Pre-Twentieth Century Fire History of Sequoia and Kings Canyon National Park: A Review and Evaluation of Our Knowledge

Anthony C. Caprio[1] and Pat Lineback[2]
[1]Ecologist, Sequoia and Kings Canyon National Park, Three Rivers, CA 93271
[2]GIS Coordinator, Sequoia and Kings Canyon National Park, Three Rivers, CA 93271

Abstract

Fire history investigations, utilizing fire scar records from trees, have been carried out in Sequoia and Kings Canyon National Park for nearly 25 years. However, the objectives for each study and the specific types of vegetation where the studies have been conducted have varied greatly. As a result, our knowledge about pre-twentieth century fire regimes in different vegetation communities and locations within the park varies considerably.

To provide improved information for fire management we have compiled and synthesized the state of our knowledge about pre-twentieth century fire frequency regimes and evaluated the consistency and strength of these data. For each of the 12 broad vegetation classes in the park we summarized pre-Euroamerican fire history data (pre-1860) derived from both local studies and data from other areas of the Sierra Nevada. This knowledge has become important input into resource and fire management planning. The current data suggested there was a "lazy-J" shaped fire frequency pattern over an elevational gradient. A spatial reconstruction of pre-Euroamerican fire frequency regimes was produced by mapping this data set over the park using GIS. We also examined the application and accuracy of this knowledge for each of the 12 vegetation classes and rated the information based on specific criteria. A fire frequency regime "knowledge" map for the park was developed that provided spatial information on the quality of our fire frequency reconstruction. We determined that current information was representative of only about 16% of the park's vegetated area, with several vegetation classes having little or no information. The highest quality information was closely associated with giant sequoia groves, lower mixed-conifer forest, and ponderosa pine forest, a result of where the majority of the fire history studies have been focused. Additionally, sites tended to be located on ridgetops or on slopes with south aspects. We found a poor understanding of past fire regimes in many areas, particularly at low and high elevations and on north aspects. Because the role of fire in these areas could be significantly different from the sampled locations, we believe caution should be used in extrapolating current knowledge**.** As park management increasingly focuses on restoration of fire based on attributes of historic pre-Euroamerican fire regimes, it is crucial that we build a solid knowledge foundation for fire management planning**.**

Introduction

Over the last 25 years, fire history studies based on tree-ring analysis of fire scarred trees, have been carried out within or adjacent to Sequoia and Kings Canyon National Park. While the purpose of the investigations has been to obtain dates of past fires, the specific objectives and techniques have varied. They have provided important ecological and management information ranging from reconstructing changes in fire frequency due to Euroamerican settlement, to understanding the relationship between fire and forest structure, to showing the interaction of climate and fire. Several of these have been seminal studies on fire history (Kilgore and Taylor 1979; Swetnam 1993) As the breadth of areas and plant communities sampled from throughout the park has expanded so has our knowledge and understanding about the underlying characteristics and variability of the pre-Euroamerican fire regimes. As a result, we have become more aware of the complex patterns and relationships of past fire regimes.

The concept of fire regimes is important since it allows us to view fire as a multi-faceted variable rather than a single event within an ecosystem (Whelan 1995). Thus areas can be classified as having a certain type of regime that summarizes the characteristics of fires, within some range of variability which can have both spatial and temporal attributes. The idea is also important because it permits us to estimate how altered the fire regime has become due to human activities and facilitates decisions on what management actions are needed to preserve or restore the regime. Fire regimes are normally defined according to specific variables including: intensity, frequency, severity, season, extent, and type of fire (Gill 1975; Heinselman 1981). For our analysis we used data acquired from fire-scarred trees in the form of fire return intervals to reconstruct a conservative estimate of fire frequency regimes. This knowledge about reconstructed frequency regimes is important for informed science-based ecosystem management (Morgan et al. 1994).

The park has recently begun to utilize and integrate this data within a GIS framework to provide information for ecologically sound management and for optimizing burn program planning (Caprio et al. this proceeding). Various models used in this GIS analysis were directly or indirectly derived from the fire history data (data from tree-ring analysis of fire scars) and historic fire records (historic data obtained from mapped fires). Using this information on fire frequency regimes in various vegetation types, an "ecological needs" model was developed to produce a map of "fire return interval departures" (FRID). This model highlights areas that have deviated most from their historic fire regimes beginning with Euroamerican settlement over 100 years ago. This modeling approach also showed potential as a tool that may be applied in other resource management settings.

Our objectives for this paper are to review our knowledge, explain methods, and provide an evaluation of the fire history data from the park and utilized within the GIS model. First, we will review the process used in reconstructing fire frequency regimes spatially across the park and describe some aspects of its utilization. Second, we present an evaluation of our knowledge about the quantity and quality of the fire history data used within the model and review limitations or problems in the application of these data. This provides the park with an improved understanding of fire in ecosystem function, with the potential for this knowledge to provide practical information to support the fire management program, and to improve future fire history sampling strategies.

Study Area

Sequoia and Kings Canyon National Park (SEKI) is 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). Major drainages are the Kern, Kaweah, Kings , and San Joaquin Rivers. The elevational gradient from the foothills to the higher peaks is steep with rapid transitions between vegetation communities. Three broad vegetation zones dominate the park (slightly over 200,000 ha are vegetated), *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 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 et al. 1977; Vankat 1982; Stephenson 1988; Potter 1994).

The climate is distinctly Mediterranean with cool moist winters and warm summers with little rainfall, although seasonal summer thunderstorms occur sporadically at higher elevations. 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, and then decreases 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. The park were founded in 1890, originally with the intent of protecting sequoia groves from logging, but has been expanded to include much of the surrounding rugged, high mountains and some foothills areas (Dilsaver and Tweed 1990).

Fire History Studies

Fire history investigations were begun about 25 years ago by Kilgore and Taylor (1979) and have continued intermittently through the present. While the specific objectives and techniques among the fire history investigations have varied. The main impetus for the studies has been to provide information for the restoration of fire within park ecosystems. The investigations have sought to obtain information on fire frequency in specific vegetation types (Kilgore ands Taylor 1979; Warner 1980; Pitcher 1981, 1987; Swetnam et al. 1992), for use in understanding forest stand structure and dynamics (Pitcher 1981; Keifer 1991; Stephenson et al. 1991; Swetnam et al. 1992), for investigating the relationship between fire and climate (Pitcher 1981; Swetnam et al. 1992; Swetnam 1993; Caprio and Swetnam 1993, 1994), to examine fire over elevational gradients (Caprio and Swetnam 1995), and to investigate the relationship between fire and growth responses in giant sequoias (Caprio et al. 1994; Mutch 1994; Mutch and Swetnam 1995). This research has given the park a growing understanding of the of pre-Euroamerican fire regimes and their complexity.

Historically, fire played a key ecological role in most Sierra Nevada plant communities (Kilgore 1973). In conifer forests fire shows an inverse relationship between fire frequency and elevation (Caprio and Swetnam 1995). The cause of fires prior to Euroamerican settlement is usually attributed to ignitions by lightning or native Americans. However, since the actual source of these fires cannot be determined, the specific cause(s) remain largely unknown. The seasonal occurrence of pre-settlement fires was similar to the contemporary late summer-early fall fire season (Swetnam et al. 1992; Caprio and Swetnam 1995). Fire intensity was variable both spatially and temporally (Stephenson et al. 1991; Caprio et al. 1994). In much of the mixed-conifer zone, fires were primarily non-stand replacing surface fires (Kilgore and Taylor 1979; Warner 1980; Pitcher 1987; Caprio and Swetnam 1995), although exceptions exist (Caprio et al. 1994). Specific regional fire years have also been identified (years in which fires have been recorded at sites from throughout the southern Sierra Nevada), usually occurring during dry years (Brown et al. 1992; Swetnam et al. 1992; Swetnam 1993). These data also document long-term variation (1000-2000 years) in the fire regime associated with climatic fluctuations (Swetnam 1993).

Fire regimes in the Sierra Nevada changed dramatically beginning with Euroamerican settlement around 1850-1870 (Kilgore and Taylor 1979; Warner 1980; Caprio and Swetnam 1995). Factors that contributed to this decline include the loss of native American populations that used fire and heavy livestock grazing that reduced herbaceous fuels available for fire spread (Caprio and Swetnam 1995). Additionally, the occurrence of fires of large size decreased dramatically during the twentieth century because of active fire suppression. These change in fire regime led to unprecedented fuel accumulations in many plant communities, structural and composition changes, and have resulted in an increased probability of widespread severe fires (Kilgore 1973).

Methods

Fire Return Intervals

Mean and maximum fire return intervals were either obtained from the literature or derived from crossdated fire-history chronologies (fire dates from scarred trees) collected at sites within or near the park. Fire frequencies, based on the return intervals, reported in this paper are “point frequency” estimates (Agee 1993) derived from specific sites usually less than one hectare in size. From the crossdated chronologies, means and “averaged maximum” return intervals were calculated using a randomization procedure. The procedure produced a more robust average interval estimate for the maximum intervals relative to a simple average or moving average. It calculated the two mean return interval estimates for 100 runs of the procedure. Each run used the number of fire intervals from a composite site record and randomly selected this number of intervals from the pool of interval lengths. The “average maximum”, a conservative estimate, was the mean of the maximum length interval selected from each run. To produce a fire frequency estimate without the influence of Euroamerican settlement (through grazing and decrease in Native American populations), we only used fire history data priot to 1860 for ponderosa, mixed conifer, and red fir forests and to 1870 for subalpine forest (based on Kilgore and Taylor 1979, Caprio and Swetnam 1995, and Caprio unpublished data). This interval estimate was summarized by vegetation class and scaled up to the landscape level using GIS. In synthesizing the data, local data were given greater weight than data from more distant locations. GIS analysis and mapping was carried out using Arc/Info, Grid, and ArcView and their extensions (ESRI 1997).

Vegetation Classification

We used the base vegetation layer from the park GIS for the spatial analysis of the fire frequency regimes by universally applying the estimates of fire frequency for each vegetation class throughout the park. The vegetation layer was derived from a series of field classifications collected in the 1960s and 1970s (NPS no date). Because slightly differing methodologies and vegetation classifications were utilized for the original classifications, the original maps were reclassed to produce a generalized vegetation map with a similar classification scheme (12 broad classes) across both Sequoia and Kings Canyon National Park (D. Graber and N. Stephenson per. comm.).

Evaluation Criteria

A "confidence estimate" was made on the data for the mean and maximum fire frequency intervals using several evaluation criteria (**Table 1**). The criteria were: the existence of fire history data for a vegetation class, was the data replicated, how well the data corresponded to the park's vegetation, and the quality of the fire-frequency data within the different vegetation classifications and aspects. Decision criteria were developed for evaluating our knowledge about the available fire history data and applied to the fire frequency information for each of the vegetation classes.

The aspect classification was derived from USGS 7.5 Minute quads (aspects (south=106 to 285° and north=286 to 105°). It was designed to capture relatively large areas of continuous aspect (greater than about 300 ha in size). Smaller micro-topographic aspects were not considered as important in determining widespread fire occurrence across the landscape. Level areas without aspect were added to the south aspect category, the assumption being that they mostly resemble south aspects.

Results and Discussion

Reconstructing Pre-Twentieth Century Fire Frequency Regimes

Fire Return Intervals

Fire scar data from within or adjacent to the park were based on 80 sampled sites that represented eight of the 12 major vegetation classes used in GIS mapping of park vegetation (**Table 2**). Estimates for the remaining classes were obtained from published literature. Average and maximum fire return intervals for the 12 vegetation classifications in Sequoia & Kings Canyon National Park varied from four to 187 years (mean) and six to 508 years (average maximum). The shortest fire return intervals were found in the lower mixed-conifer forest, particularly forest dominated by ponderosa pine and the longest fire return intervals were found in subalpine forest, usually dominated by foxtail pine or white-bark pine. A plot of the relationship between mean fire return interval and elevation showed a "lazy J"-shaped relationship (**Fig. 1**). We speculate that the relationship was primarily governed

Table 1. *Criteria used in evaluating the fire history data used in reconstructing fire frequency regimes.*

1. Does fire frequency regime information exist?
2. How many sites have been collected within a vegetation class?
3. From where was the fire frequency regime information obtained?
    a) local (within or adjacent to park)
    b) within region (southern Sierra Nevada)
    c) outside region (similar vegetation in other regions)
4. How independent were sites within a vegetation type?
5. How well distributed were sites within the park?
    a) well (>2 sites within each park zone if vegetation exists in zone)
    b) poor (<2 sites within each park zone)
6. Were sites crossdated using dendrochronological methods?.
7. Was the distribution of sites representative of north and south aspects within a vegetation class?

Table 2. *Average and maximum fire return intervals for the 12 major classifications in Sequoia & Kings Canyon National Park. Data are for the period prior to 1860 (1870 for subalpine conifer). The primary source(s) for the data are enumerated under "Reference" heading and are listed at the bottom of the table. Fire frequency regime classes for each major vegetation class were based on mean maximum fire return intervals. The frequency classes were used to reconstruct fire frequency regimes spatially across the park.*

Vegetation/Terrain Class (class code #)	Code	Mean	Max.	Freq. Class	Knowledge	Reference
(1) Ponderosa Mixed Conifer	PIPO	4	6	v. high	good	1,2,3,16,17
(2) White Fir Mixed Conifer	ABCO	10	16	high	good	1,2
(3) Red Fir Mixed Conifer	ABM	30	50	low	poor	1,4,5
(4) Lodgepole Pine Forest	PICO	102	163	v. low	v. poor	5,6,18
(5) Xeric Conifer Forest	XECO	30	50	low	v. poor	5,7,8,17
(6) Subalpine Conifer	SUAL	187	508	v. low	poor	5,9
(7) Foothills Hardwood & Grassland	FHGR	10	17	mod.	v. poor	5,10,11
(8) Foothills Chaparral	FOCH	30	60	low	estimated	12
(9) Mid-Elevation Hardwood	MEH	7	23	mod.	v. poor	3,19
(10) Montane Chaparral	MOC	30	75	low	estimated	12
(11) Meadow	MEA	40	65	low	estimated	8
(14) Giant Sequoia Forest	SEGI	10	16	high	good	13,14,15
(12) Barren Rock	ROCK					
(13) Other (mostly water)	OTHR					
Missing Data	MISS					

1 Caprio and Swetnam 1993, 1994, 1995; **2** Kilgore and Taylor 1979; **3** Stephens, unpublished data in Skinner and Chang 1996; **4** Pitcher 1981,1987; **5** Caprio unpublished data ; **6** Keifer 1991; **7** Taylor, unpublished data in Skinner and Chang 1996; **8** Skinner, unpublished data in Skinner and Chang 1996; **9** Caprio, Mutch, and Stephenson unpublished data ; **10** Mensing 1992; **11** McClaren and Bartolome 1989; **12** SNEP 1996; **13** Swetnam et al. 1991; **14** Swetnam et al. 1992; **15** Swetnam 1993; **16** Warner 1980; **17** McBride and Jacobs 1980; **18** Sheppard 1984; **19** Stephens 1997

by productivity (fuel production) and the potential for fire ignition and spread. The relationship was strongest in coniferous forest with a direct relationship between elevation and fire frequency although information for some vegetation classes is weak or nonexistent for the Sequoia-Kings Canyon area. At lower elevations the data indicated a reduced frequency and suggested an inverse relationship. The latter information represents our best estimate, but is based on limited data and may be subject to change. However, these frequencies agree favorably with our knowledge about the life-history traits of woody chaparral species (Keeley 1981; Naveh 1994). Direct extrapolation of frequencies from conifer forest into lower elevations would result in very short return intervals (<5 years) which could not be tolerated by most of these species, although the dominance of sprouting species does suggest a moderate frequency. If high frequencies did exist, it would suggest that extensive shifts in vegetation within this zone have occurred over the last 130 years, probably shifting from more open grassland with pockets of chaparral to the current composition.

Using these data as our best available information, we reconstructed fire frequency regimes by applying the frequency estimates to all major vegetation classes. To provide an easier to interpret reconstructed frequency map we aggregated similar intervals into five frequency classes (**Table 2**) for mapping (**Fig. 2**). The five frequency classes were: very high - <7 yr; high - 7 to 16 yr; moderate - 17 to 25 yr; low - 26 to 100 yr; and very low - >100 yr.

Several significant time-dependant attributes of the fire history data were not considered in this original model. First, the analysis does not consider the stochastic variation in fire intervals through time (fire interval distributions) among or within vegetation types. Such interval dependent effects of fire events can have significant influences on plant demographics and long-term plant community structure (Whelan 1995;Bond and van Wilgen 1996; Chang 1996). Additionally, the fire regime may not be stable over time but may fluctuate with environmental

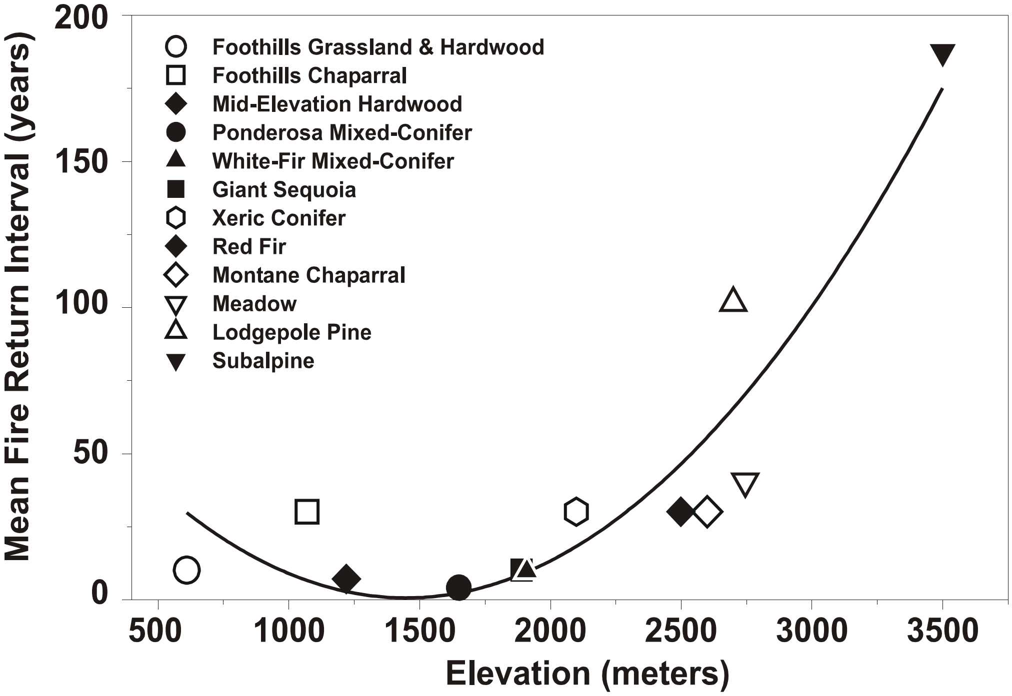

***Figure 1**. Relationship between mean fire return interval and elevation for the 12 major vegetation classes within Sequoia and Kings Canyon National Park. Elevation data for vegetation classes was obtained from Rundel et al. (1977), Vankat (1982), Potter (1994), and from the park's vegetation maps.*

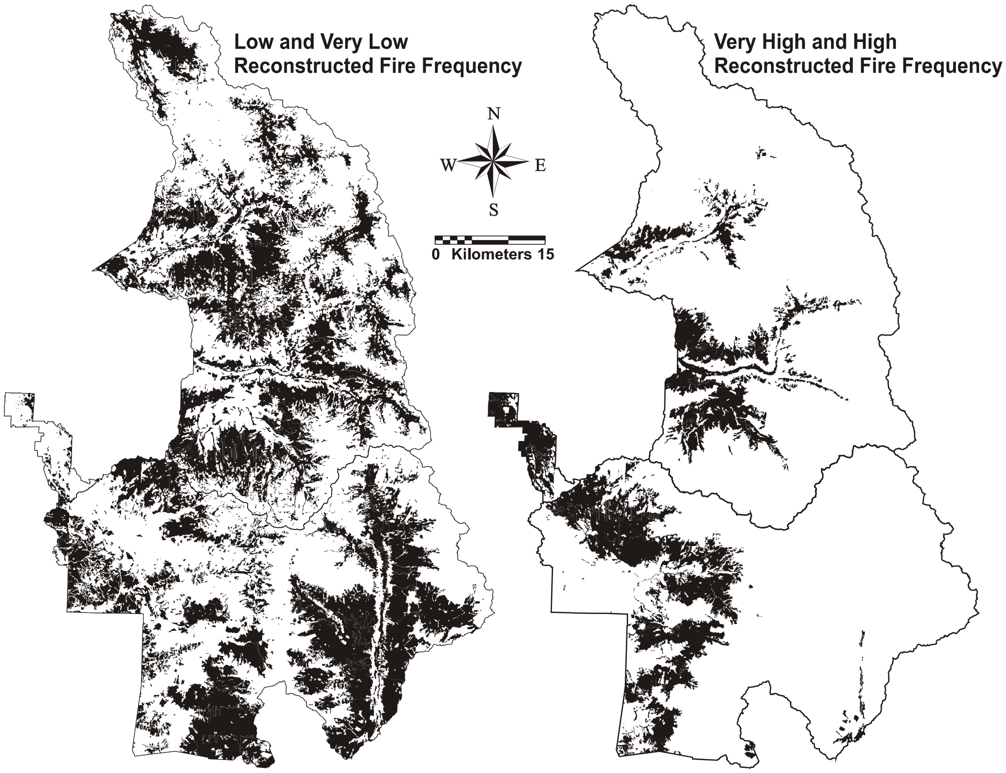

***Figure 2**. Distribution of vegetation classed as having a low or very low reconstructed fire frequency (left) or having a high or very high reconstructed fire frequency (right) based on average maximum return intervals.*

and climatic factors (Clark 1989). Thus, fire history data from a short 100-200 year period should be interpreted with this caveat in mind. The mid-to-southern Sierra Nevada is fortunate in having long-lived sequoia forests where long fire chronologies exceeding 2,000 years have been developed (Swetnam et al. 1991, 1992; Caprio et al. 1994; Baisan this conference). These are providing long-term information about changes in fire frequency related to climatic fluctuations (Swetnam 1993). However, even without this information the model of fire frequency regimes provides a valuable resource for understanding past fire regimes and guiding park management decisions.

Utilizing the Fire History Data

The park is currently integrating information about fire history with other data sets using GIS models to improve fire management tools and to obtain a better understanding of past and present ecological processes within the park. Model development was motivated by the National Park Service's mission statement to "protect and preserve" natural resources, with fire being an important process to apply in working towards this goal. The reconstructed fire frequency regimes were used to develop an “ecological needs model”. This model provided a rating index to rank areas on the need for reintroducing and maintaining fire within a particular vegetation community. This index was used to quantify the departure of the vegetation type from its pre-Euroamerican settlement fire return interval. All areas within the park’s 12 broad vegetation classes were rated based on ***fire return interval departures*** (FRID) (Caprio et al. this proceedings). Inputs into the model were $\mathbf{RI_{max}}$ and **TSLF** where, $\mathbf{RI_{max}}$ is the maximum average pre-Euroamerican settlement fire return interval for vegetation class (with 12 broad vegetation classes within the park), and ***TSLF*** (time since last fire) is the time that has passed since the most recent fire from historic fire records or using the baseline date of 1899 derived from the fire history chronologies. Both values depended on data from the fire history record. The reconstructed return intervals ($\boldsymbol{RI_{max}}$) used in the model were derived from data summarized in this paper (**Table 2**). The ***TSLF*** was derived from historic fire records (these extend back to 1921) or was based on the last widespread fire date (1899) recorded by the fire history reconstructions (see Caprio et al. this proceedings).

We also estimated the mean annual area burned prior to Euroamerican settlement within each of the 12 broad vegetation classes within the park using the summarized fire return intervals (**Table 3)** and the area of each of the 12 vegetation classes, obtained from the park’s GIS vegetation layer. This provided an estimate of which

Table 3. *Estimated mean number of hectares burned annually within each of the 12 major vegetation classes based on the fire return intervals from* ***Table 1****. Two estimates were calculated to present a range of possible values. Estimates were based on the mean maximum fire-return interval and average fire-return interval (in parenthesis). The estimate based on mean maximum provided a conservative estimate of area burned annually. Not considered were potential differences in fire frequencies on north versus south aspects which would probably result in a reduced number of hectares burned annually.*

Vegetation Class (class code #)	**Return Interval (yrs)**		**Area**	**Area Burned (ha·yr^{-1})**	
	mean max.	**(mean)**	**(ha)**	**mean max.**	**(mean)**
(1) Ponderosa Mixed Conifer	6	(4)	16,568	2,761	(4,142)
(2) White Fir Mixed Conifer	16	(10)	31,460	1,966	(3,146)
(3) Red Fir Mixed Conifer	50	(30)	26,511	530	(884)
(4) Lodgepole Pine Forest	163	(102)	39,215	241	(384)
(5) Xeric Conifer Forest	50	(30)	13,700	274	(457)
(6) Subalpine Conifer	508	(187)	31,488	62	(168)
(7) Foothills Hardwood & Grassland	17	(10)	8,882	522	(888)
(8) Foothills Chaparral	60	(30)	8,856	148	(295)
(9) Mid-Elevation Hardwood	23	(7)	3,564	155	(509)
(10) Montane Chaparral	75	(30)	10,836	144	(361)
(11) Meadow	65	(40)	5,459	84	(136)
(14) Giant Sequoia Forest	16	(10)	4,055	253	(406)
Total			**200,594**	**7,140**	**(11,776)**

vegetation classes experienced the greatest fire load (a measure of how much area can be expected to burn over time) in the past and where future fire load may be greatest as fire is reintroduced back into the ecosystem. Because fire frequency estimates from some vegetation types and aspects were weak (see section on data evaluation), actual values should only be considered as approximate at this time. Additionally, these averaged values do not consider differences caused by year-to-year variation in climate, number of ignitions, or fire spread potential that would have caused temporal variation in area burned annually. The fire history data also suggested there may be variation by vegetation class. Lower elevation forests may have burned during any given year, the result of a longer and more consistent summer dry period, while forest types such as red fir or lodgepole may burn under more specific conditions. In designing long-term fire management strategies, such variations should be given consideration since they may play a role in the dynamics of some species or communities (Whelan 1995; Bond and van Wilgen 1996).

Evaluation of Our Knowledge

Criteria

The decision criteria (**Table 1**) we developed for evaluating our fire history knowledge were applied to each of the 12 major vegetation classes. Criteria were designed to provide feedback to management and researchers on the reliability of the knowledge and to furnish guidance to improve future fire history sampling strategies. Other possible criteria we did not include in this evaluation were elevation and slope.

1. Existence of Data

We reviewed whether pre-Euroamerican settlement fire history data existed for each of the specific vegetation classes. If fire frequency estimates based on fire history data did not exist we sought other sources of information. In all cases, information from these other sources was of poorer quality and often a speculative estimate. Pre-Euroamerican fire history data existed for eight of the 12 vegetation classes. Classes without data included foothills chaparral, mid-elevation hardwood forest (estimate based on post-settlement fire history), foothills grassland and hardwood, montane chaparral, and meadows.

2. Number of Observations

In reviewing the fire history data, we also examined how many observations went into determining a fire frequency estimate, with each fire-history site considered as a single replicate or observation. The number of observations, for those vegetation classes for which we had data, varied from one site in xeric conifer forest to 20 sites in giant sequoia forest.

However, adding additional observations within a specific vegetation class did not always add precision to our estimates. This may be a result of the park's current vegetation classification not capturing the actual variability within a vegetation type. For example, in lodgepole pine forests, data from different sampling sites show large differences in the length of fire return intervals, 163 years in the Siberian outpost area (Keifer 1991 - see also Sheppard (1984) for similar long intervals in the San Jacinto Mountains) to 20 - 64 yr on the Chagoopa Plateau (Caprio unpublished data). This variation might be explained by lodgepole's occurrence over a diverse range of environmental conditions, including a wide range of elevations and moisture conditions (Rundel et al. 1977). These fire frequency differences may reflect differences in site productivity, fuel accumulation, and ignition rates. A similar situation may also exist with other vegetation classes, particularly xeric conifer and red fir. This underscores the importance of replicate sampling to capture local variation.

3. Source of Data

We evaluated the geographical source of the fire history data and rated it based on distance criteria. The criteria were: 1) source of data was local (within or adjacent to park), 2) from within the region (southern Sierra Nevada), or 3) from outside the region (similar vegetation in other regions). Local information was given a greater weight because these data should represent local fire regimes more accurately. As source distance from SEKI increased, changes in vegetation and climate would increase and the information would be potentially less representative of local conditions.

4. Distribution within Vegetation Classes

We were also interested in how well fire history collections represented each particular vegetation class across the landscape. In other words, how representative were our current fire history sites in providing information about a particular vegetation type. Our evaluation indicated that a majority of the fire history sites were associated with giant sequoia groves. This was not unexpected given the mandate and emphasis park managers have put on obtaining information about fire's role in and near sequoia groves. Nearly all fire history data available from in or near the park originated from two investigations: centered on the Grant Grove and Redwood Mountain area (Kilgore and Taylor 1979), more recently by sampling in Mountain Home, Atwell, Giant Forest, Big Stump, and Mariposa Groves (Swetnam et al. 1992; Caprio and Swetnam 1993, 1994, 1995).

5. Distribution

We also considered broad park-wide differences in forest characteristics, particularly between eastern and western portions of the park that could strongly influence fire regimes. West-side forests of the Sierra Nevada are typified by fine-scale, low contrast mosaics whereas east-side forests, typically at higher elevations within the park (see **Fig. 3**), are more fragmented and form medium-scale, high-contrast mosaics (Franklin and Fites-Kaufmann 1996). We conjecture that differences in fire frequencies would exist within vegetation classes when compared between the Kern River drainage and upper Kings River drainages (east-side) and forested zones on the west side of the park because of these patterns. We would expect reduced frequencies on the east-side due to smaller forest stand size with reduced fire contagion across the landscape. Support for this conjecture is provided by Allen et al. (1995) and Wardle et al. (1997) who observed reduced fire frequencies as forest island size decreased or topographic isolation increased, although exceptions are reported (Bergeron and Brisson 1990; Bergeron 1991). Because the vast majority of our fire history data has come from west-side forests, we felt care should be taken in extrapolating these data to east-side drainages. Dividing the park into four broad "zones" (**Fig. 3**): the Kern drainage, the Kaweah drainage (also including a small portion of the Tule drainage), the lower Kings drainage, and the upper Kings drainage (including a small portion of the San Juoquin drainage), allowed us to better evaluate the distribution of the data across the park. Of the 80 sites in or near the park only one was located in the Kings River drainage, with the majority in the Kaweah drainage.

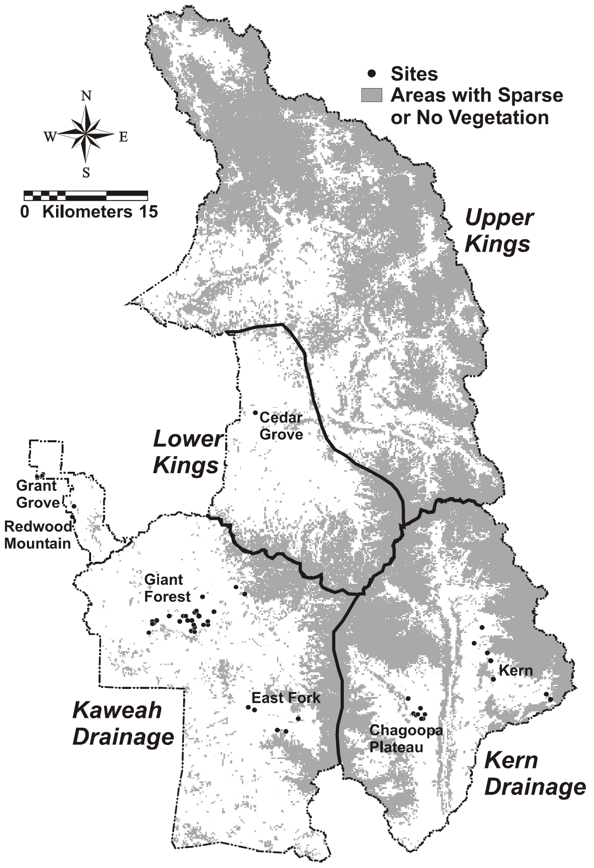

***Figure 3**. Locations of fire history sample sites within Sequoia and Kings Canyon National Park and four sample "zones" used to evaluate distribution of sites within the park. The majority of sites were located within the Kaweah River watershed with no information available from the upper Kings River watersheds.*

6. Crossdating

Use of dendrochronological techniques allows the actual calender year of each fire, and in some cases the season, to be determined from fire scarred samples (Stokes 1980; Ahlstrand 1980; Caprio and Swetnam 1995). Crossdating allows fire dates to be both temporally and spatially explicit, adding a substantial amount of precision to fire history data. Fire histories based on ring counts, as apposed to crossdating, can result in less accurate fire frequency estimates (Madeny et al. 1982) and hinder the use of fire history data spatially over a landscape where strict temporal precision is required.

7. Aspect

We also evaluated our fire history knowledge by aspect which was critical in the application of our GIS reconstructions across the landscape. Aspect can have a strong influence on fire with south and southwest aspects in the northern hemisphere being more favorable for ignitions and fire spread (Agee 1993; Pyne et al. 1996). These aspects receive greater solar radiation and tend to be warmer and drier with consequent differences in productivity, decomposition, fuel load and fuel characteristics, and fire behavior. Thus we expected fire frequency regimes on north aspects to be different from those on south aspects with a similar elevation and vegetation. This hypothesis is supported by a limited number of published fire history investigations. In ponderosa pine ecosystems of the central Rocky Mountains, Laven et al. (1980) report an average fire frequency of 34.9 years on south aspects and 64.3 years on north aspects (although they report that sample depth was limited on north slopes). Additionally, in the Jemez Mountains, New Mexico, Allen et al. (1995) found lower frequencies on north facing slopes than on south aspects in ponderosa pine and mixed-conifer forest.

Of the 80 fire history sites evaluated, 69 were located on south aspects with six of the remainder located in areas adjacent to south aspects (**Fig. 4**). Only five of the sites represented north aspects which constituted 80,882 ha (40.3%) of the 200,594 ha that are vegetated within the park (**Fig. 5**). Distribution and composition of vegetation classes among aspects was probably strongly influenced, although not solely, by fire regime characteristics. Most classes were more common on south aspects, with the exception of lodgepole pine. The strongest affinities for south aspect were ponderosa pine mixed-conifer, xeric conifer, subalpine conifer, and foothills grassland and hardwood forest.

Rating the Data

Using these criteria in a decision making process we evaluated our knowledge about fire history in the 12 vegetation classes and classed our results into six knowledge categories. These knowledge classes were used to develop a park-wide map that showed areas with good quality information and other areas where information was more speculative. A summarized description of the knowledge classes are as follows:

- **Estimated or Unknown**: No local data were available or the source of data was from literature that only reported frequency values as an estimate.
- **Very Poor**: Two or fewer independent local sites have been sampled or information was derived solely from the literature from sites sampled outside the region.
- **Poor:** Data from 3-5 local sites existed but the spatial extent of the sampling was extremely limited, some information available from outside the local area.
- **Good:** Data existed from multiple independent sites within a vegetation class located in or near the park, but gaps remained.
- **Excellent:** Adequate information from all categories existed. Our evaluation showed that no vegetation class fit this category due to the lack of information from north aspects and poor distribution from throughout the park.

The five knowledge classes were assigned to each vegetation class (**Table 2**) and mapped spatially across the park using the vegetation classification (**Fig. 6**). Most land area classed as good class fell in the lower conifer belt on the west side of the park, an area of moderate-to-high fire frequency with abundant fire scar material. This is also the area were most prescribed burning is planned or has been carried out, although it does not consider the lack of knowledge on north facing aspects. This area accounts for about 26% of the park (16% if aspect was considered) (**Fig. 7**). Areas of poor knowledge were generally located at higher elevations and in lower elevation grasslands and shrublands, areas of longer return intervals or areas that contain little or no fire scar material.

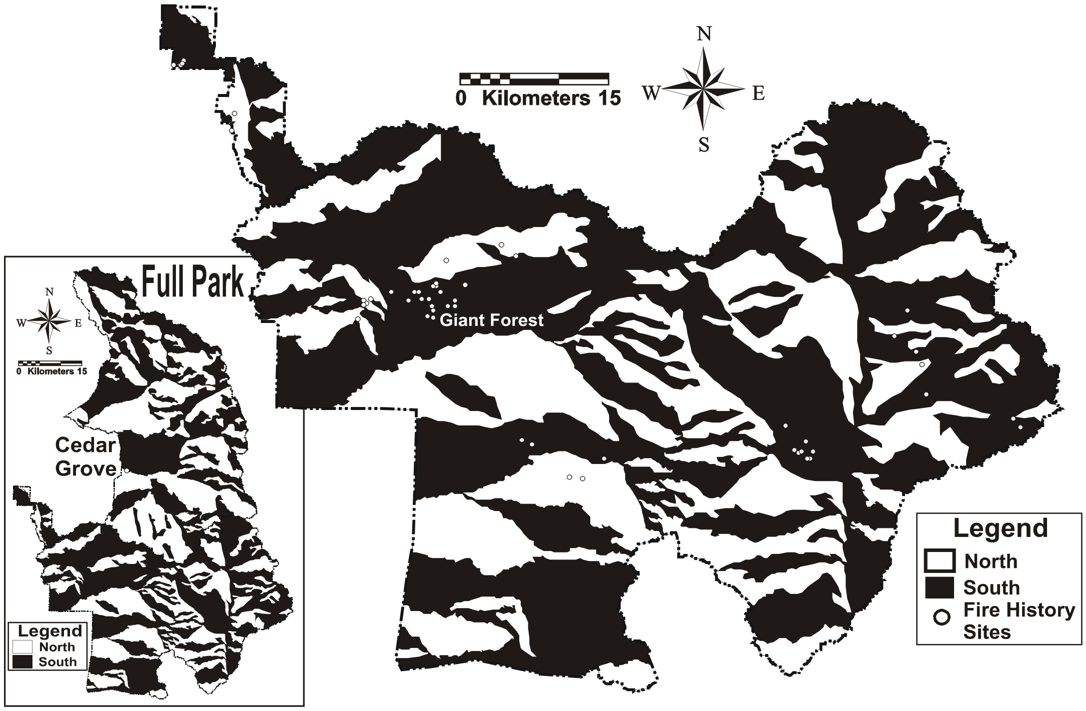

***Figure 4**. Relationship between fire history site locations and north versus south aspects within the park. Most sites sampled over the last 25 years have been located on south aspects (south=106 to 285° and north=286 to 105°.*

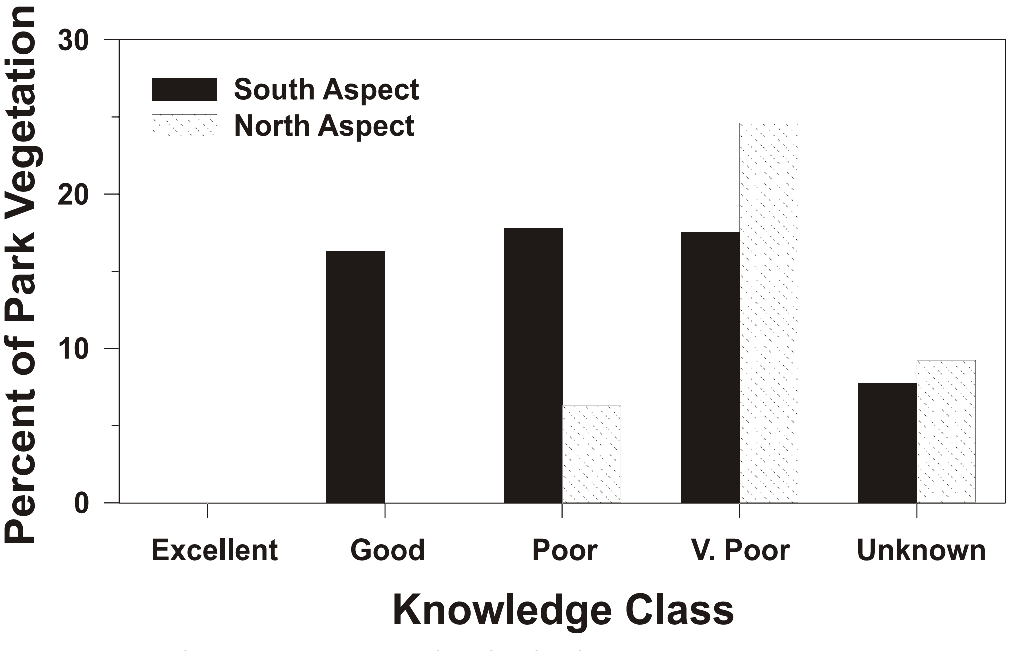

***Figure 5**. Area of the park within each of the five fire frequency regime classes (average maximum interval) by aspect. The majority of the park was classed with a low frequency (25-100 yr). With the exception of the very high class, the distribution of classes by aspect was similar. The difference in the very high class was due to the higher proportion of the ponderosa pine vegetation class on south aspects. The slightly higher values on south aspects for all frequency classes was a result of flat land areas being included with south aspects.*

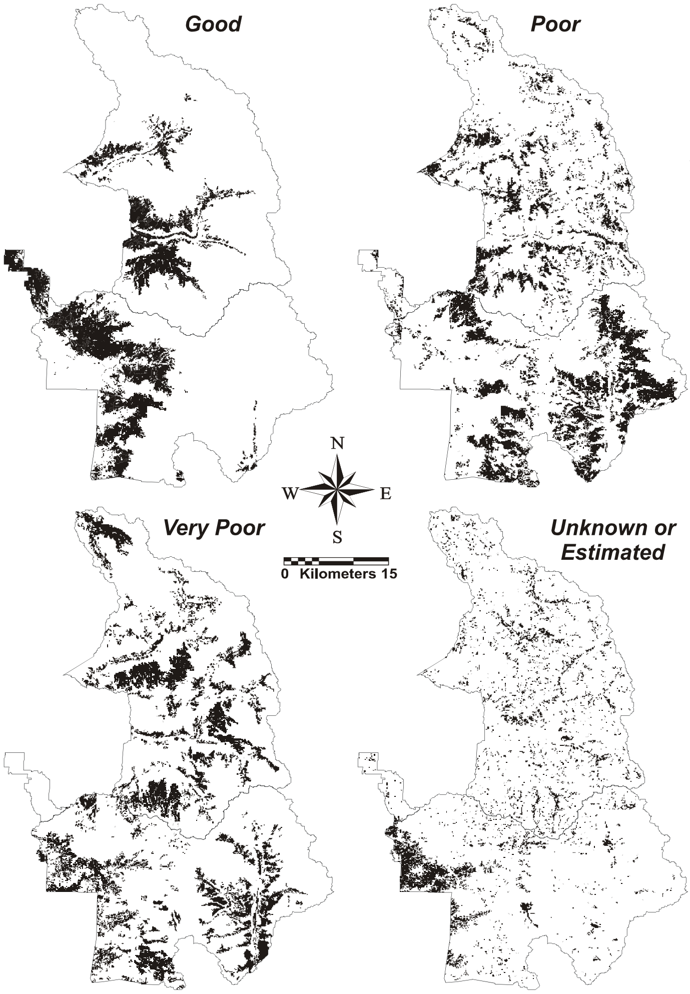

Figure 6. Maps of the spatial distribution of our knowledge about fire frequency regimes from throughout SEKI. The highest quality data exist for the mid-elevation mixed conifer and ponderosa pine belt with poor quality information from vegetation classes found at both the lowest and highest elevations.

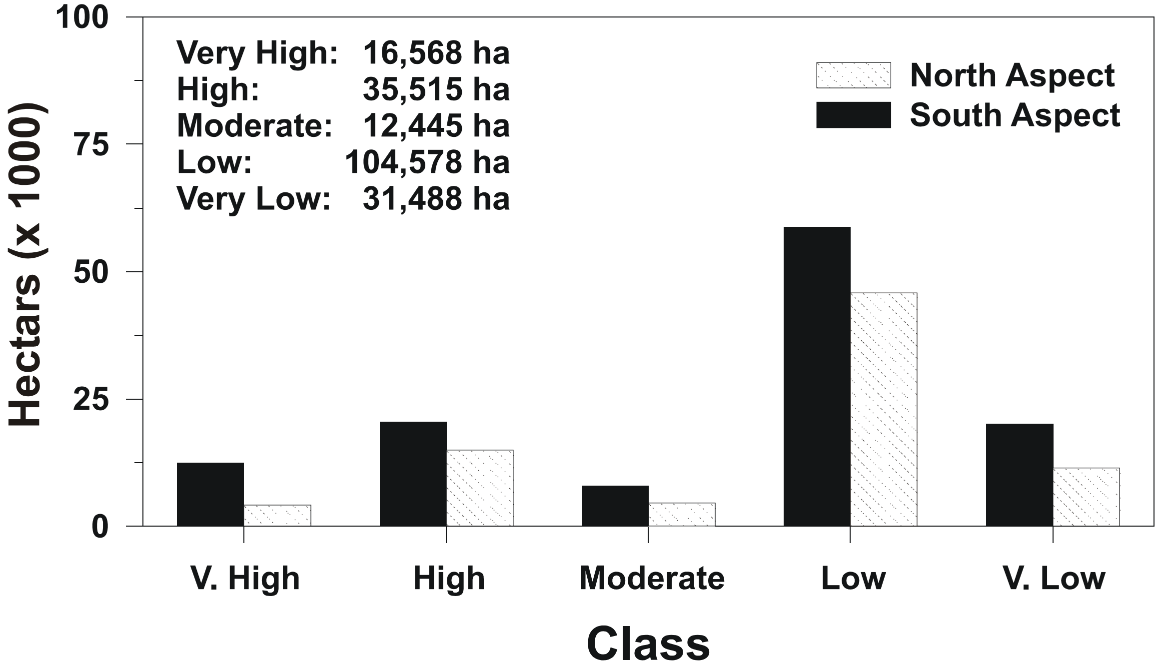

Figure 7. Percent of park vegetation in each "knowledge" class by aspect. For only about 16% of the park area do we consider our knowledge about past fire regimes to be good (26% if aspect is not considered).

Conclusions and Management Implications

Combining field data with GIS and historical knowledge can provide multiple perspectives on ecosystem dynamics to support ecosystem management (Allen 1994). Our synthesis of the fire history data for Sequoia and Kings Canyon National Park and its integration with our vegetation model using GIS allowed us to reconstruct fire frequency regimes spatially across the park. The spatially explicit fire history data illustrated the essential role of fire in shaping ecological patterns at local and landscape levels. The results emphasized that fire frequencies varied over the landscape in heterogeneous patterns we are still unraveling. The current data set provides a working model of fire frequency regimes across the park. Ongoing fire history investigations are underway to address questions raised in this evaluation and to provide verification of the model. However, this analysis has given the park better understanding of the complexity of the pre-Euroamerican fire regimes. Fire return intervals appear to have been shortest at mid-elevations in ponderosa pine forests. Our results show decreasing fire frequency with increasing elevation both above and below this point, although our knowledge for lower elevations remains uncertain. The reconstructed fire frequency data have been used to develop a GIS model (FRID) accentuating areas most in need of burning and to provide estimates of area burned annually prior to Euroamerican settlement. Both are valuable input into fire management planning.

As GIS applications become increasingly valuable in implementing ecological management at a landscape level land managers must be aware of the limitations as well as the potential uses of these tools. Detailed maps produced by GIS are only representations of the landscape several steps removed from on-the-ground reality and thus subject to misinterpretation. For this reason we evaluated our knowledge about fire history used as input. We found that we lacked or had limited information from many areas and some vegetation classes. For example, our fire history knowledge for north aspects was extremely limited and we recommend care be exercised when extrapolating this information from south aspects. Additionally, most of our high quality information about past fire regimes has been derived from lower elevation ponderosa pine and mixed-conifer forest where high fire frequencies were prevalent. Depending on the application, extrapolating these findings to the landscape as a whole may be inappropriate for some areas and vegetation classes. Differences in fire frequency regimes may be great enough that loosely interpreting burn frequencies could produce detrimental impacts.

Obtaining adequate baseline information about fire history is crucial for defining pre-Euroamerican fire regimes and their variability across landscapes. This information will assist us in understanding a key process that has shaped ecosystems at a variety of landscape levels and scales. This knowledge will also assist fire managers in building a science-based foundation for fire and ecosystem planning and management activities into the future.

Acknowledgments

David Graber provided insight on portions of the analysis and Linda Mutch reviewed and made useful comments on the paper. The analysis of fire history data presented in this paper were largely a result of the sampling efforts over many years by Bruce Kilgore, Thomas Swetnam, and their colleagues. Without the information from these and other fire history studies we would be essentially ignorant of past fire regimes in the park. As time passes the value of this data will grow as remnant fire scarred material irretrievably disappears from the landscape.

References

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

Allen, C.D. 1994. Ecological perspective: Linking ecology, GIS, and remote sensing to ecosystem management. Chapter 8. In: V.A. Sample (ed.) *Remote Sensing and GIS in Ecosystem Management*. Island Press, Covelo, CA.

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.

Alstrand, M.A. 1980. Fire history of a mixed conifer forest in Guadalupe Mountains National Park. pp. 4-7. In: M.A. Stokes and J.H. Dieterich. Proceedings of the Fire History Workshop. USDA Forest Service, GTR-RM-81, 142 pp.

Bergeron, Y. 1991. The influence of island and mainland landscapes on the boreal forest fire regime. Ecol. 72:1980-1986.

Bergeron, Y and J. Brisson. 1990. Fire regimes in red pine stands at the northern limit of the species range. Ecol. 71:1352-1364.

Bond, W.J. and B.W. van Wilgen. 1996. *Fire and Plants*. Chapman and Hall, London. 263 pp

Brown, P.M., M.K. Hughes, C.H. Baisan, T.W. Swetnam, and A.C. Caprio. 1992. Giant sequoia ring-width chronologies from the central Sierra Nevada, California. Tree-Ring Bulletin 52:1-14.

Caprio, A.C., and T.W. Swetnam. 1993. Fire history and fire climatology in the southern and central Sierra Nevada: Progress Report 1992/93 to National Park Service, Global Change Program, Southern and Central Sierra Nevada Biogeographical Area. Laboratory of Tree-Ring Research, University of Arizona, Tucson, AZ.. On file at Sequoia and Kings Canyon National Park. 14 pp.

Caprio, A.C., and T.W. Swetnam. 1994. Fire history and fire climatology in the southern and central Sierra Nevada: Progress Report 1993/94 to National Park Service, Global Change Program, Southern and Central Sierra Nevada Biogeographical Area. Laboratory of Tree-Ring Research, University of Arizona, Tucson, AZ. On file at Sequoia and Kings Canyon National Park. 16 pp.

Caprio, A.C., L.S. Mutch, T.W. Swetnam, and C.H. Baisan. 1994. Temporal and spatial patterns of giant sequoia radial growth response to a high severity fire in A.D. 1297. Final report to California Department of Forest and Fire Protection, Mtn. Home State For., Springville, CA. (Contract No. 8CA17025) by Lab. of Tree-Ring Research, Tucson, AZ, 61 pp.

Caprio, A.C. and T.W. Swetnam. 1995. Historic fire regimes along an elevational gradient on the west slope of the Sierra Nevada, California. 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.

Clark, J.S. 1989. Ecological disturbance as a renewal process: theory and application to fire history. Oikos 56:17-30.

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 Society, Three Rivers, CA. 379 pp.

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

Franklin, J.F. and J.A. Fites-Kaufmann. 1996. Assessment of late-successional forests of the Sierra Nevada. pp. 627-661. 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.

Gill, A.M. 1975. Fire and the Australian flora: a review. Australian Forestry 38:4-25.

Heinselman, M.L. 1981. Fire intensity and frequency as factors in the distribution and structure of northern ecosystems. pp. 7-57. In: H.A. Mooney , T.M. Bonnicksen, N.L. Christensen, J.E. Lotan, and W.A. Reiners (tech. coord.). *Proceedings of the Conference: Fire Regimes and Ecosystem Properties. Dec. 11-15, 1978, Honolulu, Hawaii*. USDA Forest Service, GTR-WO-26, 594 pp.

Keeley, J.E. 1981. Reproductive cycles and fire regimes. pp. 231-277. In: H.A. Mooney, T.M. Bonnicksen, N.L. Christensen, J.E. Lotan, and W.A. Reiners (tech. coord.). *Proceedings of the Conference: Fire Regimes and Ecosystem Properties. Dec. 11-15, 1978, Honolulu, Hawaii*. USDA Forest Service, GTR-WO-26, 594 pp.

Keifer, M. 1991. Age structure and fire disturbance in southern Sierra Nevada subalpine forests. MS Thesis, Univ. of Arizona, 111 pp.

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.

Madany, M.H., T.W. Swetnam, and N.E. West. 1982. Comparison of two approaches for determining fire dates from tree scars. For. Sci. 28:856-861.

McClaren, M.P. and J.W. Bartolome. 1989. Fire-related recruitment in stagnant *Quercus douglasii* populations. Canadian Journal of Forest Research 19:580-585.

Mensing, S.A. 1992. The impact of European settlement on blue oak (*Quercus douglasii*) regeneration and recruitment in the Tehachapi Mountains, California. Madroño 39:36-46.

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.

Morgan, P., G.H. Aplet, J.B. Haufler, H.C. Humphries, M.M. Moore, and W. D. Wilson. 1994. Historical range of variability: A useful tool for evaluating ecosystem change. J. Sustainable Forestry 2:87-111.

Mutch, L.S. 1994. Growth responses of giant sequoia to fire and climate in Sequoia a
MS Thesis. University of Arizona, Tucson. 242 pp.

Mutch, L.S. and T.W. Swetnam. 1995. Effects of fire severity and climate on tree-width growth of giant sequoia after burning. 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.

Naveh, Z. 1994. The role of fire and its management in the conservation of Mediterranean ecosystems and landscapes. pp. 163-185. In: J.M. Moreno and W.C. Oechel (eds.). *The Role of Fire in Mediterranean Type Ecosystems*. Springer-Verlag, NY, 201 pp.

NPS. no date. Kings Canyon National Park, California: Including Type Acreages for Mapped Portions of Sequoia National Park. Report prepared for USDI, NPS by Hammon, Jensen, and Wallen, Mapping and Forestry Services, Oakland, California.

Pitcher, D. 1981. The ecological effects of fire on stand structure and fuel dynamics in red fire forests of Mineral King, Sequoia National Park, California. MS Thesis, UC Berkeley, 168 pp.

Pitcher, D. 1987. Fire History and Age Structure in Red Fir Forests of Sequoia National Park, California. Canadian Journal of Forest Research 17:582-587.

Potter, D.A. 1994. *Guide to Forested Communities of the Upper Montane in the Central and Southern Sierra Nevada*. USDA Forest Service, Pacific Southwest Region, R5-ECOL-TP-003, 164 pp.

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

Rundel, P.W., D.P. Parsons, and D.T. Gordon. 1977. Montane and subalpine vegetation of the Sierra Nevada and Cascade Ranges. pp. 559-599. In: M.G. Barbour and J. Major (eds.). *Terrestrial Vegetation of California*. Wiley & Sons, Inc., NY. 1002 pp.

Sheppard, P.R. 1984. Fire regime of the lodgepole pine (*Pinus contorta* var. *murrayana*) forests of the Mt. San Jacinto State Park wilderness, California. MS Thesis, Cornell University, NY. 93 pp.

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.

SNEP. 1996. Sierra Nevada Ecosystem Project, Final Report to Congress: Status of the Sierra Nevada.

Stephens, S.L. 1997. Fire history of a mixed conifer oak-pine forest in the foothills of the Sierra Nevada, El Dorado County, California. pp 191-198. In: N.H. Pillsbury, J. Verner, and W.D. Tietje (tech. coord.). *Proceedings of a Symposium on Oak Woodlands: Ecology, Management, and Urban Interface Issues. 19-22 March 1996. San Luis Obispo, CA.* Gen. Tech. Rep. PSW-GTR-160, 738 pp.

Stephenson, N.L. 1988. Climatic control of vegetation distribution: the role of the water balance with examples from North America and Sequoia National Park, California. Dissertation, Cornell University, NY. 295 pp.

Stephenson, N.L., D.J. Parsons, and T.W. Swetnam. 1991. Restoring natural fire to the Sequoia-mixed conifer forest: should intense fire play a role? In: *17th Proceedings of the Tall Timbers Fire Ecology Conference*, pp. 321-337.

Stokes, M.A. 1980. The dendrochronology of fire history. pp. 1-3. In: M.A. Stokes and J.H. Dieterich. *Proceedings of the Fire History Workshop*. USDA Forest Service, GTR-RM-81, 142 pp.

Swetnam, T.W. 1993. Fire History and Climate Change in Giant Sequoia Groves. Science 262:885-889.

Swetnam, T.W., C.H. Baisan, A.C. Caprio, R. Touchan, and P.M. Brown. 1992. Tree-ring reconstruction of giant sequoia fire regimes. Final report to Sequoia, Kings Canyon and Yosemite National Parks, Laboratory of Tree-Ring Research, Tucson, AZ. 90 pp. + appendices.

Swetnam, T.W., R. Touchan, C.H. Baisan, A.C. Caprio, and P.M. Brown. 1991. Giant sequoia fire history in Mariposa Grove, Yosemite National Park. In: *Yosemite Centennial Symposium, Proceedings: Natural Areas and Yosemite: Prospects for the Future, Oct. 13-20, 1990*, Concord, Calif. NPS D-374.

Vankat, J.L. 1982. A gradient perspective on the vegetation of Sequoia National Park, California. Madroño 29:200-214.

Wardle, D.A, O. Zackrisson, G. Hörnberg, and C. Gallet. 1997. The influence of island area on ecosystem properties. Science 277:1296-1299.

Warner, T.E. 1980. Fire History in the Yellow Pine Forest of Kings Canyon National Park. pp. 89-92. 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.

Whelan, R.J. 1995, *The Ecology of Fire*. Cambridge Univ. Press, Cambridge, 346 pp.