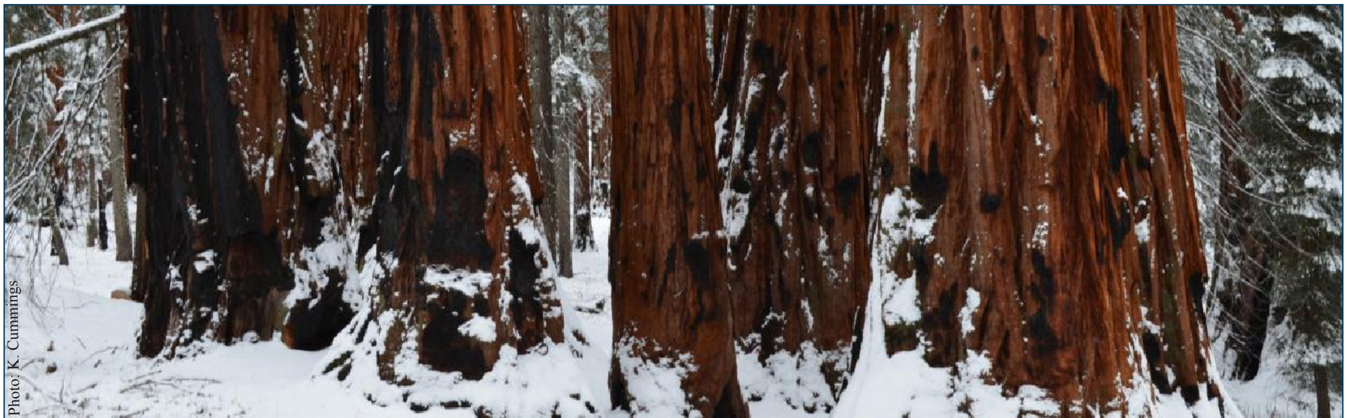

Giant Sequoia Groves

A Southern Sierra Adaptation Workshop Information Brief

DISTRIBUTION

The giant sequoia, *Sequoiadendron giganteum,* is found only within a 400 km (250 mi) long, 15 km (9 mi) wide belt along the western Sierra Nevada range, within elevations of 1,400-2,150 m (4,600-7,000 feet) depending on latitude. There are 75 groves of the giant sequoia, covering about 17,500 hectares[1](Figure 1). Groves are dominated by white fir, followed by sugar pine and giant sequoia[2].

PAST AND CURRENT MANAGEMENT

Past management actions that have affected current conditions of giant sequoia include logging, fire exclusion, and prescribed fire. Until 1980, 23% of grove area was commercially logged; 6% was selectively logged by the USFS until 1992[1,3]. As of 1996 over half of all groves prohibited commercial logging and prescribed fires, while 18% were protected from commercial logging and treated with prescribed fires. Currently, all agencies prohibit logging for sequoia commercial purposes within groves (although CDF allows commercial harvesting in young sequoia plantations near Mountain Home Grove[4]). Prescribed fire, managed wildfires, and/or mechanical thinning are used to manage grove conditions, although not all groves are treated (see Table 1 for justifications for using different management techniques). Some USFS lands also have a silviculture program and have plantations of planted sequoias[57]. Constraints on active management of groves include low risk tolerance for escaped fires, effect of smoke emissions on air quality, public opposition to thinning, costs, and potential scarring of iconic giant sequoia trees (see Figure 2). As a result, less than 20% of the forests in Sierra Nevada are currently receiving fuels treatments[5].

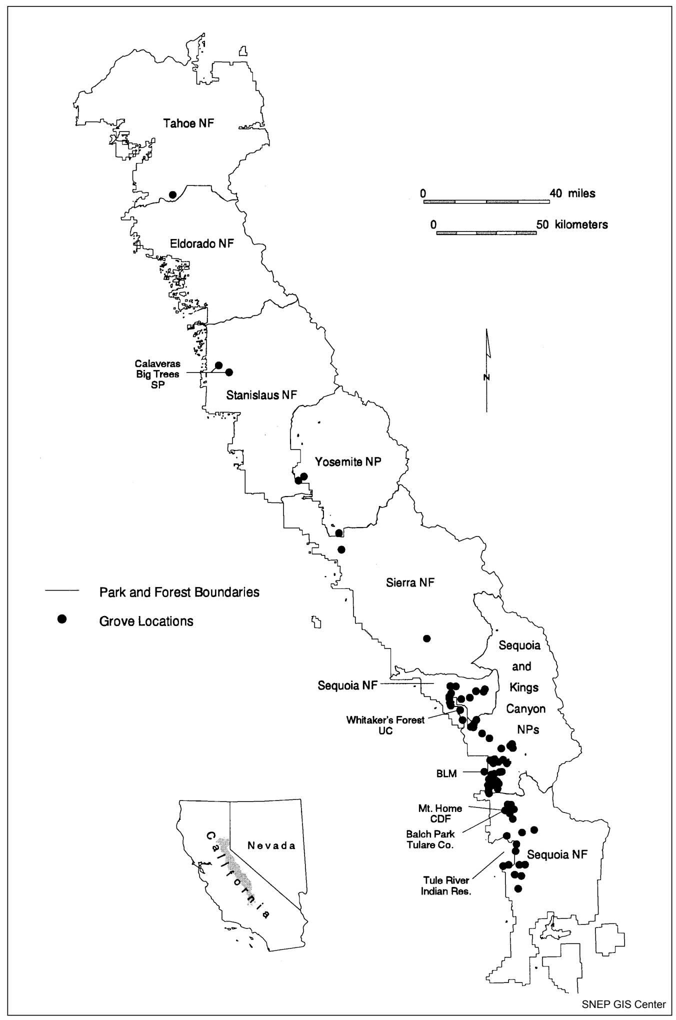

Figure 1: Location of giant sequoia groves. The USFS manages nearly half of grove area, while 28% is managed by NPS, 1% by the BLM, 11% by other public agencies (including CDF, CDPR, UC system, and Tulare County), 8% by private owners, and 4% by the Tule River Indians[3]. (Figure adapted from Sierra Nevada Ecosystems Project 1996)

Agency Abbreviations: **BLM** (Bureau of Land Management); **CDF** (California Department of Forestry and Fire Protection); **CDPR** (California Department of Parks and Recreation); **GSNM** (Giant Sequoia National Monument); **INF** (Inyo National Forest); **NPS** (National Park Service); **SEKI** (Sequoia - Kings Canyon National Parks); **SNF** (Sierra National Forest); **SQF** (Sequoia National Forest); **UC** (University of California); **USFS** (U.S. Forest Service); **YOSE** (Yosemite National Park)

Table 1: The most commonly used management tools for giant sequoia groves, their justifications and constraints				
Justifications (Positive Effects)	**Prescribed Fire**	**Mechanical Thinning**	**Mechanical Thinning + Planting**	**Mechanical Thinning + Prescribed Fire**
Creates conditions most similar to pre-Euroamerican arrival[3]	X			X
Greatly stimulates sequoia seed release[3]	X			X
Reduces density of non-sequoia understory growth[3,9]	X	X	X	X
Opens gaps which allow sunlight penetration to forest floor[3]	X	X	X	X
Kills pathogens in soil that affect sequoia seedlings[3]	X			X
Creates better soil conditions for sequoia germination: ash instead of bare mineral soil, more acidic pH and added nutrients to soil, burns away duff[4,10]	X			X
Reduces fuel load and likelihood of high severity fires that could kill adult sequoia	X	X	X	X
Promotes a significantly larger young age-class[11,12,13]	X		X	X
Increases structural heterogeneity within stands[14,15]	X	decreased	decreased	X
Increase in height and diameter of mature sequoias[16,17,18,19]	X	X	X	X
Reduces fuel load below an extreme level before fire is used[20,21]				X
Constraints (Negative Effects)				
Air quality regulations[4]	X			X
Risk of fire damage to human establishment	X			decreased
Little to no new regeneration of sequoia[3,4,22]		X	X	
Cost per acre for NPS (1970-2011)[5]*	$143-458	No data	No data	No data
Cost per acre for USFS (2004-2011)[5]*	$72-619	$252-1077	No data	No data
Creation of entry points for pathogens via cut stumps[3,23]		X	X	X
Creation of entry points for pathogens via tree scars[3]	X			X
Potential for soil compaction and erosion[3]		X	X	X
Potential for introduction of invasive plant species	X	X	X	X
Creation of roads and other access infrastructure		X	X	X
Burns of insufficient intensity to facilitate sequoia regeneration [24]	X			X

*Lands included were SEKI, YOSE, INF, SNF, and SQF. Costs were higher per acre for NPS because less acreage was burned, and prescribed burning cost decreases with acreage.

STRESSORS AND CURRENT GROVE CONDITIONS

Regeneration is one of the largest issues facing the future of the giant sequoia. Sequoias are dependent on fire and high soil moisture for successful regeneration. A proxy often used to assess grove condition is the fire return interval departure (FRID)[6]. Based on the reconstructed fire regime prior to Euroamerican settlement, low FRIDs indicate that the last fire occurred within the historic interval and extreme FRIDs indicate that five or more return intervals have passed.

In a study conducted on 70 groves located within SEKI, SNF, GSNM, UC, and CDF lands, most groves were between high and extreme departures of their natural fire interval (3 groves had low FRID, 5 had moderate, 10 had high, and 52 had extreme FRID)[6]. Furthermore, less than 20% of the Sierra Nevada's forests are receiving the fuels treatments necessary to return the forest to its natural FRID. Beyond regeneration, mortality rates of tree species co-occurring with sequoias have doubled in recent decades, possibly a consequence of warming over the last century[7,8] (although monitoring data are inadequate to determine whether mortality has increased in the sequoias themselves). See Table 2 for current and future stressors affecting giant sequoias and their adaptive capacity.

POSSIBLE FUTURE CHANGES AND SEQUOIA ADAPTIVE CAPACITY

Although predicting future climates is extremely complex, the climate models driven by the three main IPCC emission scenarios agree that temperature in the southern Sierra Nevada will warm, with predictions between +2.6 to 3.9°C by 2100[25]. Less certain is the change in precipitation – of the 18 general circulation models that include California, about half predict decreases and half predict increases for the Sierra region[25]. Even with little changes in precipitation, effective drought will increase as snow melts earlier and evaporative demand increases, and could cause changes in wildfire regimes, snowmelt patterns, and more (see Table 2).

Sequoias will be most affected by changes in fire regime and water availability, as these are the two factors most influencing their regeneration. Sequoias require relatively higher soil moisture, although their exact water requirements remain undefined. The water holding capacity of soils within study groves in SEKI was significantly higher than surrounding conifer forests[26], and one study in SQF showed that moisture was still available for uptake in the underlying bedrock[27]. The authors estimate that annual precipitation of less than 68 cm would fail to maintain this water source on upland sites past late summer. The average precipitation for 70 groves studied within SEKI, SQF, and GSNM was estimated to be 104 cm/yr, with a range from 69-115 cm/yr. If precipitation decreases, as some climate change scenarios predict, sequoias will face longer periods of drought during their growing season. Figure 3 shows projection of potential climate stress for giant sequoia groves under two different scenarios.

Giant sequoia have already shown vulnerability to warmer temperatures and the subsequent increase in drought stress in the past. Based on pollen records, giant sequoia experienced population decreases during the slightly warmer time period of 10,000-4,000 years ago[28]. Today's grove structure and locations may not be viable for the species in the future as their required climatic conditions could move higher in elevation and northward, forcing a range expansion away from the warmer and drier conditions that may be found at their current elevation range[4]. It is unknown if giant sequoia will be able to successfully migrate or if the future survival of these groves will necessitate assisted migration.

POTENTIAL MANAGEMENT STRATEGIES (WORK IN PROGRESS)

- To manage for persistence:
  - Plant and irrigate seedlings
  - Suppress fires with high risk of severity and stand replacement
  - Install fuel breaks along strategic locations to limit fire spread
  - Mechanically thin forest or use prescribed fire to reduce competition for moisture
  - Promote sequoia regeneration and forest heterogeneity with prescribed fire
- To manage for change:
  - Plant groves with drought resistant species and genotypes
  - Assist migration upslope to suitable areas for sequoia
- Delay deciding (monitor and research):
  - Monitor moisture stress
  - Research moisture requirements
  - Monitor sequoia regeneration
  - Monitor for pathogen outbreaks

Authorship Note

This information brief was created by Katy Cummings (NPS) and Koren Nydick (NPS), with review and contributions from Tony Caprio (NPS), Nate Stephenson (USGS), and Eric Winford (NPS).

Figure 2: Although fire can scar charismatic giant sequoia (left), it also creates a good environment for sequoia regeneration (right). Photo Credits: K. Cummings, NPS (left) & BLM (right).

Table 2: Current stressors, potential climate change impacts, and characteristics affecting adaptive capacity for the giant sequoia grove ecosystem

Current Stressors	Potential Impacts to Ecosystem	Potential Impact to Sequoia
Wildfire Exclusion	Homogeneous soils[29]; higher proportion of dense intermediate-aged forest patches to young patches[11,12,13]; closed forest conditions with fewer gaps[9]; lower shrub/herb abundance[22]; buildup of surface fuels[20,21]	Halted regeneration; increased likelihood of catastrophic fire; pest and pathogens infection more likely[3]
Air Pollution	Increased ozone levels	Foliar injury; lowered photosynthetic efficiency in seedlings and saplings[30,31]
	Nitrogen deposition	Reduced germination success from long-term reductions in litter decomposition rates and resulting thick litter layer; competitive advantage for species that can rapidly utilize extra N[32]; reductions in fine root biomass, increased [N] in streams, increased volatilization of N from soil, decreased C:N in soil and foliage, nitrate accumulation in foliage, altered rates of letter decomposition[33,34]
Pathogens and Pests	Infections to neighboring trees from annosus root rot (usually infects white fir) and amarillaria root disease that may touch roots with sequoia, especially in dense groves[23,35,36]. Dense stands of white fir also increase likelihood of carpenter ant infestations in sequoia[23] and bark beetle impacts to non-sequoia trees in groves[37]	Structural failure from annosus root rot and amarillaria root disease infecting roots and carpenter ants building galleries in wood[23,38,39]. Some amount of seedling predation by camel crickets, two species of geometrid moths, nematodes, meadow mice, and gophers[23]
Human Recreational Use	Soil compaction[52]; loss of soil around tree roots[40,52]	Reduced regeneration[4]; potential for increased mortality of mature trees via pathogens[4]
	Introduction of invasive plant species[3]	Reduced regeneration; alteration of fire regimes and nutrient cycling[3]
Potential Climate Change Impacts	**Potential Results**	**Potential Impact to Sequoia**
"Much Warmer/Much Drier" Scenario	Earlier and more rapid snowmelt[41]; decrease in snow pack[43]; changes in sub/surface hydrology; increased soil evaporation rate in summer[4]	Sequoia experiences drought conditions during summer growing season[42,43,44]
	Drought conditions during growing season[4]	Weakens/makes sequoia more susceptible to insect attack, disease, air pollution, etc.
	Expanding ranges of sequoia pests and pathogens[4]	Increase mortality of sequoia
	Increased fire probability at all elevations except foothills and alpine areas[45,46]; increased area burned[47]; increased frequency in SEKI/ YOSE[48]	Increase mortality of adult sequoia[49,50,51]
	Shift in range following desirable temp/ precipitation patterns for SEGI	Sequoia may move higher in elevation and northward
	Shift in plant species composition[4]	Unknown impacts for sequoia
"Moderately Warmer/Similar Precip" Scenario	Increased fire probability at almost all elevations except alpine areas[46]	Increase mortality of adult sequoia[49,50,51]
Vulnerabilities	**Explanation**	**Potential Impact to Sequoia**
Sensitivity to Moisture Levels	Although exact requirements unknown, sequoias require high soil moisture. Precipitation <68 cm may fail to maintain water available for uptake throughout the summer[27]	Regeneration failure and mortality of or weakened adult trees
Limits on Dispersal and Reproduction	Slow maturation: 20 yr until seed production, and 200 yr until max. seed production; limited seed dispersal: >400 m[52,53] with wind; little assistance through animal vectors[4]; low seed germination success[4]	Sequoia may not be able to expand range as fast as environmental conditions may change
Narrow Environmental Growth Range	Sequoias constrained by areas with cool, wet winters, warm summers with high moisture availability during growing season, and frequent fire[4,54,55]	Increased mortality of some groves if locations are no longer within desired environmental parameters; unknown if sequoia will be able to track parameter shifts across landscape
Decreased Genetic Diversity	Past contractions of sequoia population from climate changes may have decreased genetic diversity[3]	May decrease adaptive capabilities[3]
Synergistic Effects	Already weakened sequoias may become more vulnerable to new stressors and new combinations of stressors from climate change	

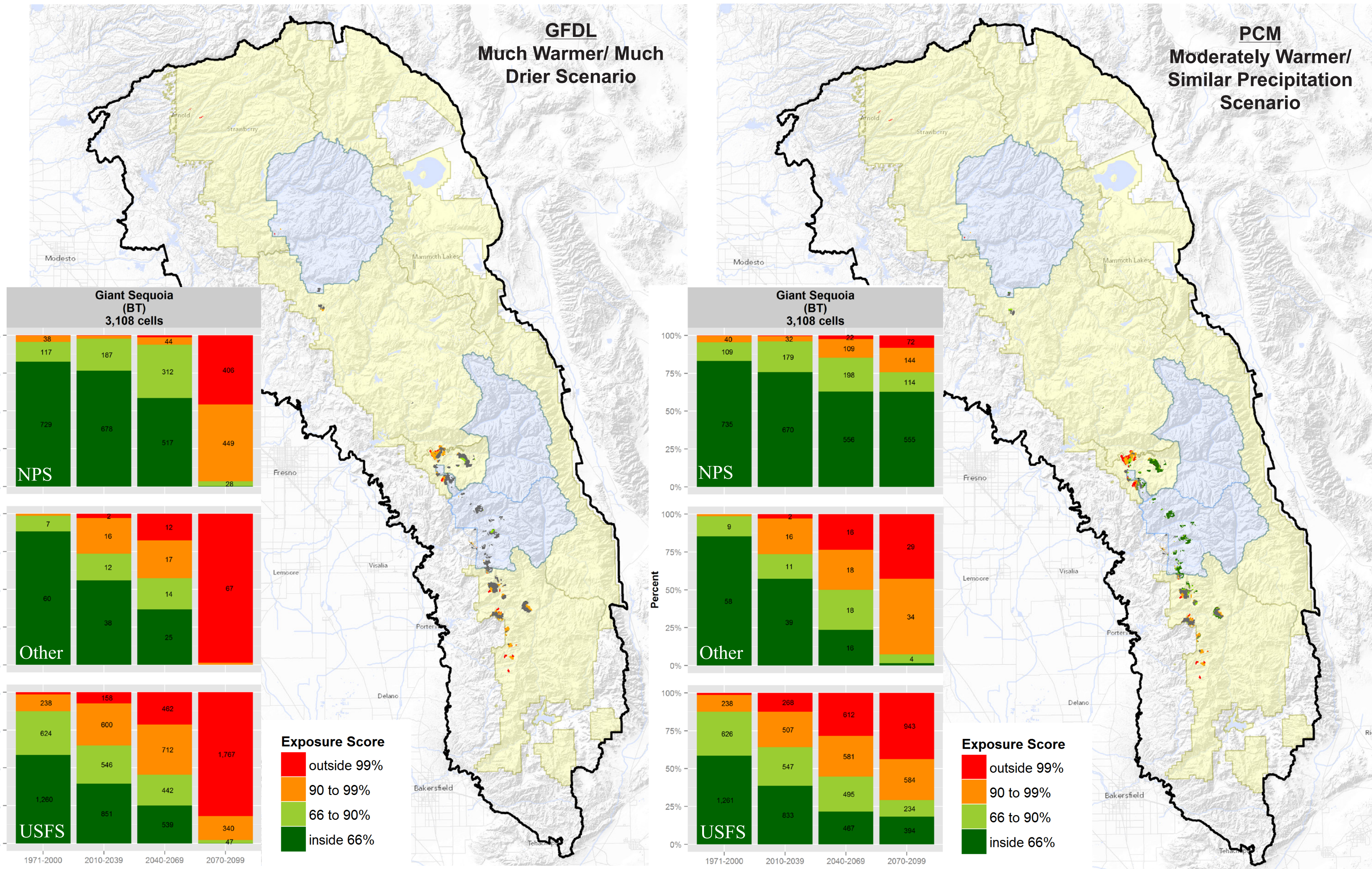

Figure 3 . Two scenarios of future climate exposure for giant sequoia groves in the southern Sierra Nevada study area. Maps show grove area predicted to be at risk soonest (high exposure in 2010-2039) in red and orange; resilient longest (low exposure in 2070-2099) in dark and light green; and at risk later (high exposure by 2070-2099) in gray. Blue borders = NPS; yellow shading = USFS. Bar graphs show percent of study area falling within different climate exposure score categories over time (1971-2000; 2010-2039; 2040-2069; 2070-2099) for NPS, other, and USFS lands. Exposure score percentiles are based on projected future climate conditions compared to the baseline (1971-2000) climate envelope for giant sequoia groves. These results use the IPCC A2 emissions scenario. From Schwartz et al. In Prep.

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