California's Forest Resources, 2001–2005

Five-Year Forest Inventory and Analysis Report

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Technical Editors

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Cover: Mount San Gorgonio. Photo by Tom Iraci.

Abstract

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This report highlights key findings from the most recent (2001–2005) data collected by the Forest Inventory and Analysis Program across all forest land in California. We summarize and interpret basic resource information such as forest area, ownership, volume, biomass, and carbon stocks; structure and function topics such as biodiversity, forest age, dead wood, and hardwood forests; disturbance topics such as insects and diseases, fire, invasive plants, and air pollution; and information about the forest products industry in California, including data on tree growth and mortality, removals for timber products, and nontimber forest products. The appendixes describe inventory methods in detail and provide summary tables of data, with statistical error, about the suite of forest characteristics inventoried.

Keywords: Biomass, carbon, dead wood, diseases, fire, forest land, insects, invasive plants, inventory, juniper, lichens, nontimber forest products, ozone, timber volume, timberland, wood products.

Contents

Summary

California's growing population relies on the state's forests to produce a wealth of environmental services, such as dispersed and developed recreation; clean air and water; fish, game, and nongame wildlife habitat; and a rich variety of commodity and specialty forest products. These forests have experienced increasing pressures and stresses brought about by climate change, invasive plants, air pollution, demand for forest products, and rampant exurban development, along with changing disturbance regimes involving fire, insects, and disease. These natural and human dynamics have increased the complexity of decisions about how California's forests are to be managed. The comprehensive, unbiased, statistically grounded information on the status of California's forest resources provided in this report will help managers and policymakers grapple with, and achieve resolution on, those tough decisions. This summary highlights a few key findings.

For a state arguably better known for its cities, beaches, deserts, and farm and ranch lands, California is surprisingly heavily forested. Forests cover about a third of the state's 100 million acres, and most of this forest (19 million acres) is publicly managed. Roughly 2 million acres are reserved in wilderness areas and state and national parks. Despite having generally lower site productivity than most private lands, and owing to sharp differences in management, public forest land accounts for a disproportionately large share of standing wood volume—65 percent of statewide volume for all trees, and 85 percent of statewide volume for the largest trees (those ≥33 inches in diameter). The volume of large trees on the 6 percent of the state's forest classified as reserved is 20 percent of the statewide total. Given the relationship between age and size, it is not surprising that most of the oldest forests (forests where stand age exceeds 200 years) are found on public land.

Forest management, a major determinant of what the forest looks like, how it functions, and what it produces over time, arises from landowner objectives. Thus, tracking ownership patterns and changes in the outlook of broad classes of owners is essential to discerning trends in forest structure and productivity. Responding to shifting priorities of the public they serve, federal forest land managers now emphasize the production of environmental services at least as much as they do wood products. One result of this change has been that most California-grown wood is now produced on private land. Although the area of private forest land in California is substantial—over 13 million acres—only about 5 million acres of it is managed by the forest industry. Roughly 7 percent of this 5 million acres is managed by a comparatively new and rapidly growing owner subclass consisting of timberland investment management organizations (TIMOs) and real estate investment trusts (REITs). These owners may or may not manage primarily for timber production, and evidence suggests that at least some of the forest land they control is ultimately destined for such nonforest uses as residential and tourism development.

Although some harvest occurs on national forests, both anecdotal and inventory evidence suggests that much of it is driven not by timber production goals but by other management objectives, such as reduction of crown fire hazard. Preliminary analysis of harvested inventory trees shows that the average diameter of trees harvested on national forests was about 14 inches, whereas average diameter on privately owned lands was about 20 inches.

Ownership and management differences are also reflected in the current forest structure. Statewide, nearly half of the volume in trees 5 to 9 inches in diameter is found on privately owned forest land; however, only about 15 percent of the volume in the largest trees (≥33 inches in diameter) occurs on these lands. Although the 2005 Resources Planning Act[1] forecasts a decline in per capita lumber consumption in the United States, population growth is expected to generate a 24-percent increase in wood consumption by 2050. Although it is the fourth largest lumber-producing state in the Nation, California is experiencing a decline in timber harvest and wood production because of increasing constraints on timber management on private lands and the precipitous decline in harvest on public forest lands. Capacity for producing wood products of all kinds fell 60 percent from the late 1980s to 2000, and the trend continues unabated—capacity for lumber production fell 15 percent from 2000 to 2005.

However, capacity of wood-using bioenergy facilities increased. Currently California bioenergy facilities have a combined capacity to generate over 470 megawatts of electricity, and further capacity increases are under consideration. Although conditions for the wood products industry appear challenging, California's high-quality timber and very productive forest land, along with the significant regional demand for wood products, will contribute to the continued viability of this industry, which employs over 112,000 Californians. As the demand for forest products increases, the proportion of in-state demand that can be met by California-grown wood will inevitably fall.

Nontimber forest products such as botanical and floral products are available in great abundance, particularly in the moister forests. Swordfern (see "Scientific and Common Plant Names") was the most abundant herb in California's forests, covering 176,000 acres, and greenleaf manzanita, covering 388,000 acres, is the most abundant shrub.

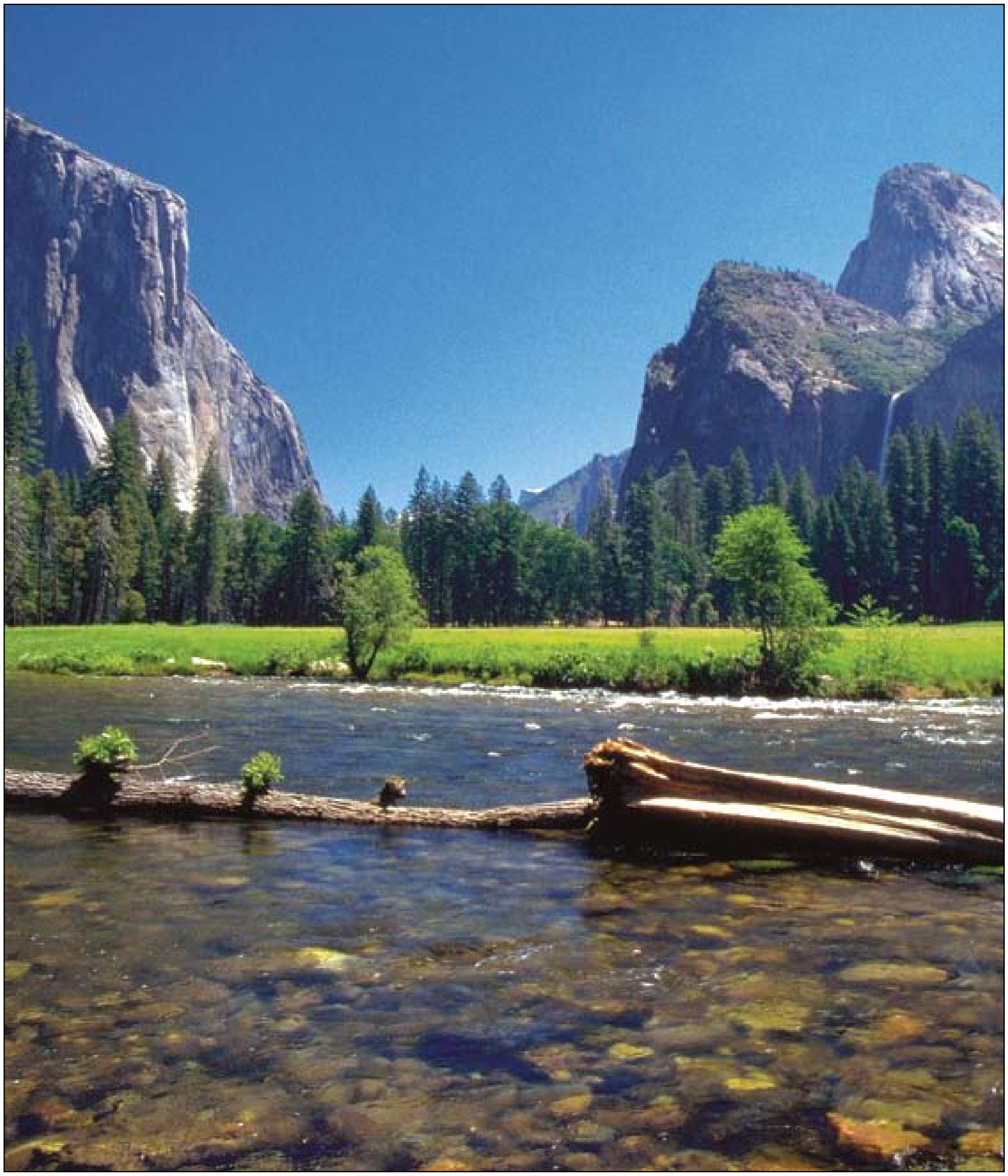
In addition to the influence of forest land ownership and management, disturbance agents—insects, diseases, air pollution, and fire—have long shaped the forested landscape of California and will continue to do so. On over half the forest land area, at least 25 percent of the basal area was observed to have damage caused by biotic or abiotic agents. About 10 percent of sampled sites exhibited a high level of ozone injury and many Sierra Nevada and greater Central Valley forests are exposed to nitrogen pollution, as indicated by lichen community composition. Over 200,000 forested acres have burned per year, on average, between 2001 and 2005. Climate change and increases in population will create greater challenges in managing and mitigating these agents.

Characterizing fire hazard in California forests is a key prerequisite to scoping the magnitude of the fuels management problem and thinking through the fuel treatment options worth pursuing to reduce the frequency of historically uncharacteristic, catastrophic, stand-replacing fire. In modeling crown fire potential under extreme weather, we found that fire would occur as a surface or conditional surface fire in

[1] Haynes, R.W.; Adams, D.M.; Alig, R.J.; Ince, P.J.; Mills, J.R.; Zhou, X. 2007. The 2005 RPA timber assessment update. Gen. Tech. Rep. PNW-GTR-699. Portland, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Research Station. 212 p.

72 percent of forests, and as a passive crown fire (with individual trees "torching" as fire climbs from the surface fuels up the ladder formed by low-hanging branches) in 20 percent of forests. In only 8 percent of forests would fire occur as an active crown fire; these are the forests where canopy density is sufficient for a fire to move from crown to crown, regardless of the presence or absence of ladder fuels. That such forests are in a slim minority suggests that, although the total area that could benefit from fuel treatment is substantial, in most cases treatment may require only the removal of ladder fuels (typically associated with smaller diameter trees) rather than thinning of the mature trees in the upper canopy.

People affect the forest even when they do not manage it, such as the impact on the forest from people moving into what is called the wildland-urban interface, a rapidly growing and probably irreversible trend. Houses being built in this interface zone account for most of the housing growth in the state over the last 10 years. The presence of more and more homes within and adjacent to the forest exerts pressure on the resource in the form of direct use (e.g., wood-cutting, mushroom collection, running with dogs, and off-highway vehicles), injury of forest vegetation by air pollutants, and the spread of exotic organisms, as well as an implied expectation that forest managers will be tasked with achieving substantial fire hazard reduction on ever-larger areas of forest land.



Yosemite Valley.

Mount Baldy.

Chapter 1: Introduction[1]

This report highlights the status of California's forest resources and demonstrates some ways in which forest inventory data can be used to address contemporary forest issues. The estimates of the amount and characteristics of California's forests provided in this report are the result of observations taken on field plots in the years 2001–2005 by the Forest Inventory and Analysis (FIA) Program of the Pacific Northwest Research Station (PNW).

The FIA Program was created within the U.S. Department of Agriculture, Forest Service in 1928 to conduct unbiased assessments of all the Nation's forested lands for use in economic and forest management planning. The FIA Program was charged with collecting forest data on a series of permanent field plots, compiling and making the data available, and providing research and interpretations from that data. Originally, all plots were assessed within a period of a few years, with periodic reassessments, typically every 10 years in the West. Four FIA units are now responsible for inventories of all forested lands in the continental United States, Alaska, Hawaii, Puerto Rico, and several Pacific island groups.

In 2000, as required by the Agricultural Research Extension and Education Reform Act of 1998 (the Farm Bill), FIA began implementing a new standardized national inventory design and method, in which a portion of all plots in each state are measured each year. Appendix 1 includes an explanation of the differences between the previous and current inventory methods. The effect of the change is that, for the first time in 70 years, all FIA units are using a common plot design, a common set of measurement protocols, and a standard database design for compilation and distribution of data. Under this unified approach, FIA is now poised to provide unbiased estimates of a wide variety of forest conditions over all forested lands in the United States in a consistent and timely manner. The new design will enable FIA units in every state to monitor changes in forest conditions, ownership, management, disturbance regimes, and climate impacts that occur through time.

This report covers all forested lands in California (fig. 1). All estimates are average values for the time between 2001 and 2005. Field crews visited each inventory plot to collect measurements of forest characteristics (fig. 2).

[1] Author: Dale Weyermann.

Figure 1—California land cover (forest/nonforest geographic information system (GIS) layer: Blackard et al. 2008; urban/water GIS layer: Homer et al. 2004)

Jeremy Fried

Figure 2—Forest Inventory and Analysis field crews take a wide variety of measurements on each forested plot they visit.

Most measurements use national protocols, but several are specific to forest issues of special interest to California and other west coast states.

Field plots are spaced at approximate 3-mile intervals on a hexagonal grid throughout a variety of forested lands in California (figs. 3 and 4). Plots span both public and privately owned forests, including lands reserved from industrial wood production (e.g., national parks, wilderness areas, and natural areas). The annual inventory involves a cycle of measurements for 10 systematic subsamples, or panels; each panel represents about 10 percent of all plots in California. A panel takes about 1 year to complete (fig. 3) although a few plots are carried over to the next year owing to unanticipated problems with accessing plots (e.g., large fires, early snowfall). In addition, funding was provided to accelerate the installation of three panels on national forests before they were scheduled. Thus, this California inventory report presents the principal findings from the first five panels (50 percent of the data that will ultimately be collected) outside national forests and eight panels (80 percent of the data) within national forests, all collected in the annual inventory between 2001 and 2005—a total of 3,542 forested plots (fig. 4). Inventory results presented are "expanded" appropriately to account for the sampling intensity, so no additional adjustments by the reader are necessary. Additional information about annual inventories is available in appendix 1 of this report and on the Web (http://fia.fs.fed.us/).

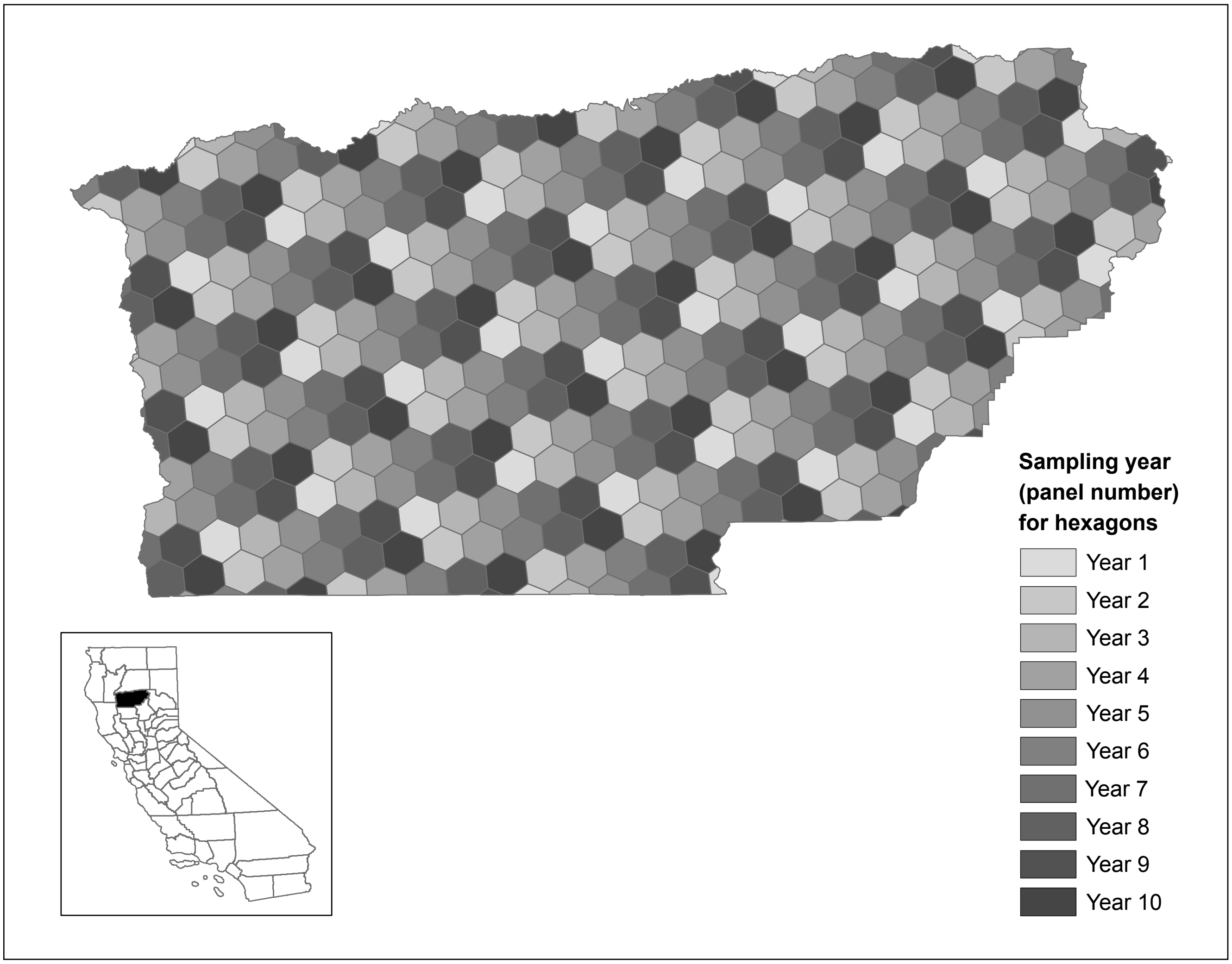


Figure 3—Example of the hexagonal grid that serves as the foundation for field plot assignment, with the cells shaded by which 1 of the 10 annual measurement panels it belongs to, magnified for Tehama County, California. All plots in one panel are sampled in 1 year.

This report presents findings that address many of California's contemporary forest issues and concerns, along with fundamental resource statistics on forest area, volume, and ownership. We also provide policy-relevant findings and statistical summaries related to wildlife habitat, biomass, carbon stocks, and forest disturbance (e.g., urban development, fire, invasive plants, insects, and diseases). Finally, we summarize findings concerning the forest products industry, removals for timber products, and the status of nontimber forest products.

This report consists of 22 issue-focused summaries of current topics in forest health and management. Each summary typically includes background information, key findings developed from the FIA inventory data, and interpretation. Data are summarized by various geographic and ecological classifications that we felt would be useful to a variety of readers (figs. 5 through 8). Appendix 1 describes the inventory design and methods. Appendix 2 contains extensive tables of measured totals accompanied by estimates of sampling error. These tables aggregate data to a variety of levels including ecological unit (e.g., ecological section or ecosection) (Cleland et al. 1997, 2005; McNab et al. 2005), county, owner group, survey unit, forest type, and tree species, allowing the inventory results to be applied at various scales and used for various analyses. Data are also available for download at http://www.fia.fs.fed.us.

Figure 4—Forested plots measured between 2001 and 2005 provide the data used in this report. Locations are approximate (forest/nonforest geographic information system (GIS) layer: Blackard et al. 2008; urban/water GIS layer: Homer et al. 2004).

Figure 5—California counties (forest/nonforest geographic information system layer: Blackard et al. 2008).

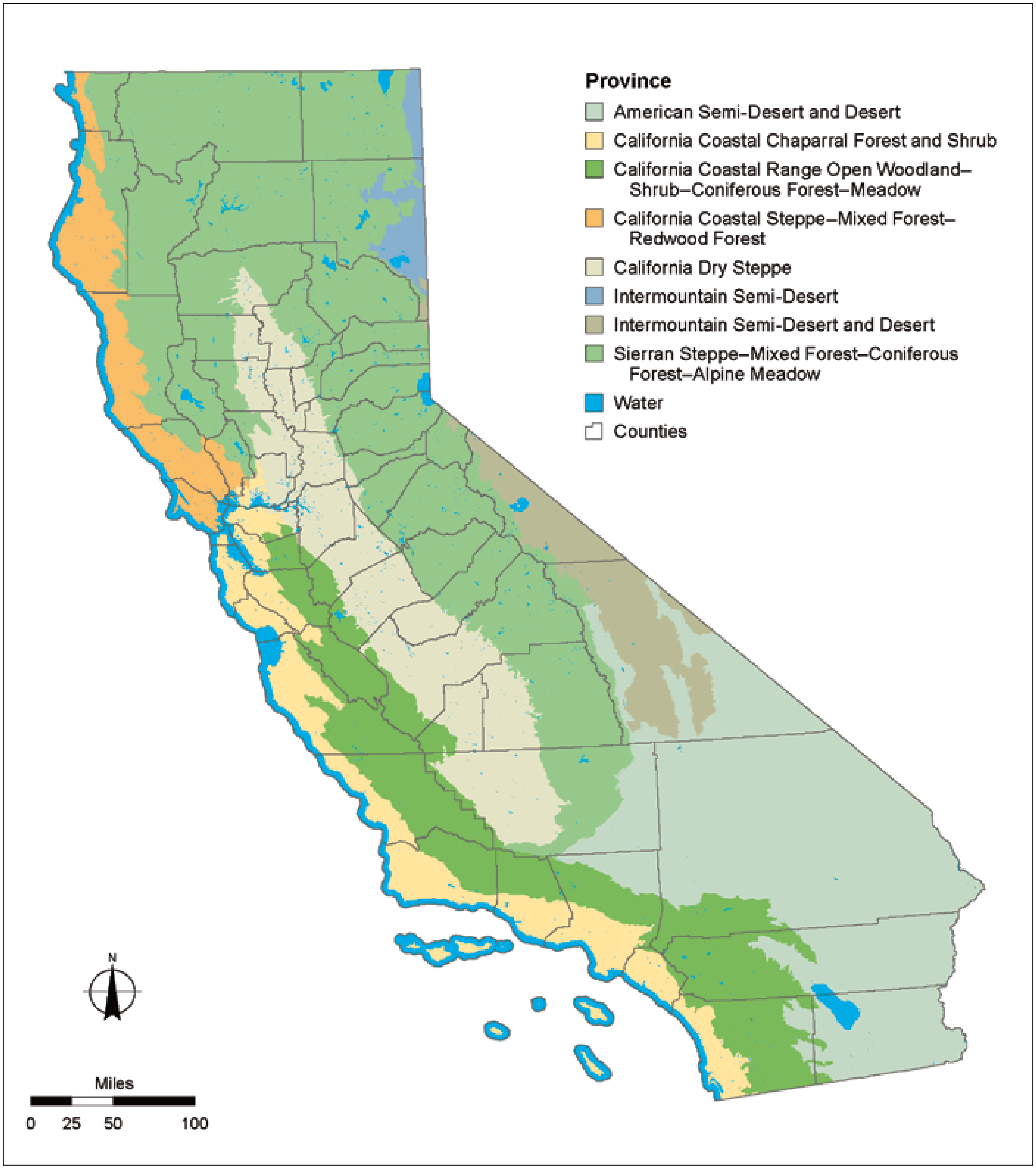
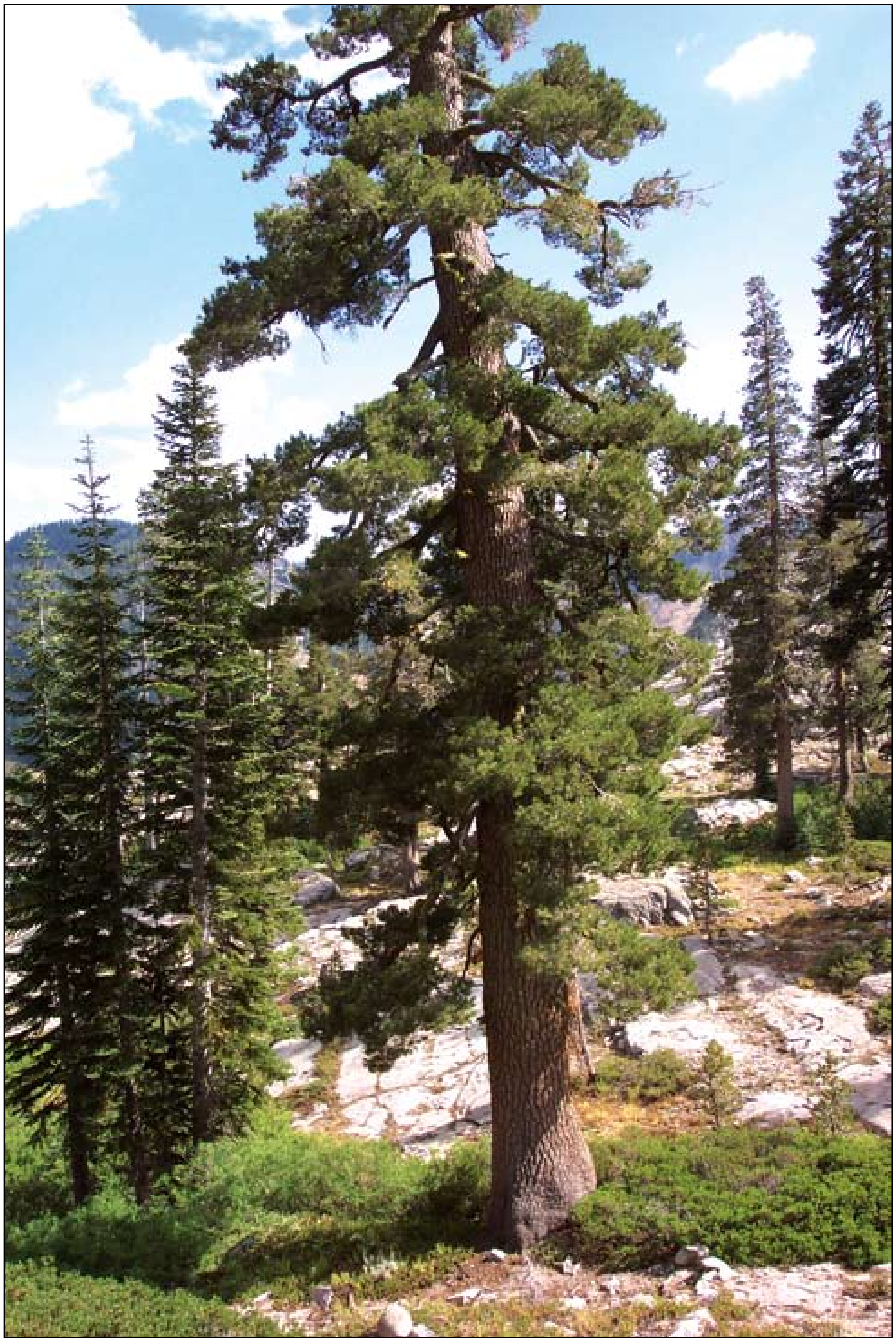


Figure 6—California ecosections (ecosection geographic information system layer: Cleland et al. 2005).

Figure 7—California forest ownership categories (ownership geographic information system layer: California Department of Forestry and Fire Protection 1997).

Figure 8—California Forest Inventory and Analysis survey units (county groupings used in this report) (forest/nonforest geographic information system (GIS) layer: Blackard et al. 2008, urban/water GIS layer: Homer et al. 2004).


Joel Thompson

Western white pine.

Chapter 2: Basic Resource Information

This chapter provides an overview of the distribution, extent, and ownership of California's extensive forests, as well as the amount of wood—volume and biomass—in them. It lays the groundwork for the more specialized analyses and summaries in later chapters. Highlights include a discussion of forest acreage held in public and private hands, characteristics of family-owned forests, and a summary of biomass and carbon stocks in relation to bioenergy and carbon credits.

Forest Area[1]

Background

The distribution of California's forest land can be traced to its climate and geography. The Sierra Nevada's northwest-southeast bulk intercepts much moisture from air masses flowing eastward from the Pacific Ocean (fig. 1). Because of these precipitation patterns, the temperature-moderating effects of elevation, and the state's predominantly Mediterranean climate with its extended summer drought, most of California's forests are found in the mountainous areas, chiefly the Sierra Nevada, Klamath, and Coast Ranges, and in the cool, mesic fog belt along the state's north and central coasts. California's geography creates a diverse assemblage of distinct combinations of climate, elevation, and soil type. Twenty ecosections have been mapped to define and classify this diversity; most of these contain some type of forest.

The composition and distribution of California's forests have been subject to ongoing change throughout millennia owing to factors such as climate, fire, insects, and diseases and in recent years have been joined by another important factor, the pressure of large-scale human development and settlement. California is home to over 30 million people, and with an accelerated rate of housing development in forested areas (Hammer et al. 2007), California is vulnerable to losing forest land through urbanization. The status and trends of forest area are fundamental indicators of forest health at national, state, and local scales and have been consistently assessed by the Pacific Northwest Research Station Forest Inventory and Analysis (FIA) Program for the last several decades.

The FIA assessment consists of both field-crew observations of forest status on the ground and aerial photointerpretation or remote sensing procedures to stratify the sample allowing more estimates of forest attributes (see app. 1 for specific information on sampling methods). International reporting criteria for gauging forest health and sustainability (e.g., Montréal Process criteria and indicators and United Nations Food and Agriculture forest resources assessment) emphasize that the trend in area of forest is one of the first indicators that nations should use in their forest assessments (USDA Forest Service 1997). The FIA Program's tracking of this trend provides statistically unbiased estimates that are not available elsewhere for these international assessments and for national and state assessments such as the Resources Planning Act Assessment (Haynes et al. 2007) and California's quintennial forest assessment (California Department of Forestry and Fire Protection 2003).

Findings

Area by land class—
Approximately one-third of California's 100 million acres meets the criteria for forest land (http://www.dof.ca.gov/html/fs_data/stat-abs/tables/a1.xls) (fig. 9). Forest land is defined as land that is at least 10 percent stocked by forest trees of any size, or land formerly having such tree cover and not currently developed for a nonforest use (see "Glossary" for a detailed definition). The minimum area for classification is 1 acre. The largest proportion of forests in California (about 20 million acres) is classified as nonreserved timberland (fig. 10). Timberland is defined as forest land that is capable of producing in excess of 20 cubic feet of wood per acre per year and where harvest is not legally prohibited. Of all survey units, the North Interior survey unit has the largest share of forest land (35 percent) (fig. 8). By ecological section, the Sierra Nevada has the largest share (30 percent) (fig. 6).

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[1] Author: Glenn Christensen.


Joel Thompson

Figure 9—Over 33 million acres in California are forested.

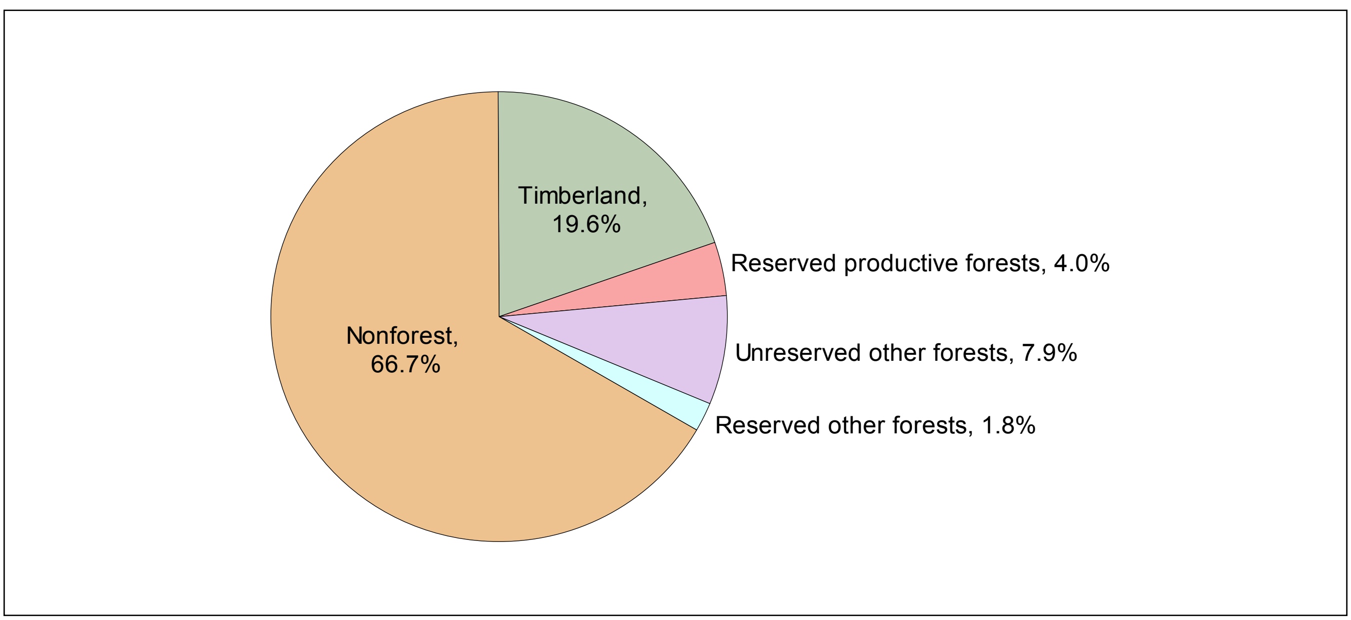

Figure 10—Percentage of area (acres) by land class category in California, 2001–2005.

Area by forest type group—
The FIA Program classifies forest land based on cover of the predominant live-tree species. More than half (about 57 percent) of California's forests are composed of softwood conifer forest types, totaling 19 million acres. Over 40 percent of acres with these types are classified in the California mixed-conifer group (8 million acres) (fig. 11). A forest type group is a combination of forest types that share closely associated species and similar productivity characteristics. The mixed-conifer group may be composed of several softwood conifer species, including Douglas-fir, sugar pine, ponderosa pine, Jeffrey pine, white fir, red fir, incense-cedar, and other true firs (see "Scientific and Common Plant Names"). Each of four other type groups (ponderosa pine, fir/spruce/mountain hemlock, other western softwoods, and pinyon/juniper) occupies close to 10 percent of the area of softwood forests. The remaining acres are divided between several other type groups, each contributing less than 10 percent of softwood forest area.

Hardwood forest types account for 40 percent (13 million acres) of California's forest land, with the last 2 percent classified as nonstocked—forest land that is less than 10 percent stocked by trees or, in some cases, that has less than 5 percent crown cover. The most common hardwood forest type in California is the western oak group. Oak forests occupy 10 million acres of forest land throughout the state (fig. 12). Although this amounts to only about 28 percent of all forest land, oak forests comprise about 73 percent of all acres classified as hardwood forest type (see the Hardwoods section for more information on oaks).

Area by productivity class—
Nearly 12 percent (4 million acres) of California's forest land is highly productive, defined as having the capacity to grow more than 165 cubic feet of wood per acre per year. About 39 percent of this highly productive land is classified as California mixed-conifer (fig. 13). Mixed-conifer forests also dominate the next highest productivity class (85 to 164 cubic feet per acre per year), accounting for about 34 percent of the forest area in this class. Redwood forests have the highest proportion of their acres (100 percent) in the highest two productivity classes. The western oak forest type group accounts for most of the area—approximately 53 percent—in the lowest productivity class (0 to 9 cubic feet per acre per year).

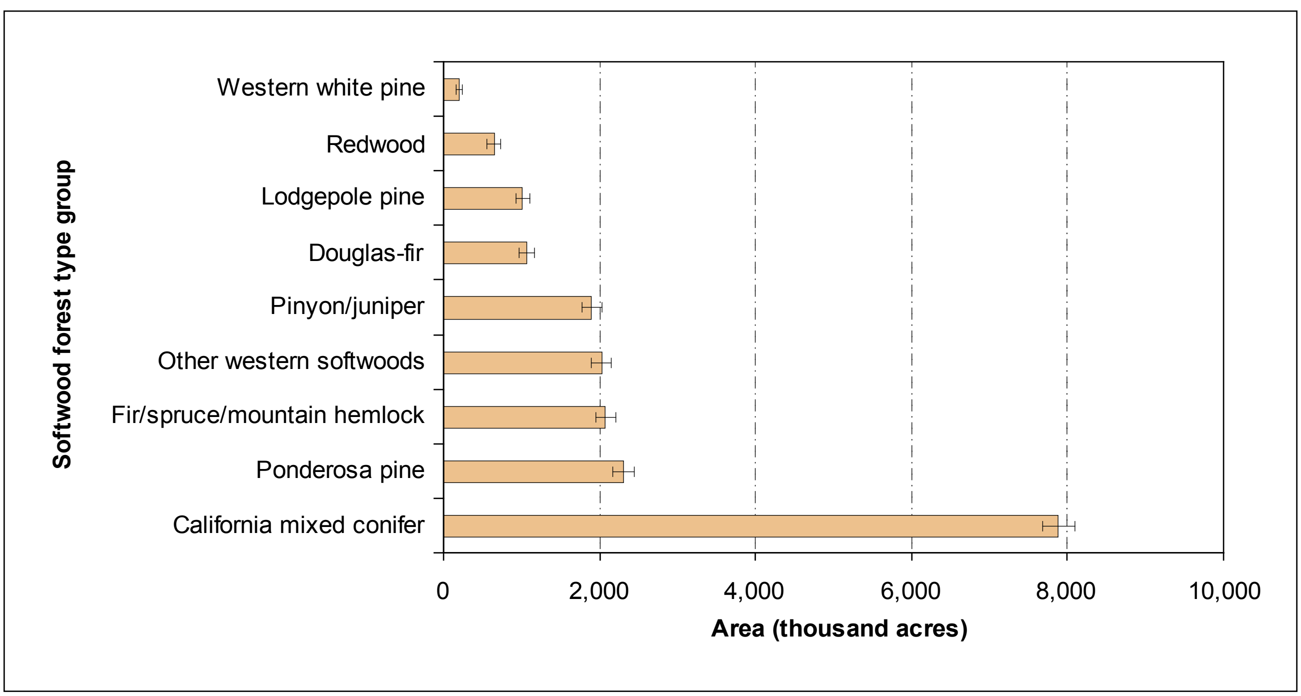

Figure 11—Area of softwood forest type groups on forest land in California, 2001–2005.

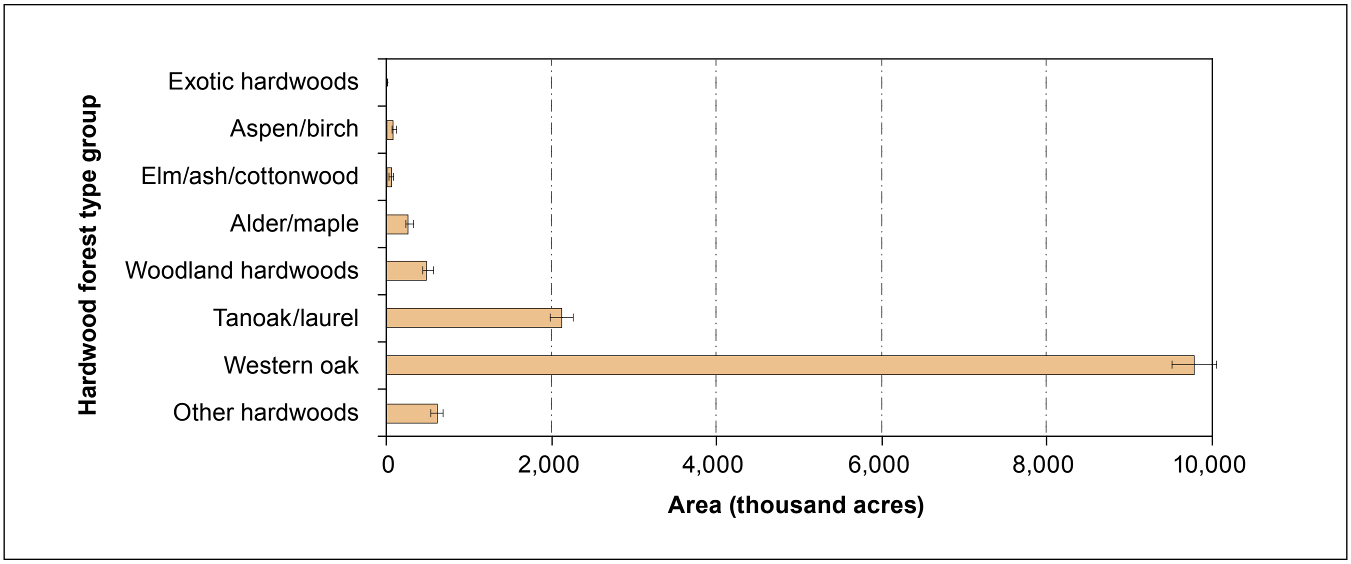

Figure 12—Area of hardwood forest type groups on forest land in California, 2001–2005.

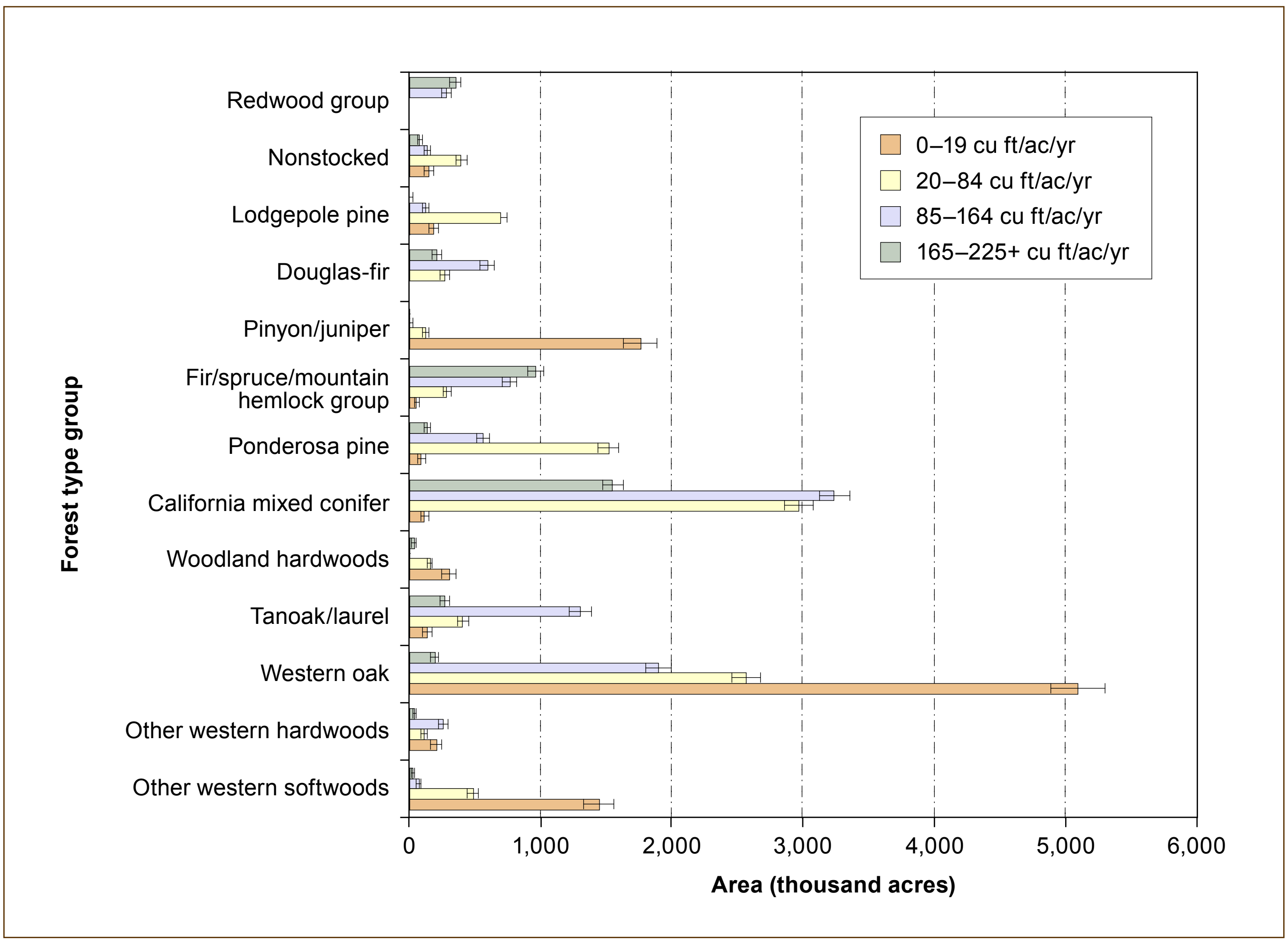

Figure 13—Area of productivity classes by forest type group on forest land in California, 2001–2005.

Interpretation

Overall, statewide acreage of forest land in California has declined from the 1950s to the 1980s but has stabilized more recently (fig. 14). Nearly all the recent decreases have occurred in the oak woodlands; only one plot in forests other than oak woodlands was converted from forest to other uses since the last inventory. We expect change in the extent and distribution of forest land, driven by pressures of development, resource demands, shifts in ownership, changing demographics, and climate change. The impact of these influences on forest area trend across the state will be monitored with repeated FIA measurements.

Forest area tables in appendix 2—

- Table 1—Number of FIA plots measured from 2001 to 2005, by land class, sample status, ownership group, California
- Table 2—Estimated area of forest land, by owner class and forest land status, California, 2001–2005
- Table 3—Estimated area of forest land, by forest type group and productivity class, California, 2001–2005
- Table 4—Estimated area of forest land, by forest type group, ownership, and land status, California, 2001–2005
- Table 5—Estimated area of forest land, by forest type group and stand size class, California, 2001–2005
- Table 6—Estimated area of forest land, by forest type group and stand age class, California, 2001–2005
- Table 7—Estimated area of timberland, by forest type group and stand size class, California, 2001–2005

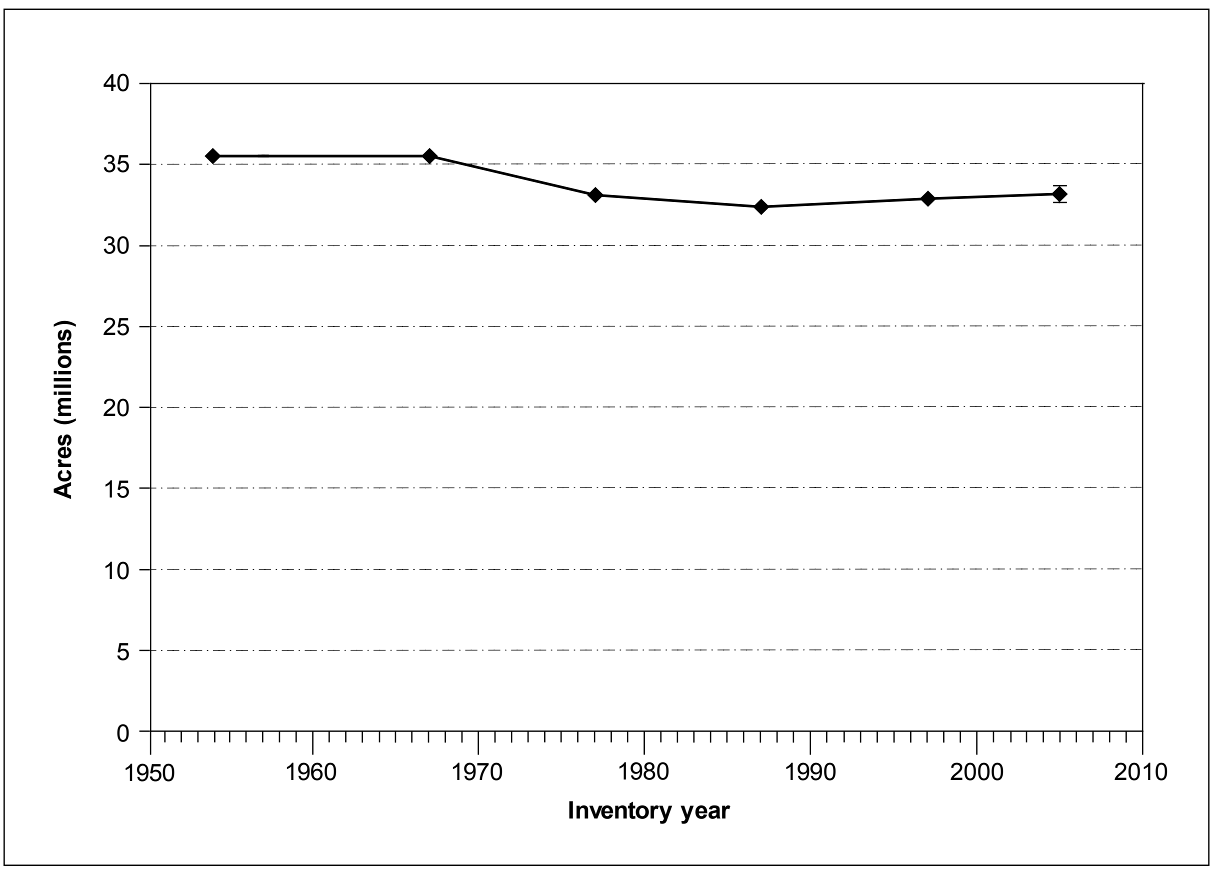

Figure 14—Area of forest land, excluding chaparral, by inventory year in California, 1953–2005 (Smith et al. 2004).

Ownership[2]

Background

Because forest owners differ in their management objectives and intentions, ownership has an important influence on the character of California forests. Federal owners are usually mandated to consider multiple management objectives including, but not limited to, wood production, protection of water resources and wildlife, enhancement of recreation, habitat conservation, and preservation of biological diversity. Although private and corporate owners may also be interested in these ecological and social objectives, they often consider other objectives more important, such as obtaining revenue from the sale of wood products or enhancing the aesthetic and amenity value of their forests. The three classes of ownership discussed here are federal, other public (e.g., state and local government), and private (including corporate and noncorporate private owners) (fig. 15).

Findings

The federal government manages over half of California's 33 million forested acres, most of this within the National Forest System (NFS) (fig. 16). Beginning in the late 1980s, wood production was increasingly deemphasized on federal forests. Production of wood fiber from federal lands decreased from an average of 40 percent of California's total between 1963 and 1987, to 23 percent between 1988 and 2000, to 10 percent between 2001 and 2006 (California State Board of Equalization 2006).

[2] Author: David Azuma.

Jane Terzibashian

Figure 15—Over one-third of California's 33 million acres of forest land are privately owned.

Federal owners—

About 22 percent of the 15.7 million forested acres of national forest land are congressionally reserved (land where management for the production of wood products is prohibited). On average, older stands with trees in larger size classes tend to be in federal forests rather than in privately owned forests and they occur at higher elevations (fig. 17); the average elevation of federal forests (4,850

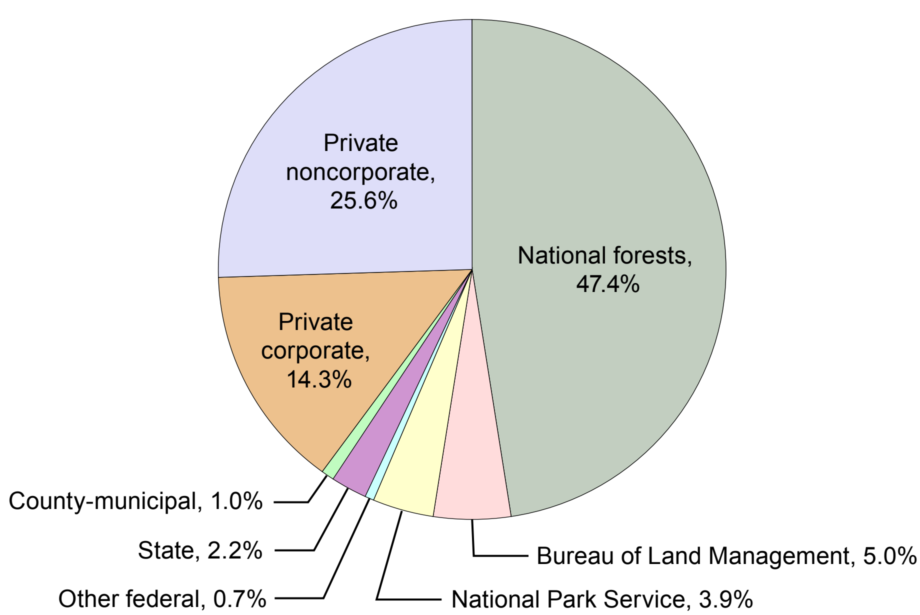

Figure 16—Percentage of forest land by owner group in California, 2001—2005.

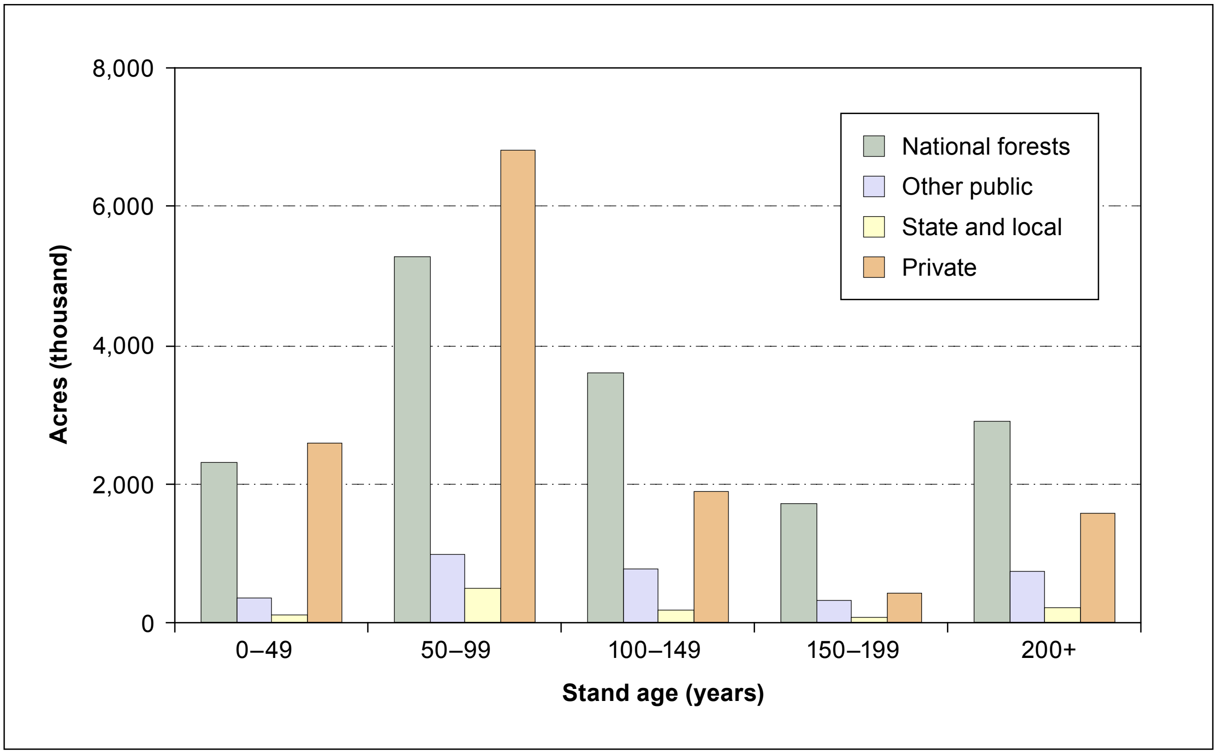

Figure 17—Area of forest land by owner group and stand age class in California, 2001–2005.

feet) is more than double that of private forests (2,344 feet). Although the majority of federal forest land is not reserved in the technical sense, administrative restrictions, as well as practical constraints related to species mix, site productivity, and soil conditions, make many acres unsuitable for wood production. The NFS reports that about 15.4 percent of available forest land is actually harvestable in California, either at full or reduced levels (USDA Forest Service 2007c)

California has about 5.8 million acres of reserved forest land. About 3.5 million of these acres are managed by NFS, mostly in wilderness areas. The remaining acreage is distributed among other public owners, including the Bureau of Land Management (BLM), the National Park Service (NPS), the U.S. Fish and Wildlife Service, and state and county parks. Forests administered by the NPS, such as those in Yosemite, Sequoia/Kings Canyon, Lassen Volcanic, and Redwood national parks, amount to 1.8 million acres. Reserved forest land tends to be in older age classes; more than 67 percent of reserved forests, about 3.9 million acres, are older than 100 years.

Private owners—

Private owners include families, individuals, conservation and natural resource organizations, unincorporated partnerships, associations, clubs, corporations, and Native American tribes. Noncorporate private owners hold about 7.9 million acres of forest land. In contrast to public forest land, private forests, on average, contain younger stands, have more acreage and volume in smaller size classes, and occur on higher-productivity land at lower elevations.

Corporate owners manage about 4.7 million acres of forest land in California. Less than 10 percent of this land is held by timberland investment management organizations (TIMOs) and real estate investment trusts (REITs), which manage around 344,000 acres.[3] These ownership groups are nonindustrial in that their corporate owners generally do not also own or control wood processing facilities. Both REITs

[3] Best, Connie. 2007. Personal communication. Pacific Forest Trust. The Presidio. 1001-A O'Reilly Avenue, San Francisco, CA 94129.

Family-Owned Forests: A Survey[4]

The National Woodland Owner Survey, a mail-in, questionnaire-based survey conducted by FIA, provides some insight into private family forest owners and their concerns, current forest management, and future intentions (fig. 18) (Butler et al. 2005, National Woodland Owner Survey 2008). In California, about 99 percent of surveyed family owners have parcels of 500 acres or less making up 58 percent of the area of family-owned forest land (fig. 19). Less than 1 percent of the surveyed owners had written management plans. Timber harvesting has been the recent focus (within the last 5 years) of a fairly large percentage of owners (33 percent), representing a similar percentage of family-owned forest acres (28 percent). The greatest concerns of respondents were issues of passing land on to heirs, fire, trespassing, exotic plants, and property taxes. Future plans for forest land differed: 4 to 7 percent of surveyed owners planned to sell, subdivide, or convert their forests.

Private forest land ownership will certainly change as owners age and pass their land on to heirs who may or may not retain it as forest land. Average parcel size has become smaller over the last 20 years and probably will continue to do so. Land use laws and regulations will influence the rate of conversion of private forest land to other uses.

[4] Author: Sally Campbell.

Figure 18—Small parcel (500 acres or less), family-owned forests make up 58 percent of the acreage in noncorporate private forest land in California.

The ownership survey revealed the following demographics of California family forest landowners:

- 84 percent are older than 55 years.
- 17 percent have earned a bachelor's or graduate degree.
- 94 percent are Caucasian.
- 63 percent are male.
- 45 percent have owned their land for more than 25 years.
- 76 percent use their land as part of their primary residence.
- At least 33 percent have harvested timber, firewood, or nontimber forest products from their land in the 5 years preceding the 2004 survey.

Figure 19—Percentage of area and percentage of number of family-owned forest holdings by size class in California, 2004.

and TIMOs own forest land as an investment category that diversifies their portfolio; as such, forest land must both compete with and complement alternative investment opportunities. The difference between REITs and TIMOs is that REITs directly own forest land, whereas TIMOs manage land that is owned by the investors.

Interpretation

Current ownership of California's forests greatly influences where forest products and other environmental services are available, and in what quantity and quality. From an ownership standpoint, the near future of California's timber products supply looks relatively stable in that the land controlled by large corporate and other private entities does not yet show evidence of imminent, rapid change. Morgan et al. (2004) cover other factors that may influence management and utilization of California's forests. A major concern with diminished wood production on NFS lands is that the burden of meeting the demand for timber products has been shifted onto other public and private lands. An aging ownership base in the noncorporate owner group and the substantial percentage of forested lands now used as primary residences adds uncertainty to the longer term future availability of these lands for timber production. It is unclear what an increased ownership shift from forest products companies to TIMOs and REITs would mean for the management of California's industrial forests. One possible outcome is that more land will be developed for nonforest uses as owners pursue greater financial returns.

Ownership tables in appendix 2—

- Table 2—Estimated area of forest land, by owner class and forest land status, California, 2001–2005
- Table 3—Estimated area of forest land, by forest type group and productivity class, California, 2001–2005
- Table 4—Estimated area of forest land, by forest type group, ownership, and land status, California, 2001–2005

Timber Volume[5]

Background

The current volume of live trees provides the foundation for estimating several fundamental attributes of forest land such as biomass, carbon storage, and capacity to produce wood products. Forest volume can serve as an indicator of forest productivity, structure, and vigor, which together serve as a broad indicator of forest health. Species-specific equations that include tree diameter and height are used to calculate individual tree volumes; these are summed across all trees to provide estimates of conditions at the forest level. The net volume estimates provided in this report for live trees do not include volume for any observed defects, such as rotten and missing sections along the stem.

Findings

California has approximately 95 billion net cubic feet (428 billion Scribner board feet) of wood volume on forest land, with a mean volume of about 2,875 cubic feet (12,879 Scribner board feet) per acre. The greatest proportion is from softwood tree species such as Douglas-fir, true firs, and pines, which collectively make up 81 percent of net live-tree volume on forest land (fig. 20). The remaining 19 percent of live-tree volume is from hardwood species, such as oaks and a mix of many other western hardwood species.

Forest land volume by ownership—
The majority (55 percent) of live-tree cubic-foot volume in California is on forested acres managed by the Forest Service (fig. 21). Most of the rest is on land owned by private noncorporate (18 percent) and corporate (14 percent) owners. State and federal forest land (excluding BLM) tends to have more volume per acre than private land (fig. 22). Average volume on state lands is notably large, reflecting the substantial areas of old-growth redwood forests within state parks and the relatively high levels of inventory on state-owned forest land.

[5] Author: Glenn Christensen.

Figure 20—The greatest volume of wood in California is found in the North Interior area (Mount Shasta area shown here).

Forest land volume by survey unit—
Most wood volume is found in the heavily forested northern portions of the state (fig. 23). As shown in the tabulation below, the North Interior survey unit has the highest total wood volume. About three-fifths of the statewide wood volume is divided evenly among three survey units, Sacramento, North Coast, and San Joaquin. The North Coast unit has the most wood volume per acre. When modeled as an interpolated map, the same trend can be seen in volume per acre—nearly all the wood volume is found in the northern two-thirds of the state.

The following tabulation shows mean and total wood volume of live trees on forest land by survey unit, with sampling error (SE) in parentheses:

Survey unit	Total volume (SE)		Mean volume (SE)		
	Billion cubic feet	*Billion Scribner board feet*	*Percent*	*Cubic feet per acre*	*Scribner board feet per acre*
North Interior	27 (0.8)	126 (4.3)	28	2,746 (74)	12,774 (434)
Sacramento	21 (0.7)	93 (3.7)	22	3,105 (96)	13,920 (555)
North Coast	20 (1.5)	87 (7.7)	22	4,381 (290)	18,578 (1,512)
San Joaquin	20 (0.8)	99 (4.7)	21	2,613 (98)	12,623 (580)
Central Coast	5 (0.7)	18 (3.5)	6	2,094 (222)	7,168 (1,281)
Southern	1 (0.2)	5 (0.9)	1	847 (102)	2,991 (520)
Total	95 (2.0)	428 (10.8)	100	2,875 (59)	12,879 (325)

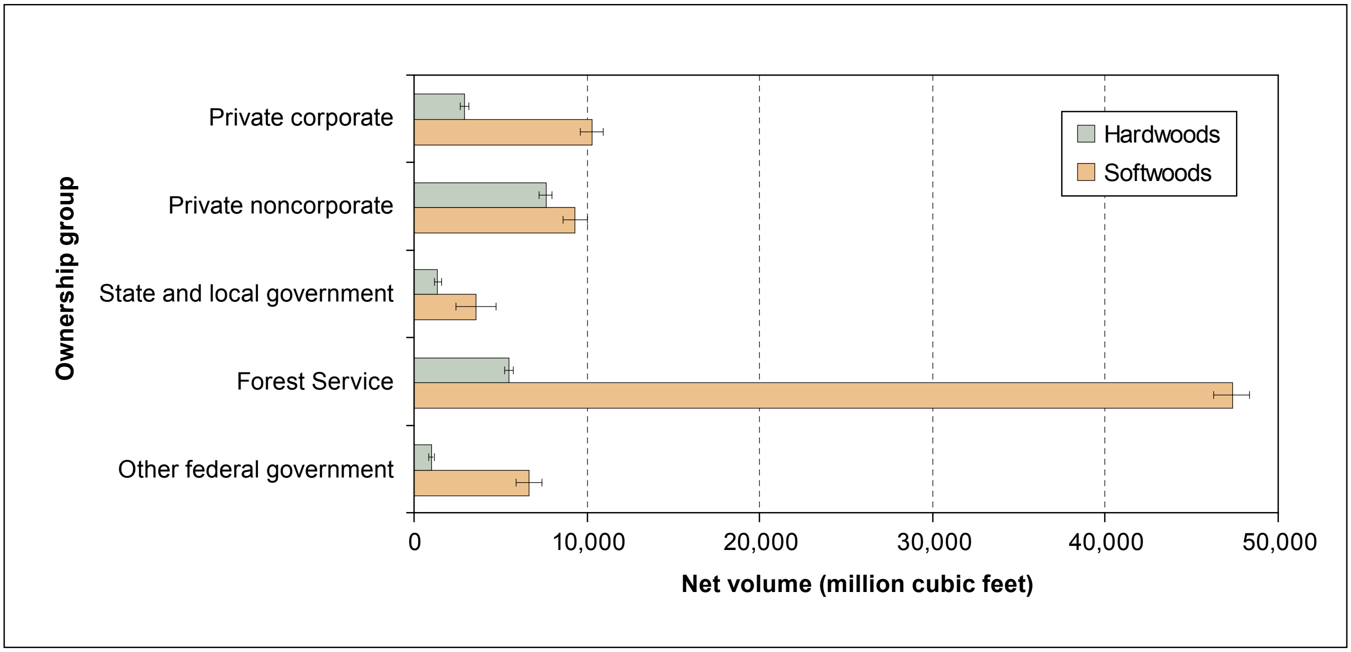

Figure 21—Net volume of all live trees by ownership group on forest land in California, 2001–2005.

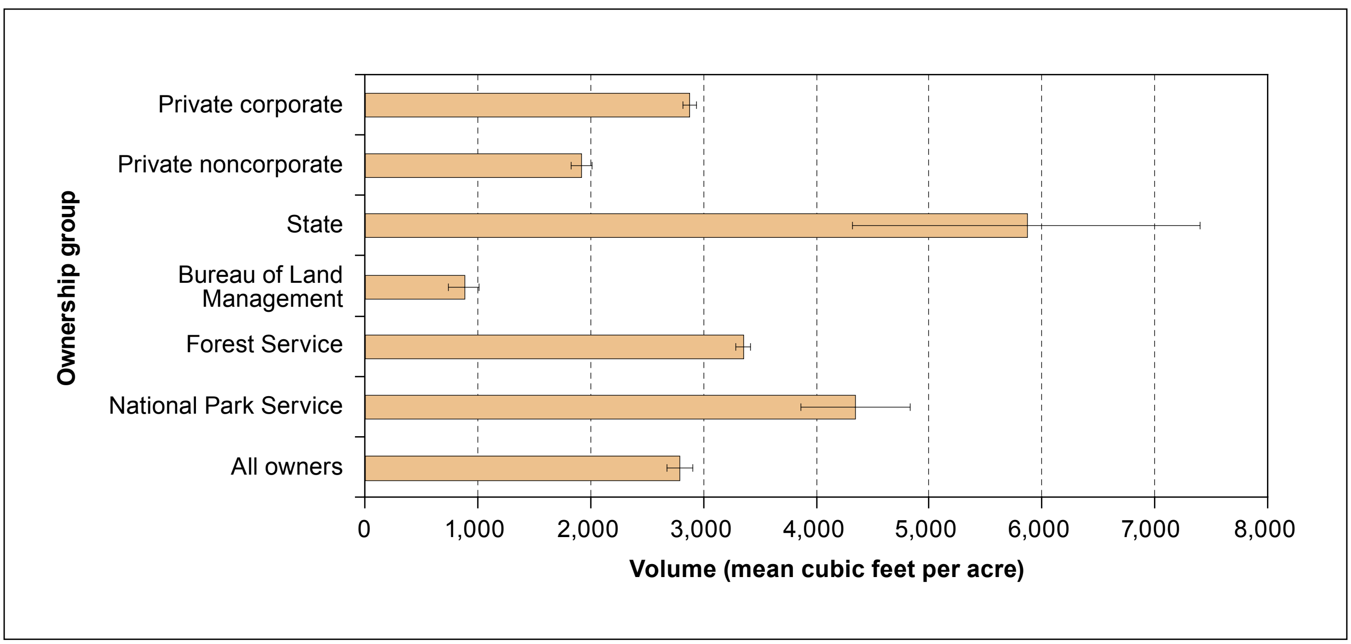

Figure 22—Mean net volume per acre of all live trees by ownership group on forest land in California, 2001–2005.

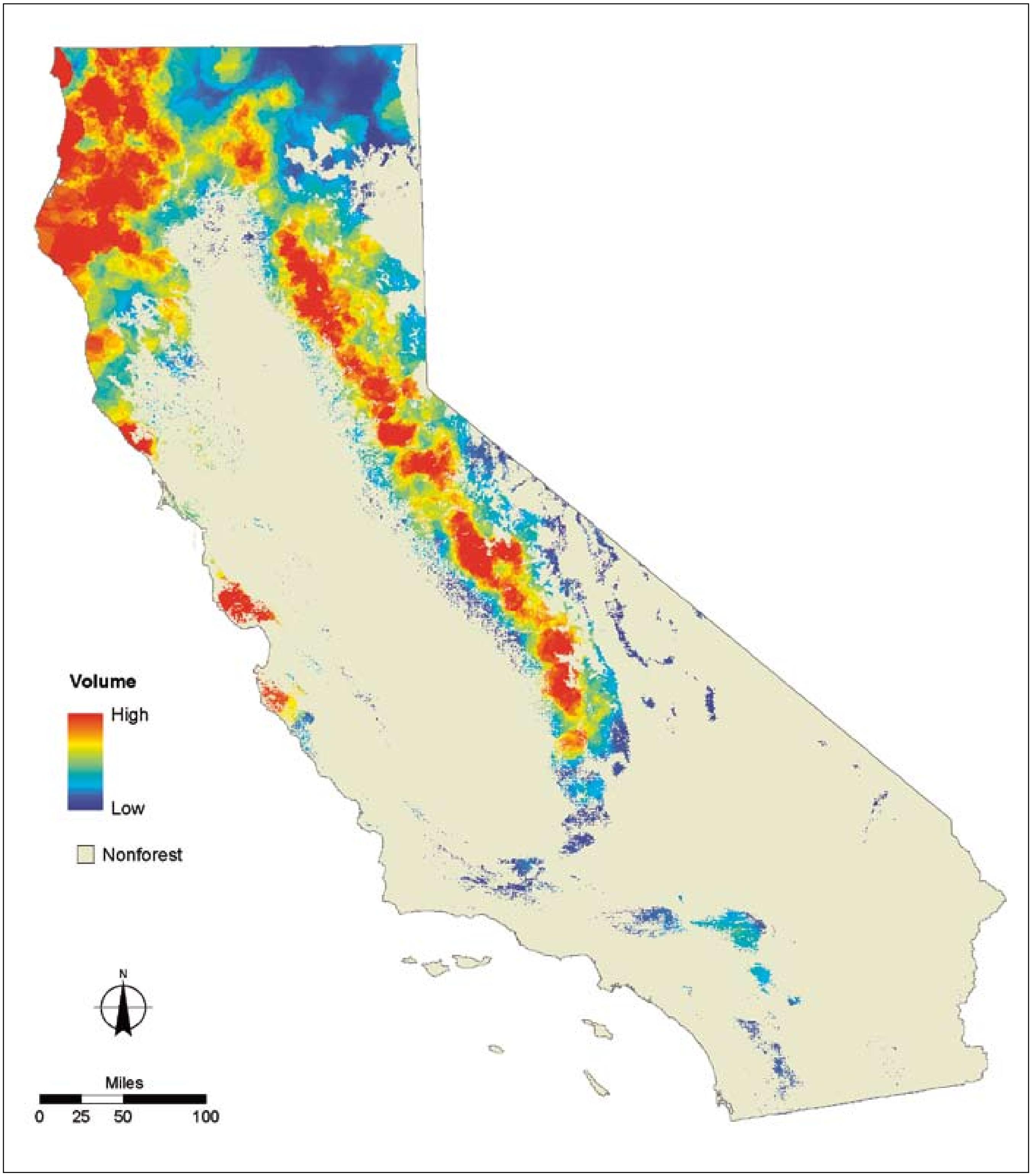

Figure 23—Estimated live tree volume (net cubic feet per acre) in California, 2001–2005. Estimates are kriged predictions of likely volume per acre on forest land, based on mean net cubic foot volume per plot (forest/nonforest geographic information system (GIS) layer: Blackard et al. 2008).

Forest land volume by diameter class—
Approximately 43 percent of live-tree volume for both softwood and hardwood trees is in trees 5 to 20.9 inches d.b.h. (fig. 24). An estimated 23 percent of all live-tree volume is in the largest diameter class (trees 37 inches d.b.h. and larger), nearly all of which are softwood trees. As presented in the previous section on ownership, a greater proportion of acres in the oldest age classes are in federal ownership (fig. 17). The same is true for volume; federal ownership contains higher wood volume than private ownership (fig. 25). Forty-four percent of the wood volume in trees of the smallest diameter class (5.0 to 8.9 inches d.b.h.) is in forests managed by the Forest Service, whereas 20 percent is in forests managed by private corporate owners. In contrast, 65 percent of the wood volume in trees in the largest diameter class (≥33.0 inches d.b.h.) is in forests managed by the Forest Service, and only 6 percent is in corporate forests.

Forest land volume by species group—
Over half (approximately 57 percent) of live-tree volume on California's forest land is in trees of three species groups: Douglas-fir, true fir, and ponderosa-Jeffrey pine. Douglas-fir accounts for most of the total volume; about 22 percent of all live-tree volume in the state is contained in trees of this species (fig. 26). The true fir species group accounts for slightly less (21 percent), and the ponderosa and Jeffrey pine species group accounts for 14 percent. Of the hardwood species, the oak species group accounts for the most volume; wood volume contained in oak trees makes up 11 percent of total cubic-foot wood volume and 59 percent of cubic-foot hardwood volume statewide.

Volume of sawtimber-sized trees on timberland[6]—
Douglas-fir accounts for 31 percent of the sawtimber volume, true firs 22 percent, and ponderosa and Jeffrey pines 18 percent (fig. 27). This is the volume of wood that is potentially available for manufacturing wood-based products. Among the hardwoods, oaks contribute the most to sawtimber volume, making up about 2 percent of the total.

[6] Sawtimber volume is defined as the boles of trees of commercial species that are large enough to produce utilizable logs (9.0 inches d.b.h. minimum for softwoods, 11.0 inches d.b.h. minimum for hardwoods), from a 1-foot stump to a minimum top diameter (7.0 inches outside bark diameter for softwoods, 9.0 inches outside bark diameter for hardwoods).

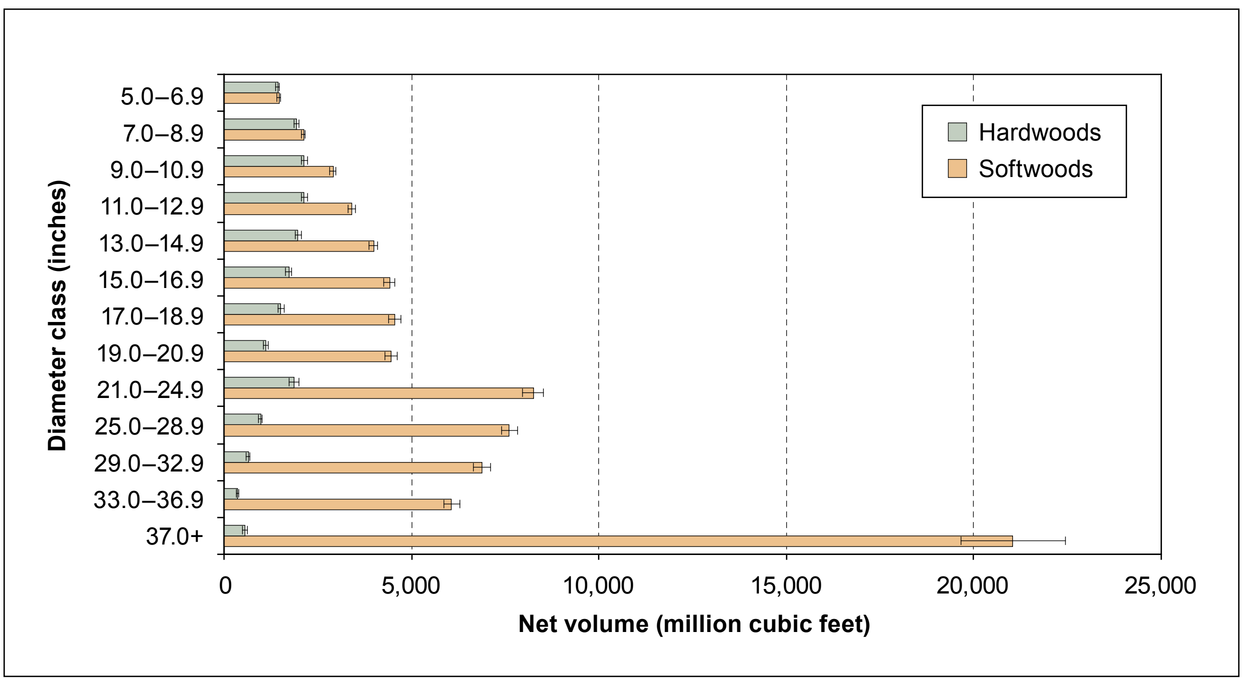

Figure 24—Net volume of all live trees by diameter class on forest land in California, 2001–2005.

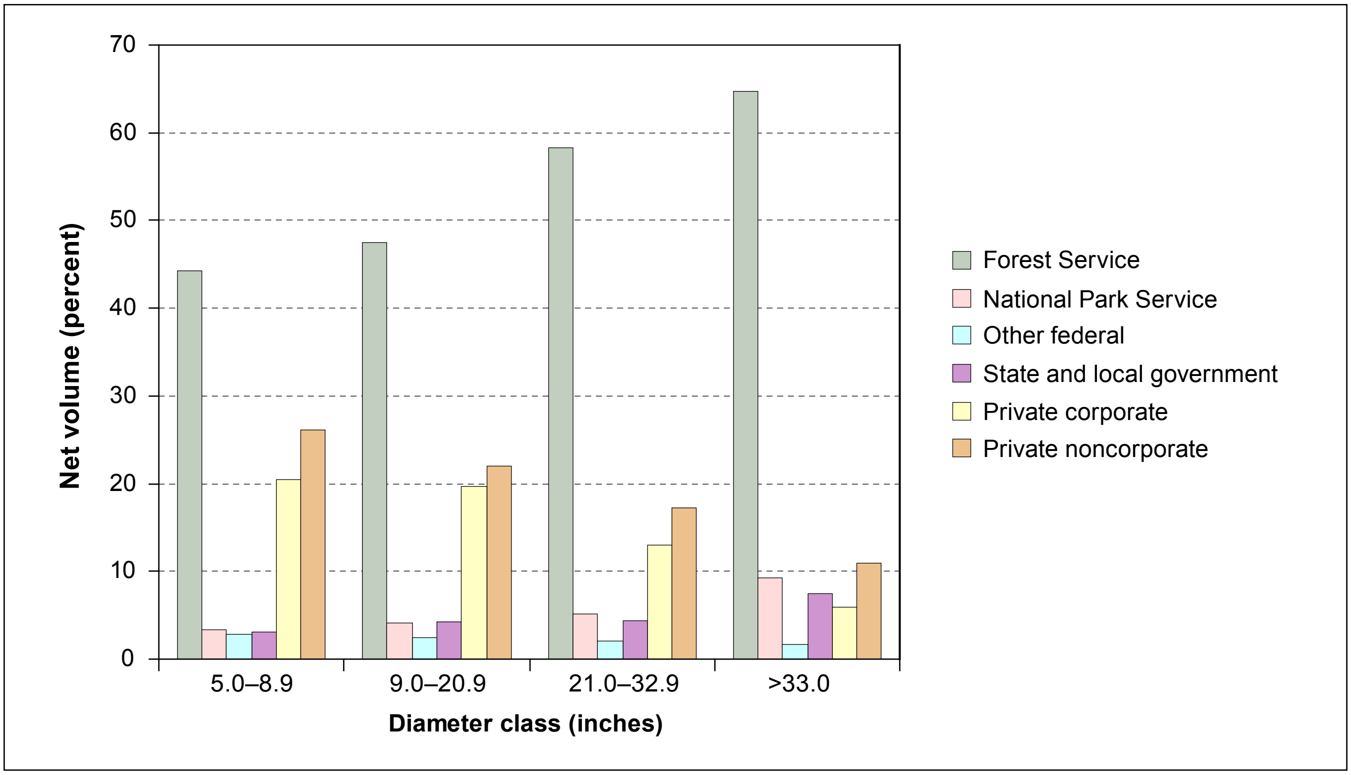

Figure 25—Percentage of net volume of all live trees by diameter class and ownership group on forest land in California, 2001–2005.

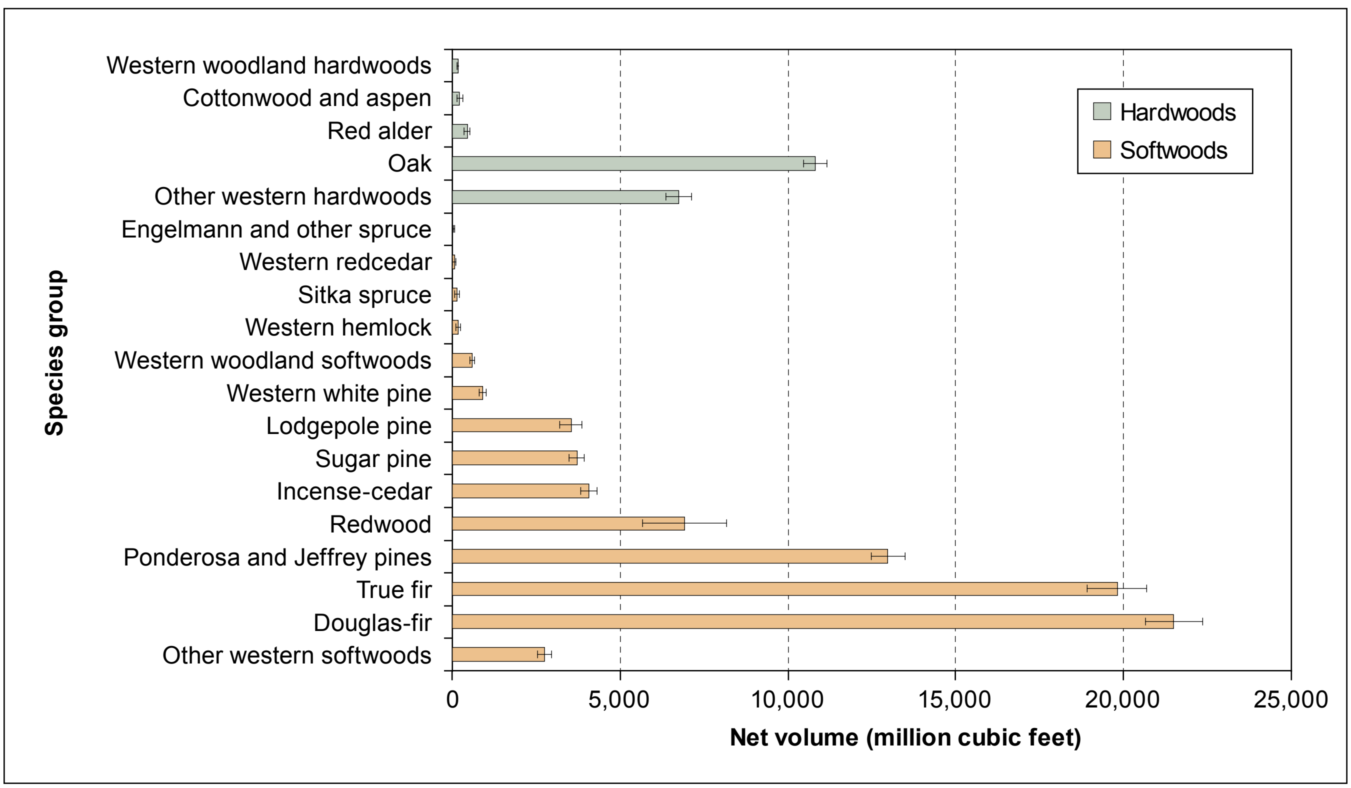

Figure 26—Total net volume of all live trees by species group on forest land in California, 2001–2005.

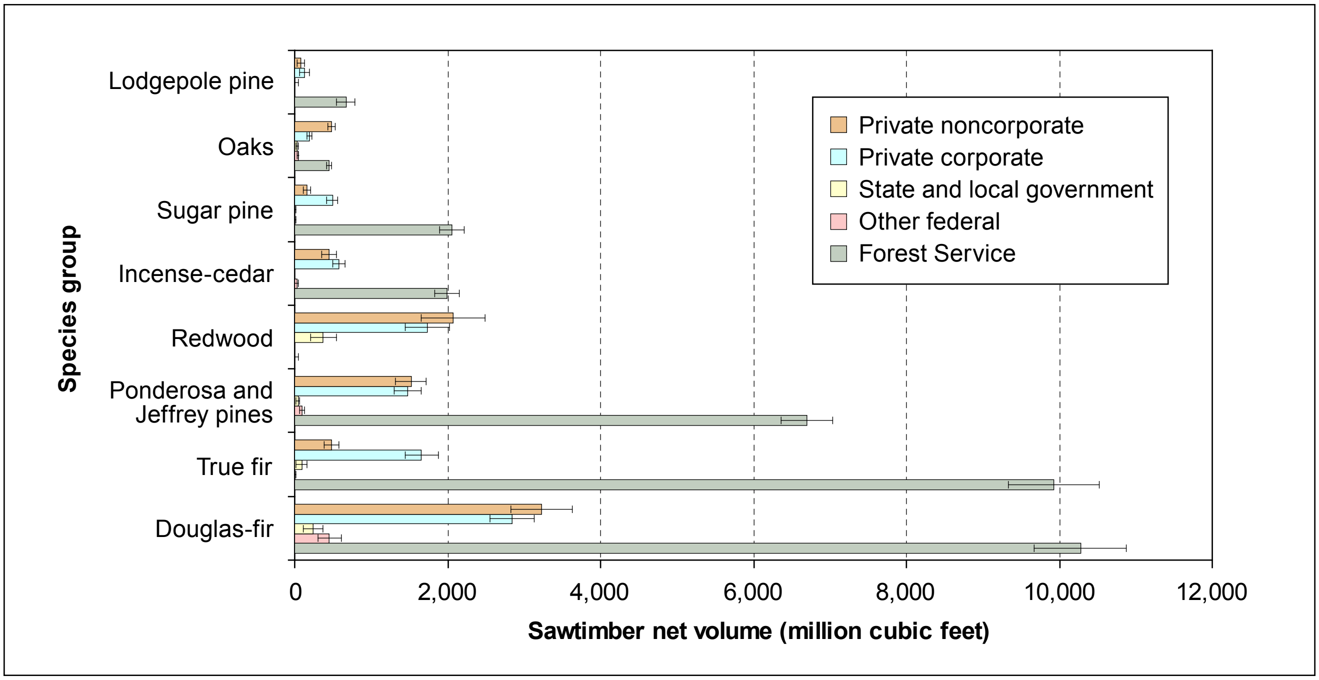

Figure 27—Net volume of sawtimber-sized trees by ownership group on timberland in California, 2001–2005. Excludes the miscellaneous mixed softwood and hardwood species groups and species groups that contribute less than 1 percent of total sawtimber volume.

Interpretation

Statewide estimates of timberland volume over the past 50 years show a recent return to levels seen in the 1950s after declines in the 1970s and 1980s (fig. 28). However, interpreting the difference between current and previous estimates is problematic because of differences between inventory methods (see periodic versus annual inventories in app. 1). Aggregation of wood volume into the six survey units traditionally used by FIA for California forest inventories reveals no major departures from the past. Most of the volume is found in forests in the North Interior, Sacramento, North Coast, and San Joaquin survey units, mainly because the climate in these areas is better able to support forest growth. Southern California forests support lower densities of trees on average. Overall, species contributing the majority of forest land volume (Douglas-fir, true firs, ponderosa and Jeffrey pines, and redwood) also are the most important commercial species. Continued consistent use of the current FIA inventory method will enable the monitoring of trends in volume and other resource attributes over time. The first statewide remeasurement of annual inventory plots is scheduled to begin in 2011.

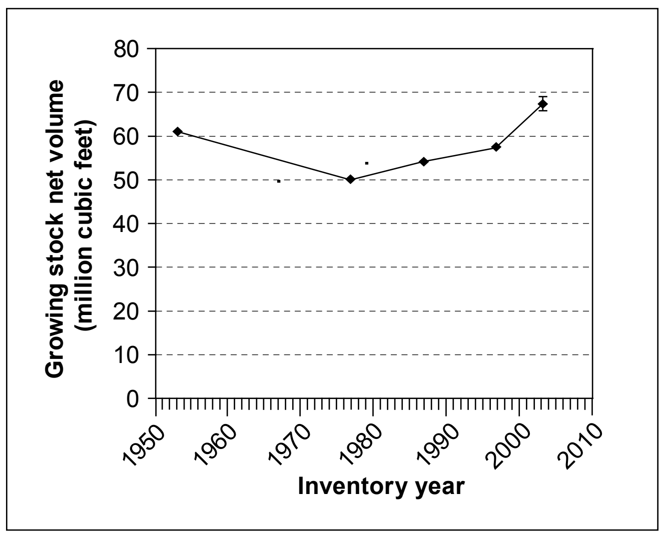

Figure 28—Net volume of growing stock on timberland by inventory year in California, 1953–2005 (Smith et al. 2004). Note: The 2001–2005 timberland volume estimate is based on the annual inventory design and protocols; the previous volume estimates are based on periodic inventories with different designs and protocols. Key differences between current and previous estimates, apart from real change, are due in large part to (1) application of plot stockability factors and stockable proportions to different sets of plots in the periodic and annual inventories (Because stockability defines productivity class, it thus influences the classification of a plot as timberland or not.) and (2) changes in definitions and protocols arising from national standardization of the inventory for qualification as tree, forest land, reserved land, and timberland.

Timber volume tables in appendix 2—

- Table 8—Estimated number of live trees on forest land, by species group and diameter class, California, 2001–2005
- Table 9—Estimated number of growing-stock trees on timberland, by species group and diameter class, California, 2001–2005
- Table 10—Estimated net volume of all live trees, by owner class and forest land status, California, 2001–2005
- Table 11—Estimated net volume of all live trees on forest land, by forest type group and stand size class, California, 2001–2005
- Table 12—Estimated net volume of all live trees on forest land, by species group and ownership group, California, 2001–2005
- Table 13—Estimated net volume of all live trees on forest land, by species group and diameter class, California, 2001–2005
- Table 14—Estimated net volume of growing-stock trees on timberland, by species group and diameter class, California, 2001–2005
- Table 15—Estimated net volume of growing-stock trees on timberland, by species group and ownership group, California, 2001–2005
- Table 16—Estimated net volume (International ¼ inch rule) of sawtimber trees on timberland, by species group and diameter class, California, 2001–2005
- Table 17—Estimated net volume (Scribner rule) of sawtimber trees on timberland, by species group and diameter class, California, 2001–2005
- Table 18—Estimated net volume (cubic feet) of sawtimber trees on timberland, by species group and ownership group, California, 2001–2005

Biomass and Carbon[7]

Background

Forest biomass and carbon accumulate in live trees, snags, and down wood in a mosaic of patterns across California (fig. 29). During forest succession, plant biomass builds up at different rates, sequestering carbon from atmospheric gases (carbon dioxide) and soil nutrients into woody tree components over time (Perry 1994). Biomass estimates from comprehensive forest inventories are essential for quantifying the amount and distribution of carbon stocks, evaluating forests as a source of sustainable fuel (biomass for energy production), and conducting research on net primary productivity (Houghton 2005, Jenkins et al. 2001, Whittaker and Likens 1975). Information about biomass and carbon accumulation in forests can help in evaluations of forest sustainability under criterion 5, defined in the Montreal Process (USDA Forest Service 1997), which calls for biomass and carbon estimates to be used as indicators to assess the role of forests in global carbon cycles.

In this section we focus on the aboveground live-tree components of forest biomass. We also make brief comparisons with dead wood biomass, which is addressed more fully in the section on dead wood. Cubic-foot volume and specific gravity constants for each species were used to compute the dry weight of the tree stem in bone-dry (oven-dry) tons (1 ton = 2,000 pounds). Stem biomass was combined with branch biomass (estimated with published equations) to compute the total aboveground dry weight of the tree (from ground to tip). Carbon mass was estimated by applying conversion factors to biomass estimates.

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[7] Author: Karen Waddell.

Karen Waddell

Figure 29—Biomass and carbon accumulate in live and dead trees of many sizes and ages in western forests.

Findings[8]

Over 2 billion tons of biomass and 1 billion tons of carbon have accumulated in live trees (≥1 inch diameter at breast height [d.b.h.]), primarily on unreserved forest land. The majority of this biomass (51 percent) was found on Forest Service land (fig. 30), where almost 24 percent of that was located on reserved forest land. Live trees on timberland contain about 1.5 billion tons of biomass and 786 million tons of carbon. Softwood forest types have double the amount of biomass and carbon of hardwood types, with biomass estimates ranging from a low of 4 million tons in the western hemlock/Sitka spruce type to a high of 724 million tons in the mixed-conifer type (fig. 31). The predominant hardwood types for biomass accumulation are the western oak group and the tanoak/laurel group, with 414 and 231 million tons of biomass, respectively.

Statewide, trees of softwood species have about 2.5 times the amount of live-tree biomass of hardwood species. Softwood biomass is heavily concentrated in trees larger than 21 inches d.b.h. (fig. 32) of which the most is in the Douglas-fir and true fir species groups. In contrast, hardwood species tend to follow a bell-shaped distribution curve, with a peak biomass in trees of the 9- to 12-inch class.

[8] In this section, all references to weight are in bone-dry tons.

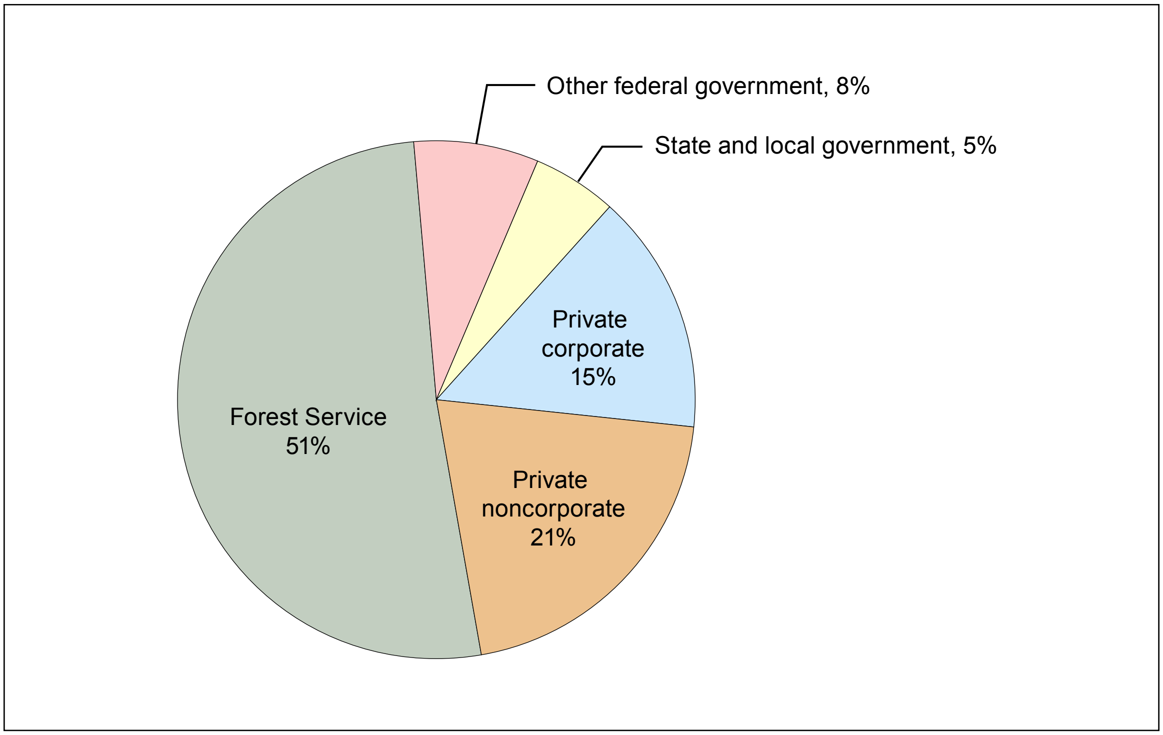


Figure 30—Percentage of aboveground live tree biomass by owner group on forest land in California, 2001–2005.

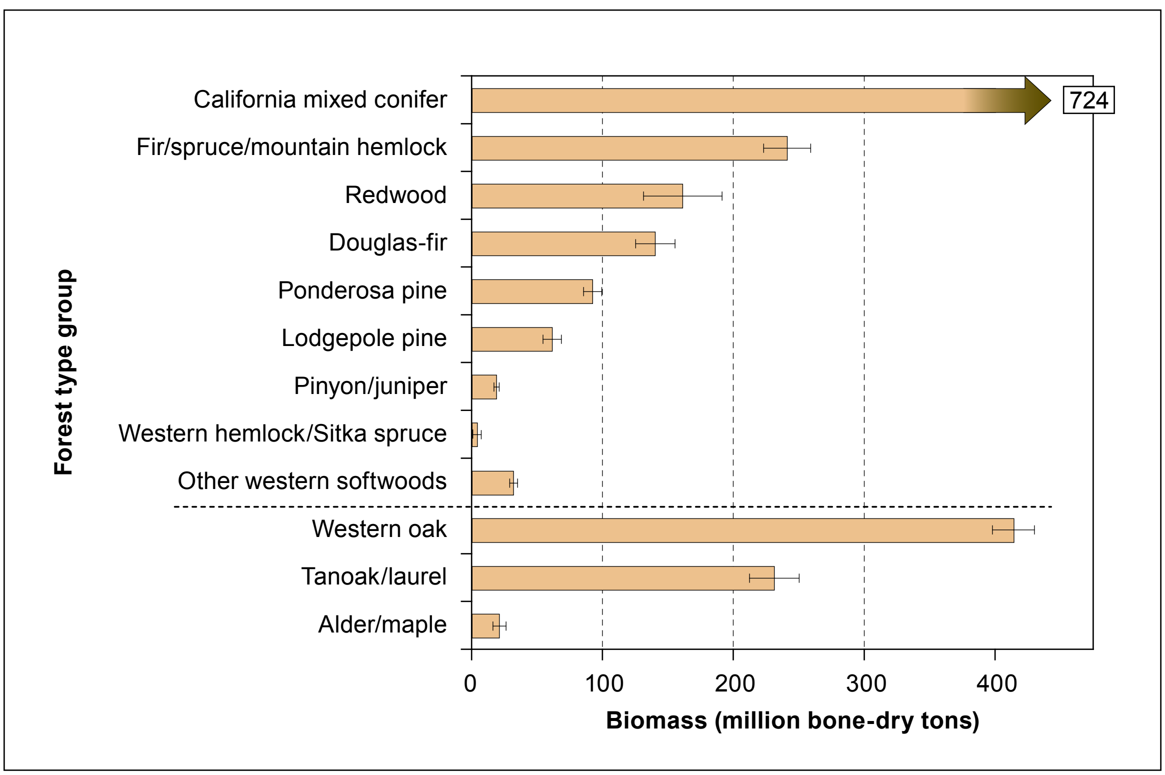


Figure 31—Aboveground live tree biomass by forest type group on forest land in California, 2001–2005.

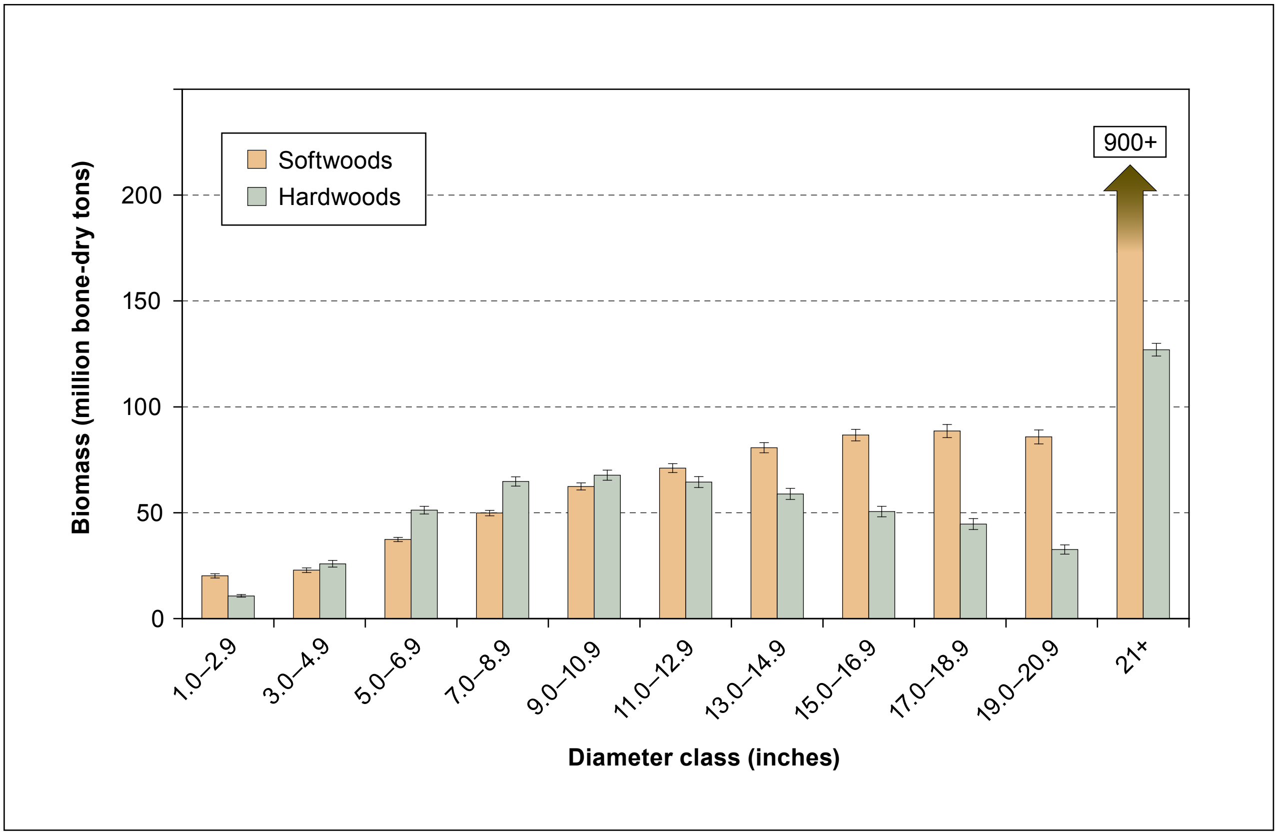


Figure 32—Aboveground live tree biomass by diameter class on forest land in California, 2001–2005.

Dead wood makes up a sizable fraction of wood biomass. Of the 2.6 billion tons of wood biomass in California, snags (≥5 inches d.b.h.) contribute 188 million tons, coarse woody material (CWM; wood ≥3 inches in diameter at the large end) contributes 226 million tons, and fine woody material (FWM; wood <3 inches diameter at the point of intersection with the sample transect) contributes 123 million tons to the forest biomass in the state.

About half of biomass is stored carbon, with about 1 billion tons stored in live trees, 97 million tons stored in snags, and 179 million tons stored in down wood (CWM and FWM combined). A closer look at the carbon allocation among live and dead materials within major forest types is shown in figure 33. Most of the carbon is stored in softwood types, with 83 percent in live trees, 9 percent in CWM, and only 8 percent in snags. The bulk of the carbon was found in forests classified as a mixed-conifer forest type, primarily in live Douglas-fir, white fir, and ponderosa pine trees.

On average, we estimated that the total biomass of live trees, snags, and CWM was about 78 tons per acre across the state, which represents a carbon mass of about 40 tons per acre. The redwood forest type group had a mean carbon mass of over 152 tons per acre (fig. 34), with 85 percent of that attributable to live trees. The combined hardwood types had less than half that, with the greatest accumulations of carbon found in the tanoak/laurel (64 tons per acre) and the alder/maple (54 tons per acre) type groups.

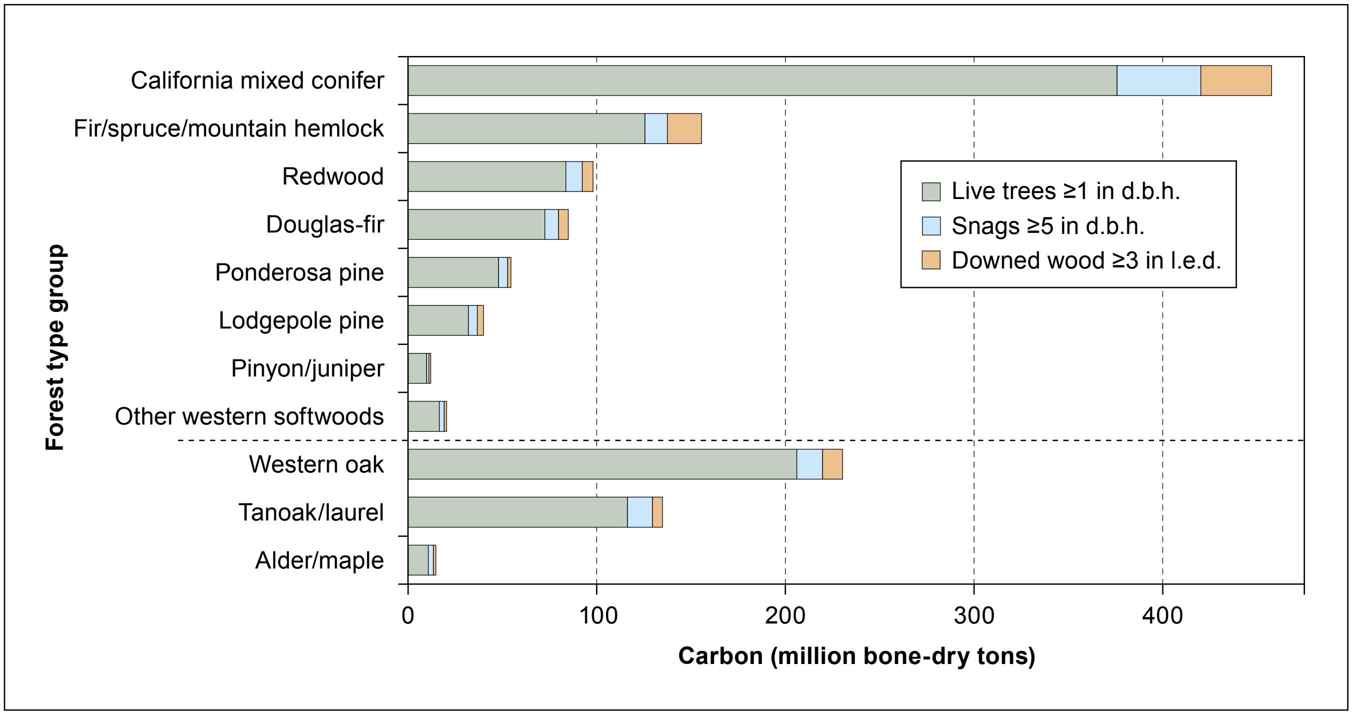


Figure 33—Carbon mass of live trees, snags, and down wood (coarse woody material) by forest type group on forest land in California, 2001–2005; d.b.h. = diameter at breast height; l.e.d. = large end diameter.

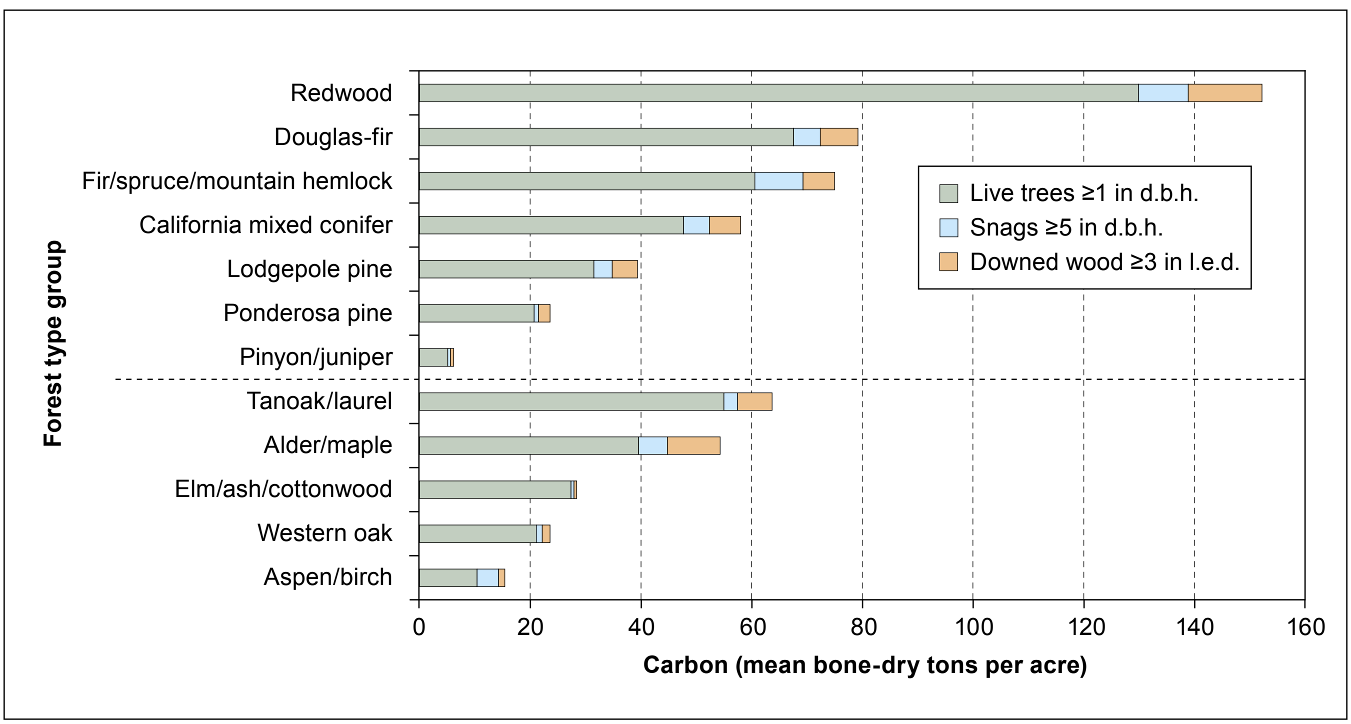


Figure 34—Mean carbon mass of live trees, snags, and down wood (coarse woody material) by forest type group on forest land in California, 2001–2005; d.b.h. = diameter at breast height; l.e.d. = large end diameter.

Interpretation

Substantial quantities of forest biomass and carbon have accumulated in California forests. The current rising interest in biomass as an alternative source of energy will accelerate the need to understand how much source material is available and where it is located. The FIA inventory shows that there is almost four times as much live-tree biomass as dead-wood biomass. This is important, because the preferred source of material for energy production comes from components of the live-tree resource, such as wood residues from harvest operations and sawmills, stems and branches from forest thinning projects, and material from biomass plantations.

For example, in northern California, a small energy company operates a wood-fired power plant that uses local mill wastes, chips, and unmerchantable whole logs (culls up to 6 feet in diameter) to generate over 375 million kWh of electricity per year. As of 2000 there were 25 wood-using biomass energy facilities throughout California (Morgan et al. 2004). As a market in carbon credits develops, actively growing forests have promise for offsetting carbon production from urban and industrial sources. For such a system to function effectively, the various carbon pools will need to be monitored carefully and adjustments made when necessary—for example, planting trees or improving forest health if and when live-tree carbon stocks are lost to insects, fire, harvest, or some other disturbance. When trees are harvested for solid wood products, monitoring techniques must recognize this shift in carbon storage and account for the carbon sequestered indefinitely within buildings, furniture, and other structural materials. Over time, the desired outcome is that California's forests function as a net sink of stored carbon.

Biomass and carbon tables in appendix 2—

- Table 19—Estimated aboveground biomass of all live trees, by owner class and forest land status, California, 2001–2005
- Table 20—Estimated aboveground biomass of all live trees on forest land, by diameter class and species group, California, 2001–2005
- Table 21—Estimated biomass of live trees on forest land by softwood species group, for merchantable tree boles, tops, limbs, stumps, and small trees, California, 2001–2005
- Table 22—Estimated mass of carbon of all live trees, by owner class and forest land status, California, 2001–2005
- Table 23—Estimated biomass and carbon mass of live trees, snags, and down wood on forest land, by forest type group, California, 2001–2005
- Table 24—Estimated average biomass and carbon mass of live trees, snags, and down wood on forest land, by forest type group, California, 2001–2005

Patrick's Point State Park.

Chapter 3: Forest Structure and Function

The diverse topics presented in this chapter share a common objective: to characterize the structure and function of California's forests. From an ecological perspective, these forests are vital to a wide variety of plant and animal species. We rely on data collected in the Pacific Northwest Research Station Forest Inventory and Analysis (FIA) inventory to describe characteristics of special habitat types such as old-growth and hardwood forests and the status of forest components such as understory vegetation, hardwoods, dead wood, tree crowns, and soils.

Older Forests[1]

Background

Older forests that are in later stages of successional development are an important part of the forest land matrix. They contribute special habitat, aesthetics, resources, and ecological services not provided by younger forests (Franklin et al. 1981). Older forests are not simply forests where little or no disturbance has occurred for long periods; disturbance is the norm in all forests and has helped shape old forests by creating openings and patches of older survivors.

The term "old" is relative; it depends on whose definition is used, the type of forest, and the regional climate. Older forests are not easily defined, because definitions rely on many complex, interacting variables. For example, the old-growth definitions assembled by Beardsley and Warbington (1996) for northwestern California national forests use site productivity, stand age, density, and diameter of live, standing dead, and down trees as criteria. The minimum stand age they used to classify forests as old growth ranged from 125 to 300 years.

By the age of 175 to 250 years, Pacific Coast forests typically attain the structure, species composition, and various functional attributes of older forests (Franklin et al. 1981, Old-Growth Definition Task Group 1986). More complex definitions for old-growth forests often cite a minimum age of 200 years, depending on productivity class and forest type (Bolsinger and Waddell 1993, Franklin et al. 1981, Old-Growth Definition Task Group 1986).

For our analysis, we have simplified the definition for older forests. Our summary uses stand age as the basis for estimates of area and age distribution. We estimate acreage by forest type for stand ages in two categories, ≥160 years old and ≥200 years old. The FIA field crews estimate stand age from the average age of predominant overstory trees, determined by counting the tree rings from small samples of wood (cores) extracted with an increment borer (fig. 35). It is not possible to determine the age of some trees because of internal rot, or because the sheer size of the tree limits the length of core that can be extracted. In addition, some species (e.g., many hardwoods) are not cored because of the risk that the core wound will make them susceptible to pathogens.

Joseph Donnegan

Figure 35—Increment cores are extracted from trees to determine the age of dominant trees in each forested stand that is sampled by Forest Inventory and Analysis.

[1] Author: Joseph Donnegan.

Findings

We estimate that approximately 13 percent (4.1 million acres) of the forest area in California has stands in excess of 160 years. About 7.5 percent (2.3 million acres) has stands in excess of 200 years. The vast majority of older forest is found on publicly owned land in national forests and national parks (see "Ownership" section for more details). The California Department of Forestry and Fire Protection recently estimated that approximately 14 percent of California's conifer forests are in old-growth condition; their hybrid assessment relied on FIA data in combination with remote-sensing imagery (California Department of Forestry and Fire Protection 2003).

Among forests with stand ages greater than 160 years, the California mixed-conifer type occupies the greatest area, accounting for 5.5 percent of total forest area (fig. 36). The remaining combined forest types with stand ages older than 160 years make up about 7.5 percent of total forest area. Although the total acreage of the foxtail/bristlecone pine and the bigcone Douglas-fir types is relatively small (75,279 and 7,245 acres, respectively) 100 percent of those types in our sample occurred in stands older than 160 years (fig. 37).

Within older California mixed-conifer stands, there is great diversity in structural characteristics, with tree diameters covering a broad range of classes (fig. 38). Although seedlings and saplings are the most abundant size class, many trees are greater than 40 inches in diameter.

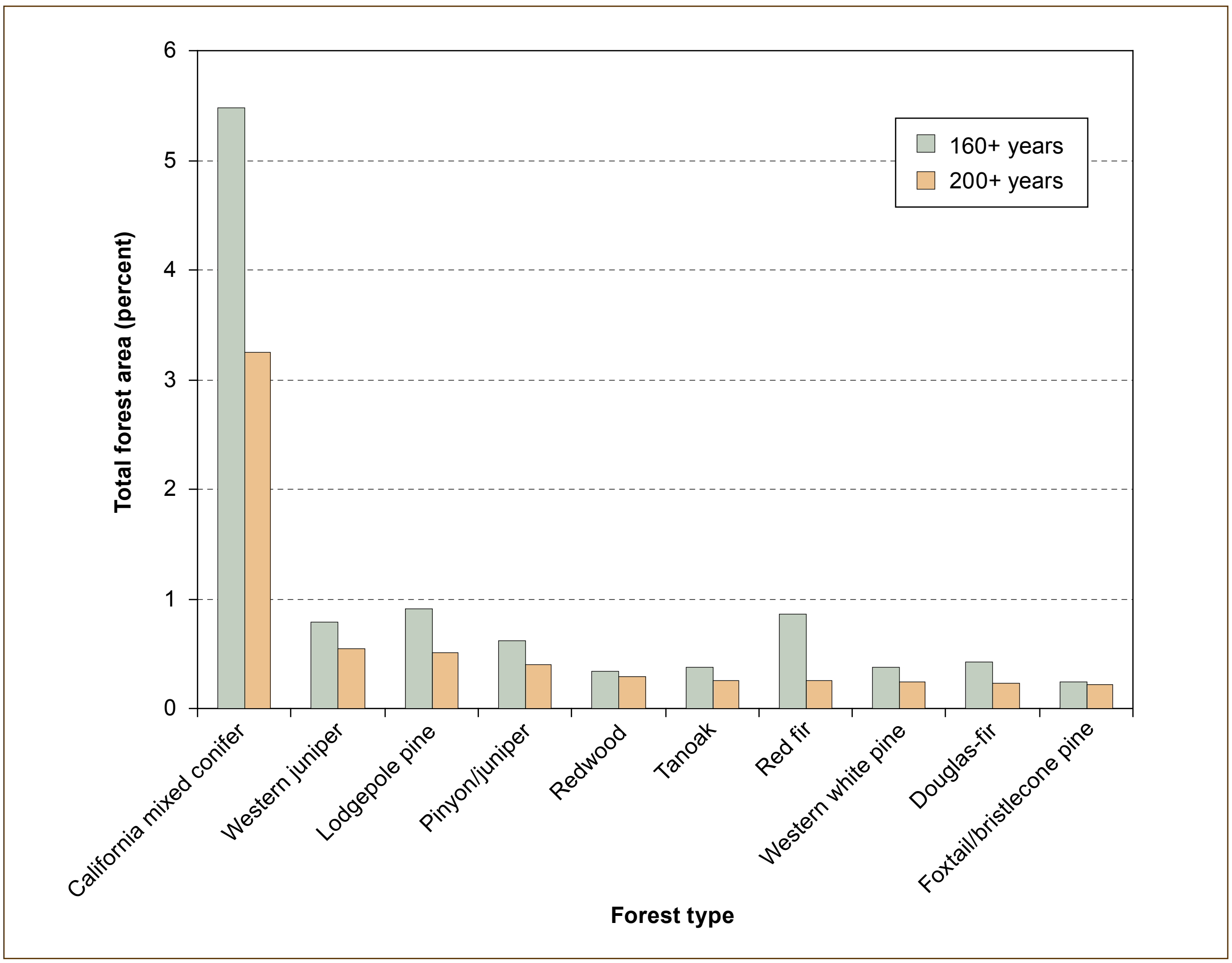


Figure 36—Percentage of total forest area by forest type for stands 160+ and 200+ years old in California, 2001–2005.

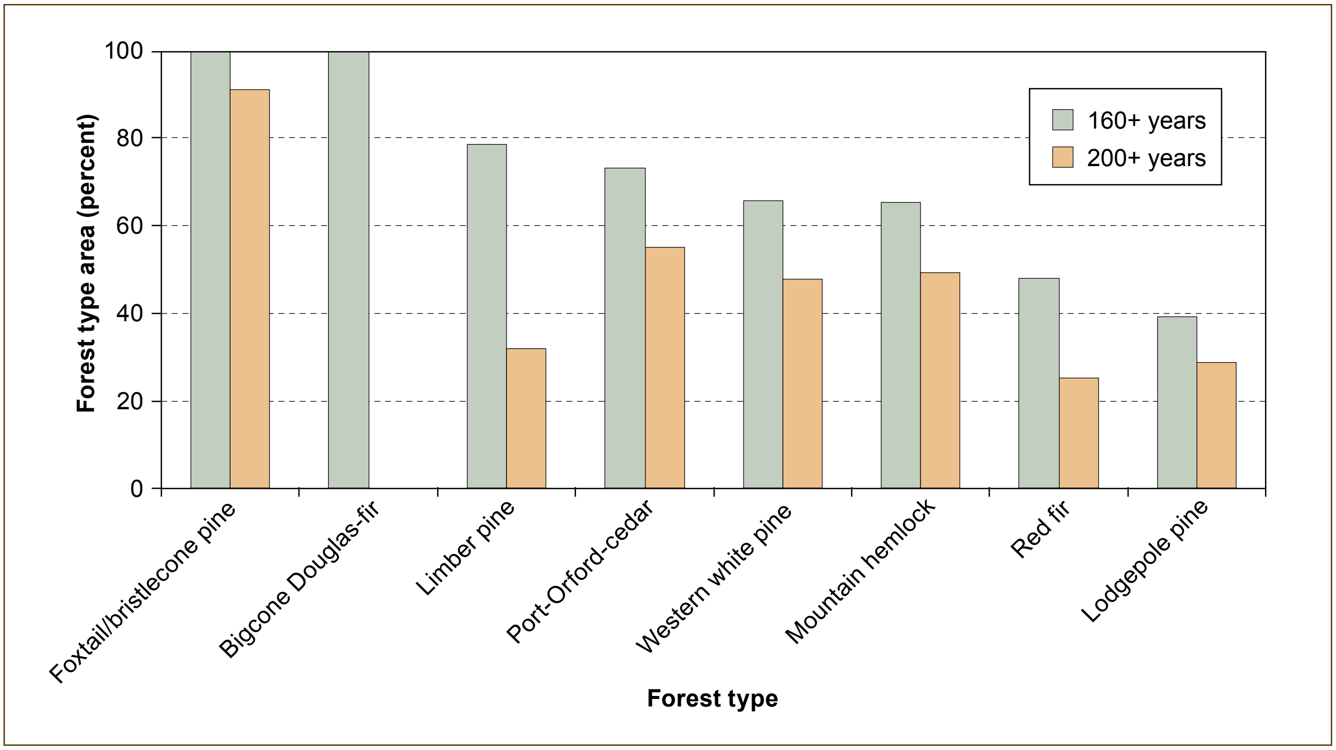


Figure 37—Percentage of softwood forest types in older forest in California, 2001–2005. Note that some forest types (e.g., redwood) do not have high percentages of their total area in older forest conditions and thus are not shown in this figure.

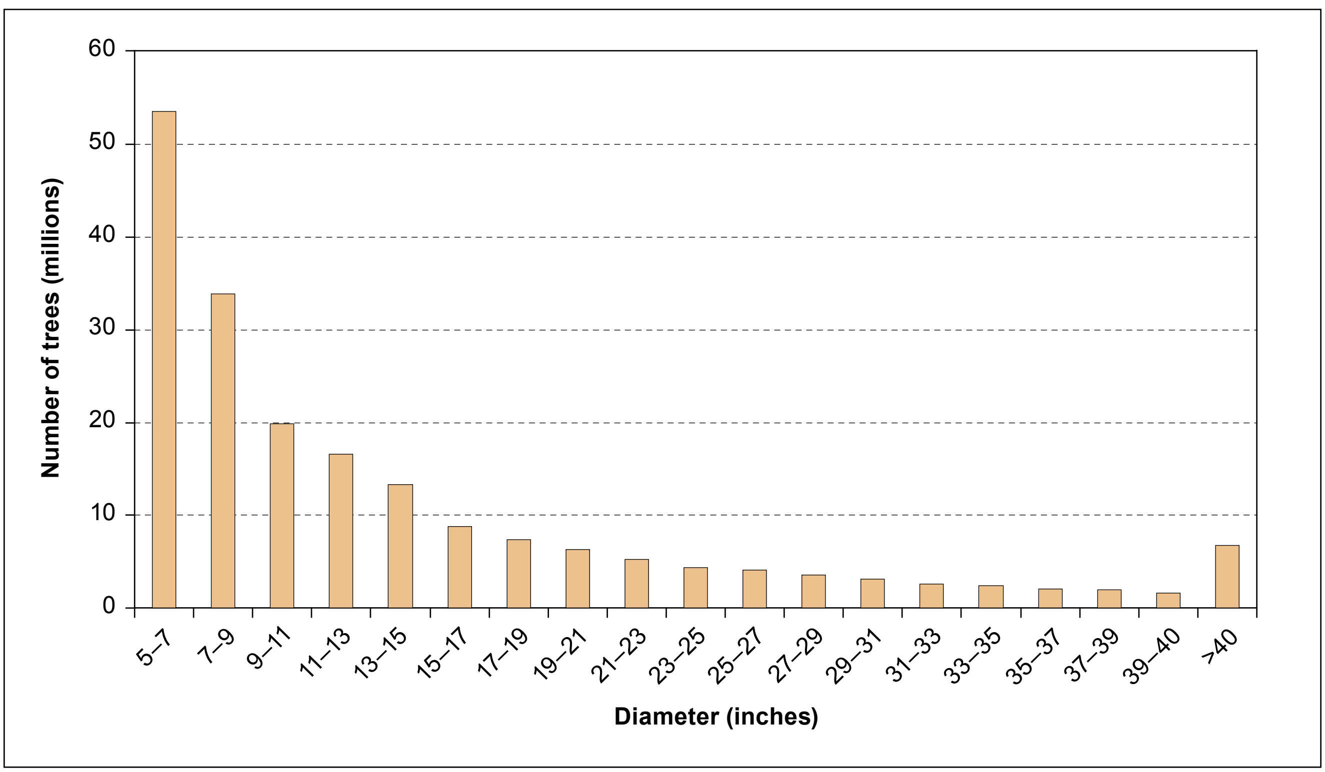


Figure 38—Number of trees by diameter class in older (>160 years old) California mixed-conifer forests on forest land in California, 2001–2005.

Recent work has helped spatially refine estimates for old growth in northwestern California national forests (Beardsley and Warbington 1996) and the Sierra Nevada (Beardsley et al. 1999). For the Klamath, Mendocino, Shasta-Trinity, and Six Rivers national forests, Beardsley and Warbington estimated that approximately 390,000 acres were covered by "pristine" old growth. Using the 2001–2005 FIA data and our simplified definition of older forest, we estimated that approximately 381,000 acres within these national forests have stand ages in excess of 160 years.

Interpretation

Prior to the widespread logging of old forests (before the mid-1800s), these forests had been changing through time from disturbances such as fire and insect outbreaks of varying severity, recurrence intervals, and disturbance synchrony across the landscape (Winter et al. 2002). The amount of old-growth forest that existed at the time of Euro-American settlement is unknown. The 1932 Copeland Report (USDA Forest Service 1932) estimated the area of California old-growth forest to be about 12.7 million acres. Data compiled from older state resource reports (1933–45) estimated the old-growth area in California at approximately 9.5 million acres (Bolsinger and Waddell 1993). Our preliminary results suggest old-growth acreage is less than half the 1933–45 estimate. Additional data will add to the precision of our initial findings.

Dead Wood[2]

Background

Dead wood contributes to the structural complexity and biological diversity of forests throughout California (fig. 39). In this report, we define dead wood as snags (standing dead trees) and down wood (dead woody material on the forest floor) of various dimensions and stages of decay. The presence of dead wood in a forest is known to improve wildlife habitat, enhance soil fertility through nutrient cycling and moisture retention, add to fuel loads, provide substrates for fungi and invertebrates, and serve as a defining element in old-growth forests (Harmon et al. 1986, Laudenslayer et al. 2002, Rose et al. 2001). Because of this, the dead wood resource is often analyzed from a variety of perspectives—too much can be viewed as a fire hazard, whereas too little can be viewed as impairing habitat quality. The amount of dead wood in a forest differs with geographic location, habitat type, successional stage, species composition, and management activities (Harmon et al. 1986, Ohmann and Waddell 2002). Information on the amount of biomass and carbon stored in dead wood can help in evaluations of forest sustainability under criterion 5, defined in the Montreal Process (USDA Forest Service 1997), which recommends that biomass and carbon estimates be used to assess the forest contribution to global carbon cycles. In this report, we analyze data on snags and down wood collected by FIA crews on over 3,500 field plots in the state, and describe the resource in broad terms at the statewide level.

Dead trees with a diameter at breast height (d.b.h.) greater than 5 inches and leaning less than 45 degrees were tallied as snags and measured using the same protocol as live trees. Down wood was sampled along linear transects on each plot under protocols that differed by diameter size class. Information was collected on fine woody material (FWM; pieces of wood <3 inches in diameter at the point of intersection with the sample transect) and coarse woody material (CWM; branches and logs ≥3 inches in diameter at the point of intersection with the sample transect and at least 3 feet long). Dead trees leaning more than 45 degrees

[2] Author: Karen Waddell.

Karen Waddell

Karen Waddell

Figure 39—Snags (top) provide structural diversity in forest stands. Down wood (bottom) improves habitat and slope stability in many forests across the state.

were tallied as down wood. Estimates of density, volume, biomass, and carbon were developed from these data.

Findings[3]

Dead wood occurs in every forest type that was sampled in California. We estimated 537 million tons of biomass, almost two-thirds of which occurs as down wood (CWM and FWM). At 36 billion cubic feet, volume of snags and CWM is almost a third of live-tree volume. About 97 million tons of carbon is sequestered in snags, whereas 178 million tons is stored in down wood (CWM = 117; FWM = 62). Statewide, we estimated there are about 5 billion down logs and 430 million snags. The North Coast survey unit had the highest mean density and biomass of dead wood per acre, but the North Interior had the largest diameter snags and logs. The redwood and alder/maple forest types had the heaviest accumulation of biomass on a per-acre basis.

Assessment of dead wood attributes is often more meaningful when comparing average per-acre estimates. Statewide, biomass of down wood (also known as fuel loading) averaged 10.5 tons per acre, varying by forest type and diameter class (fig. 40). The down wood component of the total fuel load (amount of potentially combustible material found in an area) by survey unit is shown below, displayed within the standard fuel hour-classes:

Survey unit	1-hour class	10-hour class	100-hour class	1,000-hour class	Total
			Mean tons/acre		
North Coast	0.3	1.3	4.0	12.2	17.8
North Interior	0.2	1.1	2.7	6.9	10.9
Sacramento	0.2	0.8	2.6	6.4	10.0
Central Coast	0.2	0.9	2.5	2.9	6.5
Southern	0.1	0.6	1.9	5.3	7.9
Total	0.2	0.9	2.6	6.8	10.5

The range in classes from 1 to 1000 hours corresponds to the diameter of down wood pieces as follows: 1-hour (0.1 to 0.24 inches), 10-hour (0.25 to 0.99 inches), 100-hour (1.0 to 2.9 inches), and 1,000-hour (≥3 inches). Each class refers to how fast dead woody material will burn relative to its moisture content. The heaviest fuel loads are in the North Coast and North Interior survey units, with a mean of 17.8 and 10.9 tons per acre, respectively. Flash fuels (1-hour class) have similar loads across survey units, wheras the larger fuels (1,000-hour class) are more variable.

The dimensions of down logs and snags are important when evaluating ecological characteristics of the forest. Of the heavy accumulation of biomass in the redwood and

[3] In this report, all references to weight are in bone-dry tons.

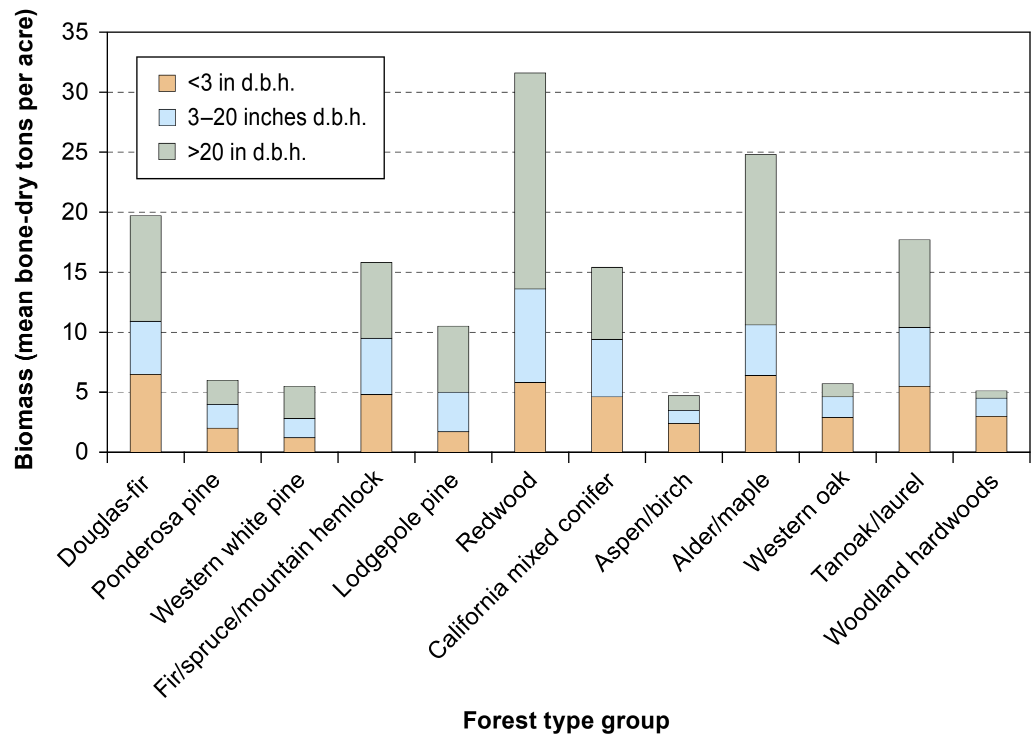


Figure 40—Mean biomass of down wood by forest type and diameter class on forest land in California, 2001–2005.

alder/maple forest types, over 50 percent was contained in large-diameter logs (≥20 inches). Although large logs contain the greatest mean volume and biomass per acre statewide, they are significantly fewer in number than small logs (3 to 19 inches in diameter). We estimated an average of 7 large logs per acre and 144 small logs per acre.

Snags had a mean biomass of 6 tons per acre and a mean density of 13 snags per acre across the state. Almost 88 percent of the snag density was in snags <20 inches d.b.h., with just 0.2 snags per acre in the very large class (>40 inches d.b.h.). Softwood forest types had the most biomass and the largest proportion of large-diameter (>20 inches d.b.h.) snags (fig. 41).

Although the total amount of dead wood present in a forest fluctuates over time, the mean density of large-diameter (≥ 20 inches) snags and down logs generally increases with stand age (fig. 42), as shown below:

	Snags		**Down wood**	
	Diameter classes			
Stand age in years	**5 to 19 in**	**≥ 20 in**	**3 to 19 in**	**≥ 20 in**
	Mean trees/acre		*Mean logs/acre*	
1 to 50	10.4	0.9	155.0	8.0
51 to 100	11.5	1.2	148.1	5.1
101 to 150	13.4	2.4	164.7	8.0
151 to 200	13	3.6	170.6	11.6
201 to 250	6.5	3.4	121.0	9.7
251 to 300	7.4	2.9	152.8	11.4
300 plus	10.7	4.4	119.8	11.8
Total	11.4	1.7	143.0	6.4

Large snags ranged from a mean of 0.9 per acre in young stands to 4.4 per acre in stands older than 300 years. In contrast, young stands appear to start out with a higher level of large down wood, most likely remnants from a stand-initiating event such as a fire or harvest. Density of down wood differed by age class, rising and falling slightly over time and reaching a high of 11.8 logs per acre in very old stands.

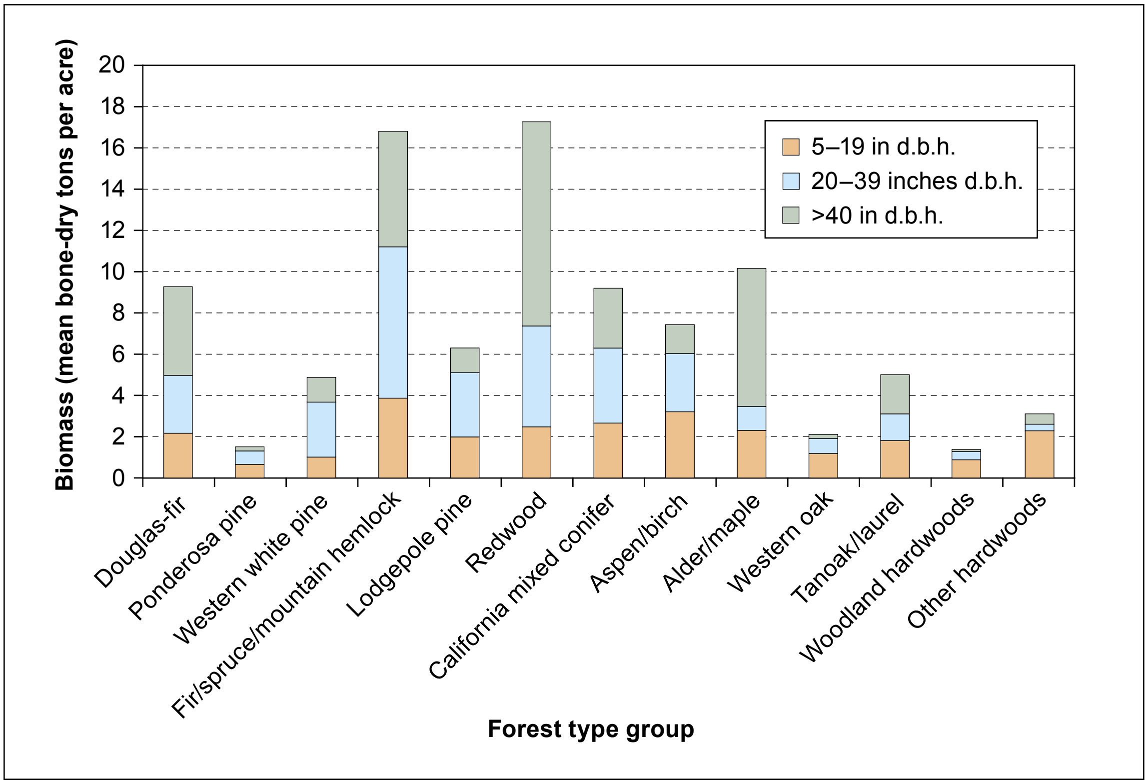


Figure 41—Mean biomass of snags by forest type and diameter class on forest land in California, 2001–2005.

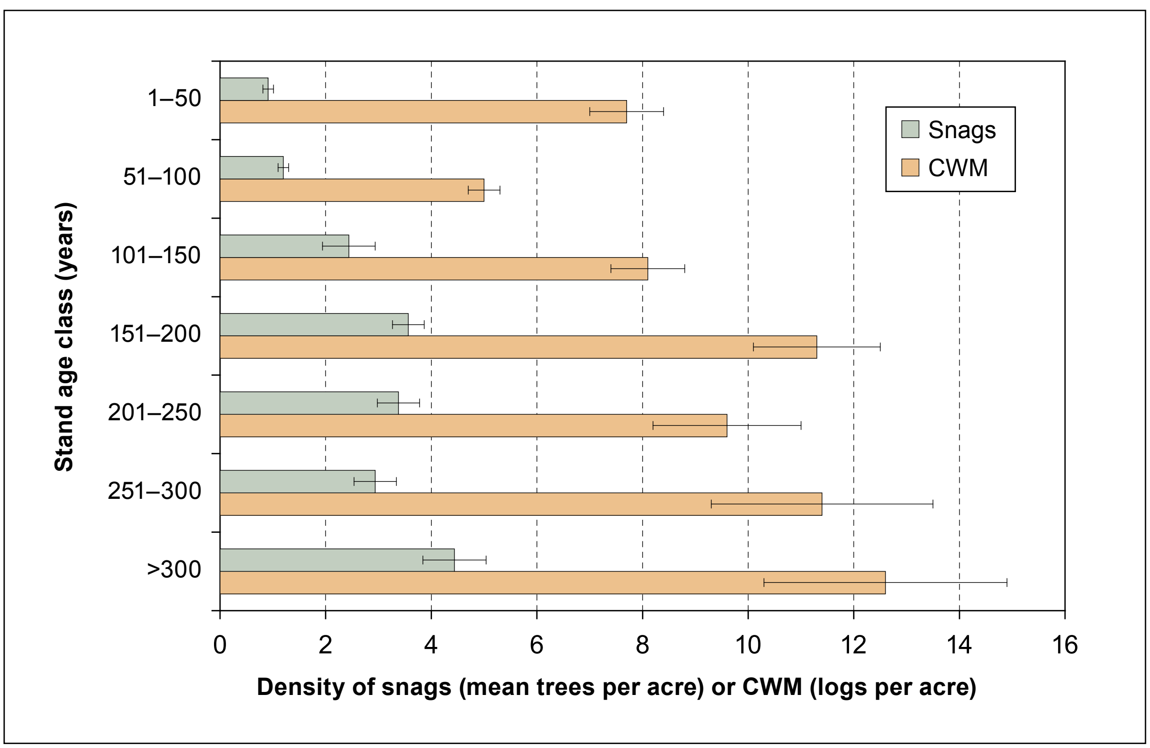


Figure 42—Mean density of down wood and snags by stand age class for large-diameter (> 20 inches) logs or snags on forest land in California, 2001–2005; CWM = coarse woody material.

Interpretation

Dead wood accumulates in different patterns across the wide variety of forest types in California. Many factors influence the size, abundance, and decay stage of dead wood, creating a mosaic of habitats and a range of potential fire behaviors across the landscape. The heavy fuel load observed in the North Coast survey unit is likely due to the greater live-tree biomass and volume accumulations that occur because of the mild, wet climate. Also, trees tend to be larger there, contributing more branches and logs to the fuel structure. Although the North Coast has higher fuel loads than all other survey units, it may not pose a higher fire risk because precipitation and fog are more common in these counties. However, land managers may find it prudent to monitor both of the northern survey units to evaluate these areas as possible sites for fuel reduction.

In general, wildlife species that use dead wood for nesting, roosting, and foraging prefer larger diameter down logs and snags. We tallied dead wood in various size classes throughout California and the estimated density of large snags may not be sufficient for some wildlife species. For example, every survey unit averaged fewer than two large snags ≥20 inches d.b.h. per acre, while smaller snags averaged 6 to 14 per acre in the same areas. Wildlife species favoring even larger snags (≥40 inches d.b.h.) would find only 0.1 to 0.5 per acre in this size class across the state, indicating that large dead wood appears to be uncommon in California habitats. This may signal the need for a more indepth analysis of these important habitat elements, in terms of size class distributions needed by individual wildlife species in different areas of the state. Various types of disturbance can radically change the habitat quality of a forest by shifting the balance of live and dead trees or FWM and CWM. Biologists and land managers may find it advisable to monitor these changes to determine whether the density and size distribution of dead wood are adequate for the wildlife species being managed.

Understanding the amount of biomass and carbon stored in dead wood will also allow us to address criterion 5 described in the Montreal Process, regarding global carbon cycles. The FIA databases contain a substantial amount of information about dead wood, including estimates of density, biomass, volume, and carbon for all dead wood components. These data could be used for a more comprehensive analysis of this resource.

Dead wood tables in appendix 2—

- Table 25—Estimated average biomass, volume, and density of down wood on forest land, by forest type group and diameter class, California, 2001–2005
- Table 26—Estimated biomass and carbon mass of down wood on forest land, by forest type group and owner group, California, 2001–2005
- Table 27—Estimated average biomass, volume, and density of snags on forest land, by forest type group and diameter class, California, 2001–2005
- Table 28—Estimated biomass and carbon mass of snags on forest land, by forest type group and owner group, California, 2001–2005

Hardwoods[4]

Background

Forests of hardwood types make up an estimated 40 percent of forest land in California, and hardwood trees compose an estimated 27 percent of total tree biomass. Most of the hardwood forest in California is oak woodland with widely spaced oaks and a shrub or grass understory. Oaks have been used by native people in California for thousands of years, providing food from acorns and material for baskets, medicines, and dye, as well as sustaining a variety of game animals. Today California residents highly value oak woodlands for their aesthetic beauty, watershed protection, wildlife habitat, grazing opportunities, and a diverse array of forest products. California oaks include a number of endemic species, such as blue oak (see "Scientific and Common Plant Names"), valley oak, and Engelmann oak, and serve to enrich the biodiversity of California wildlands.

[4] Author: Tara Barrett.

Findings

Forest conversion and oak mortality—
Oak woodlands occur primarily in the foothills, with changes in forest type occurring over a gradient from dry low-elevation sites to higher, more productive areas bordering timberlands (fig. 43). Because of proximity to areas with grazing operations and ongoing development, most conversion of forest land in California occurs in oak woodlands rather than timberlands. Between 1945 and 1975, clearing of oak woodland for rangeland averaged about 32,000 acres per year (Bolsinger 1988). The rate of clearing for rangeland has dropped substantially, but conversion of oak woodland to housing, roads, and other developed uses has since increased. Between 1991–94 and 2001–05, about 2 percent (confidence interval: 0.7 to 4.8 percent) of revisited FIA oak woodland plots were converted to developed land, amounting to approximately 18,000 acres per year. This estimate is derived from 238 plots, of which 4 were converted to urban conditions and 1 to a vineyard. Estimates do not include conversion of oak savanna (wildland with scattered oak trees and less than 10 percent canopy cover) or the fragmentation of oak woodlands by development.

Another factor in sustainability of oak woodlands is harvesting for firewood or other purposes. Only a small proportion of oaks that are harvested in California are used for timber products (Waddell and Barrett 2005). As shown in the tabulation below, 25 percent of oak forest in California shows evidence of past cutting of trees, such as the presence of old stumps. California black oak forest has the most frequent evidence of such cutting.

By contrast, presence of stumps was recorded in 50 percent of conifer forest in California. The most recent assessment of change in California oak woodlands (1981–84 to 1991–94) found that growth exceeded mortality for most oak species, perhaps owing in part to active fire suppression throughout the range of California oaks.

Oak regeneration—
Oaks generally occur in the more xeric (dry) forest lands in the state, and so tree density is low for many oak types. Statewide, more than half the area of valley oak and blue oak forest has a density of less than 50 trees per acre, as compared to about one-third of interior live oak and coast live oak forests, and one-fourth of California black oak and California white oak forests (fig. 44). For more than a century, observers have noticed sparse regeneration in many oak forest types (fig. 45), contributing to the perception that recruitment is insufficient for sustainable populations of several oak species, including blue oaks and valley oaks.

Since the 1970s, dozens of papers have been published about seedling establishment and the survival of oaks in California. We know that, in general, oak regeneration is negatively affected by plant competition, herbivory, grazing, and drought. Oak regeneration appears to be good in some areas and poor in others (Tyler et al. 2006), but we do not have a clear picture of sustainability statewide. Projecting future trends is complicated by limited information on growth and mortality of seedlings and saplings as well as uncertainty about future climate.

	Total forest area		**Forest area with stumps**		
Forest type	**Area**	**SE**	**Area**	**SE**	**Portion of total forest area**
	Acres		*Acres*		*Percent*
Blue oak/gray pine	2,939	163	608	80	21
California black oak	1,513	120	652	82	43
California white oak (valley oak)	278	54	79	29	28
Canyon live oak	2,450	148	599	78	24
Coast live oak	971	91	140	37	14
Interior live oak	1,004	103	186	46	19
Oregon white oak	613	77	132	38	22
Total	9,768	301	2,398	154	25

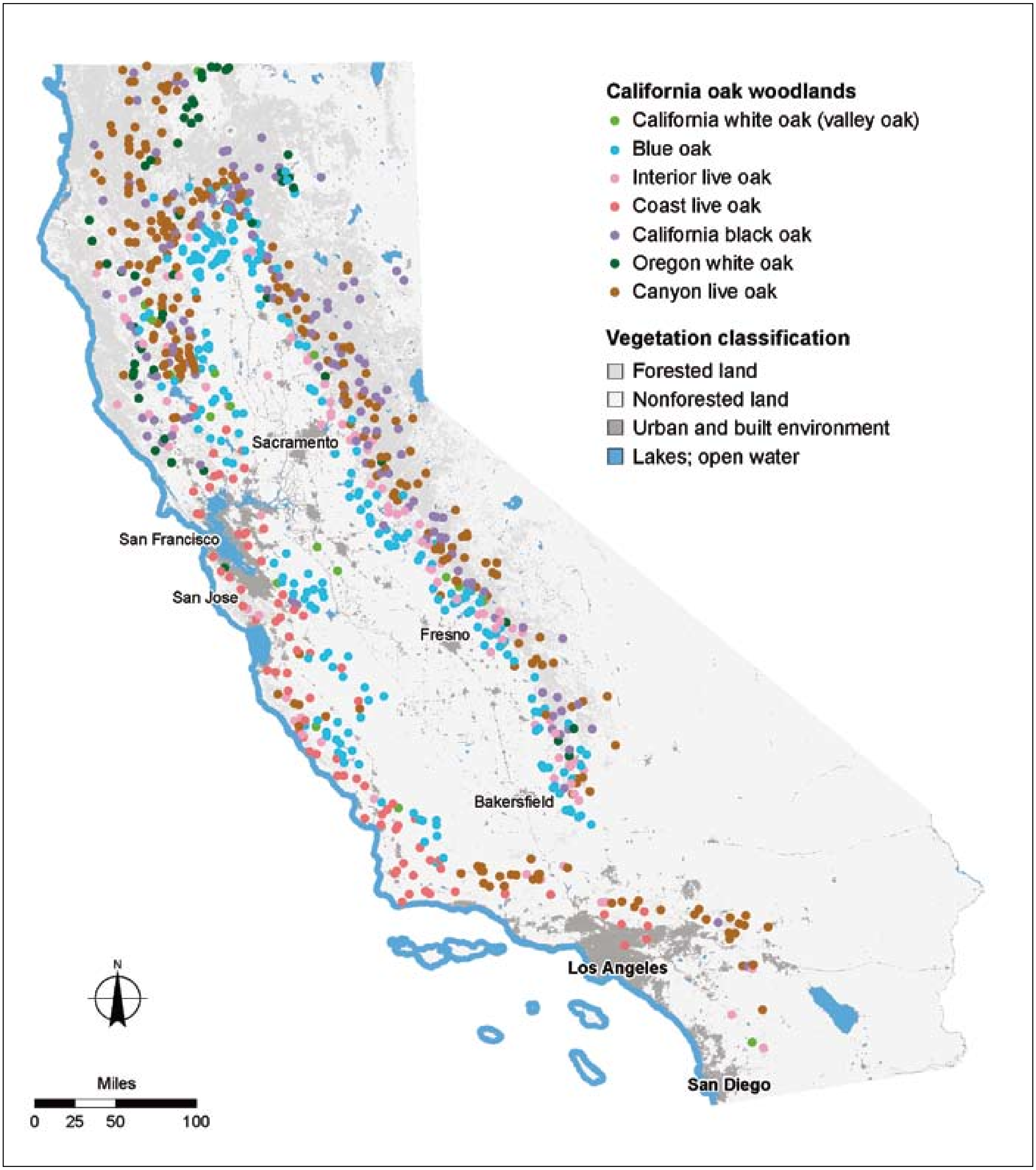


Figure 43—Oak forest types on Forest Inventory and Analysis plots in California, 2001–2005 (forest/nonforest Geographic Information System (GIS) layer: Blackard et al. 2008, urban/water GIS layer: Homer et al. 2004).

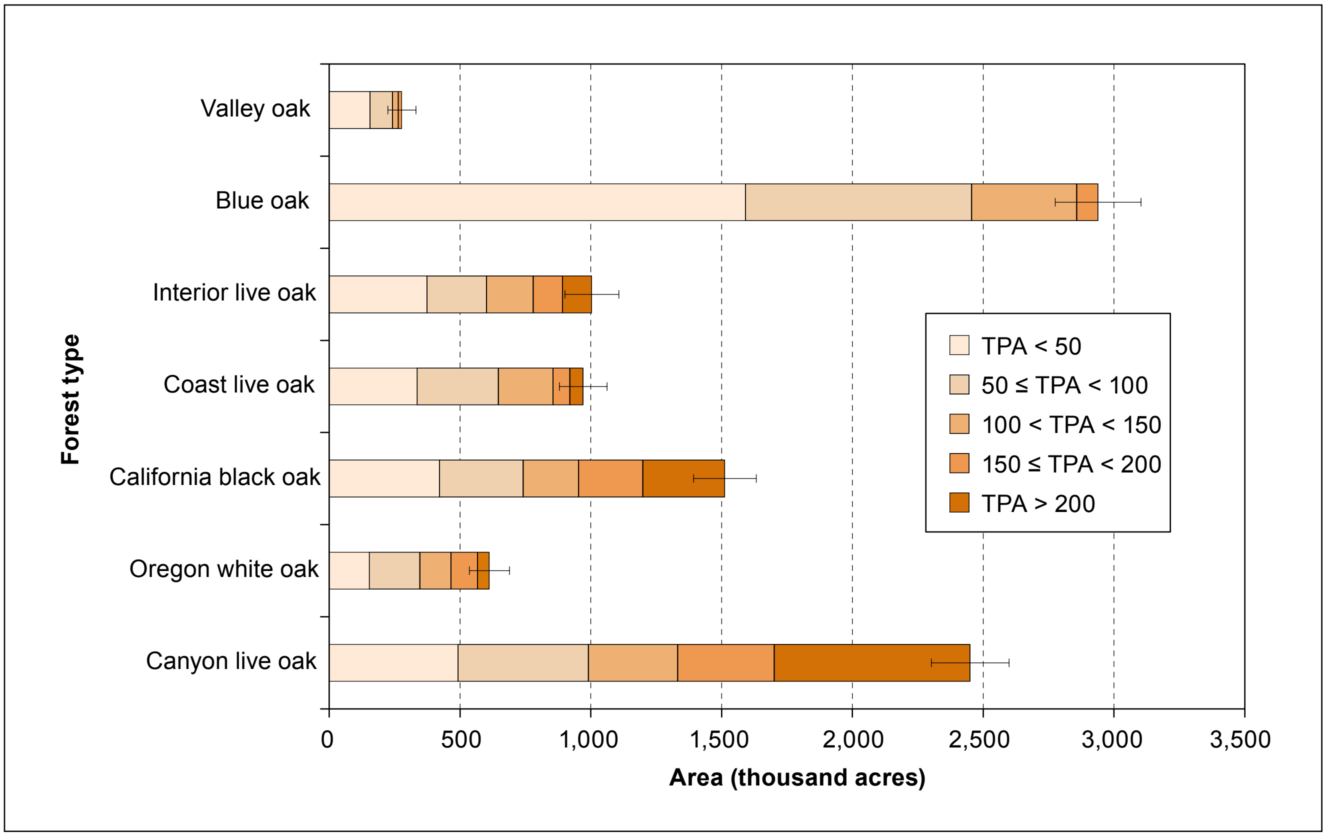
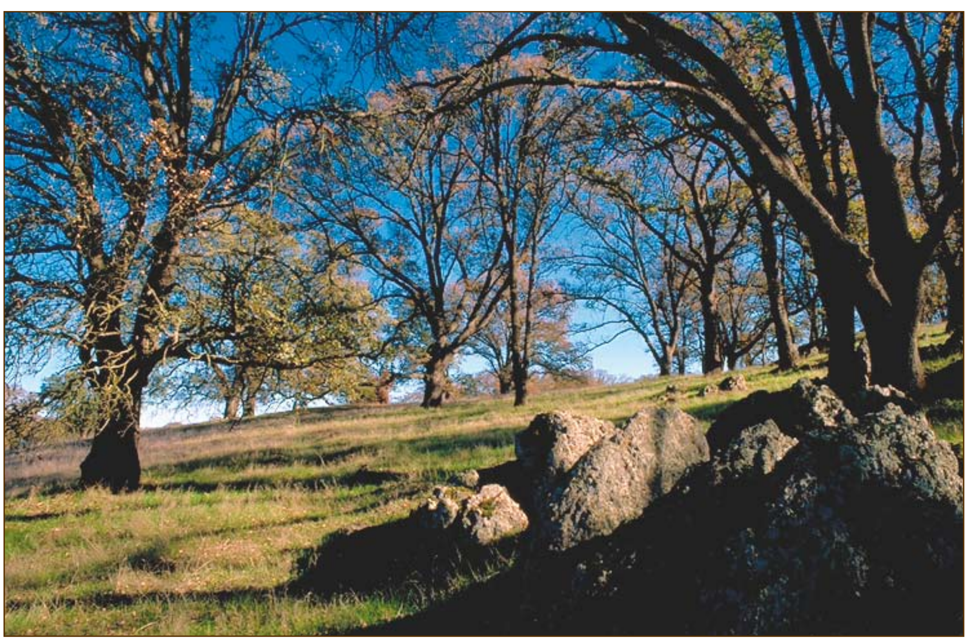


Figure 44—Area of oak forest types by density class on forest land in California, 2001–2005; TPA = trees per acre.



Dale Waddell

Figure 45—Many oak woodlands in California have few seedlings or saplings present.

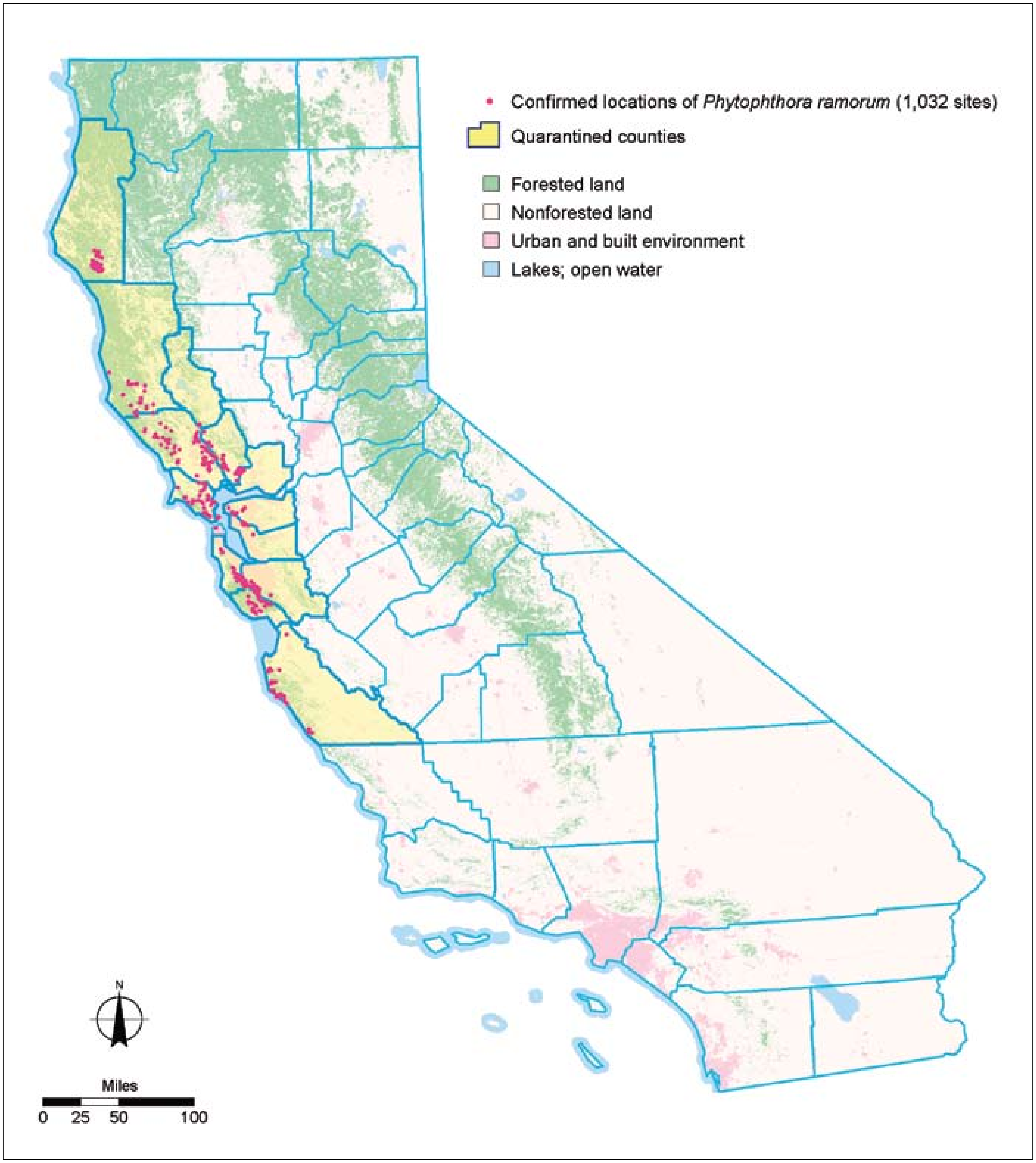


Figure 46—Confirmed locations of *Phytophthora ramorum* (California Oak Mortality Task Force 2006) and quarantined counties in California (APHIS 2007; forest/nonforest geographic information system (GIS) layer: Blackard et al. 2008; urban/water GIS layer: Homer et al. 2004).

Sudden Oak Death[5]

Sudden oak death, a disease caused by the fungus *Phytophthora ramorum*, was first noticed in tanoaks in California in 1995. Most of the major tree species in coastal California are hosts for the disease, including Douglas-fir, coast redwood, coast live oak, canyon live oak, tanoak, California black oak, California bay laurel, bigleaf maple, Pacific madrone, and California buckeye. The pathogen has a large number of additional host species, including ornamentals such as rhododendron and camellia. The disease is having a substantial economic impact on the nursery industry of California.

As of February 2007, Marin, Santa Cruz, Sonoma, Napa, San Mateo, Monterey, Santa Clara, Mendocino, Solano, Alameda, Contra Costa, Humboldt, Lake, and San Francisco Counties were quarantined for the disease (fig. 46). The FIA inventories of unreserved land in these counties show a substantial increase from the 1970s to the 1990s in host species. The increase in numbers and biomass was particularly notable in tanoak, which, along with California bay laurel, has been linked to presence and spread of the disease.

Sudden oak death increases mortality of coast live oak, tanoak, and California black oak, all three of which are important components of coastal California ecosystems. Estimates from the 2001-05 inventory show 499,000 acres of coast live oak forest in the quarantined counties, constituting 22 percent of the region's oak forest. There are an estimated 836 million tanoak trees (excluding seedlings), making tanoak the most numerous species in the quarantined area. California black oak trees, an important source of acorns for wildlife, are less common, with an estimated 54 million trees and 332,000 acres in the California black oak forest type. In the quarantined area, 78 percent of forest classified as coast live oak, tanoak, and California black oak forest is privately owned, and 7 percent is in reserved land such as state and national parks.

A 2001–05 special study of FIA plots with tanoak or bay laurel provided a rough estimate of more than 150,000 acres where the disease was present. The 2006 air survey by the Forest Health Survey program detected more than 21,000 acres of hardwood mortality in the affected counties; the current prognosis is that disease presence and tree mortality will continue to increase slowly. Control efforts are primarily aimed at preventing the spread of the disease to other parts of California and to other states and countries (fig. 47).

Tara Barrett

Figure 47—Currently, response to sudden oak death focuses on preventing spread of the disease to new areas. As a reminder for recreationists, signs like this can be found at trailheads throughout quarantined areas in coastal California.

[5] Author: Tara Barrett.

Interpretation

Conversion of oak woodland has a social impact disproportionate to the area on which it occurs because conversion usually happens in the high-visibility places where people live, work, and play. Since passage of the Oak Woodland Conservation Act in 2004, California counties have been required to include the conversion of oak woodlands in the environmental impact process specified by the California Environmental Quality Act. Consequently, there has been increased interest in oak conservation and mitigation strategies.

Tables with oak data in appendix 2—

- Table 4—Estimated area of forest land, by forest type group, ownership, and land status, California, 2001–2005
- Table 8—Estimated number of live trees on forest land, by species group and diameter class, California, 2001–2005
- Table 20—Estimated aboveground biomass of all live trees by diameter class and species group, California, 2001–2005

Tree Crowns, Soil, and Understory Vegetation[6]

Background

This chapter highlights three important FIA forest health indicators, tree crowns (the upper part of a tree including branches and leaves), soil, and understory vegetation. These are important structural components in all forest ecosystems. Each indicator can be applied to address a variety of monitoring questions. For example, the amount and vertical layering of different plant life forms (e.g., trees, shrubs, forbs, and grasses) are key determinants of wildlife habitat, fire behavior, erosion potential, and plant competition (MacArthur and MacArthur 1961, National Research Council 2000). Tree crown density, transparency, and dieback are indicators of tree vigor, impacts from disease or other stressors, and potential for mortality (Randolph 2006). Soil structure and nutrient status contribute to the diversity and vigor of vegetation across California. Because soil development is a slow process (Jenny 1941), protection from erosion, compaction, and nutrient loss is crucial to sustaining forest products and ecosystem services.

The FIA crews visually estimated crown density, foliage transparency, and dieback on phase 3 plots across California. Crown density is the percentage of area within the outline of a full crown that contains branches, foliage, and reproductive structures when viewed from the side. Transparency is the percentage of the live foliated portion of the tree's crown through which skylight is visible. Crown dieback is the percentage of the foliated portion of a crown consisting of recent branch and twig mortality in the upper and outer portions of the crown (Randolph 2006).

Soils were also sampled on phase 3 plots for both physical and chemical properties (O'Neill et al. 2005). Crews recorded forest floor thickness, soil texture, and visual indicators of erosion and soil compaction (e.g., trails and ruts). Soil samples were analyzed for moisture content, percentage of coarse fragments, bulk density, carbon (C) and nitrogen (N) content, pH, and the amounts of extractable phosphorus (P), sulfur (S), manganese, iron, nickel, copper, zinc, cadmium, and lead, as well as the exchangeable levels of sodium, potassium, magnesium, calcium, and aluminum.

Crews sampled understory vegetation on each phase 2 FIA subplot on forest land. Total cover was estimated for the following four vegetation life forms: tree seedlings and saplings (<5 inches d.b.h.), shrubs, forbs, and graminoids. Total cover of all four life forms was estimated, and also total cover of bare mineral soil.

A major benefit of the crowns, soils, and understory vegetation indicators will lie in tracking deviations from baseline conditions, meaning that the full functionality of these indicators cannot be fully realized with these first 5 years of data. Thus, the current status of each indicator is summarized only briefly below, to establish baselines for California's forests and to inform readers about the development of FIA forest health indicators.

[6] Authors: Glenn Christensen, Joseph Donnegan, and Andrew Gray.

Findings

Crown density ranged from 27 to 48 percent among species groups, with a mean of 38 percent. Mean foliage transparency was 20 percent and was greater for hardwoods than for softwoods (fig. 48). Recent crown dieback was detected for only 2.8 percent of the trees examined. Only four species groups had more than 5 percent of all trees with more than minimal (>10 percent) observed crown dieback: the western woodland softwood (14 percent, mostly pinyon pine), western woodland hardwood (14 percent, mostly mountain mahogany), cottonwood and aspen (10 percent), and oak (7 percent) groups.

Carbon and N in the top 7.9 inches of soil were positively correlated ($r^2 > 0.73$). Their abundance varied greatly across the state and was not significantly related to elevation, latitude, or soil moisture (figs. 49 and 50). On the 31 plots where soils have been remeasured to date, organic C in the forest floor layer had slightly decreased between 2000 and 2005 (6.71 percent; $t = 3.1$, $p < 0.05$). Visual signs of soil compaction were evident on 36 percent of the plots in a variety of forests across California (fig. 51). The mean compacted proportion was 6 percent of plot area. Bulk density was not significantly related to the compaction on plots (logistic regression and chi-square test: $p > 0.12$), possibly owing to fine-scale heterogeneity and because bulk density is sampled off the plot (to minimize disturbance to the sampled area), whereas evidence of compacted trails, ruts, and compacted areas is visually assessed on the plot. Bare-soil cover was greatest in the drier areas east of mountain ranges, particularly the south-central portion of California.

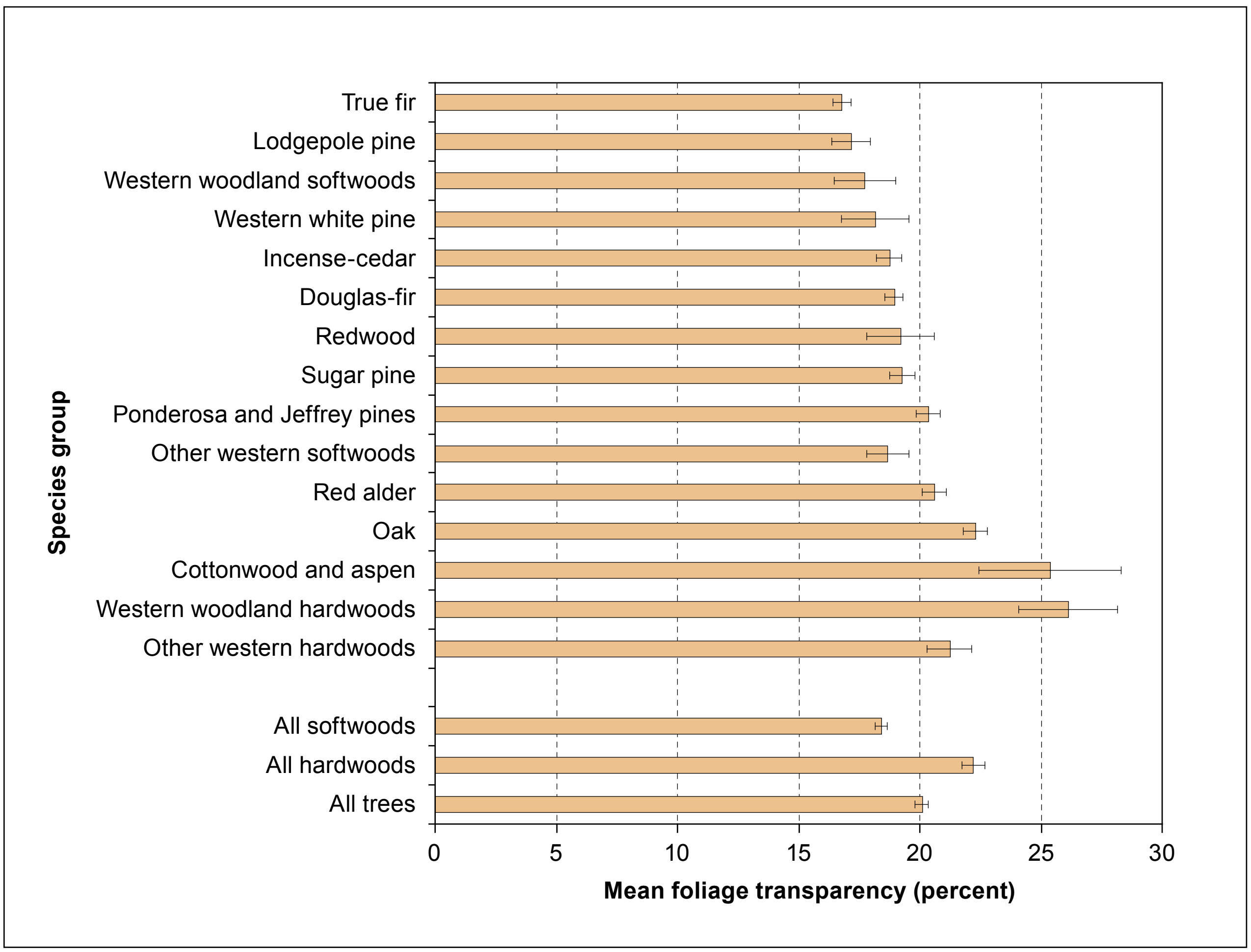


Figure 48—Mean foliage transparency by species group on forest land in California, 2001–2005.

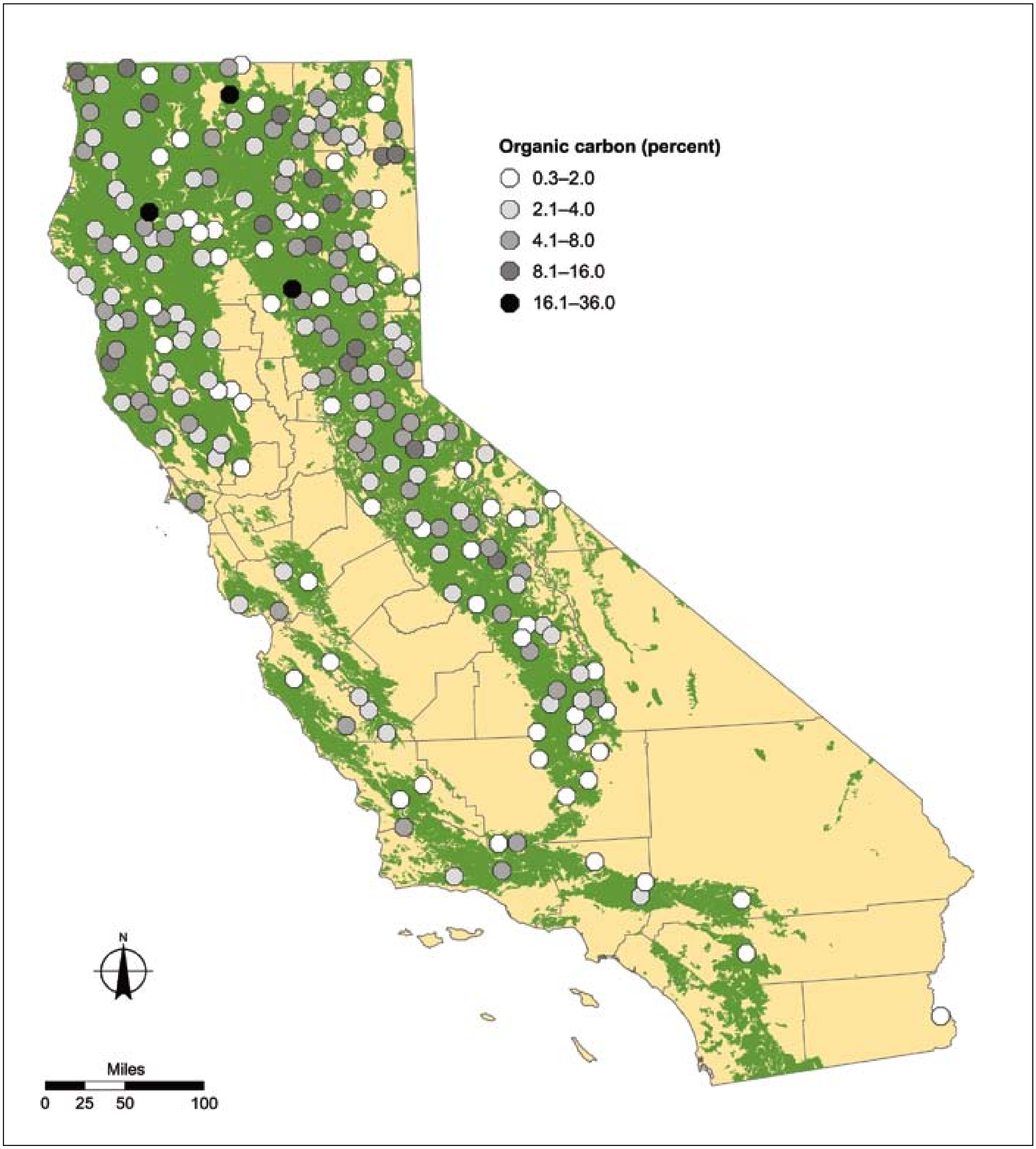


Figure 49—Soil carbon distribution on forest land in California, 2001–2005 (forest/nonforest geographic information system layer: Blackard et al. 2008).

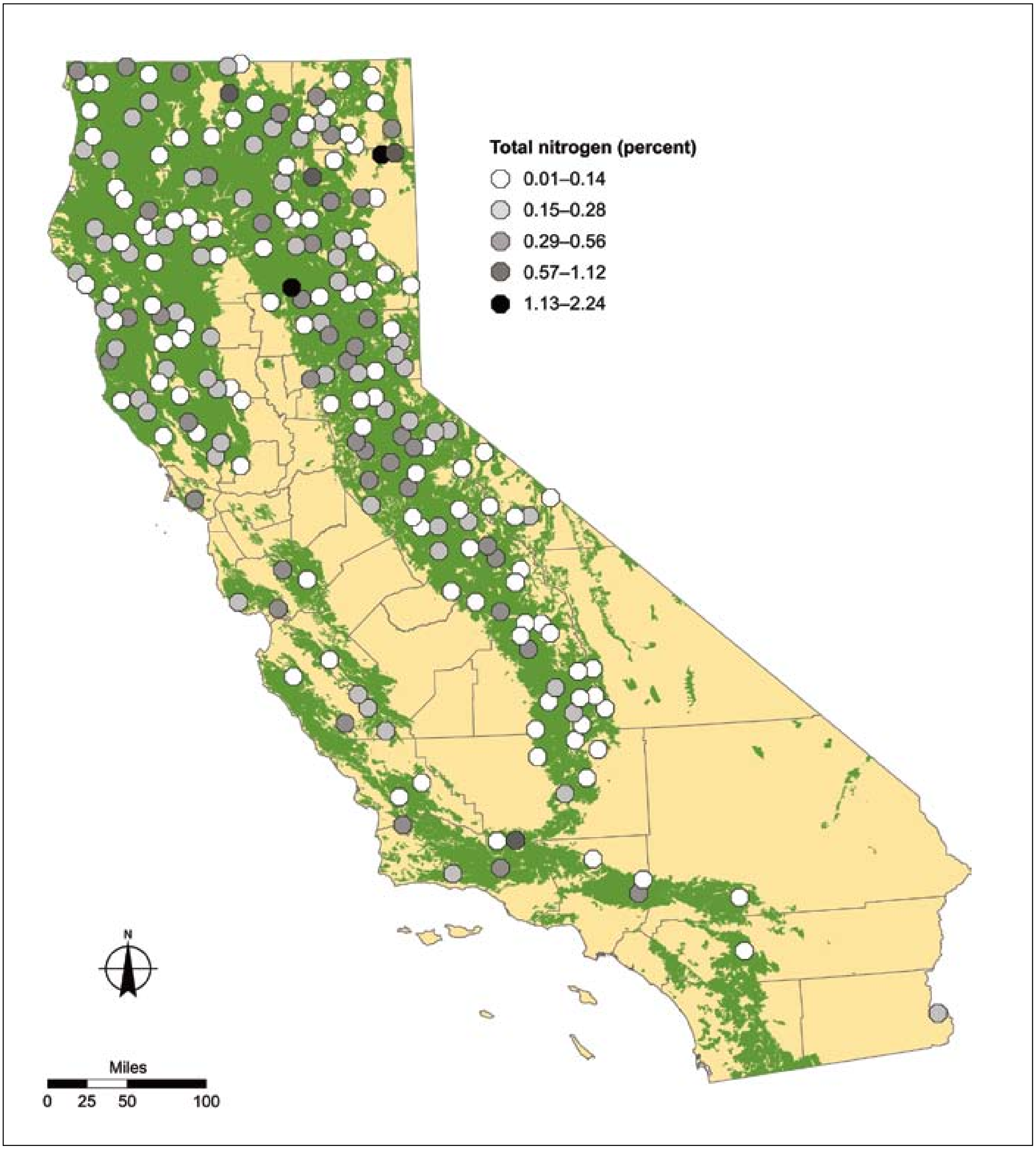


Figure 50—Soil nitrogen distribution on forest land in California, 2001–2005 (forest/nonforest geographic information system layer: Blackard et al. 2008).

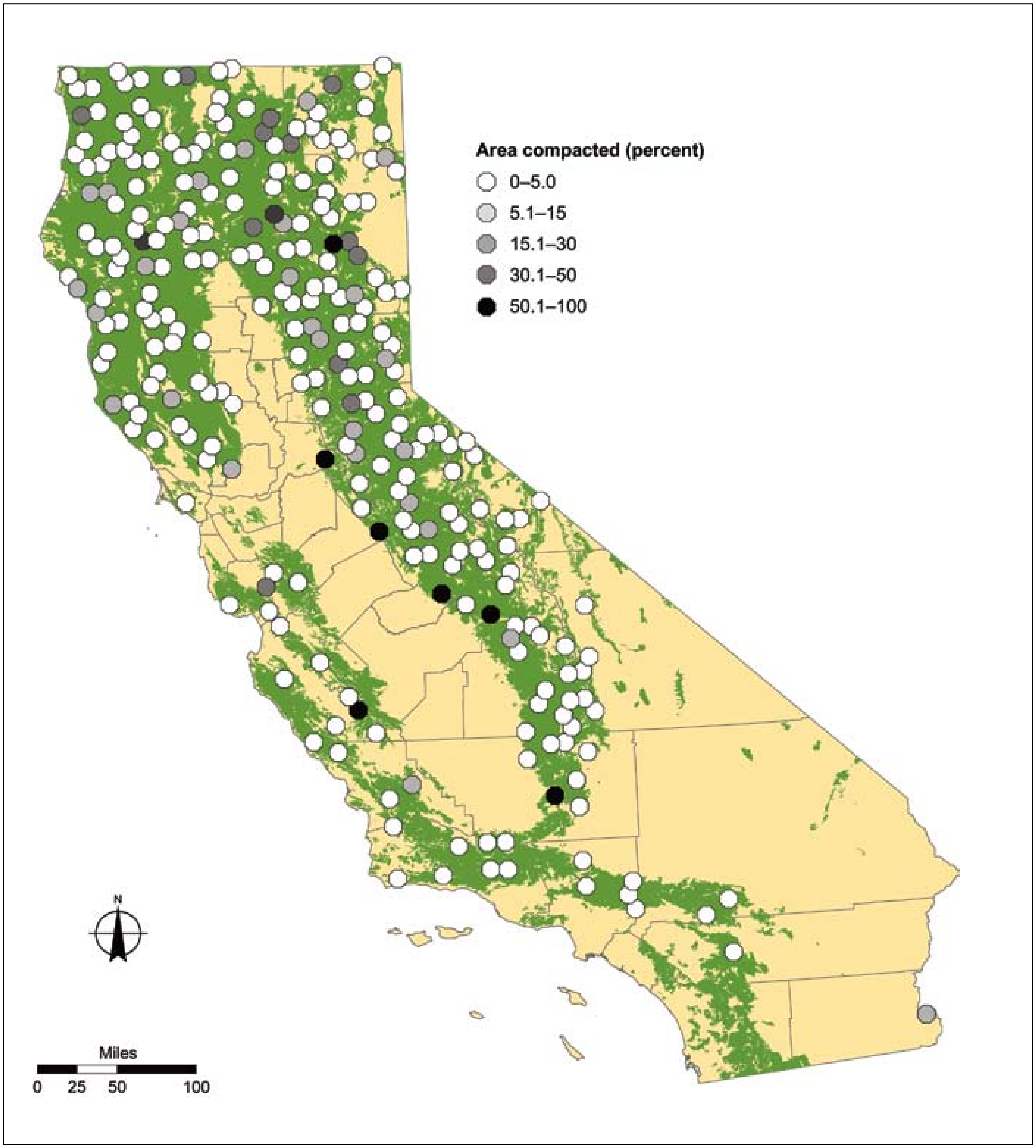


Figure 51—Evidence of soil compaction on forest land in California, 2001–2005 (forest/nonforest geographic information system layer: Blackard et al. 2008).

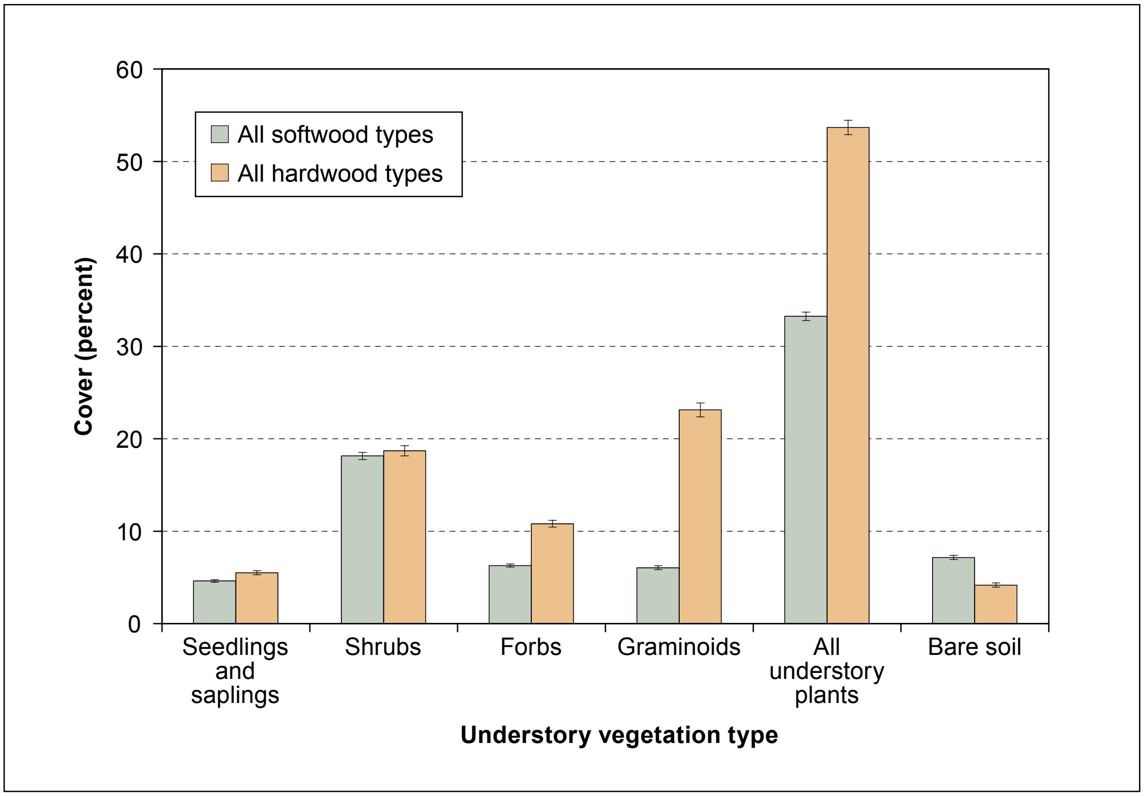


Figure 52—Cover of vegetation life forms and bare soil by softwood and hardwood forests on forest land in California, 2001–2005.

Cover of understory vegetation in California was greater in hardwood than in conifer forests (fig. 52). Within each type, shrub cover was highest in the higher moisture forest type groups (cottonwood/ash and hemlock), while graminoid cover was highest in the drier types (oak and the "other western softwoods" group). Forb cover was greatest in the hemlock and alder/maple groups (fig. 53). Understory cover was greater in stands 0 to 40 years old than in older stands (primarily due to differences in shrub cover), but cover differed little with stand age for stands over 40 years old (fig. 54).

On national forest land, the chaparral vegetation type covered 2 million acres in California's Southern and Central Coast survey units. Chamise was the most common type of chaparral, followed by the mixed and montane type (definitions follow Fried et al. 2004). These estimates differ from the estimates in Fried et al. 2004, which used an early 1990s chaparral inventory, probably because a greater range of shrub vegetation types were included in the analysis presented here and because the classification into chaparral types is highly sensitive to slight changes in abundance of a few species.

Andrew Gray

Figure 53—Dense understory cover of forbs and shrubs in a hemlock forest.

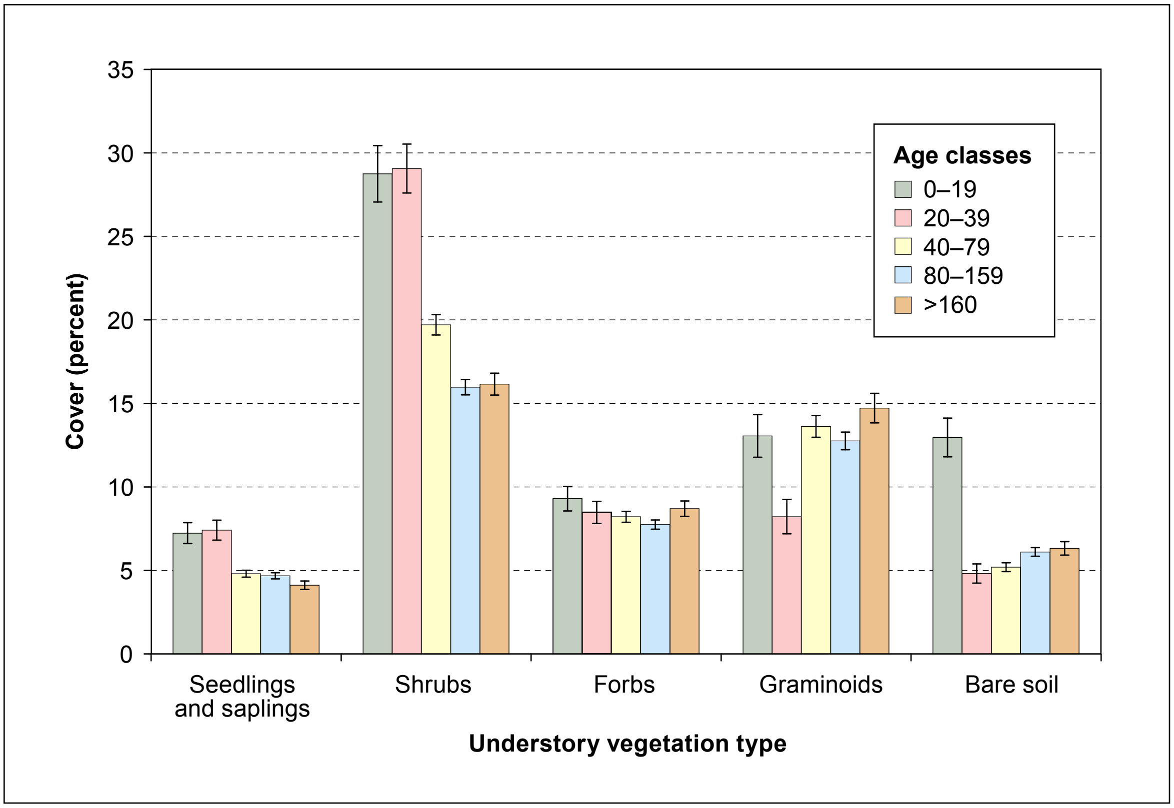


Figure 54—Cover of vegetation life forms and bare soil by forest age class on forest land in California, 2001–2005.

Area of chaparral by type on national forests in southern California is shown in the following tabulation:

Chaparral type	Area	SE
	Acres	
Chamise	821,400	68,000
Coastal transition	249,400	40,900
Mixed and montane	524,600	58,000
Mountain mahogany	136,800	30,900
Scrub oak	275,000	43,900
Total	2,007,100	77,200

Interpretation

Initial results suggest that crown decline is not widespread in California. Most dieback was found in dry forest types in the southeastern part of the state. Future remeasurements will provide more precise estimates of changes in crown health over time. The abundances of C and N were correlated but highly variable across the forests of California. Soils high in organic C are generally associated with higher levels of microbial activity and key nutrients, including N, S, and P (Mengel et al. 2001). Soils in wet, cool environments tend to be high in organic C, although this pattern was not clear in the data collected to date. Soil compaction was widely dispersed in California's forests. Compaction, which can be caused by heavy machinery, repeated use of vehicles, and trampling by humans or livestock, can inhibit plant growth by decreasing soil pore space and can lead to increased erosion during high-precipitation events.

The amount and composition of understory vegetation differed greatly among the forest types and forest age classes of California. Although all life forms were represented in all forest types to some extent, their abundance appeared to differ according to forest type. Shrubs and graminoids appeared to be particularly sensitive to the overstory tree type (softwood or hardwood) as well as the moisture availability within different forest type groups. Although vegetation abundance differed with age class, the conventional wisdom that dense young forests have very low cover of understory plants does not appear to be prevalent across California.

Tree crowns, soils, and understory vegetation tables in appendix 2—

- Table 29—Mean cover of understory vegetation on forest land, by forest type group and life form, California, 2001–2005
- Table 30—Mean cover of understory vegetation on forest land, by forest type class, age class, and life-form, California, 2001–2005
- Table 31—Estimated mean crown density and other statistics for live trees on forest land, by species group, California, 2001–2005
- Table 32—Estimated mean foliage transparency and other statistics for live trees on forest land, by species group, California, 2001–2005
- Table 33—Estimated mean crown dieback and other statistics for all live trees on forest land, by species group, California, 2001–2005
- Table 34—Properties of the forest floor layer on forest land, by forest type, California, 2001, 2003–2005
- Table 35—Properties of the mineral soil layer on forest land, by depth of layer and forest type, California, 2001, 2003–2005
- Table 36—Chemical properties of mineral soil layers on forest land, by depth and forest type, California, 2001, 2003–2005
- Table 37—Chemical properties (trace elements) of forest floor and mineral soils on forest land, by forest type, California, 2001, 2003–2005
- Table 38—Compaction, bare soil, and slope properties of forest land, by forest type, California, 2001, 2003–2005

Go to Part B