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Fire Regimes, Past and Present

ABSTRACT

Fire has been an important ecosystem process in the Sierra Nevada for thousands of years. Before the area was settled in the 1850s, fires were generally frequent throughout much of the range. The frequency and severity of these fires varied spatially and temporally depending upon climate, elevation, topography, vegetation, edaphic conditions, and human cultural practices.

Current management strategies and those of the immediate past have contributed to forest conditions that encourage high-severity fires. The policy of excluding all fires has been successful in generally eliminating fires of low to moderate severity as a significant ecological process. However, current technology is not capable of eliminating the high-severity fires. Thus, the fires that affect significant portions of the landscape, which once varied considerably in severity, are now almost exclusively high-severity, large, stand-replacing fires. The resulting landscape patterns are much coarser in grain.

Many gaps still exist in our knowledge of fire as an ecological process in the Sierra Nevada.

INTRODUCTION

Fire has been an important ecological force in Sierra Nevada ecosystems for thousands of years. In only a few vegetated areas of the Sierra would fire not be considered an important element of the ecosystem. The Mediterranean climate, with cool, wet winters and warm, dry summers, predisposes much of the Sierra Nevada to conditions that would carry fire annually. As a result, prior to the mid-1800s, many of the plant communities experienced fire at least once, and often a number of times, during the life spans of the dominant plant species. Appropriately, much of the vegetation of the Sierra Nevada exhibits traits that allow survival and/or reproduction in this environment of regular fire (e.g., Chang 1996).

The patterns in which fires occur in an area, known as the fire regime for that area, influence the nature of the vegetation mosaic to be found within a particular landscape. Knowing the history of fire in a landscape is therefore important in gaining an understanding of the role of fire in ecosystems. An understanding of fire ecology and fire history may provide managers, decision makers, and policy makers with information that will help them avoid being shocked by unanticipated situations. When one is planning for resource management, for ecosystem management, and for community well-being, a knowledge of fire history and fire ecology provides a reference for assessing how much deviation is developing from long-term past patterns and conditions (e.g., Swanson et al. 1994; Manley et al. 1995). Evaluating the probability of success of future long-term alternatives for resources or communities is problematic without considering the physical and biological potential for fire and its function in Sierran environments.

Substantial research and documentation regarding fire ecology and regimes have demonstrated the importance of fire in Sierra Nevada environments. It is not possible to summarize all of the relevant information here. This chapter provides only sufficient background to establish for the reader the general nature of, and thereby the importance of, fire in the ecosystems of the Sierra Nevada. For the reader wishing more on the topic, the references should serve as a good starting place. Kilgore 1973, Biswell 1989, and Arno in press provide excellent summaries. Additionally, though primarily focused on fire ecology in vegetation north of California, Agee 1993 and Agee 1994 summarize fire ecology information for vegetation types (i.e., mixed conifer, red fir, subalpine, and east-side vegetation types) found in the northern Sierra as well as in the

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extended SNEP study areas of the southern Cascades and northeastern California.

Unless otherwise indicated, the descriptions of past fire regimes presented in this chapter pertain to conditions before 1850. We have done this because many changes in fire regimes have occurred since the influx of Euro-American culture during and following the gold rush of the mid-1800s.

THE PALEOECOLOGICAL RECORD

Paleoecological studies show that Sierra Nevada fire regimes are dynamic in space and time on many scales. The long-term importance of fire in Sierran ecosystems is suggested by the common occurrence of charcoal in the paleoecological record of the Holocene (e.g., Smith and Anderson 1992; Davis and Moratto 1988). Analyses of fossil pollen suggest that climate and vegetation have varied considerably over this period (Woolfenden 1996). Vegetation and fire appear to have varied, sometimes greatly, in concert with the variation in climates (Davis et al. 1985). Fire may serve as a catalyst for the reorganization of vegetation during periods of rapid climate change (e.g., Whitlock 1992; Wigand et al. 1995). It is noteworthy that large charcoal peaks from the early Holocene were followed by vegetation that was considerably different from that found before this period of heightened fire activity (Edlund and Byrne 1990). However, the resolution of temporal data available for the Sierra Nevada is insufficient to define the role of fire in reorganizing vegetation at various times in the past.

The evidence from interpretation of long-term trends in sediment cores has shown that fire has been an important component of the Sierran environment since before current vegetation assemblages became established. Charcoal concentrations at one site were greatest during the warm period that followed the end of the Pleistocene, approximately 10,000 years ago (Smith and Anderson 1992). These concentrations of charcoal appear to coincide with the end of the Pleistocene vegetation typical of subalpine forests today. The charcoal concentrations were followed by species assemblages more similar to the mixed conifer forests found today at middle and lower elevations (Anderson 1990). Following this warm period there was a general cooling trend until approximately 3,000 years ago, when a relatively cooler, more moist climate regime appears to have become established. Charcoal, though varying over time with changes in climate and vegetation, is routinely present in sediment core samples (Smith and Anderson 1992).

More-detailed reconstructions of climate variations for the last few millennia have recently been developed using tree-ring analysis (e.g., Graumlich 1993; Hughes and Brown 1992; Stine 1994). These variations in temperature and moisture patterns have been found to correspond well with variations in the frequency and apparent severity of fires (Swetnam 1993). Swetnam 1993 demonstrated that thirty years was the longest period without fire in any of five sequoia groves for more than 2,000 years. These fire scar records also show that many of these same groves have now experienced more than 100 years without fire under modern management policies (Swetnam 1993).

THE ETHNOGRAPHIC RECORD

Ethnographic accounts show that Native Californians commonly used fire as a management tool in the Sierra Nevada (Reynolds 1959; Wickstrom 1987; Blackburn and Anderson 1993). Fire was used to provide many important foodstuffs and materials (Lewis 1993). The spatial extent of the influence of burning on the landscape is not known and has been subject to some debate (Barrett 1935; Wickstrom 1987). However, accounts of the frequency of fire necessary to maintain specific resources in conditions required by the various cultures suggest that extensive and very intensive burning would have been common in important vegetation types (Anderson and Moratto 1996).

Enhancing the production of foodstuffs was one important reason for burning (Wickstrom 1987). For example, acorns were a major staple in the diet of the Native Californians, and burning was reported to enhance the production of acorns. Acorn crops are described to have been improved by burning in two important ways: (1) by reducing the losses to insects and (2) by encouraging larger, more productive trees (Anderson 1993b).

A second important reason for burning was to encourage the production of basketry materials (Anderson 1993a; Lewis 1993). The better materials for making baskets were young, straight shoots of many sprouting species. As the shoots matured, they would become unsuitable due to side branching and lack of flexibility.

A third reason for burning usually given by Native Californians was to reduce the hazard of large, severe fires (Lewis 1993). The native cultures were reliant upon local resources for their livelihood. A large, severe fire could change the local plant communities in a way that affected the ability of the communities to survive in the area. For example, a large, severe fire could top-kill the old oaks that provided acorns, the main staple. These trees could not produce sufficient supplies for many years following a fire of this type.

FIRE REGIMES

Fire ecologists refer to the general characteristics of fires found within any specified area of interest as the fire regime. Fire regimes can vary considerably by vegetation and landscape. Thus, they offer a convenient way to categorize areas for study and management purposes. Fire regimes are described by the following characteristics: frequency, rotation, spatial extent, magnitude, and seasonality (White and Pickett 1985; Agee 1994). These terms are defined as follows:

Frequency: The frequency describes how often fires occur within a given time period. This characteristic is often described in terms of return intervals rather than frequency. The return interval is the length of time between fires.

Rotation: The fire rotation is the length of time necessary to burn an area equal to the area or landscape of interest. For example, if one is working with a landscape of 100,000 acres and it takes fifty years for fires to burn 100,000 acres within that landscape, the fire rotation would be fifty years. Keep in mind that all 100,000 acres need not burn if some acres are burned more than once. The only requirement for this term is a total accumulated burn area equal to the original area of interest.

Spatial extent: The spatial extent refers to the size or area covered by a fire and the spatial patterns created.

Magnitude: The magnitude of a fire refers to both its intensity and its severity. *Intensity* is a technical term used to describe the amount of energy released from a fire. Intensity may or may not be directly related to fire effects. *Severity* is related to the change in the ecosystem caused by the fire and can be either quantitatively or qualitatively related to fire effects. Fires that burn only surface fuels and in which most of the woody vegetation survives are usually considered low-severity fires. Fires that kill large trees over more than a few acres by burning their crowns are usually considered high-severity fires.

Seasonality: The seasonality, or timing, of a fire is important in relation to the moisture content of fuels, the phenology of the vegetation, and the resulting fire effects. The vegetation found within a particular ecosystem has adapted over time to the season or seasons in which the fires generally occur.

Few fire-history studies have attempted to describe all of the fire-regime characteristics just defined. Most describe the fire frequencies for points (a single tree) or small sites. These data are the easiest and least costly to obtain. Some have also included seasonality as interpreted from the location of the scar in the rings (i.e., latewood or early wood) of the year of the fire. Few studies have attempted to describe the rotation, spatial extent, or magnitude of past fires, because acquiring these data requires intensive sampling of many sites over a landscape. These latter studies are quite costly due to the time and labor involved in field sampling and laboratory analysis.

Each of the fire-regime characteristics, when used, is usually described in terms of the mean or median and sometimes in terms of a measure of variability. The median is used in this chapter because of the variability in fire-return intervals associated with vegetation types that do not have very regular, frequent fires. The median is less affected by erratic extremes than is the mean (Snedecor and Cochran 1980). The mean is often interpreted and applied in a way that would assume that the data come from a normal distribution with little variation, but fire-return intervals for many sites are often not represented by a normal distribution. Instead, they are often multimodal (Johnson and Gutsell 1994) or strongly skewed, with many shorter intervals and a few longer, extreme intervals. The pattern of fire-return intervals often varies from period to period, and a simple mean is not representative of longer records (Swetnam 1993).

FIRE HISTORY

Fire history can be reconstructed from a variety of data sources: written records, historical accounts, dendrochronology (tree-ring analysis), and the analysis of charcoal in sediments (Patterson and Backman 1988). Each of these data sources has its own limitations regarding spatial and temporal detail and accuracy. Within forested ecosystems, detailed reconstruction of fire histories before written records is possible through fire scar analysis using dendrochronology techniques (Agee 1993; Arno and Sneck 1977). Fire history, in contrast to human history, is not limited to written records or accounts.

Fire histories from fire scar analysis generally fall into one of three categories: (1) single-tree samples; (2) composites of multiple trees for specified areas (Dieterich 1980a, 1980b); and (3) composites of multiple sites for landscapes (Taylor 1993a). The single-tree sample is usually considered the most conservative estimate of past fire history for many areas (although Minnich et al. [in press] have some data to suggest this may not always be the case). This is because all fires passing a point may not have been of sufficient intensity to have scarred the single sample. Composites of multiple trees will usually provide a more comprehensive record of past fires for the site in question (Agee 1993). However, describing in spatial and temporal terms the influence of fire on landscape dynamics (age-class distributions, species composition patterns, stand structures, patch patterns, etc.) requires detailed landscape-level sampling (e.g., Teensma 1987; Morrison and Swanson

1990; Caprio and Swetnam 1995; Minnich et al. in press; Solem 1995). Because of the time and costs involved in this type of sampling, few studies of this nature have been undertaken. Instead, most fire-history studies have been site-specific, fire-return-interval studies.

In each type of fire history, the fire dates can be determined either by cross-dating (Fritts and Swetnam 1989) or by estimating correspondence among years (Arno and Sneck 1977). The cross-dating method is precise and can determine the calendar year of fires hundreds or thousands of years ago (Swetnam 1993). The second method is not as accurate in determining the actual calendar year of a fire and often underestimates the number of fires within a period of interest. However, it still provides valuable, though less detailed, fire-interval information (Madany et al. 1982) that can be useful in describing the fire regime, especially at the level of detail required by most natural resource managers.

Fire histories based on tree-ring analysis rely on interpretation of scars that formed in response to fire-caused damage in the tree ring of the year of the fire. A number of factors can influence the way in which fires are recorded as scars. Trees are the best recorders, since they are long-lived and are large enough to be able to survive fires of low to moderate intensity. Little information is usually left following fires in herbaceous or shrub communities because of heavy consumption and the fact that the parts of the plants that are above ground are often killed. In addition, the various tree species vary considerably in their susceptibility to damage or mortality by fire. In areas consisting solely of species of trees that are usually killed even by low-intensity fires, there may not be a record of fire prior to the last fire that initiated the current stand.

Fire-severity classes used in this chapter are

- Low severity: light surface fire; some small trees may be killed.
- Moderate severity: most small trees killed; some subcanopy trees killed or heavily damaged. Charring on bark of live trees. Overstory trees may occasionally be killed.
- High severity: small and subcanopy trees killed; many to most overstory trees killed.

Although none of the fire-history studies described in the next section meets the exacting standards of the randomized sampling design described by Johnson and Gutsell (1994), taken together they provide valuable information about the past temporal patterns of fires within forest stands on a localized scale. The sampling design suggested by Johnson and Gutsell was developed in forests characterized by infrequent, large, stand-replacing fires. These fires result in very coarse-grained landscape patterns. The objective of fire-history studies in such forests is primarily to describe when the last fire occurred in each patch by dating the age of the trees that regenerated after the burns. The spatial scales on which topography and vegetation vary, along with the spatial variability in fire behavior and the effects from the frequent fires in the forests of the Sierra Nevada, create very complex, fine-grained spatial patterns. Attempting to carry out a landscape-scale study based upon the design suggested by Johnson and Gutsell under these latter conditions would be very difficult and costly.

Several fire-history studies have been completed within the Sierra Nevada and adjacent geographical areas. Most of these studies have been limited to providing information on fire-return intervals (FRIs) for a small area. A few have developed fire history at the landscape scale in the Sierra (e.g., Caprio and Swetnam 1995; Kilgore and Taylor 1979). For studies of areas with vegetation similar to that in portions of the Sierra Nevada, see McNeil and Zobel 1980, Taylor and Halpern 1991, Taylor 1993a, Solem 1995, and Minnich et al. in press. Each of these will be discussed in more detail later in relation to appropriate vegetation types.

Table 38.1 summarizes fire-history information from various published and unpublished sources for the Sierra Nevada and other areas that have similar vegetation and climate. The spatial context of the return intervals is given to facilitate comparisons among the areas. There exist a number of other fire-history studies within the Sierra Nevada (e.g., Rice 1990, 1992). These were not included in table 38.1 primarily because the spatial reference for the sampling was not clear and we were unsure of the spatial comparability of the reported fire frequencies. Other studies were not included because the data were presented in a fashion that was difficult to present within the structure of table 38.1 (e.g., Mensing 1988, 1992). These latter studies are referenced in the text where appropriate.

The FRIs as presented for a small, localized place do not necessarily provide information on how fire would have influenced the landscape-scale patterns. Periods of more frequent fires may have many small, low-severity fires scattered throughout the landscape, while periods of longer FRIs may be associated with larger, more severe fires (Swetnam 1993). The spatiotemporal variation in fire frequency and severity may be important in influencing stand structure and regeneration patterns over time (e.g., Minnich et al. in press; Stephenson et al. 1991), leading to the complex spatial patterns of the vegetation that are so characteristic of the Sierra.

Landscape-scale fire-history studies are especially important to our understanding of the role of fire in Sierran ecosystems. The continued lack of such studies for the Sierra Nevada leaves important questions unresolved concerning the spatial and temporal influences of fire on vegetation dynamics, aquatic and riparian environments, wildlife habitat, coarse woody debris accumulations, and so on. Although many fire-history studies have been conducted in the Sierra, there is a considerable need to expand the geographical coverage and to conduct landscape-scale studies of fire history tied to vegetation-related dynamics.

TABLE 38.1

Fire-return intervals (FRIs) from the Sierra Nevada and areas of similar vegetation and climate.

Area and Vegetation	Median FRIs[a]	Minimum FRI[a]	Maximum FRI[a]	Years Since Last Fire	Method	Sample Area	Years of Record[b]	Location	Source
West-Side Areas									
Foothill Zone									
Blue oak–gray pine	8 (29)	2 (8)	49 (49)	14–34	Composites of multiple trees	5 ha	78–267	Northern Sierra	McClaran and Bartolome 1989
Black oak–ponderosa pine	8	2	18	82–102	Composites of multiple trees	<2 ha	Not reported	Central Sierra	S. Stephens, e-mail communi-cations with the author, 21 April and 9 and 30 May 1995[c]
	6–9[e]	2	23	Not reported	Composites of multiple trees	1 ha	175	Southern Sierra	Kilgore and Taylor 1979
Mixed Conifer Zone									
Mixed evergreen–tan oak	15 (13)	3 (5)	50 (41)	43–71	Composites of multiple trees	5–8 ha	235–245	Klamath Mountains	Wills and Stuart 1994
Canyon live oak–mixed conifer	13 (11)	7 (7)	39 (33)	5–75	Composites of multiple trees	<1 ha	112–116	Klamath Mountains	Taylor and Skinner in preparation[c]
Ponderosa pine–mixed conifer	8–10[e]	3	14	Not reported	Composites of multiple trees	1 ha	175	Southern Sierra	Kilgore and Taylor 1979
	5–11[e]	Not reported	Not reported	~3–135	Composites of multiple trees	<100 ha	~125–340	Southern Sierra	Caprio and Swetnam 1995[d]
	11 (11)	3 (5)	55 (46)	35–90	Composites of multiple trees	<2 ha	151–306	Klamath Mountains	Skinner in preparation[c]
Giant sequoia–mixed conifer	Not reported	1	15	Not reported	Composites of multiple trees	<100 ha	1,050	Southern Sierra	Swetnam et al. 1991[d]
	Not reported	1	30	Not reported	Composites of multiple trees	10–100 ha	1,350	Southern Sierra	Swetnam 1993[d]
	15–18[e]	4	35	Not reported	Composites of multiple trees	1 ha	175	Southern Sierra	Kilgore and Taylor 1979
	14–32[e]	Not reported	Not reported	~10–195	Composites of multiple trees	<100 ha	~195–380	Southern Sierra	Caprio and Swetnam 1995[d]
Douglas fir–mixed conifer	17 (16)	12 (12)	59 (18)	69	Composites of multiple trees	2 ha	169	Klamath Mountains	Agee 1991[d]
	13 (14)	3 (3)	57 (52)	26–93	Composites of multiple trees	2 ha	125–396	Klamath Mountains	Skinner in preparation[c]
	12 (15)	3 (3)	59 (59)	5–92	Composites of multiple trees	<1 ha	248–379	Klamath Mountains	Taylor and Skinner in preparation[c]
White fir–mixed conifer	12 (11)	3 (3)	33 (29)	72–82	Composites of multiple trees	1 ha	133–154	Southern Cascades	McNeil and Zobel 1980
	10 (13)	3 (5)	24 (24)	36–56	Composites of multiple trees	2 ha	192–289	Southern Cascades	Skinner unpublished data
	9 (10)	3 (4)	26 (26)	34–47	Composites of multiple trees	2 ha	214–268	Southern Cascades	Skinner unpublished data
	8 (13)	3 (3)	35 (35)	38–67	Composites of multiple trees	2 ha	103–252	Northern Sierra	Skinner unpublished data

[a]Values in parentheses are specifically pre-1850 where available. Other values are for the entire period of record.
[b]The number of years from the earliest fire scar to the latest fire scar. A range indicates multiple sample sites.
[c]Unpublished study.
[d]Cross-dated samples.
[e]These are means for the sites sampled, rounded to the nearest integer. This study reported only means and did not present data in a way to develop medians or ranges.

continued

TABLE 38.1 (continued)

Area and Vegetation	Median FRIs[a]	Minimum FRI[a]	Maximum FRI[a]	Years Since Last Fire	Method	Sample Area	Years of Record[b]	Location	Source
	12 (11)	4 (4)	32 (32)	47–101	Composites of multiple trees	2 ha	53–196	Central Sierra	Skinner unpublished data
	18 (18)	7 (7)	27 (27)	100	Single-tree sample		113	Central Sierra	Taylor 1993b[c,d]
	11–17[e]	2	39	Not reported	Composites of multiple trees	1 ha	175	Southern Sierra	Kilgore and Taylor 1979
Mixed conifer (Lake Tahoe Basin, Emerald Bay State Park)	12 (11)	3 (3)	114 (44)	0–109	Single-tree sample		97–373	Central Sierra	Rice 1988[c]
White fir	17 (16)	4 (4)	61 (39)	72–128	Composites of multiple trees	1 ha	84–154	Southern Cascades	McNeil and Zobel 1980
	9 (11)	4 (4)	56 (56)	35	Composites of multiple trees	2 ha	214	Southern Cascades	Skinner unpublished data
Riparian areas	31 (36)	7 (7)	71 (71)	49–102	Composites of multiple trees	1 ha	175–265	Klamath Mountains	Skinner in preparation[c]
Upper Montane Zone									
Jeffrey pine	16 (13)	4 (4)	157 (157)	93–139	Single-tree sample		81–345	Southern Cascades	A. H. Taylor, telephone conversation with the author, 17 May 1995[c,d]
Jeffrey pine–white fir	12 (12)	4 (4)	96 (96)	42	Composites of multiple trees	2 ha	480	Klamath Mountains	Skinner in preparation[c]
	29 (29)	4 (10)	100 (93)	93–156	Single-tree sample		88–326	Southern Cascades	A. H. Taylor, telephone conversation with the author, 17 May 1995[c,d]
Red fir–white fir	12 (11)	5 (5)	69 (69)	77–98	Composites of multiple trees	<4 ha	97–240	Central Sierra	Bahro 1993[c]
Red fir–white pine	69 (57)	14 (14)	109 (109)	102–211	Single-tree sample		31–167	Southern Cascades	A. H. Taylor, telephone conversation with the author, 17 May 1995[c,d]
Red fir	20 (20)	8 (8)	35 (35)	128	Composites of multiple trees	1 ha	63–98	Southern Cascades	McNeil and Zobel 1980
	11 (16)	1 (7)	47 (35)	45–52	Composites of multiple trees	3 ha	141–205	Southern Cascades	Taylor 1993[d]
East-Side Areas									
Ponderosa pine	16	8	32	34–75	Composites of multiple trees	<10 ha	70–169	Southern Cascades	Olson 1994[c]
	8	6	15	51	Single-tree sample		169	Southern Cascades	Olson 1994[c]
Mixed conifer (ponderosa pine–white fir)	9 (10)	3 (3)	71 (71)	40	Composites of multiple trees	<10 ha	143–362	Southern Cascades	Olson 1994[c]
Red fir	27 (21)	9 (19)	91 (22)	63–90	Composites of multiple trees	<10 ha	113–135	Southern Sierra	Hawkins 1994[c]
Red fir–Jeffrey pine	14 (14)	6 (6)	64 (23)	36–143	Single-tree sample		135–227	Southern Sierra	Hawkins 1994[c]
	17 (15)	5 (7)	56 (31)	41–43	Composites of multiple trees	<10 ha	161–243	Southern Sierra	Hawkins 1994[c]

[a]Values in parentheses are specifically pre-1850 where available. Other values are for the entire period of record.
[b]The number of years from the earliest fire scar to the latest fire scar. A range indicates multiple sample sites.
[c]Unpublished study.
[d]Cross-dated samples.
[e]These are means for the sites sampled, rounded to the nearest integer. This study reported only means and did not present data in a way to develop medians or ranges.

FIRE EFFECTS

There is generally more literature on the effects of fire than there is concerning fire history. The effects of fire on the mixed conifer forests and chaparral of the west side of the Sierra Nevada are the subject of an abundant literature, whereas the literature on fire effects for the higher elevations and the east-side forests is rather sparse (Chang 1996).

It would have been rare in most vegetation types under the Mediterranean climate and pre-1850 fire regimes for individuals of most woody species to have escaped fire during their life span. As a result, much of the Sierra Nevada vegetation exhibits traits that have allowed the various species to persist with periodic fire. Whether these plant communities are the result of community adaptations to fire (e.g., Mutch 1970) or are coincidental assemblages of species that individually developed fire-adaptive traits over long periods (e.g., Davis 1986) is subject to debate. Regardless, many of the more common Sierran vegetative communities are generally considered adapted to recurring fire (Chang 1996). This section discusss the general adaptive traits and responses of this vegetation to fire. For more detail on fire effects, including effects on soils and fauna, please refer to Chang 1996.

Conditions for successful reproduction of many plant species are most favorable immediately following a fire, owing to increased fertility, removal of potential allelochemicals (chemicals released by plants that are toxic to other plants), reduced competition, and so on (Canham and Marks 1985; Christensen 1993). Consequently, many plants have evolved adaptive traits that help them survive or reproduce after fire. Such traits include the following (Sweeney 1968; Christensen 1985; Agee 1993):

1. fire-stimulated seed germination, as in deer brush (Ceanothus integerrimus)
2. rapid growth and development that allows a complete life cycle between fires, as in many herbaceous species
3. fire-resistant buds and twigs, as in ponderosa pine (Pinus ponderosa) and Douglas fir (Psuedotsuga menziesii)
4. fire-resistant bark, as in ponderosa pine and Douglas fir
5. adventitious or latent axillary buds, as in oaks (Quercus spp.)
6. sprouting, as in chamise (Adenostoma fasciculatum)
7. serotinous cones and fire-stimulated seed release, as in knobcone pine (Pinus attenuata) and giant sequoia (Sequoiadendron giganteum)
8. fire-stimulated flowering, as in soap plant (Chlorogalum pomeridianum)

Additionally, these varied vegetative responses are often influenced by a complex interaction of external factors such as temperature, moisture conditions, heat duration (e.g., Rogers et al. 1989), and season of burn (e.g., Parker and Kelly 1989; Weatherspoon 1988).

Changes in Fuel Structure Related to Fire-Return Intervals

Because photosynthesis produces organic matter on a regular basis, vegetative biomass (fuel) accumulates with time and adds to total fuel accumulations. However, not all biomass is available fuel at any given moment. Available forest fuel is organic matter that could burn under the prevailing conditions if ignited. The amount of biomass available as fuel at any one time depends on factors such as the ratio of dead plant material to live material and fuel moisture content.

Fire plays an important role in regulating fuel accumulations. Fire also influences the horizontal and vertical continuities of fuels. The importance of fire in regulating fuel accumulations is amplified where fire occurs frequently. Under the regimes in the era before fire suppression, frequent fires would consume surface fuels, maintaining them at minimal levels. Periodic low-to-moderate-intensity fires also maintained gaps in vertical fuel continuity, inhibiting fires from moving into the crowns (e.g., Sudworth 1900; Leiberg 1902). Fire suppression in forests that previously experienced frequent fires has allowed fuels to build up both vertically and horizontally, increasing the chance of stand-replacement fires (Brown 1985; van Wagtendonk 1985; Kilgore 1987; Arno in press).

Landscape Patterns Resulting from Fire

Landscapes can be viewed as a dynamic mosaic of patches (White and Pickett 1985). The frequency, intensity, and spatial extent of successive fires, along with the vegetative response, have influenced and will continue to influence the grain and pattern of the landscape mosaic.

Fire regimes help to define the pattern or mosaic of age classes, successional stages, and vegetation types on the landscape (Turner et al. 1993). For example, periodic, low-intensity surface burning has been found to cause development of an uneven-aged stand, made up of even-aged groups of trees of various age classes (e.g., Bonnicksen and Stone 1981; Weaver 1967). Conversely, infrequent, high-intensity, stand-replacement fires result in larger patches of stands of more even age (e.g., Heinselman 1973; Hemstrom and Franklin 1982).

Because the dynamics determining landscape patterns are affected by fire regimes, characteristics of landscapes also respond to variations in fire regimes. Skinner (1995a), for example, found that forest openings have disappeared or become smaller in a remote area of the Klamath Mountains during the period of effective fire suppression.

Within a given landscape, fire behavior will vary on a variety of spatial scales, influenced by local microclimate, topography, and fuel conditions. This varying behavior will interact with the postfire climate to induce ecosystem responses that result in varying landscape mosaics (Christensen et al. 1989).

Much of the literature that discusses landscape patterns in relation to fire and changing fire regimes has concentrated on ecosystems in which the fire regimes are characterized by infrequent or long-return-interval, severe fires (e.g., Heinselman 1973; Hemstrom and Franklin 1982; Romme 1982; Baker 1989). Because of the differences in scale of the effects of such fires, most studies that discuss the spatial patterns associated with fire regimes consisting of frequent, low-to-moderate-intensity fires have concentrated more on stand-level patterns than on landscape-level patterns (e.g., Bonnicksen and Stone 1982). Generally, the relative extent of fires within a particular vegetation type appears to increase as the interval between fires lengthens (Swetnam 1993; Husari and Hawk 1994).

FIRE REGIMES OF MAJOR VEGETATION TYPES

Due to the past frequency of fires and their influences on species composition, stand structure, and spatiotemporal patterns, fire is generally considered an important ecological process throughout much of the Sierra Nevada. Some fire-regime characteristics (e.g., frequency [FRI] and seasonality) of specific vegetation types are described quite well in the Sierra Nevada. In the southern Sierra, especially in the national parks, the FRIs in ponderosa pine and mixed conifer forests (especially those with giant sequoia) are relatively well documented. Less-detailed data exist for some upper montane areas and for the foothill areas of the southern Sierra. However, for many other fire-regime characteristics, vegetation types, and geographical portions of the Sierra Nevada little data exist.

Most of the information about fire regimes in the Sierra Nevada is from studies that used tree-ring analyses to detect when and how often past fires occurred in a particular place. In the following discussions, for cases where no descriptions of the fire regimes for the Sierra Nevada were found, we have extrapolated information from studies of similar vegetation in other geographical areas, used anecdotal information from historical sources, or made inferences based upon our knowledge of fire behavior and effects. The type of source(s) used is noted in the discussions.

The northern Sierra Nevada is especially lacking in published research designed to describe the long-term fire regimes. Only a few sites, in the works of Show and Kotok (1924) and Wagener (1961), have been studied. The discussions of fire regimes for the northern Sierra Nevada therefore rely on information extrapolated from studies of similar vegetation types in the southern Cascades, the Klamath Mountains, and the southern Sierra Nevada.

The FRIs given in the following discussions are for the entire period of record unless otherwise stated. The period of record for FRIs from fire scars is the time from the earliest scar recorded for the site to the last scar recorded for the site. Refer to table 38.1 for more detail concerning the FRIs for the presettlement and postsettlement period, the length of the record, and the sizes of the sampling areas represented by the FRIs.

Foothill Zone

The foothill zone is generally below the main belt of the conifer forests and above the Sacramento and San Joaquin valleys. The blue oak–gray pine woodlands, chaparral, mixed evergreen woodlands, and black oak–ponderosa pine forests are the more common vegetation types found in the foothills (Parsons 1981). Little is known about fire history in these vegetation types. Woodlands usually promote fast-moving fires, generally of low severity, in herbaceous fuels that may not leave a record as scars in trees. Chaparral, on the other hand, usually supports severe fires that kill the above-ground parts of the plants. For the latter, only the time elapsed since the last fire can be reconstructed. The discussions that follow for these vegetation types should be viewed in this light.

Considerable evidence exists that the Native Californians burned frequently, usually in the late summer or fall months, within the foothill areas (Anderson 1993a; Lewis 1993). The spatial extent of this burning is unknown but appears to have been substantial, at least near communities, considering the amount of postfire resources required (Anderson and Moratto 1996). This burning increased the number of fires that would otherwise have been expected from lightning alone. Generally, fewer lightning strikes occur, and fewer resulting fires are ignited, in the lower elevations than farther upslope (Komarek 1967; van Wagtendonk 1991b). The relative proportion of the area burned by human-caused fires to that burned by lightning-caused fires could vary considerably under different intensities of management.

Blue Oak–Gray Pine

The blue oak–gray pine woodland is common throughout the lower elevations of the Sierra Nevada. Common trees are blue oak (Quercus douglasii), gray pine (Pinus sabiniana), interior live oak (Q. wislizenii), and California buckeye (Aesculus californica).

Fire History. Two fire-history studies are available for blue oak–gray pine woodlands, only one of which is from the Sierra Nevada proper. The one study in the Sierra Nevada is McClaran and Bartolome 1989, from the University of California Sierra Foothill Range Field Station east of Marysville. The median FRIs on two sites were 7 and 9 years. The study found shortened FRIs during and following the settlement period (post-1848). The pre-1848 FRIs ranged from 8 to 49 years, with a median of 28.5, whereas post-1848 FRIs ranged from 2 to 17 years with medians of 7 to 8 years.

Mensing (1988) found that fire frequency recorded as fire scars in blue oaks on three sites in the Tehachapi Mountains had changed considerably since European settlement. He found mean FRIs for the presettlement period to range from 9.6 to 13.6 years. During the settlement period (1843–1865), the mean FRIs were 3.3 to 5.8 years, and post-1865 FRIs ranged from 13.5 to 20.3. Interestingly, he found a period of more than 60 years (the 1860s to the 1920s) that lacked any evidence of fire scars. He found this period to coincide with the introduction of livestock grazing, suggesting a reduction in available fuels. A similar coincidence of grazing with fire scar reduction in the Sierra Nevada has been noted by Vankat and Major (1978).

Fire Effects. The blue oak–gray pine woodlands are well adapted to frequent, quick-moving, low-intensity surface fires (Arno in press). Fuels are usually light, and the primary carrier of fire is the surface herbaceous vegetation. Notably, the surface vegetation has changed from consisting largely of perennials in presettlement times to being dominated by introduced annuals (Heady 1977). Historically, the perennials may have limited the season of burning. Annuals, on the other hand, may promote an earlier onset to the burning season because they dry and cure earlier than the perennials.

The trees usually survive these surface fires except where increased fire intensity is created by fallen, dead trees or an increased density of understory shrubs. The oaks and buckeyes are strong sprouters when occasional fires do kill the above-ground portions of the plants. Most of the understory shrubs are scattered individuals or groups of species usually associated with chaparral. The frequency of fire in this vegetation type usually keeps the shrub cover limited.

Shrubs

Most shrub communities in the Sierra are considered chaparral. Chaparral is a term applied to communities of predominantly evergreen shrubs adapted to hot, dry summers and periodic fire typical of Mediterranean climates (Hanes 1977; Kilgore 1981; Barro and Conard 1991). Chaparral is common in the lower elevations of the Sierra Nevada, usually between the oak woodlands and the conifer forests and on steep, often rocky, south-facing slopes of canyons. Species composition varies considerably both locally and regionally in the chaparral. Some important common species are chamise, scrub oak (Quercus dumosa), interior live oak, manzanitas (Arctostaphylos spp.), ceanothus (Ceanothus spp.), toyon (Heteromeles arbutifolia), yerba santa (Eriodictyon californicus), and California buckeye. Locally important nonchaparral shrub communities are found where Brewer's oak (Q. garryanna var. brewerii) is an important component.

The severe nature of the fires and the intermingling of many rural communities with areas of chaparral present a considerable challenge to natural resource managers regarding the need to ensure public safety as well as to manage wildlife habitat and watersheds (Sparks and Oechel 1984).

Fire History. Despite the common occurrence of chaparral and its importance to management, fire history for chaparral in the Sierra Nevada is lacking. Historical information is limited to fire records from this century and previous anecdotal accounts (Parsons 1981). Fire-history information about chaparral in California is generally confined to studies in the Coast and Transverse Ranges. These longer-term studies are from charcoal in oceanic sediment deposits (Byrne et al. 1977; Mensing 1993). Because of differences in lightning frequency and burning conditions, these studies may present conservative estimates of fire frequency for inland areas (Keeley 1982).

FRIs in chaparral appear to be quite variable, depending upon local site conditions, proximity to areas of aboriginal human use, and elevation. Chaparral FRIs generally have been estimated to be twenty to fifty years with ranges of approximately ten to more than a hundred years (Keeley 1982; Kilgore 1987; Barro and Conard 1991). FRIs in chaparral types have been limited to estimates because the severe nature of the fires in chaparral renders the areas unsuited to the reconstruction of fire history from dendrochronological techniques (Minnich and Howard 1984). However, Johnson and Gutsell (1994) suggest that FRIs in chaparral may be estimated by using a randomized spatial sampling design similar to that used in boreal forest types to determine the years since the last fire for various portions of the landscape. It is unlikely that this approach will work well in landscapes that have been affected by the extremely large fires of the last few decades, because the large fires will probably have destroyed the previous age-class patterns.

Fire Effects. Due to the dense growing habit of shrubland vegetation and the long dry season, fires in this type of community are usually severe and kill most above-ground portions of the vegetation (Christensen 1985; Barro and Conard 1991). Many of the shrubs found in foothills respond to fire by resprouting, germinating from seeds stored in soil seed banks, or both (Sweeney 1956; Keeley 1977; Parker and Kelly 1989). There is often a flush of herbaceous growth in the first few years following a fire that diminishes as the shrubs regain dominance (Sampson 1944; Sweeney 1956). Variations in FRIs differentially favor the various species, depending upon their method of response to fire. Variations in FRIs and species responses over time can lead to diverse patterns of vegetative communities, whereas short FRIs with little variation may lead to a reduction in vegetative diversity (Keeley 1991).

Closed-Cone Conifers

The closed-cone conifers are pines and cypresses that have adapted to fire by storing seeds in cones on the trees for many years. The resin melts from the heat of a crown fire and releases the seeds into a prepared seedbed. These trees are not as common in the Sierra Nevada as in the Klamath Mountains or the Coast Ranges, but they do occur in widely scattered areas, usually associated with chaparral, mostly in the central and northern Sierra (Griffin and Critchfield 1976). The more common species are knobcone pine and McNab cypress (Cupressus macnabiana). Knobcone pine appears to do well on poor soils in a fire regime similar to that of chaparral and is often found growing within and among chaparral stands (Vogl et al. 1977). The McNab cypress is more limited in distribution and is generally confined to areas in which the soils are derived from ultrabasics (Griffin and Stone 1967), where fuels are often limited. This may provide a longer minimum FRI than in the surrounding vegetation, due to the slower buildup of fuels on these sites (e.g., Vogl et al. 1977).

Fire History. We were unable to find any fire-history work related to the closed-cone conifers of the Sierra. FRIs for stands of closed-cone conifers are probably similar to, if not slightly longer than, those of the surrounding chaparral stands (Minnich and Howard 1984).

Fire Effects. As we stated earlier, the heat from fire opens the cones of closed-cone conifers and allows the seeds to disperse. Knobcone pine is a short-lived tree. It is found on sites where severe, stand-replacement fires usually occur within the life span of the tree. These species often regenerate dense stands following stand-replacement fires. The young trees can begin to produce cones by ten years of age. A loss of these species could be the result in areas of successful fire suppression. Once the trees die and fall over, a subsequent fire will either kill the seeds through the intense heat in the heavy fuel or consume the cones outright (Vogl et al. 1977; Howard 1992; Esser 1994).

Black Oak–Ponderosa Pine

The black oak–ponderosa pine forests and woodlands burned quite frequently with fires generally of low to moderate severity. Two factors contributed to this general fire regime: the ease of ignition and fire spread due to the relatively loose fuel beds of long needles and oak leaves (e.g., Rothermel 1983) and the regular use of fire to manage this forest type by the native tribes of the Sierra Nevada (Lewis 1993).

Fire History. Historical FRIs in these forests were generally from two to twenty-three years (Kilgore and Taylor 1979; S. Stephens, U.S. Forest Service, Pacific Southwest Research Station, e-mail communication with the author, April 29 and May 9 and 30, 1995), commonly being less than ten years (Swetnam et al. 1991; Swetnam 1993). Once it has been scarred, ponderosa pine usually becomes a good recorder of fire. The open wounds often do not heal rapidly and are easily scarred subsequently by even light fires (McBride 1983). This characteristic of ponderosa pine may allow for the development of more comprehensive fire histories than in areas where the species is absent or sparse.

Fire Effects. The primary carrier of fire in black oak–ponderosa pine communities historically was probably grass and herbaceous vegetation with some needle and leaf litter. However, as was discussed previously for the blue oak–gray pine woodlands, the surface vegetation has changed from consisting largely of native perennials in presettlement times to being made up primarily of introduced annuals (Heady 1977). Again, historically the predominance of perennials may have narrowed the season of burning, whereas the annuals may promote an earlier onset to the burning season because they dry and cure earlier than the perennials.

Landscape Patterns

Little data exist to describe the historical landscape patterns of the foothill zone. Much of the information in this regard is from anecdotal accounts from the early to mid-1800s. The patterns were probably spatially complex in some areas and more simple in others, depending upon topography, soils, and past fire history. Areas dominated by grasses and herbaceous vegetation, with or without a tree component, would likely have supported frequent, low-severity fires. These areas could have remained for long periods as grasslands, savannas, or open woodlands.

Areas dominated by shrubs would probably show greater temporal variation due to the nature of the severe burns. These burns would then be followed by various stages of succession until a subsequent fire. The rates of fuel accumulation could vary both temporally and spatially over the landscape and could potentially lead to diverse patterns of age classes (Minnich 1983) and species composition (Keeley 1991).

Mixed Conifer Zone

The mixed conifer zone is the main middle-elevation zone of Sierran forest. The mixed conifer type varies from potentially being dominated by ponderosa pine to consisting largely of white fir (Abies concolor), with sugar pine (Pinus lambertiana) being an important component in many areas. This variation is generally associated with elevation, site quality, and topographic moisture effects (Rundel et al. 1977). Other tree species of importance in this zone are incense cedar (Calocedrus decurrens), black oak, and Douglas fir. A variety of hardwoods, shrubs, and herbaceous plants are also associated with the mixed conifer forests.

The lower portion of this zone, where ponderosa pine is often dominant, is commonly used to describe the characteristic fire regime of the Sierra Nevada. Generally, it is associated with frequent fires of low to moderate severity (Kilgore 1973). However, the fire regime can vary considerably in both frequency and pattern of severity by topographic position, site quality, vegetation, and other local factors.

Most published fire-history information for the Sierra comes from the southern Sierra. The fire histories are generally associated with the Yosemite, Sequoia, and Kings Canyon National Parks, with limited data from elsewhere. Often the fire histories were developed using giant sequoia samples because the long-lived trees have distinct rings that are easily cross-dated, have clear scars, and preserve a long record of fires and climate variation in the tree rings.

In contrast to the southern Sierra, the northern Sierra has very little published fire-history information available. The climate, while still Mediterranean, is more mesic than that of the southern Sierra. The northern Sierra Nevada receives precipitation in greater and more consistent amounts than the southern Sierra at equivalent elevations (Major 1977). Vegetation changes along this moisture gradient. Vegetation assemblages in the northern Sierra are often similar in species composition to those found in the southern Cascades and the Klamath Mountains. However, many of these species are missing or rare in the southern Sierra (Rundel et al. 1977). Due to these differences, the discussions of fire regimes in the northern Sierra Nevada draw on data available for similar vegetation from the southern Cascades and the Klamath Mountains.

Most of the divisions of the mixed conifer zone into vegetation types in the discussion that follows are based on Fites 1993 or on discussions with J. A. Fites at various SNEP Science Team meetings during the winter and spring of 1995.

Mixed Conifer–Ponderosa Pine

Ponderosa pine is found throughout the mixed conifer belt of the Sierra Nevada. The characteristic fire regime of much of the Sierra Nevada (frequent fires of low to moderate severity) favored the development of ponderosa pine–dominated forests on many different types of sites where the species is seral to other conifers (Wright 1978; Agee 1993; Arno in press). Ponderosa pine, being a shade-intolerant species (Oliver and Ryker 1990), is rarely a late-successional dominant. Exceptions exist where the sites are continually disturbed (usually by fire) or are warmer, are dryer, or have limited soil development compared with other mixed conifer sites (Agee 1993; Fites 1993).

Some of the earlier attempts to reconstruct FRIs from fire scars in the Sierra Nevada were in mixed conifer forests dominated by ponderosa pine (Show and Kotok 1924; Wagener 1961). Wagener found median FRIs of five to seven years (with a range of two to thirty years) for five sites ranging in size from 15 to 35 ha (37 to 86 acres). However, the fire scar portion of these studies essentially ignored west-side mixed conifer in the northern Sierra Nevada (Wagener 1961), as have more recent studies. Except in areas where fuel accumulates slowly due to local site conditions (e.g., Arno in press), there is no reason to believe that FRIs for ponderosa pine–dominated sites in the northern Sierra Nevada would be greatly different from those in other parts of its range (e.g., the southern Sierra Nevada, the southern Cascades, or the Klamath Mountains).

Median FRIs for seven sites from the Klamath Mountains, where the mixed conifer–ponderosa pine forest types are similar to those in the northern Sierra, were seven to fifteen years (with a range of three to fifty-five years) (Skinner in preparation).

Mixed Conifer–Canyon Live Oak

Canyon live oak (Quercus chrysolepis) is a widespread species that is found from the upper foothills into the mixed conifer belt (Myatt 1980). Where canyon live oak is an important component of the mixed conifer forests, it is typically associated with steep slopes and shallow, often rocky soils. Canyon live oak is often found with ponderosa pine on the harsher sites and with Douglas fir and / or sugar pine on the more mesic sites (Fites 1993).

Fire History. There appear to be no published fire histories of mixed conifer forests dominated by canyon live oak in the Sierra Nevada. The fire frequencies were probably similar to, if not longer and more variable than, those of other mixed conifer areas, due to lower fuel accumulations and less-continuous fuels because of site conditions (e.g., Minnich 1980; Fites 1993; Skinner 1995b). However, this is not always the case. Where conifers are well represented in the stands, a more consistent fuel bed can accumulate (e.g., Skinner 1978).

The characteristic fire regime of this type of forest was probably one of relatively frequent, spatially variable fires of low to moderate severity. In a fire-history study from the Klamath Mountains, median FRIs of eleven years (with a range of three to fifty-five years) were found on three sites by Taylor and Skinner (in preparation).

Fire Effects. Following the 1987 wildfires, Weatherspoon and Skinner (1995) found only small, widely dispersed patches of apparently stand-replacing fire effects in a large, roadless area near Hayfork in the Klamath Mountains. Much of the fire had apparently been a surface fire of low to moderate severity. The study assessed only sites considered commercial forestlands. However, much of the area is marginal or noncommercial forestland with a major component of canyon live oak. The large proportion of canyon live oak, often associated with generally sparse, discontinuous surface fuels, along with the strong atmospheric temperature inversions that are characteristic of the region, may have contributed to the minimal damage observed in the intermixed commercial forestlands.

Mixed Conifer–White Fir

Within the mixed conifer zone are broad areas where white fir is considered a major climax component and, depending upon the disturbance history of the sites, can make up a considerable portion of the stand, especially on more mesic sites (Laacke 1990). Many of these sites have supported frequent fires in the past (table 38.1), as evidenced by the occurrence of ponderosa and sugar pine (e.g., Agee 1993). It is in the upper elevations of the mixed conifer zone, where white fir often makes up a large component of the stands, that the greatest density of lightning fires has been found (van Wagtendonk 1986).

Fire History. In the southern Sierra, the fire regime was generally one of frequent fires of mostly low to moderate severity, with occasional, typically small, patches of high-severity fires (Kilgore 1973). The local FRIs vary in a pattern similar to the variation in potential species mixtures over the landscape (Kilgore and Taylor 1979; Caprio and Swetnam 1995). FRIs generally increase with increasing elevations (McNeil and Zobel 1980; Caprio and Swetnam 1995). In areas where white fir is well represented by large, old trees, the FRIs were likely to have been longer and more variable than those in areas where larger, older white fir are found only occasionally (Agee 1993).

The median FRIs for mixed conifer–white fir forests appear to have ranged from approximately seven to twenty years (with a range of three to forty years) for the southern Sierra Nevada (Kilgore and Taylor 1979; Caprio and Swetnam 1995). In the northern Sierra and the southern Cascades, the median FRIs ranged from eight to twelve years (with a range of three to thirty-five years) (table 38.1).

Fire Effects. The variation in actual species dominance is probably related to the local consistency of past fires. Those areas where fires were frequent, with little variation in the frequency, would tend to favor ponderosa pine. In areas where the fires were somewhat less frequent, especially where there was more variation in the frequency and severity, more sugar pine, Douglas fir, and white fir would tend to be found (e.g., Agee 1994).

Mixed Conifer–Giant Sequoia

The fire history of giant sequoia groves has been studied more than that of any other forest type of the Sierra Nevada. The giant sequoias are particularly interesting for studies involving tree-ring analysis because of the longevity of the species.

Fire History. In a study of five sequoia groves along a north-south 160 km (93 mi) transect, Swetnam (1993) found that during the last 1,500 years or so the longest fire-free period in any grove was thirty years before the 1860s. Generally, prior to 1860, the maximum FRIs were less than fifteen years, with mean FRIs of approximately three to eight years. Importantly, most of these fire scars (63%–92%) were found in latewood or between rings, suggesting that the fires occurred in either late summer or fall (Swetnam et al. 1992).

Fire Effects. The fire regime of mixed conifer forests dominated by giant sequoia has been described as being characterized by frequent fires of low to moderate severity (e.g., Kilgore and Taylor 1979; Kilgore 1981; Swetnam et al. 1991; Swetnam 1993; Caprio and Swetnam 1995), with occasional areas of locally high-severity fires, where small patches of reproduction (young trees) and individuals occasionally burn more intensely (Stephenson et al. 1991).

Giant sequoias have closed cones (Harvey et al. 1980) that release seeds following relatively intense fires and regenerate best where seeds are scattered onto bare soil in open conditions (Stephenson et al. 1991). Fire appears to be a necessary ecological process to provide for adequate long-term reproduction in giant sequoia forests (Stephenson 1994).

Mixed Conifer–Douglas Fir

Douglas fir can be an important component of the mixed conifer forest in the northern Sierra. These areas are usually associated with more mesic conditions than those where ponderosa pine is more important (Fites 1993). Because of the moister, cooler conditions of these areas and the relatively compact fuel beds of short needles, these sites probably burned somewhat less frequently and less regularly than areas where the longer-needled pines are more dominant. Since we know of no published fire-history data from the Sierra Nevada for this forest type, we must rely on data from similar forests found in the Klamath Mountains and the southern Cascades.

Fire History. Presettlement median FRIs for areas of mixed conifers dominated by Douglas fir in the Klamath Mountains were found by Agee (1991) to have been sixteen years (with a range of twelve to fifty-nine years), by Skinner (in preparation) to have been ten to nineteen years (with a range of three to fifty-seven years) for seven sites, and by Taylor and Skinner (in preparation) to have been eleven to eighteen years (with a range of three to fifty-nine years) for six sites. The sites represented by these studies are geographically distributed from near Oregon Caves National Monument (southern Oregon) to near Castle Crags State Park (northern California). They cover a variety of elevations and topographic positions. Since they are so consistent for these geographically dispersed sites, we suggest that they may be representative of the type in the northern Sierra Nevada. Confirmation of this hypothesis will require fire-history studies in the Sierran mixed conifer–Douglas fir forests.

Fire Effects. It is important to note the range of intervals in the FRIs in this type. Most sites show infrequent longer periods (more than twenty-five years) without fire scars. Since the median intervals are not greatly different from those for the ponderosa pine–dominated areas, an important difference between these vegetation types may be the range of variability. This variability would periodically allow young trees to survive to reach a size and condition to become resistant to low-severity fire. Once Douglas fir is established on a site, the compact litter bed composed of short needles would also help reduce the intensity of subsequent surface fires (e.g., Rothermel 1983). As a mature tree, Douglas fir is quite resistant to fires of low to moderate intensity. The nonresinous, thick bark of Douglas fir does not appear to allow the tree to scar as readily as other species (e.g., ponderosa pine, incense cedar, and sugar pine), and it may heal more rapidly (McBride 1983; Skinner and Taylor in preparation). Due to the susceptibility of Douglas fir to fire damage as a seedling or sapling, it may be better suited to fire regimes where generally frequent (ten to twenty years) but variable FRIs allow the occasional survival of younger trees (e.g., Agee 1994).

Mixed Conifer–Tan Oak

The mixed conifer–tan oak (Lithocarpus densiflorus) forests of the northern Sierra are similar to those referred to as mixed evergreen forests in the Klamath and north Coast Ranges (Gudmunds and Barbour 1987). These forests are generally found within the mixed conifer zone at lower elevations associated with relatively high annual precipitation (Fites 1993).

Fire History. Fire histories for tan oak–dominated forests are from the Klamath Mountains of northwestern California and southwestern Oregon. Wills and Stuart (1994), in a study conducted near the Forks of the Salmon, found median FRIs to have been fifteen years (with a range of three to fifty years) on three sites. Agee (1993) reports a mean return interval of eighteen years for the type near Oregon Caves National Monument. The fire regime in mixed evergreen forests generally consisted of frequent fires of low to moderate severity, with occasional fires of locally high severity (Agee 1993). The FRIs were more variable than those of the mixed conifer–ponderosa pine forests.

Fire Effects. The tan oak, madrone (Arbutus menziesii), and other hardwoods of these forests are easily top-killed by fires of moderate or high intensity, but sprout vigorously following fire. The Douglas fir often associated with these forests can survive moderate fires when mature but may be killed in severe fires. Consequently, following a severe fire, sites can be dominated for extended periods by tan oak and other hardwoods, since recurring fires often kill the Douglas fir seedlings while the hardwoods continually resprout (e.g., Agee 1993).

Montane Chaparral

Throughout the mixed conifer zone and the upper montane are tracts dominated by shrubs often called montane chaparral. Some common species associated with these shrub fields are greenleaf manzanita (Arctostaphylos patula), deerbrush, snowbrush (Ceanothus velutinus), mountain whitethorn (C. cordulatus), bitter cherry (Prunus emarginata), and bush chinkapin (Castanopsis sempervirens) (Sampson and Jespersen 1963). Huckleberry oak (Quercus vaccinifolia) can be important on relatively poor sites (Rundel et al. 1977; Fites 1993).

Fire History. We were unable to find any fire-history studies that would shed light on FRIs for these vegetation types. The FRIs were probably quite variable due to the influence of poor growing conditions. The FRIs would often likely have been longer and more variable than those for the adjacent forest types within the mixed conifer zone. These areas sometimes have widely scattered individuals or clumps of old trees associated with the shrubs (Fites 1993). The large, old trees in these latter areas could potentially be used to determine the fire history of various sites of interest.

Fire Effects. These montane shrub fields can be rather stable communities on soils associated with poor growing conditions (Bolsinger 1989; Sampson and Jespersen 1963). However, many shrub fields of montane chaparral are the result of secondary succession initiated by stand-replacing fires, logging, or other disturbance (e.g., Leiberg 1902; Bock and Bock 1977; Bolsinger 1989). Most montane chaparral shrub species are disturbance adapted and can resprout or germinate from seeds stored in the soil following a fire (Kauffman 1990). Once a shrub field is established, the shrubs can maintain dominance for long periods. Fires that recur during the life of the shrubs and prior to the establishment of the succeeding forest will tend to maintain the shrub fields (Wilken 1967).

Landscape Patterns

For the mixed conifer zone there exist only anecdotal accounts of landscape patterns for most of the area prior to the 1900s. It is likely that by this time much of the mixed conifer had been affected by various activities associated with the settlement period (Cermak and Lague 1993). Many of the written accounts from the beginning of the twentieth century do not clearly indicate whether they describe presettlement conditions or conditions that reflect the effects of the settlement period (e.g., Sudworth 1900; Leiberg 1902).

Due to the physical structure of the landscapes (e.g., topography, geomorphology, etc.), it is likely that the landscapes of the mixed conifer zone varied considerably in their spatiotemporal patterns of species composition, age classes, and stand densities at a variety of scales. Cermak and Lague (1993) relate numerous accounts of vegetation that describe everything from open, parklike stands of large trees to thick stands of trees to dense stands of shrubs. However, there are little data to describe the extent of these conditions or to quantify what is meant by open, thick, dense, or other such descriptive terms. Recognizing the lack of such data, the California Spotted Owl EIS Team made a concerted effort to attempt landscape-scale characterizations for the Sierra, using the knowledge of specialists from a variety of disciplines (Toth et al. 1994).

It is impossible at this time, due to the lack of data, to conclusively describe the pre-1850s landscape characteristics and how they changed prior to the 1900s. However, based on available knowledge of fire history, fire effects, fire behavior, and the accounts noted previously, we surmise that the landscape patterns in the mixed conifer zone were of a relatively fine scale (e.g., Bonnicksen and Stone 1982; Stephenson et al. 1991). Large, old trees appear to have been characteristic of many forested areas. However, this certainly does not imply that varying sized patches of shrubs or younger trees were not present in the landscape. Variation in tree size and species composition was likely to be greater horizontally (across the landscape) than vertically (within a single stand). It appears that many forested areas were generally more open than they are today, due mostly to the frequency of fires. This may have promoted more grasses and herbs than are associated with most forest stands today. It is likely that riparian areas often served as barriers to low-intensity and some moderate-intensity fire movement, thus contributing to landscape diversity (see the discussion of riparian areas later in this chapter). The northerly aspects most likely had different species compositions from and greater densities of trees than the southerly aspects, as well as different scales of group, aggregation, or stand patterns. Fires were probably more variable in their severity and frequency on moist sites than on dryer sites. See Toth et al. 1994 for more detail concerning characteristics of landscape patterns.

In addition to site characteristics and landscape structure, past patterns of fire occurrence are likely to have influenced the patterns of species composition and dominance within the mixed conifer zone. The differences among the various species in traits that affect their survival of low-to-moderate-intensity fire (e.g., bark thickness, longevity, susceptibility to rots, etc.) may help suggest the characteristics of past fire regimes. An example would be bark thickness. The five widely spread conifers (ponderosa pine, sugar pine, Douglas fir, incense cedar, and white fir) develop thick bark when mature and are generally resistant to low-intensity fires (e.g., Starker 1934; Minore 1979; Wright and Bailey 1982). However, they vary in the relative ages at which they develop bark thick enough to withstand low-intensity fires. Thick bark generally develops rapidly in ponderosa pine and more slowly in white fir and incense cedar (Weaver 1974), with sugar pine and Douglas fir developing it at an intermediate rate. These differences among the species suggest that the spatiotemporal variability of fires may differentially influence the survival of young trees. More regular FRIs were likely to have been found in areas dominated originally by ponderosa pine. Where sugar pine and Douglas fir were a significant portion of the dominant trees, the frequency and intensity of fire may have been more variable, though fires were still generally frequent. Greater variability in both frequency and intensity would probably have occurred where white fir constituted a major proportion of the dominant trees. Thus, the variation in spatial and temporal fire patterns is likely to influence the variation in species composition of the mixed conifer zone over the landscape.

Upper Montane Zone

The upper montane zone includes the red fir (Abies magnifica), Jeffrey pine (Pinus jeffreyi), lodgepole pine (P. contorta var. latifolia), western white pine (P. monticola), aspen (Populus tremuloides), and vegetation found in the higher elevations of white fir forests and woodlands (Rundel et al. 1977; Potter 1994). These forest types are found at altitudes and in topographic areas of high lightning frequency when compared with the mixed conifer or foothill zones (van Wagtendonk 1991a). The upper montane zone can be found on both the west and east sides of the Sierra Nevada. However, most research on fire history is from the west side, except in the southern Cascades.

In Sequoia National Park, Vankat (1983) found that the upper montane conifer types accounted for approximately 53% of the area of the park and 76% of the lightning ignitions. Although fires occur frequently in the upper montane zone, they are not likely to spread readily over the landscape except under unusual conditions. This is due to the shortness of the fire season, the compactness of the fuel beds, and the relatively common natural fuel breaks (meadows, rock outcrops, etc.).

The fire regimes in these upper montane areas are likely to be more variable in frequency and in severity than are those from the lower elevations (Agee 1993). The number of fires for a 1 ha (2.5 acre) upper montane Jeffrey pine–white fir site in the Klamath Mountains was found to vary considerably from one century to the next (Skinner in preparation). Six fires occurred in the 1500s, one in the 1600s, nine in the 1700s, four in the 1800s, and three between 1900 and 1944 (the year of the last fire). Mixed conifer sites at lower elevations in the same watershed were found to have had less temporal variation in the numbers of fires recorded in fire scars. Similar variation has been found on Jeffrey pine–white fir and red fir–white pine sites in upper montane areas of Lassen Volcanic National Park (A. H. Taylor, Department of Geography, The Pennsylvania State University, telephone conversation with the author, May 17, 1995).

Table 38.1 summarizes the high degree of variation in FRIs in upper montane forest types. Local variation in fuel continuity may contribute considerably to the variability in the FRIs from site to site.

Red Fir

The fire regimes of red fir forests appear to vary considerably from landscape to landscape. The surface litter is often sparse and compact (Parker 1984) and is usually not conducive to rapid fire spread. In landscapes broken up by many rock outcrops and meadow systems, such as those characteristic of the central and southern Sierra (e.g., Vale 1987), the fire regimes are characterized by longer FRIs (Pitcher 1987). Longer FRIs in landscapes of Lassen Volcanic National Park have been found where fuel accumulations are low and the fuel bed is broken by outcrops of volcanic rock (A. H. Taylor, telephone conversation with the author, May 17, 1995). However, in areas of more continuous litter beds, as are often found in the northern Sierra and the southern Cascades, the FRIs appear to have been shorter (Taylor 1993a). Fires in these areas, although patchy, appear to spread more easily over larger areas. Pre-suppression-period fire rotations in red fir landscapes within the Caribou Wilderness in the southern Cascades were found to have been approximately seventy years (Taylor 1995a).

Stand-replacing fires appear to have occurred infrequently (Taylor and Halpern 1991; Agee 1993). Leiberg (1902) reported sizable areas in the red fir zone of the Feather River where brush fields appeared to be the result of severe burns.

Some fires in red fir forests have been observed to spread primarily through branch wood and large woody debris, since the compact needle beds do not readily spread fire (Toth et al. 1994). This pattern of spotty fire spread helps contribute to the patchy nature of the burns. These patterns of fire occupance in red fir appear to hold for both the west side and the east side of the range (e.g., Hawkins 1994).

In the lower elevations of the upper montane, white fir can be a major component (Potter 1994), often mixing with red fir. Taylor (1993a) and Taylor and Halpern (1991) have reported on disturbance regimes and stand dynamics in forests of mixed red fir and white fir in the southern Cascades of northern California. They found that fire and wind had been major disturbance factors contributing to spatial patterns of age and tree sizes. White fir, generally more resistant to damage at a younger age than red fir (C. P. Weatherspoon, U.S. Forest Service, Pacific Southwest Research Station, personal conversation with the author, May 18, 1995), may occupy areas where FRIs are more regular than those where red fir is found without white fir.

Jeffrey Pine

The Jeffrey pine forests of the upper montane appear to have had more variable FRIs than the lower-elevation pine forests. Jeffrey pine is found from the upper mixed conifer zone through the upper montane on the west slope and extends onto the east slope of the Sierra. In the upper montane zone, Jeffrey pine is often associated with white fir, red fir, white pine, lodgepole pine, and other species (Rundel et al. 1977). Jeffrey pine is similar to ponderosa pine in its fire-associated characteristics.

Jeffrey pine is often found on more extreme sites (sites that are colder, drier, or more nutrient deficient) than many of its associates (Jenkinson 1990). Because of this, fire histories of Jeffrey pine forests may show much greater variability than those of its close relative, ponderosa pine. The increased variability is related to a limited burn season, slow fuel accumulations, and, often, landscapes broken up by rock outcrops. The fire regimes for Jeffrey pine forests in the southern Cascades (A. H. Taylor, telephone conversation with the author, May 17, 1995) and in the Sierra San Pedro Martir (Minnich et al. in press) appear to have followed the pattern of less frequent and more variable FRIs than would be expected of lower-elevation ponderosa pine forests of the Sierra Nevada.

Mean fire frequency prior to this century in forests dominated by Jeffrey pine and ponderosa pine in the Caribou Wilderness in the southern Cascade Range was found to be 18.8 years (the FRIs ranged from 5 to 39 years) for an area of 127 ha (314 acres). Fire rotation was determined to be 70 years (Taylor 1995a).

Aspen

We are aware of no published studies concerning aspen fire regimes in the Sierra Nevada. Elsewhere throughout the western United States it is recognized that stand-replacement fire has often played a major, yet infrequent, role in the development and maintenance of aspen stands (Kilgore 1981; Jones and DeByle 1985). However, because of the types of sites that aspen generally occupies in the central and southern Sierra (e.g., around moist meadows, near rock piles at the base of cliffs, etc.), many of these stands may be relatively stable and unrelated to fire (Rundel et al. 1977). In the northern Sierra Nevada and the southern Cascades, aspen may often be successional to more tolerant conifers such as white fir or red fir (Potter 1994). FRIs in these locations are likely to be quite variable and long. Fires have been shown to kill competing conifers and regenerate otherwise declining aspen stands (Brown and DeByle 1989; Bartos et al. 1991). Where aspen has become established, it may be able to survive more frequent fires in a shrub state similar to that described by Leiberg (1902).

Lodgepole Pine

Fire has long been recognized as an important ecological process in lodgepole pine forests (e.g., Clements 1910). Lodgepole pine is commonly thought of as a closed-cone conifer requiring the heat of fires to open the cones. However, this feature is absent from the species in the Sierra Nevada (Lotan and Critchfield 1990). The spatial patterns of age classes within stands of lodgepole pine in the central Sierra have been reported to be of a fine grain usually associated with small gaps rather than the large gaps created by the extensive crown fires characteristic of the type in the Rocky Mountains. Mature stands are often open and have sparse surface fuels (Parker 1986). These conditions do not easily promote ignition and fire spread (van Wagtendonk 1991b).

Fire History. No published information exists concerning fire history in the lodgepole pine forests of the upper montane in the Sierra. The type may have a fire regime that is intermediate between the red fir–white fir or Jeffrey pine–red fir forests and the subalpine areas.

Data from landscape-level studies in Lassen Volcanic National Park (A. H. Taylor, telephone conversation with the author, May 17, 1995) and the adjoining Caribou Wilderness area (Solem 1995; Taylor 1995a) in the southern Cascades suggest a disturbance regime similar to that reported by Stuart et al. (1989) for south-central Oregon. The primary difference was that there were more frequent fires in the Caribou Wilderness (Solem 1995). The mean FRI for nine-point samples of trees with multiple scars in stands dominated by lodgepole pine was 34.5 yrs (with a range of 28 to 41 years). The fire rotation prior to this century in two lodgepole pine–dominated areas of the Caribou Wilderness was calculated to be 57 years (162 ha [400 acres]) and 104 years (92 ha [228 acres]) (Taylor 1995a).

Fire Effects. The lodgepole pine–dominated forests of the Caribou Wilderness are multiaged but show the influence of larger-scale episodic events through the dominance of age classes by one or a few even-aged cohorts. These even-aged cohorts appear to be related to past fire events (Solem 1995).

Landscape Patterns

A greater variability in the spatial and temporal pattern may have developed in the upper montane zone than in the lower mixed conifer zone. The variability in landscape patterns is likely a result of a number of factors, such as heavy snow packs that can linger late into the year, influencing fire probability; patterns of soils and exposed rock; and compact litter beds, as well as other factors discussed in more detail previously.

Variation in the spatial extent and severity of individual fires helps lead to a dynamic, complex pattern of dominance by age classes and species over the landscape. Fire sizes estimated from fire scars, age classes, and other patterns of treering variation in the Caribou Wilderness ranged from 22 ha to 1,067 ha (55 acres to 2,635 acres), with a median size of 101 ha (250 acres). Small fires appear to have been mostly of low severity, whereas larger burns had considerable portions affected by moderate-to-high-severity fire (Taylor 1995a).

Subalpine Zone

Subalpine areas of the Sierra Nevada are characterized by forests of widely spaced trees of short stature that often straddle the crest of the range (Rundel et al. 1977). These types generally have limited, usually discontinuous fuel accumulations (Kilgore and Briggs 1973; USFS 1983). Characteristic trees are mountain hemlock (Tsuga mertensiana), white bark pine (Pinus albicaulis), western white pine (P. monticola), foxtail pine (P. balfouriana), limber pine (P. flexilis), and western juniper (Juniperus occidentalis), with lodgepole pine in the lower portions. Subalpine areas receive a greater proportion of lightning strikes than do lower-elevation forests (van Wagtendonk 1991a). However, the number of ignitions is disproportionately low (Vankat 1983; van Wagtendonk 1991b).

Overall, fires are infrequent and of low severity within the subalpine types (Kilgore 1981). Only occasionally, and usually on relatively small areas, do the fires become more severe. Because of the nature of fire in the upper montane and subalpine forests, the National Park Service initiated a prescribed natural fire program in these areas more than two decades ago (van Wagtendonk 1986).

Keifer (1991) reports a study in the subalpine zone of Sequoia–Kings Canyon National Parks, where lodgepole pine and foxtail pine are found. She found that monospecific lodgepole stands always had evidence of past fires, whereas evidence of past fires was found only occasionally in the foxtail pine stands. The areas where the two species intermingled were intermediate in evidence of past fire. She noted that lodgepole pine recruitment appears to be pulsed with the age classes associated with past fires. Conversely, where foxtail pine stands showed evidence of fires the recruitment appeared to be more sporadic and not necessarily associated with fires. She suggests that the response to fire of lodgepole pine (a thin-barked tree) is regeneration in gaps created when the thin-barked trees are killed by fire. Foxtail pine, on the other hand, exhibits thicker bark, which may better protect the trees from the low-intensity fires characteristic of the zone. Climate variation and factors other than fire influencing mortality may account for foxtail pine recruitment patterns.

East-Side Ecosystems

We were unable to find published information concerning fire for the east side of the Sierra Nevada or the east side of the southern Cascades in California. Limited data from the southern Cascades in Lassen National Forest were supplied by Olson (1994) for three east-side mixed conifer stands dominated by ponderosa and Jeffrey pine with white fir and incense cedar present. He found median FRIs of eight to sixteen years (with a range of six to thirty-two years).

Agee (1993, 1994), individually and as part of the Eastside Forest Ecosystem Health Assessment, recently published reviews of the fire regimes for most of the vegetation types that would be found on much of the east-side SNEP assessment area. Finding only limited fire-history information specific to the SNEP assessment area, we refer the reader to these recent summaries as well as to Chang 1996.

Riparian Areas

Riparian areas are generally zones of transition from the terrestrial uplands to aquatic habitats. Riparian zones can be identified by vegetation that requires large amounts of free or unbound soil water. Because of available water and many other vegetative characteristics associated with riparian areas, these zones are disproportionately more important to many wildlife species than their limited extent on the landscape would indicate (Thomas et al. 1979).

We are not aware of any published fire-history studies that would shed light specifically on riparian fire regimes in the Sierra Nevada, southern Cascades, Klamath Mountains, or the east side of the Sierra-Cascade crest. Agee (1993) has conceptually described the probable relationships of fire with riparian areas of various forms. Agee suggests that narrower riparian zones will be more likely to have been more frequently disturbed by fire than will wider riparian zones, and that riparian zones in dryer areas will probably burn more frequently than those in wetter areas.

Skinner (in preparation) gathered fire-history data from four riparian areas along the east side of the Shasta-Trinity

Divide in the Klamath Mountains within the Sacramento River watershed north of Lake Shasta. These data were gathered from within the riparian zone and will be summarized here because of the lack of other data.

The forest type adjacent to all four sites would generally be described as the Klamath enriched mixed conifer type (e.g., Sawyer and Thornburgh 1977). Species common to all four sites were willows (Salix spp.), western azalea (Rhododendron occidentale), Port Orford cedar (Cupressus lawsoniana), and various grasses, sedges, and forbs associated with wet meadow systems. Other common species on these sites were spiraea (Spiraea douglasii), Sierra laurel (Leucothoe davisiae), thimbleberry (Rubus parviflorus), mountain alder (Alnus incana sp. tenuifolia), and California pitcher plant (Darlingtonia californica). Elevations ranged from 1,400 to 1,900 m (4,600 to 6,300 ft). Two sites were on north-trending, gently sloped swales, and two were on steeper south-facing slopes. The sites were all less than 1 ha (2.5 acres) each.

Fire History

The fire histories, which dated from the mid-1600s, suggest that riparian areas generally have longer and more variable FRIs than nearby upland sites. The pre-1850 median FRIs for north-facing swales were 31 and 36 years (with a range of 9 to 71 years). The time since the last fire scar formed on these sites was 49 and 95 years. The pre-1850 median FRIs for the south-facing slopes were 26 and 52 years (with a range of 7 to 65 years). No fires had been recorded in the stumps for 58 and 102 years. Nearby (less than 500 m [1,650 ft] away) upland sites had pre-1850 median FRIs of 12 and 15 years (with a range of 6 to 44 years).

On the west side of the Shasta-Trinity Divide, in the watershed of the East Fork of the Trinity River, data were collected for two 1 ha (2.5 acre) sites that were separated by a small creek with a well-developed riparian zone. The forest types were Klamath enriched mixed conifer with riparian species similar to those described previously. These sites were in the middle third of a long north-facing slope at an elevation of approximately 1,450 m (4,750 ft).

This fire history, dated from the mid-1500s, suggests that a narrow riparian zone only a few meters wide may have longer and more variable FRIs than adjacent upland sites. The pre-1850 median FRIs were 13 and 14 years (with a range of 5 to 47 years). Sixty-one years had passed since the last fire scar was formed. A total of nineteen fires was recorded for the period. Of these nineteen fires, only ten (53%) were recorded on both sides of the riparian zone. The median FRI for the fires recorded on both sides of the riparian zone was 29 years (with a range of 7 to 47 years).

Fire Effects

Many species associated with riparian areas are angiosperms that often can respond to fire by sprouting. Although the available moisture on these sites produces vegetation (potential fuel) readily, FRIs may be longer than in the surrounding stands. Consequently, fires may tend to burn more severely, at least locally, when they do occur. However, the severity of fires may often be restrained by higher fuel moistures associated with riparian zones.

Localized severe burns in riparian areas may not greatly affect aquatic habitat at the landscape scale, depending upon the proportion of the riparian habitat that is burned severely (Amaranthus et al. 1989).

Landscape Patterns

Riparian areas may serve as effective barriers to many low-intensity and some moderate-intensity fires and thus influence landscape patterns beyond their immediate vicinity.

TWENTIETH-CENTURY FIRE REGIMES

The twentieth-century fire regimes of the Sierra Nevada are generally quite different from those prior to Euro-American settlement. Many factors occurring in the 1800s and early 1900s combined to induce drastic changes in fire regimes. Additionally, these factors have contributed to landscape patterns that are still evident today. We will first describe the major factors that contributed to the change in the fire regimes and then will discuss the nature of current Sierra Nevada fire regimes.

Factors in the Nineteenth Century That Helped Influence Changes in Fire Regimes

The following factors, mostly occurring in the 1800s, have combined to dramatically alter fire regimes in the Sierra. However, the effects of these factors were not spatially or temporally universal.

Population Decline among the Native Peoples

The populations of native peoples were declining throughout the nineteenth century. Initially the decline was due to diseases introduced by Europeans, and later it was augmented by systematic extermination and forced relocation (Beesley 1996; Cook 1971). These events caused considerable disruption of traditional land-use patterns and cultural practices (Moratto et al. 1988), probably including a reduction in the use of fire. Reductions in fire frequencies in the early 1800s have been noted on some higher-elevation mixed conifer sites. It has been hypothesized that these reductions may have been related to the decline in the native populations (Caprio and Swetnam 1995). Kilgore and Taylor (1979) suggest that the decrease in fires by the late 1800s for their study area may have been related to the decline in burning by natives.

Influx of Miners

Fire was used to aid in general land clearing during the settlement period and was associated with vegetation type conversions in some areas (Barrett 1935). There was a great influx of miners into the Sierra Nevada following the discovery of gold in 1848 (Beesley 1996). Leiberg (1902) noted that many areas that appeared to have been forested at one time had been converted to brush fields by severe fires, many of which appeared to be related to the mining locations.

Extraction of Wood Material during the Settlement Period

Extensive logging to provide materials to support mining and other settlement activities took place in many locations, for example, Nevada City, Placerville, and Lake Tahoe Basin (Beesley 1996; McKelvey and Johnston 1992). Shakes from sugar pines were more valuable than lumber and could often be produced economically where general logging did not take place because of distance to markets and lack of economical transportation (McKelvey and Johnston 1992). The extraction of shakes, lumber, and firewood left great quantities of residues behind, since the portions of the trees with limbs attached were often not used (Beesley 1996). The residues then fueled subsequent high-severity wildfires that would kill extensive tracts of residual and second-growth trees. These fires were notably more severe than fires that burned in forested areas that had not been subjected to the extraction of the wood materials (Leiberg 1902).

Sheepherding

Heavy grazing in the late 1800s appears to have reduced the landscape effects of fires in many areas. This alteration of fire regimes appears to have been effected in two basic ways by the large-scale sheepherding of the late 1800s and early 1900s. First, sheepherders burned extensive areas in higher elevations and more mesic sites to promote more forage for their herds (Barrett 1935; McKelvey and Johnston 1992). This burning was aimed at reducing the number of downed logs and patches of seedlings and saplings (Sudworth 1900). Second, the intensive grazing was also associated with nearly barren or very lightly covered ground (Sudworth 1900; Leiberg 1902). The combined effect of these practices appears to have been a significant reduction in fuel continuity that limited the actual spread of the fires by the late 1800s, so that many areas show an actual decrease in fire frequency as recorded in fire scars at that time (Vankat and Major 1978). This reduction in fire frequency associated with periods of heavy livestock grazing has been recorded in other areas of the western United States as well (e.g., Savage and Swetnam 1990; Mensing 1992).

Fire-Exclusion Policy

The move toward fire exclusion began early in California. The first law against starting fires was issued under Spanish rule in 1793 (Barrett 1935). This was aimed at halting Indian burning of grasslands, because it deprived the Spanish-owned horses and other livestock of forage. In the late 1800s, foresters were making strong arguments to persuade the public to support fire exclusion so that wood production would be higher in the future (California State Board of Forestry 1888). By the turn of the century, fire exclusion was becoming a general policy among government agencies, although it was not yet fully accepted by the public (Husari and McKelvey 1996; Office of the State Forester 1912).

Twentieth-Century Fire Regime Changes

Due to the initiation of fire-exclusion policies in the late nineteenth and early twentieth centuries, as well as to the suite of factors just discussed, the characteristic fire regimes of many forests of the Sierra Nevada appear to have changed dramatically since the mid-1800s. Before the nineteenth century, the characteristic fires affecting large portions of the landscape would most likely have been of low or low to moderate severity, with patches of higher severity. By the late twentieth century, the characteristic fire was generally of high severity, with only small portions of low to moderate severity. Those forests that have experienced the greatest changes are most likely those on productive sites where fires were more frequent in the past (Weatherspoon et al. 1992), for example, ponderosa pine, black oak, and mixed conifer stands.

The justification for eliminating fires was based primarily on the perceived damage done to the forests. Damage in this sense was related to two factors. First, the surface fires would often cause fire wounds to the bases of trees that reduced the value of these trees and, usually over many centuries, would contribute to the demise of the individual trees. Second, the frequent surface fires were noted to maintain the stands in open conditions by killing most seedlings and saplings in the understories and leaving the forests with low stocking levels (Sudworth 1900; Leiberg 1902; Show and Kotok 1924).

Despite the initial reluctance of local human populations to accept fire exclusion, there appeared to be the beginnings of successful reduction of fires by the end of the first decade of the twentieth century (Office of the State Forester 1912). Nationally, the disastrous fires of 1910 in the northern Rockies helped coalesce political support for exclusion of fire (Agee 1993). Data from the records of the national forests show a steady decline, especially in numbers and acres of human-caused fires, over most of this century (McKelvey and Busse 1996; Weatherspoon and Skinner 1996). However, numbers and acres of fires do not tell the whole story of the change in fire regimes. The major changes in fire regimes are related to the type of fire behavior and the spatial patterns associated with the fires. Fire behavior associated with most forest types in California has changed considerably over this century.

Sudworth (1900), Leiberg (1902), and Show and Kotok (1924) all remark that crown fires and extensive areas of mortality (except in previously logged areas) were unusual at the time of their studies. Show and Kotok (1929) describe the characteristic fires associated with major vegetation types in the late 1920s. Only chaparral and brush types were generally associated with crown fires. Forests composed of ponderosa pine or mixed conifers were associated with surface, litter fires, with crown fires being uncommon. They note that places where crown fires occurred were associated with logging slash or dense, young, second-growth stands. Fires in the upper montane forests were generally described as ground fires that moved primarily through duff. This is a very different picture from that of today, where most wildfires, if not immediately suppressed, quickly become at least severe surface fires capable of killing very large trees. A few examples of recent large, stand-replacement fires in the SNEP study area are the Scarface (1977), Indian (1987), Stanislaus Complex (1987), Stormy (1990), Cleveland (1992), Fountain (1992), and Cottonwood (1994) fires.

Early in the fire-exclusion era, Benedict (1930) indicated that the fire hazard was increasing even as the policy was leading to the achievement of the goal of increasing regeneration survival and ensuring greater stocking levels of trees. He noted that fire-suppression costs were increasing dramatically with the change in stand structures and fuel conditions. Please see Arno (in press) and Weatherspoon and Skinner 1996 for further discussion of fuels and fuel buildup during the fire-suppression era.

As most fires are now suppressed when they are quite small, the frequency of the fires that affect the landscape now appears to be related primarily to the occurrence of burning conditions that are outside the range that modern fire-fighting technology can deal with. Warm, dry summers guarantee that severe burning conditions will occur each year at some point. These conditions occur most often at the lower elevations and are less frequent as elevation increases. The significant fires now are more likely to occur during severe burning conditions of the inevitable drier years (McKelvey and Busse 1996).

Before the fire-exclusion policy, many fires probably burned for weeks or months. Those ignited in midsummer would have been able to burn until the fall rains or snows extinguished them (e.g., Agee 1993). These fires would have burned under a variety of weather conditions, ranging from hot, dry, and windy to relatively benign. This temporal variation in weather would influence fire behavior such that the resulting spatial patterns could be quite variable over the landscape. Even today, when a fire has burned for an extended period the result has been considerable spatial variation in the fire's severity. Recent examples are prescribed natural fires in the national parks of the Sierra (e.g., Kilgore and Briggs 1973); the 1987 wildfires in the Klamath Mountains (e.g., Weatherspoon and Skinner 1995); and the 1994 Dillon lightning fires (USFS 1995), also in the Klamath Mountains.

A characteristic of twentieth-century fire regimes that is different from those prior to the fire-exclusion policy is the spatial extent and pattern of severe burns. Most fires today, including the large, severe fires, usually burn for only a few days. These fires generally burn under severe conditions that exceed the capabilities of suppression forces. When burning conditions moderate, the fires are quickly contained. The result is a more uniform spatial pattern within the burned area and a more coarse grain to the landscape mosaic as a whole.

HISTORICAL RANGE OF VARIABILITY

The historical range of variability (also called the reference variability, the natural range of variability, etc.) has recently been recognized as an important consideration in natural resources management (Swanson et al. 1994; Manley et al. 1995). Ecosystems are dynamic and constantly change in response to various environmental factors (Sprugel 1991; Johnson et al. 1994). Within the appropriate spatial and temporal context, the historical range of variability can provide a reference for assessing the status and possible trends of ecosystems (Laudenslayer and Skinner 1995).

The review of fire regimes given in this chapter, especially regarding the accumulating evidence from fire-history studies, reveals that many Sierran fire regimes (and associated vegetative characteristics) today may be outside their historical range of variability. The attendees at the paleoecology workshop held by SNEP in October of 1994 arrived at the same consensus: Sierran forest ecosystems, viewed at the scale of the Sierra Nevada, are outside the historical range of variability as to fire frequency and severity and associated stand structures and landscape mosaics.

The magnitude of the deviation from the historical range depends upon the spatial and temporal scale one considers. A small, localized area of less than a few hundred acres may not be outside conditions that existed sometime in the past. However, as we look at larger and larger areas, the conditions today are less and less likely to have existed during the last few hundreds of years. Large landscape patterns of relatively homogeneous multilayered forest stands, generally broken only by large changes in site conditions (rocky outcrops, thin soils, etc.) were probably uncommon before the twentieth century.

Many historical factors have contributed to the change in fire regimes. Yet it should be noted that only one of these factors, the implementation of a fire-exclusion policy, has been applied universally in the Sierran landscape. The effects of Euro-American settlement on the native populations and cultures were certainly pervasive. Nevertheless, we lack knowledge of the spatial extent of the native cultural influence on the fire regime (Anderson and Moratto 1996). However, we do know that the application of the fire-exclusion policy has been universal in the Sierra for much of this century (though it has recently been modified in the national parks).

Table 38.1 shows that the time since the last fire is generally equal to or greater than the longest FRI recorded for most of the sites. These fire-history studies suggest that the fire-exclusion strategy has been very successful in eliminating low-severity fires and most moderate-severity fires (those characteristic of the pre-1850s) from the Sierra. However, the attempt to exclude all fires from the environment has been only partially successful. Since it is not within current technological capabilities to suppress many fires burning under extreme conditions, the current management strategy has shifted the characteristic fire regime to one of infrequent, severe, large fires. This shift means that severe fires, rather than being rare events, have become the rule.

Both Leiberg (1902) and Sudworth (1900) comment on how open the forests in their areas of examination were. They each described the landscapes as characterized by large trees (except around previously logged and mined areas) that were widely spaced with sparse undergrowth. Of course, there were exceptions in local areas, such as the South Fork of the Feather River (Leiberg 1902) and others (Cermak 1988), but according to most accounts these latter areas were the exception. Both Sudworth (1900) and Leiberg (1902) also indicate that the fires in their time generally stayed on the surface. Only in unusual cases were extensive areas of larger trees killed, except where there had been considerable logging slash. These descriptions of landscapes and fire behavior are quite different from today's typical escaped fires and resulting landscape patterns, where the patches with high proportions of tree mortality are much larger (it is not unusual for a fire to kill thousands of acres of trees) and are continuous over the landscape. What was described as typical fire behavior in the forests (mostly low-severity, surface fire) is now atypical.

These human-induced changes in the characteristics of Sierran fire regimes have taken place during a climatic period that appears to have been unusually warm and moist when compared to previous centuries (Stine 1996; Woolfenden 1996; Hughes and Brown 1992; Graumlich 1993). A warmer and moister climate would likely have induced a variety of complex responses in Sierran ecosystems. For example, there is evidence that subalpine tree ecosystems have responded to this climatic variation through expansion near the upper tree line (Taylor 1995b). We think it is likely that these climatic variations may have affected the fire regimes even in the absence of the modern human influences described earlier. However, at this time we can only speculate on the direction and magnitude of change in the responses of the fire regimes to the anomalous warm, moist period. Nevertheless, the Mediterranean climate of warm, dry summers and cool, wet winters has remained a dominant feature.

We suggest that it is improbable that the overall effects of the recent variation in climate on the FRIs and fire regimes would have approached the direction and magnitude of the changes brought about by the various modern human policies and activities. The warm, dry summers would likely have continued to support fires in most years at all but the highest elevations (the historical fire records certainly support this). Fire frequencies would likely have varied somewhat from past patterns, but we reason that fires would have remained frequent due to the warm, dry summers. Swetnam (1993), in describing long-term trends in fire frequency and associated climate patterns, indicates that fire frequency appears to be more strongly related to temperature than to moisture trends. Based on Swetnam 1993, Stine (1996) reasons that fire frequency, in the absence of modern fire-exclusion policies, would feasibly have increased over the past century in response to the increase in temperatures. Of course, the higher elevations, where snowpacks would remain for extended periods, and the less-exposed aspects would likely have experienced greater variation in FRIs due to increased moisture.

The rapidity of the changes in fire regimes over the last century appears to be remarkably unprecedented, especially considering the current climatic regime and the vegetation assemblages that can easily support frequent fire. Thus, if current management strategies are continued indefinitely, it is difficult to predict where this extraordinary, rapid change in fire regimes will ultimately lead, especially with the potential of future warmer and drier climate patterns. However, if warm, dry years become more common, as many suggest is likely, we would expect the recent paradigm of large, severe fires to continue.

RESEARCH NEEDS

There is much we do not know about the ecological role of fire in Sierra Nevada ecosystems. We have some idea of the progression of change in Sierran ecosystems since Euro-American settlement and the direction of change that would be necessary to develop vegetation conditions to restore more fire-resilient landscapes. However, we have only limited knowledge of fire as a continuing, ecological process. Much of our knowledge of how fire influences ecosystems is only in regards to fire as a single event (usually following many years of fire exclusion), not as a continuing, ongoing process. The resolution, or at least the partial resolution, of a number of poorly understood subjects would help greatly to formulate appropriate management goals and strategies and to determine appropriate methods for fire and ecosystem management. The following are some of the research areas that we believe are important.

Spatial-Temporal Dynamics

The spatial and temporal interactions of fire and Sierran ecosystems have not been extensively researched. Two general categories of research in this regard need to be addressed. First, there is need for information regarding the effects of frequent fires of low to moderate severity. This will be discussed in more detail later. Second, fire-history studies designed to describe patterns of fire and landscape dynamics over time are needed in order to resolve many management-oriented questions. These questions concern the interactions of fire and spatiotemporal patterns of landscapes. The ability to model these interactions (e.g., Miller 1994) will be extremely important as managers attempt to project the potential effects of various alternative management strategies.

There are two areas of need regarding spatiotemporal dynamics. First, fire-history information is lacking for the northern Sierra Nevada. The southern Sierra Nevada (primarily the national parks) is the source for most published fire-history studies. There are sufficient differences in moisture regimes and vegetation between the northern and southern Sierra to suggest that fire-history studies for the northern Sierra would be very valuable for long-term management. It should be emphasized that the fire-history record is being lost. Much of the logging over the past few decades has removed many of the old trees that contained the fire scar record. As time progresses, less and less of this record will be recoverable due to decomposition of the remaining material (e.g., stumps, logs, snags, etc.).

Second, as has been recounted throughout this chapter, very little published research has been designed to describe the influence of fire on spatial and temporal patterns of landscapes. The long-term spatiotemporal dynamics of landscapes appear to be related to climate variations, but the relationships are poorly understood. Until studies are undertaken specifically to address the role of fire in landscape dynamics, many questions will remain unresolved, for example, (1) how to evaluate appropriate long-term fire-management strategies, (2) how to project the effects of the spatiotemporal patterns of fire on wildlife habitat (e.g., food and cover patterns), and (3) how to model fire in landscapes as an ecosystem process.

Influence of Frequent Fire on Accumulations of Coarse Woody Debris

Setting appropriate standards and guidelines for coarse woody debris (CWD) in forests having fire regimes of frequent, low-to-moderate-severity fires requires research to specifically address the relationship between CWD and fire frequency. Available information describing the accumulations and function of CWD is generally not based on work within forests of functioning frequent, low-to-moderate-severity fire regimes. Much of the information is from ecosystems where fire was much more infrequent than that originally found in the Sierra Nevada (e.g., Maser and Trappe 1984; Harmon et al. 1986; Harmon et al. 1987). Associated information from the Sierra Nevada represents ecosystems affected by years of fire suppression. Continual suppression of the fires in many of these forests has probably increased CWD accumulations above that in pre-suppression-era forests.

Characterization of Old-Growth Forests under the Influence of Frequent Fires

Developing appropriate descriptions and guidelines for old-growth forests characterized by frequent fires of low to moderate severity will remain problematic until research designed to address the relationship between old-growth characteristics and fire is undertaken. The definition of old-growth forests has become standardized based upon work done in climates and forests of the Pacific Northwest that are quite different from those found in the Sierra Nevada (e.g., Franklin et al. 1981; Franklin and Spies 1991a, 1991b). In addition, definitions of old-growth forests in the Sierra Nevada were based upon describing sites that met the Pacific Northwest definitions and that had not been significantly disturbed by fire in recent years (Fites et al. 1992). These descriptions, while representing current conditions of old growth, are not necessarily representative of stands dominated by large, old trees that existed under a functioning presettlement fire regime. It is likely that stand structure, species composition, and understory conditions were very different in many presettlement old-growth stands from those in the old-growth stands found today. The conditions found in many old-growth stands today are at least in part the result of years of fire suppression and may not represent conditions characteristic of presettlement old growth. Research that includes landscape-level fire-history studies and large-scale prescribed fire programs is necessary to adequately develop Sierra Nevada descriptions of sustainable old-growth forests.

Smoke as an Ecosystem Process

The role that smoke management ultimately plays in achieving air-quality objectives may be a determining factor in the amount of prescribed fire eventually used for ecosystem management (e.g., Sandberg 1987). An estimate of smoke production from pre-suppression-era fire regimes based upon our understanding of those fire regimes would help build a baseline description of long-term patterns of air quality. Fahnestock and Agee (1983) have done something similar in regards to the Olympic Mountains of Washington. An assessment of the background levels of smoke that were characteristic of the pre-suppression-era fire regimes will provide policy makers and managers with information that will help them make more-informed choices concerning the long-term programmatic use of fire. Such information will help minimize the imposition of unnecessary restrictions on the use of prescribed fire (e.g., Cahill et al. 1996).

Fire Effects

Although much has been written about the effects of fire, much of the existing information is based upon describing the effects of unplanned wildfires. Few studies exist on the effects of recurring, low-to-moderate-severity fires that would have been more characteristic of the pre-suppression-era fire regimes. There are also few studies that display the effects of fire suppression on potential ecosystem responses to fire (e.g., Swezy and Agee 1991).

Interactions among Disturbance Agents

The interactions among various disturbance agents are poorly understood. Ferrell (1996) suggests that many of the factors that contribute to hazardous fire conditions in forests also increase the vulnerability of the forest to large-scale disturbance from insects and pathogens. Interdisciplinary studies designed to describe the complex interactions among the multiple agents of change (e.g., Gara et al. 1985; USFS 1994) will be necessary to gain a more comprehensive understanding of and to project the potential results of various management strategies.

MANAGEMENT IMPLICATIONS AND CONCLUSION

Fire was an important, regular ecological process in most vegetative communities of the Sierra Nevada for thousands of years before the last century. Euro-American settlement and management activities in Sierran ecosystems over the last 150 years or so have caused many changes in Sierran fire regimes and in the vegetation associated with those regimes. These changes include the significant reduction of fire occurrence, accompanied by a general increase in the density of woody vegetation and an accumulation of associated fuels over broad landscapes. Consequently, although most fires are kept quite small through fire-suppression activities, escaped fires often become large, severely burned patches.

For most of this century, fire has been regarded as a nuisance, as a destructive agent, or occasionally as a tool. In spite of the fact that a number of works on fire in natural resources management have been available for decades (e.g., Weaver 1943; Sampson 1944; Shantz 1947; Biswell et al. 1952), the ecological function of fire has been ignored, denied, or treated as an interesting but inconsequential, academic curiosity by most managers and policy makers (Mount 1969). Only recently, in response to attempts to define and carry out more comprehensive ecosystem management, has the ecological role of fire been generally acknowledged (e.g., Agee 1974; Williams 1993; Manley et al. 1995).

It is often said that an important first step to resolving a problem is to recognize or admit that the problem exists. Apparently, society in general is beginning to recognize that the failure to appreciate the role of fire in western North American ecosystems has contributed greatly to what has been characterized as a general forest health problem (e.g., Knudson 1994; Sampson and Adams 1994; Phillips 1995).

It is unlikely that fire will ever be as unrestrained as it was in past eras. Fire suppression will always play an important role in managing the Sierra Nevada. There are too many cultural values at risk to disallow it (Agee 1994). However, we know that fires are inevitable given modern climate and vegetation. Developing forest structures and landscape patterns that are comparable to those that developed under the more frequent fire regimes of the past will plausibly help ameliorate the ecosystem disruptions caused by the severe fires that are beyond fire-suppression capabilities. The chapters that follow in this section address various ways of analyzing and approaching strategies to deal with the ecological and cultural problems associated with the current condition of Sierra Nevada ecosystems.

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