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An Overview of Fire in the Sierra Nevada

ABSTRACT

Fire, ignited by lightning and Native Americans, was common in the Sierra Nevada prior to 20th century suppression efforts. Presettlement fire return intervals were generally less than 20 years throughout a broad zone extending from the foothills through the mixed conifer forests. In the 20th century, the areal extent of fire was greatly reduced. This reduction in fire activity, coupled with the selective harvest of many large pines, produced forests which today are denser, with generally smaller trees, and have higher proportions of white fir and incense cedar than were present historically. These changes have almost certainly increased the levels of fuel, both on the forest floor and "ladder fuels"—small trees and brush which carry the fire into the forest canopy. Increases in fuel, coupled with efficient suppression of low and moderate intensity fires, has led to an increase in general fire severity.

We suggest extensive modification of forest structure will be necessary to minimize severe fires in the future. In high-risk areas, landscapes should be modified both to reduce fire severity and to increase suppression effectiveness. We recommend thinning and underburning to reduce fire-related tree mortality coupled with strategically placed defensible fuel profile zones (DFPZs). DFPZs are areas in which forest structure and fuels have been modified to reduce flame length and "spotting", allowing effective suppression.

This chapter is an overview of work by the fire-subgroup of the Sierra Nevada Ecosystem Project. Details concerning these findings are found in Skinner and Chang 1996; Chang 1996; Husari and McKelvey 1996; McKelvey and Busse 1996; Erman and Jones 1996; van Wagtendonk 1996; and Weatherspoon 1996.

THE ECOLOGICAL ROLE OF FIRE

> "The most potent factor in shaping the forest of the region has been, and still is, fire."
> Leiberg 1902, 40

For thousands of years, the periodic recurrence of fire has shaped the ecosystems of the Sierra Nevada (Skinner and Chang 1996). Because fire was so prevalent in the centuries before extensive Euro-American settlement (presettlement), many common plants exhibit specific fire-adapted traits such as thick bark and fire-stimulated flowering, sprouting, seed release and/or germination (Chang 1996). In addition, fire affected the dynamics of biomass accumulation and nutrient cycling, and generated vegetation mosaics at a variety of spatial scales (Chang 1996). Because fire influenced the dynamics of nearly all ecological processes, reduction of the influence of fire through 20th century fire suppression efforts in these ecosystems has had widespread (though not yet completely understood) effects.

PATTERNS OF FIRE: PAST AND PRESENT

Estimates of presettlement median fire return intervals (length of time between fires), as recorded in fire scars, are typically less than 50 years (figure 37.1). More specifically, records from the foothill zone, mixed conifer zone, and east side pine showed median fire return intervals consistently less than 20 years.

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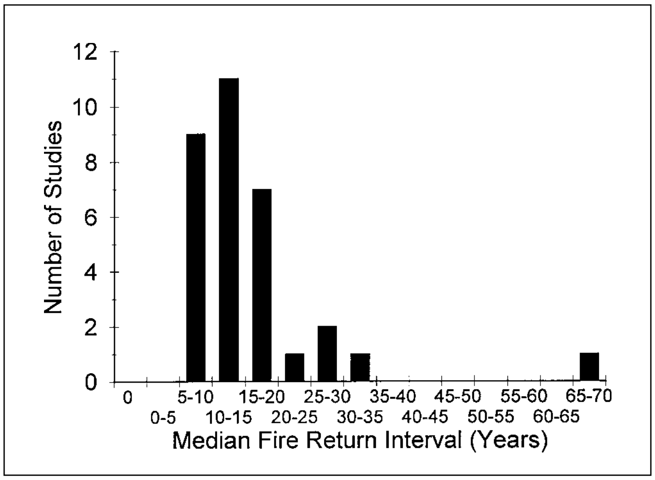

FIGURE 37.1

A histogram showing the number of tree ring studies (Skinner and Chang 1996) by median fire return interval. Only one study found a median return interval greater than 50 years.

Fire affects landscapes at a variety of scales, yet there have been few landscape-scale fire-history studies (Skinner and Chang 1996). Most fire history studies describe fire return intervals for local sites of generally 250 acres or less. The few existing landscape-scale fire-history studies found significant variation of fire occurrence from place to place (e.g., Kilgore and Taylor 1979; Caprio and Swetnam 1995). Fire return intervals varied in response to site and environmental factors such as ignition source, fuel accumulation, fuel moisture, and burning conditions (Kilgore and Taylor 1979). Furthermore, climate variation over many centuries is reflected in more frequent, less extensive fires during warmer periods and less frequent, more extensive fires during cooler periods (Swetnam 1993). Despite variability in fire occurrence patterns and uncertainties in how fire affected landscapes, we believe that the composite picture provided by these studies is compelling: presettlement fires were common enough to significantly affect forest structure and composition over much of the Sierra Nevada.

Knowledge of presettlement fire patterns helps to explain reports by early observers that describe the forests and woodlands as generally open (Sudworth 1900; Leiberg 1902). Sierra Nevada forests and woodlands at the turn of the century were altered by intense grazing by sheep and associated burning patterns in the late 1800s (McKelvey and Johnston 1992). However, these disturbances would have had a modest impact on the canopy trees that, according to Sudworth (1900), were large and on average 250 to 350 years old.

The general structure of forests and woodlands shaped by frequent fires may appear stable for decades or sometimes centuries, at least when viewed at the landscape level (1000s of acres). The pattern of change is usually limited in spatial extent (Skinner and Chang 1996), with patterns of tree mortality leading to patches of different sizes and ages of trees frequently confined to individuals or small groups. This pattern of mortality is most often caused by endemic insect activity, stem breakage due to weakening of trees from fire or physical scarring, or localized severe fire conditions sufficient to kill the canopy trees directly.

Fire regimes characteristic of presettlement conditions in the Sierra Nevada have been disrupted in the 20th century. The Forest Service has mapped fires since 1908, and these maps can be used to estimate the acreage burned in each forest type (McKelvey and Busse 1996). Fire rotation times were calculated from these data and compared with fire return intervals derived from fire scars (table 37.1). Fire rotation is defined as the number of years necessary to burn an area equal in size to an area of interest, in this case a forest type. Fire return intervals are based on the number of times a point (or small area) burned over a period of time. To compare the two metrics, we need to make the assumption that the fire return intervals generated from fire-scar studies represent the forest types in which they exist and therefore approximate fire rotations. Given this assumption, the deviation between current rates and presettlement fire return intervals is one to two orders of magnitude (table 37.1). We believe that this change is far too great to be accounted for by differences in measurement, climate, or potential biases associated with fire-scar data. Fire suppression has been extremely effective in the 20th century.

Another, and perhaps more subtle, difference between current and presettlement fire patterns lies in the recent decrease in fire frequency with increasing elevation. Throughout the 20th century, little of the higher elevation zones have burned (McKelvey and Busse 1996). This is in contrast to presettlement median fire return intervals that differed relatively little from the foothills through the upper mixed-conifer zone (table 37.1). The distribution of fires in the 20th century is closely associated with droughty conditions (McKelvey and Busse 1996) and probably is due to the effective suppression of low-to-

TABLE 37.1

Historic fire return intervals compared with 20th century patterns. Historical data are extracted from various sources (Skinner and Chang 1996) and are the average median return intervals for each forest type. Recent fire data are fire rotations based on area burned during the 20th century (McKelvey and Busse 1996).

	Fire Return Period	
Forest Type	**20th Century**	**Pre-1900**
Red fir	1,644	26
Mixed conifer-fir	644	12
Mixed conifer-pine	185	15
Ponderosa pine	192	11
Blue oak	78	8

moderate intensity fires. Before settlement, 10 times as much area in the foothills burned when compared with the 20th century, whereas 60 times as much burned in the red fir zone (table 37.1).

It is notable that 4,232 ha of the 38,828 ha red fir zone of Yosemite National Park has burned since a prescribed natural fire (PNF) program was initiated in 1972. Under this PNF program the calculated fire rotation is 163 years (van Wagtendonk 1995) for a much greater proportion than has burned outside the park (table 37.1). The PNF program has begun to approach presettlement fire rotation levels after 24 years.

CHANGES IN FUELS

The dramatic reduction in area burned in the 20th century, combined with the effects of forest management practices and generally warmer-moister climatic conditions (Graumlich 1993; Stine 1996), has almost certainly led to substantial increases in quantity and changes in arrangement of live and dead fuels. While data from the early 20th century are not available to test this assertion rigorously, it is based on comparisons with early conditions inferred from numerous historical accounts, documented fire histories, and structures of uncut stands (Kilgore and Sando 1975; Parsons and DeBenedetti 1979; Bonnicksen and Stone 1982; van Wagtendonk 1985; Biswell 1989; Weatherspoon et al. 1992; Chang 1996; Skinner and Chang 1996; Weatherspoon and Skinner 1996).

Live and dead fuels increased along with the development of denser conifer forests. These increases in stand density were concentrated mainly in small and medium size classes of shade-tolerant and fire-sensitive tree species. Lacking fire, the thinning that has occurred has been due to competition (primarily for water and light), diseases, and insects. The result has been a large increase in the amount and continuity of live forest fuels near the forest floor that provide a link between surface fuels and upper canopy layers. The lack of fire has also caused dead fuels on the forest floor to accumulate in excess of their presettlement levels.

The impact of forest management in the 20th century has primarily been to accelerate these trends. Logging on Forest Service and private lands has been primarily of the large overstory trees—accelerating growth in the dense understory and increasing landscape-level homogeneity of fuel structure (Weatherspoon 1996; McKelvey and Johnston 1992). Such cuttings, especially when combined with no treatment of slash (harvest-created fuel), increase the vulnerability of stands to damage from wildfires (Weatherspoon 1996). The national parks, while still maintaining extensive areas of large, old trees, have also experienced increased density of shade tolerant understory trees.

Therefore, compared with presettlement conditions, the current Sierra Nevada forests are generally younger, denser, smaller in diameter, and more homogeneous. Almost certainly there is increased dead biomass and on many sites increased live biomass as well (Weatherspoon and Skinner 1996). Due to high productivity and various forest management activities, the lower and middle-elevation mixed conifer forests have likely experienced greater change in structure and fuels conditions than have either higher elevation forests or foothill vegetation (Weatherspoon and Skinner 1996).

CHANGES IN FIRE INTENSITY

Frequently in the following chapters the assertion is made that fires today are more intense than either presettlement fires, or fires in the early 20th century. More precisely, the assertion is that current fires burn much larger contiguous areas at high intensities, resulting in a larger proportion of the burned area suffering severe fire effects. We have no direct data to support these assertions, but, as with the increase in fuels, such a conclusion is consistent with information available from fire history studies and other sources. The frequency and extensiveness of fires that occurred in the presettlement era were simply too high to allow the accumulation of dead fuel and live “ladder” fuels that support extensive crown fires.

Accounts of early surveyors explicitly state that crown fires were uncommon. In 1899, when George Sudworth was surveying the central Sierra Nevada, fires were so routinely encountered that “travel through a large part of the territory was at times difficult on account of dense smoke” (Sudworth 1900, p. 560). Nevertheless, Sudworth states of these, and previous fires:

> Fires of the present time are peculiarly of a surface nature, and with rare exception there is no reason to believe that any other type of fire has occurred here. (Sudworth 1900, P. 557)

and

> The incidences in this region where large timber has been killed outright by surface fires are comparatively rare. Two cases only were found. . . . One of these burns involved less than an acre, and the other included several hundred acres. (Sudworth 1900, P. 558)

Statements such as these by Sudworth would be absurd if they referred to today’s forests. It is not likely that Sudworth could spend a year traversing the central Sierra Nevada today without at least noting the large burned patches created by stand replacing fire, sometimes covering tens of thousands of acres.

Leiberg surveyed an area north of where Sudworth worked, much of which is currently in the Tahoe and Plumas National Forests. Of the 2.8 million acres that he judged had burned at least once in the preceding 100 years, he concluded that total tree mortality had occurred on 214 thousand acres (Leiberg 1902). In making this determination, however, Leiberg assumed that most meadows and chaparral fields were fire-generated (Leiberg 1902). Even if this assumption was correct (which is doubtful), total tree mortality had occurred on less than 8% of the area burned.

THE ROLE OF SUPPRESSION

Many human uses and management activities have influenced patterns in Sierra Nevada ecosystems over the last century (e.g., grazing, logging, mining, recreation, settlement, fire management). However, only fire suppression has been applied throughout the Sierra Nevada landscape. Until recently, whatever the vegetation, if staff was available, fires were actively and vigorously suppressed. As a result, the fire suppression policy of the 20th century has played a primary role in the human induced changes in many Sierra Nevada vegetation types.

Though stand conditions and fire suppression methodologies and goals have changed during the 20th century (Husari and McKelvey 1996), the effect of suppression on a number of fire attributes has remained remarkably constant. An analysis of fires occurring on the national forests of the Sierra Nevada suggest there is no general time trend in total area burned (McKelvey and Busse 1996), and patterns of location have also remained stable. The relationships between fire occurrence and elevation have remained essentially constant (McKelvey and Busse 1996), as have the distributions of fire sizes for most national forests, the Eldorado and Stanislaus Forests being exceptions (Erman and Jones 1996). Of fires reaching a size of 100 acres or more, human caused fires have exceeded lightning fires in numbers and total area burned throughout this century. Only in the last two decades have the largest fires been caused by lightning (McKelvey and Busse 1996).

Recent Changes in Fire Suppression Resources

There is no question that we have the most mobile and highly organized fire suppression force ever assembled. However, the overall pool of available work force and equipment has recently declined (Husari and McKelvey 1996).

The number of fire suppression resources available for initial attack peaked during the 1970s and early 1980s and was declining by the late 1980s. Both the California Department of Forestry and Fire Protection and the U.S. Forest Service have seen an approximate 10% reduction in the numbers of engines since the peak (Husari and McKelvey 1996). Although these declines are somewhat offset by increases in the numbers of state hand crews, the latter are generally used as reinforcements and not for initial assault.

The New Role of Lightning

In recent decades, the proportion of burned area contributed by lightning-caused fires has increased while the proportion burned by human-caused fires has decreased (McKelvey and Busse 1996; Weatherspoon and Skinner 1996). Additionally, both the number and size of human-caused fires have decreased. In contrast, the size of lightning fires has increased in the past three decades, particularly in the late 1980s and early 1990s (McKelvey and Busse 1996; Weatherspoon and Skinner 1996). If increased difficulty in suppressing individual fires was the only factor, one might expect an increase in the size of both lightning and human-caused fires.

A potential explanation for the recent increase in the proportion of area burned by lightning fires could lie in the temporal concentration of lightning strikes—lightning-caused ignitions often occur simultaneously during thunderstorms, overwhelming suppression resources.

A fire suppression organization that is efficient, highly organized and extremely mobile can usually control solitary ignitions even when staffing is limiting. When multiple ignitions occur, however, work force availability can become pressing: suppression resources allocated to one fire are not available for additional fires. For multiple simultaneous ignitions, the densities of resources available for initial attack are therefore critically important (Husari and McKelvey 1996).

While declines in suppression resources coincided with an increase in large lightning-caused fires in the Sierra Nevada, the extent to which they contributed to these lightning events is unknown. California experienced many large lightning-caused fires in 1977 (Biswell 1989) during the period of peak regional levels of suppression resources. Though none of the largest of these were in the Sierra Nevada, many occurred in the extended SNEP study area (i.e., Cascade Range and Modoc Plateau).

The increase in proportion of total burned area accounted for by lightning fires may be influenced by changing fuel conditions associated with fire suppression and other management activities (e.g., increasing stand densities, accumulating woody debris) discussed previously and in the next section. It is reasonable to expect these changes in fuel conditions to contribute to fires that are more difficult to control. Furthermore, it is likely that the effects of increasing suppression difficulty, despite suppression resource levels, would first become apparent under conditions of numerous, widespread, simultaneous ignitions (Weatherspoon and Skinner 1996).

THE ROLE OF FUEL TREATMENTS

The Rationale for Fuels Management

Fires in Sierra Nevada forests and woodlands occur less frequently and cover much less area than they did in the presettlement era; however, they are more likely to be more uniformly severe. These large, severe fires, in aggregate, are well outside the range of sizes and severity expected for the presettlement era and thus may be detrimental to the integrity and sustainability of Sierran ecosystems. Furthermore, the current prevalence of such fires is socially unacceptable.

The continuing accumulation of large quantities of forest biomass that fuel severe wildfires points to a need to increase the treatment of fuels substantially. To reduce the total area and average size burned by severe fires, designing treatments in landscape-level patterns that are strategically logical for fire management would be preferable. Concurrently, restoring more of the ecosystem functions associated with frequent low- to moderate-severity fires that previously characterized most Sierra Nevada forest ecosystems would be desirable (Weatherspoon and Skinner 1996).

The foothills and lower elevation mixed conifer zones have experienced rapid population growth in recent decades and this is unlikely to cease soon. The prevalence of private lands divided among many landowners, often with houses scattered through the landscape, makes it essential that cooperation among landowners, local entities, and fire agencies take place on a broad scale to effectively deal with the threat to human life and property.

Changing Stand Structure and Fire Behavior

The recent changes in forest structure in the Sierra Nevada probably have affected fire behavior in various ways (Weatherspoon 1996). Current forests are generally much denser than under presettlement conditions, and they contain more surface and ladder fuels (intermediate layers of smaller trees and shrubs). These changes create forests that are more likely to support large, severe fires.

Before the 20th century, forests and woodlands were generally more open. Such forests and woodlands have higher surface temperatures, lower relative humidities, dry more quickly, ignite more easily, and burn more rapidly than the dense forests of today. However, though the flame lengths can be high, fires in the more open forests and woodlands are more likely to be predominately surface fires. The more open conditions are less likely than multilayered, closed-canopy forests to support crown fires or have extensive areas of the overstory trees killed.

Potential Effects of Fuels Treatments on Fire Behavior

The recent accumulations of biomass (both living and dead) that fuel wildfires necessitate the development of strategies to manage fuels to reduce the extent of area burned by severe fire and to help ease the reintroduction of fire as an ecological process. Many fuels treatments involve thinning the smaller diameter trees or biomass removals (Weatherspoon 1996), in essence producing stands structurally similar to what are thought to have been presettlement conditions. Resulting forest structures will be more open, less likely to support crown fire, and less likely to exhibit extensive areas of severe fire effects. The post-treatment fire behavior will be strongly affected by the quantity of surface fuels left on site. Removal of trees necessary to open the stand (increasing drying and wind at the forest floor) usually produces much more severe fire behavior if slash is left untreated on site (van Wagtendonk 1996). Fuel treatments will need to be applied periodically to maintain effectiveness over time. If we fail to maintain treated areas, we will again be faced with hazardous fuel conditions.

Strategic Planning of Fuels Treatments

Given the massive scope of the fuels problem and budget constraints, a carefully-considered, landscape-level strategy is required. On public lands, treatments conducted to reduce the hazard of severe wildfires should be compatible with overall desired conditions for sustainable ecosystems. For private lands, creative processes will be needed that can balance society’s desire to reduce the threat to lives, property, and resource values with land owners’ individual goals and property rights. Treatments need to begin in the most logical, efficient, and cost-effective places. Additionally, the rate of treatment needs to be carefully planned: In the short term, rates of biomass removal may need to exceed rates of production, to return Sierra Nevada forests to a more sustainable, fire-resilient condition (Weatherspoon and Skinner 1996).

We believe a successful fuels management strategy can be based on three components: (1) a series of broad “defensible fuel profile zones” (DFPZs) to be described later; (2) use of fire for restoring natural processes while meeting fuels management goals; and (3) expansion of fuels treatments to other appropriate areas of the landscape, consistent with desired ecosystem conditions. In the short- to midterm (at least the first decade), installation and maintenance of DFPZ networks probably offer the greatest potential for reducing the area and average size burned by large, high-severity wildfires in the Sierra Nevada, and consequent losses of lives, property, and resource values. Increased use of prescribed fire should take place concurrently.

Development of DFPZs involves thinning and otherwise treating fuels as needed to reduce fire hazards. However, areas to be treated should be contiguous and reflect a planned strategy. DFPZs provide a zone of reduced fire intensity and reduced spotting potential (van Wagtendonk 1996) where suppression forces have a reasonable chance of stopping a fire.

We see DFPZs only as the first step in landscape-wide fuels treatments, not as the final solution. In this context, they should provide a foundation from which to extend subsequent prescribed burning or other treatments to broader areas of the landscape. A DFPZ network will help to achieve improved forest health, greater landscape diversity, increase availability of open forest habitats dominated by large trees, and, thus, probably a greater approximation of presettlement conditions along the ridges and upper southerly slopes where they would be concentrated. Periodic maintenance of DFPZs will be essential to their continued effectiveness, as with any fuel treatment. However, their contiguity, usually easy access (providing for easier, cheaper re-treatments), intended value for staging suppression forces, and protecting property and resources, increases the probability that they will be maintained (Weatherspoon and Skinner 1996).

Evaluating Fire Risk

One important factor that should be considered for selecting fuel treatment strategies is risk of fire occurrence based on historical patterns. An evaluation of fire-occurrence risk in high-value areas (e.g., wildland-urban interface areas, national and state parks, productive resource lands, and ecologically significant areas) should help prioritize the location of DFPZs and other fuel treatment areas. An assessment of risk of fire occurrence was developed from Forest Service records of fires mapped for the 20th century (McKelvey and Busse 1996), and the zones of highest risk were found in the foothills. During periods of drought, the area of high fire risk extends into the lower portions of the mixed conifer zone.

Use of Prescribed Fire

Prescribed fire is frequently advocated as a tool that can be used for landscape level fuel reduction while simultaneously restoring fire as an ecosystem process. We recognize the important role that prescribed fire can, and should, play in managing Sierra Nevada ecosystems; however, we must caution against reliance on prescribed fire as the only solution.

Practical and political considerations restrain reliance on prescribed fire, even for the more restricted objectives of restoration and maintenance of natural processes in parks and wilderness (Parsons and Botti in press). Both management ignited and prescribed natural fires (PNFs) ignited by lightning will occasionally escape prescriptions and boundaries, potentially resulting in unacceptable impacts and the ultimate threat of additional restrictions on fire use (such as those following the 1988 Yellowstone fires)(Botti and Nichols 1995). Additional constraints on prescribed fire programs include inadequate funding, inadequate number of personnel (due to competition for trained personnel during active wildfire seasons), and air quality restrictions. The difficulties of carrying out a prescribed fire program are illustrated by the failure of the fire management program at Sequoia and Kings Canyon National Parks to approach the presettlement fire return frequency for the giant sequoia groves in spite of a well funded, aggressive program (Parsons 1995).

Modifying Fire Suppression Strategy

Although permitting low- and moderate-intensity wildfires to burn can provide benefits, the vast majority of ignitions in the Sierra Nevada are suppressed. Fire managers have been required to select the most economically efficient suppression option without considering the potential resource benefits of wildfires. Fires that would contribute to achieving presettlement vegetation conditions are regularly suppressed while small, because they are easy and inexpensive to put out. However, flexibility in present federal fire management policy exists that is rarely exercised outside the National Parks and a few wilderness areas in the Sierra Nevada. Fire managers may use less than full control strategies for fire suppression provided the strategy chosen is projected to incur the least cost of suppression plus loss of resource values. Use of appropriate suppression responses, expanded use of prescribed fire and use of PNF both inside and outside wilderness should be evaluated based on fire regime, expected fire behavior and weather regime throughout the Sierra Nevada. Agencies should seriously consider using managed wildfires to meet resource objectives in combination with prescribed fire and other forms of fuels treatment. Indeed, the proposed fire policies for the U.S. Departments of Agriculture and Interior would allow land managers the flexibility to use wildland fires to meet management objectives (USDI/USDA 1995).

CONCLUSION

Fire has been, and will continue to be, a major influence on Sierra Nevada landscapes. Each summer conditions occur where fires can easily ignite and spread due to the Mediterranean climate characterized by cool, wet winters and warm, dry summers. Under this prevailing climate, fire has served as a frequent, potent influence on Sierra Nevada ecosystems for millennia.

The combination of human uses and management activities over the last century and a half has profoundly altered fire regimes. The area influenced by low- and moderate-intensity fires in the Sierra Nevada landscapes has been greatly reduced. This has resulted in changes in forest structures and landscape patterns. Today many Sierra Nevada landscapes will more readily support more uniformly severe large fires than were characteristic of presettlement conditions.

It is likely that occurrence of large, severe fires will continue in the Sierra Nevada into the indefinite future. Fuel treatments may provide a long-term solution by reducing the likelihood of tree mortality and crown fires and producing defensible zones in which fires can be more successfully controlled. Fuel treatments must be periodically maintained to avoid a return to hazardous conditions. Initial treatment costs are often high and there will be continuing costs for maintenance. It is crucial that fuel treatment areas are carefully located to increase effectiveness and minimize costs. We must devise ways to provide the necessary financing, and where practical use the harvest of biomass to help pay for the needed treatments. The foothill zone will present the greatest challenge to manage fire effectively to protect human life and property, whereas, the mixed conifer and upper montane zones may present the greatest challenge from an ecological and resource perspective.

Even an extremely aggressive fuels treatment program will take more than a decade to accomplish. After more than a century of changing forest structures and fuel conditions, realizing significant regional shifts in fire behavior will take time, determination, and good financing. Judicious planning will help to achieve ecological goals while reducing the spatial extent and effects of severe fires.

Future Needs

Each of the following chapters has developed recommendations and assessed future needs that are best understood in the details of the separate reports. Together they lay the framework for action, better management, and better understanding of the critical role fire plays in the human and ecological landscape of the Sierra Nevada.

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