System Indicators

Forest Health and Carbon Storage

SIERRA NEVADA CONSERVANCY

DRAFT Report

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Introduction

This fourth report in the System Indicators series focuses on Sierra Nevada forests, and includes indicators related to Forest Health and Biomass/Carbon Storage on forest lands. In addition, this report describes the extent, character, and ownership of forest land in the Sierra Nevada Conservancy (SNC) Region.

Two of the nineteen indicators approved by the SNC Governing Board are incorporated into this report: Forest Health and Carbon Storage. Forest Health is a particularly difficult indicator to frame and quantify, as there is no consensus on exactly what defines forest health. Fires, and fire suppression, are certainly critical elements of forest health. Yet wildfire in the Sierra Nevada is a larger issue that goes beyond forest health, since it impacts woodland, grassland, and communities throughout the Region as well. In this light, aspects of wildfire as it relates to forest health are incorporated into this report; Fire Threat, in the broader scope and context, will be covered in a subsequent stand-alone System Indicators report.

Indicators of Forest Health

Because forest health cannot be characterized by any single, simple measure, three data sets are used to provide an indication of the health of the forests in the Region: fire return interval departure, wildfire threat to ecosystems, and forest pest impact and threat.

Prior to fire suppression efforts and forest management priorities of the last century and a half, Sierra Nevada forests experienced frequent wildfires mostly of low severity, which were part of maintaining a healthy forest. Fire Return Interval tracks the frequency at which wildfire revisits the same land over and over. A comparison of the frequency of fire return between the "natural" state and modern times is reflected in the Fire Return Interval Departure (FRID). The amount of departure between now and then puts land into a Condition Class. A higher Class number identifies a greater divergence in fire return rates and indicates forest land where frequent low severity fire, the primary ecological process shaping Sierra forests, has not been occurring. The acreage in each Condition Class is one Forest Health indicator. A reduction in the acreage from a higher to lower condition class would indicate improving forest health if those additional acres are burned at low severity.

CAL FIRE prioritizes landscape as to its risk and susceptibility to high severity wildfire. A second Forest Health indicator is the acreage of forest landscape that is prioritized as High threat for severe wildfire. A reduction over time in the acreage of forest categorized as High threat would indicate one aspect of improving forest conditions.

Similarly, CAL FIRE prioritizes forest land with regard to the severity of current pest impact and the threat to forest of potential pest infestation. The acreage prioritized as High for both impacts and threat comprise the last Forest Health indicator.

Biomass/Carbon Storage

Using U.S. Department of Agriculture Forest Service (USFS) Forest Inventory and Analysis (FIA) data, the amount of above-ground biomass can be mapped by SNC Subregion, forest type, and

land ownership. The amount of stored carbon can be estimated from the dry biomass figures. This indicator will track the total tonnage of above-ground biomass and the amount of carbon it contains.

Highlights

- Productive forest land within the SNC Region totals over 10.5 million acres, covering 43 percent of the Region.
- Plumas and Shasta Counties have the most forested acres (1.4 and 1 million respectively within the SNC Region) followed closely by Lassen and Tulare Counties (about 900,000 each.)
- Seventy percent of Sierra forests are under public ownership; Yuba, Butte, and Calaveras Counties have the least public forest land with 39%, 37%, and 34% respectively. Public ownership of forest land in Fresno, Alpine, Inyo, Mono, and Tulare Counties runs from 95 to 98 percent.
- In a historical, natural and healthy fire regime, nearly half of Sierra forests would experience fire mostly of low severity every 12 years and three-quarters would experience fire every 20 years. However, only two-tenths of one percent of Sierra forest land has burned repeatedly at least every 20 years in modern times, and 74% of Sierra forest land has not had a single wildfire or prescribed burn in the last 103 years.
- Much of the Sierra forest land is vulnerable to high severity wildfire. More than half of forest land within the Region– 5.5 million acres – is classified as 'high priority' by CAL FIRE for treatment to prevent severe wildfire threats. The North Central and North Subregions had the most high priority acres with 1.6 million and 1.5 million respectively.
- High severity wildfire poses a threat to watershed function, particularly in the northern half of the SNC Region. Nearly two-thirds of the watershed area in the North Central and North Subregions are classified as high threat.
- Insects and diseases are a natural and necessary part of healthy forests, but tree mortality has increased from historical rates. About 3.6 million acres of Sierra forest land is identified for some amount of restoration due to pest damage, with 1.2 million acres classified as high priority.
- Sierra mixed-conifer is the most impacted forest type from pest damage, with 1.7 million acres (36 percent of this forest type) identified for restoration need to mitigate damage.
- Over one million acres of Sierra forest not yet significantly impacted by pests are identified for some level of need to prevent future pest infestation.
- Sierra productive-forest land holds about 840 million tons of above-ground dry biomass, representing about 420 million tons of stored carbon. About 62% of this biomass/carbon is on public lands.
- Nearly half of total forest biomass is in mixed conifer forest. The North Central Subregion contains the most forest biomass, followed by the South Subregion (with 220 million and 175 million tons respectively).

Overview of Sierra Nevada Forests

Sierra Nevada forests are a beautiful, diverse, and extensive resource to California residents. Of the 25 million acres in the Sierra Nevada Conservancy Region, over ten-and-a-half million are covered with productive forests. Forest land is defined as land that is at least 10% covered by trees. Productive forest lands are forests that is at least 10% covered of commercial tree species including Ponderosa Pine, Incense Cedar, White and Red Fir, Lodgepole, and Sugar and Jeffrey Pine. Productive forest land is the definition used here in order to distinguish the subject of this report from forested areas at lower elevation where oak woodlands cover at least 10% of the landscape. These two types of forest have substantially different uses and regulatory environment. Oak woodlands have primarily been used as rangelands for cattle grazing while productive forest lands in private ownership have traditionally been used for timber and biomass harvesting regulated by the California Department of Forestry and Fire Protection (CAL FIRE) under the California Forest Practices Act.

Sierra Nevada forests are diverse with different tree species growing at different elevations and latitudes. Different 'forest types' with characteristic combinations of trees are shown in Figure 1. Traveling east and uphill from the great California Central Valley, grassland and foothill oak woodlands give way to Ponderosa Pine, mixed conifer, and Jeffrey Pine forests, leading to sub-alpine forests and bare peaks at the crest of the mountain range. On the east side of the crest, the landscape dries and gives way to eastside pine forests and Pinyon-Juniper types. Shrub dominated areas of chaparral and combinations of hardwood and conifers are found in rugged canyons throughout the range. These bands of vegetation generally increase in elevation at the southern end of the range as temperatures get warmer.

Of the 10.5 million acres of productive forest land in the SNC Region, 70% is owned by the public while 30% is privately owned (see Table 1). Of the 7.5 million acres of public land, 84% is administered by the U.S. Forest Service (USFS), 13% by the National Park Service (NPS), 2% by the U.S. Bureau of Land Management (BLM), and 1% by other public agencies including the Bureau of Indian Affairs, Department of Defense and local and state government. The 3 million acres of private land is owned by a range of small to larger ownerships including industrial timber companies and non-governmental organizations (NGOs) such as the Nature Conservancy.

Table 1. Ownership of productive forest land in the Sierra Nevada

Ownership	Acres	Percent of forest land owned	Percent of public forest land owned
USFS	6,322,189	59%	84%
NPS	962,589	9%	13%
BLM	149,187	1%	2%
Other Public	102,780	1%	1%
Private/NGO	3,143,291	29%	------
Grand Total	10,680,037		

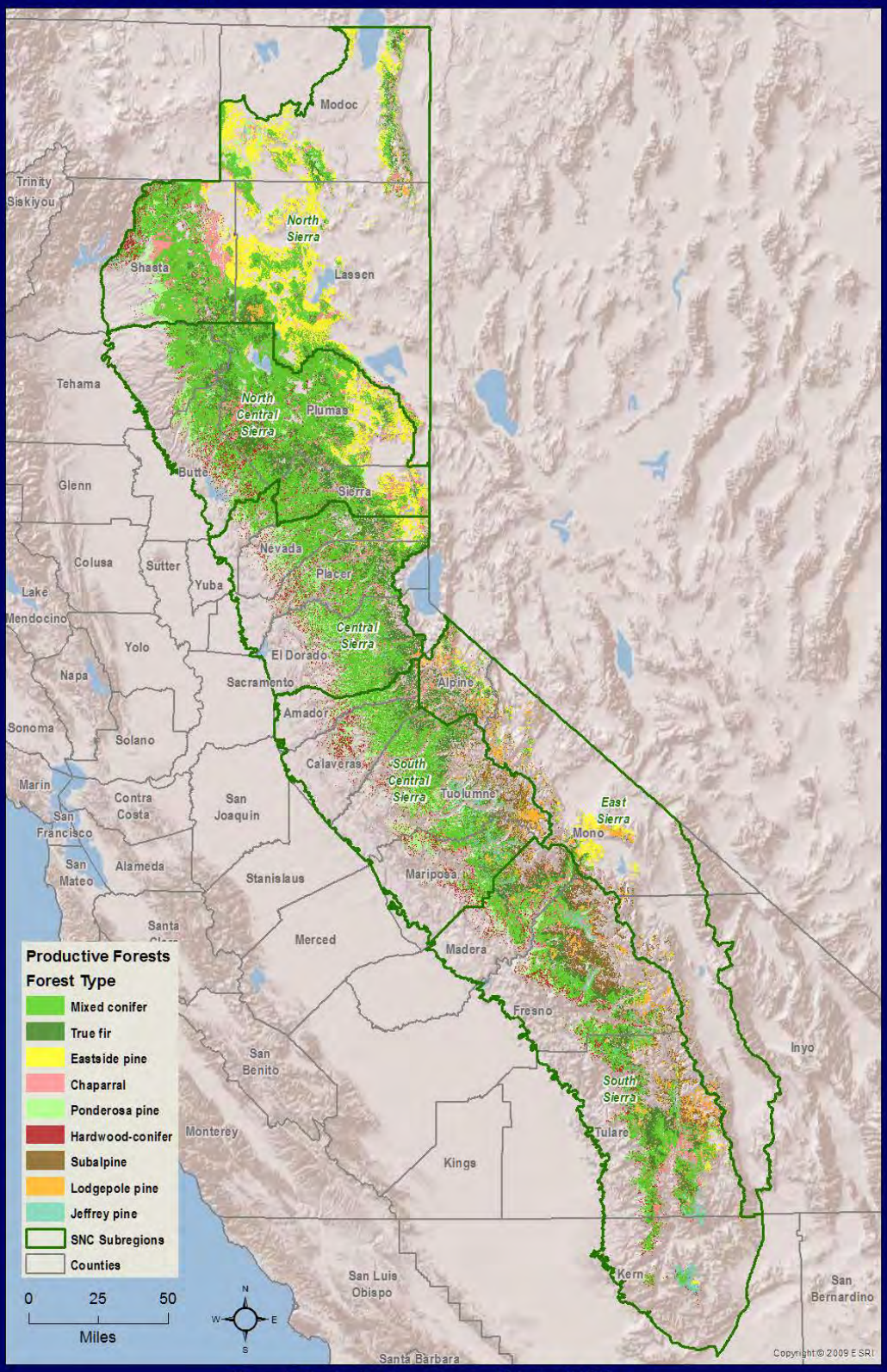

Figure 1. Productive forest types within the SNC Region

The vast majority of public forests in the Sierra Nevada are contained within eleven National Forests and four National Parks. Private forest lands are primarily found at lower elevations and in the most productive of the forest types (ponderosa pine and mixed conifer). Sierra forests are managed for multiple objectives depending on ownership and resources contained therein. Private landowners have a range of ownership goals including producing income, maintaining natural amenities and enjoying rural lifestyles (Ferranto et al., 2011). Regardless of ownership, Sierra forests are a critical source of services to the state of California and it's residents, supplying human living space, recreation, drinking water, wood products, wildlife habitat, carbon storage and myriad other benefits.

Ownership patterns vary by Subregion (see Figure 2). The East Subregion has the fewest acres of productive forestland with just over half a million acres, but the highest public ownership at 97%. The largest amount of productive forest land is in the North Central Subregion, with 2½ million acres, 68% of which is publicly owned. The South and South Central Subregions have the highest acreage of ownership by the National Park Service, with 426,000 and 443,000 acres respectively.

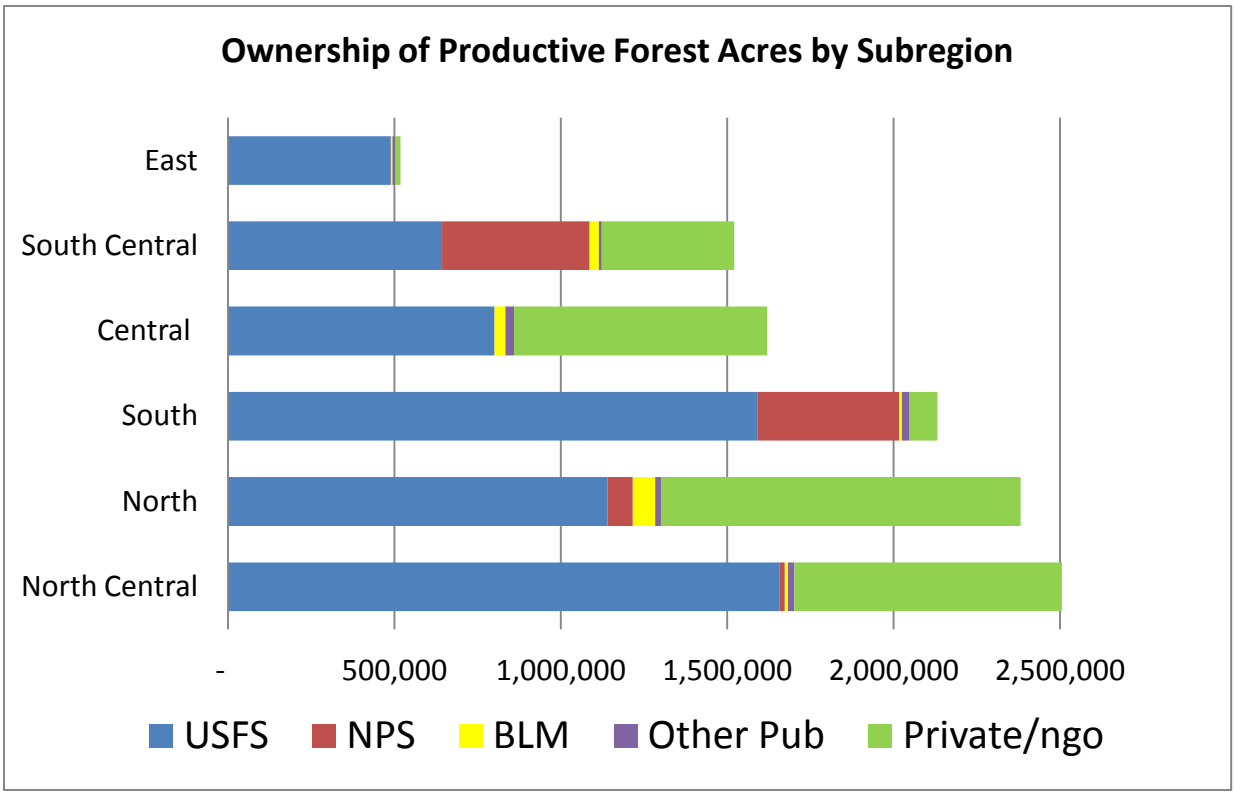

Figure 2. Acres of ownership of forest land in the Sierra Nevada Region by Subregion

Counties in the Sierra Nevada have a range of ownerships and acreages of productive forest land (see Table 5 in Appendix). Plumas and Shasta Counties have the most forested acres with about 1.4 million and 1 million acres (within the SNC Region) respectively. Lassen and Tulare Counties are next with about 900,000 acres each. Inyo, Mono, and Alpine Counties, all in the East Subregion have the most public land with 97%, 97%, and 96% respectively. Yuba, Butte, and Calaveras have the least public forest land with 39%, 37%, and 34% respectively (see Figure 3).

Although the Sierra's forest resources are diverse and abundant, the ability of these forests to supply services to California is dependent on the health and integrity of the forest ecosystem. Multiple threats to Sierra forests include an increase in scale and intensity of wildfires, a rapidly changing climate with warming and a decreased snow pack, and increased residential and urban development in forested areas.

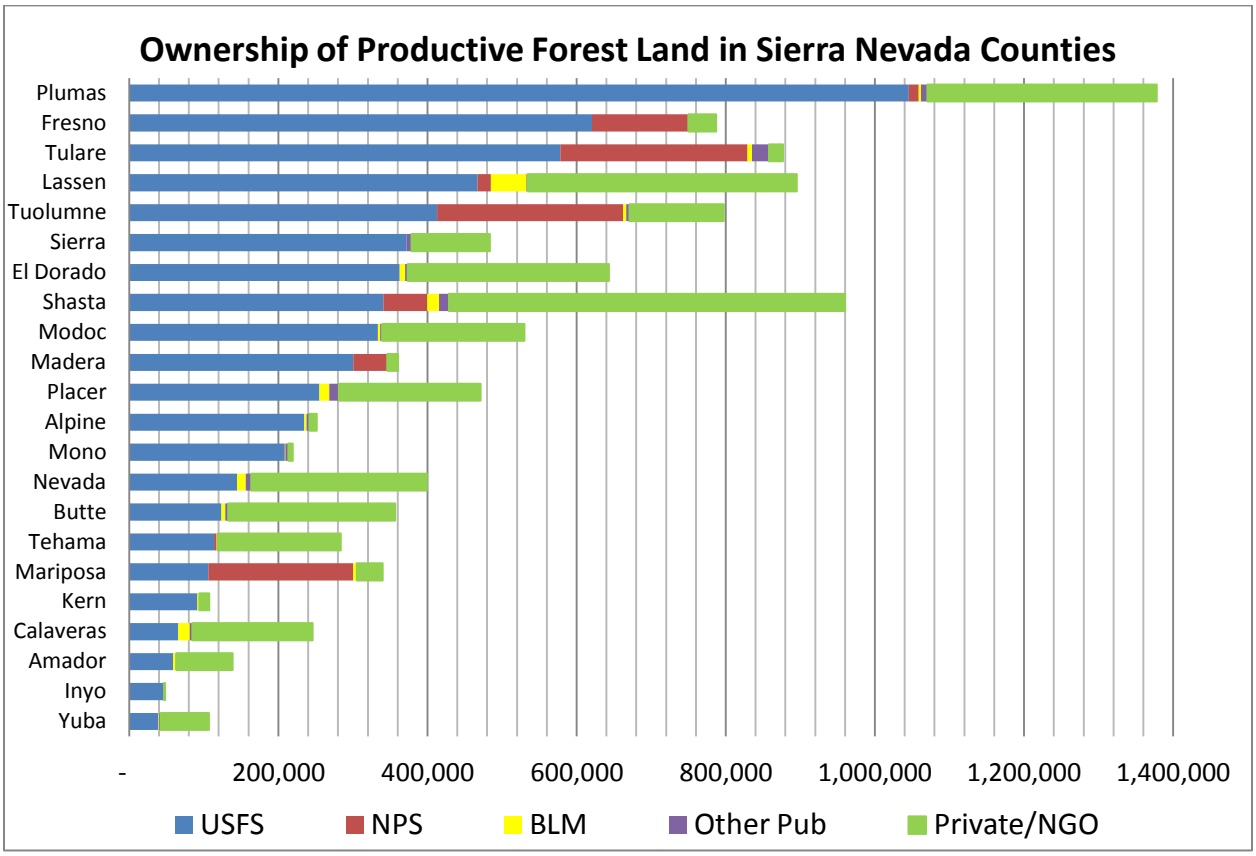

Figure 3. Ownership of productive forest land in the Sierra Nevada by county

Forest Indicators

The goal of this document is to report on the status and health of Sierra Nevada forests through a series of indicators developed from publicly available geospatial data. Indicator data presented here is collected regularly by state and federal agencies using established protocols and quality control procedures. Use of these data will allow for periodic review in the status of Sierra Nevada forests. Results from recent research on Sierra forests is included here to help inform and interpret the meaning of indicator data. Forest indicators presented here reflect different components of Sierra "forest health". Though forests are more than their individual trees, trees are the keystone species defining the forest and an examination of their health and conditions can offer much insight on the health of forested ecosystems overall.

Individual tree health can be measured by the current rate of mortality caused by wildfires, insects and disease. However, current levels of mortality may not be an indication of future levels of mortality during drought or fire. Currently healthy trees may be at risk from insects during droughts. A tree in overcrowded forests where fires have been suppressed for nearly a hundred years is at much higher risk of future mortality than a tree in a more open and resilient forest though both are currently "healthy". Lastly, climate is changing. Since current and future warming will cause new stresses on trees and forests in the Sierra, current patterns of forest health cannot be assumed to indicate future patterns.

Data presented here sheds light on insects and diseases in Sierra forests as well as the overall standing biomass contained therein. Information on the amount and type of wildfire experienced in Sierra forests is also included here as an indicator about the health of forest ecosystems.

Forest Health Indicators Related to Fire

The relationship between wildfire and forest health is a complicated one. In the recent past, fire was a profound sculptor of the entire California landscape. Frequent low intensity wildfire was the key "disturbance" mechanism shaping Sierra Nevada forests before fire suppression, mining, logging, and development started in the middle of the 19th century. Recent estimates of prehistoric fire are that between 4½ and 12 million acres burned in California every year, or about 5% to 12% of the states' lands (Stephens et al., 2007).

The exclusion of wildfire from western forests has had a number of profound ecological impacts, especially in the Sierra Nevada. Frequent fires used to consume dead wood and fuels on the forest floor and thin out the small trees in the understory. Without fire, fuels and small trees have proliferated, leading to increased stress on larger trees due to water competition, increases in tree species that are less tolerant of fire such as white fir, displacement and reduction of understory plants due to shade, displacement of deciduous vegetation by conifers, especially in riparian areas, reduction and loss of mountain meadows to conifer encroachment and reduction and loss of more open and non-forested habitats. There is also some evidence that fire suppression, by increasing moisture stress, increases a forest's susceptibility to insects and disease (Savage 1997).

Adding to the effects of fire suppression, large areas of Sierra forests were logged in rapid succession in the last century and a half, causing a new generation of forest to grow up that is of relatively uniform age and size in many areas. This combined history of impacts has led to a huge build up in forest fuels and small trees, which has in turn led to an increase in the size and frequency of high severity fires where most or all trees are killed. The average and maximum sizes of patches of high severity fire doubled in the Sierra Nevada between 1984 and 2006 from about 7 and 124 acres to 13 and 292 acres (Miller et al., 2008). Wildfires now routinely kill many large trees over larger areas than would have been the case before fire suppression. High-severity fire where all trees were killed did occur before settlement, however recent studies estimate the average size of high severity fire patches to have been only about four acres in the upper mixed conifer of the Sierra Nevada (Collins and Stevens 2010).

Fire Return Interval Departure

The change in time between fires in Sierra Nevada forests can be examined to shed light on the health of the Sierra forest ecosystem. The larger the departure from the frequency of fire under which forested ecosystems evolved, the less "healthy" the forest, because low severity fires have not been cleaning out the understory of brush and small trees. Forest managers have been conducting forest fuels treatments such as forest thinning, masticating brush, and creating fuel breaks over large areas to reduce these impacts. These treatments act as a surrogate to fire in that they mitigate a number of the ecological impacts of fire suppression. Research confirms that these treatments do indeed reduce the density of forests and so the health of individual trees without many negative side effects (Stephens et al., 2012). Fuels reduction projects have also been shown to reduce the severity of wildfires and so the likelihood of survival of trees in the burned areas (Safford et al., 2012).

Treatments have also been widely undertaken to reduce the ecological impacts described above including conifer removal from meadows and aspen stands. However, although these treatments are somewhat effective, they do not fully replace fire as the primary shaper of Sierra forests. For example, aspen restoration is most effective after fire stimulates new shoots to grow up where old trees have burned. The seeds of some rare plants need the chemical stimulus of fire to germinate and recolonize a site. Unfortunately, many of the ecological effects of low severity fire on forest ecosystem function are not well understood. Therefore, the length of absence of low severity fire from the forest can be seen as one indicator of its ecological health.

Fire return interval departure data is available for the state of California as a whole from the U.S. Forest Service and a subset was analyzed for the productive forest areas of the Sierra Nevada. The pre-settlement or "reference" fire return interval is an estimate of how often, on average, a given forest type likely burned in the three or four centuries prior to Euro-American settlement in the middle of the 19th century. Reference FRI has been determined by researchers through analysis of fire scars in tree rings in live and dead trees. Results show that forested areas previously burned every 11 years on average in the warmer and drier lower elevation forests such as ponderosa pine up to only every 133 years for sub-alpine forests where it takes much longer for fuels to accumulate and dry (Stephens et al 2007) (see Figure 4). The current fire

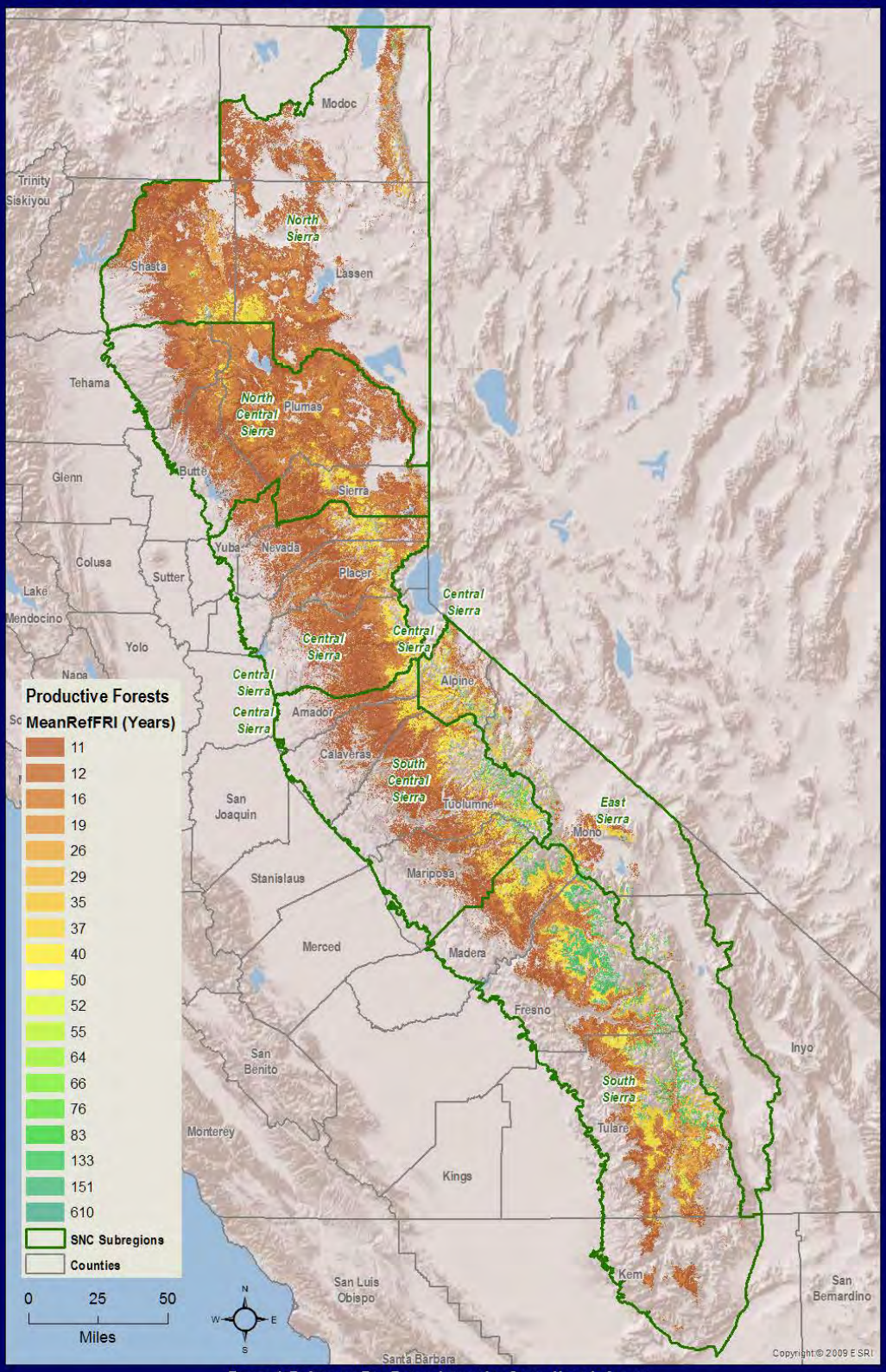

Figure 4. Reference Fire Return Interval in Sierra Nevada forests.
Average number of years between fires before fire suppression, logging and development started in the 1850's.

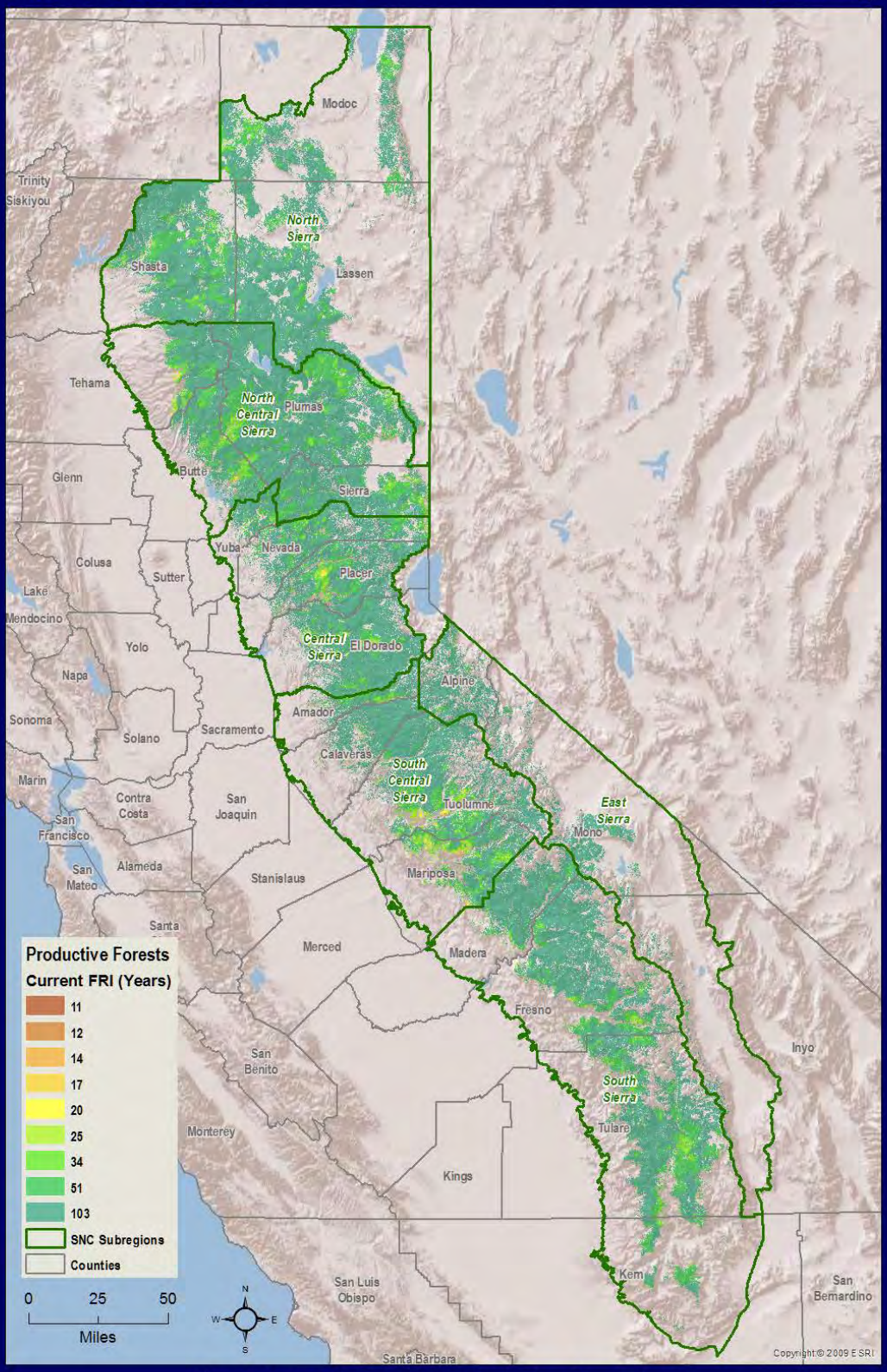

Figure 5. Current Fire Return Interval in the Sierra Nevada forests

return interval is calculated by dividing the number of years in the fire record (2010-1908=103 years) by the number of fires occurring between those dates in a given area.

Looking at Sierra forests as a whole, about 46% of the ten-and-a-half million acres would have burned at least every 12 years on average, and 76% would have burned at least every 20 years on average. This compares to less than 0.2 percent that currently burns at least every 20 years, most of which is in the National Parks, which more regularly use prescribed fire and managed wildfire (natural fires that are allowed to continue burning under suitable conditions and control) to achieve fuels reduction and forest management objectives (North et al 2012). A total of 74% of the Sierra landscape has not had a single wildfire or prescribed burn in the last 103 years (see Figure 5).

Condition Class is a measure of the extent to which fires since 1908 are burning at frequencies similar to before Euro-American settlement (a comparison between current and mean reference FRI). Classes include Class 1 where there has been up to a 33% departure; Class 2 with 33 to 67% departure; and Class 3 with more than a 66% departure from pre-settlement fire return interval. Condition classes are positive where fires are burning less often than under pre-settlement conditions, while negative classes are found where fires are burning more often. Both positive and negative Condition Class 1 are grouped together because they are both within 33% of the mean pre-settlement value.

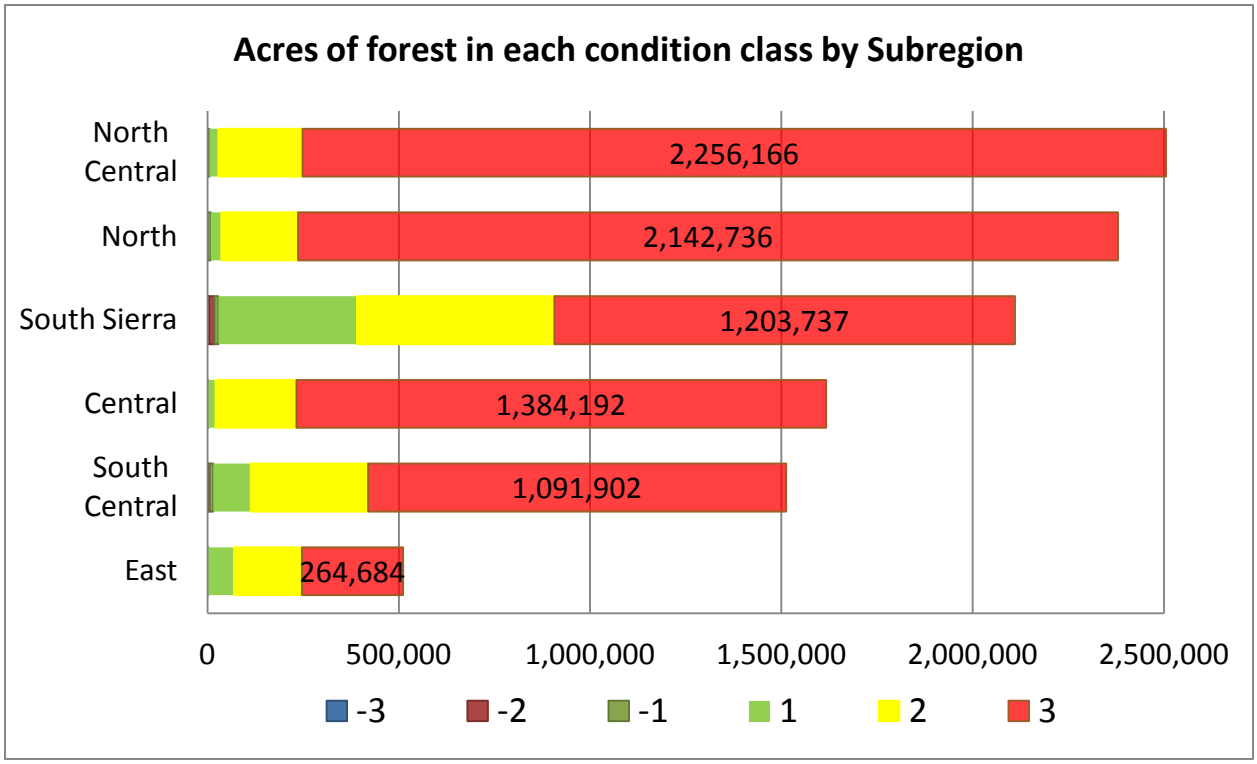

Figure 6. Acres in each fire condition class in Sierra Nevada Subregion, 2010. Class 1 has a 33% departure; Class 2 has a 33 to 67% departure; and Class 3 has more than a 66% departure from pre-settlement fire return interval. Fires burn less often in positive condition classes than under pre-settlement conditions, while fires burn more often in negative classes.

Seventy-eight percent of the productive forests in the Sierra are in Class 3, 15% are in Class 2 and 6% are in Class 1. The Subregions of the Sierra with the highest percentage of forests in Class 3 are the North and North Central Sierra, each with 90%. The Central and South Central Subregions have 85% and 72% in Class 3 respectively. The South and East Subregions have the smallest percentages of forest areas in Class 3 at 56% and 51% respectively (see Figure 6).

The ownership with the lowest percentage of acres in Class 3 is the National Park Service where many years of prescribed burning have re-introduced fire into forests. NPS lands are also more likely to be at higher elevations where fires were less frequent so they are not as far "behind" in years in which burns would have happened under a natural fire regime (North et al., 2012). The U.S. Forest Service is second with 75% of their Sierra forest acreage in Class 3. Private landowners have 98% of their forests in condition class 3 (see Figure 7).

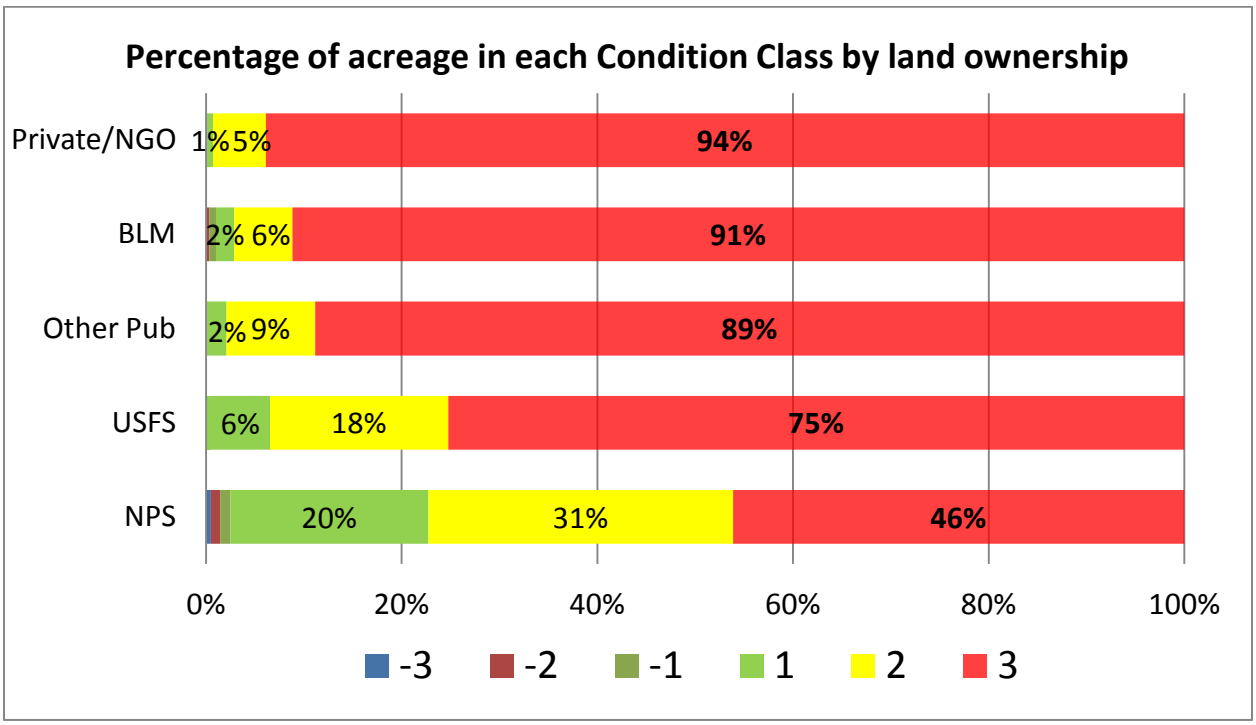

Figure 7. Ownership of Sierra Nevada forests by fire condition class.

Severe Wildfire Threats to Ecosystems

Although Sierra Nevada forests evolved under a regime of frequent low severity fire, wildfires today typically burn at higher severity over larger areas, meaning that most if not all, of the trees are killed (Miller et al., 2008). High severity fire, burning over a large area, threatens the ecosystem services provided by forests including drinking water, soil stabilization, wildlife habitat and recreation. So, although lack of fire can be seen as an indicator of lack of forest heath, too much high severity fire kills many trees and causes other dramatic negative impacts on forest ecosystems.

Data about severe wildfire threats to ecosystems in California was assembled by the CAL FIRE Fire and Resource Assessment Program (FRAP) in 2010 (CAL FIRE 2010). CAL FIRE identified ecosystems where the threat of high severity wildfire to ecosystem services is highest and classified them into low, medium, and high priority landscapes for addressing the threats. These areas were identified as locations where treatments to reduce fire impacts such as fuels reduction through prescribed fire, mechanical thinning, grazing and other approaches were needed. These types of treatments have been shown to effectively reduce the severity of fire and so, the impacts to forested ecosystems (Safford et al., 2012).

CalFire identified Sierra mixed conifer forests as the ecosystem with the largest area of high priority landscape of any in California, with 3.7 million acres. Within Sierra Nevada forests, almost 5½ million acres, or half the total acreage, was classified as high priority for treatment to prevent severe wildfire threats to forest ecosystems (see Figure 9).

Within the Sierra Nevada, the North Central Subregion had the most high priority acres with 1.6 million, followed by the North Subregion with about 1.5 million. The South and South Central Subregions had about half that much. The East Subregion had very little forest area where ecosystems were prioritized for action to relieve the threat of severe wildfires (see Figure 8).

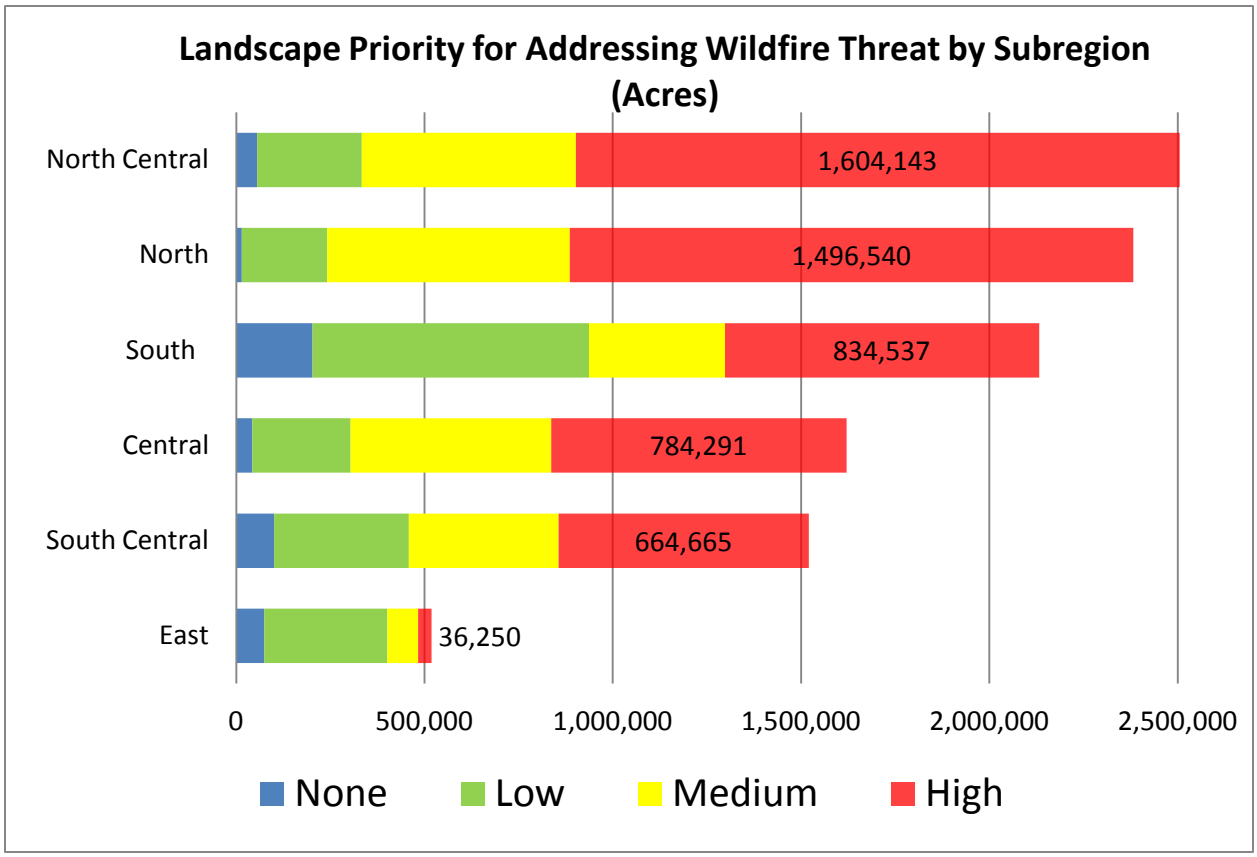

Figure 8. Landscape Priority for addressing severe wildfire threats to ecosystems for each Subregion

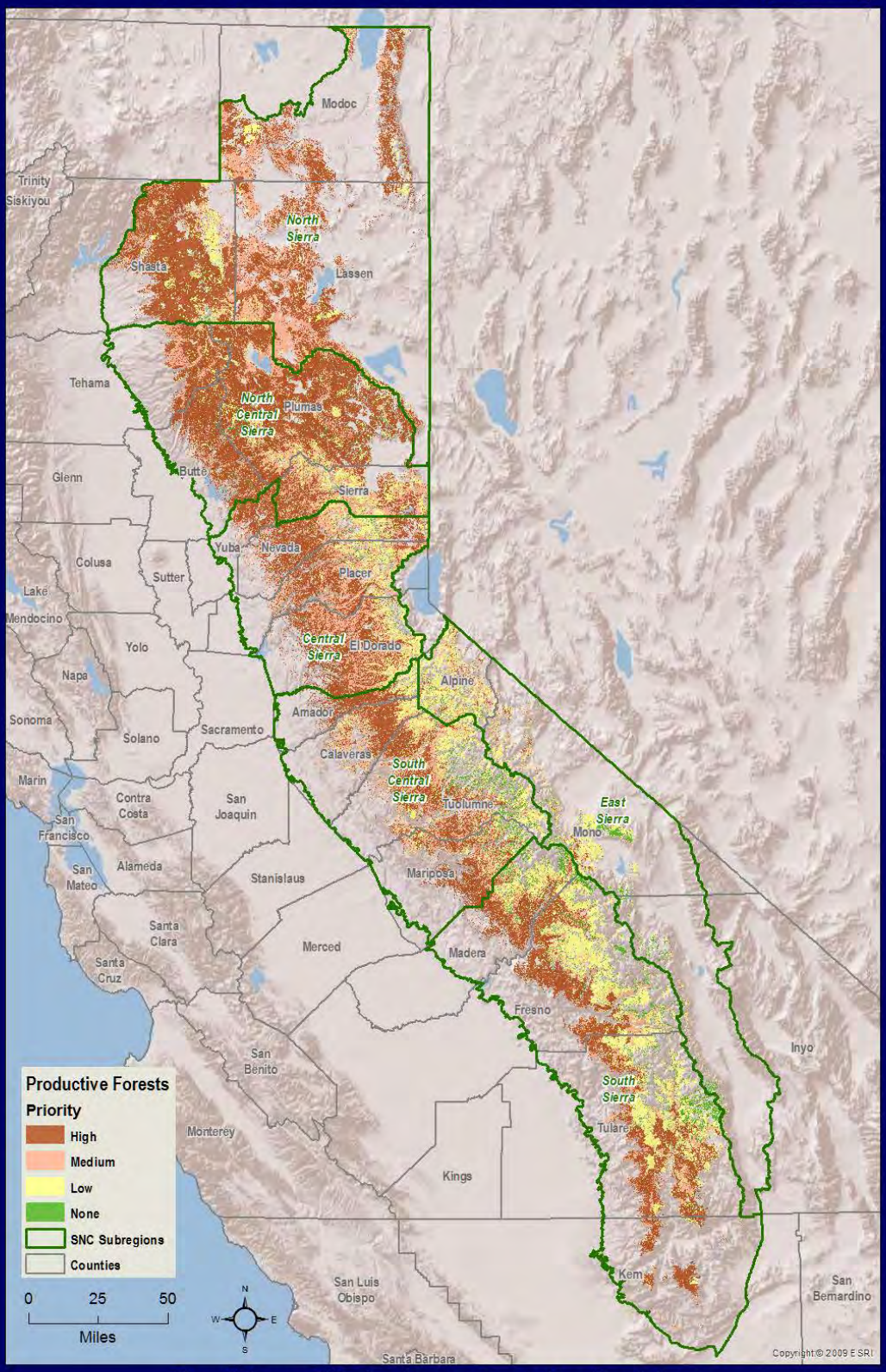

Figure 9. Severe wildfire threat to ecosystems in Sierra Nevada forests

The National Park Service, again, has the lowest percentage (25%) of its acres in high priority for addressing severe wildfire threat (see Figure 10). The U.S. Forest Service is second with 48% of its acres rated as high priority. Other public agencies including the Bureau of Land Management, private landowners and NGOs all have around two-thirds of their acres in High Priority status.

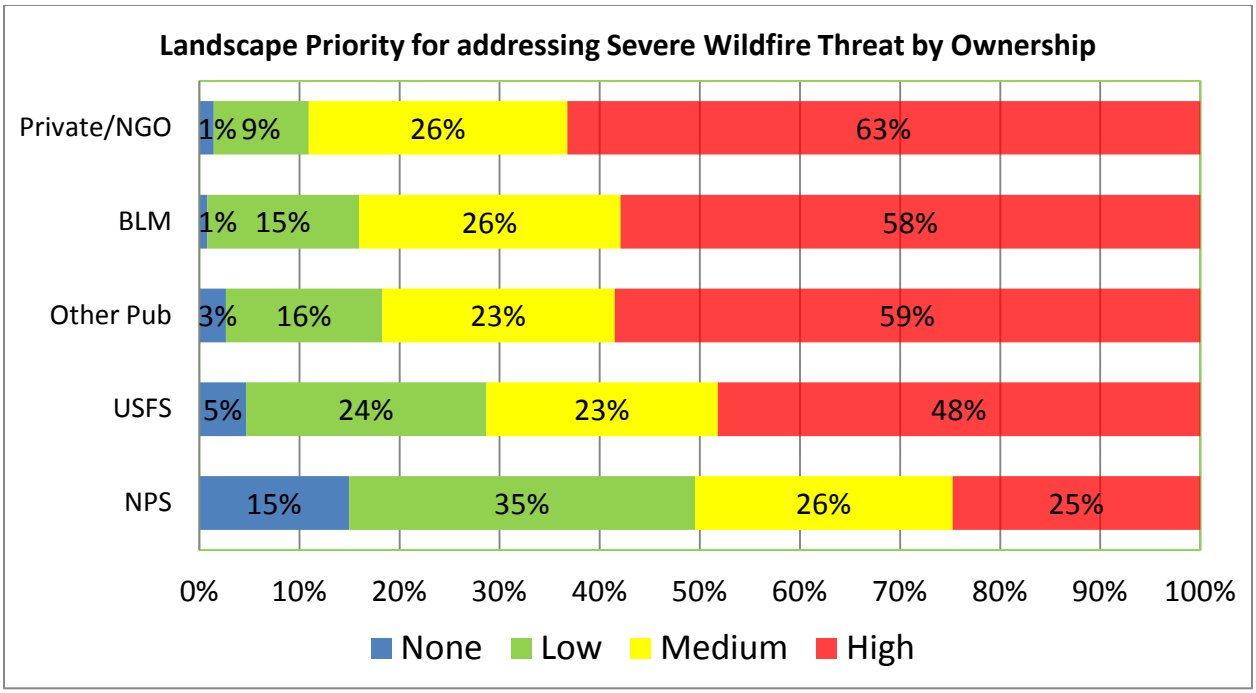

Figure 10. Landscape priority for addressing wildfire threats to ecosystems for different ownerships

CAL FIRE did an additional analysis to identify watersheds where a high percentage of the landscape is at risk for damage from severe wildfires. The Sierra Nevada Region data is shown in Figure 12. High severity fire can have dramatic impacts on watershed function, including increasing the volume and likelihood of increased sediment delivery. Fires consume the litter layer, exposing soils to erosive precipitation and killing plants whose roots give the soil strength to avoid slumps. The larger the area within a watershed that is threatened by high severity fire, the greater the concern.

The Subregions with the highest threat to watersheds are the North and North Central Subregions, with an average percentage of watersheds threatened of 63% and 64% respectively (see Figure 11).

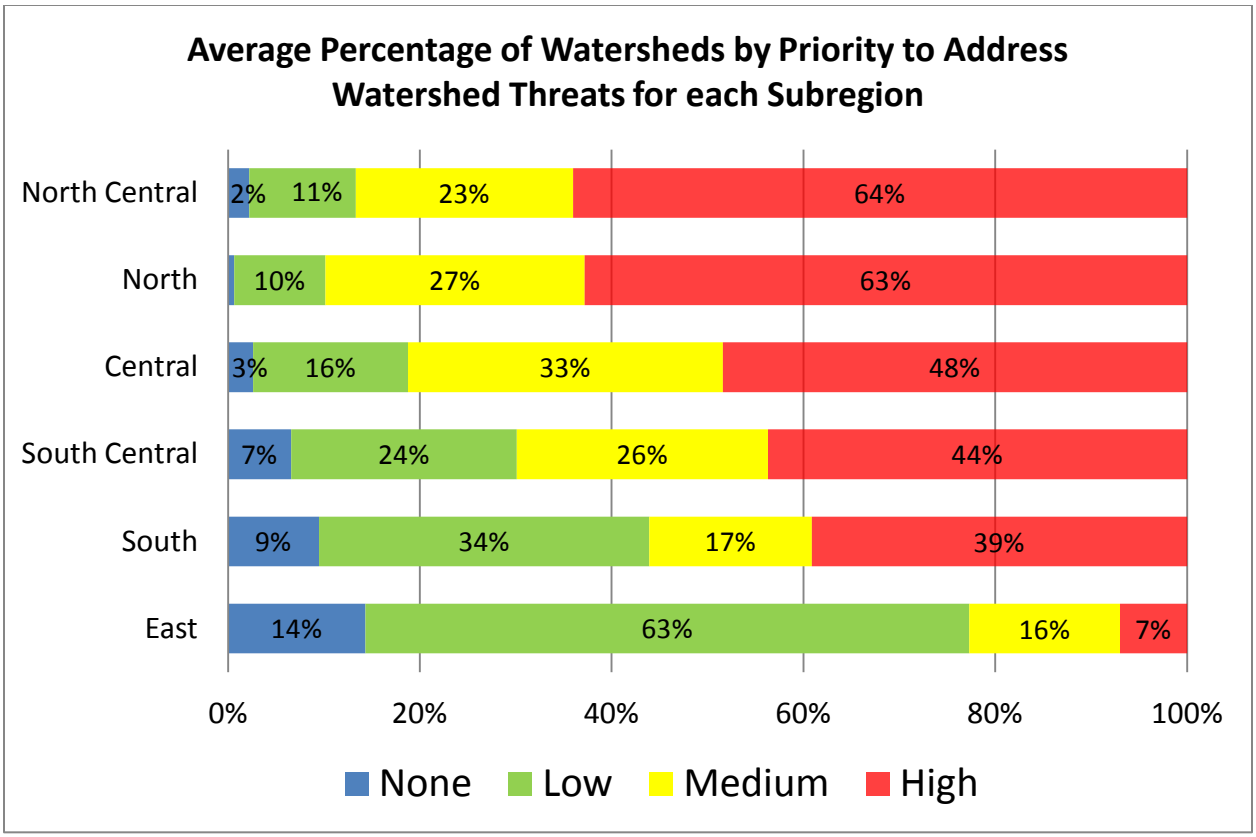

Figure 11. Average percentage of watershed by Subregion in each priority to address severe wildfire threat

Watershed areas which have already withstood wildfire damage to their ecosystems and so are at high priority for restoration of their forests were identified by CAL FIRE (see Figure 13.) The Sierra Nevada watersheds with the highest percent of forested areas to be restored are found in the North Central Subregion. The Butte Creek Watershed in Butte County and the East Branch of the North Fork Feather River in Plumas County had 10% and 9% of their area in high priority to restore damage from wildfire damaged ecosystems during the 2010 assessment. Significant areas of the Feather River Watershed have burned since this assessment was completed.

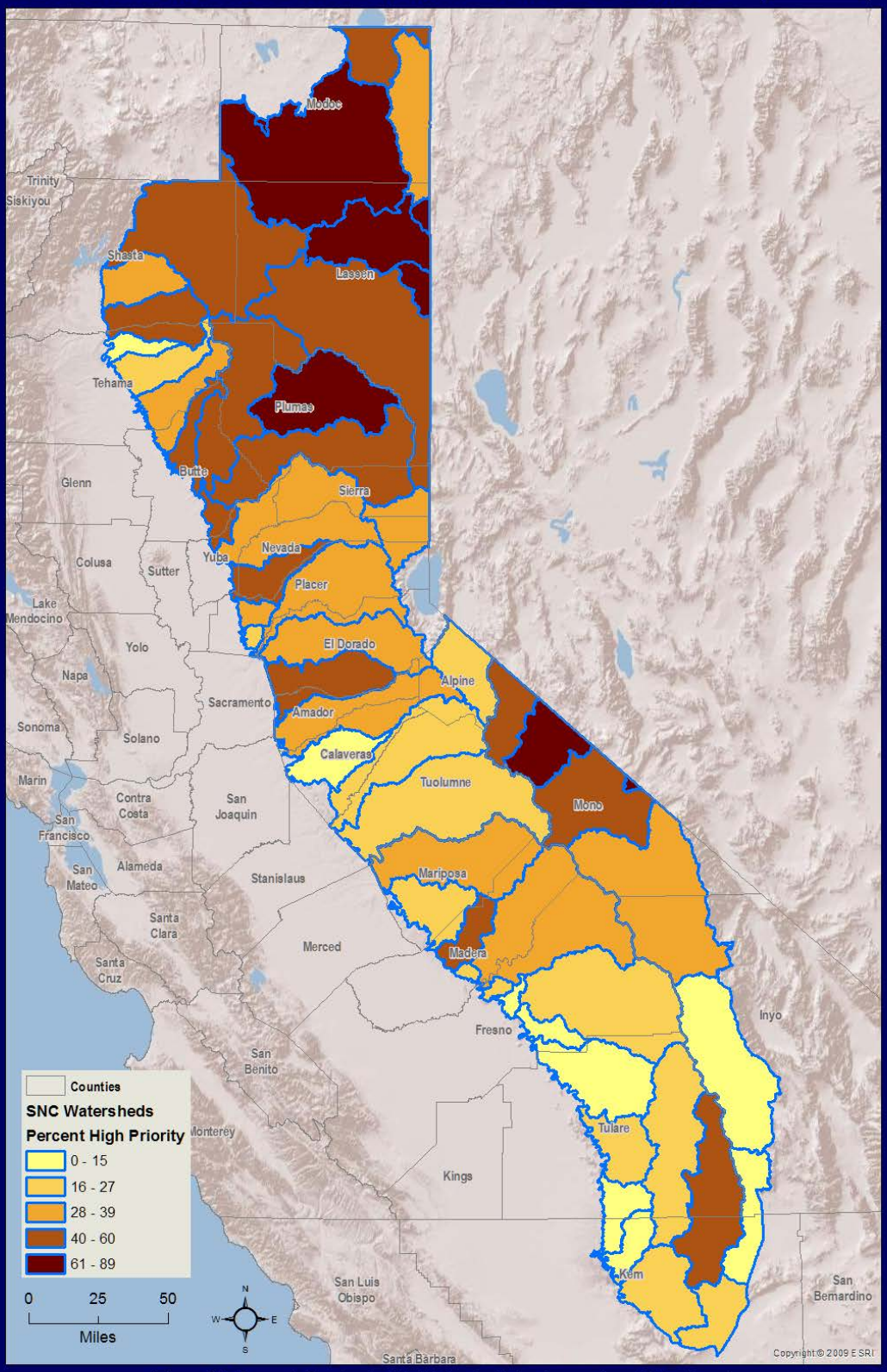

Figure 12. Percent of watershed in high priority landscape for wildfire threat

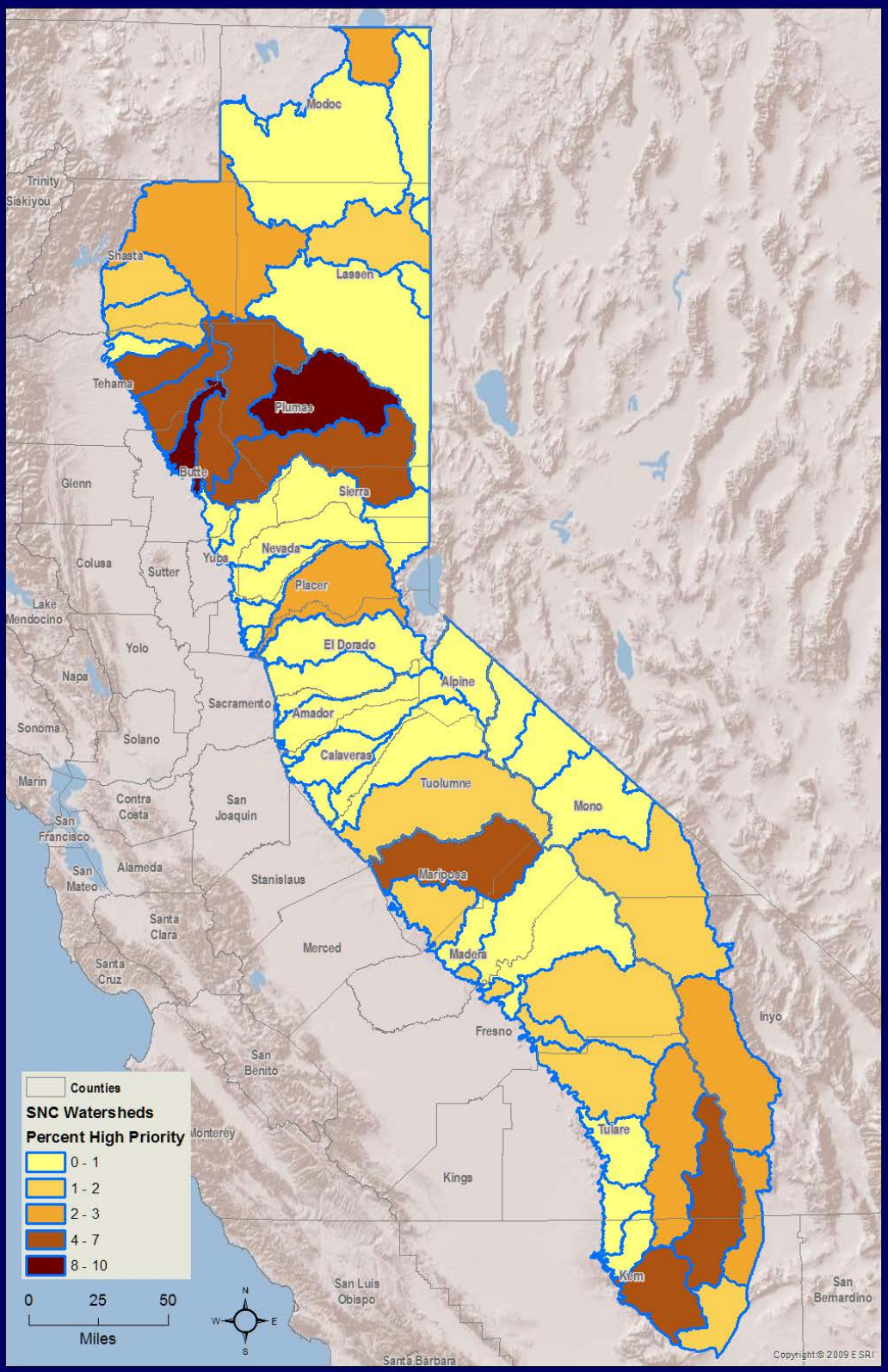

Figure 13. Percent of watershed in high priority landscape for restoration from wildfire

Forest Health Indicators Related to Pests

Like wildfire, insects and diseases are a natural and necessary part of Sierra forest ecosystems. Insects that kill trees also prey on other insects and provide food for wildlife. Tree diseases and rots speed decay of wood back into nutrients for the next generation of trees. Tree mortality from insects and disease (together known as forest pests) is usually localized, affecting only a few trees in a small area. However, epidemic levels of mortality occasionally occur as happened in the large numbers of Southern California trees killed by drought and insects in the late 1990s (Christensen et al., 2008).

Insects typically kill trees that are weakened by other stressors such as lack of moisture, sunlight, nutrients or growing space. Bark beetles gain entry to trees by boring through bark where females lay eggs in tunnels excavated beneath the bark. This disrupts the conductive tissue below the bark and eventually kills the tree once it is girdled. Trees respond to beetle attacks by sending pitch to the entry wounds to try to push the beetles out. Trees that are stressed are less able to respond and so more likely to succumb and die.

Forests typically experience background levels of tree mortality from pests until large scale stressing events such as drought or wildfire weakens large numbers of trees, enabling pests to cause epidemic levels of mortality over large areas. The background rate of tree mortality is generally considered to be about 1% a year (van Mantgem and Stephenson 2007).

However, there is evidence from research in the Sierra and across the West that the background rate of tree mortality has been increasing. One study conducted using a network of old-growth forest plots in the Sierra found that tree mortality due to forest pests and stress increased on average by 3% per year, meaning that the rate nearly doubled between 1983 and 2004, from about 1% a year to about 2% a year (van Mantgem and Stephenson 2007). Researchers found that both pine and fir trees had a similar increase in mortality. They suggested that the primary cause is increased drought stress due to increases in temperature as a result of climate change. Mortality increased regardless of elevation, tree density or competition.

Warming is thought to contribute to increasing mortality by increasing drought stress on trees while at the same time stimulating the growth and reproduction of insects and pathogens that attack trees. Warming is thought to have played a key role in recent large episodes of forest dieback elsewhere in Western North America (van Mantgem et al., 2009). Researchers suggest that Sierra and other water-limited forests “are sensitive to temperature-driven drought stress, and may be poised for die-back if future climates continue to feature rising temperatures without compensating increases in precipitation” (van Mantgem and Stephenson 2007, page 914).

Forest Pest Impact and Threat to Ecosystems

Data from forest pest threats to ecosystems in California has been assembled and published by CAL FIRE (CAL FIRE 2010). They identified ecosystems where the current impact and future threat from forest pests to ecosystem services is highest and classified them into low, medium,

and high priority landscapes for addressing the threats. CAL FIRE found over 6 million acres impacted by forest pests in California. Sierra mixed conifer forests were identified as the most impacted forest type in the state with over 1.7 million acres, or 36% of the forest identified for restoration to mitigate impacts of past damage. In the Sierra Nevada, almost 1.2 million acres were identified as high priority areas for restoring lands impacted by pests (see Figure 15). Seventy-six percent of priority landscapes are on lands managed by the U.S. Forest Service (USFS) and 17 percent are on privately owned lands.

CAL FIRE also prioritized the forested areas where action to reduce future forest pest impacts is needed (see Figure 16). Actions could include removal of dead and dying trees near community infrastructure, removal of live vegetation at risk due to being next to dead or dying trees, and removal of soil harboring pathogens. Other actions could include education and outreach to land owners and forestry assistance programs. Over one million acres of Sierra forest not yet significantly impacted by pests are identified for some level of need to prevent future pest infestation, with over 227,000 acres identified as high priority. Of the forest land identified as high priority for preventing pest outbreaks, 75% was USFS and 14% was private (see Figure 14).

Altogether, Forest Service land contains almost 1.1 million acres of high priority areas to treat for pest impacts or pest prevention, over 10% of its ownership. Privately owned land has 236,000 acres of high priority area identified for impact or prevention treatment.

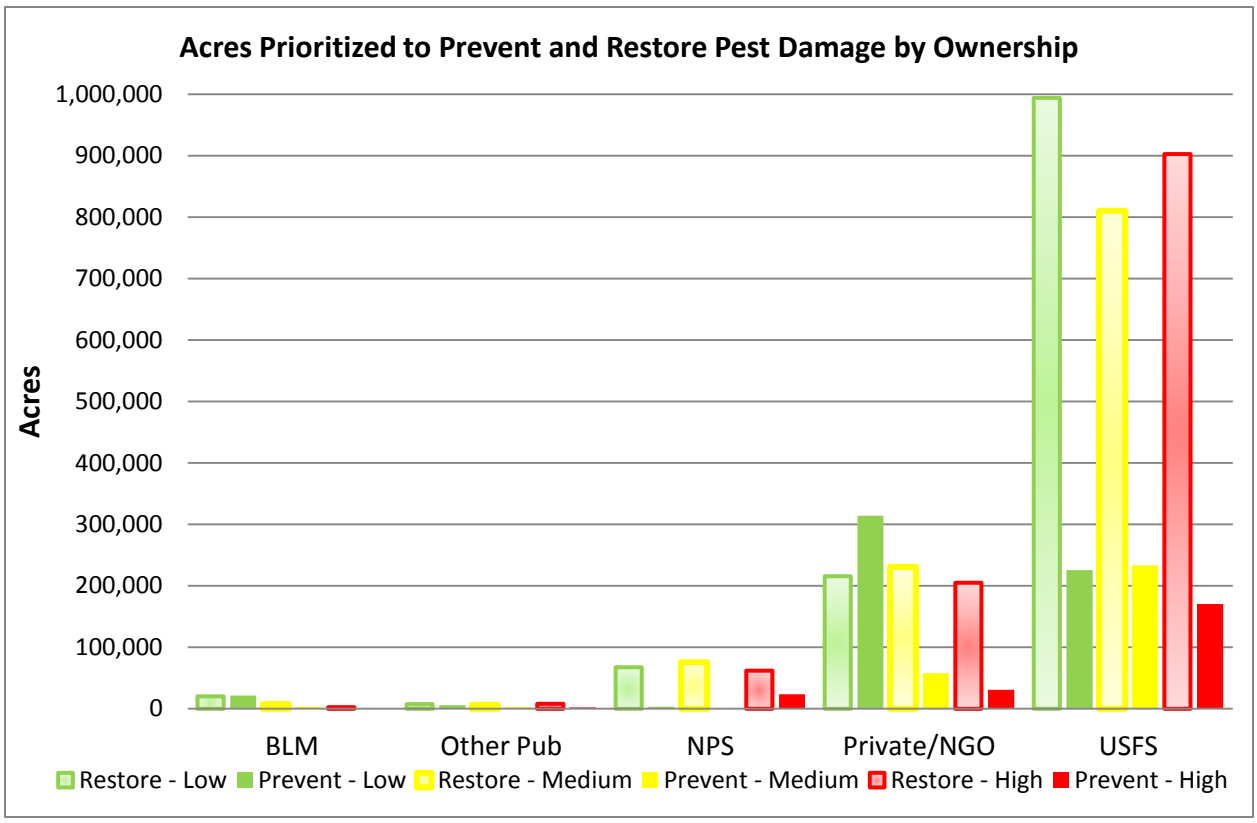

Figure 14. Acres prioritized for prevention and restoration of pest damage by landowner

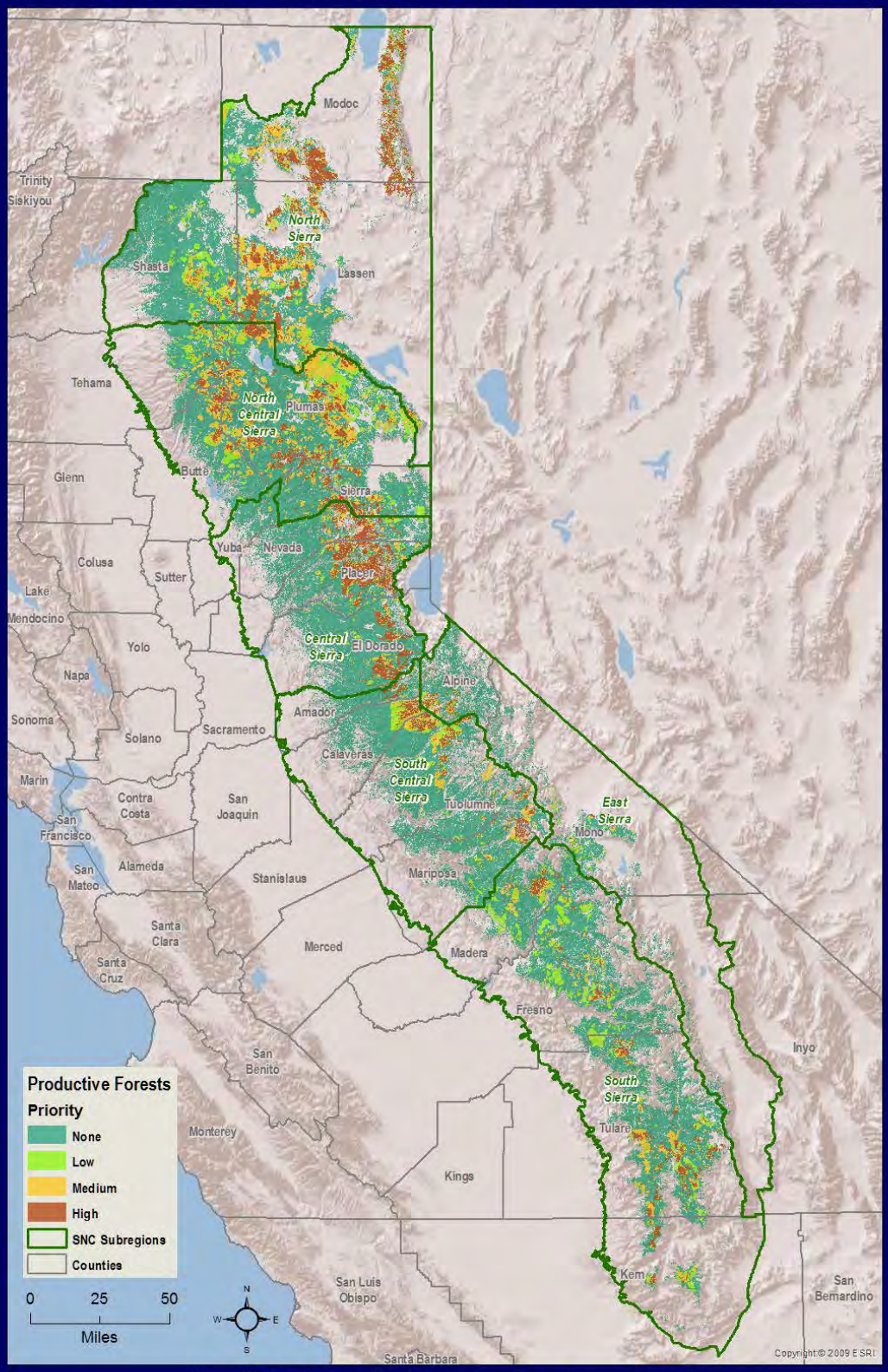

Figure 15. Priority forest lands for treatment to restore pest impacts

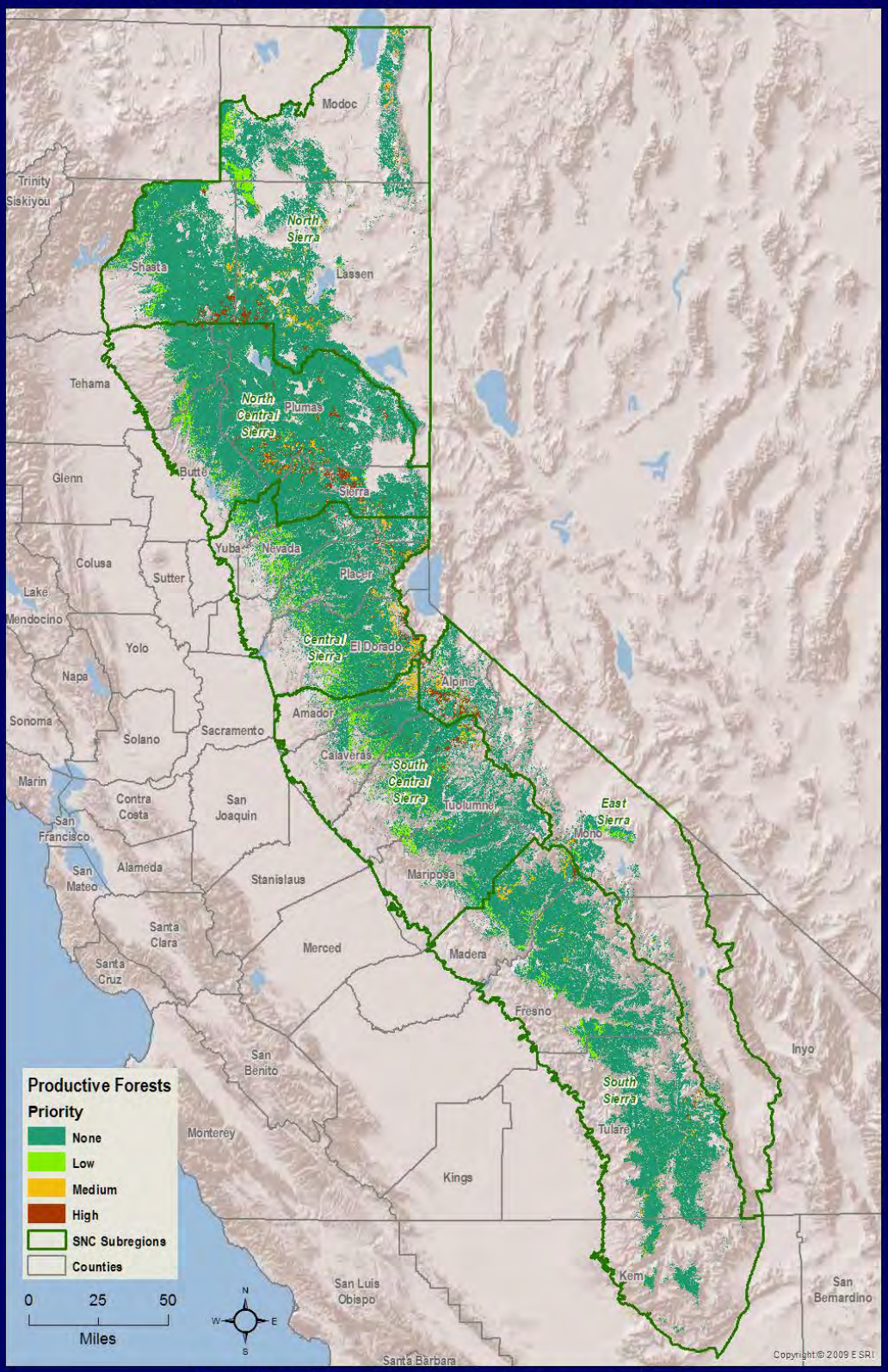

Figure 16. Priority forest lands for preventing future pest outbreaks

Forest Pest Impact and Threat to People

When they cause epidemic levels of mortality, forest pests have a disruptive influence on human communities. Dead and dying trees can fall and block major transportation routes, hit power lines (sometimes starting fires), or crush structures. An estimated 3.5 million trees died due to the combined effects of drought and insects between 1998 and 2003 on forest land in the counties of San Bernardino, Riverside, San Diego, and Los Angeles. The overall mortality rate for conifers over this period was 13% (Christensen et al., 2008). This mass die off spurred coordinated efforts from land management and regulatory agencies to remove over 1.5 million dead trees. This effort cost $225 million over three years (CAL FIRE 2010). CAL FIRE has the authority, with the approval of the California Board of Forestry and Fire Protection (BOF) to declare a Zone of Infestation for native and exotic insect and disease pests. This enables them to go on private lands to attempt pest eradication or control. In 2010 there were Zones of Infestation declared for bark beetles in the Lake Tahoe basin and the Southern California Mountains.

The amount of forest pest damage in the Sierra, though notable, has not reached the scale of impacts found elsewhere such as the Southern California Mountains. Areas of high priority are small and localized. The five communities in the Sierra Nevada with the most acres needing mitigation to restore pest damaged forests are all found at elevations above 4,900 feet (see Table 2). Truckee in Nevada County has the most acres of high priority for action to protect public safety with 550, comprising 3% of the acres within the community. Bear Valley in Alpine County has fewer high priority acres to treat at 263, but this makes up 8% of the community's acres (see Figure 17).

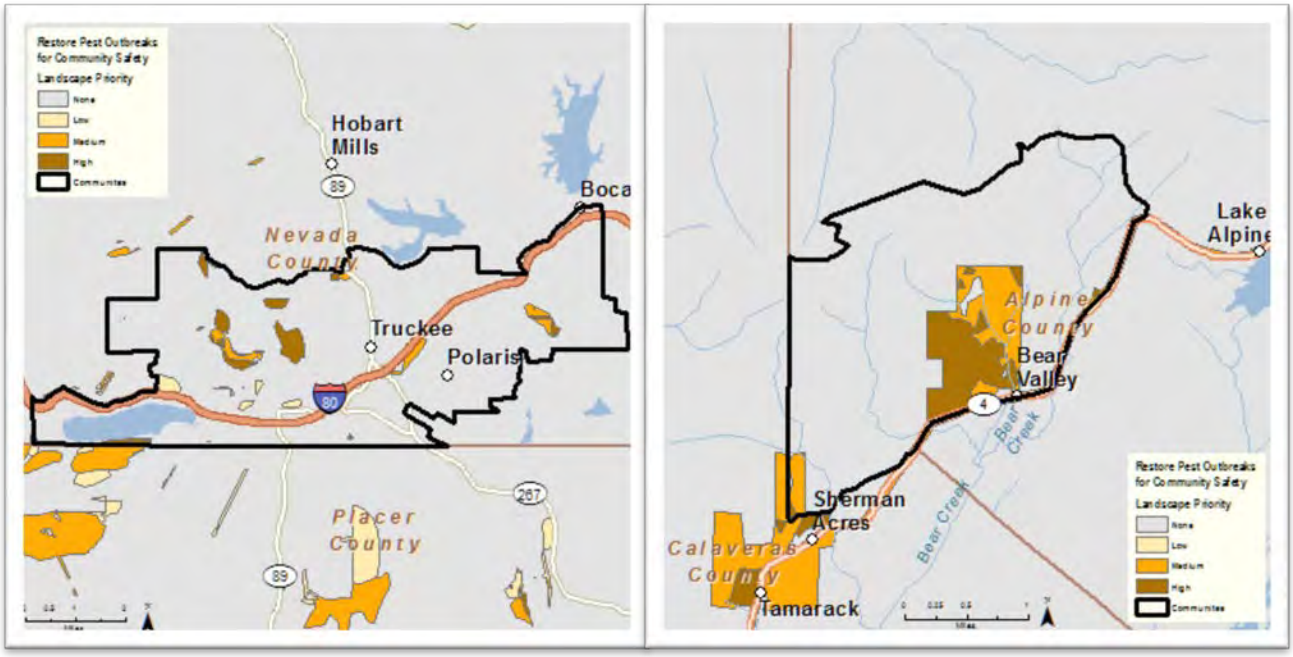

Figure 17. Community acres prioritized for restoration of pest damage for community safety

Table 2. Top five communities with high priority landscape area for restoring forest pest impacts for public safety

Community – County Population Elevation (feet)	Priority Landscape Acres Percentage				Total Community Acres
	None	Low	Moderate	High	
Truckee – Nevada 16,000 5817’	20,510 95%	172 1%	317 1%	550 3%	21,550
Bear Valley – Alpine 120 7100’	2,768 84%	7 0%	272 8%	263 8%	3,310
Plumas Eureka – Plumas 320 6014’	2,327 92%	45 2%	103 4%	50 2%	2,526
Mineral – Tehama 120 4918’	27,976 98%	397 1%	69 0%	29 0%	28,470
Shaver Lake – Fresno 630 5627’	21,459 97%	493 2%	206 1%	22 0%	22,180
Grand Total	878,258	3,768	2,253	1,019	885,297

Forest Biomass and Carbon Storage

Carbon is a major constituent of life on Earth, forming an essential component of fossil fuels, vegetation and complex molecules in animals. Forest ecosystems actively participate in the 'carbon cycle' in many ways. Trees take in carbon dioxide, use the carbon molecules to form their woody structure and release the oxygen to the atmosphere where it is breathed in by animals. Trees die, decay and release carbon dioxide back into the atmosphere. Carbon is stored in dead wood on the forest floor and also leaches into the soil, as rain and snow soak dead leaves on the forest floor and then soak into the ground. Carbon dioxide is emitted when forests burn and later when trees killed by pests and fire start to decay. Carbon based fossil fuels are expended to power heavy equipment used to harvest and transport wood products. Those wood products in turn store carbon for decades or centuries in some cases. Woody byproducts from forests are burned to generate electricity which substitutes for carbon in fossil fuels that would have otherwise been used.

The storage of carbon by forests has received increased attention in recent years because of the realization that forests play a critical role in stabilizing large amounts of carbon in the global carbon cycle. There is a growing scientific consensus that the amount of carbon dioxide in the atmosphere has drastically increased since the industrial revolution, changing climate patterns and leading to warming in the Sierra Nevada and California as a whole. As a result, many people are now interested in developing methods to maintain and increase the amount of carbon stored in forests to slow down the increase in carbon in the atmosphere.

The amount of carbon stored in forests is estimated from actual tree measurements. The total living weight of trees in a forest is about half water. The other half is called biomass. Biomass is generally considered to be an indicator of the productivity of the ecosystem. The more productive the forest ecosystem, the higher the biomass that can be found there. Forest biomass is about half carbon. The other half is made up of other elements necessary for tree health and function. Current estimates of forest biomass are based on the weight of above ground living tree matter (minus the half that is water) calculated by using forest inventory data. Carbon is then estimated by halving the amount of biomass per unit area, and is usually expressed in short tons per acre.

The current methods of estimating carbon in forests are not very precise, in part because information on the amount of carbon stored by forest soils is not widely available. Forest soils store carbon as one of a number of 'pools' which also include live and dead trees, forest litter and fuels. More carbon is actually stored in soils in Northern Canadian forests than in the standing live and dead trees. This is because cold causes vegetation to decompose very slowly leading to large areas of carbon rich soil and peat bogs. Conversely, tropical forests store very little carbon in the soil because warm and moist conditions cause organic matter to decompose very quickly. In these tropical systems, most carbon is stored as standing biomass. Carbon stored in Sierra soils is in between these two extremes.

A recent estimate made by looking at data from trees, snags, soils and litter in over 1,100 forest stands (Stewart et al., 2011) suggested California mixed conifer forests store about 107 total

tons of carbon per acre. Only half the stored carbon is found in trees while 21% is contained in the soil (see Table 3).

Table 3. Average distribution of forest carbon in tons per acre for mixed conifer forest

Forest Component	Live tree	Soil	Forest floor	Dead/ Down	Dead tree	Under story	Total
Tons of carbon per acre	55	22	17	8	5	1	107
Percent of total carbon per acre	51%	21%	16%	7%	4%	1%	100%

The U.S. Forest Service Forest Inventory and Analysis (FIA) program has developed a spatially explicit dataset of above ground live forest biomass made from measured forest inventory plots for the United States (Blackard et al., 2008). The data was developed by combining FIA plot data and Moderate Resolution Imaging Spectrometer (MODIS) derived image composites and other information into ecologically similar mapping zones for forests of the United States. A subset of data on forest biomass (about half of which is carbon) for the Sierra Nevada was analyzed here. Measurement of below ground biomass was not done, meaning that these estimates are incomplete.

The total above ground biomass accumulation of all productive forests in the Sierra Nevada was almost 840 million tons (see Table 4). About 62% of this forest biomass was owned by the U.S. Forest Service, which is only slightly more than their percentage of Sierra forest land ownership (60%). Concentrations of biomass ranged from very low to over 700 tons per acre in a few isolated giant Sequoia groves in the South Central and South Subregion (see Figure 18).

Table 4. Above ground biomass in the Sierra by ownership

Ownership	Biomass tons (American short tons)	Percent of Total Biomass	Percent of Total Acres
USFS	519,427,710	62%	60%
Private	225,744,095	27%	28%
Other public	93,341,550	11%	11%
Total	838,513,355		

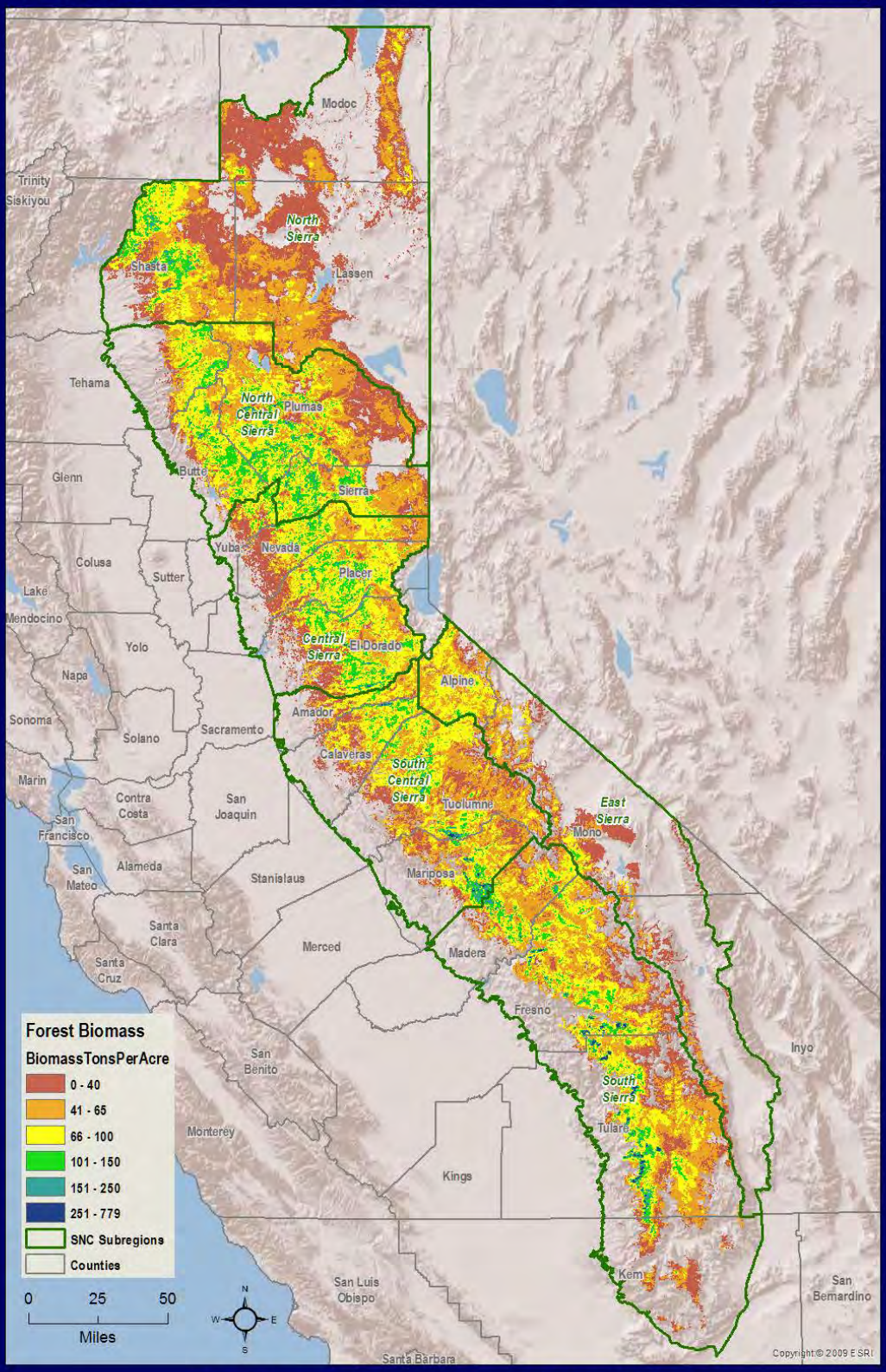

Figure 18. Tons of standing forest biomass within the SNC Region

The highest concentration of forest biomass was found in the North Central Subregion where over a quarter of the biomass in the Sierra Nevada is found, with about two thirds of that being publicly owned (see Figure 19). The lowest concentration of biomass was in the East Subregion with only about 4% of the Sierra total, of which 97% was publicly owned.

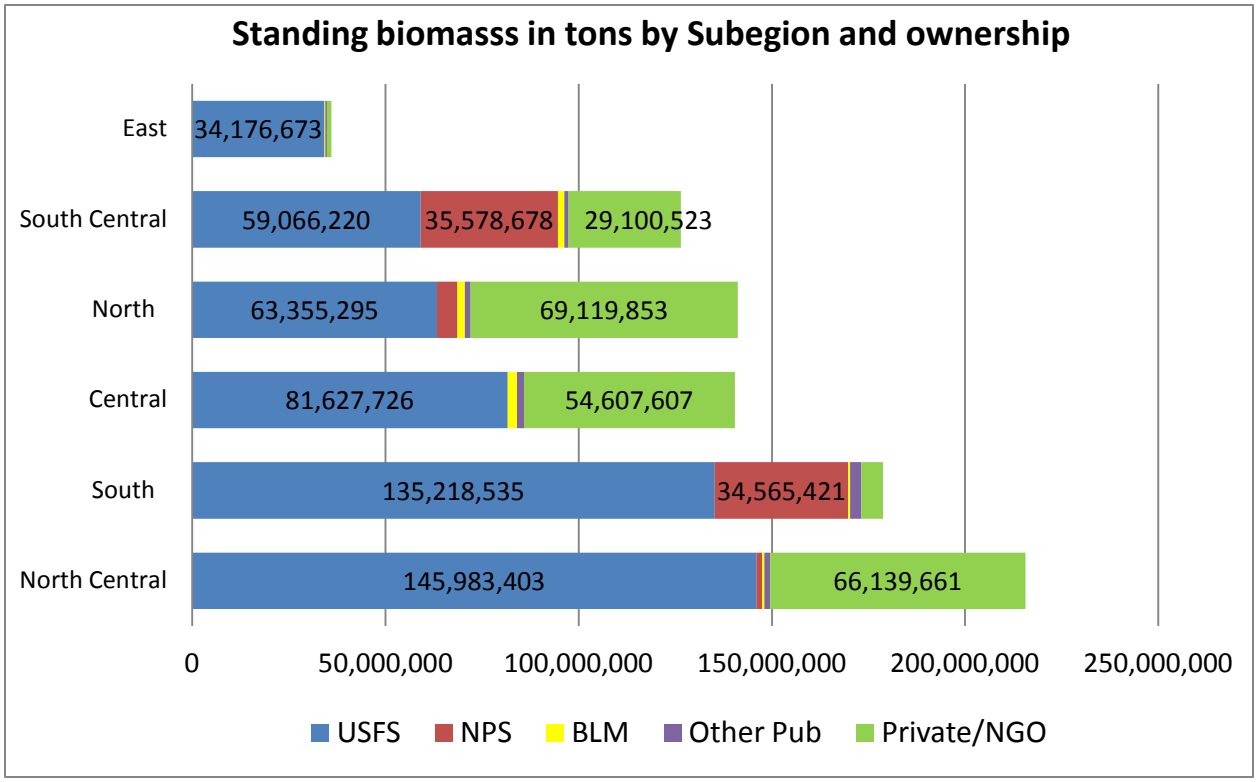

Figure 19. Standing biomass in Sierra Nevada forests

Biomass averaged about 80 tons per acre across all forest types though this included a wide range of values from about 30 tons per acre for pinyon-juniper forests to an average of 94 tons per acre in mixed conifer forests. Just over half of the standing biomass was found in the mixed conifer forest type (see Figure 20).

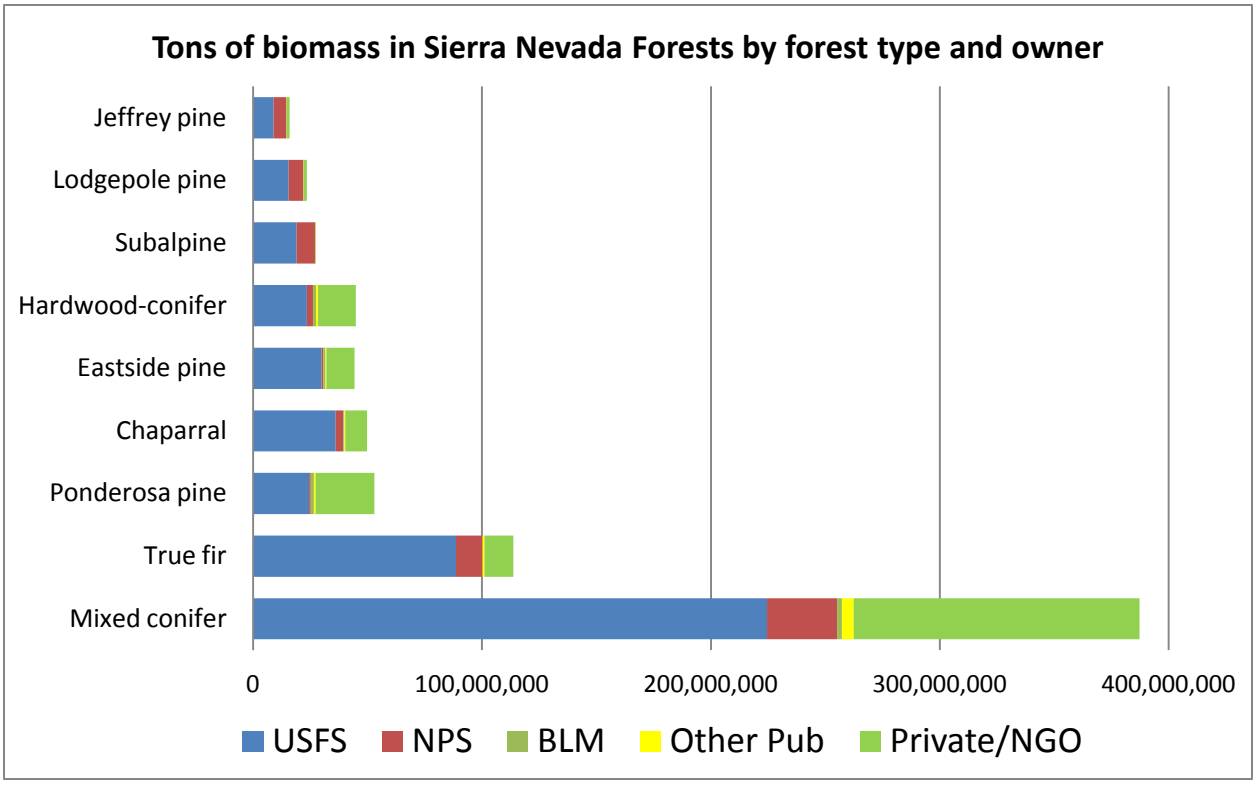

Figure 20. Tons of Biomass in Sierra Nevada forests by forest type and owner

Since the calculation of standing forest biomass has only been done once to date using FIA data, there is no data available on the trends in biomass storage in Sierra Nevada forests. However, recent statewide trends may be extrapolated to the Sierra. CAL FIRE's 2010 assessment found that, in general, trees are growing more quickly than they are currently being removed by harvesting so that standing forest biomass in the state continues to build. However, if current wildfire trends continue, it is possible that will start to decrease. They found that forest disturbance from harvesting peaked between 1986 and 1992, while disturbances caused by fire have been most common between 1992 and 2000 (CAL FIRE 2010). Another recent analysis by the U.S. Forest Service predicts that standing biomass and associated carbon storage is at risk from wildfire and pest damage in the long-term and so will be determined by how the forest is managed for those risks over the next 100 years (Goines and Nechodom, 2009).

Sierra Nevada forests are currently storing over 840 million tons of biomass. This is probably an increase from historic levels due in part to fire suppression and the reduction in harvesting on public lands. Increasing carbon storage in this way is a benefit to moderating the causes of climate change in the short term. However, in the longer term, it elevates the risk because dense forests are more likely to experience stand-replacing fires that kill many trees and so lead to a large release of carbon when fire killed trees decay.

Another recent analysis by the U.S. Forest Service predicts that standing biomass and associated carbon storage is at risk in the long-term. The analysis predicts California national

forests will become net emitters of carbon by the end of the century because by mid-century forests will accumulate carbon at a slower rate than they lose it through wildfire, pest mortality and inter-tree competition. Carbon storage will be determined by how the forest is managed for those risks over the next 100 years (Goines and Nechodom, 2009).

Though most studies agree that active management to reduce wildfire and forest pest threats reduces carbon storage in the short term, there is less agreement about how and whether thinning improves the stability of carbon storage in the long term. Several recent studies found that consideration of the fate of removed woody material is very important when calculating whether forest fuels reduction reduces long term carbon storage. Using a carbon life cycle analysis, one study found that treated forests in the Sierra "sequester more carbon dioxide than a baseline no-action scenario after 50 years when the woody biomass removed is used for energy generation and the system has frequent fires" (Winford and Gaither 2012, page 7). Another study found that forest fuels treatments reduced loss of carbon to wildfire by 57% but that when carbon removed from the site is added to carbon loss to wildfire, total carbon loss is about 15% greater in treated forests than untreated. However, authors added that "If thinned trees were milled into lumber or the chips used as biofuel, a treatment's carbon loss could be reduced" (North and Hurteau 2011, page 1118).

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References

Blackard, J.A., Finco, M.V., Helmer, E.H., Holden, G.R., Hoppus, M.L. Jacobs, D.M., Lister, A.J., Moisen, G.G., Nelson, Riemann, R., Ruefenacht, B., Salajanu, D., Weyermann, D.L., Winterberger, K.C., Brandeis, T.J., Czaplewski, R.L., McRoberts, R.E., Patterson, P.L., and R.P. Tymcio. 2008. *Mapping U.S. forest biomass using nationwide forest inventory data and moderate resolution information*. Remote Sensing of Environment 112: 1658–1677.

CalFire. 2010. *California's Forest and rangelands: 2010 Assessment.* California Department of Forestry and Fire Protection, Fire and Resource Assessment Program. Sacramento, Ca. 343 pages. Available on-line at http://frap.fire.ca.gov/assessment2010.html.

Christensen, G.A., Campbell, S.J. and J.S. Fried, tech eds. 2008. California's forest resources, 2001–2005 Five year Forest Inventory and Analysis report. Gen. Tech. Report – PNW-GTR-763. Portland Oregon. U.S. Forest Service Pacific Northwest Research Station, 183 pages.

Collins B.M. and S.L. Stephens. 2010. Stand-replacing patches within a mixed severity fire regime: Quantitative characterization using recent fires in a long-established natural fire area. *Landscape Ecology* 25: 927–939.

Ferranto, S., Lynn Huntsinger, Getz, C., Nakamura, G., Stewart, W., Drill, S., Valachovic, Y., DeLasaux M. and M. Kelly. 2011. Forest and rangeland owners value land for natural amenities and as financial investment. California Agriculture. V65(4): 184-191.

Goines, B. and M. Nechodom. 2009. National forest carbon inventory scenarios for the Pacific Southwest Region (California). U.S. Forest Service, Climate Change Interdisciplinary Team. Vallejo, CA. Region 5. Unpublished report. 81 pages.

North, M., Collins, B.M. and S. Stephens. 2012. Using fire to increase the scale, benefits and future maintenance of fuels treatments. Journal of Forestry 110(7): 392-401.

North, M.P. and M.D. Hurteau. 2011. *High-severity wildfire effects on carbon stocks and emissions in fuels treated and untreated forest.* Forest Ecology and Management 261: 1115–1120.

Miller, J.D., Safford, H.D., Crimmins, M. and A.E. Thode. 2008. *Quantitative evidence for increasing forest fire severity in the Sierra Nevada and Southern Cascade Mountains, California and Nevada, USA*. Ecosystems. DOI: 10.1007/s10021-008-9201-9

Safford, H.D., Stevens, J.T., Merriam, K., Meyer M.D., and A.M. Latimer. 2012. *Fuel treatment effectiveness in California yellow pine and mixed conifer forests*. Forest Ecology and Management 274 (2012): 17–28.

Savage, M. 1997. *The role of anthropogenic influences in a mixed-conifer forest mortality episode.* Journal of Vegetation Science 8: 95-104.

Stephens, S.L., Martin, R.E., and N.E. Clinton. 2007. *Prehistoric fire area and emissions from California's forests, woodlands, shrublands, and grasslands.* Forest Ecology and Management 251: (2007) 205–216.

U.S. Forest Service, 2011. *California Fire Return Interval Departure (FRID) map metadata: description of purpose, data sources, database fields, and their calculations.* 32 pages. Available on-line at http://www.fs.fed.us/r5/rsl/clearinghouse/r5gis/frid/.

van Mantgem, P.J., Stephenson, N.L., Byrne, J.C., Daniels, L.D., Franklin, J.F., Fulé, P.Z., Harmon, M.E., Larson, A.J., Smith, J.M., Taylor, A.H., and T.T. Veblen. 2009. *Widespread increase of tree mortality rates in the Western United States*. Science 323, 521-524.

van Mantgem P.J. and N.L. Stephenson. 2007. *Apparent climatically induced increase of tree mortality rates in a temperate forest.* Ecology Letters, 10: 909–916.

Winford, E.M., and J.C. Gaither Jr. 2012*. Carbon outcomes from fuels treatment and bioenergy production in a Sierra Nevada forest.* Forest Ecology and Management 282: 1–9.

Appendix

Table 5. Acres of Sierra Nevada forest land by county and land owner

Owner	Alpine	Amador	Butte	Cala-veras	El Dorado	Fresno	Inyo	Kern*	Lassen	Madera	Mari-posa	Modoc
BIA	114	205	210	74	1	19		1	564	77	207	1,959
BLM	3,262	3,430	5,035	15,491	7,006	3	202	2,629	47,507	173	4,165	3,092
NGO					106						941	
NPS						129,046			17,774	45,391	194,342	
Other Fed					270							111
Other Pub	3,451	252	3,698	3,423	3,123	141	89	146	1,471	23	166	557
Private	9,933	75,541	224,024	161,058	270,171	37,275	1,319	13,232	360,789	14,317	33,793	190,829
USFS	234,725	59,060	123,843	65,761	362,845	620,573	46,591	91,322	467,157	300,356	106,118	333,505
County Total	251,484	138,488	356,810	245,806	643,523	787,057	48,201	107,330	895,262	360,337	339,732	530,053
%Public	96%	45%	37%	34%	58%	95%	97%	88%	60%	96%	90%	64%
%Private	4%	55%	63%	66%	42%	5%	3%	12%	40%	4%	10%	36%

Owner	Mono	Nevada	Placer	Plumas	Shasta*	Sierra	Tehama	Tulare	Tuolumne	Yuba	Total
BIA			18	781	1,511	640	2	16,649	149	11	23,193
BLM	770	11,584	13,339	2,731	16,094		882	6,055	4,253	845	148,547
NGO		63	954	415		498	952		30		3,959
NPS	5			13,607	58,666		3,383	250,972	249,403		962,589
Other Fed		192	5,865					290	51	60	6,839
Other Pub	3,915	7,395	6,747	8,175	11,889	5,588	984	5,751	4,268	2,130	73,382
Private	5,956	235,221	189,180	306,950	531,022	104,870	163,578	18,996	126,228	65,035	3,139,317
USFS	208,695	144,595	255,141	1,045,249	340,714	372,144	113,844	578,145	412,880	38,927	6,322,190
County Total	219,341	399,050	471,244	1,377,908	959,896	483,740	283,625	876,858	797,262	107,008	10,680,015
%Public	97%	41%	60%	78%	45%	78%	42%	98%	84%	39%	71%
%Private	3%	59%	40%	22%	55%	22%	58%	2%	16%	61%	29%

*Shasta and Kern Counties have additional productive forest lands situated outside the Sierra Nevada Conservancy boundary.