reduction activities using prescribed fire, not to exceed 4,500 acres, and mechanical treatments not exceeding 1,000 acres such as crushing, piling, thinning, pruning, cutting, chipping, mulching, and mowing. However, this hazardous fuels reduction CE is not available for use in areas within the jurisdiction of the U.S. Court of Appeals for the 9th Circuit Court at this time (which encompasses the Strategy Area), as discussed in the preamble to the final rule (73 FR 61305 October 15, 2008). As a matter of policy, NPS does not currently use this CE (NPS 2015). If this CE becomes available to NPS in the future, it could be a good option for Strategy projects on federal lands consistent with the activities covered by the CE. The new 2020 40 CFR 1500-1508, CEQ Implementing NEPA Regulations, allow federal agencies to consider use of all Federal Agency CEs.

3.3 USE OF EXISTING ENVIRONMENTAL IMPACT STATEMENTS

There are two existing NEPA environmental impact statements (EIS) that could be used to streamline Strategy projects on federal lands: the EIS for the Golden Gate National Recreation Area Fire Management Plan and the Point Reyes National Seashore Fire Management Plan EIS, as described below. Refer to Section 1.3, "Existing Environmental Information," for links to these documents.

- The Golden Gate National Recreation Area 2005 Fire Management Plan EIS covers approximately 11,000 acres of NPS lands directly managed by Golden Gate National Recreation Area in Marin County and allows for the implementation of vegetation treatment on up to 510 of these acres per year using mechanical treatments and prescribed fire. The majority of the Fire Management Plan planning area is in Marin County, but also includes lands in nearby counties.
- The Point Reyes National Seashore 2004 Fire Management Plan EIS includes 70,046 acres of NPS lands within Point Reyes National Seashore and 18,000 acres of the northern district of the Golden Gate National Recreation Area, which is managed by Point Reyes National Seashore. The entire Fire Management Plan planning area is in Marin County. The EIS included vegetation treatment of up to 3,500 acres per year using prescribed fire and

mechanical treatments. Vegetation treatment would primarily consist of hazardous fuel reduction on high priority areas (e.g., along road corridors, around structures, and in strategic areas to create fuel breaks).

These documents could be used for NEPA coverage of Strategy projects that are within the areas covered by these documents and that are consistent with the vegetation treatments included in the Fire Management Plans and covered by the EISs. Stakeholders would work with NPS NEPA staff to determine a project's consistency with the EIS and which mitigation measures should be incorporated into the project plan. NPS staff would prepare a Memorandum to File if the project description is consistent with those described in EIS. Given the EISs are over 15 years old, it may be more appropriate to tier a CE off the EIS and make the CE available for public comment in the NPS Planning, Environment and Public Comment system.

3.4 OTHER NEPA DOCUMENTS

Similar to what is described in Section 2.5, "Other CEQA Documents," above, the circumstances under which a stand-alone NEPA document could be required for Strategy projects (or 'proposed action' under NEPA) would be uncommon, because all federal lands in the Strategy Area are covered by the two NPS EISs identified in Section 1.3. If a proposed action on federal lands does not qualify for one of the above NEPA exclusions and is outside of the scope of the two EISs that have been prepared in Marin County (refer to Section 3.3 above), for example because an activity is proposed that was not included in an EIS, then a new NEPA document may be required. An EA would then be required to evaluate the proposed action, and if no significant effects are identified, then a Finding of No Significant Impact (FONSI) would be issued. An EIS would be required if the proposed action would result in significant environmental effects, although preparation of a new EIS would require a significant level of time and effort.

4 MULTI-JURISDICITONAL PROJECTS

4.1 PRINCIPLES FOR MULTI-JURISDICTIONAL PROJECTS

Vegetation treatment projects in Marin County will likely often span multiple jurisdictions and require multi-jurisdictional coordination. Early outreach and communication with those agencies with jurisdiction over parts of a project (e.g., lands, resources) and other interested parties will be key to the success of a project.

Initially, the lead agencies need to be confirmed for guiding the CEQA or NEPA compliance of a Strategy environmental document. For NEPA, the lead agency would typically be NPS, because it manages the public federal lands in Marin County. Regarding a CEQA lead agency, several agencies may have jurisdiction or permit approval authority over projects implementing the Strategy, such as State Parks, the Parks Conservancy, Marin County Parks, and Marin Water, depending on the project and resources involved. However, the authority of each agency would be geographically limited. The CEQA lead agency selection could logically be aligned with the land manager of the project area. Other public agencies with a discretionary approval (e.g., CAL FIRE grant) may assume the lead agency role for a project, for example if an NGO is the project proponent.

Once the lead agencies are confirmed, a vehicle for expressing agency commitments to a collaborative environmental review process would be appropriate, such as a memorandum of understanding or similar instrument. This instrument would define roles, communication/coordination protocols, decision-making approach, key designated leaders representing each agency, and relevant procedural guidelines. The role definition should include which agency official(s) will approve an environmental document for release as a draft to the public and who, or what bodies, will review and certify/approve adequate completion of the environmental review process, including timeframes. Understanding who will approve public release of environmental documents is important so the responsible person can be briefed at key milestones along the way to smooth and speed the approval step. (Lack of this understanding is a common shortcoming that has disrupted environmental document schedules.) Knowing up front the final environmental document and project approval processes is also important for schedule management, whether it involves an executive administrator and/or a board and what public hearings are anticipated. The lead agencies should also reach out to other agencies with approval authority over covered lands and covered activities to establish consultation approaches. One of the key steps to promoting the streamlining of future Strategy project approvals will be providing the information that CEQA responsible agencies and federal regulatory agencies need in the environmental document to rely on it to the maximum extent possible as the environmental clearance for their follow-up approvals. Examples of multi-jurisdiction forest health and wildfire resiliency projects include the Yuba Foothills Healthy Forest Project and North Yuba Landscape Resilience Project. Both these projects include CEQA and NEPA approvals for projects on private land and federal land (refer to https://www.yubawater.org/337/Yuba-Foothills-Healthy-Forest-Project and https://www.yubaforest.org/ for more information; also refer to Section 1.3, "Existing Environmental Information" for a link to the Yuba Foothills Healthy Forest Project PSA/Addendum, which serves as the project's CEQA compliance).

4.2 PARALLEL CEQA AND NEPA PROCESSES

In some cases, Strategy projects may require both CEQA and NEPA documentation and parallel compliance processes may need to occur. The various types of CEQA and NEPA documents that may need to be prepared are described in Section 2, "CEQA Compliance," and Section 3, "NEPA Compliance." It is important to note that CEQA does not apply to "prescribed fire, thinning, or fuel reduction projects" undertaken on federal lands to reduce the risk of high-severity wildfire that have been reviewed under NEPA and where the role of the state is limited to providing funding, staff, and Good Neighbor Authority stewardship support (refer to Section 2.3.1, "Statutory exemptions" above).

4.3 JOINT CEQA/NEPA DOCUMENT

Joint CEQA/NEPA documents are another avenue to achieve environmental compliance when both CEQA and NEPA documents need to be prepared for a Strategy project. However, the use of a joint document will rarely be a preferred approach because many other compliance strategies exist, as described in the sections above. For example, several streamlining opportunities are available for vegetation treatment projects in Marin County, whether they are adequately addressed in an existing environmental document (such as the CalVTP or BFFIP Program EIRs) or are covered by existing CEQA exemptions or NEPA exclusions. Refer to Section 2, "CEQA Compliance," and Section 3, "NEPA Compliance," for a summary of the existing streamlining opportunities that can be used for environmental compliance. Furthermore, issues commonly arise to delay and complicate the process when integrating these requirements, including points of conflicting contents or procedures, interdependencies between multiple permit approvals, varying process timeframes, and complex information needs with gaps between environmental documentation and permitting.

5 OTHER REGULATORY COMPLIANCE

Sections 5.1 – 5.6 of this guidance document discuss several of the permits, reviews, and approvals that are typically required for the types of actions anticipated to occur under the Forest Health Strategy. Below are recommendations for complying with several of the regulatory requirements, other than CEQA and NEPA, likely needed to implement projects under the Forest Health Strategy. The intent of these recommendations is to address how integration of other regulatory requirements in addition to CEQA/NEPA could be approached to establish an efficient process that is effective in increasing the pace and scale of Strategy project implementation.

5.1 CLEAN WATER ACT COMPLIANCE

The federal Clean Water Act requires states to develop a program to protect the quality of water resources from the adverse effects of nonpoint source water pollution (i.e., water pollution that comes from many diffuse sources and is transported primarily via rainfall or snowmelt). Several Regional Water Quality Control Boards consider vegetation management projects to be a large source of nonpoint source pollution and require compliance with their vegetation and land disturbance-related Waste Discharge Requirements. The San Francisco Bay Region, which includes Marin County, is primarily urban and therefore the San Francisco Bay Regional Water Quality Control Board does not offer Waste Discharge Requirements (or Conditional Waivers of Waste Discharge Requirements) for vegetation management activities. However, forest health projects in Marin County must comply with any applicable Basin Plan prohibitions (e.g., prohibitions of discharges to specific water features). Additionally, the State Water Board is requiring all projects utilizing the CalVTP Program EIR to follow the requirements of their Vegetation Treatment General Order, described below.

5.1.1 State Water Resources Control Board's Vegetation Treatment General Order

The State Water Resources Control Board (State Water Board) approved in July 2021 a statewide water quality order for vegetation treatment activities conducted in conformance with the CalVTP (Vegetation Treatment General Order or General Order; https://www.waterboards.ca.gov/water_issues/programs/nps/veg_treatment.html). The General Order helps streamline the State Water Board's oversight of CalVTP implementation across the state. The General Order depends on applicable CalVTP requirements to ensure that vegetation treatments are conducted in a manner that is protective of water quality, in lieu of requiring Waste Discharge Requirements or Conditional Waivers of Waste Discharge Requirements in regions where they are required. Projects are automatically enrolled in the General Order (via implementation of SPR AD-7 from the CalVTP Program EIR), and no new conditions or fees are required. The State Water Board will issue a notice of applicability letter to each project. Additionally, the General Order satisfies compliance with SPR HYD-1 (Comply with Water Quality Regulations) from the CalVTP Program EIR.

The General Order is applicable to projects utilizing the CalVTP Program EIR which meet the following requirements:

- Provide vegetation treatment project information to CAL FIRE, in compliance with CalVTP Program EIR SPR AD-7 (refer to the CalVTP Implementation Database webpage for information on reporting requirements for PSAs: https://bof.fire.ca.gov/projects-and-programs/calvtp/calvtp-implementation-database/);
- Prepare a PSA or PSA/Addendum under the CalVTP Program EIR;
- Identify and implement applicable SPRs and Mitigation Measures from the CalVTP Program EIR to reduce impacts related to water quality;
- Make a "within the scope" finding with the CalVTP Program EIR;
- Comply with Regional Water Quality Control Board Basin Plan prohibitions if applicable (Marin County is in the San Francisco Bay Basin); and
- Allow State Water Board or Regional Water Quality Control Board staff access to site for compliance if necessary.

5.2 COASTAL ACT COMPLIANCE

A Coastal Development Permit is generally required for development proposals within the Coastal Zone. The Coastal Act defines development broadly to include not only typical land development activities but also changes in the intensity of use of land or water. Vegetation treatment projects that involve removal of major vegetation often fall within the definition of development and require a Coastal Development Permit. Given the urgent need for vegetation treatments within areas of the Coastal Zone, a more efficient compliance pathway for coastal projects would help increase the pace and scale of coastal vegetation treatment projects. The California Coastal Commission, CAL FIRE, and other state agencies continue to discuss potential solutions to increasing the pace and scale of critical fire fuel treatments in the coastal zone, while also protecting sensitive coastal resources. One option is to pursue a Public Works Plan, as described below.

5.2.1 Public Works Plans

A Public Works Plan (PWP) is a tool to allow a suite of related activities that would otherwise trigger the need for individual Coastal Development Permits to instead be analyzed as an integrated and coordinated system. PWPs enable the California Coastal Commission (Commission) to promote greater efficiency for planning public works projects by providing an alternative to project-by-project review (Public Resources Code Section 30605). These plans establish a framework for comprehensive planning, review, and permitting in a single document.

In 2021, Santa Cruz County Resource Conservation Districts (RCD), San Mateo County RCD, and the Upper Salinas-Las Tablas RCD approved PWPs for their forest health and fire resilience programs. The PWPs were developed to function as companions to the CalVTP Program EIR for the next 10 years. Projects in the plan areas that fit within and are consistent with the applicable PWP and are designed with RCD oversight will be able to utilize the PWP. The PWPs require project proponents using the PWP to implement applicable requirements from the CalVTP Program EIR as well as additional Coastal Vegetation Treatment Standards that provide additional guidance and clarity for projects within the Coastal Zone. Any state or local agency proposing a treatment project in the PWP Program Area and preparing a PSA using the CalVTP Program EIR could use the PWP, in coordination with RCD and Commission staff. Before beginning each specific project, the project proponent must submit notice to the Commission in the form of a Notice of Impending Development, which requires the Commission to determine whether the submitted project is consistent with the standards within the PWP, or if additional conditions are necessary to make it consistent.

Currently, Coastal Commission review and coastal development of each Strategy treatment project would be needed and an individual Coastal Development Permit would likely be required for each project, as there is no streamlined permitting process covering Marin County areas at this time. The recent LCP amendments include Policy C-BIO-4.b, "Integrated Planning for Fire Risk, Habitat Protection, and Forest Health." This policy includes the development of a permitting process in the Coastal Zone that expedites review of projects related to minimizing fire risk or promoting native vegetation health. One option to consider for implementation of this policy could be the preparation of a PWP. A public agency with jurisdiction in the Marin County Coastal Zone could prepare a PWP for forest health and fire prevention projects within the Marin County LCP area. Coordination of a CalVTP PSA and the Coastal Act PWP implementation process could be explored to achieve the most efficient and streamlined environmental review. Projects on federal land or with a federal lead agency can continue to comply with the Coastal Zone Management Act through the Commission's Federal Consistency Office.

5.3 ENDANGERED SPECIES ACT COMPLIANCE

This section provides information on the potential for implementation of the Forest Health Strategy projects to result in "take" of state and/or federally listed species, how to avoid take, and when permitting may be required. Take of listed species is prohibited by the federal and state Endangered Species Acts. Take is defined as follows:

- Endangered Species Act: Harass, harm, pursue, hunt, shoot, wound, kill, trap, capture, or collect, or to attempt to engage in any such conduct. (16 U.S.C., §1532 (19))
  - Harass is further defined as: An intentional or negligent act or omission which creates the likelihood of injury to wildlife by annoying it to such an extent as to significantly disrupt normal behavioral patterns which include, but are not limited to, breeding, feeding, or sheltering. (16 U.S.C., §1532 (19); 50 C.F.R. § 17.3)
  - Harm is further defined as: An act which actually kills or injures wildlife. May include significant habitat modification or degradation that kills or injures wildlife by significantly impairing essential behavior patterns, including breeding, feeding, or sheltering. (16 U.S.C., §1532 (19); 50 C.F.R. § 17.3)
- California Endangered Species Act: Hunt, pursue, catch, capture, or kill, or attempt to hunt, pursue, catch, capture, or kill (Fish and Game Code §86)

For projects with a federal lead agency (e.g., the National Park Service) or a federal nexus (e.g., through issuance of a permit or granting of funding by a federal agency), interagency coordination and consultation between the involved federal agency and U.S. Fish and Wildlife Service (USFWS) or National Oceanic and Atmospheric Administration

(NOAA) Fisheries proceeds under Section 7 of the federal Endangered Species Act. USFWS and NOAA Fisheries issued biological opinions regarding the effects to listed species which would result from the Golden Gate National Recreation Area and Point Reyes National Seashore Fire Management Plans. Further details about the authorizations are provided below.

Incidental take permits for non-federal agencies are pursuant to California Fish and Game Code Section 2081(b) and the federal Endangered Species Act Section 10(a)(1)(B). A federal incidental take permit application would also require the preparation of a Habitat Conservation Plan (HCP). Preparation of an HCP is a complex and cumbersome process and typically requires several years to complete. However, treatment projects may be fully or partially implemented with careful forest health treatment design and robust avoidance and minimization measures such that federal or state take authorization would not be required in compliance with the federal and state Endangered Species Acts.

USFWS (2018) provides guidance to project proponents regarding when an incidental take permit is needed under Section 10. This USFWS incidental take under Section 10 of the Endangered Species Act guidance memorandum (https://www.fws.gov/endangered/esa-library/pdf/Guidance-on-When-to-Seek-an-Incidental-Take-Permit.pdf) states that the requirement for an incidental take permit is only activated when non-federal activities are likely to result in the take of listed wildlife. USFWS (2018) further clarifies that the standard for determining if activities are likely to result in incidental take is whether that take is "reasonably certain to occur." CDFW has not provided similar guidance regarding the trigger for an incidental take permit under the California Endangered Species Act. Therefore, an appropriate standard for a state incidental take permit would be that treatment activities are considered "unlikely" to result in take if there is a low likelihood of take and "likely" to result in take if there is greater than a low likelihood of take. If take is unlikely with measures, obtaining a state or federal incidental take permit is not required. If take is likely even with implementation of measures, obtaining state and federal take authorizations is recommended.

Significant habitat modification is considered take under the federal Endangered Species Act. Often, implementation of a forest health project would not result in significant modification of habitat for a listed species with implementation of measures because habitat function for the species would be maintained. However, in some cases, treatment may increase the potential for a species to use the area after initial treatment because removal or modification of certain vegetation may result in habitat that would be of greater value to the species. Because initial treatments may increase the potential for a species in an area, the likelihood of take could increase in an area after initial treatment. Therefore, although an initial treatment may not require incidental take authorizations, subsequent maintenance treatments may require obtaining them.

5.3.1 Existing Take Authorization

GOLDEN GATE NATIONAL RECREATION AREA

USFWS issued a biological opinion for the implementation of Alternative C (the preferred alternative) of the proposed Fire Management Plan at the Golden Gate National Recreation Area, as described in the Golden Gate National Recreation Area Fire Management Plan Draft Environmental Impact Statement dated March 2005. USFWS concluded that even with implementation of conservation measures, incidental take of mission blue butterfly (*Icaricia icarioides missonensis*), California red-legged frog (*Rana draytonii*), and San Francisco garter snake (*Thamnophis sirtalis tetrataenia*) may result from the proposed project. USFWS issued incidental take authorization for these three listed species. The biological opinion includes additional measures that must be implemented for the incidental take authorization to remain valid. Note that the San Francisco garter snake is a fully protected species under the California Fish and Game Code and no injury or killing of this species is authorized by California law.

NOAA Fisheries issued a programmatic biological opinion for the Golden Gate National Recreation Area Fire Management Plan (Alternative C) and its effects on Central California Coast coho salmon (*Oncorhynchus kisutch*) and Central California Coast steelhead (*O. mykiss*). The programmatic biological opinion included protection measures for these species. Additionally, pursuant to the Magnuson-Stevens Fishery Conservation and Management Act, NOAA Fisheries evaluated the Fire Management Plan for adverse effects on essential fish habitat for coho salmon, a species federally managed under the Pacific Coast Salmon Fishery Management Plan. NOAA Fisheries did not issue an incidental take statement with the programmatic biological opinion and instead Golden Gate National Recreation Area must consult separately with NOAA Fisheries on each fire management activity described in the Plan (except for emergency fire suppression). In addition, NOAA Fisheries specified that essential fish habitat recommendations may be provided with the Endangered Species Act consultations for each fire management activity.

POINT REYES NATIONAL SEASHORE

USFWS issued a biological opinion for the implementation of Alternative C (the preferred alternative) of the proposed Fire Management Plan at Point Reyes National Seashore and the Golden Gate National Recreation Area in Marin County, as described in the Draft Fire Management Plan Environmental Impact Statement for Point Reyes National Seashore and North District of Golden Gate National Recreation Area dated January 2004. USFWS concluded that even with implementation of conservation measures, incidental take of Myrtle's silverspot butterfly (*Speyeria zerene myrtleae*) and California red-legged frog (*Rana draytonii*) may result from the proposed project. USFWS issued incidental take authorization for these two listed species. The biological opinion includes additional measures that must be implemented for the incidental take authorization to remain valid.

The National Park Service consulted with NOAA Fisheries pursuant to Section 7 of the federal Endangered Species Act.

5.3.2 Take Avoidance

PLANTS LISTED UNDER ESA OR CESA

Take is not allowed without a permit for plants listed under CESA or the California Native Plant Protection Act. For plants listed under ESA, take is not allowed without a permit on federal land or for federal actions on private lands. Take of listed plants where there is no federal jurisdiction involved, and in accordance with state law, does not violate ESA. The following types of measures could be tailored for a given project or species to avoid or reduce the risk of take:

- Perform protocol-level surveys to determine presence or absence of a species, following agency protocols and guidelines if available (https://wildlife.ca.gov/Conservation/Survey-Protocols).
- If listed plants are present, establish a no-disturbance buffer around the area occupied by listed plants. The size and shape of the buffer zone should be determined by a qualified professional (e.g., botanist) and may be informed by factors such as plant phenology at the time of treatment (e.g., whether the plants are in a dormant, vegetative or flowering state), the individual species' vulnerability to the treatment method being used, site hydrology, changes in light, edge effects, and potential introduction of invasive plants and noxious weeds.
- In cases where it is determined by a qualified professional that the listed plants would benefit from treatment in the occupied habitat area even though some loss of the listed plants may occur during treatment activities, CDFW and/or USFWS should be consulted to determine if take would occur and if compensatory mitigation for loss of individuals would be required. The CalVTP Program EIR allows for loss of listed and other special-status plants under certain circumstance if a qualified professional, CDFW and/or USFWS, and substantial evidence conclude that the plant would benefit from treatment.

WILDLIFE LISTED UNDER ESA OR CESA

Take is not allowed without a permit for wildlife listed under ESA or CESA or fully protected by the Fish and Game Code. The following types of measures could be tailored for a given project and species to avoid or reduce the risk of take:

- Perform protocol-level surveys to determine presence or absence of a species, following agency protocols and guidelines if available (https://wildlife.ca.gov/Conservation/Survey-Protocols).

- If listed or fully protected species are present, implement treatment a sufficient distance outside of occupied habitat such that take will not occur and/or implement treatment outside of the species sensitive period (e.g., outside of nesting or breeding season).
- In habitat occupied by listed or fully protected species, maintain the habitat function by maintaining any habitat features that are necessary for breeding, foraging, shelter, or movement of the species (e.g., trees with complex structure, trees with large cavities, trees with nesting platforms, dens, tree snags, downed woody debris, high canopy cover).

EXAMPLE OF TAKE AVOIDANCE STRATEGY

The Final EIR for the Hill Campus Wildland Vegetative Fuel Management Plan (https://capitalstrategies.berkeley.edu/hill-campus) prepared for the University of California, Berkeley, provides options for implementation of treatment while simultaneously avoiding take of Alameda whipsnake (*Masticophis lateralis euryxanthus*), a federally and state-listed species. To avoid take, a site-specific habitat assessment and avoidance measures are required. Site-specific treatment activity restrictions included seasonal work windows, limits on heavy equipment use, limits within certain vegetation communities, requirements for biological monitors, and maintenance of certain habitat features. In areas where it is infeasible to implement these requirements while still meeting the objectives of the project, an option for consultation with CDFW and USFWS, incidental take authorization, and other mitigation options are also provided.

5.4 CALIFORNIA FISH AND GAME CODE SECTION 1602 COMPLIANCE

All diversions, obstructions, or changes to the natural flow or bed, channel, or bank of any river, stream, or lake in California that supports wildlife resources are subject to regulation by CDFW under Section 1600 et seq. of the California Fish and Game Code. Section 1602 requires any entity to notify CDFW before beginning any activity that may substantially divert or obstruct the natural flow or change the bed, channel, or bank of any river, stream, or lake; change or use any material from the bed, channel, or bank of any river, stream, or lake; or deposit or dispose of material where it may pass into any river, stream, or lake. CDFW interprets the code to potentially apply to work undertaken within the flood plain of a water body because activities carried out in the floodplain may cause material to pass into a river, stream, or lake. CDFW requires a Lake and Streambed Alteration Agreement (LSAA) if they determine that a project will substantially alter a river, stream, or lake, and may adversely affect fish or wildlife resources. NPS does not have to comply with the Fish and Game Code on federal lands. However, if NPS is a partner for a project on non-federal land, they would still have to comply with state regulations.

During coordination with CDFW and the Board of Forestry and Fire Protection for the CalVTP Program EIR in 2019, CDFW recommended notification under Section 1602 for vegetation treatment activities occurring within riparian habitat because riparian vegetation is generally a component of the channel or band of a river, stream, or lake and alteration of the riparian habitat may substantially adversely affect fish and wildlife resources associated with the river, stream, or lake. Notification should describe the treatment activities, map the vegetation to be removed, identify the impact avoidance identification methods to be used (e.g., flagging), and identify appropriate protections for the retention of shaded riverine habitat, including buffers and other applicable measures to prevent erosion into the waterway. Based on the information provided in the notification, CDFW determines whether those activities have potential to substantially adversely affect fish or wildlife resources and therefore require an LSAA.

Riparian habitats that are diverse in both the composition of vegetation species and physical habitat structure are likely to accommodate a wider variety of wildlife than less diverse habitats. Reducing structural complexity and species diversity can reduce habitat functions for many species. However, removal of dead and dying trees, encroaching upland species, invasive plants, and excess understory vegetation growth can also have beneficial effects because it would leave more water and nutrients available for native riparian hardwood trees and can improve riparian habitat health. If project objectives require vegetation treatment in riparian habitat, the following types of measures could be included to help avoid substantial adverse effects by designing treatments to avoid loss or degradation of riparian habitat functions and values:

- Vegetation retention standards for overstory and understory. Native riparian vegetation typically should be retained in a well distributed multi-storied stand composed of a diversity of species similar to that found before the start of treatment activities.
- Tree size retention parameters. A scientifically based, project-specific retention size parameter for native riparian tree removal could be determined and may be informed by considering site-specific factors such as site hydrology, erosion potential, suitability of wildlife habitat, presence of sufficient seed trees, light availability, and changes in stream shading.
- Measures to avoid vegetation removal that could reduce stream shading and increase stream temperatures.
- Measures to avoid pile burning, fire ignition, or fire containment lines within riparian habitat.

5.5 CLEAN AIR ACT COMPLIANCE

5.5.1 Prescribed Burning Requirements

Allowable open burning types in the Bay Area Air Quality Management District (Air District) include wildland vegetation management. Wildland vegetation management is defined by the Air District as prescribed burning by a state or federal agency, or through a cooperative agreement or contract involving the state or federal agency, conducted on land predominantly covered with chaparral, trees, grass, coastal scrub, or standing brush (refer to the Air District's Open Burning Regulation for additional information on allowable open burning types; https://www.baaqmd.gov/~/media/dotgov/files/rules/reg-5-open-burning/documents/rg0500.pdf?la=en). To conduct a prescribed burn within the Air District, the following procedures must be implemented.

- At least 30 days before burning. Submit a Smoke Management Plan to the Air District through the Prescribed Fire Information Reporting System (PFIRS; https://ssl.arb.ca.gov/pfirs). The Smoke Management Plan must be approved by the Air District before burning.
- Day before the burn: Submit an Ignition Authorization Request before 9:00 a.m. through the PFIRS to request a 24-hour burn day decision.
- Day of the burn: Burning may not occur until a final acreage/pile allocation is received.
- Day after the burn: Submit total amount of vegetation burned and status of the burn on PFIRS no later than 12:00 p.m.
- Unless prohibited by Fire Officials, wildland vegetation management burning may be conducted on permissive burn days only.

For more information, refer to Procedures for Conducting Wildland Vegetation Management Fires (Prescribed Burning) in the Bay Area on the Open Burn Notification and Status website (https://www.baaqmd.gov/permits/open-burn).

5.6 CULTURAL RESOURCES AND TRIBAL CULTURAL RESOURCES

Cultural resources are classified as historical resources or archaeological resources. Under State CEQA Guidelines Section 15064.5(a), they include districts, sites, buildings, structures, or objects generally older than 50 years and considered to be important to a culture, subculture, or community for scientific, traditional, religious, or other reasons. For the purposes of this discussion, "historical resource" is used to describe built-environment resources (standing buildings [e.g., houses, barns, outbuildings, cabins] and intact structures [e.g., dams, bridges, roads, districts]. Public Resources Code (PRC) Section 21074 defines tribal cultural resources:

a) "Tribal cultural resources" are either of the following:

   1) Sites, features, places, cultural landscapes, sacred places, and objects with cultural value to a California Native American tribe that are either of the following:

      A) Included or determined to be eligible for inclusion in the California Register of Historical Resources.

      B) Included in a local register of historical resources as defined in subdivision (k) of Section 5020.1.

   2) A resource determined by the lead agency, in its discretion and supported by substantial evidence, to be significant pursuant to criteria set forth in subdivision (c) of Section 5024.1. In applying the criteria set forth in subdivision (c) of Section 5024.1 for the purposes of this paragraph, the lead agency shall consider the significance of the resource to a California Native American tribe.

b) A cultural landscape that meets the criteria of subdivision (a) is a tribal cultural resource to the extent that the landscape is geographically defined in terms of the size and scope of the landscape.

c) A historical resource described in Section 21084.1, a unique archaeological resource as defined in subdivision (g) of Section 21083.2, or a "nonunique archaeological resource" as defined in subdivision (h) of Section 21083.2 may also be a tribal cultural resource if it conforms with the criteria of subdivision (a).

Section 106 compliance under the National Historic Preservation Act is required for all project activities on National Park Service land or where federal funding is involved. Compliance requires the identification, evaluation, and protection of resources that are eligible for listing in the National Register of Historic Places; compliance also requires the federal lead agency to engage in Native American consultation. As part of project compliance, a Sacred Lands File and Native American contacts list should be requested from the Native American Heritage Commission (NAHC) to determine affiliated groups who should be contacted regarding the project; the NAHC updates the list whenever a tribal group requests to be added. Similarly, CEQA requires the identification and protection of resources eligible for listing in the California Register of Historical Resources. CEQA (PRC Section 21080.3.2) additionally requires formal consultation with tribes to protect tribal cultural resources, as described in the following section.

To support mitigation measures and other requirements in previously prepared CEQA and NEPA environmental documentation, cultural resource specialists typically prepare stand-alone cultural resources documentation that normally involves the following steps: 1) tribal outreach, 2) pre-field research and record searches, 3) field surveys, 4) historical and archaeological resource recordation and evaluation, and 5) avoidance or mitigation.

5.6.1 Outreach and Formal Consultation

Native American consultation is required pursuant to PRC Section 21080.3 (AB 52, Statutes of 2014) and requirements under Section 106. To comply, the project proponent will contact the NAHC for a review of their Sacred Lands File. The project proponent will also obtain the latest Native Americans Contact List from NAHC. The results from NAHC typically take three to four weeks to receive. Using the appropriate Native Americans Contact List, the project proponent will notify the geographically-affiliated Native American Tribes in the counties where the treatment activity is located. The notification will contain the following and should be sent as soon as this information is available.

- A written description of the treatment location and boundaries.
- Brief narrative of the treatment objectives.
- A description of the activities used (e.g., prescribed burning, mastication) and associated acreages.
- A map of the treatment area at a sufficient scale to indicate the spatial extent of activities.
- A request for information regarding potential impacts to cultural resources from the proposed treatment.
- A detailed description of the depth of excavation, if ground disturbance is expected.

Tribes have 30 days to respond to the initial notification letter. Under PRC Section 21080.3.2, the lead agency does not have an obligation to follow up if tribes do not respond during that timeframe; however, under Section 106, lead agencies are expected to conduct follow-up outreach. Once a tribe has requested consultation, the lead agency has 30 days to respond; there is no statutory limit on how long consultation lasts. Consultation concludes when either: agreement is reached regarding avoidance of mitigation of any significant effect on a tribal resource; or, when a party concludes in good faith, after reasonable effort, that agreement cannot be reached.

The Board of Forestry and Fire Protection completed consultation pursuant to PRC Section 21080.3.1 during preparation of the CalVTP Program EIR; therefore, consultation does not need to be conducted for individual projects using the Program EIR. However, CalVTP SPR CUL-2 includes for a requirement for further tribal coordination during PSA preparation.

5.6.2 Record Searches and Surveys

The second step in preparing cultural resources documentation is an archaeological and historical records search with the appropriate California Historical Resources Information System; in Marin County, this is the Northwest Information Center (NWIC) at Sonoma State University, located in Rohnert Park. An archaeological and historical resource record search will be conducted per the applicable state or local agency procedures. Search results from NWIC take an average of four weeks to receive. Instead of conducting a new search, the project proponent may use recent record searches (typically less than 5 years old) containing the treatment area requested by a landowner or other public agency. The NWIC record search, combined with the NAHC Sacred Lands File search, and tribal input, will inform the approach to tribal cultural resources for a CEQA or NEPA document; a NEPA document will require the input of the federal lead agency for any known cultural resources on their land.

If the NWIC search reveals that prior cultural surveys incorporated intensive coverage, and if the surveys are less than 5 years old, and/or if no historic or archaeological resources were previously identified, then it could be found that no additional ground survey would be necessary. If additional surveys are required, the project proponent will coordinate with a qualified archaeologist, or architectural historian for built environment resources, to conduct a site-specific survey of the treatment area. A survey report will be completed for every cultural resource survey completed. The specific requirements, including possible monitoring, resource avoidance, or recordation and evaluation of the resource, will comply with the applicable state or local agency procedures.

5.6.3 Avoidance

Project-specific design strategies and BMPs can be developed to avoid adverse effects to resources. These could include:

- If the records search identifies built historical resources, as defined in Section 15064.5 of the State CEQA Guidelines, the project proponent will avoid these resources. To avoid, within a buffer (e.g., 50 feet of the built historical resource), there will be no prescribed burning or mechanical treatment activities. Buffers less than 50 feet for built historical resources will only be used after consultation with and receipt of written approval from a qualified architectural historian. If the records search does not identify known historical resources in the treatment area, but structures (i.e., buildings, bridges) over 50 years old that have not been evaluated for historic significance are present in the treatment area, they will similarly be avoided.
- If archaeological resources are identified within a treatment area, the project proponent will avoid these resources. If they cannot be avoided, a qualified archaeologist will assess whether the find qualifies as a unique archaeological resource, or an historical resource, as defined in Section 21083.2(g) or Section 15064.5 of the State CEQA Guidelines, respectively.
- If the find is indigenous in nature, the archaeologist, in coordination with the culturally affiliated tribe(s), will determine if the resource is a tribal cultural resource, as defined by Section 21074 of the State CEQA Guidelines. The project proponent, in consultation with culturally affiliated tribe(s), will then develop effective protection measures for tribal cultural resources located within treatment areas. It should be noted that some tribes have expressed the view that the best way to protect tribal resources is to conduct the vegetation treatment activities

instead of full avoidance. For example, the Yuba Foothills Healthy Forests Project PSA/Addendum includes project-specific protection measures recommended by the tribe and incorporated into the project. Refer to Section 1.3, "Existing Environmental Information," for a link to the PSA/Addendum; refer to Attachment A, MMRP, Project-Specific Refinement to SPR CUL-6 for recommended measures.

- The project proponent will train all crew members and contractors implementing treatment activities on the protection of sensitive archaeological, historical, or tribal cultural resources. Workers will be trained to halt work if archaeological resources are encountered on a treatment site and the treatment method consists of physical disturbance of land surfaces (e.g., soil disturbance). The training will also address the need for confidentiality and penalties for removing or intentionally disturbing Tribal and cultural resources, such as those identified in the Archeological Resources Protection Act.

6 RECOMMENDATIONS FOR NEXT STEPS

The following sections identify next steps to develop additional information that could benefit the implementation of Strategy projects.

6.1 BENEFICIAL EFFECTS OF TREATMENT ON PLANTS AND WILDLIFE

CEQA does not require analysis or disclosure of beneficial effects. However, some plants and wildlife may experience an overall benefit from a treatment project despite the loss of some individuals during treatment implementation.

The CalVTP allows for loss of listed or other special-status plants in cases where it is determined by a qualified professional that the listed or special-status plants would benefit from treatment in the occupied habitat area even though some loss of the plants may occur during treatment activities. The CalVTP Program EIR allows for loss of listed and other special-status plants if a qualified professional demonstrates with substantial evidence that habitat function is reasonably expected to improve with implementation of the treatment. Substantial evidence includes reference to scientific studies demonstrating that the species (or similar species) has benefitted from increased sunlight due to canopy opening, eradication of invasive species, or otherwise reduced competition for resources, and the substantial evidence must be documented in the CalVTP PSA. If it is determined that treatment activities would be beneficial to listed or special-status plants, no compensatory mitigation will be required under the CalVTP Program EIR.

Similarly, the CalVTP allows for some loss or disturbance of non-listed special-status wildlife species in cases where it is determined by a qualified professional that the non-listed special-status wildlife would benefit from treatment in the occupied habitat. For a treatment to be considered beneficial to non-listed special-status wildlife, the qualified RPF or biologist will demonstrate with substantial evidence that habitat function is reasonably expected to improve with implementation of the treatment (e.g., by documenting tribal traditional knowledge or citing tribal traditional knowledge or scientific studies demonstrating that the species (or similar species) has benefitted from increased sunlight due to canopy opening, eradication of invasive species, or otherwise reduced competition for resources), and the substantial evidence must be included in the PSA. If it is determined that treatment activities would be beneficial to special-status wildlife, no compensatory mitigation will be required.

It is recommended that a literature review of the beneficial effects of treatment on species likely in the Strategy area is conducted to provide the substantial evidence for the benefits to these plants and wildlife for compliance with the CalVTP Program EIR.

6.2 NPS CATEGORICAL EXCLUSIONS

As described in Section 3.2, "Categorical Exclusions," above, the 2015 NPS NEPA Handbook describes several NEPA CEs available for use on federal lands under NPS jurisdiction. One CE applicable to hazardous fuel management (43 CFR 46.210 (l)) covers post-fire rehabilitation activities and would only help the stakeholders with post-wildfire hazardous fuel reduction projects. However, the U.S. Department of Interior NEPA regulations include an additional

CE for hazardous fuels reduction activities (43 CFR 46.210 (k)) that is not listed in the Handbook, which covers hazardous fuels reduction activities more broadly. Unfortunately, this hazardous fuels reduction CE is not currently available for use in the Strategy Area and, as a matter of policy, NPS does not use it. However, if this CE becomes available to NPS in the future, it could be a good option for Strategy projects on federal lands consistent with the activities covered by the CE (i.e., hazardous fuels reduction activities using prescribed fire, not to exceed 4,500 acres, and mechanical treatments not exceeding 1,000 acres such as crushing, piling, thinning, pruning, cutting, chipping, mulching, and mowing).

It is recommended that the stakeholders monitor the status of this CE and the next iteration of the NPS NEPA Handbook in case this CE, or a new one like it, become a viable option for use in the Strategy Area. Additionally, the 2020 40 CFR 1500-1508, CEQ Implementing NEPA Regulations, allows federal agencies to consider use of all Federal Agency CEs, which may be adopted to cover Strategy projects.

6.3 COASTAL ACT COMPLIANCE PATHWAYS

As described in Section 5.2, "Coastal Act Compliance," above, Strategy projects in the Coastal Zone may be required to obtain a coastal development permit. Currently, agencies and organizations implementing and funding vegetation treatment projects in Marin County (e.g., Marin Wildfire Prevention Authority) are discussing the possibility of preparing a PWP. Discussions continue with the California Coastal Commission about developing other streamlining approaches for approval of necessary fuel break, fuel treatment, and ecosystem restoration projects. It is recommended that the stakeholders monitor the status of coastal compliance pathways and engage in coordination with the Coastal Commission about the subject. Stakeholders may consider pursuing a PWP collaboratively with the other agencies in the LCP area.

7 REFERENCES

CAL FIRE. *See* California Department of Forestry and Fire Protection.

California Department of Forestry and Fire Protection. 2010. (July 26). *Procedures for Compliance with the California Environmental Quality Act on CAL FIRE Projects.* Sacramento, California. Page 4.

National Park Service. 2015. *National Park Service NEPA Handbook*.

NPS. *See* National Park Service.

U.S. Fish and Wildlife Service. 2018 (April 26). *Guidance on Trigger for an Incidental Take Permit under Section 10 (a)(1)(B) of the Endangered Species Act Where Occupied Habitat or Potentially Occupied Habitat Is Being Modified*. Letter memorandum to Regional Directors 1-8. Washington, D.C.

USFWS. *See* U.S. Fish and Wildlife Service.

APPENDIX D: EXAMPLE PRE-GENERATED WATERSHED REPORT

Marin County Forest Health Watershed Report

Watershed Name	**Headwaters Redwood Creek (HUC 14)**
Acres	**3,880.0**

Report Contents

This report contains environmental information for the watershed, including 18 maps. Each map provides insight into landscape elements that inform users about Marin County's forest health. The following pages include tables and maps of the watershed's fire history, vegetation, topography, landcover and forest structure.

Watershed Forest Health Information

The table below provides a summary of environmental variables for the watershed (percentages are of watershed unless otherwise noted):

Metric	Summary Information
Miles of Streams[1]	77.4 mi. (1.7 % of County)
Stream Seasonality[1]	Perennial - 11.3 mi. (14.5%), Intermittent - 18.0 mi. (23.3%), Ephemeral - 48.1 mi. (62.2%)
Aboveground Carbon[2]	155.5 tons/ha aboveground live carbon (county avg = 27.7 tons/ha)
Wildfire Hazard Potential[3]	Very Low - 83.8 ac. (2.2%); Low - 1310.8 ac. (33.8%); Moderate - 1455.1 ac. (37.5%); High - 864.9 ac. (22.3%)
One Tam Wildfire Hazard[4]	Lowest - 2.0 ac. (0.1%); Moderate - 5.8 ac. (0.2%); High - 203.0 ac. (5.2%); Very High - 867.6 ac. (22.4%); Highest - 2801.6 ac. (72.2%)
Impervious Land Cover in Watershed[5]	Paved Road - 35.4 ac. (0.9%); Dirt/Gravel Road - 21.1 ac. (0.5%); Other Paved Surface - 8.9 ac. (0.2%); Building - 5.6 ac. (0.1%); Other Dirt/Gravel Surface - 3.9 ac. (0.1%)
Protected Open Space[6]	California Department of Parks and Recreation - 2330.2 ac. (60.1%); Marin Municipal Water District - 915.9 ac. (23.6%); Other Protected - 537.3 ac. (13.8%)
Ladder Fuels (Forest Areas Only)[7]	Low - 753.7 ac. (19.4%); Medium - 779.4 ac. (20.1%); High - 599.9 ac. (15.5%); Very High - 584.8 ac. (15.1%); Not Forested - 1162.1 ac. (30.0%)
Canopy Gaps[8]	<.5% of Canopy 2010-2019 Gap - 1696.4 ac. (43.7%); .5 - 1.5% of Canopy 2010-2019 Gap - 717.8 ac. (18.5%); 1.5 - 2.5% of Canopy 2010-2019 Gap - 473.6 ac. (12.2%); 2.5 - 5.5% of Canopy 2010-2019 Gap - 574.7 ac. (14.8%); >5.5% of Canopy 2010-2019 Gap - 417.4 ac. (10.8%)

Metric	Summary Information
Standing Dead[8]	<.5% of Canopy Standing Dead - 3161.8 ac. (81.5%); .5 - 2.5% of Canopy Standing Dead - 626.2 ac. (16.1%); >2.5% of Canopy Standing Dead - 91.9 ac. (2.4%)
Threatened or Converting Oak Stands[8]	Threatened with Conversion to Douglas-fir - 31.1 ac. (0.8%); Actively Converting to Douglas-fir - 14.1 ac. (0.4%)
Redwood Structural Classification[8]	Small <60 feet--More Vertical Structure - 117.1 ac. (3.0%); Medium 60-110 ft--Less Vertical Structure - 86.3 ac. (2.2%); Medium 60-110 ft--More Vertical Structure - 360.2 ac. (9.3%); Largest 140 ft +--Less Vertical Structure - 4.5 ac. (0.1%); Largest 140 ft +--More Vertical Structure - 38.4 ac. (1.0%); Large 110-140 ft--Less Vertical Structure - 95.1 ac. (2.4%); Large 110-140 ft--More Vertical Structure - 246.2 ac. (6.3%)
Douglas fir Structural Classification[8]	Small <60 feet--Less Vertical Structure - <.1 ac. (<.1%); Small <60 feet--More Vertical Structure - 468.2 ac. (12.1%); Medium 60-110 ft--Less Vertical Structure - 82.6 ac. (2.1%); Medium 60-110 ft--More Vertical Structure - 379.7 ac. (9.8%); Large 110-140 ft--Less Vertical Structure - 8.3 ac. (0.2%); Large 110-140 ft--More Vertical Structure - 26.9 ac. (0.7%)
Bishop Pine Structural Classification[8]	Late Seral, Open and Shrubby - 2.9 ac. (0.1%)
Sargent Cypress Structural Classification[8]	Taller, non-Serpentinite Soil - 1.8 ac. (<.1%); Shorter, non-Serpentinite Soil - 1.1 ac. (<.1%)
Departure from Desired Conditions[9]	Lowest - 1949.5 ac. (50.2%); Low - 365.7 ac. (9.4%); Moderate - 488.3 ac. (12.6%); High - 186.5 ac. (4.8%); Very High - 210.4 ac. (5.4%); Highest - 679.6 ac. (17.5%)
Treatment Feasibility[10]	Feasible - Road Access, Hand Crew - 531.2 ac. (13.7%); Feasible - Road Access, Mechanical - 346.0 ac. (8.9%); Feasible - Trail Access Only, Hand Crew - 63.3 ac. (1.6%); Feasible - Trail Access Only, Mechanical - 19.6 ac. (0.5%); Limited Feasibility - Poor Access - 442.7 ac. (11.4%); Limited Feasibility - Steep - 1373.0 ac. (35.4%); Low Feasibility - Near Stream or Riparian Veg/Wetland/Water - 1103.6 ac. (28.4%); Low Feasibility - Serpentine - 0.4 ac. (<.1%)

Vegetation Map Information

Map #8 depicts vegetation types across the selected watershed. The Vegetation Map is useful for understanding the distribution of vegetation communities and reflects the landscape in summer, 2018. This map was created using high resolution imagery, lidar data, machine learning and aerial image interpretation.

To download Marin's vegetation data visit: https://pacificvegmap.org/

Watershed Information: Vegetation Types & Acreages

List of fine scale vegetation classes and total acreages found within the selected watershed as shown in the Vegetation Map (Map #10):

Common Name	National Vegetation Classification Fine Scale Map Class	Acres	% of Watershed
Pseudotsuga menziesii – (Notholithocarpus densiflorus – Arbutus menziesii) Alliance	Douglas-fir - tanoak - madrone forest	965.8	24.9%
Sequoia sempervirens Alliance	Coast redwood forest	947.7	24.4%
Umbellularia californica Alliance	California bay woodland	705.4	18.2%
Baccharis pilularis Alliance	Coyote brush scrub	510.4	13.2%
Arctostaphylos glandulosa Alliance	Eastwood manzanita chaparral	245.0	6.3%
Quercus wislizeni – Quercus chrysolepis (shrub) Alliance	Canyon live oak - Interior live oak chaparral	93.6	2.4%
Californian Annual & Perennial Grassland Mapping Unit	California Annual and Perennial Grassland	81.8	2.1%
Arctostaphylos (nummularia, sensitiva) – Chrysolepis chrysophylla Alliance	Glossy leaf manzanita - Golden chinquapin chaparral	44.6	1.1%
Adenostoma fasciculatum Alliance	Chamise dominated chaparral	42.9	1.1%
Quercus agrifolia Alliance	Coast live oak woodland	33.8	0.9%
Arctostaphylos (bakeri, montana) Alliance	Baker or Mount Tamalpais chaparral	31.5	0.8%
Developed	Developed	28.9	0.7%
Acer macrophyllum – Alnus rubra Alliance	Bigleaf maple - red alder woodland	27.1	0.7%
Major Road	Major Road	20.0	0.5%
Frangula californica ssp. californica – Baccharis pilularis / Scrophularia californica Association	Coffeeberry - coyote brush/ bee plant shrubland	15.1	0.4%
Salix lasiolepis Alliance	Arroyo willow thickets	13.9	0.4%
Shrub Fragment	Shrub Fragment	12.6	0.3%
Quercus chrysolepis Alliance	Canyon live oak woodland	11.4	0.3%
Eucalyptus (globulus, camaldulensis) Provisional Semi-Natural Assocation	Non-native Eucalyptus woodland	9.9	0.3%

Common Name	National Vegetation Classification Fine Scale Map Class	Acres	% of Watershed
Genista monspessulana Semi-Natural Association	French broom patches	5.5	0.1%
Arbutus menziesii Alliance	Pacific madrone dominated woodland	4.0	0.1%
Californian Cliff, Scree & Rock Vegetation Group	Californian Cliff, Scree & Rock Vegetation	3.1	0.1%
Forest Fragment	Forest Fragment	3.0	0.1%
Non-native Forest	Non-native Forest	2.9	0.1%
Hesperocyparis sargentii / Ceanothus jepsonii – Arctostaphylos spp. Association	Ultramafic cypress / musk brush - manzanita woodland	2.9	0.1%
Pinus muricata – Pinus radiata Alliance	Bishop pine - Monterey pine forest and woodland	2.9	0.1%
Artemisia californica – (Salvia leucophylla) Alliance	California sagebrush - (purple sage) scrub	2.6	0.1%
Ceanothus cuneatus Alliance	Wedge leaf/Buck brush ceanothus chaparral	2.4	0.1%
Quercus durata Alliance	Leather oak chaparral	2.1	0.1%
Pinus radiata Plantation Provisional Semi-Natural Association	Non-native Monterey pine stand	1.8	<.1%
Notholithocarpus densiflorus Alliance	Tanoak woodland	1.6	<.1%
Non-native Shrub	Non-native Shrub	1.6	<.1%
Arctostaphylos (canescens, manzanita, stanfordiana) Alliance	Hoary, common, and Stanford manzanita chaparral	1.4	<.1%
Hesperocyparis macrocarpa Ruderal Provisional Semi-Natural Association	Non-native Monterey cypress stands	0.5	<.1%

Soils Map Information

Map #16 shows soil types as depicted in the Natural Resource Conservation Service Soil Survey Geographic Database (NRCS SSURGO). The type and characteristics of soil play an important role in determining the density and type of vegetation on a site, as well as the potential for erosion and debris flow. Understanding soil type can help inform decisions about forest health, vegetation management and post-fire restoration. More information on Marin County soils, and the characteristics and information associated each the soil map units, can be found in the Marin County Soil Survey (1985)

To learn more about soil classifications and how soil classifications can be utilized in natural resource management, please visit the description of SSURGO Database page from the NCRS.

Watershed Information: Soils

The table below lists the soil type classifications for the selected watershed as shown in the map (Map #16):

Soil Type	Acres	% of Watershed
Maymen-Maymen variant gravelly loams, 30 to 75 percent slopes	996.3	25.7%
Centissima-Barnabe complex, 30 to 50 percent slopes	965.6	24.9%
Centissima-Barnabe complex, 50 to 75 percent slopes	667.9	17.2%
Cronkhite-Barnabe complex, 30 to 50 percent slopes	451.4	11.6%
Dipsea-Barnabe very gravelly loams, 50 to 75 percent slopes	219.7	5.7%
Cronkhite-Barnabe complex, 15 to 30 percent slopes	170.0	4.4%
Tocaloma-McMullin complex, 50 to 75 slopes	80.5	2.1%
Saurin-Bonnydoon complex, 15 to 30 percent slopes	70.2	1.8%
Bonnydoon gravelly loam, 30 to 75 percent slopes	68.3	1.8%
Cronkhite-Barnabe complex, 50 to 75 percent slopes	64.9	1.7%
Blucher-Cole complex, 2 to 5 percent slopes	57.8	1.5%
Saurin-Bonnydoon complex, 50 to 75 percent slopes	38.0	1.0%
Tamalpais-Barnabe variant very gravelly loams, 50 to 75 percent slopes	15.3	0.4%
Tocaloma-McMullin-Urban land complex, 15 to 30 percent slopes	7.6	0.2%
Saurin-Bonnydoon complex, 30 to 50 percent slopes	6.1	0.2%
Henneke stony clay loam, 15 to 50 percent slopes	0.4	<.1%

Fire History

Map #3 shows where there have been wildfires in the past 160 years within the watershed of interest. Also included are maps of number of times burned and time since last burn. The fire perimeter data includes polygons that represents wildfire perimeters for wildfires between 1859 and 2021. Wildfires before 1930 are from Arthur Dawson's spatial reconstruction of Marin's fire; more recent perimeters come from CAL FIRE.

Watershed Information: Fire History Summary

The table below lists all major fires that have occurred in the watershed of interest between 1859 and 2021 as shown in the fire map (Map #3).

Year	Fire Size (Acres)	Percent of Watershed
1932	170.6	4.4%
1931	175.3	4.5%
1926	262.4	6.8%
1919	353.1	9.1%
1916	155.2	4.0%
1913	509.2	13.1%
1904	188.6	4.9%
1893	116.3	3.0%
1889	227.6	5.9%
1881	3881.4	100.0%
1859	3881.4	100.0%

Invasive Plants Observations

Invasive Plants

The table below lists Cal-IPC rated weed observations within the watershed of interest (Calflora, 02/2022). Species shown in bold are on the One Tam EDRR (Early Detection Rapid Response) expanded plant list (as of April 2022). EDRR Priority is listed where applicable.

Common Name	Scientific Name	Priority
Cootamundra wattle	Acacia baileyana	N/A
Silver wattle	Acacia dealbata	N/A
Blackwood acacia	**Acacia melanoxylon**	**Priority 2**
Goatgrass	**Aegilops triuncialis**	**Priority 1**
Thoroughwort	**Ageratina adenophora**	**Priority 2**
Redtop	Agrostis stolonifera	N/A
Silvery hairgrass	Aira caryophyllea	N/A
Stink bean	**Albizia lophantha**	**Priority 1**
White flowered onion	Allium triquetrum	N/A
Prostrate cape weed	**Arctotheca prostrata**	**Priority 2**
Giant reed	Arundo donax	N/A
Slim oat	Avena barbata	N/A
English lawn daisy	Bellis perennis	N/A
Purple false brome	Brachypodium distachyon	N/A
Black mustard	Brassica nigra	N/A
Common mustard	Brassica rapa	N/A
Rattlesnake grass	Briza maxima	N/A
Soft chess	Bromus hordeaceus	N/A
Red brome	Bromus madritensis ssp. Rubens	N/A
Downy chess	**Bromus tectorum**	**Priority 1**
Butterfly bush	**Buddleja davidii**	**Priority 1**
Sea rocket	Cakile maritima	N/A
Italian thistle	Carduus pycnocephalus	N/A
Hanging sedge	**Carex pendula**	**Priority 1**
Sea fig	Carpobrotus chilensis	N/A
Iceplant	Carpobrotus edulis	N/A
Purple star thistle	**Centaurea calcitrapa**	**Priority 1**

Common Name	Scientific Name	Priority
Tocalote	Centaurea melitensis	N/A
Yellow starthistle	**Centaurea solstitialis**	**Priority 2**
Chasmanthe	Chasmanthe floribunda	N/A
Bullthistle	Cirsium vulgare	N/A
Old man's beard	**Clematis vitalba**	**Priority 1**
Poison hemlock	Conium maculatum	N/A
Cabbage tree	Cordyline australis	N/A
Andean pampas grass	**Cortaderia jubata**	**Priority 2**
Pampas grass	**Cortaderia selloana**	**Priority 2**
Cotoneaster	**Cotoneaster franchetii**	**Priority 2**
Milkflower cotoneaster	**Cotoneaster lacteus**	**Priority 2**
Woolly cotoneaster	Cotoneaster pannosus	N/A
Hawthorn	**Crataegus monogyna**	**Priority 2**
Monbretia	Crocosmia Xcrocosmiiflora	N/A
Bermuda grass	Cynodon dactylon	N/A
Scotch broom	**Cytisus scoparius**	**Priority 2**
Portuguese broom	**Cytisus striatus**	**Priority 1**
Orchardgrass	Dactylis glomerata	N/A
Cape ivy	**Delairea odorata**	**Priority 2**
Foxglove	**Digitalis purpurea**	**Priority 2**
Wild teasel	**Dipsacus fullonum**	**Priority 2**
Stinkwort	**Dittrichia graveolens**	**Priority 1**
Pride of madeira	Echium candicans	N/A
Upright veldt grass	**Ehrharta erecta**	**Priority 2**
Medusa head	**Elymus caput-medusae**	**Priority 1**
Latin american fleabane	Erigeron karvinskianus	N/A
White stemmed filaree	Erodium brachycarpum	N/A
Blue gum	**Eucalyptus globulus**	**Priority 2**
Gopher plant	Euphorbia lathyris	N/A
Eggleaf spurge	**Euphorbia oblongata**	**Priority 2**
Reed fescue	**Festuca arundinacea**	**Priority 2**
Common fig	Ficus carica	N/A

Common Name	Scientific Name	Priority
Fennel	**Foeniculum vulgare**	**Priority 2**
Fumitory	Fumaria officinalis	N/A
Bridal broom	Genista monosperma	N/A
French broom	**Genista monspessulana**	**Priority 2**
Herb robert	Geranium purpureum	N/A
Robert's geranium	Geranium robertianum	N/A
Waxy mannagrass	Glyceria declinata	N/A
Canary ivy	**Hedera canariensis**	**Priority 2**
English ivy	**Hedera helix**	**Priority 2**
Canary ivy	Hedera helix ssp. canariensis	N/A
Licorice plant	**Helichrysum petiolare**	**Priority 2**
Monterey cypress	Hesperocyparis macrocarpa	N/A
Mustard	Hirschfeldia incana	N/A
Common velvetgrass	Holcus lanatus	N/A
Klamathweed	**Hypericum perforatum**	**Priority 2**
Smooth cats ear	Hypochaeris glabra	N/A
Hairy cats ear	Hypochaeris radicata	N/A
Holly	**Ilex aquifolium**	**Priority 2**
Horticultural iris	**Iris pseudacorus**	**Priority 1**
Redhot poker	Kniphofia uvaria	N/A
Oxe eye daisy	**Leucanthemum vulgare**	**Priority 2**
Glossy privet	**Ligustrum lucidum**	**Priority 2**
Hyssop loosestrife	Lythrum hyssopifolia	N/A
White horehound	Marrubium vulgare	N/A
Mayten	**Maytenus boaria**	**Priority 1**
Pennyroyal	Mentha pulegium	N/A
Wide leaved forget me not	Myosotis latifolia	N/A
Mexican feathergrass	Nassella tenuissima	N/A
Olive	Olea europaea	N/A
Creeping wood sorrel	Oxalis corniculata	N/A
Bermuda buttercup	Oxalis pes-caprae	N/A
Stink bean	Paraserianthes lophantha	N/A

Common Name	Scientific Name	Priority
Yellow parentucellia	Parentucellia viscosa	N/A
	Passiflora tarminiana	N/A
Kikuyu grass	**Pennisetum clandestinum**	**Priority 2**
Harding grass	**Phalaris aquatica**	**Priority 2**
Canary island date palm	Phoenix canariensis	N/A
Pokeweed	Phytolacca americana	N/A
Monterey pine	Pinus radiata	N/A
Victorian box	Pittosporum undulatum	N/A
Annual beard grass	Polypogon monspeliensis	N/A
Cherry plum	Prunus cerasifera	N/A
Firethorn	**Pyracantha angustifolia**	**Priority 2**
Crowfoot, creeping buttercup	Ranunculus repens	N/A
Black locust	Robinia pseudoacacia	N/A
Rosy sandcrocus	Romulea rosea	N/A
Himalayan blackberry	**Rubus armeniacus**	**Priority 2**
Purple awned wallaby grass	**Rytidosperma penicillatum**	**Priority 2**
Pincushions	Scabiosa atropurpurea	N/A
Cutleaf burnweed	Senecio glomeratus	N/A
Coastal burnweed	Senecio minimus	N/A
Milk thistle	Silybum marianum	N/A
New zealand nightshade	**Solanum aviculare**	**Priority 1**
Spiny sowthistle	Sonchus asper	N/A
Johnsongrass	Sorghum halepense	N/A
Spanish broom	**Spartium junceum**	**Priority 2**
Field hedge parsley	Torilis arvensis	N/A
Rose clover	Trifolium hirtum	N/A
Gorse	**Ulex europaeus**	**Priority 1**
Vinca	Vinca major	N/A
Mexican fan palm	Washingtonia robusta	N/A
Callalily	Zantedeschia aethiopica	N/A
French broom	genista monspessulana	N/A
Garden nasturtium	tropaeolum majus	N/A

Rare Plants Observations

Rare Plants

The table below lists rare plant observations within the watershed of interest (CNDDB, 12/2021). Occurrences were selected from the CNDDB database if they had a California listing of Endangered, Threatened or Rare, or a State Ranking in this list: S1, S1?, S1.2, S1S2, S1S3, S2.1, S2, S2.2, S2?, S2S3, S3, S3.2, SX, SH. Taxonomical Groups include Bryophytes, Dicots, Dune, Herbaceous, Lichens, Marsh, Monocots, Scrub.

Common Name	Scientific Name
Napa false indigo	Amorpha californica var. napensis
Mt. Tamalpais manzanita	Arctostaphylos montana ssp. montana
Marin manzanita	Arctostaphylos virgata
Thurber's reed grass	Calamagrostis crassiglumis
San Francisco Bay spineflower	Chorizanthe cuspidata var. cuspidata
Mt. Tamalpais thistle	Cirsium hydrophilum var. vaseyi
Tiburon buckwheat	Eriogonum luteolum var. caninum
minute pocket moss	Fissidens pauperculus
dark-eyed gilia	Gilia millefoliata
Diablo helianthella	Helianthella castanea
Santa Cruz tarplant	Holocarpha macradenia
thin-lobed horkelia	Horkelia tenuiloba
small groundcone	Kopsiopsis hookeri
marsh microseris	Microseris paludosa
Marin County navarretia	Navarretia rosulata
Tamalpais oak	Quercus parvula var. tamalpaisensis
Santa Cruz microseris	Stebbinsoseris decipiens
Tamalpais jewelflower	Streptanthus batrachopus
Mt. Tamalpais bristly jewelflower	Streptanthus glandulosus ssp. pulchellus

Marin County Forest Health Watershed Report

Important Resources

The following links are provided to help users better understand how to interpret map reports.

- Pacific Veg Map: This site provides access to fine scale vegetation, topographic, wildland fuels and other mapping data for Marin.
- Marin Forest Health Web Map: Contains the spatial data shown in this report.

Contact Information

Questions or comments? Please contact Danny Franco at dfranco@parksconservancy.org

Map Titles and Order

1. 2018 Ortho Imagery
2. 2014 Ortho Imagery
3. Land Ownership
4. Fire Overview:
    a. Fire History (1859-2020)
    b. Pyrologix - Wildfire Hazard Potential
    c. Pyrologix - Suppression Difficulty Index
5. Marin Wildfire Hazard
6. Time Since Last Burned
7. Number of Times Burned
8. Ladder Fuels
9. High Fire Hazard Woody Vegetation
10. Fine Scale Vegetation Map
11. Open Canopy Oak Woodland Alliances
12. Forest Stand Metrics #1
    a. Relative % of Hardwood Cover
    b. Mean Stand Height '19 (ft.)
    c. Absolute Cover of Vegetation > 15 ft.
13. Forest Stand Metrics #2
    a. % of Canopy Gaps Formed 10'-19'
    b. % Standing Dead '19
    c. % Canopy Density Change 10'-19'
14. Oak Stands At-Risk to Doug-fir Conversion
15. Forest Structural Classification
    a. Douglas Fir Structural Classification
    b. Redwood Structural Classification
    c. Bishop Pine Structural Classification
16. Thalwegs and Flow Accumulation
17. Slope (Degrees)
18. Soils
19. Impervious Surfaces, Fire Department Response, and WUI/Defensible Spaces
    a. Impervious Surfaces
    b. Fire Department Response Areas
    c. Defensible Spaces
20. Departure From Desired Conditions
21. Treatment Feasibility

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[1] U.S. Geological Survey, *National Hydrography Dataset (ver. USGS National Hydrography Dataset Best Resolution (NHD) for Hydrologic Unit (HU) 4 – 2001*, (2020), distributed by the United States Geological Survey https://www.usgs.gov/core-science-systems/ngp/national-hydrography/access-national-hydrography-products

[2] Landscape Ecology Modeling, Mapping, and Analysis (LEMMA) group, Mean Aboveground Live Biomass Tons per Hectare, (2017), distributed by Oregon State University, https://lemmadownload.forestry.oregonstate.edu/

[3] Vogler, Kevin; et. al., *Contemporary Wildfire Hazard Across California*, (June 30th, 2021), distributed by Pyrologix, http://pyrologix.com/reports/Contemporary-Wildfire-Hazard-Across-California.pdf

[4] 2020 Marin Wildfire Hazard Index, Tamalpais Lands Collaborative (One Tam), *Marin Regional Forest Health Strategy*.

[5] 2018 Marin Countywide Fine Scale Vegetation Map. Tamalpais Lands Collaborative (One Tam). Online: https://vegmap.press/marin_vegmap_datasheet

[6] California Protected Areas Database (CPAD), (December 2021), distributed by Green Info Network, https://www.calands.org/wp-content/uploads/2021/12/CPAD-2021b-Database-Manual.pdf

[7] Golden Gate National Parks Conservancy, Marin County Ladder Fuels, 64 ft resolution, (December 19th, 2019), distributed by Tukman Geospatial, https://tukmangeospatial.egnyte.com/dl/iWdGQxTebV

[8] 2018 Marin Countywide Fine Scale Vegetation Map. Tamalpais Lands Collaborative (One Tam). Online: https://vegmap.press/marin_vegmap_datasheet

[9] 2018 Departure from Desired Conditions Index, Tamalpais Lands Collaborative (One Tam), *Marin Regional Forest Health Strategy*

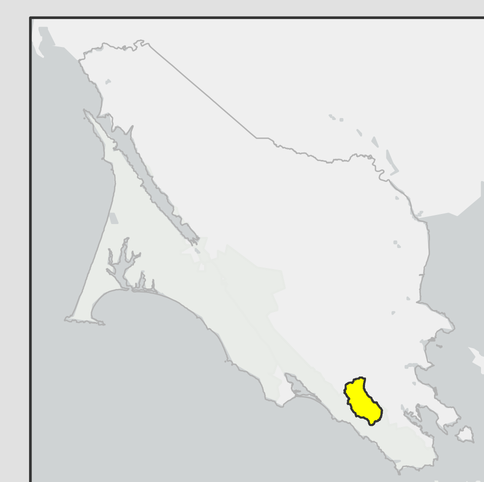
[10] 2019 Treatment Feasibility Classification, Tamalpais Lands Collaborative (One Tam), *Marin Regional Forest Health Strategy*

2018 Imagery and Place Names

Headwaters Redwood Creek HUC 14

About This Map

This map shows place names and high resolution (6-inch) orthoimagery from summer, 2018.



1:24,865

0 0.5 1 Miles

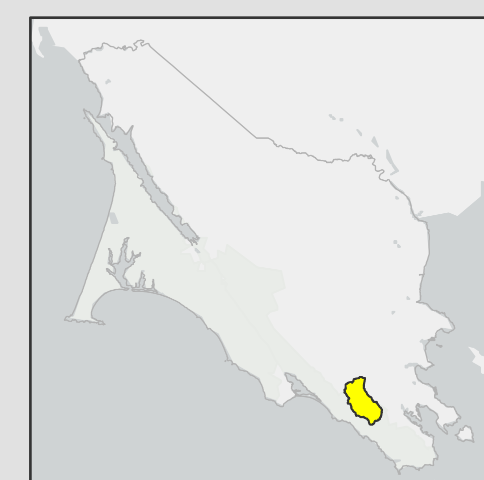
Map 2

2014 Imagery and Place Names

Headwaters Redwood Creek HUC 14

About This Map

This map shows place names and high resolution (6-inch) orthoimagery from summer, 2014.



1:24,865

0 0.5 1 Miles

Land Ownership

Headwaters Redwood Creek HUC 14

Private Parcels >= 10 acres

California Conservation Easement Database

United States National Park Service

California Protected Areas Database

City Agency

Community Services District

County Agency - Parks

Federal Agency

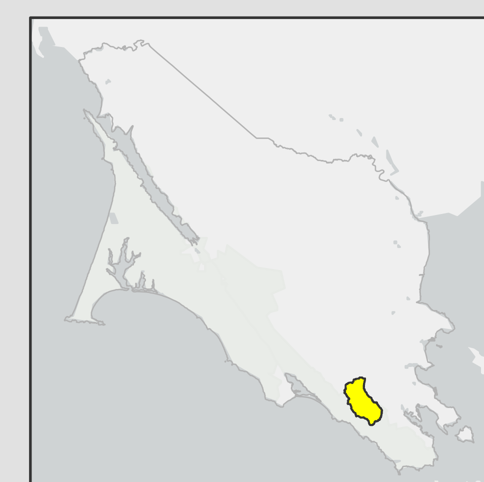
Recreation/Parks District

State Agency

Water District

About This Map

This map shows public and private land ownership. The California Protected Areas Database depicts lands that are owned in fee and protected for open space purposes by over 1,000 public agencies or non-profit organizations. The California Conservation Easement Database is a database defining easements and deed-based restrictions on private land. These restrictions limit land uses to those compatible with maintaining it as open space. Lands under easement may be actively farmed, grazed, forested, or held as nature reserves. Easements are typically held on private lands with no public access. The parcels layer displays all private lands greater than or equal to 10 acres.



1:24,865

0 0.5 1 Miles

Fire History

About This Map

This map shows 1859-2021 fire perimeter history for Marin County. The fire history data was collected by Aurthur Dawson (Baseline Consulting). The data was compiled into a timeline from a number of sources, including CALFIRE, the California Digital Newspaper Collection, the National Park Service, Marin County Fire Chief's Association, and "Fire History of the Marin Municipal Water District and Marin County Open Space District" (Gaudinski 1990).

Note that Marin's fire history does not include undocumented fires or pre-1930 wildfires less than 160 acres.

Fire History (1859-2020)

- 1859 - 1900
- 1901 - 1940
- 1941 - 1980
- 1981 - 2020

Wildfire Hazard Potential

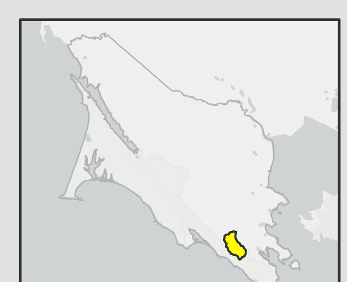
About This Map

This map, created by Pyrologix, is meant to provide foundational information about wildfire hazards across all land ownerships in California. Such information supports fuel management planning decisions, as well as revisions to land and resource management plans. This wildfire hazard assessment considers several spatial components including likelihood of a fire burning, the intensity of a fire if one should occur, the exposure of human communities based on their locations, and the susceptibility of those communities to wildfire.

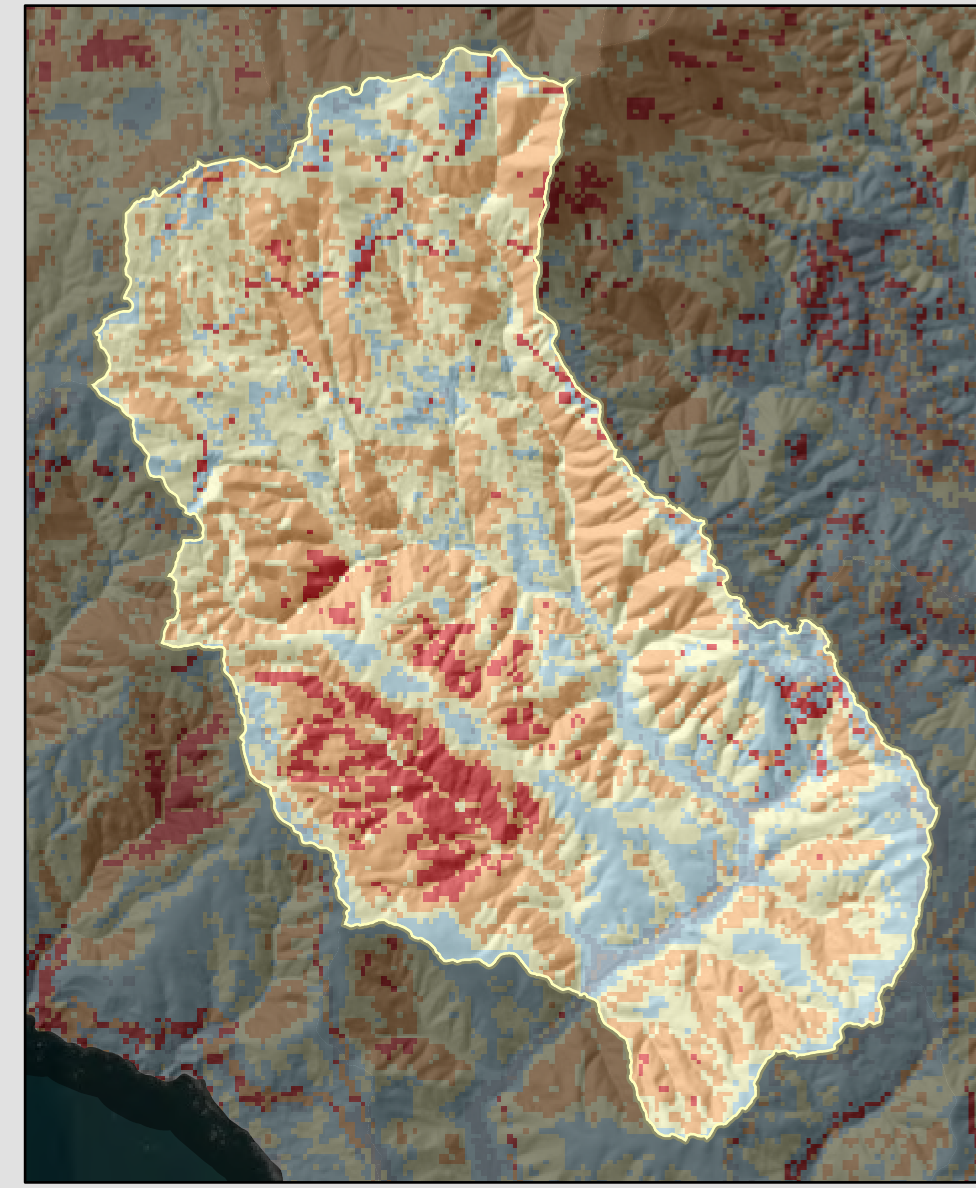
http://pyrologix.com/reports/Contemporary-Wildfire-Hazard-Across-California.pdf

Pyrologix - Wildfire Hazard Potential

- NA
- Very Low
- Low
- Moderate
- High



Suppression Difficulty Index



About This Map

This map, created by Pyrologix, shows a rating of relative difficulty in performing fire control work. The Suppression Difficulty Index (SDI) factors in topography, fuels, expected fire behavior under severe fire weather conditions, firefighter line production rates in various fuel types, and accessibility (distance from roads/trails) to assess relative suppression difficulty. The SDI can be used to help inform strategic and tactical fire management decisions.

http://pyrologix.com/reports/Contemporary-Wildfire-Hazard-Across-California.pdf

Pyrologix - Suppression Difficulty Index

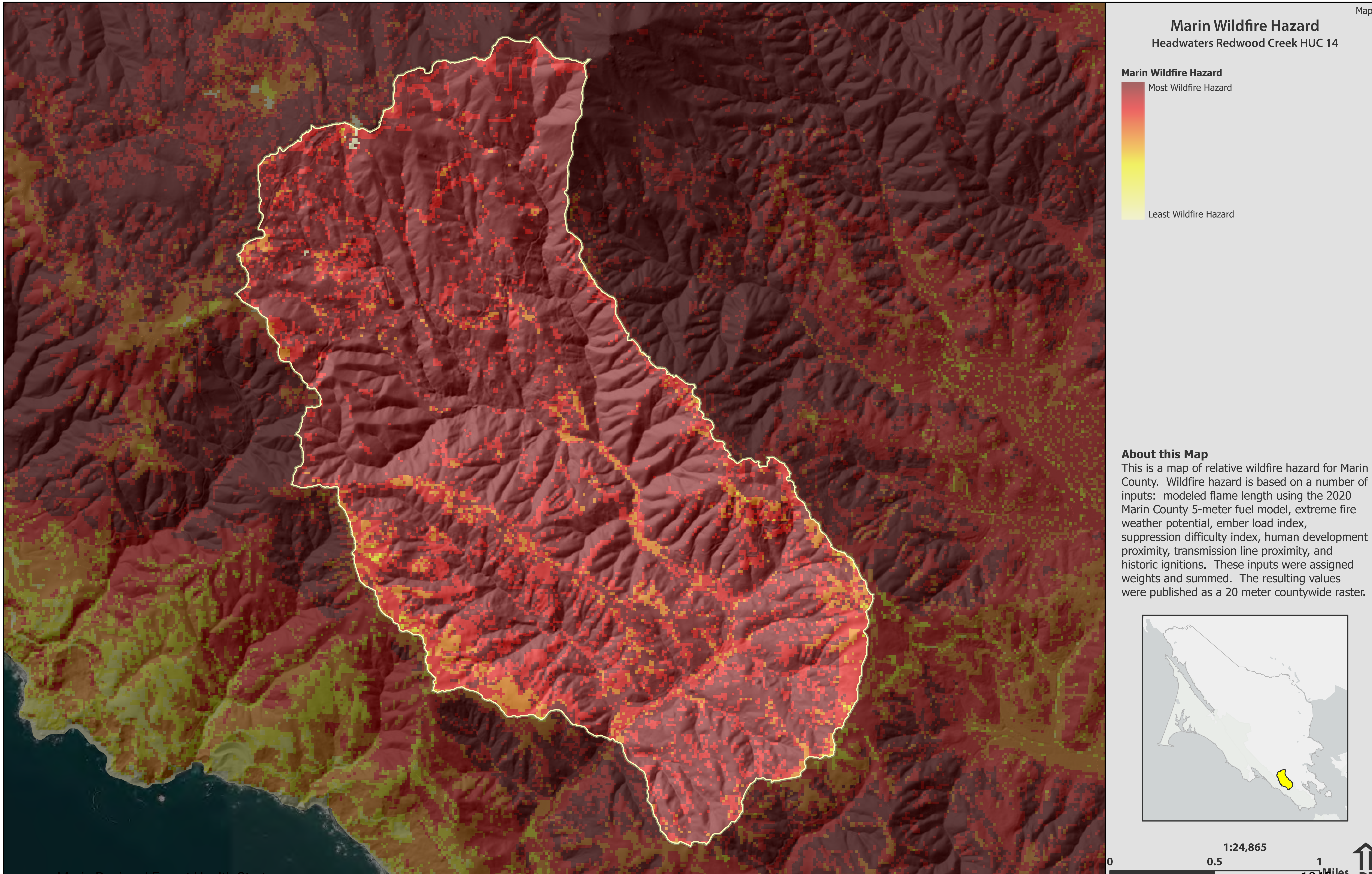
- Water / Ice
- Little to No Difficulty
- Very Low Difficulty
- Low Difficulty
- Moderate Difficulty
- High Difficulty
- Very High Difficulty

1:43,427

0 0.7 1.4 Miles

Marin Wildfire Hazard

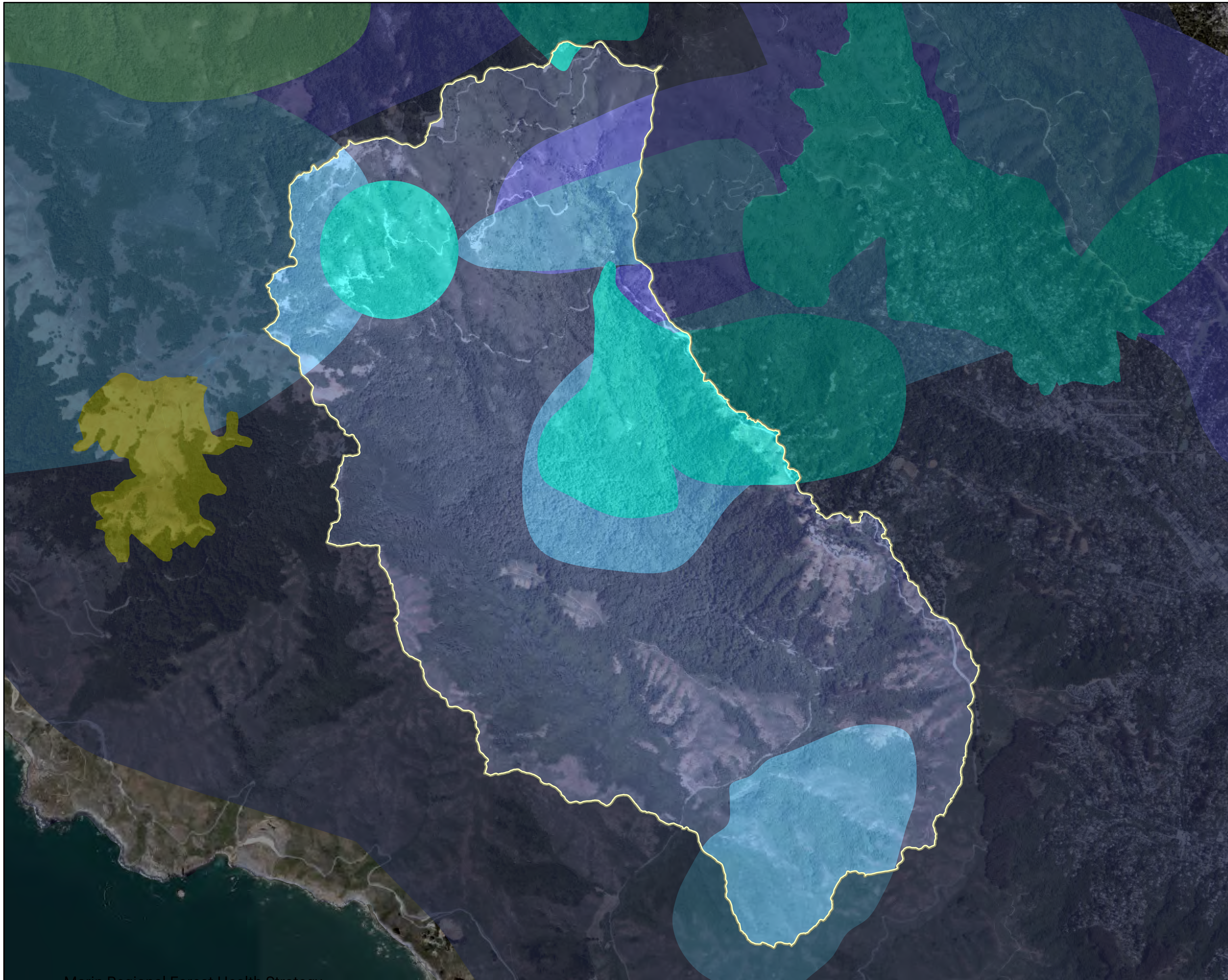
Headwaters Redwood Creek HUC 14



About this Map

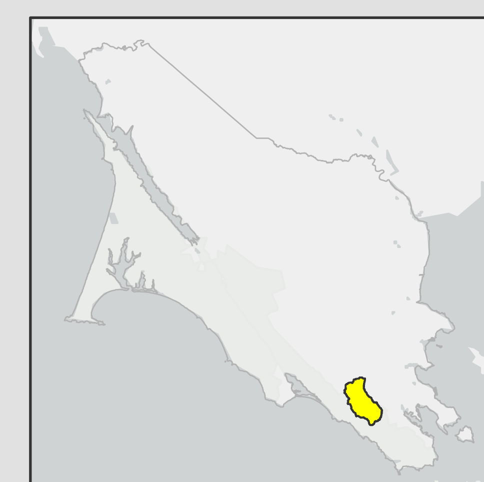
This is a map of relative wildfire hazard for Marin County. Wildfire hazard is based on a number of inputs: modeled flame length using the 2020 Marin County 5-meter fuel model, extreme fire weather potential, ember load index, suppression difficulty index, human development proximity, transmission line proximity, and historic ignitions. These inputs were assigned weights and summed. The resulting values were published as a 20 meter countywide raster.

Time Since Last Burned
Headwaters Redwood Creek HUC 14



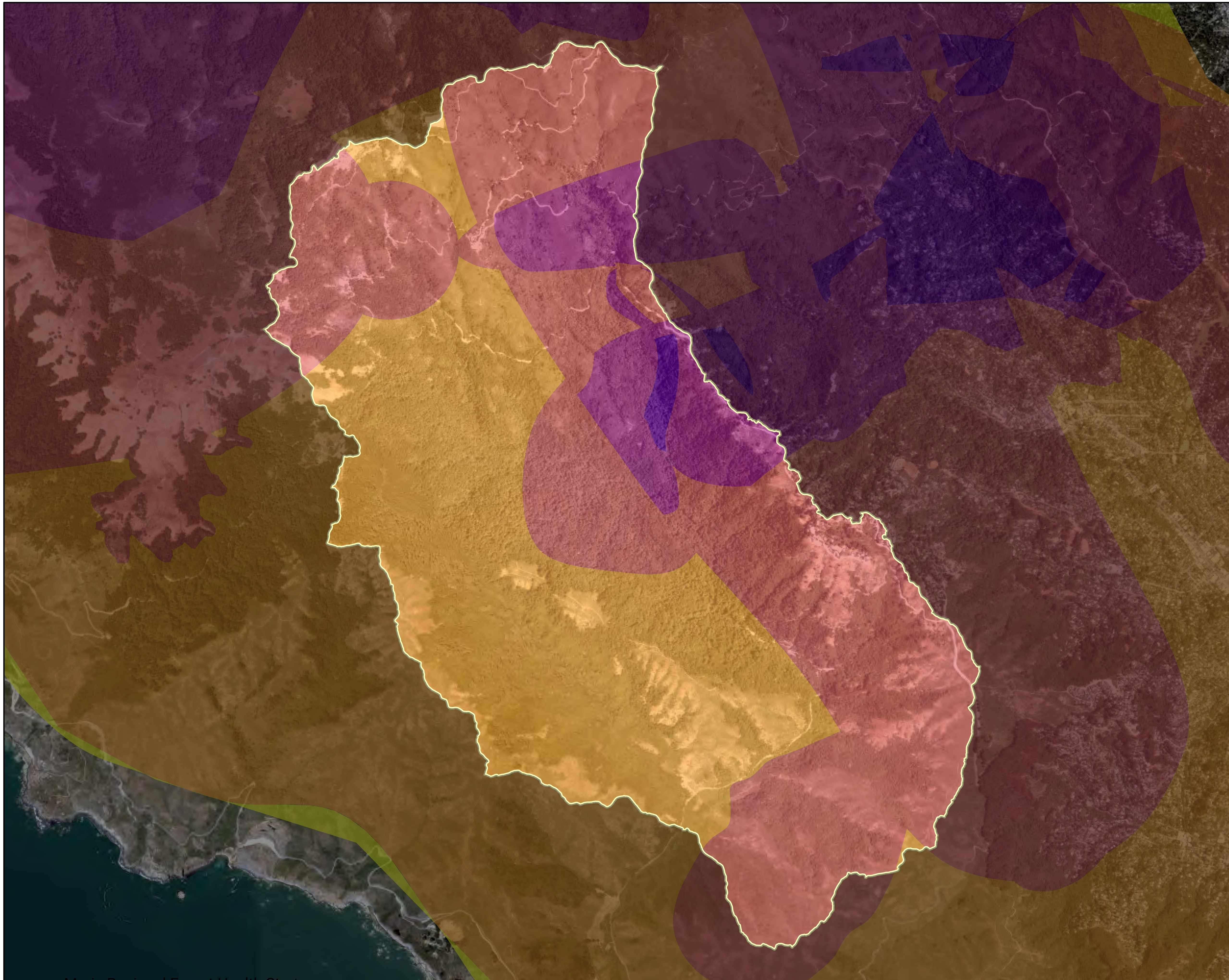
Time Since Last Burned (Years)
- 31 - 40
- 61 - 80
- 81 - 100
- 101 - 120
- 121 - 140
- 141 - 163

About This Map
This map shows the number of years since the last time a wildfire occurred. Time since last burned was calculated from Arthur Dawson's spatial approximations of fire perimeters. Note that Arthur Dawson's spatial reconstruction of Marin's fire history does not include undocumented fires or pre-1930 wildfires less than approximately 160 acres. Also note that the horizontal accuracy of pre-1940 perimeters is much lower than that of more recent fire perimeters.



1:24,865

0 0.5 1 Miles



Map 7

Number of Times Burned

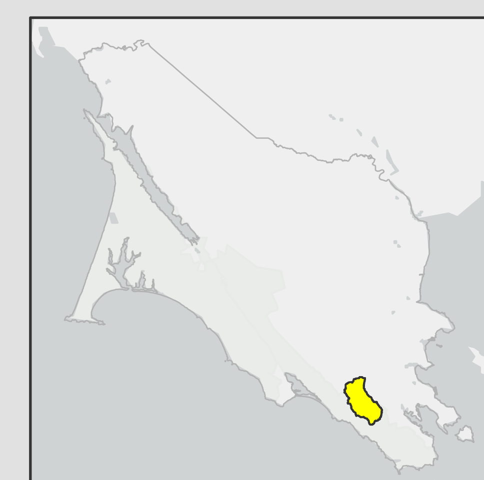
Headwaters Redwood Creek HUC 14

Number of Times Burned (1859-2020)

- 1
- 2
- 3 - 4
- 5 - 6
- 7 - 8

About This Map

This map shows the number of times wildfires have occurred from 1859 to 2020. Number of times burned was calculated from Arthur Dawson's spatial approximations of fire perimeters. Note that Arthur Dawson's spatial reconstruction of Marin's fire history does not include undocumented fires or pre-1930 wildfires less than approximately 160 acres. Also note that the horizontal accuracy of pre-1940 perimeters is much lower than that of more recent fire perimeters.

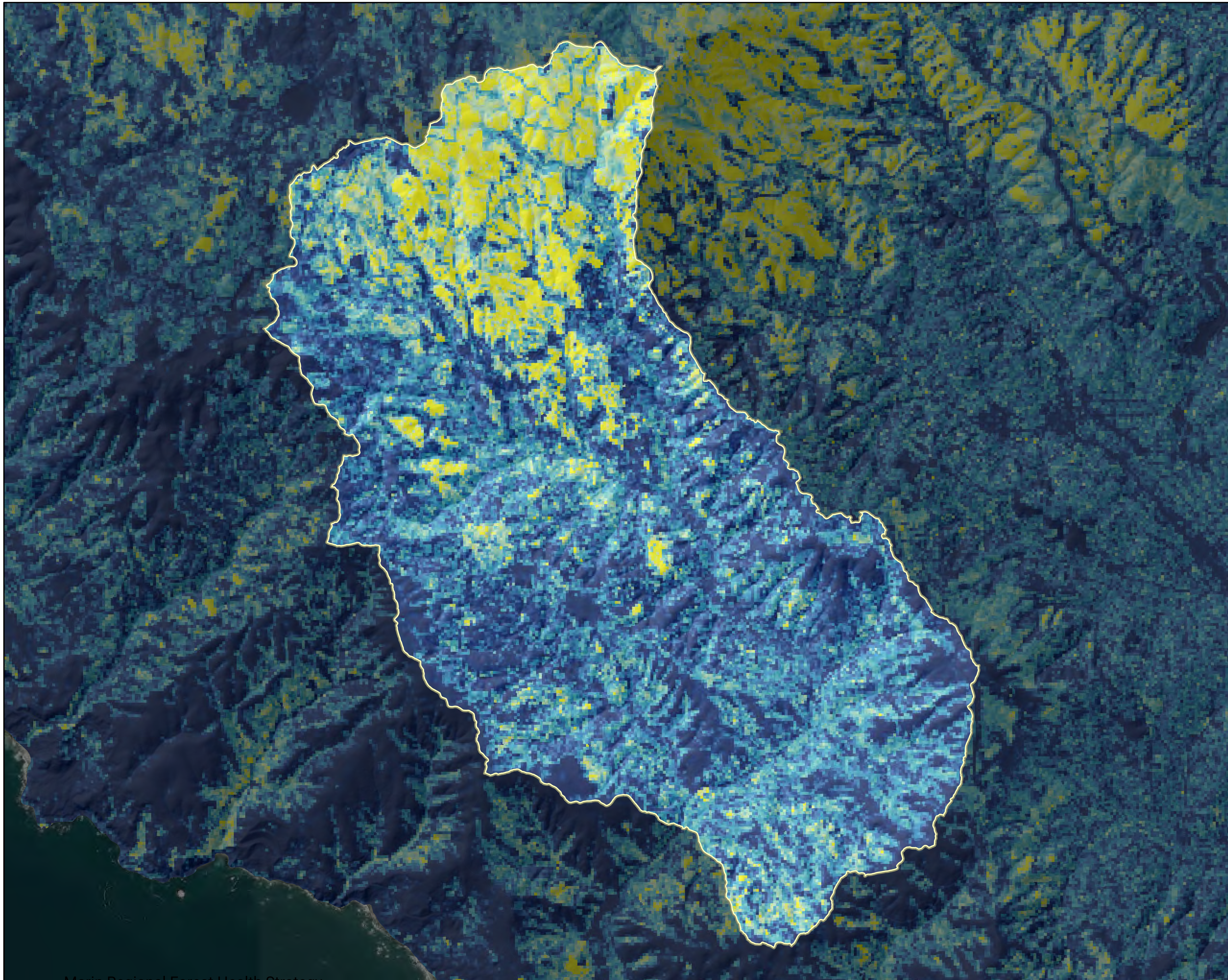


1:24,865

0 0.5 1 Miles

Ladder Fuels

Headwaters Redwood Creek HUC 14



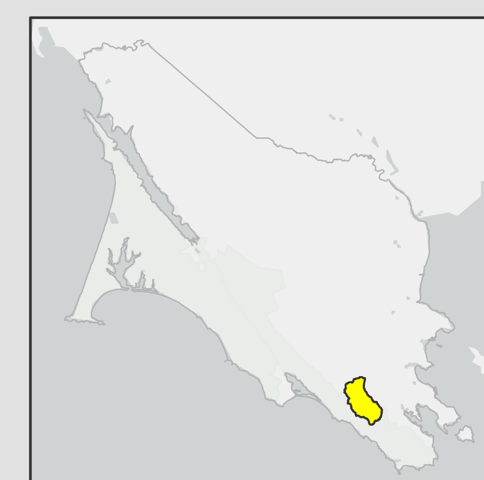
2019 Ladder Fuels (1-4 meters above ground)

High

Low

About This Map

This map shows the density of ladder fuels: living and dead vegetation in the vertical stratum between 1 and 4 meters above the ground. Ladder fuels create vertical fuel continuity, which can allow fire to transition from the surface into the canopy. Reducing vegetation in this stratum is a key element in a fire resilient landscape. The ladder fuels in this map were derived from winter 2019 lidar data and reflect 2019 conditions.

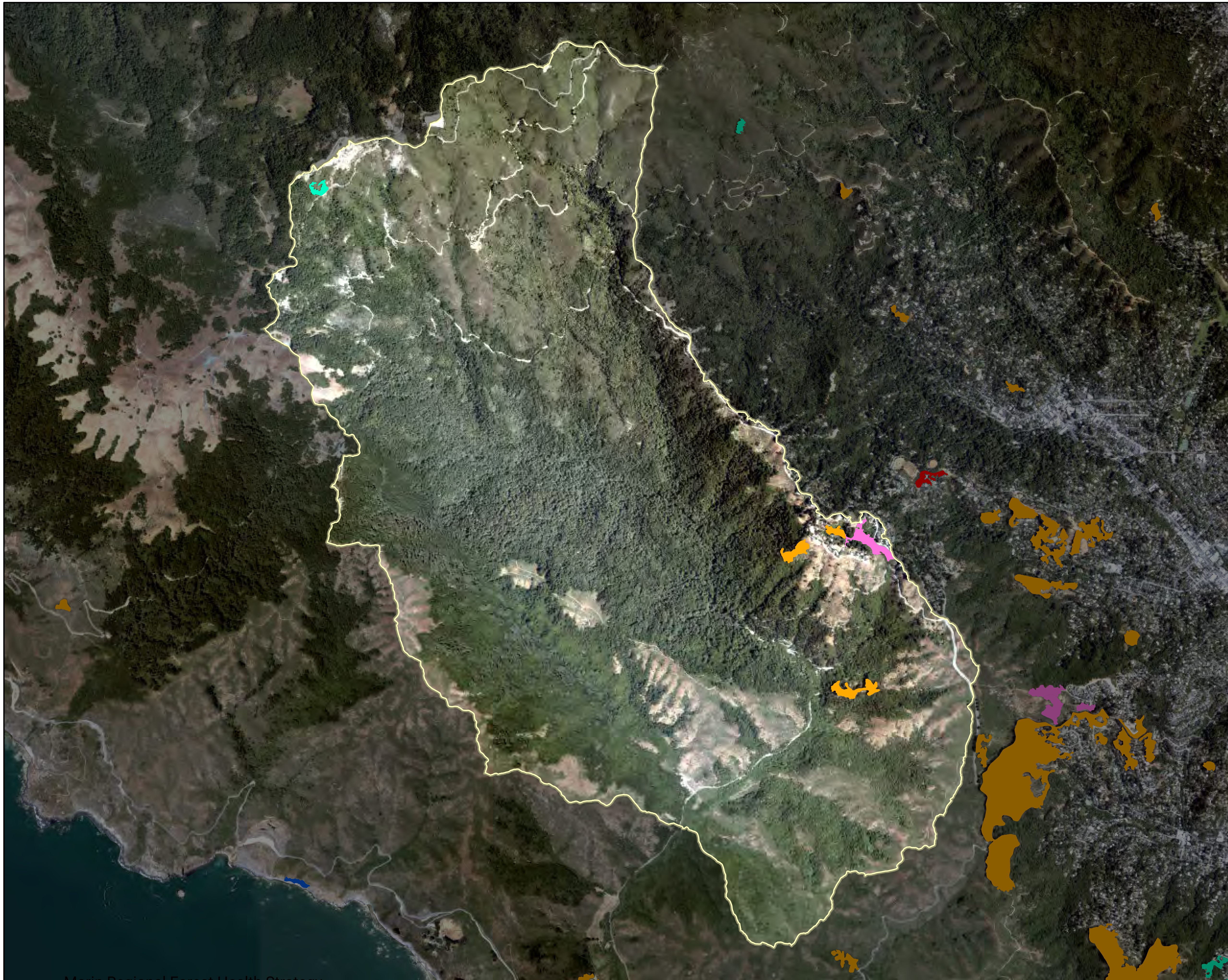


1:24,865

0 0.5 1 Miles

High Hazard Non-native Woody Vegetation

Headwaters Redwood Creek HUC 14



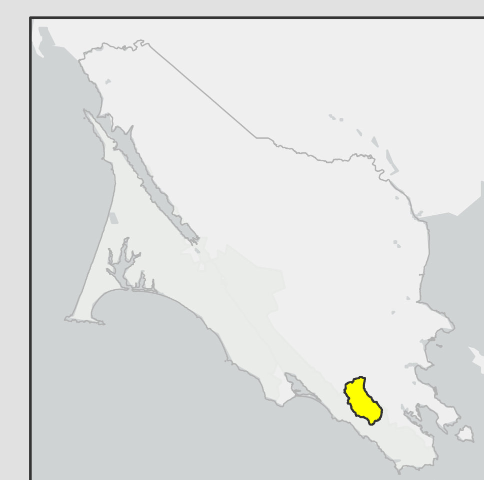
High Fire Hazard Woody Vegetation

- Genista monspessulana Semi-Natural Association
- Eucalyptus (globulus, camaldulensis) Provisional Semi-Natural Assocation
- Pinus radiata Plantation Provisional Semi-Natural Association
- Acacia spp. – Grevillea spp. – Leptospermum laevigatum Semi-Natural Alliance
- Cortaderia (jubata, selloana) Semi-Natural Alliance

About This Map

This map shows Marin County Fine Scale Vegetation Map polygons that are non-native and associated with high fire hazard. The following map classes are included: Genista monspessulana Semi-Natural Association, Eucalyptus (globulus, camaldulensis) Provisional Semi-Natural Assocation, Pinus radiata Plantation Provisional Semi-Natural Association, Acacia spp. – Grevillea spp. – Leptospermum laevigatum Semi-Natural Alliance, and Cortaderia (jubata, selloana) Semi-Natural Alliance.

Note that wildfire hazard is a function of many more variables than dominant canopy vegetation.

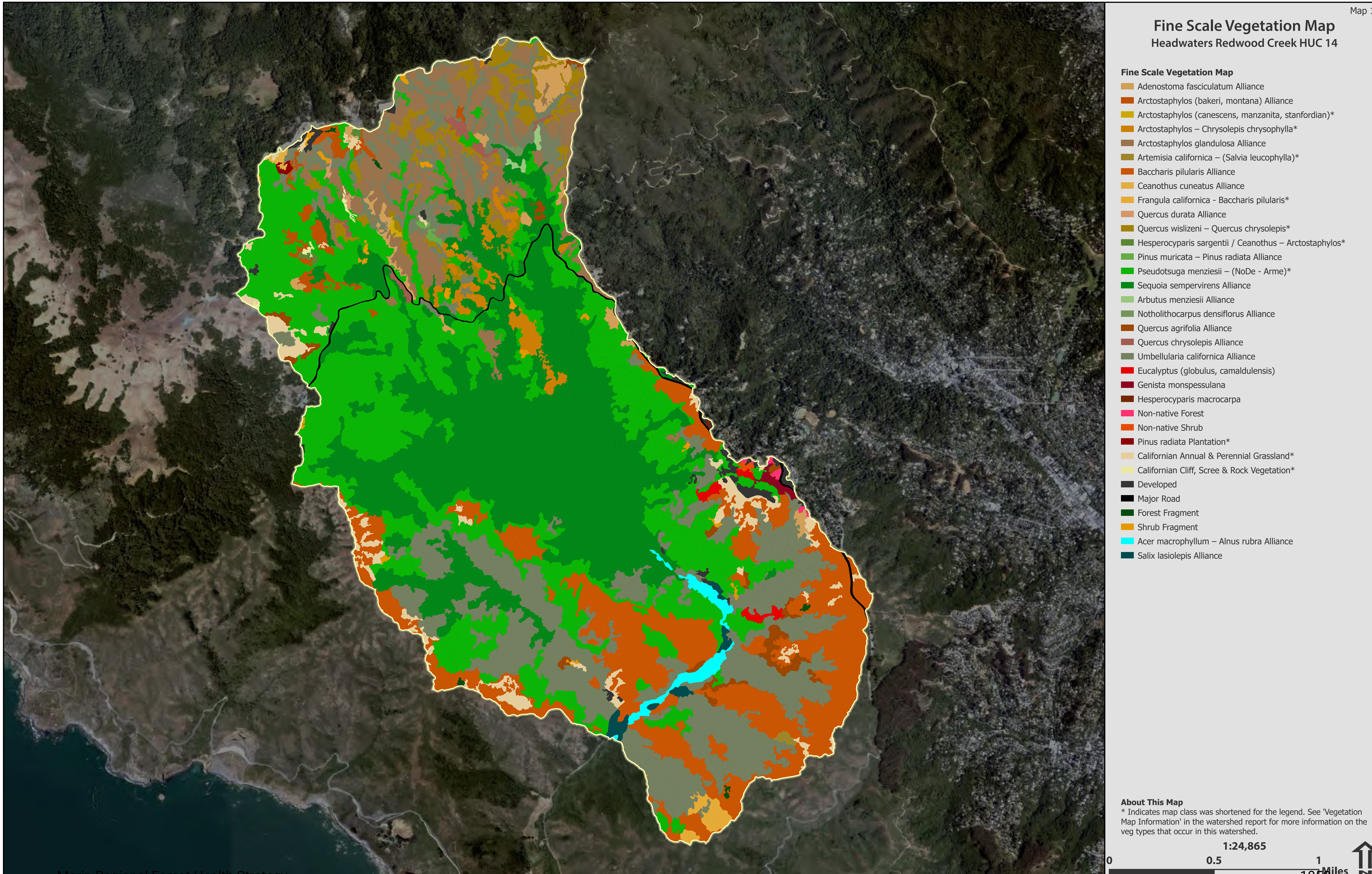


1:24,865

0 0.5 1 Miles

Fine Scale Vegetation Map

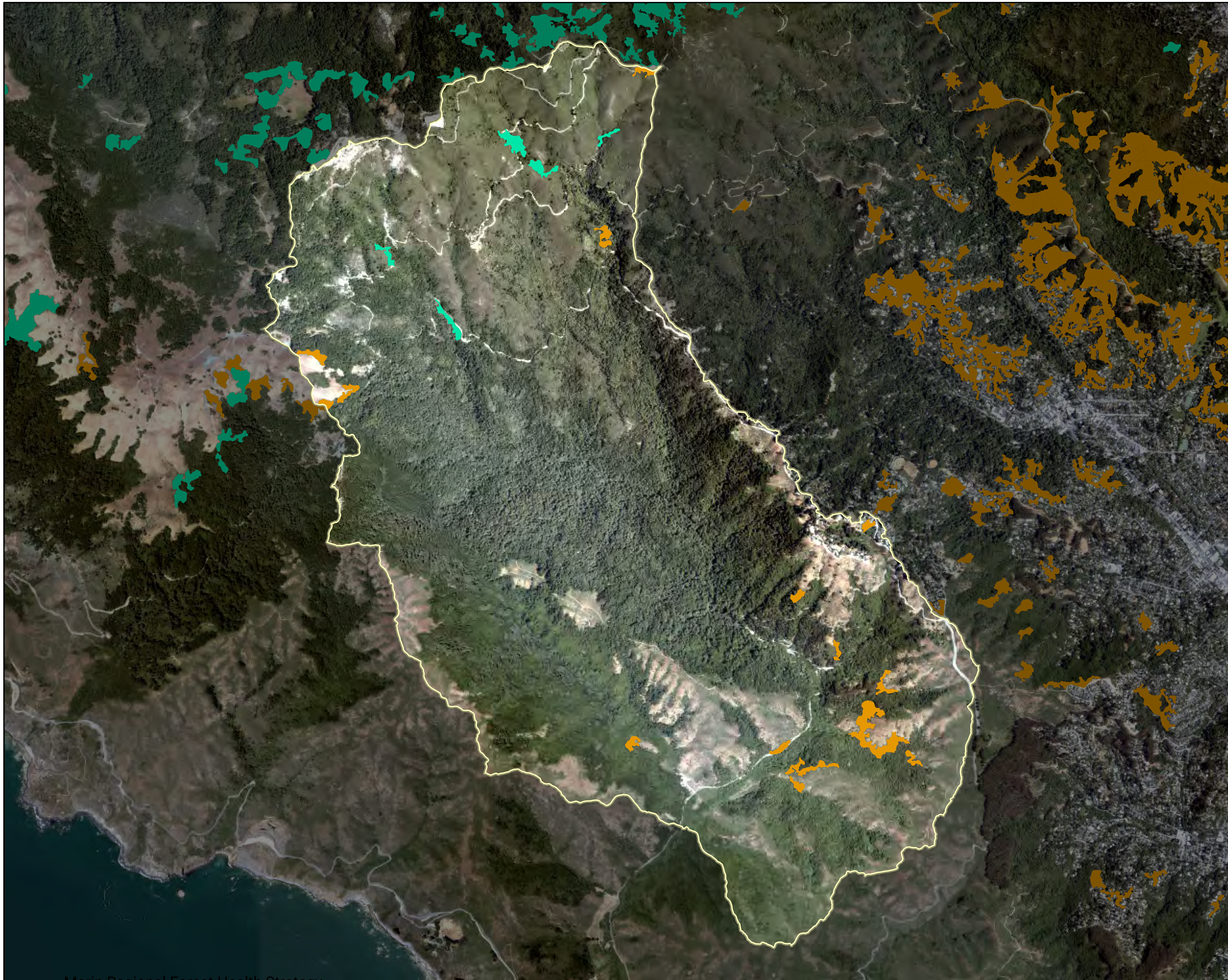
Headwaters Redwood Creek HUC 14



Map 11

Open Canopy Oak Woodland Alliances

Headwaters Redwood Creek HUC 14

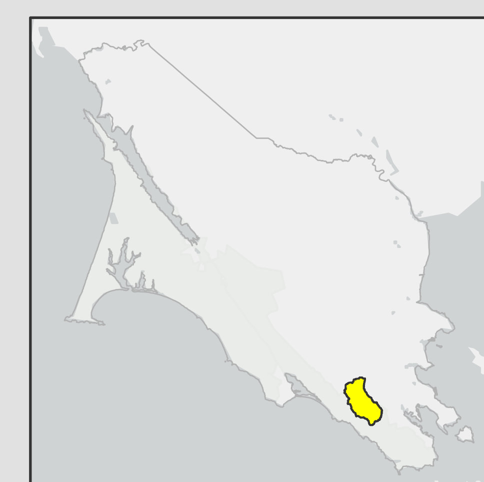


Open Canopy Oak Woodland Alliances

- Quercus agrifolia Alliance
- Quercus chrysolepis Alliance

About This Map

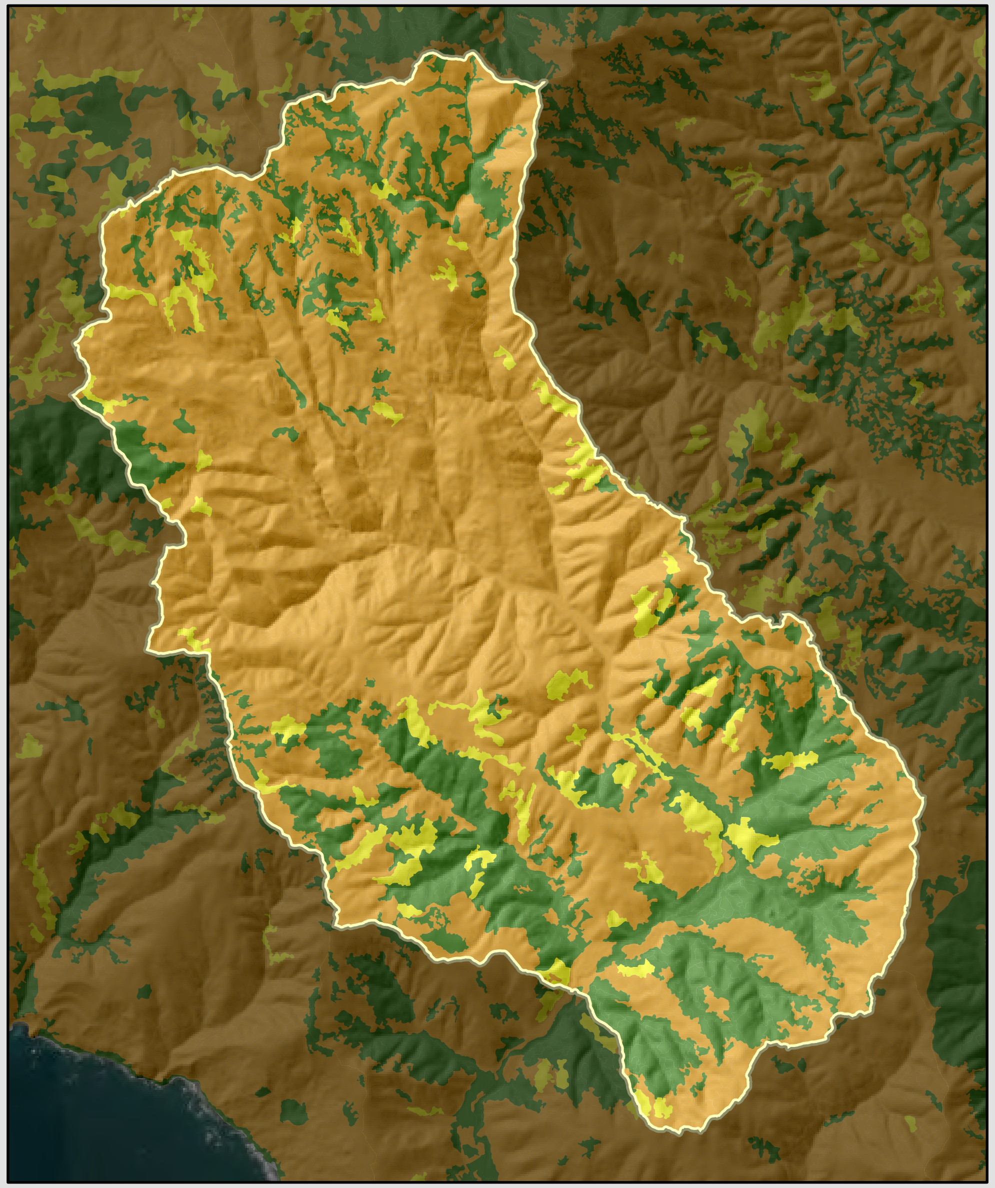
This map shows open canopy oak woodland alliances from the Marin County Fine Scale Vegetation Map. These alliances include: Quercus lobata Alliance, Quercus kelloggii Alliance, Quercus (agrifolia, douglasii, garryana, kelloggii, lobata, wislizeni) Alliance, Quercus chrysolepis Alliance, Quercus agrifolia Alliance, Quercus garryana Alliance, and Quercus douglasii Alliance.



1:24,865

0 0.5 1 Miles

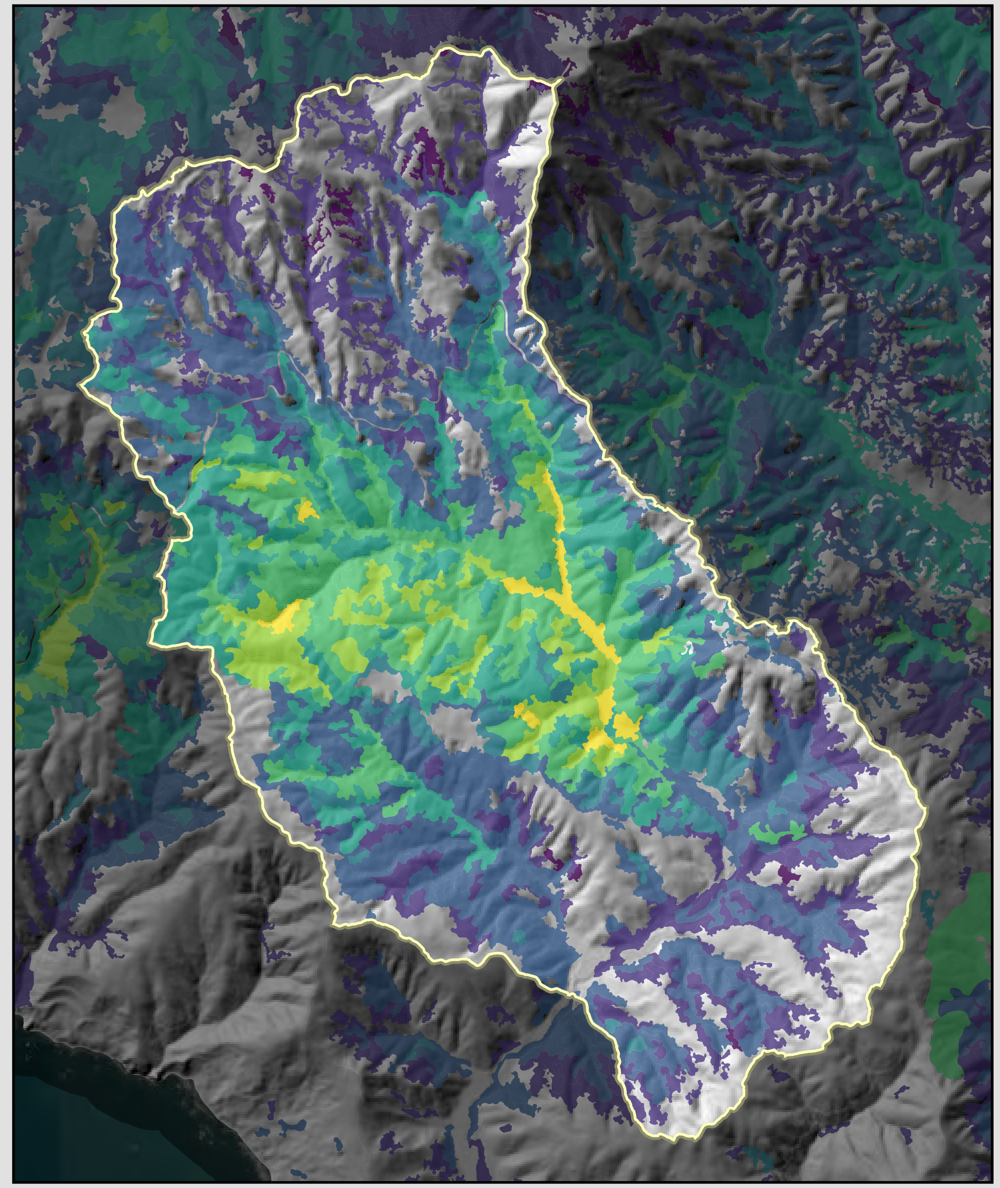
Relative % of Hardwood Cover



About This Map
Relative hardwood cover represents the percent of trees in a stand that are hardwoods (as seen from above). Relative hardwood cover plus relative conifer cover always adds up to 100%. Relative hardwood cover was assigned by Aerial Information Systems (AIS) using manual interpretation of the 2018 4-band, 6-inch resolution orthoimagery.

Relative % of Hardwood Cover
- <=25% Relative Hardwood
- 26-60% Relative Hardwood
- >60% Relative Hardwood

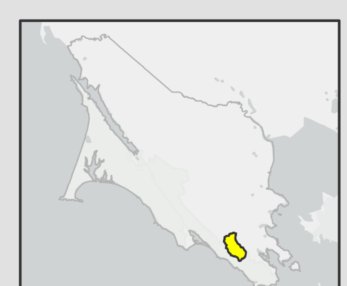
Mean Stand Height



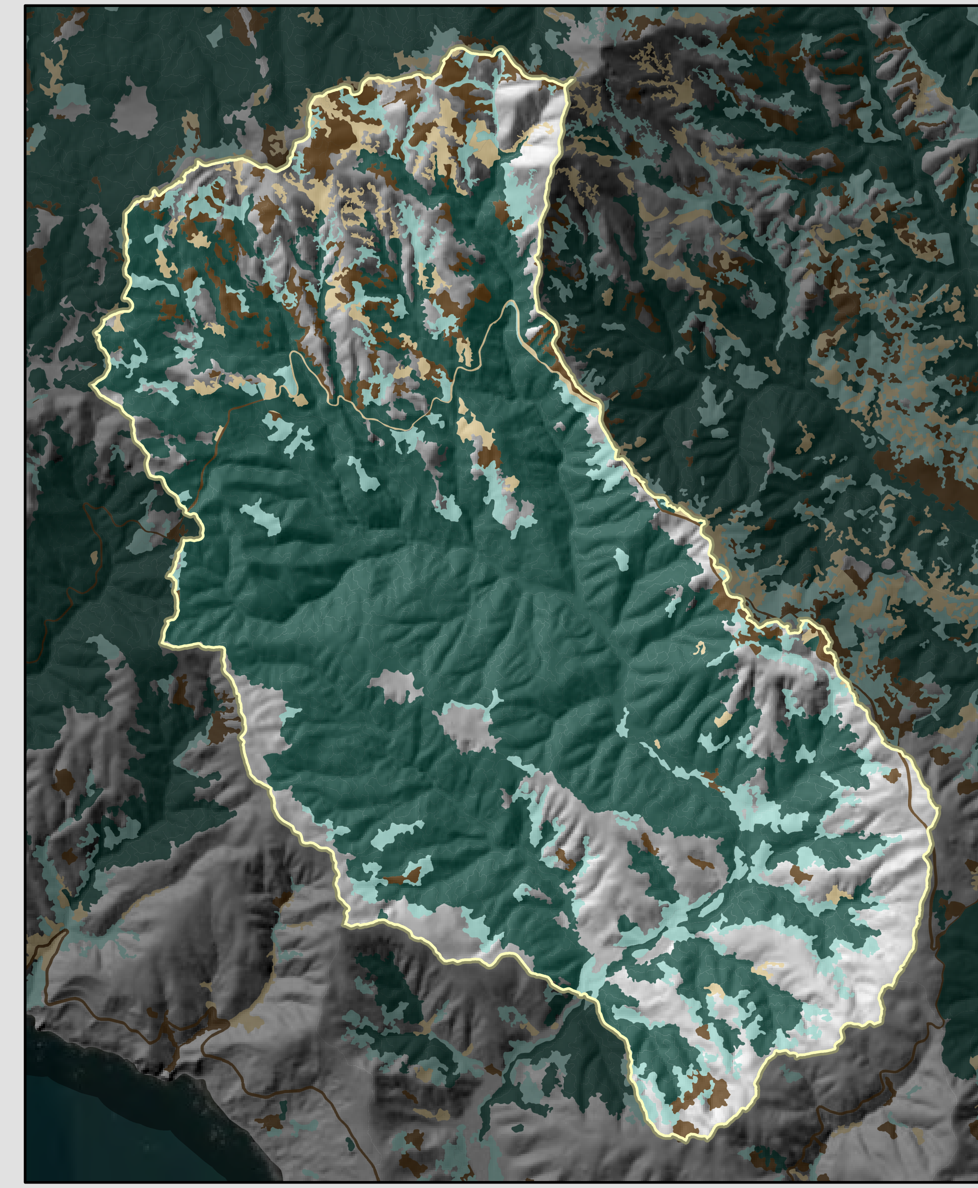
About This Map
This map shows the mean stand height (ft.) of vegetation stands > 10 feet tall. This metric represents the state of the landscape in winter 2019, when countywide lidar was collected.

Note that gray areas are either unvegetated or have a mean height less than 10 feet tall - in these areas the lidar derived hillshade is visible.

Mean Stand Height '19 (ft.)
- 10 - 20
- 21 - 40
- 41 - 60
- 61 - 80
- 81 - 100
- 101 - 120
- 121 - 140
- 141 - 172



Absolute Cover of Vegetation



About This Map
This map shows the absolute cover of vegetation > 15 feet tall within stands. This metric represents the state of the landscape in winter 2019, when countywide lidar was collected.

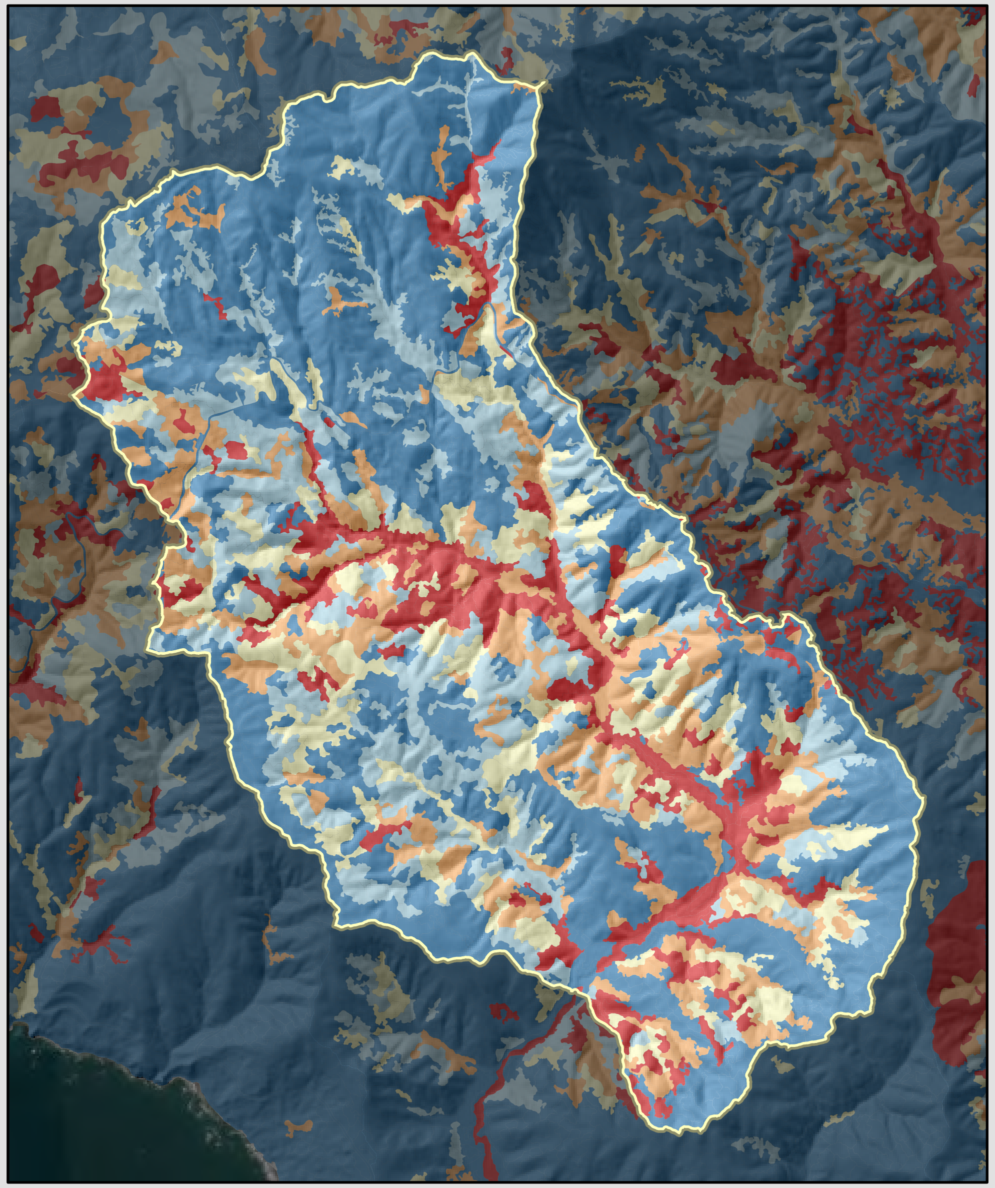
Note that gray areas are either unvegetated or have a mean height less than 15 feet tall - in these areas the lidar derived hillshade is visible.

Absolute Cover of Vegetation > 15 ft.
- 10-25% Cover
- 26-50% Cover
- 51-75% Cover
- >=76% Cover

1:43,427

0 0.7 1.4 Miles

% of Canopy Gaps Formed



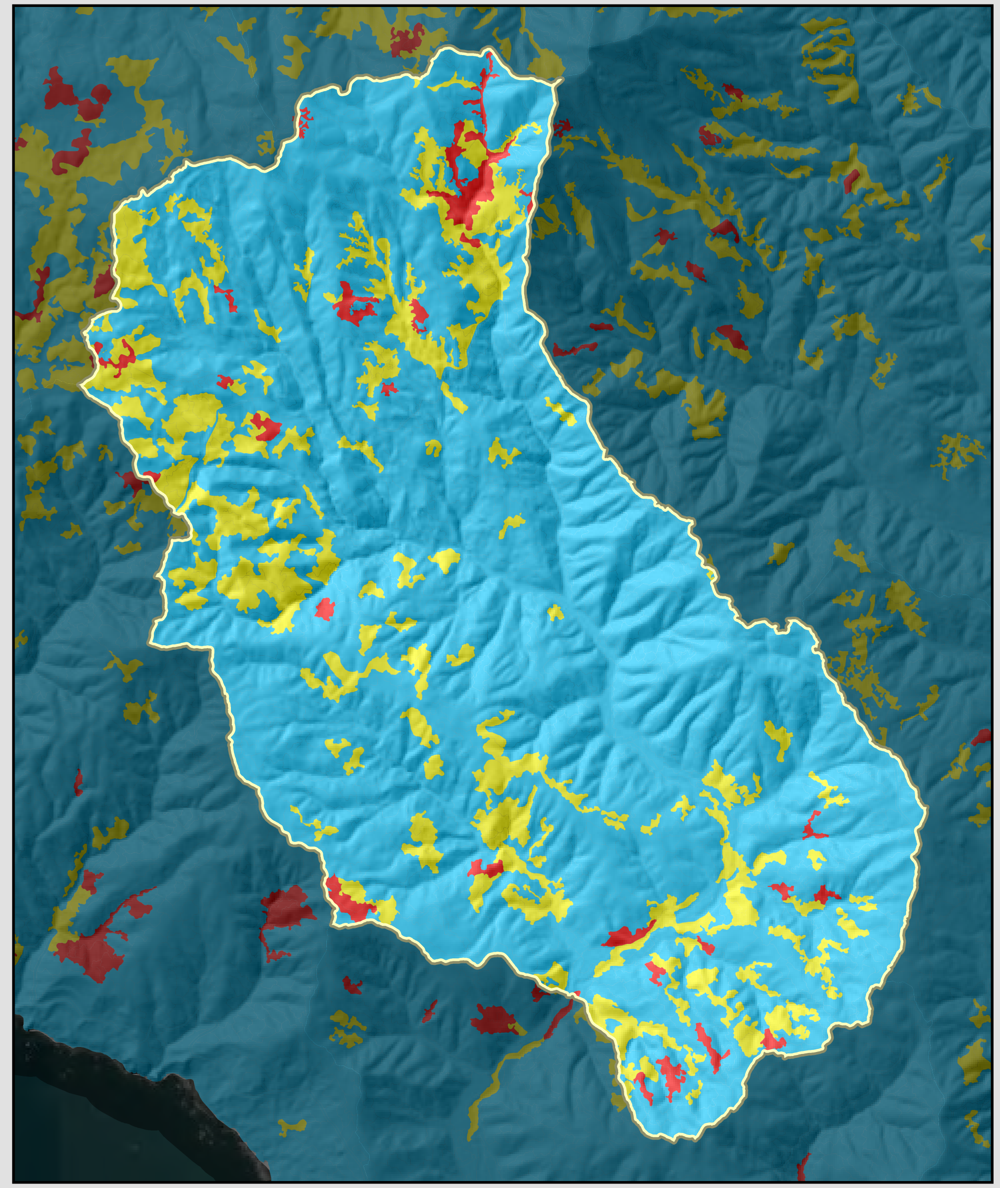
About This Map

This map shows percentage of forested stand canopy area that was a gap formed between 2010 and 2019. Canopy gap analysis was conducted using Canopy Height Model (CHM) differencing, where analysts calculated the difference between the CHM value in 2019 minus the CHM value in 2010. This analysis was performed in Trimble Ecognition, where the lidar CHM differencing was followed by noise removal to remove anomalous gaps. Analysts then removed gaps less than 40 sq. ft., and positive gaps along the coast and in urban areas.

% of Canopy Gaps Formed 10'-19'

- <.5% of Canopy 2010-2019 Gap
- .5 - 1.5% of Canopy 2010-2019 Gap
- 1.5 - 2.5% of Canopy 2010-2019 Gap
- 2.5 - 5.5% of Canopy 2010-2019 Gap
- >5.5% of Canopy 2010-2019 Gap

% Standing Dead

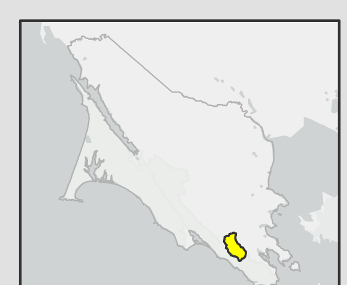


About This Map

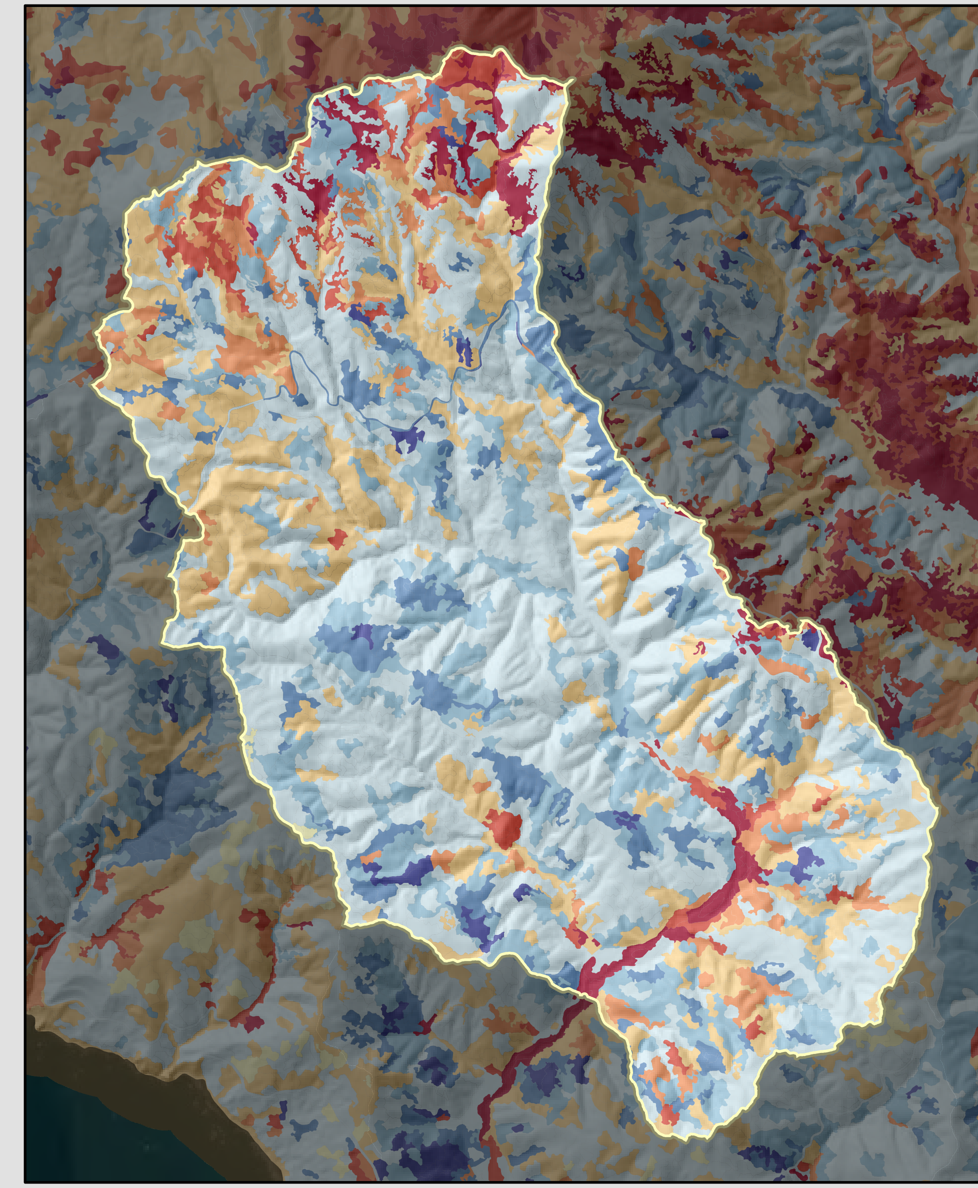
This map estimates the percentage of the woody canopy > 7 feet tall that did not have a living crown in 2018/2019. Standing dead vegetation was mapped using a combination of object- based image interpretation using Trimble Ecognition, which produced an estimate of standing dead vegetation using a combination of 2018 high resolution imagery and 2019 lidar. The automated output from Ecognition was reviewed and manually edited by Aerial Information Systems. Using 6-inch resolution 2018 4-band imagery, AIS adjusted the % standing dead value up or down where the automated result from Ecognition overestimated or underestimated standing dead vegetation.

% Standing Dead '19

- <.5% of Canopy Standing Dead
- .5 - 2.5% of Canopy Standing Dead
- >2.5% of Canopy Standing Dead



% Canopy Density Change



About This Map

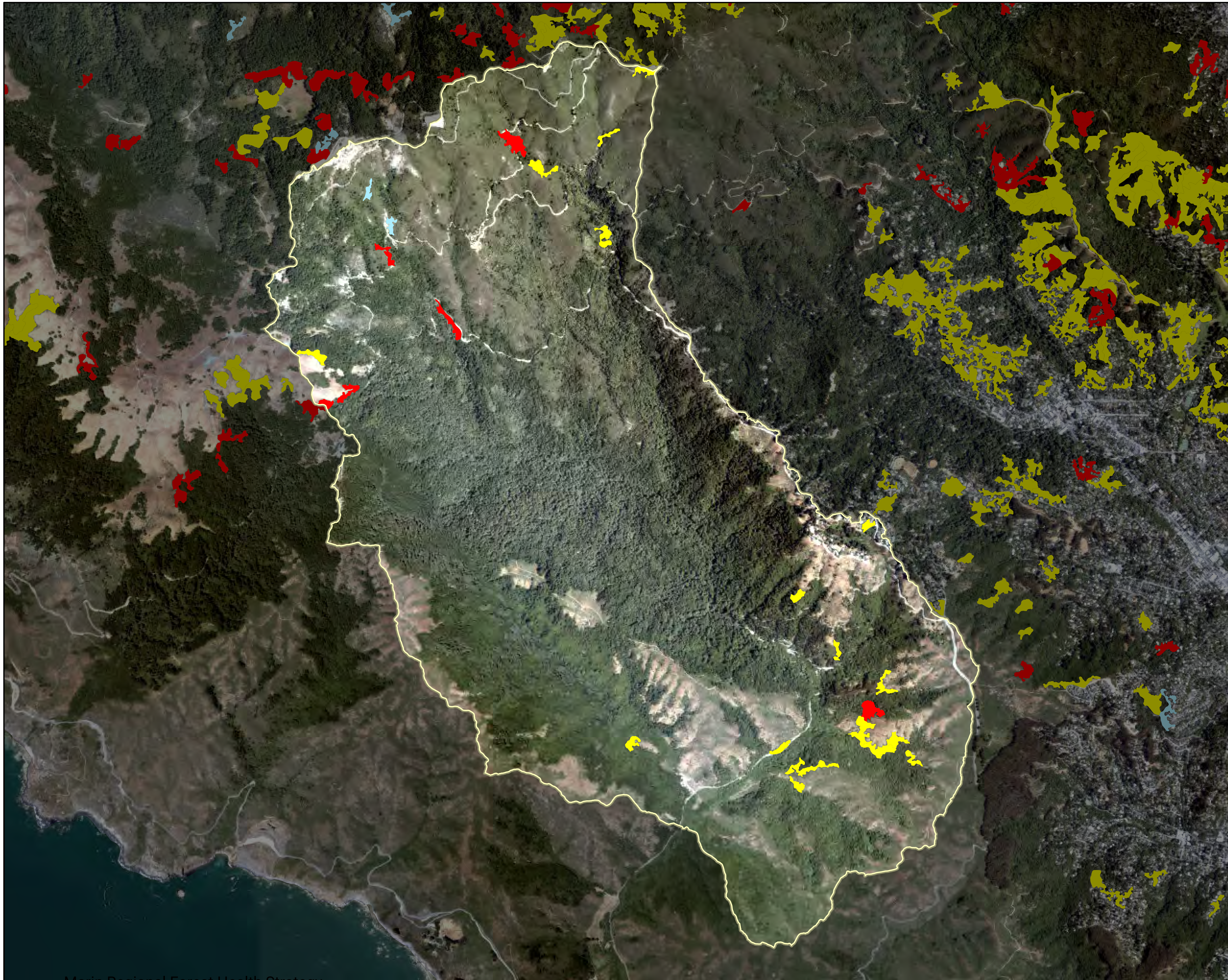
This map shows lidar-derived canopy density change for all lidar returns over 10 feet from 2010 to 2019. Canopy density was calculated for forested stands using all lidar returns over 10 feet above the ground. Canopy density was calculated for the 2010- and 2019-point clouds. The resulting 2010 1-meter canopy density raster was subtracted from the 2019 raster, creating a 2010 to 2019 canopy density change value, which was binned up into 9 classes. Note that 2019 lidar was collected in mid-winter and 2010 lidar was collected in late spring. For some areas, especially those with deciduous vegetation, a loss in canopy density may be driven by leaf phenology rather than meaningful density or vigor changes.

% Canopy Density Change 10'-19'

- >10% Density Loss
- 5 - 10% Density Loss
- 2.5 - 5% Density Loss
- 0 - 2.5% Density Loss
- No Change
- 0 - 2.5% Density Gain
- 2.5 - 5% Density Gain
- 5 - 10% Density Gain
- >10% Density Gain

1:43,427

0 0.7 1.4 Miles



At-Risk Oak Stands

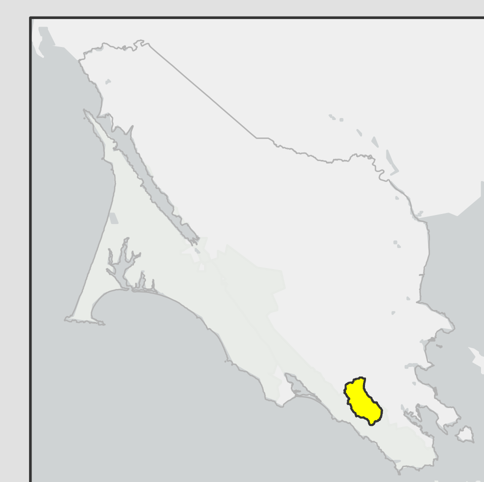
Headwaters Redwood Creek HUC 14

Oak Stands At-Risk to Doug-fir Conversion

- Actively Converting to Douglas-fir
- Threatened with Conversion to Douglas-fir
- Not Threatened or Converting

About This Map

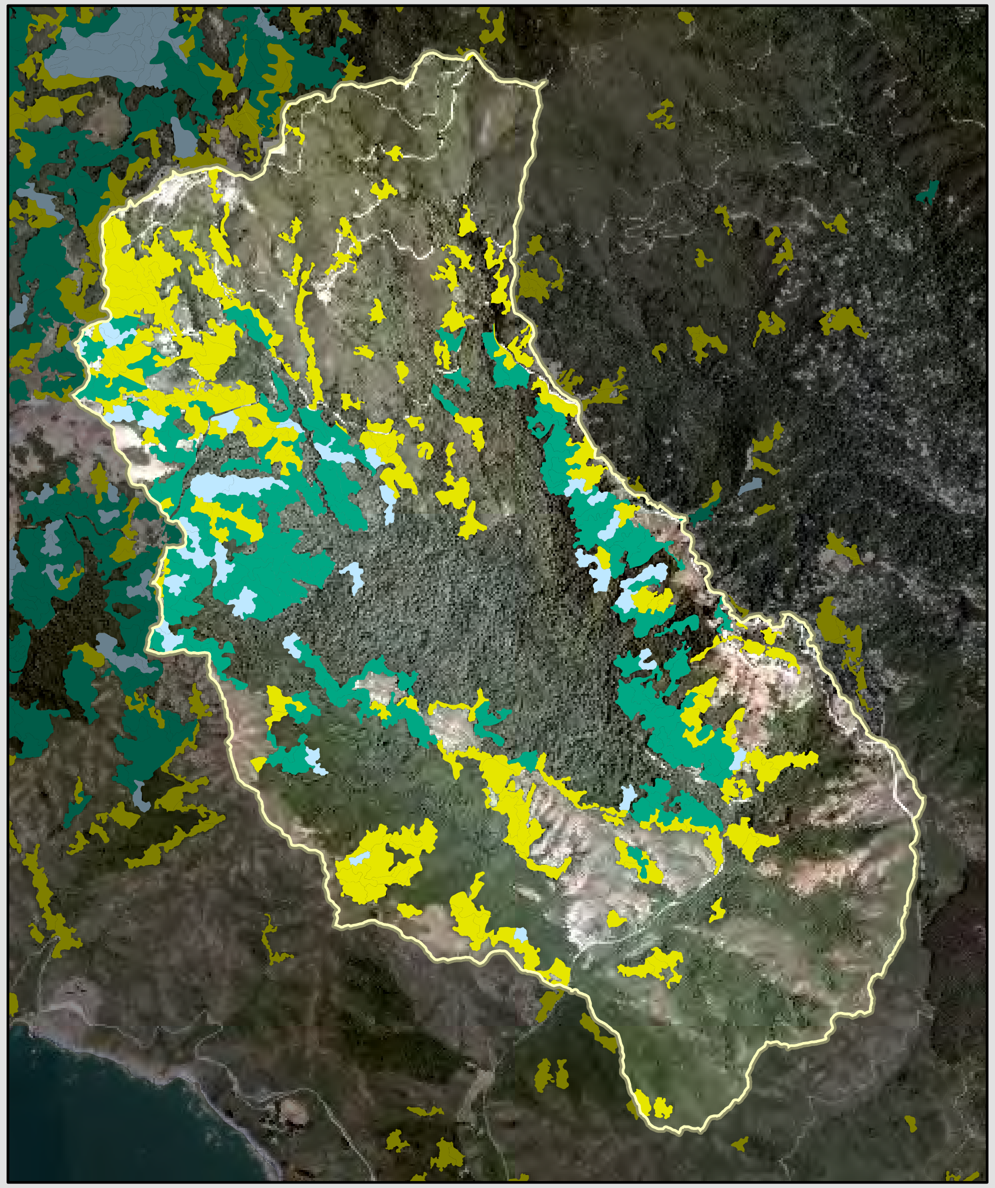
This map shows oak stands that are threatened with conversion to Douglas-fir, or that are in the process of converting. In Northern California, many areas of oak woodland are converting to Douglas-fir forests. This conversion stems from fire exclusion and other changes in land use and land management. This layer labels oak stands that may be either threatened with conversion or actively in the process of converting to Douglas-fir. Converting stands are oak stands where the vegetation map indicates that the stand has greater than or equal to 10% relative conifer cover. Threatened stands are oak stands within .25 air miles of either a conifer stand (excluding Sargent's cypress) or an actively converting oak stand.



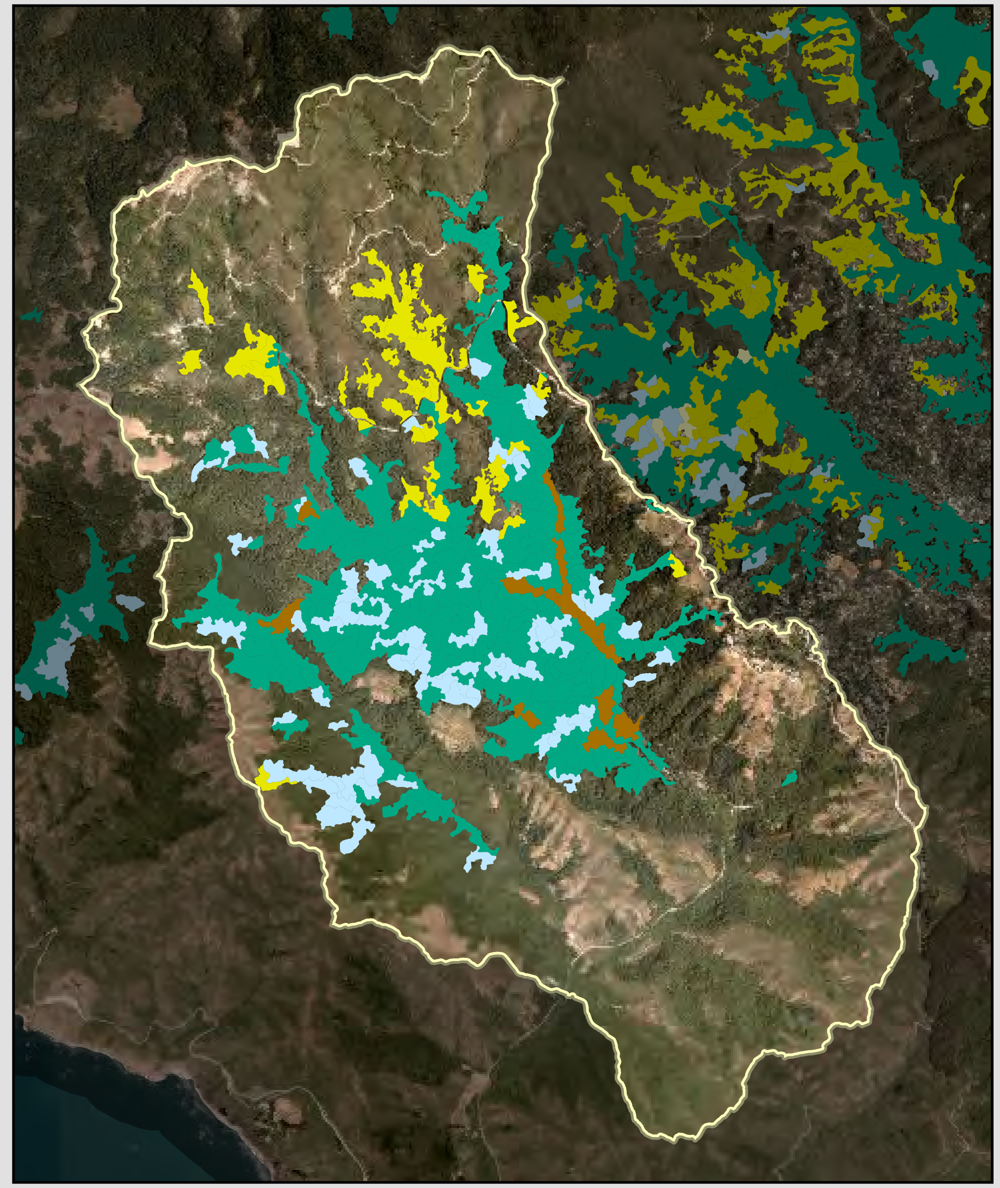
1:24,865

0 0.5 1 Miles

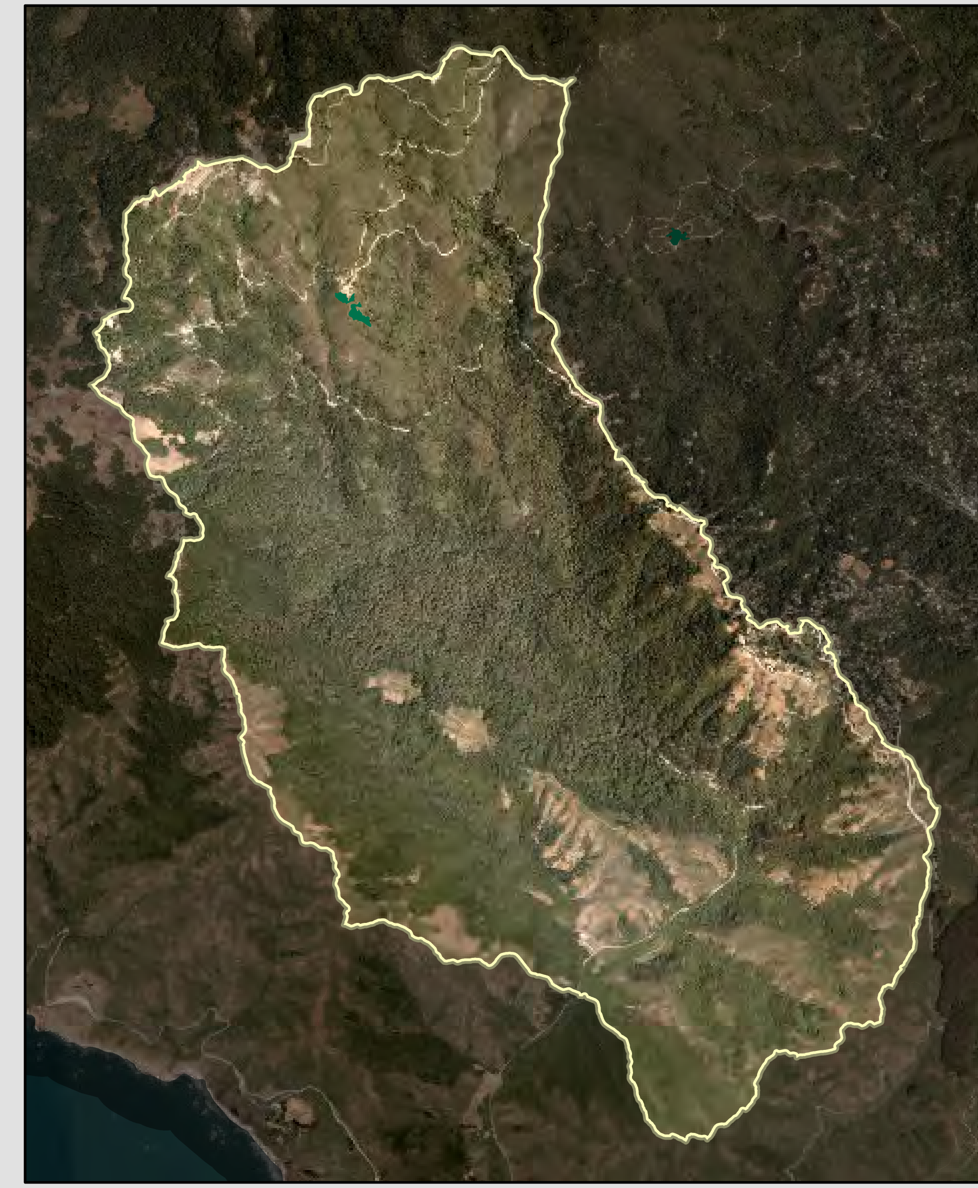
Doug-Fir Structural Classification



Redwood Structural Classification



Bishop Pine Structural Classification



About This Map
This map shows Douglas-fir classified by structural class, using lidar-derived metrics. Each Douglas-fir stand in Marin County was assigned a structural class that represents tree height and vertical structure. Structural classes were assigned using a combination of the lidar derived mean stand height and the stand's coefficient of variation for mean height (the standard deviation of mean stand height divided by mean stand height). Using these two variables, five structural classes were developed using ground condition data from One Tam land managers as a guide. This metric represents the state of the landscape in winter 2019, when countywide lidar was collected.

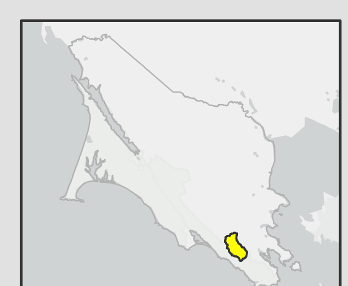
Note: An intermediate structural class was developed for Douglas-fir and Coast Redwood of 110-140 feet. While not displayed in this map, it is in the Forest Structure attribute table and may be useful for some applications.

Douglas Fir Structural Classification
- Small (<60 ft.) - LESS Vertical Structure
- Small (<60 ft.) - MORE Vertical Structure
- Med to Lge (60-140 ft) - LESS Vertical Structure
- Med to Lge (60-140 ft) - MORE Vertical Structure

About This Map
This map shows Redwood classified by structural class, using lidar-derived metrics. Each Redwood stand in Marin County was assigned a structural class that represents tree height and vertical structure. Structural classes were assigned using a combination of the stand's lidar derived mean height and the stand's coefficient of variation for mean height (the standard deviation of mean stand height divided by mean stand height). Using these two variables, five structural classes were developed using ground condition data from One Tam land managers as a guide. This metric represents the state of the landscape in winter 2019, when countywide lidar was collected.

Note: an intermediate structural class was developed for Douglas-fir and Coast Redwood of 110-140 feet. While not displayed in this map, it is in the Forest Structure attribute table and may be useful for some applications.

Redwood Structural Classification
- Small (<60 ft.) - LESS Vertical Structure
- Small (<60 ft.) - MORE Vertical Structure
- Med to Lge (60-140 ft) - LESS Vertical Structure
- Med to Lge (60-140 ft) - MORE Vertical Structure
- Largest Stands (140 ft. +mean height)



About This Map
This map shows Bishop pine classified by structural class, using lidar-derived metrics. Structural classes for Bishop pine were based on lidar-derived canopy cover, lidar-derived canopy gap information, mapping of standing dead trees, relative conifer cover, and fire history. Fire history was used to determine late-seral versus mid-seral status; canopy cover, relative conifer cover, and mortality were used to further divide the late-seral and mid-seral stands into more detailed structural classes.

Note that Bishop pine does not occur in many Marin County watersheds.

Bishop Pine Structural Classification
- Late Seral, Open and Shrubby

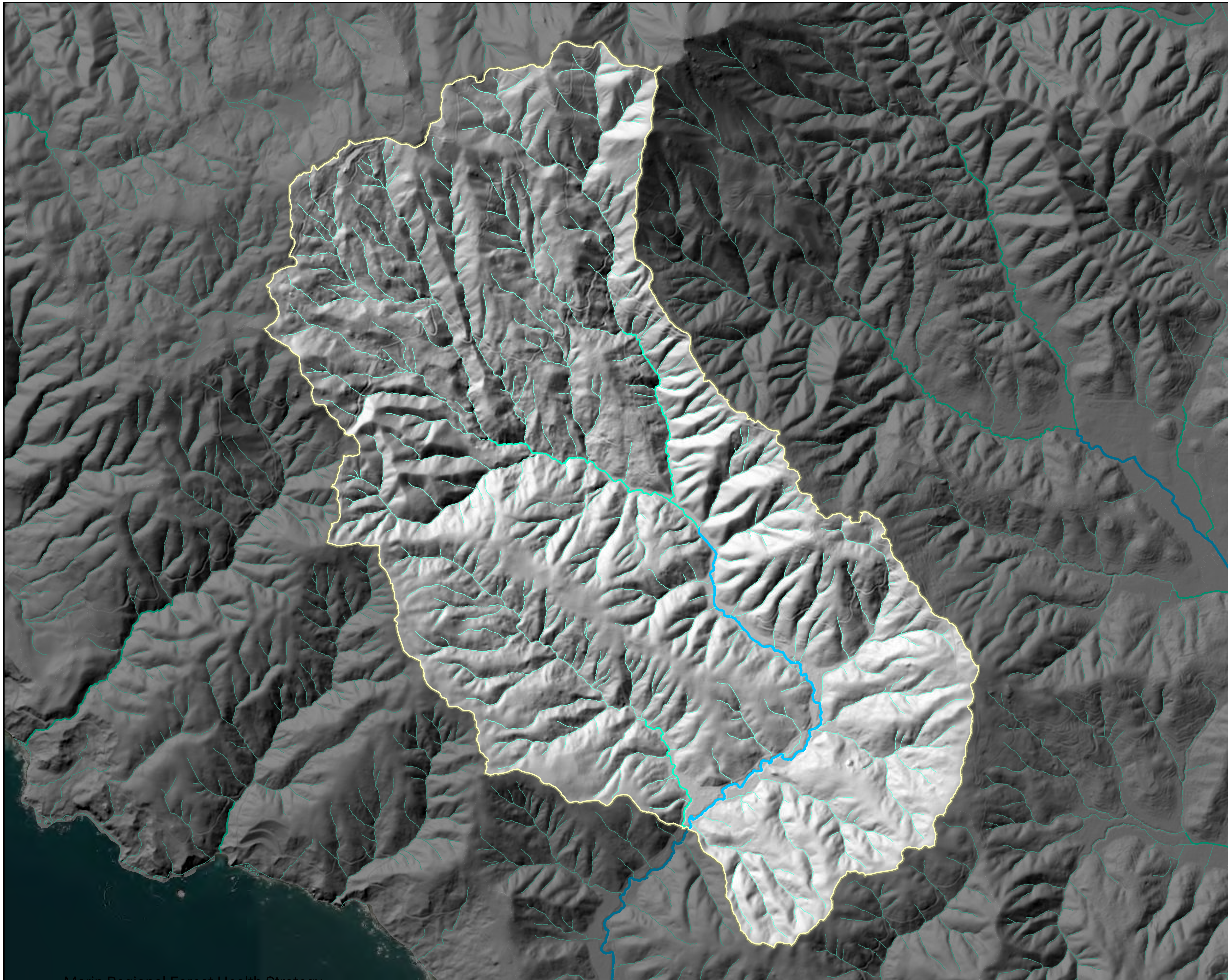
1:43,427

0 0.7 1.4 Miles

N

Thalwegs and Flow Accumulation

Headwaters Redwood Creek HUC 14

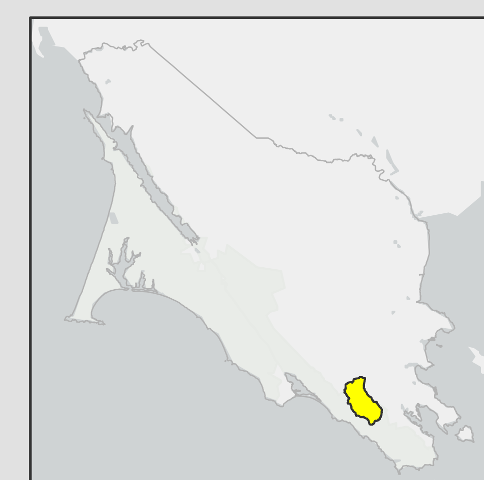


Upstream Catchment Area (Acres)

- 0 - 500
- 500 - 2000
- 2000 - 5000
- Ponds, Lakes, and Reservoirs

About This Map

This map shows lidar-derived stream thalwegs and water bodies on top of the Marin County lidar derived hillshade map. Stream thalwegs are symbolized by their upstream catchment area. Hillshades show the landscape in shaded relief, revealing the landscape with varying illumination and shadowing. Hillshades are a great reference data source for mapping streams and roads and for understanding a property's physical geography. Because lidar penetrates the forest canopy, hillshades are useful for seeing roads and trails that in aerial photography are occluded by vegetation. The hillshade was created from winter 2019 lidar data.

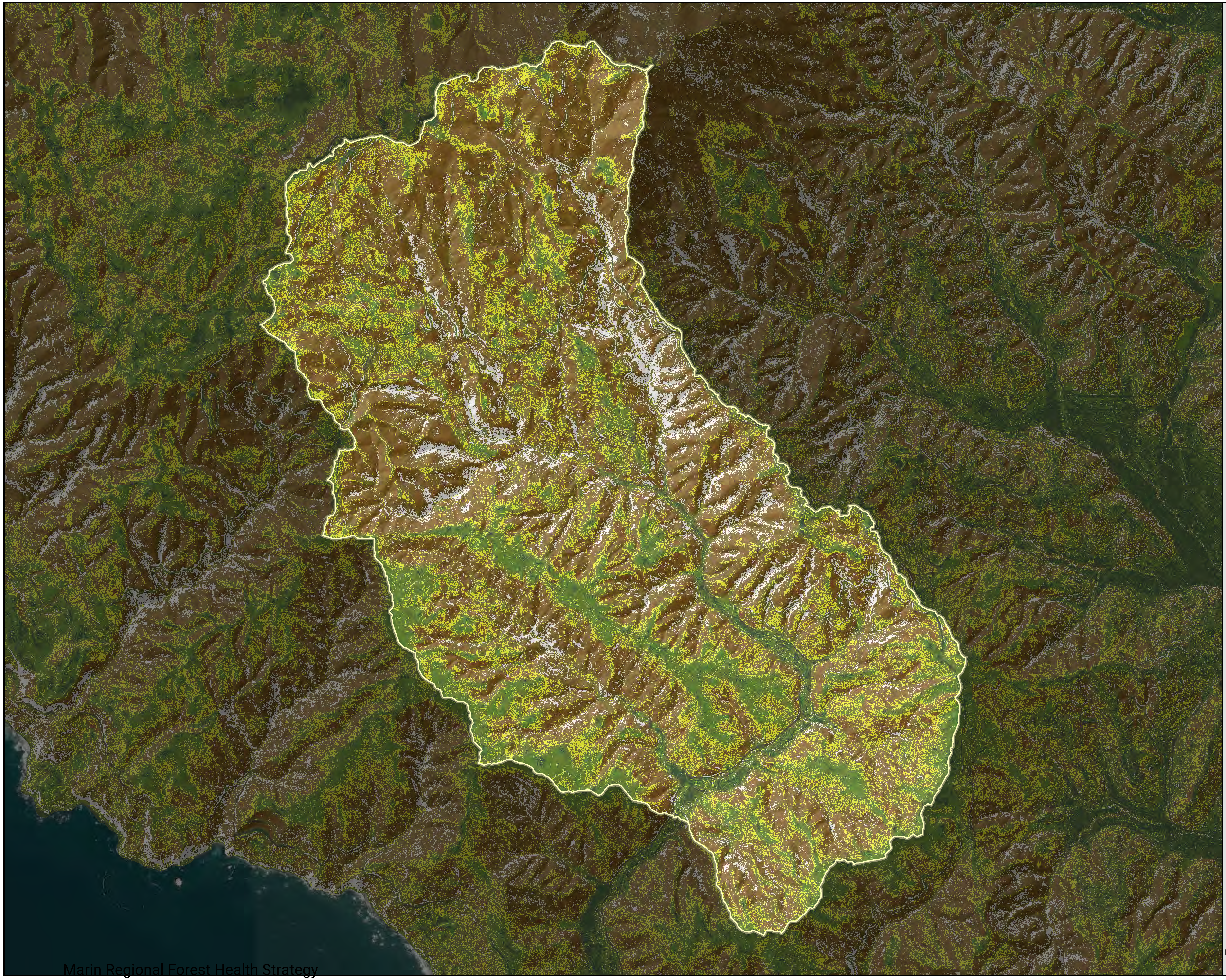


1:24,865

0 0.5 1 Miles

Slope

Headwaters Redwood Creek HUC 14

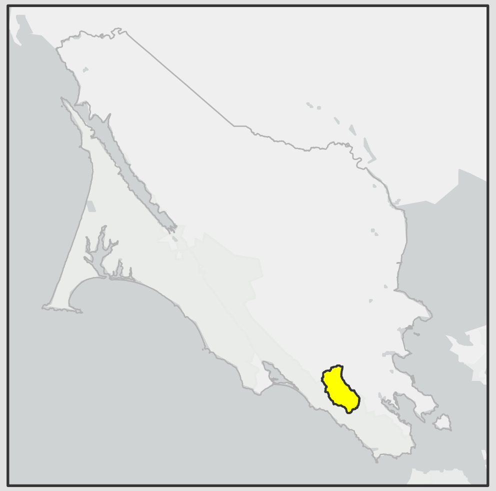


Slope (Degrees)

- 0-5
- 5-17
- 17-22
- 22-40
- 40-89

About This Map

This map depicts the downhill slope (in degrees). It is classified into 4 classes from the gentlest slopes shown in green to the steepest slopes shown in white. Slope is an important driver of fire behavior. Fire burns more intensely and spreads more rapidly on steeper slopes, and fire suppression is easier on gentle slopes. Slope can also be an important factor in planning fuel treatment strategies. Gentle slopes near roads can be much easier to treat than steep areas because of the difficulty of moving machinery and working on steep ground.



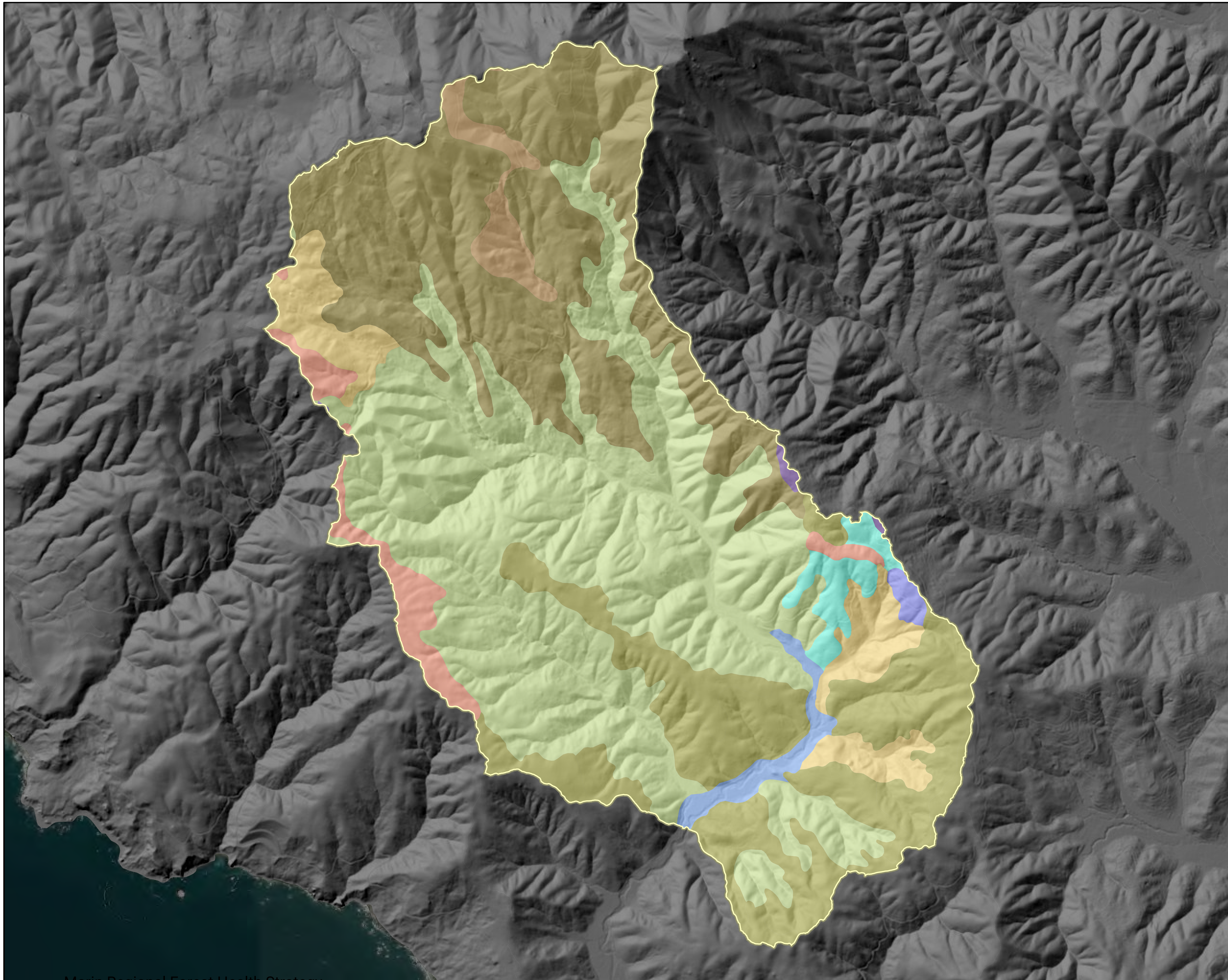
1:24,865

0 0.5 1 Miles

N

Soils

Headwaters Redwood Creek HUC 14



Soils

- Blucher-Cole complex
- Bonnydoon gravelly loam
- Centissima-Barnabe complex
- Cronkhite-Barnabe complex
- Dipsea-Barnabe very gravelly loams
- Henneke stony clay loam
- Maymen-Maymen variant gravelly loams
- Saurin-Bonnydoon complex
- Tamalpais-Barnabe variant very gravelly loams
- Tocaloma-McMullin complex
- Tocaloma-McMullin-Urban land complex

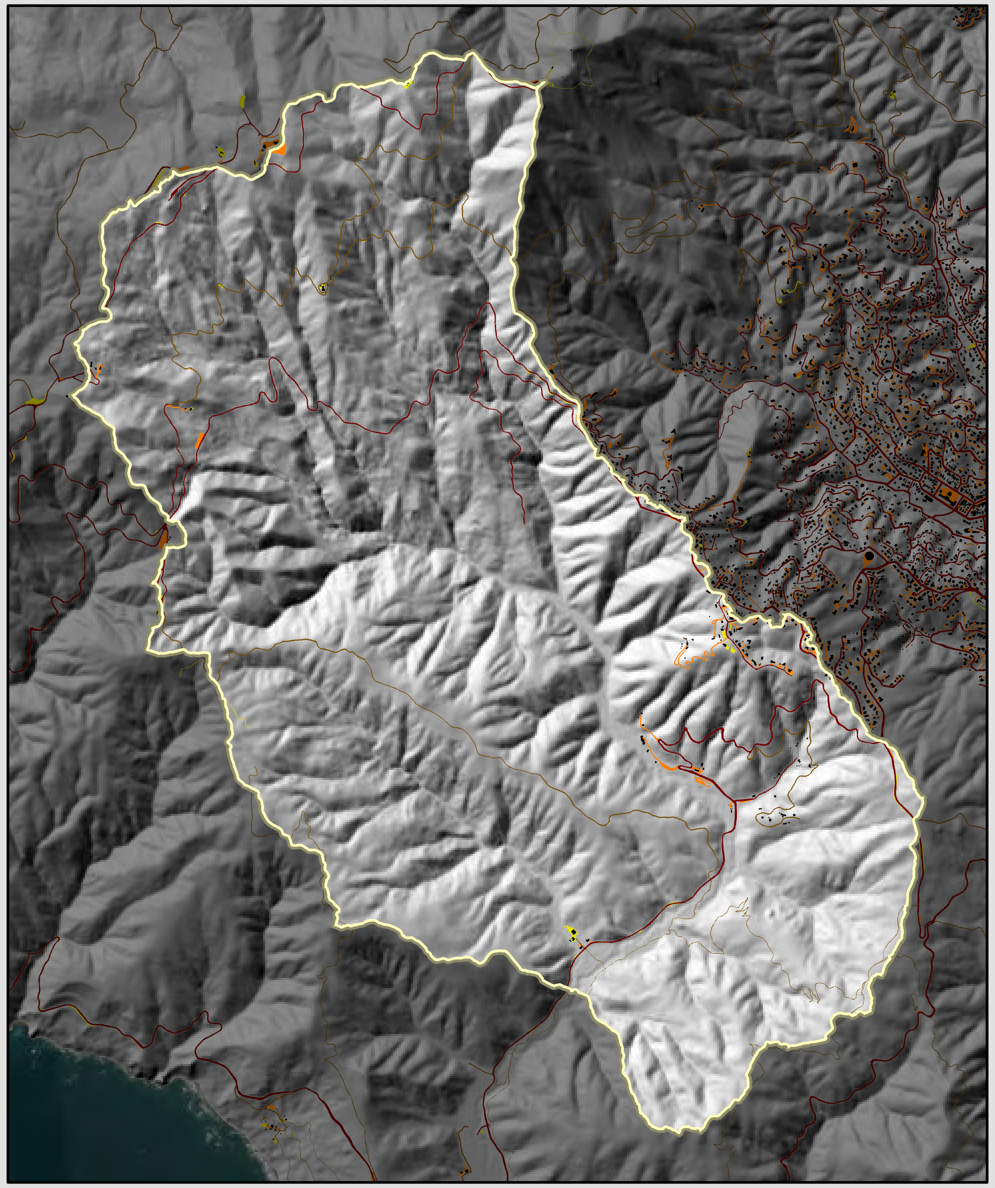
About This Map

See 'Soils Map Information' page in the watershed report located at the beginning of this pdf.

1:24,865

0 0.5 1 Miles

Impervious Surfaces



About This Map

This map shows a 5-class fine-scale polygon vector representation of all artificial impervious surfaces in Marin County. The impervious map represents the state of the landscape in summer, 2018.

Impervious Surfaces

- Other Paved Surface
- Building
- Dirt/Gravel Road
- Other Dirt/Gravel Surface
- Paved Road

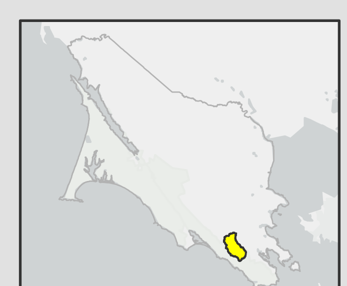
Fire Department Response Areas

About This Map

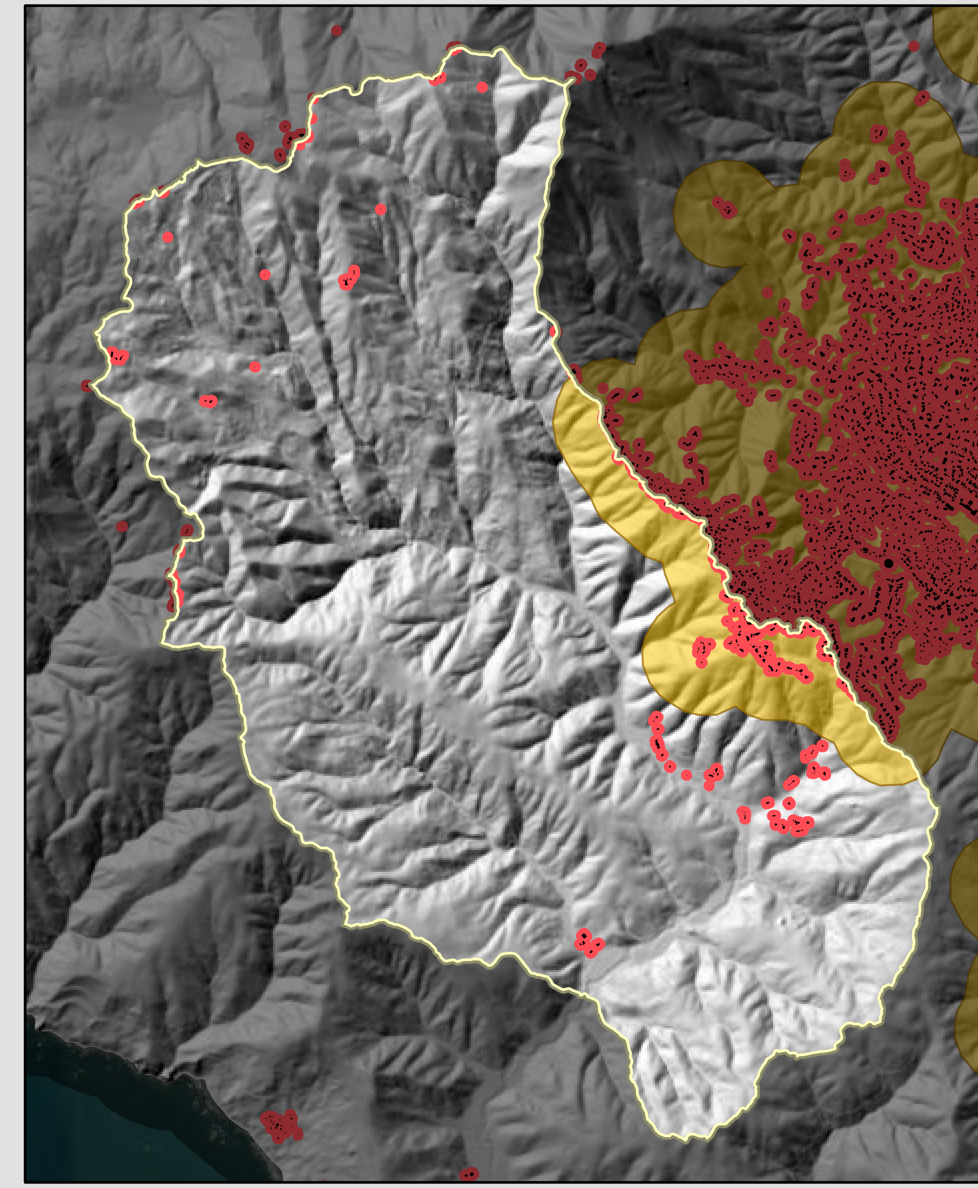
This map shows fire service boundaries in Marin County.

Fire Department Response Areas

- Southern Marin Fire Protection District
- Stinson Beach Fire Protection District
- Larkspur Fire Department
- Mill Valley Fire Department
- County Fire (CSA 31)



WUI and Defensible Spaces



About This Map

The Wildland Urban Interface (WUI) is the area where buildings and wildland vegetation are in proximity and intermix. Wildland fires that pose a direct threat to humans generally occur in the WUI. Defensible space buffers are a 100-foot break between buildings and vegetation meant to slow or stop the spread of wildfire. The buildings shown on this map were extracted from 2019 lidar data and buffered to show the 100 foot 'defensible space' area around the structure. Transmission lines from the California Public Utilities Commission (CPUC) greater than 30 kV are also shown on this map.

For more information visit https://www.readyforwildfire.org/

100 Ft. Building Buffer

- 100 Ft. Building Buffer

Buildings

- Buildings

Wildland Urban Interface

- Wildland Urban Interface

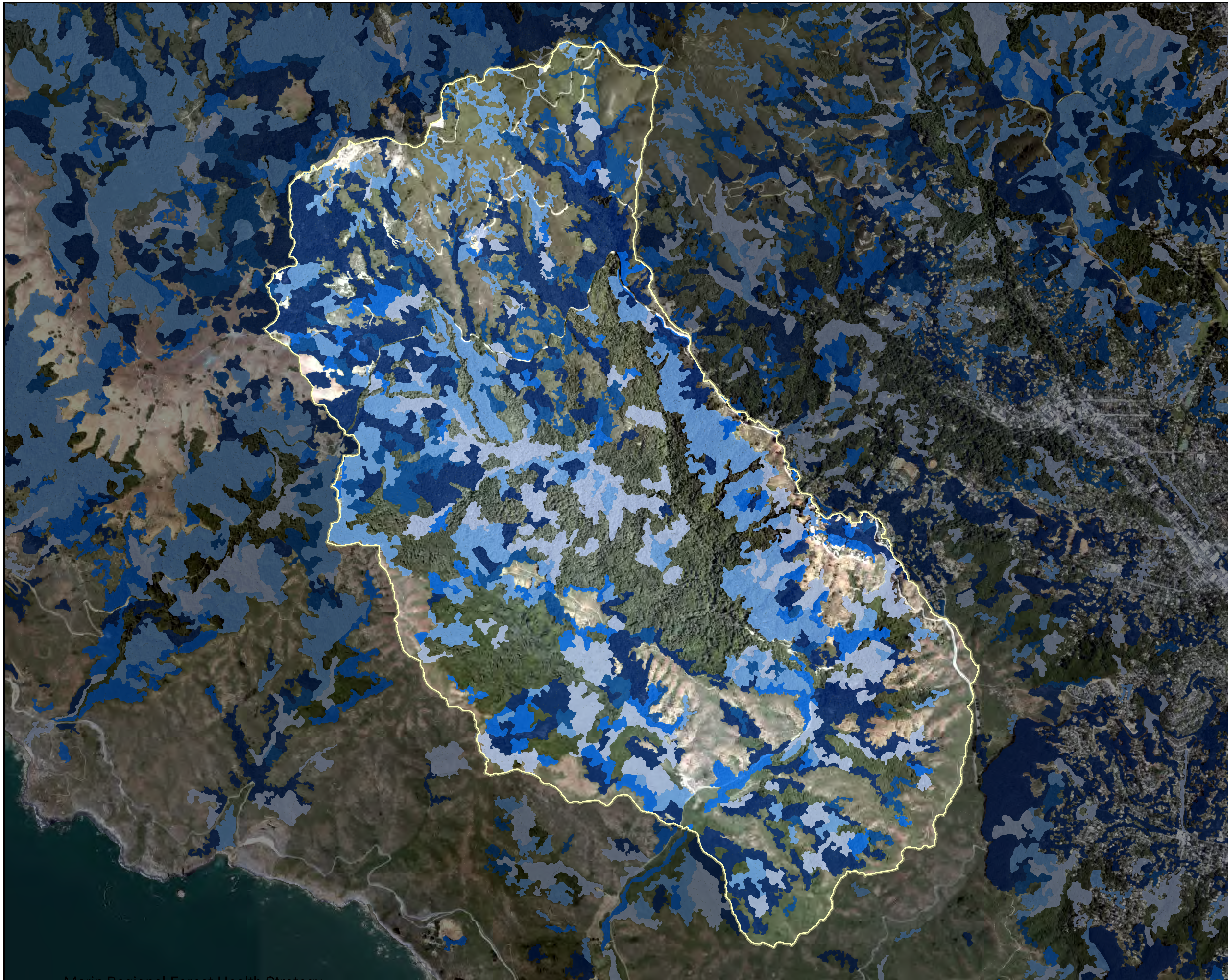
1:43,427

0 0.7 1.4 Miles

October 5, 2022 Headwaters Redwood Creek HUC 14

Departure From Desired Conditions

Headwaters Redwood Creek HUC 14

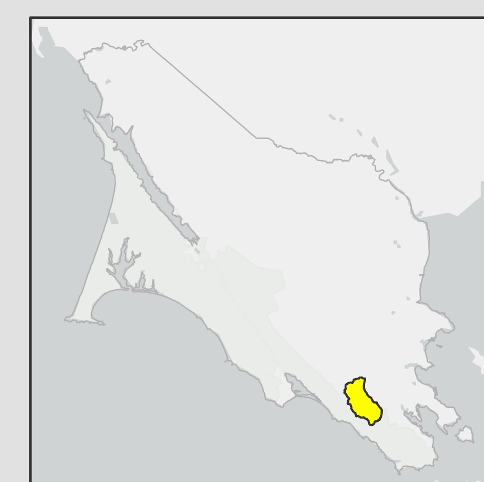


Departure From Desired Conditions

- 6 - Most Departed
- 5
- 4
- 3
- 2 - Least Departed
- 1 - Not a Forest Lifeform

About this Map

This map shows departure from desired conditions for native and non-native forest only. It was modeled by assigning scores based on forest health attributes. Short (less than 60 feet) stands of Douglas-fir received 4 points, medium (60-110 ft.) stands of Douglas-fir received 3 points, short redwood received 2 points, non-native woody vegetation received 10 points, and points were added for areas with significant standing dead trees. Stands with high and very high ladder fuels were assigned 2 and 3 points, respectively. Finally, threatened and converting oak stands were assigned three points. Scores were totaled and the resulting raw score was classified into 6 classes with 1 representing the smallest departure from desired conditions and 6 representing the largest departure.



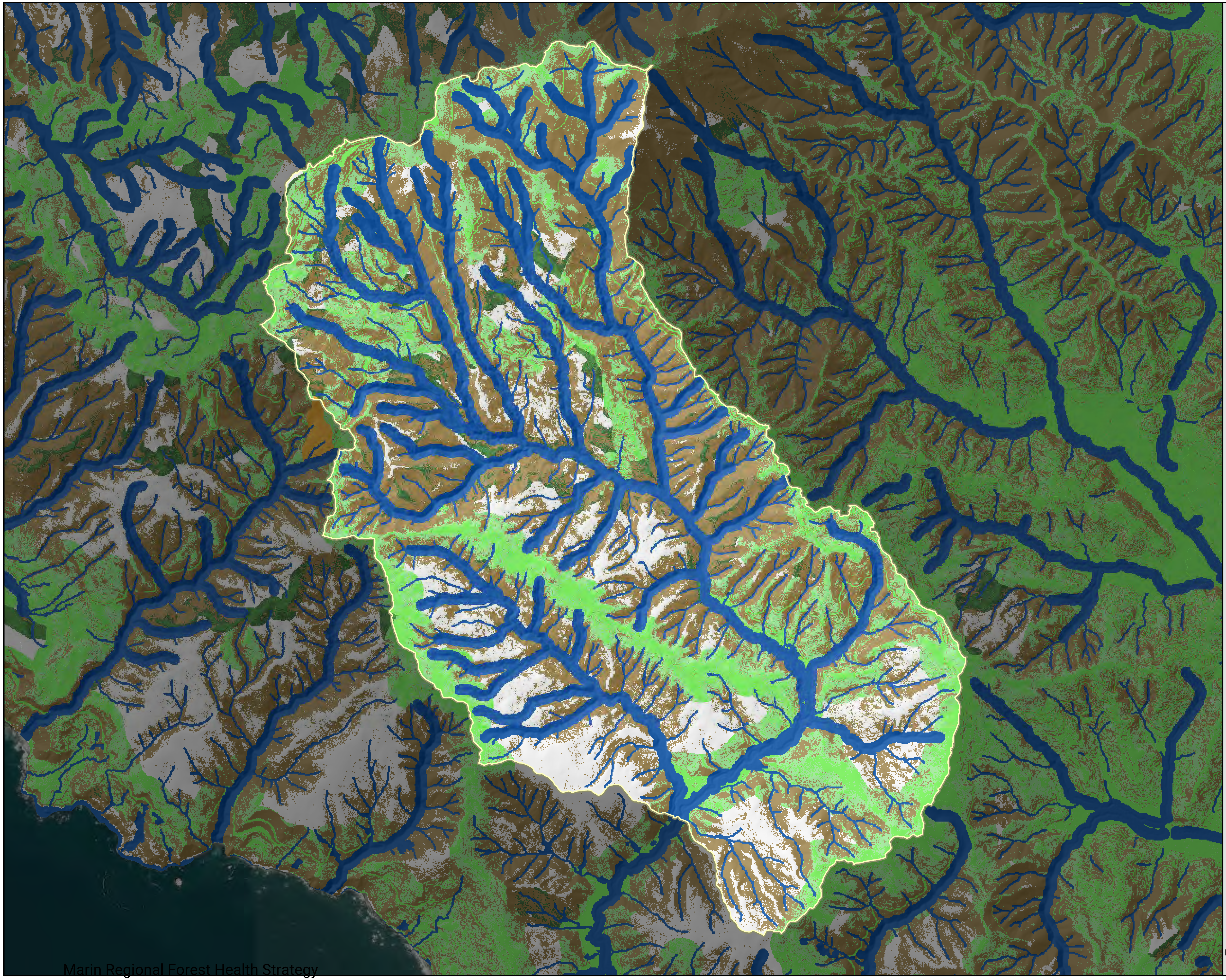
1:24,865

0 0.5 1 Miles

Map 21

Treatment Feasibility

Headwaters Redwood Creek HUC 14



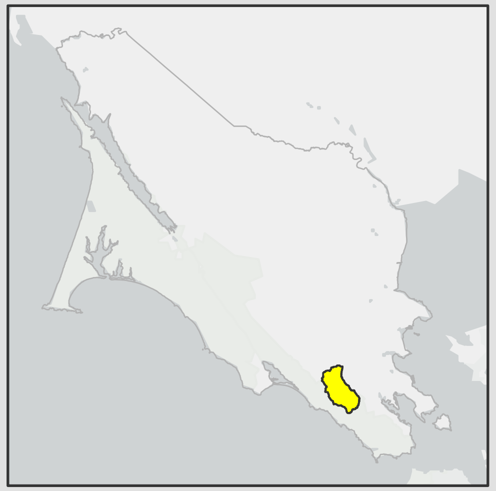
Treatment Feasibility

- Limited Feasibility - Poor Access
- Limited Feasibility - Steep
- Low Feasibility - Near Stream or Riparian Veg/ Wetland/Water
- Low Feasibility - Serpentine
- Feasible - Road Access, Mechanical
- Feasible - Road Access, Hand Crew
- Feasible - Trail Access Only, Mechanical
- Feasible - Trail Access Only, Hand Crew

About This Map

This 5-meter resolution Mechanical Treatment Feasibility raster provides information about the feasibility of mechanized vegetation management. This map highlights areas where management could potentially be challenging due to slope, access, and/or regulatory constraints.

The Marin Mechanical Treatment Feasibility was based on a similar analysis by North et. al (2015) for mechanized treatment feasibility across National Forests in the Sierra Nevada. The Mechanical Treatment Feasibility assessment provides a map of treatment feasibility based on the following set of criteria: slope, proximity to hydrology/wetlands, and distance to roads/trails. This assessment utilizes a set of geospatial datasets to spatially represent these constraints on mechanical treatment of woody vegetation.



1:24,865

0 0.5 1 Miles

APPENDIX E: OPPORTUNITIES FOR ADDITIONAL STUDY

This appendix lists forest health research and management questions identified by project partners during development of the *Marin Regional Forest Health Strategy*. Addressing these questions would help resolve conceptual model uncertainties and determine if key assumptions are correct, which would in turn support selecting the best forest health treatment and monitoring methods.

CLIMATE CHANGE RANGE SHIFT

One of the expected impacts of climate change is that geographical ranges for some species will change. For example, in California, as temperatures increase and rainfall decreases or is concentrated in fewer rainfall events, species may begin to shift from present distribution patterns.

- Is assisted migration for species a viable treatment type? Note that this is a broad question with many factors to consider including species, life history, dispersal capacity, the potential for climatic microrefugia, translocation sites, and distance between sites and populations.

MONITORING METHODS & COORDINATION

- What are the best accepted methods for measuring landscape-scale changes in ecosystem services, such as biodiversity, carbon sequestration, and water yield?
- Below-ground carbon and carbon levels of some vegetation types need more data collection. What are the best methods to collect this data at a landscape scale?
- What methods can be used to assess the singular and cumulative impacts (positive or negative) of forest health treatments on wildlife at the landscape scale?
- How can agency partners best coordinate post-fire analysis, results, and cross-agency learning?
- How should agencies coordinate monitoring across jurisdictional boundaries and standardize pre- and post-treatment monitoring methodologies?
- Should Marin land management agencies and the Marin Wildfire Prevention Authority collaborate to fund and implement countywide data collection, treatment tracking, and monitoring to ensure efficiency, provide for shared learning, and measure outcomes of forest health treatments?

TREATMENTS

- How can new forest health approaches or technologies be tested and accelerated towards implementation (e.g., inoculation reduction or disease resistance)?
- How do selective thinning treatments impact carbon sequestration and carbon stocks over the short term and long term? How does beneficial fire influence carbon sequestration and carbon stocks over the short term and long term? How do treatment types compare in terms of carbon stocks and in relation to climate change impacts?
- Should revegetation and assisted migration be included as treatments for Douglas-fir, other conifer species, and/or more general mesic forest types that may benefit from climate adaptation strategies? Although not included in the current Conceptual Model for these forest types, these approaches could be incorporated into future conceptual models and management plans.
- Resistance to pitch canker tends to build in an area over time (Gordon et al., 2010; Gordon et al., 2020). Given this, what is the value of breeding Bishop pine for resistance to revegetate infected stands, and how does that compare to allowing natural resistance to build over time?
- What combination of treatments are most effective for serotinous species, oak species, and other vegetation communities that benefit from fire for regeneration? Specifically, what beneficial fire applications, in combination with selective thinning and/or understory vegetation treatments, are most effective at promoting seedling germination? Does soil scarification or duff removal have a role in these treatments?

QUESTIONS FOR UNDERSTANDING FOREST HEALTH

- What relationship, if any, is there between forest stands with elevated levels of canopy mortality and persistent canopy gaps and environmental variables such as slope, aspect, microclimate, soil type, etc.
- What is the distribution of second-growth coast redwood and Douglas-fir in Marin County, and when was each area last logged?
- How is the long-term carrying capacity (e.g., number of trees per hectare) of forested lands predicted to shift because of climate change? How should carbon sequestration goals be modified given the potential for future landscapes to support lower tree densities?
- Is there a link between conifer encroachment into Open Canopy Oak Woodlands and other vegetation communities and other environmental variables such as soil moisture? How does potential on-going removal of Douglas-fir to preserve species heterogeneity and biological diversity fit in with carbon sequestration goals?
- What are the senescence thresholds for Sargent cypress and Bishop pine? When do old trees stop producing enough viable seed to ensure future stand regeneration?

- Studies indicate that Sargent cypress seed germination ability is negatively impacted by prolonged exposure to high temperatures; there appears to be a trade-off between temperature and exposure time for stimulating seed release while simultaneously maintaining viable seed. Will longer-lasting or high-intensity fires threaten seed viability?
- What will be the relationship between climate change and the impact of pathogens such as *Fusarium circinatum* and/or *Endocronartium harknessii* on Bishop Pine forests (Lee et al., 2019). How will changes in fog patterns, temperature, and rainfall patterns influence Bishop pine resistance and/or susceptibility to pathogens. Similarly, how will climate change influence impacts to trees susceptible to *Phytophthora ramorum* and other species of *Phytophthora*?
- What will be the long-term trend in the relationship between pathogen-impacted forests and fuel arrangements? Will the disease cycle continually contribute to potentially hazardous fuel arrangements in certain forests, and how will that trend vary in managed versus unmanaged areas?
- In the absence of fire and other forms of disturbance (e.g., grazing), what are the conversion dynamics between forest types other than Douglas-fir and Open Canopy Oak Woodlands? Are other hardwood forests, such as pacific madrone (*Arbutus menziesii*) at risk to Douglas-fir or other conifer conversion? Does fire exclusion favor some evergreen hardwood species, for example *Umbellularia californica* (California bay), and as a result should managers similarly consider those species as a potential threat to biological diversity and heterogeneity?
- Further study into historic fire regimes in Marin County, especially frequency and spatial patterning, maintained through Coast Miwok cultural burning and prescribed fire use by early ranching prior to the period of Euro-American record-keeping.

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Gordon, T.R., Kirkpatrick, S.C., Aegerter, B.J., Fisher, A.J., Storer, A.J., & Wood, D.L. (2010). Evidence for the occurrence of induced resistance to pitch canker, caused by *Gibberella circinata* (anamorph *Fusarium circinatum*), in populations of *Pinus radiata*. *Forest Pathology, 41* (3), 227-232. https://doi.org/10.1111/j.1439-0329.2010.00678.x

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