California Forest Carbon Plan

Managing Our Forest Landscapes in a Changing Climate

May 2018

The California Forest Carbon Plan was prepared by the Forest Climate Action Team. Members of the Forest Climate Action Team are:

- Office of Governor Edmund G. Brown Jr.
- California Natural Resources Agency
- California Environmental Protection Agency
- California Department of Forestry and Fire Protection
- California Air Resources Board
- State Board of Forestry and Fire Protection
- Sierra Nevada Conservancy
- California Tahoe Conservancy
- California Department of Parks and Recreation
- California Department of Fish and Wildlife
- California Department of Conservation
- California Department of Water Resources
- State Lands Commission
- California Department of Public Health
- USDA Forest Service
- Bureau of Land Management
- National Park Service
- Rural Counties Representatives of California
- California State Association of Counties

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Table of Contents

FOREWORD

California's forests, wildlands and adjacent communities have seen significant impacts associated with climate change over the past eight years. The series of destructive events includes:

- Largest forest fire in the state's history: Rim Fire (2013), 257,314 acres burned.[1]
- Largest wildfire in the state's recorded history: Thomas Fire (December 2017), 282,000 acres.[1]
- Deadliest wildfire complex in the state's history: Northern California Fires (October 2017), over 40 deaths.[1]
- Most destructive California wildfire: Tubbs Fire (October 2017), 5,643 structures destroyed.[1]
- Record drought: The 2012–2016 drought was unprecedented in its combination of warmth and dryness.[2]
- Record tree mortality: Due to drought, insects, and high stand density (2010-2017), 129 million trees died, mostly concentrated in 10 "high-priority" counties in the Sierra Nevada.[3]

Even as California works to come to grips with these realities, it faces uncertainties about what climate change has in store for us, in the short-, middle-, and long-term. This plan lays out recommended actions to achieve healthy and resilient forests based on what we know today about our forests and how climate change will evolve in California. Because of the limitations of our knowledge, we must continually monitor changes (with new and improved data) and learn from new scientific discovery. The worsening threats to our forests mean we cannot wait for better information before we act, but must begin acting now and adjust these actions as we learn more over time.

Fortunately, there are good opportunities and models for collaborative efforts to address forest health and resilience at the landscape level. These include:

- $220 million in funds for California Climate Investment grants in the California Department of Forestry and Fire Protection's fiscal year 2017-18 budget, and a $160 million appropriation request in the 2018-19 Governor's Budget, for forest health, fire prevention, and urban forests;
- The Sierra Nevada Conservancy's Watershed Improvement Program, and the collaborative landscape-level work occurring with the U.S. Department of Agriculture's Forest Service and other partners under its umbrella;
- A growing number of Good Neighbor Authority agreements between the Forest Service and state agencies to implement forest restoration work on National Forest lands;
- The collaborative, state-local-federal government framework and accomplishments of the Governor's Tree Mortality Task Force in addressing the massive tree mortality event in the Sierra Nevada;[4]
- An expanding number of signatories to the Memorandum of Understanding for the Purpose of Increasing the Use of Fire to Meet Ecological and Other Objectives;

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[1] CAL FIRE statistics, accessed December 26, 2017: http://cdfdata.fire.ca.gov/incidents/incidents_statsevents

[2] Mount, J., B. Gray, C. Chapelle, G. Gartrell, T. Grantham, P. Moyle, N. Seavy, L. Szeptycki, B. Thompson. (2017). Managing California's Freshwater Ecosystems: Lessons from the 2012-2016 Drought. Public Policy Institute of California, Sacramento, CA. November 2017. 54 p. http://www.ppic.org/wp-content/uploads/r_1117jmr.pdf

[3] USDA Forest Service. (2017). 2017 Tree mortality aerial detection survey results. Pacific Southwest Region, Vallejo, CA. https://www.fs.usda.gov/Internet/FSE_DOCUMENTS/fseprd566251.pdf and accompanying media release https://www.fs.usda.gov/Internet/FSE_DOCUMENTS/fseprd566303.pdf

[4] Task Force Website available at: http://www.fire.ca.gov/treetaskforce/

- The California Board of Forestry and Fire Protection is nearing completion of the Vegetation Treatment Program Programmatic Environmental Impact Report, which will facilitate environmental review for forest health and resilience projects on nonfederal lands in California;
- Completion of the updated 2017 Climate Change Scoping Plan, by the California Air Resources Control Board, which further emphasizes the role and importance of our natural and working lands, including forests, in addressing climate change mitigation; and
- The federal Fiscal Year 2018 Consolidated Appropriations Act included the Wildfire and Disaster Funding Adjustment, which helps to address the "fire borrowing" issue that has shifted Forest Service Forest Restoration funding to use for fire suppression and thereby limited the agency's ability to restore National Forest Lands.

0 Executive Summary

California is blessed with 33 million acres of forestland and an urban forest canopy that together capture and clean our water supply, provide habitat for countless wildlife, cool our cities, support local economies, and serve as spiritual and cultural centers for indigenous and local communities across the state. Forested lands also are the largest land-based carbon sink with trees and underbrush drawing carbon from the atmosphere and storing it in their cellulosic structure and in forest soils. Growing evidence, however, suggests these lands will become a source of overall net greenhouse gas (GHG) emissions if actions are not taken to enhance their health and resilience and to reduce the threats they face from wildfire, insects, disease, and a changing climate.

Most California forest types evolved with relatively frequent, typically low-intensity fire as an ecosystem process that provided forest resilience and renewal. Loss of traditional Native American fire use practices coupled with the introduction of fire suppression policies in the early in the 20th century has served to greatly reduce the role of fire in the natural ecological process. This role is better appreciated today, however, and broad, collaborative efforts are underway to increase use of fire for ecosystem function.

Decades of fire exclusion, coupled with drought and the stressors associated with climate warming, have dramatically increased the size and intensity of wildfires and bark beetle infestations and have exposed millions of urban and rural residents to unhealthy smoke-laden air. These conditions threaten progress toward meeting the state's long-term climate goals.

Recent wildfires have been the deadliest, most destructive, costliest, and largest in state history, while more than 129 million trees, primarily in the Sierra Nevada, have died from drought and insects since 2010. It is estimated that as many as 15 million acres of California forests need some form of restoration. This area is composed of approximately 10 million acres of federal lands[5] and 5 million acres of private and other public lands ranked as high priority for reducing wildfire threats to maintain ecological health.[6] California's urban forests also face multiple challenges, including drought, climate warming, and invasive exotic insects.

This Forest Carbon Plan considers opportunities to reverse these recent and historic adverse trends and firmly establish California's forests as a more resilient and reliable long-term carbon sink, rather than a GHG and black carbon emission source. The Plan provides multiple strategies to promote healthy and resilient wildland and urban forests that protect and enhance forest carbon and the broader range of public benefits from all forests in California. It emphasizes working collaboratively at the watershed or landscape scale to restore resilience to all forestlands in the state.

Achieving the goals of this plan will require a sustained commitment and funding from the state and federal governments. The fiscal year 2017-18 State budget marked the first year California dramatically increased funding for forest health and fire prevention programs through an appropriation of $220 million from the California Climate Investment Fund. The 2018-19 proposed state budget includes an additional $160 million. To add to the areas treated using these and other public funds, revenue-generating sustainable timber harvests on working forests also will be needed. Non-fiscal measures, such as technical assistance, efficient permitting processes, and commitment to collaborative efforts also can help to facilitate the accomplishment of the goals of this plan.

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[5] Nine million acres on National Forest lands and one million acres on Bureau of Land Management lands.

[6] California Department of Forestry and Fire Protection, 2010. Acres reported here are from a separate GIS analysis to produce forested acres by ownership class.

Structure and Key Findings

This Forest Carbon Plan describes forest conditions across California based on the best available information and provides a projection of future conditions given the ongoing and expected impacts of climate change. It also describes goals and related specific actions to improve overall forest health, enhance carbon storage resilience, increase sequestration, and reduce GHG emissions, and provides principles and policies to guide and support those actions. These principles and policies, which are grounded in existing laws and regulations, elevate enhancement of carbon sequestration and storage and reduction of black carbon and GHG emissions alongside the broader range of public benefits California's forests provide.

The key findings of the plan include:

- California's forested landscapes provide a broad range of public and private benefits, including carbon sequestration.
- The long-term impacts of excluding fire in fire-adapted forest ecosystems are being manifested in rapidly deteriorating forest health, including loss of forest cover in some cases.
- Extreme fires and fire suppression costs are increasing significantly, and these fires are a growing threat to public health and safety, to homes, to water supply and water quality, and to a wide range of other forest benefits, including ecosystem services.
- Reducing carbon losses from forests, particularly the extensive carbon losses that occur during and after extreme wildfires in forests and through uncharacteristic tree mortality, is essential to meeting the state's long-term climate goals.
- Fuel reduction in forests, whether through mechanical thinning, use of ecologically beneficial fire, or sustainable commercial timber harvest to achieve forest health goals, involves some immediate loss of forest carbon, but these treatments can increase the stability of the remaining and future stored carbon.
- Current rates of fuel reduction, thinning of overly dense forests, and use of prescribed and managed fire are far below levels needed to restore forest health, prevent extreme fires, and meet the state's long-term climate goals.
- Where forest stands are excessively dense, forest managers may have to conduct a heavy thinning to restore resilient, healthy conditions, which, among other benefits, will subsequently facilitate the reintroduction of prescribed fire as an ecological management tool.
- Sustainable timber harvesting on working forests can substantially improve the economic feasibility of these treatments to achieve forest health goals at the scale necessary to make an ecologically meaningful difference.
- Where necessary and appropriate, incentives should be provided to land managers to support adequate implementation of the forest treatments identified in this plan.
- Where forestlands have been diminished due to fires, drought, insects, or disease, they should be reforested with ecologically appropriate tree species from appropriate seed sources.
- The scale and combination of needed treatments and their arrangement across the landscape is likely to be highly variable and dependent on the local setting.
- The state must work closely with Federal and private landowners to manage forests for forest health, multiple benefits, and resiliency efficiently at a meaningful scale.
- The limited infrastructure capacity for forest management, wood processing, and biomass utilization, and the limited appropriately trained or licensed supporting workforce, are major impediments to forest restoration and ongoing forest management.

- Regionally-based efforts can best identify the areas that pose the greatest threat to forest health and offer the best opportunities to restore resilience.
- Landscape- or watershed-level collaboration—with leadership by federal agencies such as the USDA Forest Service and U.S. Bureau of Land Management, state agencies such as Conservancies and CAL FIRE, nongovernmental organizations, and large private landowners—is the most promising approach to greatly increasing the pace and scale of forest restoration treatments.
- Working forest conservation easements protect important forestland threatened with conversion to non-forest uses and can help to avoid to non-forest uses that will result in GHG emissions rather than carbon sequestration.

Proposed Actions

Below is a summary of the goals of the Forest Carbon Plan. The majority of these goals have a target date of 2030 for full implementation; this is intended to align with 2030 interim targets that were established through California's 2017 Climate Change Scoping Plan.[7] Other target dates are used where timelines already exist in another established state or federal plan (e.g., all targets associated with the State Wildlife Action Plan have 2025 target dates), or for activities that currently have elevated scales of implementation that will need to be surpassed to effectively reach the targeted 2030 goals. For example, the 2020 short-term target for fuels reduction rates would be a benchmark on the route to the 2030 targeted scale. These short-term benchmarks provide an opportunity to evaluate progress to date, consider the effects of actions taken, and utilize new information and data to guide longer-term goals for 2030 and beyond. Collaboration and identification of incentives will be critical to achieving these goals.

A. Significantly increase the pace and scale of forest and watershed improvements on nonfederal forest lands through incentives and other mechanisms:
    1. By 2020, increase the rate of forest restoration and fuels treatment, including prescribed fire, from the recent average of 17,500 acre/years to 35,000 acres/year.
    2. By 2030, further increase the rate of forest restoration and fuels treatment to 60,000 acres/year.
    3. By 2030, increase the area reforested annually by 25 percent above the current level.
    4. By 2025, expand areas of high priority habitat by 5 percent above current levels, as provided in the State Wildlife Action Plan.
    5. Ensure that timber operations conducted under the Forest Practice Act and Rules contribute to the achievement of healthy and resilient forests that are net sinks of carbon.
    6. Promote increasing the acreage of forest carbon projects and remove barriers to their implementation.
    7. Increase rate of treatment to approximately 500,000 acres per year on non-federal lands to make an ecologically meaningful difference at a landscape scale. This estimate provided by CAL FIRE is an aspirational goal based on consideration of ecological need and predictions of capacity to implement treatments. This acreage is currently more than what CAL FIRE considers operationally feasible. It should be considered a target to work toward, and is achievable pending increased resources and expanded markets for woody materials. These treatments types can include all those identified in items 1-6 above, as well as other appropriate treatment types.

[7] California Air Resources Board 2017a.

8. By 2030, lead efforts to restore 10,000 acres of mountain meadow habitat in key locations.

B. Support Federal goals and actions to improve forest and watershed health and resiliency:
    1. By 2020, on lands managed by the USDA Forest Service, increase health and resiliency treatments from the current approximately 250,000 acres/year to 500,000 acres/year, and on BLM managed lands increase from approximately 9,000 acres/year to 10-15,000 acres/year.
    2. By 2030, eliminate the current USDA Forest Service Reforestation Need balance and sustain future treatments at levels where annual additions are matched by treatments.
    3. By 2030, increase forest resilience through treatments including fuels reduction, managed fire, prescribed fire, noxious weed removal, and road improvements to reduce sedimentation, resulting in resource benefits to approximately 9 million acres on National Forest System Lands in California.
    4. By 2030, bring resource benefits to approximately 1.2 million acres of forests and woodlands on Bureau of Land Management lands in California through national landscape conservation networks, landscape mitigation strategies, native seed rehabilitation and restoration, and vegetation treatments including fuels reduction, managed and prescribed fire, and weeds management. Forestry and fuel reduction targets will expand from a current average of 9,000 acres/year to 20,000 acres/year.
    5. By 2030, the USDA Forest Service will restore 10,000 acres of mountain meadow habitat and target reliable funding for such activities on National Forest System lands in California.

C. Prevent forest land conversions through easements and acquisitions, as well as land use planning:
    1. By 2030, increase the acreage of forestland protected by conservation easements by 10 percent with a focus on areas that are threatened by development and can effectively sequester and store resilient carbon while providing wildlife habitat, protecting watershed values, and supporting other forest ecosystem benefits.
    2. Promote the adoption of regional transportation and development plans, such as SB 375 Sustainable Communities Strategies and Climate Action Plans, and recognize the climate change mitigation impacts of land use and forest conditions in those plans.

D. Innovate solutions for wood products and biomass utilization to support ongoing forest management activities.
    1. Expand wood products manufacturing in California, and take actions to support market growth scaled to the longer-term projections of forest productivity and resource management needs.
    2. Increase the total volume of carbon stored through greater use of durable wood products from California forests, particularly in buildings.
    3. Continue public investment to build out the 50 megawatt (MW) of small scale, wood-fired bioenergy facilities mandated through SB 1122 (Rubio, 2012).
    4. Maintain existing bioenergy capacity at a level necessary to utilize materials removed as part of forest restoration. In the short term, it is critical to meet the public safety and tree disposal needs stemming from widespread tree mortality in the central and southern Sierra Nevada.
    5. Continue to support research into the potential to convert woody biomass into transportation fuels and other potential products.

6. Develop and support the generation of and markets for soil amendments from forest biomass for agricultural, rangeland, municipal, and residential use, to advance the goals of the Healthy Soils program and other efforts.

E. Support key research, data management, and accountability needs.
   1. Centralize and standardize tracking of implementation activities to meet Forest Carbon Plan targets to account for all efforts; quantify carbon sequestration and GHG and black carbon emission outcomes; identify areas of underperformance; and effectively work toward the ultimate performance objective of maintaining California's forests as net sinks of carbon. Develop a centralized database or other information management system to track implementation.
   2. Complete forest carbon inventories (stocks and emissions), accounting methodologies at multiple scales, and GHG emissions projections for both a reference case and scenarios that include increased management and conservation activity.
   3. Standardize methods, data, and modeling across state agencies (and Federal agencies, where possible) to facilitate planning for forest health and resilience management activities across ownership boundaries.
   4. Develop and disseminate tools to assist landowners and local and regional land use planners and forest managers in assessing current forest conditions and desired future conditions.
   5. Develop a better understanding of how different fire types and different forest fuels affect black, brown, super-aggregate, and GHG carbon emissions.

F. Protect and enhance the carbon sequestration potential and related benefits of urban forests.
   1. Protect the existing tree canopy through policies and programs targeting ongoing maintenance and utilization of industry best management practices.
   2. By 2030, increase total urban tree canopy statewide by 10 percent above current levels, targeting disadvantaged and low-income communities and low-canopy areas, with a preference for planting species and varieties that provide substantial carbon storage and are resilient to climate-linked stressors.
   3. Assist local governments and others in locating optimal sites for early green infrastructure solution implementation.
   4. Provide resources and technical assistance to local governments as they assess local policies and regulations for urban forestry and green infrastructure.

Recommendations for Implementation

Successful implementation will require collaboration by a diverse array of state and federal agencies, tribes, local governments, nongovernmental organizations, and individual private landowners. Forest health outcomes derived from this work will benefit a broad constituency of stakeholders, with many benefits being realized over a long timescale. There is a clear need to identify and increase the resources available for implementation in a manner that reflects these broad beneficiaries, and to identify and pursue ways to improve the efficiency of any funds spent. The Forest Carbon Plan makes the following recommendations to initiate and guide implementation:

A. Regionalize implementation of the Forest Carbon Plan. The California Natural Resources Agency (including CAL FIRE, the Board of Forestry and Fire Protection, and State Conservancies in particular), California Environmental Protection Agency (including the Air Resource Board in particular), and the USDA Forest Service Pacific Southwest Region (to the extent that its capacity allows) will be responsible for ensuring that the Forest Carbon Plan is implemented regionally.

B. Work collaboratively at the large landscape or watershed scale (e.g., the Sierra Nevada Conservancy's Watershed Improvement Program) to (a) define critical biophysical and often social units for analysis and projects, and (b) establish priorities for the areas most in need of treatment.

C. Identify and cultivate traditional and new sources of public funding, and public-private partnerships, to support the proposed actions A-F described above and to implement them at the regional level.

D. Explore opportunities for regulatory and policy changes and streamlining to advance the activities described in this Plan and implemented at the regional level. These might include:

    1. Increase use of prescribed and managed fire for restoration.
    2. Streamline planning and permitting for certain restoration activities.
    3. Reduce small landowners' financial barriers to land management.
    4. Identify approaches to balance potentially competing objectives, such as prescribed fire, air quality, and human health protection.
    5. Develop new wood products and biomass facilities.
    6. Modify the restrictions on the export of sawlogs from federal and other public lands when domestic mills are not able to process logs or markets do not exist for certain species.

1 Introduction

1.1 Vision Statement

The Forest Climate Action Team member organizations share the overarching goal of securing California's forests as healthy, resilient net sinks of carbon that provide a range of ecosystem and societal benefits while reducing greenhouse gas and black carbon emissions associated with uncharacteristic wildfire events, tree mortality and other disturbances, as well as management activities and conversion.

The overarching Forest Climate Plan goal speaks of forest health and resilience. While "forest health" is challenging to define,[8] the following central concepts are illustrative:

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.[9] 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.[10]

Resilience:

- 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.[11]

These definitions of forest health and resilience recognize that forest ecosystems are dynamic. There is no singular, static, steady-state healthy/resilient forest condition that will apply to all lands or even one forest type or stand at all times. Establishment of resilient forest conditions will often require adaptation and management intervention.

The Forest Carbon Plan has the following vision for forest protection, enhancement, and innovation:

- Sustainable forests that are a net sink of carbon.
- Healthy forests that are adapted and/or resilient to anticipated climate change effects such as increased warming, greater forest insect and disease threats, and higher wildland fire risks.
- Forests that provide for healthy watersheds and water supplies in terms of quality, quantity, and infrastructure).
- Forests that provide management opportunities that generate long-term economic benefits for landowners, workers, and communities.

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[8] Sulak and Huntsinger, 2012
[9] U.S. Department of Energy, 2017
[10] USDA Forest Service, 2010
[11] Holling, 1973

- Working forests that produce wood products and biomass for energy while being managed to maintain forest health and biodiversity.
- Forests that are protected from fragmentation and conversion and that provide a diverse range of high-quality, interconnected habitat types for terrestrial and aquatic wildlife species.
- Forests that provide an abundance of outdoor recreational and tourism opportunities.
- Forest that support people's well-being through connection to place, cultural identities, and contexts for social and spiritual engagement.
- Expanded and more sustainably managed urban forests that are net carbon sinks and that deliver multiple benefits to urban residents.

1.2 Purpose and Scope of the Forest Carbon Plan

The Forest Carbon Plan presents an assessment of forest health across California based on the best currently available information. The Plan also provides a description of anticipated future conditions given the ongoing and expected impacts of climate change on forested ecosystems. It is important to note that some of the information available on current forest conditions and projected future conditions tends to lag somewhat behind the significant increase in large severe wildfire and extensive tree mortality that has occurred in California over the past few years. With the understanding that underlying science will be continually updated, this Plan lays out a set of forest management goals based on best available information. Achievement of these goals will move our forests towards a more ecologically resilient state. The Plan identifies implementation pathways to increase the pace and scale of achieving these conditions. This Plan also presents a vision for the role that urban trees can play when considered part of the overall carbon balance of California's forests, and the other values they can provide to communities across the state.

The Forest Carbon Plan provides guidance and input to the Natural and Working Lands Implementation Plan described in the California's 2017 Climate Change Scoping Plan.[12] Similarly, the California Air Resources Board's (CARB) Short-Lived Climate Pollutant Reduction Strategy points to the Forest Carbon Plan as an important mechanism for addressing black carbon emissions from forest sources such as wildfire.[13]

Through the Forest Carbon Plan and other collaborative work in local, regional and state-wide initiatives, the Forest Climate Action Team aims to develop and implement plans to improve the health and resilience of California's forests, increase their carbon storage potential, and minimize their atmospheric emissions of GHG and black carbon. While the Forest Carbon Plan primarily targets carbon storage and emissions, it also emphasizes improving and safeguarding interrelated ecosystem services and benefits, as well as social and economic considerations.

1.3 Public Process in the Development of the Forest Carbon Plan

The Forest Climate Action Team invited public participation in the development of the Forest Carbon Plan as shown in the following timeline:

- The FCAT website (http://www.fire.ca.gov/fcat/) has served as a general outreach, communication, and information sharing platform since development of the Plan began in spring 2015.

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[12] California Air Resources Board, 2017a

[13] California Air Resources Board, 2017b

- In February and March 2015, FCAT held initial public scoping workshops:
    - Sacramento (webcast with five webcast satellite locations: Bishop, Eureka, Fresno, Richmond, and Sonora)
    - Arcadia (Los Angeles County)
    - Anderson (near Redding)
- In August 2015, FCAT members participated in a public meeting on California Climate Investments from the Greenhouse Gas Reduction Fund in Oroville.
- In March 2016, FCAT released the Forest Carbon Plan Concept Paper and held two public workshops:
    - Sacramento (webcast)
    - City of Shasta Lake (near Redding)
- Written comments received on the Forest Carbon Plan Concept Paper were posted to the FCAT website.
- In July 2016, FCAT held two stakeholder meetings to gather more detailed regional input:
    - Sierra Nevada—Auburn
    - North Coast—Santa Rosa
- In January 2017, FCAT released a full draft of the Forest Carbon Plan
- In February 2017, FCAT held a public workshop in Sacramento (webcast)
- A team of scientists reviewed and commented on the January 2017 draft of the Forest Carbon Plan.
- Public and scientist reviewer comments in the January 2017 draft of the Forest Carbon Plan were posted to the FCAT website.
- On request, FCAT members have met with individual stakeholders or groups of stakeholders.

1.4 Organization of the Forest Carbon Plan

- Section 1, Introduction: Describes the vision, scope, and purpose of this plan.
- Section 2, Science Snapshot: Provides a summary of historic and current forest conditions, climate impacts on California forests, and fuel treatments to enhance forest health.
- Section 3, Goals: Describes the goals and objectives for wildland (non-urban) forest health along with targeted supporting activity levels.
- Section 4, Implementation: Discusses the implementation of the goals established in Section 3.
- Section 5, Measuring Progress: Describes the monitoring and reporting of annual outcomes for all goals and objectives.
- Section 6, Forests of California Today: Expands on the historic conditions and current challenges facing California forests, details ownership patterns, and describes forest carbon storage dynamics.
- Section 7, Forest Carbon Storage Dynamics and Accounting: Presents the ways in which carbon stored in forested lands is measured and quantified, and some results from inventories.
- Section 8, Urban Forestry: Describes the goals, objectives, and implementation strategies for urban forests.
- Section 9, Benefits of Healthy Forests: Describes the benefits provided by protecting and restoring forests through the management actions of the plan.
- Section 10, Forest Materials Utilization Pathways: Identifies biomass utilization needs and potential market pathways that will allow woody material generated through increased management and restoration activities to be utilized in a manner that complements California climate change objectives.
- Section 11, State Legislation and Regulation: Summarizes the recent forest-related policy arena.

- Section 12, Research Needs: Describes planning, monitoring, modeling, and other research needs that will be critical to successful implementation of the plan.
- Section 13 presents brief conclusions and recommendations:
- Section 14 provides the complete detailed list of references.
- Section 15 provides a list of acronyms used in the report.

Additionally, there are two appendices to the Plan:

- Appendix 1: Presents a tabular summary of modeled climate change impacts to the extent of individual California forest tree species.
- Appendix 2: Documents harvested wood product carbon calculation methods.

2 Science Snapshot

2.1 Forest Carbon Cycle

Forest ecosystems are an important part of the carbon cycle. Forests take in carbon dioxide from the atmosphere through photosynthesis and store carbon in biomass and in soil. Biomass is a term used to denote live and dead plant material in ecosystems, and includes trees, shrubs, plants, woody debris, litter, and roots. The capture of carbon by forests from the atmosphere is termed sequestration. In turn, forests release carbon dioxide and other greenhouse gases and climate pollutants during respiration, decay, or combustion of plant materials. Through growth, natural disturbance, and management actions such as burning, pre-commercial thinning, harvest, and utilization, carbon is stored and released at varying rates. As shown in Figure 1,carbon moves among "pools" such as live vegetation, standing dead vegetation, the atmosphere, and soil organic matter as part of an integrated system. For example, harvest can transfer carbon from live forest carbon pools to dead pools, as well as to harvested wood products pools. The quantity of material stored in a pool at a given point in time is referred to as the carbon stock and the rate at which the stock changes over time is the carbon flux. Forests can transition between being a carbon sink and source over time given the range of management practices and variable biotic and abiotic stressors or disturbances. Quantities of carbon are typically expressed as units of mass of carbon or of carbon dioxide equivalent (CO_2e). One mass unit of carbon is equivalent to 3.67 mass units of CO_2. Most of the figures in this document are scaled to metric tonnes of carbon. One metric tonne is equivalent to approximately 2,205 pounds.

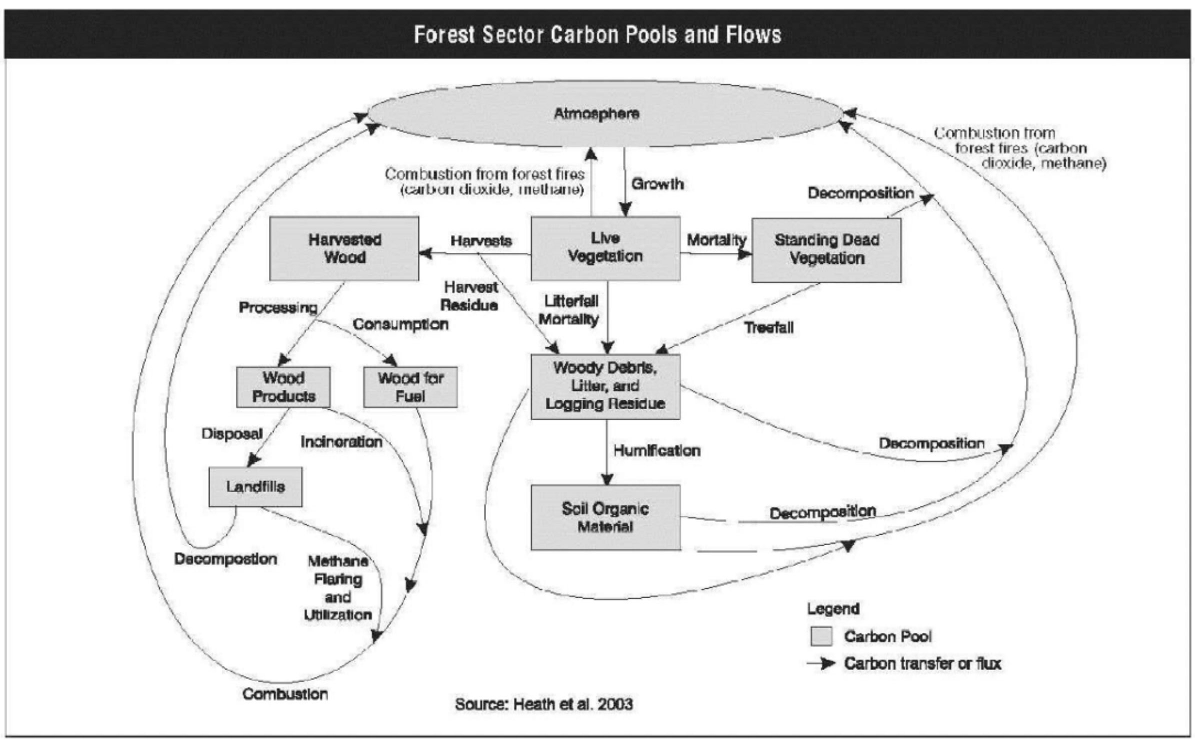

Figure 1. Forest Sector Carbon Pools.[14]

[14] Heath et al., 2003

2.2 Summary of Recent Forest Carbon Inventories[15]

Federal and state programs provide comprehensive inventory estimates of the carbon stored in California forests. In the first California Forest Ecosystem and Harvested Wood Product Carbon Inventory, the USDA Forest Service Forest Inventory and Analysis (FIA) program calculates that the average annual forest carbon stock for the time period of 2006-2015 is 1.30 billion metric tons (MT) of carbon in above ground live and dead biomass, with approximately 1.10 billion MT of carbon in live trees and understory vegetation and the remainder in dead pools.[16] Additionally, 734 million metric tons (MMT) of carbon were stored in below ground in live and dead biomass and soil organic carbon. This amounts to a total of 2.04 billion MT of carbon. In this report, data from the FIA Program also were used to evaluate changes in growth, mortality, and removals in the aboveground live (AGL) tree carbon pool on all ownerships on plots first measured between 2001 – 2005 and then remeasured between 2011 – 2015. This analysis shows that, overall, above ground live trees in California forests were sequestering carbon at a rate 6.5 MMT carbon per year, or 23.9 MMT carbon dioxide equivalent (CO_2e) per year during this period. When all forest pools are considered, California's forests are sequestering 34.4 MMT CO_2e per year, and when land-use changes and non-CO_2 emissions from wildfires are accounted for, the total net sequestration is 32.8 MMT CO_2e per year. These estimates do not distinguish potential benefits from carbon stored long term in the form of charcoal nor do they account for potential harmful effects of particulate matter released to the atmosphere from fires. The large-scale, high-severity wildfire and tree mortality events in California over the last 5 years underscore the need to increase monitoring frequency and/or intensity from FIA and other data sources to better quantify the impacts of these events on forest ecosystems and the State's carbon sequestration goals.

Estimates of carbon stocks and sequestration for California forests also have been conducted using remote-sensing-based methods in combination with FIA data by the California Air Resources Board. Using these methods, Gonzalez et al.[17] reported an AGL vegetation carbon stock of approximately 870 MMT carbon in 2001 and 840 MMT carbon in 2010, for a net loss in the AGL pool of 29 MMT carbon in California forests for the period of 2001 – 2010.[18] However, the authors estimate tree growth undetected by remote sensing of approximately 47 MMT carbon during this period. When this undetected growth is applied, the 2001 – 2010 AGL stock-change in forests evaluates to +18 MMT carbon and would increase the 2001 stock of 870 MMT carbon to 888 MMT carbon in 2010. When annualized, the AGL stock-change rate evaluates to +2 MMT carbon per year or +7.3 MMT CO_2e per year. However, when area change from forest to other vegetation types is included and the undetected growth is applied, this becomes a net loss of 0.81 MMT CO_2e per year in the AGL tree pool.[19] This estimate does not account for any carbon that may be transferred to other forest or wood product pools, nor does it quantify black carbon or other emissions that may have implications for global warming potential such as particulate matter emissions. It also does not include change associated with forest land conversions to other land-uses.

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[15] Forest carbon inventories are discussed in greater detail in section 7 of the Forest Carbon Plan.

[16] Christensen et al. 2017

[17] Gonzalez et al. 2015

[18] Analysis is for California forests that remain forests throughout the duration of the analysis period and does not include forest losses from conversions to other land-uses or non-forest vegetation types. See table 2, forest-forest IPCC land categories.

[19] Data from Gonzalez et al. 2015; -29 MMT C ("Forest-forest" category in Table 2, p. 75) + 47 MMT C (undetected growth, p. 75 text) = + 18 MMT C; + 18 MMT C/9 year time period = 2 MMT C/yr, + 7.3 MMT CO_2e; with vegetation type conversions, -17 MMT C ("tree-tree category in table 2, p. 75) + (-9 MMT C "tree-shrub") + (-23 MMT C "tree-other") + 47 MMT C (undetected growth) = -2 MMT C/9 year time period = -0.22 MMT C/yr, -0.81 MMT CO_2e/yr.

Some of the differences between these estimates may be attributed to the different time periods of analysis, land category definitions such as inclusion of shrub-dominated land in the Gonzalez estimate but not in the FIA estimate, slight differences in the carbon fraction of biomass used in the calculations for each estimate, trade-offs associated with sources and methods, and experimental error. Opportunities to further understand processes occurring in California's forests should become available as advances are made in both remote sensing-based techniques and as the FIA program continues to refine methods to calculate carbon pools and to account for disturbance processes. Additional information on the inventories is included in Section 7.

Compared to historic conditions, many forest types in California now have considerably higher live carbon stocks in smaller trees and in the dead pool; these forest conditions are more vulnerable to fire, pest outbreaks, and other disturbances.[20] [21] [22] [23] Consequently, much of the current stocks of aboveground live carbon are not stable and are likely to show significant losses into the future, especially as changes in climate continue to affect the timing, frequency, intensity and extent of disturbances such as wildfire and pest outbreaks.

2.3 The Role of Fire in Historic and Current Forest Conditions

Fire has historically been a natural and critical ecological component of many California forest landscapes. For example, prior to 1900, wildfires in many California mixed conifer forests were predominantly low-intensity and removed excess fuel, thinned vegetation, and reduced competition for nutrients and water, resulting in healthy forests resilient against drought and native bark beetle outbreaks. It is estimated that over 4.5 million acres burned annually in California prior to European settlement, with much of the fire started or managed by indigenous peoples,[24] and most of it completed to achieve ecological objectives that were supportive of their needs.[25] Outside of the redwood region, the result of frequent fire was a mosaic landscape dominated by very large pine trees that were clumped.[26,27,28] Occasionally a clump of trees would be killed by fire, with spacing between clump canopies limiting the extent of high fire severity events. As a result, high severity fire made up a low percentage of many historic fires, allowing for a mosaic of forest seral stages within small areas that provided complex habitat structure with nesting and foraging habitat for a broad range of species. The large pine trees that dotted the landscape of the Sierra Nevada, for example, held very substantial amounts of carbon.

After European settlement, many California forests began to change. Logging removed many of the larger old growth trees, which not only removed much of the live forest carbon from the forest but also reduced canopy height, making it easier for fire to enter the canopy. European settlement eventually led to a nearly

[20] Collins et al. 2011
[21] North, Hurteau, & Innes, 2009
[22] Lydersen et al. 2013
[23] Earles et al. 2014
[24] Stephens et al., 2007
[25] Anderson, 2006
[26] North, 2012a
[27] Taylor, 2000
[28] Anderson & Moratto, 1996

comprehensive exclusion of fire on the landscape and the absence of any of the proactive large-scale "protoagricultural" landscape management techniques that had been employed by Native Americans.[29,30,31]

Forest carbon density is a function of tree size and number over a given area. The stability of that carbon is a function of stand structure (size, number, and spatial arrangement of trees and shrubs), its interaction with disturbances, including fire, pests and insects, and harvest, and climate. In Sierra Nevada mixed conifer forests, where the forest retains large trees on the landscape, current forests store more carbon than historic forests, due to increased tree densities.[32] However, in stands that no longer retain these large trees, there is approximately 25 percent less carbon than existed prior to 1900.[33] Thus, despite their openness and heterogeneity, historic forests contained significantly more carbon than current fire-suppressed forests. Furthermore, the carbon in these historic forests was generally more stable because it was predominantly stored in large, living trees that were resilient to disturbance. As a result, very little carbon was emitted post-disturbance and the large trees rapidly sequestered that carbon, creating a stable forest carbon landscape. Even in forests today that store more overall carbon than historic forests, more of this carbon is stored in higher densities of small, fire-prone trees than in the past.[34] [35] [36] [37]

With fire removed from the landscape, forests that typically experienced fire frequently (in some cases every ten years) began to miss fire cycles, known as Fire Return Intervals[38] (FRI). As more FRI were missed, dead material began to build up and fire-adverse species began to move in.

Figure 2 shows the status of California's Fire Return Interval Departure (FRID) across the landscape, where condition one (green) is within historic parameters, condition two (orange and tan) is a 33 – 67 percent departure from historic parameters, and condition three (yellow or red) is more than 67 percent departed from this historic fire return intervals. A negative value indicates fire is occurring more frequently than historically (e.g., on shrublands), and a positive value indicates fire is occurring less frequently than historically. As can be seen from the colors on the map, red areas where fire occurs significantly less often than historic fire rates dominate much of the state. In Southern California, the yellow-tone colors indicated that fires occur more frequent than historically. For more details on regional Fire Return Intervals, refer to *California's Forests and Rangelands: 2018 Assessment*.[39]

Today, many forested areas have missed five or more natural cycles. The biomass buildup and species change that have resulted, combined with other factors, has led to an increase in fire severity when fire does finally return to those areas, compared to historical levels.[40] Multiple missed FRIs have resulted in

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[29] Kimmerer and Lake, 2001
[30] Anderson and Moratto, 1996
[31] Keeley, 2002
[32] Collins et al., 2011
[33] North, Hurteau, & Innes, 2009
[34] Collins et al., 2011
[35] North, Hurteau, & Innes, 2009
[36] Lydersen et al., 2013
[37] Earles et al., 2014
[38] As defined in Safford & Van de Water, 2014, "Fire return interval departure (FRID) analysis quantifies the difference between current and presettlement fire frequencies, allowing managers to target areas at high risk of threshold-type responses owing to altered fire regimes and interactions with other factors."
[39] A new Fire and Resource Assessment Program (FRAP) report will be released in early 2018, and will be posted to: http://frap.fire.ca.gov/.
[40] Mallek, Safford, & Viers, 2013

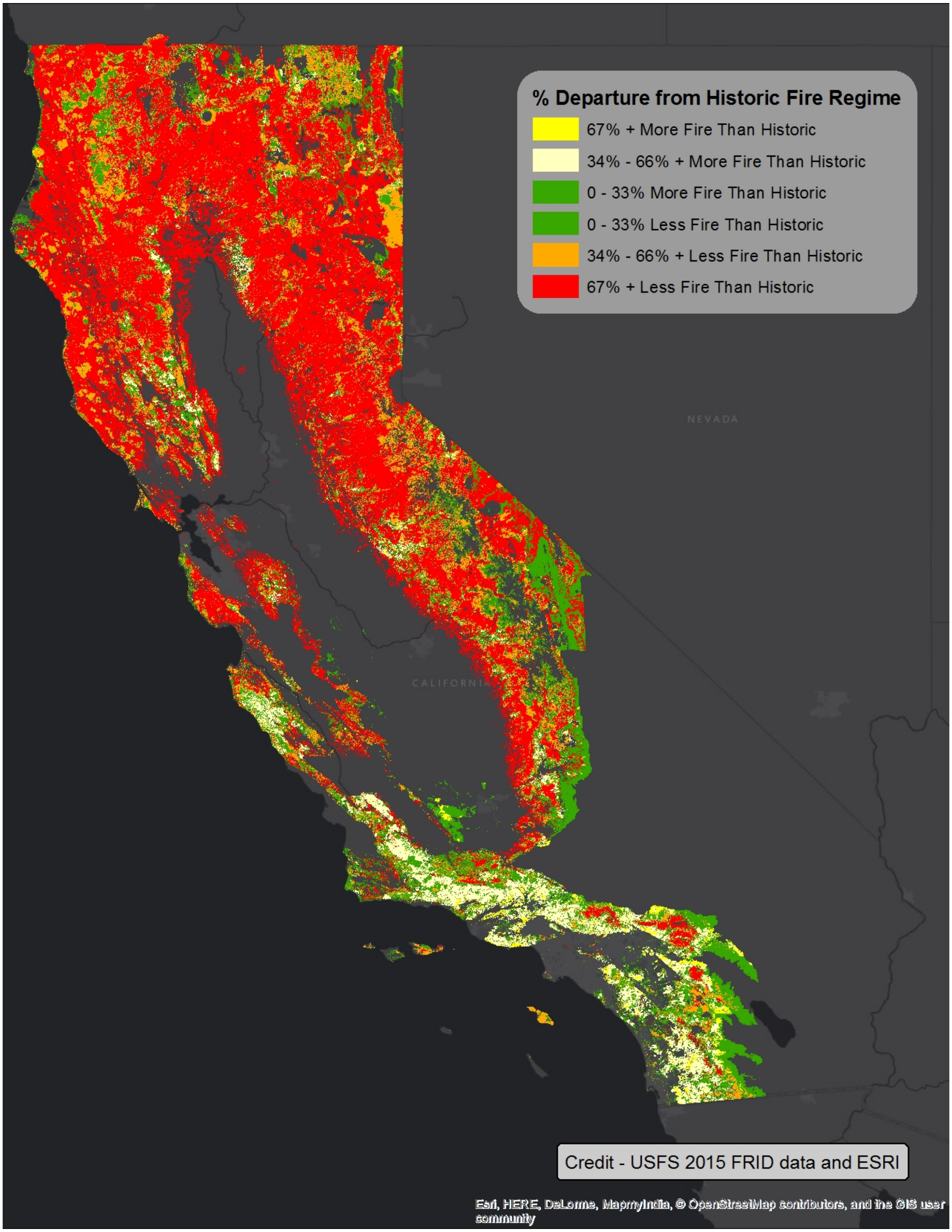

Figure 2. Fire Return Interval Departure for California.

overly-dense stands comprised of smaller trees and in some cases a shift in species type and, thus, habitat suitability. This has created a relatively homogenous forest landscape with few available niches, which respond similarly to disturbance, resulting in a post-disturbance homogenous landscape, in stark contrast to the historic diverse conditions. From a carbon perspective, more of the forest carbon in modern, fire-suppressed forests is in vulnerable smaller trees and in the dead pool, not in large, live conifer trees. The limited resource availability in these forests (e.g., water, sunlight) stunts growth and reduces annual carbon sequestration. Disturbance events, such as fire, drought, and insect and diseases, mobilize significant portions of the forest carbon back to the atmosphere and shift much or all the forest carbon into the dead pool, where it will decay and emit its carbon back to the atmosphere over several decades. Depending on climate conditions and the impact of the disturbance on soils and seed banks, regrowth of the live forest carbon pool in the disturbed area could be delayed a decade or more.

2.4 Climate Impacts on California Forests

Climate change will continue to exacerbate existing stressors on the state's forested landscapes, diminish carbon sequestration rates, and decrease the quantity, quality, and stability of carbon stocks. Future climate change estimates predict increases in temperature, increases in atmospheric CO_2 concentrations, and changes in the amount and distribution of precipitation, all of which can act as stressors on forests. Recent forest trends along with climate change modeling efforts are providing a glimpse of the changes we may expect under climate change conditions and if forest management efforts are not significantly increased. Taking a broad view of temperate forests, including those in California, Millar and Stephenson (2015), conclude that continuing climate change is likely to push many of these forest areas toward large-scale transformations; however, they note that management actions can moderate these transitions and minimize losses of important ecosystem services.

2.4.1 Fire and Tree Mortality Trends

Over the last few decades, wildfires in California's conifer forests have grown bigger and have exhibited increasingly large patches of severe fire. Figure 3 shows how the average annual forest acreage burned (the green bars on left in each set) on a decadal basis has increased significantly in California from the 1950s through 2017. Between 2003 and 2012, the US Southwest experienced a 1,266 percent increase in burned area compared to the period of 1973 – 1982.[41] Fire severity has been increasing as well, which is out of the historical norm. Surveyors in the 1800s wrote that large tree death from fire was an uncommon occurrence, and by the 1980s, approximately 20 percent of fire footprints were severely burned.[42]

By the early 2000s, the percent of high severity in fires over 500 acres in size increased to almost 30 percent,[43] and the Rim Fire of 2013 and King Fire of 2014 were almost 40 percent and 50 percent high severity, respectively. High severity burn patches were historically small, commonly less than ten acres in size, which allowed living trees on the edges to quickly reseed the burned area, and helped create diverse habitat in a small area.[44] In contrast to this healthy functionality, the King Fire had a single high-severity burn patch of over 30,000 acres in size and the Rim Fire had a high-severity burn patch over 50,000 acres.[45]

[41] Westerling, 2016
[42] McKelvey et al., 1996
[43] Miller et al., 2009
[44] Miller et al., 2012
[45] Jones et al., 2016

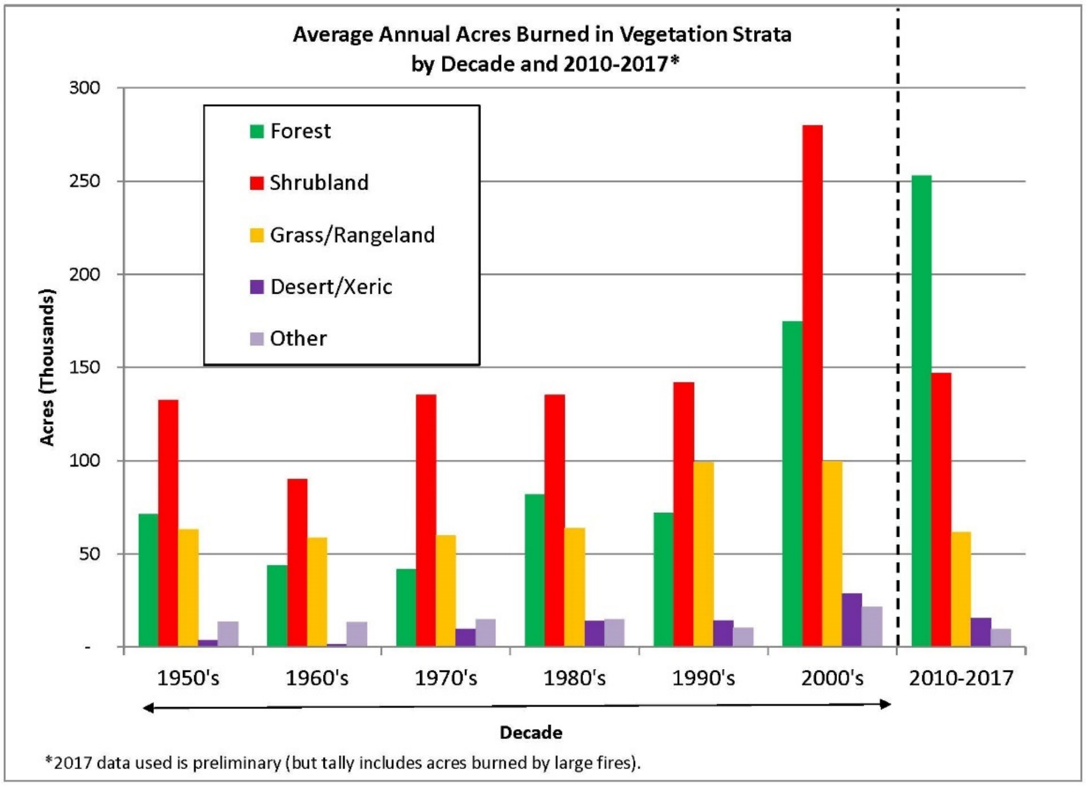

Figure 3. Decadal Mean Annual Burn Rate by Vegetation Type, 1960s – 2010s (abbreviated).

Source: California Department of Forestry and Fire Protection, Fire and Resource Assessment Program, Sacramento.

Similarly, tree mortality from native bark beetles and cycles of drought are part of the natural forest cycle in many forests in California. In the 1970s, over 12 million trees died in a three-year period from bark beetles, and an estimated 3.5 million died in the early 2000s in southern California. The recent drought and warmer temperatures have driven much higher levels of mortality over a much larger area of the state. Aerial surveys found that a total of more than 129 million trees died during 2010 – 2017 over an area of 8.8 million acres, with the vast majority in the Sierra Nevada region.[46] While the drought is a clear driver in the insect induced mortality, it is important to recognize that the already existing lack of resiliency in many forests is also a significant contributing factor. North et al. (2009) found higher than expected large tree mortality in untreated stands, "possibly due to collateral bark beetle attacks when high densities of small-diameter stems surround large trees of the same species."

A recent study examined the effect of sudden oak death (SOD) mortality as a driver of fire severity in the 2008 Basin Complex Fire.[47] Compared to healthy forest areas, those forest areas affected by SOD and

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[46] USDA Forest Service, 2017

[47] Chen et al., 2017

adjacent to areas affected by SOD were more likely to exhibit greater fire severity. The researchers attributed this outcome to higher surface fuel loads in the SOD-affected areas.

2.4.2 Species Range Shift

Climate change impact modeling completed as early as the 1990s began to predict a shift in distributions of vegetation types as climate change progressed. Researchers are already seeing this shift occurring. When they compare vegetation surveys for the Sierra Nevada region from the early 1900s to those of today, vegetation species are moving upslope, meaning some vegetative types are being found at higher elevations than in the past. As this shift continues, it will have significant implications for how future forests will look and function. For example, with increased warming forests may expand their range further upslope to areas where they could not survive previously, increasing the potential carbon pool while also potentially reducing water supply downstream by increasing evapotranspiration. However, high-elevation tree species adapted narrowly to historical temperature ranges at those elevations will be particularly vulnerable to range contraction and extirpation. At the same time, we may see lower elevation forest mixed conifer forests trend to shrublands in more southerly parts of the Sierra Nevada.

In support of CAL FIRE's Forest and Range Assessment, researchers at University of California, Davis conducted an analysis to predict shifts in ranges for tree and shrub species under future climate scenarios (Appendix 2). In addition, a climate exposure analysis was run for six major vegetation types to estimate climatic risk under future climate scenarios. Two climate models (CNRM-CM5, which projects a warm and wet future climate; and MIROC-ESM, which projects a hot and dry future climate) and two levels of climate warming emissions were used.

The results of the study indicate that climatic stress may be most acute under higher emission scenarios and geographically at low to mid elevations across the Sierra. The North Coast region appears to face a lesser level of climate stress. [48] Figure 4 shows the spatial pattern and locations that are expected to experience the greatest climatic stress, defined as locations where vegetation currently resides, but where future climate conditions will likely be unsuitable for that vegetation type. The State Wildlife Action Plan provides additional analysis of potential shifts in vegetation.[49]

2.4.3 Climate Change Will Increase Stresses on Forest Health

There is not consensus on how climate change will impact future precipitation patterns or levels in California based on current climate models, but scientists agree that temperatures will be warmer, more precipitation will fall as rain rather than snow, and that extended droughts will likely be more common.

Historically, the most significant widespread effect on vegetation has been conifer mortality associated with bark beetles and severe moisture stress. Conifer mortality tends to increase when annual precipitation is less than about 80% of normal. Trees stressed by inadequate moisture levels have their normal defense systems weakened to the point that they are highly susceptible to attack by bark, engraver, and wood-boring beetles. Areas with high tree density or trees not adapted to a site are very susceptible to high levels of mortality. Forest stand conditions and weather patterns influence when, where, and the extent to which tree mortality occurs. A dramatic rise in the number of dead trees follows one to several years of inadequate moisture. Dense stands are particularly susceptible to bark beetle attacks due to stress caused by constant competition for limited resources. Stressed trees are suitable host material for bark beetles,

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[48] Thorne et al., 2016

[49] California Department of Fish and Wildlife, 2015

and their successful colonization results in more beetles and high levels of tree mortality. The more severe and prolonged the drought, the greater the number of dead trees.[50]

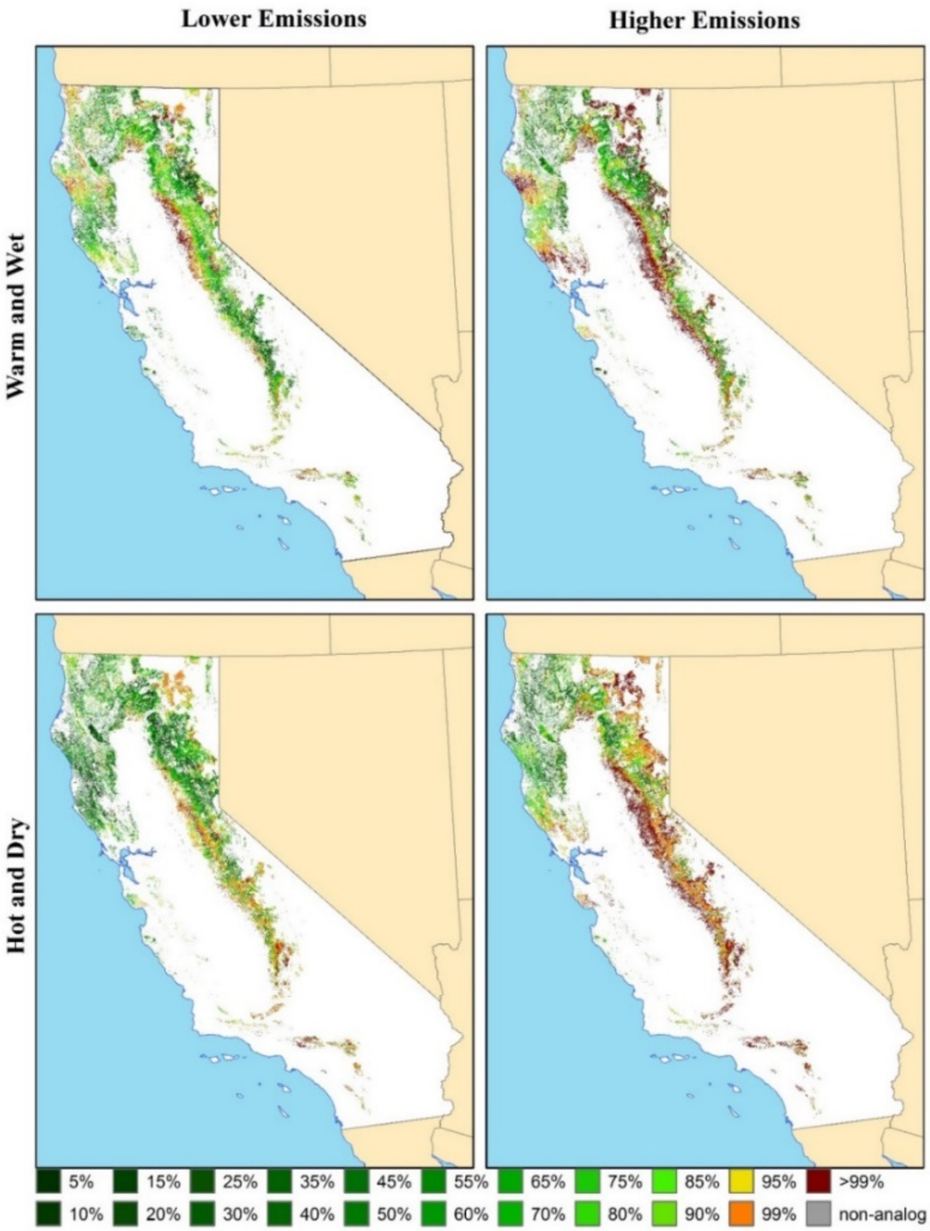

Figure 4. Combined Exposure Map of 6 Wildlife Habitat Relationship (WHR) Types to the End of the Century (2070-2099).

Note: WHR types represented include: MHC = Montane Hardwood Conifer; MHW = Montane Hardwood; RFR = Red Fir; EPN = Eastside Pine; SMC = Sierra Mixed Conifer; KMC = Klamath Mixed Conifer.
Source: Climate Related Species Distribution Model Database: A report for California Department of Forestry and Fire Protection[51]

[50] USDA Forest Service Region 5 Forest Health Program Staff, 2016
[51] Thorne et al., 2016

Prior to the insect and drought-related tree mortality crisis that has recently impacted California, the USDA Forest Service Forest Health Protection Program forecasted insect and disease-related tree mortality across the United States from 2013 to 2027.[52] According to the USDA Forest Service risk assessment, treed areas in California, without remediation steps, will lose at least 25% of standing live basal area of trees greater than one inch in diameter over a 15-year time frame (2013 to 2027) due to insects and diseases on an area of 5.7 million acres (predominantly located in the Sierra Nevada), or 12 percent of the total treed area in the state (Table 1).[53]

Table 1. Statewide Summary of Expected Insect and Disease Risk Areas by 2025.

State	Risk Area (acres)	Treed Area (acres)	State Area (acres)	% of State with Trees	% of Treed Acres at Risk
California	5,697,000	47,237,000	101,218,000	47	12

Source: Table 4, Krist Jr. et al. 2014

Based on this analysis, there are five National Forests in California facing significant losses from insects and disease on a large percentage of the forested base, as summarized in Table 2. The estimates in their report are based on current trends and did not include expected changes in weather patterns based on climate change projections.

Table 2. Highlighted National Forests with Very High Levels of Expected Tree Loss from Insects and Disease.

National Forest	Treed Area (1,000 acres)	% Treed	Total Basal Area Loss (1,000 sq. ft)	Basal Area Loss Rate, %	Basal Area Loss Rate (sq ft./acre)	Area at Risk (1,000 acres)	% of Treed Area at Risk
Modoc	1,743	88	32,005	32	18	675	39
Lassen	1,333	97	44,180	28	33	651	49
Sierra	1,317	93	47,380	27	36	480	36
Tahoe	1,199	99	31,494	18	26	353	29
Plumas	1,379	99	34,569	18	25	320	23

Source: Table 8, Krist Jr. et al. 2014

Although the results of the risk analyses in terms of predicted levels of mortality was highest for these five National Forests (Table 2), many other treed areas throughout the State are also currently susceptible to high levels of tree mortality.

[52] Krist Jr. et al., 2014. Note that this study applies to "treed lands," that is, areas with a measurable tree presence. This is much broarder than areas typically falling under definitions of "forest land," for example, and includes urban as well as wildland areas.

[53] Krist Jr. et al., 2014; Figure 22, Table 4, and Table 8

2.5 Wildfire Emissions Are Likely to Increase

With the estimated increase in wildfire burn area across California under climate change and no change in present management, wildfire emissions (such as CO_2, carbon monoxide, and particulates, including black carbon) are estimated to increase as well. Using 1961 – 1990 as the baseline period, end-of-century (2100) wildfire emissions are projected to increase by 19 – 101% (median increase 56%) in California for a medium-high temperature scenario. The largest modeled emissions increases were concentrated in northern California.[54] If status quo forest management and global GHG emissions continue, there will be a significant increase in wildfire smoke in California and the subsequent human health impacts that result from more smoke in the air at the worst times (i.e., late summer when air quality problems are already most severe).[55] GHG emissions will increase commensurate with that smoke. Without action, as fire occurrence, size, and intensity increase under climate change, smoke from fires even in remote areas will impact populated regions with greater frequency and duration, imperiling the health of a greater percentage of the population.[56]

As described earlier, despite the extensive fire suppression efforts of the last decade or two, undesired fire burn area has increased significantly since the 1980s, as has fire severity. A recent study has attributed 55% of the increase in dry fuels to human-caused climate change, resulting in an increased burn area of 4.2 million acres between 1984 and 2015.[57] While California is experiencing the nascent effects of what climate change will bring later this century, the impacts are already significant and expected to get worse. Wildfire activity is associated not only with the increasing dead pool fuel stocks and ladder fuels that may be found in unhealthy forests, but also is tied to earlier spring snowmelt and warmer temperatures.[58] Using low, medium, and high emissions profiles for climate change predictions, burned area in California is estimated to increase between 36% and 74% by 2085.[59] Regardless of emissions profile, most of the forested areas in Northern California are predicted to experience a growth in burned area by 2085 of over 100% above 1975 reference levels.[60] Since 2000, an annual average of 630,000 acres of wildlands of all types have burned in California[61], an increase of 2.4 times over the reference period.

Like wildfire activity overall, fire severity has been increasing over the last few decades as demonstrated in the Moonlight, Chips, King, and Rim fires, among others. Fires with higher proportions of fire severity than historic have been significantly impacting California air quality in recent years with their massive plumes that affect large areas for weeks at a time. The plumes can emit millions of metrics tons of CO2e in a few weeks. In areas that burn at high severity, future emissions from the burned area may be up to five times greater than the active fire emissions[62]. In a forest wildfire, less than 15% of the carbon in a stand is usually emitted in the plume[63]. In a high severity burned area, the remaining 85% will decay in subsequent decades or be emitted in a future wildfire plume[64]. The loss of sequestration and subsequent decay from the now dead

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[54] Hurteau, Westerling, Wiedinmyer, & Bryant, 2014
[55] Schweizer & Cisneros, 2016
[56] Schweizer & Cisneros, 2016
[57] Abatzoglou & Williams, 2016
[58] Westerling, 2016
[59] Westerling et al., 2011
[60] Westerling et al., 2011
[61] Based on CAL FIRE Fire and Resource Assessment Program fire perimeter GIS data.
[62] Auclair & Carter, 1993
[63] Campbell, Fontaine, & Donato, 2016
[64] Campbell, Fontaine, & Donato, 2016

trees make the stand a net source of emissions for a decade or more[65] until the trees regrow sufficiently to out-sequester the carbon release from the decaying material.

Recent observations suggest that a portion of the high severity burn areas within these fires may not reestablish as forests, but rather will transition to shrub or grassland systems.[66] Fire frequency has been found to increase in these areas as fuel conditions are created that allow for repeated high-severity fire in short succession, hindering the regrowth of forest and maintaining shrub dominance.[67] New research suggests that as a result of the shift in the vegetation composition and fuel loads across the west from forest to non-forest, fire severity may decrease in much of the western US by 2050.[68] At the same time, this shift in vegetation would result in a significant decrease in carbon stocks in vegetated areas in the western United States.[69] This transition from mature forest to shrub without active reforestation in areas where climate conditions will still support forests represents a long-term, if not semi-permanent, reduction in forest carbon capacity.

As climate change advances and concentrations of carbon dioxide increase, the availability of CO_2 for plant growth may interact in unknown ways with factors that may influence wildfire activity, such as longer growing seasons, shifting or expanded territory (climate supports forests at higher elevations), and drought. While increased CO_2 availability may overwhelm negative growth pressures (e.g., water stress) from climate change and spur growth, it may spur growth early in the year, which then dries out late in the fire season, leading to more burned area. Alternately, if drought does suppress growth and therefore the amount of vegetation available to burn, that would result in decreased carbon sequestration in untreated areas compared to treated areas.[70]

2.5.1 Burning Forests Emit Black Carbon, a Short-Lived Climate Pollutant

Climate science unequivocally underscores the need to immediately reduce emissions of short-lived climate pollutants (SLCPs), which include black carbon, methane, and fluorinated gases. SLCPs are powerful climate forcers, responsible for an estimated 40 percent of current net climate forcing. Action to reduce these pollutants today will provide immediate benefits as the effects of our policies to reduce longer-lived GHGs further unfold.[71] CARB's Short-Lived Climate Pollutant Strategy[72] establishes the state's overarching policy for addressing SLCPs.

Black carbon is a SLCP that contributes to climate change air pollution and negative human health impacts.[73] It is a component of fine particulate matter, which has been identified as a leading environmental risk factor for premature death.[74] It is produced from the incomplete combustion of fossil fuels and biomass burning, particularly from older diesel engines and forest fires. Black carbon warms the atmosphere by absorbing

[65] Dore et al., 2012
[66] Collins & Roller, 2013
[67] Coppoletta, Merriam, & Collins, 2016
[68] Parks et al., 2016
[69] Parks et al., 2016
[70] Dore et al., 2012
[71] California Air Resources Board, 2017b
[72] California Air Resources Board, 2017b.
[73] Haikerwal et al., 2015
[74] California Air Resources Board, 2017b

solar radiation and influencing cloud formation, and further accelerates heat absorption and melting by darkening the surface of snow and ice.

Scientists have known for some time that sources that emit black carbon also emit other short-lived particles that may have either a cooling or warming effect on the atmosphere. Lighter colored particles, for example, tend to reflect rather than absorb solar radiation and so have a cooling rather than warming impact. Until recently, scientists thought that the impact of lighter colored and reflecting organic carbon from combustion sources largely offset the warming impact of black carbon from this source. However, new studies have suggested that certain fractions of organic carbon known as “brown carbon” could be a stronger absorber of solar radiation than previously understood.[75,76] The warming effect of brown carbon may exceed the cooling impact of other organic carbon particles; hence, quantification of energy absorption is necessary so that climate models can evaluate the net climate effect of organic carbon.[77]

The California Air Resources Board’s (CARB) black carbon inventory looked at black carbon from forests as a non-anthropogenic emissions source. The largest source of black carbon emissions in California is wildfire: An average wildfire season contributes two-thirds of current black carbon emissions in the state.[78] There is very little knowledge surrounding black carbon production rates, timing, and the implications (on production and timing) of burn conditions. Regular, low-intensity burning (including wildfire, prescribed fire, and managed fire) can reduce fuel loads that cause large, severe fires, promoting ecosystem health and, therefore, system resilience. It also is clear that the avoidance of large fires, in turn, reduces human exposure to black carbon.[79]

Particulate matter emissions from wildfires can be substantial and result in exceedances of California PM10 standards.[80] Recent studies of wildfire smoke plumes indicate that particulate matter emissions from wildfires may be significantly higher than indicated by standard emission factors under the National Emissions Inventory and that prescribed burning may be effective at reducing fine particle emissions.[81] Because reducing black carbon from wildfire could contribute to meeting California’s climate goals, it is important to address this information gap regarding these emissions moving forward.

2.6 Treatments to Address Forest Resilience and Carbon

Forest vegetation treatments, such as prescribed and managed fire, mechanical fuels reduction, sustainable timber management, and other similar stand-density management treatments are essential tools to restore forest health and resiliency and to enable forests to be net sinks of carbon over time and to provide a range of other ecosystem and social benefits. Treatments in densely stocked and unhealthy stands can vary in method used and forest structure outcomes, and therefore can lead to different impacts on forest carbon in both the short and long term. These treatments can yield a range of woody materials with uses including biomass energy, compost, composite wood products, and solid wood products. Sustainable commercial timber harvest to maximize forest health goals may generate revenue to increase the area of forests treated

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[75] Jacobson, 2014
[76] Kodros et al., 2015
[77] California Air Resources Board, 2017b
[78] California Air Resources Board, 2017b
[79] Long et al., 2017
[80] Cisneros et al., 2012.
[81] Liu et al., 2017.

for resilience, including both the commercially harvested areas and other areas receiving non-commercial restoration treatments.

Extensive and timely thinning of significant areas of California's forests, and reintroduction of prescribed and managed fires, where feasible, will make forests healthier and more resilient to insects and disease for many generations to come, while significantly reducing the threats to life, property, forest carbon stocks, and other forest benefits.

Many of California's forests currently have higher densities of small trees and fewer large trees on the landscape overall compared to historic forests.[82, 83, 84] These conditions have detrimental implications for both the resilience of forests and the quality of forests as a carbon sink. In dense stands, competition for scarce resources can stunt individual tree growth rates, and therefore, sequestration rates. Stands that have reduced tree competition, achieved by prescribed fire, mechanical or manual fuels treatment, or commercial thinning, can experience greater growth rates in the live trees that remain,[85] allowing carbon sequestration rates to increase over time. Stressful conditions, such as drought, can stunt the growth of overly dense stands; it can take years for these stands to recover once the drought subsides, while healthier stands may continue sequestering carbon across those years.[86,87]

Individual large trees store and sequester more carbon than individual small trees.[88] As an example, one large, old sugar pine tree, approximately 300 years old, stores as much carbon as 175 younger, 30-year-old white fir. While older large trees store and sequester more carbon than small trees, in overgrown forests with a high density of small trees they can be more vulnerable to mortality from forest pests and drought stress.[89]

The mortality of large trees causes significant carbon to shift from live to dead pools, along with a significant drop in annual sequestration rates. While this shift may not cause noticeable changes in the total amount of forest carbon,[90] more of the carbon pool is shifted into dead material which is unstable, and the overall sequestration rate of the stand slows and may be negated by emissions from increased decay over time. If the dead pool emissions exceed carbon sequestration, the forest becomes a net source of GHGs to the atmosphere, contributing to California's overall annual emissions totals. In some cases, there are opportunities to convert dead pool materials to forest products that can store carbon or to energy that can displace fossil fuel combustion.

Although fuels reduction treatments result in short-term forest carbon losses through biomass removal, studies have shown that carbon can quickly be recovered to pre-treatment levels if large, fire-tolerant

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82 Stephens et al., 2015
83 North, Hurteau, & Innes, 2009
84 North, 2012b
85 Wiechmann et al., 2015b
86 Dore et al., 2012
87 Anderegg et al., 2015
88 Stephenson et al., 2014
89 North, Hurteau, & Innes, 2009
90 Wiechmann et al., 2015a

overstory trees are not removed in large quantities.[91, 92, 93, 94] Treatments also reduce the impact of future stress events on the remaining trees, allowing them to continue to sequester and grow. The net result is that, within a decade or two of treatment, the larger, more resilient remaining trees and other forest carbon pools (e.g., soils) will contain the carbon lost due to the treatment removal of biomass and the stand will be growing at a faster rate than if the treatment had not occurred. [95]

2.6.1 Treatment Types and Application

An important element in attaining the goals of the Forest Carbon Plan is to transfer carbon stocks from many small, closely-spaced, fire-vulnerable trees into a smaller number of resilient larger trees. Some of these trees of various sizes may be harvested and be incorporated in to long-lasting wood products, where they will continue to store carbon for long periods.

To reach the Forest Carbon Plan goals, there are many treatment methods that could be employed, including:

- Prescribed and managed fire;
- Understory thin;
- Overstory thin;
- Understory or overstory thin followed by prescribed fire;
- Light to heavy thinning;
- Sustainable commercial timber harvest.

Each treatment type confers an immediate carbon cost from forest carbon and equipment operation emissions perspectives, but depending on the fate of the material removed, carbon release to the atmosphere can be minimized, substituted, or significantly delayed. To learn more about some of the methods used in these individual treatment types, please see Knapp et al. (2012)[96] or the Methods section of North et al (2009).[97]

The USDA Forest Service Pacific Southwest Research Station produced two General Technical Reports[98,99] to provide a general guide to restoration treatments in certain forests in California. These reports highlight the need to restore heterogeneity in forests with a focus on clusters of large fire-resilient trees. Stephens and Moghaddas (2005) analyze seven traditional silvicultural systems and two types of reserve systems used in the Sierra Nevada for their fuels treatment outcomes.[100] Restoration, fuels, or other treatment types for redwood and Douglas-fir forests also have been described and discussed.[101]

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[91] Dore et al., 2012
[92] Wiechmann et al., 2015a
[93] Stephens et al., 2009
[94] Hurteau & North, 2010
[95] Wiechmann et al., 2015b
[96] Knapp et al., 2012
[97] North, Hurteau, & Innes, 2009
[98] North et al., 2009
[99] North, 2012a
[100] Stephens and Moghaddas, 2005.
[101] See e.g., Teraoka, 2012; Giusti, 2012; O'Hara et al., 2012; Engber et al. 2016; Berrill et al., 2016.

The methods and prescriptions for forest treatments are site-specific and are often determined by a combination of factors including existing conditions, desired outcome conditions, access, cost, revenues, resource needs, impediments, and size of area to be treated. In any case, selection of forest management and restoration practices should be informed by the expected future changes, and selected methods should be robust over a wide range of plausible future climate change outcomes. Looking specifically at the effects of fuels reduction treatments on US forests that historically burned frequently with low- to moderate intensity fire regimes, including mixed conifer and ponderosa pine forests, a review by Stephens et al. (2012) found that:

> Most available evidence suggests that fuel-reduction objectives are typically accomplished with few unintended consequences, because most ecosystem components (vegetation, soils, wildlife, bark beetles, carbon sequestration) exhibit very subtle effects or no measurable effects at all….[102]

It should be noted, however, that Stephens and Moghaddas (2005) specifically called out research that indicated plantation treatments, overstory removal, and single tree selection may not effectively reduce fire behavior, especially fire-caused mortality under high and extreme fire weather conditions.[103] The efficacy of fuel treatments, both in terms of reduced fire behavior/intensity, and in terms of impacts (e.g., mitigating post-fire mortality of dominant trees) can and will be influenced by a variety of factors. In cases of fires burning under extremely dry fuels and severe fire weather, fuel treatments can be less effective than if burned under more moderate conditions. The size of fuel treatments, treatment age, past disturbance or treatment history, and local factors may also play a role.[104]

Modeling that included the Stanislaus National Forest suggests that, because of the fire deficit, annually treating at least three percent of the landscape results in a 40 percent improvement in resilience to large landscape fire disturbances, allowing the landscape to peak in resilience over 20 years of annual treatments.[105] Most of the treatment benefits were achieved within the first decade of modeled treatments. This approach would move California forests closer to the landscape management completed by Native Americans in prehistory, better preparing California forests for future disturbance.

Vegetation management treatments, such as thinning and restoration of ecological fire processes, are among the most effective tools available for reducing bark beetle-caused tree mortality[106]. Forest thinning promotes resiliency by enhancing tree vigor, which reduces a tree's susceptibility to bark beetles and lowers the potential for severe fire. With droughts projected at greater rates combined with warmer temperatures in a climate-altered future, the risk posed by insects, particularly native bark beetles will likely increase if California's forests remain untreated, unhealthy, and overcrowded.[107] Forest restoration has been demonstrated to attenuate outbreaks of bark beetles under current climate conditions[108] and it provides the best opportunity to minimize outbreaks under a more strenuous climate.

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[102] Stephens et al., 2012, at p. 558.
[103] Stephens & Moghaddas, 2005
[104] Lyderson et al., 2017
[105] Finney et al., 2007
[106] Fettig et al., 2007
[107] Young et al., 2017
[108] Kolb et al., 2016

Recent field reports suggest that treated stands are experiencing significantly lower mortality rates. Based on field research conducted in 2014 in low elevation (below 6,900 feet) mixed conifer stands in Kings Canyon, Sequoia, and Yosemite national parks, van Mantgem et al. found that on previously burned (6 to 28 years earlier) plots, conifer species had significantly lower mortality rates as compared to unburned plots.[109] Similar results were found in a study reviewing the results of 40 years of managed wildfire in the Illilouette Creek Basin in Yosemite National Park.[110] With data collected in 2014 and their paper published two years later, following additional drought years, van Mantgem et al. indicated uncertainty as to what the continued effect of the drought may have had on the relative mortality rates in burned and unburned stands.[111]

Mechanical treatment is not appropriate everywhere, and there are limitations on the landscape that prevent some treatment methods from being applied. Malcolm North and colleagues estimated under current legal, operational, and administrative constraints the area available for mechanical treatment on National Forest System Lands in the Sierra Nevada region ranges from 25 percent to 70 percent of productive forestland for a given National Forest.[112] Figure 5 shows the areas that are not mechanically treatable in the Sierra and that these areas are more prevalent in some parts of the region. Depending on the reasons for the constraints (e.g., slope, distance to road, sensitive species habitat), adjacent areas could be mechanically treated to reduce the risk of uncontrolled fire from entering areas that are not mechanically treatable. Likewise, prescribed fire or managed wildfire could potentially be used, whether areas are mechanically treatable or not. Despite heavy fuel loads, overgrown forested areas far removed from their normal fire rotation can be safely burned in a prescribed fire under the right conditions, but may require multiple entries in short succession to achieve forest health goals. Similar to the constraints on mechanical treatments, there are many constraints to using prescribed and managed fire. Prescribed and managed fires are less likely to be used in the wildland urban interface, and therefore mechanical treatments and the excess biomass they produce will consistently need a disposal outlet, preferably utilization-based, from these areas.

2.6.2 Carbon Impacts of Treatment Methods

The treatment methods described above have greenhouse gas emission reduction and carbon sequestration outcomes that vary in the short and long term depending on application type, site conditions, and fate of extracted biomass, including both material burned for energy production and utilized as wood products.

The first treatment in a stand that is very departed from its natural disturbance regime is necessarily a more carbon-impactful treatment in order to begin to shift the carbon in the stand to the larger trees. Once treated, maintaining the health of the stand requires subsequent disturbance, either natural or human-caused. The timing of subsequent treatments depends on the historic FRI and the results of the previous treatment. Some stands are so far removed from their historic patterns that reestablishing disturbance may result in unforeseen challenges. Some stands are so overstocked that a first entry of mechanical fuels reduction or hand thinning is necessary before it is safe to introduce prescribed fire treatments or consider managed fire treatments. In general, retreatment is required within 20 years of an initial treatment to maintain stand health and fire risk benefits. Retreatment involves the removal of significantly less carbon than the first treatment, and is more likely to be performed via prescribed or managed fire, where

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109 van Mantgem et al., 2016
110 Boiserame et al., 2016
111 van Mantgem et al., 2016
112 North et al., 2015a

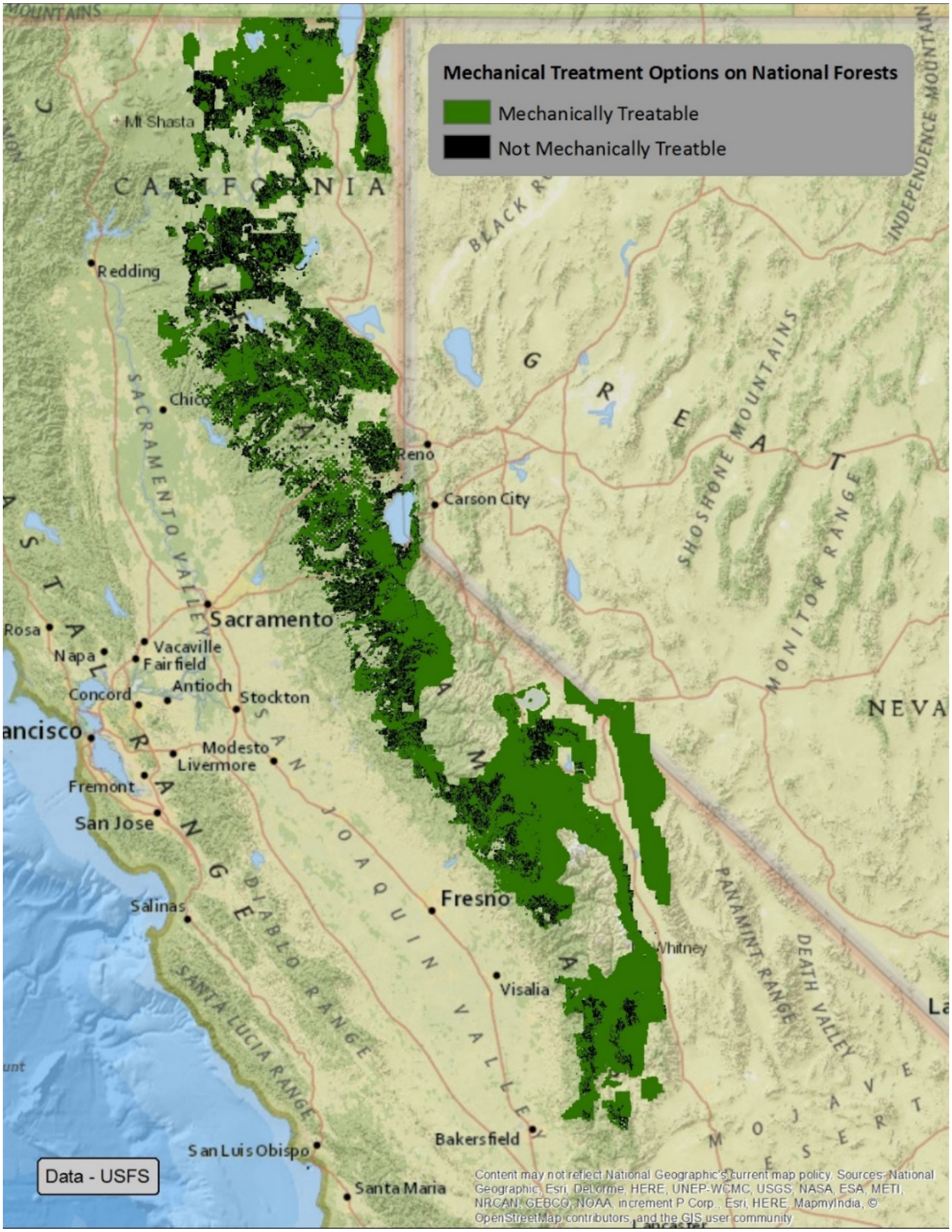

Figure 5. Scenario "A" of Recent Research into the Limitations of Using Mechanical Treatments, Showing Where Mechanical Treatment Options Are Significantly Constrained on National Forests in the Sierra Nevada.

Source: USDA Forest Service

Depending on the treatment type and how much carbon was removed during the treatment or transferred to the dead pool following treatment (i.e., unintended mortality), the amount of carbon removed from the forest by treatment, but not necessarily released back to the atmosphere (e.g., sequestered in long-lasting wood products), can be sequestered back into the remaining trees in the stand in as little as ten years. Without factoring in biomass utilization benefits from excess biomass removed during treatment, a recent study in the Sierra Nevada found that prescribed fire and mechanical understory-thin treatments resulted in stands that sequestered the equivalent amount of carbon removed from the forest during treatment within ten years.[113] With the exception of the overstory thin and burn treatments, which saw unintended mortality affect the resulting stand structure, the treatments in this study are expected to sequester their lost carbon within 15 to 20 years if stand growth continues on the same trend. All treated areas within the study experienced positive net ecosystem productivity over the ten years of the study (2002 – 2011), while the control plots had net negative ecosystem productivity over that same period, despite not experiencing a significant disturbance event. The results indicate that these treatments were successful in shifting the carbon in the stand from smaller trees into larger, healthier trees, and these larger trees had more access to needed resources to continue to grow while the unhealthy control stand was unable to continue growing and sequestering carbon.

North et al. (2009) detail the carbon emissions associated with implementing certain treatments as well as the carbon implications of hauling forest material offsite and milling.[114] As described in Section 10, the carbon costs associated with these activities can be reduced or offset by expanding the biomass utilization infrastructure network. If a biomass utilization outlet is unavailable, the excess biomass from thinning treatment is typically either masticated and put back on the forest floor or piled and burned. While masticating excess biomass and spreading the material back on the forest floor helps recycle nutrients, it can potentially increase fire intensity for the first few years until the material decays. Masticated material also represents a short-term carbon source. Pile burning of material immediately releases carbon emissions back to the atmosphere with attendant implications for emission of GHG and criteria air pollutants. However, pile burning is necessary to remove thinned materials in remote locations, locations where markets for thinned materials are nascent, or where costs and/or resource impacts of removal and transport are high. A wider range of alternative disposal methods must emerge to reduce pile burning as an alternative.

Prescribed and managed fires also represent immediate release of emissions to the atmosphere, with some of the carbon sequestered back into the soil as charcoal.[115] Recent research in California is beginning to shed more light on how the distribution of pyrogenic carbon in trees versus the forest floor varies with fire severity.[116] For example, a recent study found that new measurements of particulate pollution from Western wildfires were significantly higher than previous estimates, and that prescribed burning produces less particulate emissions than wildfires.[117] Another recent study suggests an approach by which forest managers and air quality districts can use to restore more natural fire regimes while minimizing impacts to

[113] Wiechmann et al., 2015b
[114] North et al., 2009
[115] Wiechmann et al., 2015a.
[116] Maestrini et al., 2017.
[117] Liu et al., 2017.

public health.[118] Additional research could help inform strategies for utilizing prescribed and managed fire in a manner that reduces overall forest emissions and protects public health.

Dore et al. (2012) observed the interaction of productivity and environmental conditions during their research on the effects of treatment and fire on an existing ponderosa pine stand in Arizona.[119] The researchers found that treated forests were better able to sustain their carbon sequestration rates under significantly hotter and drier conditions than the untreated stands. Given our potential future under climate change, the increasing range of climate conditions under which the forests could remain productive through treatment could be critical to continued carbon storage. Even when a drought hit the study area in the third year following the implementation of their treatments, the authors observed that during the drought the treated site had higher carbon uptake than the untreated site, despite the fact that the treated site had fewer trees and leaf area. This is significant given Anderegg et al.'s findings[120] that drought not only impacts tree growth (and therefore carbon sequestration rates) during the drought itself, but also that growth rates post-drought can remain stunted for one to four additional years. If the same pattern holds true in treated versus untreated stands as found in Dore et al.,[121] then the treatment benefits could extend beyond drought periods.

2.7 The Landscape or Watershed Scale

The watershed level has proven to be an appropriate organizing unit for analysis and for the coordination and integrated management of the numerous physical, chemical, and biological processes that make up a watershed ecosystem.[122] Similarly, a watershed can serve as an appropriate reference unit for the policies, actions, and processes that affect the biophysical system, and providing a basis for greater integration and collaboration. Forests and related climate mitigation and adaptation issues operate across these same biophysical, institutional, and social gradients.

Because of these factors, the Forest Carbon Plan proposes working regionally at the landscape or watershed scale. The appropriate scale of a landscape or watershed to work at will vary greatly depending upon the specific biophysical conditions, land ownership or management patterns, and other social or institutional conditions. The importance of a socioecological system approach to forest management has been stressed for successful management of forests in the Sierra Nevada and Southern Cascade, for example:

> A socioecological system is a dynamic association of biophysical and social factors that interact and continuously adapt to regulate flows of critical resources, such as biodiversity, water, nutrients, energy, materials, infrastructure, and knowledge.[123]

The Sierra Nevada Adaptive Management Project offers another example of a collaborative adaptive management effort that was focused in particular on incorporating scientists, scientific experimentation, and substantial public process into a landscape-level adaptive management process.[124] Similar approaches have been described for California redwood forests as well.[125]

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[118] Long et al., 2017.
[119] Dore et al., 2012
[120] Anderegg et al., 2015
[121] Dore et al., 2012
[122] California Department of Water Resources, 2013.
[123] Long et al., 2014.
[124] Conklin et al., 2015
[125] Hartley, 2011.

3 Goals

California's overarching climate goal for forests is to manage them as healthy and resilient net sinks of carbon that provide a range of ecosystem and societal benefits while reducing GHG and other carbon emissions associated with management activities, conversion, wildfire events, and other disturbances. This goal is not intended to maximize carbon storage in California forests, but to have our forest be net sinks while providing many other important benefits.

This section describes targeted activity levels needed in each of the following three primary objectives to meet these goals:

1. *Enhance*: Expand and improve forest management to enhance forest health and resilience, resulting in enhanced long-term carbon sequestration and storage potential.
2. *Protect*: Increase protection of California's forested lands and reduce conversion to non-forest uses, resulting in a more stable forested land base.
3. *Innovate*: Pursue innovations in wood products and biomass utilization in a manner that reduces or offsets GHG emissions; promotes land stewardship; and strengthens rural economies and communities.

These goals and objectives are being established through a climate change lens and are intended to be responsive to the conditions described in Sections 2 (Science Snapshot) and 6 (Forests of California Today). They will be pursued holistically to support the broader Forest Health Vision enumerated in Section 1 and existing natural resource policies, which include: protecting, maintaining, and restoring watersheds; conserving plant and wildlife habitat; and improving the health, well-being and economic resilience of forested communities and other communities that depend on them. Some of the actions necessary to achieve these goals may result in short-term emissions or reduced carbon stocks that are needed to secure long-term goals for resilience, higher levels of stable carbon sequestration and storage, and other ecosystem benefits.

Targeted activity levels identified by this section in many cases are not achievable with current fiscal resources. These targets are presented to generally illustrate the scope and scale of increases in services needed to meet projected needs. Specific needs by region will be refined over time to reflect the findings from ongoing research and collaboration.

Potential funding sources include California Climate Investments from the Cap-and-Trade program, state bond funds, Timber Regulation and Forest Restoration Fund grants, state or federal fuel reduction grants, commercial harvest operations, private forest conservation funds, Federal Farm Bill funds delivered through the Natural Resource Conservation Service and the USDA Forest Service, and other federal grant programs.

The management targets in this section are supported by a coarse-scale data analysis completed to provide an approximation of the extent of forest resources currently under threat and in need of forest treatments to improve long-term carbon storage and forest health and resilience goals. To the extent practicable, targets or goals are specified separately for National Forest System forestlands (15.4 million acres), BLM forestlands (1.5 million acres), and private and State forestlands (13.5 million acres).

The goals discussed in this Forest Carbon Plan are mostly presented in units of acres treated or protected. The expected climatic benefits of these activities in terms of CO_2e reductions, will be broadly estimated in the forthcoming Natural and Working Lands Implementation Plan and further refined as work goes forward at the project, regional, or landscape level. For the natural and working lands sector, California's 2017 Climate Change Scoping Plan proposes "…an intervention based reduction goal of at least 15 – 20 MMT CO_2e

by 2030 as a reasonable beginning point for further discussion and development based on the State's current preliminary understanding of what might be feasible."[126,127] This goal will be reevaluated during the development of the Natural and Working Lands Implementation Plan to determine if it should be adjusted in light of ongoing analyses to estimate the GHG mitigation potential of the sector. Forests are expected to contribute significantly to this statewide goal.

Monitoring and reporting of overall annual outcomes for all goals and objectives is described in Section 5, Measuring Progress. To better monitor forest carbon storage and fluxes, this Plan recommends exploration of increasing the periodicity of FIA plot remeasurement to once every 5 years (from the current rate of once every ten years) or increasing FIA plot intensity (i.e., number of sample plots), or other enhancements to the inventory data and methods. This exploration should be done jointly by CARB, CAL FIRE, the Board of Forestry and Fire Protection, and the Natural Resources Agency as a part of the collaborative work on the natural and working lands carbon inventory called for in SB 859 of 2016.

3.1 Expand and Improve Forest Management to Enhance Forest Health and Resilience

Forests are shaped by disturbance and background levels of tree mortality. However, elevated tree mortality from overly dense stand conditions, fire exclusion, lack of or poor forest management practices, and impacts related to drought and climate change can have a substantial effect on the forest carbon balance. Wildfire is the single largest source of carbon storage loss and GHG emissions from forested lands: of the estimated 150 million metric tons of carbon lost from forests from 2001-2010, approximately 120 million metric tons of carbon was lost through wildland fire.[128] Wildfire also is the single biggest source of black carbon emissions.[129] Reducing the intensity and extent of wildland fires through tools such as fuels reduction, prescribed or managed fire, thinning, and sustainable timber management practices is therefore a top priority.

An estimated 20 million acres of forestland in California with high wildfire threat may benefit from fuels reduction treatment to reduce the risk of wildfire and the resulting carbon loss and black carbon and GHG emissions that follows, while also improving ecosystem health.[130] For example, it is estimated that less than 20 percent of forests in the Sierra Nevada region receive fuel treatments that are needed.[131] Forest treatments of any type should have multiple objectives that strengthen provision of a broad range of services to both people and ecosystems. These objectives may include improved wildlife habitat, protection of water resources, resilience of recreational lands, and production of wood products, among others.

The objectives and activities described here are divided between federal lands and all other lands, i.e., private, state-owned, and other publicly owned lands. In any case, implementation is expected to involve working across ownership and jurisdictional borders. Activities should be prioritized and coordinated by appropriate partners within each region.

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[126] California Air Resources Board 2017a, at p. 82.

[127] In adopting the 2017 Climate Change Scoping Plan on December 14, 2017, the Air Resources Board approved Resolution 17-46 (https://www.arb.ca.gov/board/res/2017/res17-46.pdf), which (at page 9) directed the CARB Executive Director to work with the Natural Resources Agency, Department of Food and Agriculture, and CalEPA to reevaluate this quantitative goal (by September 30, 2018) and "determine if the goal should be adjusted in light of ongoing analyses to estimate the GHG mitigation potential of this sector."

[128] California Air Resources Board, 2016a

[129] California Air Resources Control Board, 2017b.

[130] California Department of Forestry and Fire Protection, 2010

[131] North et al., 2012

3.1.1 Improve Health and Resilience on Private and State/Local Public Forestland

The forest management deficit in California is significant, on both private forestlands, especially among smaller ownerships, and on nonfederal public forestlands. To address this, action by both state and federal agencies and by private landowners will be needed, as discussed in Section 4, Implementation. The following targets are intended to address nonfederal forest lands, including private, state, and local government (federal forestlands are addressed in Section 3.1.2, which follows):

Target for Nonfederal Forest Lands:

- By 2020, double the current rate of forest restoration and fuels reduction treatments, including prescribed fire, through the CAL FIRE Vegetation Treatment Program from the recent average of 17,500 acres per year to 35,000 acres per year.
- By 2030, increase forest restoration and fuels treatments, including mechanical thinning and prescribed burning, from the current rate of approximately 17,500 acres per year to 60,000 acres per year.[132] This target is based on CAL FIRE's determination of an operationally feasible increase in activity through its Vegetation Treatment Program.
- Through CAL FIRE's Forest Practice Program and the Timber Regulation and Forest Restoration Program, ensure that timber operations conducted under the Forest Practice Act and Rules contribute to the achievement of healthy and resilient forests that are net sinks of carbon, with due consideration given to all forest carbon pools.
- Promote increasing the acreage of forest carbon projects and remove barriers to their implementation.
- In order to address forest health and resiliency needs identified statewide on nonfederal lands, CAL FIRE has estimated that the rate of treatment of all types would need to be increased to approximately 500,000 acres per year to make an ecologically meaningful difference at a landscape scale. This estimate is based on consideration of ecological need and predictions of capacity to implement treatments. It should be considered an aspirational target to work toward. This goal is achievable with increased resources and expanded markets for woody materials. These treatments include those that generate revenue from harvest materials, such as commercial thinning and regeneration harvests.

Commercial and non-commercial private landowners should be empowered to improve management for carbon sequestration and other public benefit outcomes through mechanisms such as incentive payments for one-time forest improvement activities or long-term management changes, technical assistance, and education. Mechanisms to incentivize one-time or temporary actions include grant programs, such as CAL FIRE's California Forest Improvement Program (currently supported by the Timber Regulation and Forest Restoration Fund), Fire Prevention Grants (previously State Responsibility Area Fire Protection Fee Fund, now shifted to California Climate Investments), and Forest Health Grant Program (California Climate Investments). The first year (FY 2014/15) of California Climate Investments Forest Health and Urban and Community Forestry programs initiated 66 projects that are expected to reduce GHG emissions by 3.2 MMT CO2e over the course of implementation.

Incentives for long-term management changes should include conservation easements (see Section 3.1) that include forest improvement terms, such as requirements to grow large trees and to retain some or all of these large trees over time. Additional long-term management strategies include other contractual

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[132] California Board of Forestry and Fire Protection, 2017

arrangements, such as those required for participating in California's compliance market forest offsets program or other voluntary forest carbon crediting standards. Nineteen MMT CO_2e in compliance and early action offset credits have been generated from California-based forest offset projects and registered with CARB as of November 2017.[133.] A recent study evaluated the California forest offset program and found that it advances additionality of emissions reductions and can contribute to other benefits.[134]

3.1.2 Improve Health and Resilience on Federal Forestlands

While the USDA Forest Service and the Bureau of Land Management (BLM) determine management activities on their lands, which make up over half of California's forestlands, they have existing commitments to increase forest resilience in alignment with California's own forest health goals, which include federally managed lands. As a result of the strong partnership between federal land managers and state agencies, some of the California objectives and targets presented here are expected to unfold on federal lands. Given the intermix of federal, state, local, and private forestlands, these partnerships are critical to success.

USDA Forest Service

The USDA Forest Service goals are based on a commitment to land and resource management informed by the principles of ecological restoration. These goals are driven by policies and practices dedicated to making land and water ecosystems healthier and more resilient under current and future conditions.[135]

- By 2020, increase treatments from the current approximately 250,000 acres per year to 500,000 acres per year on National Forest System Lands in California.
- Increase forest resilience through treatments including fuels reduction, managed and prescribed fire, noxious weed removal, road improvements to reduce sedimentation, resulting in resource benefits to approximately nine million acres on National Forest System Lands in California by 2030.

Potential funding sources include USDA Forest Service funds, other federal agency funds, California Climate Investment grants, state bond funds, and private and nongovernmental organization partner funds. Other funding sources for National Forest System lands include compensatory mitigation (404/401 Clean Water Act), private capital partnerships, voluntary carbon projects, and partnerships with downstream beneficiaries.

Ongoing state and federal cooperative efforts under the Agricultural Act of 2014 ("Farm Bill") that leverage Good Neighbor Authority can help to advance opportunities on National Forest System Lands. Other authorities that provide collaborative mechanisms to allow the Forest Service to engage partners across the boundary to increase pace and scale of forest restoration treatments include Stewardship Authority, Cooperative Funds Act, and Granger Thye. Additional cooperative efforts in place with the state and other partners that can be used to meet ecological restoration goals include agreements to expand the use of fire on the landscape and agency commitments to support the California Headwaters Partnership and the Sierra Nevada Watershed Improvement Program. Another collaborative framework the USDA Forest Service could use is the National Cohesive Wildland Fire Management Strategy.

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[133] California Air Resources Board, 2017c
[134] Anderson et al., 2017
[135] USDA Forest Service, 2015a

U.S. Department of Interior

The U.S. Department of Interior's Wildland Fire Resilient Landscapes Program is a new approach to achieve fire resiliency goals across landscapes with the collaborative efforts defined in the National Cohesive Wildland Fire Management Strategy, and in support of Secretarial Order 3336 - Rangeland Fire Prevention, Management, and Restoration. The approach uses integrated, place-based partnerships among programs, activities, and organizations to increase resilience to fire.[136] In addition, the BLM utilizes a landscape-scale management approach to better support balanced stewardship of the diverse natural resources, ecosystems, and values on public lands.

- By 2020, on BLM managed lands increase treatments from the current approximately 9,000 acres/year to 10-15,000 acres/year.
- Increase forest and woodland resilience through national landscape conservation networks, landscape mitigation strategies, native seed rehabilitation and restoration, and vegetation treatments including fuels reduction, managed and prescribed fire, and weeds management. The goal will result in resource benefits to approximately 1.2 million acres of forests and woodlands on BLM public lands in California by 2030 and include forestry and fuels reduction targets expanding from the current annual average of 9,000 acres to 20,000 acres.

Potential funding sources include federal funds such as regular appropriations and Healthy Landscapes funds, California Climate Investments grants, state bond funds, and private forest conservation organization funds.

3.1.3 Restore Ecosystem Health of Wildfire- and Pest-Impacted Areas through Reforestation

The reestablishment of forests impacted by fire, insects, disease, and other disturbances secures a variety of important natural and social ecosystem services for the public. Planting of desired native tree species and genotypes will be needed in addition to natural regeneration in some areas to accelerate reforestation with climate-adapted trees in targeted areas, prevent conversion of forest ecosystems to shrub or grassland ecosystems, and advance carbon storage capacity in the landscape.

In order to make a significant reduction in USDA Forest Service Region 5 reforestation needs, an equally significant investment of human and financial resources will be needed. Various sources of funding are being sought by the Forest Service to help address the reforestation backlog on National Forest System lands, including California Climate Investments from the Cap-and-Trade Program. Several State and Federal programs and funding sources are available to assist with reforestation on nonfederal lands. The USDA Forest Service has made progress in reestablishing new forests, for example, reforesting 16,400 acres in federal FY 2017; and there is an additional 249,000 acres in need of reforestation treatments on National Forest System Lands in California[137]

The 2010 FRAP Assessment report estimated 2.35 million acres are high priority for restoring wildfire-impacted areas statewide.[138] The USDA Forest Service estimates that the bark beetle and drought mortality event of recent years has resulted in 8.8 million acres of nonfederal forest and woodland areas with tree

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[136] U.S. Department of the Interior, 2015

[137] Al Olson, Acting Deputy Regional Forester, Pacific Southwest Region, USDA Forest Service in presentation to the California Board of Forestry and Fire Protection, January 24, 2018.

[138] California Department of Forestry and Fire Protection, 2010

mortality over the 2010-2017 period,[139] although only a portion of this area is likely to need reforestation actions such as tree planting.

Selection of seeds and seedlings for reforestation under a changing climate must consider and make choices among strategies of resistance, resilience, and transition (including assisted migration).[140] Once established, seedlings will need treatment to reduce fuels and competing vegetation to increase the likelihood of reforestation success. Periodic future treatments, where allowed, can be implemented to help create forest structures and compositions that will be resilient to the stressors anticipated in coming decades. The following are the reforestation goals for lands managed by the USDA Forest Service and for nonfederal lands, respectively:

- On understocked nonfederal lands (where not subject to Forest Practice Act timber harvest reforestation requirements), increase annual area reforested by 25% over the current level by 2030.
    - To achieve this goal, CAL FIRE (through its Forest Resource Improvement Program) and other state entities will continue to work cooperatively with the Natural Resource Conservation Service (including its Environmental Quality Incentives Program), USDA Forest Service (through its State and Private Forestry Program and Nursery Program), Forest Landowners of California, reforestation seedling growers, and other partners to increase funding for site preparation and reforestation assistance on non-industrial private forest lands and the availability of appropriate seedlings for planting.

Ongoing and potential funding sources include California Climate Investments, Timber Regulation and Forest Restoration Fund, state bond funds, federal Farm Bill funds delivered through the Natural Resource Conservation Service and the USDA Forest Service, and private conservation organization funds.

- On National Forest System lands, eliminate the current USDA Forest Service Region 5 Reforestation Need balance by 2030 and sustain future treatments at levels where annual additions are matched by treatments. Maintain seed collection, storage, and seedling production capacities to meet anticipated needs. Identify suitable seed collection areas and maintain existing seed orchards, to support future needs. Utilize genetically improved planting stock, while matching seedling source to anticipated climates.

Ongoing and potential funding sources include federal funds, California Climate Investments, state bond funds, private conservation organization funds.

3.1.4 Maximizing Forest Health Goals in Sustainable Commercial Timber Harvesting Operations

In addition to fuels reduction and prescribed and managed fire treatments, sustainable commercial timber harvesting on private and public lands, where consistent with the goals of owners or with management designations and done to maximize forest health goals, can play a beneficial role, both in thinning dense forests and financing additional treatments. Although there are trade-offs with in-forest carbon stores, sustainably managed working forests can further provide climate mitigation benefits. Commercial timber harvest within a sustainable management regime to maximizing forest health goals also creates revenue

[139] USDA Forest Service, 2017
[140] Millar & Stephenson, 2015.

opportunities to fund additional forest treatments and should be seen as a tool in the maintenance of our forests as healthy, resilient net sinks of carbon.

An example of the linkage between one wood product, timber, and forest restoration was shown in the 1992 Fountain Fire near Redding. Almost all the 41,300 acres of industrial private forests that burned were reforested soon after the fire, financed by revenues from salvage timber harvests.[141] Box 1 provides a case study of forest restoration following the Fountain Fire.

3.1.5 Restore Mountain Meadow Habitat

Forested areas often contain multiple types of habitat, including meadows and riparian areas. These landscapes provide many ecosystem and recreational benefits. Healthy, functioning meadows host a diverse plant community with deep rooting systems that retain water, carbon, and other nutrients and provide important habitat for wildlife and other species. As meadows become degraded, plant diversity and rooting depth are reduced, thus decreasing water and carbon retention; GHGs are emitted as a part of this process. Management and restoration activities that restore riparian and meadow areas may in turn result in more carbon being retained in these areas, and continue to provide habitat for wildlife and other organisms. The California Water Action Plan [142] specifically recognizes the importance of restoring key mountain meadow habitats through broad, collaborative actions.

The commitments below also are supported in the Sierra Meadows Strategy,[143] which was developed by the Sierra Meadows Partnership. The Partnership has members from multiple state and federal agencies and nongovernmental organizations and has an overarching goal of restoring and/or protecting 30,000 acres of mountain meadows across all ownerships in the Sierra Nevada by 2030. The USDA Forest Service is a member, as is the California Department of Fish and Wildlife and the State Water Resources Control Board. The Sierra Meadows Strategy recommends several approaches and goals for meadow restoration. While the 30,000-acre meadow restoration goal is an overarching, joint goal of the Sierra Meadows Partnership, this plan suggests the following allocation of efforts as a starting point for the achievement of this goal.

State Target

- The State, through its members on the Sierra Meadows Partnership, will lead efforts to restore 10,000 acres of mountain meadow habitat in key locations by 2030 and target reliable funding for such activities.[144,145]

Federal Contribution

- In addition to the state target, the USDA Forest Service will restore 10,000 acres of mountain meadow habitat by 2030 and target reliable funding for such activities on National Forest System Lands in California.

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[141] Zhang et al, 2008
[142] California Natural Resources Agency, 2016a.
[143] Drew et al., 2016
[144] California Department of Water Resources, 2013
[145] California Natural Resources Agency, 2016a

Box 1. Forest Restoration following the 1992 Fountain Fire.

Recognized at the time as one of the worst fires in California history, the Fountain Fire started on August 20, 1992 in the Southern Cascade Mountains, 40 miles east of Redding. By the time it was controlled eight days later, the fire had burned over 64,000 acres and destroyed more than 300 homes. While it seemed like an insurmountable task to resurrect the devastated landscape, largely composed of private industrial forestlands including Roseburg Resources, Sierra Pacific Industries and W.M. Beaty managed lands, the area is now well on its way to a full recovery. Twenty-five years later, the young, vigorously growing forest is once again providing a home for forest wildlife, and the streams, whose condition was of great concern, are again teeming with fish, amphibians and other aquatic life.

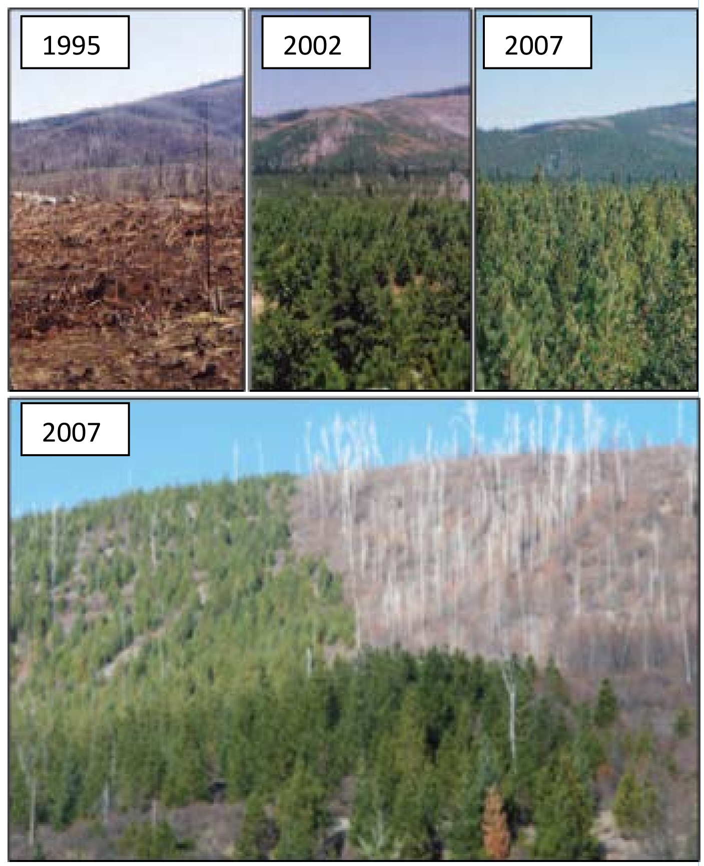
History has shown us that forests devastated by large scale wildfires do not rapidly recover on their own. The intensity and scale of large scale fires can compromise the natural ability of an ecosystem to regenerate, thus taking many decades, if not centuries, for natural succession processes to restore a forest to the pre-fire condition. However, if managed properly, the rehabilitation of a forest can achieve dramatic results in a few decades.

The successful recovery of the Fountain Fire was largely due to the restoration that landowners undertook immediately after the fire. Within weeks, operations were underway to salvage the dead timber, turning fire-charred trees into useful, carbon-storing wood products. Soil erosion was minimized, six fish-bearing streams were protected, and replanting of tree seedlings just seven months after the fire. To ensure the ongoing success of these recovery efforts, the timberlands have been actively managed since that time.

The Forest Foundation estimated that forests and shrublands burned in the Fountain Fire released 11.9 million tons of GHGs into the atmosphere through combustion and the subsequent decay of dead trees and shrubs. That is equivalent to the GHG emissions from more than 2.1 million cars for one year.[146] Because of the harvesting of dead trees and the forest restoration effort on these private industrial forestlands, it is estimated that about 8.1 million tons of carbon dioxide will be stored in wood products and growing trees over the next 100 years,[147] offsetting some of the impacts from the disastrous fire. Without this effort to re-establish trees, the land would have turned to shrub cover for many years, as many of the neighboring lands that were not restored did, resulting in far less carbon sequestration. Some of the burned and replanted forests have already been thinned, producing biomass for utilization and serving to concentrate future growth on fewer, larger trees.

On the industrial lands, herbicides were used to control competing vegetation, providing an opportunity for research on native plant diversity. A chronosequence study on this site and two nearby burned sites (the Pondosa Burn of 1977 and the Tamarack Burn of 1986) indicated that initial plant diversity was richer in untreated plots.[148] But that diversity quickly fell as aggressive shrubs dominated the sites. Within 8 years, both species richness and diversity were greater in herbicide-treated areas.[149]

The Fountain Fire restoration effort illustrates how taking immediate action to restore forests that have been severely damaged can benefit the environment by quickly restoring forest cover and once again sequestering atmospheric carbon.



Upper panels: plantation at the age of 0 years (1995), 7 years (2002), and 12 years (2007). Lower panel: Contrast of tree-planted and nonplanted areas December 2007. *Upper photos by Ted Silbersteins; lower by Jianwei Zhang.*

[146] Webster, 2007,
[147] Webster, 2007
[148] Zhang et al., 2008
[149] DiTomaso et al., 1997

Nongovernmental Organization Contributions

- With the State and USDA Forest Service committing to address 20,000 acres of the 30,000-acre goal, FCAT makes an assumption that non-governmental organizations may be able to provide the resources needed to restore the last 10,000 acres of the goal.

Potential funding sources for achieving the 30,000-acre goal include California Climate Investments, state bond funds, federal funds, and private conservation organization funds.

3.2 Increase Protection of Forested Lands and Reduce Conversion to Non-Forest Uses.

California's forestland base has been relatively stable over the past three decades at approximately 32 million acres of forestland. However, due to regional development pressures, some forests are being fragmented or fully converted to commercial, agricultural, residential, or other land uses. Some forest species (e.g., oaks; see Appendix 2) may be at greater risk than others. Conversion can deforest and fragment forest lands, degrade forest health, disrupt wildlife habitat, and increase risk of wildfire, even if the development footprint itself is small relative to total forest acreage. Conservation easements may be particularly important where rare forest resources, such as private old growth forests, are at risk of conversion.

A variety of forestland protection mechanisms can be used to reduce the rate of conversion and degradation, including conservation easements, mitigation practices driven by the California Environmental Quality Act, county-level zoning ordinances, establishment of GHG thresholds at the local level, and incentives for private landowners to maintain forestland as resilient forest. The California Forest Legacy Program, the Wildlife Conservation Board, and other forest conservation granting programs directly protect forest lands through State funding for working forest and other conservation easements.[150,151,152] Collaboration between state agencies, land trusts and other related non-governmental organizations helps leverage non-state funds to conserve additional lands. Other protection strategies include land use and tax incentives that enable the financial viability of forest ownership, and sharing best practices with private funders and federal agencies to ensure coordinated conservation strategies statewide. The following actions will advance this objective:

- By 2030, increase the acreage of forestland protected by conservation easements by 10 percent with a focus on areas that are threatened by development and can effectively sequester and store resilient carbon while providing wildlife habitat, protecting watershed values, and supporting other forest ecosystem benefits.
- These easements—which can protect both forests that are managed for timber harvest (sometimes called "working forests") and those that are not—will be paired with stewardship plans.
- Promote the adoption of regional transportation and development plans that consider the climate change impacts of land use and management, particularly in jurisdictions with substantial forest resources. Relevant planning processes include SB 375 Sustainable Communities Strategies and Climate Action Plans.
- Provide support and technical assistance for counties, cities and regions to integrate forest resource conservation priorities into local and regional plans, drawing from Regional Conservation Investment

[150] California Department of Forestry and Fire Protection, 2016a
[151] USDA Forest Service, 2016a
[152] Wildlife Conservation Board, 2016

Strategies, Natural Community Conservation Plans, Habitat Conservation Plans, the State Wildlife Action Plan, and critical agricultural lands where those plans already exist.

Beyond conservation of existing forests, the current spatial extent of certain forest habitat types may be expanded. Through development of the 2015 State Wildlife Action Plan, the state identified terrestrial vegetative communities that are a high priority for conservation based on their benefits to fish and wildlife; for many of these priority vegetation types, increasing acreage is identified as a key conservation goal. Several of the vegetation communities or habitat types prioritized in the plan are forested, including California Forests and Woodlands, Pacific Northwest Subalpine Forest, and North Coastal and Montane Riparian Forest and Woodland. The following target will advance this objective:

- By 2025, expand acres of high priority forest habitat by five percent from 2015 acres.[153] This target may be adjusted as the State Wildlife Action Plan is periodically updated.

3.3 Innovate Solutions for Wood Products and Biomass Utilization to Support Ongoing Forest Management Activities

In order to support the goals of this Forest Carbon Plan, wood and biomass material generated by timber harvesting, forest health, restoration and hazardous fuels treatments must be either utilized productively or disposed of in a manner that minimizes net GHG and black carbon emissions. Timber and other biomass harvest volumes are expected to increase as a result of the forest management activities outlined above. These volumes will include green and dead trees suitable for timber production, smaller-diameter green and dead trees with little traditional timber value, and tops and limbs.

Removal will result in a temporary drop in carbon in standing live pools, which is replaced over time as carbon is sequestered in new tree growth on the treated area. Green and useable dead timber is milled into lumber and other wood products that can store carbon in use for many decades. While some of the residual biomass from treatment activities may be left in place for habitat or other purposes, strategic utilization of the remainder can divert material from decay and open pile burning and produce net GHG benefits outside of the forest. Utilization of this material contributes to beneficial uses including durable wood products, compost and other soil amendments, animal feed and bedding, and production of renewable electricity and biofuels. Substituting imported wood products with locally-produced wood products can yield an immediate net benefit from lower transportation emissions. Research, development and implementation activities underway in energy, wood products, and soil amendment fields should be evaluated for utility in meeting disposal needs on regional and community scales.

A resilient forest products and biomass strategy is one that includes a diversity of utilization markets end uses that is scaled to handle the material generated through both public and private sector forest management activities. A regional approach should be used, in which material production and utilization is balanced at scales appropriate to given markets and sustainable forest management. The costs of transporting forest biomass are significant relative to the material's value, so distance from source to processing site will determine commercial feasibility. Regional and local approaches will also be better suited to discussions related to facility siting, economic development strategies, local impacts of forestry operations, and climate resilience of both natural resources and the human populations that depend on them.

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[153] California Department of Fish and Wildlife, 2015

There is significant support for productive wood product and biomass utilization at the state level, which is described in detail in Section 10, Forest Materials and Utilization Pathways. The actions and targets described here underscore, accelerate, and expand on those commitments:

- Expand wood products manufacturing in California, and take actions to support market growth scaled to the longer-term projections of forest productivity and forest health needs. In particular, State agencies should identify potential for expanded and new markets and undertake actions to accelerate their development. In order to advance this goal, State agencies and partners from the private sector, community groups, NGOs, and federal land management agencies should seek to implement the recommendations and pilot projects identified in "Recommendations to Expand Wood Products Markets in California," the product of the Wood Products Working Group established through SB 859 of 2016.[154] These recommendations establish a Rural Economic Development Steering Committee at the Governor's Office of Planning and Research and describe the activities that specific State agencies will undertake to expand wood products markets in the near term, given existing funding and statutory capabilities. These recommendations are described in detail in Section 10.
- Increase the total volume of carbon stored through greater use of long-lived wood products from California forests, particularly in buildings.
- Build out the 50 MW of small scale, wood-fired bioenergy facilities mandated through SB 1122 (Rubio) of 2012. Continue public investment in this build-out through the California Energy Commission's EPIC program. Expedite contracting and interconnection for facilities fueled by feedstock from tree mortality High Hazard Zones[155], as described in Governor Brown's State of Emergency Proclamation on the Tree Mortality Epidemic.[156]
- Maintain large-scale bioenergy capacity, most immediately at a scale necessary to meet the public safety and tree disposal needs posed by widespread tree mortality in the central and southern Sierra Nevada. This is supported through the electricity procurement requirements in California Public Utility Commission Resolution E-4770, which calls for solicitation of 50MW through the BioRAM procurement process, and SB 859 of 2016, which calls for procurement of 125 MW of bioenergy from facilities sourcing the majority of feedstock from tree mortality High Hazard Zones.
- Continue to support research into the potential for conversion of woody biomass to transportation fuels both statewide and regionally. Identify opportunities to support deployment of emerging fuels technologies, particularly those that advance multiple climate objectives and can utilize associated funding synergies.
- Support the Healthy Soils Initiative, led by the California Department of Food and Agriculture, which will help develop and support the generation of, and markets for, biochar and other amendments, such as compost, from forest biomass for agricultural, rangeland, municipal, and residential applications.

3.4 Create Capacity for Collaborative Planning and Implementation at the Landscape or Watershed Level

While there are some recent mechanisms that facilitate collaborative planning and implementation of forest restoration work at the landscape or large watershed scale (e.g., Good Neighbor Authority, Collaborative

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[154] California Natural Resources Agency, 2017

[155] High hazard zones are areas with elevated tree mortality and high fire threat that are a hazard to public safety, community assets and related infrastructure represent the primary focus of these zones. Where appropriate broader watershed protection and other important environmental services (i.e. water resources, carbon storage, wildlife habitat) will also be considered.

[156] Brown, 2015

Forest Landscape Restoration Program, Stewardship Contracting Authority, Watershed Improvement Program), as the Western Governors Association recently noted:

> …there is little to no formal incentive for the management agencies and collaboratives to ensure collaboration work happens in a timely and efficient manner that achieves a pace and scale of restoration that matches the ecological, social, or economic needs of public and private forestlands and communities... Despite this good work, the full benefits of these collaborative efforts have not been realized on the land.[157]

To support collaborative planning and implementation of forest restoration work, State and Federal agencies should:

- Encourage and support staff participation in collaborative efforts.
- Provide training on methods for successful collaboration.
- Provide staff or fund contractors to provide facilitation services, collect and analyze data, perform environmental review, and provide other support to collaborative efforts.
- Make State funds available to support projects on Federal lands that contribute to State goals and local communities.
- Seek support from nongovernmental organizations or other appropriate private sector entities.
- Provide cost-share grants or other financial support to allow local governments and nongovernmental organizations to meaningfully participate in collaborative efforts.
- Expand the use of State and local Conservation Corps, veterans crews, or Conservation Camp inmate crews to implement projects on the ground.
- Work to strengthen the social and financial connections between downstream water users and forested source watersheds, through mechanisms such as AB 2480 (Bloom) of 2016[158] and the California Water Action Plan.[159]
- Work to conduct permitting programs and environmental review processes efficiently, while ensuring that the related environmental protection standards are achieved.

3.5 Protect and Expand Urban Forests

California's urban forests are important not only because of their substantial social, environmental, and economic values, but also because 95% of Californians live in urban areas. The Forest Carbon Plan proposes to protect and enhance the carbon sequestration potential of urban forests in support of the broader goal to manage California's forests as resilient stores of carbon, while producing other benefits. This goal will be accomplished by protecting and expanding the existing tree canopy:

- Protect the existing tree canopy through policies and programs targeting ongoing maintenance and utilization of industry best management practices.
- By 2030, increase total urban tree canopy statewide by 10 percent above current levels, targeting disadvantaged and low-income communities and low-canopy areas, with a preference for planting species and varieties that provide substantial carbon storage and are resilient to climate-linked stressors.[160]

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[157] Western Governors' Association, 2017
[158] Assembly Bill 2480, 2016
[159] California Natural Resources Agency, 2016a
[160] Canopy cover is currently 15% of urban area; Bjorkman et al., 2015

- CAL FIRE's Urban and Community Forestry Program, the Natural Resources Agency Urban Greening Program, and the Region 5 USDA Forest Service Urban and Community Forestry Program will work to achieve these goals through collaboration with local agencies and state-wide and local urban forestry NGOs.

Potential funding sources include California Climate Investments, state bond funds, the Environmental Enhancement and Mitigation Grant Program, USDA Forest Service Urban and Community Forestry grants, local governments, and urban forestry NGOs.

Based in part on CAL FIRE's Urban and Community Forestry Program Strategic Plan 2013 – 2018, the following are suggested management actions that will help to achieve the above goals:[161]

- Move green infrastructure solutions from being an exceptional occurrence closer to being standard practice by 2030 through policy guidance and incentives.
- Ensure that tree canopy cover and green infrastructure project increases are prioritized in disadvantaged and low-income communities to maximize the impact of increases in tree canopy cover that are achieved.
- Ensure consideration of water needs and climate as part of the species selection process and that water-efficient tree care practices are used.
- Assist local governments and others in assessing their urban forest resources and better managing them. This can be done by obtaining urban tree canopy cover data to share on a periodic basis, performing urban tree inventories on a periodic basis, and putting comprehensive, long-term urban forest management plans in place.
- Assist local governments and others in locating optimal locations for early green infrastructure solution intervention.
- Provide resources and technical assistance to local governments as they assess local policies and regulations for urban forestry and green infrastructure.
- Consider creating incentives for the use of best management practices, including tree maintenance and preservation, by local governments and others. This would help protect large, established trees and increase both short-term and long-term tree canopy above the baseline.
- Improve and expand utilization of urban forest biomass that is removed due to pests and disease or for valid management purposes. Seek the highest and best use for this resource, rather than viewing it as a waste product.

The state, through CAL FIRE and CNRA, currently provides urban forestry grants and urban greening grants through the California Climate Investments program supported by cap-and-trade proceeds. These grant funds create incentives for local activity, result in quantifiable GHG emission reductions, and require best management practices in order to receive funding. Such grants contribute to tree canopy cover goals by financing tree planting and care, providing incentives for the preservation of existing tree canopy through better management and policy, and encouraging improved maintenance practices. The State can also improve outcomes at the local and regional scales through continued spatial data sharing, collaborative programs, technical assistance, direct investment, and improved methods for quantifying the value of ecosystem services, including carbon sequestration and other GHG benefits of urban trees. Because, urban forests are long-lived, and it is difficult to manage them adequately on often-fluctuating city budget cycles. Municipal and community-level support will be essential to meeting these targets.

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[161] California Department of Forestry and Fire Protection, 2013

3.6 Work to Address Research Needs

Section 12 of the Forest Carbon Plan identifies research that is needed to further support ongoing work to understand and address forest climate change issues in California. While the list of research recommendations provided is lengthy and somewhat aspirational, all participants in the implementation of the Forest Carbon Plan need to work together and with other partners to find opportunities to make headway on these research needs.

4 Implementation

Implementation of the Forest Carbon Plan goals should be undertaken by a diversity of public and private actors, who will need to collaborate to achieve success. Forest health and resiliency outcomes derived from this work will benefit a broad constituency of stakeholders, with many benefits realized over a long timescale. There is a clear need to identify and increase the resources available for implementation so that they better reflect these broad beneficiaries. Similarly, it is important to identify and advance strategies to make programs more efficient and funds more effectively utilized. This Section describes the overarching considerations for implementation of the Forest Carbon Plan.

4.1 Responsibility

Working collaboratively through the Forest Climate Action Team structure, the California Natural Resources Agency (including CAL FIRE, the Board of Forestry and Fire Protection, and State Conservancies in particular), California Environmental Protection Agency, and the USDA Forest Service Pacific Southwest Region (to the extent that its capacity allows) will be responsible for ensuring the Forest Carbon Plan's regional implementation. Together, these entities will be responsible for providing leadership and working to find needed resources and overcome identified barriers to achieving the goals and approaches developed in this Plan, including fostering regional implementation.

4.2 Regional Prioritization and Implementation

The overarching Forest Carbon Plan goal of securing forests that are healthy and resilient net sinks of carbon that provide a range of ecosystem and societal benefits, while reducing GHG and black carbon emissions associated with management activities, conversion, wildfire events, and other disturbances is a statewide objective, but one that is best pursued through strong local or regional partnerships. While statewide data on forest conditions can inform priority landscapes for forest health and resiliency, decisions for how to prioritize implementation of forest health protection and management and restoration practices at the ecoregional level need to include local actors. These local actors, including private and public land owners/managers, local and regional governments, local offices of state agencies, and NGOs active in forest conservation and restoration and wood products market development, must be leaders in collaborative processes to develop regional priorities, pursue funding and other needed resources, and implement on-the-ground treatments.

Therefore, regionalization of the goals and targets described in Section 3 is an important next step for Forest Carbon Plan implementation. The forest conditions described in detail at the ecoregional scale in the forthcoming *California's Forests and Rangelands: 2018 Assessment* can serve as a starting point for new consensus-building conversations or can bolster existing work.[162] Existing forest management collaborations may serve as the best venues for implementation; some current California collaborations are listed in Box 2. Going forward, it will be necessary to identify the convening, planning, financing, project work, and other resources and policies that would best serve local implementation collaborations and to pursue those through state, federal, and other channels.

The following forest characteristics and indicators of forest health and resilience risk should guide regional prioritization across all regions of the state:

- Forests projected to be at risk due to climatically-driven stressors.
- Forests at greatest risk to high-severity events (e.g., fire, insect outbreak)

[162] A new Fire and Resource Assessment Program (FRAP) report will be released in early 2018, and will be posted to: http://frap.fire.ca.gov/.

- Stands with existing large trees
- Forests at high risk of type-conversion (e.g., forest to shrub or grass vegetation)
- Overly dense forests with large growth potential
- Forests critical to state and local water quality and supply
- Areas with high habitat values at risk, such as spotted owl Activity Centers
- Areas that need to be reforested after high mortality events
- Forests at risk of conversion to other uses, including development and agriculture
- Previously treated areas that are in need of follow-up "maintenance" treatments, which are generally less costly and may be able to be accomplished via prescribed fire.

Box 2. Examples of Existing Forest Health or Restoration Collaborations.

- Sierra Nevada Watershed Improvement Program (Sierra Nevada Conservancy and USDA Forest Service, with other state and local agencies and nongovernmental organizations)
- Collaborative Forest Landscape Restoration Act Projects (USDA Forest Service and other partners, on a landscape/regional basis)
- Memorandum of Understanding for the Purpose of Increasing the Use of Fire To Meet Ecological and Other Management Objectives (many signatory agencies and nongovernmental organizations)
- Cohesive Strategy Projects and Landscape Management Demonstration Areas (e.g., South Fork American River Fire-Adapted 50 Project, led by the USDA Forest Service with partners)
- Landscape Conservation Cooperatives through the US Geological Survey (USGS)
- Collaborative Climate Adaptation Committees established on a regional basis throughout California
- Joint Chiefs Landscape Restoration Partnership Program (USDA Forest Service and Natural Resources Conservation Service)
- California Headwaters Partnership (USDA Forest Service and Sierra Nevada Conservancy with other state and local agencies and nongovernmental organizations)
- Community wildfire protection plans (local collaborative groups)
- Tuolumne Community and Watershed Resilience Program (implementing the National Disaster Resilience Competition program)
- Yosemite-Stanislaus Solutions (USDA Forest Service, Bureau of Land Management, National Park Service, Sierra Nevada Conservancy, local agencies, and many nongovernmental organizations)
- Amador-Calaveras Collaborative Group (USDA Forest Service, Bureau of Land Management, Sierra Nevada Conservancy, local agencies, and many nongovernmental organizations)
- The North Coast Resource Partnership (local government, Tribes, watershed groups, and other interested partners)
- Good Neighbor Authority Project Agreements (USDA Forest Service and the State of California)
- Local and County Fire Safe Councils found throughout the state.

4.2.1 Working Collaboratively at the Regional or Large Landscape Scale

Agencies, nongovernmental organizations, and landowners should undertake forest health and resilience assessments and actions at the large landscape scale to maximize ecoregional and statewide benefits. Land use and forest management activities on any given parcel or within any single forest stand are important, but ecoregional resilience depends on forest conditions across property lines. Large landscapes may be defined by a combination of factors including ecoregional limits, watershed boundaries, biological needs, and regional economies. This imperative is further articulated in Sections 6 (Forests of California Today) and 10 (Wood Products and Biomass Utilization). Management for large landscape outcomes requires significant collaboration among both public and private land owners/managers, and the agencies that are responsible for the protection of the wide range of forest-based natural resources. Landscape-level collaboration, such as exemplified in Box 2, is one of the critical elements needed for the success of this Forest Carbon Plan. Figure 6 presents regional collaboratives and emphasis areas on National Forest System lands in California. Successful implementation of this Plan will require these kinds of collaborative efforts in all forested ecoregions.

An immediate implementation opportunity exists with the Sierra Nevada Watershed Improvement Program (WIP). This effort is guided by and MOU between Natural Resources Secretary John Laird and Forest Service Regional Forester Randy Moore. The initiative is coordinated by the Sierra Nevada Conservancy in partnership with the Forest Service, with the support of a wide range of state, federal and local agencies. The objectives of the WIP are well-aligned with this Forest Carbon Plan. Box 3 provides a detailed discussion of one new collaborative efforts under the WIP in the Lake Tahoe-Central Sierra area.

While willing collaboration among parties (agencies, landowners, nongovernmental organizations, e.g.) to serve mutual interests typically does not require any special authorities, a number of specific federal authorities can facilitate and expand cooperation. Two brief examples from Box 2 are highlighted here.

- Congress established the **Good Neighbor Authority** as a part of the 2014 Farm Bill with the objective of improving coordination across federal, state, and private boundaries for projects addressing hazardous fuels, insect and disease, and watershed restoration.

  The Forest Service may enter into an agreement with the governor or any State agency to perform forest, rangeland, and watershed restoration services on National Forest System lands. The Forest Service may partner directly with state agencies to perform activities, or through subcontracts.

  The Pacific Southwest Region of the Forest Service entered into a Master Good Neighbor Authority Agreement with the California Natural Resources Agency in January 2016. Subsequently the Forest Service has entered into two project-level agreements with CAL FIRE (on the Eldorado and Sierra National Forests) and is working on a third (Lassen National Forest).

- Congress established the **Collaborative Forest Landscape Restoration Program** (CFLRP) and the Collaborative Forest Landscape Restoration Fund under Title IV of the Omnibus Public Land Management Act of 2009. As described by the Forest Service,[163] the purpose of the Collaborative Forest Landscape Restoration Program is to encourage the collaborative, science-based ecosystem restoration of priority forest landscapes. CFLRP is part of an "all lands approach to forest restoration" and involves close coordination with other landowners to encourage collaborative solutions through landscape-scale operations. There are three CFLRP projects in California:
  - Amador Calaveras Cornerstone Collaborative
  - Burney-Hat Creek Basins Collaborative Landscape Restoration Project
  - Dinkey Landscape Restoration Project

Many important partners will be needed for implementation of the Forest Carbon Plan, and other factors are critical to the success of collaborative efforts in addition to willing participants. Table 3 describes the

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[163] For more information on CFLRP, see: https://www.fs.fed.us/restoration/CFLRP/overview.shtml.

potential roles in implementation each entity may best able to bring. While some partners, such as the USDA Forest Service or CAL FIRE, may have a large number of potential roles compared to other partners such as small private forest owners, all entities bring critical elements to the implementation process.

4.3 Opportunities

4.3.1 Identify and Utilize Funding Opportunities and Other Resources

Existing funding sources for collaborative processes (including neutral, third-party facilitators in some cases), forestland protection, management and restoration, and investment in wood products and biomass utilization include public funding through a range of state and federal programs as well as various forms of commercial and non-commercial private investment. The goals for forest health and resilience described in this plan call for, in most instances, a significant increase in the pace and scale of management activity beyond what can be supported by existing funding levels.

The complex collaboration and implementation strategies needed to achieve the goals of this Forest Carbon Plan will need to leverage resources from existing state, federal and private efforts. Box 4 lists some of the various state and federal programs that share broader forest health and resilience priorities and contribute to forest carbon goals. These programs should be taken into consideration in designing funding approaches, although some of these funding sources are subject to annual appropriation decisions and shifting revenue availability themselves. For example, the California Conservation Corps (CCC) is a valuable resource for forest and other natural resource management, as well as youth development, and provides those services through its own annual budget as well as through external collaboration and funding (see Box 5 for more information on the CCC).

Two recent funding actions, one in place, another prospective, could provide substantial resources for a number of the goals and actions recommended in the Forest Carbon Plan: AB 109 (Ting, Chapter 249, Statues of 2017), which provided new State budget allocations from Cap-and-Trade through California Climate Investments Program, and SB 5 (De León, Chapter 852, Statutes of 2017), which placed a bond act on the ballot for the June 5, 2018 California Election. The below sections look at each of these in detail.

AB 109, Budget Act of 2017. This act provides California Climate Investment funding in several areas that can support the goals in this Plan:

- **Natural Resources Agency:** Urban Greening Grant Programs, $26,000,000.
- **Office of Emergency Services:** Grants to local fire departments within High Fire Severity Zones to support activities directly related to the reduction of greenhouse gas emissions caused by uncontrolled wildfires and other activities, $25,000,000.
- **California Conservation Corps:** Training and Work Program, $5,195,000
- **Department of Forestry and Fire Protection:** State and local healthy forest and fire prevention programs and projects that improve forest health and greenhouse gas emissions caused by uncontrolled wildfires, including but not limited to, vegetation management, forest overgrowth reduction, biomass energy generation, and measures to ensure fires are more consistent with historic regenerative fire regime, $200,000,000. Urban Forestry Programs, $20,000,000. Additionally, CAL FIRE will be funded with cap and trade proceeds to continue the fire prevention work that was previously funded via the State Responsibility Area Fire Prevention Fee.

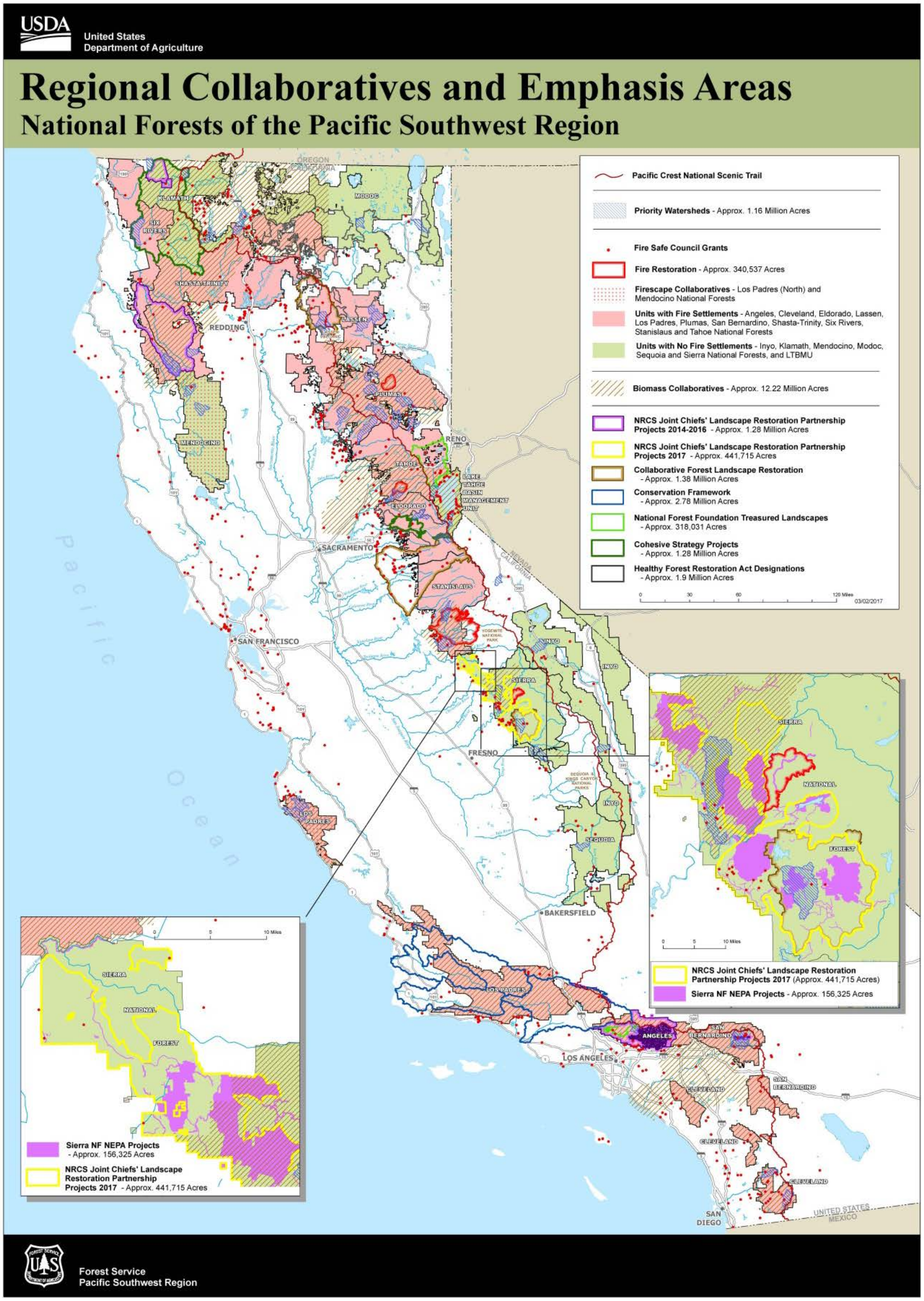

Figure 6. National Forest Regional Collaboratives and Emphasis Areas.

Figure courtesy of USDA Forest Service Pacific Southwest Region.

Box 3. Large Landscape Collaborative – The Tahoe-Central Sierra Initiative.

Building upon the activities of the California Governor's Tree Mortality Task Force and several large-scale regional efforts, the Sierra Nevada and Tahoe Conservancies, in partnership with the USDA Forest Service, are proposing a Tahoe-Central Sierra Initiative. The planning landscape is comprised of the Lake Tahoe Basin and the watersheds of the American, Bear, Yuba, Carson, and Truckee Rivers. Although tree mortality and other drought impacts have been much more severe, to date, in the southern Sierra, the central Sierra and the Lake Tahoe Basin are also likely to face devastating impacts without an aggressive coordinated effort among the region's public agencies, the private sector, and key stakeholder groups. A robust forest health program in the central Sierra could help in prevent, or at least slow, the effects of the pine bark beetle.

The Tahoe-Central Sierra Initiative will seek to accelerate implementation of large landscape forest health projects and the development of biomass utilization infrastructure, while providing the opportunity to explore innovative process, investment, and governance tools. The initiative is a key component of the Sierra Nevada Watershed Improvement Program, a collaborative effort led by the State's Sierra Nevada Conservancy and the USDA Forest Service. The Tahoe-Central Sierra Initiative's objectives will be achieved through the following goals and activities:

- Supporting, developing and implementing science-based large landscape projects with integrated design, implementation and monitoring;
- Accelerating planning, permitting and implementation of high priority projects;
- Increasing and leveraging federal, state, local, and private funding;
- Integrating research and monitoring into activities to guide creation of fire and climate resilient forests and fire–adapted communities across ownerships;
- Developing a regional biomass utilization strategy to improve air quality, reduce GHG emissions, and offset forest restoration costs;
- Establishing a regional, science-based, conservation planning and implementation framework in concert with existing efforts;
- Developing a collaborative communications network that will share and amplify messages about successes, needs, lessons learned, and opportunities to duplicate innovative pilot approaches in other locations;
- Developing a strong relationship between this landscape and nearby urban areas so that downstream stakeholders can see firsthand the impact of restoration activities in their upstream headwaters; and
- Exploring a pilot to demonstrate the possibility of successful private investment in headwaters restoration to yield an improvement in ecological services for investors.

To learn more, visit: www.restorethesierra.org

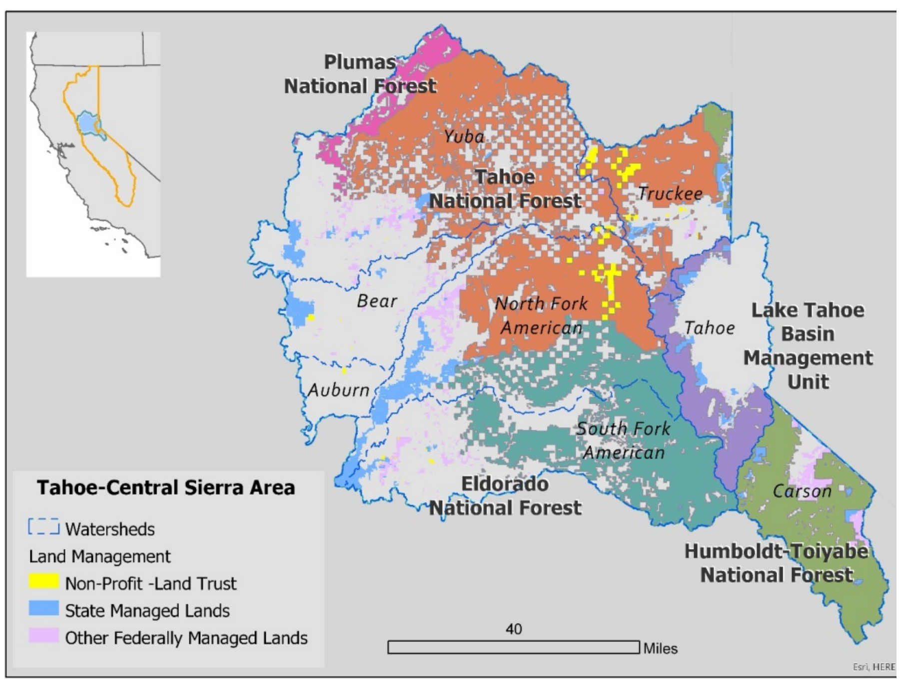

Table 3. Important Plan Implementation Entities and Their Potential Roles.

Entities	Convene Collaboratives	Participate in Collaboratives	Implement Mgmt. on Own Lands	Implement Mgmt. on Others Lands	Provide Funding for Work on Own Lands	Provide Funding for Work on Others' Lands	Share Expertise	Facilitate Permitting Processes	Provide Social License
Federal Agencies									
USDA Forest Service	X	X	X	X	X	X	X	X	
Bureau of Land Management	X	X	X		X		X		
National Park Service	X	X	X		X		X		
Natural Resources Conservation Service	X	X				X	X		
Tribes	X	X	X	X	X	X	X		
State Agencies									
CA Natural Resources Agency		X				X	X		
CA Environmental Protection Agency		X				X	X		
CAL FIRE	X	X	X	X	X	X	X	X	
Conservancies	X	X	X	X	X	X	X		X
CA Conservation Corps		X		X			X		
Dept. of Parks and Recreation	X	X	X		X		X		
State Lands Commission	X	X	X		X		X		
Dept. of Conservation	X	X				X	X		
Dept. of Fish and Wildlife	X	X	X		X	X	X	X	
Dept. of Water Resources	X	X				X	X		
Regional Water Quality Control Boards	X	X				X	X	X	
Resource Conservation Districts	X	X		X		X	X		
Local Agencies									
County Governments	X	X	X				X	X	
County Government Representative Associations	X	X					X		
Fire Districts		X	X	X	X	X	X		
Private Entities		X							
Fire Safe Councils		X		X		X	X		X
Small Forest Landowners		X	X		X		X		X
Large Forest Landowners	X	X	X	X	X	?	X		X
Watershed Groups	X	X		X		X	X		X
Environmental or Conservation Organizations	X	X	X	X	X	X	X		X
Resource Development and Conservation Councils		X				X	X		X
Restoration Organizations		X	X	X	X	X	X		X
Foundations	X	X				X	X		X

Box 4. Current Funding Sources for Forest Restoration

- *CAL FIRE:*
  - California Forest Improvement Program (California Climate Investments, Timber Regulation and Forest Restoration Fund, USDA Forest Service Forest Stewardship Funds)
  - Vegetation Management Program (California Climate Investments)
  - Urban and Community Forestry Program (California Climate Investments, USDA Forest Service Forest Stewardship Funds)
  - Forest Stewardship Program (USDA Forest Service Forest Stewardship Funds, California Climate Investments)
  - Forest Legacy Program (USDA Forest Service Forest Legacy Funds)
  - L.A. Moran Seed Bank and Reforestation Nursery (Timber Regulation and Forest Restoration Fund)
  - Pest Management Program
- *Natural Resources Agency*: Urban Greening (California Climate Investments).
- *Sierra Nevada Conservancy*: Proposition 1 Watershed Improvement Program
- *Department of Water Resources*: Proposition 1 Integrated Water Resources Management Program
- *Department of Fish and Wildlife:*
  - Proposition 1 Restoration Grant Programs
  - Wetlands Restoration for Greenhouse Gas Reduction Program (California Climate Investments)
  - State Wildlife Grant Program.
- *California Conservation Corps*: Efforts to assist firefighting and fuels management throughout California.
- *National Disaster Resiliency Competition*: A federal grant program through Housing and Urban Development designed to help communities in recovering from—and preparing for the next—natural disaster, this program identified Tuolumne County as a recipient of their 2016 competition.
- *USDA Forest Service and NRCS*
  - Joint Chiefs' Landscape Restoration Partnership
  - USDA Forest Service Landscape Scale Restoration Program (LSR)
  - Natural Resources Conservation Service (U.S. Department of Agriculture): Environmental Quality Incentives Program and other grant programs.

Box 5. Role of the California Conservation Corps in Advancing Forest Health.

The California Conservation Corps (CCC) is an important resource for addressing needs for environmental protection as well as providing employment development opportunities for young adults. Corpsmembers provide services that allow land management partners to protect, monitor, and care for land. Corpsmembers spend thousands of hours each year improving forest health, reducing the threat of fires, and planting trees. In the 2015-fiscal year, CCC spent almost 50,000 hours on forest improvements, over 300,000 hours on fire hazard reduction activities and over 5,000 hours planting trees. Work the CCC accomplishes to advance forest health includes brush clearance, controlled burns, fire hazard reduction, fire suppression, fuelbreaks/fire lines, slash removal/burning, removal of invasive species, timber stands thinning, urban forestry protection, and tree planting.

State Responsibility Area (SRA) Projects: Since 2012, CCC crews have collaborated with CAL FIRE to reduce and remove deadly ladder fuels and overgrown vegetation on lands within the State Responsibility Area (SRA). The focus of these efforts has been to slow the potential spread of wildfire and create buffer zones around evacuation routes. Funding through SRA has allowed CCC to be responsive to locally designated, critical fire prevention projects by covering the costs of the crews that work on the projects approved by local CAL FIRE Units, Fire Safe Councils, and Fire Protection Districts. Work completed has:

- Reduced fuel loads and created fuel breaks in State Parks, freeing up Parks personnel to concentrate on facility maintenance/repair or providing new services to the public.
- Benefitted emergency response organizations by widening access and evacuation routes.
- Created fuel breaks in the Wildland Urban Interface areas located adjacent to homeowners, Fire Safe Councils, local and regional parks, and private reserves or conservancies (entities that do not have the budgets to service the lands outside of their defined boundaries).
- Provided Post-Fire rehabilitation to remove dead and dying trees and prevent soil erosion to preserve and protect water quality.
- Provided additional training opportunities for Corpsmembers including Basic Fire Training, Chain Saw Training, Burn Pile Training, Exotic Plant Identification/Eradication, and Chipper Training.

Crew members conduct roadside fuels reduction project. *Photo courtesy of CCC.*

Sample SRA Project: Sierra County Fuel Load Reduction (Placer CCC Center, FY 15/16): With direction from the Sierra County Department of Public Works, crews hand-thinned hazardous fuels and vegetation to create a safe fuel break and road clearance within the county right of way on Ridge Road between Pike and Alleghany communities in Sierra County. Hand crews removed ladder fuels, shrubs, and small trees. Cut materials were chipped and broadcast on site. Crews worked a total of 5,528 hours completing 35 acres of fire hazard reduction work. The project provided public benefit through the reduction of wildfire risk by removing encroaching vegetation, ladder fuels, and snags from the understory. During the project, Corpsmembers had the opportunity for training in various areas of employable skills including identifying and removing heavy accumulations of surface fuels, identifying and creating horizontal separation of crowns, and chainsaw operation and maintenance, as well as team building skills. Corpsmembers learned how to reduce wildfire risk through the removal of encroaching vegetation by the use of power equipment and manual labor. The crew also learned about the different vegetation and other shrub cover in the understory.

- **Department of Fish and Wildlife:** Wetland restoration projects that will be managed to provide benefits for at least 50 years, underpinned by conservation easements or equivalently enforceable conservation agreements that endure for at least 50 years, $15,000,000.
- **Wildlife Conservation Board:** Climate adaptation projects that result in enduring benefits, with at least 60 percent of funds used for conservation easements or other long-term agreements that conserve natural and working lands for the benefit of climate adaptation and resilience, and other funds to be used to develop and implement natural and working lands adaptation and resiliency planning, $20,000,000.

SB 5, California Drought, Water, Parks, Climate, Coastal Protection, and Outdoor Access for All Act of 2018. This bond act, appearing as Proposition 68 on the June 2018 primary ballot, if approved by the voters, would provide bond-funded grants in several areas that can support the work called for in this Plan:

- **Department of Parks and Recreation:** Restoration, preservation, and protection of existing park facilities and units, including projects for the protection of natural resources to provide climate resilience, water supply, and water quality benefits, not less than $25,000,000.
- **Sierra Nevada Conservancy:** For purposes specified in its governing statue, $30,000,000
- **State Coastal Conservancy:** Grants and expenditures for the protection, restoration, and improvement of coastal forest watersheds, including managed forest lands, forest reserve areas, redwood forests, and other forest types, $20,000,000.
- **Wildlife Conservation Board:** A wide range of projects, including projects to improve climate adaptation and resilience of natural systems, $18,000,000. Protection, restoration, and improvement of upper watershed lands in the Sierra Nevada and Cascade mountains, including forest lands, meadows, wetlands, and riparian habitat in order to protect and improve water supply and water quality, improve forest health, reduce wildfire danger, mitigate the effects of wildfires on water quality and water supply, increase flood protection, or to protect or restore riparian or aquatic resources, $60,000,000.
- **Department of Forestry and Fire Protection:** Projects that provide ecological restoration of forest, including but not limited to forest restoration activities that include hazardous fuels reduction, post-fire watershed rehabilitation, prescribed or managed burns, acquisition of forest conservation easements or fee interests, and forest management practices that promote forest resilience to sever wildfire, climate change, or other disturbances, $50,000,000. Not less than 30 percent of these funds to be allocated to urban forestry projects; 50 percent to be allocated to the Sierra Nevada Conservancy for projects implemented under the Watersheds Improvement Program.
- **California Conservation Corps:** A range of projects including those to rehabilitate or improve local or state parks, restore watersheds and riparian zones, regional and community-level fuel reduction, resource conservation and restoration projects, $40,000,000. Not less than 50 percent of these funds to be allocated to local community conservation corps.

Federal funding for the USDA Forest Service and other federal land managers also is vulnerable, both to annual budget appropriations and priorities and to "fire-borrowing," a condition wherein unobligated USDA Forest Service funding is reallocated to fight wildfire, leaving restoration objectives underfunded. Nationally, USDA Forest Service spending on wildland firefighting has risen from 16 percent of their budget in 1995 to 52 percent in 2015, and is projected to demand 67 percent of their budget by 2021.[164] Agency wildfire costs were $1.7 billion in federal FY2015, $1.6 billion in FY2016, and a record $2.35 billion in FY 2017.[165]

After many years of efforts in Congress to address the "fire borrowing" issue, the federal Fiscal Year 2018 Consolidated Appropriations Act included the Wildfire and Disaster Funding Adjustment, which helps to address this issue and should increase the availability of funds for restoration work on National Forest Lands. This budgetary change does not take full effect until federal fiscal year 2020, however. By changing the way budgets are structured so that disaster or emergency relief funds would be used to pay for fire suppression cost overruns, funds initially allocated for restoration activities would not need to be transferred to fire expenditures as they are now. The restoration activities needed to help prevent large high severity wildfire events in the future could still be funded, regardless of the fire season.

Private landowner capacities range from limited resources (small forestland owners) to significant resources (corporate forestland owners) to support treatments to improve forest health and resilience. In some cases, this work can be done as a part of revenue-generating commercial timber harvests; in other cases, it can be done as a part of non-commercial forest management activities, some of which may be eligible to receive funding from state and federal programs such as those listed in Table 4. For some private landowners, state and federal grant programs may be problematic, because the programs typically work on a reimbursement basis, and the landowners may not be able to front the funds to do the on-the-ground work. In any case, the ability of private landowners to generate revenue through sustainable commercial timber harvests is a critical element in their active management of their forestland to maintain forest health and resilience.

The insufficiency of existing funding to fulfill the needs identified in this Forest Carbon Plan highlights the need to identify new funding sources and mechanisms. Some opportunities for generating new revenue for forest health include:

- **Funding for Ecosystem Services:** Linking and communicating the socio-economic benefits, or ecosystem services,[166] provided by healthy forests to other sectors or markets could generate financing for forest protection and restoration. These financing mechanisms link ecosystem service producers and consumers directly, or through an organizing entity that functions to structure transactions and deliver on benefits. These arrangements can be funded by public and private entities, including non-profit organizations with a mission-driven interest in the outcome (e.g., a land trust can raise capital for a conservation easement). Signed into law in 2016, AB 2480 identified watersheds as part of California's water infrastructure, further presenting an opportunity to grow constituencies around the multiple ecosystem services forested watershed investments deliver. Ecosystem service linkages are further described in Section 8, Benefits of Healthy Forests.
- **GHG Market Offset Programs:** The CARB compliance market offset programs for improved forest management, reforestation, and avoided conversion are clearly linked to climate objectives. These projects allow the carbon sequestration benefits accruing from those activities to be monetized through sale of offsets. While not all the offset projects enrolled in the CARB

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[164] USDA Forest Service, 2015c

[165] Forest Service fire expenditure data provided by Forest Service Pacific Southwest Region staff.

[166] Heal et al., 2005

program are located in California, offsets represent one opportunity to link producers and consumers of environmental services. Forest offset projects in California have generated 19 MMT CO_2e in early action and compliance offset program credits registered with CARB as of November 2017. In addition, California-based voluntary forestry offset projects are in place under programs such as those of the Climate Action Reserve,[167] providing further offsets.
- **Direct Benefits to Local and State Water Quality and Supply:** Collaborative watershed investments can bring together water utilities and users, air quality management districts, flood control districts, and land owners and managers to jointly implement watershed and riparian restoration efforts that reduce utility and district capital and operational costs and promote forest health activities.
- **Innovative Wood Products and Biomass Utilization:** Economic conditions and technological innovations can drive growth in markets for biomass utilization in wood products or energy. These opportunities can strengthen regional forestland economies and capacity to support forest health activities. New funding opportunities for wood products and biomass utilization are further described in Section 10, Forest Material Utilization Pathways.

Other, non-monetary resources are needed to advance the goals of this plan as well. Information, technical assistance, and tools to identify forest conditions and recommend best management practices for private landowners would be useful in facilitating engagement in regional collaborations. As the Forest Carbon Plan proceeds into implementation, local and regional actors should identify the information and tools needed to achieve the Plan's goals so that the state and federal agencies can seek resources to supply these at the appropriate scale and in the most effective forms.

4.3.2 Working within Environmental Regulatory Frameworks

Working within environmental regulatory frameworks is always a critical responsibility for agencies and private entities. The California Environmental Quality Act (CEQA) and the Forest Practice Act and Rules are two of the most important laws pertaining to management of non-federal lands. On federal forestland, the National Environmental Policy Act (NEPA) and agency-specific land management laws are very important. These laws ensure we protect our forests and the ecosystem services they provide. Meeting the requirements of these laws can be costly and time consuming, and at times agency actions are subject to litigation or administrative appeals. There are provisions under some of these statutes and related regulations to streamline review or permitting process or to exempt certain activities. Where appropriate, agencies, landowners, and managers implementing programs of projects may want to utilize some of the options that these statutes and regulations provide for more efficient approaches to achieving environmental compliance.

Flexible Regulatory Elements of Major State Statutes or Regulations

There are opportunities for project proponents to conduct forest health improvement work or address other immediate forest management needs through ministerial permitting processes[168] Actions by both the Legislature and the Board of Forestry and Fire Protection have recently provided new ministerial permit options for management that can help to restore forest resilience, such as the Forest Practice Rule section 1038(k) exemption for the removal of dead and dying trees. In conjunction with these

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[167] Climate Action Reserve, 2012

[168] For example, this CAL FIRE publication provides a summary comparison of different Exemption, Emergency, and discretionary permit options for conducting fuel reduction treatments on nonfederal forestlands: http://www.readyforwildfire.org/docs/files/File/04123-Bark-Beetle-Campaign_Brochure_web_LINOA.pdf

current permits, oversight by responsible agencies remains important, particularly because the use of several exemptions has been significantly expanding recently. For example, recent legislation (AB 1958, Wood, Stats. 2016, Ch. 583; AB 2029, Dahle, Stats. 2016, Ch. 563; SB 92, Committee on Budget and Fiscal Review, Stats. 2017, Ch. 26) requires the Board of Forestry and Fire Protection and CAL FIRE, working with the participation of the Department of Fish and Wildlife and the Regional Water Quality Control Boards, to review and submit a report to the Legislature by the end of 2018:

> The report shall include an analysis of exemption use, whether the exemptions are having the intended effect, any barriers for small forest owners presented by the exemptions, and measures that might be taken to make exemptions more accessible to small forest owners. The report shall also include recommendations to improve the use of those exemptions and emergency notice provisions.[169]

A substantial area of forestland is treated each year under exemptions and emergency notices under the Forest Practice Act and Rules. Some of these statistics are provided in Section 6 of this document, Forests of California Today.

CEQA provides for the development of programmatic environmental impact reports (EIRs) that address the potential environmental impacts of a program at a broad level. Once a programmatic EIR is in place, project-level environmental assessment work can be greatly reduced, facilitating project implementation, while still ensuring a high level of environmental protection. The Board of Forestry and Fire Protection is currently working to complete a programmatic EIR for CAL FIRE's Vegetation Treatment Program, which has a major intent of restoring forests and reducing fuels through prescribed fire, mechanical and hand treatment, herbivory, and other techniques.[170] Successful completion of the Vegetation Treatment Program Programmatic EIR could facilitate the CEQA review process for fuels reduction activities on nonfederal forest lands in the state.

The draft programmatic EIR[171] focuses on three general treatment classes with estimated "tree-dominated" acres to be treated annually:

- **Wildland-Urban Interface (WUI)**:[172] treatments will be focused in WUI-designated areas, and generally consist of fuel reduction to prevent the spread of fire between wildlands and structures, or vice versa. (9,016 acres treated annually)
- **Fuel Breaks:** strategically placed vegetation treatments that actively support fire control activities. (2,949 acres)
- **Ecological Restoration:** vegetation treatments will generally occur outside the WUI in areas that have departed from the natural fire regime as a result of fire exclusion. Ecological restoration treatments will focus on restoring ecosystem resiliency by moderating uncharacteristic wildland fuel conditions to reflect historic vegetative composition and structure, including cultural landscapes. (10,592 acres).

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169 California Public Resources Code § 4589.
170 See the Board of Forestry and Fire protection website: http://bofdata.fire.ca.gov/board_committees/resource_protection_committee/current_projects/vegetation_treatment_program_environmental_impact_report_%28vtpeir%29/
171 California Board of Forestry and Fire Protection, 2017
172 Wildland urban interface is roughly defined as the zone where natural areas and development meet. https://www.fws.gov/fire/living_with_fire/wildland_urban_interface.shtml.

Flexible Regulatory Elements of Major Federal Laws

- The Healthy Forest Restoration Act created a process for States to nominate, landscapes that are experiencing, or at risk of, an insect or disease epidemic to the US Secretary of Agriculture. Projects in areas approve by the Secretary of Agriculture can be eligible for expedited NEPA, administrative, and judicial review processes. To date, California has nominated, and the Federal government has approved, the designation of 10.7 million acres under this program, which covers 45 percent of National Forest System Lands in California.
- The 2014 Farm Bill provided the USDA Forest Service with a NEPA Categorical Exclusion (CE) for insect and disease projects on areas up to 3,000 acres in size, where those projects are a product of collaborative processes. The CE can result in a reduction of the cost and time needed for forest restoration projects. So far, the Forest Service has treated 1,200 acres under this process.

4.3.3 Seize Opportunities to Increase Use of Prescribed and Managed Fire

In fall 2015, the USDA Forest Service Pacific Southwest Region, National Park Service Pacific West Region, CAL FIRE, Sierra Nevada Conservancy, multiple environmental organizations, and two prescribed fire councils signed the Memorandum of Understanding for the Purpose of Increasing the Use of Fire to Meet Ecological and Other Management Objectives (MOU).[173] The MOU recognizes that the state's wildland ecosystems have evolved with fire, which provides resilience and renewal. The purpose of the MOU is to: "…document the cooperation between the parties to increase the use of fire to meet ecological and other management objectives in accordance with…" specified provisions. Modifications to the MOU are currently underway and a number of additional agencies and organizations have signed on to it.

Some of the challenges in increasing the use of prescribed and managed fire include air quality, risk of fire extending into areas that were not intended to burn, the difficulty of applying managed fire on private forestlands, and the risks of using either technique near communities. Despite these challenges, there are examples of the successful use of prescribed fire in California, such as for regular forest management at Big Basin State Park, described in Box 6.

4.3.4 Assist Small Landholders with Land Management

FIA data indicate that there are 7.6 million acres of non-corporate forest land in California, and that 61 percent (about 4.6 million acres) of that land is family-owned parcels of 500 acres or less. There are significant financial barriers to small landholder management, including costs associated with completing a timber harvesting plan (THP) or nonindustrial timber management plan (NTMP). In-place statutes have modified the costs for landowners to prepare applications for discretionary permits for commercial timber operations,[174,175] but the costs of regulatory compliance still may exceed the benefits, making forest management financially infeasible. In some cases, financial assistance may be available to landowners to complete forest improvement activities that do not generate timber revenues. There are ongoing discussions on reducing the regulatory cost of forest management through legislative and regulatory changes and by increasing market opportunities. Progress on this topic is

[173] USDA Forest Service, 2015d
[174] AB 904, 2013
[175] AB 1492, 2012

needed to make it more feasible for small landowners to carry out forest health and resilience improvement work while still ensuring that natural resources are protected.

4.3.5 Explore Approaches to Securing Exemptions to Federal Restrictions on the Export of Sawlogs from Federal and Other Public Lands.

Federal and state restrictions on log export from public lands have ebbed and flowed since the 1800s, with major adjustments made in the late 1980s and early 1990s.[176] While these restrictions were appropriate when they were enacted, conditions in California are much different today, where dozens of mills have closed in recent decades. Material from drought- and beetle-ravaged and severely burned forests far exceeds California's current mill capacity. Federal statutes and regulations in this area do provide processes for securing exemptions from export restrictions in certain circumstances, including an excess of materials beyond domestic processing capacities; these exemptions could be further explored.

[176] Daniels, 2005

Box 6. Use of Prescribed Fire at Big Basin State Park.

Big Basin Redwoods State Park in Santa Cruz County includes some of California's most storied redwood forests. The Park's history is rooted in the beginning of the movement to save the redwoods at the start of the 20th century. Today, Big Basin contains some of the largest and oldest organisms on the planet, and is home to rare and magnificent wildlife. For example, the state endangered and federally threatened Marbled Murrelet nests in the upper canopy of redwood trees and makes famously long daily journeys to the ocean to feed. Stewardship of this landscape is important both for wildlife like the Murrelets, which are dependent on old growth forest for their survival, and for the hundreds of thousands of visitors who visit the park each year. Protecting redwood forests has also taken on another meaning in recent years, as redwoods form some of the most carbon-dense ecosystems in the state.

Image: Jonathan Knowles

The photo shows a member of the State Parks burn crew during a 2011 prescribed burn. These burns are generally low-severity and are designed to clear surface fuels (woody debris) rather than live trees.

Managers at Big Basin Redwoods State Park strive to maintain healthy forest conditions that protect old growth and restore older forest conditions at the park. At times, they must take a hands-on approach to ecosystem stewardship. Since 1978, managers have utilized prescribed fire as a management tool at the park. Each year, California State Parks managers and CAL FIRE crews collaborate to treat 100 – 300 acres of redwood forest through prescribed burns.

These burns increase resilience and continue a practice employed by native people of the region for thousands of years. Coast Redwood forests are typically in foggy, moist regions with infrequent lightning strikes. In this climate and in the absence of natural ignition sources, it is unlikely that redwoods would encounter much wildfire in the absence of humans. However, native people from the Big Basin area frequently used fire as a management tool, often starting in nearby grasslands to stimulate food and other resource production. As a result, fire scars from the trees indicate that these forests may have burned every ten to15 years.[177] Fire provides important functions in the forest, such as stimulating nutrient cycling and promoting redwood tree resprouting. Thus, State Parks has found that continued use of prescribed burning is crucial for cultural values as well as for protecting the ecological integrity of these iconic natural resources.

[177] Stephens & Fry, 2005

5 Measuring Progress

Monitoring adherence to this plan and measuring progress is crucial to its success. This Plan contains both high-level performance objectives for climate change mitigation—securing California's forestlands as a net carbon sink and reducing the GHG and black carbon emissions associated with wildfire events and management activities—and implementation goals that are intended to lay out on-the-ground forest protection and management and related activities that will move forests across the state towards resilient conditions. Monitoring progress towards these objectives must also measure other key benefits of healthy forest systems, including biodiversity, watershed function, and economic and ecological sustainability.

Monitoring, performance assessment, and public reporting must be consistent, transparent, and useful to stakeholders. Because of the rapid and unprecedented changes many California forests are undergoing, comprehensive and timely monitoring is required to help us better understand the continuing challenges climate change poses for forest's health their capacity to sequester carbon. Working with landowners, communities, collaborative stewardship groups, tribes, and others on monitoring and adaptive management responses will be critical to measuring progress and responding to what is found.

5.1 Monitoring and Reporting on Carbon Stock and Emissions of GHGs and Black Carbon

As detailed in Section 7, Forest Carbon Storage and Accounting, forest carbon stocks and GHG emissions will be tracked through existing statewide carbon inventory efforts undertaken by CARB (the natural and working lands inventory) and the Board of Forestry and Fire Protection (AB 1504 forest and harvested wood products carbon accounting). These efforts will use a combination of stock-change and GHG flux approaches to measure forest carbon and GHG emissions statewide in metric tons of carbon. Measurements will be conducted on an annual or biennial calendar-year basis, depending on the cycles of the Board of Forestry and Fire Protection and CARB monitoring programs, and will be relative to a ten-year baseline period beginning in 2001 and ending in 2010. Black carbon emissions will be assessed separately from GHG emissions.

The state's forest carbon monitoring must be aligned with federal and international standards for carbon accounting and forest management (e.g., USDA Forest Service, other federal climate programs, and guidance of the Intergovernmental Panel on Climate Change). Where possible, state-produced and maintained planning tools and databases should be accessible to local land-use decision-makers and private and public landowners to facilitate adoption of best practices and information-sharing across jurisdictions.

5.2 Monitoring and Reporting on Implementation Activities

Monitoring of forest carbon is complex. The carbon cycle is influenced by dynamic ecological systems that have high spatial and temporal variation. Long term investments are needed to support ongoing monitoring and refinement of assessment methods. State agencies and entities will coordinate on monitoring and will evaluate and make recommendations on new data and assessment methods. This should include the development of landscape scale carbon accounting tools, in order to avoid the inherent flaws in using a project by project approach when dealing with efforts to restore landscape resilience.

Centralized and standardized systems for tracking implementation activities to meet the Forest Carbon Plan goals and targets established in Section 3 will be necessary to fully account for all efforts, identify areas of underperformance, and effectively work towards the ultimate performance objective of maintaining California's forests as healthy and resilient net sinks of carbon. This Plan sets a number of acreage-based numerical targets, or numerical ranges, for implementation of forest management activities over time. The Plan's implementation will flow across programs of various responsible local, state and federal agencies and actions of local public and private landowners and managers.

In many cases, reporting structures or tools are in place for consistent tracking that can be accessed and utilized to support policy-making and implementation along multiple channels. For example, forest management activities are currently undertaken or funded by federal and state agencies including the Natural Resources Conservation Service, CAL FIRE, the California Department of Parks and Recreation the California Department of Fish and Wildlife, and the Sierra Nevada and California Tahoe conservancies, among others. However, there is currently no centralized database that includes a full listing of forest management and conservation activities that have taken place and are underway throughout California. Forest management and conservation activities are initiated by public and individual private landowners and entities, and are either voluntary or mandated actions. Voluntary actions are funded by a range of state, federal, local and private funding sources, through various programs, often of limited duration tied to funding availability.

State and federal agencies currently maintain a number of databases that track and report on management and conservation activities:

- CAL FIRE uses CalMAPPER and has a database with certain information contained in timber harvesting plans, emergency and exemption harvesting notices, forest improvement projects, and fuels reduction[178];
- The California Department of Fish and Wildlife uses the California Environmental Data Exchange Network[179], EcoAtlas[180], and Miradi[181] for various project types and programs;
- CNRA maintains grant-specific information associated with bond initiatives[182];
- The USDA Forest Service reports forest activities through regional and national databases[183]; and
- CARB maintains a databases of forest carbon offset projects and a database and map of California Climate Investment projects funded through the Greenhouse Gas Reduction Fund.

These databases vary in their level of detail and are not currently fully compatible. Also, most of these databases are not designed to provide data on expected carbon stock or GHG or black carbon emissions associated with management and conservation activities. Developing a centralized database or an automated system that can pull and standardize data from disparate sources will be important to track progress in a way that links policies, programs and funding sources to outcomes.

Toward this end, the CNRA will seek to develop and implement a centralized database or other information management system to track implementation activities identified in this Forest Carbon Plan across its boards, departments, and offices. Where possible, this system will be designed to

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[178] California Department of Forestry and Fire Protection, 2016b, 2016c
[179] State Water Resources Control Board, 2016
[180] California Water Quality Monitoring Council, 2016
[181] Conservation Measures Partnership and Sitka Technology Group, 2016
[182] California Natural Resources Agency, 2016b
[183] USDA Forest Service, 2016b, 2016c

accommodate additional inputs from local and federal agencies and organizations to build a complete picture of statewide implementation activities.

5.3 Additional Monitoring and Reporting on Benefits

Multiple programs already in place also can serve to monitor and report on the benefits of managing our forests to be healthy and resilient net carbon sinks. Progress on benefits will be determined through existing state and federal periodic assessments, including:

- Natural and Working Lands Climate Change Implementation Plan[184]
- State Wildlife Action Plan;
- California Forests and Rangeland Assessment;
- California Water Plan;
- California Forest Pest Conditions Annual Report;
- USDA Forest Service Forest Health Monitoring Reports;
- California Integrated Report on Clean Water Act Sections 303(d) and 305(b)
- CAL FIRE Urban and Community Forestry Program Strategic Plan
- Economic data from the California Employment Development Department and the U.S. Bureau of Economic Analysis.

5.4 Model Under Development: CALAND

CNRA, in collaboration with CARB, California Department of Food and Agriculture, CalEPA, and the Governor's Office of Planning and Research, are engaged in development of the California Natural and Working Lands Carbon and Greenhouse Gas (CALAND) model. The model is being developed by Lawrence Berkeley National Laboratory (LBNL) under contract to CNRA, and began development in August 2016. Two inter-agency entities, a Steering Committee and a Technical Advisory Committee, have been convened to guide and inform its development. Federal partners, the academic research community, professional experts, and the public at large have also provided valuable technical input. The first iteration of the model, Version 1, was developed to inform the 2017 Scoping Plan Update. It established the scope of work for building projections of GHG and carbon sequestration on natural and working lands, and identify issues for further investigation. Version 2, which is underway now, builds on Version 1. A technical description is of CALAND Version 2 was released in September 2017.[185]

CALAND is a data-driven, empirical model of the California landscape carbon budget and associated GHG emissions. It follows an Intergovernmental Panel on Climate Change (IPCC) Tier 3 approach that tracks carbon stocks and fluxes annually using California-specific data.[186] Its primary function is to estimate the changes in California landscape carbon and GHG emissions due to various management targets with respect to a historical business-as-usual scenario. Model dynamics include ecosystem carbon exchange, wildfire, land use based cover change, and a suite of management practices. Annual emissions of CO_2, CH4, and black carbon are calculated based on the respective carbon pathways within the overall carbon budget. The utilization of forest biomass for wood products and bioenergy is also included, and their respective emissions are also quantified.

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[184] To be developed by CARB in conjunction with the Natural Resources Agency, Department of Food and Agriculture, CalEPA, and other agencies by November 30, 2018.
[185] Di Vittorio & Simmonds, 2017
[186] Intergovernmental Panel on Climate Change, 2006

The CALAND model and other land-based modeling or quantification tools will be used to quantitatively assess the activities set forth in the Natural and Working Lands Implementation Plan identified in California's 2017 Climate Change Scoping Plan. CALAND will quantify the expected net GHG and black carbon emissions outcomes of a suite of land management and conservation activities on Natural and Working Lands, including forests, relative to a statewide, business-as-usual emissions scenario through 2030, 2050, and 2100 using historical data and recent trends, including climate change. It will model the expected impacts of land conservation, restoration, and management activities the State expects to undertake and scale up to meet the climate change mitigation reduction goal identified in the Scoping Plan, over those same time periods.

This quantitative analysis of net GHG emissions over time, tied to a suite of activities, will be a valuable evaluative tool to guide expenditures across multiple programs within CNRA and its boards, departments, and Conservancies. Clarity on expected net GHG reduction outcomes will improve tracking of expected GHG outcomes across relevant programs, regardless of whether the primary purpose of those programs is to reduce GHG emissions. CNRA expects that the version of CALAND used in the Natural and Working Lands Implementation Plan will continue to evolve after 2018 to support programmatic assessments, and in a manner that complements related projections currently under development at CARB, as well as the CARB Inventory for Natural and Working Lands.

6 Forests of California Today

6.1 The Western Forest Context

The conditions of California's forests today share similar conditions with forests elsewhere in the western United States, where forest health problems, increasing wildfire, and the effects of a changing climate are common themes. Clark and colleagues found:

> Large stand-level shifts underway in western forests already are showing the importance of interactions involving drought, insects, and fire. Diebacks, changes in composition and structure, and shifting range limits are widely observed.[187]

Most forests across the western United States are fire-prone, and their ecosystems have adapted to fire as a primary source of disturbance.[188] In fact, wildfire is an essential part of these ecosystems, and many of the native tree and plant species are dependent on periodic disturbance from wildfire. Altered wildfire regimes and changes due to land management have affected forest structure. A century of fire suppression, preferential harvesting of large, fire resistant trees, and controversy surrounding timber harvesting on public lands have all contributed to create the forests we have today. Under these conditions many western forests are now overly dense, unhealthy, and continue to experience large and severe wildfires.

6.2 California's Forests

California has a large forestland base of approximately 32 million acres, or almost one-third of the state.[189] California forests are exceptionally diverse, with a wide variety of tree species, including many types of conifers (e.g., Douglas-fir, ponderosa pine, sugar pine, red and white fir, bristlecone pine, incense-cedar, coast redwood, giant sequoia), and many species of oaks and other hardwoods (e.g., blue oak, black oak, coast live oak, tanoak). This diversity of forests results from a similar diversity of climatic zones, soils, elevations, and other environmental factors.

Given the diversity of California's forest ecosystems, it is important to be able to distinguish basic differences between them, at least at a general level, to be able to discuss their specific condition, risks, and appropriate management goals. The ecoregions used within the Forest Carbon Plan were developed by CAL FIRE as part of the Fire and Resource Assessment Program Assessment update process and are based on Bailey's ecological sections (Figure 7).

An ecoregion represents a large landscape area that shares common environmental conditions, natural communities, and assemblage of species. Bailey's ecological sections are part of a national hierarchical framework. The largest ecosystems are domains, which are groups of related climates that are differentiated based on precipitation and temperature. Divisions represent a further refinement of the climates within domains and are differentiated based on precipitation levels and patterns as well as temperature. Divisions are subdivided into provinces, which are differentiated based on vegetation or other natural land covers. Eco-sections, called ecoregions in this report, are subdivisions of provinces. The map below shows these units as used in the Forest Carbon Plan. For this report the term ecoregion and eco-section refer to the same planning unit.

[187] Clark et al., 2016
[188] Agee, 1996
[189] California Department of Forestry and Fire Protection, 2010

Figure 7. CAL FIRE Ecoregions Based on Bailey's Ecosystem Sections.

6.3 Ownership Patterns

California's forestland is divided between private and public ownership (see Table 4 and Figures 8 and 9). The federal government manages 58 percent of these lands, with the remaining areas under state and local government (3.4 percent) and private management (39 percent). The proportions of forest in public or private ownership in California have not changed substantially over the past several decades and the extent of forestland has remained stable. Use and management can differ across any given ownership type. Of the estimated 32 million acres of forestland, approximately 17 million acres are timberland.[190] The USDA FS manages 54 percent of timberland, other federal entities manage 2%, private corporate entities own 25 percent and private noncorporate entities own 19 percent. Total unreserved forestland[191] makes up an estimated 67 percent of public forest, with the remaining 33 percent in reserved status unavailable for timber harvest.

Table 4. Forestland Area by Land Status and Ownership Group, California 2006 – 2015.

	Ownership Group							
	USDA FS	BLM	NPS	Other Federal	State, Local, other Public	Private Corporate	Private Non-corporate	Total
Land status	Thousand acres							
Unreserved forestland:								
Timberland	8,895	310	--	13	141	4,168	3,091	16,618
Other unreserved forestland	2,517	941	--	176	169	680	4,508	8,991
Total, unreserved	11,412	1,251	--	189	310	4,848	7,599	25,609
Reserved forestland:								
Reserved productive forestland	2,791	51	981	4	329	--	--	4,156
Other reserved forestland	1,195	211	451	20	458	--	--	2,335
Total, reserved forestland	3,986	262	1,432	24	787	--	--	6,491
Total, forestland	15,398	1,513	1,432	213	1,097	4,848	7,599	32,100

Source: USDA Forest Service Forest Inventory Analysis (FIA) Program[192]

[190] Forest is considered timberland if it is growing on ground that is capable of significant annual tree volume growth and considered available for timber management, even if it isn't managed for that objective.
[191] Unreserved forestland includes both timberland, defined above, and other unreserved forestland, which has productivity of less than 20 cu. ft./ac/yr.
[192] Christensen et al., 2017

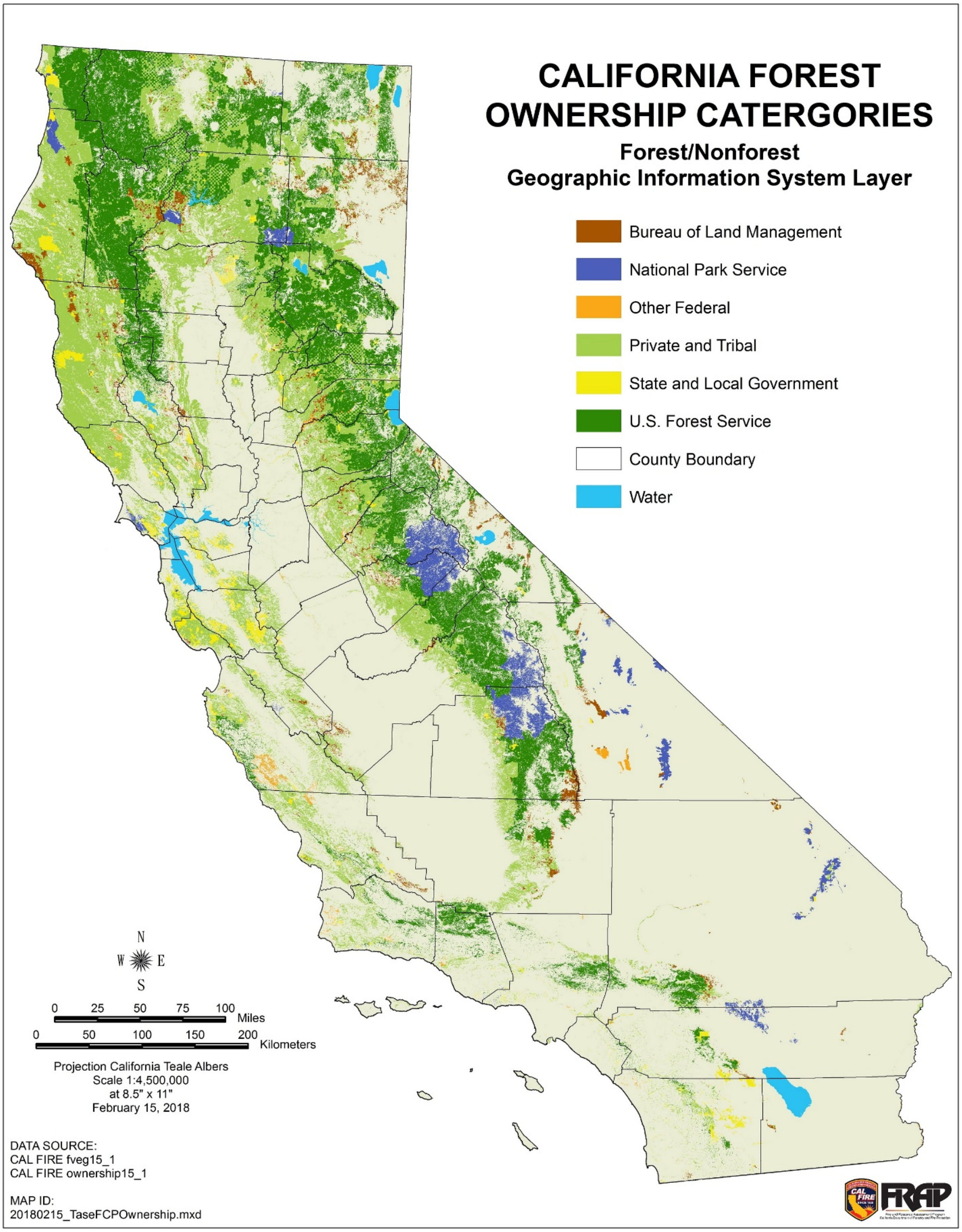

Figure 8. Ownership of Forestland in California.

Source: California Department of Forestry and Fire Protection. 2018. Ownership of forested land in California [map]. Sacramento.

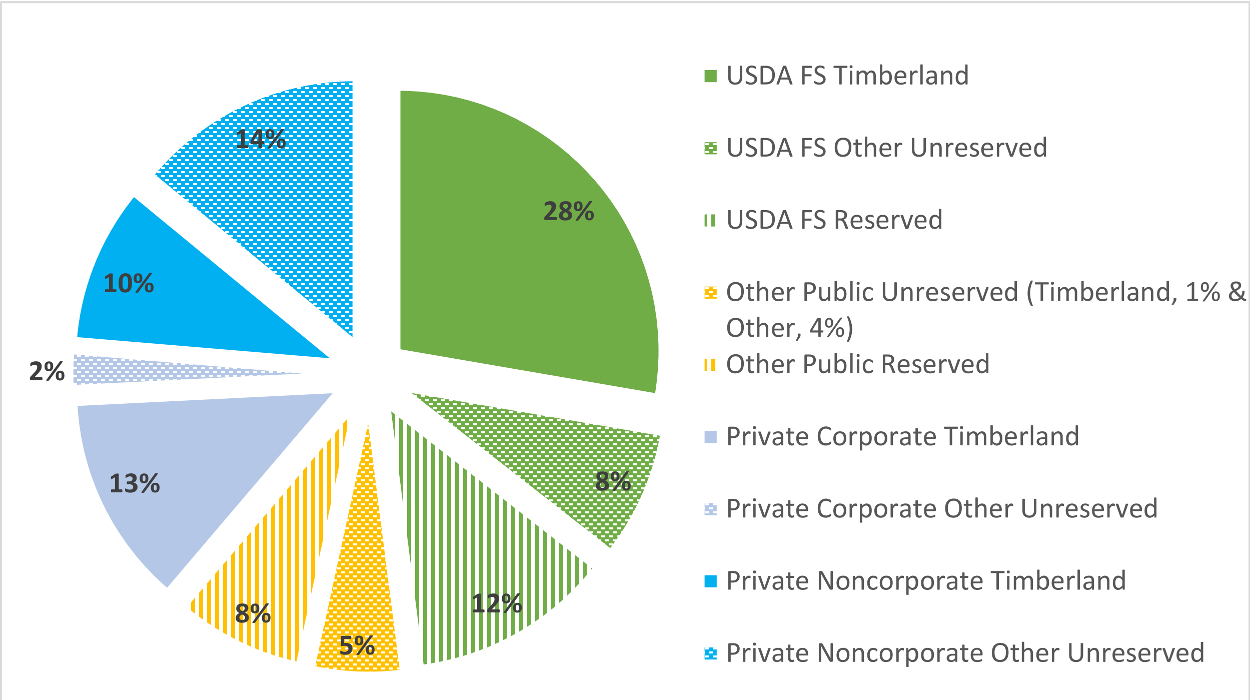

Figure 9. Forestland Base by Owner and Reserve Status.

Timber Harvest Activity on Private Lands

For private forestlands in California, most treatment of forest lands for sustainable forest management, including forest health and resilience, is commercial timber harvest activity conducted under the Z'Berg-Nejedly Forest Practice Act and the associated Forest Practice Rules. Commercial harvest activities occur under a number of kinds of permits, including discretionary permits that require review and approval [such as Timber Harvesting Plans (THPs), Nonindustrial Timber Management Plans (NTMPs), Working Forest Management Plans (WFMPs)] and ministerial project notifications that do not require advance approval (such as Emergency and Exemption Notices). The area of private forestland receiving commercial timber management treatments is much greater than the area receiving non-commercial fuels reduction treatments or post-fire replanting, for example.

Timber harvest volume has generally declined since the mid- to late-1980s, when it peaked at 4.6 billion board feet (56 percent from private lands and 44 percent from public) in 1988.[193] Table 5 presents California timber harvest volumes for the past decade. Recent harvest levels are less than half of what they were in the mid-1980s, and the proportion of the harvest coming from public lands has dropped substantially from that period as well. Approximately 298 million board feet of timber were cut from California's National Forests in federal fiscal years 2017. [194]

[193] State Board of Equalization, 2016

[194] Ko, J, Ecosystem Services Program Manager, Pacific Southwest Region, USDA Forest Service, 2017. Personal communication.

Table 5. California Timber Harvest Volumes, 2007 – 2016.

Year	Total Volume (million board feet)	Percent Private	Percent Public
2007	1,626	88.5	11.5
2008	1,372	92.8	7.2
2009	805	92.6	7.4
2010	1,161	88.3	11.7
2011	1,288	87.8	12.2
2012	1,307	88.6	11.4
2013	1,645	86.4	13.6
2014	1,466	84.0	16.0
2015	1,591	87.1	12.9
2016	1,503	85.4	14.6
Average	1,376	88.2	11.9
Source: California Department of Tax and Fee Administration; http://www.boe.ca.gov/proptaxes/pdf/harvyr2.pdf			

Table 6 provides a summary of indicators of the level of annual commercial timber harvest activity on private lands for calendar year 2017. It is important to note that these are not a direct measure of acres treated during 2017. Once approved, a THP may be valid for up to seven years. Thus, a THP approved in 2017 might not be harvested for several years, while a THP approved in 2013 could be harvested all or in part in 2017. Landowners are not required to report the acres of a THP that are operated in a given year, and CAL FIRE does not track this data. When a landowner files a Notice Timber Operations (NTO) under an NTMP, an Emergency Notice, or an Exemption Notice, the permit is valid for one year from the date of filing.

The GHG implications of timber harvesting must be assessed as a part of THPs, NTMPs, and WFMPs. This responsibility of the project proponent stems from CEQA as well as the Forest Practice Act and Rules. The Forest Practice Act provides the Legislative intent that:

> (a) State forests play a critical and unique role in the state's carbon balance by sequestering carbon dioxide from the atmosphere and storing it long term as carbon….
> (d) There is increasing evidence that climate change has and will continue to stress forest ecosystems, which underscores the importance of proactively managing forests so that they can adapt to these stressors and remain a net sequesterer of carbon dioxide.
> (e) The Board, the Department, and the State Air Resources Board should strive to go beyond the status quo sequestration rate and ensure that their policies and regulations reflect the unique role forests play in combating climate change.

The Forest Practice Act further directs:

> The Board shall ensure that its rules and regulations that govern the harvesting of commercial tree species, where applicable, consider the capacity of forest resources, including above ground and below ground biomass and soil, to sequester carbon dioxide emissions sufficient to meet or exceed the state's greenhouse gas reduction requirements for the forestry sector, consistent with the scoping plan adopted by the State Air Resources Board pursuant to the California Global Warming Solutions Act of 2006 (Division 25.5 (commencing with Section 38500) of the Health and Safety Code). [PRC § 4551(b)(1)]

Note that the language requires that multiple forest carbon pools are addressed, including soils. The Board of Forestry and Fire Protection is currently working to revise its directions ("Technical Rule Addendum No. 2") for the consideration of GHGs as a part of timber harvesting cumulative impacts assessments.

6.4 Climate Impacts on Forest Health

Climate is a primary driver of the dynamics of forest and range ecosystems, especially the type, abundance, and productivity (including rates of carbon sequestration) of species. Future climate change scenarios predict increases in temperature, increases in atmospheric carbon dioxide concentrations, and changes in the amount, form, and distribution of precipitation.[195] Altering these fundamental climate variables will result in changes in tree growth, in the range and distribution of species, and in disturbance regimes (e.g., wildfires, outbreaks of pests, invasive species). Relatively small changes in temperature and precipitation can affect reforestation success, growth, susceptibility to pests, and forest productivity. However, forests in healthier and more resilient conditions are less vulnerable to these changes.

Historically, forests in California experienced periods of drought and temperature changes over the centuries and were in general resilient to these changes. As climate change impacts unfold over the next few decades, it is important to recognize that the forest structure, health, and resilience of today's forests are already significantly altered from historic conditions. As a result, scientists agree that California forests in their current condition will not be as successful in absorbing these changes as they once were.

Given the long lifespan of trees in a forest stand, from decades to hundreds of years, the effects of climate change on disturbance regimes may become apparent prior to noticeable changes in forest species composition. Altered disturbance regimes include changes in the timing, frequency and magnitude of wildfires, pest infestations, and other agents of disturbance. While disturbances occur regularly in these ecosystems, large changes in the patterns of disturbance could make forests less resilient, especially in unhealthy stands already under significant stress from competition. Observations also suggest that unhealthy stands adjacent to healthy stands can lead to the loss of the healthy stands, too. This is being seen with the bark beetle activity in the Southern Sierra, where beetles first attack unhealthy stands, then move on healthier stands.

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[195] Dale et al., 2001

Table 6. Private Forestland Commercial Harvesting Permit and Notification Types, Number, and Acreage, Calendar Year 2017.

Permit or Notice Type	Number Approved or Received	Acres	Comments
Timber Harvesting Plan (THP)	230 approved	107,424	Valid for up to 7 years.
Nonindustrial Timber Management Plan (NTMP) Notice of Timber Operations	150 received	24,698	Valid for one year. This acreage number may be more reflective of the total ownership area under the NTMPs than of the actual acreage harvested, since NTOs do not require reporting on acres to be operated.
Emergency Notices	116 received	10,677	Valid for one year.
Exemption Notices	2,277 received	3,185,378	Valid for one year. Most acres are not actually treated since large landowners typically file, for their entire ownership, an Exemption Notice for harvesting dead, dying or diseased trees of any size in amounts less than 10 percent of the average volume per acre, and then harvest opportunistically across their ownership.

Source: CAL FIRE Forest Practice Program.

Vegetation types with restricted ranges may be more vulnerable than others, and are already under stress from land use changes such as expansion of the wildland urban interface and management issues.[196] Existing resilient forest stands may not demonstrate significant impacts from effects of climate change, but forests recovering from a high severity event may have difficulty reestablishing.

Climate change impacts on disturbance regimes are already affecting forests. Until recently, much of California was in the fifth year of a severe drought. Recent research has demonstrated that up to 27 percent of this drought can be ascribed to climate change-driven warming.[197] The lengthy drought in California made many forests water stressed and thus less resilient to wildfire and more susceptible to bark beetles, especially overly dense forests that have missed multiple natural fire return cycles. Increased beetle activity from climate change leaves behind greater tree mortality. Bark beetles are native to California and outbreaks and tree mortality as a result are well documented and important for forest structure diversity. However, the levels of tree mortality from bark beetles in recent years is unprecedented in California.

[196] Foster, 2003
[197] Williams et al., 2015

Research on other forests types across the West that have been experiencing similar levels of mortality help provide insights into our current situation, but none describe the situation we face in the southern Sierra.[198] The USDA Forest Service Fire Behavior Assessment Team (FBAT) have studied two recent fires through high beetle-mortality areas to help close these gaps in our knowledge. In the Cedar Fire of 2016, FBAT found the critical intensity, a measure of likelihood of a tree to torching, for red phase ponderosa pine and incense cedar to be less than 10% the value of neighboring live trees (the larger the number, the less likely to torch)[199]. The FBAT found similar conditions in the 2017 Pier Fire where recent dead trees torched more rapidly than live trees.[200] The team found that gray phase trees "did not often torch" but fire intensity through gray phase plots was higher than normal because of the high levels of dead fuel loading on the surface[201]. As the millions of recently killed trees begin to decay and continue to dominate the landscape, new challenges will arise regardless of future fire severity. Firefighters could face a similar situation seen in the 2016 Beaver Creek Fire (Colorado), where the standing dead trees posed too big of a threat to firefighters and prevented them from entering those stands to fight the fires.[202]

With California-based research lacking, we are still trying to better understand how our current level of mortality will affect future fire behavior. Until we have more knowledge in this area, a cautious and measured approach is called for in dealing with the multiple threats of the recently killed trees. However, the science is clear on how to reduce tree susceptibility to drought, bark beetles, and fire. Despite the warmer temperatures and exceptional drought, healthy forests are exhibiting a fraction of mortality of adjacent unhealthy forests. Additionally, low severity fire has been shown to increase production of tree defenses against bark beetles, which then wanes if fire is absent too long, leaving the trees more vulnerable to attack.[203]

Extended drought and earlier snowmelt may become the new norm, as southern California is expected to see conditions up to 30 percent drier and one to two degrees Fahrenheit hotter than historical norms in the next 15 years.[204] Additionally, increasing temperatures and decreasing precipitation caused by climate change contribute to dry and hot conditions favorable for wildfires and will therefore continue to increase the risk for wildfire beyond what California faces today. Fire seasons in the U.S. West have already increased by 78 days since the mid-1980s,[205] and greater increases in the length of fire seasons in coming years are likely. In the U.S. Southwest, human-caused changes to forest structure also are primary contributors to the recent growth in wildfire activity.[206]

As discussed in the Science Snapshot (Section 2.2.3), tree growth and carbon sequestration rates are stunted during drought periods. The findings reported above have important implications for the benefits of forest treatments on the resiliency of forest carbon sinks in times of drought.

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[198] Reiner, 2017
[199] Reiner et al., 2016
[200] Reiner et al., 2017
[201] Reiner et al., 2017
[202] Paul, 2016
[203] Hood et al., 2015
[204] Krist Jr. et al., 2014
[205] Westerling et al., 2006
[206] Westerling, 2016

6.4.1 Insects and Diseases

Native insects and diseases are an integral part of California's forests and provide important ecosystem functions. Most are host specific, only attacking one or a few closely related tree species. At endemic levels, insects and diseases and the dead trees they leave behind provide food or habitat for wildlife, recycle nutrients within the environment, thin over-stocked stands, create essential snags and forest openings, and help maintain forest diversity.

Non-native insect and disease pests, also called exotic or invasive species, can cause great harm to forests. Recent exotic insect arrivals have attacked numerous tree species. Trees often lack natural resistance to these pests with which they have not co-evolved and many such pests can thrive on a large range of hosts. Invasive pests can impact the environment by causing local or widespread species extinctions, displacing native species, altering forest fire behavior,[207] or increasing tree mortality above expected background levels.

Some insects and diseases are found at varying levels throughout California while others are found predominantly in specific regions of the state. Table 7 lists the major forest pests in the state by ecoregion.

Table 7. Major California Forest Pests.

Ecoregion	Native Pests	Exotic Pests
Eastside	Bark Beetles, Root Disease	Satin Moth
Sierra Nevada and Cascade Range	Bark Beetles, Root Disease, Dwarf Mistletoes	White Pine Blister Rust
Klamath and Interior Coast Range	Bark Beetles, Root Disease, Defoliator Insects	Port Orford Root Disease, White Pine Blister Rust
North Coast	Bark Beetles, Root Disease, Animal Damage	Sudden Oak Death
Central Coast and Interior Ranges	Bark Beetles, Root Disease, Foliar Diseases	Sudden Oak Death, Pitch Canker Disease
South Coast and Mountains	Bark Beetles, Defoliator Insects, Root Disease, Air Pollution	Gold Spotted Oak Borer, Polyphagous Shot Hole Borer, Kuroshio Shot Hole Borer

Source: CAL FIRE Pest Management Program Staff.

According to the USDA Forest Service's National Insect and Disease Forest Risk Assessment, 2013 – 2027,[208] California is at risk of losing at least 25 percent of standing live forest due to insects and disease. This equates to over 5.7 million acres, or 12 percent of the total forested area in the state. Some species are expected to lose significant amounts of their total basal area, for example: whitebark pine is projected to lose 60 percent of basal area,[209] while lodgepole pine is projected to lose 40 percent. Since future climate change is not modeled within the risk assessment, and current drought conditions are not accounted for in these estimates, this forecast may be an underestimate. The projected climate

[207] Simard et al., 2011
[208] Krist Jr. et al., 2014
[209] Basal area refers to the cross-sectional area of a tree, usually measured at 4.5 feet from the ground ("breast height"). It is usually expressed in terms of square feet of tree basal area per acre of stand area, thus providing a relative measure of the occupancy of the site.

changes over the next 15 years are expected to significantly increase the number of acres at risk from already highly destructive species such as mountain pine beetle.

Sudden oak death, a disease caused by the non-native *Phytophthora ramorum*, has been found in California since the mid-1990s. It has a host range of over one hundred species but is most damaging and deadly to tanoaks and true oaks (*Quercus* spp.). Three to four million trees have been killed by the disease in the central and northern coastal regions of the state to date. The mortality has resulted in changes in stand species compositions, reduced mast production for wildlife, loss of cultural heritage and traditions for Native American tribes in the area, and an increased fire danger due to increased fuel loads. In particular, redwood tree mortality has been found to increase during wildfires in areas with high sudden oak death mortality of tanoaks.[210]

A warmer and drier climate may have several implications for sudden oak death disease. The disease may spread more slowly since it requires humid and wet conditions for infection. However, when infections do occur, mortality may increase due to the greater stress of a hotter and drier climate. It is uncertain how disease and climate change will impact long-term changes in stand structure and composition.

Native bark beetles are currently causing high levels of tree mortality in California.[211] When, where, and the extent to which mortality occurs is primarily influenced by forest stand and drought conditions. A dramatic rise in the number of trees killed by bark beetles follows one to several years of drought: the more severe and prolonged the drought, the greater number of dead trees. Dense groups of trees are particularly susceptible to bark beetle attacks due to stress caused by competition for limited resources, and stressed trees equate to suitable host material for bark beetles and successful reproduction results in more beetles and higher levels of tree mortality.[212] A number of other factors in overly dense stands increase the damage bark beetles can inflict. Dense stands have decreased airflow, allowing successful attack pheromones to remain in the air for longer, attracting more beetles to join in the attack.[213] Stands with similar species closer together are within easier reach to bark beetles, compared to a more open stand with a more diverse species makeup.[214] Large trees are preferred by bark beetles and where large trees are surrounded by smaller trees, bark beetles are able to launch more attacks on the larger tree, draining its defenses to the point that the attacks eventually become successful.[215]

Tree mortality is on the rise in California (Box 7). In response to the very high levels of tree mortality concentrated in the Sierra Nevada, Governor Edmund G. Brown Jr. issued an emergency proclamation on October 30, 2015.[216] Under authority provided under the 2013 Farm Bill, the Secretary of Agriculture and the Chief of the USDA Forest Service as of late 2015 had designated 6.7 million acres of National Forest System Lands in California as insect- and disease-threatened. For certain collaborative projects less than 3,000 treated acres in size, this designation can provide a streamlining of National Environmental Policy Act planning processes.

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[210] Metz et al., 2013
[211] USDA Forest Service, 2017
[212] USDA Forest Service, 2016d
[213] Fettig & Hilszczański, 2015
[214] Fettig & Hilszczański, 2015
[215] North, Hurteau, & Innes, 2009
[216] Brown, 2015

There is usually a lag time between drought years and tree mortality, and the recent sharp rise in mortality reflects the cumulative impacts of the past five years of drought. Field data from the USDA Forest Service State and Private Forestry Aerial Detection Surveys in 2016 show elevated tree mortality associated with bark beetles primarily in the southern Sierra Nevada and in southern California mountains.[217,218] As shown in Figure 10, tree mortality has also increased significantly in the northern Sierra Nevada from 2014 to 2017. High-level statistics from the Forest Service Aerial Detection Survey underscore the extent of the recent die-off:

- At least 129 million dead trees are associated with severe drought, bark beetles, and warmer temperatures, based on 2010 through 2017 surveys.
- From 2015 to August 2016 alone, 62 million trees died, not including trees that died in fires, such as the 132,000-acre Soberanes Fire of 2016.
- A cumulative area of 8.8 million acres with some level of drought related tree mortality were mapped in California over the 2010-2017 period.

6.4.2 Forest Fragmentation

Forest fragmentation through urbanization, conversion for agriculture, other large-scale land use changes, or cumulative small-scale changes can negatively impact forest health. Isolated and disconnected forest stands often have less diversity and resilience to changing conditions. There is a reduction in gene flow within species and in habitat connectivity for wildlife. Insects and diseases may become more concentrated with the potential for greater damage and localized species extinctions. Wildland fire probabilities increase with more human presence. This section summarizes the most impactful fragmenting activities facing California forests today: growth in the wildland-urban interface and marijuana cultivation.

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[217] Information available from Forest Service website: http://www.fs.usda.gov/main/catreemortality/home

[218] More recently there are reports from the field that increasing tree mortality also is being seen further north in the Sierra Nevada mountains.

Box 7. Tree Mortality and Carbon: Southern Sierra

Tree mortality in California has reached previously unseen levels, with 62 million trees dying in 2016 from disease, bark beetle, and drought, not including trees killed by fire. Of the recorded non-fire tree mortality, over 50 million were in the forests of the southern Sierra Nevada. From a carbon perspective, this represents 50 million trees that are no longer pulling carbon from the atmosphere but instead will release their carbon back to the atmosphere. Adding to the dead pool, the carbon in these trees will slowly decay over the next few decades, be quickly released in future fire events, or (to a likely rather limited extent) be used in in a biomass industry. The timing and form (e.g., carbon dioxide, methane, black or brown carbon) of these trees' carbon emissions will have major implications for California's climate forcing emissions and air quality.

There remain significant gaps in our understanding of the sizes of trees that have died (although larger trees are typically preferred by bark beetles) therefore it is difficult to make accurate estimates of the amount of carbon that has transitioned from the aboveground live to aboveground dead carbon pools. Further refinement, discussion, and data are needed to better understand the carbon consequences of 2016's mortality. Tree mortality and aboveground live carbon that has transitioned to the dead pool in 2016 is estimated by southern Sierra Nevada county, below.

County	Number of Dead Trees	Metric tons of carbon	Metric tons of CO_2e
Placer	574,000	150,000	500,000
El Dorado	1.4 million	350,000	1,400,000
Amador	665,000	200,000	700,000
Calaveras	1.8 million	500,000	1,800,000
Tuolumne	6.1 million	1.6 million	6 million
Mariposa	6.7 million	1.8 million	6.5 million
Madera	8.8 million	2.5 million	9 million
Fresno	12.1 million	3.4 million	12.5 million
Tulare	13.2 million	3.7 million	13.4 million
Total	**51 million**	**14.2 million**	**51.8 million**

The tree mortality in unhealthy forests in 2016 has resulted in over 50 million metric tons of CO2e changing to the dead pool. This recent tree mortality adds to unstable dead carbon pool that has been building this decade, with 129 million trees dying since 2010 (USDA Forest Service 2017), before factoring in trees killed by fire.

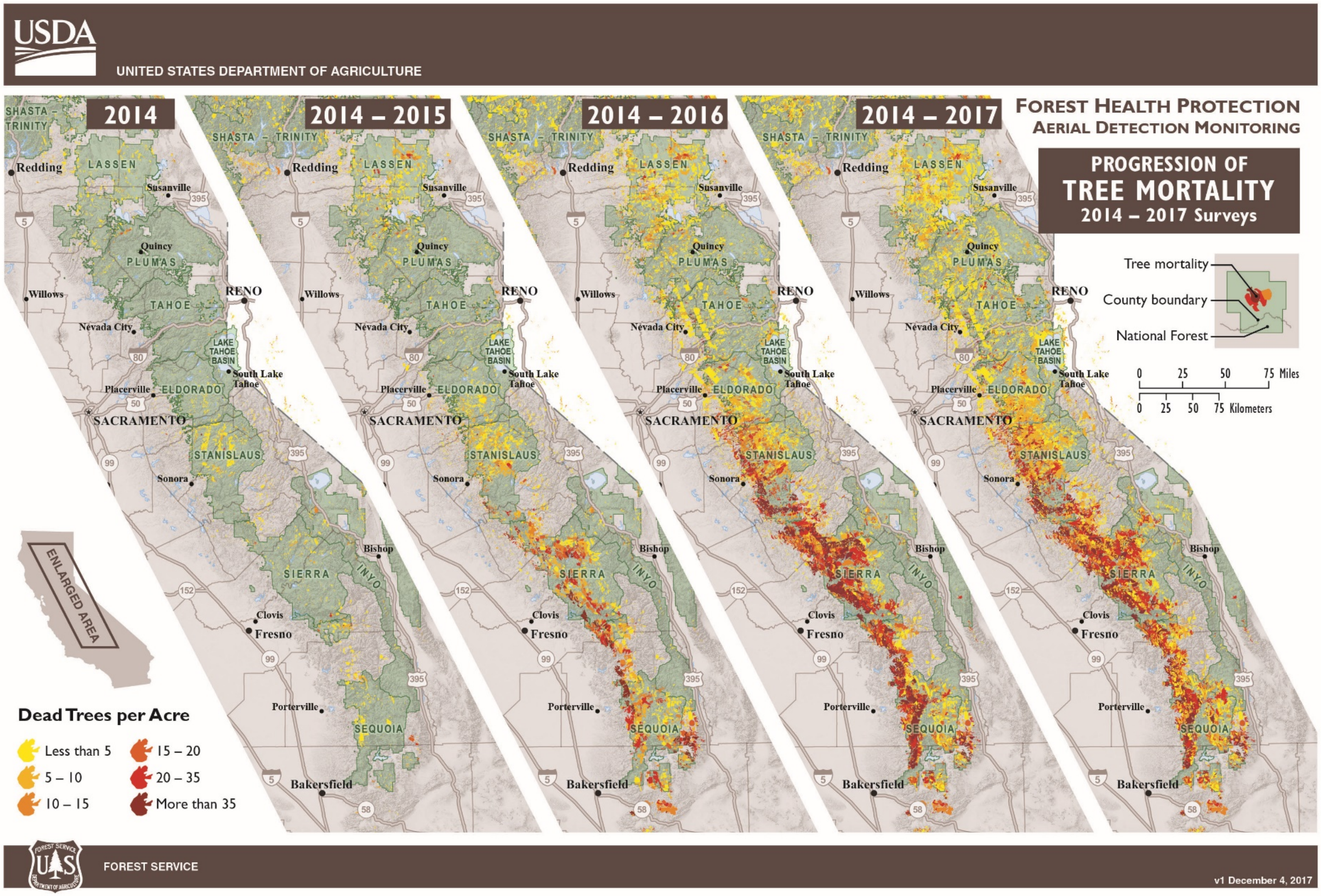

Figure 10. Progression of Tree Mortality in the Sierra Nevada, 2014-2017.

Source: USDA Forest Service 2017.

6.4.3 Wildland-Urban Interface

Depicted in Figure 11 is the wildland urban interface, the geographical intersection of two disparate systems: wildland and land occupied by human-inhabited structures. At this intersection, structures and vegetation are close enough that a wildland fire could spread to structures or fire could spread from structures to ignite vegetation. This type of development degrades and fragments wildlife habitat and contributes to loss of structures and human life during wildfires.

The wildland urban interface is composed of both interface and intermix communities. The distinction between these is based on the characteristics and distribution of houses and wildland vegetation across the landscape. Intermix wildland urban interface refers to areas where housing and wildland vegetation intermingle, while wildland urban interface refers to areas where housing is in the vicinity of a large area of dense wildland vegetation.[219] Martinuzzi et al. estimated total California wildland urban interface at 6.73 million acres, including 1.96 million acres of interface and 4.78 million acres of intermix.

Strong state and national programs are required for a concerted community effort wherever structures are near flammable vegetation.[220] For example, Fire Adapted Communities, Fire Adapted Communities Learning Network, and FIREWISE encourage integrative and cooperative partnerships aimed at landowner education.[221] In addition, risk assessment is an important component of any county general plan, and the wildland-urban interface/intermix must be considered as part of these local planning efforts. State and federal programs may inform or make suggestions to improve this process, but in the end, it is the responsibility of local jurisdictions to consider the safety and risk associated with development in these areas.

As part of the Vegetation Treatment Program Draft Programmatic Environmental Impact Report,[222] CAL FIRE estimated the acreage of wildland urban interface available[223] for fuels treatment activities. The results are presented below in Table 8. Focusing just on tree-dominated landscapes, the analysis found that almost 3.3 million acres were available for treatment statewide.

6.4.4 Marijuana Cultivation

Illegal marijuana production on forestlands has been a serious issue in the state of California, with negative impacts to humans, wildlife, and natural systems in general. The recent legalization of marijuana cultivation for recreational purposes may also pose threats to forestland, however, appropriately licensed and regulated grows are likely to pose less of an environmental threat than those that are operated outside the law. In forests, marijuana grow sites are often cleared of trees and other. This clearance results in GHG emissions, loss of carbon, and loss of the trees' carbon sequestration capacity. Further, these activities often result in erosion and sediment deposition into streams and lakes. Wildlife in the area, such as bear or deer, may be poached or snared. Fertilizer, pesticide, and rodenticide used at grow sites can have direct, detrimental effects on local wildlife. For example, necropsies of Pacific fisher carcasses on the Sierra National Forest found that 85 percent tested positive for rodenticides and that

[219] Martinuzzi et al., 2015
[220] National Science and Technology Council, 2015
[221] Schoennagel et al., 2004
[222] California Board of Forestry and Fire Protection, 2017
[223] "Available," under the Vegetation Treatment Program Draft Programmatic Environmental Impact Report, refers to land, within State Responsibility Area, that is capable of undergoing a WUI fuels treatment, fuel break, or ecological restoration treatment.

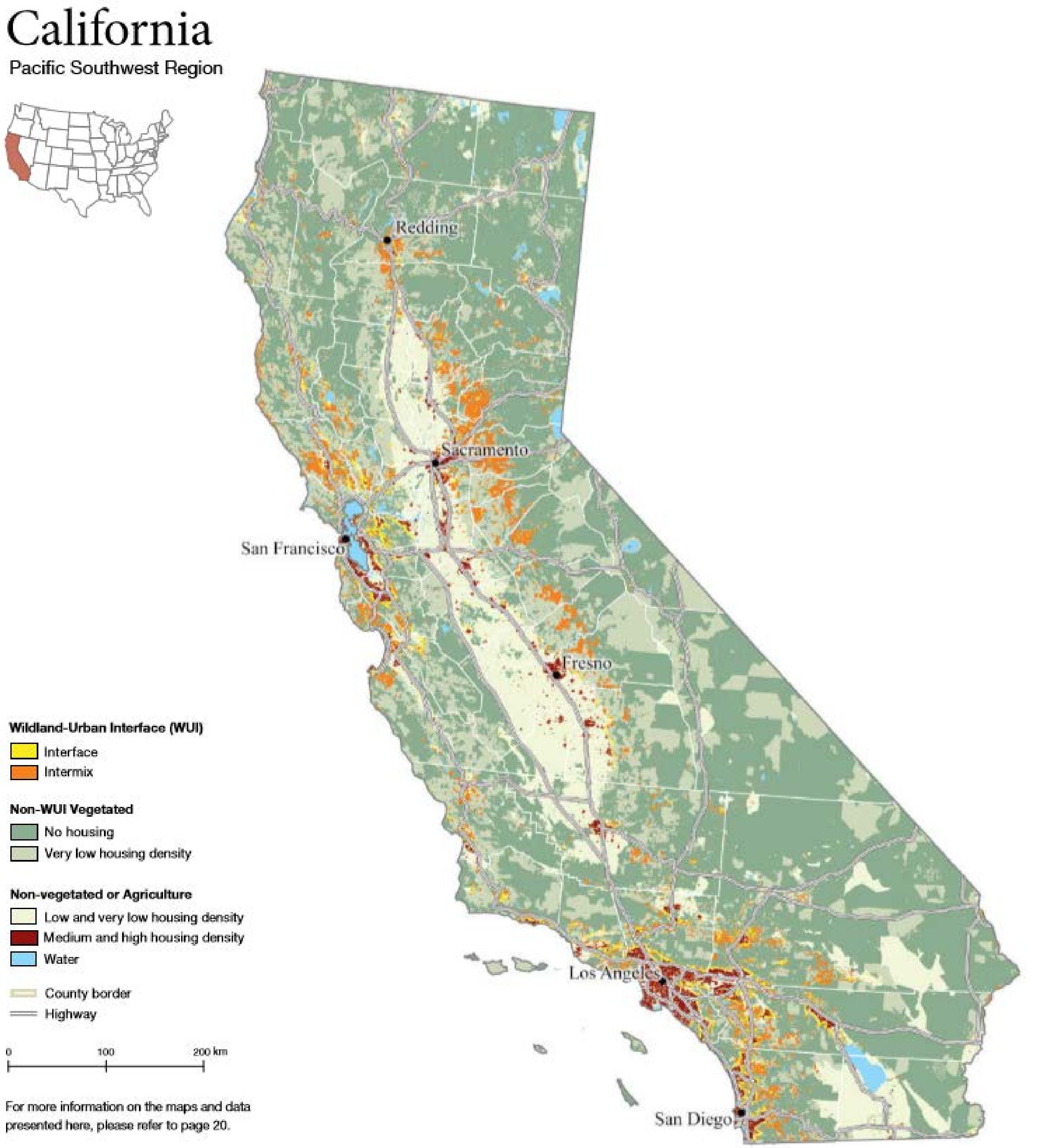

Figure 11. Wildland Urban Interface in 2010.

Source: Martinuzzi et al., 2015

Table 8. Available Acres within the WUI Treatment Area by Vegetation Formation.

Bioregion	Tree Dominated	Shrub Dominated	Grass Dominated	Total by Bioregion
Bay Area/Delta	607,476	171,056	811,789	1,590,320
Central Coast	48,053	274,592	665,025	987,670
Colorado Desert	2,923	84,924	3,999	91,846
Klamath/North Coast	1,263,995	192,208	457,094	1,913,297
Modoc	261,157	151,723	104,478	517,358
Mojave	35,913	180,471	27,910	244,294
Sacramento Valley	17,150	4,007	541,777	562,933
San Joaquin Valley	9,758	28,788	123,999	162,545
Sierra Nevada	943,683	280,476	1,519,475	2,743,634
South Coast	104,736	883,080	263,152	1,250,968
Total by Vegetation Type	3,294,843	2,251,324	4,518,698	10,064,865
Source: California Board of Forestry and Fire Protection, 2017.				

illegal marijuana cultivation sites were the most likely source.[224] The chemicals used by marijuana growers also may end up in nearby water sources, degrading water quality.

In addition to degrading water quality, marijuana grow sites have negative effects on water quantity; marijuana production is very water-intensive, and the illegal diversion of water to irrigate marijuana plants further exacerbated drought conditions. Diminished stream flow because of marijuana cultivation adversely impacts state and federally listed salmon and steelhead as well as amphibians and other sensitive species. Grow sites themselves can become dumping grounds for trash and human waste, severely degrading habitat. The sites can pose significant risks to human safety: hikers, hunters, and anglers may stumble upon armed growers and other defenses.

The state is working diligently to combat illegal marijuana cultivation, but it is a challenge. The California Department of Fish and Wildlife and the Regional Water Quality Control Boards are working in priority watersheds to bring illegal marijuana grows into compliance with environmental laws and to remediate the harmful effects of illegal grows on fish, water, and wildlife. The fiscal year 2014 – 15 and 2015 – 16 budgets provided an increase of $1.5 million to the Department of Fish and Wildlife to regulate and enforce unauthorized water diversions and pollution to surface and groundwater as a result of marijuana cultivation. The 2016 – 17 budget provided an additional $7.7 million to expand these efforts. In the 2017 - 18 budget, the Department of Fish and Wildlife enforcement program is receiving $5.4 million from the newly established Cannabis Control Fund for the first time. Further, the passage of Proposition 64 in the November 2016 election will provide additional resources to clean up abandoned sites.

[224] Thompson et al., 2013.

7 Forest Carbon Storage and Accounting

7.1 California Forest Carbon Inventory Programs

The following sections describe the two state programs that have responsibilities for reporting on forest carbon storage through forest and wood products and GHG emissions associated with the forest sector. These two programs, the Board of Forestry and Fire Protection's AB 1504 Forest Ecosystem and Harvested Wood Product (HWP) Carbon Inventory and the Air Resources Board's Statewide Emissions Inventory, respectively, will be closely coordinated through the collaboration of technical staffs and under policy guidance from their respective managers. An internal Forest Carbon Inventory Technical Committee will ensure interagency collaboration at the technical level.

7.1.1 AB 1504 Forest Carbon Inventory

The Board of Forestry and Fire Protection (BOF) is mandated to maintain a vigorous, resilient and healthy forest land base in California, which supports the ecological needs of the forest ecosystem and its human dependencies.[225] Maintaining a resilient forest ecosystem and harvested wood product carbon sink is one element within the BOF's overarching mandate to ensure forest health. AB 1504 (Skinner)[226] requires the BOF to ensure, where applicable, that its rules, regulations, and policies governing the harvesting of commercial tree species consider the capacity of the forest sector, including above ground and below ground biomass and soil, to sequester 5 MMT CO_2e annually by 2020.[227]

To assess whether the AB 1504 goals are being met, a forest ecosystem and harvested wood product (HWP) carbon inventory has been completed for the BOF (i.e., AB 1504 inventory).[228] The AB 1504 inventory reports both carbon stocks and certain carbon and other GHG emissions. USDA Forest Service Forest Inventory and Analysis (FIA) Program data is the primary data source. All wildland forest ownerships are included in the AB 1504 inventory, because the BOF has a statutory responsibility to represent the state's interest in federal matters pertaining to forestry and the protection of the state's interests in forest resources on private lands[229], and because the federal government manages more than half of the forest land within the state's forest sector (see section 6.3, Ownership Patterns). This carbon inventory approach will allow the BOF to report information using the standard ownership classes and forest status (e.g., timberland, reserve) categories used by FIA, across more than 30 million acres of federal, state, other public and private forested lands within California.

Carbon stocks associated with forestland, land converted to forestland, and forestland converted to non-forest uses are addressed in the first AB 1504 report as an approximation, with methods and data to be refined in future reports. In addition to carbon, other select greenhouse gases are important components of a forest carbon inventory. The AB 1504 report will include other greenhouse gas emissions, such as from fire, decay, or landfills, in consultation with CARB and the USDA National Greenhouse Gas Inventory (NGHGI).[230] Urban forests are not included in the AB 1504 inventory as they are in the Intergovernmental Panel on Climate Change (IPCC) settlements category, rather than forestland. IPCC states that shrublands with high proportions of woody biomass may be considered a type of grassland, so for the purposes of AB

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225 California Board of Forestry and Fire Protection, 2008.
226 Assembly Bill 1504, 2010
227 Assembly Bill 1504, 2010
228 Christensen et al., 2017
229 California Public Resources Code § 740
230 U.S. Department of Agriculture, 2016

1504 chaparral is considered part of the grassland category and is not included in the inventory.[231] These lands are not currently represented in FIA Program data.

The first AB 1504 report[232] was released in December 2017 and focused primarily on forest ecosystem carbon stocks, with an overview of carbon in harvested wood products (HWP). A second report anticipated in 2018 will include annual updates to forest ecosystem carbon stocks and will address HWP carbon stocks in more detail. While updated carbon inventory tables can still be provided annually, after the two initial reports the BOF may re-evaluate how often a detailed synthesis and trend-analysis report will be needed to ensure meeting the net sequestration goals in AB 1504 or other statewide inventory needs. Initial reports will be developed through agreements between CAL FIRE and the USDA Forest Service Pacific Northwest Research Station[233] and will be consistent with IPCC and previous forest carbon reporting efforts at the national level.

The AB 1504 inventory method for forest ecosystem carbon pools relies on FIA Program data, which uses a ground-based, permanent plot re-measurement system. In 2001, the FIA program transitioned from a periodic to an annual inventory in which a sub-sample of all plots (i.e., panel) is measured, providing systematic coverage within each county, ownership, and forest reserve class. Initial measurement of all panels was completed between 2001 and 2010. The first re-measurement of all panels will be completed by 2020. This updated direct measurement approach of the same trees over time captures and quantifies growth well, which can be a limitation in remote sensing-based forest carbon inventory methods.[234] This updated method also directly accounts for mortality and changed conditions, is repeatable, allows for low errors, and is consistent with forest carbon inventory data nationally.[235]

The baseline period used for AB 1504 reporting is 2001 to 2010, and the first report also includes an inventory for 2006 to 2015, the most recent ten-year time-period analyzed by FIA. The time-period between 2001 to 2010 is an adequate baseline as it comprises the first full FIA annualized measurement cycle and includes climatic conditions that are likely to be more representative of future climatic conditions than would an earlier period (e.g., one that includes 1990, the baseline year for AB 32 GHG emission reduction requirements).

The carbon stock reported in each year will be the ten-year rolling average of carbon stocks, so the value reported for 2015 is the average carbon stock over the period of 2006 to 2015. Changes in carbon stocks will be evaluated against the baseline reference period to determine trends. Rates of change will go beyond a simple stock-change evaluation and instead will be estimated using re-measured plots that capture actual net change on an individual tree/component basis. If forests statewide are performing as a net sink, the net change in carbon stock over the period should be positive. Although episodic change may not be captured as immediately as with remote sensing-based methods, these changes will still be captured during the FIA measurement cycle. Additional investments in the FIA program would provide more frequent and reliable estimates of growth, removals, and mortality. Use of remote sensing applications may also supplement FIA change detection. Additionally, CAL FIRE, the USDA Forest Service, and other agencies track a variety of forest activities, such as timber harvest, fuels reduction, tree mortality, land conversions and fire activity and severity. These data also can support characterizing change detected through the FIA program or remotely sensed data.

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[231] IPCC, 2006

[232] Christensen et al., 2017

[233] The U.S. Forest Service Pacific Northwest Research Station handles the FIA program for California.

[234] Saah et al. 2015

[235] Christensen et al. 2016

Table 9 describes the carbon pools that are addressed in the AB 1504 report. Forest carbon stocks are provided for each pool, forest type, ecoregion, and land owner and also will be aggregated to provide statewide estimates. Gross growth, mortality by cause, removals, and net change also will be provided.

Table 9. Forest Ecosystem and Harvested Wood Product Carbon Pools Addressed in AB 1504 Reporting.

Aboveground Forest Ecosystem Carbon Pools	Belowground Forest Ecosystem Carbon Pools	Harvested Wood Product Carbon Pools
Live trees	Live tree roots	Products in-use
Dead trees	Dead tree roots	Products at the landfill
Live understory vegetation	Live understory vegetation roots	Products burned with energy capture
Dead understory vegetation	Dead understory vegetation roots	Products burned without energy capture
Down wood	Soil organic carbon	To be developed: Avoided emissions
Litter		

In the second AB 1504 report, anticipated to be completed before the end of 2018, carbon that is transferred from forest ecosystem pools to long-lasting wood products will be accounted for in HWP pools. Carbon stocks for HWP pools will be based on a production approach, i.e., all timber that is produced from all ownerships in California will be evaluated regardless of whether it is consumed within the state of California or is exported to other states or countries. Additionally, products may still be in use or at the landfill from historic harvests. The HWP carbon accounting will include these products for as far back as harvest data allow. Further, when by-products of commercial harvest and fuels reduction (i.e., logging slash or sub-merchantable biomass) are utilized to create energy, emissions from fossil fuel-based energy, in-forest decay, and open-pile burning may be reduced. Wood products can also have a lower emissions profile than more energy-intensive building materials such as cement and steel. Inclusion of a third pool consisting of avoided emissions therefore more fully describes the carbon benefits associated with forests and wood products.[236] Still, benefits can be difficult to quantify given, for example, complex electricity markets and opaque global steel supply chains, and a goal for future AB 1504 reports is to find methods for doing this. It should be noted that in a full GHG inventory, IPCC guidance states that emissions associated with burning wood for energy are to be reported in the energy sector for informational purposes only, and should not count towards overall emissions in that sector.[237] Additionally, while it is argued that actual avoided emissions are important in recognizing the long-term benefits of HWP, currently there is no IPCC guidance on addressing these, so inclusion of this pool is also for informational purposes only at this time.

Ultimately, the AB 1504 forest and harvested wood product carbon inventory, in combination with the CARB inventory, can serve as reporting mechanisms for evaluating the carbon goals of the Forest Carbon Plan. This accounting will be undertaken through the process established to accomplish the mandates in AB 1504 and SB 859 and will be completed by December 30, 2018. AB 1504 will provide field-based reporting on carbon stocks listed under Table 9 and an established statewide baseline.

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[236] Perez-Garcia et al., 2005
[237] IPCC, 2006

The BOF recognizes there are data gaps regarding forest and harvested wood product carbon accounting and other factors to better inform policy decisions. The following efforts are being made to address these data gaps:

- 2018 Logging utilization study – BOF, CAL FIRE, USDA Forest Service
  - Will update information on logging residuals that remain in forests
  - Will quantify potential effects of increased utilization (i.e., decay, avoided fossil fuel and open pile burning emissions)
- 2018 Biomass study – USDA Forest Service
  - Will further refines biomass equations relied upon for carbon estimates
- 2018 Mill energy-use study – BOF, CAL FIRE, USDA Forest Service
  - Will provide information on the carbon footprint specific to the California timber industry, including avoided fossil fuel emissions from burning wood and residues for bioenergy

7.1.2 CARB Statewide Emissions Inventory

AB 32 and SB 859 obligate CARB to develop a statewide greenhouse gas (GHG) inventory. The inventory represents sectors such as energy production, industry, waste and recycling, transportation and communities, water resources, and natural and working lands. CARB's Natural and Working Lands GHG Inventory ("CARB Inventory") reports both carbon stock and GHG flux associated with stock-change on categories of forests and other lands.[238] This inventory primarily will be used to measure the state's progress in meeting the State's long-term climate goals under AB 32 and SB 32. Like the AB 1504 inventory, the baseline reference period for the CARB inventory is 2001 – 2010. Satellite imagery supplemented with FIA and other data informs CARB's estimates of carbon stock in wildland forests and other lands. Chaparral is included in the forestland category for the purposes of the CARB inventory. The inventory includes carbon stocks, stock-change, and GHG flux between discrete points in time, capturing natural processes such as growth and mortality, disturbance events such as wildfire, timber harvests and other activities, land conversions to other uses, and fluxes associated with wood processing and the disposition of discarded wood products. Unlike the AB 1504 inventory which takes the production accounting approach for wood products, the atmospheric flow approach of carbon accounting in the CARB inventory includes imported harvested wood products.[239] The CARB inventory serves as an important source of information to assess the net GHG flux associated with forests and other lands, and interactions with other sectors. CARB plans to update the Natural and Working Lands Inventory on a bi-annual basis.

7.1.3 Black Carbon Emissions

Where possible, the AB1504 report will support CARB inventory methods to address black carbon emissions from wildfire.[240] To develop the first edition Short-Lived Climate Pollutants inventory, CARB used the elemental carbon fraction of a ten-year average of modeled Particulate Matter 2.5 ($PM_{2.5}$) emissions from wildfires in the period 2001 – 2011, to represent average conditions and avoid large year-to-year variations in the inventory. Similar to carbon stock figures, black carbon emissions will be assessed as a rolling average of annual emissions over ten year periods, expressed both in metric tons carbon and as carbon dioxide equivalent. Data on emissions from prescribed fire can also be tracked and reported.

7.2 Opportunities for Collaboration on Carbon Inventories

As discussed above, both the BOF and CARB are obligated to report on forest carbon and GHG emissions. SB 859 calls for CARB, in consultation with CNRA and CAL FIRE, to engage in a comprehensive review and

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[238] California Air Resources Board, 2016a

[239] For more information on IPCC accounting approaches, see IPCC 2006

[240] California Air Resources Board, 2016b

complete a standardized GHG inventory for natural and working lands, including forests, by December 30, 2018. At the same time, the BOF and CAL FIRE have a need to address technical issues to better inform policy decision-making, such as AB 1504 inventory data gaps and refinements, and relevant options for establishing alternative forest management scenarios and projections. Further, there may be issues of specific interest such as establishing methods for project-scale monitoring to capture GHG benefits from activities where neither FIA nor remote sensing methods are adequate, or defining the role remote sensing technology can play in risk assessment, planning and prioritization. There is an opportunity to streamline these efforts to address the various statewide inventory needs. In addition, land carbon quantification efforts at jurisdictional levels, such as counties, may provide sources and methods that could aid accounting for other categories of forest and woodlands statewide.

There are also opportunities for the AB 1504 and CARB inventories to complement each other. Examples include:

- AB 1504 forest and HWP carbon stock inventories could serve as a data source to inform CARB's Inventory. Collaboration can ensure AB 1504 data outputs are suitable for CARB data inputs.
- Similarly, the CARB methods for addressing other GHG emissions from woody materials, such as methane from decay or landfills, could be incorporated into the AB 1504 inventory.
- Efforts through the AB 1504 inventory can provide technical support for determining factors specific to the CARB inventory. For example, staff working on AB 1504 may locate data to refine CA-origin wood export and import estimates, which could assist CARB in establishing the level of within-state wood product consumption and HWP landfill emissions.
- CAL FIRE staff, working with FIA program staff for the AB 1504 inventory, could identify and facilitate transfer of data relevant to the CARB inventory. For example, there is currently a pilot urban forest FIA program underway for cities that can provide funding. Work began in San Diego in fall 2017 that could help establish a carbon stock, but cannot address flux for another 10 years, provided the program continues. Nevertheless, this information could support the CARB urban forest carbon inventory.
- CARB and BOF could work together to examine the need for and seek the resources to increase the frequency or intensity of the FIA plot measurement cycle in California, or other approaches, in order to better capture forest carbon dynamics.

In addition to broad-level forest carbon inventories, quantification of ecosystem carbon stocks, stock-change and associated GHG flux is also occurring at the project level. For example, the Compliance Offset Protocol – U.S. Forest Projects contains requirements tailored to the monitoring, reporting and verification of forest offset projects registered in the compliance offset program. Similarly, project-level accounting methods are included in land-based GHG reduction projects undertaken with the support of the California Climate Investments program. The State is also evaluating other efforts looking at land carbon accounting at jurisdictional levels, such as counties within California and states within other countries.

7.2.1 Results from California Forest Carbon Inventories

The carbon contained in a forest represents the accumulated carbon dioxide uptake and carbon sequestration in woody tissues and soils. The difference in the amount of biomass contained in a forest between two points in time represents the overall change in in-forest carbon stocks resulting from growth, mortality, harvest or other disturbances over time. An overview of the forest carbon cycle was provided in Section 2.

This report relies primarily on FIA data for forest carbon statistics. As there can be a great deal of interannual variation in growth, removals and mortality, the 2003 *IPCC Good Practice Guidelines* recognize that incorrect conclusions about long-term trends can be drawn from annual net sequestration rates.[241] Conversely, IPCC also recognizes that using long-term trends to estimate annual net sequestration can under- or over-estimate actual growth, removals and mortality in a single year. Nevertheless, IPCC recommends using average net sequestration values as they are influenced little by interannual variations. As described in section 7.1.1, during the 10-year FIA measurement cycle carbon stocks are provided as a moving 10-year average, while flux is provided as the average annual flux from the plots that have been re-measured. At the end of the 10-year measurement cycle, the flux will be provided as a 10-year annual average. In this way, the inventory is not designed to capture discrete annual events, such as specific wildfires or pulses in tree mortality, although the overall trend from these events will ultimately be apparent in the data. The large scale, high severity wildfire and tree mortality events in California over the last 5 years underscore the need to increase monitoring frequency and/or intensity from FIA and other sources to better quantify the impacts of these events on forest ecosystems and the State's carbon sequestration goals. However, the direct-measurement approach of the same trees over time captures and quantifies growth well, which can be a limitation in other, remote-sensing-based forest carbon inventory methods.[242] This updated method also directly accounts for mortality and changed conditions, is repeatable, allows for low errors, and is consistent with forest carbon inventory data nationally.[243]

As detailed below, calculations based on data collected for the FIA Program between 2006 – 2015 demonstrate that average annual carbon stocks stored in California forests are 1.30 billion metric tons (MT) of carbon in above ground biomass and 734 million metric tons (MMT) of carbon below ground, including within the soil (Table 10 and Figure 12). This amounts to a total of 2.04 billion MT of carbon. Data from the FIA Program, described in section 7.1.1, also were used to evaluate changes in growth, mortality, and removals in the above ground live tree pool on all ownerships on plots first measured between 2001 and 2005 and remeasured between 2011 and 2015, finding a net gain of 6.5 million metric tons (MMT) carbon per year (23.9 MMT CO2e per year).[244] See the *AB1504 Forest Ecosystem and Harvested Wood Product Carbon Inventory: 2006-2015* for additional information on FIA Program data by ecological regions.[245] When all forest pools are considered, California's forests are sequestering 34.4 MMT CO_2e/year, and when land-use changes and non-CO_2 emissions from wildfires are accounted for, the total net sequestration is 32.8 MMT CO_2e/year. The difference between these results and those from the estimates for the California Air Resources Board[246] was previously discussed in Section 2.2.

Despite the recent pulses in mortality from wildfire and pests, carbon stored in dead pools and growth from remaining live trees is still enough to currently maintain California's forests as a net sink. Recent research suggests that, during drought, forest carbon stocks are destabilized, and that drought-induced beetle mortality can transfer large portions of live above-ground carbon into the dead biomass pool that then serves as a protracted emission source due to decay.[247] Over time, if decay and mortality exceeds growth for an extended period California's forests could become a net source of emissions. A detailed discussion on the recent tree mortality impacts to forest carbon sequestration can be found in the AB 1504 inventory.[248]

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[241] IPCC, 2003
[242] Saah et al. 2015
[243] Christensen et al. 2016
[244] Christensen et al., 2017
[245] Christensen et al., 2017
[246] Gonzalez et al., 2015
[247] Earles et al., 2014
[248] Christensen et al. 2017

Table 10. Average Annual Above- and Below-Ground Forest Carbon Stocks, 2006 - 2015 (excludes harvested wood products; units in 1,000 metric tons of carbon).

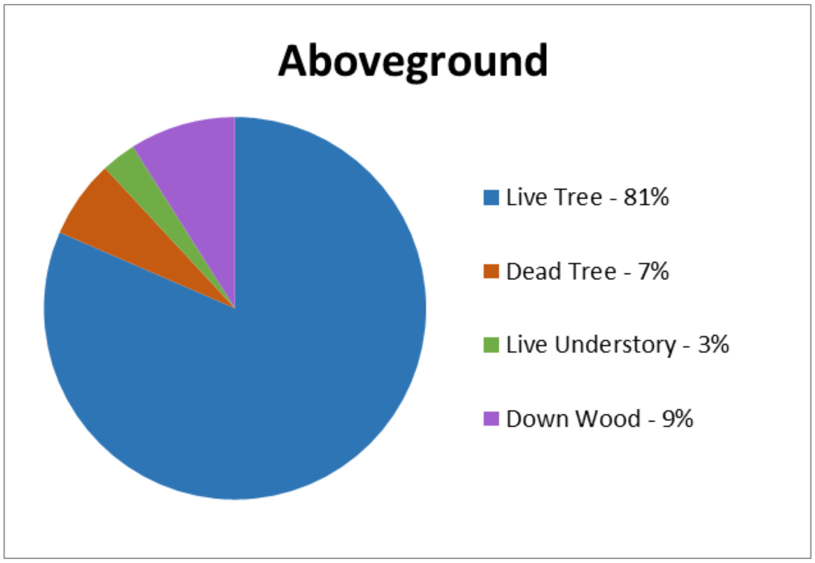
Owner	Above Ground	Below Ground	Total
	thousand metric tons C		
USDA Forest Service:	693,140	380,990	1,074,130
Other federal government:	114,600	68,440	183,040
Local	13,287	6,932	20,218
State	48,647	18,930	67,577
Other public	447	396	843
Private Corporate Forestland	204,130	119,330	323,460
Non-corporate private:	228,760	139,250	368,010
All owners	1,303,000	734,270	2,037,270[1]

[1]Totals may be off due to rounding

Source: USDA Forest Service FIA.[249]

Above ground includes: live tree, above ground dead tree, down wood, and aboveground understory vegetation. Belowground includes: Below ground live and dead tree roots, below ground understory roots, and soil organic carbon. The results exclude harvested wood products.

[249] Derived from Christensen et al. 2017



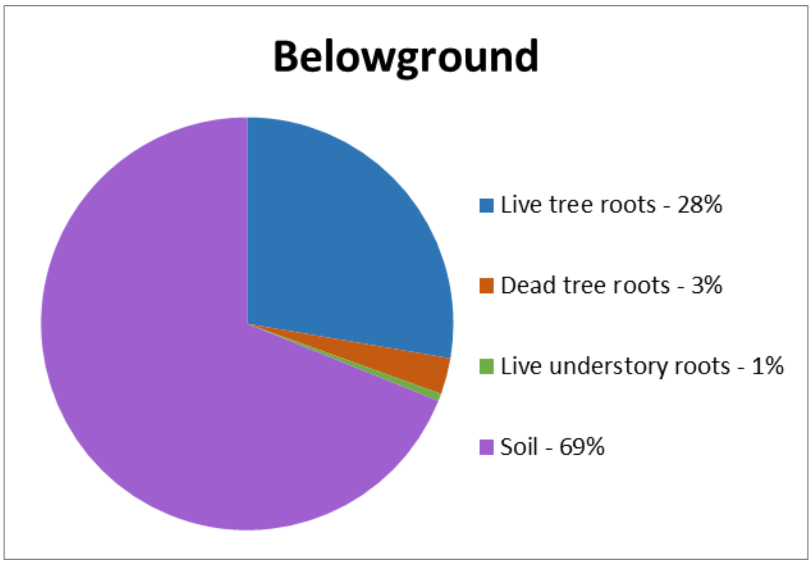


Figure 12. Average Annual Above- and Below-Ground Forest Carbon Stock, 2006-2015.

Source: USDA Forest Service FIA.[250]

This section's information on carbon storage in forests is based primarily on information collected by the FIA Program. Sources and methods meet Intergovernmental Panel on Climate Change guidelines for GHG inventory, and FIA Program products are used to fulfill federal, national, and international reporting obligations. This section provides summaries of estimates for carbon stocks in above- and below-ground carbon pools. Estimates for above-ground forest carbon include live trees, understory vegetation, down woody material and standing dead trees. Below-ground carbon pools include live and dead roots, and soil organic carbon. Carbon contained in wood products is also presented, based on results derived from McIver et al. (2015) and others.[251]Above-ground carbon is stored predominantly in live tree carbon pools, which represent 81 percent of the above-ground carbon. The understory vegetation (three percent), dead

[250] Derived from Christensen et al., 2017
[251] McIver et al., 2015

standing vegetation (seven percent) and down woody material (nine percent) make up the remaining fraction. Soil organic carbon is the largest storage component (69 percent) of the below-ground carbon pool, followed by below-ground live (twenty-eight percent) and below-ground dead tree material (three percent) and belowground dead understory roots (one percent).

7.2.2 Carbon Storage by Forest Types

California possesses a great diversity of forest types, each with unique characteristics and responses to climate conditions. The FIA Program database reveals which forest types contain the greatest amount of carbon in the aggregate and on a per-acre basis (Table 11). Estimated from FIA Program data (2001 – 2010) on a per-acre basis, forest types with higher levels of live tree carbon density include: redwood (122 metric tons carbon per acre); Douglas-fir (72 MT C per acre); fir, spruce and mountain hemlock (70 MT C per acre); California mixed conifer group (57 MT C per acre); tanoak and laurel (62 MT C per acre); and alder and maple (50 MT C per acre). The forest types that store the largest total amounts of carbon are the California mixed conifer group and the western oak group, which reflects the areal extent of these types.

Table 11. Average Above Ground Carbon Density by Forest Type Group, 2006-2015 (metric tons C/acre).

Forest Type Group	Live Trees	Dead Trees	Down Wood	Total
Softwoods:	*metric tons C/acre*			
Redwood	108.5	4.2	9.7	122.4
Douglas-fir	61.9	3.7	6.5	72.1
Fir/spruce/mountain hemlock	57.5	6.9	5.4	69.8
California mixed conifer	48.2	4.0	5.2	57.4
Lodgepole pine	30.5	3.3	4.4	38.2
Ponderosa pine	21.0	0.7	2.5	24.3
Pinyon/juniper woodlands	4.2	0.3	1.2	5.7
Hardwoods:				
Tanoak/laurel	53.4	3.1	5.4	61.8
Alder/maple	40.6	3.2	6.6	50.4
Elm/ash/cottonwood	22.0	0.6	1.8	24.4
Western oak	19.2	1.2	1.9	22.3
Aspen/birch	12.1	0.5	3.0	15.6

Source: USDA Forest Service FIA.[252]

[252] Derived from Christensen et al., 2017

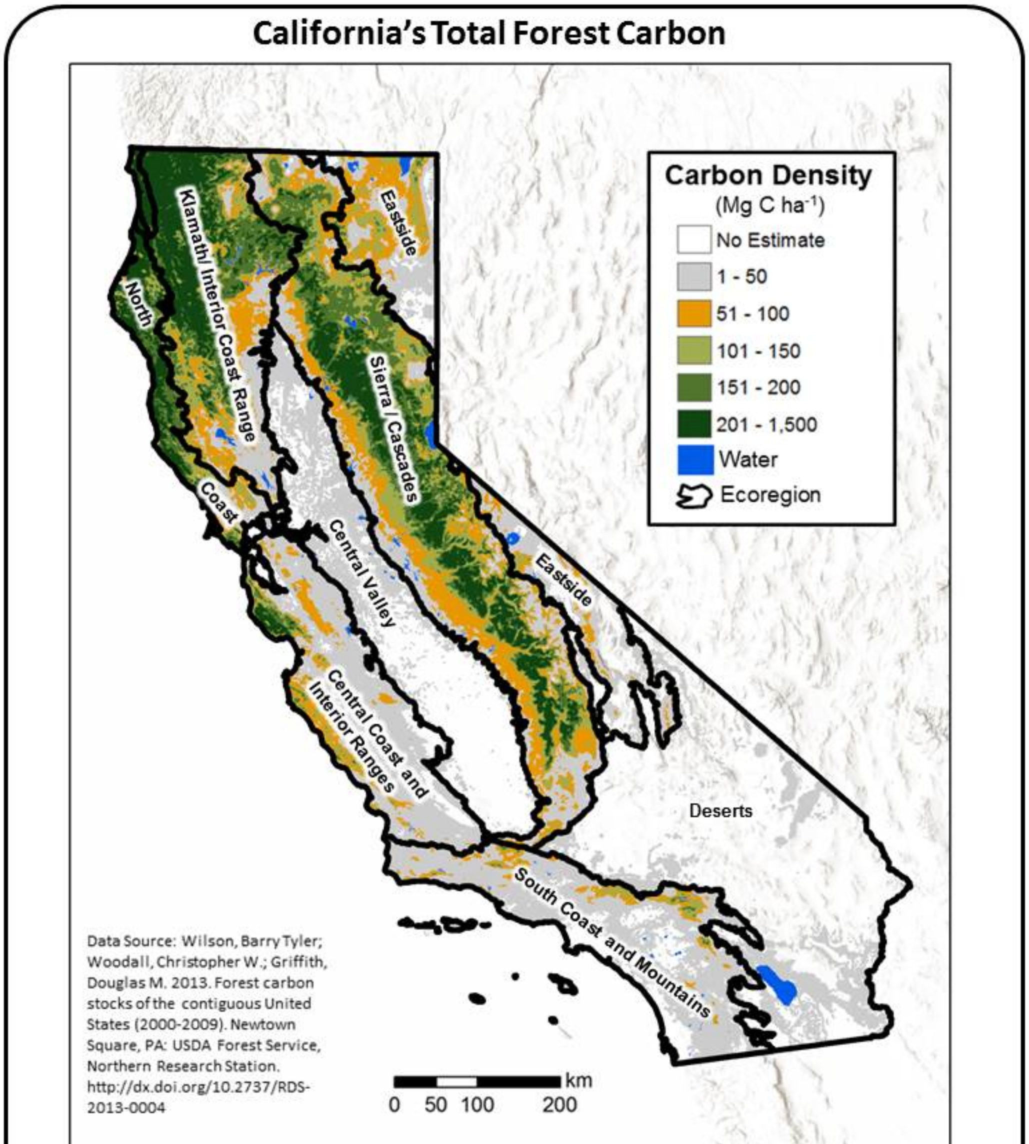
7.2.3 Carbon in Forests – Regional Patterns

The redwood and Douglas-fir forests concentrated in the North Coast and Klamath interior coast range ecoregions contain the highest forest carbon densities in the state (Figure 13). Redwood trees, compared to other large conifers, are largely resistant to native insects and diseases allowing them to be reliable and secure places for long-term carbon storage. The Sierra-Cascades ecoregion contains several large conifer species, which include ponderosa pine, sugar pine, Douglas-fir, incense cedar, white fir, red fir, and giant sequoia. This region also contains one of the largest reserves of carbon in California forests, but is susceptible to several native insects and diseases such as the mountain pine beetle, fir engraver, white pine blister rust, and dwarf mistletoe, particularly where fire has been suppressed from the forests for decades. As detailed earlier, over the past several years, drought stress combined with unhealthy forest conditions and bark beetles has killed millions of trees in the southern Sierra Nevada. These areas and other areas in the region that have been devastated by high severity fire are at strong risk to type-convert, where conditions are such that the forest may not be able to regrow and would instead be succeeded by shrub or grassland. Conversion to shrub or grassland would have a significant impact on California's future carbon storage, since these land types contain 15 percent or less carbon per acre than forested acres.[253] The forests and woodlands of the Central and South Coast Regions generally contain lower forest carbon density than those in the Sierra. These Central and South Coast forests are comprised of several oak species such as coast live oak and blue oak along with smaller and shorter-lived conifers such as Monterey pine, bishop pine and knob cone pine. The coastal pine species tend to have shorter lifespans than those in the Sierra and have adapted to higher severity stand replacement fire with serotinous cones. Some longer-living conifer species (e.g., redwood and Douglas-fir) are also present in this area in smaller numbers as well.

Table 12 shows that the Sierra/Cascades ecoregion has the greatest total carbon stocks (953 MMT), followed by the Klamath/Interior Coast Ranges (578 MMT). The Central Valley ecoregion has the lowest total stocks (3 MMT). Regional variation of carbon stocks is addressed in more detail in the AB 1504 Report and CAL FIRE's forthcoming 2018 Fire and Resource Assessment.[254]

[253] Gonzalez et al., 2015

[254] A new FRAP Assessment will be released in early 2018, and will be posted to: http://frap.fire.ca.gov/.



	Ecoregion Area (km²)							
Mg C ha⁻¹	Sierras/ Casacade	Central Valley	North Coast	Klamath/ Interior Coast Ranges	Central Coast and Interior Ranges	South Coast and Mountains	Deserts	Eastside
No Estimate	2,926	43,248	879	1,193	11,500	19,711	85,170	15,297
1-50	18,695	5,541	2,177	8,897	19,075	17,944	6,935	11,760
51-100	18,331	120	13,962	6,854	4,235	2,693	21	7,485
101-150	14,417	1	1,946	5,999	1,543	900	0	2,897
151-200	16,002	0	3,548	9,145	831	368	0	403
201-1500	16,435	0	6,292	13,952	937	9	0	61

Figure 13. Total Forest Carbon Density for California (2000 to 2009) from FIA. Includes live tree above-ground forest carbon, live tree below-ground forest carbon, forest down dead carbon, forest litter carbon, forest standing dead carbon, forest soil.

Table 12. Average Annual Above- and Below-Ground Forest Carbon Stock by Region, 2006-2015 (thousand MT carbon).

Ecological Regions	Above-Ground	Below-Ground	Total
	thousand metric tons C		
Central Coast and Interior Ranges	64,460	33,641	98,101
Central Valley	1,516	1,428	2,944
Eastside	41,532	54,497	96,029
Klamath/Interior Coast Ranges	383,621	194,093	577,713
North Coast	191,809	77,184	268,994
Sierra/Cascades	599,509	353,693	953,202
South Coast and Mountains/Deserts	20,535	19,778	40,313
Total	1,302,982	734,314	2,037,296

Source: USDA Forest Service FIA.[255]

Above ground includes: above ground live tree, above ground dead tree, down wood and understory vegetation. Belowground Includes: below ground live and dead tree roots, below ground understory roots, and soil organic carbon. Excludes Harvested Wood Products storage.

7.2.4 Carbon Storage in Wood Products and Other Uses

This section summarizes carbon contained in wood products, biomass for energy, and other utilization resulting from forest management and commercial timber harvest. Some forest management activities remove carbon from forests in the form of harvested woody material. These activities include thinning, timber harvest, and mechanical methods of fuels treatment. Under some circumstances, the removed carbon may be utilized in ways that can have net positive GHG benefits. For example, the carbon contained in a long-lived wood product can persist in a solid state for long periods, and some products may reduce demand for more fossil fuel energy or GHG-intensive building materials such as concrete or steel. Woody residues used in place of fossil fuels for energy may result in overall reductions in GHG emissions. The carbon, GHG, and climate implications of forest management and forest-product systems are an area of active research, and the quantification of the movement of carbon through these wood products pools is an important component of a forest carbon inventory.

Fuel treatment is a necessary action on millions of acres across the state to protect forest carbon, and one result of fuel treatment is the removal of excess biomass. With no utilization outlet for harvested woody material, it would either be chipped and incorporated back into the forests where it would quickly decay and emit to the atmosphere, or pile burned, emitting significant quantities of particulate matter and GHGs.

[255] Derived from Christensen et al. 2017

7.2.4.1 Carbon in Harvested Wood Products and Byproducts

Milling and manufacturing processes convert harvested wood into lumber and other products. The following information on carbon in harvested wood products is based on green timber harvest volumes for a single year, 2012, reported in McIver et al. (2015)[256] and updated via McIver and Morgan, (2017)[257] to better reflect the contributions of timber, slash, and bark. A description of methods to convert harvest volumes for timber, residues, bark, and slash to carbon mass and carbon dioxide mass equivalents for the Forest Carbon Plan are described in Appendix 2. The information in this section should be used to understand how a single year of harvest with its associated byproducts contribute to a carbon profile of wood used in products and burned for energy. Based on these calculations, in 2012 approximately 1.06 MMT of carbon was processed into finished lumber and other products and 1.20 MMT of carbon was burned for energy production, including slash and bark byproducts (Table 13). Further analysis of carbon that persists in wood products 100 years after the 2012 harvest are addressed in Table 14.

For commercial trees harvested for timber products, 47 percent of the harvested carbon ended up in finished lumber, 10% in landscaping and other products, seven percent in veneer and other products, seven percent in pulp and fiberboard products, 29 percent in mill residues combusted for energy, and 0.08 percent in unutilized residue [Table 13(a)]. Please note these percentages are not the same as the proportion of the volume of timber harvest by product due to different volume to mass conversions for solid wood products and residues.

Commercial timber harvest operations also resulted in bark as a byproduct. Sixty-three percent of the carbon in bark byproduct was combusted for energy and 37 percent of the carbon in bark byproduct became landscaping and other products [Table 13(b)]. Fifty-nine percent of landscaping and other products was comprised of residues from harvested wood, and 41 percent from the bark byproduct from harvested wood.

Slash (i.e., tops, limbs and associated bark) was another byproduct of the commercial timber harvest operations and, when removed from the forest, was exclusively combusted for bioenergy [Table 13(c)]. Some slash and sub-merchantable material is left in the forest and transfers carbon to dead wood pools (e.g., logging residuals). These residuals eventually decompose or are disposed of through open pile-burning and are not accounted for in Table 13, but are accounted for in the FIA plot measurements of forest ecosystem carbon pools. Logging residuals associated with the 2012 harvest are approximately 108 MMCF, [258] representing 0.59 MMT C. This quantity does not include submerchantable material cut for forest health and fuels reduction. If increasing the utilization of logging residuals and sub-merchantable material were economically and logistically possible, more carbon benefits could be gained.

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[256] McIver et al., 2015

[257] McIver and Morgan, 2017

[258] USDA Forest Service. 2012. Forest Inventory and Analysis Timber Products Output Database, CA 2012 report year, Table 9. https://srsfia2.fs.fed.us/php/tpo_2009/tpo_rpa_int2.php

Table 13. (a) 2012 Timber Harvest Carbon in End-Uses (Percentage represents the proportion of carbon contributed by each product from primary timber harvest; please note this is not the same as proportion of the volume of timber harvest by product due to different volume to mass conversions for solid wood products and residues); (b) Carbon Associated with Utilization of Bark Byproduct in 2012 (Percentage represents the proportion of carbon contributed by each use of bark); and (c) Carbon Associated with Utilization of Slash (i.e., tops and limbs) Byproduct in 2012 (Percentage shows slash is exclusively combusted for energy.).

(a) Timber Harvest

% of Harvest C	C (Metric Tons)	CO_2(e) (Metric Tons)	Category	Volume (MMCF)*
47%	635,498	2,330,372	Finished lumber	115.4
10%	138,913	509,393	Landscaping products	24.5
7%	92,516	339,257	Veneer and other products	16.8
7%	98,656	361,773	Pulp and fiberboard products	17.4
0.08%	1,134	4,158	Unutilized residue	0.2
29%	394,058	1,445,012	Mill residues combusted for energy**	69.5
Total	1,360,776	4,989,965		243.6
(b) Byproduct - BARK				
% of Byproduct C	C	CO2(e)	Category	Volume (MMCF)*
63%	166,128	609,192	Bark combusted for energy**	43.3
37%	97,522	357,615	Landscaping products	17.2
Total	263,651	966,807		60.5
(c) Byproduct - SLASH (i.e., tops and limbs)				
% of byproduct C	C	CO2(e)	Category	Volume (MMCF)*
100%	640,455	2,348,547	Slash combusted for energy**	116.3

*Million cubic feet. Harvest volumes reported in McIver et al. 2015 and updated via McIver and Morgan 2017 letter to FCAT are converted to carbon values for the Forest Carbon Plan. See Appendix 2 for methods.

**Carbon values associated with wood products combusted for bioenergy represent an emission. In a lifecycle analysis, net emissions for these products may be reduced when factoring in fossil fuel energy displacement, but is not calculated here.

It should be noted that in these calculations, bark and slash are addressed separately as they reflect additional utilization rather than trees that are specifically harvested for products/uses. Additionally, wood removed from the forest for commercial or personal-use fuelwood is not accounted for in Table 13. The values in Table 13 also only represent a snapshot in time and do not reflect carbon storage and emissions in products harvested in previous years, nor do they reflect a lifecycle analysis that factors in allocation of primary products (i.e., lumber, veneer, etc.) to specific end-uses (i.e., construction, manufacturing, etc.) and the associated wood product half-lives. Consequently, these values do not provide an inventory of typical harvested wood product carbon pools such as products in-use versus products at the landfill. Lastly, these values do not reflect avoided emissions from wood product substitution of more energy-intensive materials or from burning wood instead of fossil fuels for energy.

See Table 13 for the amount of carbon and carbon dioxide equivalent associated with each wood product/byproduct.

7.2.4.2 Carbon Profile of Solid Wood Products and Wood Products Combusted for Energy

While bark and slash are typically analyzed separately from primary timber harvest products, for the purposes of the Forest Carbon Plan they are included when looking at the carbon profile of solid wood products and wood products combusted for energy.

In 2012, 60 percent of the carbon in solid wood products came from finished lumber, 22 percent from landscaping and other products (including bark contributions), nine percent from veneer and other products, nine percent from pulp and fiberboard products, and 0.08 percent from unutilized residue (Figure 14).

Seventy-three percent of the carbon associated with wood products combusted for bioenergy came from harvest slash (i.e., tops and limbs), 16 percent from mill residues, and 11 percent from bark (Figure 15).

Last, 70 percent of harvested wood products in 2012 came from private corporate timberlands, 13 percent from private non-corporate timberlands, 14 percent from USDA Forest Service timberlands and three percent from other public timberlands (Figure 16). Nearly all the wood from timber harvested (97 percent) was processed in California.

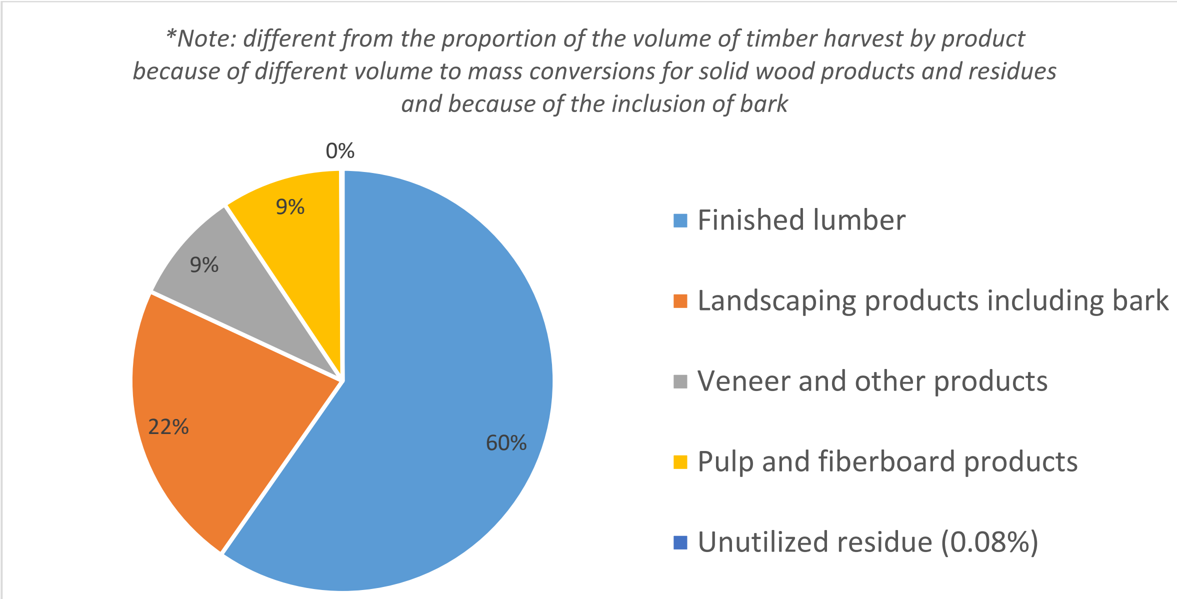

Figure 14. Carbon Profile for Solid Wood Products, 2012.

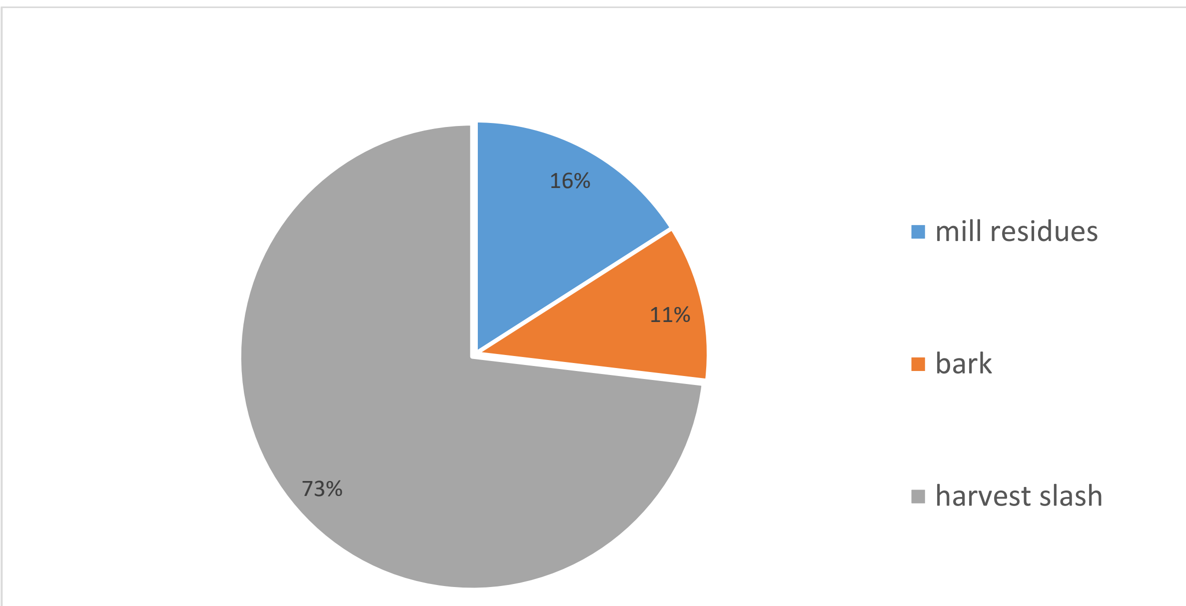

Figure 15. Carbon Profile for Wood Associated with Energy Combustion, 2012.

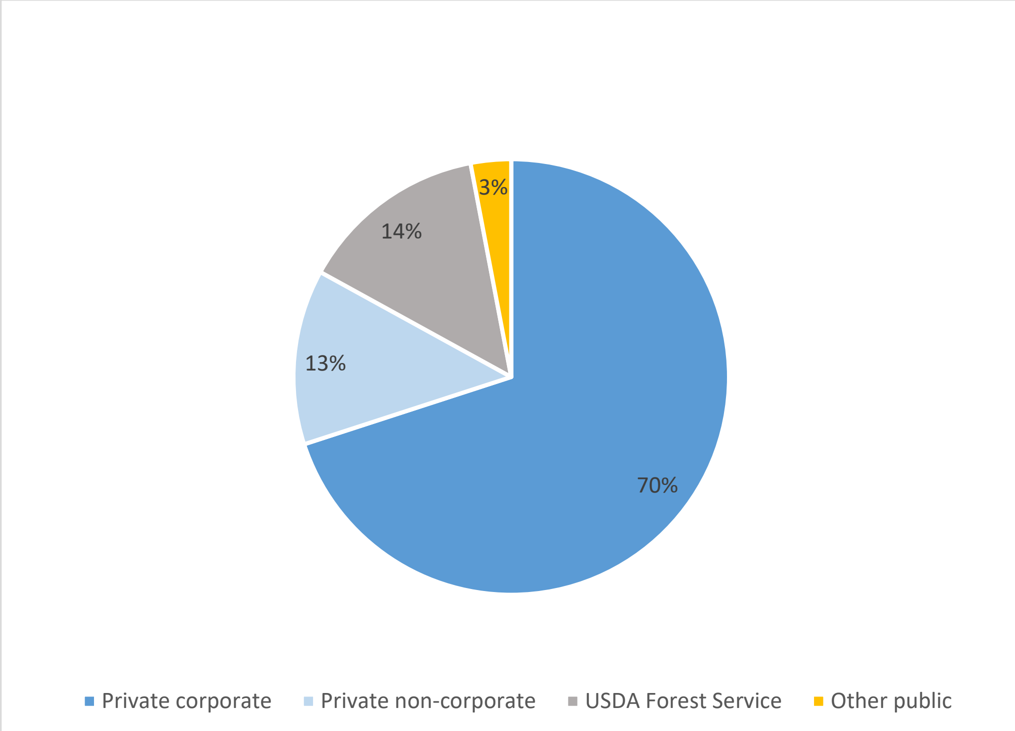

Figure 16. Percentage of 2012 Harvest by Ownership.

It also should be noted that timber harvest data from 2012 is not necessarily representative of historical timber harvest. Timber harvesting has declined since the mid-1980s. McIver et al. (2015), estimated that timber harvesting in California was 1.4 billion board feet in 2012, and this represents a decline of 18 percent from 2006 (1.7 billion board feet) and a 39 percent decline from 2000 (2.3 billion board feet).[259] However, the most recent data from the Department of Tax and Fee Administration show that the 2015 and 2016 harvests were higher than in 2012 (see Table 5, above).

7.2.4.3 More Comprehensive Harvested Wood Products Carbon Estimates

The diversity in the mix of products derived from timber harvests has been fairly consistent over time with a notable increase in utilization for bioenergy in recent years.[260] Stewart and Sharma (2015) estimated that when carbon storage in wood products is included in forest carbon accounting, managed forest stands show substantial carbon sequestration benefits over unmanaged stands.[261] In a related study, Stewart and Nakamura (2012) estimated that using revised coefficients on mill and consumer wood utilization efficiencies from newer data substantially improves the estimates of climate benefits from harvested wood products.[262]

Wood products produced from forests in the state take the form of durable products, such as dimensional lumber and panels. These primary products are converted into secondary products such as buildings and landscaping products where they can reside for a limited time. The various uses of wood products follow

[259] McIver, 2015
[260] Note, however, that much of the material burned in biomass power plants in California comes from sources other than forestlands, such as agricultural and urban forest waste materials.
[261] Stewart & Sharma, 2015
[262] Stewart & Nakamura, 2012

different lifecycle pathways and have different rates of disposal. Once disposed of, discarded wood products decay over time back to the atmosphere, a process which is dependent on the manner of disposal. In anaerobic environments, such as landfills, wood decay ceases after several decades, leaving a remainder carbon fraction that persists in solid form indefinitely.

Using data from the Board of Equalization, Saah et al. (2015) estimated the amounts of wood product carbon generated from timber harvests in California from 2001 to 2010.[263] These methods were built upon for analysis in the Forest Carbon Plan and are described in Appendix 2. Over the period, approximately 90 percent of harvested wood product was generated from privately-owned forests, with the majority of produced wood product utilized within the state. Using national and state mill efficiencies, wood product lifetimes and factors governing the fate of discarded wood products Saah et al. then estimated carbon losses to the atmosphere associated with each year's wood product cohort from 2001 to 2010, over 100-year timeframes (Table 14).

Table 14. California Ten-Year Annual Average (2001 – 2010) Harvested Wood Products Carbon Storage after 100 Years.

		Metric Tons of Carbon		
Source	Description	Public Ownership	Private Ownership	Total
Smith et al., 2010, 2006	10-year average annual storage from harvested wood products (2001 to 2010)	53,394	488,208	541,604
Stewart and Nakamura, 2012	10-year average annual storage from harvested wood products (2001 to 2010)	59,146	540,796	599,940

Source: Derived from Saah et al., 2015, see Appendix 2 for methods.

Based on national factors reported by Smith et al. (2006), it was estimated that after 100 years, approximately 65 percent of wood product carbon would eventually be returned to the atmosphere. Using state-specific factors reported by Stewart and Nakamura (2012), the estimate was 61 percent. Using this approach, it was estimated that the ten-year annual average of wood products in storage from 2001 to 2010 ranges between 541,604 and 599,940 metric tons of carbon per year. Long-term storage estimates from harvest activities on public lands ranges from 53,394 to 59,146 metric tons of carbon per year, while estimates range from 488,208 to 540,796 metric tons of carbon per year from harvest on private lands. This analysis does not include potential carbon benefits from wood products in use from harvests prior to the time period of analysis, from additional utilization of slash and bark byproducts, from substituting for more energy-intensive materials like cement or steel, or from reduced emissions from fossil fuel displacement.

Based on 2012 timber harvest volumes, carbon values remaining in storage after 100 years are similar to those based on the 2001 – 2010 harvests (Table 15). The data in this table do not address additional

[263] Saah et al., 2015

emissions from utilization of slash and bark for bioenergy in year 1 or additional storage benefits from utilization of bark for wood products, as reported in Table 13.

Table 15. Carbon Remaining in Storage 100 Years after 2012 CA Timber Harvest.

Method	Metric tons of Carbon, TOTAL
Smith et al. (2006)	483,075
Stewart and Nakamura (2012)	553,057

As mentioned in Section 5, a more comprehensive harvested wood products carbon inventory that factors in primary product ratios and end-uses, product lifetimes, etc. will occur in the second AB 1504 Forest and Harvested Wood Product Carbon Inventory report in 2018 and will build off the work completed for the Forest Carbon Plan.

7.2.5 Carbon Stock-Change Rates

Using data from FIA Program reports, changes in live tree carbon stocks on all ownerships were evaluated on plots first measured between 2001 – 2005 and then remeasured between 2011 – 2015.[264] FIA allows for a statistically robust process for estimating forest structure information (in this case net change in carbon stocks), including sample estimates of variability that offer insight into the confidence of the estimate, or sample error around a given parameter. As in any sample-based approach to estimation, increasing sample sizes improves the reliability of a given estimate. Likewise, increasing the temporal remeasurement cycle would make the process more sensitive to capturing specific time-series changes like disturbance, which may only show a response for a limited time.

Above-ground carbon change was evaluated in trees that were live at the first visit, and live, dead, or harvested ten years later. Changes were summarized over a large sample of plots in each of four owner/reserve classes that represent over two-thirds of California's forest land and virtually all its timberland. Only "Other Public" lands were omitted as a discrete ownership category in this summary. Nearly all the forest land excluded from this analysis falls under the FIA categories "Other Forest" (productivity of less than 20 cubic ft./acre/year) or "Reserved" (e.g., State and National parks)—areas that are, for the most part, not actively managed in terms of timber culture or harvest. However, "Other Public" is accounted for in the "All Forest" category, as that category includes estimates based on every owner class, both timberland and other forest, and both reserved and unreserved. This analysis does not include changes in carbon stocks in other forest and soil carbon pools or wood products and other end uses. Additionally, impacts from land-use change are not addressed here.

Growth, mortality by cause, removals, and net carbon change information have been summarized as per acre averages by three ownership and two reserve classes and for all forests, as described previously (see Figure 17).[265] This categorization is necessary to understand how forest carbon dynamics vary among owner classes and the styles of management they can be considered to represent, given that forest area is not evenly distributed among owners or reserve classes. Ultimately, the change in the live tree carbon pool on any given forested acre is a function of the gains from growth on live trees minus the losses to this pool from mortality and harvest. While those live tree pools can experience losses, some amount of carbon is transferred to other pools and remains stored in dead trees and harvested wood products and therefore

[264] Christensen et al., 2017
[265] Christensen et al., 2017

does not represent a total loss in carbon storage. Additionally, as stated in previous sections, additional benefits in the form of avoided emissions from wood product substitution of more energy intensive materials or from burning wood instead of fossil fuels for energy can result from harvested wood products.

Net change is provided in metrics of carbon dioxide equivalent rather than carbon as it represents the net flux of carbon to and from the atmosphere and between pools.

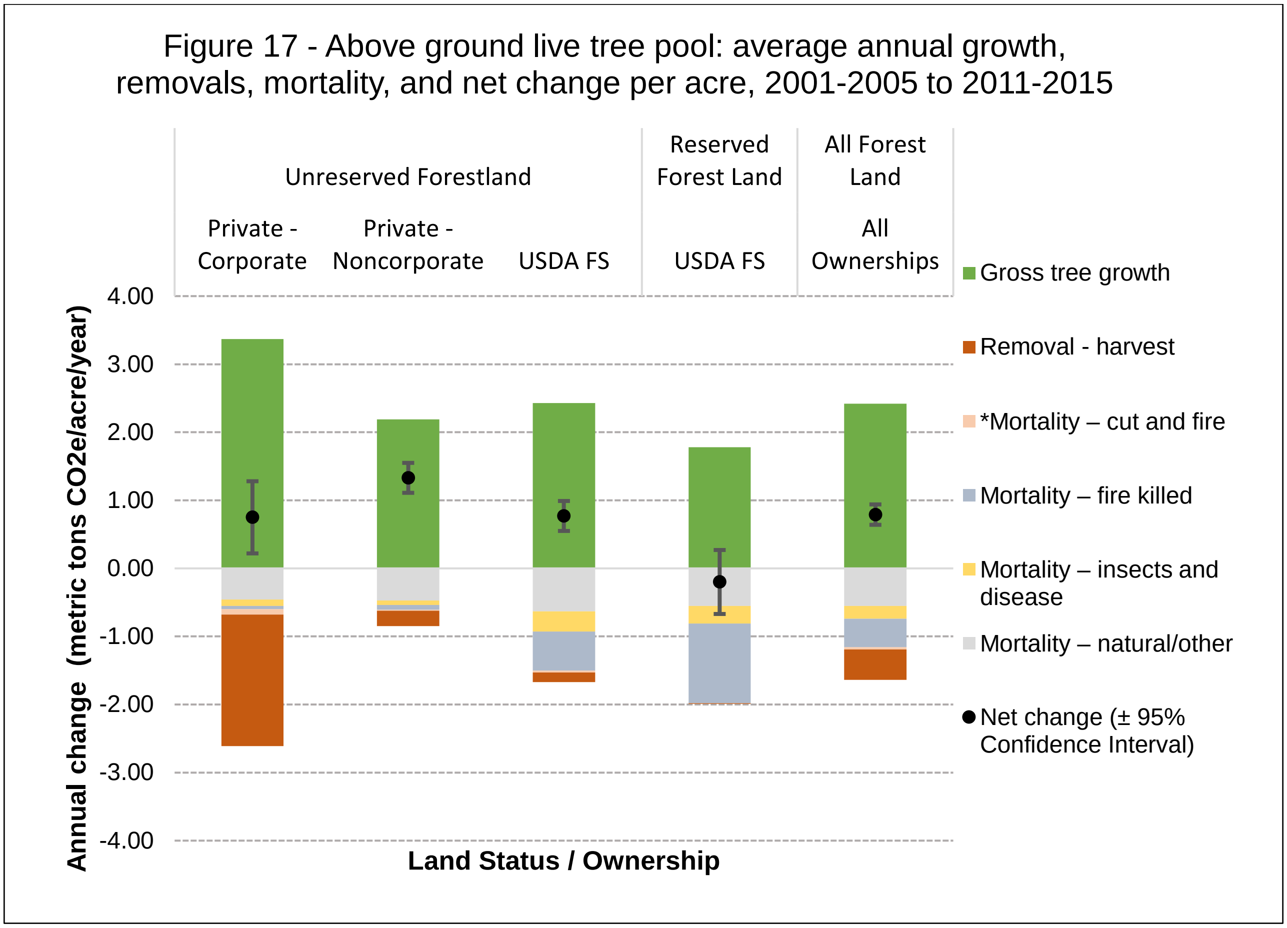

Figure 17. Above Ground Live Tree Pool: Average Annual Growth, Removals, Mortality, and Net Change by Owner and Land Status on Plots Initially Measured between 2001-2005 and Remeasured between 2011-2015 (metric tons CO_2e/acre/year).

* Mortality – Cut and fire: plots where tree mortality has occurred due to both harvest and fire.

Source: USDA Forest Service FIA.[266]

Due to differences in the amount of forestland in each owner and reserve class, the total impact to net changes in carbon stocks varies. Table 16 summarizes total gross growth, mortality, removals and net change by three ownership and two reserve classes and for all forests. Again, “Other Public” is accounted for in the “All Forest” category.

[266] Derived from Christensen et al., 2017

Table 16. Statewide Average Annual Growth, Removals, Mortality, and Net Change for the Above Ground Live Tree Pool by Disturbance, Owner, and Land Status on Plots Initially Measured between 2001-2005 and Re-Measured between 2011-2015 (thousand metric tons carbon dioxide equivalent per year).

	UNRESERVED FORESTLAND			RESERVED FORESTLAND	ALL FORESTLAND[2]
	Private, Corporate	Private, Non-Corporate	USDA Forest Service	USDA Forest Service	Total
	thousand metric tons CO2 equivalent per year				
Gross tree growth	18,554	13,772	25,983	7,188	**73,253**
Removal - harvest	-10,664	-1,476	-1,467	-22	**-13,645**
Mortality – fire killed	-278	-449	-6,077	-4,689	**-12,566**
Mortality – cut and fire[1]	-466	-49	-326	0	**-842**
Mortality – insects and disease	-488	-435	-3,162	-1,039	**-5,728**
Mortality – natural/other	-2,525	-2,988	-6,743	-2,203	**-16,543**
Net live tree	4,133	8,375	8,208	-765	**23,929**
				95% confidence interval	**4,575**

[1]Mortality – Cut and fire: plots where tree mortality has occurred due to both harvest and fire.

[2]Includes other public forestland.

Source: USDA Forest Service FIA.[267]

As reflected in Figure 17 and Table 16 above, the live tree removals from harvest and mortality is generally less than growth on both unreserved private and public forestland. The changes in growth, mortality, and removals among ownership groups reflect the relatively higher growing capacity of much of the private lands and different forest management goals and approaches between ownership classes. This results in characteristic patterns of carbon stocks and change that are unique for each ownership group.

- National Forest System Reserved Forestland: This category is representative of lands permanently reserved from wood products utilization through statute or administrative designation, including designated wilderness areas. While there is moderate growth on these lands, it appears to be slightly outpaced by mortality rates. There are no harvest removals, but there is high mortality from wildfire, pests, disease, and other disturbance agents. The rate of mortality from fire-killed trees is approximately 23.4 times higher on USDA Forest Service reserved forestlands than on unreserved private corporate forestland, 16.7 times higher than on unreserved private non-corporate forestland, and 2.1 times greater than on USDA Forest Service unreserved forestland. Thus, these lands exhibit net losses of live tree carbon on the order of 0.20 metric tons of carbon dioxide equivalent (CO_2e) per acre per year, or 0.82 MMT CO_2e per year. In turn, decay or disturbance processes transfer carbon from the dead tree pool to the atmosphere or to the soil. The sampling estimate for this land type carries a large degree of sample variability, particularly when viewed in context with the very small mean value.
- National Forest System Unreserved Forestland: Unreserved forestland is comprised of both timberland and other forestland. Timberland is available for harvest and capable of producing commercial crops of trees. Combined, these lands have higher per-acre rates of growth than reserve lands. They have a small rate of removal from harvest, and have slightly lower levels of mortality per acre per year than reserve lands. The rate of natural, non-fire/non-pest related

[267] Derived from Christensen et al., 2017

mortality is highest on these lands, but is within 1.1 – 1.4 times the rate on both USDA Forest Service reserve lands and private lands. The rate of harvest on these federal lands has declined since the 1980s as a result of factors including changing management goals, declining USDA Forest Service budgets, endangered species protections, and legal challenges. For example, some timber offerings go unsold due to lack of bids. Further, costs of timber sale planning, layout, and environmental planning often exceed the revenue that can be generated from the sale. Growth is higher than mortality on these lands, but growth is much closer to mortality than on private non-corporate forests. These forests experience a net gain in carbon at a rate of 0.77 metric tons of CO_2e per acre per year, or 8.2 million metric tons of CO_2e per year.

- National Park Service Lands: Although these landscapes represent a small percentage (4.5 percent) of California's forested areas and were not highlighted in Figure 16 and Table 16, they are important for reasons of management application. The NPS takes a hands-on restoration and fire/fuels management approach and has received fewer legal challenges to their management efforts, resulting in landscapes that are more robust and resilient than most public landscapes in California. Active management policies that encourage the use of prescribed and managed fires has resulted in significant decreases in high severity fire compared to adjacent lands, as well as increased water quantities from their forests.[268]
- Private Corporate Forestland:[269] Private corporate forestland includes both timberland and other forestland. On private corporate forestland growth is high and exceeds removal and mortality, reflecting the practice of sustained yield as required by California's Forest Practice Act and Rules. These forests are managed to create relatively little annual mortality and the harvested volume is less than forest growth. Rates of removals from harvest and thinning are highest on these lands, but the rate of fire-related mortality is lowest. These forests experience a net gain in carbon at a rate of 0.75 metric tons of CO_2e per acre per year, or 4.1 MMT of CO_2e per year. In 2012, these lands contributed 70 percent of the total harvest (Figure 16) and are therefore an important contributor to the carbon stored long-term in harvested wood products and reduced emissions from burning wood instead of fossil fuels for energy. Owing to lower sampling densities than on public lands, estimates associated with private lands do show higher sample error, but when viewed within the general context of total net change, these lands likely serve as net sinks for carbon.
- Private Non-Corporate Forestland:[270] This category represents private ownerships for which timber production may or may not be a primary management objective. The rate of gross growth is high on these lands, while the rate of natural, non-fire related mortality is low. The rate of fire-related mortality is also quite low, although it is higher than on private corporate forestland. As these lands exhibit high growth rates, lower harvest per acre than corporate forestland, and have relatively low levels of mortality, these forest lands see the highest net sequestration rates on the order of 1.33 metric tons of CO_2e per acre per year, or 8.4 million metric tons of CO_2e per year.
- State and Local Government Forestland: Although these lands are not highlighted in Figure 17 or Table 16, this category of ownership manages a much smaller fraction of the forest land base, and is represented by smaller-acreage ownership patterns. However, it is characterized by higher levels

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[268] Boisramé et al., 2016

[269] Per FIA definitions, "An ownership class of private forest lands owned by a company, corporation, legal partnership, investment firm, bank, timberland investment management organization (TIMO), or real estate investment trust (REIT)."

[270] Per FIA definitions, "Private forest land owned by nongovernmental conservation or natural resource organizations; unincorporated partnerships, associations, or clubs; individuals or families; or Native Americans.

of growth that exceed mortality and low levels of removal. The bulk of the area, 788,000 acres or 72 percent, is in reserved status such as parks.

Private non-corporate forestland has the highest rate of sequestration per acre (Figure 17), and despite making up 10 percent less of the forestland base than USDA Forest Service unreserved forestland, these forests sequester the greatest total amount (Table 16). A net 33 percent increase in carbon stock from private non-corporate forestland came from only 24 percent of the California forestland base (Figure 18, Figure 9). A net 13 percent increase in carbon stock from private corporate forestland came from 15 percent of the forestland base. A net 39 percent increase in carbon stock from USDA FS reserved and unreserved forestlands combined came from 48 percent of the forestland base. Lastly, a 15 percent increase in carbon stock from other public and private lands came from 13 percent of the forestland base. Private non-corporate forestlands provided slightly less of a net increase in carbon stocks than all USDA FS forestlands, despite being just half the size.

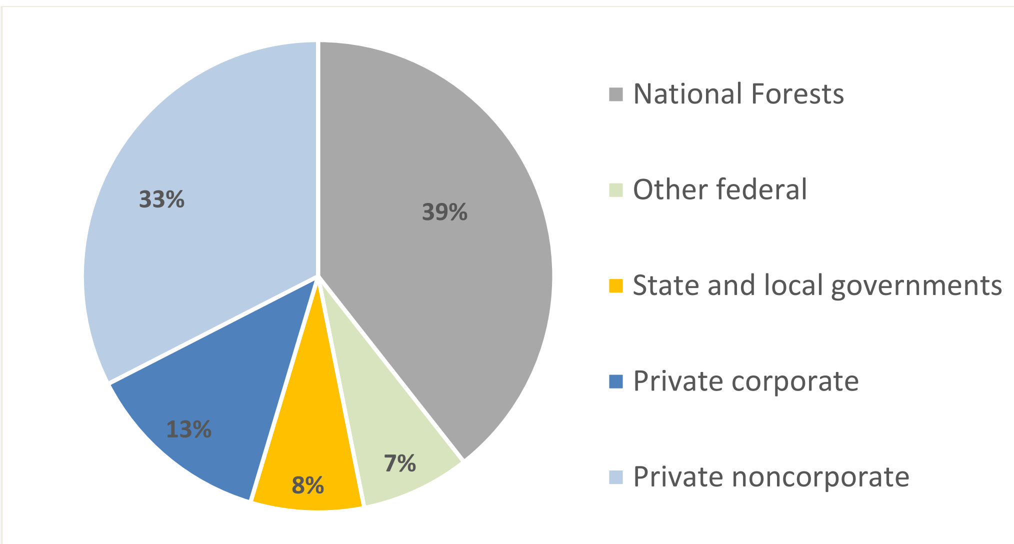

Figure 18. Percent of Average Annual Forest Carbon Stock Increase by Owner, 2001-2005 to 2011-2015.

Source: USDA Forest Service FIA.[271]

7.3 Discussion of Forest Carbon

Forest carbon is stored in both forest ecosystems and, to a lesser extent, in harvested wood products. The degree to which California forests operate as a sink or source is influenced by land management, weather, and a range of forest health issues (e.g., growth, tree mortality from drought, pest and disease outbreaks, wildfire severity). In recent years, prolonged drought conditions have resulted in elevated tree mortality that is widespread across the southern Sierra. The combination of drought impacts and extensive wildfires has made forests lose significant capacity for storing carbon. For all forestlands, improving forest health and managing to reduce losses from mortality can greatly increase the carbon balance on forestlands. On commercial and other actively managed forestlands in California, efficient uses of long lasting wood products and residues for energy can yield GHG benefits. Key inventory findings include:

[271] Christensen et al., 2017

- Based on FIA Program data from 2006-2015, all California forests combined on all ownerships were performing as a net sink and are sequestering carbon at an average rate of 0.79 metric tons of CO_2e per acre per year, or 0.22 metric tons of carbon per acre per year.
- Based on FIA Program data from 2006 – 2015, California forests have substantial carbon storage; 1,303 MMT above ground and 734 MMT below ground, for a total of 2,037 MMT.
- Based on remeasurements taken between 2011 and 2015, carbon sequestration in the live tree pool (in-forest) was estimated at 7.4 MMT of CO_2e per year on National Forest System unreserved and reserved forestlands, 4.1 MMT on private corporate forestland, 8.4 MMT on private noncorporate timberlands, and 4.0 MMT on other public lands. The net change in the live tree pool across all forestlands is estimated at 23.9 MMT of CO_2e per year.
- When other forest pools, soils, non-GHG emissions from wildfire, and changes from land-use are accounted for, the net change is 32.8 MMT CO_2e per year, meeting the AB 1504 goal of sequestering 5 MMT CO_2e per year, assuming the contribution of flux associated with wood products does not drastically lower rates.
- Analysis of recent timber harvest data (2012) suggests an approximately 1.06 MMT of carbon was processed into finished lumber and other products and 1.20 MMT of carbon was burned for energy production, including slash and bark byproducts. Material from harvest is divided between wood products and bioenergy, with less than one percent unused material.
- Analysis completed for the Forest Carbon Plan estimates the ten-year average wood products in storage from 2001 to 2010 to range between 0.542 and 0.600 MMT of carbon annually. Long-term wood products storage estimates from harvest activities on public lands ranges from 0.053 to 0.059 MMT of carbon per year, while private lands estimates range from 0.488 to 0.541 MMT of carbon per year from private land harvest activities.
- On a per-acre basis, conifer forest types have enormous carbon capture and storage potential.
- FIA Program data suggest that on private forestland growth is outpacing losses from harvest and mortality (excluding wood product storage), and exceeds that of National Forest System lands.
- FIA Program data show that non-corporate forestland has the greatest net growth (i.e., growth minus mortality and harvest excluding wood product storage).
- Based on FIA Program data, tree mortality from forest health-related causes results in substantial declines in forest carbon. These data indicate that tree mortality rates are highest on federal forest lands in reserve (e.g., wilderness), where mortality is slightly outpacing growth.

8 Urban Forestry

Urban forest refers to native or introduced trees and related vegetation in urban and near-urban areas, including, but not limited to, urban watersheds, soils and related habitats, street trees, park trees, residential trees, natural riparian habitats, and trees on other private and public properties.[272]

California's urban forests are both similar to and different from wildland forests in form and function with regard to species composition, ecological and urban function, management, and climate change impacts. Urbanized areas constitute approximately 5 percent of the state's area, and it is estimated that the tree canopy, the spatial extent by which urban tree cover is measured, occupies approximately 15 percent of all urban areas.[273, 274] Thus, the urban tree canopy covers approximately 791,725 acres of California. While census-defined urban areas represent only about five percent of the state's land area, this is where almost 95 percent of the state's population, or over 35 million people, reside.

The "stocking rate" of urban forests is estimated to be just over one-third (36.3%) of its potential statewide, meaning both tree density and canopy cover has room to grow.[275, 276] A large proportion (61 percent) of urban area in California is considered to have low tree canopy cover of two to ten percent.[277]

The urban forest is made up of both native and non-native tree species. Tree selection is typically ad hoc or based on the benefits a tree offers to residents and urban function. Whereas wildland forests are dominated by native tree species with few exceptions, many urban forests in California are dominated by species not native to that location or even the continent. Criteria for urban tree selection differ by locality but can include consideration of aesthetics; site suitability with regards to space, water, and light needs as well as interactions with surrounding infrastructure; and maintenance needs over time.

Urban forests in California, like wildland forests, are being impacted by climate change and drought. Elevated temperatures, reduced precipitation, and reduced landscape watering all contribute to mortality and health issues. Water needs and climate should always be considered when selecting species, but there are water-efficient and water-inefficient ways to maintain trees through periods of drought. Increasing the water use efficiency of tree maintenance can reduce mortality from drought, so these methods should be adopted by public and private stewards statewide.

Invasive pests and diseases continue to enter the state and cause damage to urban forests. The golden spotted oak borer, polyphagous shot hole borer, and Kuroshio shot hole borer are examples of such pests that are currently affecting urban forests. The two shot hole borer species are of particular concern as they have wide host species ranges. Sudden oak death is also a major disease problem in northern California urban forests.

8.1 Benefits of Urban Forests

Urban trees have always been valued for their aesthetics and other passive improvements to streetscapes, but are becoming increasingly valued for their potential to contribute to the state's climate and water management goals. Trees cool urban and surrounding areas, which mitigates the public health impacts of excessive heat and criteria air pollution; reduce energy demand for cooling; and improve conditions for

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[272] California Public Resources Code Section 4799.09, 1978
[273] Klass-Schultz, 2016
[274] Bjorkman et al., 2015
[275] McPherson et al., 2016
[276] Bjorkman et al., 2015
[277] Bjorkman et al., 2015

active transportation options such as walking and bicycling.[278] Some of these values have been estimated monetarily statewide: reduced energy use from canopy shading and cooling saves an estimated $568 million annually. Annual benefits to water infrastructure, including rainfall interception, reduced water pollution, and reduced flood risk, are estimated at $324.6 million.[279] The economic activity associated with urban forestry in 2009 in California was $3.6 billion, and urban forestry related jobs in California totaled over 60,000 in that year.[280]

Trees and other vegetation are a critical component to urban greening programs and objectives statewide, and provide evaporative cooling to their surroundings. Absence of vegetation exacerbates warming caused by heat absorption (e.g., dark pavement and roofs) and heat-generating sources (e.g., engines) concentrated in urban areas. The resulting phenomenon is called the Urban Heat Island (UHI) effect. [281] The UHI can lead to daytime temperatures in urban areas on average one to six degrees Fahrenheit higher than in rural areas, while nighttime temperatures can be as much as 22 degrees Fahrenheit higher as the heat is gradually released from buildings and pavement.[282, 283] Increasing the amount of vegetation in cities, in addition to increasing area covered by water-permeable surfaces, increases evapotranspiration and combat the UHI. Trees also lower temperatures and provide shade at street level, which improves livability and encourages active transportation. Areas with the greatest UHI effect and air pollution are seen as priority areas for tree planting.[284] Box 8 on the following page contains more information about Urban Heat Islands.

Urban greenspace, including tree canopy, provides well-documented cognitive, public health and community benefits of. These include:

- Strengthening of social cohesion within communities[285]
- Support for cognitive functioning and place attachment[286, 287]
- Support for psycho-social-spiritual engagement[288]
- Increased physical activity[289]
- Decreased childhood obesity[290]
- Longevity among seniors[291]
- Improved concentration among children with attention deficit disorder[292]

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[278] McPherson & Simpson, 2015
[279] McPherson et al., 2016
[280] Templeton et al., 2013
[281] California Environmental Protection Agency, 2015
[282] California Environmental Protection Agency & California Department of Public Health, 2013
[283] U.S. Environmental Protection Agency, 2008
[284] Bjorkman et al., 2015
[285] Sullivan et al., 2004
[286] Gómez-Baggethun et al., 2013
[287] Place attachment and meaning are the person-to-place bonds that evolve through emotional connection, meaning, and understandings of a specific place and/or features of a place (Shumaker & Taylor, 1983). Higher levels of place attachment are positively associated with environmental stewardship (Clayton & Myers, 2011), pro-environmental attitudes, and climate change adaptation (Adger et al., 2013).
[288] McMillen et al., 2016
[289] Kaczynski & Henderson, 2007
[290] Wolch et al., 2011
[291] Takano et al., 2002
[292] Taylor & Kuo, 2009

- Amelioration of stress,[293] and
- Self-reported quality of health.[294]

Box 8. Urban Heat Islands

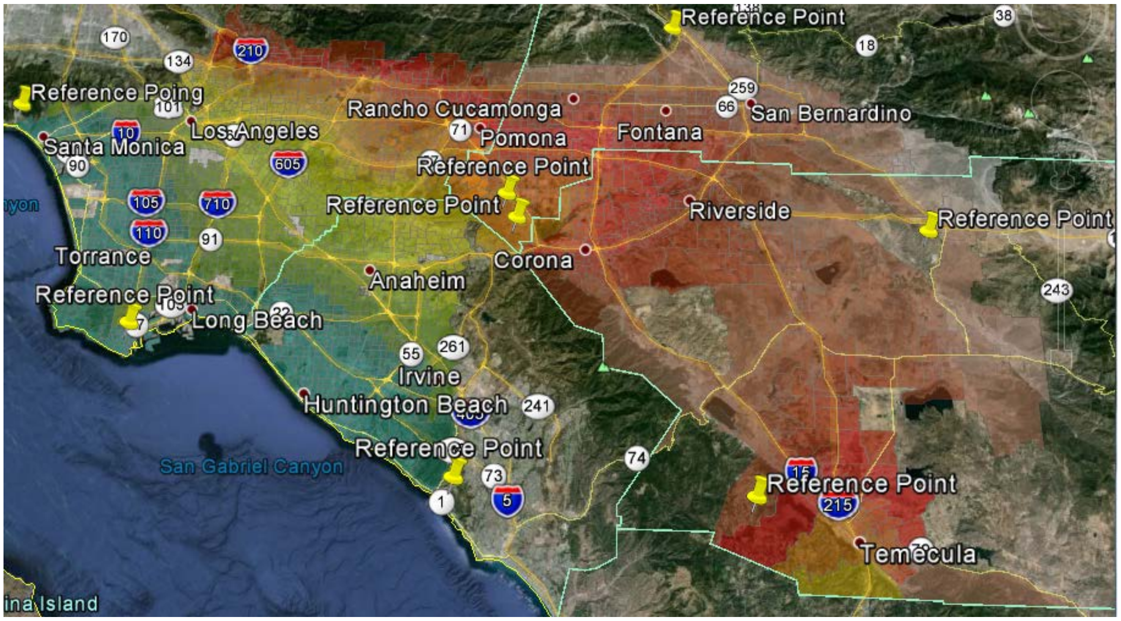
Large urban areas often experience higher temperatures, greater pollution and more negative health impacts during hot summer months when compared to rural communities. This phenomenon is known as the urban heat island (UHI). Heat islands are created by a combination of heat-absorptive surfaces (such as dark pavement and roofing), heat-generating activities (such as engines and generators) and the absence of vegetation (which provides evaporative cooling). Sometimes, due to wind and topography, the heat island can be created in one area and manifest as increased heat in another area.

In July 2015, CalEPA released a study on urban heat islands, “Creating and Mapping an Urban Heat Island Index for California.” The study defines and examines the characteristics of the urban heat island based on atmospheric modeling, and assigns an urban heat island index (UHII) for each census tract in and around selected urban areas throughout the state.

The modeling shows that urban areas with relatively well-defined boundaries (i.e., urban islands) typically exhibit single- or multi-core UHIIs. On the other hand, large urban archipelagos and coastal regions, such as the Los Angeles Basin and the Santa Clara Valley consist of sustained and contiguous urban land use with no well-defined boundaries, except for breaks by topography.

In urban archipelagos, urban heat is continuously injected into an air mass advecting across the urban area. As a result, an air mass warms up continuously, masking localized rises and falls in temperature along the trajectory. Thus, the local UHI in an archipelago additionally includes the superimposed effects of upwind urban warming. In this case, the UHII often peaks in areas near the downwind edges of the archipelago.

In coastal areas, the UHIs are also superimposed on the onshore warming of air, so the UHIs in these regions and in urban archipelagos also capture that warming effect.



Urban Heat Island Index in Southern California. Yellow pegs indicate reference points, used to calculate difference between urban and nonurban temperatures.

[293] Adevi & Mårtensson, 2013
[294] van den Berg et al., 2010

California's urban tree canopy also includes trees that produce food. Community managed agricultural production areas have been documented in multiple urban areas of California, including low-income neighborhoods.[295, 296] In response to strong community interest, San Francisco, Los Angeles, and San Diego have recently updated municipal policies to facilitate urban agriculture. Along with the benefits already described for the urban canopy, urban agriculturalists and their networks enjoy benefits of food as well as the social networks, social cohesion, and cultural identity that are fostered through the acts of planting, stewarding, harvesting, preparing, and sharing the food grown on trees. These trees are found in a range of spaces from public to private areas, non-profit and commercial enterprises, and range from actively managed farms to untended lots. Examples include gardens, orchards, farms, schools and more.

There are important social equity implications to consider in urban forestry programs, given the fact that the urban forest canopy and its benefits is not distributed equally across communities. As shown in Table 17, disadvantaged communities typically have less canopy than wealthier communities: 76 percent of the census tracts in disadvantaged urban communities have less than ten percent tree cover, while 39 percent of census tracts in non-disadvantaged communities have less than ten percent tree cover. By recommending focusing on urban areas with low tree cover percentages, this Plan's urban forestry goals prioritize canopy-enhancing and green infrastructure projects in disadvantaged and low-income communities.

Table 17. California Disadvantaged Communities Percent Tree Canopy in Urban Areas.

	Disadvantaged (25.3 Percent of all tracts)		Non-Disadvantaged (74.7 percent of all tracts)	
Urban Tree Canopy Cover	Number of Census Tracts	Percent of Disadvantaged Tracts	Number of Census Tracts	Percent of Non-Disadvantaged Tracts
<10 percent	1,498	75.8	2,244	38.5
10-20 percent	406	20.5	2,172	37.3
>20 percent	72	3.6	1,407	24.2
Total Number of Tracts	1,976	100	5,823	100

Data Notes: 2012 Census-defined California urban areas only. Total number of urban census tracts is 7,799. Disadvantaged community status is based on CES scores of > 75 percent. Source: Bjorkman et al., 2015.

Management of the urban tree canopy varies widely across the state and at the local level. Usually, management of publicly accessible urban trees is the responsibility of a combination of parties, including local government, private landowners, and local nongovernmental organizations established to support the urban forest at the community or city-wide level. Utility companies play a role where trees interact with utility infrastructure, such as power, water, and communications lines. Private landowners host the urban forest in their yards and as part of landscaping.

All of these actors will need to be engaged in order to manage California's urban forests as a resilient store of carbon. Baseline planning and management decisions will occur at the local level. Local governments and organizations may need assistance in conducting inventories that assess the extent and conditions of existing urban forests and planning for maintenance and expansion. Urban forests also benefit from the

[295] Galt et al., 2014
[296] Peña, 2015

stewardship of organizations and individuals in the communities they shelter; the impacted public should therefore be involved in project planning to encourage participation in establishment and long-term stewardship. The case study in Box 9, a tree planting project undertaken by the Koreatown Youth and Community Center and CityPlants in Los Angeles, is one example of a community-based organization working together with a city and local neighborhoods to grow the urban canopy.

8.2 Carbon Stored in Urban Forests

According to Bjorkman et al. (2015), an estimated 28 MMT of C is stored in the urban forests of California, including both above- and below-ground components.[297] On an annual basis, the amount of carbon dioxide sequestered by urban forests was estimated to be almost 2 million metric tons of C per year[298]. This estimate is based on tree growth rates associated with existing statewide urban forest cover at a point in time, and does not include effects from new plantings, mortality, or removals. The amount of carbon dioxide emissions avoided was estimated to be 0.4 million metric tons of C per year, attributed to modeled reductions in building energy use.

There are a number of tools to quantify urban forest carbon storage. The USDA Forest Service urban tree carbon calculator[299] can be used to estimate carbon sequestered and stored by a tree over time, and also estimates avoided emissions. The iTree suite of tools is a joint project of the USDA Forest Service and the Davey Tree Expert Company which can be used to quantify carbon benefits and many benefits of urban forests. There are also both regulation-level carbon protocols through CARB and voluntary carbon protocols through Climate Action Reserve.

[297] Bjorkman et al., 2015

[298] This estimate was developed with significantly different methods than those that have been used on non-urban forestlands, so comparisons of carbon sequestration rates between these two gross forest types should be make with caution.

[299] https://www.fs.usda.gov/ccrc/tools/tree-carbon-calculator-ctcc

Box 9: Community Forestry – Koreatown Youth and Community Center and CityPlants

Koreatown Youth and Community Center (KYCC) provides numerous community services in the Koreatown neighborhood of Los Angeles, as well as surrounding neighborhoods. Many of these neighborhoods are located in disadvantaged communities. KYCC is a partner with CityPlants, the tree planting coordination organization of the City of Los Angeles Mayor's Office. KYCC received an Urban and Community Forestry Greenhouse Gas Reduction Fund grant from CAL FIRE in FY2014-15, and leveraged funds from the Los Angeles Department of Water and Power that are used to purchase and grow trees. These trees are then distributed to organizations like KYCC. KYCC in turn leveraged their own funding in combination with grant funding to complete transformational tree planting work in disadvantaged communities.

The grant project area is within the City of Los Angeles, bounded by the neighborhood of Pico-Union to the north, Arlington Boulevard to the west, Vernon Avenue to the south, and the 110 Freeway to the east. The 69 census tracts where this project is located are designated as disadvantaged communities by CalEPA using CalEnviroScreen[300] 2.0. Communities like these bear a disproportionate burden of the effects of climate change, the urban heat island effect among them. The project both engages the communities in the project area and will address resident concerns by increasing tree canopy cover. By developing relationships and involving local communities in the process and the work, the community will have ownership of the transformative results.

By planting 1,120 trees and making needed infrastructure modifications to support growing large trees, this project will result in GHG reductions of approximately 1,900 metric tons CO_2e. In addition to the GHG reduction, the project will increase permeability and water capture potential by adding mulch to hard-packed soil and by increasing the number of trees and expanding their planting sites; conserve potable water by removing turf on medians and coordinating turf removal in yards; conserve electricity by planting hundreds of shade trees near residences thereby reducing the need for air-conditioning; reduce the heat island effect by creating a dense canopy; reduce particulate matter in residential neighborhoods by planting near-roadway trees; and add beauty and increased property values to disadvantaged communities.

[300] Office of Environmental Health Hazard Assessment, 2014

9 Benefits of Healthy Forests

Restoring degraded forests into healthy, resilient ecosystems, offers a range of quantifiable and intrinsic benefits in addition to carbon storage. [301] Environmental benefits include clean air, clean water, and wildlife habitat; and socioeconomic benefits include opportunities for recreation, tourism, and economic development through the forest management (including both urban and wildland forests) and wood products industries. Since steps to increase one benefit may at times reduce another, at times there are tradeoffs between benefits. However, there are also many positive inter-relationships between the benefits discussed here. Understanding these inter-relationships and making tradeoff choices among them is best addressed at the regional or project level. Achieving healthy and resilient forests throughout California, as described in this Plan, will increase the value of natural ecosystems to all Californians.

The Forest Carbon Plan does not independently propose targets or direct protocols for the benefits expected from the activities it recommends. Other State plans, assessments, and regulations have well-established monitoring procedures and performance targets already in place, which are not duplicated here. Those performance targets and monitoring protocols will serve as the measures of benefits to the specific goals in this Forest Carbon Plan. These plans and standards are enumerated in Chapter 5, "Measuring Progress."

Box 10 provides an example of how working at the landscape scale on the McCloud River watershed can help to provide forest health and resilience along with a wide range of other benefits.

9.1 Sustainable Rural Economies

Rural economies benefit from healthy forests and the employment and economic activity generated by tourism, forest health treatments, and sustainable commercial timber harvest. Wood products and outdoor recreation industries can both contribute significantly to the economic wellbeing of rural communities. Outdoor recreation generates significant local and regional income, creating over 691,000 direct jobs throughout the state.[302] In 2012, California's wood products industry direct employment was approximately 52,200 workers, with more than $303 billion earned annually through the primary and secondary wood and paper products, private sector forestry and logging, and forestry support activities.[303] Spending on activities related to healthy and resilient forests contributes to training and job opportunities and earnings in these sectors, as well as the potential for local tax revenue collection on the goods and services purchased.

It is important to maintain the economic sustainability of these sectors so that land managers can afford to undertake the management actions needed to improve forest health and reduce fuels. While some forest management activities may pay for themselves through wood products production and other existing revenue streams, most of the restoration activities needed on National Forest System Lands, other public lands, and small private land ownerships will require investment. Sustainable forest product and service industries within a given region present opportunities to supplement public and other investments.

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[301] Region 5 USDA Forest Service has recently produced a series of infographics, called "Nature's Benefits," that document the environmental and economic values of National Forest System lands in California: https://www.fs.usda.gov/detail/r5/landmanagement/?cid=FSEPRD535860. They address air, recreation, water, energy, and local economies.

[302] Outdoor Industry Association, 2017

[303] McIver et al, 2015.

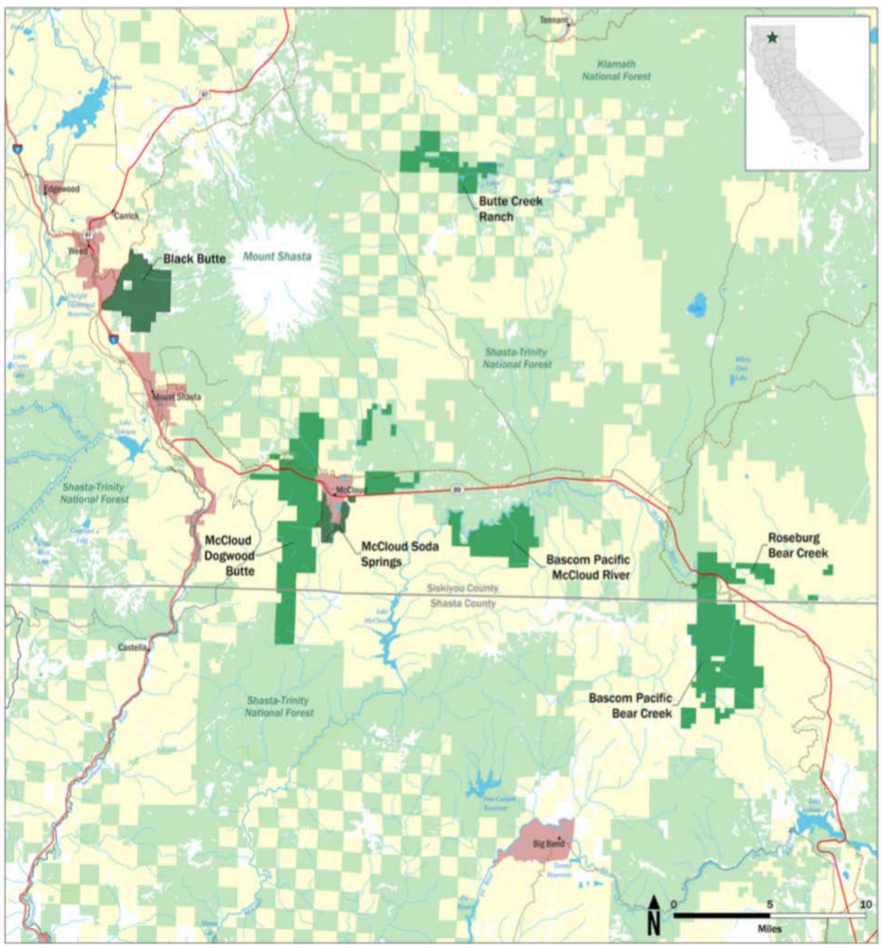
Box 10: Integrating Conservation and Improved Forest Management in the McCloud Watershed.

Courtesy of the Pacific Forest Trust

The vast forested arc of mountains that encircle California's northern Central Valley holds enormous carbon stores, globally important biodiversity, and serves as the water fountain for the state. This roughly 10-million-acre region provides an outstanding opportunity to safeguard and improve the watersheds feeding California's most important reservoirs, provide for wildlife adaptation at a landscape scale, and restore larger, more resilient stores of carbon, while also reducing the risk of catastrophic fire. With roughly a fifty-fifty public and private ownership, this region at the intersection of Northern Sierra, Southern Cascade, and Klamath mountains can provide a living and enduring demonstration of cooperative management across federal and well-managed private lands.

Employing a suite of restoration management approaches, these forests could transform from relatively homogeneous, often crowded younger forests to older, more natural forests with a mix of species and age classes that are more fire and stress resistant and resilient. Thinnings and controlled burns and managing for older, more stress resistant stands are key management strategies. Such restoration is particularly important for many public forests. Equally, with larger private ownerships, there is the opportunity to conserve well-managed private forests to ensure a cohesive and functional watershed for the future, avoiding a patchwork of fragmented and degraded forest holdings.

Mt. Shasta Headwaters Conservation Area



An example of this approach is in the McCloud watershed. In 2016, the Hancock Timber Resource Group worked with the Pacific Forest Trust to conserve 20 square miles of well-managed private forest, creating permanent connectivity between 2.15 million acres of public lands. Conducted in cooperation with Department of Fish and Wildlife and the Wildlife Conservation Board and state and private funding, this contributes to California's climate adaptation goals. It will double the carbon stocks on this forest over 50 years, removing 1.8 million metric tons of CO_2e from the atmosphere, equivalent to the annual emissions of 380,000 cars, while maintaining continuous management and timber flows. The project benefits many imperiled species that rely on this crucial habitat while expanding access for recreational uses. It conserves over 30 miles of streams and creeks as well as 74 springs, providing critical cold water to the McCloud River, a key water source for the state.

This management approach melds restoration with collaboration across public and private ownerships. Implemented over the larger landscape, such approaches will benefit all Californians in multiple ways, from safely reducing excess carbon dioxide to promoting adaptation to revitalizing rural economies and safeguarding the state's water supplies.

9.1.1 Outdoor Recreation and Tourism

The variety of recreational opportunities in California forests attracts both in- and out-of-state tourists. From wilderness excursions, hunting and fishing, rock climbing, and snow sports to motorized and non-motorized activities, recreation opportunities contribute significantly to the economies of rural communities. The outdoor recreation sector alone is a vital contributor to the state's tourism industry sector, generating $92 billion in direct travel spending, $30.4 billion in wages and salaries, and $6.2 billion in state and local taxes.[304,305] Visitors to National Forest System lands in California number over 24 million annually, deriving $2 billion in value, and contributing over $700 million to local economies with over 18,000 jobs.[306] These economic contributions, resulting from visitor spending, include service-based jobs and earnings as well as sales and lodging tax revenues that are critical in supporting local public services. Recreation and tourism benefits are important factors that drive public support for forest conservation efforts: one of the strongest predictive factors that determine public support of diverse forest projects is whether the project is perceived to improve access to recreational opportunities.[307] Recreation and tourism also provide opportunities to interact with family and friends, one of the main reasons Californians enjoy outdoor recreation.[308] These social interactions can strengthen relationships among people as well as between people and place.

Human health can also be enhanced through recreation opportunities that allow California's citizens greater access to and activity options within the outdoors. This increased access can improve public health conditions and provides significant mental health benefits. Additionally, at least 56 percent of Californians participate in one or more outdoor recreation activities, with many of these activities taking place in the state's forests,[309]contributing greatly to Californians' quality of life.

Uncharacteristically large and severe wildfires can, likewise, negatively affect access to and support for outdoor recreation. Forests impacted by high severity events, such as wildfire, storms, or insect outbreaks, can be dangerous for recreation as falling trees are a hazard. These conditions can close trails and campgrounds for extended periods, especially when funding is not available to immediately respond to these conditions. Smoke impacts on recreational activities were common during the King Fire in 2014, with an Ironman Triathlon in the Lake Tahoe area canceled due to health concerns.[310] More research needs to be done on how megafires impact tourist decisions, both to specific areas near the fire and the state as a whole.

9.1.2 Wood Products and Biomass Industries

Wood products manufacturing and various biomass utilization pathways contribute to local and regional economies by creating jobs and generating revenue through forest management and restoration activities; commercial harvesting; product manufacturing and energy or fuels production and related support businesses (e.g., sales and marketing); and transportation and shipping. Sustainable industries support stable land ownership, which underpins the entire forest economy, and broader economic activity in a

[304] Outdoor Industry Association, 2017
[305] Visit California, 2016
[306] USDA Forest Service National Visitor Use Monitoring Program (https://www.fs.fed.us/recreation/programs/nvum/); Rosenberger et al., 2017
[307] Barrio & Loureiro, 2010
[308] Roberts et al., 2009
[309] Outdoor Industry Association, 2017
[310] Ironman.com, 2014.

region. More detailed information on wood products and biomass markets can be found in Section 10, "Forest Materials Utilization Pathways."

9.2 Non-Timber Forest Products

Non-timber forest products (NTFP) have a high importance to a range of stakeholder groups but their collection is less understood and documented than traditional timber products. NTFP collected in California include bark, berries, boughs, bulbs, grasses, Christmas trees, cones, ferns, fungi (mushrooms), mosses, nuts, roots, seeds, fuelwood, transplants, insects, and wildflowers. These products are highly valued for their "medicinal properties, decorative uses, native propagations, landscaping, family or tribal tradition, or for ceremonial purposes."[311] Native Americans and tribes in California have a particular depth and breadth of knowledge about NTFP. Like other indigenous people, they have been collecting NTFP for centuries and continue to collect them as part of traditional practices for material and cultural survival.[312] Some NTFP are also collected by a wider group of stakeholders for recreational purposes and commercial sale.

9.3 Forest-Related Emissions and Public Health

In addition to sequestering carbon dioxide, trees can remove airborne pollutants such as ozone, nitrogen dioxide, and particulate matter via uptake by leaf and needle surfaces. Forests can also be a source of air pollution resulting from wildfire or open pile burning of biomass. Forest management and biomass utilization can play important roles in the air quality benefits of forests: by treating forests to reduce the potential for severe wildfires, and using the waste products from the forest in a productive way, there is the opportunity to reduce wildfire and wood-waste-burning emissions that have impacts on both human health and the climate.[313] However, utilization of forest biomass for energy production also has to take into account the air pollutant emissions from biomass power plants and potential impacts of those emissions on human health. This is especially the case when those facilities are in urban areas that are distant from the forest already have high air pollution burdens.

Studies suggest stand-replacing forest fires are increasing in frequency and extent and climate change will likely exacerbate the situation by leading to increases in wildfire size and severity.[314, 315, 316] While treatments that involve the use of prescribed fire can result in similar emissions constituents, the scale of those emissions is much smaller compared to a wildfire.[317] In addition, such activities are regulated based on local favorable atmospheric conditions and managed to minimize air quality impacts.[318] Prescribed fires are timed to occur when impacts on the region will be minimal and during periods when air quality is good. Megafires, on the other hand, tend to occur during months when air quality is already bad, exacerbating the situation with little control of the duration of the impacts. Reviewing public policy and wildfire emissions of recent megafires, Schweizer and Cisneros concluded that "policy makers need to question the path of full suppression and ask the question—is fire suppression the most appropriate way to protect air

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[311] USDA Forest Service, 2016e
[312] Emery and Pierce, 2005
[313] Stephens et al., 2009
[314] Westerling et al., 2006
[315] Miller & Safford, 2009
[316] Garfin et al., 2013
[317] The findings of a recent study by Liu et al. (2017) suggest that the measured particulate matter emission factor from wildfires is "substantially larger than that from prescribed fires, which may reflect different fire behavior and fuel conditions between prescribed fires and wildfires." (p. 18).
[318] Wiedinmyer & Hurteau, 2010

quality or just the easiest way for us today to handle a difficult decision while we mortgage the health of future generations?”[319]

With wildfire comes smoke, which contains black carbon and other climate pollutants including nitrogen oxides (NO_x), a precursor to ozone. Black carbon is a very small particle ($PM_{2.5}$) that is formed with incomplete combustion and is characteristic of wildfires. Black carbon represents a public health risk for cardiovascular and respiratory disease, as well as cancer and, potentially, birth defects.[320]

While a number of external factors affects how and what type of smoke is formed, where it goes, and how long humans are exposed to it, research is clear that wildfire smoke and all of its constituents are unhealthy for humans.[321,322,323] Managing forests and watersheds for greater health and resilience reduces the risk for large scale, destructive fire. This risk reduction, in turn, will reduce human exposure to wildfire smoke on the intense and extended timescales experienced in the last ten years, improving public health in the immediate fire area as well as populations affected for the many hundreds of miles that wildfire smoke can travel.[324]

The health impacts of air pollution are likely to be modified by climate change, due mainly to the exposure of populations to increased levels of air pollutants and the enhanced pollutant emission and production rates in a warmer climate: climate change is projected to increase cardiovascular and respiratory morbidity and mortality associated with ground-level ozone.[325,326] Most California residents are currently exposed to levels at or above the current State ozone standard during some parts of the year. Exposure to ozone has been shown to be associated with decreased lung function, respiratory symptoms, hospitalizations for cardiopulmonary causes, emergency room visits for asthma, and premature death.[327] At higher daily concentrations, ozone increases asthma attacks, hospital admissions, daily mortality, and days of restricted activity and school absences.[328]

The mobilization of historic pollutant loads is another danger from forest fires. For much of the 20th century, automobiles used a lead additive in fuel to reduce engine problems. Over 4.5 MMT of lead additives were used in California alone.[329] As a result of this application, soils around urban areas and within urban airsheds saw significant increases in lead concentrations in excess of the background levels, some of which was transported into the vegetation and ultimately soils throughout the airshed. Soil contamination is persistent and continues to contaminate vegetation, due to continual uptake of nutrients and water.

When forests growing in contaminated soils burn, as occurred in the Williams Fire of 2012 near Los Angeles, they can release toxins that have accumulated in the soil to the atmosphere: lead, zinc, nickel, and copper, among others, can be re-emitted to the air in the smoke plume.[330] These containments

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[319] Schweizer & Cisneros, 2016
[320] U.S. Environmental Protection Agency, 2016
[321] Reisen et al., 2015
[322] Liu et al., 2016
[323] Delfino et al., 2009
[324] Liu et al., 2016
[325] Sujaritpong et al., 2013
[326] Confalonieri et al., 2007
[327] Drechsler et al., 2005
[328] Committee on Estimating Mortality Risk Reduction Benefits from Decreasing Tropospheric Ozone Exposure, 2008
[329] Odigie & Flegal, 2014
[330] Odigie & Flegal, 2014

become constituents of smoke and ash that spreads downwind of the fire site. Water sampling in recently burned watersheds in southern California in the 2000s found a more than 100-fold increase in copper, lead, and zinc contaminants in the water compared with nearby unburned basins.[331] More research needs to be done to identify forests near urban areas with increased contaminant loads, and appropriate treatment methods need to be identified to ensure that management activities—or uncontrolled wildfire—do not affect and remobilize the contaminants.

9.4 Water Quality, Timing, and Yield

As described in the California Water Action Plan, investments in forest health in headwaters help provide high-quality water downstream.[332] At least 60 percent of California's developed water supply comes from forested watersheds in the Sierra Nevada.[333] National Forest Land watersheds yield 50 percent of the state's water supply.[334] The USDA Forest Service Strategic Plan: FY2015-2020 recognizes that a strategic objective of the agency is to provide abundant clean water and maintain watersheds in good condition.[335] The California Department of Water Resources also highlights the nexus between forest management and water resources in its California Water Plan Update 2013 Forest Management Resource Management Strategy.[336] Healthy forested ecosystems can improve the quality and supply of these water resources, and contribute to resilience by regulating the timing of spring melt. The forested lands of California are of significant value to both California and the nation as a whole, as exemplified by the designation of the California Headwaters Partnership Region as one of seven Resilient Lands and Waters regions in the United States; see Box 11.

High sediment loads, conveyed during the high-flow events common in California's precipitation regime, typically occur for a number of years after large, high-severity fires. This sediment and debris can reduce reservoir capacity, increase water turbidity, interfere with other critical infrastructure, and negatively affect aquatic habitat. Post-fire reforestation and restoration can improve watershed health and benefit water resources. Forest management efforts help to reduce the need to remove silt and debris from reservoirs and recharge basins, make more space for water supply storage and hydropower generation capacity, and increase the economic value of these activities.

High severity fires can expose snowpack to direct sunlight, shifting melt times to earlier in the spring when the water flowing downstream is less able to be captured. This exposure can persist for decades, until forests regrow. Forest management actions have been shown to increase snowpack accumulation and retention over previously burned over, unhealthy, as well as overgrown forests.[337]

Timing of flows is also tied to the feasibility of hydropower production. Severe wildfires such as the Rim and King Fires resulted in significant reservoir impairment downstream, through erosion and resulting sedimentation in watercourses, affecting both reservoir capacity and water quality for hydropower production. Through timing and mandated reservoir curves informing operational actions, there may be more or less water available for hydropower production during the height of need, California's summer.

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[331] Stein et al., 2012
[332] California Natural Resources Agency, 2016a
[333] Sierra Nevada Conservancy, 2014
[334] Brown et al., 2016
[335] USDA Forest Service, 2015b
[336] California Department of Water Resources, 2013
[337] Sankey et al., 2015

Box 11: Sierra Nevada Watershed Improvement Program.

Courtesy of the Sierra Nevada Conservancy

Sierra Nevada forests and watersheds are at a crucial point. A four-year drought, a century of fire suppression, widespread tree mortality due to insect attacks and disease, and a changing climate have led to an increased risk of large, damaging wildfires. The Sierra Nevada Watershed Improvement Program (WIP) is a coordinated, integrated, collaborative program to restore the health of California's primary watersheds through increased investment and needed policy changes.

The Sierra Nevada Conservancy and the U.S. Forest Service, Pacific Southwest Region are the primary coordinators of the Sierra Nevada Watershed Improvement Program, but given the scope and scale of this program, the WIP is heavily reliant on the active engagement and participation of many other partners. A Memorandum of Understanding between the California Natural Resources Agency and the U.S. Forest Service Pacific Southwest Region has been signed, committing to ongoing, high-level support of the WIP. In addition, the Sierra Nevada WIP has been endorsed by a diverse group of organizations, as well as state and federal agencies. This recognition includes the WIP's identification as an important element for implementing the Forest-Service-initiated California Headwaters Partnership.

These program goals are:

Increasing Investment: The current level of state, federal, local, and private investment in our forested watersheds is inadequate to meet the need. The consequences of overgrown, unhealthy forests result in far greater outlays than the costs than the restoration work needed. These outlays come in the form of fire suppression, losses of property and infrastructure, other socio-economic costs, and environmental impacts. Opportunities to establish more reliable funding sources for restoration in the Sierra exist, but we need coordination among federal, state, and local agencies and private partners. Potential funding sources include State Funding, Federal Funding, and Private or Beneficiaries-Pay Funding, such as social bonds, or "pay for success" financing; valuing ecosystem services; end user water fees (public goods charge); and private and foundation investment targeted at ecological outcomes.

Addressing Policy-Related Barriers: Several policy-related barriers need to be addressed in order to restore our forests and watersheds to a healthier state.

Increasing Infrastructure: The lack of wood and biomass processing infrastructure in the Sierra Nevada is a significant impediment to forest restoration efforts. We must enhance the Sierra's forest-related infrastructure if it is to handle the pace and scale of needed restoration. Infrastructure projects are integral to the Watershed Improvement Program because they utilize biomass to provide energy and reduce fire risk. They also help improve local socio-economic conditions.

To learn more about the Sierra Nevada Watershed Improvement Program, and to access resources such as the Watershed Information Network, visit www.restorethesierra.org.

From a quantity perspective, it is possible to manage forests to increase the annual average amount of water they deliver, although measuring this can be challenging. The Nature Conservancy conducted a meta-analysis of 150 existing studies on forest management and water supply and analyzed the impacts on potential water yield of a number of diverse forest management strategies. The analysis found possible returns of between zero and six percent in overall potential yield.[338] Recent research conducted as part of the Sierra Nevada Adaptive Management Project carried out water quantity measurements and modeling to examine how forest fuel treatments and fires affected water flows.[339] On one site in this study, researchers found that found that implementation of "strategically placed landscape treatments" creating an 8 percent reduction in vegetation resulted in a runoff increase of at least 12 percent for the first 20 years, eventually decreasing to 9.8 percent by year 30, compared to a no-treatment scenario. A second site in the study, where precipitation rates were lower, had a substantially lower runoff increase of 3 percent at 30 years. Another study, located in Arizona examined the snow retention rate of a number of locations under a variety of treatments. Treated sites resulted in greater snow accumulation, as well as longer snowpack persistence into the spring. While the effects of forest management on water supply requires additional research in California, it is a promising co-benefit for managing California's forests as carbon sinks.

9.5 Wildlife Habitat

California forests are a biological hotspot of wildlife diversity. Climate, geology, and ecological processes (fire, water, nutrient cycles, etc.) combine to create habitats and connectivity corridors that support the abundance of high biodiversity and endemism found in the state. The threats to forestlands discussed in this Plan can also impact wildlife and their habitat, as can certain management practices that lead to the reduction of habitat diversity and the simplification of forest structure. The key to long-term preservation of wildlife is the conservation, improvement, reestablishment, and management of their habitats.[340] Active forest management can restore forests so that they are more representative of a diverse, native, fire-dependent ecosystem. While active management will not touch every acre of forestland in California, management should be implemented in a manner that supports ecological function of unmanaged areas, including designated wilderness, and vice-versa.

In the absence of fire over the past 100 years, many forests in California have transitioned away from historically prevalent plant species mixes and towards species that thrive in shady, dense conditions that are characteristic of a fire-suppressed landscape. This has negatively affected the availability of some habitats. Restoration activities should be implemented in a way that protects crucial habitat types and elements for a range of species, including sensitive and listed species. Land managers should pursue best practices that balance the need to thin forests while protecting wildlife habitat including implementing treatments outside of the breeding season, retaining large snags that do not pose threats to public safety or significantly conflict with management goals, and promoting the retention of a diverse set of native trees.[341] Treatments also need to minimize the risk of introducing exotic invasive species or providing opportunities for their spread.

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[338] Podolak et al., 2015
[339] Conklin et al., 2015
[340] California Department of Forestry and Fire Protection, 2010
[341] Jones et al., 2016

Large areas of high severity wildfire, out of character with historic patterns, pose a threat to the state's treasured biodiversity. Recent research[342] has found that the California Spotted Owl (*Strix occidentalis occidentalis*), a California bird species of special concern, is extirpated from sites experiencing uncharacteristically high severity fire. Additionally, after the King Fire, these owls avoided the high severity burn areas when foraging as well, instead foraging on the fringes of the high severity burn where burn severity was more moderate and in line with historic burn patterns.[343] This finding should inform future forest management in accounting for the needs of California's sensitive, threatened, and endangered species. Jones et al. (2016) stated "increasing frequent megafires pose a threat to spotted owls and likely other old-forest species and, as a result, suggests that forest ecosystem restoration and old-forest species conservation may be more compatible than previously believed." In contrast, post-fire extinction rates in areas of low severity burning –which would be characteristic of prescribed fire – was estimated to be zero.[344, 345] These conclusions, while drawn from a single study, coincide with other research that has been completed, including projections that all high-quality owl habitat will be lost to severe wildfire within 75 years if the present fire pattern is continued.[346]

There are no treatment activities on a significant number of federally managed acres that host sensitive, threatened, and endangered species because of current federal management objectives and federal and state regulatory and permitting processes. While some of these lands could be treated from an ecological and legal perspective, the cost of doing so, in both time and financial resources, tends to be prohibitive. Management is not prohibited by regulatory mandate, but rather results from insufficient budgets or a preference on the part of managers to avoid potential negative effects or legal challenges. Absence of management on these lands means foregoing many of the benefits treatment could provide, and potentially unintentionally harming some of the resources regulations aim to protect. The potential loss of the California Spotted Owl described above is an example of this no-management outcome.

9.6 Historic and Cultural Resources

Because of their thousands of years of intimate ancestral, cultural, subsistence, and spiritual connections to forests and forest-associated habitats, Native Americans and tribes are discussed separately here. While tribes realize all the same benefits from forests that others do, they stand to be impacted in different ways by changes to forests. As with many other indigenous people, the way Native Americans and tribes perceive and categorize the benefits from forests can be distinct from the conventional Western categories of ecosystem services. Traditional activities related to subsistence, such as hunting, fishing, trapping, gathering berries and fibers for basketry, are seen not as employment or recreation, but primarily as activities that perpetuate family and cultural traditions and knowledge, provide physical and cultural sustenance for families, and support an ongoing spiritual connection to the land and its resources.[347, 348, 349, 350] These intrinsic and intangible values are not widely understood by outside groups, nor can they be quantified.

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342 Jones et al., 2016
343 Jones et al., 2016
344 Lee et al., 2012
345 Roberts, 2011
346 Stephens et al., 2016
347 Anderson & Moratto, 1996
348 Kimmerer & Lake, 2001
349 McAvoy et al., 2004
350 U.S. Department of Agriculture, 2014

While a wide range of people value California forests for non-timber forest products (NTFP), the relationships Native Americans and tribes have with these resources is closely tied to their psycho-social-spiritual, cultural, and physical well-being. This is reflected in their vast knowledge of plants and their uses. As one example, an ethnobotanical study from the 1920s – 1930s documented the knowledge of Costanoan Indians of central California. This included 157 plants and their uses: 63 for food, 101 for medicinal preparations and 48 were used in other ways as raw materials, such as for fuel, cordage, construction materials and containers, clothing, tools and musical instruments. Other plant uses might include applications as detergents, cosmetics and dyes, poisons, insecticides and hallucinogens.[351] Due to socioecological change over time, ethnobotanical knowledge may have declined but the practices and relationships to natural cultural resources continue to evolve, adapt, and perpetuate values and culture. The loss of access to NTFP, and perhaps especially traditional foods (e.g., acorns) and their habitats, can affect more than diets: it can threaten the associated knowledge and identities embedded in stories, ceremonies, songs, and the community processes of collecting, preparing, and sharing foods.[352, 353]

Examples of fire-associated plants valued highly by Native Americans and tribes:

- willows (*Salix* L. sp.),
- Indian hemp (*Apocynum* L.),
- milkweed (Asclepias L.),
- skunkbush sumac (*Rhus trilobata* Nutt.),
- sedges (*Carex* L.),
- deergrass (*Muhlenbergia rigens* (Benth.) Hitchc.),
- California redbud (*Cercis orbiculata* Greene),
- Pacific dogwood (*Cornus nuttallii* Audubon ex Torr. & A. Gray),
- beargrass (*Xerophyllum tenax* (Pursh) Nutt.);
- California black oak (*Quercus kelloggii* Newberry),
- beaked hazelnut (*Corylus cornuta* Marshall),
- elderberry (*Sambucus* L.),
- woodland strawberry (*Fragaria vesca* L.),
- blueberry (*Vaccinium* L.);
- snake lily (*Dichelostemma* Kunth),
- mariposa lily (*Calochortus* Pursh),
- camas (*Camassia* Lindl.),
- wild tobacco (*Nicotiana* L.),

(Anderson 1994, 1999, 2006a).

(Taken directly from Lake and Long 2014: 176)

In the past, Native Americans and tribes used fire as a tool for managing access to healthy habitats and populations of valuable species (see sidebar). The absence of fire, or non-traditional applications of fire (such as uncharacteristically severe fire) poses a threat to cultural resources and traditional cultural knowledge and lifeways.[354, 355] Beyond culturally important plants and animals, wildfire also threatens Native American and tribal homes, safety, economies, and cultural sites. It is important to note that sacred sites and heritage sites in forests are a critical aspect of living culture that is not just frozen in times past as archaeological sites, they are elements of cultural practices today. More information on the history of fire can be found in Section 2.3.

In addition to preserving traditional cultural resources and practices, responsible forest management helps some of California's Native American Tribes today. (Box 12) A growing number of examples exist that make use of these peoples' legacy knowledge of and connection with their lands to shape forests into resilient,

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[351] Bocek, 1984
[352] Nabhan, 2010
[353] Vinyeta & Lynn, 2013
[354] Karuk Tribe Department of Natural Resources, 2010
[355] Lake & Long, 2014

Box 12. Tribal Forestry – Maidu Summit Consortium at Tásmam Kojóm (or Humbug Valley).

Courtesy of the Maidu Summit Consortium

Tribal non-profit stewards large restorative forest landscape, by way of a unique and exciting new management scenario.

In the increasingly threatened mixed-conifer forests of Plumas County, along the picturesque high-montane meadow that most Californians now call Humbug Valley, an important and monumental restoration project is well underway. After a land grant recommendation by Pacific Forest and Watershed Lands Stewardship Council was made in 2013, the Maidu Summit Consortium (MSC) is now poised to reclaim this culturally and spiritually significant site, so that it may be restored.

Tásmam Kojóm will be carefully managed based upon the Maidu cultural and philosophic perspectives as expressed through traditional ecology. Tásmam Kojóm is an important place for demonstrating how Maidu traditional ecology and contemporary ecological science can be woven together for the benefit of the land. It also is essential to the perpetuation of the unique culture from which our traditional ecology was derived.

For our basic survival, our People knew of the complexity and importance of maintaining resilient and productive forests. Until not so long ago, our daily lives included the human workings required of the active stewardship of healthy and balanced forest communities, the very means of our existence. When it comes to conservation of natural resources, this work held meaning near and far when considering the extent and distribution of Tribal People across what is now the State of California.

Long-term, large landscape-level projects such as ours will demonstrate how much potential California forests hold for producing more of the highest-quality fresh water found here, critical evermore to the survival of modern people living elsewhere in our state. We also feel that slowing the devastating effects of air pollution is done by better managing forest growth cycling and transpiration over much longer periods of time. Smart forest carbon planning is our path forward.

It is also extremely important to note the rural development investment potential work like ours provides to economically stressed communities in the Sierra.

MSC have contracted with Ascent Environmental to help guide ongoing planning work, which is presently supported by the Stewardship Council, Sierra Nevada Conservancy, and the Lannan Foundation. The California Department of Fish and Wildlife also will be partners in co-managing certain aspects of the project.

Learn more at: http://www.maidusummit.org/current-projects.html carbon-capturing landscapes. In many cases, Tribes have legal and financial resources additive to conventional landscape management agencies', and their participation can create synergies in application, permitting, and financing forest management activities. In return, participating Tribes have the opportunity to work on and, in some cases, manage landscapes to which they have historic and pre-historic ties. This connection can increase tribal financial, organizational, and institutional capacity, giving these entities some of the essential tools for operating as a sovereign nation within the most populous and ecologically diverse state in the nation.

9.7 Reduced Long-term Costs for Fire Suppression[356]

The federal Resources Planning Act Assessment[357] estimates that forests in the western states, including California, are likely to be increasingly affected by large, intense fires that are the result of complex interactions between past management practices and changing climate. Unhealthy forests in the low- to middle elevations are overly dense and homogenous with large amounts of down woody fuels, and are more prone to large intense wildfires.[358] These conditions pose higher risks and costs for access and firefighting activities. In addition, large, intense, wildfires in forests not adapted to them can lead to long-term change, including vegetation type conversion, more frequent fire return intervals, and ultimately higher fire suppression costs. Despite these changes, wildfire suppression in the US remains highly effective at putting out fires, with nearly 98 percent of all ignitions suppressed before reaching 300 acres.[359]

For low- and mid-elevation forests in California, health and resilience implies restoration of conditions (lower stem densities, larger and more fire-resistant trees, reduced fuel loads) that support a reduction in the propensity for highly damaging and costly wildfires and other disturbance events such as drought and insects. Activities aimed at improving resilience in these forests are often centered around reduction of hazardous fuels and modification of degraded stand structure.[360, 361] Forest management policies on various scales have highlighted the importance of these activities,[362] but, as discussed earlier, the pace and scale of implementation has lagged far behind need, owing to societal and organizational barriers and disincentives.[363, 364]

Between 1985 and 1999, the annual cost for federal firefighting exceeded $600 million only twice. Between 2012 and 2015, federal agencies spent no less than $1.6 billion each year on firefighting. In 2015, costs surpassed $2 billion for the first time.[365] The USDA Forest Service, which accounts for about 70 percent of these federal costs, spent 16 percent of its 1995 appropriated budget on firefighting; in 2015, firefighting accounted for more than 50 percent.[366] Fire suppression increasingly has come at the expense

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[356] Note that the 2010 Strategic Fire Plan for California (http://bofdata.fire.ca.gov/hot_topics_resources/fireplanrevison_final_04_06_16.pdf) provides important direction from CAL FIRE and the Board of Forestry and Fire Protection on how the state approaches all facets of fire protection. This plan is currently under revision, with completion anticipated in mid-2018.
[357] USDA Forest Service, 2016f
[358] Stephens et al., 2016
[359] Calkin et al., 2005
[360] Hessburg et al., 2015
[361] North et al., 2009
[362] NCWFMS, 2014
[363] North et al., 2015b
[364] Calkin et al., 2015
[365] National Interagency Fire Center, 2015
[366] U.S. Department of Agriculture, 2015

of many other programs, including fuel and vegetation management and forest restoration that could help prevent severe fires from occurring.

While fire suppression will continue to be vitally important in protecting lives, property, and other assets at risk, continued exclusion of fire from California's dry fire-adapted forests without commensurate restoration and fuel reduction will result in continued buildup of fuels and conditions which support more damaging fire that is difficult and costly to control. In a self-reinforcing fashion, more damaging wildfire can promote more risk aversion and discounting of long-term benefits of restoration.[367] Mitigation of this feedback loop can reduce suppression costs in the long-term.[368] Restoring California's forests to a condition less prone to severe fire will be more cost effective over time, but it will require a long-term perspective, commitment, and significant structural changes in wildland fire and vegetation management.

Various frameworks have been proposed for this type of restructuring and re-focusing on resilience, and a "one size fits all" approach will not work, given the complexities and barriers in different regions, communities and forests.[369, 370, 371] As an element of fire and forest management, land use planning will need to take a central role. In California alone, there are 2.2 million housing units within the Wildland Urban Interface (WUI), 83 percent of which are in dense Interface, and 17 percent of which are in more sparsely populated Intermix.[372] Restoration treatments in the WUI may require more intensive fuel treatments and focus on home ignition zones. In non-reserve forests, achieving health and resilience may require road networks for access to conduct management and restoration activities such as thinning and prescribed burning, which will also improve fire suppression access. In more remote areas, naturally ignited or prescribed fire may be used under moderate weather conditions to reduce fuels loads and restore forest structure. In this type of framework, fires can be suppressed and managed at lower size and intensity, thus not only lowering fire suppression costs but also improving forest health and resilience.

[367] Calkin et al., 2015
[368] Collins et al., 2013
[369] North et al., 2015b
[370] Stephens et al., 2016
[371] Calkin et al., 2015
[372] FRAP, 2016

10 Forest Materials Utilization Pathways

California is a major producer of timber, while at the same time importing the majority of its wood for consumption from other states and countries. Thus, there is a significant opportunity to build on current production capacity and know-how to increase in-state production of wood products through sawlogs, small diameter trees, and other woody materials supplied from sustainably managed working public and private forests, which are an important part of the implementation strategy for the Forest Carbon Plan. Understanding the implications of wood products production and consumption, including the sustainable management of our forests to produce raw materials for these products, will be an essential component of determining overall strategies needed to achieve the State's climate change objectives.

Wood products, bioenergy, and biofuels markets are linked to the health of California's forests and statewide climate goals in two ways: as revenue-generating mechanisms to finance forest management and restoration activities, and as biomass utilization pathways that can reduce net greenhouse gas (GHG) and black carbon emissions associated with land management, the occurrence of catastrophic wildfires, and emissions from the electricity and transportation sectors. State engagement on research, development, and deployment of technologies that are aligned with climate goals can result in reduced net emissions across the forest, electricity, and transportation sectors. The need for both forest management and lower-emission and carbon-sequestering biomass utilization will grow as the state, along with federal land managers and private landowner partners, acts to achieve the forest management and restoration goals laid out in this Forest Carbon Plan and the 2017 Climate Change Scoping Plan. The need for increased forest management and the associated wood processing and biomass utilization infrastructure exists in nearly every forest-dependent region of the state.

California sawmills produced almost seven percent of the softwood lumber produced in the United States and about five percent of total U.S. consumption in 2012. At the same time, approximately 80 percent of the lumber and 90 percent of all wood products (lumber as well as plywood and veneer, pulp products, and industrial products) used in California are imported from out-of-state.[373] More than half of all timber harvested in California originates in five counties, led by Shasta (16 percent of 2012 state total) and Humboldt (15.1 percent). Nearly all of the timber harvested in California is processed in-state, and a 2003 study found that 62.5% of lumber produced in California is used in-state.[374] Approximately 52,200 workers, earning more than $3.3 billion annually, were employed in the primary and secondary forest products industry in California in 2012.[375] The 298 million board feet of timber cut from California's National Forests in federal fiscal year 2017 sold for $12,922,628, an equivalent of $40,095,647 in lumber value of manufactured wood products.[376]

These statistics indicate that California imports the vast majority of wood used in-state, and that California has a significant, although concentrated, timber harvest and wood products manufacturing industry. The deficit of lumber produced in-state, when viewed alongside the contraction and concentration of the timber industry over the past three decades, suggests there is room for growth of in-state production of lumber and other wood products. California sawmill capacity fell approximately 70 percent between the late 1980s and 2012. This decline is attributed to the interplay of several factors: an insufficient number of

[373] Battles et al., 2013
[374] McIver et al., 2015; Laaksonen et. al., 2003
[375] McIver et al., 2015
[376] Personal communication, Jason Ko, Ecosystem Services Program Manager, Pacific Southwest Region, USDA Forest Service, Vallejo, CA. December 13, 2017.

mills, a reduction in timber harvesting, reduced availability of timber in areas that experienced high levels of harvest over a short period, high transportation costs that make long-distance transport of raw logs cost prohibitive, the automation of wood processing and increases in efficiencies, and price volatility that has impacted the sector as a whole. There are approximately 77 wood products processing facilities in California currently, down from 262 in 1968. Total employment in California's primary and secondary forest products industry is approximately half of what it was in 1990.[377]

An interagency body was formed to make recommendations to expand wood products markets in California, pursuant to the legislative mandate in SB 859.[378] A Rural Economic Development Steering Committee was established at the Governor's Office of Planning and Research in October 2017 with the intent to pursue the recommendations laid out by this SB 859 Wood Products Working Group. The Wood Products Working Group recommended focusing on increasing demand for higher value products and promoting localized manufacturing to best serve the parts of the Sierra hardest hit by tree mortality and other regions where limited wood processing infrastructure exists. Based on the information available to the Wood Products Working Group, the recommendations focus on markets for (a) engineered mass timber and wood-based composite panel products used in building construction, retrofits, and remodeling, and (b) wood processed for use in other industries and applications, including wood cellulosic nanotechnology applications and biochar.

The following are the Working Group's recommendations, organized around three key strategies. These will be pursued through the Rural Economic Development Steering Committee and associated working groups comprised of state agencies under existing statutory authorities and resources, and partners from federal and local governments, industry, community groups, and NGOs:

- Remove state barriers and create pathways to success, with a focus on the challenges inherent in redeveloping sites, permitting both new manufacturing operations and the use of new wood materials, and gap financing to incentivize broader investment.
    - Improve process for remediation and redevelopment of former sawmill and other rural industrial sites.
    - Accelerate use of mass timber construction through outreach on building codes, use of lifecycle GHG emissions analysis for construction materials, and encouraging low-carbon building for state facilitates, where feasible.
    - Support ongoing financial assistance and assurances by creating an information clearinghouse of existing state financial resources and incentives applicable to wood products industries, and by identifying resource gaps in state and federal financial assistance programs.

- Promote innovation, with a focus on building the institutional infrastructure necessary to bring new wood products to market.
    - Support and utilize applied research and development
    - Encourage investment in new product testing
    - Promote California-grown and California-manufactured wood products
    - Strengthen partnerships between the wood products industry, rural economic development organization, and academia

[377] McIver et al., 2015; California Department of Forestry and Fire Protection, 2010
[378] California Natural Resources Agency, 2017

- Invest in human capital, with a focus on assuring that the necessary workforce is available and trained appropriately to staff new wood products operations, and that the building blocks of innovation in this sector exist in the California's public technical and higher education systems.
    - Expand accredited associate degree and certificate programs
    - Strengthen career pathways

Successful implementation of this strategy will result in economic and social benefits including development of revenue streams to fund forest health treatments partially or in full; skilled job creation in rural areas and downstream wood products manufacturing and use; and improved diversification and resilience of rural economies. Increased in-state timber production and wood products manufacturing also ensures that an increasing percentage of lumber and other wood products used in California is produced in alignment with California's high standards for environmental protection, both in the forest and during manufacturing. It also minimizes emissions from transport of wood products.

The carbon sequestration and emission reduction benefits of wood products can be multiple and varied. Diversion of material from open pile burning, the traditional method of in-field disposal, to renewable energy and fuels reduces GHG, black carbon emissions, and criteria pollutant emissions from the forestry sector and contributes to meeting the state's Renewable Portfolio Standard and Low Carbon Fuel Standard. And soil amendments such as compost and biochar can contribute material to advance the state's Healthy Soils Initiative.

Traditional lumber products and engineered wood products such as cross-laminated timber and oriented strand board can displace metals, bricks, and concrete, which have higher lifecycle GHG emissions than wood, in both low- and mid-rise building. Wood material substitutions have been shown to displace an estimated 3.9 tons CO_2e per ton of dry wood used.[379] Many engineered products can be manufactured from smaller dimensional lumber and from wood chips, which makes these products potential higher-value channels for traditionally low-value material.

10.1 Traditional and New Wood Products

The California Forest Practice Act, which governs nonfederal timber operations in California, cites carbon sequestration as "a critical and unique role" that forests play in the state's carbon balance.[380] The Act also identifies that climate change is a threat that to forests' carbon sequestration role and that it will continue to stress public and private forest ecosystems. It further states that proactive "sustainable management practices," which "include potential changes to existing forest practices and land use regulations," are important for maintaining forests' carbon-sequestration role. California's detailed timber harvest regulations seek to balance the ecological, societal, economic, and other public trust values of California forests with those of landowners. These regulations include requirements that nonfederal timber harvests meet replanting or "stocking" requirements within five years.[381]

Where forests are managed for timber production, carbon is removed in the form of harvested trees, but subsequently utilized as harvested wood products capable of storing carbon for over a century. Working forests managed for sustainable timber production can provide greater carbon storage (including long-lasting wood products) than unmanaged forests. [382] The primary products of commercial timber

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[379] Sathre & O'Connor, 2010
[380] California Public Resources Code Section 4512.5, 2010
[381] California Department of Forestry and Fire Protection, 2016e
[382] Stewart & Nakamura, 2012; Ryan et al., 2010; Lippke et al., 2008; Lippke et al. 2011; Oneil & Lippke, 2010;

operations are lumber, other wood products, and biomass energy, but a number of other products are created as the byproducts of these operations (Table 13 in Section 7.2.4.1). Based on information in McIver et al. it was estimated that, in 2012, 2.2 million metric tons of carbon was processed into energy, finished lumber, and other products in California.[383] In the reporting year, less than one percent of the products went unused. For commercial trees harvested for timber products, 47 percent of the harvested carbon ended up in finished lumber; mill residues combusted for energy comprised 29 percent. The carbon profile of wood associated with energy combustion is composed of harvest slash (73 percent), mill residues (16 percent), and bark (11 percent) (see Figure 15). How the byproducts of forest management and wood product production are managed has implications for California's overall GHG and black carbon emissions, and is discussed below.

Long-term storage in harvested wood products is an important component of the carbon sequestration strategy in this plan. While current utilization practices throughout the full wood products use cycle increases the carbon benefit, as compared with historic estimates[384], wood products do decay over time, eventually returning carbon to the atmosphere. The climate change impacts of this decomposition are dependent on the manner of disposal. In anaerobic environments (such as in landfills), the byproducts of wood decay include methane, a short-lived climate pollutant. In open air (such as in buildings), wood can last a long time, though it will decompose and slowly release carbon over its lifetime. As detailed in Section 7.2.4.3, it is estimated that 61 percent of wood product carbon would be returned to the atmosphere through decay or combustion after 100 years.[385] The ten-year carbon storage in wood products from harvesting from 2001 to 2010 ranged from 0.304 and 0.337 MMT of carbon per year in California, with the bulk of this (approximately 90 percent) coming from private forestlands.

California is the largest consumer of engineered wood products west of the Mississippi River, yet in-state production volumes are virtually zero.[386] Mass timber[387] is a growing category of wood products that has the potential to grow significantly in California and advance the State's climate change and green buildings objectives. Mass timber is more commonly used for construction in Europe and saw a dramatic increase in use as a structural element in the past decade; Canada and Oregon have recently pushed to mainstream its use in North America. As a construction material, mass timber is favored by designers for its strength, affordability, aesthetics, construction efficiency, structural performance, small carbon footprint, and ability to achieve substitute for or work alongside concrete, steel or masonry as a structural element.

The 2016 version of the California Building Standards Code,[388] which went into effect in January 2017, defines the allowable wood use in buildings and includes references to Mass Timber systems, such as the decade-old mechanically laminated decking (2304.9.3) and, more recently, cross-laminated timber (2303.1.4). Informing developers and design professionals of these recent code provisions and encouraging low-carbon building may help facilitate the increased use of mass timber, build its

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Bergman et al., 2012.

[383] McIver et al., 2015

[384] Stewart and Nakamura, 2012

[385] Stewart and Nakamura, 2012.

[386] The Beck Group, 2015

[387] Mass timber is typically characterized by the use of solid wood panels for wood, floor, and roof construction. It refers to products including cross-laminated timber, nail-laminated timber, glue-laminated timber, dowel-laminated timber, structural composite lumber, and wood-concrete composites.

[388] The 2016 Edition of the California Building Standards Code, California Code of Regulations, Title 24 (CBC) was published July 1, 2016 and has been effective statewide since January 1, 2017. It is based on based on the 2015 Edition of the International Building Code.

acceptance within the building industry, and encourage the development of mass timber manufacturing in California.

As recommended by the SB 859 Wood Products Working Group[389], the state could facilitate greater use of mass timber in construction through:

- *Building Code Outreach*
  The State could engage local and county planning offices, developers, and architects on the use of wood and mass timber in buildings by providing a targeted description of current California Building Standards Codes, particularly new elements that went into effect in 2017.

- *Encouraging Low-Carbon Building Statewide*
  The state could develop and use life cycle assessment of building materials and encourage builders and local and county planning offices to select and incentivize, respectively, those materials which have the lowest lifecycle GHG emissions and support other statewide climate change mitigation policies, as described in the 2017 Scoping Plan Update and the Forest Carbon Plan. Acceptable methods of such a whole building life cycle assessment are codified in the voluntary measures of the 2016 Green Building Standards Code (CALGreen Part 11 of Title 24) Section A5.409.

- *Encouraging Low-Carbon Building for State Facilities*
  The state could establish guidelines that encourage use of cost-effective building materials with lower lifecycle GHG emissions for new State-owned and/or state-occupied buildings.

10.2 Woody Biomass

Woody biomass generated from forest management activities can be used to produce wood products, such as landscaping materials, compost, and wood stove pellets, and is playing an increasing role in forestry. [390] Market forces tend to favor low grade, small diameter trees (eight inches to 12 inches) and wood residues that can be chipped and used as fuel or sold for uses other than saw logs.[391,392] Wood chips and smaller dimensional lumber can also be transformed into engineered products used in buildings, including tall wood buildings. However, there are significant economic barriers in that it is particularly expensive to haul heavy, moisture-rich, low-energy wood over long distances,[393,394] and the market in California for woody biomass is not yet fully developed to the point where diversification plays a role in price stability.

Biochar is another biomass-derived product, created either as a byproduct of bioenergy generation and biofuel production or as a primary product. Heating biomass in the absence of oxygen is a process called *pyrolysis,* which thermo-chemically transforms organic material into a stable char residue that resists decomposition, while also producing bio-oil and syngas that can generate renewable energy or be used as

[389] California Natural Resources Agency, 2017.
[390] O'Neill & Nuffer, 2011
[391] Evans & Finkral, 2009
[392] Barbour et al., 2008
[393] Becker et al., 2009
[394] Han et al., 2004

intermediate feedstock for biofuels.[395] The char residue is called biochar.[396,397,398] Carbon originally sequestered in the biomass will be stored for a much longer time in biochar (on the order of millennia) because it is significantly more inert than the original feedstock from which it is derived.[399,400] When biochar is put in the soil, it provides additional adaptive capacity for forests and other lands by helping soils retain moisture through increased tilth.[401] Currently, excess forest material that could be pyrolyzed is burned in open piles or left to decompose in the forest. Other wood, primarily from urban sources, undergoes anaerobic digestion in landfills in the absence of oxygen, a process that releases methane, a strong GHG. A facility must be managed specifically for the production of biochar to produce material that meets the standards and needs for its application. The Healthy Soils Initiative, led by the California Department of Food and Agriculture, will help produce, support the generation of, and develop markets for biochar as well as compost from forest biomass for use in agricultural, rangeland, municipal, and residential soil amendments.[402]

Nano-cellulose particles can be prepared from any cellulose source material, but wood pulp is normally used. This material can then be used to create plastics, food additives, antimicrobial films, lightweight body armor, and ballistic glass. This is a very early technology which does not yet have consistently viable markets.

10.3 Biomass Energy

Biomass generated from forest management activities can be used to generate electricity, heat, and transportation fuel, although there are technological and economic challenges in doing so. Renewable biomass contributes to achieving the state's Renewable Portfolio Standard and Low-Carbon Fuel Standard. Where implemented, renewable biomass can reduce the need for fossil fuels and associated GHG and criteria pollutants and support rural economies where biomass is sourced and where facilities are sited.

The emission reduction benefits of diverting biomass to bioenergy and biofuel production depend on the energy production and control technologies in place. In addition, the public health impacts of bioenergy and biofuel production are dependent on facility-level emissions of criteria pollutants, population exposure, and proximity of biomass to processing facility. For these reasons, state investments in energy technology development and deployment are focused on the next generation of low-emission bioenergy technologies and construction of facilities located close to forest biomass sources, which also will promote forest health and economic development in rural forested regions.

One recent study compared nitrogen oxides (NO_x), black carbon, carbon dioxide (CO_2), methane (CH_4), $PM_{2.5}$, and carbon monoxide (CO) emissions of biomass burned in open piles to emissions produced at an 18 MW bioenergy facility utilizing a fluidized bed boiler and efficient control technology. Inclusive of emissions associated with transportation and biomass processing, the diversion of biomass from pile burn to bioenergy facility was found to significantly reduce GHGs, black carbon, and other pollutants (see Figure 19).[403] These results suggest that diverting biomass from open pile burn to productive use in a controlled facility or other controlled use should be an intentional consideration in forest carbon policy going

[395] Weisberg et al., 2010
[396] Gaunt & Driver, 2010
[397] Lehmann, 2007
[398] Roberts et al., 2010
[399] Woolf et al., 2010
[400] Lehmann, 2007
[401] Sohi, 2009
[402] California Department of Food and Agriculture, 2016
[403] Baker et al., 2015

forward, particularly as more biomass is generated through the targeted increased forest management activities outlined in this Plan. While feasibility of fuel reduction projects may require reliance on pile burning in the near term, the California's 2017 Climate Change Scoping Plan recommends:

> Innovate biomass utilization such that harvested wood and excess agricultural and forest biomass can be used to advance statewide objectives for renewable energy and fuels, wood product manufacturing, agricultural markets, and soil health, resulting in avoided GHG emissions relative to traditional utilization pathways. Associated activities should increase the resilience of rural communities and economies.

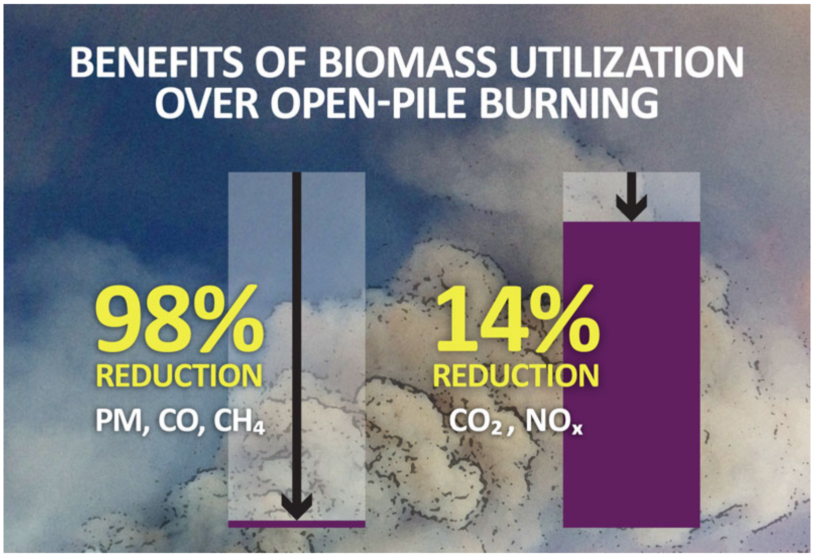

Figure 19. Emissions Comparison between Bioenergy Production and Open-Pile Burning.

Source: Baker et al., 2015. Open pile burning is still the only feasible alternative in many locations and cannot be eliminated unless or until other appropriate fuel disposal options are available.

10.3.1 Challenges for Bioenergy and Biofuel Development

Woody biomass utilization has historically played a cyclical role in California forestry over time.[404] Concerns over rising energy costs, climate change, forest health, and hazardous fuel buildups have led to executive orders and legislation that encourage the use of trees and woody plants as sources of energy. However, significant technical and economic challenges are associated with biomass utilization for bioenergy and biofuel development.

For instance, it is expensive to haul heavy, moisture-rich, low-energy-density wood over long distances.[405,406] Haul distance, along with other site-specific variables, such as forest type and condition, influence the market value for wood energy chips. Biomass projects can potentially offer net benefits to the public in scenarios where utilizing waste from commercial timber harvests will help reduce risk of

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[404] O'Neill & Nuffer, 2011
[405] Becker et al., 2009
[406] Han et al., 2004

damage to forest watershed, reduce costs of fire suppression and wildfire emissions, and/or meet other forest management objectives.[407,408,409,410]

Furthermore, several critical barriers must be addressed to allow for effective utilization of forest biomass for transportation fuels. These include: high costs of aggregating feedstocks and delivering finished biofuels from remote and inaccessible locations, and high capital costs of mature technologies. Additionally, emerging technologies for woody biomass conversion show significant promise, but will require public financial support to help mitigate perceived risks and overcome early technology development costs. These critical barriers may require targeted government funding in the near term to be solved.

10.3.2 Statutory Requirements for Forest Biomass

Markets for biomass energy in California are complex and in flux. The vast majority of California's biomass conversion facilities were built in the 1980s, when regulatory and economic conditions were more favorable. Now these plants are 25 – 30 years old and need upgrades. The number of biomass facilities producing energy in the state has diminished over time primarily due to economic factors. Facilities are shutting down or idling due to expiring power contracts. Expiring bioenergy contracts are often not renewed as bioenergy generation prices struggle to compete with cheaper wind, solar, and natural gas. To aid new biomass plants, SB 1122 (Rubio, Chapter 612, Statute of 2012) established a feed-in tariff to new bioenergy facilities that are 3 MW and less. This program, called the Biomass Market Adjusting Tariff (BioMAT) program, tasks the three largest Independently Owned Utilities (IOUs) to procure their share of 250 MW of bioenergy, with 50 MW allocated to facilities that use forest material from sustainable forest management.[411] In September 2016, Governor Brown signed AB 1923 (Wood)[412], which adjusts the BioMAT size limits to allow electric generators to have a nameplate capacity of 5 MW while maintaining the export limit to the grid of 3 MW. In addition, in 2016 the Legislature passed SB 859, which requires that investor-owned utilities and the larger local publicly owned utilities purchase their proportionate share of 125 megawatts of electricity from existing bioenergy facilities that use a specified percentage of fuel from High Hazard Zones (HHZ) in California.

Biomass energy markets are supported by the state's Renewables Portfolio Standard (RPS). California's RPS, established in 2002 under SB 1078, requires all electricity retailers in the state to procure a portion of retail sales from renewable energy sources, including biomass energy. Subsequent legislation (SB 107), an executive order (2008, Schwarzenegger) and SB X1-2 (2011, Simitian) accelerated California's RPS by establishing increasingly progressive renewable energy targets for the state's load serving entities. In October 2015, Governor Edmund G. Brown, Jr. signed into legislation SB 350, requiring both retail sellers and publicly owned utilities to increase their procurement of eligible renewable energy resources to 50% of retail sales by 2030.[413]

Facilities that generate electricity using biodiesel derived from biomass feedstock, a biomass fuel, or biomethane derived from digester gas and/or landfill gas are eligible for the RPS. Eligible feed stocks for biomass facilities certified under the RPS include, in part, "any organic material not derived from fossil

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[407] Lowell et al., 2008
[408] Mason et al., 2006
[409] Snider et al., 2006
[410] Liu, 2016
[411] California Public Utilities Commission, 2017
[412] Assembly Bill 1923, 2016
[413] California Energy Commission, 2017a

fuels, including, but not limited to, …, mill residues that result from milling lumber, rangeland maintenance residues, …, wood and wood waste from timbering operations, and any fuel that qualify as 'biomass conversion,'" as defined in Public Resources Code section 40106.[414] Currently, 35 biomass facilities in California are certified and eligible for RPS, and five biomass facilities are pre-certified with future commercial operations dates. These 40 facilities have a combined nameplate capacity of 950 MW. Of these 40 biomass facilities, 23 were operational at the end of 2016. Additionally, there are 15 biomass facilities located out of state that are certified as eligible for California's RPS and 3 more that are pre-certified. The out-of-state facilities have a combined nameplate capacity of approximately 1182 MW. Facilities that generate electricity from biomethane derived from digester gas and/or landfill gas, and meeting specific contract and delivery requirements, are also eligible for the RPS but are not reflected in the above numbers.

In addition, California's Low Carbon Fuel Standard (LCFS), administered by ARB, provides a strong and long-term incentive for low-carbon fuels, including those derived from forest biomass. Recent research (see Box 13) indicates that the value of available carbon credits can help to support profitable forest biomass conversion to low carbon biofuels.

Strong policies are critical to fostering development of biomass markets. Biomass utilization could support activities to reduce hazardous forest fire conditions and support a resources-based industry in local communities, although whether biomass end use can fully support the cost of harvesting activities is dependent on the value of the end use. For example, selling biomass into energy production markets is likely to be only a marginal driver of harvesting activities, but biofuel markets hold more promise due to higher prices for transportation fuels and the potential for sale of LCFS credits. A systematic approach to climate change mitigation statewide and across sectors necessitates an understanding of the interrelationship of forestry activities and energy markets and policies designed for synergies across those sectors.

10.3.3 Forest Biomass Research and Development

The California Energy Commission's (CEC) research and development on biomass in general, and forest biomass and forest management activities in particular, is supported under the Electric Program Investment Charge (EPIC) Program, the Natural Gas Research, Development, and Demonstration (RD&D) Program, and the Alternative and Renewable Fuel and Vehicle Technology Program's Sustainability Research.

Specifically, under the CEC's Energy Research and Development Division, the EPIC Program's 2012 – 2014 Triennial Investment Plan allocated 20 percent of funding, or a minimum of $27 million,[415] for bioenergy technology development and demonstration (TD&D).[416] EPIC's 2015 – 17 Triennial Investment Plan allocated $18 million for bioenergy TD&D and $5 million for bioenergy applied research and development (R&D).

Research and development on forest biomass and forest management activities addresses the broad challenges to the widespread commercialization of bioenergy systems. The emphasis for applied R&D in the first EPIC investment plan was on modular bioenergy systems for forest/urban interface which will support sustainable collection, management, and power generation from forest residue thinning. The

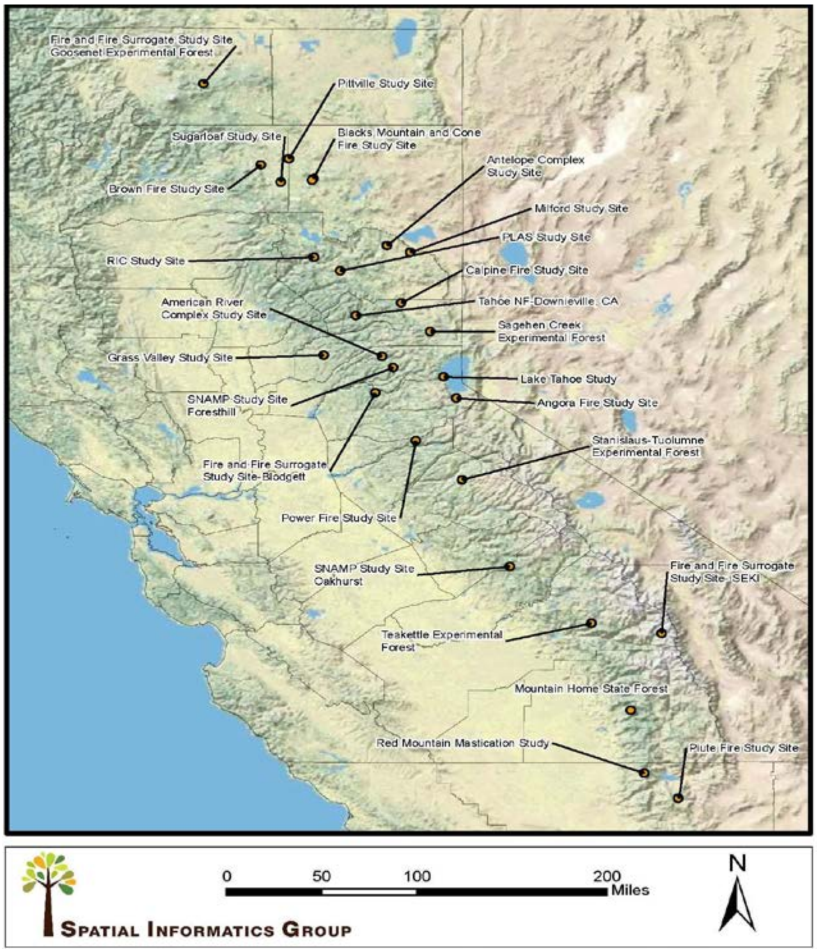
[414] California Public Resources Code section 40106, 1989
[415] California Energy Commission, 2012
[416] California Energy Commission, 2015

Box 13. Sustainability of Biomass Utilization.

A suite of interrelated studies was integrated to evaluate the sustainability of increased forest biomass utilization for transportation fuels under differing management practices across public and private lands and under expected fire regimes. Several field studies at the stand scale quantified the direct ecological effects of treatments and wildfires. Other studies using these field data modeled effects of treatments and wildfires on carbon stocks within the forest under a range of site conditions. Twelve individual tasks were included to address ecological, environmental, and socio-economic dimensions of biomass harvest.

In one task under this project, researchers assessed the large-scale impacts of forest practices designed to reduce risk of severe wildfire by developing an analytical tool that simulates 40-year impacts of optimally selected treatments on net carbon sequestration, costs of implementation, and reduction of tree mortality in severe fires.

The BioSum model was applied on California's total timberland base, using Forest Inventory and Analysis data, to evaluate optimum treatment sequences for reducing severe fire probabilities in each stand. The model evaluated dozens of promising management prescriptions with respect to a set of key metrics. By optimizing to select the best 40-year sequence of prescriptions to minimize fire hazard for each stand, the resulting scenarios also improved overall forest health as indicated by multiple performance metrics such as improved stand vigor, increased long-term net carbon sequestration, and reduced mortality losses. Implementing these optimal silvicultural sequences over a 40-year time horizon would eventually reduce the fire hazard across most of California's timberlands by 50 percent.



Map of facility locations for one scenario

Another task examined how a sustainable biomass utilization industry could be developed in California. This analysis also investigated how a set of biofuel production facilities using forest residues can provide sufficient revenue for forest biomass utilization. Using a spatially-explicit site simulation model, various scenarios were analyzed to identify the optimal number of facilities, their locations, sizes, gross revenues, and total throughput.

Under modeled scenarios that cover all areas generating substantial forest residuals, several dozen facilities could be sited within the State, each producing 15 – 20 million gallons of biofuels per year. This assumes that federal lands are included in forest restoration management plans, and also assumes currently favorable carbon credit market prices for low carbon biofuels from forest biomass. The resulting build out would sustainably utilize 9.2 million bone-dry tons (BDT) per year, and generate gross revenues, including carbon credit sales, of close to $1 billion per year.

applied R&D in the second plan complements the efforts in the first plan by targeting other key areas such as:

- Identifying and customizing application of advanced conversion technologies in a larger forest or woody biomass application to support sustainable forest management practices and help reduce fire hazards;
- Improving performance and efficiency in electricity and heat generation (this area now largely supporting the state's efforts to address the problem of wide-scale tree mortality); and
- Evaluating economic feasibility and environmental performance potential of specific locations for development of forestry biomass power plants.

EPIC investment plans are implemented through grant solicitations. The CEC's first bioenergy solicitation under EPIC addressed key challenges such as costs and environmental impact, improved efficiency by demonstrating bioenergy technologies that are proven in the pilot or bench scale, and demonstration of effective business models for bioenergy systems. The TD&D efforts placed emphasis on community-scale bioenergy facilities and on low emission or zero emission distributed generation technologies, including combined heat and power.

The CEC released an EPIC bioenergy solicitation in summer 2016 to address fire-hazard reduction focused forestry biomass to energy. In response to the Governor's 10-30-2015 Proclamation of a State of Emergency to protect communities against unprecedented tree die-off, the EPIC program accelerated the release of the bioenergy solicitation by a year and dedicated $15 million of the $23 million available for bioenergy research to support technologies that can help mitigate drought-related tree mortality. The solicitation has both applied research and development (AR&D, $5 million) and TD&D ($10 million) components that propose solutions for biomass from high hazard zones. The AR&D supports early stage development on technologies and strategies for the sustainable use of forest residue and thinning to generate renewable electricity, while reducing catastrophic fire hazards. The projects funded through this research group must use technologies and strategies sized for environmentally and economically sustainable use of locally available woody biomass resources and provide benefits to local communities and IOU electricity ratepayers. The TD&D component was designed to demonstrate innovative technologies, techniques, and deployment strategies to expand the efficient and sustainable use of California's woody biomass from the CAL-FIRE-defined high hazard zones (per the Governor's Proclamation of a State of Emergency) to generate electricity and, where possible, useful thermal energy. Additionally, the woody biomass must be a byproduct of sustainable forest management activities as defined by the CPUC's BioMAT program.

The solicitation was highly subscribed with fifty-seven abstracts submitted in Phase 1. Twenty-eight abstracts passed Phase 1 and twenty-three applied to Phase 2. Due to the high demand and number of passing projects, and input from the legislature, an additional $10.7 million was allocated to forestry biomass projects for a grand total of $33,721,278 in the EPIC bioenergy solicitation.[417] However, since the additional awards were announced, most of the demonstration projects proposed for awards experienced major setbacks, including loss of the developer, and delays in finalizing CEQA documentation and project financing. Sierra Energy declined its proposed award for a demonstration project in Chinese Camp during contract negotiations for various reasons, including the need to focus resources on commissioning

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[417] California Energy Commission, 2017b

activities for its Fort Hunter-Liggett project, also funded by the Energy Commission. The three remaining demonstration projects are pending as of December 2017.

The EPIC 2018-2020 Triennial Investment Plan, pending CPUC approval, includes "Improving the Value Proposition of Bioenergy" as an area of future EPIC research.[418] The proposed bioenergy R&D will continue to address issues with managing biomass waste from forests, including sustainable forestry management strategies to reduce wildfire risk; agriculture; and other sources of organic waste while helping achieve the state's RPS. The proposed R&D emphasizes thermochemical conversion of biomass as a means of addressing the unprecedented number of dead and dying trees and the biomass power plant closures that has impacted not only the forest sector but also the agriculture sector, particularly in the Central Valley where orchard waste management has become a problem. The bioenergy R&D initiatives address some of the barriers to achieving the full potential of biomass gasification and other conversion strategies, with a goal of making these technologies cleaner, more efficient, and cost-effective. The initiatives help address location-challenged biomass resources, as well as low-emission generation technologies, pollution control, and other technologies that can utilize low-quality biogas for bioenergy.

In 2015, the Natural Gas RD&D Program allocated about $4.4 million for biogas and renewable natural gas research. These programs include bioenergy research that also supports advancements for biochemical and thermochemical conversion of other organic wastes to renewable natural gas research. The Natural Gas RD&D program aims to lower the cost, improve the efficiency and reduce associated emissions of the production of biogas, cleanup, upgrading to pipeline quality biomethane, and onsite use for power generation. Opportunities for forest biomass include conversion to syngas via a thermochemical process and subsequent upgrading to biomethane through a process such as methanation. As of 2017, the funded projects have completed initial bench-scale testing and are preparing for pilot demonstrations in real-world operating environments.

In 2017, the Natural Gas RD&D Program proposed $4 million to fund forest-biomass-to-renewable-natural-gas research, development, and demonstration projects. This research, approved by the California Public Utilities Commission as part of the FY2017-18 Natural Gas R&D Budget Plan, is designed to support pre-commercial technologies and strategies to enable economic conversion of forest waste biomass to renewable natural gas of suitable quality for pipeline injection in California. This research is expected to be funded in 2018.

10.3.4 Forest Biomass for Transportation Fuels

The CEC's Alternative and Renewable Fuel and Vehicle Technology Program (ARFVTP) has funded three small-scale forest biomass demonstration projects, and two additional technologies for converting ligno-cellulosic agricultural waste materials such as orchard wood into biofuels. Profitable implementation of the latter projects would demonstrate the efficacy of these emerging technologies on forest biomass, providing the foundation for gradual migration of new projects into more remote forest locations.

Additionally, the ARFVTP has funded research conducted by the USDA Forest Service. The USDA Forest Service Pacific Southwest Research Station, supported by university and private subcontractors, recently completed an applied research project, which evaluates treatment sustainability and provides tools to evaluate and prescribe sustainable harvest and utilization of forest biomass in California. Tasks include:

- Developing a revised version of the BioSum model, which analyzes the impacts of alternative forest treatment prescriptions under site-specific conditions in California forest lands;

[418] California Energy Commission, 2017c

- Quantifying carbon storage and mass balances following wildfire on treated and untreated stands, to quantify benefits from treatments to reduce the intensity of high severity fires;
- Modeling economic viability and identifying potential locations for forest biofuel facilities, based on existing conversion technologies and on treatment costs and biofuel credit price scenarios;
- Measuring wildlife and forest ecological impacts from recent fires, to assess rates of forest recovery from high severity wildfires in both treated and untreated stands; and
- Quantifying the efficacy of fuel reduction treatments and looking at their impacts on reducing wildfire severity and lowering carbon emissions from wildfire.

The CEC is making plans for a targeted ARFVTP solicitation for forest biofuels projects in the near future, as a dedicated solicitation or as part of a larger funding opportunity. Funding from outside the ARFVTP allocation process would greatly facilitate such an offering. Since many forest communities are among the most socio-economically challenged in the state, and lie within or in near proximity to impacted air districts, such a solicitation would complement emerging State policy goals.

11 State Legislation and Regulation

Forest lands, even those held in private ownership, are considered "public trust" resources: that is, although the landowners manage forests for their specific objectives, their management must preserve certain societal values inherent in them. These values generally include benefits such as water quality and quantity, wildlife and their habitat, aesthetics and recreation, and air quality, as discussed in Section 8. Our natural resource management regulations are in place because of the public trust values inherent to California's landscapes, and protecting these values is an underlying objective inherent in all new state legislation.[419]

11.1 State Statutory Framework

While the California Environmental Quality Act (CEQA; Public Resources Code Section 21000 et seq.) provides overarching protections for the state's environment, the Z'berg-Nejedly Forest Practice Act, passed in 1973, establishes the primary vision, values, and regulatory framework around which all non-federal forest lands in California must be managed. It is recognized as the most comprehensive forest regulatory framework in the nation.[420] This Act is implemented through the Forest Practice Rules (FPRs), which are promulgated by the Board of Forestry and Fire Protection.

The FPRs require landowners to complete and receive CAL FIRE approval for a Timber Harvesting Plan (THP) prior to most forest management efforts. This CEQA-equivalent document takes into consideration stream course protection, risk to wildlife and habitat, fire protection, water quality issues, and sustainable forest yield, among other factors. As part of the regulatory process, a THP is submitted to, and must be reviewed by CAL FIRE (the lead agency), the Department of Fish and Wildlife, the Regional Water Quality Control Board, the California Geological Survey. Most of these agencies also administer their own resource protection laws for fish, wildlife, and water quality as a part of this process.

There are circumstances in which a permit is not required. These are called emergencies or exemptions. Currently, some of the most well-known and well-used exemptions include those for dead and dying trees and for substantially damaged timberlands (FPR Section 1038).

The cost and complexity of California's FPRs can create challenges for, small, private forestland owners. These landowners own approximately 20 percent of California's forested landscape,[421] but the FPRs are structured in a way that makes active management prohibitively expensive for many of them. The State has attempted to ameliorate this concern with solutions such as the Nonindustrial Timber Management Plan (NTMP) and the more recent Working Forest Management Plan program, enacted through AB 904 (Chapter 648, Statutes of 2013). While these strategies reduce regulatory costs for landowners in the long term, they still present substantial up-front costs that are problematic for some small landowners.

The California Forest Improvement Program,[422] or CFIP, is an incentive program for landowners holding less than 5,000 acres of forestland. It provides cost-share funds for development of forest management plans and conducting forest improvement work, such as tree planting, thinning, addressing insects and disease, reducing stream sedimentation, and improving wildlife habitat. While this program currently provides meaningful investment into California's forest resources, its resources do not match the scale of need for forest health and resilience improvements on small forestland holdings.

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[419] Morrison et al., 2007
[420] Morrison et al., 2007
[421] American Forest Foundation, 2015
[422] Authorized under California Public Resources Code § 4790 *et seq.*

Another law relevant to Forest Carbon Plan implementation is AB 1492 (Chapter 289, Statutes of 2012, Committee on Budget). The bill intends to:

- Ensure continued sustainable funding for the state's timber harvest regulation program to protect the state's forest resources;
- Support in-state production of timber within the state's environmental standards, and promote and encourage retention of forests and forested landscapes;
- Create a funding source for the restoration of the state's forested lands and promote restoration of fisheries and wildlife habitat and improvement in water quality;
- Promote restoration and management of forested landscapes consistent with the California Global Warming Solutions Act of 2006 (AB 32).

AB 1492 established the Timber Regulation and Forest Restoration Fund (TRFRF) to finance the timber harvest regulatory programs at state agencies and a grants program for forest restoration. These funds are generated by a one percent assessment on lumber and wood products sold at the retail level in California. CAL FIRE, the Department of Fish and Wildlife, and the State Water Board currently administer forest restoration grant programs using these funds. These funds also are supporting enhancements to the reforestation seed bank and the re-establishment of reforestation seedling production at CAL FIRE's L.A. Moran Reforestation Center, located in Davis.

11.2 Recent Forest-Related Legislation

Forest issues have seen an increase in legislative attention and regulation over the past several years. Some of the legislation passed is listed below, including how it may affect California's forest management efforts.

- SB 859 (Chapter 368, Statutes of 2016, Committee on Budget and Fiscal Review): Among other things, this bill established new procurement requirements for bioenergy generated with forest-sourced biomass from tree mortality High Hazard Zones in California.[423] It also calls for CARB, in consultation with CNRA and CAL FIRE, to complete a standardized GHG emissions inventory for natural and working lands, including forests by December 31, 2018. Further, the legislation directed CNRA to establish a working group on expanding wood products markets that can use woody biomass, especially that from high hazard zones determined by the Tree Mortality Task Force. Recommendations from the working group were completed in October 2017.[424]
- AB 2480 (Chapter 695, Statutes of 2016, Bloom): This statute identifies watersheds as part of California's water infrastructure. While no implementation conditions are included, it is possible that this bill could result in increased investment in California's headwaters in the future.
- AB 417 (Chapter 182, Statutes of 2015, Dahle): This bill provides the Board of Forestry and Fire Protection with additional flexibility in setting post timber harvest tree stocking standards in order to, in part, contribute to specific forest health and ecological goals as defined by the Board.
- SB 1122 (Chapter 612, Statutes of 2012, Rubio): This bill requires production of 50 megawatts of biomass energy using byproducts of sustainable forest management from fire threat treatment areas as determined by CAL FIRE. The aim of the law is distributed generation of small-scale power facilities less than 5 MW (a change enacted by AB 1923) and delivering 3 MW to grid.

[423] High Hazard Zones are areas designated by California State government as being in greatest need of dead tree removal due to severe tree mortality levels caused by 5 years of drought and subsequent bark beetle infestations. These areas are designated in two tiers, representing both potential direct threat to people, buildings and infrastructure from falling trees (Tier One), as well as broader fire risk and forest health considerations (Tier Two).
[424] California Natural Resources Agency, 2017

- AB 1504 (Chapter 534, Statutes of 2010, Skinner): This statute requires the Board of Forestry and Fire Protection to ensure that its rules and regulations that govern timber harvesting consider the capacity of forest resources to sequester carbon dioxide emissions sufficient to meet or exceed the state's GHG reduction target for the forestry sector, consistent with the AB 32 Climate Change Scoping Plan goal of 5 million metric tons CO_2 equivalent sequestered per year. The Board is implementing an annual monitoring and reporting process, based on USDA Forest Service Forest Inventory and Analysis data, to meet this requirement. The first report is anticipated in late 2017.
- SB 1386 (Chapter 545 Statutes of 2016, Wolk): This bill declares it to be the policy of the state that the protection and management of natural and working lands, including forests, is an important strategy in meeting the state's greenhouse gas reduction goals, and requires all state agencies, departments, boards, and commissions to consider this policy when revising, adopting, or establishing policies, regulations, expenditures, or grant criteria relating to the protection and management of natural and working lands.

12 Research Needs

New information and tools will have a great impact as the Forest Carbon Plan begins implementation at the regional level and as strategies turn into actions. Key studies already underway include research to support CNRA's Fourth Climate Change Assessment,[425] and research by Lawrence-Berkeley National Lab to support the natural and working lands component of the 2017 Climate Change Scoping Plan. As other gaps in knowledge emerge, key research priorities must be identified, developed, and funded to ensure that science-based, cost-effective strategies continue to move the state of practice forward, informing government agencies, private businesses and landowners of the best investments.

This section compiles, by topic area, several important research needs that were identified through the Forest Carbon Plan's development. Finding opportunities to address these needs will be part of the Plan's implementation actions (see Section 4).

12.1 Planning, Monitoring, and Modeling

- Enhance the predictive capacity of forest health and forest carbon models to aid in planning, policymaking and investment.
- Standardize methods, data, and modeling across government agencies and landowners to facilitate planning for forest health management activities across ownership boundaries and at the landscape scale.
- Improve the accuracy and precision of forest carbon inventories. Develop a forest carbon monitoring program that reports on forest carbon stock changes more frequently than current methods, such as shortening the FIA sampling cycle to 5 years (as is done in a number of Southern states) from the current 10 years, and/or measuring stocks on an annual basis using a remote sensing technique such as LiDAR. This more rapid updating of forest carbon stocks, especially when paired with information forest carbon emissions, will greatly aid adaptive management under the current circumstances of relatively rapid forest change.
- Develop an information management system to track implementation activities across local, state and federal agencies and private landowners in a standardized way that includes cost and other elements that would allow for improvement in cost-efficiency and overall effectiveness over time.
- Perform full GHG and carbon lifecycle analyses for wood products and biomass utilization pathways, including those imported from out of state and sold in California, to inform policymaking and potential incentives and regulation related to wood products markets, building codes, and energy.

12.2 Forest Restoration and Protection

- Initiate and continue research relating to appropriate restoration efforts in areas affected by uncharacteristic wildfire or tree mortality or both, including incorporation of climate change modeling.
- Develop a multi-disciplinary science panel to track and study new issues that arise with climate change and/or interactions of forest stressors significantly beyond levels previously experienced, for example tree mortality and fire behavior.
- Develop best management practices consisting of silvicultural systems that are likely to create forest structure and composition that are likely to be optimal over a wide range of as-yet unknown future climate situations.

[425] California Natural Resources Agency, 2016c

- Continue research into the long-term impacts of forest management practices on site productivity and resilience. This is especially important where natural disturbance has been suppressed for decades and response to reintroduced disturbance may have unexpected outcomes.
- Forest soils sequester substantial quantities of carbon, however there is a need for more research, specific to California forests, on how management activities affect soil carbon pools, as well as how climate change will affect these pools over time.
- Gain a better understanding on how to minimize the watershed and habitat impacts and the stress on forest species from forest treatment activities.
- Obtain better information on genetic and species selection of tree planting stock that can best thrive under changing climate conditions.
- Correlate, to the extent possible, actions taken to enhance carbon storage with downstream water supply quantity values. Pay special attention to forest losses and changes due to climate change, including forests moving upslope.
- Identify forests at greatest risk to type conversion.
- Identify areas with the most forest carbon at the greatest risk to loss.

12.3 Forest Management and Markets

- Comprehensively calculate the costs and benefits of forest treatment activities compared with a status quo approach, to include suppression, insurance, water quantity and quality, recreation, wildlife habitat, air quality, and other ecosystem services.
- Develop new products/markets for excess biomass material.
- Identify soil types that are best suited for biochar integration, and the best application strategies for this material.
- Develop opt-in carbon maximization practices for forests that are managed for other uses, including timberlands, similar to the Natural Resources Conservation Service farming strategies.

12.4 Forest Carbon Emissions

- Develop a better understanding of how different fire types (i.e., low, medium, severe, and pile burning) and different forest fuels affect black, brown, and superaggregate carbon emissions to better understand how different management practices affect climate forcing potential and human health.
- Investigate the process of forest dead pool decay and emission rates and timeframes.

12.5 Education

- Develop and disseminate tools to assist landowners and local and regional land use planners and forest managers in assessing current forest conditions and desired future conditions for carbon resiliency and forest health, identifying management activities to facilitate the transition to a resilient state, and providing information on potential sources of technical assistance and funding.
- Develop infrastructure for relaying advisories and information about upcoming prescribed burns to populations likely to be impacted.
- Amplify fire prevention education in WUI areas, since these continue to be areas of substantial human-caused fire ignitions.

12.6 Urban Forestry

- Develop a comprehensive needs assessment for urban forests, looking at threats and overall conditions statewide, as well as coordinated monitoring and pest detection.

13 Conclusions and Recommendations

California's Forest Carbon Plan seeks to secure California's forests as healthy, resilient net sinks of carbon that provide a range of ecosystem and societal benefits while reducing greenhouse gas and black carbon emissions associated with management activities, conversion, wildfire events, and other disturbances. Wildland and urban forests both have important roles to play in securing these benefits.

The best available science shows that forests will experience unprecedented stresses related to climate change, including unusually severe wildfire, pest and disease outbreaks, and changes in temperature and water availability. Recent experience in California's forests is highly consistent with these predicted shifts, with catastrophic outcomes for life, property, and environment. Due to historical management practices including fire suppression, many forests are not resilient to these disturbance stresses in their current condition. Forest managers, public and private, must account for all of these factors when making decisions.

Our efforts should focus pragmatically on achievable rather than ideal desired future conditions in California, with full recognition of the ecological, social, and institutional variability across this large, complex state. This State cannot fully return to fire regimes representative of conditions prior to European settlement. California's population of 39 million people presents cultural preferences, life and property safety hazards, smoke/air quality sensitivities, and demands for environmental services that cannot be ignored. As one example of paths forward, the fire and land management communities and air quality regulators are collaborating to identify and overcome current cultural, regulatory, and institutional barriers to increased fire use for restoration, while still working to protect air quality and human health.

Forests sequester and store large amounts of carbon and have the potential to store this carbon in a more resilient state. However, wildfire and mortality from drought, pests, and disease cause the release of carbon from forests. Overly dense forests may paradoxically sequester less carbon in the long run than their potential. Managing for forest health and resilience can increase long-term carbon sequestration and storage; reduce vulnerability to wildfire, drought, pests, and disease; boost rural economies; increase the many benefits from the forest that the state relies on; and be central to California meeting of its climate goals. Reducing carbon emissions and increasing sequestration and storage are essential to meeting the State's long-term climate goals. The Forest Carbon Plan is a foundational component of the Natural and Working Lands Climate Change Action Plan identified in the 2017 Climate Change Scoping Plan.

The managers of public and private forestland across the state should fulfill their stewardship responsibilities to manage their lands to achieve resilient, carbon favorable conditions. Given the forest conditions found in many areas of the state today, it will take substantial, long-term investment in thinning and fuels reduction (including prescribed and managed fire), reforestation, sustainable timber harvest, and other treatments at a large scale to achieve and maintain an ecologically meaningful increase in forest health and resilience.

California has demonstrated a commitment to funding these priorities through current and proposed appropriations of $380 million in California Climate Investment Funds. However, to realize the goals of this plan, state funds and forest health actions will need to be matched by increased local, private, and federal investment as well as revenues generated from timber harvested within a plan to maximize forest health benefits.

This Forest Carbon Plan further emphasizes working collaboratively at the watershed, landscape, or community scale to restore resilience to all forestlands and urban forests in the state. Cooperative approaches by State agencies (such as CAL FIRE, Conservancies, and the Department of Fish and Wildlife), federal agencies (such as the USDA Forest Service, Bureau of Land Management, National Park Service, and

Natural Resources Conservation Service), tribes, local governments, nongovernmental organizations, and large private landowners are the most promising way to identify and implement appropriate management strategies, including forest restoration treatments.

The scientific understanding of many aspects of climate change is still new and evolving. The accounting and measurement approaches to design robust and effective adaptation and mitigation methods are not well developed, primarily because they require large-scale experiments. California has an opportunity to establish a leadership role by implementing such experiments in the forest sector. In order to strengthen California's ability to understand and adapt to climate change, this report recommends strengthening forest inventory data collection under the Forest Inventory and Analysis program.

Successful implementation of the Forest Carbon Plan will require ingenuity, strong partnerships, filing in gaps in science, and greater financial and information resources. It also will require commitments to stay the course to 2030, 2050, and beyond, so that California's forests can continue to serve as a resilient carbon sink and as a source of ecological, economic, and spiritual abundance for current and future generations of Californians.

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15 List of Acronyms

AB	Assembly Bill
AGL	above ground live
AR&D	advanced research and development
ARFVTP	Alternative and Renewable Fuels and Vehicle Technology Program
BioMAT	biomass market adjusting tariff
BDT	bone-dry tons
BLM	Bureau of Land Management
BOF	Board of Forestry and Fire Protection
CA	California
CalEPA	California Environmental Protection Agency
CAL FIRE	California Department of Forestry and Fire Protection
CARB	California Air Resources Board
CCC	California Conservation Corps
CEC	California Energy Commission
CEQA	California Environmental Quality Act
CH4	methane
CLT	cross-laminated timber
CNRA	California Natural Resources Agency
CO	carbon monoxide
C02	carbon dioxide
CO2E	carbon dioxide equivalent
CPUC	California Public Utilities Commission
EPIC	Electric Program Investment Charge
FIA	Forest Inventory and Analysis
FPR	Forest Practice Rule
FRI	fire return intervals
FRID	fire return interval departure
FS	Forest Service
GHG	greenhouse gas
HHZ	high hazard zone
HWP	harvested wood product
IOU	investor-owned utility
IPCC	International Panel on Climate Change
KYCC	Koreatown Youth and Community Center
LBNL	Lawrence Berkeley National Laboratory
LCFS	Low Carbon Fuel Standard
MMT	million metric tons
MT	metric ton
MW	megawatt
NEPA	National Environmental Policy Act
NGHGI	National Greenhouse Gas Inventory
NGO	nongovernmental organization
NO_x	oxides of nitrogen
NPS	National Park Service
NTFP	non-timber forest products

$PM_{2.5}$	particulate matter smaller than 2.5 micrometers in size
R&D	research and development
RPS	renewable portfolio standard
SB	Senate bill
SOD	sudden oak death
TD&D	technology development and demonstration
THP	timber harvesting plan
UHI	urban heat island
UHII	urban heat island index
USDA	United States Department of Agriculture
WHR	Wildlife Habitat Relationships

Appendix 1: Estimated Changes in Extent for Individual Tree Species

This summary table provides more details from the work of Thorne et al. (2016) that was presented in Section 2. The table shows current extent of presence of the individual species (in 1,000 of acres) and the increase or decrease of extend of the species under the four modeled climate change scenarios over three periods of time. A key to the species name abbreviations is provided below.

Tree Species Code	Tree Species Name	Individual Tree Species Gained/Lost Acres (Thousands)												
			CNRM RCP 4.5			CNRM RCP 8.5			MIROC RCP 4.5			MIROC RCP 8.5		
		Current	2010-2039	2040-2069	2070-2099	2010-2039	2040-2069	2070-2099	2010-2039	2040-2069	2070-2099	2010-2039	2040-2069	2070-2099
ABCO	white fir	15,527	4,850	2,106	308	4,900	1,775	-5,993	3,336	-1,483	-3,849	4,018	-3,319	-9,792
ABMA	California red fir	4,630	2,975	1,241	224	3,319	988	-1,536	2,119	-200	-1,730	35	-3,289	-3,989
ADFA	chamise	15,240	8,710	9,764	11,800	5,505	9,436	15,911	6,359	7,666	8,962	5,018	5,640	9,503
AMDU2	burrobush	23,876	-721	542	1,832	-1,609	1,557	-88	2,624	7,241	9,123	3,793	10,750	14,490
ARCA11	coastal sagebrush	15,248	-883	1,102	2,348	68	1,854	7,995	4,312	4,948	3,965	3,445	3,724	7,289
ARMA	whiteleaf manzanita	15,698	503	1,141	1,950	1,145	-707	6,432	-2,413	-3,686	-2,298	-3,909	-2,825	263
ARME	Pacific madrone	15,205	2,429	3,603	6,106	1,065	2,916	10,494	-1,754	-2,368	-1,159	-2,796	-1,134	-559
ARPA6	greenleaf manzanita	12,816	-176	-1,750	-4,034	-4,351	-5,427	-9,763	-3,350	-4,218	-5,933	-1,791	-5,164	-8,853
ARTR2	big sagebrush	22,804	-3,085	-4,428	-5,670	-4,754	-5,448	-15,003	-2,288	680	-73	3,502	4,503	-2,013
ARVI4	sticky whiteleaf manzanita	11,377	6,056	7,286	9,246	6,945	8,941	16,445	2,536	2,252	4,386	2,874	4,406	6,522
BAPI	coyotebrush	23,145	-794	2,904	3,712	2,500	1,273	9,474	1,980	-1,420	-721	2,710	1,684	5,256
CADE27	incense cedar	15,819	8,804	7,620	7,021	9,243	10,546	3,981	6,261	4,195	3,807	6,066	2,559	-2,726
CECU	buckbrush	21,491	4,998	3,474	2,837	1,271	-2,002	-1,710	-1,377	-2,063	-1,879	-372	-709	1,342
CEIN3	deerbrush	13,035	2,435	2,857	3,728	4,477	6,914	10,525	4,156	4,043	5,566	2,750	4,716	5,381
CHSE11	bush chinquapin	4,772	-457	-1,798	-2,187	-1,664	-2,394	-3,366	-1,776	-2,222	-2,922	-1,050	-2,942	-3,982
CORA	blackbrush	4,824	-1,100	-1,519	-1,651	-494	-2,206	-3,346	-458	736	-1,110	378	2,226	-665
ERFA2	Eastern Mojave buckwheat	31,074	7,734	7,814	7,422	7,212	6,536	9,342	1,009	5,716	4,190	4,170	7,448	9,795
JUCA	Southern California walnut	5,613	1,297	2,885	5,027	1,522	4,244	9,404	2,209	4,342	6,498	2,291	3,484	8,786
JUOC	western juniper	10,934	-3,973	-7,446	-8,525	-6,836	-9,173	-9,921	-2,676	-6,723	-8,051	-3,299	-8,578	-10,392
LATR2	creosote bush	23,156	-1,187	285	1,501	-1,065	3,129	215	2,490	4,994	4,597	3,482	4,331	5,645
NODE3	tanoak	8,230	2,710	2,853	3,831	1,952	1,709	1,524	-788	-3,105	-3,349	-2,937	-3,604	-5,003

Tree Species Code	Tree Species Name	Individual Tree Species Gained/Lost Acres (Thousands)												
			CNRM RCP 4.5			CNRM RCP 8.5			MIROC RCP 4.5			MIROC RCP 8.5		
		Current	2010-2039	2040-2069	2070-2099	2010-2039	2040-2069	2070-2099	2010-2039	2040-2069	2070-2099	2010-2039	2040-2069	2070-2099
PIAL	whitebark pine	1,969	-1,089	-1,474	-1,745	-1,035	-1,655	-1,952	-1,424	-1,719	-1,881	-1,707	-1,969	-1,969
PICO3	Coulter pine	3,005	1,309	-19	-653	1,578	-403	-557	450	-855	-1,027	1,017	-651	-63
PIJE	Jeffrey pine	18,475	4,693	2,309	-530	1,524	-1,188	-11,188	1,957	-570	-2,455	2,149	-2,947	-10,970
PILA	sugar pine	15,174	7,121	4,848	4,599	6,235	6,646	2,268	1,933	-444	-1,171	2,755	-1,232	-5,086
PIMO	singleleaf pinyon	4,881	5,887	4,693	2,992	4,521	2,816	-2,175	5,825	6,944	6,798	8,471	8,430	5,257
PIPO	ponderosa pine	19,801	3,558	5,425	4,936	5,000	7,582	6,312	5,614	5,152	5,293	2,912	2,604	-654
PISA2	California foothill pine	19,778	2,599	2,947	2,947	3,323	444	4,179	621	-306	13	-484	-491	3,341
POTR5	quaking aspen	6,664	1,618	-2,040	-3,548	-2,015	-4,364	-5,644	-951	-2,756	-3,734	6,548	-830	-4,594
PSMA	bigcone Douglas-fir	1,653	6,925	4,580	4,067	5,450	4,090	3,265	1,192	1,358	2,034	1,778	1,523	3,176
PSME	Douglas-fir	17,101	-1,715	-1,909	-1,371	-3,092	-5,717	-1,733	-4,973	-8,793	-9,153	-4,614	-7,068	-7,672
QUAG	California live oak	17,391	9,053	10,650	11,416	6,547	7,376	15,565	8,788	7,121	7,409	6,698	6,247	9,099
QUCH2	canyon live oak	20,696	5,269	4,804	4,911	6,043	6,517	5,438	1,069	139	102	579	-168	-3,432
QUDO	blue oak	26,706	2,530	3,391	3,713	2,379	330	3,817	4,680	5,001	3,692	2,386	2,317	3,142
QUEN	Engelmann oak	1,030	2,175	3,289	4,756	5,972	7,943	9,416	2,252	4,172	4,275	2,925	5,751	6,911
QUGA4	Oregon white oak	10,689	800	2,196	3,577	1,762	4,030	10,658	-2,256	-1,454	-49	-473	1,184	1,667
QUKE	California black oak	20,188	7,059	8,762	9,117	7,614	10,267	8,782	7,282	6,134	6,536	5,808	4,587	3,230
QULO	valley oak	26,540	6,480	8,946	11,456	3,763	4,921	14,039	5,977	3,529	6,181	7,971	7,142	13,434
QUWI2	interior live oak	12,910	9,533	9,157	10,329	10,527	12,659	16,342	3,404	4,444	7,954	4,076	5,095	10,234
SEGI2	giant sequoia	838	1,172	1,669	1,984	1,073	1,674	1,948	1,294	1,256	969	1,435	68	-287
SESE3	redwood	7,063	-370	38	-985	928	-3,093	-1,456	-1,469	-3,383	-3,843	-2,876	-3,075	-3,089
UMCA	California laurel	18,076	-2,126	-2,126	-1,738	-932	-3,980	734	-5,101	-7,452	-7,418	-6,321	-7,379	-8,123
YUBR	Joshua tree	5,369	365	-840	-1,636	-941	-2,809	-4,574	-1,277	-662	-1,031	-1,671	-837	-2,245
ABMAS	Shasta red fir	1,590	816	-285	-664	1,252	-447	-1,217	-242	-1,471	-1,559	-557	-1,566	-1,590
PAAC3	Jerusalem thorn	9,965	6,712	8,558	13,283	3,622	8,321	14,520	2,381	7,093	8,354	2,747	10,980	18,629

Appendix 2: Harvested Wood Product Carbon Calculation Methods

METHODS TO CONVERT 2012 HARVESTED WOOD PRODUCT VOLUMES TO CARBON AND CARBON DIOXIDE MASS (i.e., Forest Carbon Plan Table 11)

- Green harvested timber volumes and their allocations to different products were reported in Figure 6 in McIver et al. 2015,[426] and clarifications on bark volumes were provided by McIver and Morgan 2017.[427]
- To convert these timber volumes to carbon values, cubic foot volumes must be converted to mass.
- To convert cubic foot volumes to wood mass for solid wood products and logging residuals, wood density is required. See below for how wood density was determined.
- To convert cubic foot volumes to wood mass for bark and mill residues, the definition of 1 Bone Dry Unit (BDU)[428] was used. See below for a description.

(1) Obtaining wood density values - Solid wood products

- Oven dry wood densities on a green volume and 12% moisture content basis by species from the U.S. Forest Service Forest Products Lab Wood Handbook (GTR-190, 2010) were summarized in Table 1A of Miles and Smith (2009).
- Wood density values were taken from Table 1A (Miles and Smith 2009) for the species comprising the 2012 timber harvest reported in McIver et al. 2015.
- Wood density values associated with moisture content of 12% are commonly used when estimating biomass from processed forest product volumes (i.e. lumber, veneer, etc.)[429] Oven dry densities associated with a moisture content of 12% are often higher than green wood because as wood dries, it shrinks and occupies less volume, therefore increasing density. However, because McIver et al. 2015 is reporting on the allocation of timber harvest volumes to different finished products in terms of green volume, oven-dry wood density values on a green volume basis for each commercial species represented in the 2012 harvest were used.
- An average oven-dry wood density weighted by the species composition of the 2012 timber harvest volume[430] was then calculated, to be used in converting harvest volumes for solid wood products to mass. See Table 1 for calculations.
- **The resulting weighted average softwood density is specific to the species composition of the 2012 timber harvest and should not be used for calculations on timber harvest volumes in other years.**

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[426] McIver et al. 2015
[427] McIver & Morgan, 2017
[428] McIver et al. 2015
[429] Miles & Smith 2009
[430] McIver et al. 2015

Table 1: Values used to calculate average oven-dry wood density weighted by species composition of 2012 timber harvest volume (McIver et al. 2015). Wood densities from the U.S. Forest Service Forest Products Lab Wood Handbook (GTR-190, 2010), summarized in Table 1A of Miles and Smith (2009).

	2012 HARVEST VOLUME				GREEN VOLUME BASIS		
	MMBF	MMCF	CF	% OF HARVEST VOLUME	OVEN DRY WOOD DENSITY (LBS/CF)	WEIGHT (LBS)	WEIGHTED DENSITY
DF	405.2	74	74,485,294	0.28	28.1	2,093,036,765	8.54
*TRUE FIR	380.2	70	69,889,706	0.27	22.8	1,593,485,294	6.41
PP	251.1	46	46,158,088	0.18	23.7	1,093,946,691	4.41
REDWOOD	209	38	38,419,118	0.15	22.5	864,430,147	3.48
SP	86.4	16	15,882,353	0.06	21.2	336,705,882	1.36
IC	70.1	13	12,886,029	0.05	21.8	280,915,441	1.14
**LP / JP / GIANT SEQUOIA / WESTERN RED	18.2	3	3,345,588	0.01	22.45	75,108,456	0.32
WESTERN HEMLOCK	4	1	735,294	0.00	26.2	19,264,706	0.08
		TOTALS	261,801,471			6,356,893,382	24.28
				AVERAGE SOFTWOOD DENSITY WEIGHTED BY SPECIES (LBS/CF)		***24.28	

*average for WF/CA RF

*Average for LP, JP, Giant Sequoia, Incense Cedar

*Specific to the species composition of the 2012 CA timber harvest and should not be used for carbon calculations on timber harvest volumes in other years or from other states

(2) Obtaining wood density values – Mill residues/bark

- To convert cubic foot volumes to wood weights for bark and mill residues, the definition of 1 Bone Dry Unit (BDU) = 96 cubic feet = 2400 pounds[431] was used. Calculated bark/residue masses derived from Figure 6, which is specific to CA, were checked against the BDUs provided in Table 21 of McIver et al. 2015, which includes residues from out-of-state logs processed at CA mills and does not include residues from CA logs shipped out-of-state for processing. These values were similar, but not the same, which was expected.

(3) Convert wood volume million cubic feet (MMCF) to cubic feet (CF)

MMCF * 1,000,000 = CF

(4) Convert cubic foot volume (vol) to mass (lbs)

It is important to note that we are using wood mass rather than weight, which incorporates the moisture content and is unnecessary to determine the equivalent carbon mass of the wood.

Solid wood:

Basic equation to convert solid wood product/logging residuals volume to mass:

Mass = (vol) * D_{OD}

Vol = timber harvest volume

D_{OD} = wood density

Solid wood, products

- Vol = 2012 timber harvest volume in the finished lumber and veneer products[432] and volume of logging residuals[433]
- D_{OD} = 24.28, average oven dry wood density weighted by species composition of 2012 volume (**Table 1**)

Solid wood, bioenergy

- Vol = 2012 timber harvest volume of slash burned for bioenergy (figure 6, McIver et al. 2015).
- D_{OD} = 24.28 average oven dry wood density weighted by species composition of 2012 volume (**Table 1**)

Bark/Residues:

Vol (CF) / 96 cu. ft solid wood equivalent = Bone Dry Units

Bone Dry Units * 2400 lbs = weight (lbs)

(BDU definition from McIver et al. 2015)

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[431] McIver et al. 2015
[432] Figure 6, McIver et al. 2015, excluding bark as described in McIver & Morgan, 2017
[433] USDA Forest Service. 2012. Forest Inventory and Analysis Timber Products Output Database, CA 2012 report year, Table 9. https://srsfia2.fs.fed.us/php/tpo_2009/tpo_rpa_int2.php

- **Bark, products Vol =** 2012 timber harvest volume for bark used in landscaping products[434]
- **Bark, bioenergy Vol =** 2012 timber harvest volume for bark combusted for bioenergy[435]
- **Mill residues, products Vol =** 2012 timber harvest mill residue volume for landscaping and other products.[436]
- **Mill residues – bioenergy Vol =** 2012 harvest volume mill residue for bioenergy[437]
- **Unutilized residue Vol =** 2012 harvest volume ending up as unutilized residue[438]

(5) Convert wood mass (lbs) to carbon and carbon dioxide mass (metric tons C and CO2e)

- Volumes (cubic feet) were converted to mass in pounds using the methods described above.
- Wood mass in pounds was converted to mass in kilograms (1 lb = .4535924 kilograms).
- Wood mass (kilograms) was converted to kilograms of carbon, assuming dry biomass is 50% carbon.[439] No difference in wood mass to carbon conversions assumed for wood, residues, or bark.
- Kilograms of carbon were converted to metric tons of carbon (1000 kg = 1 metric ton)
- Metric tons of carbon were converted to metric tons of carbon dioxide equivalent (1 metric ton C = 3.67 tons CO2e).

METHODS TO DETERMINE PERSISTENT HWP CARBON 100 YEARS AFTER HARVEST (i.e. FCP Table 12, 13)

Harvest volumes in the 2001-2010 period reported by the California Board of Equalization were used to estimate quantities of wood product carbon persisting in solid form after 100 years. Carbon estimates were made from wood volumes harvested from private and public timber lands for each harvest year cohort, and then averaged for reporting in Table 12. National factors from Smith et al. (2006) and California-specific factors from Stewart and Nakamura (2012)[440] were used in the calculations to illustrate contrasting results. Example calculations are shown below using a harvest volume from 2001.

(1) Calculate conversion factor for wood volume to metric tons carbon

The following values were used:

- To remain consistent with methods used to calculate Table 10, weighted average softwood density for commercial tree species based on species composition for 2006 harvest calculated and rounded to the nearest whole number – 24 lbs/cu. ft. This value is on par with the value calculated based on the 2012 harvest and is likely adequate for use for harvest years 2001-2010.
- 24 lbs/cu. ft. * 0.5 carbon fraction of wood[441] = 12 lbs C/cu. ft

[434] calculated from McIver et al. 2015 figure 6 updates in McIver and Morgan, 2017
[435] calculated from McIver et al. 2015 figure 6 updates in McIver and Morgan, 2017
[436] calculated from McIver et al. 2015 figure 6 updates in McIver and Morgan, 2017
[437] calculated from McIver et al. 2015 figure 6 updates in McIver and Morgan, 2017
[438] figure 6, McIver et al. 2015
[439] Ryan et al., 2010
[440] Actual values discussed in Stewart and Nakamura 2012 available in the University of CA Cooperative Extension Carbon Sequestration Tool for Timber Harvest Plans, online at: http://ucanr.edu/sites/forestry/Carbon_Sequestration_Tool_for_THPs/
[441] Ryan et al., 2010

- This value is different than the value used for the CA Air Resources Board inventory[442] of 15.11 lbs. C/cu. ft., for Pacific Southwest Softwood,[443] which was derived from the softwood density for Douglas-fir only (29.52 lb/cu. ft.) and a carbon fraction of 0.512 for Douglas-fir.[444] The softwood density for Douglas-fir is higher than the densities of other commercial species in CA, which could lead to an overestimation of carbon.
- 5.35 board feet per cubic foot of sawlogs[445]
- Please note this is different from the mathematical conversion of 12 board feet per cubic foot used in harvested wood product carbon estimates for the CA Air Resources Board.[446] The mathematical conversion does not account for differences in log sizes, losses from trim, saw kerf, estimated recovery of board feet lumber tally per board feet Scribner, modern sawmill technology, etc. For a detailed discussion on board foot to cubic foot conversions see Keegan et al. (2010).

(12 lb C/cu. ft.) * (1 cu. ft./5.35 board ft.) * (0.454 kg/lb) * (1,000,000 board ft./1 mmbf) * (1 metric ton/1000 kg) = 1,018 metric tons C/mmbf

- 1,018 metric tons C/mmbf is higher than the 572 metric tons C/mmbf used for the CA Air Resources Board.447 The value is higher due to the board foot to cubic foot ratio used here. When timber product ratios and product end-uses are factored in, the conversion can be higher (1,433 – 1,866 metric tons C/mmbf448).

Consider harvest volume in 2001 (CA Timber Harvest Statistics, Board of Equalization)

1,603 million board-feet (mmbf)

Convert harvest wood volume to carbon mass (Metric tons C)

1,603 mmbf X (1,018 Metric tons C/mmbf) = 1,631,854 Metric tons C

(2) Estimate 100-year carbon loss associated with wood products, using Smith et al. (2006) factors:

Decimal fractions for wood carbon loss over 100 years:[449]

0.349 fraction emitted with energy capture

0.296 fraction emitted without energy capture

Estimate 100-year carbon loss:

1,631,854 Metric tons C X 0.349 = 569,517 Metric tons C emitted with energy capture

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[442] Saah et al., 2015
[443] Skog & Nicholson, 2000
[444] Birdsey, 1992
[445] Morgan et al., 2012
[446] Saah et al., 2015
[447] Saah et al., 2015
[448] Stockmann et al., 2014
[449] Smith et al. 2006, Table 6, Pacific Southwest Softwood

1,631,854 Metric tons C X 0.296 = 483,029 Metric tons C emitted without energy capture

Sum loss:

569,517 + 483,029 = 1,052,546 Metric tons C emitted over 100 years

(3) Estimate carbon persisting in solid wood products after 100 years, using Smith et al. (2006) factors:

1,631,854 – 1,052,546 = 579,308 Metric tons C

(4) Estimate 100-year carbon losses associated with wood products, using Stewart and Nakamura (2012) factors:

Decimal fraction of initial wood carbon lost over 100 years:[450]

1 – 0.3932 = 0.6068

Estimate 100-year carbon loss:

1,631,854 Metric tons C X 0.6068 = 990,209 Metric tons C emitted

(5) Estimate carbon persisting in solid wood products after 100 years, using Stewart and Nakamura (2012) factors:

1,631,854 – 990,209 = 641,645 Metric tons C

*Steps 3 and 5 completed for harvest volumes for each year between 2001-2010, and then averaged to provide the values in FCP Table 12**

(6) Estimate 100-year carbon losses associated with wood products from 2012 harvest volume using Smith et al. (2006) factors:

- Use the carbon associated with the 2012 timber harvest volume from table 10 that ends up in solid wood products/residues, excluding slash, bark
- Apply this volume to the Smith et al. 2006 and Stewart and Nakamura 2012 factors

1,360,776 Mg C X 0.349 = 474,911 Mg C emitted with energy capture

[450] Stewart and Nakamura 2012, available in the University of CA Cooperative Extension Carbon Sequestration Tool for Timber Harvest Plans, online at: http://ucanr.edu/sites/forestry/Carbon_Sequestration_Tool_for_THPs/

*Actual emissions in year 0 from mill residues used for bioenergy = 394,058, 29% of 2012 timber harvest rather than 17% in year 0 per Smith et al. 2006

1,360,776 Mg C X 0.296 = 402,790 Metric tons C emitted without energy capture

Sum loss:

474,911 + 402,790 = 877,701 Metric tons C emitted over 100 years

(7) Estimate carbon persisting in solid wood products from 2012 harvest volume after 100 years, using Smith et al. (2006) factors:

1,360,776 – 877,701 = 483,075 Metric tons C

(8) Estimate 100-year carbon losses associated with wood products from 2012 harvest volume, using Stewart and Nakamura (2012) factors:

1,360,776 Mg C X 0.6068 = 825,719 Metric tons C emitted

(9) Estimate carbon persisting in solid wood products after 100 years from 2012 harvest volume, using Stewart and Nakamura (2012) factors:

1,360,776 – 825,719 = 535,057 Metric tons C

*Additional emissions of 806,583 metric tons C from additional utilization of slash/bark for bioenergy in year 1, plus additional storage benefits from 97,522 metric tons of carbon from bark used for wood products, not calculated out 100 years. Neither are accounted for in these calculations.

*Steps 6-9 used in constructing FCP Table 13

Summary table (i.e. FCP Table 12). Estimates of circa 2001 wood product carbon persisting after 100 years.

Method	Metric tons C
Smith et al. (2006)	579,308
Stewart and Nakamura (2012)	641,645

Summary table (i.e. FCP Table 13). Estimates of 2012 wood product carbon persisting after 100 years.

Method	Metric tons C
Smith et al. (2006)	483,075
Stewart and Nakamura (2012)	553,057

APPENDIX 4 REFERENCES

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