



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

Appendix 21 – Altered Fire Regimes

Natural Resource Report NPS/SEKI/ NRR—2013/665.21



ON THE COVER

Giant Forest, Sequoia National Park
Photography by: Brent Paull

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John J. Battles
Dept. of Environmental Science, Policy, and Management
UC Berkeley
130 Mulford Hall #3114
Berkeley, CA 94720

Tadashi Moody
Spatial Informatics Group
3248 Northampton Ct.
Pleasanton, CA 94588 USA
www.sig-gis.com

David S. Saah
Spatial Informatics Group
3248 Northampton Ct.
Pleasanton, CA 94588 USA
www.sig-gis.com

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Scope of the analysis

A suite of abiotic and biotic stressors poses risks to the ecological integrity of Sequoia-Kings Canyon National Parks (SEKI, Exline et al. 2009). Foremost among these is the alteration of temporal and spatial characteristics of fires, or the fire regime. Disruption of fire regime in Sequoia-Kings Canyon National Parks since 1860 has created the potential for large, uncharacteristically severe fires in forests where such catastrophic events happened rarely, if ever, in the past (Caprio and Graber 2000).

Because the Sierra Nevada encompasses such wide latitudinal and elevational ranges, its ecological communities vary dramatically. Grasslands and woodlands occur in the foothills; conifer forests dominate the midslopes; and alpine barrens cover the mountain peaks. However, in virtually all zones where burnable vegetation is present, fire plays an important role (Skinner and Chang 1996). Various reconstruction methods such as sediment records, pollen and macrofossils, and tree fire scar records on the long-lived giant sequoia (*Sequoiadendron giganteum*) and other species indicate that fire has been present for millennia in the Sierra Nevada (Sugihara et al. 2006). Evidence of Native American use of fire for cultural purposes dates back nearly 9,000 years (Anderson and Moratto 1996).

Settlement in the Sierra Nevada in the mid-19th century by European Americans started the shift in the natural fire regimes. However the policy of comprehensive fire exclusion applied throughout the first half of the 20th century has caused widespread changes in Sierra Nevada vegetation (Gruell 2001). The impact of this policy on the fire regime for particular vegetation types is evident in many lines of fire history evidence. Lower- and middle-elevation montane forests are of particular concern. Here, the lack of periodic low- and mixed-intensity fires has led to an increase in tree density, a buildup of forest fuels, and a more continuous fuel supply (Sugihara et al. 2006, Collins et al. 2011). As a result, many of these forests are at risk today of large, uncharacteristically severe wildfires that may impose long-term damage to these ecosystems (Miller et al. 2009). Current research also suggests that some of the observed trends in fire frequency, timing and severity may be tied to ongoing shifts in the climate (Westerling et al. 2006).

Managers and scientists from Sequoia-Kings Canyon (SEKI) and Yosemite National Parks were among the first public land managers to recognize the dangers caused by comprehensive fire exclusion and suppression. In 1968, the US National Park Service adopted a policy that included fire management as an approach to “preserve natural conditions” as stipulated in the 1964 Wilderness Act (Stephens and Ruth 2005). As a result, programs were started in these parks in the late 1960’s and early 1970’s that not only incorporated management ignited prescribed fire, but also allowed fires in certain designated regions to burn, in order to achieve management goals such as fuels reduction and ecosystem process restoration (Caprio and Graber 2000, Collins and Stephens 2007). A joint federal program in the late 1990’s defined these management fires as “Wildland Fire Use for Resource Benefit” (WFU fires), but adoption of these principles and techniques outside of the National Parks has been slow to take hold. For example, in the National Forests, the emphasis has been on mechanical fuel treatments as a way to restore ecosystem structure and protect resources, guided by such planning processes as the National Cohesive Wildland Fire Management Strategy (Forest and Rangelands 2011) and the Sierra Nevada Forest Plan Amendment (SNFPA 2004). Both management fires and mechanical

fuel treatments face serious obstacles, as land managers in the Sierra Nevada attempt to use them as tools to treat millions of at-risk acres (Sugihara et al. 2006, Keeley et al. 2009).

In addition to increased fire hazard, these altered fire regimes can act as stressors themselves on various elements of the ecosystem. Many plant species in fire-prone ecosystems have evolved with fire as a regular perturbation. Their life history characteristics (e.g. reproduction and growth) are tied to specific aspects of the fire regime. Thus changes to the associated fire regimes may have consequences for their persistence (Webster and Halpern 2010, Keeley 2010). Overall forest health involves complex interactions among the primary agents of disturbance: fire, insects, and diseases. Perturbations of one agent can accentuate the risk posed by the others. For example, in Yosemite National Park, fire suppression in the last century has led to increases in tree density and shifts in composition toward more shade-tolerant species in the unmanaged Sierran conifer forests (Collins et al. 2011, Scholl and Taylor 2010). The density and homogeneity of the contemporary forests put them at greater risk for insect outbreaks and disease irruptions, as well as greater crown fire potential. Changes in fire behavior such as increased intensity and crown fire may also affect insect and disease levels. The spread of invasive species can be affected by uncharacteristically severe wildfires. For example, the disturbance to the soil caused by wildfire can promote the establishment of invasive plants (Lambert et al. 2010). Wildlife, water quality and air resources are all tied to the spatial and temporal patterns of fire regimes.

Critical questions

Given the importance of fire in the SEKI landscape, we characterize both the temporal and spatial trends in fire extent, frequency, and severity. Here we focus on fire's role as stressor since alterations to the fire regime can impact multiple focal natural resources. Specifically we ask:

1. What is the contemporary fire history of SEKI (1917-2010)?
2. How much does the current frequency and extent of fire vary from the pre-settlement fire regime?
3. How does the current fire hazard vary across the landscape?
4. What are the projected trends in wildfire risk for SEKI with a changing climate?

Data sources and types used in analysis

1. Fire perimeter maps.

Historical fire perimeters for both prescribed and wildfires within SEKI were obtained from the California Department of Forestry and Fire Protection Fire Resources Assessment Program (FRAP). FRAP maintains a statewide database, updated annually (FRAP 2010). The data is complete from 1917 through 2010 and includes all reported fires greater than 4 ha (10 ac) for timberlands, greater than 20.2 ha (50 ac) for shrublands, and greater than 121.5 ha (300 ac) for grasslands. Note that the footprint of the Parks has grown since 1917. Thus some of the historical fires were outside of National Park Service (NPS) management and reporting protocols. Nevertheless, the fire history of these lands is relevant to the current and future condition of the Parks. Therefore we conducted the analysis for the contemporary boundaries of SEKI. Also, the FRAP database is a compilation of information from multiple sources including the NPS and the US Forest Service. Each agency has its own conventions for recording and reporting wildfires. For the sake of consistency, we used the fire perimeter records consolidated and archived by FRAP for this analysis.

2. The SEKI vegetation map.

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 vegetation classifications to inform our spatial analysis of fire frequency in the Parks.

3. Pre-settlement fire return interval (FRI) and departure index (FRID).

Fire return interval (FRI) for a particular place on a landscape is defined as the time between subsequent fires. Pre-settlement (i.e., before European American settlers arrived) fire return intervals have previously been estimated for different vegetation types in SEKI through a variety of methods, including fire scar studies in timbered areas, increment core studies examining

regeneration patterns, investigation of Native American cultural practices, and paleoecological studies (Caprio and Lineback 2002).

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, termed the Fire Return Interval Departure index (FRID). FRID values represent the ratio of the time since last fire to the pre-historic fire return interval. In SEKI in 2010, the indices ranged from -1 (recently burned area) up to 17 which indicates that the time since last fire is 17 times longer than the historic fire return interval. See Caprio et al (1997) for a complete discussion of the index. Below we briefly summarize its calculation and application.

The FRID is a way to compare the current “time since last fire” (TSLF) to the estimated pre-settlement FRI. It is the ratio of the difference between the current and expected TSLF, and the expected maximum TSLF (Caprio and Graber, 2000).

$$(1) \text{ FRID} = (\text{TSLF} - \text{RI}_{\text{max}}) / \text{RI}_{\text{max}}$$

where: FRID = fire return interval departure index

TSLF = time since last fire

RI_{max} = maximum average return interval for the vegetation class

Negative FRID index values indicate areas where the expected return interval has not been exceeded. Zero or positive return intervals indicate areas where the expected maximum return interval has been equaled or exceeded. Each unit of the index indicates the number of return intervals exceeded.

FRID values are updated for SEKI each year to account for the most recent fires. FRID scores are also classified into general departure classes as follows:

1 = Extreme (5 or more maximum return intervals surpassed)

2 = High (between 2 and 5 maximum intervals surpassed)

3 = Moderate (between 0 and 2 maximum intervals surpassed)

4 = Low (the last fire occurred within the maximum interval time period, ≤ 0)

To explore recent trends in the fires regime, we quantified changes in FRID at SEKI from 1996 through 2010. As reported in Caprio and Lineback (2002), the natural fire return interval varies greatly across the SEKI landscape. For example, ponderosa pine forests are expected to burn with a mean frequency of every four years while subalpine conifer stands are estimated to burn with a mean frequency of every 187 years. Thus the vegetation map for SEKI serves as the baseline reference for the FRID estimates. In 2007, a new vegetation map for SEKI was implemented. To avoid confounding differences in the vegetation map with differences in the fire regime, we evaluated trends in the FRID for time frames where the underlying vegetation map was consistent. Therefore we report FRID trends from 1996 through 2005 and from 2007 through 2010. We omitted 2006 from the analysis to provide a clean break between the two periods. A longer retrospective analysis is possible – FRID can be calculated from annual fire

perimeter data and vegetation maps. However we restricted this analysis to the available information.

4. Fire hazard severity zones (FHSZ).

FRAP developed the fire hazard severity zones (FHSZ) to map areas of significant fire hazards in California based on fuels, terrain, weather, and other relevant factors. The model attempts to characterize fire hazard using information on expected rate-of spread, past fire history and asset exposure. The data used here represent the FHSZ's adopted by California Department of Forestry and Fire Protection in 2007 (FRAP 2010).

5. Fire risk projections to 2085.

We obtained fire risk data (Westerling and Bryant 2008) to explore the potential changes in burned area for SEKI under various climate change scenarios. The data model the ratio of additional fire risk for an area as compared to the expected burned area for each grid cell. The ratio of additional risk was calculated for 30 year averaged periods ending 2020, 2050, and 2085, for three global circulation models and two emissions scenarios.

As noted by Westerling and Bryant (2008), climate affects wildfire risk primarily through its effect on moisture availability. Indeed, the observed increase since the mid-1980's in wildfire activity in the forests of the American West was associated with increased spring and summer temperatures and earlier snowmelt (Westerling et al. 2006). The fire risk model used projections of future climate for California to estimate the potential changes in wildfire due to climate effects on moisture availability.

Westerling and Bryant (2008) obtained results from three global climate models (GCMs) where downscaled data were available on a daily basis (Cayan et al. 2008). The three models were the GFDL model (version CM2.1, NOAA Geophysical Dynamics Laboratory, Princeton New Jersey), the CNRM model (Center National Weather Research, Toulouse, France), and the PCM1 model (National Center for Atmospheric Research in Boulder, Colorado). They used the downscaled data from the nearest grid point (1/8 degree grid) to project statewide changes. Impacts were analyzed for two greenhouse gas emissions scenarios: A2 (relatively high emissions) and B1 (low emissions). For the A2 scenario, carbon dioxide (CO₂) emissions continue to climb throughout the century, reaching almost 30 Gt yr⁻¹ (gigatonnes per year), so that by the end of the century CO₂ concentration reaches more than triple its pre-industrial level. For the B1 scenario, CO₂ emissions peak just below 10 Gt yr⁻¹ in mid-century before dropping below present-day levels by 2100. The B1 scenario corresponds to a doubling of CO₂ concentration relative to its pre-industrial level by the end of the century (Cayan et al. 2008).

The six possible climate scenarios (3 GCM's and 2 emission scenarios) predicted consistent increases in air temperature during the next century but the magnitude of the increases vary by model and by location. Changes in precipitation were more variable and generally of much smaller magnitude. In all cases future projections diverged more sharply for the A1 emissions scenario (Cayan et al. 2008). We used the interactive data server and visualization tool, Cal-Adapt, to extract the projections for the two grid-points that fell within SEKI (Cal-Adapt 2011).

Reference conditions

We followed the approach of Caprio and Graber (2000) by defining the reference condition as the fire regime in SEKI prior to Euro American settlement (1860). As explained in Caprio and Lineback (2002), the unaltered fire regime varies greatly by vegetation type and aspect. They identified 12 different vegetation classes with mean fire return intervals that range from 4 years (Ponderosa Mixed Conifer) to 187 years (Subalpine Conifer) and burn rates from 136 ha yr⁻¹ (Meadows) to more than 3,000 ha yr⁻¹ (White Fir Mixed Conifer, Ponderosa Mixed Conifer). Also fire frequency varies by aspect with south facing slopes burning on average about three times more often for a given vegetation type (Caprio and Graber 2000). For the SEKI landscape, Caprio (2009) provided the most up-to-date reconstruction of the unaltered fire regime (Fig. 1). Based on extensive fire history research, Caprio and Lineback (2002) provide a range of average annual fire extent (unaltered) in SEKI from 11,776 ha yr⁻¹ to 7,140 ha yr⁻¹. By definition (Caprio et al. 1997), the reference condition in regard to the FRID is 0.

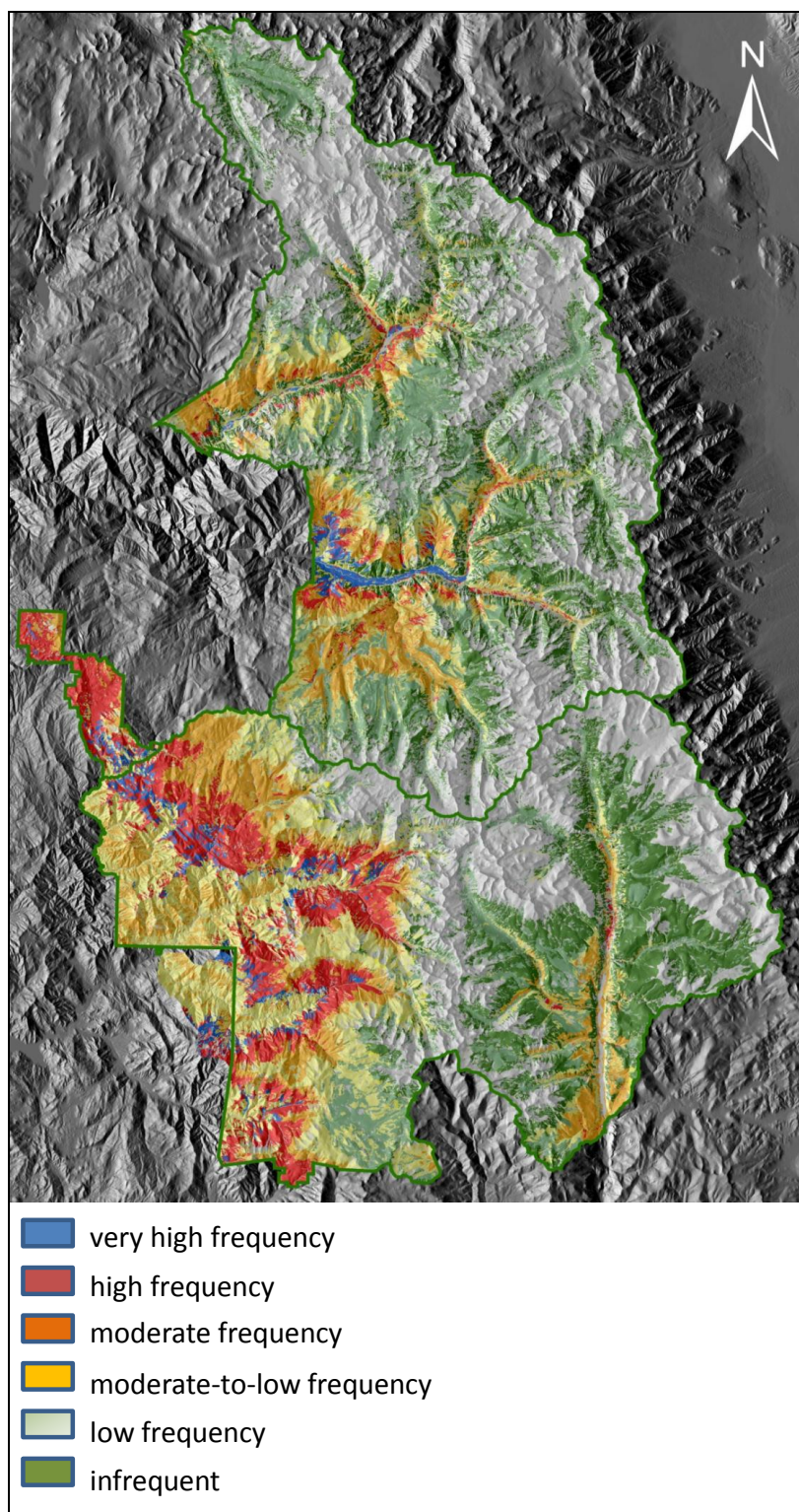


Figure 1. Distribution of fire frequency on the SEKI landscape before Euro American settlement. From Caprio 2009. Frequency classes are: very high = <7 yr, high = 7 to 16 yr, moderate = 17 to 25 yr, moderate-low = 26 to 100 yr, low = >100 yr, and infrequent = fire occurrence is rare to none (Caprio and Lineback 2002).

Temporal and spatial analyses

Contemporary Fire History

Fire histories for particular landscapes can be described in terms of the mean and variance in fire extent, frequency, severity, and seasonality. Alterations to any of these characteristics may have effects on ecosystem structure and function. With the available data we examined the temporal and spatial trends on the SEKI landscape of two key elements --fire extent and fire frequency. Alterations in fire severity patterns, fire seasonality and the resultant fire effects, do have important consequences for these systems, but are not analyzed here.

Caution must be exercised when examining trends in contemporary fire history records. It is likely that the quality and accuracy of reporting for both fire ignitions and extents has changed significantly over the past 100 years. However, when examining the annual area burned within SEKI, we can look at two distinct eras: the suppression era of 1917-1968, defined by active fire suppression and no prescribed fire (Caprio and Graber 2000), and the fire management era of 1969-present, wherein both prescribed fires and WFU fires occurred along with suppression fires. Considering only fires that exceeded the FRAP size thresholds (described above), the fire suppression era was characterized by a significantly lower but highly variable annual area burned compared to the fire management era. During the suppression era, 510 ha burned on average each year, with virtually all fires (98%) classified as suppression fires. Annual area burned exhibited great temporal and spatial variability (Table 1, Fig. 2, Fig. 3) in this era, with a coefficient of variation (standard deviation/mean) of 244%. During the fire management era, fire extent averaged 1,068ha yr⁻¹ with a coefficient of variation of 126%. By area, the large majority of these fires were either prescribed or WFU fires (classified as management fires by Caprio and Graber 2000). Thus the active fire management program in SEKI appears to have both increased the area burned and reduced the year-to-year variability (Fig. 2).

Along with the increase in area burned, the number of fires exceeding FRAP thresholds have become more frequent since 1968, although some proportion of this increase is almost certainly due to better reporting (Fig. 2). The implementation of active fire management in the late 1960's can account for a large part of the increase. Moreover, "significant" fire years (i.e., years with > 1,000 ha burned, after Caprio and Graber 2000) have become more frequent concurrent with SEKI's active burning program. From 1969 to 2010, significant fires occurred once in every 1.8 years compared to one in every 17 years from 1917 to 1968.

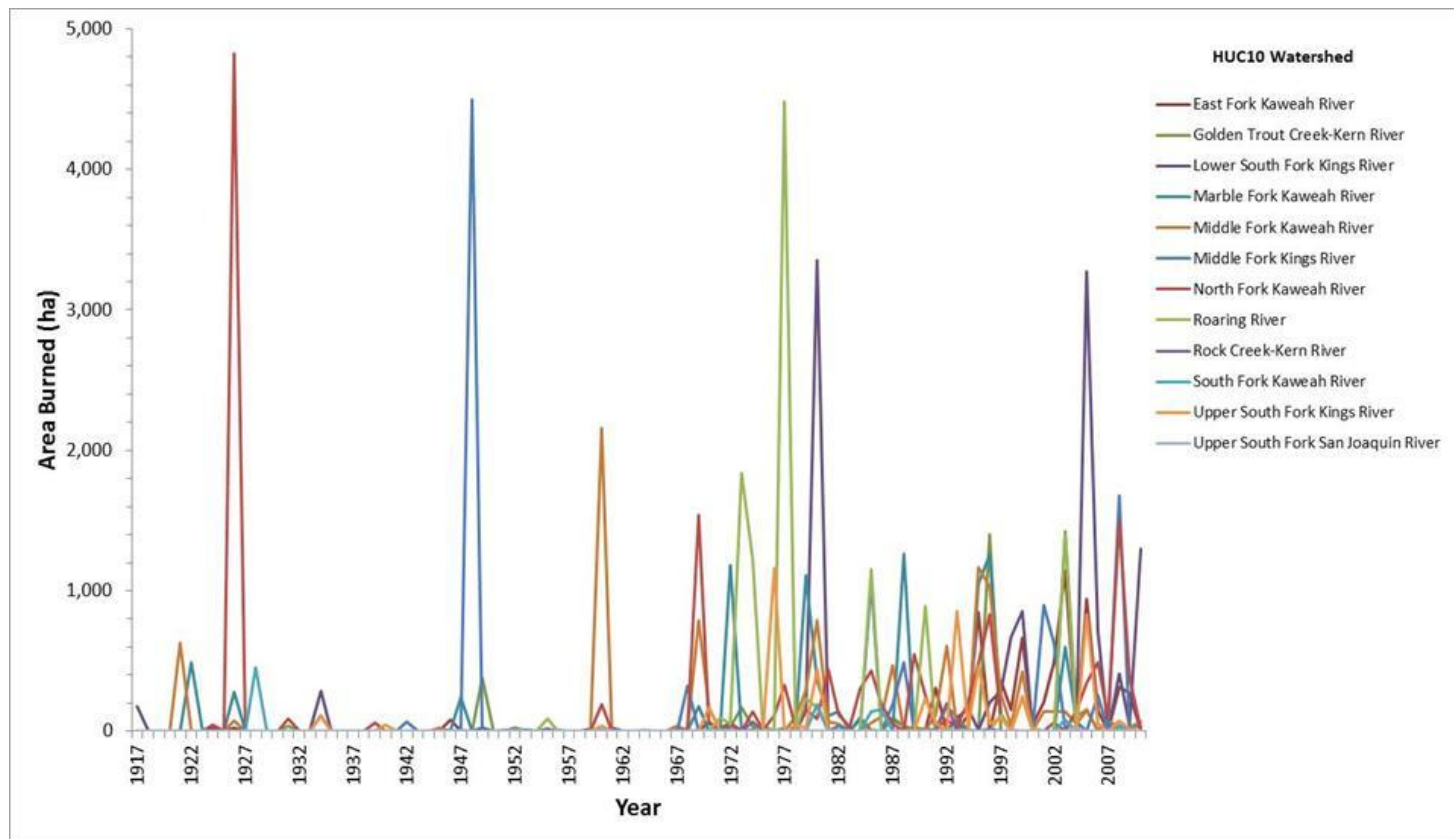
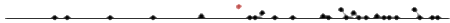


Figure 2. Annual area burned within SEKI by HUC10 watershed (1917-2010). Data from the fireperimeter maps (FRAP 2010).

Fire activity is concentrated in the western half of the Parks, particularly in the Kaweah River drainages and the Lower South Fork of the Kings River (Fig.3). These are also the locations in the Parks with the greatest concentration of the most fire prone vegetation types. For example, the five watersheds (HUC 10) in the Kaweah River drainage along with the Lower South Fork of the Kings River contain more than 90% (approximately 23,000 ha) of the vegetation classes with very high (Ponderosa Mixed Conifer) or high (White Fir Mixed Conifer, Giant Sequoia Forest) fire frequency (Caprio and Lineback 2002). Since most of the frequently burned vegetation (Fig. 1) occurs in these watersheds, it is not surprising that fire activity is concentrated in this region of SEKI. On average fire frequency is higher in the Kaweah Basin (mean = 0.53 fires yr⁻¹) than in the rest of the basins within the Parks (mean= 0.44 fires yr⁻¹, Table 1). However it is not only the frequency of fire that determines the area burned. The size of fires matters as well. The best linear model for predicting total area burned in a watershed was the one that included both fire frequency and maximum fire size (Fig.4, $p < 0.001$, $R^2 = 0.98$). Models with only maximum fire size or fire frequency explained less than 65% of the variation in area burned. Interestingly there was no significant interaction between fire frequency and maximum fire size.

Finally, it is important to recognize the role of fire management. Prescriptions have targeted forests in the Kaweah Basin. Out of all the prescribed burning done in SEKI, 81% of the area has been in the Kaweah Basin. At the same time, the Kaweah has experienced a disproportionate share of fire. Since 1917, 48% of all fires regardless of origin have occurred in the Kaweah River basin. For comparison, the Kaweah only accounts for 23% of the land base. Clearly, temporal and spatial patterns of fire in SEKI are driven by a mix of ecology and management.

Table 1. Frequency and extent of fire in SEKI from 1917 to 2010 by HUC 10 Watershed. Data from the fire perimeter maps (FRAP 2010). Only fires that reach the FRAP thresholds for reporting are included. The red points denote the maximum fire observed in the watershed.

Watershed (HUC10)	Year 1917 2010	Max (ha)	Total (ha)	Frequency (yr ⁻¹)
East Fork Kaweah River		1,149	6,488	0.53
Golden Trout Creek-Kern River		1,423	4,393	0.46
Lower South Fork Kings River		3,350	12,102	0.54
Marble Fork Kaweah River		1,264	8,758	0.65
Middle Fork Kaweah River		2,157	10,354	0.68
Middle Fork Kings River		4,501	10,305	0.43
North Fork Kaweah River		4,824	14,920	0.69
Roaring River		4,482	12,070	0.52
Rock Creek-Kern River		201	344	0.31
South Fork Kaweah River		456	1,114	0.35
Upper South Fork Kings River		1,163	5,067	0.50
Upper South Fork San Joaquin River		21	21	0.23

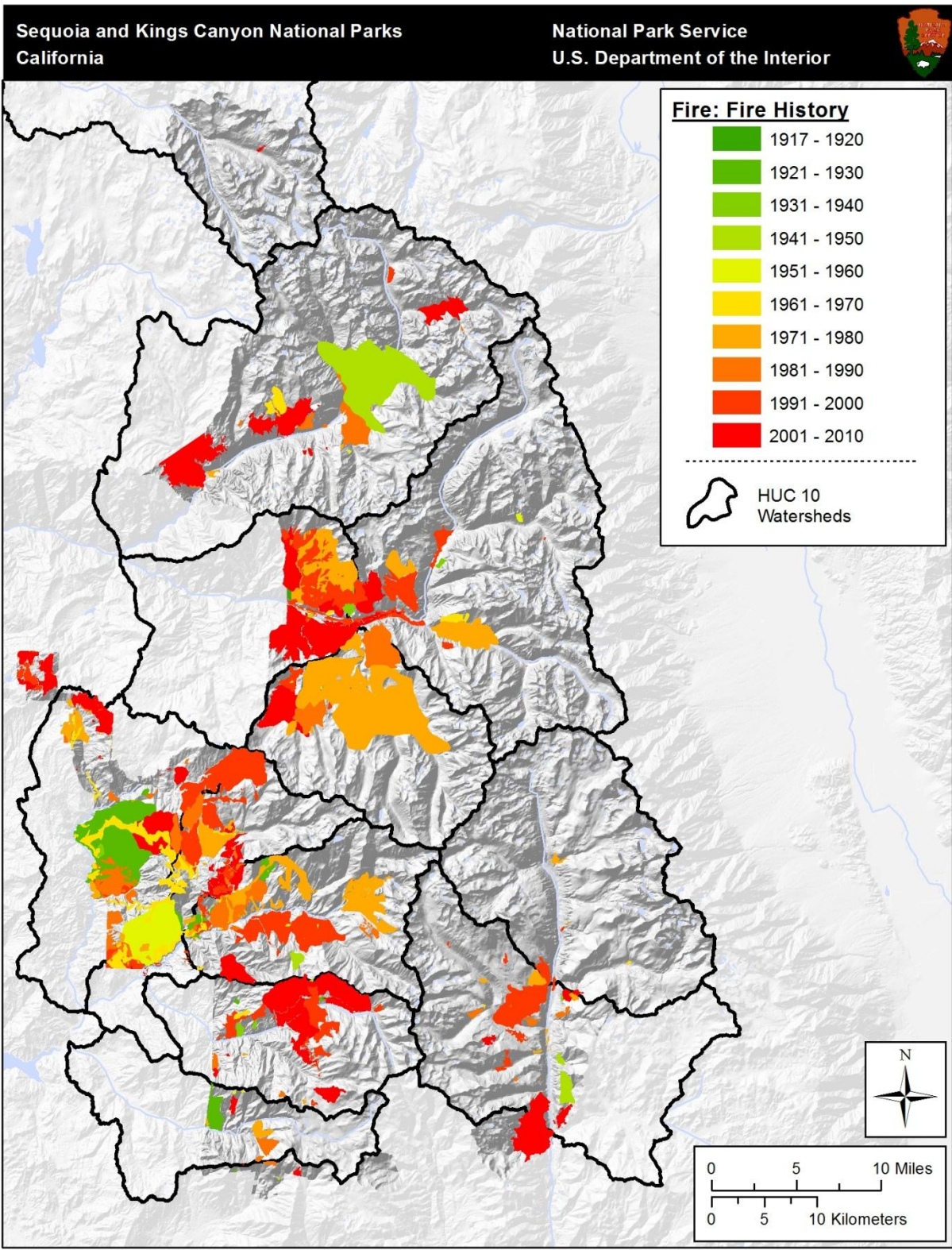


Figure 3. Fire history within SEKI by decade and watershed, 1917-2010. Data from the fire perimeter maps (FRAP 2010).

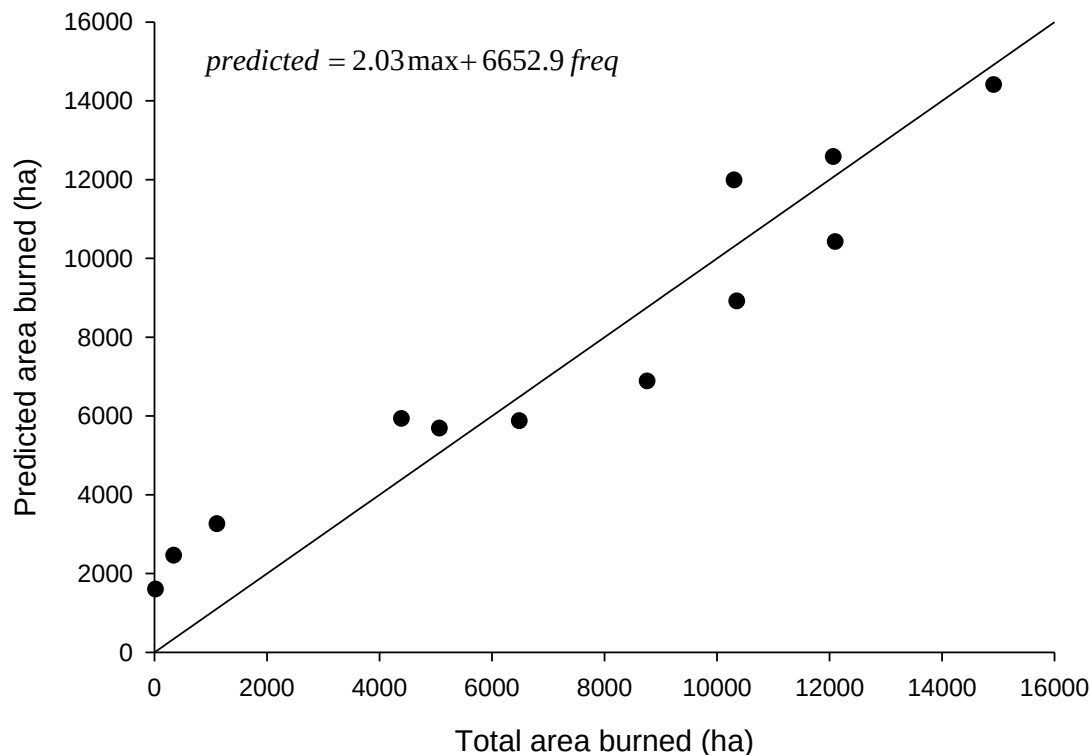


Figure 4. Linear model illustrating fit between predicted and observed total area burned in each HUC 10 watershed at SEKI. Predicted area is a linear function of fire frequency (freq, yr-1) and maximum fire (max, ha). Data from 1917-2010.

Fire Return Interval Departure (Frid) Index

As described above, Caprio et al. (1997) developed the FRID to quantify the extent of the alteration in fire regime. A valuable feature of the FRID is that it accounts for the variation in the natural fire regime that exists across the landscape. Thus it is an ecologically relevant measure of the alteration in the fire regime. Since 1996, raw FRID scores have been updated each year to account for new fires. In 2010, FRID values in SEKI ranged from -1 to 17 (Fig. 5).

In 2010, approximately 36% of the landscape with burnable vegetation (i.e., vegetation classes with an estimated fire frequency) was characterized as having moderate, high, or extreme departure (exceeding their expected fire return interval), while 64% of the burnable landscape had not exceeded its expected maximum return interval (Table 2). Departure from the historic fire regime (FRID > 0) was most common in the Kaweah River basin (Fig. 5, Table 2) where 65% of the burnable landscape was in moderate, high, or extreme departure class. In contrast, outside of the Kaweah Basin only 19% of the Parks departed from the expected fire return interval.

Between 1996 and 2010, more than 11,000 ha were burned (approximately 1/3 of all fires) in prescribed fires (Table 3). As explained by Caprio and Graber (2000), the most ecologically urgent areas of the Parks were targeted for prescription. Managers prioritized the extreme and high departure classes for treatment. As a result, 2.8% of the landscape in extreme or high departure classes in 1996 had its natural fire interval restored (i.e., moved to the low class) by 2005 (Table 4). Overall during the interval, 6.4% of the burnable area improved in terms of departure class while 6.2% worsened (Table 4). The most common trend (87.4%) was no change.

The pattern continued between 2007 and 2010. In relative terms, there was a larger than average reduction in the extreme and high departure classes (1.5%) but in absolute terms, most of SEKI did not improve – 96.4% stayed the same (Table 5).

Table 2. Summary of 2010 fire departure class for HUC 10 watersheds in SEKI. Only burnable area is included in the calculation of percentages.

Watershed (HUC 10)	Departure Class			
	Extreme	High	Moderate	Low
East Fork Keweah River	19%	10%	29%	43%
Golden Trout Creek-Kern River	1%	1%	17%	80%
Lower South Fork Kings River	3%	1%	11%	85%
Marble Fork Keweah River	15%	6%	41%	38%
Middle Fork Keweah River	18%	15%	30%	37%
Middle Fork Kings River	4%	3%	21%	72%
North Fork Keweah River	22%	24%	23%	30%
Roaring River	2%	0%	18%	80%
Rock Creek-Kern River	1%	0%	15%	84%
South Fork Keweah River	23%	14%	34%	29%
Upper South Fork Kings River	2%	2%	15%	80%
Upper South Fork San Joaquin River	0%	0%	15%	85%
TOTAL	8%	6%	22%	64%

Table 3. Annual area burned in SEKI by prescribed and wildfire from 1996-2010. Data from the fire perimeter maps (FRAP 2010). Note that the wildfire category includes lightning fires that were allowed to burn (i.e., WFU's).

Year	Prescribed Fire (ha)	Wild Fire (ha)
1996	361	4,426
1997	1,133	215
1998	861	13
1999	2,078	339
2000	40	22
2001	137	1,106
2002	687	635
2003	1,190	3,627
2004	266	162
2005	2,018	3,676
2006	686	981
2007	169	83
2008	842	3,211
2009	498	273
2010	147	1,276
Total	11,113	20,045

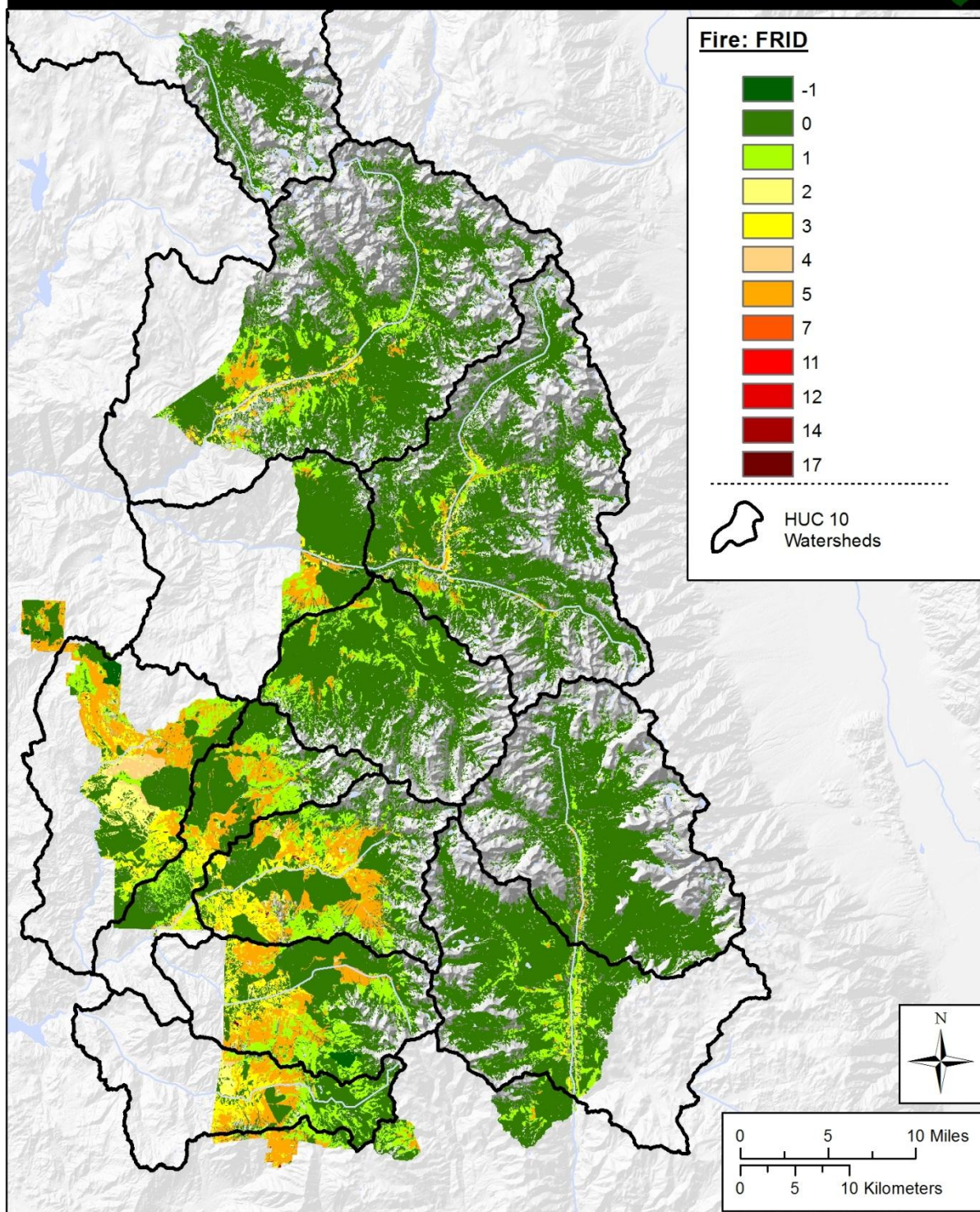


Figure 5.Fire return interval departure (FRID) classes for SEKI for 2010.

Table 4. Change in area (proportion) of FRID classes, 1996-2005. Green cells show net improvement in FRID class, grey show no net change, and orange show net worsening.

		FRID 2005				Grand Total
		Extreme	High	Moderate	Low	
FRID 1996	Extreme	13.03%	0.02%	0.32%	2.43%	15.80%
	High	2.78%	2.70%	0.02%	0.37%	5.87%
	Moderate	0.00%	0.67%	22.29%	3.24%	31.20%
	Low	0.01%	0.00%	2.70%	44.43%	47.14%
Grand Total		15.82%	3.39%	30.32%	50.46%	100%

Table 5. Change in area (proportion) of FRID classes, 2007-2010. Green cells show net improvement in FRID class, grey show no net change, and orange show net worsening.

		FRID 2010				Grand Total
		Extreme	High	Moderate	Low	
FRID 2007	Extreme	8.13%	0.00%	0.08%	1.13%	9.34%
	High	0.00%	5.85%	0.04%	0.33%	6.23%
	Moderate	0.06%	0.05%	21.02%	0.90%	22.03%
	Low	0.05%	0.03%	0.88%	61.44%	62.40%
Grand Total		8.25%	5.93%	22.01%	63.81%	100%

Fire Hazard Severity Zones (Fhsz)

The California Department of Forestry and Fire Protection's Fire Resources and Assessment Program (FRAP) developed a classification scheme to map areas of significant fire hazard in California. They define fire hazard as physical conditions related to fire (FRAP 2010). Wildlands (like SEKI) are first divided into zones (81 ha minimum mapping unit) based on the dominant vegetation and the slope. FHSZ differs from FRID in that FHSZ predicts the physical nature of the fire itself. It estimates for a zone the likelihood of fire and how hot it will burn. There is no ecological underpinning to the FHSZ as in the FRID. Thus FHSZ complements the FRID values. In 2007, approximately 39% of the burnable landscape at SEKI was classified as very high fire hazard, with the other 61% of the landscape falling in either moderate or high classifications (Table 6). However, very high zones were much more common in the Kaweah River basin (Fig. 6, Table 6). For example, 76% of the burnable area in the Kaweah was rated a very high hazard.

Table 6. Summary of 2007 fire hazard severity zones for HUC 10 watersheds in SEKI. Only burnable area is included in the calculation of percentages. Data from FRAP (2010).

Watershed (HUC 10)	Fire Hazard Severity Zone		
	Very High	High	Moderate
East Fork Keweah River	64%	14%	22%
Golden Trout Creek-Kern River	33%	10%	58%
Lower South Fork Kings River	20%	80%	0%
Marble Fork Keweah River	79%	15%	6%
Middle Fork Keweah River	89%	5%	6%
Middle Fork Kings River	15%	67%	18%
North Fork Keweah River	96%	3%	1%
Roaring River	6%	75%	20%
Rock Creek-Kern River	11%	0%	89%
South Fork Keweah River	53%	6%	41%
Upper South Fork Kings River	3%	96%	1%
Upper South Fork San Joaquin River	0%	0%	100%
TOTAL	39%	35%	26%

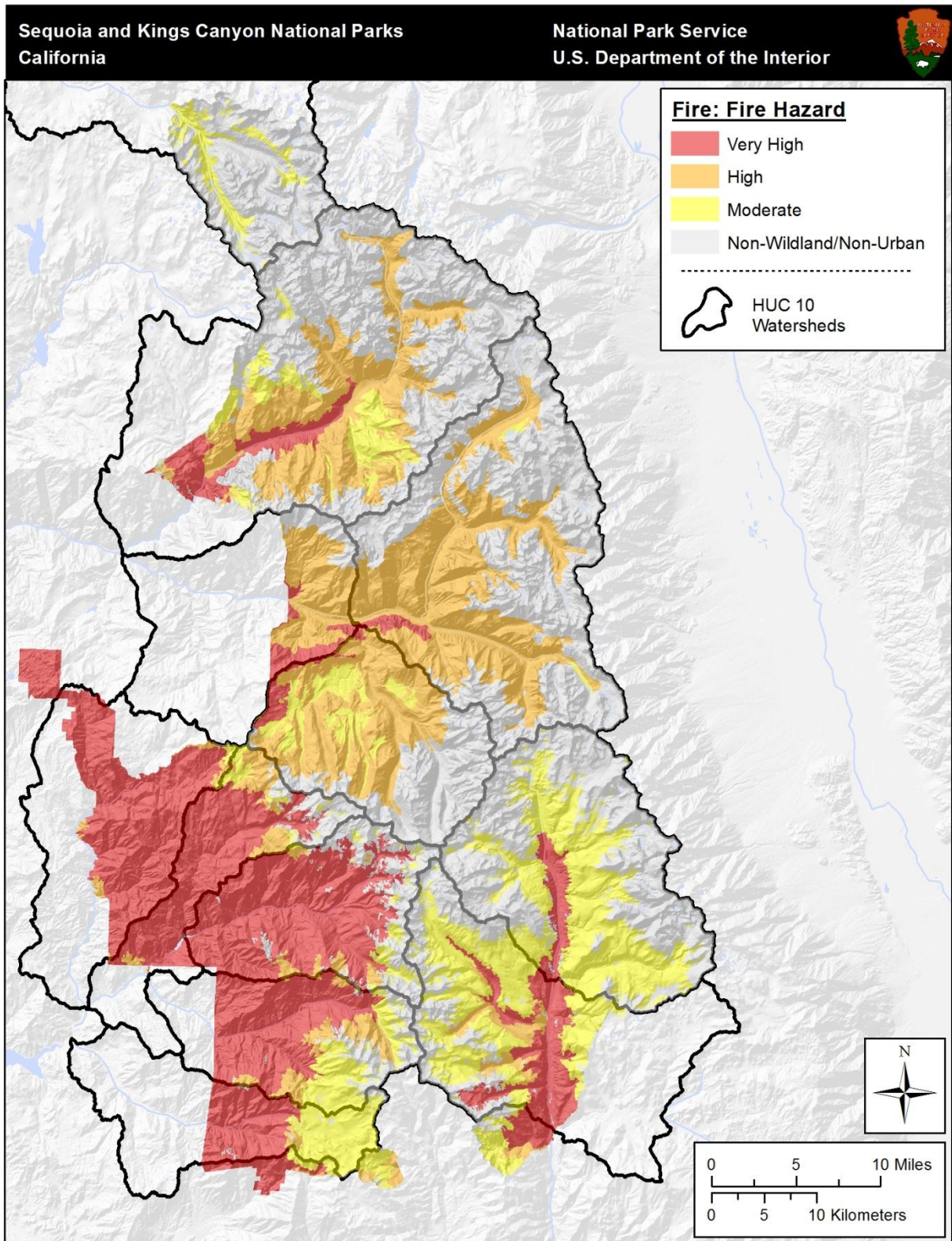


Figure 6. Fire hazard severity zones within SEKI as of 2007. Data from FRAP (2010)

Fire Risk Projections

Two of the grid points from downscaled climate projections used in wildfire risk model fell within SEKI. The center of one grid encompassed the western edge of the Park with a center point elevation of 1,676 m; the other point was due east at 3,435 m in elevation. All six projections for the two points anticipate increased risk of fire in SEKI throughout the 21st century. Risk was always greater assuming an A1 emission scenario and the magnitude of the increased risk was greater at higher elevation. For SEKI, the GFDL model predicted the most extreme changes in climate while the PCM1 the least. CNRM produced mid-range estimates. Given the CNRM climate predictions and A1 emission scenario, fire risk was anticipated to more than double by 2085 at low elevations and more than triple at higher elevations (Figure 7). Under the low emission scenario, the risks were limited to less than double the 2010 baseline at both sites. However, global CO₂ emissions have been accelerating. Since 2000, the observed rate surpasses the most fossil-fuel intensive scenarios (Raupach et al. 2007). Thus conservatively, the fire risk is predicted to more than double by 2085 for SEKI.

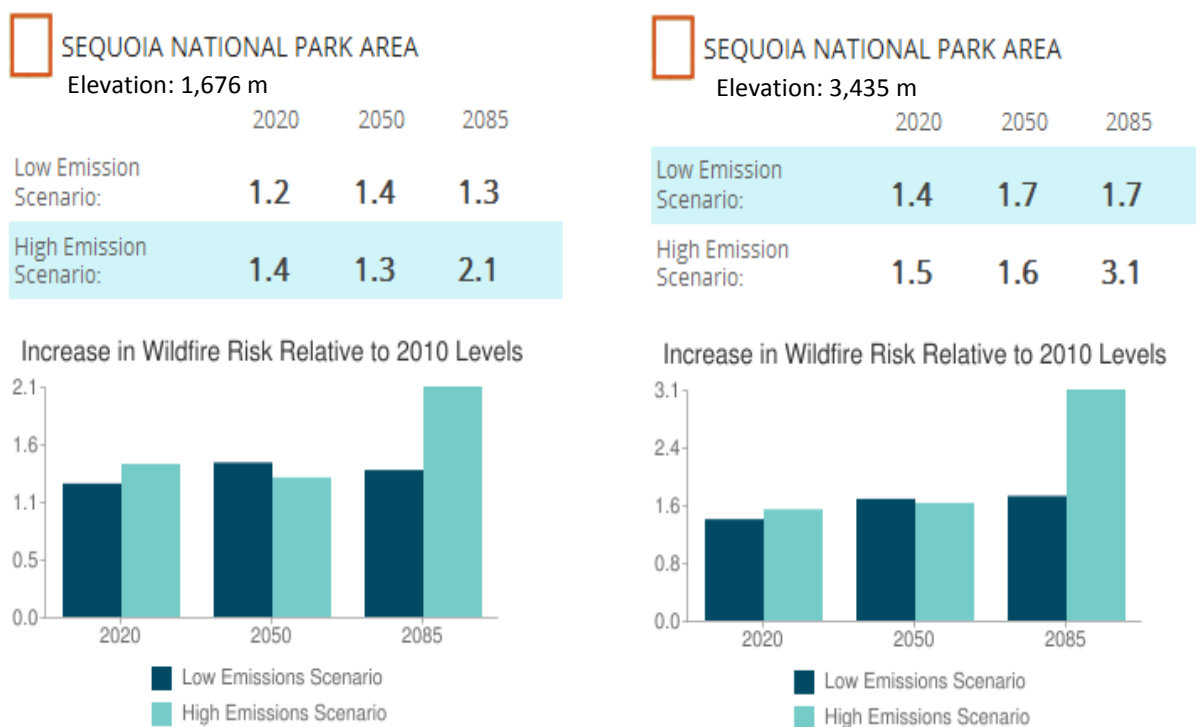


Figure 7. Projections and graphics from wildfire risk tool in Cal-Adapt for two grid cells within SEKI. Results downscaled from CNRM GCM.

Analysis Uncertainty

Confidence in the answers to the critical questions posed in this review span a gradient with the primary determinant being the source of data. The recent (last century) fire history of SEKI is based on direct observation. Thus the uncertainty in the fire perimeters is due to observation errors and/or recording errors. However given the straightforward procedures for delimiting fire perimeters, any errors are likely to be negligible for the purpose of this assessment.

The FRID analysis uses the fire perimeter records for SEKI but also relies on the vegetation maps and the estimates of the fire regimes for the defined ecosystems. Caprio and Lineback (2002) rated their knowledge of the fire return interval for the major terrain classes at SEKI. For the 12 classes, the ratings varied from good (e.g., ponderosa mixed conifer, five sources including published studies) to very poor (mid-elevation hardwood, data from unpublished sources and reports) to estimated (foothill chaparral, no specific data but estimated from the literature). The FRID ratings inherit this knowledge rating. However for the fire-prone vegetation classes (i.e., ponderosa mixed conifer, white fir mixed conifer and giant sequoia), subsequent research in similar forest types in Yosemite National Park (Collins et al. 2011, Scholl and Taylor 2010) has supported the fire return intervals used in the FRID.

The fire hazard analysis takes a completely different approach than the FRID. Severity is based on modeled output of fire behavior given available information of vegetation and terrain. The model and data follow national standards in fire management but there is no formal assessment of their uncertainty. The future fire risks are projections only. They represent a scientifically legitimate and well-vetted attempt to explore a range of possible futures.

Assessment

Methods

We relied on the 2010 FRID database maintained by the Parks to quantify the stress imposed by the altered fire regime. Specifically, we calculated the means of the raw FRID values for all burnable 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 watersheds. We adapted the rating system of Caprio et al. (1997) to describe the extent of the risk posed by departures from the historic fire regime. Average FRID values < 0 (i.e., low departure class) indicate that the historic fire return interval has been maintained and thus forests in this condition were ranked as “good.” FRID indices ≥ 0 and ≤ 2 (i.e., moderate departure class) 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 (i.e., high and extreme departure classes), we considered the altered fire regime as a cause for “concern.” As discussed above, there was no quantitative basis to evaluate the confidence in the fire return interval departure (FRID) index. However it is a well-vetted and widely used metric. Consequently we attributed moderate confidence to mean FRID values.

To document recent trends, we summarized changes in the fraction of the watershed in the high and extreme departure classes from 1996 to 2005 and then from 2007-2010 (Table 7). As noted

above, the gap in the timeline accommodates the remapping of the SEKI vegetation that was completed in 2007 (USGS-NPS 2007). We considered a composite decrease of 25% or more in high/extreme FRID class across the 12 year interval as a meaningful improvement in the fire regime. Composite changes were calculated as a weighted mean with the change from 1996 to 2005 representing 9 years and the change from 2007 to 2010 representing 3 years. We used the same approach to measure changes in the fraction of the landscape in the low departure class (Table 8). A composite increase of 25% or more in a watershed was considered as a meaningful improvement in the fire regime. Any watershed with a 25% net decrease in the high/extreme or increase in the low departure class was assigned an improving trend. Any watershed with a 25% net increase in the high/extreme or decrease in the low departure class was assigned a declining trend. Less than a 25% change in either direction was considered evidence of no trend.

Results

For 14% of the burnable SEKI landscape, fire has been absent for two or more cycles. Spatially, the departure is concentrated in the Kaweah River drainage (Fig.8) where 33% of the burnable landscape is in high or extreme conditions. Moreover for two watersheds in the Kaweah, there was cause for concern regarding the extent of the alteration (Fig.8). Outside of the Kaweah, the Parks were much closer to the historic fire regime.

Despite the widespread departure from the natural fire regime for much of SEKI, the dominant trend since 1996 was one of “no change.” In other words, stress related to the altered fire regime had not increased since 1996 (Table 7, Table 8). Indeed for three watersheds in SEKI, there was net improvement (Table 7, Table 8, Fig.8).

Discussion

The condition assessment of the altered fire regime (Fig. 8) based on the 2010 FRID values correspond to the fire hazard analysis (Fig. 6). SEKI is vulnerable to fire stress and the risks are concentrated in the Kaweah Basin. However, despite annual burn rates that are well short of the natural fire cycle, SEKI fire management has limited the extent of the damage by targeting high priority areas (Caprio and Graber 2000). In other words, the trends have not worsened during the last 12 years and in a few cases improved. Nevertheless, the longer-term prospects are more worrisome. One, no amount of fine tuning can overcome a burn program that falls far short of the natural regime. And two, the climate is working against the fire managers by increasing the potential for catastrophic wild fire (Westerling and Bryant 2008).

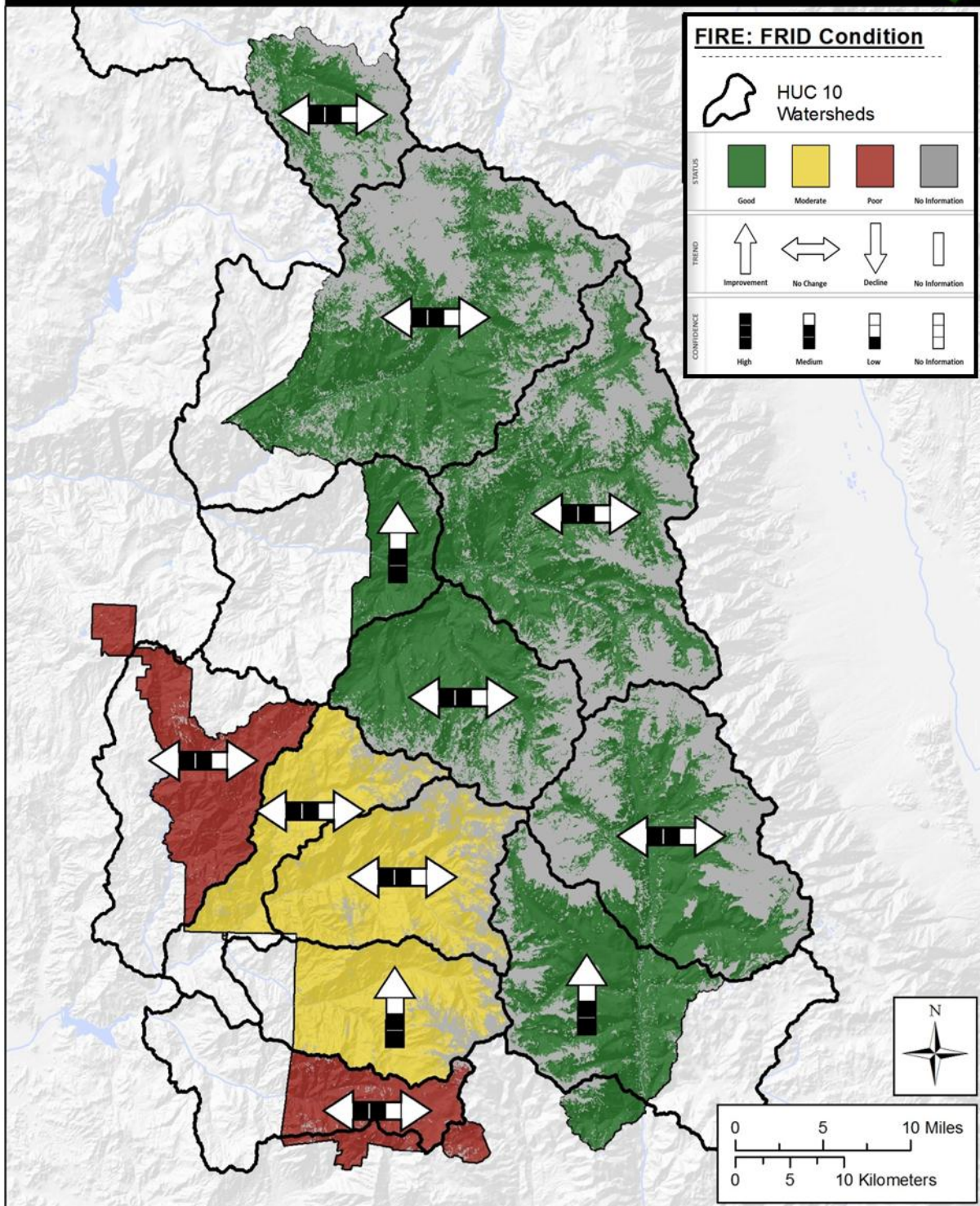


Figure 8. Condition assessment for the altered fire regime in SEKI. Assessment based on weighted averaged (by HUC 10 watershed) of FRID classes. Non-burnable landscapes (grey) represented as having no information (grey) regarding the fire regime. See text for details.

Gaps in Understanding

The role of fire in the ecology and management of SEKI is extraordinarily well-studied compared to other fire-prone ecosystems. Nevertheless, Caprio and Lineback (2002) judged only three of the 12 vegetation classes at SEKI to have “good” knowledge of their fire return interval. In addition, the FRID does not consider the severity of fire. It simply notes whether any fire has occurred in a given interval. Clearly not all fires have the same ecological impact. Finally, there is no good measure of the stresses imposed on ecosystems by too frequent fire. Already an increase in fire frequency is a concern for the foothill chaparral (Keeley et al. 2009) and may be more of concern in the future as the climate warms (Fig. 7). Expanding the FRID to better capture the multifaceted influence of fire on the SEKI ecosystem would be an important area for future research.

Table 7. Trends in % of burnable area in high/extreme departure class (FRID > 2) at SEKI. Decreases in area with high/extreme departure (blue) indicate movement toward a less altered fire regime. Increases in area with high/extreme departure (red) indicate toward a more altered fire regime. Watersheds highlighted in green improved 25% or more during the interval; no highlights indicate changes < 25% during interval.

Watershed (HUC 10)	% change		% of burnable area with FRID > 2			
	96-05	07-10	1996	2005	2007	2010
East Fork Kaweah River			43%	32%	29%	28%
Golden Trout Creek-Kern River			4%	2%	2%	2%
Lower South Fork Kings River			28%	22%	14%	4%
Marble Fork Kaweah River-Kaweah River			29%	24%	21%	21%
Middle Fork Kaweah River			43%	40%	33%	33%
Middle Fork Kings River			16%	16%	10%	7%
North Fork Kaweah River			52%	54%	52%	46%
Roaring River			10%	10%	2%	2%
Rock Creek-Kern River			0%	0%	1%	1%
South Fork Kaweah River			33%	38%	37%	37%
Upper South Fork Kings River			10%	8%	4%	4%
Upper South Fork San Joaquin River			0%	0%	0%	0%

Table 8. Trends in % of burnable area in the low departure class (FRID ≤ 0) at SEKI. Increases in area with low departure (blue) indicate movement toward a less altered fire regime. Decreases in area with high/extreme departure (red) indicate toward a more altered fire regime. Watersheds highlighted in green improved 25% or more during the interval; no highlights indicate changes < 25% during interval.

Watershed (HUC 10)	% change		% of burnable area with FRID ≤ 0			
	96-05	07-10	1996	2005	2007	2010
East Fork Kaweah River			15%	30%	43%	41%
Golden Trout Creek-Kern River			79%	84%	80%	80%
Lower South Fork Kings River			21%	49%	85%	71%
Marble Fork Kaweah River			37%	40%	38%	45%
Middle Fork Kaweah River			24%	20%	37%	36%
Middle Fork Kings River			50%	51%	72%	68%
North Fork Kaweah River			18%	19%	30%	22%
Roaring River			55%	59%	80%	80%
Rock Creek-Kern River			89%	89%	84%	84%
South Fork Kaweah River			22%	21%	29%	29%
Upper South Fork Kings River			61%	62%	80%	81%
Upper South Fork San Joaquin River			71%	71%	85%	85%

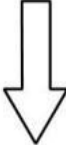
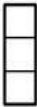
Literature Cited

- Anderson, M.K. and M.J. Moratto. 1996. Native American Land-Use Practices and Ecological Impacts. pp. 187-206. In: Sierra Nevada Ecosystem Project, Final Report to Congress: Status of the Sierra Nevada, Vol. II, Assessments and Scientific Basis for Management Options. 1528 pp.
- Cal-Adapt. 2011. Exploring California's climate change research. <http://cal-adapt.org/>. Last Accessed 2011/11/11.
- FRAP. 2010. Fire Resources Assessment Program. California Department of Forestry and Fire Protection. <http://frap.cdf.ca.gov/> . Last Accessed 2011/10/07.
- Caprio, A. C., C. Conover, M. Keifer, and P. Lineback. 1997. Fire Management and GIS: A Framework for Identifying and Prioritizing Fire Planning Needs. *In* 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-EuroAmerican Fire Regimes to the Sierra Nevada? pp 233-241. In: Cole, David N.; McCool, Stephen F.; Borrie, William T.; O'Loughlin, Jennifer (comps). Proceedings: Wilderness Science in a Time of Change-- Vol. 5 Wilderness Ecosystems, Threats, and Management; 1999 May 23-27; Missoula, MT. Ogden, UT: U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station. Proceedings RMRS-P-15-VOL-5.
- Caprio, A. C. and P. Lineback. 2002. Pre-twentieth century fire history of Sequoia and Kings Canyon National Park: A review and evaluation of our knowledge. Miscellaneous Publication 1. Association for Fire Ecology.
- Caprio, A.C. 2009. Natural stressor condition assessment: Altered fire regime. Internal document. Sequoia Kings Canyon National Parks, Three Rivers, CA.
- Collins B. M., S. L. Stephens. 2007. Managing natural wildfires in Sierra Nevada wilderness areas. *Frontiers in Ecology and the Environment*: 5:523-527.
- Collins, B.M., R.G. Everett and S.L. Stephens. 2011. Impacts of fire exclusion and recent managed fire on forest structure in old growth Sierra Nevada mixed-conifer forests. *Ecosphere* 2, art51.

- Cayan, D. R, E. P. Maurer, M. D. Dettinger, M. Tyree, and K. Hayhoe. 2008. Climate change scenarios for the California region. *Climatic Change* 87:S21–S42.
- Exline, J., D. Graber, R. Reynolds, N. Stephenson, P. Stine, C. Sydoriak, and D. Whitall. 2009. The Strategic Framework for Science in Support of Management in the Southern Sierra Nevada Ecoregion: A Collaboratively Developed Approach. Developed by the National Park Service, Sequoia/ Kings Canyon National Parks; The US Geological Survey, Western Ecological Research Center; The USDA Forest Service, Pacific Southwest Research Station; and The USDA Forest Service, Sequoia National Forest/ Giant Sequoia National Monument. June 10, 2009. 24 pp.
- Forest and Rangelands. 2011. National Cohesive Wildland Fire Management Strategy. <http://www.forestsandrangelands.gov/>. Last accessed 2011/11/26.
- Gruell, G.E. 2001. Fire in Sierra Nevada Forests: A Photographic Interpretation of Ecological Change Since 1849. Mountain Press Publishing Company, Missoula, Montana. 238 pp.
- Keeley, J.E., G.H. Aplet, N.L. Christensen, S.C. Conard, E.A. Johnson, P.N. Omi, D.L. Peterson and T.W. Swetnam. 2009. Ecological foundations for fire management in North American forest and shrubland ecosystems. USDA Forest Service: PNW-GTR-779.
- Keeley, J.E. 2010. Fire on California landscapes. *Fremontia* 38:2-6.
- Lambert, A.M., C. D'Antonio, and T.L. Dudley. 2010. Invasive species and fire in California ecosystems. *Fremontia* 38:29-36.
- Miller J.D., H.D. Safford, M. Crimmins and A.E. Thode, 2009. Quantitative evidence for increasing forest fire severity in the Sierra Nevada and southern Cascade mountains, California and Nevada, USA. *Ecosystems* 12:16-32.
- 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.
- Raupach M. R., G. Marland, P. Ciais, C. Le Quere, J. G. Canadell, G. Klepper, and C. B. Field. 2007. Global and regional drivers of accelerating CO₂ emissions RID E-9419-2010. *Proceedings of the National Academy of Sciences of the United States of America* 104:10288-10293.

- Scholl A. E. and A. H. Taylor. 2010. Fire regimes, forest change, and self-organization in an old-growth mixed-conifer forest, Yosemite National Park, USA. *Ecological Applications* 20:362-380.
- SNFPA. 2004. Sierra Nevada Forest Plan Amendment. US Forest Service. Region 5. <http://www.fs.fed.us/r5/snfpa/index.html>. Last accessed 2011/11/26.
- Skinner, C.N. and C. Chang. 1996. Fire Regimes, Past and Present. pp. 1041-1069. In: Sierra Nevada Ecosystem Project, Final Report to Congress: Status of the Sierra Nevada, Vol. II, Assessments and Scientific Basis for Management Options. 1528 pp.
- Stephens S. and L. Ruth. 2005. Federal forest-fire policy in the United States. *Ecological Applications* 15:532-542.
- Sugihara, N.G., J.W. Van Wagtendonk, K.E. Shaffer, J. Fites-Kaufman, and A.E. Thode (eds). 2006. *Fire in California Ecosystems*. Univ. Calif. Press, Berkeley. 596 pp.
- USGS-NPS. Vegetation Mapping Program. 2007. Sequoia and Kings Canyon National Parks photo interpretation report. Three Rivers, California.
- Webster, K. M. and C. B. Halpern. 2010. Long-term vegetation responses to reintroduction and repeated use of fire in mixed-conifer forests of the Sierra Nevada. *Ecosphere* **1** (5). DOI: 10.1890/ES10-00018.1.
- Westerling, A.L, Hildago, H.G., Cayan, D.R., and T.W. Swetnam. 2006. Warming and Earlier Spring Increase Western U.S. Forest Wildfire Activity. *Science* 313: 940-943.
- Westerling, A. L., Bryant, B. P., 2008. Climate Change and Wildfire in California. *Climatic Change* 87: s231-s249

Appendix 1. Master Symbology Table Used in Condition Assessment Map

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

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