Returning Fire to the Mountains: Can We Successfully Restore the Ecological Role of Pre-Euroamerican Fire Regimes to the Sierra Nevada?

Anthony C. Caprio and David M. Graber

Abstract

Considerable debate has focused on whether pre-Euroamerican fire can be restored at landscape scales. This paper examines the resultant conditions of Sequoia and Kings Canyon National Park's burn program relative to the knowledge about past fire regimes in this ecosystem. Estimates of past fire return intervals provide management direction and were used to develop approximations of area burned prior to Euroamerican settlement. This information was used to develop simple methods to compare fire management achievements against historic benchmarks. Two analyses were used to evaluate the results of the burn program relative to pre-settlement conditions. These were a reconstruction of annual "area burned" within major vegetation classes and an analysis of "fire return-interval departures" (FRID) with and without management fires over the last 30 years. Given the current information base about fire regimes, the "area burned" analysis indicated the burn program continues to fall behind relative to forest change, while the FRID analysis suggested the program has had a substantial impact on areas with the greatest ecological need for burning.

Introduction

Striking changes in structural and functional components of Sierran ecosystems have occurred since 1860, largely due to alternations in the pre-Euroamerican settlement fire regime (Leopold and others 1963; Kilgore 1973; Vankat and Major 1978) . Shifts in the fire regime have been attributed to multiple causes, including intense grazing which removed fine fuels important for fire spread, loss of Native American populations as an ignition source, and more recently, 20th century fire suppression efforts (Kilgore and Taylor 1979; Caprio and Swetnam 1995). Today unnaturally heavy fuel accumulations occur in many of the park's fire-dependant forest ecosystems along with associated increases in forest stand densities (Kilgore 1972; Parsons 1978; Vankat and Major 1978). With these shifts have come changes in fire regime characteristics with large stand-destroying burns occurring in plant communities where such burns were exceedingly rare or unknown in the past. Because NPS policy states that parks will protect natural resources, life, and property from unnatural wildfires, and restore and maintain natural fire regimes to perpetuate natural processes and values, an active fire management program has been implemented within the parks.

The fire management program in Sequoia and Kings Canyon National Parks (SEKI) began using prescribed fire extensively in 1968 (Bancroft and others 1985), when the first large prescribed burn on NPS lands in the western states was ignited (Kilgore 1971). Overall fire management goals of this active program have been to restore and maintain fire as a natural process to the maximum extent possible. However, specific program objectives have generally

In: Cole, David N.; McCool, Stephen F. 2000. Proceedings: Wilderness Science in a Time of Change. Proc. RMRS-P-000. Ogden, UT: U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station.

A. C. Caprio is Ecologist and Fire Research Coordinator, Science and Natural Resources Management Division, Sequoia and Kings Canyon National Parks, 47050 Generals Highway, Three Rivers, CA 93271-9651 (tony_caprio@nps.gov). D. M. Graber is Science Advisor, Sequoia and Kings Canyon National Parks, 47050 Generals Highway, Three Rivers, CA 93271-9651 (david_graber@nps.gov).

focused on fuel reduction, although they have recently been undergoing modification to include ecological function and the preservation and restoration of the structural components of plant communities (Keifer and others, this proceedings). Since 1921, when written historic fire records began, 60,370 ha have burned in the parks with 34,776 ha (58%) having been some form of management fire (either a human ignited prescribed burn or a lightning ignited burn given various names over the years–"let burns", "prescribed natural fire", and most recently "wildland fire used for resource benefit"). Today the parks are one of the leading NPS units using fire for resource benefits.

However, although SEKI is a leader in utilizing fire, there continues to be considerable debate on whether the program has been successfully restoring the ecological role of fire within park ecosystems. We offer here a quantitative evaluation of fire management program achievements over the last 30 years in reducing fuels and restoring fire as an ecological process relative to historic benchmarks based on pre-Euroamerican conditions. We used two approaches to evaluate the effectiveness. The area-burned approach extends the ideas of several authors (Van Wagtendonk 1995; Graber and Parsons 1998) by applying information on fire return intervals (FRI) derived from fire history studies (such as calculated by Parsons (1995) or Parsons and Botti (1996) for sequoia groves) to derive an estimate of what the annual average area burned prior to 1860 might have been. Our second approach used a geospatial model of fire return interval departures (FRID) from pre-Euroamerican conditions (Caprio and others 1997, and in press) to evaluate quantitative and spatial aspects of the SEKI burn program. Actual 1998 FRID values were compared to 1998 FRID values for a hypothetical landscape where management burns had not been carried out.

Study Area

Sequoia and Kings Canyon National Parks are located in the south central Sierra Nevada and encompass some 349,676 ha (864,067 ac) extending from the Sierra crest to the western foothills on the eastern edge of the San Joaquin Valley. Topographically the area is rugged with elevations ranging from 485 to 4,392 m (1,600 to 14,495 ft). The parks are drained by the Kern, Kaweah, Kings, and San Joaquin Rivers. The elevation gradient from the foothills to the higher peaks is steep on both the east and west margins of the Sierra with rapid transitions between vegetation communities. Three broad vegetation zones dominate the park (slightly over 200,000 ha are vegetated by forest, shrub, or grassland communities), *foothills* (485 to 1,515 m) composed of annual grasslands, oak and evergreen woodlands, and chaparral shrubland, *conifer forest* (1,515 to 3,030 m) with ponderosa (Pinus ponderosa Dougl.), lodgepole (P. contorta Dougl. var Murrayana Englm.), giant sequoia (Sequoiadendron giganteum [Lindl.] Buchholz), white fir (Abies concolor Lindl. & Gord.), and red fir (A. magnifica Murr.) forests, and *high country* (3,030 to 4,392 m) composed of subalpine forests with foxtail pine (P. balfouriana Jeff.), white-bark pine (P. albicaulis Englm.), alpine vegetation, and unvegetated landscapes. A variety of classification schemes have been defined for vegetation within the park (Rundel and others 1977; Vankat 1982; Stephenson 1988).

The climate is Mediterranean with cool moist winters and warm summers with rainfall limited to sporadic summer thunderstorms associated with monsoonal flow from the Southwest. Precipitation increases as elevation increases, to about 102 cm (40 in) annually, from 1,515 to 2,424 m on the west slope of the Sierra, decreasing as one moves higher and to the east (Stephenson 1988). Substantial snow accumulations are common above 1,515 m during the winter. Total annual precipitation during the period of record has varied from 30 to 130 cm at Ash Mountain in the foothills and from 38 to 214 cm in Giant Forest at a mid-elevation location.

European settlement of the area began in the 1860s with extensive grazing, minor logging, and mineral exploration. Sequoia National Park and Grant National Parks (now part of Kings Canyon National Park) were founded in 1890 with the intent of protecting sequoia groves from logging. Over time significant new areas have been added to the Parks, including the Kern Drainage (1926), while much of the upper portion of the upper Kings drainage was set aside as Kings Canyon National Park (1940 and 1965) (Farquhar 1965; Dilsaver and Tweed 1990).

Methods

Burn Area Analysis

We applied summarized FRI data (R_{avg} and R_{max}) to each of the 12 major vegetation classes currently defined for the parks (Caprio and Lineback, in press). R_{avg} was based on average FRI while R_{max} was a more conservative estimate based on average maximum intervals. Both were based primarily on dendrochronological samples for the period from 1700 to 1860. Because of the importance of aspect in affecting fire behavior and spread (Agee 1993; Pyne and others 1996) we refined FRI estimates and vegetation classes to include this influence and provide a more realistic estimate of area burned. Such shifts in FRI by aspect have been reported by several investigations (Laven and others 1980; Allen and others 1995; Taylor and Skinner 1998). FRI summarized in Caprio and Lineback (in press) were obtained from a variety of sources and were generally representative of south aspects with the exception of the estimate for red fir forest (data from Pitcher 1987 and Caprio 1998). Additionally, preliminary results from recent field work in SEKI comparing differences in FRI between north and south aspects within the East Fork of the Kaweah watershed also suggest strong differences, with FRI about three-times greater in mid-elevation conifer forest on south aspects relative to similar north aspects (Caprio unpublished data). To be conservative we only doubled the values on south aspects relative to north aspects.

Area estimates for north and south aspects for the 12 major vegetation classes were delineated using GIS (**Fig. 1**), with south aspects defined topographically as aspects from 105-184° and north as 185-104°(Caprio and Lineback in press). Aspects were interpreted and digitized from topographic maps (1:25,000) with areas greater than 250 contiguous hectares mapped. Lastly, average annual area burned annually prior to Euroamerican settlement was determined by dividing the area within a vegetation class and aspect by the FRI for that class and aspect and summing these across categories.

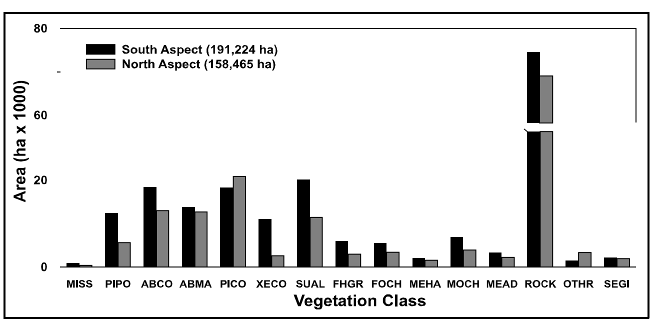

Figure 1. Area of each vegetation class by aspect used to calculate burn area values. See table 2 for explanation of vegetation class codes (non-vegetation types not listed in table 2 are MISS= missing; ROCK= rock; OTHR=other).

FRID Analysis

Resource managers at Sequoia and Kings Canyon National Parks have been developing an "ecological needs model" that conservatively categorizes vegetation types based on departures from pre-Euroamerican settlement fire return intervals (FRID) (Caprio and others 1997, and in press). Landscape units defined in this model may be further categorized to allow integration of information about burn status– such as whether an area is unburned, undergoing restoration burns, or is in a maintenance condition– within the FRID values.

Fire Return Interval Departure

$$(FRID) = \frac{TSLF - RI_{max}}{RI_{max}}$$

in which,

> RI_{max} = *maximum average return interval for the vegetation class (maximum values provide a conservative estimate)*

and,

> *TSLF (time since last fire) = time that has passed since the most recent fire based on historic fire records or using a baseline date of 1899 derived from fire history chronologies.*

The departure index ranged from negative one to 16 given our data set with a starting TSLF of 1899 and a minimum RI_{max} value of six (formula is modified from Caprio and others (1997) to give departure values as positive numbers). We reclassed the index values into four rating categories that were likely to capture current forest conditions and the need for burning

Table 1. Fire return interval departure (FRID) index for each ecological need category.

Extreme	High	Moderate	Low
≥5	<5 and ≥2	<2 and ≥0	<0

based on historic FRI (**Table 1**).

Our analysis compared the differences between FRID values across the landscape relative to what they would have been if no management burns had occurred between 1968 and 1998. We defined management burns for this analysis as being either management ignited prescribed fire (MIPF) or prescribed natural fire (PNF). Maps and data were developed using ArcInfo/GRID and ArcView for the “actual” 1998 FRID and the alternative 1998 “no management ignitions” FRID. Comparison of these two sets of geographic data allowed quantitative and spatial comparisons to be made about the Park’s burn program. Additionally, hypothetical annual FRID values with “no fire occurrence” since 1899 were calculated for a period beginning in 1900. This provided a baseline that allowed us to contrast the impact of various fire scenarios relative to a no-fire landscape. Our FRID analysis did not include an aspect component since this element had not yet been integrated into the geospatial model on which FRID is calculated.

Results

Burn Area Analysis

Average area burned annually from 1921 to 1968 under full fire suppression was 325 ha relative to 1,504 ha burned annually following the initiation of management burning (**Fig. 2**). Significant fire years, with greater than 1,000 ha burned, only occurred three times prior to 1969 (1926, 1948, 1950), compared to sixteen times since 1969. Overall, 60,370 ha have burned in the parks with 34,776 ha (58%) being some form of management fire. Since 1969, 45,111 ha have burned with 34,776 ha (77%) of this from management fires.

Total area burned annually without separating aspects was estimated to be 11,697 ha using R_{avg} and 7,142 ha using R_{max}. When aspect differences in FRI were considered, reconstructed estimates for the combined average area burned annually in the two parks was 10,006 ha•yr^{-1} using R_{avg} and 6,113 ha•yr^{-1} using R_{max} (**Table 2** and **Table 3**). The vegetation types with the greatest contribution to area burned annually were ponderosa-mixed conifer (PIPO), white fir-mixed conifer (ABCO), and red fir (ABMA) respectively. Vegetation classes that were minor contributors to the

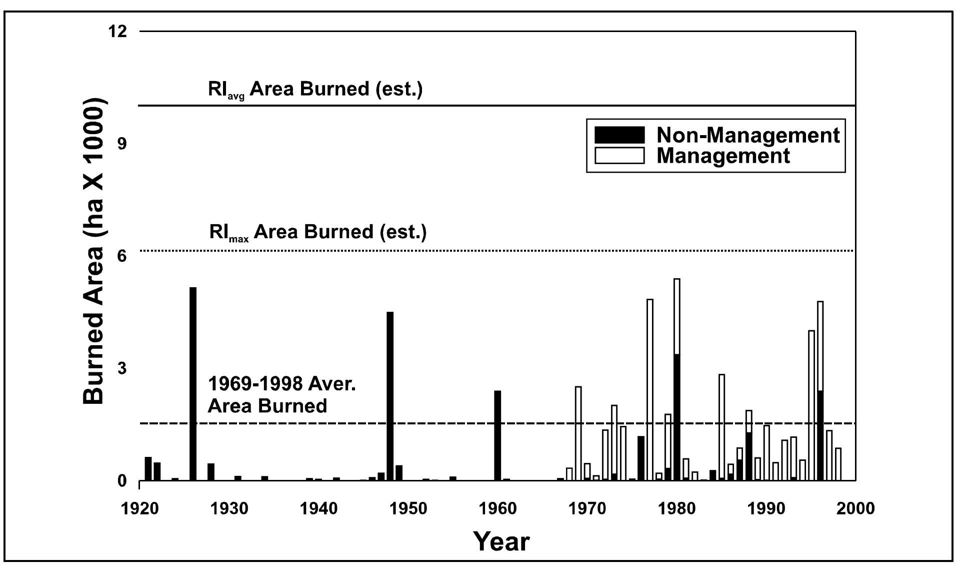

Figure 2. Area burned annually within SEKI since 1921 by management and non-management fires. Comparison of area burned over the last 30 years relative to estimates area burned prior to Euroamerican settlement is shown by horizontal lines. The greatest annual area burned by management ignited fires occurred in 1977 while the greatest number of hectares burned in any given year since 1921 occurred in 1980.

Table 2. Burn area values based on average fire return intervals (R_{avg}). Return interval values were based on Caprio and Lineback (in press).

Vegetation Class (code)		R_{avg} North	R_{avg} South	Ha/Yr North	Ha/Yr South	Ha/Yr Combined
Ponderosa-Mixed Conifer Forest	PIPO	8	4	662.9	2,816.4	3,479.3
White Fir Mixed Conifer Forest	ABCO	20	10	716.7	1,712.9	2,429.6
Red Fir Forest	ABMA	30	15	477.9	811.8	1,289.7
Lodgepole Pine Forest	PICO	204	102	100.3	183.8	284.2
Xeric Conifer Forest	XECO	60	30	59.1	338.6	397.7
Subalpine Conifer Forest	SUAL	374	187	30.6	107.3	137.8
Foothill Hardwoods and Grasslands	FHGR	22	11	155.8	495.9	651.8
Foothill Chaparral	FOCH	60	30	54.1	187.0	241.2
Mid-elevation Hardwood Forest	MEHA	14	7	119.4	270.4	389.8
Montane Chaparral	MOCH	60	30	65.6	230.1	295.7
Meadow	MEAD	80	40	32.1	72.3	104.5
Giant Sequoia Groves	SEGI	20	10	100.3	204.9	305.2
Total				2,574.8	7,431.5	10,006.4

annual area burned included: montane chaparral (MOCH), lodgepole pine forest (PICO), foothill chaparral (FOCH), subalpine forest (SUCO), and meadow (MEAD). Annual contribution was dependant on both total area occupied by a vegetation type and the length of the FRI. While the area occupied by ponderosa-mixed conifer was only about 42% of the area of lodgepole pine forest, the vegetation class with the largest area in the parks, it burned about twenty-five times more frequently. The result was the greatest average area burned annually of all the vegetation classes.

The reconstructed estimates of area burned annually also indicated that about three times more area burned on south aspects than on north aspects. Aspect differences in annual area burned were greatest for xeric conifer forest and ponderosa pine-mixed conifer forest (5.7 and 4.2 times more area burned on south than north aspects respectively). Minimal differences were suggested for red fir, lodgepole pine forest, and sequoia-mixed conifer forest (only 1.7, 1.8, and 2 times more area on south versus north aspects).

FRID Analysis

Our FRID analysis produced detailed geo-spatial output that provided both quantitative information and maps of FRID categories that were an important tool for visually interpreting changes in FRID.

Table 3. Values based on average maximum fire return intervals (R_{max}). Return interval values were based on Caprio and Lineback (in press).

Vegetation Class	R_{max} North	R_{max} South	Ha/Yr	Ha/Yr South	Ha/Yr Combined
Ponderosa - Mixed Conifer Forest	12	6	441.9	1,877.6	2,319.5
White Fir Mixed Conifer Forest	32	16	447.9	1,070.6	1,518.5
Red Fir Forest	50	25	286.7	487.1	773.8
Lodgepole Pine Forest	326	163	62.8	115.0	177.8
Xeric Conifer Forest	100	50	35.4	203.2	238.6
Subalpine Conifer Forest	1016	508	11.3	39.5	50.7
Foothill Hardwoods and Grasslands	34	17	100.8	320.9	421.7
Foothill Chaparral	120	60	27.1	93.5	120.6
Mid-elevation Hardwood Forest	46	23	36.3	82.3	118.6
Montane Chaparral	150	75	26.2	92.0.0	144.5
Meadow	130	65	19.8	44.5	64.3
Giant Sequoia Groves	32	16	62.7	128.1	190.8
Total			1,595.0	4,554.3	6,113.3

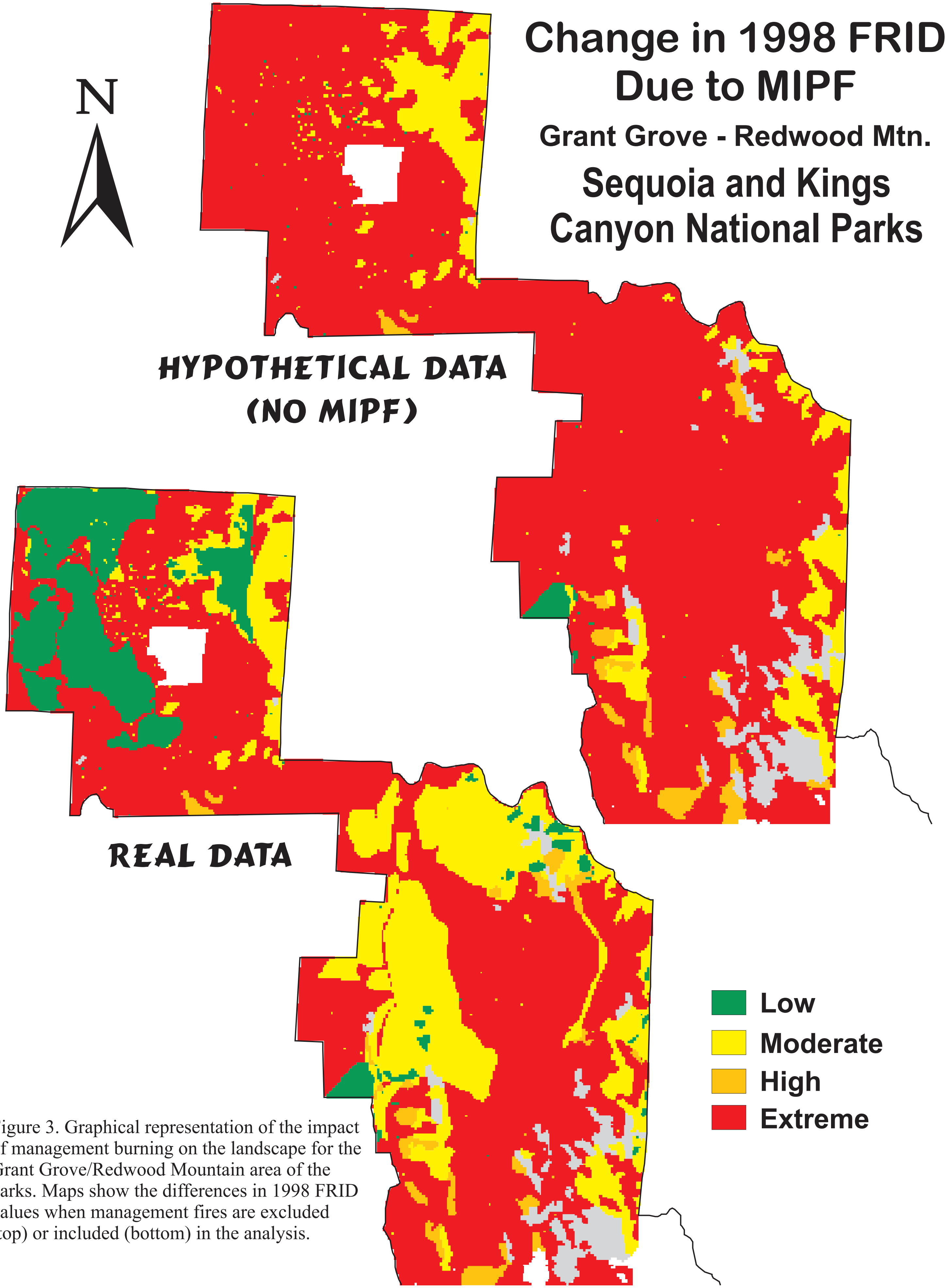

Figure 3. Graphical representation of the impact of management burning on the landscape for the Grant Grove/Redwood Mountain area of the parks. Maps show the differences in 1998 FRID values when management fires are excluded (top) or included (bottom) in the analysis.

Table 4. Area in the 1998 hypothetical FRID (no fires since 1899) and the actual 1998 FRID, the percent change, and area and percent change due to all non-management and management fires respectively.

FRID Class	Hypoth. (ha)	Actual (ha)	(% △)	Non-Mgmt △(ha)	(% △)	Mgmt △(ha)	(% △)
Extreme	52,069	31,208	-40.0	-6,509	-12.3	-14,374	-27.7
High	12,443	13,267	6.6	1,144	9.3	-325	-2.7
Moderate	65,347	60,935	-6.8	-2,769	-4.3	-1,671	-2.5
Low	70,681	95,126	34.6	8,265	11.4	16,150	23.2

Comparison of the maps showed attributes of current and no-management burn FRID and information about how and where they differed. Striking differences were obvious by visual inspection of the actual 1998 FRID map to the 1998 FRID map where all management fires had been removed (**Fig. 3**).

Baseline estimates of FRID, if no fires had occurred in the parks since 1899 (**Fig. 4**), showed change in FRID through time with "break points" when FRID values jumped between categories. This baseline provided values against which to assess "actual" burn area values. Additionally, understanding the temporal location of the break points was important in interpreting changes in FRID through time. Specific shape and location of the break points depended on how the four FRID categories (low, moderate, high, extreme) are defined and spatial area of the various vegetation classes.

We made comparisons of three potential FRID outcomes: actual 1998 FRID, hypothetical 1998 FRID if no fires had occurred since 1899, and 1998 FRID excluding management burns (**Fig. 5**). The difference between the hypothetical and the actual 1998 FRID showed change due to all fires that have occurred since 1921. The difference between the hypothetical 1998 FRID and the 1998 no management FRID showed the impact of all suppressed fires since 1921. To evaluate the burn program over the last 30 years we used the difference between the actual 1998 FRID and the 1998 FRID without management fires. The difference between these provided an estimate of change in 1998 FRID due to management burns. This comparison of 1998 data indicates that the SEKI burn program has reduced area in the extreme category by 28% and increased area in the low category by 23%) (**Table 4**). Only moderate or little change was observed in the moderate and high 1998 FRID category. These data show the current state of all areas burned since 1968 and do not reflect information about the specific category of the areas burned. Visual interpretation shows that areas with greatest changes in FRID values are the Grant Grove-Redwood Mountain area, Cedar Grove, Sugarloaf Valley, and both the Swanee area of the Marble Fork and much of the Middle Fork of the Kaweah River. Some areas (Redwood Mountain, Middle Fork of the Kaweah, and Swanee), where burns had been carried out in the 1970s and 1980s with no subsequent burning has taken place since, are now reverting back to higher FRID categories.

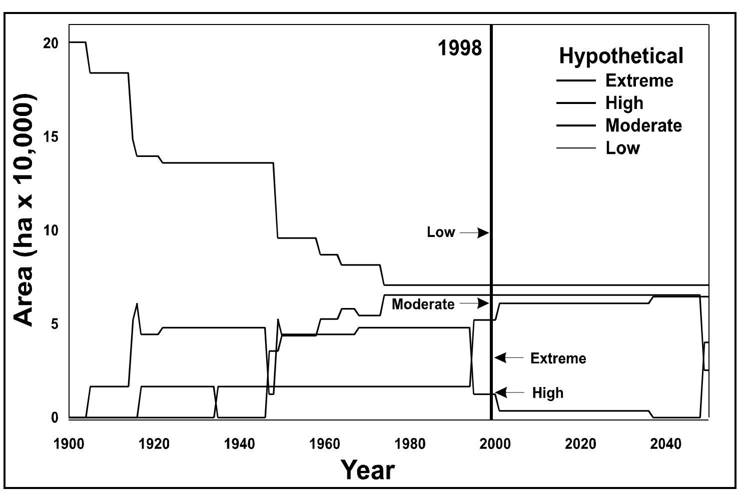

Figure 4. Change in FRID category values through time (since 1899) if complete fire suppression had been achieved since 1899. These values provide a baseline to compare current values and recent changes in FRID. Specific rates of change through time and inflection points depend on FRI for specific vegetation class. Actual FRID category values for 1998 are shown along the vertical dotted line and show a greater than expected area in the "low" category and a lower than expected area

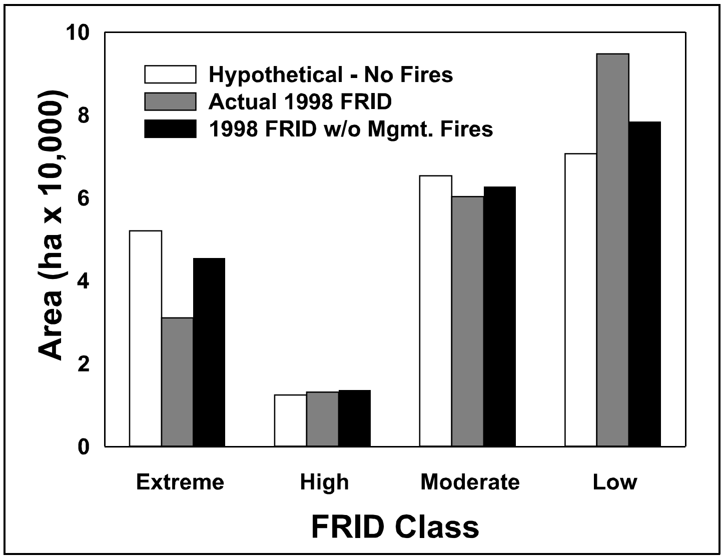

Figure 5. Area in the four FRID classes under three management scenarios. These include no fires since 1899 (complete fire suppression), actual 1998 FRID values, and 1998 FRID values if no management burning had occurred. The difference between the actual 1998 FRID and 1998 FRID without management fires represents the impact of the fire management program for the last 30 years on FRID values. The greatest changes are in the "high" and "low" categories.

Discussion

Burn Area Analysis

Aspect differences in area burned annually (**Table 2** and **Table 3**) are greater than expected based on simple FRI and total area categorized as south aspect (191,224 ha) versus north (158,465 ha) (the few flat areas are categorized as south aspect). Overall differences appeared to be due to changes in FRI and aspect by vegetation class. Most importantly, vegetation types with the highest fire frequency are located on south aspects. For example, ponderosa pine-mixed conifer, with the shortest average FRI, is more prevalent on south aspects (11,266 vs 5,303 ha; **Fig. 1**) along with xeric conifer (10,158 vs 3,544 ha), although FRI are longer for the latter and do not have as great an influence on the final differences.

The values given for annual area burned are mean values. Actual area would be quite variable from year-to-year, ranging from years with little or no area burned. to years when very large areas burned. Variation is predominantly a result interannual fluctuations in weather and ignition sources.

The analysis also indicates that prior to Euroamerican settlement, the location which had the greatest contribution to acreage burned in the parks, on a year-to-year basis, was lower-elevation conifer forest on south aspects. These areas probably exhibit the greatest degree of change due to fire exclusion over the last 140 yrs. This suggests they may be areas (ponderosa pine-mixed conifer forest found on south aspects) where fire managers should concentrate burn efforts for fire restoration. Once restoration is completed, maintenance of fire as a natural ecosystem process will be easier and larger land units could be burned with fewer operational resources.

Several potential problems exist with the current FRI data set used in the analysis. While we have high quality information from some vegetation classes, particularly on south aspects, data is of much poorer quality from other classes and on north aspects (Caprio and Lineback in press). Sampling is currently being carried out in the parks to provide higher quality information about past fire regimes across a broad range of vegetation types and aspects (Caprio 1997, 1998). Our current estimate that fire return intervals were two-times greater on south than north aspects was based on results from other regions in the West, supported by preliminary findings from within-park sampling at mid-elevation sites (Caprio unpublished data). Additionally, our current vegetation map contains discrepancies and lumps some similar vegetation associations. For example, the FRI found in ponderosa pine forest (3-4 years) is the shortest recorded in any vegetation type within the parks (Warner 1980; Caprio unpublished data) but the current vegetation classification lumps this type with ponderosa pine-mixed conifer. Similarly, western juniper, pinyon pine, and Jeffrey pine communities are all combined into xeric conifer although fire tolerances among the species are quite different (Wright and Bailey 1982).

Comparison of the two estimates for average pre-Euroamerican settlement area burned annually (**Fig. 5**) show that the burn program has not reached the R_{avg} (10,006 ha) nor the more conservative estimate based on R_{max} (6,143 ha), although area burned during several years (1977, 1980, 1995 and 1996) approached the later (**Fig. 2**). The long term average of 1,504 ha from 1969 to 1998 fell well below these estimates. A plot of cumulative area burned over time (**Fig. 6**), both pre-Euroamerican and current, demonstrates the trajectory of divergence in annual area burned. Thus the parks are continuing to fall behind in area that needs to be burned if pre-Euroamerican settlement conditions are the objective.

Notably, in no year since 1921 (when written fire records begin) does the area burned approach the R_{avg} or R_{max} level found prior to Euroamerican settlement. We believe this is a result of the dramatic vegetation and fuel changes that began in the 1860s and continued with fire suppression activities in the 20th century. Intense grazing at the end of the 19th century (by the early 1890's Farquhar (1965) cites historic documents which indicate that over 500,000 sheep were being grazed in the Kings and Kern drainages) which probably broke up contiguous areas of fine fuel and caused temporary compositional shifts (at a minimum) in plant communities. Additionally, pre-Euroamerican settlement fires probably burned for long periods of time during the dry summer/fall months, periodically flaring up and making runs over large areas. While 20th century suppression actions may not have been able to catch all initial starts they would have been highly successful at containing burns during quiescent periods which would effectively limit final fire size. Lastly, there is the possibility that the difference is due to the loss of Native American ignitions, although no direct evidence exists for or against this.

FRID Analysis

FRID analysis is a new GIS data/fire management technique being utilized at SEKI to assist in burn planning and operations. It has been useful in providing ecological input into fire management planning and operations. Additionally, a variety of new types of information have been derived from the procedure. Our results reflect one of these analyses where actual FRID values were compared to FRID

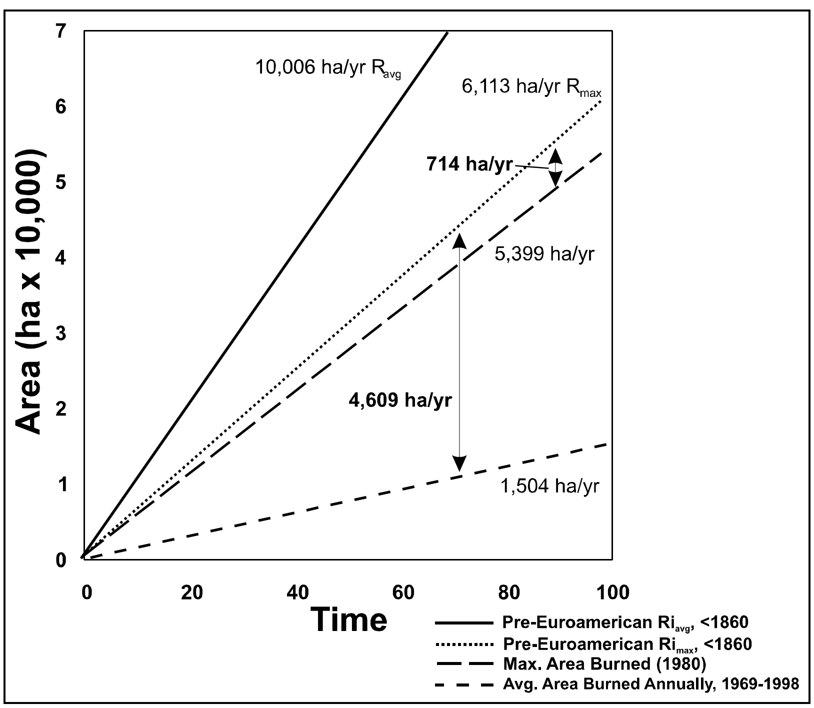

Figure 6. Accruement of area burned over time based on reconstructed pre-Euroamerican fire regimes (R_{avg} as average FRI and R_{max} as average maximum FRI), the average actual area burned between 1969 and 1998, and the year with the maximum area burned between these dates (1996).

values from several potential historic fire management scenarios. While our analysis centers on past management decisions, this type of analysis could be used to extrapolate outcomes into the future to examine alternative management strategies.

The results of our FRID analysis portray the outcome of 30 yr of management burning quite differently than the results of the “area burned” analysis. It suggests the park’s burn program is having substantial positive effects on many areas that have departed most significantly from pre-Euroamerican fire regimes. The difference in the results between the “area burned” analysis and FRID analysis reflect the spatial output of the latter and that departures, which do not accrue annually, are grouped into specific categories with an upper limit of change. However, while large areas of the park have been treated, the FRID analysis also highlights areas where initial restoration burns took place, but subsequent restoration burns have not been executed (our current projection is that two-to-four restoration burns may be required to treat areas before burning can be considered to be routine maintenance). In these locations any restoration gain from the initial burn is being lost as forest conditions revert back toward preburn conditions.

However, several problems still exist in using FRID that should be considered when interpreting output. They have been reviewed by Caprio and Lineback (in press) but include problems with the underlying vegetation map, aspect differences in fire regimes that have not yet been incorporated into the FRID model, and spatial limitations on the geographic extent of our fire regime knowledge across the park that are used to drive the model in a diverse ecosystem.

The two analyses provide a valuable review and a first estimate of long-term targets for a burn program based on actual pre-Euroamerican settlement fire return intervals within specific vegetation classes and aspects. Use of these types of evaluation techniques can be useful for determining long-term success of a burn program and in guiding future direction in either highly managed or wilderness landscapes. However, such an evaluation requires a certain level of knowledge about past fire regimes within an ecosystem to provide an assessment with some accuracy.

Additional research that is needed should focus on relationships between the amplitude of FRID and the associated vegetative and fuel response for each vegetation type. If, for example, it is not possible for one reason or another to achieve a three-to-five year fire return interval in ponderosa pine, but it is possible to maintain a 12 year interval, is this latter rate sufficient to achieve desired ecological and fuel objectives within the bounds of normal range of variation?

Constraints

The challenge that still remains, however, is how can large areas be burned that are indicated by the fire history reconstructions? Greater area can be achieved through the combined effects of using larger, variable-intensity ignitions (Parsons 1995) and by increasing the reburning of areas burned in the recent past. The tree-ring fire history record suggests that large areas burned annually because a few common vegetation types burned at frequent intervals. The most important of these was ponderosa pine-mixed conifer, followed by white fir and sequoia-mixed conifer. Frequent fires could occur in these vegetation types because burns were low intensity understory fires with rapid fuel recovery (fuels components were probably a matrix of herbaceous species, the subshrub mountain misery (Chamaebatia foliolosa Benth.) and litter fall). In ponderosa pine-mixed conifer, reburns of a site would often occur within two or three years of the preceding fire (Caprio and Swetnam 1995; Caprio unpublished data). In contrast, the burn program at SEKI has carried out very few secondary burns following initial restoration burns which has hindered efforts to boost area burned over the long term. If a concerted effort were to be made to balance repeat burning with initial restoration ignitions, greater success might be achieved. Currently, considerable time and effort are applied to carrying out initial restoration burns resulting in limited area burned annually due to the difficulty of implementation. Secondary restoration and eventually maintenance burns, where fuel, smoke, and potential escape problems are minimal, could successfully accomplish much greater acreage annually.

A variety of constraints are encountered when the practicality of carrying out a burn program on the scale intended to replicate pre-Euroamerican settlement conditions is examined. These include limited funding, unnatural fuel loads and forest structure where burning is difficult, air quality issues, availability of qualified personnel and other resources, political boundaries that may require continued use of managed fire, cultural and archeological concerns, occurrence of rare or invasive exotic species, difficulty in maintaining long-term management goals, poor knowledge about past and current ecosystem processes, fire regimes and structural components used for decision making, and inadequate standards to evaluate a burn program (Mitchell 1995; Parsons 1995; Parsons and Botti 1996; Parsons and Landres 1998). Additionally, an ecosystem-level burn program must be carried out within a diverse and dynamic landscape with a high degree of biotic complexity. While burning *X* amount of area appears to be a simple goal, in actuality there are a suite of additional ecosystem elements that must be addressed by a fire program. Restoration of natural fire means returning fires to an ecosystem that burns with similar effects, frequencies, intensities, and other characteristics of pre-Euroamerican settlement fire (Parsons and van Wagtendonk 1996). It must be understood that spatial and temporal heterogeneity of fire within ecosystems are important and need to be incorporated into a burn program (Parsons and Botti 1996).

Conclusion

Our two analyses provide a quantitative evaluation of the burn program at Sequoia and Kings Canyon National Parks over the last 30 years using new methods. They suggest that while some progress has been made, considerable gaps still exists between the accomplishments of our current burn program in burning large annual area relative to what our reconstructed pre-Euroamerican estimates are. The difference is important because it indicates we are not maintaining fire as a natural process to the extent that policy prescribes. This goal will be accomplished when contemporary fires burn with similar characteristics to pre-Euroamerican settlement fires (Parsons and van Wagtendonk 1996). This may be achieved through either natural ignitions or management ignitions where burning with naturally ignited fires is difficult or restricted. The difference also highlights that there will probably always be constraints limiting achievements. These may be insurmountable at specific locations and alternative means of achieving management goals may be required.

Acknowledgments

We thank Karen Folger and Pat Lineback at Sequoia and Kings Canyon National Parks for assistance in the GIS analysis and for discussion of ideas used in developing the FRID data used in this analysis. Corky Conover and many others have maintained and updated the historic fire records and maps we used.

References

Agee, J.K. 1993. *Fire Ecology of Pacific Northwest Forests*. Island Press, Washington, D.C. 493 pp.

Allen, C.D., R. Touchan, and T.W. Swetnam. 1995. Landscape-scale fire history studies support fire management action at Bandelier. Park Science 15:18-19.

Bancroft, L., T. Nichols, D.J. Parsons, D.M. Graber, B. Evison, and J. Van Wagtendonk. 1985. Evolution of the natural fire management program at Sequoia and Kings Canyon National Parks. pp. 174-180. In: J.E. Lotan, B.M. Kilgore, W.C. Fischer, and R.W. Mutch (tech. coord.). *Proceedings–Symposium and Workshop on Wilderness Fire. Nov. 15-18, 1983, Missoula, MT.* USDA Forest Service Gen. Tech. Rep. INT-182.

Caprio, A.C. and T.W. Swetnam. 1995. Historic fire regimes along an elevational gradient on the west slope of the Sierra Nevada, California. pp. 173-179. In: J.K. Brown, R.W. Mutch, C.W. Spoon, R.H. Wakimoto (tech. coord.). Proceedings: *Symposium on Fire in Wilderness and Park Management: Past Lessons and Future Opportunities, March 30-April 1, 1993, Missoula Montana*. USDA Forest Service, INT-GTR-320, 283 pp.

Caprio, A.C. 1997. Fire History. pp. 51-54. In: A.C. Caprio (ed.). Mineral King Risk Reduction Project: Monitoring, Inventory, and Research. 1996 Annual Report, USDI NPS, on file at Sequoia and Kings

Canyon National Parks. 75 pp.

Caprio, A.C. 1998. Fire History. pp. 56-61. In: A.C. Caprio (ed.). Mineral King Risk Reduction Project: Monitoring, Inventory, and Research. 1997 Annual Report, USDI NPS, on file at Sequoia and Kings Canyon National Parks. 91 pp.

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: Proceedings– 1997 ESRI GIS Conference, San Diego, CA.

Caprio, A.C., C. Conover, M. Keifer, and P. Lineback. in press. Fire management and GIS: a framework for identifying and prioritizing fire planning needs. In: Proceedings of the Conference on Fire in California Ecosystems: Integrating Ecology, Prevention, and Management. Nov. 17-20, 1997, San Diego, CA.

Caprio, A.C. and P. Lineback in press. 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.

Dilsaver, L.M. and W.C. Tweed. 1990. ***Challenge of the Big Trees: A Resource History of Sequoia and Kings Canyon National Parks***. Sequoia Natural History Association, Inc. Three Rivers, CA. 379 pp.

ESRI. 1997. ArcView. Environmental Systems Research Institute, Inc., Redlands, CA

Farquhar, F.P. 1965. ***History of the Sierra Nevada***. Univ. of Calif. Press, Berkeley, Calif. 262 pp.

Graber, D.M. and D.J. Parsons. 1998. Twenty-six years of prescribed fire management in Sequoia and Kings canyon National Parks: What has been accomplished in restoring fire and its effects? Abstract In: T.L. Pruden and L.A. Brennan. Fire in Ecosystem Management: Shifting the Paradigm from Suppression to Prescription. Tall Timbers Fire Ecology Conference Proceedings, 20:244

Keifer, M., N.L. Stephenson and J. Manley. In review. Prescribed fire as the minimum tool for wilderness forest and fire regime restoration: a case study from the Sierra Nevada, California. In: Cole, David N.; McCool, Stephen F. 2000. Proceedings: Wilderness Science in a Time of Change. Proc. RMRS-P-000. Ogden, UT: U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station.

Kilgore, B.M. 1971. The Role of Fire in Managing Red Fir Forests. ***Trans. 36th North Amer. Wildlife and Nat. Res. Conf.***, pp. 405-416.

Kilgore, B.M. 1973. The ecological role of fire in Sierran conifer forests: its application to national park management. Quaternary Research. 3:496-513

Kilgore, B.M. and D. Taylor. 1979. Fire history of a sequoia-mixed conifer forest. Ecology 60:129-142

Laven, R.D., P.N. Omi, J.G. Wyant, and A.S. Pinkerton. 1980. Interpretation of fire scar data from a ponderosa pine ecosystem in the central Rocky Mountains, Colorado. pp. 46-49. In: M.A. Stokes and J.H. Dieterich (tech. coord.). *Proceedings of the Fire History Workshop. October 20-24, 1980, Tucson, Arizona*. USDA Forest Service, GTR-RM-81.

Leopold, A.S., S.A. Cain, C.M. Cottam, J.M. Gabrielson, and T.L. Kimball. 1963. Wildlife management in the national parks. Amer. Forests 69:32-35, 61-63.

McBride, J.R. and D.F. Jacobs. 1980. Land use and fire history in the mountains of southern California. pp. 85-88. In: M.A. Stokes and J.H. Dieterich (tech. coord.). ***Proceedings of the Fire History Workshop. October 20-24, 1980, Tucson, Arizona***. USDA Forest Service, GTR-RM-81.

Mitchell, B. 1995. The Federal Clean Air Act and its impact on fire management programs. pp. 74-76. In: J.K. Brown, R.W. Mutch, C.W. Spoon, R.H. Wakimoto (tech. coord.). Proceedings: *Symposium on Fire in Wilderness and Park Management: Past Lessons and Future Opportunities, March 30-April 1, 1993, Missoula Montana*. USDA Forest Service, INT-GTR-320, 283 pp.

Parsons, D.J. 1995. Restoring fire to giant sequoia groves: what have we learned in 25 years? pp. 256-258. In: J.K. Brown, R.W. Mutch, C.W. Spoon, R.H. Wakimoto (tech. coord.). Proceedings: *Symposium on Fire in Wilderness and Park Management: Past Lessons and Future Opportunities, March 30-April 1, 1993, Missoula Montana*. USDA Forest Service, INT-GTR-320, 283 pp.

Parsons, D.J. and S.J. Botti. 1996. Restoration of fire in National Parks. pp 29-31. In: C.C. Collin and S.F. Arno (eds.). The use of fire in forest restoration. USDA For. Serv. Gen. Tech. Rep. INT-GTR-341. 86 pp.

Parsons, D.J. and P.B. Landres. 1998. Restoring natural fire to wilderness: how are we doing? pp. 366-373. In: L.A. Brennan and T.L. Pruden (eds.). *Fire in ecosystem management: shifting the paradigm from suppression to prescription. Proceedings of the Tall Timbers Fire Ecology Conference, No. 20*. Tall Timbers Research Station, Tallahassee, FL.

Parsons, D.J. and J.W. van Wagtendonk. 1996. Fire research and management in the Sierra Nevada national parks. pp 25-48. In: W.L. Halvorson and G.E. Davis (eds.). Ecosystem management in the national parks. Tucson, AZ: University of Arizona Press.

Pitcher, D.C. 1987. Fire history and age structure in red fir forests of Sequoia National Park, California. Canadian Journal of Forest Research. 17:582-587.

Pyne, S.J., P.L. Andrews, and R.D. Laven. 1996. *Introduction to Wildland Fire*. John Wiley and Sons, Inc., NY, 769 pp.

Taylor, A.H. and C.N. Skinner. 1998. Fire history and landscape dynamics in a late-successional reserve, Klamath Mountains, California, USA. Forest Ecology and Management 111:285-301.

Van Wagtendonk, J.W. 1995. Large fires in wilderness areas. pp. 113-116. In: J.K. Brown, R.W. Mutch, C.W. Spoon, R.H. Wakimoto (tech. coord.). Proceedings: *Symposium on Fire in Wilderness and Park Management: Past Lessons and Future Opportunities, March 30-April 1, 1993, Missoula Montana*. USDA Forest Service, INT-GTR-320, 283 pp.

Wright, H.A. and A.W. Bailey. 1982. Fire Ecology: United States and Southern Canada. John Wiley & Sons, Inc., New York, 501 pp.