Castle Dome and Mount Shasta.

Redwoods.

Mount San Gorgonio.

Chapter 4: Disturbance and Stressors

Major disturbance agents and stressors such as insects, diseases, invasive species, air pollution, and fire are among the most powerful agents shaping the structure, species composition, and ecological function of forests. We explore the influence of these agents through analysis of both plot data and predictive models.

Insects, Diseases, and Other Damaging Agents[1]

Background

Insects, diseases, and other damaging agents can have both detrimental and beneficial effects on forest ecosystems (fig. 55). The frequency and severity of damage to trees by biotic agents, such as insects and diseases, and abiotic agents, such as fire and weather, are influenced by a number of factors, ranging from forest structure and composition to management policies and activities. Effects include defoliation, decay, reduced growth, increased susceptibility to other stressors, and mortality. These impacts can affect ecosystem structure, composition, and function. Introduced insects and diseases such as white pine blister rust (*Cronartium ribicola*) or sudden oak death (*Phytophthora ramorum*) can often have more rapid and intense impacts on ecosystems than native organisms.

The Pacific Northwest Research Station Forest Inventory and Analysis (FIA) Program collects data on damaging agents for each measured live tree and also maps root disease when present. These systematically collected FIA data complement localized ground surveys and the annual aerial survey conducted by the USDA Forest Service forest health protection (FHP) program, which maps occurrence of defoliation and mortality observed from the air. The FIA plot-based sampling protocol allows estimation of acres, trees per acre, basal area, and volumes affected by each agent to be summarized across forest types or large geographic areas. Information is most reliable for damage agents that are common and broadly distributed and least reliable for unevenly distributed, less common agents such as newly established nonnative organisms.

Findings

About 18 percent of live trees greater than 1 inch in diameter showed signs or symptoms of insects or diseases; damage by animals, weather, or fire; or physical defects

[1] Authors: Sally Campbell and Dave Azuma.

Figure 55—Fruiting body of stem decay fungus, *Laetiporus sulphureous*.

such as a dead or missing top or stem crack, check, fork, or crook. By comparison, in the Oregon inventory, 27 percent of trees were recorded as damaged. Of the two most common conifer species in California, 11 percent of Douglas-fir (see "Scientific and Common Plant Names") and 20 percent of white fir trees were damaged. Of the two most common hardwoods, 18 percent of canyon live oak and 10 percent of tanoak trees were damaged. More than 18 million acres had over 25 percent of the basal area affected by one or more damaging agents (figs. 56 and 57). The volume of live trees greater than 5 inches in diameter with one or more damaging agents was almost 34 billion cubic feet—34 percent of total volume (figs. 56 and 57). The overall level of damage was somewhat higher in the San Joaquin, Central

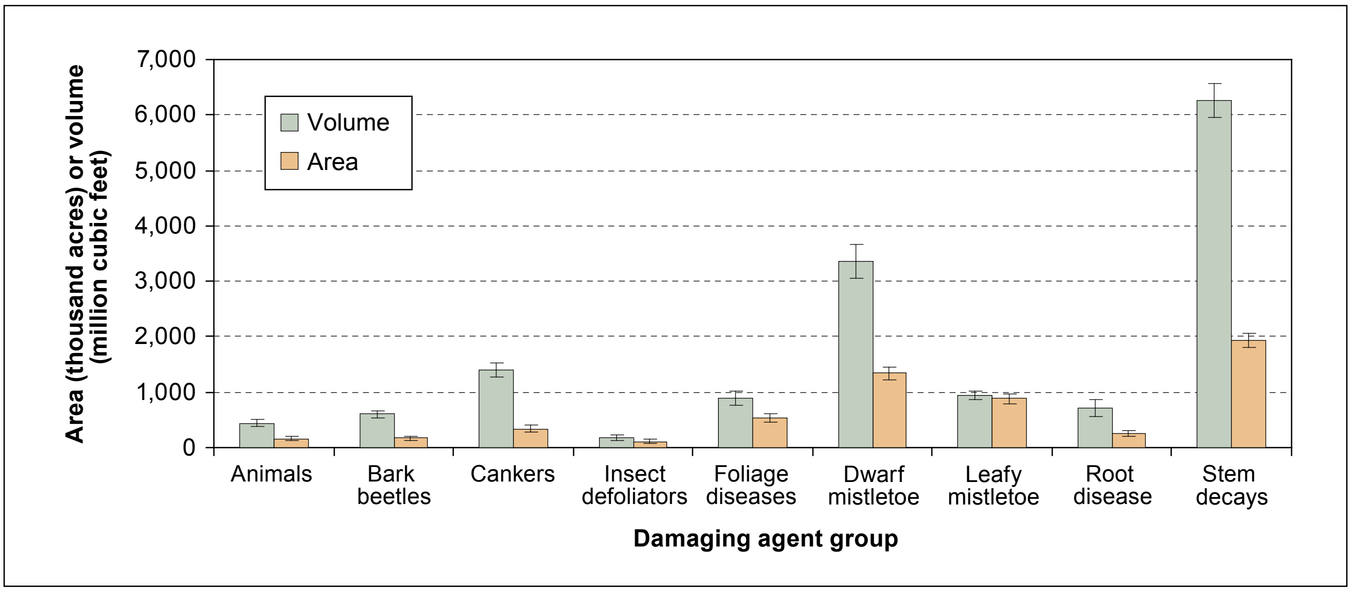

Figure 56—Area and volume of live trees affected by one or more biotic agents on forest land in California, 2001–2005; volume is gross volume of live trees ≥ 5 inches diameter at breast height.; acres are those with ≥ 25 percent of the basal area with damage.

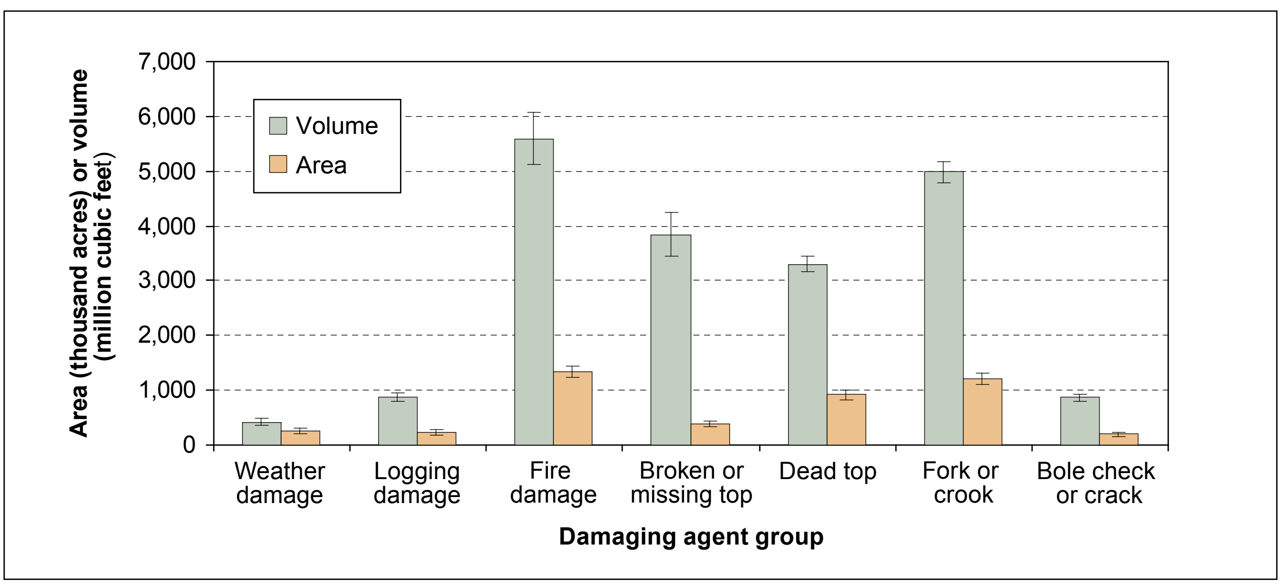

Figure 57—Area and volume of live trees affected by one or more abiotic agents on forest land in California, 2001–2005; volume is gross volume of live trees ≥ 5 inches diameter at breast height; acres are those with ≥ 25 percent of the basal area with damage.

Coast, and Southern survey units than in the others. The most prevalent types of damage, in terms of numbers of trees affected, were physical defects and damage caused by abiotic agents (fig. 57). Of the biotic agents, stem decays and dwarf mistletoes affected the highest volume and the most acres in California (figs. 56 and 58).

Interpretation

Some of the most common biotic (living) agents—stem decays and dwarf mistletoes—are generally more prevalent in unmanaged or older stands. If the current management trends on federal forests continue, we would expect to see increases in these agents on national forests and other federal lands; conversely, we would expect decreases or continued lower levels on private and nonfederal forests, where stands are younger and more intensively managed. The incidence and impact of many insects and diseases are closely tied to past forest management practices that have influenced forest structure and composition.

Some of the greatest threats to California's forests are from native organisms such as bark beetles, whose populations and impacts are increased by drought, high stand densities, and climate change. Recent bark beetle epidemics in southern California and British Columbia, Canada, are attributed to a number of these factors (British Columbia Ministry of Forests 2006, Pedersen 2003, USDA Forest Service 2005, Walker et al. 2006). Introduced insects and diseases also pose significant threats. The impact of an "old" introduced disease—white pine blister rust—on California's five-needle pines is well documented (Kliejunas and Adams 2003), whereas assessments of impacts from newer diseases such as sudden oak death are still underway (California Oak Mortality Task Force 2007). Introduced insects and diseases not yet discovered may also present large risks (Pimentel et al. 2005).

Although FIA under-records bark beetles, insect defoliators, and foliage diseases owing to a number of factors,[2] results of widespread bark beetle epidemics should be observable in future FIA tree mortality data. Annual aerial surveys can also provide excellent, timely information on insect- and disease-caused defoliation. Tracking the incidence of damaging agents over time will become particularly important as changes in climate and in human activities affect the structure and composition of California's forests.

Damaging agent tables in Appendix 2—

- Table 39—Estimated number of live trees with damage on forest land, by species and type of damage, California, 2001–2005
- Table 40—Estimated area of forest land with more than 25 percent of basal area damaged, by forest type and type of damage, California, 2001–2005
- Table 41—Estimated gross volume of live trees with damage on forest land, by species and type of damage, California, 2001–2005
- Table 42—Estimated number of live trees with damage, acres of forest land with greater than 25 percent of the basal area damaged, and gross volume of live trees with damage, by survey unit and ownership group, California, 2001–2005

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[2] Bark beetles, insect defoliators, and foliage pathogens are likely under-recorded because FIA has difficulty in detecting symptoms of bark beetle attack on live trees prior to mortality, spatially and temporally heterogeneous defoliation events do not necessarily coincide with FIA plot visits, and some damage occurs on upper portions of trees in dense stands, making it hard to detect.

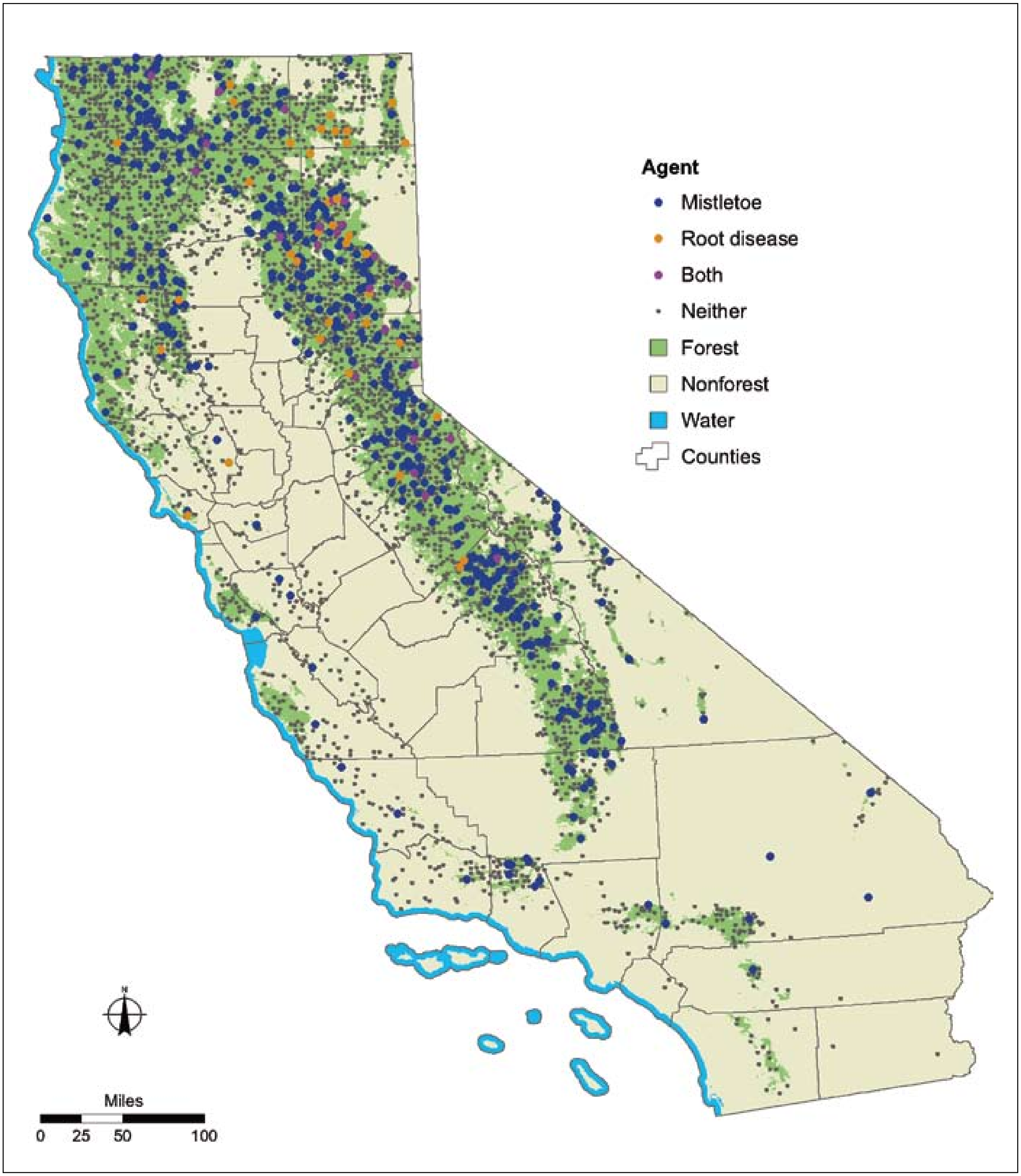

Figure 58—Root disease and dwarf mistletoe incidence on visited Forest Inventory and Analysis plots in California, 2001–2005 (forest/nonforest geographic information system layer: Blackard et al. 2008).

Insect-Related Conifer Mortality in Southern California[3]

Between 1998 and 2003, the mountainous areas of southern California (all or parts of the San Bernadino, San Jacinto, Palomar, and Cuyamaca/Laguna ranges) experienced below average precipitation and an extensive outbreak of insect activity that affected conifer stands in this region (fig. 59). The trees in these forests were already under stress from anthropogenic atmospheric agents (ozone, nitrogen oxides, etc.), and the additional stress of extended drought probably exacerbated the insect outbreak, consisting primarily of bark and engraver beetles. The outbreak manifested itself differently in different geographic regions—in the San Jacinto and San Bernadino ranges, the true fir forests were affected the most; in San Diego County, the pine types were most affected.

Figure 59—Conifer mortality in southern California.

An estimated 3.5 million trees were killed. The overall mortality rate for conifers over this 5-year period was 13 percent, and the mortality rate for gray pine, bigcone Douglas-fir, and ponderosa pine exceeded 50 percent. Given the steady increase in residential development in the southern California mountain areas during the 20th century, elevated tree mortality poses increased safety risks to the region's inhabitants. The risk of dead trees falling on nearby homes, roads, and power lines was sufficiently alarming to motivate formation of three multiagency task forces: Mountain Area Safety Taskforce (MAST) in both San Bernardino and Riverside Counties, and Forest Area Safety Taskforce (FAST) in San Diego County, to facilitate rapid removal of dead trees. This response demonstrates the importance of preventive interaction among communities that have become, for practical purposes, cities, located in and near forests with dying trees.

The following tabulation shows the number of conifer trees greater than 5 inches diameter at breast height (d.b.h.) that died between 1998 and 2003 on forest land in the counties of San Bernardino, Riverside, San Diego, and Los Angeles, by species (Walker et al. 2006):

[3] Author: David Azuma.

Species	Live and dead	Dead	Dead
	Number of trees		*Percent*
Bigcone Douglas-fir	90,797	49,243	54
Coulter pine	840,473	375,546	45
Gray pine	4,167	4,167	100
Incense-cedar	1,920,557	2,835	0
Jeffrey pine	6,059,420	654,034	11
Limber pine	38,846	1,994	5
Lodgepole pine	702,573	11,139	2
Ponderosa pine	447,086	256,959	55
Singleleaf pinyon pine	6,811,831	495,879	7
Sugar pine	1,045,522	215,200	21
Western juniper	1,214,356	9,363	1
White fir	8,444,104	1,440,597	17
Total	27,619,532	3,506,955	13

Invasive Plants[4]

Background

Invasions of nonnative plants into new areas are having a large impact on the composition and function of natural and managed ecosystems. Invasive plants can directly affect the composition and function of ecosystems. They may also have a large economic impact, either by changing or degrading land use, or through the costs of eradication efforts, which cost the U.S. economy over $35 billion per year (Pimentel et al. 2005).

Nonnative plant invasions competitively exclude desired species, alter disturbance regimes, and are a primary cause of extinction of native species (D'Antonio and Vitousek 1992, Mooney and Hobbs 2000, Vitousek et al. 1996). Despite the importance of invasive plants, most emphasis is given to their local eradication, and so there is little comprehensive information about the extent and impact of nonnative invasions. There is little quantitative information about the magnitude of the problem, which plants are having the most impact, and where these plants are found.

The following summary relies on estimates of the most abundant species found on phase 2 plots. Crews estimated cover of the three plant species with the highest cover in each of three life forms—shrub, forb, and graminoid—as well as of any other species with ≥3 percent cover. Because phase 2 field seasons include several months when many species are not in bloom, and because plant identification skills differ, species were selected for analysis that were readily identifiable by most crews. Because the definition of "invasive" can be quite subjective, all readily identifiable species that were listed as nonnative to the United States (USDA Natural Resources Conservation Service 2000) were selected for analysis. The proportion of plot area covered by each species was multiplied by the number of acres each plot represented in the inventory to estimate area covered.

Findings

The most common invasive plant found on phase 2 plots in California was cheatgrass, which covered 144,000 acres of forest land (fig. 60). Several other nonnative grasses were recorded frequently, including bristly dogstail grass (see "Scientific and Common Plant Names"), soft brome, and medusahead. Yellow star-thistle was the most abundant nonnative forb, covering 32,000 acres of forest land, and Himalayan blackberry was the most abundant nonnative shrub, covering 34,000 acres. The ecosections with the highest proportion of area covered by the selected nonnative species were in the foothills and interior Coast Ranges around the Great Valley (fig. 61).


Leslie J. Mehrhoff, University of Connecticut, Buwood. org

Figure 60—Cheatgrass is the most common invasive plant in forests of California.

[4] Author: Andrew Gray.

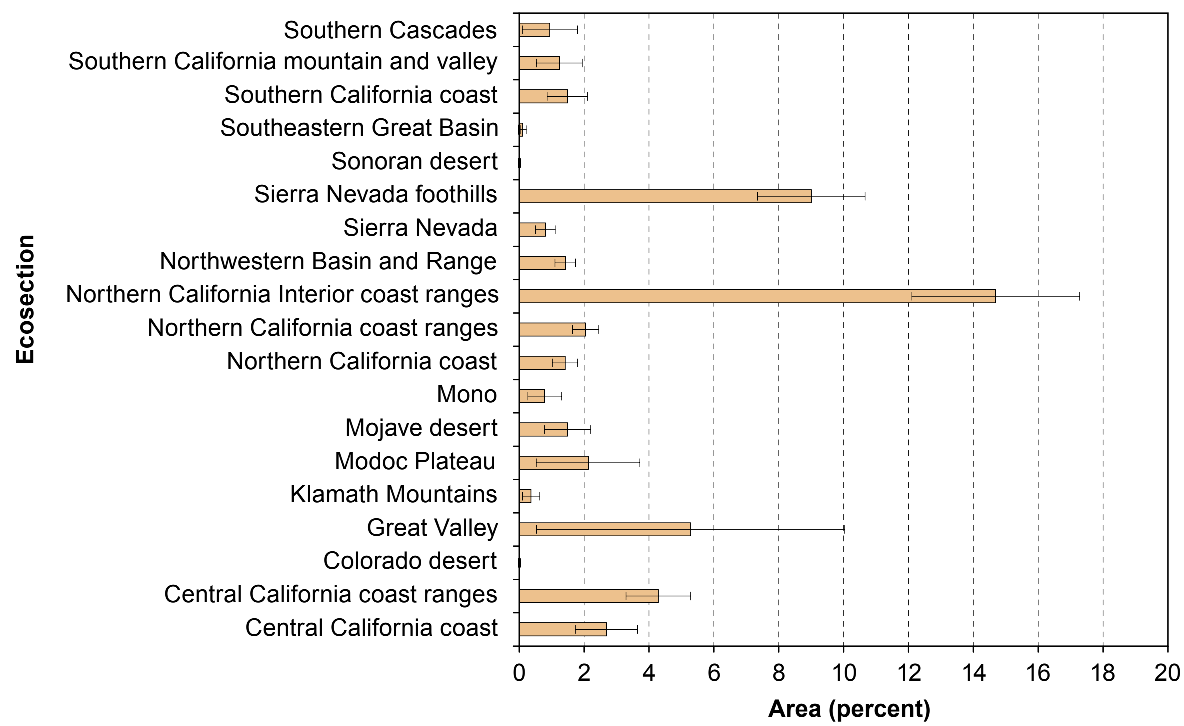

Figure 61—Percentage of area covered by selected nonnative invasive species, by ecosection on forest land in California, 2001–2005.

Interpretation

Nonnative invasive plant species appear to be well established in California's forested lands, with several species covering 50,000 acres or more. Current trends suggest that their importance will increase; for example, knotweed and false brome have high potential to expand their range in California (California Invasive Plant Council 2005). Many of the currently problematic invasive species are grasses or composites associated with relatively dry, open forest habitats.

This combination of sites and species makes the inventory of invasives challenging. The species can be difficult to identify with certainty, and their growing season (when they are most identifiable) is short. The FIA phase 3 vegetation indicator, based on sampling by botanists during the growing season, has yet to be implemented in California. If it were implemented, it could provide comprehensive information on species composition that could inform national indicators on the impacts of invasive plants (Gray and Azuma 2005, Heinz Center 2002). However, the Phase 3 plot density is too low to assess the distribution of most individual species. The FIA phase 2 sample does provide that comprehensive information for readily identifiable species, and potentially for other species if dedicated identification training were to be provided.

Invasive plants table in appendix 2—

- Table 43—Estimated area of forest land covered by selected nonnative vascular plant species, by life form and species, California, 2001–2005

Air Quality[5]

Background

Air quality is an ongoing concern for forest health in California, where population growth is expected to cause increased pollutant emissions from automobiles, industry, and agriculture. The effects of air pollution on vegetation and lichens are variable; common manifestations are visible injury to foliage; reduced growth; increased susceptibility to other stressors such as insects, disease, or drought; and premature mortality (Takemoto et al. 2001). As pollution-sensitive individuals are damaged or killed, ecosystem productivity, structure, and function are affected. Such changes can, for instance, adversely affect wildlife dependent on these species for food or habitat.

The FIA Program monitors injury to plants sensitive to ozone (O_3) and epiphytic (tree-dwelling) lichen communities to evaluate forest air quality. These bioindicators are a valuable supplement to preexisting air quality networks, which measure pollutants at a limited number of forested sites.

Ozone Injury Background

Ozone is highly phytotoxic and is considered a top ecological threat in California (U.S. Environmental Protection Agency 2006) (figs. 62 and 63). For the FIA O_3 indicator, foliar injury was scored on three or more O_3-susceptible plant species at each of 65 ozone plots (biosites). Injury data were combined into a biosite index that indicates local potential or risk for O_3 damage (Coulston et al. 2003). With geospatial interpolation[6] of biosite indices averaged over 6 years, we can predict relative risk to susceptible vegetation across a broader geographic area and identify O_3 problem areas where adverse effects to forest health are more likely. The FIA biosite network is the only statewide O_3 detection program that uses bioindicators to monitor O_3 impacts to forest vegetation.

Dan Duriscoe

Figure 62—Ozone injury on blue elderberry causing interveinal necrosis.

Ozone Injury Findings

Ozone injury was consistently detected at many California biosites between 2000 and 2005, indicating site conditions conducive to plant susceptibility and tropospheric O_3 high enough to visibly damage sensitive plant species (fig. 64). Symptoms were detected on five species: ponderosa pine, Jeffrey pine, blue elderberry, mugwort, and skunkbush. Most biosites (83 percent) had a low biosite index, indicating a low risk of injury. About 10 percent had a high biosite index and thus a high risk of injury (fig. 65). More than 267,000 acres, representing 596 million cubic feet of wood volume, are at moderate to high risk, as estimated from the intersection of modeled biosite indices with FIA plot data (Campbell et al. 2007).

[5] Authors: Sally Campbell and Sarah Jovan.

[6] Interpolation of gridded maps of the biosite index for each year 2000-2005 was done with gradient inverse distance weighting (GIDS). The GIDS technique combines multiple linear regression with inverse distance weighting interpolation, and, like other recently developed interpolation techniques, incorporates elevation as a covariate.

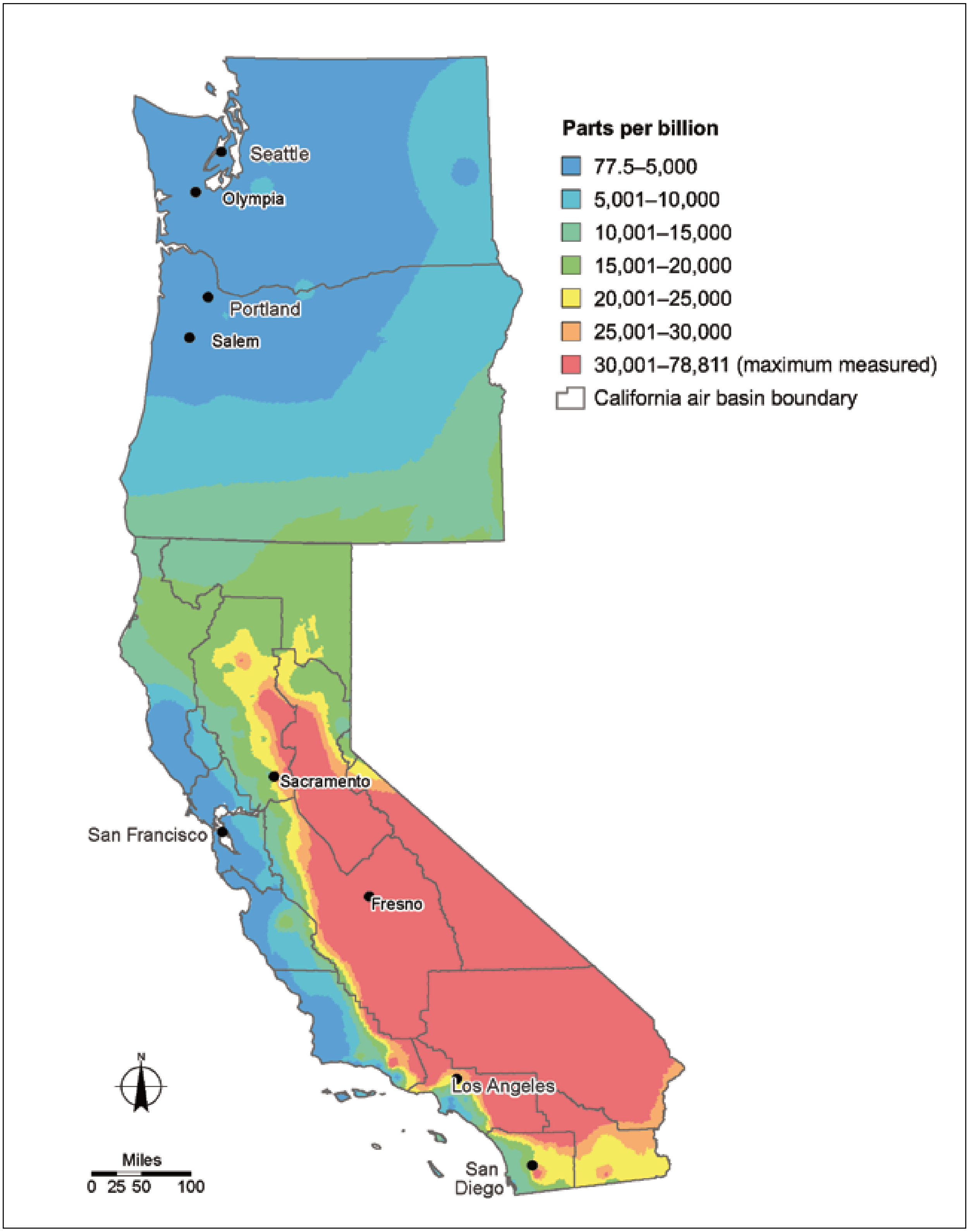

Figure 63—Average ozone exposure in Washington, Oregon, and California, based on cumulative hourly ozone concentrations exceeding 60 parts per billion (SUM60) June 1 to August 31, 8am to 8pm, 2001 to 2005 (SUM60 ozone data: U.S. Environmental Protection Agency 2006).

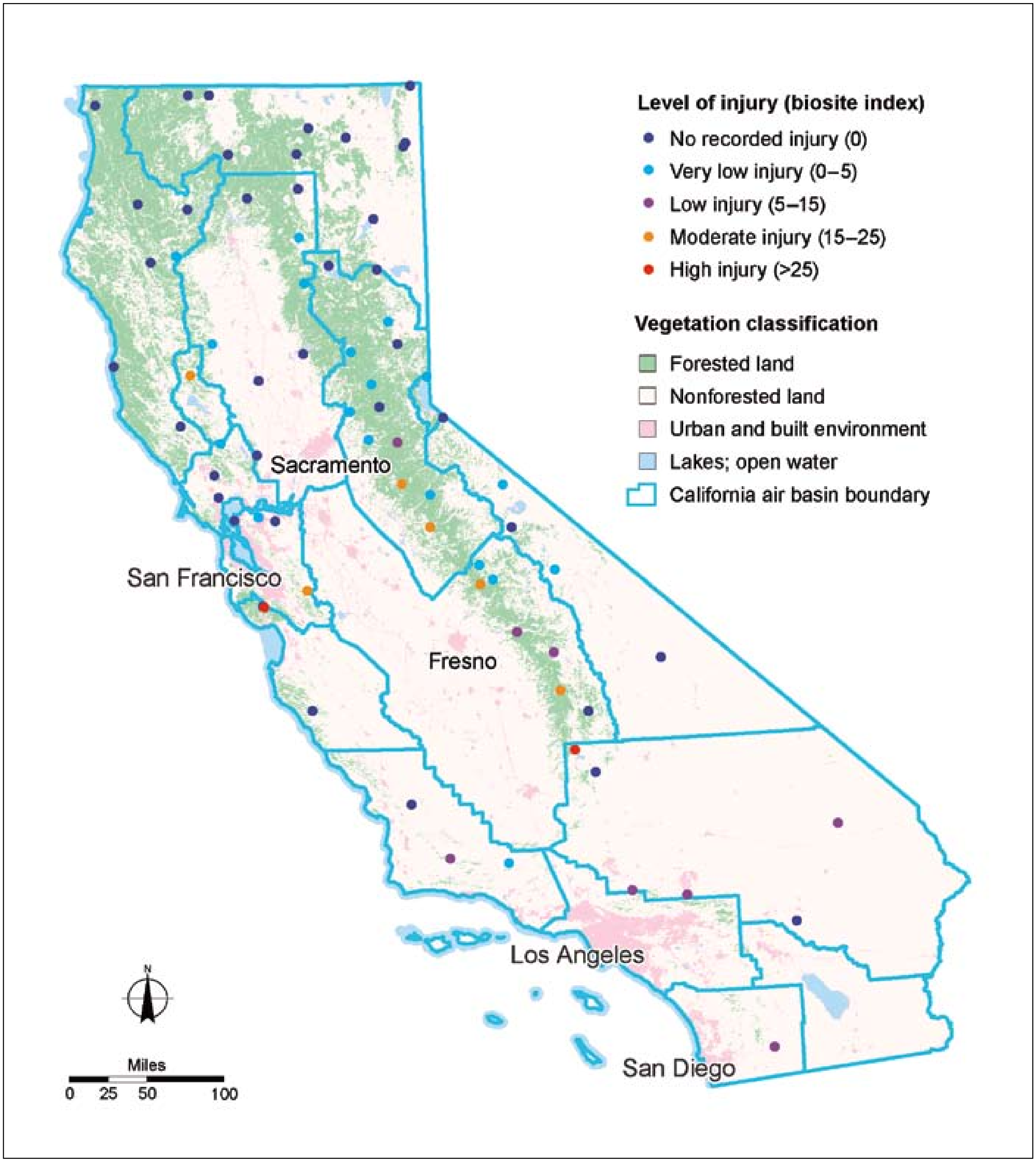

Figure 64—Forest Inventory and Analysis ozone biosites and average level of injury (average biosite index) in California, 2000–2005 (forest/nonforest geographic information system (GIS) layer: Blackard et al. 2008, water/urban GIS layer: Homer et al. 2004).

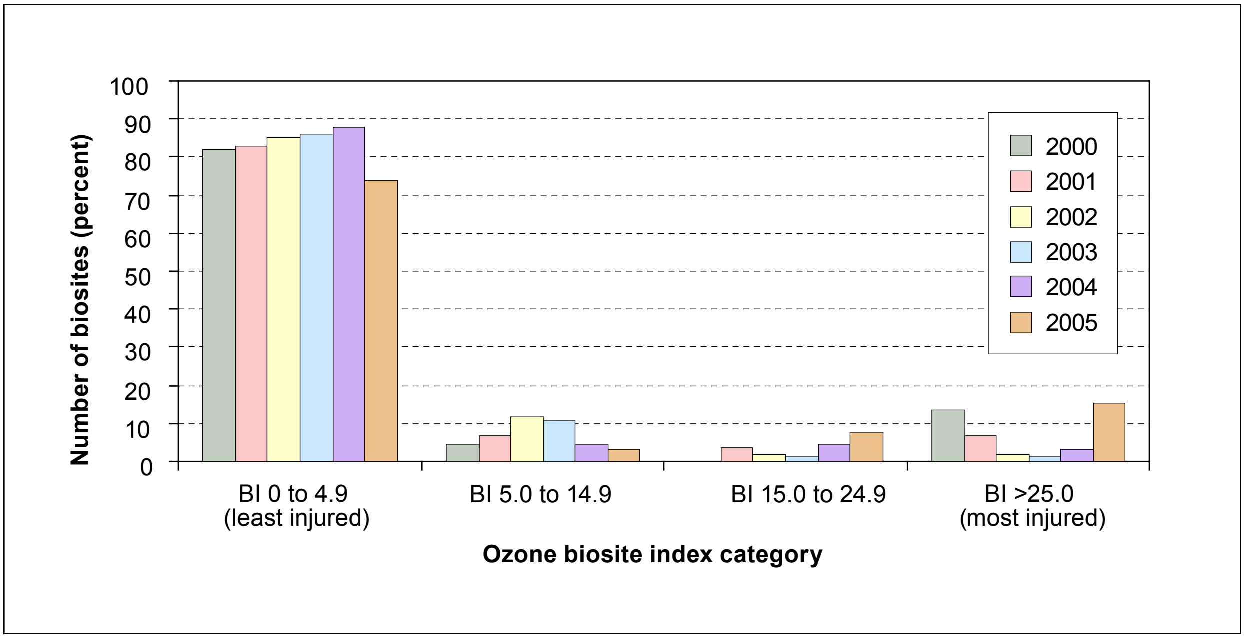

Figure 65—Percentage of ozone biosites by biosite index (BI) class in California, 2000–2005.

Ozone Injury Interpretation

The spatial distribution of FIA biosites with injured bioindicator plants is generally consistent with ambient O_3 monitoring data; regions of high O_3 exposure (fig. 63) tend to coincide with detection of foliar injury. However, there are some discrepancies between average exposure levels and detected injury, presumably because the ambient O_3 is higher than normal in some years and because of natural variability in environmental conditions conducive to O_3 uptake and injury. Ozone concentrations consistently exceed state and national standards in many of California's air basins (Cox et al. 2006) and, as demonstrated by our results, O_3 is injuring forest species in a number of locations in California. Efforts to abate vehicular and industrial emissions have been successful in reducing O_3 from past levels, but continued efforts will be needed as emissions increase with increasing population (Carroll et al. 2003). Annual reassessment of bioindicators on the FIA biosite network will allow statewide tracking of temporal and geographic fluctuations in O_3 injury.

Lichen Community Background

Lichens add considerably to forest biodiversity in California. They contribute to nutrient cycling and provide wildlife with forage and nesting materials. Lichen communities are excellent air quality bioindicators because some species are highly sensitive to pollutants such as acid rain, sulfur dioxide, and nitrogen (N) (fig. 66). For the FIA lichen community indicator, field crews survey epiphytic (tree-dwelling) lichens at 0.94-acre plots and estimate their diversity and abundance. With the help of multivariate models, FIA lichen data are used to score air quality at each plot and evaluate risks to forest health. Two of four models needed for California are complete, covering the greater Central Valley (Jovan and McCune 2005) and the greater Sierra Nevada regions (Jovan and McCune 2006). The models may also be used for mapping and tracking climate change with FIA lichen data (Jovan, in press).

Tim Wheeler

Figure 66—*Physcia adscendens* (gray) and *Xanthoria* spp. (orange) are indicator species of nitrogen, known as nitrophytes.

Lichen Community Findings

Results from 5 years of surveys (1998–2001, 2003) provide strong evidence that many greater Central Valley forests are exposed to N pollution (fig. 67). Plots receiving the worst air quality scores were dominated (up to 100 percent) by nitrophytic lichens, which are weedy species characteristic of high N environments (fig. 66). The worst sites, as might be expected, tended to be forests downwind of large urban areas and intensive agriculture.

Evidence of N pollution was also detected in some Sierra Nevada forests. Surveys of lichen communities indicated that a major N hotspot lies downwind of the San Joaquin Valley, covering forests of the southern Sierra Nevada Range, and stretching northward to include Yosemite National Park (fig. 68). Air quality studies confirm high N deposition to parts of this region (Fenn et al. 2003). Farther north, estimates of high N impact were more widely dispersed across the landscape.

Lichen Community Interpretation

Nitrogen is a key element for all life, but too much of it can be ecologically detrimental. Excessive N alters lichen, plant, and fungal communities, acidifies soil, causes faster accumulation of forest fuels, and increases emissions of greenhouse gases from the soil (Fenn et al. 2003). Remeasurement of lichen communities in 2009 will allow FIA to track changes in N as well as the proliferation of other pollutants that affect lichens.

Air quality tables in appendix 2—

- Table 44—Summary of lichen community indicator species richness on forest land, by location, California, 1998–2001, 2003
- Table 45—Summary of air quality on forest land in the Greater Central Valley as indicated by the Lichen Community Indicator, California, 1998–2001, 2003
- Table 46—Summary of air quality on forest land in the Greater Sierra Nevada as indicated by the Lichen Community Indicator, California, 1998–2001, 2003
- Table 47—Summary of climate on forest land as indicated by the Lichen Community Indicator, derived from the temperature gradient of Jovan and McCune's (2004) model, California, 1998–2001, 2003
- Table 48—Summary of climate on forest land as indicated by the Lichen Community Indicator, derived from the moisture gradient of Jovan and McCune's (2004) model, California, 1998–2001, 2003
- Table 49—Ozone injury summary information from ozone biomonitoring plots, by year, California, 2000–2005

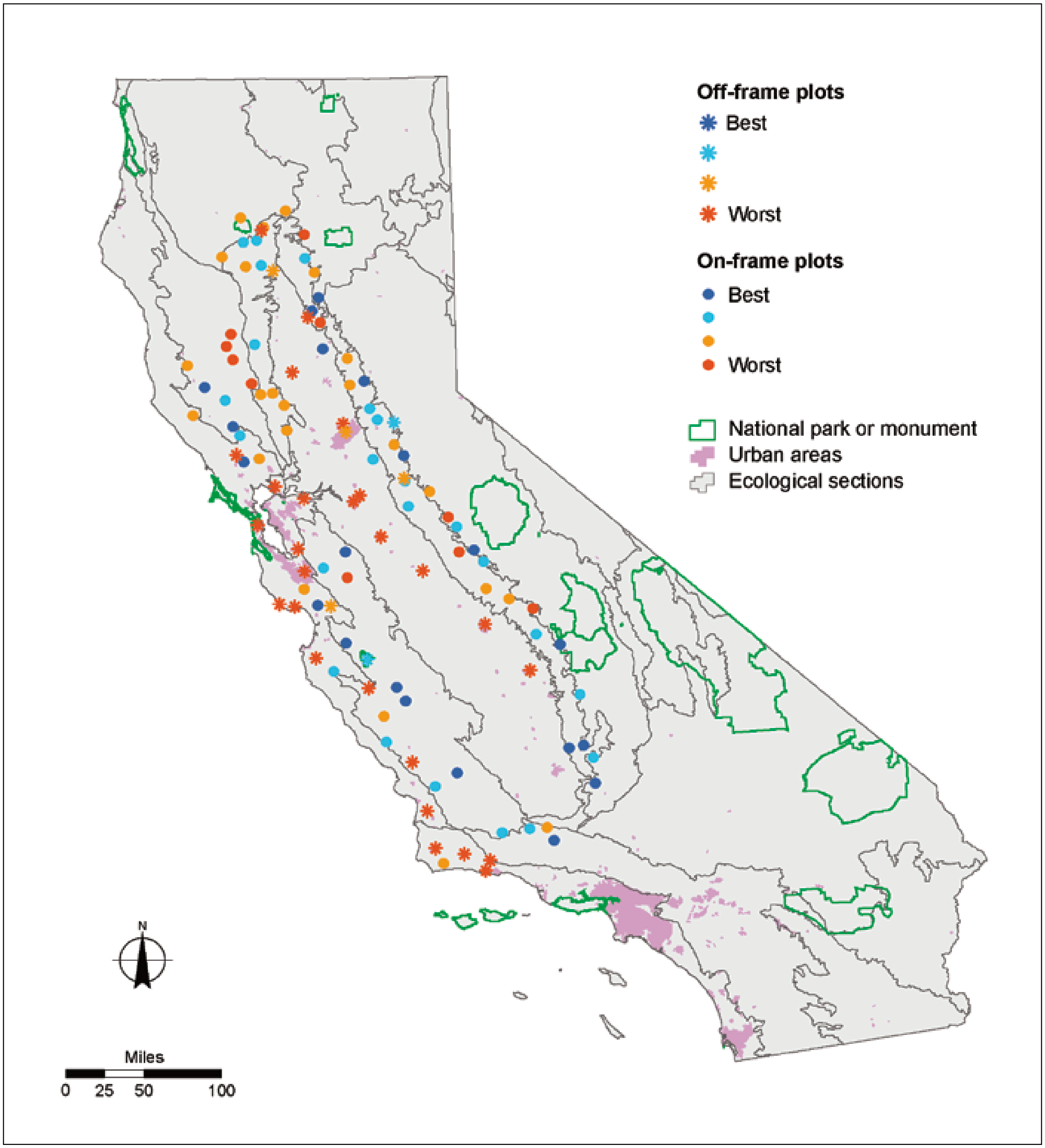

Figure 67—Air quality scores on forest, urban, and agricultural plots in the greater Central Valley, California, 1998–2001, 2003 (Jovan and McCune 2005; ecosection geographic information system (GIS) layer: Cleland et al. 2005; urban GIS layer: U.S. Geological Survey 2001).

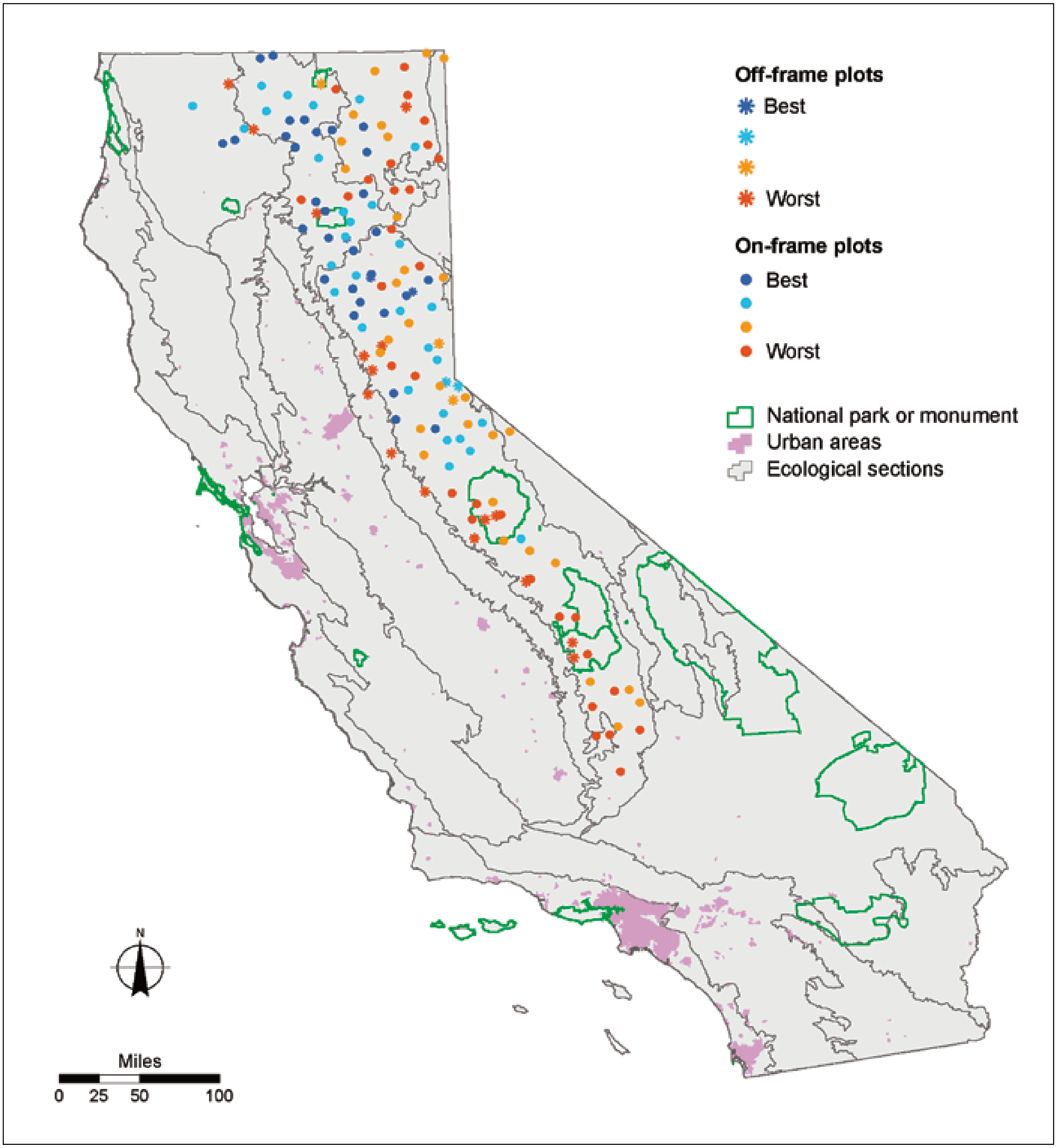

Figure 68—Air quality scores on forest, urban, and agricultural plots in the greater Sierra Nevada, California, 1998–2001, 2003 (Jovan and McCune 2006; ecosection geographic information system (GIS) layer: Cleland et al. 2005; urban GIS layer: U.S. Geological Survey 2001).

Fire Incidence[7]

Background

Nearly all forest types in California have the potential to experience crown or surface fire, although fire incidence differs considerably by region and forest type (fig. 69). State and federal agencies estimate the sizes of all wildland fires and some prescribed fires, map the perimeters of larger fires, and calculate statistics on fire incidence for the lands over which they have fire-protection responsibility. Agencies' fire incidence reports seldom specify the vegetation type that was burned, and in addition, different agencies use different reporting thresholds. Therefore, reliable and consistent estimates of annual burned area of forest across all ownership classes are lacking. The FIA field crews record evidence of surface and crown fire that occurred since the previous plot visit (usually 5 to 10 years), making it possible to estimate both the average forest area and percentage burned per year.

Findings

Over the decade 1995–2004, an estimated 213,000 acres of forest per year burned statewide (range 106,000 to 345,000). Year-to-year variability was considerable, and no statistically unambiguous trends in area burned were observed (fig. 70). The average annual forested area that burned was

[7] Authors: Jeremy Fried and Glenn Christensen.

Jerry Beatty

Figure 69—Evidence of fire recorded by field crews can be the result of prescribed burns, as shown here, or naturally caused fires.

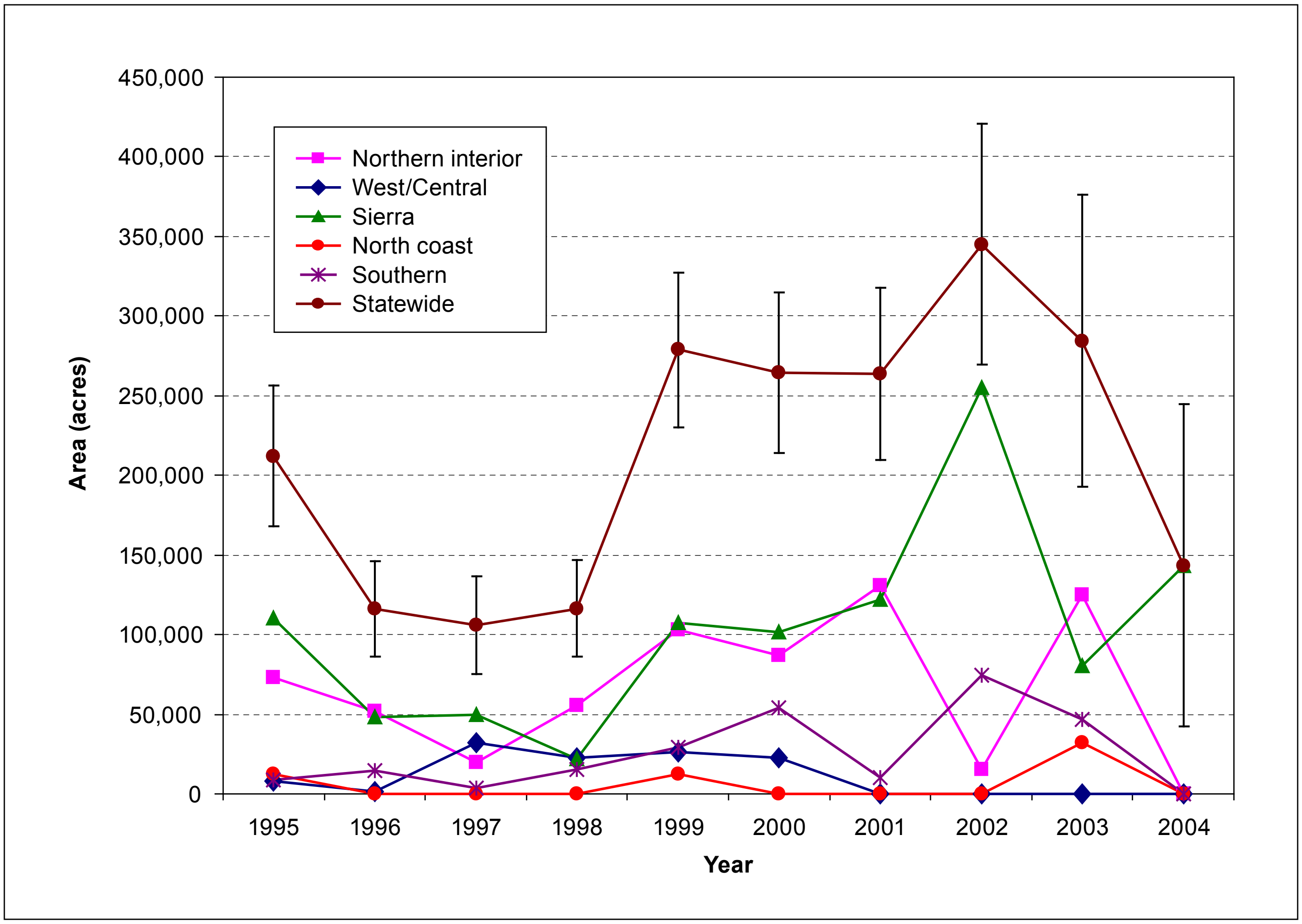

Figure 70—Area of forest burned by ecosection group on forest land in California, 1995–2004.

0.67 percent of the total forested area statewide; the percentage of total burned area ranged from 0.33 percent in 1997 to 1.08 percent in 2002. There was much regional variability as well; the annual 10-year average percentage of burned forest land ranged from 0.24 percent in the North Coast ecosection to 1.11 percent in the Southern ecosection, as shown in this tabulation:[8]

Ecosection	Forest burned, 1995–2004	SE
	Mean percent	*Percent*
Northern Interior	0.50	0.07
North Coast	0.24	0.15
Sierra	0.90	0.12
West/Central	0.57	0.15
Southern	1.11	0.26
Total	0.67	0.06

These estimates compare favorably with data derived from fire perimeter maps maintained by the California Department of Forestry and Fire Protection (CDF) for fires larger than 300 acres, and by the USDA Forest Service Pacific Southwest Region for fires larger than 10 acres.

[8] Ecosection groupings (see fig. 6 in chapter 1): Northern Interior—Klamath Mountains, Northwestern Basin and Range, Northern California Coast Ranges, Northern California Interior Coast Range, Southern Cascades, and Modoc Plateau; West/Central—Central California Coast Ranges, Central California Coast, and Great Valley; Sierra–Sierra Nevada Mountains and Sierra Nevada Foothills; North Coast—Northern California Coast, Southern California—Mono, Colorado Desert, Sonoran Desert, Mojave Desert, Southern California Coast, and Southeastern Great Basin.

Those data suggest an average annual burned area (wildfire and prescribed fire combined), across all vegetation types, of 505,000 acres statewide (range 184,000 to 978,000). The CDF statistics show that only 20 percent of the burned area between 1996 and 2005 on nonfederal lands was forest or CDF-defined woodland. Given that federal lands have a much higher proportion of forest land than of other vegetation types, the ratio of burned area observed by FIA to burns mapped by CDF and the Forest Service (213:505 = 0.42) is entirely plausible. Because FIA does not collect a complete ground-based sample of nonforest lands, it is not possible to estimate the area burned in nonforest vegetation types.

Caveats

Because fire is a relatively rare event, the number of plots where recent fire is observed is small—in fact, for some years in some regions, observations from inventory plots suggest no fire whatsoever. Not surprisingly, then, standard errors on estimates of area burned are large. Generating estimates for smaller subsets of the forest land base (e.g., ownership classes or particular forest types) is impractical because of the small sample, because of inconsistent differentiation of fire type (e.g., surface or crown fire) and origin (e.g., prescribed or wildfire), and because field crews do not usually have the training to assess a severity level. For these reasons, for this analysis, all burned acres are pooled. However, we have no reason to believe our estimates are any less accurate than those based on geographic information system (GIS) databases. Many fire incident reports in these databases have no information on size of the fire. The databases also show large discrepancies between reported sizes and the GIS-calculated burned area. Moreover, the minimum size for inclusion of a fire differs from one database to another. These common problems may contribute to under- or overestimations of the actual burned area.

Interpretation

The year-to-year variability is too large to assess whether there is an increasing trend in area burned in California's forests over the past 10 years. Increased media attention to wildfires and ever-more-earnest discussion among land managers, however, suggests the necessity to more actively manage wildland fuels and generates the impression that area burned is increasing.

We lack landscape-scale historical or paleoecological data to compare with today's average annual rate of 0.67 percent of forest land burned, and so we cannot determine whether this rate represents a departure from historical rates. It is also likely that the distribution of acres burned among severity classes and forest types is changing with climatic fluctuations, but the inventory is not designed to efficiently detect such changes.

Fire incidence table in appendix 2—

- Table 50—Total acres of forest land with a forest fire incident, by year and ecosection group, California, 1995–2004

FIA BioSum[9]

Background

Mechanical treatments to reduce fuel loadings in forests have the potential to produce large quantities of non-merchantable wood. Conventional wisdom suggests that effective treatment requires that large numbers of small stems be removed at considerable cost, and that this harvested material has little or no value.

One widely considered approach to this problem is to develop forest bioenergy production facilities that simultaneously generate renewable energy and increase employment opportunities in rural areas, while achieving economies of scale in harvesting and processing operations (fig. 71). Scientists at PNW-FIA developed an analytical system, FIA BioSum (Forest Inventory and Analysis Biomass Summarization), to guide investors seeking to exploit such opportunities and land managers seeking to attract investment. This system can evaluate a multitude of fuel-treatment prescriptions; assess their economic feasibility in terms of harvest yields and costs, haul costs, and product values; and offer a model-based characterization of the achieved reduction in fire hazard.


Jeremy Fried

Figure 71—Mechanical fuel treatment typically involves the removal of numerous small trees that have little or no value as sources of wood products; much of this material is chipped and used as feedstock for biomass-fired power plants.

Approach

The FIA BioSum integrates data and simulation programs, using linked spatial and relational databases, into a geographically explicit analytic framework for summarizing potential biomass production from fuel treatments (Daugherty and Fried 2007, Fried 2003, Fried et al. 2005, Fried and Christensen 2004). The system relies on publicly available data e.g., inventory plots and GIS layers representing roads, existing wood processing facilities, and land ownership) and off-the-shelf computer simulators. The simulators apply stand prescriptions, assess fire hazard, and evaluate fuel-treatment costs via joint optimization of treatments and processing facility siting. The system requires numerous analytic assumptions, for example, to identify which acres are eligible for treatment, what constitutes effective treatment, which logging system to use, appropriate choices of unit haul costs and product prices, and fuel-treatment prescription options. These inputs to the simulation system are best developed in consultation with local experts in fire, fuels, silviculture, and harvest operations.

Findings

The FIA BioSum was applied to a 28-million-acre, mostly forested landscape spanning four ecosections in central and southern Oregon and northern California (fig. 72). As shown below, when the model is set to maximize net revenue, this area can produce $5.9 to $8.9 billion through the treatment of 2.8 to 8.1 million acres, depending on how the problem is constrained. About 61 million to 124 million green tons of woody biomass would be recovered for power generation, sufficient to operate a network of bioenergy plants with a combined capacity of 496 to 1009 megawatts (MW) over a 10-year period. In these scenarios, estimated production potential for merchantable wood products ranges from 8.3 to 12.4 billion cubic feet, most of which would be derived from the harvest of trees larger than 12 inches d.b.h (modeling determined that treatments in which removals are

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[9] Authors: Jeremy Fried and Glenn Christensen.

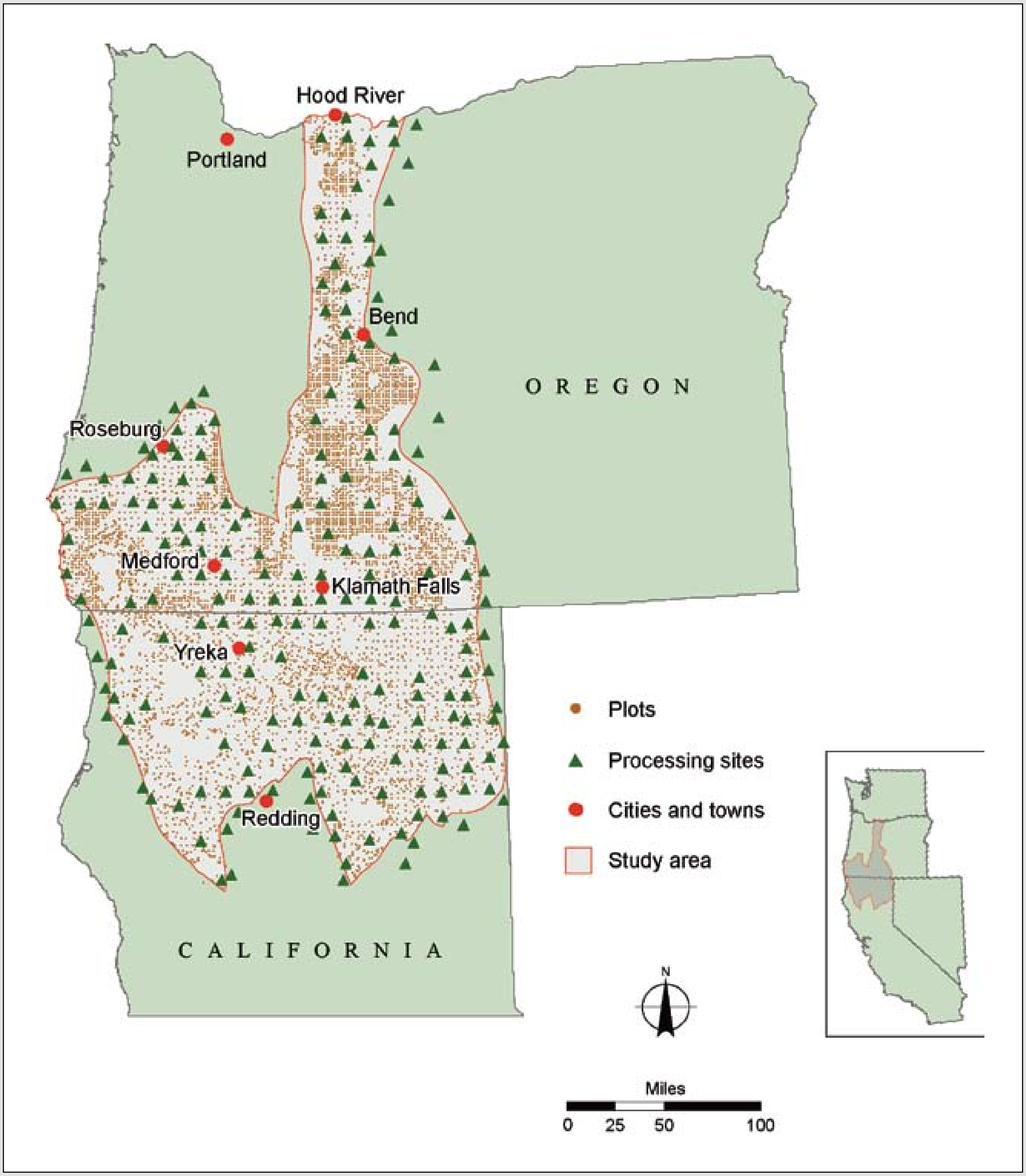

Figure 72—Oregon/California BioSum study area showing locations of inventory plots, sites evaluated as potential power generating facilities, and major cities.

restricted to trees smaller than 10 inches are completely ineffective in reducing crown fire hazard). As shown in the tabulation below, model results depend on the level of treatment effectiveness required, and also on whether all eligible acres are treated (which would entail subsidy on some acres) or only those that contribute positive net revenue to the enterprise.

We evaluated a range of power-generating capacities and conversion efficiencies to assess the tradeoffs of building lower versus higher capacity plants (e.g., increased hauling costs for transporting wood chips longer distances to reach a higher capacity plant). Results suggest that unless small-capacity (<15 MW) facilities achieve efficiencies that are at least 90 percent of what can be achieved by large-capacity facilities, they do not represent a viable alternative given the large amount of biomass removed. The locations selected by the optimization model as the best places to build bioenergy facilities were comparatively insensitive to capacity constraints. Locations that were selected when minimum electrical generation capacity was set high were a subset of those selected when the minimum capacity constraint was set low, lending support to the idea that some places in the forested landscape are inherently well-suited for bioenergy facilities under a variety of potential wood supply and energy pricing scenarios, by virtue of their location on the transportation network relative to where fuel treatments would occur (fig. 73).

The FIA BioSum framework provides a statistically representative foundation for assessing the opportunities to use "waste" from fuel treatments to expand bioenergy generation capacity. Results of these optimizations should not be the only basis for a decision to develop a fuel-treatment program. Decisionmakers will need to factor in the nonmarket benefits and costs of hazard reduction, other resource goals of landowners and land management agencies, and the reluctance of investors to commit capital without a reasonable expectation of sufficient fuel supply. Nevertheless, FIA BioSum provides a starting point for land management agencies to address the fuel supply issue, and serves as a tool for further analysis.

	Scenario			
	1	**2**	**3**	**4**
Constraint on acres treated[a]	Any	All	Any	All
Constraint on effectiveness[b]	Moderate/high	Moderate/high	High	High
Net revenue ($billion)	8.94	6.65	7.15	5.88
Merchantable net revenue ($billion)[c]	7.71	4.74	6.24	4.61
Biomass net revenue ($billion)[c]	1.23	1.92	0.91	1.27
Merchantable volume (billion ft^3)[c]	10.93	12.41	8.35	9.22
Delivered biomass (million green tons)	81.21	123.87	60.92	84.40
Area treated (million acres)	4.49	8.12	2.84	4.05
Highly effective area treated (million acres)	2.53	3.21	2.84	4.05
Number of facilities	31	47	23	30
Bioenergy capacity (megawatts)	661	1009	496	688

[a] "Any" allows the model to select optimal number of acres to treat; "all" requires treatment of all acres that meet effectiveness constraint.
[b] Moderate effectiveness requires a modeled improvement in resistance to active crown fire; high effectiveness requires modeled improvement in resistance to both active and passive crown fire. These criteria limit the number of acres considered in analysis; with the "high" constraint, only high-effectiveness acres are considered for treatment.
[c] Onsite treatment costs are only deducted from merchantable gross revenue. Biomass net revenue equals delivered value net of haul costs.

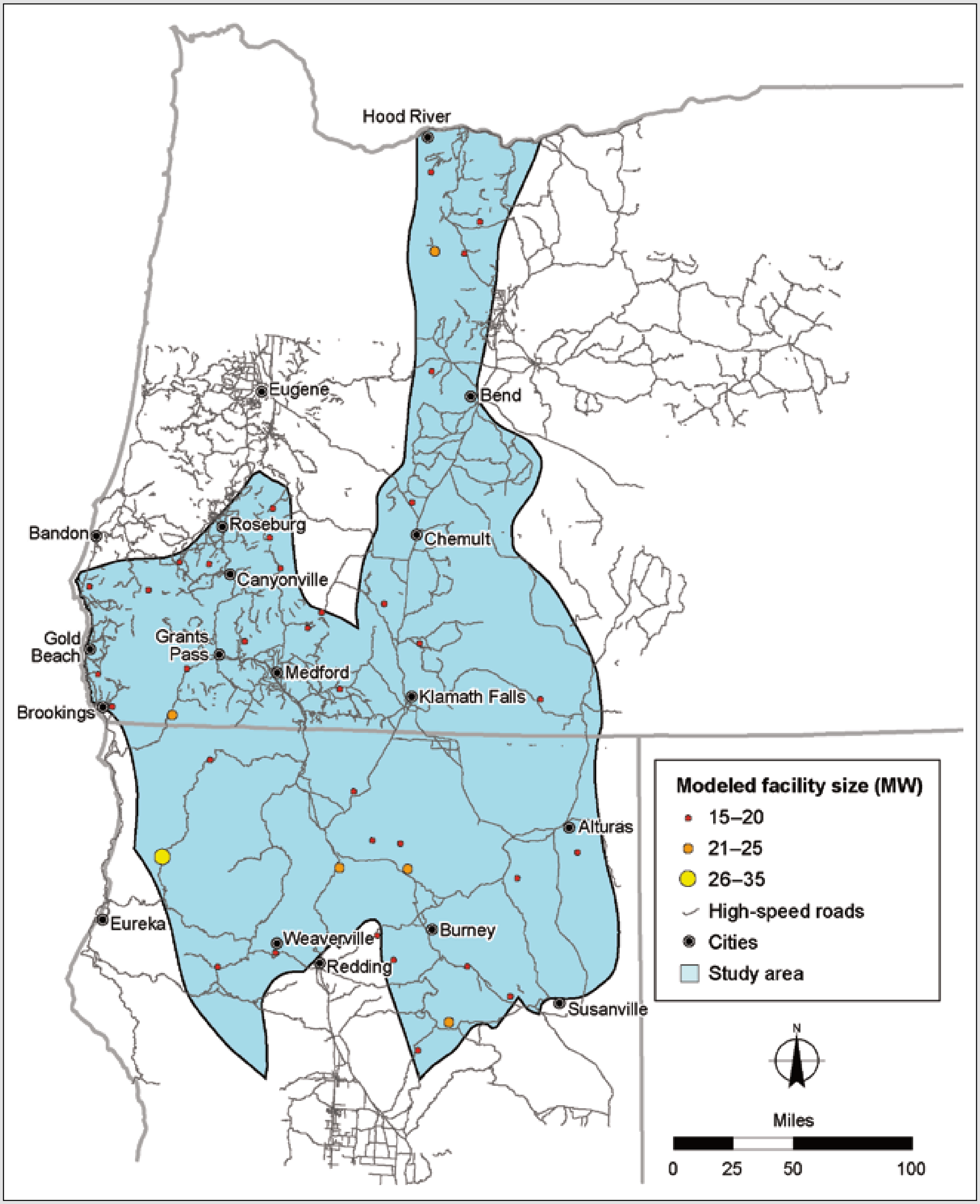

Figure 73—Model-recommended forest bioenergy production facilities, with a minimum 5-megawatt (MW) capacity, and high-speed road network.

Wildland-Urban Interface[10]

Background

Urban and suburban development in or near forests and shrublands is commonly referred to as the wildland-urban interface (WUI) (fig. 74). Housing development in the WUI causes habitat loss and fragmentation (Theobald et al. 1997), threatens wildlife populations (Soulé 1991), and decreases biodiversity (McKinney 2002).

Figure 74—Urban and suburban development in or near forests and shrublands is commonly referred to as the wildland-urban interface. Photo by USDA Forest Service.

Development within the WUI is also a growing concern nationally because of the increasing number of homes destroyed by wildland fire in these areas (National Interagency Fire Center 2007). Protecting homes during WUI fires is extremely challenging (Cohen 2000, Winter and Fried 2001). Human-caused fire ignitions, which tend to be concentrated in WUI areas (Cardille et al. 2001), were responsible for 43 percent of the record-setting 13,113 square miles of forest that burned in the United States during the 2000 fire season (National Interagency Fire Center 2007). In 2003 and 2007, over 4,200 and 3,027 homes, respectively, were destroyed by wildland fires, nearly all of them in southern California during October fires.

We estimated the area of WUI using definitions derived from the Federal Register and the California Fire Alliance (2001),[11] along with census data and land cover maps from the National Land Cover Database (Radeloff et al. 2005). In this analysis, we defined the vegetation cover component to include shrubs and grasses as well as forests (Hammer et al. 2007). Two types of WUI are recognized: interface, in which communities directly abut wildland areas but there is a clear demarcation between development and wildland; and intermix, in which homes and other buildings are surrounded and overtopped by vegetation and resemble islands scattered in a sea of wildland fuel. Using housing density data collected by the census in 1990 and 2000, we estimated changes in WUI area by WUI type and number of homes within this zone.

Findings

The area of WUI and the number of homes within it grew substantially over the 1990s. Intermix communities grew more in area, while interface communities saw the

	Area			Homes		
WUI type	**1990**	**2000**	**Percentage of change**	**1990**	**2000**	**Percentage of change**
	Thousand acres		*Percent*	*Thousands*		*Percent*
Interface	1,789	1,804	0.9	3,164	3,480	10
Intermix	4,678	5,225	11.7	1,306	1,634	25.1
Total WUI	6,467	7,029	8.7	4,469	5,114	14.4

[10] Author: Jeremy Fried. This highlight is adapted from work published as Hammer, R.B.; Radeloff, V.C.; Fried, J.S.; Stewart, S.I. 2007. Wildland-urban interface growth during the 1990s in California, Oregon, and Washington. International Journal of Wildland Fire. 16: 255–265.

[11] Wildland–urban interface is defined as the area where houses meet or intermingle with undeveloped wildland vegetation, and more precisely as areas with a housing density greater than 1 house per 40 acres and dominated by wildland vegetation (USDA and USDI 2001), or situated within 1.5 miles of an area covered in wildland vegetation (California Fire Alliance 2001).

greatest housing increase (see tabulation below). As of 2000, the 5.2 million acres of intermix WUI accounted for 74 percent of WUI area but for only 32 percent of WUI homes. However, the area of intermix WUI grew nearly 12 percent between 1990 and 2000, accounting for most of the overall growth in WUI acres (nearly 97 percent). Growth in intermix WUI areas also accounted for the greatest percentage increase in number of homes: 25.1 percent, a figure far in excess of the 9.2 percent growth in housing across all California.

As illustrated by the comparison of WUI residential growth in two ecosections in the tabulation below, the dynamics of growth in the WUI differ considerably within the state. The number of WUI homes built in the 1990s is much greater in southern California, although WUI homes constitute only 61 percent of the total housing increase there. Housing growth is distributed almost evenly between intermix and interface areas. By comparison, the Sierra foothills region is heavily forested and a hotspot of urban immigration. Virtually all new homes there were built in the WUI, with well over 75 percent located in intermix areas—the WUI type that has expanded the most in area over the decade.

WUI can be found in virtually every California county; however, some of the biggest concentrations of forested WUI are in the foothills of the central Sierra, around the margins of the San Francisco Bay area, and in the mountains of southern California (fig. 75). These areas have considerable acres of wildland intermix, a sub-WUI class in which the average housing density of fewer than 1 house per 40 acres is considered insufficient to meet the requirements for the definition of WUI. These wildland intermix areas have strong potential to become WUI in the near future, unless political or market forces intervene to slow the trend.

Interpretation

Although it may seem small relative to California's total land area (100 million acres), the 7 million acres of WUI calculated in this analysis is considerable relative to the total forest land area of 33 million acres. A substantial fraction of WUI consists of grass and shrub-covered lands, particularly in southern California, and thus does not contribute to the FIA estimate of forest land. Nonetheless, these results are strong evidence that a great deal of forest land has already been affected by development.

Continued WUI growth at rates seen in the 1990s are likely to place extraordinary pressure on California's forest resources. Effects will be especially pronounced in forested regions with rapidly expanding WUI, such as the Sierra Nevada foothills (23 percent) and Sierra Nevada mountains (12 percent). In these regions nearly all new homes are added to intermix areas, where the pressures on forest land in terms of resource use, introduction of exotic invasives, and imperatives to reduce fire hazard are likely to be extraordinary. Without land use controls, strict zoning, or powerful financial counterincentives, increasing rates of conversion of forest land to developed uses are likely to greatly alter the productivity, health, and ecosystem integrity of California's forests.

	1990	2000	Change	Percentage of change
	Thousands of homes			*Percent*
Southern California Coast Ecosection:				
Interface WUI	812	891	79	9.7
Intermix WUI	298	369	71	24.0
Not WUI	2,983	3,078	95	3.1
Percentage in WUI	27	29	61	
Sierra Nevada Foothills Ecosection:				
Interface WUI	56	64	8	14.1
Intermix WUI	119	152	32	26.9
Not WUI	22	22	0	0
Percentage in WUI	89	91	100	

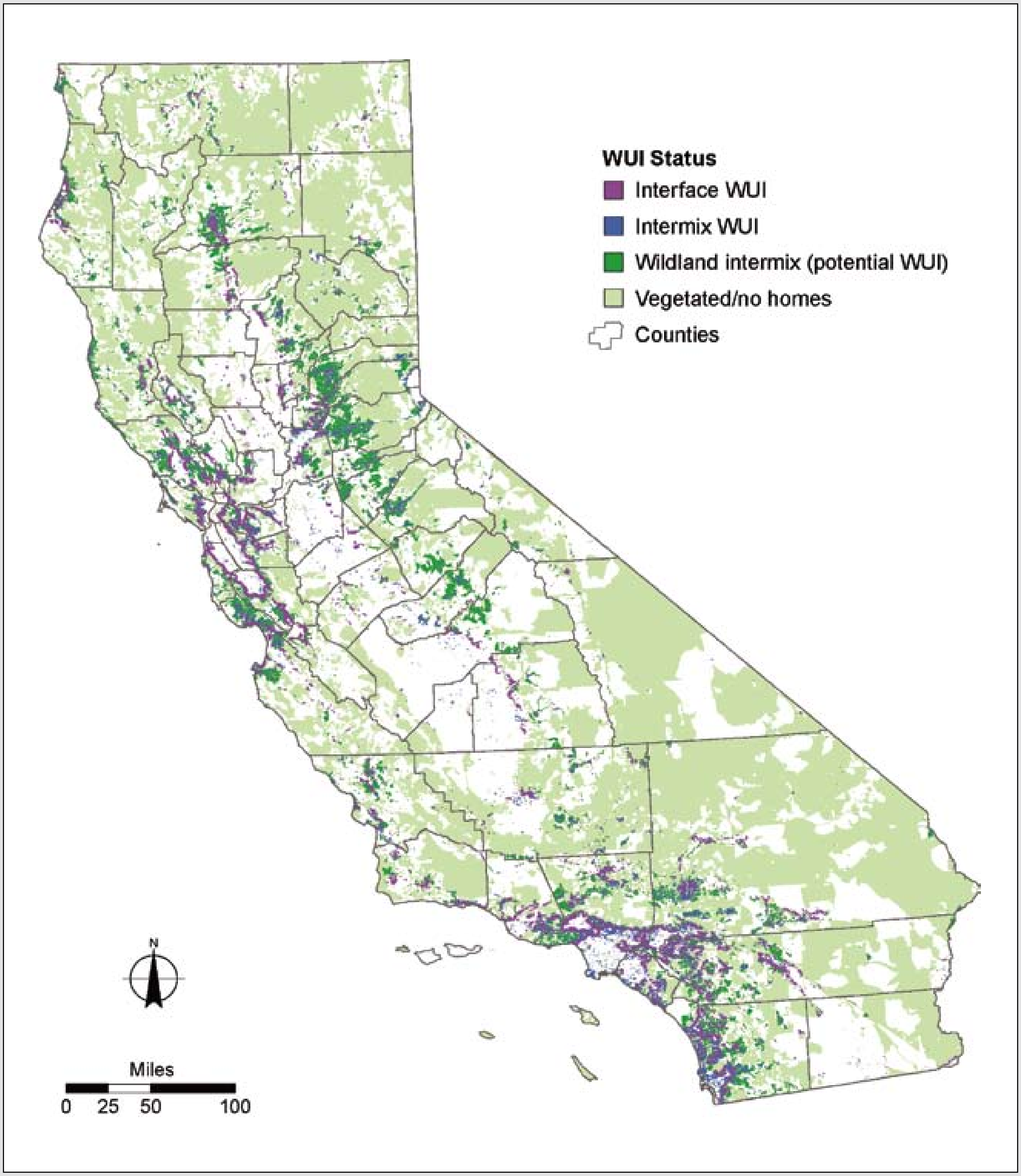

Figure 75—Wildland-urban interface (WUI) areas by type.

Figure 76—Stands within the McNally Fire in California experienced a variety of fire regimes including mixed-severity with both surface and crown fire (left) and severe crown fire with 100-percent tree mortality (right).

Crown Fire Hazard[12]

Background

Reduction of fire hazard has emerged as a priority issue in California, where fuel treatments are proposed on an unprecedented scale. Characterization of fire hazard often focuses on crown fire potential—the tendency of a forest stand to experience crown rather than surface (ground) fire—because crown fires are typically stand-replacing events (fig. 76). Before an effective fuel treatment program can be developed, it is essential to know initial hazard levels and identify where hazard reduction is most technically, economically, and socially feasible (see, e.g., Barbour et al. 2008; Vogt et al. 2005). The FIA inventory provides an unprecedented opportunity to assess the extent of crown fire hazard across all land ownerships, ecosection groups, and forest types. Examining these statistics on a proportional basis, by forest type and geographic distribution, provides key insights into factors associated with high crown fire hazard.

All plots with forested conditions[13] were simulated with the Forest Vegetation Simulator (FVS) and its Fire and Fuels Extension (FFE) (Reinhardt and Crookston 2003) to calculate indices of crown fire potential and fire type under severe fire weather. Each inventory plot was assigned to the appropriate FVS variant by GIS overlay with the FVS variant layer (USDA Forest Service 2007a), and default values were used for all fuel parameters other than those derived from the tree-level data collected by FIA.[14] Fire type under severe weather was modeled by FFE as one of four classes (see tabulation below), and results were analyzed and mapped.[15]

[12] Authors: Jeremy Fried and Glenn Christensen.

[13] The FVS-FFE was applied to all conditions classified as forested on the ground. Despite this classification, some plots contained few or no trees, and therefore stand attributes the model uses to estimate crown fire potential (e.g., canopy bulk density, height to canopy base) could not be calculated reliably. The FFE assumes that sparsely forested conditions have a surface fire regime, which may or may not be true depending on stand structure in the remainder of the area (outside the plot footprint).

[14] Surface fuels were determined via lookup tables based on stand structure (wildlife habitat relationship class in the Western Sierra Nevada) and forest type. For the severe fire weather scenario, FFE default parameters were used such that 20-foot windspeed was set at 20 miles per hour, temperature at 70 degrees F; 1-, 10-, 100-, and 1,000-hour fuel moisture at 4, 4, 5, and 10 percent, respectively; duff-fuel moisture at 15 percent; and live-fuel moisture at 70 percent.

[15] To enable better visualization of the geographic distribution of fire regimes, local kriging interpolation was performed on the ordinal variable, fire type, as if it were a ratio (continuous) variable. This produced a surface of crown fire potential from the plot data, with values ranging from 1 (surface fire) to 4 (active crown fire).

Fire type	Fire characteristics
Surface	Crowns do not burn; only surface fuels on the forest floor burn.
Conditional surface	Existing crown fire will continue as a crown fire, but if canopy gaps interrupt crown fire spread, it will convert to a surface fire and not reinitiate as a crown fire.
Passive	Some crowns will burn as individual trees or groups of trees "torch," with fire climbing from the surface via "ladders" of dead branches and lesser vegetation.
Active	Fire moves through the tree crowns and reinitiates as a crown fire in the event that canopy gaps interrupt its progress.

Findings

Patterns for the crown fire potential indices and fire type were similar, so for simplicity, only the fire type results are reported here. Statewide, under extreme fire weather conditions, fire would likely occur as surface fire on 72 percent of the forest. Active crown fire would be expected on only 7 percent of the forest, and passive crown fire on 20 percent. There is substantial regional variation—for example, only 3 percent of forests in the West/Central and North Coast ecosection groups would have active crown fires under severe weather conditions, whereas 8 to 9 percent of forests in the rest of the state would have active crown fire (fig. 77). It is difficult to predict how these differences in potential hazard translate to events on the ground because incidence of severe weather also differs among these regions.

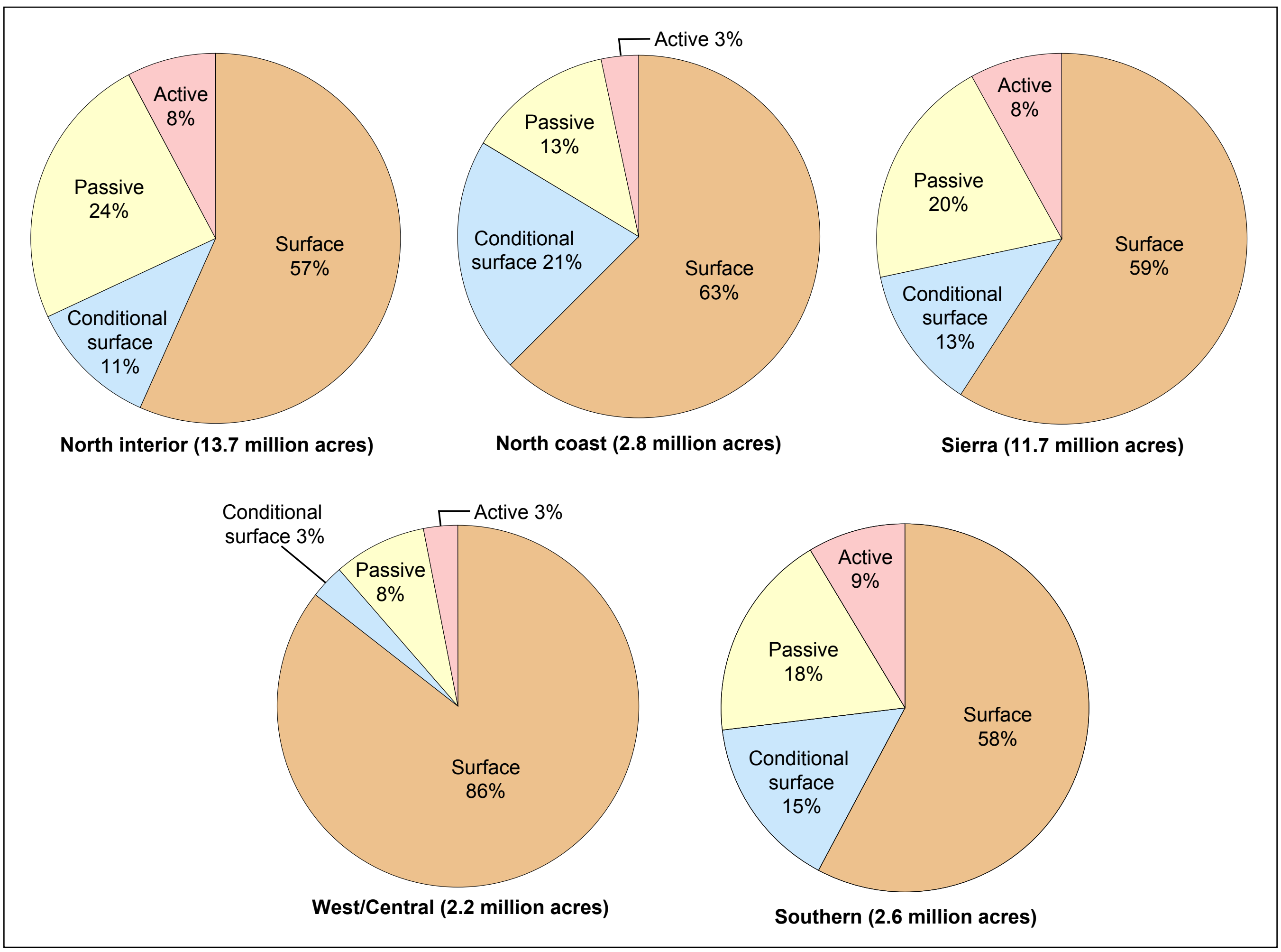

Figure 77—Percentage of forest land in each modeled fire type category by ecosection group in California, 2001–2005.

Incidence of crown fire also appears to differ by forest type. Simulation showed that among the four most prevalent coniferous forest type groups, fir/spruce/hemlock has the highest incidence of active crown fire, and ponderosa pine and Douglas-fir have the lowest (fig. 78), probably because fir/spruce/hemlock forests have denser canopies and are more likely to contain ladder fuels. However, passive crown fire is quite common in ponderosa pine and, to a lesser extent, the mixed-conifer forest type. Fire regime also differs by ownership group (fig. 79), with state lands predicted to have the highest percentage of forests in surface or conditional surface fire regimes (82 percent) and national forest predicted to have the lowest (67 percent). These differences could be due to differences in management, but may also be traceable to differences in age class structure, forest type, and stand history.

Remarkably distinct patterns can be observed in the geographic distribution of likely fire type. Most notable are the concentration of elevated crown fire potential in the northern Sierra and Northern Interior regions and the virtual absence of passive and active crown and conditional-surface fire regimes in the oak forests and woodlands typical of the lower-elevation forests of the state (fig. 80).

Interpretation

These data paint a different picture of fire hazard and fuel treatment opportunity than do maps of fire regime condition class (Schmidt et al. 2002; see the maps at www.fs.fed.us/fire/fuelman/curcond2000/maps.html). These maps depict most of the area in at least some ecosection groups (notably Northern Interior) as having significantly departed from historical fire regimes, and, by implication, being in urgent need of intervention to reduce fire hazard. Even under the extreme fire weather assumed for this analysis, less than half of the forested lands are predicted to develop crown fires, and an even smaller fraction (<10 percent) can be expected to develop active crown fire. Although crown-fire potential models such as FFE have yet to be rigorously validated against behavior of actual fires, many fire managers regard them as suitable for "ballpark" predictions of what is likely to occur.

These results have implications both for the scope of fuel treatment programs and for the challenges that firefighters will face. In the context of firefighting, building a fire line that disrupts the continuity of surface fuels can be effective in stopping fire spread in areas prone to surface fires. In areas where crown fire, if it occurs, is likely to be

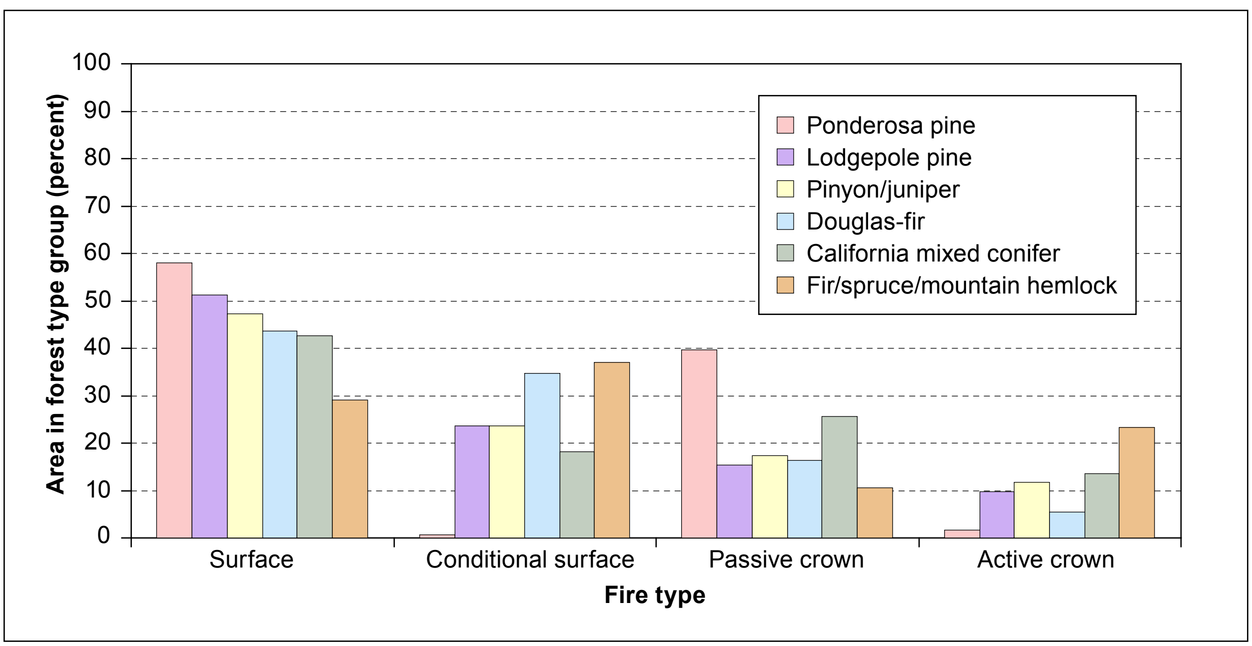

Figure 78—Percentage of forest land in each of the six most prevalent coniferous forest type groups in each modeled fire type class in California, 2001–2005.

Figure 79—Percentage of forest land in each modeled fire type category by ownership group in California, 2001–2005.

passive, trees will torch individually, and most may die. On those more limited areas where active crown fire is likely to occur, a far more labor- and time-intensive job of line-building to remove standing trees would be required for fire containment efforts to be successful.

From the standpoint of implementing fuel treatments, these results suggest that, if the objective is to reduce crown fire hazard, only a fraction of the forested landscape is likely to benefit from fuel treatment. Spatial analyses of fuel treatments have demonstrated that treating a small percentage of the landscape can reduce landscape-scale fire hazard significantly and sometimes cost-effectively (Finney 2001). These results suggest that the fuels management challenge may be more tractable than has been assumed.

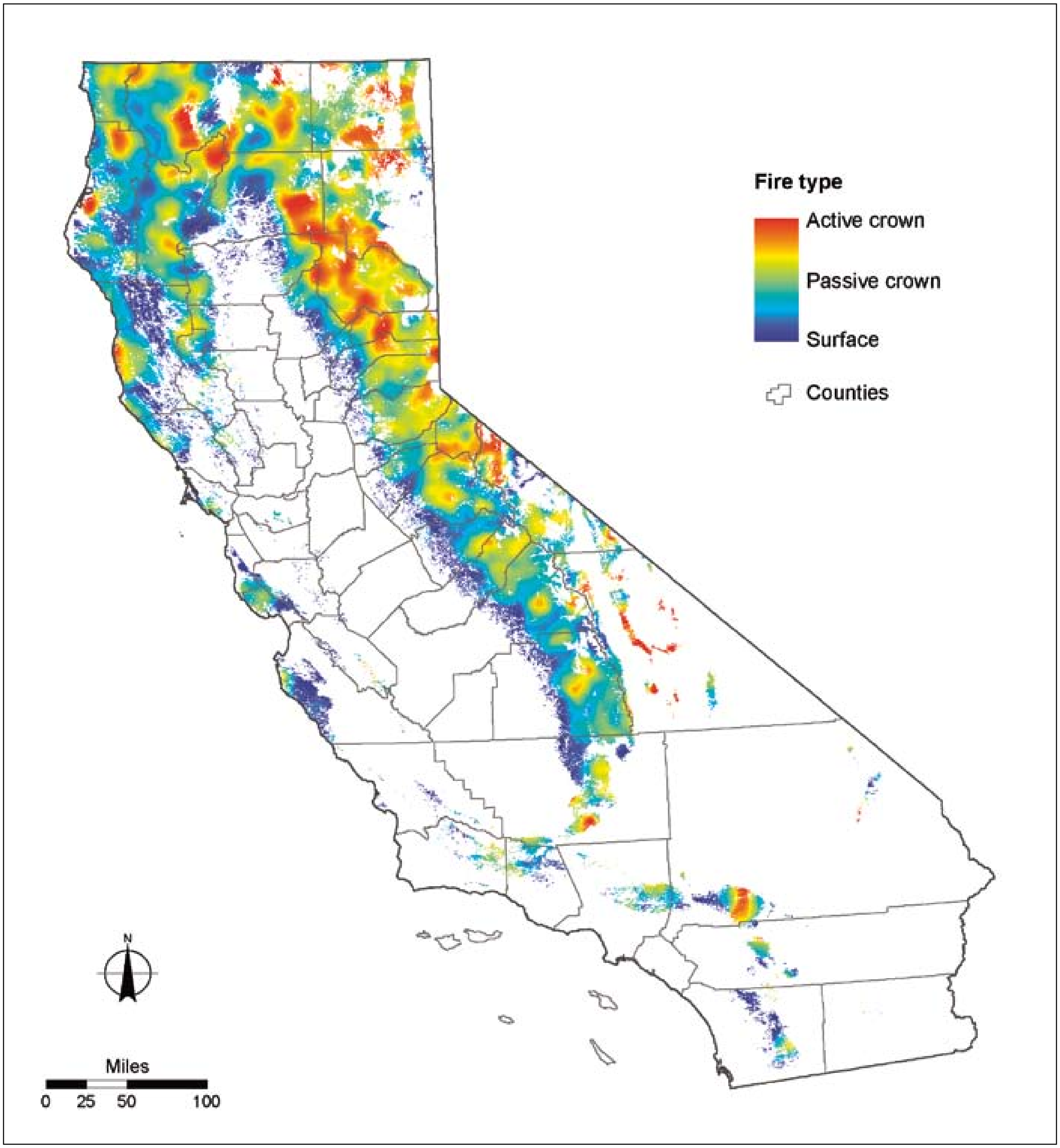

Figure 80—Predicted likely fire type in forested areas using kriging as a modeling method (forest/nonforest geographic information system layer: Blackard et al. 2008).

Olaf Kuegler

Bristlecone pine.

Chapter 5: Products

California's forests are an essential source of raw materials for goods and services used every day by the state's 36 million residents. The forest products industry makes important contributions to California's economy and environment by supplying wood products, employment and income, tax revenue, and a number of other amenities and services benefiting the people of California. This chapter examines the productive capacity of California's forests and its contribution to the state's economy and environment.

California's Primary Forest Products Industry[1]

Background

California's forest products industry utilizes timber harvested from California and from other states in the Western United States (fig. 81). The industry provides social and economic benefits by supplying society with wood products, such as lumber and biomass energy, and also through employment and income associated with land management, timber harvesting, and wood products manufacturing. The availability of forests for future harvests and the remaining capacity of the primary forest products industry to utilize timber are important issues facing Californians today.

In cooperation with the Pacific Northwest Research Station Forest Inventory and Analysis (FIA) Program, the Bureau of Business and Economic Research at the University of Montana conducts a periodic census of California's primary forest products industry (i.e., timber processors and users of mill residue). This census is the source of information presented below. It provides detail on timber harvest and flow, as well as comprehensive information about the state's timber processing sectors, product volumes, sales values, and mill residue (Morgan et al. 2004).

[1] Authors: Todd A. Morgan and Charles E. Keegan, Bureau of Business and Economic Research, University of Montana.

Todd Morgan

Figure 81—Timber from California forests, as well as other states, supplies the forest products industry in California.

Findings

During 2000, 93 primary forest products facilities operated in 28 of California's 58 counties. These facilities included 47 sawmills, 2 veneer plants, 5 medium density fiberboard (MDF) and particleboard plants, 25 bioenergy facilities, and 14 other facilities, including plants for manufacturing pulp and paper, bark products, shakes, shingles, posts, poles, and pilings (fig. 82).

Sales from California's primary forest products industry were about $2.3 billion in 2000. California was its own largest market for wood and paper products, accounting for $1.4 billion (62 percent) of sales in 2000. Nearly all of the energy and electricity produced by the bioenergy sector was used in-state. The majority (63 percent) of lumber produced in California was sold in California, whereas about one-half (47 percent) of product sales from the residue-utilizing sector were in-state. Other primary wood products were sold in higher proportions out-of-state, with California retaining less than 1 percent. The majority (97 percent) of these products were sold in other Pacific Coast States.

Product	**2000 product sales value**
	Thousands of U.S. dollars
Lumber, timbers, and associated products	$1,492,190
Residue-utilizing sector[a]	$463,990
Energy and electric	$260,235
Other primary wood products[b]	$77,044

[a] Residue-utilizing sector includes pulp, paper, board, and decorative bark manufacturers.
[b] Other primary wood products include veneer, shakes, shingles, posts, poles, and pilings.

Based on sales value and volume of timber processed, sawmills were the largest component of California's forest products industry during 2000, producing 3.1 billion board feet of lumber and achieving sales close to $1.5 billion. The volume-weighted statewide average overrun in 2000 was 1.53 board feet of lumber produced per board foot (Scribner) of timber processed. California sawmills generated more than 3.4 million dry tons of mill residue during 2000, and nearly all of this residue was utilized. Other facilities produced 184,000 dry tons of residues during 2000.

Sawmills and veneer plants together used about 2,217 miiliion board feet (MMBF, Scribner) of timber, 97 percent of the timber received by California timber processors during 2000. The bioenergy sector used almost 55 MMBF of timber. California's total capacity to process timber in 2000 was nearly 2.7 billion board feet (Scribner), of which 83 percent was utilized to process nearly 2.3 billion board feet of timber. California was a net importer of timber, using 151 MMBF (Scribner) of out-of-state timber, while slightly less than 120 MMBF of California timber was shipped to other states for processing.

Consuming almost half (1.7 million dry tons) of the wood residue generated by California's primary wood products industry during 2000, the bioenergy sector is quite important to the industry. The bioenergy sector is composed of cogeneration facilities at sawmills as well as stand-alone facilities using mixtures of urban, agricultural, and mill wastes, timber, and even geothermal energy to generate electricity. The total energy-producing capacity of the wood-using bioenergy facilities exceeded 470 megawatts. During 2000, these facilities generated and sold over 3.1 million megawatt-hours of power.

Approximately 112,700 workers, earning $4.5 billion annually, were directly employed in California's primary and secondary wood and paper products industry during 2000. About 25,000 of these workers were employed in the primary sectors (i.e., harvesting and processing of timber or private land management), earning approximately $900 million in labor income. The secondary component of the industry employed 87,700 workers, who earned approximately $3.6 billion. The secondary industry includes firms that further process outputs from the primary industry; for example, window frame and door manufacturers, truss and remanufacturing facilities, and furniture and packaging makers.

Interpretation

California remains one of the top four softwood lumber-producing states, but faces increasing regulation of timber harvesting practices along with declining harvest levels (see "Removals" section). Improved milling technology has increased product recovery (i.e., overrun) while allowing

Figure 82—Active California primary forest products facilities by county and resource area, 2000. (forest/nonforest geographic information system (GIS) layer: Blackard et al. 2008; water GIS layer: Homer et al. 2004).

increased utilization of smaller diameter trees. The bioenergy sector's demand for mill residue has likewise contributed to increased utilization of wood fiber. However, the capacity of California's forest products industry to process timber declined nearly 60 percent from the late 1980s to 2000, and dropped further as additional facilities closed between 2000 and 2005. Lumber production declined 15 percent from 2000 to 2005 (Western Wood Products Association 2006). However, quality timber, good growing sites, and high regional demand for wood products may allow California's forest products industry to prosper in a highly regulated operating environment.

Growth, Removals, and Mortality[2]

Background

Increases or decreases in timber volume can be explained by examining growth, removals, and mortality of trees. Comparing removals and mortality to growth addresses one aspect of forest sustainability; when removals and mortality exceed growth, total tree volume will decline. In localized areas, removing trees to reduce risk from fire or insect outbreaks can cause removals to exceed growth, but may benefit the health of the stand. Conversely, widespread mortality from some agent of disturbance such as bark beetles may offset growth gains and thus slow stand development (fig. 83).

Because the current FIA inventory differed from past inventories in how the different parts of the forest land base were measured (i.e., forest land, timberland, and inclusion or exclusion of reserved land), and because the inventories used different definitions of forest attributes (e.g., growing stock), it is not possible to simply compare prior published results with current results to estimate change in the net volume of trees. To minimize the definition-based effects, we estimated net change based on revisited plots and assessed them under our current algorithms and definitions. We estimated current annual gross growth from increment cores taken from a subset of softwood trees on the revisited plots. The difference between net change and current annual gross growth is our estimate for removal and mortality.

[2] Author: Olaf Kuegler.

Findings

As shown in the tabulation below, growth of softwood trees on timberland exceeds removals and mortality in California, on both National Forest System (NFS) and noncorporate private lands. On corporate private, state, and local government lands, removals and mortality estimates exceed growth estimates. However, because the sampling error associated with all these estimates is large, none of the differences are statistically significant.

Owner group	Annualized net change: Total	Annualized net change: SE
	Thousand cubic feet	
NFS	117,042	168,537
State and local	-5,458	23,093
Corporate private	-5,929	65,842
Noncorporate private	84,140	67,023
Total	189,794	194,246

On average in California, NFS timberlands are the least productive (as measured by gross growth) compared with corporate lands and noncorporate private. State and local governments control very little of California's timberland area (1.3 percent), so the growth estimate for this ownership group is very imprecise. Softwood gross growth is shown in the following tabulation:

Owner group	Total	SE
	Cubic feet per acre per year	
NFS	85.13	4.35
State and local	261.86	89.93
Corporate private	104.84	12.44
Noncorporate private	109.29	28.39
Total	94.78	5.59

Caveats

The design and definitions used in past inventories are significantly different from those used in our current inventory (see app. 2). The design has changed from a variable-radius to a fixed-radius plot design and from five to four subplots with only the center location of one subplot being the same. As a result, only a small fraction of trees were remeasured

Figure 83—Growth of trees is offset by harvesting and mortality. The mortality shown here was likely caused by bark beetles and/or drought.

in the current annual inventory. Although it is still valid to estimate overall net change based on these different designs, there are some inherent problems. For this chapter we have tried to minimize procedural differences between inventories by comparing only subplots from the two inventories that have the same center location and by applying the same definitions and algorithms to both data sets (i.e., for growing stock, timberland, reserved land, forest type, tree volume). However, a small bias introduced by measurement or model error that may exist in one inventory and not in the other will exaggerate the estimate of net change.[3]

[3] Because overall softwood trees on timberland grow about 3 percent per year, a total volume bias of only 1 percent per year amounts to about a 30 percent difference in gross growth.

We estimated gross growth by taking tree cores from a subset of trees in our current inventory. Although the field crew was instructed to core one live tree for each condition, representing each species and crown class, that was not always possible. This introduces a small bias with an unknown direction into our gross growth estimate.[4] Furthermore, increment cores were not cross-dated, and standardized ring-width indices were not developed.

[4] The estimated bias for total volume for California, using the trees selected for gross growth estimate, is 7.1 percent, with a standard error of 2.2 percent. In contrast, the estimated bias for total volume, using the first tree per species, crown class, and condition is 2.3 percent, with a standard error of 2.2.

Removals and mortality are estimated as the difference between gross growth and net change. Even if these estimates are unbiased, they are still subject to sampling error. Thus, the estimate for removals and mortality can be negative. Although such an estimate is still unbiased, it is of course logically untenable. Furthermore, any bias in the gross growth or the net change estimates is also present in removals and mortality estimates.

Past inventories were conducted between 1991 and 1999, whereas the current inventory covers 2001 though 2005. As a result, the remeasurement period differs between 2 and 14 years.

Finally, the sampling errors for most of our estimates are very large compared to the estimates. The reader should be careful to take into account the sampling error when interpreting the estimates.

In 2005, PNW-FIA began collecting information that can be used for growth, mortality, and harvest. The data include remeasurement of previous trees assessed in two of the five periodic subplots and recording of natural mortality and harvest on all five prior subplots. These new data will allow better estimates of change for the next report

Growth, removals, and mortality table in appendix 2—

- Table 51—Estimated gross growth, net change, removals, and mortality of growing stock for softwood species on timberland, by species group and owner, California, 2001–2005

Removals for Timber Products[5]

Background

Volume removed from forest inventory during timber harvesting is known as removals (fig. 84). Removals are an important indicator of timber harvest sustainability. Removals that exceed growth could indicate overharvesting and decreasing forest inventory, whereas growth that greatly

[5] Authors: Todd Morgan and Charles Keegan, Bureau of Business and Economic Research, University of Montana.

Todd Morgan

Figure 84—Logging in California forests.

exceeds removals could signal the need for vegetation management to regulate density and species mix, inhibit insect and disease outbreaks, or reduce wildfire hazard.

Removals can come from two sources: the growing-stock portion of live trees (live trees of commercial species meeting specified standards of quality or vigor), or dead trees and other non-growing-stock sources. The two general types of removals are timber products harvested for processing by mills and logging residue (i.e., volume cut or killed but not used). Removals, as reported here, are based on a 2000 census of California's primary forest products industry (Morgan et al. 2004) and a 2004 study of logging utilization in California (Morgan and Spoelma, in press).

Findings

California's 2000 timber harvest for industrial wood products was 2.25 billion board feet (Scribner), and dead trees accounted for 106.4 million board feet (5 percent). The 2000 harvest was about 67 percent of the average annual harvest for the previous 20 years, and only 51 percent of the 50-year average (fig. 85). California's 2004 and 2005 timber harvests were slightly higher than those of the previous 3 years, but lower than in 2000.

Removals for timber products totaled 627.8 million cubic feet (MMCF) during 2000. Growing stock accounted for 444.5 MMCF (71 percent) of removals for products, with the remainder coming from other sources including

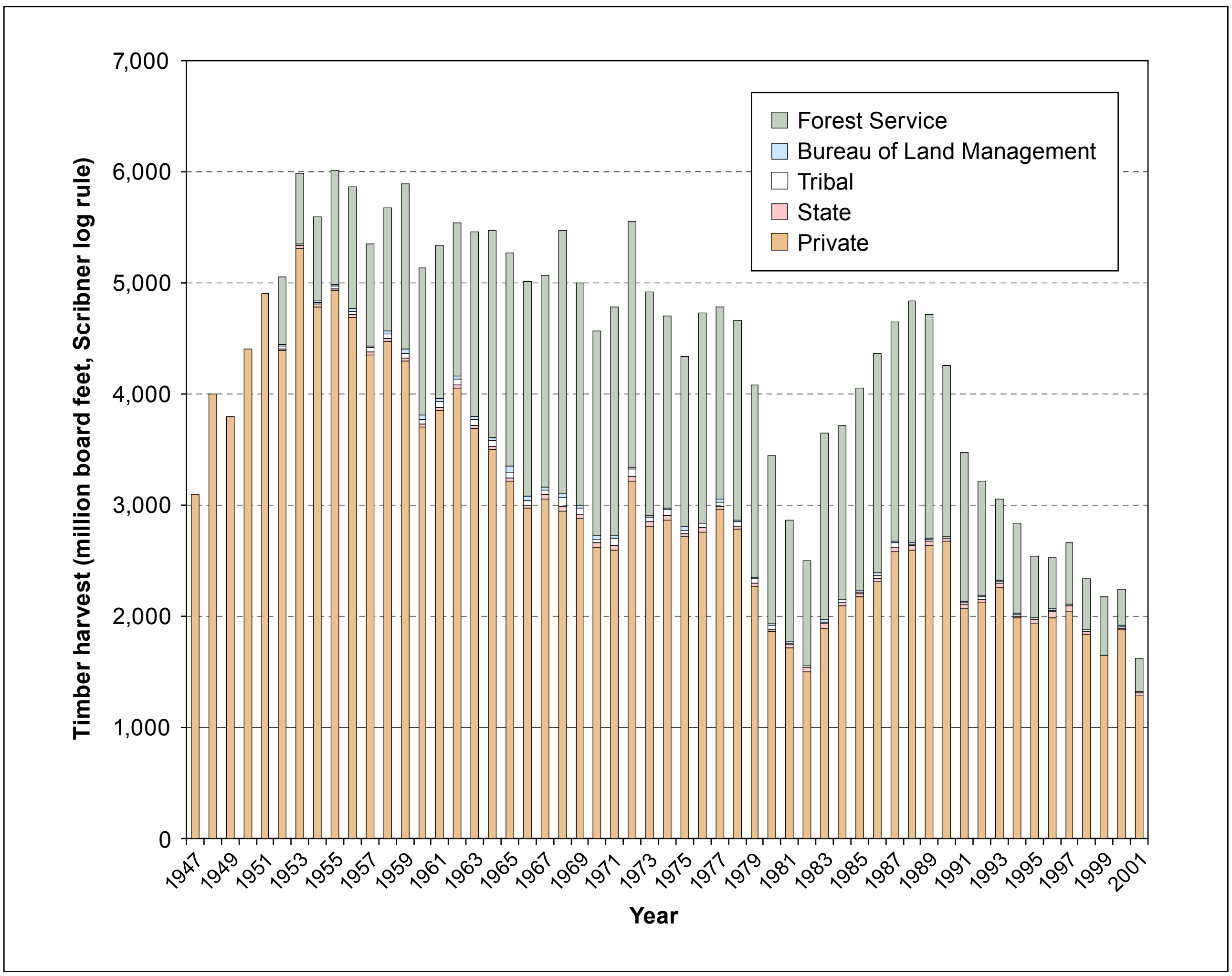

Figure 85—Timber harvest by ownership in California, 1947–2001 (Bolsinger 1980, California State Board of Equalization 2006, Warren 1985-2000).

dead trees. Saw logs were the leading product harvested, accounting for 62 percent of removals for products. Fuelwood, including industrial fuel and residential firewood, accounted for 33 percent, while veneer logs accounted for just 5 percent of removals for products. Softwoods dominated California's harvest, accounting for nearly 99 percent of removals for timber products. The largest volumes of hardwoods were used for fuelwood and pulpwood.

Total removals from California's forests during 2000 were 771.7 MMCF. This included 627.8 MMCF used for timber products and 143.8 MMCF of logging residue left in the forest as slash. Growing-stock removals were 469.2 MMCF. Nearly 95 percent (444.5 MMCF) of growing-stock removals went to produce products, and 5 percent (24.8 MMCF) was not used. Saw logs were the largest component (78 percent) of growing-stock removals, followed by industrial fuelwood (10 percent), and veneer logs (6 percent).

Private corporate timberlands provided 50 percent (232 MMCF) of growing-stock removals, whereas other private and tribal lands supplied 34 percent (160 MMCF). National forests supplied 15 percent of the volume removed from growing stock. Other public landowners, including the Bureau of Land Management and the state of California, provided slightly more than 1 percent.

Douglas-fir was the leading species harvested, accounting for almost 27 percent (125 MMCF) of growing-stock removals (fig. 86). True firs, ponderosa pine, and redwood represented about 21, 18, and 16 percent of growing stock removals, respectively. Sugar pine, cedars, hemlock, lodgepole pine, other pines, and spruces together accounted for 17 percent of growing-stock removals. Hardwoods, including red alder, accounted for less than 1 percent (3 MMCF). Douglas-fir was the leading species harvested for saw logs, and true firs led the veneer log and fuelwood harvest.

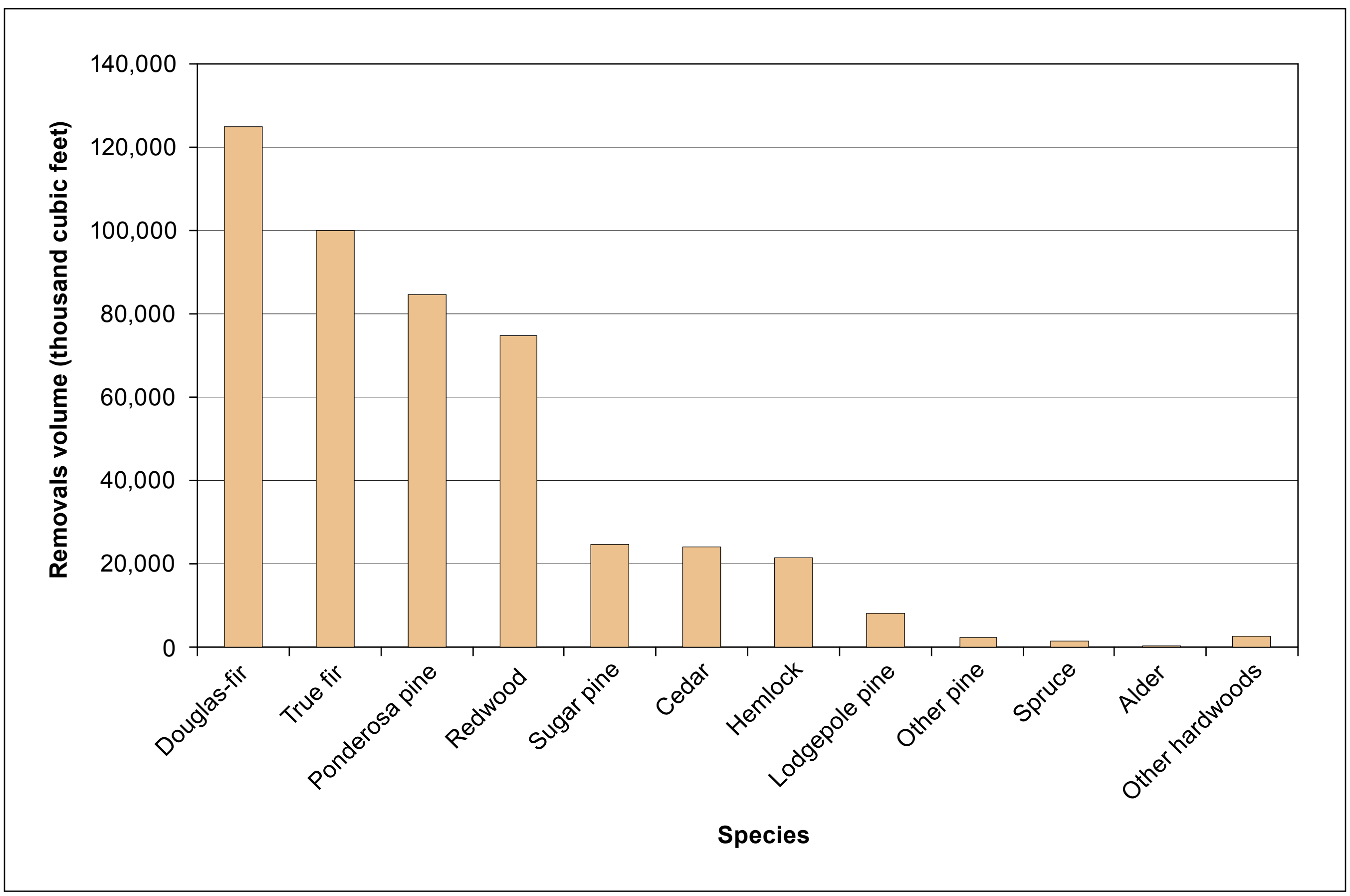

Figure 86—Volume of growing stock removals by tree species in California, 2000. (Morgan et al. 2004).

Interpretation

Sustainability of California's forests depends on sustainable harvest levels and a forest products industry capable of using wood removed from inventory. Statewide, forest growth substantially exceeded harvest. Decreases in California's timber harvest have largely been the result of harvest reductions from national forests. These harvests declined 86 percent between 1988 and 2001, although volume harvested from private lands decreased 43 percent over the same period. These declines in in-state timber harvest volumes have made California's citizens and forest products industry increasingly reliant on out-of-state timber; the volume of imported timber increased 995 percent between 1988 and 2000. Continuing declines in California's timber harvest will impact both the industry and the ability to conduct vegetation management as timber processors and forest operators go out of business.

Removals for timber products tables in appendix 2—

- Table 52—Total roundwood output by product, species group, and source of material, California, 2000
- Table 53—Volume of timber removals by type of removal, source of material, and species group, California, 2000

Nontimber Forest Products[6]

Background

Nontimber forest products (NTFP) are species harvested from forests for reasons other than production of timber commodities (e.g., lumber and plywood). Vascular plants, lichens, and fungi are the primary organisms included in NTFPs (Jones 1999), and are collected for subsistence, recreation, education, and commercial enterprise (Vance et al. 2001). The NTFPs are fundamental to many botanical, floral, and woodcraft industries and are important to medicinal and natural-food industries.

Although harvest of NTFPs is prevalent in Pacific coast forests, relatively little is known about their overall abundance or how they are affected by different land management practices. It is also unclear whether current levels of harvesting are sustainable or whether they are harming the resources (Everett 1997). Because FIA crews record the cover of the most abundant, readily identifiable vascular plant species found on each phase 2 plot, the inventory can provide useful baseline information on the status and trends of many NTFP species (Vance et al. 2002). Crews also collect samples of epiphytic lichens found on phase 3 plots, allowing the assessment of selected lichen NTFPs.

Lists of vascular plant NTFPs were compiled from the literature (Everett 1997, Jones 1999, Vance et al. 2001) and compared with species recorded on FIA plots. Species that were considered readily identifiable by most crews (i.e., common shrubs or common and distinctive herbs) were included in the analyses, as well as seedlings and saplings of selected tree species (under the assumption that most boughs are harvested from small trees). Cover of each species was averaged across all sampled subplots, and the area covered on each plot extrapolated to all forest land with standard inventory statistics.

Findings

The herb species with the greatest cover was swordfern, which covers 176,000 acres; brackenfern was the next most widespread herb, covering 142,000 acres. The shrubs with the greatest cover were greenleaf manzanita (388,000 acres) (fig. 87), California huckleberry (265,000 acres), and

Andrew Gray

Figure 87—Greenleaf manzanita is the nontimber forest product that covered the greatest area on forest lands in California, 2001–2005.

[6] Authors: Andrew Gray and Sarah Jovan.

whiteleaf manzanita (227,000 acres). The cover of NTFP tree seedlings and saplings was generally low except for Douglas-fir, which covered 128,000 acres. Plant NTFPs were most prevalent in moist ecosections; the Northern California Coast section (fig. 88) had the greatest percentage of area covered by NTFP plants. Lichen NTFPs were common, with wolf lichen recorded on 54 percent of the forested plots.

Interpretation

California's forests appear to have abundant resources of NTFP vascular plant species, including those used for floral, medicinal, and woodcraft businesses (e.g., swordfern, St. John's wort, and greenleaf manzanita, respectively) and those important for subsistence and recreation (e.g., Oregon grape and California huckleberry). The proportion of plants of a species that produce the desired quality of greens or fruits is unknown, so the utilizable resource may be somewhat less than that suggested by estimates of the covered area. These figures will provide an important baseline for changes over time and could be used for more detailed analyses by ownership or geographical unit.

Nontimber forest products tables in appendix 2—

- Table 54—Estimated area of forest land covered by vascular plant nontimber forest products, by plant group and species, California, 2001–2005
- Table 55—Percentage of forested plots with selected lichen nontimber forest products present, by species, California, 2001–2005

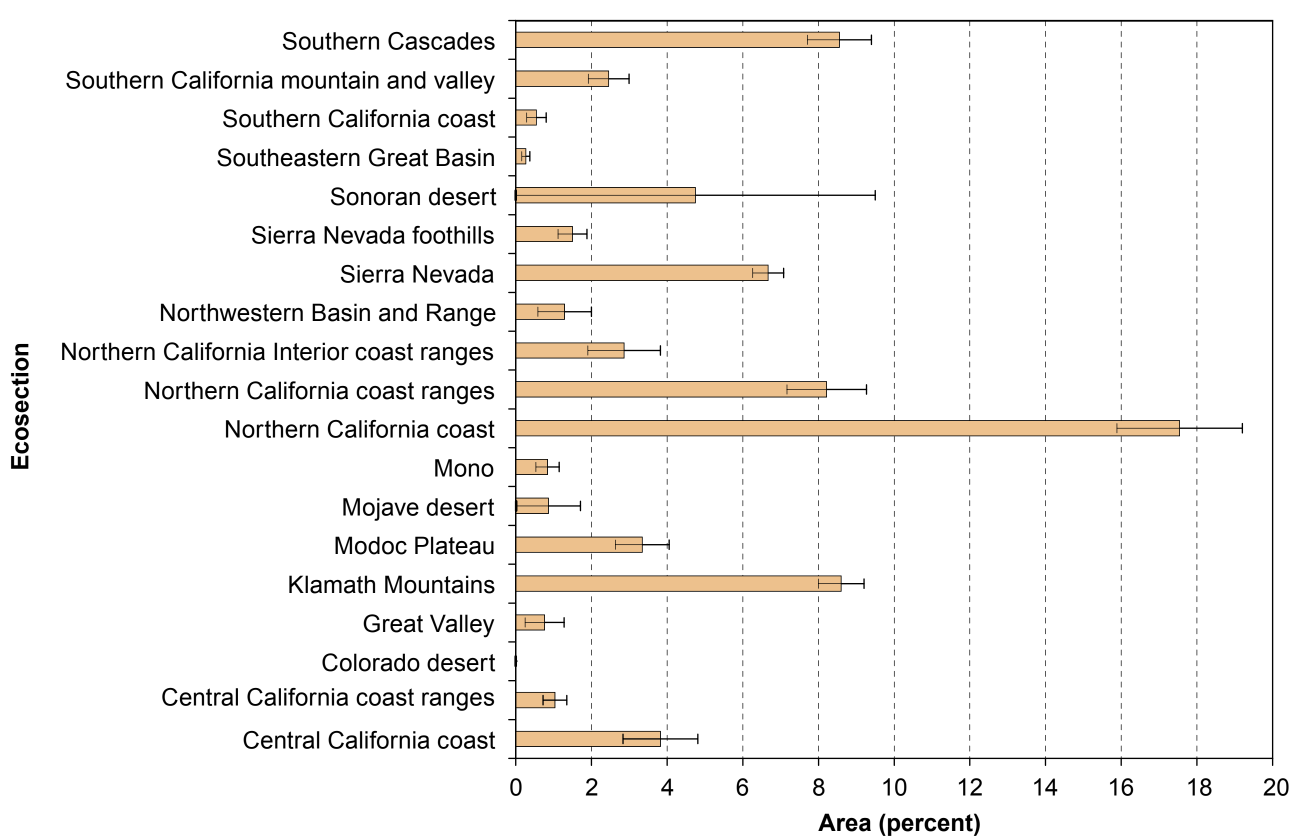

Figure 88—Percentage of forested area covered by selected vascular plant nontimber forest products by ecosection on forest land in California, 2001–2005.

Conclusions

This report has presented an overview of California's forest resources, highlighting information that is new as well as confirming previously known information. We expect some readers will be eager to see more indepth research and analysis on selected topics to fully understand current status, change, and relationships in California's forests. Some possible areas of future work include, but are not limited to, more comprehensive reporting and analysis of forest fuels, carbon dynamics, forest productivity, and forest health issues such as the extent of sudden oak death.

We expect that our own PNW-FIA research staff as well as researchers and analysts from other programs and institutions will investigate many of the questions that can be addressed with the annual inventory data, especially once a full cycle of data has been collected.

The annual FIA inventory, as currently designed, will continue into the future provided funding and support for it are maintained. As directed by the 1998 Farm Bill (Section 253[c] of the Agricultural Research, Extension, and Education Reform Act of 1998), findings from the inventory will be published every 5 years. For California, the next report is scheduled for 2012, after a full cycle of data collection has been completed on all FIA plots.

Glossary

abiotic—Pertaining to nonliving factors such as temperature, moisture, and wind (Goheen and Willhite 2006).

aerial photography—Imagery acquired from an aerial platform (typically aircraft or helicopter) by means of a specialized large-format camera with well-defined optical characteristics. The geometry of the aircraft orientation at the time of image acquisition is also recorded. The resultant photograph will be of known scale, positional accuracy, and precision. Aerial photography for natural resource use is usually either natural color or color-infrared, and is film based or acquired using digital electronic sensors.

air quality index—Value or set of values derived from a multivariate model that examines the composition of lichen communities at each plot to provide a relative estimate of air quality.

aspect—Compass direction that a slope faces.

basal area—The cross-sectional area of a tree trunk.

biodiversity—Variety and variability among living organisms and the ecological complexes in which they occur. Diversity can be defined as the number of different items and their relative frequencies. http://www.epa.gov/OCEPAterms/bterms.html. (21 March 2008).

bioenergy—Renewable energy made available from materials derived from biological sources. http://en.wikipedia.org/wiki/Bioenergy. (21 March 2008).

biomass—The aboveground weight of wood and bark in live trees 1.0 inches diameter at breast height (d.b.h.) and larger from the ground to the tip of the tree, excluding all foliage. The weight of wood and bark in lateral limbs, secondary limbs, and twigs under 0.5 inch in diameter at the point of occurrence on sapling-size trees is included in the measure, but on poletimber- and sawtimber-sized trees this material is excluded. Biomass is typically expressed as green or ovendry weight in tons (USDA Forest Service 2006).

biosite index, ozone—A value calculated from the amount and severity of ozone injury at a site (biosite) that reflects local air quality and plant response and therefore potential risk of ozone impact in the area represented by that biosite (Campbell et al. 2007).

biotic—Pertaining to living organisms and their ecological and physiological relations (Helms 1998).

board foot—A volume measure of lumber 1 foot wide, 1 foot long, and 1 inch thick equal to 144 cubic inches. http://www.ccffa-oswa.org/B.html. (21 March 2008).

bole—Trunk or main stem of a tree (USDA Forest Service 2006).

bulk density—Mass of soil per unit volume. A measure of the ratio of pore space to solid materials in a given soil, expressed in units of grams per cubic centimeter of ovendry soil (USDA Forest Service 2006).

carbon mass—The estimated weight of carbon stored within wood tissues. On average, carbon mass values are about half of biomass values for trees, and are summarized as thousand tons or mean tons per acre.

carbon sequestration—Incorporation of carbon dioxide into permanent plant tissues (Helms 1998).

chapparal—A shrubland or heathland plant community found primarily in California, USA, that is shaped by a Mediterranean climate (mild, wet winters and hot dry summers) and wildfire. A typical chaparral plant community consists of densely-growing evergreen scrub oaks and other drought-resistant shrubs. It often grows so densely that it is impenetrable by large animals and humans. http://en.wikipedia.org/wiki/Chaparral. (21 March 2008).

coarse woody material (CWM)—Down dead tree and shrub boles, large limbs, and other woody pieces that are severed from their original source of growth. CWM also includes dead trees that are leaning >45 degrees from vertical and are still supported by roots, as well as those severed from roots or uprooted (USDA Forest Service 2006).

cogeneration facilities—One or more parallel generation units producing both electrical energy and steam or another form of useful energy for industrial, commercial, heating, or cooling purposes. http://www.srpnet.com/about/econ/terms.aspx. (21 March 2008).

compaction (soil)—Process by which soil grains are rearranged so as to come into closer contact with one another, resulting in a decrease in void space and an increase in soil bulk density (Helms 1998).

corporate land—An ownership class of private lands owned by a company, corporation, legal partnership, investment firm, bank, timberland investment management organization (TIMO), or real estate investment trust (REIT).

crook—Abrupt bend in a tree or log (Helms 1998).

crown fire—Fire that spreads across the tops of trees or shrubs more or less independently of a surface fire. Crown fires are sometimes classed as running (independent or active) or dependent (passive) to distinguish the degree of independence from the surface fire (Helms 1998).

crown—The part of a tree or woody plant bearing live branches or foliage (Helms 1998).

current gross annual growth—The total growth of a given stand of trees, within a defined area, over the period of 1 year.

cyanolichen—Lichen species containing cyanobacteria, which fixes atmospheric nitrogen into a form that plants can use.

damage—Damage to trees caused by biotic agents such as insects, diseases, and animals or abiotic agents such as weather, fire, or mechanical equipment.

defoliation—Premature removal of foliage (Goheen and Willhite 2006).

diameter at breast height (d.b.h.)—Diameter of a tree stem, located at 4.5 feet above the ground (breast height) on the uphill side of a tree. The point of diameter measurement may vary on abnormally formed trees (USDA Forest Service 2006).

dieback—Progressive dying from the extremity of any part of the plant. Dieback may or may not result in death of the entire plant (Helms 1998).

disturbance—Any relatively discrete event in time that disrupts ecosystem, community, or population structure and changes resources, substrate availability, or the physical environment (Helms 1998).

down woody material (DWM)—Dead material on the ground in various stages of decay, including coarse and fine woody material. Previously named down woody debris (DWD). The DWM indicator for Forest Inventory and Analysis (FIA) includes measurements of depth of duff layer, litter layer, and overall fuelbed; fuel loading on the microplot; and residue piles (USDA Forest Service 2006).

ecological region—A top-level scale in a hierarchical classification of ecological units subdivided on the basis of global, continental, and regional climatic regimes and broad physiography. Ecological regions (ecoregions) are further subdivided into domains, divisions, and provinces. The next level down in the hierarchy, subregion, is divided into ecological sections (ecosections) and subsections (Cleland et al. 1997).

ecosections—A level in a hierarchical classification of ecological units for a geographic area delineated on the basis of similar climate, geomorphic processes, stratigraphy, geologic origin, topography, and drainage systems (Cleland et al. 1997).

ecosystem—A spatially explicit, relatively homogeneous unit of the Earth that includes all interacting organisms and components of the abiotic environment within its boundaries. An ecosystem can be of any size: a log, a pond, a field, a forest, or the Earth's biosphere (Helms 1998).

elevation—Height above a fixed reference point, often the mean sea level. http://en.wikipedia.org/wiki/Elevation. (21 March 2008).

endemic—1. Indigenous to or characteristic of a particular restricted geographical area. Antonym: exotic. 2. Referring to a disease constantly infecting a few plants throughout an area. 3. A population of potentially injurious plants, animals, or viruses that are at low levels (see Epidemic) (Helms 1998).

epidemic—1. Entomology: pertaining to populations of plants, animals, and viruses that build up, often rapidly, to unusually and generally injuriously high level. Synonym: outbreak. Many insect and other animal populations cycle periodically or irregularly between endemic and epidemic levels. 2. Pathology: a disease sporadically infecting a large number of hosts in an area and causing considerable loss (Helms 1998).

epiphytic—Describing a plant growing on but not nourished by another plant. (Helms 1998)

erosion—The wearing away of the land surface by running water, wind, ice, or other geological agents (USDA Forest Service 2006).

federal land—An ownership class of public lands owned by the U.S. government (USDA Forest Service 2006).

fine woody material (FWM)—Down dead branches, twigs, and small tree or shrub boles <3 inches in diameter not attached to a living or standing dead source (USDA Forest Service 2006).

fire regime—The characteristic frequency, extent, intensity, severity, and seasonality of fires within an ecosystem (Helms 1998).

fixed-radius plot—A circular sampled area with a specified radius in which all trees of a given size, shrubs, as well as other items, are tallied (USDA Forest Service 2006).

forb—A broad-leaved herbaceous plant, as distinguished from grasses, shrubs, and trees (USDA Forest Service 2006).

forest industry land—An ownership class of private lands owned by a company or an individual(s) operating a primary wood-processing plant (USDA Forest Service 2006).

forest land—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. The minimum area for classification as forest land is 1 acre. Roadside, streamside, and shelterbelt strips of timber must be at least 120 feet wide to qualify as forest land (USDA Forest Service 2006).

forest type—A classification of forest land based upon and named for the tree species that forms the plurality of live-tree stocking (USDA Forest Service 2006).

fork—The place on a tree where the stem separates into two pieces; usually considered a defect.

fuel treatment—Any manipulation or removal of wildland fuels to reduce the likelihood or ignition or to lessen potential fire damage and resistance to control; e.g., lopping, chipping, crushing, piling, and burning. Synonym: fuel modification, hazard reduction (Helms 1998).

fuelwood—Wood salvaged from mill waste, cull logs, branches, etc., and used to fuel fires in a boiler or furnace. http://nfdp.ccfm.org/compendium/products/terminology_e.php. (21 March 2008).

fungus—Member of a group of saprophytic and parasitic organisms that lack chlorophyll, have cell walls made of chitin, and reproduce by spores; includes molds, rusts, mildews, smuts, mushrooms. Fungi absorb nutrients from the organic matter in which they live. Not classified as plants; instead fungi are placed in the Kingdom: Fungi (Goheen and Willhite 2006).

geospatial—The combination of spatial software and analytical methods with terrestrial or geographic data sets. Often used in conjunction with geographic information systems and geomatics. http://en.wikipedia.org/wiki/Geospatial. (21 March 2008).

geothermal energy—The word "geothermal" is derived from words literally meaning "Earth" plus "heat." To produce electric power from geothermal resources, underground reservoirs of steam or hot water are tapped by wells and the steam rotates turbines that generate electricity. http://www.ngdc.noaa.gov/seg/hazard/stratoguide/glossary.html. (21 March 2008).

graminoid—Grasses (family Gramineae or Poaceae) and grasslike plants such as sedges (family Cyperaceae) and rushes (family Juncaceae). http://www.biology-online.org/dictionary/Graminoid. (21 March 2008).

grassland—Land on which the vegetation is dominated by grasses, grasslike plants, or forbs (Helms 1998).

greenhouse gas—A gas, such as carbon dioxide or methane, which contributes to potential climate change. http://www.epa.gov/OCEPAterms/gterms.html. (21 March 2008).

growing stock—All live trees 5 inches d.b.h or larger that are considered merchantable in terms of saw-log length and grade; excludes rough and rotten cull trees (USDA Forest Service 2006).

hardwood—Tree species belonging to the botanical subdivision Angiospermae, class Dicotyledonous, usually broad-leaved and deciduous (USDA Forest Service 2006).

herbivory—The consumption of herbaceous vegetation by organisms ranging from insects to large mammals such as deer, elk, or cattle. http://www.biology-online.org/dictionary/Herbivory. (21 March 2008).

increment borer—An auger-like instrument with a hollow bit and an extractor, used to extract thin radial cylinders of wood (increment cores) from trees having annual growth rings, to determine increment or age (Helms 1998).

interpolation—A method of reallocating attribute data from one spatial representation to another. Kriging is a more complex example that allocates data from sample points to a surface. http://hds.essex.ac.uk/g2gp/gis/sect101.asp. (21 March 2008).

invasive plant—A plant that has spread or is likely to spread into native flora or managed plant systems, develop a self-sustaining population, and become dominant or disruptive. Invasive plants may be either native or nonnative. http://www.invasivespeciesinfo.gov/docs/council/isacdef.pdf. (21 March 2008).

ladder fuel—Combustible material that provides vertical continuity between vegetation strata and allows fire to climb into the crowns of trees or shrubs with relative ease. Ladder fuels help initiate and ensure the continuation of a crown fire (Helms 1998).

late-successional reserves (LSRs)—Federally managed forests held in reserve for wildlife habitat and thus set aside from most commercial logging. The LSRs may contain old clearcuts as well as old-growth forests. Logging may be allowed in an LSR if it will accelerate development of old-growth characteristics. http://www.umpqua-watersheds.org/glossary/gloss_l.html. (21 March 2008).

lichen—An organism consisting of a fungus and an alga or cyanobacterium living in symbiotic association. Lichens look like masses of small, leafy, tufted or crust-like plants (USDA Forest Service 2006).

live trees—All living trees, including all size classes, all tree classes, and both commercial and noncommercial species for tree species listed in the FIA field manual (USDA Forest Service 2006).

mean annual increment (MAI) at culmination—A measure of the productivity of forest land expressed as the average increase in cubic foot volume per acre per year. For a given species and site index, the mean is based on the age at which the MAI culminates for fully stocked natural stands. The MAI is based on the site index of the plot (Azuma et al. 2004).

mesic—Describes sites or habitats characterized by intermediate moisture conditions; i.e., neither decidedly wet nor dry (Helms 1998).

microclimate—The climate of a small area, such as that under a plant or other cover, differing in extremes of temperature and moisture from the larger climate outside (Helms 1998).

MMBF—A million board feet of wood in logs or lumber (Helms 1998).

model—1. An abstract representation of objects and events from the real world for the purpose of simulating a process, predicting an outcome, or characterizing a phenomenon. 2. Geogrpahic information system (GIS) data representative of reality (e.g., spatial data models), including the arc-node, georelational model, rasters or grids, polygon, and triangular irregular networks (Helms 1998).

Montréal Process—In September 1993, the Conference on Security and Cooperation in Europe (CSCE) sponsored an international seminar in Montréal, Canada, on the sustainable development of boreal and temperate forests, with a focus on developing criteria and indicators for the assessment of these forests. After the seminar, Canada drew together countries from North and South America, Asia, and the Pacific Rim to develop criteria and indicators for nontropical forests and, in June 1994, the initiative now known as the Montréal Process began. The European countries elected to work as a region in the Pan-European Forest Process in the followup to the Ministerial Conferences on the Protection of Forests in Europe. http://www.mpci.org/rep-pub/1999/broch_e.html#2. (21 March 2008).

mortality—The death of trees from natural causes, or subsequent to incidents such as storms, wildfire, or insect and disease epidemics (Helms 1998).

multivariate analysis—Branch of statistics concerned with analyzing multiple measurements that have been made on one or several individuals (Helms 1998).

municipal land—Land owned by municipalities or land leased by them for more than 50 years (USDA Forest Service 2006).

mycorrhiza—The usually symbiotic association between higher plant roots (host) and the mycelia of specific fungi. Mycorrhizae aid plants in the uptake of water and certain nutrients and may offer protection against other soil-borne organisms (Helms 1998).

national forest lands—Federal lands that have been designated by Executive order or statute as national forest or purchase units and other lands under the administration of the U.S. Department of Agriculture, Forest Service, including experimental areas and Bankhead-Jones Title III lands (Azuma et al. 2004).

Native American lands—Tribal lands, and allotted lands held in trust by the federal government. Native American lands are grouped with farmer and miscellaneous private lands as other private lands (Azuma et al. 2004).

native species—Plant species that were native to an American region prior to Euro-American settlement. For vascular plants, they are the species that are not present on the USDA NRCS (2000) list of nonnative species (see Nonnative species) (USDA Natural Resources Conservation Service 2000).

nitrophyte—One of a group of lichen species that grow in nitrogen-rich habitats.

nitrogen oxides (NO_x)—Gases consisting of one molecule of nitrogen and varying numbers of oxygen molecules, produced in the emissions of vehicle exhausts and from power stations. Atmospheric NO_x contributes to formation of photochemical ozone (smog), which can impair visibility and harm human health. http://www.climatechange.ca.gov/glossary/letter_n.html. (21 March 2008).

noncorporate forest land—Private forest land owned by nongovernmental conservation or natural resource organizations; unincorporated partnerships, associations, or clubs; individuals or families; or Native Americans.

nonnative species—Plant species that were introduced to America subsequent to Euro-American settlement. Nonnative vascular plants are present on the USDA NRCS (2000) list of nonnative species (USDA Natural Resources Conservation Service 2000).

nonstocked areas—Timberland less than 10 percent stocked with live trees. Recent clearcuts scheduled for planting are classified as nonstocked area (Azuma et al. 2004).

nontimber forest products (NTFP)—Species harvested from forests for reasons other than production of timber commodities. Vascular plants, lichens, and fungi are the primary organisms included in NTFPs.

old-growth forest—Old-growth forest is differentiated from younger forest by its structure and composition, and often by its function. Old-growth stands are typified by the presence of large older trees; variety in tree species, sizes, and spacing; multiple canopy layers; high amounts of standing and down dead wood; and broken, deformed, or rotting tops, trunks, and roots (Franklin et al. 1986).

other private lands—Lands in private ownership and not reported separately. These may include coal companies, land trusts, and other corporate private landowners (USDA Forest Service 2006).

overrun—Difference between the log scale of a shipment of timber and the volume of actual lumber obtained from it. http://forestry.about.com/library/glossary/blforglo.htm. (21 March 2008).

overstory—That portion of the trees, in a forest of more than one story, forming the uppermost canopy layer (Helms 1998).

owner class—A variable that classifies land into categories of ownership. Current ownership classes are listed in the field manual (USDA Forest Service 2006).

owner group—A variable that combines owner classes into the following groups: Forest Service, other federal agency, state and local government, and private (USDA Forest Service 2006).

ownership—A legal entity having an ownership interest in land, regardless of the number of people involved. An ownership may be an individual; a combination of persons; a legal entity such as corporation, partnership, club, or trust; or a public agency. An ownership has control of a parcel or group of parcels of land (USDA Forest Service 2006).

ozone, tropospheric (O_3)—A regional, gaseous air pollutant produced primarily through sunlight-driven chemical reactions of nitrogen oxide (NO_2) and hydrocarbons in the troposphere (the lowest layer of the atmosphere). Ozone plays a significant role in greenhouse warming and urban smog and causes foliar injury to deciduous trees, conifers, shrubs, and herbaceous species (Air and Waste Management Association 1998).

pathogen—Parasitic organism directly capable of causing disease (Helms 1998).

phytotoxic—Poisonous to plants (Helms 1998).

prescribed burn—Deliberate burning of wildland fuels in either their natural or their modified state and under specified environmental conditions, usually to make the site less susceptible to severe wildfire. Synonym: controlled burn, prescribed fire (Adapted from Helms 1998).

private land—An ownership group that includes all family, individual, corporate, nonpublic conservation and natural resource organizations, unincorporated partnerships, associations, clubs, and Native American lands.

public land—An ownership group that includes all federal, state, county, and municipal lands (USDA Forest Service 2006).

pulpwood—Whole trees, tree chips, or wood residues used to produce wood pulp for the manufacture of paper products. Pulpwood is usually wood that is too small, of inferior quality, or the wrong species for the manufacture of lumber or plywood. http://nfdp.ccfm.org/compendium/products/terminology_e.php. (21 March 2008).

quadrat—The basic 3.28 square feet sampling unit for the Phase 3 Vegetation Indicator (USDA Forest Service 2006).

rangeland—Expansive, mostly unimproved lands on which a significant proportion of the natural vegetation is native grasses, grass-like plants, forbs, and shrubs. Rangelands include natural grasslands, savannas, shrublands, most deserts, tundra, alpine communities, coastal marshes, and wet meadows. http:/en.wikipedia.org/wiki/Rangeland. (21 March 2008).

regeneration (artificial and natural)—The established progeny from a parent plant, seedlings or saplings existing in a stand, or the act of renewing tree cover by establishing young trees naturally or artificially. May be artificial (direct seeding or planting) or natural (natural seeding, coppice, or root suckers) (Adapted from Helms 1998).

remote sensing—Capture of information about the Earth from a distant vantage point. The term is often associated with satellite imagery but also applies to aerial photography, airborne digital sensors, ground-based detectors, and other devices. http://www.nsc.org/ehc/glossar2.htm. (21 March 2008).

reserved forest land—Land permanently reserved from wood products utilization through statute or administrative designation. Examples include national forest wilderness areas and national parks and monuments (USDA Forest Service 2006).

richness—The number of different species in a given area, often referred to at the plot scale as alpha diversity and at the region scale as gamma diversity (USDA Natural Resources Conservation Service 2000).

riparian—Related to, living in, or associated with a wetland, such as the bank of a river or stream or the edge of a lake or tidewater. The riparian biotic community significantly influences and is influenced by the neighboring body of water (Helms 1998).

sampling error—Difference between a population value and a sample estimate that is attributable to the sample, as distinct from errors due to bias in estimation, errors in observation, etc. Sampling error is measured as the standard error of the sample estimate (Helms 1998).

sapling—A live tree 1.0 to 4.9 inches in diameter (USDA Forest Service 2006).

saw log—A log meeting minimum standards of diameter, length, and defect for manufacture into lumber or plywood. The definition includes logs, with a minimum diameter outside bark for softwoods of 7 inches (9 inches for hardwoods) (Adapted from Connor et al. 2004 and Azuma et al. 2004).

sawtimber trees—Live softwood trees of commercial species at least 9.0 inches in d.b.h. and live hardwood trees of commercial species at least 11.0 inches d.b.h. At least 25 percent of the board-foot volume in a sawtimber tree must be free from defect. Softwood trees must contain at least one 12-foot saw log with a top diameter of not less than 7 inches outside bark; hardwood trees must contain at least one 8-foot saw log with a top diameter of not less than 9 inches outside bark (Azuma et al. 2004).

seedlings—Live trees <1.0 inch d.b.h. and at least 6 inches in height (softwoods) or 12 inches in height (hardwoods) (USDA Forest Service 2006).

shrub—Perennial, multistemmed woody plant, usually less than 13 to 16 feet in height, although under certain environmental conditions shrubs may be single-stemmed or taller than 16 feet. Includes succulents (e.g., cacti) (USDA Forest Service 2007b).

shrubland—A shrub-dominated vegetation type that does not qualify as forest.

slope—Measure of change in surface value over distance, expressed in degrees or as a percentage (Helms 1998).

snag—Standing dead tree ≥5 inches d.b.h. and ≥4.5 feet in length, with a lean of <45 degrees. Dead trees leaning more than 45 degrees are considered to be down woody material. Standing dead material shorter than 4.5 feet are considered stumps (USDA Forest Service 2007b).

softwood—Coniferous trees, usually evergreen having needles or scale-like leaves (Smith et al. 2004).

specific gravity constants—Ratio of the density (weight per unit volume) of an object (such as wood) to the density of water at 4 degrees C (39.2 degrees F) (Helms 1998).

stand age—Average age of the live dominant and codominant trees in the predominant stand size class (USDA Forest Service 2006).

state land—An ownership class of public lands owned by states or lands leased by states for more than 50 years (USDA Forest Service 2006).

stocked/nonstocked—In the FIA Program, a minimum stocking value of 10 percent live trees is required for accessible forest land (USDA Forest Service 2007b).

stocking—1. At the tree level, the density value assigned to a sampled tree (usually in terms of numbers of trees or basal area per acre), expressed as a percentage of the total tree density required to fully use the growth potential of the land. 2. At the stand level, the sum of the stocking values of all trees sampled (Bechtold and Patterson 2005).

stratification—A statistical tool used to reduce the variance of the attributes of interest by partitioning the population into homogenous strata (Bechtold and Patterson 2005).

succession—The gradual supplanting of one community of plants by another (Helms 1998).

surface fire—A fire that burns only surface fuels, such as litter, loose debris, and small vegetation (Helms 1998).

sustainability—The capacity of forests, ranging from stands to ecological regions, to maintain their health, productivity, diversity, and overall integrity in the long run, in the context of human activity and use (Helms 1998).

terrestrial—Of or relating to the Earth or its inhabitants; of or relating to land as distinct from air or water. http://www.merriam-webster.com/dictionary/terrestrial. (21 March 2008).

timberland—Forest land that is producing or capable of producing >20 cubic feet per year of wood at culmination of mean annual increment (MAI). Timberland excludes reserved forest lands (USDA Forest Service 2006).

transect—A narrow sample strip or a measured line laid out through vegetation chosen for study (Helms 1998).

tree—A woody perennial plant, typically large, with a single well-defined stem carrying a more or less definite crown; sometimes defined as attaining a minimum diameter of 3 inches and a minimum height of 15 feet at maturity. For FIA, any plant on the tree list in the current field manual is measured as a tree (USDA Forest Service 2006).

understory—All forest vegetation growing under an overstory (Helms 1998).

unreserved forest land—Forest land that is not withdrawn from harvest by statute or administrative regulation. Includes forest lands that are not capable of producing in excess of 20 cubic feet per acre per year of industrial wood in natural stands (Smith et al. 2004).

upland—Any area that does not qualify as a wetland because the associated hydrologic regime is not sufficiently wet to produce vegetation, soils, or hydrologic characteristics associated with wetlands. In flood plains, such areas are more appropriately termed non-wetlands. http://www.biology-online.org/dictionary/Upland. (21 March 2008).

veneer log—A high-quality log of a desirable species suitable for conversion to veneer. Veneer logs must be large, straight, of minimum taper, and free of defects. http://www.agnr.umd.edu/MCE/Publications/Publication.cfm?ID=78. (21 March 2008).

vascular plant—A plant possessing a well-developed system of conducting tissue to transport water, mineral salts, and sugars. http://www.biology-online.org/dictionary/Vascular_plant. (21 March 2008).

wilderness—1. According to the Wilderness Act of 1964, "a wilderness, in contrast with those areas where man and his works dominate the landscape, is hereby recognized as an area where the earth and its community of life are untrammeled by man, where man himself is a visitor who does not remain." 2. A roadless land legally classified as a component area of the National Wilderness Preservation System and managed to protect its qualities of naturalness, solitude, and opportunity for primitive recreation. Wilderness areas are usually of sufficient size to make maintenance in such a state feasible (Helms 1998).

wildfire—Any uncontained fire, other than prescribed fire, occurring on wildland. Synonym: wildland fire (Adapted from Helms 1998).

wildland—Land other than that dedicated for uses such as agricultural, urban, mining, or parks (Helms 1998).

wildland forest—A large continuous tract of forest with few or no developed structures on it. Delineated on aerial imagery for the purpose of detecting land use change. The FIA Program and the Oregon Department of Forestry jointly use a minimum of 640 acres with fewer than five developed structures to designate wildland forest.

wildland-urban interface (WUI)—A popular term used to describe an area where various structures (most notably private homes) and other human developments meet or are intermingled with forest and other vegetative fuel types. http://www.borealforest.org/nwgloss13.htm. (21 March 2008).

xeric—Pertaining to sites or habitats characterized by decidedly dry conditions (Helms 1998).

Common and Scientific Plant Names[1]

Common name	Scientific name
Trees:	
Alder	*Alnus* spp.
Ash	*Fraxinus* spp.
Aspen, quaking aspen	*Populus tremuloides* Michx.
Bigcone Douglas-fir	*Pseudotsuga macrocarpa* (Vasey) Mayr
Bigleaf maple	*Acer macrophyllum* Pursh
Birch	*Betula* spp.
Bishop pine	*Pinus muricata* D. Don
Bitter cherry	*Prunus emarginata* (Dougl. ex Hook.) D. Dietr.
Black cottonwood	*Populus balsamifera* L. ssp. *trichocarpa* (Torr. & A. Gray ex Hook.) Brayshaw
Blue oak	*Quercus douglasii* Hook. & Arn.
Boxelder	*Acer negundo* L.
Brewer spruce	*Picea breweriana* S. Wats.
Bristlecone pine	*Pinus aristata* Engelm.
California black oak	*Quercus kelloggii* Newberry
California Buckeye	*Aesculus californica* (Spach) Nutt.
California juniper	*Juniperus californica* Carr.
California nutmeg, California torreya	*Torreya californica* Torr.
California red fir	*Abies magnifica* A. Murr.
California sycamore	*Platanus racemosa* Nutt.
California white oak	*Quercus lobata* Née
California-laurel	*Umbellularia californica* (Hook. & Arn.) Nutt.
Canyon live oak	*Quercus chrysolepis* Liebm.
Cedar	*Thuja* spp.
Cherry and plum species	*Prunus* spp.
Coast live oak, California live oak	*Quercus agrifolia* Née

Common name	Scientific name
Cottonwood	*Populus* spp.
Coulter pine	*Pinus coulteri* D. Don
Curl-leaf mountain mahogany	*Cercocarpus ledifolius* Nutt.
Cypress	*Cupressus* spp.
Douglas-fir	*Pseudotsuga menziesii* (Mirbel) Franco
Elm	*Ulmus* spp.
Engelmann oak	*Quercus engelmannii* Greene
Engelmann spruce	*Picea engelmannii* Parry ex Engelm.
Foxtail pine	*Pinus balfouriana* Grev. & Balf.
Fremont cottonwood	*Populus fremontii* S. Wats.
Giant chinquapin, golden chinquapin	*Chrysolepis chrysophylla* (Dougl. ex Hook.) Hjelmqvist
Giant sequoia	*Sequoiadendron giganteum* (Lindl.) Buchh.
Grand fir	*Abies grandis* (Dougl. ex D. Don) Lindl.
Gray pine, ghost pine	*Pinus sabiniana* Dougl. ex Dougl.
Great Basin bristlecone pine	*Pinus longaeva* D.K. Bailey
Hawthorn	*Crataegus* spp.
Hemlock	*Tsuga* spp.
Incense-cedar	*Calocedrus decurrens* (Torr.) Florin
Interior live oak	*Quercus wislizeni* A. DC.
Jeffrey pine	*Pinus jeffreyi* Grev. & Balf.
Knobcone pine	*Pinus attenuata* Lemmon
Limber pine	*Pinus flexilis* James
Lodgepole pine	*Pinus contorta* Dougl. ex Loud.
Maple	*Acer* spp.
Mesquite	*Prosopis* spp.
Monterey cypress	*Cupressus macrocarpa* Hartw. ex Gord.
Monterey pine	*Pinus radiata* D. Don
Mountain hemlock	*Tsuga mertensiana* (Bong.) Carr.
Noble fir	*Abies procera* Rehd.
Oak	*Quercus* spp.
Oregon ash	*Fraxinus latifolia* Benth.
Oregon crabapple	*Malus fusca* (Raf.) Schneid.
Oregon white oak	*Quercus garryana* Dougl. ex Hook.
Pacific dogwood	*Cornus nuttallii* Audubon ex Torr. & Gray
Pacific madrone	*Arbutus menziesii* Pursh
Pacific silver fir	*Abies amabilis* (Dougl. ex Loud.) Dougl. ex Forbes
Pacific yew	*Taxus brevifolia* Nutt.
Pine, pinyon	*Pinus* spp.
Ponderosa pine	*Pinus ponderosa* P. & C. Lawson
Port-Orford-cedar	*Chamaecyparis lawsoniana* (A. Murr.) Parl.
Red alder	*Alnus rubra* Bong.
Redcedar, juniper	*Juniperus* spp.
Redwood, coast redwood	*Sequoia sempervirens* (Lamb. ex D. Don) Endl.
Sargent's cypress	*Cupressus sargentii* Jepson
Screwbean mesquite	*Prosopis pubescens* Benth.
Shasta red fir	*Abies magnifica* A. Murr. var. *shastensis* Lemmon
Singleleaf pinyon	*Pinus monophylla* Torr. & Frém.
Sitka spruce	*Picea sitchensis* (Bong.) Carr.
Spruce	*Picea* spp.
Subalpine fir	*Abies lasiocarpa* (Hook.) Nutt.
Sugar pine	*Pinus lambertiana* Dougl.
Tanoak	*Lithocarpus densiflorus* (Hook. & Arn.) Rehd.

Common name	**Scientific name**
Tasmanian bluegum	*Eucalyptus globulus* Labill.
True fir species	*Abies* spp.
Twoneedle pinyon, Colorado pinyon	*Pinus edulis* Engelm.
Utah juniper	*Juniperus osteosperma* (Torr.) Little
Washoe pine	*Pinus washoensis* Mason & Stockwell
Western hemlock	*Tsuga heterophylla* (Raf.) Sarg.
Western honey mesquite	*Prosopis glandulosa* Torr.
Western juniper	*Juniperus occidentalis* Hook.
Western larch	*Larix occidentalis* Nutt.
Western redcedar	*Thuja plicata* Donn ex D. Don
Western white pine	*Pinus monticola* Dougl. ex D. Don
White alder	*Alnus rhombifolia* Nutt.
White fir	*Abies concolor* (Gord. & Glend.) Lindl. ex Hildebr.
Whitebark pine	*Pinus albicaulis* Engelm.
Shrubs:	
Blue elderberry	*Sambucus nigra* L. ssp. *cerulea* (Raf.) R. Bolli
California huckleberry	*Vaccinium ovatum* Pursh
California yerba santa	*Eriodictyon californicum* (Hook. & Arn.) Torr.
Chamise	*Adenostoma fasciculatum* Hook. & Arn.
Creeping barberry	*Mahonia repens* (Lindl.) G. Don
Currant spp.	*Ribes* spp.
Cutleaf blackberry	*Rubus laciniatus* Willd.
Dwarf mistletoe	*Arceuthobium* spp.
Dwarf Oregon grape	*Mahonia nervosa* (Pursh) Nutt.
English holly	*Ilex aquifolium* L.
English ivy	*Hedera helix* L.
European black elderberry	*Sambucus nigra* L.
Greanleaf manzanita	*Arctostaphylos patula* Greene
Hairy manzanita	*Arctostaphylos columbiana* Piper
Himalayan blackberry	*Rubus discolor* Weihe & Nees
Kinnikinnick	*Arctostaphylos uva-ursi* (L.) Spreng.
Manzanita	*Arctostaphylos* spp.
Oregon boxleaf	*Paxistima myrsinites* (Pursh) Raf.
Oregon grape	*Mahonia aquifolium* (Pursh) Nutt.
Pacific ninebark	*Physocarpus capitatus* (Pursh) Kuntze
Pinemat manzanita	*Arctostaphylos nevadensis* Gray
Pipsissewa	*Chimaphila umbellata* (L.) W. Bart.
Pursh's buckthorn	*Frangula purshiana* (DC.) Cooper
Red elderberry	*Sambucus racemosa* L.
Rose spp.	*Rosa* spp.
Salal	*Gaultheria shallon* Pursh
Scotch broom	*Cytisus scoparius* (L.) Link
Scouler's willow	*Salix scouleriana* Barratt ex Hook.
Skunkbush	*Rhus trilobata* Nutt.
Snowberry	*Symphoricarpos* spp.
Snowbrush ceanothus	*Ceanothus velutinus* Dougl. ex Hook.
Sticky whiteleaf manzanita	*Arctostaphylos viscida* Parry
Thinleaf huckleberry	*Vaccinium membranaceum* Dougl. ex Torr.
Vine maple	*Acer circinatum* Pursh
Willow	*Salix* spp.

Common name	Scientific name
Forbs:	
Brackenfern	*Pteridium aquilinum* (L.) Kuhn
British Columbia wildginger	*Asarum caudatum* Lindl.
Bull thistle	*Cirsium vulgare* (Savi) Ten.
Canada thistle	*Cirsium arvense* (L.) Scop.
Common beargrass	*Xerophyllum tenax* (Pursh) Nutt.
Common yarrow	*Achillea millefolium* L.
Hairy cat's ear	*Hypochaeris radicata* L.
Heartleaf arnica	*Arnica cordifolia* Hook.
Horsetail	*Equisetum* spp.
Mugwort	*Artemisia douglasiana* Bess.
Pacific trillium	*Trillium ovatum* Pursh
Purple foxglove	*Digitalis purpurea* L.
Spreading hedgeparsley	*Torilis arvensis* (Huds.) Link
St. John's wort	*Hypericum perforatum* L.
Stinging nettle	*Urtica dioica* L.
Swordfern	*Polystichum munitum* (Kaulfuss) K. Presl
Thistle spp.	*Cirsium* spp.
Western pearly everlasting	*Anaphalis margaritacea* (L.) Benth.
Western wormwood	*Artemisia ludoviciana* Nutt.
Yellow star-thistle	*Centaurea solstitialis* L.
Graminoids:	
Bristly dogstail grass	*Cynosurus echinatus* L.
Cheatgrass	*Bromus tectorum* L.
Common velvetgrass	*Holcus lanatus* L.
Compact brome	*Bromus madritensis* L.
False brome	*Brachypodium sylvaticum* (Huds.) Beauv.
Medusahead	*Taeniatherum caput-medusae* (L.) Nevski
Orchardgrass	*Dactylis glomerata* L.
Ripgut brome	*Bromus diandrus* Roth
Silver hairgrass	*Aira caryophyllea* L.
Slender oat	*Avena barbata* Pott ex Link
Soft brome	*Bromus hordeaceus* L.
Wild oat	*Avena fatua* L.
Lichens:	
Beard lichen	*Usnea hirta* (L.) F.H. Wigg.
Beard lichens	*Usnea* spp.
Brown-eyed sunshine lichen	*Vulpicida canadensis* (Rasanen) J. E. Mattsson & M.J. Lai
Crottle	*Parmelia saxatilis* (L.) Ach.
Lace lichen	*Ramalina menziesii* Taylor
Lungwort lichen	*Lobaria pulmonaria* (L.) Hoffm.
Old man's beard	*Bryoria fremontii* (Tuck.) Brodo & D. Hawksw.
Orange wall lichen	*Xanthoria polycarpa* (Hoffm.) Rieber
Rosette lichen	*Physcia adscendens* (Fr.) H. Olivier
Witch's hair lichen	*Alectoria sarmentosa* (Ach.) Ach.
Wolf lichen	*Letharia vulpina* (L.) Hue

[1] This table includes Latin and common names of plant species mentioned in this report and accompanying tables. A great many more species, particularly of life forms other than trees, are recorded in the inventory data but are absent from this table because they are not directly mentioned in this report.

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Metric Equivalents

When you know:	Multiply by:	To find:
Inches	2.54	Centimeters
Feet	.3048	Meters
Miles	1.609	Kilometers
Acres	.405	Hectares
Board feet	.0024	Cubic meters
Cubic feet	.0283	Cubic meters
Cubic feet per acre	.06997	Cubic meters per hectare
Square feet	.0929	Square meters
Square feet per acre	.229	Square meters per hectare
Ounce	28349.5	Milligrams
Pounds	.453	Kilograms
Pounds per cubic foot	16.018	Kilograms per cubic meter
Tons per acre	2.24	Megagrams per hectare
Degrees Farenheit	.55 (°F – 32)	Degrees Celsius
Kilowatt hours	3,409	B.t.u. (mean)

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