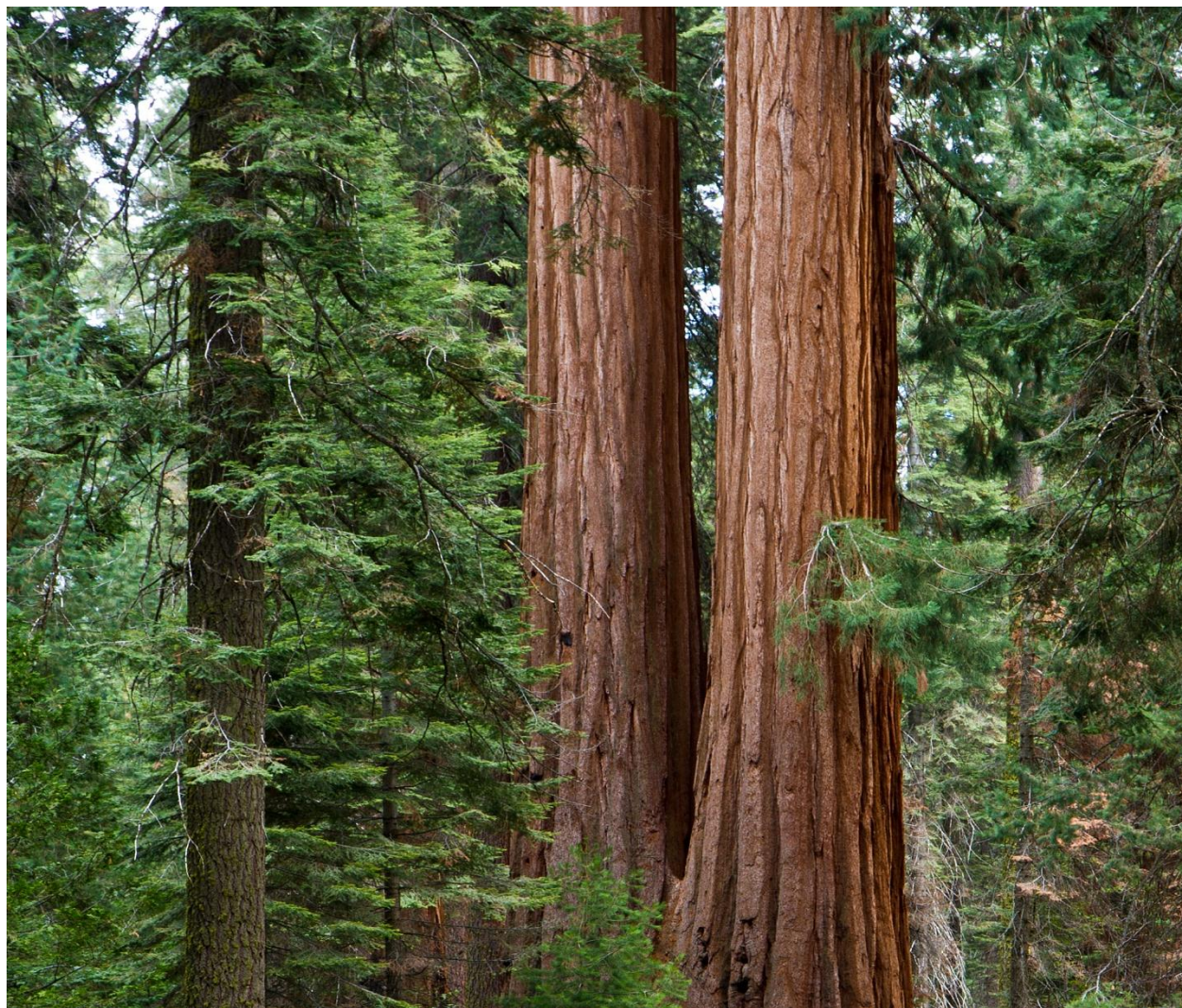




A Natural Resource Condition Assessment for Sequoia and Kings Canyon National Parks

Appendix 9 – Five-needle Pines

Natural Resource Report NPS/SEKI/ NRR—2013/665.9



ON THE COVER

Giant Forest, Sequoia National Park
Photography by: Brent Paull

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Appendix 9 – Five-needle Pines

Natural Resource Report NPS/SEKI/ NRR—2013/665.9

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Scope of Analysis

Five-needle (white) pines are an important component of the upland forest and alpine woodland communities in Sequoia-Kings Canyon National Parks (SEKI, Table 1). Five species occur in SEKI: foxtail pine (*Pinus balfouriana*), limber pine (*Pinus flexilis*), sugar pine (*Pinus lambertiana*), western white pine (*Pinus monticola*), and whitebark pine (*Pinus albicaulis*).

These trees occur throughout the Parks (Map 1) and in aggregate are constituents of more than 200,000 ha of vegetation (Table 1). Five-needle pines are often considered foundational species due to their role in promoting biodiversity, creating locally stable conditions for other species, and stabilizing fundamental ecosystem processes (Tomback et al. 2001, Ellison et al. 2005). Five-needle pines across North America are currently threatened by a combination of factors including outbreaks of native and exotic insects and diseases, altered fire regimes, air pollution, and climate change (van Mantgem et al. 2004, Tomback and Achuff 2010). For this analysis, we evaluate the current status and future vulnerability of these five tree population in SEKI. While these trees occur in communities, our focus here is on the population dynamics of these five species.

Critical Questions

The critical question is whether populations of five-needle pines are declining in SEKI. However we lack the comprehensive demographic information for four out of the five species to estimate the population growth rate. Only for sugar pine do we have the necessary information (van Mantgem et al. 2004) and even this analysis is limited in spatial extent (3 sites in SEKI, all in the Kaweah River Basin, 692 trees). For the other species, we have no demographic information. Instead we will rely on comparing static size distributions to evaluate population status.

In addition, we need a means to measure the impact of potential stressors on the pine populations. In planning for the NRCA, we identified white pine blister rust (*Cronartium ribicola*), altered fire regimes, and air pollution (ozone and nitrogen deposition) as the primary, quantifiable threats to the five-needle pine species. Again van Mantgem et al. (2004) demonstrate the most informative approach. They measured the impact of two stressors on sugar pine demographic rates. In absence of such information, we will quantify the spatial correlation between the presence of five-needle pine populations in the landscape and the magnitude of known stressors. Specifically we will address the following questions:

What is the range and composition of the five-needle pine populations in SEKI?

Do the current size distributions of the five-needle pines suggest declining or stable populations?

What is the aggregate impact of known stressors on the five-needle pine populations?

Data Sources

1. The SEKI vegetation map (USGS-NPS 2007).

The vegetation map for SEKI provides a spatially explicit and hierarchical classification scheme that incorporates the physiognomy of the landscape and the species composition of the plant community. It follows the national standard for vegetation classification and was adapted from mapping schemes initially developed for Yosemite National Park (NatureServe 2004). Wall-to-wall spatial coverage is based on the photointerpretation of high resolution imagery that was refined and validated with an extensive field sampling effort. The final map for SEKI was completed in 2007 (USGS-NPS 2007). We used the indicator species produced as part of the classification scheme to define the range of habitats for each of the five-needle pine species.

2. Data from the natural resource inventory (NRI) for SEKI (Graber et al. 1993).

In 1985, the National Park Service initiated a plot-based parkwide survey of the vascular plants. Plot locations were selected according to a stratified random sampling scheme using the 1-km UTM coordinate grid (Fig. 1). Each 1 km UTM intersection represented a potential sample point; clusters of these points were visited throughout the two parks in such a way as to maximize efficiency and to provide broad geographical coverage of slope, elevation, and aspect classes present in the parks. Data were collected from 0.1 ha circular plots (17.8 m radius). Within each plot, the diameter at breast height (dbh) was recorded for all trees taller than 1.4 m and with a diameter of 1 cm or more. In extremely dense plots, diameters were estimated. A total of 628 plots were established between 1985 and 1996. A small subset was measured more than once. Using the location of the plot center, we attributed each plot with the characteristics of its

SEKI vegetation map polygon. Thus each NRI plot was assigned to a physiognomic and vegetation class. The NRI data represents the most detailed, unbiased, and comprehensive information on the status of the vegetation in SEKI.

3. Data from the USDA Forest Service's Forest Inventory and Analysis (FIA) program (<http://fia.fs.fed.us/>).

The USDA Forest Service conducts a national inventory of forest resources (i.e. FIA) that includes a network of field plots distributed at a density of approximately one plot per 2,492 ha. Measurements in these plots (Phase 2) include nested sampling of trees (species identification,

dbh, status, canopy position). In the western United States, FIA plots are measured on a ten-year cycle. The fraction measured in any individual year is used as a representative sample of all plots in the region. Details on the design of the inventory and access to the data are available online (<http://fia.fs.fed.us/>). From the 2010 FIA database, we downloaded the data for all plots in the boundaries of the protected area centered ecosystem (PACE) that encompasses SEKI. We then screened the data for the most recent measurement for all annual plots in the PACE. There were a total of 951 plots

measured since FIA revised their protocols to measure individual trees (2001). These data represent a contemporary and regional perspective on the status of the southern Sierran forests and woodlands. Our analysis of these data provided context for interpreting the status of each of the five-needle pine populations in SEKI.

4. Data from the survey of white pine blister rust in SEKI (Duriscoe and Duriscoe 2002).

Between 1995 and 1999, the incidence of white pine blister rust was measured across the ranges of the susceptible tree species (the five-needle pines: sugar pine, western white pine, foxtail pine, whitebark pine, and limber pine) in SEKI. The complete inventory included 154 plots with 50 susceptible trees in each plot. See Duriscoe and Duriscoe (2002) for details on the sampling strategy. Based on the location of the blister rust plots, we assigned a vegetation alliance to each plot. These data provided the means to quantify blister rust infection in a spatially explicit fashion.

5. 2010 FRID database maintained by SEKI

To measure the extent of the alteration to the fire regime and to monitor management actions, Caprio et al. (1997) developed a geospatial model that estimated the extent of departure from the historic fire return interval for each vegetation type in the Parks (Fire Return Interval Departure, FRID). FRID values are calculated as the ratio of the time since last fire to the historic fire return interval. In SEKI, the indices ranged from -1 (just burned area) up to 16 which indicates that the time since last fire is 16 times longer than the historic fire return interval. See Caprio et al (1997) for a complete discussion of the index.

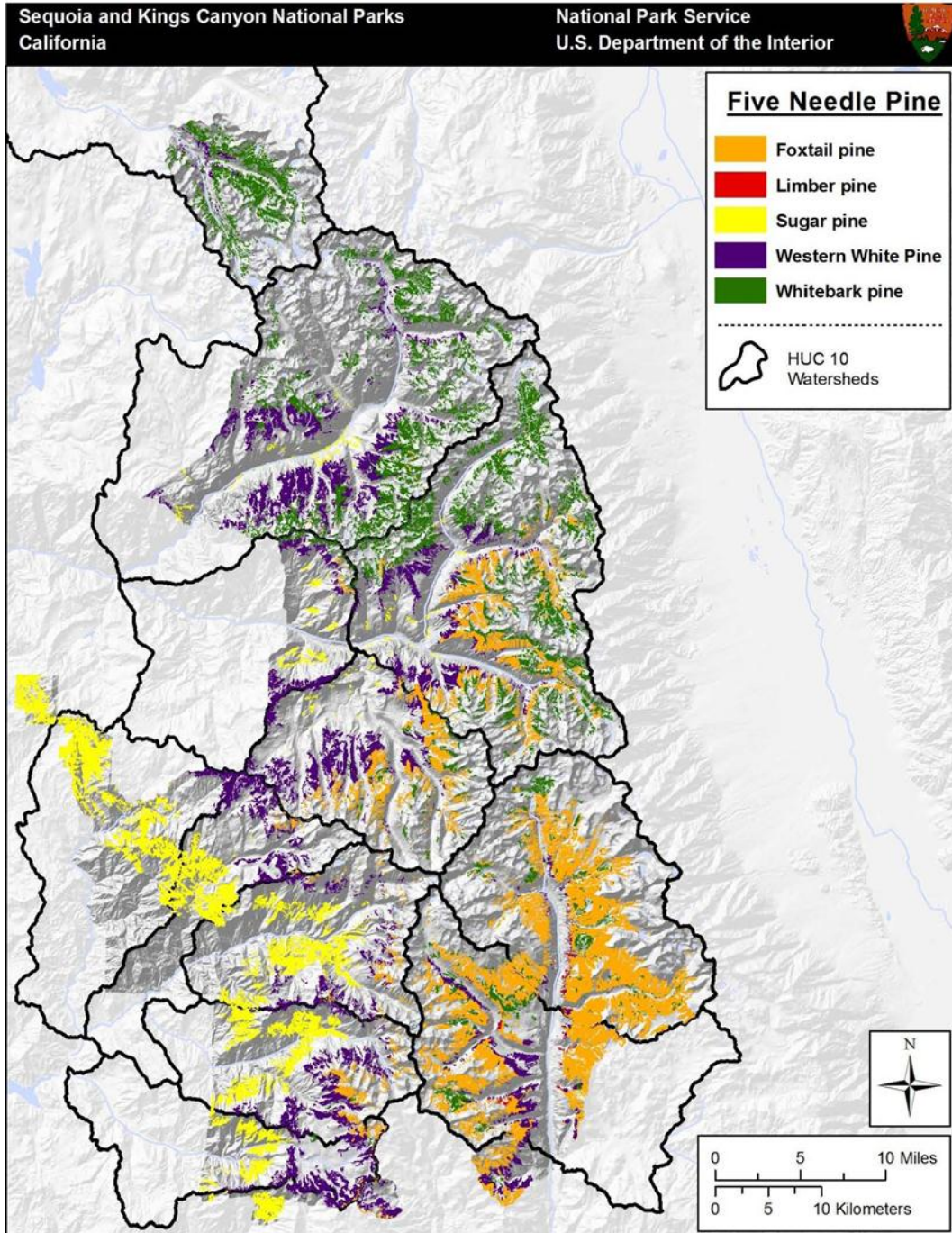
Reference Conditions: Current status of five-needle pine species

Introduction

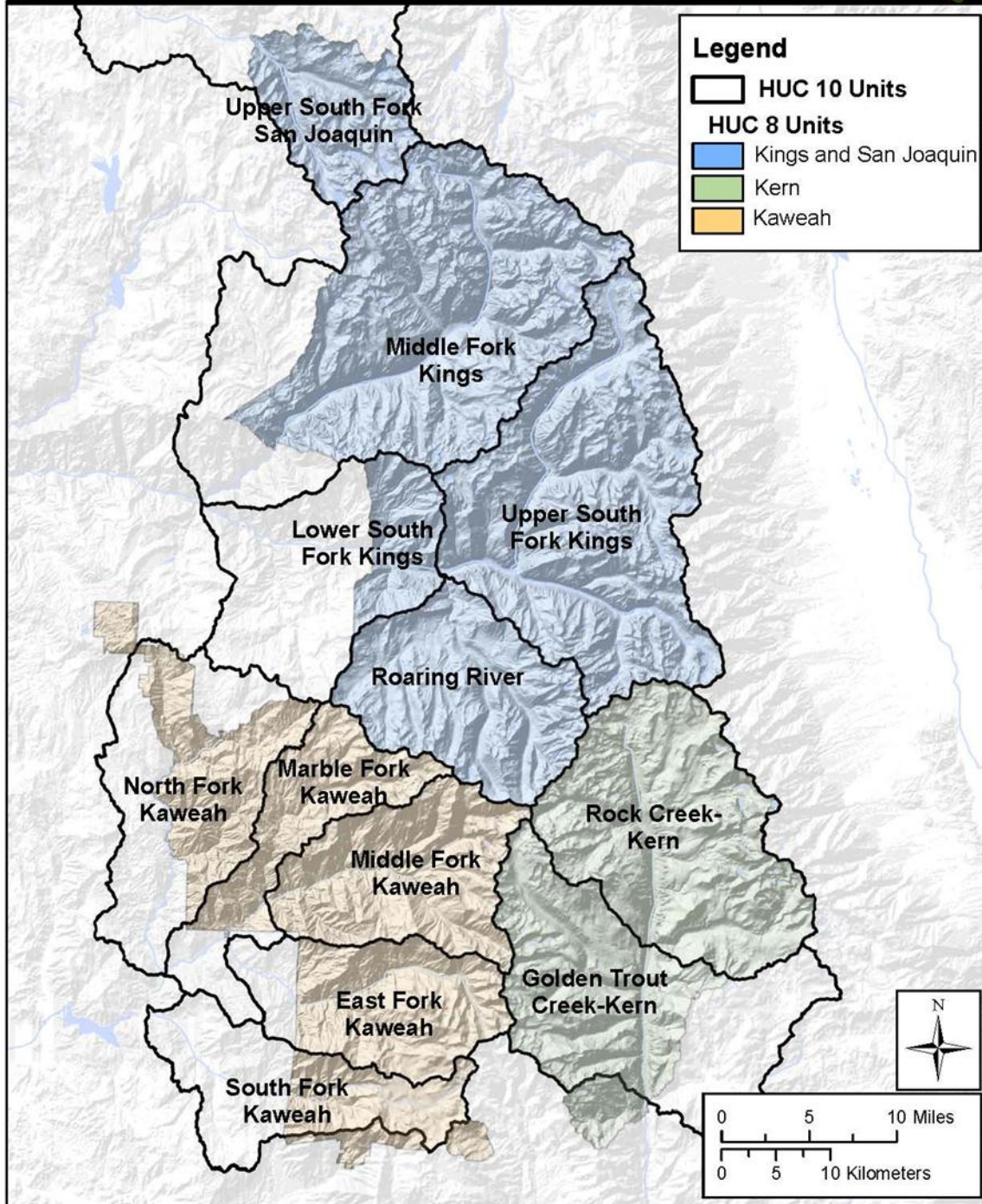
The five-needle pine species occur across a continuum of habitats in SEKI from alpine barrens to montane forests, from the South Fork of the San Joaquin River to the South Fork of the Kaweah River. While they are closely related phylogenetically and share a growth form (evergreen, needle-leaved trees), they span a spectrum of life-history strategies. Although our ultimate goal is an integrated, spatially explicit assessment of this focal resource, the first step was to describe and quantify the constituent elements. To meet this objective, we summarized key aspects of the ecology of these species and their distribution in SEKI.

Methods

To quantify the extent of the species, we identified all the alliances in the SEKI vegetation map where each species was considered a characteristic or diagnostic species (Map 1). The naming conventions used in the vegetation classification included reference to a species if that species occurred in at least 80% of the classification plots (NatureServe 2004). This approach defines the core distribution of the species in SEKI. It does not delineate the full extent of its habitat. For example, sugar pine occurrence is certainly greater than its core area. It is a component of mixed conifer forests in Kern and Kings River HUC 8 (Map 2) but not common enough to be listed on the vegetation alliance (Map 1). Duriscoe and Duriscoe (2004) used different vegetation maps and different criteria to define the potential distribution of five-needled pines in SEKI. However, in total, the resulting range maps (Map 1, Figure 2 in Duriscoe and Duriscoe 2004) are strikingly similar upon comparison. The overlap between the two maps provides some assurance that the species distributions were accurately mapped. In addition, we augmented the analysis of the vegetation map with NRI data. We identified all the NRI plots that included at least one individual of each species. We used the tree and environmental data from the NRI plots to calculate distributional and forest composition metrics.



Map 1. Distribution of five-needle pine species in Sequoia Kings Canyon National park. Data Source: SEKI vegetation map



Map 2. Location and relationship of HUC 10 and HUC 8 watersheds in Sequoia-Kings Canyon National Parks. Data source: SEKI GIS databases.

As noted above, we lack the demographic information to evaluate the population trajectory of the five-needled pines. However, for sugar pine, van Mantgem et al. (2004) constructed population models for populations from 2 long-term, unburned plots in Kaweah Basin (Map 2). In aggregate they tracked the fate of 591 trees over 5-15 years. In addition, they constructed size-structured matrix population models from measured growth, survival, and recruitment rates and projected population trends. We discuss the specifics of their findings below. However, it is worth noting that the most stable sugar pine population in their study (Crystal Road) had a size distribution that followed a reverse-J distribution.

In the absence of demographic data, we constructed static size-distribution curves for the five-needled pine species in the Parks. We expected that stable populations would have a reverse-J distribution of sizes. In other words, we expected more trees in the smaller size classes and progressively fewer trees in the larger size classes. For comparison, we also calculated the size distributions for the same species from the FIA data in the PACE. While we recognize the limitation of this approach, stark differences between the tree size distributions would suggest further investigations as to why.

Results

Whitebark pine. Whitebark pine is widely distributed throughout western North America but is locally restricted to high elevations. In SEKI, the interquartile elevation range is from 3,268 to 3,424 m with most common habitats being alpine barrens and alpine woodlands (Table 1). It is a long-lived species that can tolerate harsh environmental conditions. In the Sierra Nevada, whitebark pine is considered more of a late seral species that is not particularly dependent on fire (Tomback and Achuff 2010). In SEKI, its range is extensive with more than 50,000 ha of potential habitat. However while it is a frequent member of these communities, it is not the dominant species. Its relative abundance (as measured by contribution to live tree biomass, Table 2) of 34% was exceeded by lodgepole pine (60.3%).

Foxtail pine. Foxtail pine is a California endemic that is characteristic of high-elevation forests in the Sierra Nevada and Klamath Mountains (Tomback and Achuff 2010). Foxtail pine habitat was the most extensive of the five-needle pines in SEKI. It is also largely an upper-subalpine species but occurred at slightly lower elevations than whitebark pine and predominated in woodlands as opposed to barrens or forests (Table 1). Foxtail is a light-demanding but environmentally tolerant species that often forms open, monodominant stands near timberline (Tomback and Achuff 2010). Indeed at SEKI, it was the most abundant species across its habitat (Table 2).

Sugar pine. Sugar pine is a major component of the Sierra Nevada mixed conifer forest. Unlike the other five-needle pine species at SEKI, it does not grow at high elevations. Rather it is a mid-elevational, forest species (Tomback and Achuff 2010, Table 1). Also unlike the other five-needle pine species, it was not often included as a “type” species in the vegetation classification, thus our definition of its extent is an underestimate. However the NRI plots, which are an unbiased sample of SEKI vegetation, provided another means to judge its extent. It occurred in 70 NRI plots out of a total of 628 (Table 2). The simple ratio suggests that sugar pine occurs across 11% of the landscape. Sugar pine is moderately tolerant of understory conditions and is considered a fire-resistant species (Tomback and Achuff 2010). While a common component of the massive mixed conifer-white fir forest, it was not the most abundant member (Table 2).

Table 1. Distribution of the five-needle pine species in Sequoia-Kings Canyon National Parks. The vegetation extent follows the final mapping classification (USFS-NPS 2007), Elevation range and distribution by vegetation class based on NRI plot data.

Species	Extent (ha)	NRI Plots (n)	Evaluation Intequartile Range (m)		Barren (%)	Dwarf-shrub (%)	Forest (%)	Herbaceous Vegetation (%)	Woodland (%)
Whitebark pine (PIAL10)	55,225	23	3,268	3,424	32	0	11	16	37
Foxtail pine (PABA11)	67,949	43	3,146	3,317	14	0	16	7	58
Sugar pine (PILA10)	38,126	70	1,800	2,076	2	0	87	0	6
Western white pine (PIMO20)	53,965	20	2,744	2,976	8	0	54	0	23
Limber pine (PIFL10)	544	0	-	-	-	-	-	-	100*

*Note: No NRI plots in Limber pine type (PI=3150).

Table 2. Summary of forest metrics for the vegetation alliances in Sequoia-Kings Canyon National Parks where at least one of the five-needled pine species was considered an indicator species. The vegetation extent follows the final mapping classification (USFS-NPS 2007), Forest metrics are reported with means and standard errors in parentheses. Calculations based on NRI plot data.

Species	Extent (ha)	NRI Plots (n)	Biomass (Mg ha ⁻¹)	Basal Area (M ² ha ⁻¹)	Density (stems ha ⁻¹)	PAIL10 (%)	PIBA11 (%)	PILA10 (%)	PIMO20 (%)	Dominant Species
Whitebark pine (PIAL10)	55,225	23	119.6 (26.5)	26.9 (5.1)	510 (103)	34.0	6.70	0	0	PICO10: 60.3%
Foxtail pine (PABA11)	67,949	43	152.9 (16.7)	35.5 (3.1)	203 (20)	2.8	57.6	0	2.0	PICO10: 35.2%
Sugar pine (PILA10)	38,126	70	444.8 (28.3)	58.1 (6.0)	566 (54)	0	0	17.1	0	ABCO11: 38.5%
Western white pine (PIMO20)	53,965	20	187.1 (28.3)	36.7 (5.0)	354 (57)	-	8.9	0.8	23.8	PICO10: 39.0%
Limber pine (PIFL10)	544	0	-	-	-	-	-	-	-	-

*Note: No NRI plots in Limber pine type (PI=3150).

Western white pine. Western white pine forms the most diverse associations throughout its broad geographic distribution in western North America (Tomback and Achuff 2010). At SEKI, it straddled the forest-woodland boundary at SEKI (Table 1) and often occurred along with the other five-needle pines (Table 2). Western white pine is only moderately tolerant of shade and its regeneration is strongly dependent on disturbance, particularly fire (Tomback and Achuff 2010).

Limber pine. In the Sierra Nevada, limber pine occurs chiefly in windy, droughty and rocky sites (Tomback and Achuff 2010). It has the most restricted distribution (544 ha) of the five five-needle pines within the Parks. Populations were almost exclusively confined to canyon walls of the main drainages within the Kern watershed (Map 1). Limber pine did not occur in any of the NRI plots and thus we cannot more fully describe its composition.

Size distributions. For each five needle-pine species in SEKI, we observed an approximate reverse-J relationship between tree abundance and diameter class (Figure 1). However, in the PACE, we found no foxtail pines in the smallest class (<10 cm) and a relatively small number of foxtail pine trees in the 10 to 20 cm class (Figure 2). For the other five-needle pine species in the PACE, tree abundance declined exponentially from the smallest to largest diameter class (Figure 2).

Discussion

The five-needle pine species are a diverse group in terms of their abundance and distribution in SEKI. Based on inventory data, there is no obvious population decline in four of the five species. Note: limber pine is rare in the Parks and we have no inventory data. So we exclude limber pine from further consideration. Tree densities attest to the abundance of the species. In their range, the minimum average density was more than 200 stems ha⁻¹. All of the populations in SEKI have more small trees than big trees suggesting a stable age distribution. The only cause of concern was for foxtail pine in the PACE, where there was a clear shortage of small (< 20 cm dbh) trees (Figure 2). Thus in the region, but not in SEKI per se, there may be some factors limiting the successful recruitment of foxtail pine.

Despite the abundance and apparent stability of the five-needle pine populations in SEKI, the results from van Mantgem et al. (2004) illustrate the potential for rapid change. For the two unburned plots in the Kaweah Basin, van Mantgem et al. (2004) report annual mortality rates for sugar pine of 6.3% yr⁻¹ (Suwanee Creek) and 3.0% yr⁻¹ (Crystal Road). Both of these rates are higher than the composite tree mortality rate in this forest type (approximately 1.5% yr⁻¹, van Mantgem and Stephenson 2007). Moreover, blister rust was implicated in half the observed sugar pine deaths in Suwanee Creek and a third of the deaths in Crystal Road. These death rates suggest complete turnover on the order of 17 to 33 years – a very rapid pace of change for a species that typically lives to be hundreds of years old. As of 2004, there was no definitive evidence that these high mortality rates were leading to population decline, but the trends make decline in the near-future seem likely.

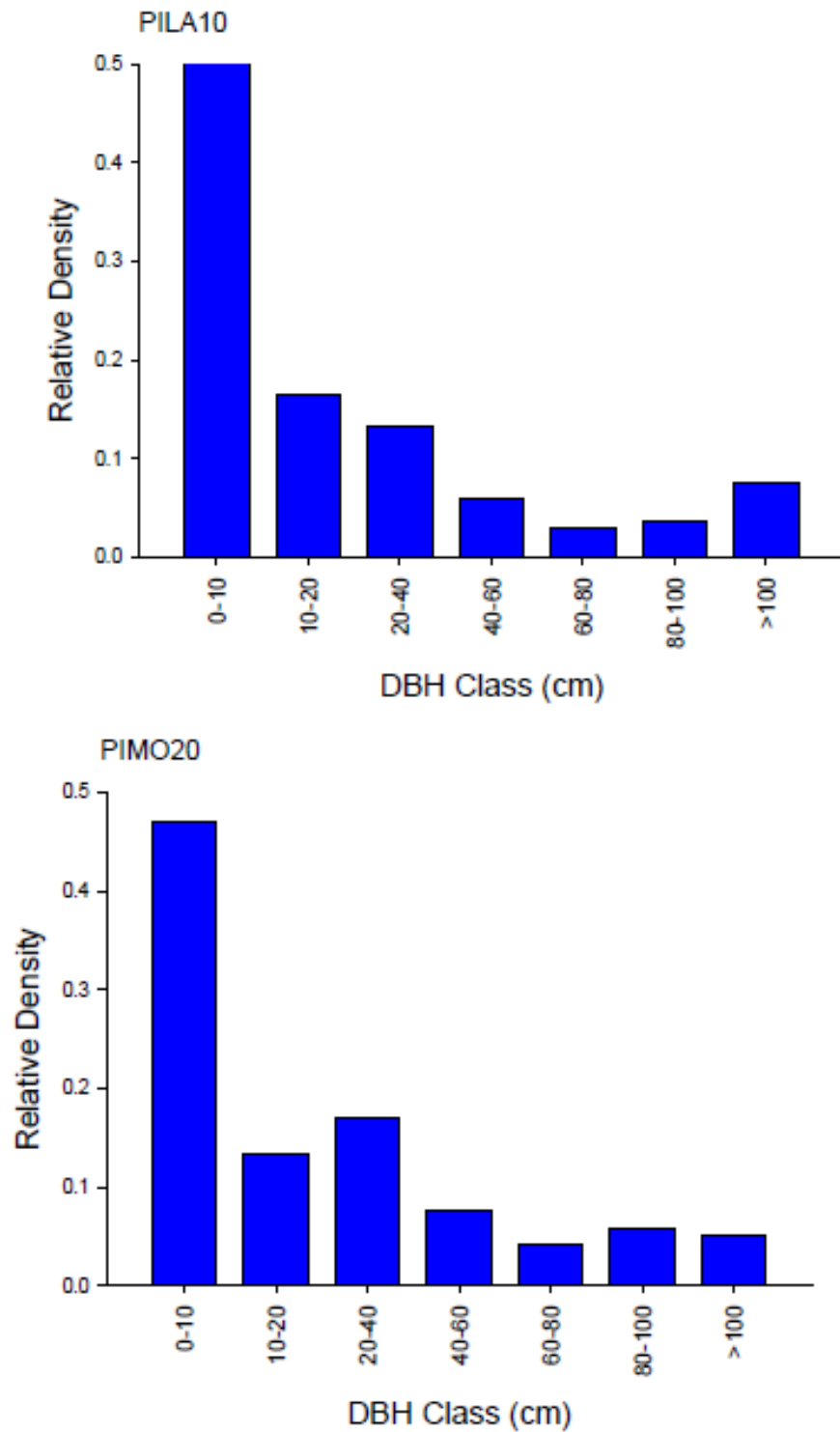


Figure 1. Diameter distribution of five-needled pin trees based in SEKI. Data source: NRI plot inventory.

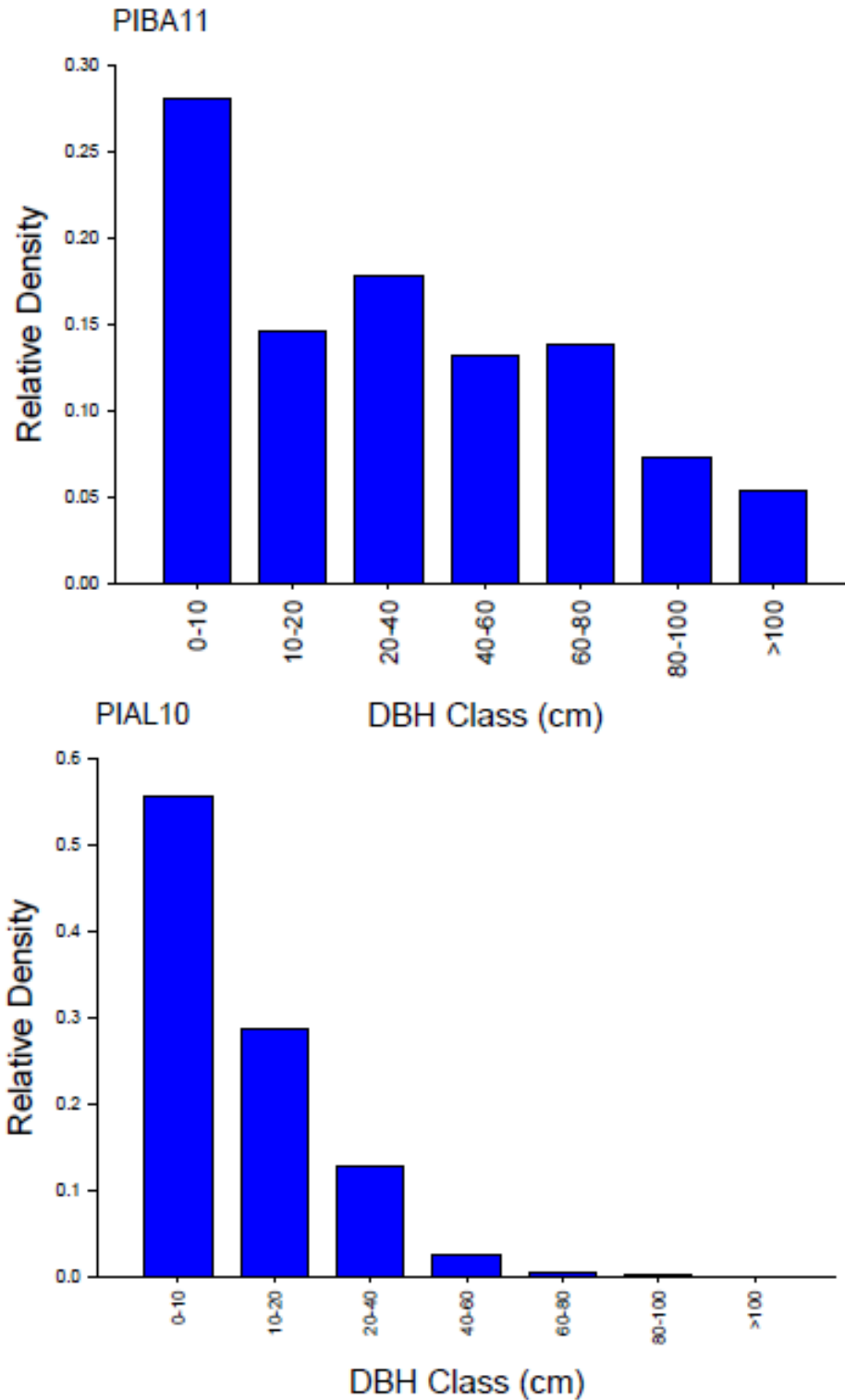


Figure 1 (continued). Diameter distribution of five-needled pin trees based in SEKI. Data source: NRI plot inventory.

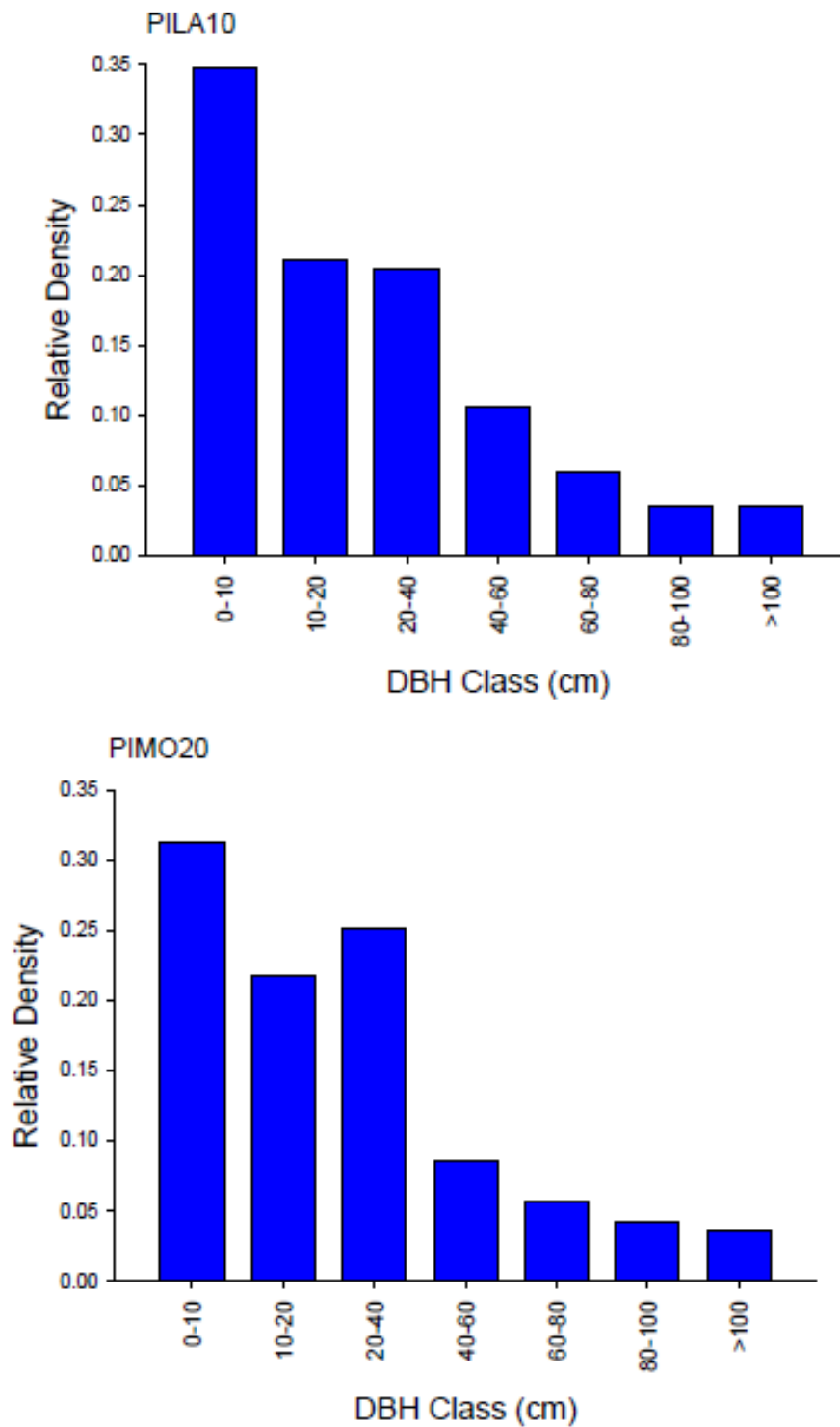


Figure 2. Diameter distribution of five-needled pine trees based in the PACE. Data source: FIA.

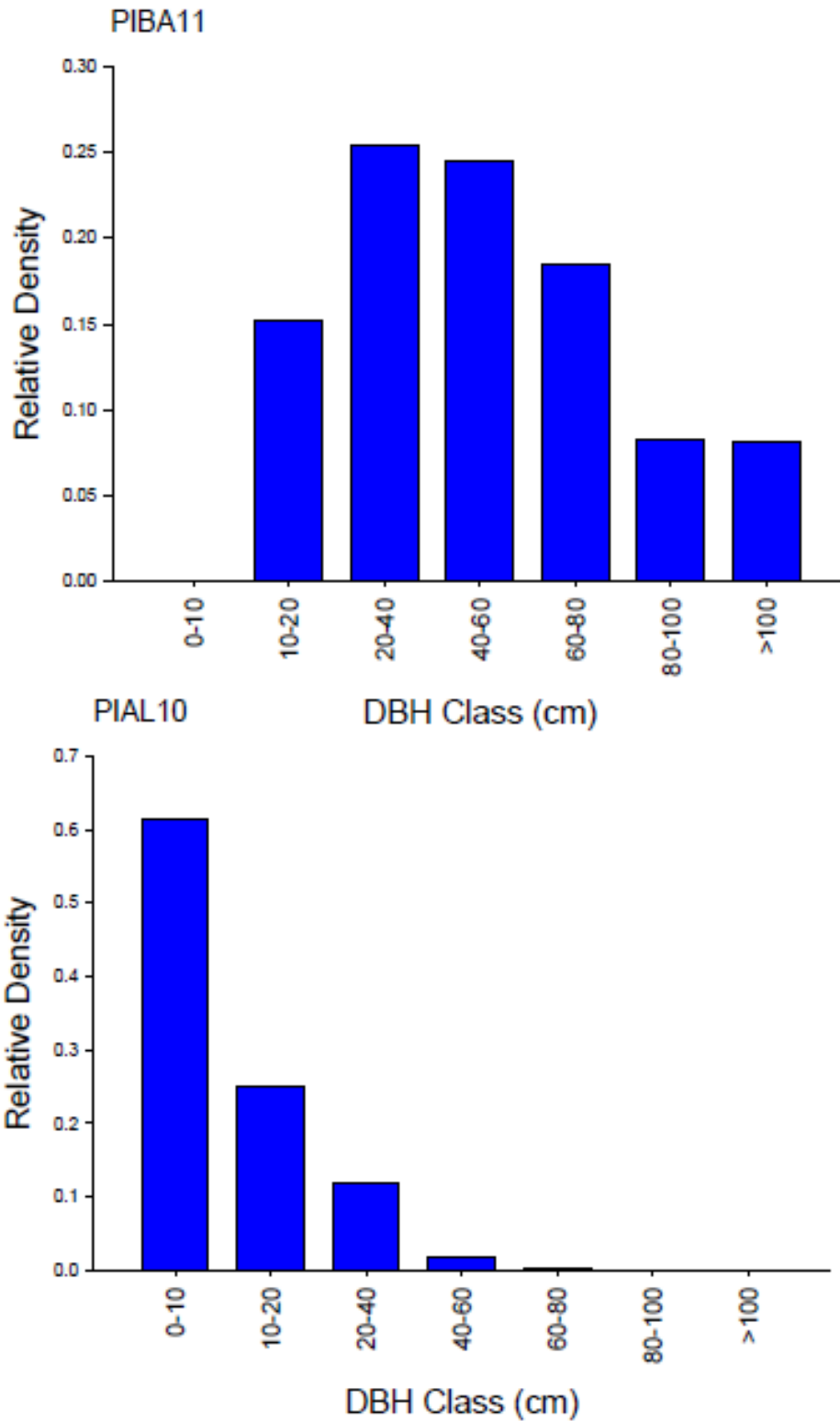


Figure 2 (continued). Diameter distribution of five-needled pine trees based in the PACE. Data source: FIA.

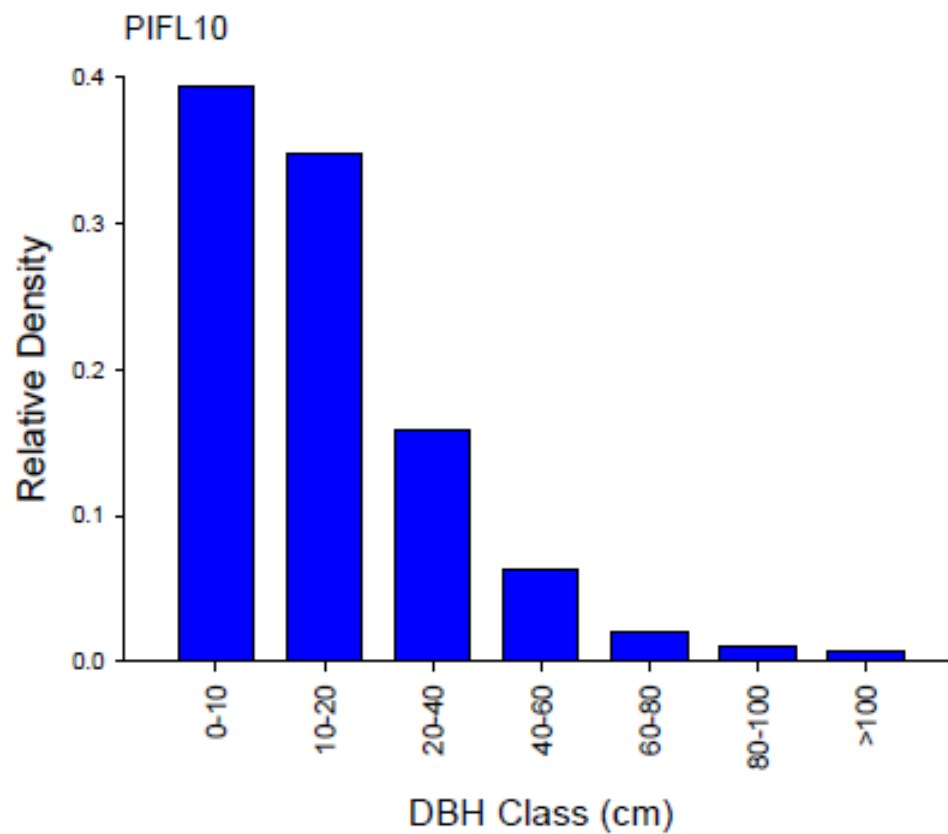


Figure 2 (continued). Diameter distribution of five-needled pine trees based in the PACE. Data source: FIA.

Stressors

Introduction

The goal with regard to stressors was to estimate the magnitude of the impact of white pine blister rust, altered fire regimes, ozone pollution, and nitrogen deposition on the five-needle pine species. We begin with an overview of each stressor and then follow with a spatial analysis using the available information. Through this estimate of vulnerability, we hope to provide insights into the current and future status of the five-needle pines at SEKI.

White Pine Blister Rust

A particularly destructive threat to five-needle pines is the exotic fungal pathogen *Cronartium ribicola* (J.C. Fischer in Rabenhorst), which causes white pine blister rust in five-needle pines. White pine blister rust ranks as one of the most destructive disease introductions in history (Tomback and Achuff 2010). Its life cycle is complex with five different spore stages on two completely unrelated hosts: five-needle pines and shrubs in the genus *Ribes* (gooseberries and currants). These shrubs are ubiquitous in the understories of Sierran conifer forests. A recent discovery found that plants in the genera *Castilleja* and *Pedicularis* can also serve as alternate hosts for *C. ribicola* (McDonald et al. 2006). The spores that infect pines are produced in the late summer/early fall under cool and very moist conditions. This cool and moist environment must be maintained for the spores to survive and infect the pine host via the leaf stomata. The infection spreads from the leaf to the branch or bole. The resulting cankers can kill the tree directly by girdling it or indirectly by predisposing an infected tree to secondary pests and pathogens (Geils et al. 2010).

Measures to eliminate or contain this pest constitute the most extensive and expensive effort of its kind in US forestry (Maloy 1997). In general, the blister rust control program is regarded as a failure. Initially there was hope that the epidemic could be constrained to a few outbreak centers in the Sierra Nevada. The dry Mediterranean summer was considered an environmental barrier to the dispersal of the spores that in combination with the vigilant removal of afflicted trees, could limit the spread. However “waves” of infection in the 1970s and 1980s distributed the disease over large areas of California. Although mortality due to blister rust is still patchy throughout the Sierra Nevada, there is mounting evidence that where blister rust infections occur, declines in pine populations will follow (Kinloch and Dulitz 1990, van Mantgem et al. 2004).

White pine blister rust was detected in SEKI in 1969 and has since spread throughout the range of the host species in the Parks (Duriscoe and Duriscoe 2002). Sugar pine and western white pine have the highest rate of infection in SEKI (Duriscoe and Duriscoe 2002). Sugar pine is an important and widespread component of SEKI forests. On average, it accounts for more than 7% of the aboveground live tree biomass. Western white pine is much less abundant in SEKI (<1% of the aboveground live tree biomass) but it is a dominant species in the western white pine-lodgepole pine forest alliance which covers more than 100 km² of SEKI.

A single dominant gene exists in sugar pine that confers virtual immunity to blister rust (Kinloch et al. 1970), although the gene has low frequency in natural populations. Gene frequency varies through the range of sugar pine from 0 in the southern Cascade Range to 0.08 in the southern Sierra Nevada (Kinloch 1992). At Mountain Home Demonstration Forest in the southern Sierra Nevada, Kinloch and Dulitz (1990) estimated a gene frequency of 0.076 in the seedling

population. Thus approximately 15% of parent trees at Mountain Home have major gene resistance. At Blodgett Forest Research Station in the central Sierra Nevada, only 5% of the screened sugar pine parents (130 trees) were rust-resistant (R. Heald, personal communication).

Foxtail pine, limber pine, and whitebark pine are considered foundation species (Tomback and Achuff 2010) in SEKI's timberline forests. These species can occur in pure stands and occupy treeline and subalpine environments that can be too harsh for other species. These species, therefore, can have significant impacts on ecosystem processes and community dynamics (Tomback et al. 2001). The impact of white pine blister rust on whitebark pine is of particular concern as this species recently qualified for listing as a threatened or endangered species (current status is that listing is "warranted but precluded" by the need to protect higher priority species). Throughout much of their range, whitebark and limber pine are declining due to white pine blister rust infection as well as outbreaks of mountain pine beetle (*Dendroctonus ponderosae*). For instance, in the northern Rocky Mountains, white pine blister rust induced whitebark pine mortality reached 90% in stands in Glacier National Park, 70-96% mortality in Idaho, and 42% mortality in western Montana (Kendall 1994). Currently, white pine blister rust and mountain pine beetle present less of a threat in the Sierra Nevada relative to other parts of the pine's range. However, it is unknown how much of the estimated area of whitebark pine habitat in the Sierra Nevada is affected by blister rust or mountain pine beetle (McKinney et al. 2011). In response to a recent (September 2010) request on the status and distribution of whitebark pine in Yosemite (YOSE) and Sequoia and Kings Canyon National (SEKI) Parks from the US Fish and Wildlife Service, McKinney (2010) reported an annual mortality rate of 0.5% yr⁻¹ from 1996 to 2010. These results are from one of the USGS long-term demography plots (1.25 ha) in YOSE and represent the only available estimate of mortality. Inferences from standing dead tree inventories suggest similar low rates for whitebark pine trees in SEKI. However these same inferences point to higher rates of mortality for whitebark in YOSE. As we detail below, blister rust infection rates were exceedingly low in the high elevation whitebark pine stands at SEKI (Duriscoe and Duriscoe 2002). Also there is no evidence of an incipient outbreak of mountain pine beetle in SEKI although the beetle was noted as present in YOSE and is present in the region (McKinney 2010). Although white pine blister rust induced declines in foxtail pine have not been reported, rust infection of foxtail pine has been found in both its northern (Dunlap 2006) and southern populations (Duriscoe and Duriscoe 2002). White pine blister rust has been observed on one foxtail pine in SEKI (Duriscoe and Duriscoe 2002). No white pine blister rust infection of limber pine has been reported within park boundaries (Duriscoe and Duriscoe 2002); however the ecological effects of current rust-induced mortality are a significant management concern elsewhere in its range (Schoettle 2004).

Altered Fire Regimes

Fire plays a fundamental role in the ecology of the five-needle pines in the Sierra Nevada (Caprio and Lineback 2002, van Mantgem et al. 2004, Fites-Kaufman et al. 2007). Fire suppression policy has led to significant changes in forest communities, including an increased rate and extent of succession that has contributed to population declines in the five-needle pine species. As the fire return interval increased, the number of suitable openings for five-needle pine seed germination declined (Keane and Morgan 1994). More shade-tolerant species have thrived and replaced five-needle pines (Kendall and Keane 2001, Arno 2001, Keane 2001, Murray et al. 2000). Further, in the event of a fire, multilayered fir canopies can contribute to higher surface fire intensities and flame lengths (Lasko 1990). This facilitates the conversion of a

low to moderate severity mixed fire regime to a stand replacing, crown fire regime (Steele 1960, Loope and Gruell 1973, Arno et al. 1993). Disruption of the pre-European fire regime in Sequoia-Kings Canyon National Parks since 1860 has created the potential for large, stand-destroying fires in forests where such catastrophic events happened rarely if ever in the past (Caprio and Graber 2000).

Ozone pollution

The interaction of geography, climate, and emissions patterns shape ozone production and transport, contributing to high ozone exposure in the southern Sierra, particularly during California's warm, dry, summers. Pollutants emitted in the San Francisco Bay Area and Central Valley are forced south and east by prevailing winds. Once deep in the San Joaquin Valley, the Sierra Nevada and Tehachapi mountains block passage of air, resulting in the production and accumulation of ozone in the southern Sierra (Carroll et al. 2003, Beaver and Palazoglu 2009). Ambient ozone levels typically peak in late summer, at the nadir of water availability for perennial plants (Gulke 2002).

Southern Sierra ozone concentrations regularly surpass national ambient air quality standards (NAAQS) with summer average daily maximums of 70-95 parts per billion by volume (Carroll et al. 2003). Sequoia and Kings Canyon National Parks are perennially among the National Parks with the worst air quality; the Park Service describes the effects of ozone here as "among the most severe in North America for non-point source pollution" (Sullivan et al. 2001, Landers et al. 2008). Sequoia and Kings Canyon National Parks regularly exceeded the NAAQ 8-hour standard (75 ppb) during the summer months: 66 days were in exceedance at Ash Mountain in 2010 (NPS 2010).

Ozone levels at or above the NAAQ standard can cause damage in sensitive species. For example, ozone injury to ponderosa (*Pinus ponderosa*) and Jeffrey pines (*Pinus jeffreyi*) is evidenced by yellowing of needles in a distinctive pattern known as chlorotic mottle. Other bioindicators include an increase in deciduous needle habit, shortened needles, fewer annual whorls per branch, and decreased crown density (Gulke 1998). Bytnerowicz et al. (1999) documented extensive ozone damage in the southern Sierra.

Nitrogen deposition

The direct and indirect effects of excess nitrogen deposition on California's conifer forests have only recently been investigated. Current evidence suggests consequences of nitrogen deposition include reductions in fine root biomass, increased nitrate concentrations in stream water, increased volatilization of nitrogen from the soil, decreased C:N ratios in soil and foliage, nitrate accumulation in foliage of understory and overstory plants, and altered rates of litter decomposition (Fenn et al. 1996, Fenn and Poth 1999a, Fenn and Poth 1999b, Temple et al. 2005).

Chronic nitrogen deposition in California mixed conifer forests has been shown to result in litter accumulation on the forest floor by stimulating litter production and simultaneously causing long-term reductions in litter decomposition rates (Fenn et al. 1996, Berg 2000, Fog 1988). The resulting thick litter layer can reduce the germination of pine seeds. Through this and other means, nitrogen enrichment may alter species composition and competitive interactions among species (Takemoto et al. 2001). Many pine species are particularly well adapted to nitrogen

limited environments and excess nitrogen deposition may result in a competitive advantage for species that can more rapidly utilize extra nitrogen (Chapin 1980). Further, deposition of excess nitrogen has the potential to impact nutrient uptake and allocation in nitrogen-limited forests and to modify tree response to stressors (Takemoto et al. 2001).

Methods

Our assessment of the five-needle pine species was integrated to the watershed level. For this NRCA, the finest spatial resolution was defined by the of USGS hydrological unit code 10 (HUC 10, mean size = 292 km²; range from 94 to 627 km², Map 2). We used the SEKI vegetation map to calculate the area-weighted contribution of each five-needle pine alliance to the overall watershed average.

Results

White Pine Blister Rust

Almost 22% of the sugar pine trees in the blister rust monitoring plots had symptoms of white pine blister rust infection; for western white pine, it was slightly less than 4% (Duriscoe and Duriscoe 2002). However, there was great variation in the level of infection. Many survey plots had no infected trees. For example, 12 out of the 43 survey plots with at least one sugar pine tree had no rust and 42 out of the 52 plots with at least one western white pine had no rust (data from Duriscoe and Duriscoe 2002). To summarize the distribution, we calculated the mean incidence of rust for each species (Table 3). Incidence was calculated as the number of infected trees/total number of trees in the plots. As noted by Duriscoe and Duriscoe (2002), there is a strong elevational gradient in the level of infection with little evidence of rust at the highest elevation. This may explain, in part, the lower impact of white pine blister rust on the high elevation pine species. Duriscoe and Duriscoe (2002) observed infected whitebark and foxtail (1 tree) pines in SEKI (outside of survey plots) and no infected limber pines were observed.

Since rust is a non-native pest, we considered any presence to be a stress. If the mean incidence was greater than 10%, it was rated a cause for concern. The analysis of white-pine blister rust incidence by HUC 10 watershed indicated that infection levels in four of the HUC 10 watersheds warrant concern (Table 4, Map 3). This analysis also reflected the spatial heterogeneity of white-pine blister rust infection within the Park (0 to 17.3%, Table 4, Map 3). Incidence was highest in the North Fork of the Kaweah River (Table 4).

Altered Fire Regimes

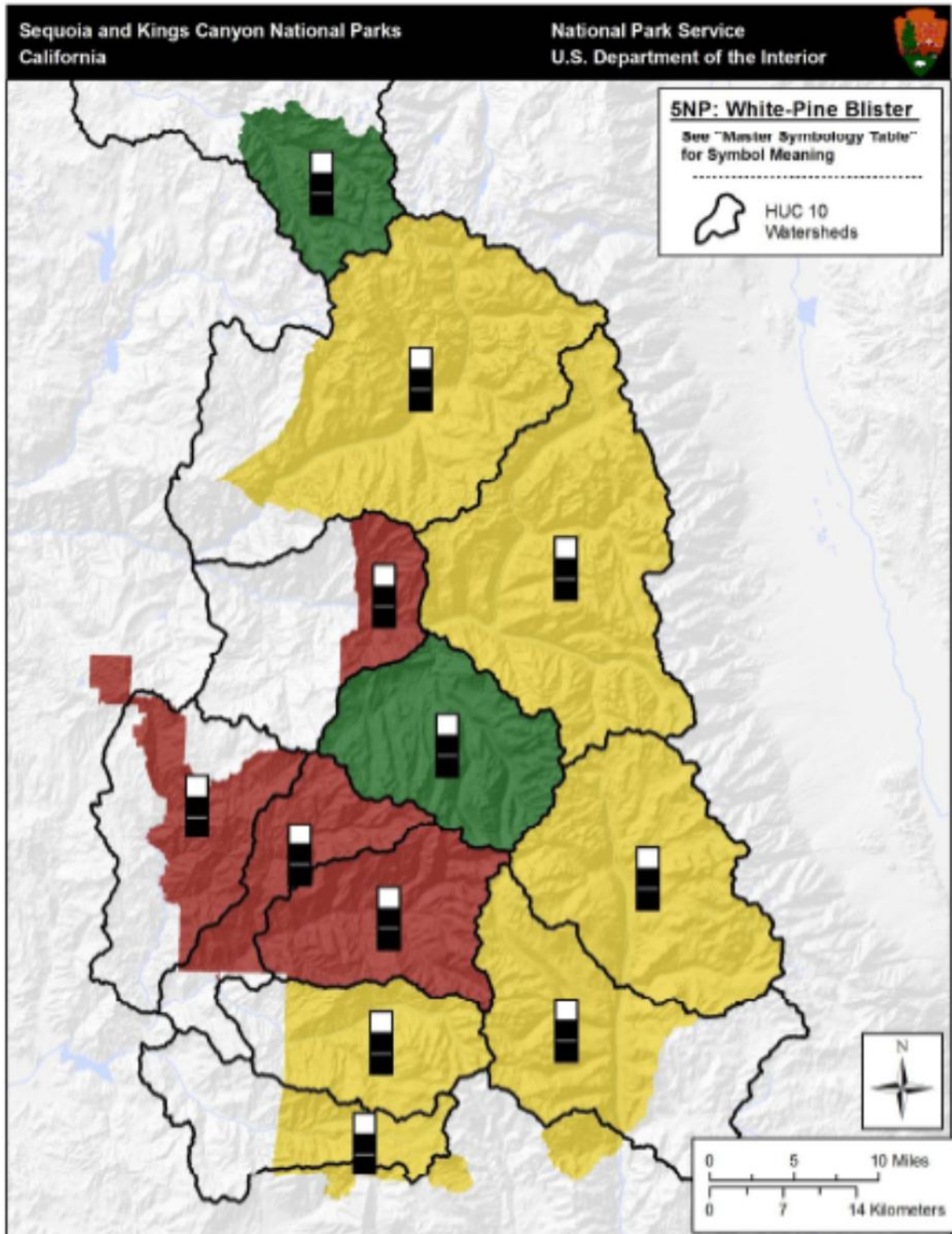
We used the 2010 FRID database maintained by the Parks to quantify the stress imposed by altered fire regimes. Specifically, we calculated the means of the raw FRID values for the five-needle pine forest alliances. Note that since the FRID is effectively normalized by vegetation type (Caprio et al. 1997), area weighted means do provide unbiased summaries for defined landscape units and allow direct comparison among alliances. We adapted the rating system of Caprio et al. (1997) to describe the extent of the risk posed by departures of from the historic fire regime. Average FRID values < 0 indicate that the historic fire return interval has been maintained (Caprio et al. 1997) and thus forests in this condition were ranked as “good.” FRID indices ≥ 0 and ≤ 2 indicate that the time since the last fire is up to two times longer than the maximum return interval. We assigned FRID indices in this range as reason for “caution”. If the mean FRID > 2, we considered altered fire regimes as a cause for “concern.”

Table 3. Incidence of white-pine blister rust for each five-needled pin species in Sequoia-Kings Canyon National Parks.

Species	Name	Number of Trees	Blister Rust Present	Number of Plots	Incidence by plot (mean±SE)
PIAL10	Witebark pine	1,422	0	43	0
PIBA11	Foxtail pine	1,941	0	52	0
PIFL	Limber pine	31	0	1	0
PILA	Sugar pine	1,941	389	43	21.9 (3.4)
PIMO	White pine	1,829	92	52	3.7 (1.84)

HUC 10	Incidence (%)
Middle Fork Kings River	6.6 (28)
Upper South Fork San Joaquin River	0 (5)
East Fork Kaweah River	9.2 (12)
North Fork Kaweah River	17.3 (6)
Marble Fork Kaweah River	13.7 (9)
Lower South Fork Kings River	14.3 (4)
South Fork Kaweah River	3.3 (4)
Golden Trout Creek-Kern River	2.9 (15)
Upper South Fork Kings River	8.6 (21)
Rock Creek-Kern River	0.1 (19)
Middle Fork Kaweah River	12.9 (12)
Roaring River	0 (7)

Table 4. Incidence of with-pine blister rust by HUC 10 watershed in Sequoia-Kings Canyon National Parks. Coding: Green = “good;” yellow = “caution;” red = “concern.” The number of blister rust survey plots follows the mean incidence in parentheses.



Map 3. Condition assessment of blister rust incidence on sugar pine (PILA) and western white pine (PIMO) in Sequoia Kings Canyon National Parks. Data source: Duriscoe and Duriscoe 2002. See Mas Symbology Table in Appendix 2.

Our analysis indicates that the historic fire return interval has been maintained at the HUC 10 scale for foxtail, limber, and whitebark pines (Table 5). In six of the HUC 10 watersheds, the mean FRID values for western white pine indicate reason for caution (all ≥ 0 and ≤ 1). Sugar pine values show the largest departures from historic fire return intervals with mean FRID > 2 for six of the HUC 10 watersheds (Table 5). In fact, mean FRID for sugar pine at the HUC 10 scale was ranked as “good” only in the Lower South Fork Kings River watershed (Table 5). The South Fork Kaweah River watershed had the highest departure for sugar pine (FRID=5.2, Table 4). When FRID values were averaged for all species at the HUC 10 watershed level, only the Kaweah River drainage had mean FRID values > 0 (Table 8, Map 4). Further, among the five-needle pine forest types, only sugar pine FRID was > 0 when averaged across the Park (mean FRID=2.9, Table 9).

Ozone pollution

Ozone levels at or above the NAAQ standard can cause damage in sensitive species (Grulke 1998). Bytnerowicz et al. (1999) documented extensive ozone damage in the southern Sierra; Duriscoe (1990) recorded specific symptoms of ozone damage to sensitive pine species in SEKI forests in the western edge of the Parks. Importantly, Panek et al. (Air Quality NRCA) demonstrated that the index of ozone damage on three-needle pines recorded by Duriscoe (1990) from field surveys corresponded to mean ozone concentration. Thus we used the ozone condition assessment developed by Panek et al. (Air Quality NRCA) to quantify the potential impact of ozone on the five-needle pines. Specifically, “concern” was defined as ozone exposure greater than the 80 ppb (the federal 8H primary standard threshold of 75 ppb + 5 ppb to account for uncertainty). “Good” was 8hr ozone concentrations < 70 ppb. “Caution” was assigned to concentrations between these values (70-80 ppb). For the five-needle pine alliances in each HUC 10 watershed, we calculated the average 8hr ozone exposure. Ozone exposure exceeded the 8-hr federal standard in several watersheds and was highest in the North Fork of the Kaweah River (94 ppb, Table 6, Table 8, Map 5). These levels lead to observable injury in sensitive pine species (Panek et al. Air Quality NRCA). The sugar pine forest alliance experienced the highest ozone pollution with an average 8-hr exposure of 88.4 ppb (Table 9).

Nitrogen pollution

We used the critical loads for nitrogen for the mixed conifer forest as defined by Fenn et al. (2010) to assess the stress imposed on the five-needle pine species by nitrogen pollution. We then summarized exposure for the five-needle pine forest alliances in each HUC 10.

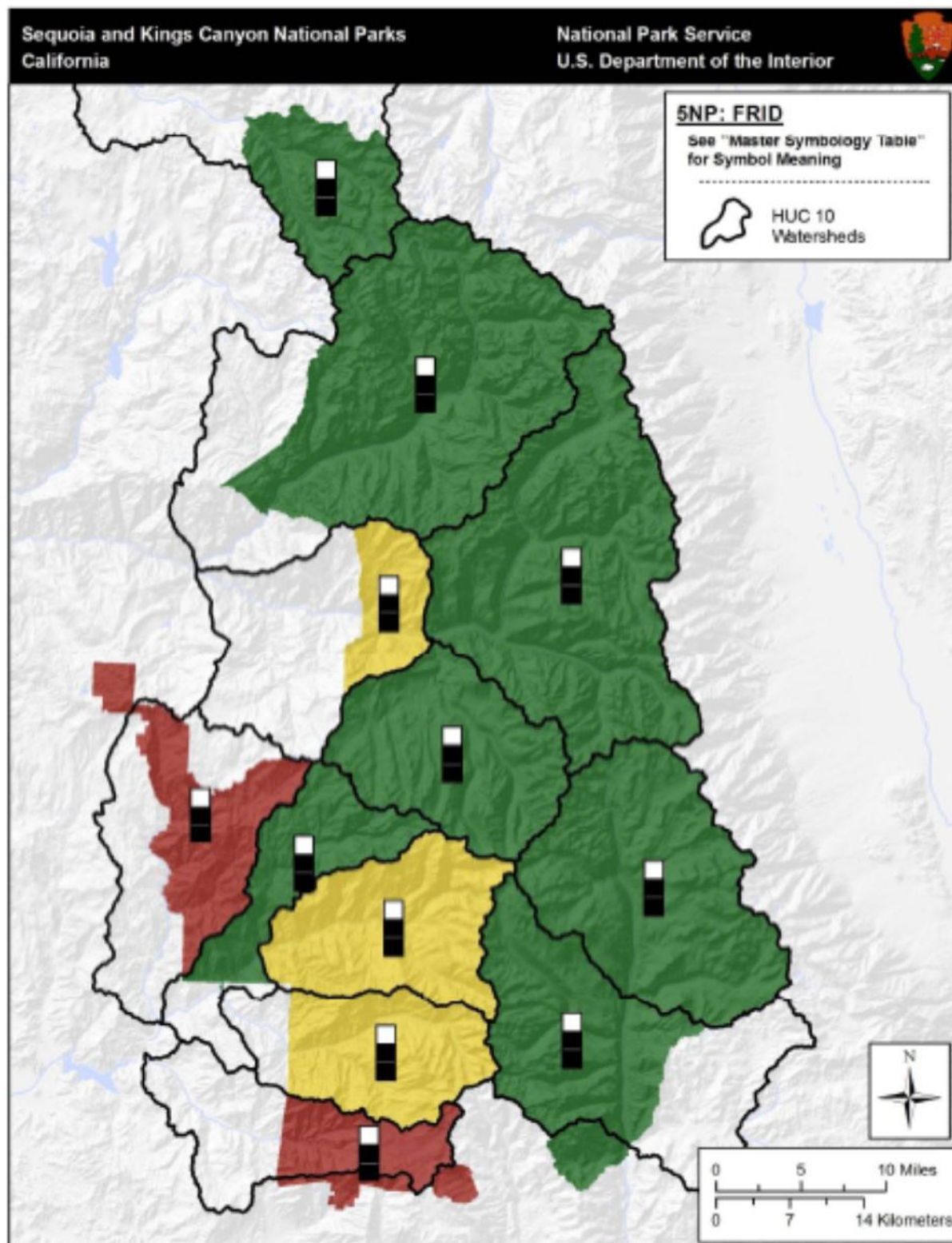
Across the Parks, nitrogen deposition was generally below the threshold considered damaging to ecosystems ($< 5.2 \text{ kg ha}^{-1} \text{ yr}^{-1}$). Only the sugar pine alliance received nitrogen above this threshold (Table 7, Table 9). For sugar pine, the North Fork Kaweah, South Fork Kaweah, and Marble Fork Kaweah watersheds all received levels of nitrogen above the threshold (Table 7). When averaged for all species, only the North Fork Kaweah drainage ranked as cause for concern (Table 8, Map 6).

Table 5. Mean fire return interval departure (FRID) by HUC10 watershed in Sequoia-Kings Canyon National Parks summarized for each five-needed pine forest type. Values are the means for all polygons in each forest type.

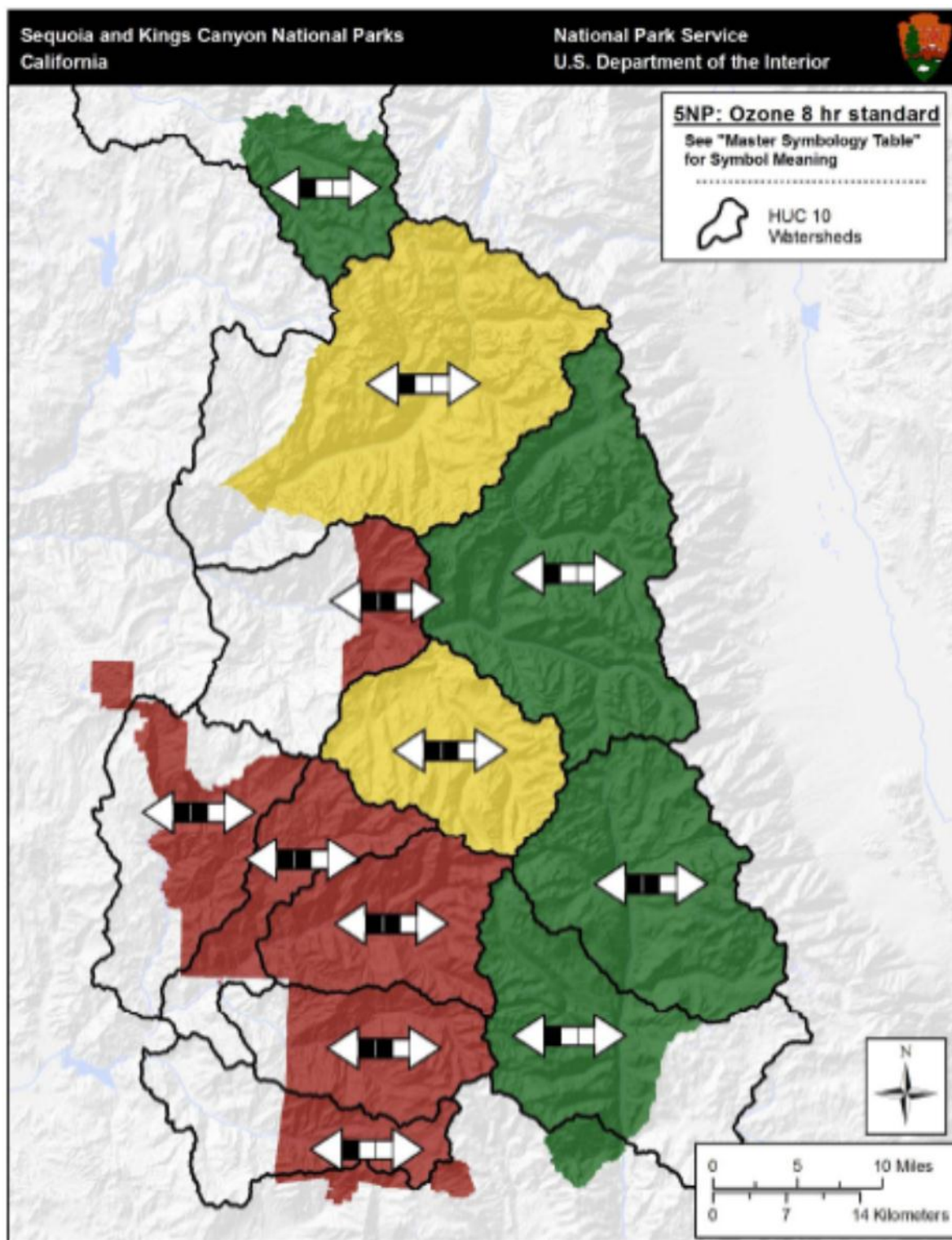
HUC 10	Foxtail pine	Limber pine	Sugar pine	Western white pine	Whitebark pine
Middle Fork Kings River	-0.8	-	3.0	-0.1	-0.6
Upper South Fork San Joaquin River	-	-	-	-0.8	-0.5
East Fork Kaweah River	-0.8	-	3.3	0.3	-0.3
North Fork Kaweah River	-	-	2.8	0.5	-
Marble Fork Kaweah River	-0.8	-	1.7	0.2	-0.8
Lower South Fork Kings River	-0.8	-	-0.6	0.0	-0.8
South Fork Kaweah River	-0.7	-	5.2	0.1	-0.3
Golden Trout Creek-Kern River	-0.8	-0.7	-	-0.3	-0.4
Upper South Fork Kings River	-0.8	-	2.1	-.03	-0.6
Rock Creek-Kern River	-0.8	-0.8	-	0.2	-0.5
Middle Fork Kaweah River	-0.8	-	2.7	0.8	-0.7
Roaring River	-0.8	-	0.9	-0.5	-0.6

Table 6. Mean ozone concentration 8 hr standard (ppb) by HUC 10 watershed in Swquoia-Kings Canyon National Parks summarized for each five-needle pine forest type. Values are the means for all polygons in each forest type.

HUC 10	Foxtail pine	Limber pine	Sugar pine	Western white pine	Whitebark pine
Middle Fork Kings River	78.4	-	78.3	76.8	72.0
Upper South Fork San Joaquin River	-	-	-	68.8	67.2
East Fork Kaweah River	76.5	-	85.5	81.5	77.0
North Fork Kaweah River	-	-	94.4	80.5	-
Marble Fork Kaweah River	78.2	-	93.1	82.6	76.6
Lower South Fork Kings River	77.1	-	77.9	85.8	86.8
South Fork Kaweah River	82.5	-	91.0	85.7	81.9
Golden Trout Creek-Kern River	68.4	68.5	-	71.7	69.1
Upper South Fork Kings River	67.5	-	73.0	69.9	69.3
Rock Creek-Kern River	63.6	69.8	-	67.3	63.1
Middle Fork Kaweah River	78.2	-	82.7	81.4	74.6
Roaring River	70.6	-	81.9	75.4	69.0



Map 4. Condition assessment for the fire return interval departure index for five-needle pines in Sequoia Kings Canyon National Parks. Data source: SEKI GIS databases. See Master Symbology Table in Appendix 2.



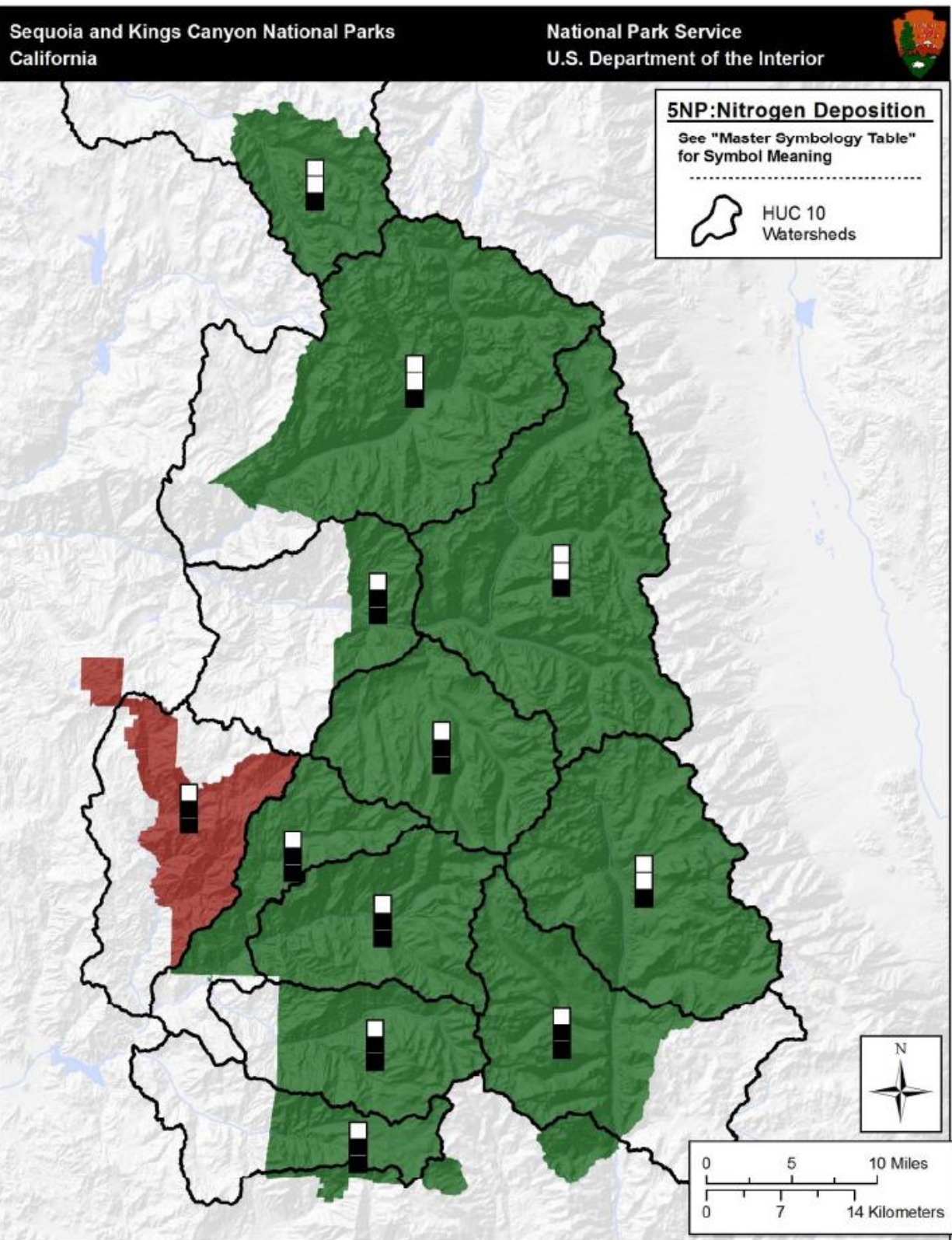
Map 5. Condition assessment for ozone exposure for five-needle pines in Sequoia Kings Canyon National Parks. Data source: NRCA Air Quality Assessment. See Master Symbology Table in Appendix 2.

Table 7. Mean nitrogen deposition ($\text{kg ha}^{-1} \text{ yr}^{-1}$) by HUC 10 watershed in Sequoia-Kings Canyon National Parks summarized for each five-needle pine forest type. Values are for the means for all polygons in each forest type.

HUC 10	Foxtail pine	Limber pine	Sugar pine	Western white pine	Whitebark pine
Middle Fork Kings River	2.3	-	1.8	2.0	2.2
Upper South Fork San Joaquin River	-	-	-	2.0	2.0
East Fork Kaweah River	2.2	-	4.0	2.6	2.3
North Fork Kaweah River	-	-	9.6	3.9	-
Marble Fork Kaweah River	3.1	-	6.1	3.4	2.6
Lower South Fork Kings River	2.6	-	1.5	2.3	2.9
South Fork Kaweah River	2.1	-	6.5	3.7	2.6
Golden Trout Creek-Kern River	1.7	1.3	-	1.6	1.8
Upper South Fork Kings River	2.1	-	2.1	2.1	2.1
Rock Creek-Kern River	1.4	1.3	-	1.4	1.6
Middle Fork Kaweah River	2.6	-	3.0	2.2	2.4
Roaring River	2.0	-	1.9	2.0	2.0

Table 8. Mean impact for the major abiotic stressors of five-needle pines at Sequoia-Kings Canyon National Parks summarized by HUC. Results pertain only to the five-needle pine forests in each HUC 10 watershed. Coding: Green = “good;” yellow = “caution;” red = “concern.”

HUC 10	FRID	Ozone concentration 8hr standard (ppb)	NDEP (kg ha ⁻¹ yr ⁻¹)
Middle Fork Kings River	-0.3	74.2	2.1
Upper South Fork San Joaquin River	-0.6	67.3	2.0
East Fork Kaweah River	1.5	82.6	3.1
North Fork Kaweah River	2.6	94.0	9.3
Marble Fork Kaweah River	1.0	88.3	4.8
Lower South Fork Kings River	-0.3	83.5	2.2
South Fork Kaweah River	2.1	87.1	4.7
Golden Trout Creek-Kern River	-0.6	69.1	1.7
Upper South Fork Kings River	-0.6	68.9	2.1
Rock Creek-Kern River	-0.7	63.7	1.4
Middle Fork Kaweah River	1.9	81.9	2.7
Roaring River	-0.6	72.9	2.0



Map 6. Condition assessment of nitrogen deposition for five-needle pines in Sequoia Kings Canyon National Parks. Data Source: NRCA Air Quality Assessment. See Master Symbology Table in Appendix 2.

Table 9. Mean impact for the major abiotic stressors of five-needle pines at Sequoia-Kings Canyon National Parks summarized by forest type. Results pertain only to the five-needle pine forests in each HUC 10 watershed. Coding: Green = “good;” yellow = “caution;” red = “concern.”

Species	FRID	Ozone concentration 8hr standard (ppb)	NDEP (kg ha ⁻¹ yr ⁻¹)
Foxtail pine	-0.8	67.2	1.7
Limber pine	-0.7	69.2	1.3
Sugar pine	2.9	88.4	6.0
Western white pine	0.0	77.5	2.3
Whitebark pine	-0.6	69.7	2.1

Assessment

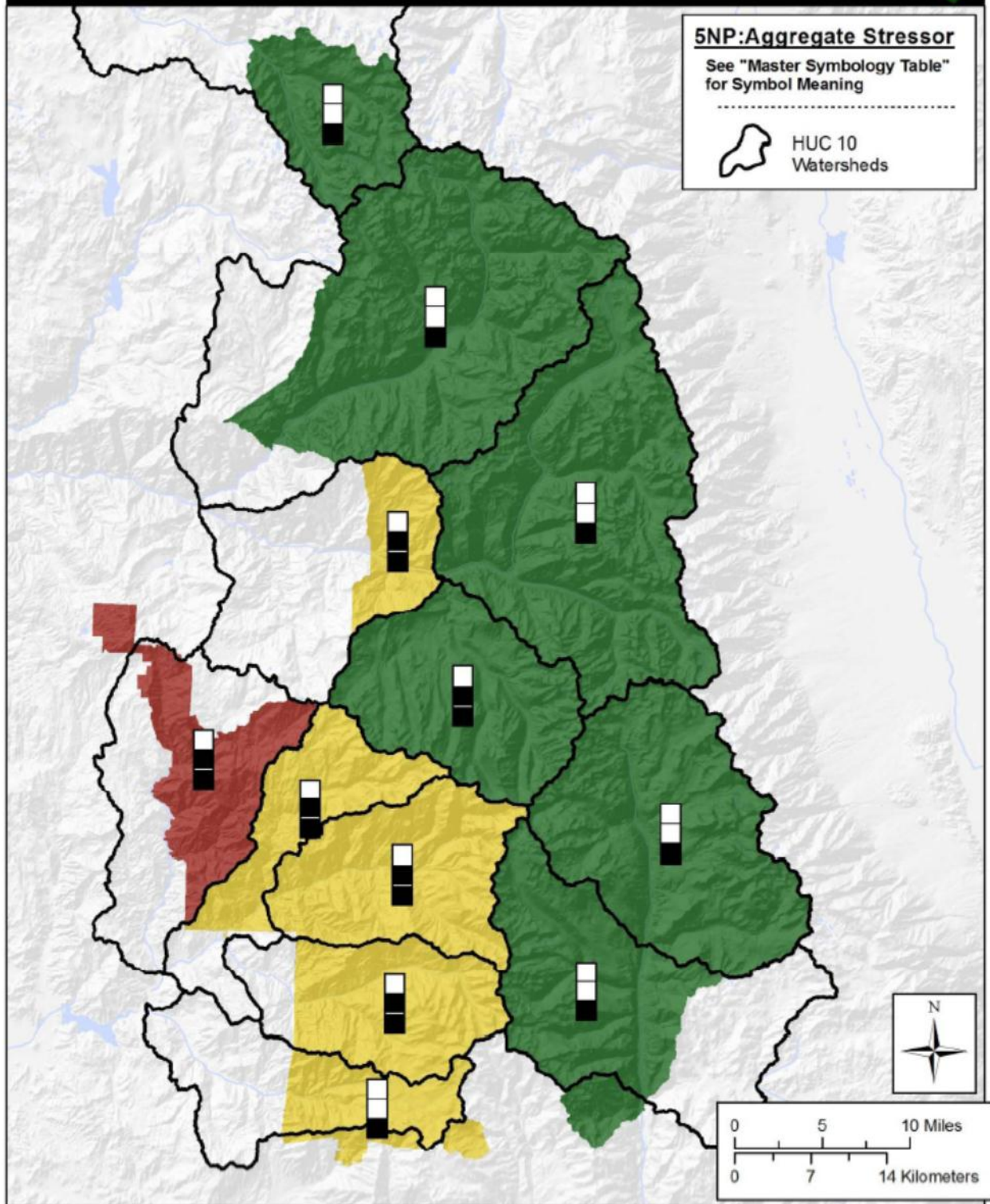
Our assessment of the current status of the five-needle pine species is limited by a lack of demographic information. This type of data is available only for sugar pine (van Mantgem et al. 2004). van Mantgem et al. (2004) showed that white pine blister rust and fire exclusion are negatively affecting sugar pine populations. Most of the studied, unburned populations had negative growth rates. However, the response was slow and evidence for general population declines was equivocal. Their study suggests that both white pine blister rust and fire exclusion will play significant roles in determining sugar pine's population trajectory (van Mantgem et al. 2004).

For western white pine, limber pine, whitebark pine, and foxtail pine; we have no demographic information. Instead we relied on a comparison of static size distributions to evaluate population status. For each five needle-pine species in SEKI, the observed reverse-J relationship between tree abundance and diameter class suggests stable populations with sufficient regeneration. The lack of foxtail pine regeneration in the PACE may reflect more stable foxtail pine populations in SEKI. However, the FIA data does not provide an extensive sampling of recruitment. The plots used to sample trees in the lower size classes are small and, therefore, the shortage of small foxtail pine trees in the PACE may result from a sampling effect.

In this assessment we considered just four of the plethora of stressors that may be impacting the five-needle pine species in Sequoia-Kings Canyon National Parks. We averaged the extent of major stressors by HUC 10 watershed (Map 7) to provide a simple aggregate view of the biotic and abiotic agents known to threaten the five-needle pines. These agents (i.e., white pine blister rust, altered fire regimes, and air pollution) were concentrated in the Kaweah River drainage but also notably impacted the five-needle pines in the Lower South Fork Kings River watershed (Map 7).

Our limited analysis suggests that sugar pine populations in the Parks warrant the most concern. Sugar pine was the most impacted by white pine blister rust, altered fire regimes, and air pollution (ozone and nitrogen deposition). For each of these studied stressors, the potential impact on sugar pine ranked as cause for concern (Table 9). For western white pine, the impact values for white pine blister rust, departure from historic fire return interval, and ozone exposure, were in the "caution" range. Currently, foxtail, limber, and whitebark pines appear to be relatively unaffected by the stressors quantified in this assessment. The impact values for each quantified stressor were in the "good" range for these three species.

While our analysis of stressors clearly suggests that sugar pine populations are highly stressed, in part, this result reflects a sampling bias resulting from our definition of the sugar pine population (i.e., alliances in the SEKI vegetation map where the species was considered a characteristic or diagnostic species). This definition resulted in an oversampling of sugar pines in the Kaweah Basin which had the highest levels of each of the studied stressors.



Map 7. Vulnerability assessment for five-needle pines in Sequoia Kings Canyon National parks. Results based on the aggregation of the major abiotic and biotic stressors developed in this report. See Master Symbology Table in Appendix 3.

The studied stressors are obviously cause for concern and demand monitoring, particularly given the importance of the five-needle pine species (Ellison et al. 2005). Further, we assessed only a small fraction of the plethora of stressors that may impact the five-needle pine species in Sequoia-Kings Canyon National Parks. Certainly, the exposure of five-needle pines to this multitude of stressors is cause for concern.

Gaps in Understanding

We documented a host of factors that may negatively affect the five-needle pines at SEKI. Initially we evaluated these stressors in isolation, and then, in absence of better information, we averaged their influence to get an idea of their potential aggregate impact on the forests (Map 7). However, these stressors undoubtedly interact. Stress from air pollution can weaken trees and predispose them to damage by drought, insects, and disease, and the reverse can also occur (USEPA 1980, Allen and Brashears 1998, Miller and McBride 1999). At the physiological level, Panek (2004) established that for the western Sierra region, peak ambient ozone concentrations do not correspond with peak ozone uptake in ponderosa pine. Further, the deposition of nitrogen has the potential to impact nutrient uptake and allocation in nitrogen-limited forests and modify tree response to stressors (Takemoto et al. 2001). The compounded effects of multiple stressors have caused dramatic shifts in community composition, trophic linkages, and overall ecosystem function in many communities (Paine et al. 1998) including forests dominated by a long-lived conifer (Eschtruth and Battles 2009). We need to know whether the stressors present at SEKI work in concert or opposition. We need to know if their impacts are additive or exponential.

Our ability to accurately assess the current condition of the five-needle pines was limited by the lack of well defined reference conditions for these species. Population level data including mortality rate, growth rate, and recruitment for each species across its distribution would improve this assessment.

Recommendations for future study/research

Our recommendations for future research at SEKI are to remeasure the NRI plots and to integrate the available datasets. The value of remeasuring permanent plot data cannot be overstated. The survey of white pine blister rust conducted in SEKI from 1995 to 1999 (Duriscoe and Duriscoe 2002) should also be repeated. This survey used permanently marked plots with tagged trees and would, therefore, provide an estimate of both changes in the incidence of white pine blister rust infection and five-needle pine mortality. We recommend expansion of the monitoring system for white pine blister rust to better capture changes in blister rust incidence and severity. In addition, these plots should be monitored for mountain pine beetle. The substantial impact of mountain pine beetle on white pine populations in the US Rocky Mountains, the beetles' current occurrence in California, and the strong link between beetle outbreaks and warmer temperatures/drought, suggest that this species could have a severe effect on pine population dynamics in the near future (McKinney 2010). The Sierra Nevada Inventory and Monitoring program implemented a long-term monitoring of high-elevation white pine communities in SEKI in 2011 (McKinney et al. in revision). This project will establish 48 monitoring plots for foxtail and whitebark pine in SEKI. More plots which adequately capture all five-needle pine species throughout their range and more frequent monitoring would improve the ability to capture future changes in the impacts of white pine blister rust and mountain pine beetle.

The role of multiple stressors acting simultaneously or sequentially on the five-needle pine species is an important area for future study at SEKI. There has been little research specifically targeting possible synergistic effects of multiple stressors. The interactions between white pine

blister rust, fire suppression, and air pollution are poorly understood. Further, the predicted impacts of climate change in the western United States (e.g., range shifts, drought conditions, changes in fire regimes) and the potential for outbreaks of mountain pine beetle intensify the need to provide insights into the complex interactions among both anthropogenic and natural stressors in forest ecosystems.

Literature Cited

- Allen, C.G. and D.D. Breshears. 1998. Drought-induced shift of a forest-woodland ecotone: rapid landscape response to climate variation. *Proceedings of the National Academy of Science* 95:14839–14842.
- Arno, S. F., 2001: Community types and natural disturbance processes. In: *Whitebark pine communities: Ecology and restoration*. Ed. By Tomback, D. F.; Arno, S. F.; Keane, R. E. Washington, DC: Island Press, pp. 74–88.
- Arno, S. F., E. Reinhardt and J. Scott. 1993. Forest structure and landscape patterns in the subalpine lodgepole pine type: A procedure for quantifying past and present conditions. USDA Forest Service, Intermountain Research Station, General Technical Report INT-270, Ogden Utah.
- Beaver, S. and A. Palazoglu. 2009. Influence of synoptic and mesoscale meteorology on ozone pollution potential for San Joaquin Valley of California. *Atmospheric Environment* 43: 1779–1788.
- Berg, B. 2000. Litter decomposition and organic matter turnover in northern forest soils. *Forest Ecology and Management* 133: 13-22.
- Bytnerowicz, A., M.E. Fenn, P.R. Miller and M.J. Arbaugh. 1999. Wet and dry pollutant deposition to the mixed conifer forests. In: Miller, P.R., McBride, J.R. (Eds.), *Oxidant Air Pollution Impacts in the Montane Forests of Southern California*. Ecological Series 134. Springer, pp. 235–269.
- Caprio, A., C. Conover, M. Keifer, and P. Lineback. 1997. Fire management and GIS: a framework for identifying and prioritizing fire planning needs. In: *Proceedings: Fire in California Ecosystems: Integrating Ecology, Prevention, and Management*. San Diego, CA.
- Caprio, A.C. and D.M. Graber. 2000. Returning Fire to the Mountains: Can We Successfully Restore the Ecological Role of Pre-Euro-American Fire Regimes to the Sierra Nevada? U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station. RMRS-P-15-VOL-5: 233-241.
- Caprio, A.C. and P. Lineback. 2002. Pre-Twentieth Century Fire History of Sequoia and Kings Canyon National Parks: A Review and Evaluation of Our Knowledge. In: *Proceedings of the Conference on Fire in California Ecosystems: Integrating Ecology, Prevention, and Management*. Nov. 17-20, 1997, San Diego, CA. AFE Misc. Publ. No. 1.
- Carroll, J., P.R. Miller, and J. Pronos. 2003. Historical perspectives on ambient ozone and its effects on the Sierra Nevada. In: *Ozone air pollution in the Sierra Nevada: distribution and effects on forests*. Bytnerowicz, A., Arbaugh, M.J., and Alonso, R., Eds. In: *Developments in Environmental Science*, Krupa, S.V., Ed. No. 2. Elsevier.

- Chapin, F.S. 1980. The mineral nutrition of wild plants. *Annual Review of Ecology and Systematics* 11: 233-260.
- Dunlap, J. 2006. Blister rust in California's high-elevation pines. *Nutcracker Notes* 10:8–9.
- Duriscoe, D.M. 1990. Cruise survey of oxidant air pollution injury to *Pinus ponderosa* and *Pinus jefferyi* in Saguaro National Monument, Yosemite National Park, and Sequoia and King's Canyon National Parks. NPS/ADQ-90/003. Denver, CO: Air Quality Division, U.S. Department of the Interior, National Park Service. 68 p.
- Duriscoe, D. M., and C. S. Duriscoe. 2002. Survey and monitoring of white pine blister rust in Sequoia and Kings Canyon National Parks: Final report on 1995–1999 survey and monitoring plot network. Science and Natural Resources Management Division Sequoia and Kings Canyon National Parks, Three Rivers, California.
- Ellison, A. M., M. S. Bank, B. D. Clinton, E. A. Colburn, K. Elliott, C. R. Ford, D. R. Foster, B. D. Kloeppel, J. D. Knoepp, G. M. Lovett, J. Mohan, D. A. Orwig, N. L. Rodenhouse, W. V. Sobczak, K. A. Stinson, J. K. Stone, C. M. Swan, J. Thompson, B. von Holle, and J. R. Webster. 2005. Loss of foundation species: consequences for the structure and dynamics of forested ecosystems. *Frontiers in Ecology and the Environment* 3:479-486.
- Eschtruth, A.K. and J.J. Battles. 2009. Assessing the relative importance of disturbance, herbivory, species diversity, and propagule pressure in exotic plant invasion. *Ecological Monographs* 79:265-280.
- Fenn, M.E.; Poth, M.A; Johnson, D.W. 1996. Evidence for nitrogen saturation in the San Bernardino Mountains in southern California. *Forest Ecology and Management* 82: 211-230.
- Fenn, M.E.; Poth, M.A 1999a. Nitrogen deposition and cycling in Mediterranean forests: The new paradigm of nitrogen excess. In: Miller, Paul R.; McBride, Joe R., editors. *Oxidant air pollutant impacts in the montane forests of southern California*. Ecological Studies No. 134. New York: Springer; 288-314.
- Fenn, M.E.; Poth, M.A 1999b. Temporal and spatial trends in streamwater nitrate concentrations in the San Bernardino Mountains, southern California. *Journal of Environmental Quality* 28: 822-836.
- Fites-Kaufman, J., P. Rundel, N. Stephenson, and D.A. Weixelman. 2007. Montane and subalpine vegetation of the Sierra Nevada and Cascade ranges. In: Barbour, M., Keeler-Wolf, T., Schoenherr, A.A. (Eds.), *Terrestrial Vegetation of California*. University of California Press, Berkeley, pp. 456–501.
- Fog, K. 1988. The effect of added nitrogen on the rate of decomposition of organic matter. *Biological Review* 63: 433-462.

- Geils, B. W., K.E. Hummer, Hunt, R.S., 2010: White pines, Ribes, and blister rust: a review and synthesis. *Forest Pathology* 40, 147–185.
- Graber, D.M., S.A. Haultain, and J.E. Fessenden. 1993. Conducting a biological survey: a case study from Sequoia and Kings Canyon National Parks. Pp. 17-35 in *Proceedings of the Fourth Conference on Research in California's National Parks*. S.D. Veirs, Jr., T.J. Stohlgren, and C. Schonewald-Cox, eds. Transactions and Proceedings Series 9. Davis, Calif.: National Park Service.
- Gulke, N. 1998. Physiological responses of ponderosa pine to gradients of environmental stressors. In: *Oxidant air pollution impacts in the montane forests of southern California*, P. R. Miller and J. R. McBride, eds., Springer, New York, 126-163pp.
- Gulke N., H. Preisler, C. Rose, J. Kirsch, and L. Balduman. 2002. Evaluating the role of drought stress on ozone uptake in ponderosa pine. *New Phytologist* 154: 154:621-632.
- Keane, R. E., 2001a: Successional dynamics: Modelling an anthropogenic threat. In: *Whitebark pine communities: Ecology and restoration*. Ed. By Tomback, D. F.; Arno, S. F.; Keane, R. E. Washington, DC: Island Press, pp. 159–192.
- Keane, R. E. and P. Morgan 1994. Decline of whitebark pine in the Bob Marshall Wilderness complex of Montana, USA. Pages 245-253 in W. C. Schmidt and F. K. Holtmeier, compilers. *Proceedings of the International workshop on subalpine stone pines and their environment: The status of our knowledge*. USDA Forest Service. Inter-mountain Research Station, General Technical Report INT-GTR-309, Ogden, Utah.
- Kendall, K. C. 1994. Whitebark pine monitoring network. Pages 109-118 in K. C. Kendall and B. Coen, editors. *Workshop proceedings: Research & management in whitebark pine ecosystems*. USDI National Biological Service, Glacier National Park, West Glacier, Montana.
- Kendall, K. C.; Keane, R. E., 2001: Whitebark pine decline: Infection, mortality, and population trends. In: *Whitebark pine communities: Ecology and restoration*. Ed. By Tomback, D. F.; Arno, S. F.; Keane, R. E. Washington, DC: Island Press, pp. 221–242.
- Kinloch, B. B., Jr., Parks, G. K., and Fowler, C. W. 1970. White pine blister rust: simply inherited resistance in sugar pine. *Science* 167: 193-195.
- Kinloch, B. B. 1992. Distribution and frequency of a gene for resistance to white pine blister rust in natural populations of sugar pine. *Canadian Journal of Botany* 70:1319–1323.
- Kinloch Jr, B. B.; Dulitz, D. J., 1990: White pine blister rust at Mountain Home Demonstration State Forest: a case study of the epidemic and prospects for genetic control. Res. Pap. PSW-204. Berkeley, CA: U.S. Department of Agriculture, Forest Service, Pacific Southwest Research Station. 7 p. [Online]. Available: <http://www.treesearch.fs.fed.us/pubs/30626>

- Landers, D.H., S.L. Simonich, D.A. Jaffe et al. 2008. The Fate, Transport, and Ecological Impacts of Airborne Contaminants in Western National Parks (USA). PA/600/R-07/138. U.S. Environmental Protection Agency, Office of Research and Development, NHEERL, Western Ecology Division, Corvallis, Oregon.
- Lasko, R. J. 1990. Fire behavior characteristics and management implications in whitebark pine ecosystems. Pages 319-324 in W. C. Schmidt and K. J. McDonald, compilers. Proceedings-Symposium on whitebark pine ecosystems: Ecology and management of a high-mountain resource. USDA Forest Service, Intermountain Research Station, General Technical Report INT-270, Ogden, Utah.
- Loope, L. L. and G. E. Gruell. 1973. The ecological role of fire in the Jackson Hole area, northwestern Wyoming. *Quaternary Research* 3:425-443.
- Maloy, O. C., 1997: White pine blister rust control in North America: a case history. *Annual Review of Phytopathology* 35, 87–109. [Online]. doi: 10.1146/annurev.phyto.35.1.87
- McDonald, G.I., Richardson, B.A., Zambino, P.J., Klopfenstein, N.B., and Kim, M.S. 2006. *Pedicularis* and *Castilleja* are natural hosts of *Cronartium ribicola* in North America: a first report. *Forest Pathology* 36: 73–82.
- McKinney, S.T. 2010. Response to request for information on the status and distribution of whitebark pine in Yosemite, Sequoia, and Kings Canyon National Park. NPS Inventory & Monitoring. Sierra Nevada Network. El Portal, CA.
- McKinney, S. T., T. Rodhouse, L. Chow, G. Dicus, L. Garrett, K. Irvine, S. Mohren, D. Odion, D. Sarr, and L. A. Starcevich. 2011. Monitoring white pine (*Pinus albicaulis*, *P. balfouriana*, *P. flexilis*) community dynamics in the Pacific West Region: Klamath, Sierra Nevada, and Upper Columbia Basin Networks. Natural Resource Report NPS/XXXX/NRR—2011/XXX. National Park Service, Fort Collins, Colorado, *in second revision*.
- Miller, P.R. and J.R. McBride. 1999. Oxidant Air Pollution Impacts in the Montane Forests of Southern California: A Case Study of the San Bernardino Mountains. In: *Ecological Studies*, Vol. 134. Springer, New York, 441 pp.
- Murray, M.P., S. C. Bunting, and P. Morgan. 2000. Landscape trends (1753-1993) of whitebark pine (*Pinus albicaulis*) forests in the West Big Hole Range of Idaho/Montana, U.S.A. *Arctic, Antarctic, and Alpine Research* 32, 412-418.
- NatureServe. 2004. Classification of the Vegetation of Yosemite National Park and Surrounding Environs in Tuolumne, Mariposa, Madera and Mono Counties, California. Modified for use in Sequoia and Kings Canyon National Parks. Sacramento, CA 95814
- NPS. 2010. National Park Service Ozone Standard Exceedances in National Parks, 2010 Annual Summary. Online at: <http://nature.nps.gov/air/Monitoring/exceed.cfm>.

- Paine, R.T., M.J. Tegner, and E.A. Johnson 1998. Compounded perturbations yield ecological surprises. Springer-Verlag, Ecosystems 1: 535–545.
- Panek, J.A. 2004. Ozone uptake, water loss and carbon exchange dynamics in annually drought stressed *Pinus ponderosa* forests: measured trends and parameters for uptake modeling. Tree Physiology 24, 277–290.
- Panek, J.A., D. Saah, and A. Esperanza. Air Quality. Appendix X to *Natural Resources Condition Assessment NPS/XXXX/NRCA—20XX/XXX* .
- Schoettle, A.W. 2004. Ecological Roles of Five-Needle Pines in Colorado: Potential Consequences of Their Loss. In: Snieszko, Richard A.; Samman, Safiya; Schlarbaum, Scott E.; Kriebel, Howard B., eds. 2004. Breeding and genetic resources of five-needle pines: growth, adaptability and pest resistance; 2001 July 23–27; Medford, OR, USA. IUFRO Working Party 2.02.15. Proceedings RMRS-P-32. Fort Collins, CO: U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station.
- Steele, R. W. 1960. The role of forest fire in the Bob Marshall Wilderness Area. Montana Forest and Conservation Experiment Station, School of Forestry, University of Montana Report #1, Missoula.
- Sullivan, T., D. Pearson, C. Blanchard, and S. Tanenbaum. 2001. Assessment of Air Quality and Air Pollutant Impacts in Class I National Parks of California. April 1 2001. In cooperation with National Park Service Air Resources Division.
- Takemoto, B.K.; Bytnerowicz, A.; Fenn, M.E. 2001. Current and future effects of ozone and atmospheric nitrogen deposition on California's mixed conifer forests. Forest Ecology and Management 144: 159-173.
- Temple, P.J., A. Bytnerowicz, M. E. Fenn, and Mark A. Poth. 2005. Air Pollution Impacts in the Mixed Conifer Forests of Southern California. USDA Forest Service Gen. Tech. Rep. PSW-GTR-195.
- Tombac, D. F., and P. Achuff. 2010. Blister rust and western forest biodiversity: ecology, values, and outlook for white pines. Forest Pathology 40:186-225.
- Tombac, D.F., Arno, S.F. and Keane, R.E. (Eds.) 2001. Whitebark Pine Communities - Ecology and Restoration. Island Press. 440 pp.
- US Environmental Protection Agency. 1980. Photochemical Oxidant Air Pollution Effects on a Mixed Conifer Forest Ecosystem (Ed. O.C. Taylor). EPA.600/3-80-002, Environmental Protection Agency, Corvallis, OR.
- USGS-NPS. Vegetation Mapping Program. 2007. Sequoia and Kings Canyon National Parks photo interpretation report. Three Rivers, California.

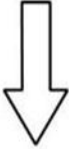
- van Mantgem, Phillip J., Nathan L. Stephenson, MaryBeth Keifer, and Jon Keeley. 2004. Effects of an introduced pathogen and fire exclusion on the demography of sugar pine. *Ecological Applications* 14:1590–1602.
- van Mantgem, P. J. and N. L. Stephenson. 2007. Apparent climatically induced increase of tree mortality rates in a temperate forest. *Ecology Letters* 10:909-91

Appendix 1

Appendix 1. Species list for all trees in Natural Resource Inventory database for Sequoia-Kings Canyon National Parks. The JCODE abbreviation and common name are referenced throughout this report.

JCODE	Genus	Species	Subspecies	Common name
ABCO10	<i>Abies</i>	<i>concolor</i>		white fir
ABMA10	<i>Abies</i>	<i>magnifica</i>	<i>magnifica</i>	California red fir
ABMA11	<i>Abies</i>	<i>magnifica</i>	<i>shastensis</i>	Shasta red fir
ACMA10	<i>Acer</i>	<i>macrophyllum</i>		big-leaf maple
AECA10	<i>Aesculus</i>	<i>californica</i>		California buckeye
ALRH10	<i>Alnus</i>	<i>rhombifolia</i>		white alder
CADE10	<i>Calocedrus</i>	<i>decurrens</i>		incense cedar
CEBE10	<i>Cercocarpus</i>	<i>betuloides</i>		birchleaf mountain
CEOC10	<i>Cercis</i>	<i>occidentalis</i>		western redbud
CONU10	<i>Cornus</i>	<i>nuttallii</i>		mountain dogwood
FRDI10	<i>Fraxinus</i>	<i>dipetala</i>		California ash
JUOC10	<i>Juniperus</i>	<i>occidentalis</i>	<i>australis</i>	Sierra juniper
PIAL10	<i>Pinus</i>	<i>albicaulis</i>		whitebark pine
PIBA11	<i>Pinus</i>	<i>balfouriana</i>	<i>austrina</i>	foxtail pine
PICO10	<i>Pinus</i>	<i>contorta</i>	<i>murrayana</i>	lodgepole pine
PIFL10	<i>Pinus</i>	<i>flexis</i>		limber pine
PIJE10	<i>Pinus</i>	<i>jeffreyi</i>		jeffrey pine
PILA10	<i>Pinus</i>	<i>lambertiana</i>		sugar pine
PIMO10	<i>Pinus</i>	<i>monophylla</i>		single leaf pinyon pine
PIMO20	<i>Pinus</i>	<i>monticola</i>		western white pine
PIPO10	<i>Pinus</i>	<i>ponderosa</i>		pacific ponderosa pine
PIPO11	<i>Pinus</i>	<i>ponderosa x jeffreyi</i>		
PLRA10	<i>Platanus</i>	<i>racemosa</i>		western sycamore
POBA11	<i>Populus</i>	<i>balsamifera</i>	<i>trichocarpa</i>	black cottonwood
POTR10	<i>Populus</i>	<i>tremuloides</i>		quaking aspen
PREM10	<i>Prunus</i>	<i>emarginata</i>		bitter cherry
QUCH10	<i>Quercus</i>	<i>chrysolepis</i>		canyon live oak
QUDO10	<i>Quercus</i>	<i>douglasii</i>		blue oak
QUKE10	<i>Quercus</i>	<i>kelloggii</i>		California black oak
QUWI10	<i>Quercus</i>	<i>wislizeni</i>	<i>wislizeni</i>	interior live oak
RHIL11	<i>Rhamnus</i>	<i>ilicifolia</i>		holly-leaf redberry
SASC21	<i>Salix</i>	<i>scouleriana</i>		Scouler's willow
SEGI10	<i>Sequoiadendron</i>	<i>giganteum</i>		giant sequoia
TOCA10	<i>Torreya</i>	<i>californica</i>		California nutmeg
TSME10	<i>Tsuga</i>	<i>mertensiana</i>		mountain hemlock
UMCA10	<i>Umbellularia</i>	<i>californica</i>		California bay

Appendix 2. Master Symbology Table Used in Condition Assessment Maps

STATUS				
	Good	Moderate	Poor	No Information
TREND				
	Improvement	No Change	Decline	No Information
CONFIDENCE				
	High	Medium	Low	No Information

The Department of the Interior protects and manages the nation's natural resources and cultural heritage; provides scientific and other information about those resources; and honors its special responsibilities to American Indians, Alaska Natives, and affiliated Island Communities.

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