CHAPTER 4

Fire and Fuels

❄ CRITICAL FINDINGS

Ecological Functions of Fire Fire is a natural evolutionary force that has influenced Sierran ecosystems for millennia, influencing biodiversity, plant reproduction, vegetation development, insect outbreak and disease cycles, wildlife habitat relationships, soil functions and nutrient cycling, gene flow, selection, and, ultimately, sustainability.

Effects of Climate Climatic variation plays an important role in influencing fire patterns and severity; fires have been most extensive in periods of dry years.

Presettlement Fire Regimes In most lower-elevation oak woodland and conifer forest types of the Sierra Nevada, presettlement fires were frequent, collectively covered large areas, burned for months at a time, and, although primarily low to moderate in intensity, exhibited complex patterns of severity.

Effects of Suppression Fire suppression in concert with changing land-use practices has dramatically changed the fire regimes of the Sierra Nevada and thereby altered ecological structures and functions in Sierran plant communities.

Fuel Conditions Live and dead fuels in today's conifer forests are more abundant and continuous than in the past.

Effects of Logging Timber harvest, through its effects on forest structure, local microclimate, and fuel accumulation, has increased fire severity more than any other recent human activity.

Fire Size Trends The commonly expected consequence of decades of fire suppression—that large, infrequent fires are becoming larger and small, frequent fires smaller—is generally not confirmed by records for twentieth-century Sierran forests.

Fire Surrogates Although silvicultural treatments can mimic the effects of fire on structural patterns of woody vegetation, virtually no data exist on the ability to mimic ecological functions of natural fire.

Urban-Wildlands Intermix Projected trends in urban settlement—homes intermixed with flammable wildlands—place an increasing number of homes and people at high risk of loss from wildfire unless hazards are mitigated.

ASSESSMENT

Fire represents both one of the greatest threats and one of the strongest allies in efforts to protect and sustain human and natural resources in the Sierra Nevada. Residents and visitors alike are well aware of the threats posed by summer wildfires. A growing density of homes and other structures coupled with the increased amount and continuity of fuels resulting from twentieth-century fire suppression have heightened concern about threats to life and property, as well as the health and long-term sustainability of forests, watersheds, and other natural resources. Yet fire has been an integral part of the Sierra Nevada for millennia, influencing the characteristics of ecosystems and landscapes. Today, state, federal, and local agencies put enormous resources into efforts to reduce fire occurrence while at the same time advocating the need to use fire to promote healthy ecosystems. The challenge we face is how to restore some aspects of a more natural fire regime while at the same time minimizing the threat wildfire poses to human and natural resources and values.

The Nature and Ecological Role of Presettlement Fire

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

Fire has long been a natural component of Sierra Nevada ecosystems. For thousands of years preceding Euro-American settlement, fires burned frequently—typically multiple times each century—in most Sierran vegetation types. The hot, dry summer mediterranean climate provided suitable weather conditions and dry fuels for burning. Lightning provided a ready ignition source, supplemented by Native Americans, who used fire for a variety of purposes. Fires could spread until weather conditions or fuels, or both, were no longer suitable.

Fire-scar records in tree rings have shown variable fire-return intervals in presettlement times. Median values are consistently less than twenty (and as low as four) years for the foothill, ponderosa pine, and mixed conifer zones of the Sierra Nevada (table 4.1). Only one study—in high-elevation red fir—found a median fire-return interval greater than thirty years. Using total area and our best understanding of the range of fire-return intervals for each of the major vegetation types, and a simplified assumption that, for each type, total area divided by fire-return interval equals area burned annually, we see that it was not uncommon for hundreds of thousands of acres to be burned in the Sierra Nevada in a given

❄ *Fire—Alternative Views*

All SNEP scientists agree that fire has played a significant if not dominant role in shaping the vegetation pattern; the departure of views begins with the relative certainty of fire frequency and spatial intensity in presettlement times. There is too little compelling evidence and incomplete rangewide research to conclude a precise pattern of fire frequency or severity in presettlement times. There were very probably areas that burned frequently (less than ten-year intervals), but some areas within the same vegetation type probably escaped burning for much longer periods and built up sufficient fuel loads to burn with high intensity if ignition occurred under favorable burning conditions. This point of difference in views centers on the belief that there were probably many variations in the return frequencies and fire intensity patterns that contributed to the mosaic of vegetation patterns on the landscape today.

A second major point of difference relates to the relative "openness" of forests before the disturbances caused by settlers. The alternative view concludes, from the same evidence, that forest conditions were not largely "open or parklike," in the words of John Muir; rather, there was a mix of dark, dense, or thick forests in unknown comparative quantities. Select early accounts support an open, parklike forest, but there were many similar accounts that describe forest conditions as dark or dense or thick. J. Goldsborough Bruff, a forty-niner who traveled the western slopes of the Feather River drainage between 1849 and 1851, kept a detailed diary. He clearly distinguished between open and dense forest conditions and recorded the dense condition six times more often than the open. Many other accounts of early explorers (e.g., John C. Frémont, Peter Decker, William Brewer) identify dark or impenetrable forest; the presettlement forest was far from a continuum of open, parklike stands. From these records it seems clear that Sierran forests were a mix of different degrees of openness and an unknown proportion in dark, dense, nearly impenetrable vegetative cover with variations from north to south and foothill to crest.

A third point of departure has to do with the frequency of stand-terminating fires in presettlement times. One group concludes that such events were rare or uncommon. The alternative view is that stand-threatening fires were probably more frequent. They were heavily dependent upon combinations of prolonged drought, an accumulation of dead material resulting from natural causes (e.g., insect mortality, windthrow, snow breakage), and severe fire weather conditions of low humidity and dry east winds coupled with multiple ignitions, possibly from lightning associated with rainless thunderstorms. Such fires were noted during the last half of the nineteenth century by newspaper accounts, official reports (John Leiberg, U.S. Geological Survey, 1902), and diaries; most were apparently caused by settlers, stockmen, or miners. Fuel loads were obviously sufficient at that time, thus strongly suggesting that similar conditions existed in earlier times with unknown frequencies.

year. Yet fire frequency, intensity, and severity varied through time and across the landscape in response to variations in climate, number of lightning ignitions, topography, vegetation, and human cultural practices.

TABLE 4.1

Historic fire-return intervals compared with twentieth-century patterns. Historical data are extracted from various sources (volume II, chapter 38) and are the average median return intervals for each forest type. Recent fire data are fire rotations based on area burned during the twentieth century. (From volume II, chapter 41.)

	Fire-Return Period (Years)	
Forest Type	**Twentieth Century**	**Pre-1900**
Red fir	1,644	26
Mixed confier–fir	644	12
Mixed conifer–pine	185	15
Ponderosa pine	192	11
Blue oak	78	8

Presettlement fire strongly influenced the structure, composition, and dynamics of most Sierra Nevada ecosystems. Many species and most communities show clear evidence of adaptation to recurrent fire, further demonstrating that fire has long been a regular and frequent occurrence. This is particularly true in the chaparral and mixed conifer communities, where many plant species take advantage of or depend on fire for their reproduction or as a means of competing with other biota.

The variable nature of presettlement fire helped create diverse landscapes and variable forest conditions. In many areas frequent surface fires are thought to have minimized fuel accumulation, keeping understories relatively free of trees and other vegetation that could form fuel ladders to carry fire into the main canopy. The effects of frequent surface fires would largely explain the reports and photographs of those early observers who described Sierran forests as typically "open and parklike." However, such descriptions must be tempered by other early observations emphasizing dense, impenetrable stands of brush and young trees.

Several lines of evidence indicate that most presettlement fires were dominated by areas of low to moderate severity, with high-severity portions (fire sufficiently intense to kill most large trees) most often restricted to localized areas, often a fraction of an acre to several acres—or occasionally several hundred acres—in size. Predominately high-severity fires larger than a few thousand acres almost certainly occurred but were probably less common than they are today. This picture of presettlement fire is supported by our understanding of fuel dynamics as well as information derived from forest age structure analysis, written accounts of early fires, and observations of modern fires.

Periodic fires performed a number of ecological functions. Fire damaged or killed some plants, setting the stage for regeneration and vegetation succession. Many plants evolved fire-adapted traits, such as thick bark, and fire-stimulated flowering, sprouting, seed release, and / or germination. Fire influenced many processes in the soil and forest floor, including the organisms therein, by consuming organic matter and by inducing thermal and chemical changes. And it affected the dynamics of biomass accumulation and nutrient cycling and generated vegetation mosaics at a variety of spatial scales.

Native Americans adapted to this natural role of fire and controlled it to some extent for their own benefit. They are known to have used fire to clear brush from around their dwellings and to enhance habitat for game species. There is reason to believe that in local areas their activities added to the background lightning-induced fire frequency.

Effects of Human Activities Beginning in the Mid-1800s

Euro-American influence on fire in the Sierra Nevada began before the mid-1800s. By this time many Native American populations had been decimated by disease and genocide, and their traditional use of fire had been greatly reduced. The rapid influx of settlers into California following the discovery of gold, however, initiated more profound changes in the role of fire in Sierra Nevada ecosystems. Logging was undertaken initially to supply the mines and later to support the growing population of the new state. Timber volumes harvested in the Sierra Nevada continued to increase into the twentieth century, reaching a peak in the 1970s and 1980s. Typically, loggers harvested fire-resistant species and large trees, and these were replaced by greater numbers of much more fire-susceptible smaller trees. This pattern of biomass removal contrasted markedly with that of presettlement surface fires, which tended to kill (and later consume) small trees and leave many large trees to survive. Large quantities of debris left after logging led to severe fires, establishing vegetation patterns still evident today. A new pattern of ignitions, characterized in part by careless and indiscriminate burning, was introduced by miners, sheepherders, settlers, and loggers. In other areas there is evidence that heavy grazing by millions of sheep in the late 1800s may have effectively altered fuel conditions to reduce the influence or extent of fires.

The Role and Consequences of Fire Suppression

Suppression of wildland fires had been established as state and federal policy by early in the twentieth century. Following a series of disastrous fires in 1910 and a period of trial and debate about the merits of "light burning" as a management tool in forests and rangelands, intentional broadcast burning was repudiated and aggressive fire control became firmly entrenched. Only in recent decades have the benefits of prescribed fire become widely apparent.

Combined with the loss of ignitions by Native Americans,

❄ *Careless and Indiscriminate Fire Use*

We note here a report in 1888 to the California Board of Forestry (H. S. Davidson): "A half century following the Gold Rush was a period of the careless and indiscriminate use of fire consuming each year thousands of acres of fine timber, endangering and often destroying the property of settlers, menacing the homes of all those who live in timbered regions, the forest fire, year after year continues its ruinous course, unrestrained by the law, and unheeded by the majority of the people. Anyone traveling through the Sierras cannot fail to notice the large number of charred and half burned stumps of large trees, often twenty feet high, whose tops have fallen when the trunks were half consumed, and were themselves wholly or partially consumed upon the ground. These fires often assume such proportions that the atmosphere at a distance of 50 miles from the scene of the conflagration will assume that hazy appearance caused by dense smoke." Burning by sheepmen became so common from the 1870s through 1900 that the newspapers often printed stories about smoky fall days. In 1889 C. M. Dabney of Fresno, in a plea for control of sheep grazing and sheepherder fires, claimed, "There seems to be a combination of sheepmen . . . who pay no taxes, have no homes, defy our laws, and who say they do not understand English, to burn these magnificent forests as they go along." P. Y. Lewis, who herded sheep in the upper Mokelumne River drainage in 1876–77 asserted: "We started setting fires and continued setting them until we reached the foothills. We burned everything that would burn." And John Muir noted, "The entire forest belt is thus swept and devastated from one extremity of the range to the other" by sheepherder-set fires. This period of fire damage led to the first state laws prohibiting the setting of fires, either willingly or negligently, and a similar federal policy.

fire suppression resulted in significant reductions in area burned by wildfires during the twentieth century. For example, by comparing average annual acreage estimated to have burned during the presettlement period (based on fire history data) with twentieth-century fire-return intervals (table 4.1), we find that the annual area burned during this century has been reduced to approximately 10%, 3%, and 2% of presettlement values for the blue oak, mixed conifer, and red fir forest types, respectively.

The virtual exclusion of widespread low- to moderate-severity fire has affected the structure and composition of most Sierra Nevada vegetation, especially in low- to middle-elevation forests. Conifer stands generally have become denser, mainly in small and medium size classes of shade-tolerant and fire-sensitive tree species. Vertical fuels have become more continuous, contributing to more spatially homogeneous forests (figure 4.1). Selective cutting of large overstory trees and the relatively warm and moist climate that has characterized much of the twentieth century may have reinforced these trends by producing conditions favorable to the establishment of tree seedlings and other plant species. Coupled with fire suppression, these conditions permitted the extensive development of dense, young forests. As a result, stands in many areas have experienced increased mortality recently from the cumulative effects of competition (primarily for water and light), drought, insects, disease, and, in some cases, air pollution. The increased density of young trees together with increased fuels from fire suppression and tree mortality have created conditions favorable to more intense and severe fires. Moreover, severe fires are more likely to be large because they are more difficult to suppress, although data on large fires in the Sierra indicate that current fire sizes vary greatly among national forests. While we cannot be sure whether more absolute area has burned in severe fires in the twentieth century than in pre-contact times, it is clear that within those areas that do burn, a greater proportion of fire is high-severity than in the past.

Several lines of evidence suggest that quantities of live and dead fuels have increased over the course of the twentieth century, although data from the early part of the century are not available to test this assertion directly. Over the same period suppression technology has improved, but in recent years available fire-fighting resources have declined. The net effect on a number of fire attributes has remained remarkably constant.

Trends in Fire Size

Total area burned in the Sierra shows no overall trend during the twentieth century, in contrast to the marked reduction in burned area from the presettlement era to the twentieth century. This stability contrasts with striking declines in area burned during the first half of the century and increases in area burned after about 1970 that have been documented for other areas in the western United States. Other patterns also have remained stable, including (1) the relationship between fire occurrence and elevation (i.e., more area burns at lower elevations); (2) the relationship between climate and annual area burned (i.e., more area burns in warmer, drier years); and (3) average fire sizes for most national forests in the Sierra Nevada.

In other significant respects, however, fire characteristics have changed. Although human-caused fires have exceeded lightning fires in number and total area throughout this century (figure 4.2), the proportion of total area burned by lightning-caused fires and the average size of lightning fires have increased in recent decades, particularly in the late 1980s and early 1990s. A likely explanation stems from the fact that, unlike human ignitions, many lightning ignitions occur simultaneously during thunderstorms, stretching available fire-fighting resources so thin that not all fires receive adequate initial attack. The increase in total area and average size of lightning fires in recent decades may reflect, in part, a reduction in overall suppression resources. At least as important may be general increases in wildfire hazard (fuel quantities),

FIGURE 4.1

Development of vertical fuels through ingrowth of white fir in a stand of mixed conifer as a result of fire suppression. (Photo by Constance I. Millar.)

The catastrophic Cleveland wildfire of 1992 near Highway 50 partially on the Eldorado National Forest. (Photos by Douglas Leisz.)

which tend to increase difficulty of control and exacerbate limitations in fire-fighting resources. Expanded human settlement in the urban-wildland intermix has also complicated fire suppression by focusing resources on protection of structures.

An evaluation of fire-occurrence risk based on U.S. Forest Service records of twentieth-century fires identified an elevation pattern, with the highest risk in the foothill and lower mixed conifer zone (figure 4.3 and plates 4.1 and 4.2). Maps documenting fuel loads on national forest lands in the Sierra reflect another estimate of risk (plate 4.3).

Prescribed Fire

Prescribed fire has proven an effective tool to reduce fuel loads and fire hazards while restoring a process important for maintaining ecosystem functions. However, practical and political considerations may limit future expansion of this approach. Although prescribed fire is useful in restoring and maintaining natural fire regimes in parks and wilderness areas, it remains to be seen whether the logistical, economic, and social constraints on widespread deployment of prescribed fire for fuel hazard reduction can be overcome. In some places, mechanical fuel reduction, often in conjunction with prescribed fire, can also be of use in reducing fuels and fire hazards.

Challenges for Fire Management

Human activities during the past 150 years have caused a number of fire-related changes in the Sierra Nevada. Fires occur less frequently and collectively cover much less area than they did in the presettlement era. Widespread low- to moderate-severity wildfires have been virtually eliminated because these are the fires that are suppressed most easily. As a result, the ecological functions performed by such fires (e.g., nutrient mineralization, soil sterilization, and understory thinning) have been largely lost, with some known and many

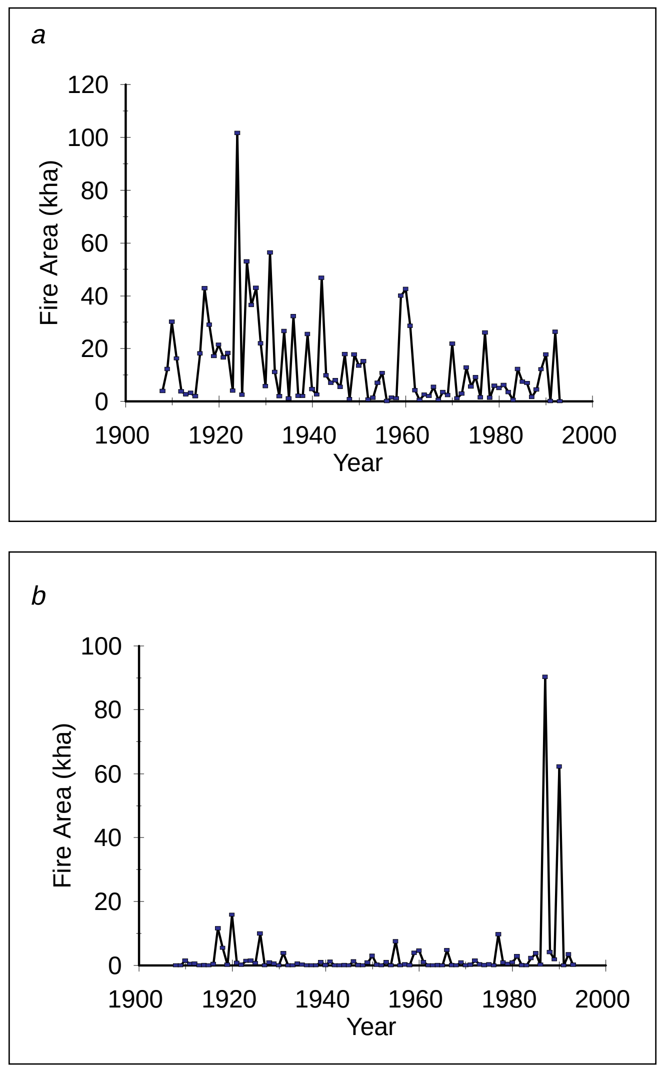
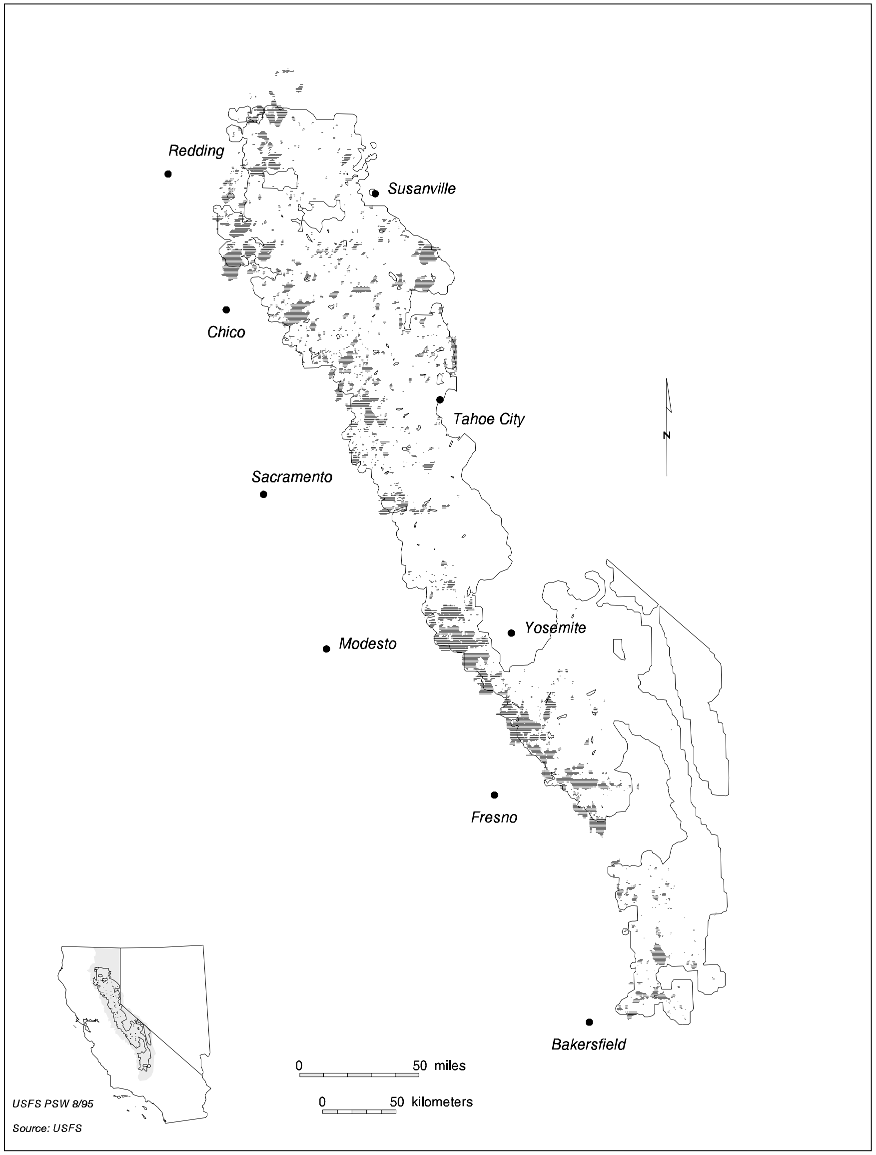


FIGURE 4.2

Acres burned by fires in the Sierra Nevada, 1908–92. *Top (a):* Human-caused fires. *Bottom (b):* Lightning-caused fires. (From volume II, chapter 41.)



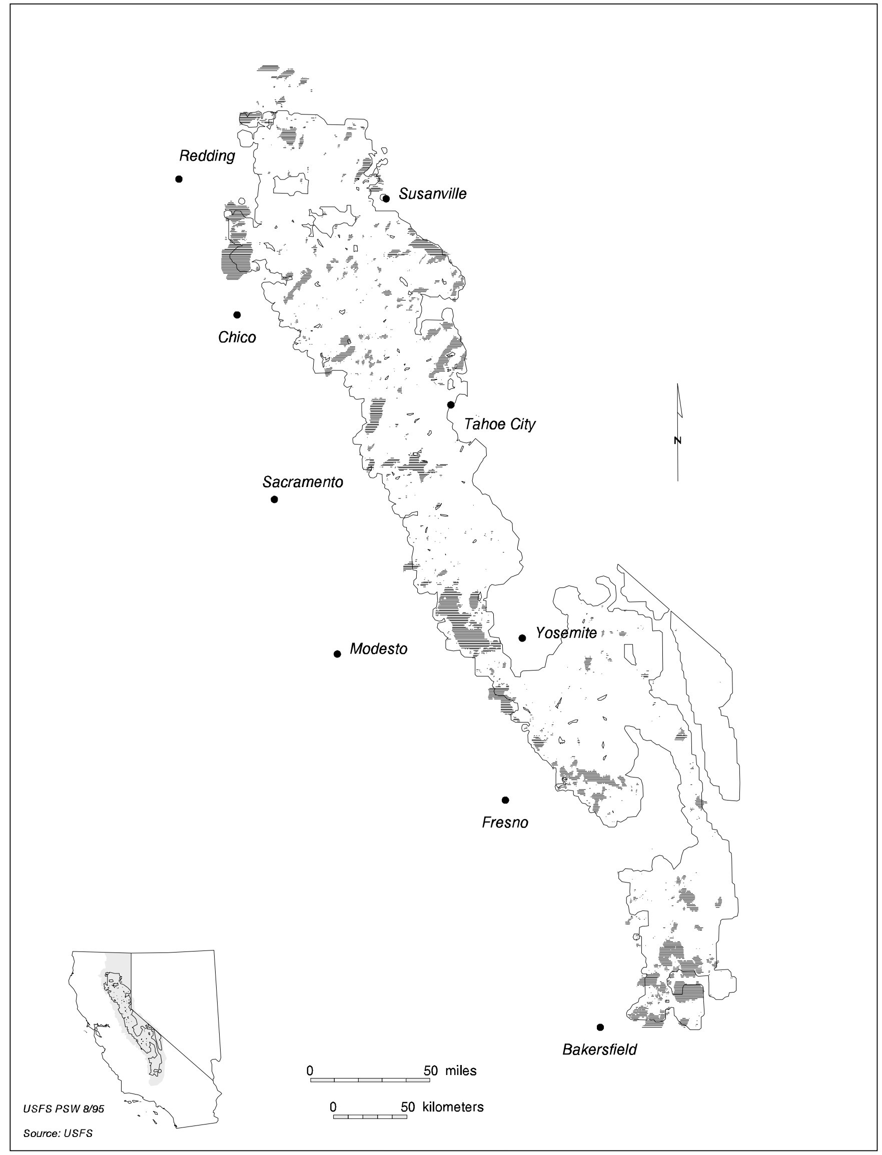


FIGURE 4.3

Fires on and around USFS national forest lands within the SNEP core area. *Left:* Fires from 1900 to 1939. *Right:* Fires from 1940 to 1993. (From volume II, chapter 41.)

A ponderosa pine–Douglas fir stand treated with prescribed fire in 1979 and burned in 1987 during the Elk Complex wildfire. By 1992, when this photo was taken, grass and herbaceous vegetation covered the ground among trees of different ages. (Photo by Carl N. Skinner.)

unknown consequences. Furthermore, largely because of fire suppression, fuels—both live and dead—have increased in quantity and continuity, thereby increasing the probability of large, high-severity wildfires. In fact, the fires that do occur are likely to be large and more uniformly severe; these are the fires not readily suppressed. It is these high-severity fires that most conflict with human values and thus pose the greatest concerns about life, property, and natural resource values. The propensity for the rapidly increasing population of the Sierra Nevada to build in flammable areas without mitigating fire hazards and risks has increasingly placed homes and other valuable property at risk of loss to severe wildfires, making potential solutions to the problem increasingly difficult. Many hundreds of homes have been destroyed by wildfires in the Sierra Nevada over the past few decades (e.g., 148 homes and 164 other structures were destroyed in the 1988 49er fire near Nevada City).

In short, we have three major fire-related "problems" in the Sierra Nevada: (1) too much high-severity fire and the potential for much more of the same; (2) too little low- to moderate-severity fire, with a variety of ecological changes attributable at least in part to this deficiency; and (3) a large number of homes and other structures at risk due to both existing and continued rural development in areas with extreme fire hazards that are not reduced to acceptable levels. Clearly, these are not just "fire problems." They influence virtually all resources and values in the Sierra Nevada and cut across all of SNEP's subject areas. These three problems can be translated into three closely related and complementary broad goals for fire management in the Sierra Nevada: (1) reduce substantially the area and average size of acres burned by large, high-severity wildfires; (2) restore more of the ecosystem functions of frequent low- to moderate-severity fire; and (3) encourage a more rational approach for the intermix of homes and wildland vegetation with high fire-risk hazard. Making significant progress toward these goals will require long-term vision, commitment, and cooperation across a broad spectrum of land-management agencies and other entities. The problems were created over a long time, and they certainly cannot be solved rapidly.

STRATEGIES

There are many possible approaches and strategies for addressing issues relating to the management of fire and hazardous fuels in the Sierra Nevada. We have addressed only a few of these in our illustrations.

Goals

1. Substantially reduce the potential for large high-severity wildfires in the Sierra Nevada in both wildlands and the wildland-urban intermix.
2. Restore historic ecosystem functions of frequent low- and moderate-severity fire.
3. Help communities understand and eliminate unacceptable fire hazards and risks that threaten the safety of people and homes in the wildland-urban intermix.
4. Aid counties, other local governments, and fire districts in attaining and maintaining fire-safe fuel conditions concurrent with all new development or in redirecting development to areas of lower fire hazard.

Possible Solutions

Reducing the potential for large, high-severity fires while at the same time increasing the area burned and the ecosystem effects produced by low- and moderate-intensity fires would reduce the fire hazard to property and lives in developed areas as well as reduce the total acreage burned at high severity. It might actually increase the total area burned compared with the past few decades. Such a program would, by necessity, require the effective development of institutional frameworks to facilitate interaction, financial support, and cooperation among agencies, local governments, and private interests. It is inconceivable that fire in its presettlement extent and frequencies could be restored fully to the Sierra Nevada.

The following are possible solutions addressing the identified problems:

- Prioritize fuel treatment areas to minimize the likelihood and spread of large, severe fires, based on broad, landscape-level analyses of risk and hazard to both human settlements and wildlands.
- Develop a system of "defensible fuel profile zones" (DFPZs), initially using a variety of silvicultural treatments, to limit the spread of large, severe fires. Once developed, these DFPZs will serve as areas of entry into larger landscapes to facilitate more widespread fuel treatments, such as prescribed fire, and will allow more widespread use of wildfire to meet management objectives.
- Increase substantially the use of prescribed fire (natural or management ignition) in areas where restoration of natural processes is emphasized.
- Develop programs for the increased use (through containment and confinement strategies) of low- and moderate-intensity wildfires to achieve goals of restored ecosystem processes, resource management, and human safety.
- Develop fuel-management demonstration areas. For the purpose of public education, some demonstration areas would illustrate vegetative conditions necessary to reduce the severity and extent of large, severe wildfires. These areas would be developed by a suite of treatment methods so that the public can adequately observe and managers can learn from the various resulting conditions. Other demonstration areas would be located to provide a social arena for developing the institutional framework necessary to carry out large, strategic fuel-management projects. Of particular value in this context may be projects in wildland-urban intermix areas such as those found in Nevada, Placer, and El Dorado Counties.
- Develop a collaborative institutional structure (e.g., an "Issue Command Structure," similar to the Incident Command System used for fire suppression and other emergencies) so that federal, state, and local agencies and communities could join together to plan, establish goals, finance, and execute programs to accomplish the fire-safety objectives.
- Make visible those counties (e.g., El Dorado) and communities (e.g., Incline Village, Lake Tahoe, Nevada, and Pine Mountain Lake Development, Tuolumne County, California) that have implemented effective programs through General Plans, ordinances, and actions that either avoid new development in high fire-hazard zones, require full mitigation of the hazards concurrent with development, or are correcting hazardous fuel conditions in existing developments.

Defensible Fuel Profile Zones in Support of Goals 1 and 3

A key component of the proposed strategies is development of a network of broad DFPZs. Whereas initially addressing goals 1 and 3, the DFPZs will actually help to address all of the stated fire-related goals. Fuel-reduction treatments will be designed to address the specific local issues (e.g., establishing a community defense zone, or breaking up areas of continuous high-hazard fuels, or designating a strip or block of land to form a zone of defensible space where both live and dead fuels are reduced).

Such DFPZs are best initially placed primarily on ridges and upper south and west slopes and, where possible, along existing roads. They also should be located with respect to urban-wildland intermix and other high-value areas (such as old-growth or wildlife habitat areas), areas of high historical fire occurrence, and/or areas of heavy fuel concentration. Thinning from below and treatment of surface fuels should result in fairly open stands, dominated mostly by larger trees of fire-tolerant species. DFPZs need not be uniform, monotonous areas, however, but may encompass considerable diversity in ages, sizes, and distributions of trees. The key feature should be the general openness and discontinuity of crown fuels, both horizontally and vertically, producing a very low probability of sustained crown fire. Care must be exercised in the design and construction so that forest aesthetic values are largely retained and watershed values are not impaired. The open-canopied conditions would favor relatively abundant herbaceous growth. Stands probably would be somewhat similar to those that dominated many ridges and upper south slopes in presettlement times (on average, more open than on other sites because of more xeric conditions and more frequent fires). The heavy thinning will promote faster growth of trees into large size classes less susceptible to fire damage. Further details of this approach are provided in volume II, chapter 56.

DFPZs should offer multiple benefits by providing not only local protection to treated areas (as with any fuel-management treatment) but also (1) safe zones within which firefighters have improved odds of stopping a fire, (2) interruption of the continuity of hazardous fuels across a landscape, and (3) various benefits not related to fire, including, for example, improved forest health, greater landscape diversity, and increased availability of relatively open forest habitats dominated by large trees.

DFPZs are an initial, not an exclusive, focus for fuel-man-

A defensible fuel profile zone would be dominated by relatively large trees but would encompass considerable diversity in ages, sizes, and distributions of trees. The key feature would be the general openness and discontinuity of crown fuels, both horizontally and vertically. (Photo by Douglas Leisz.)

agement activities. The DFPZs are not a final solution. Rather, they should be viewed as an initial step in bringing large portions of landscapes into more defensible and fire-resilient condition. As the hazard level of various landscapes is brought down, the DFPZs will tend to blend into the surrounding landscapes. It must be recognized that desirable fuels conditions, once achieved, will require periodic maintenance or conditions will revert to hazardous states.

How will society pay for all the fuels management that will be necessary, given the huge areas that need to be treated? Given historical levels of funding and the current direction of federal budgets, it seems highly unlikely that federally appropriated funds will make more than a dent in the problem. Most of the limited appropriated funds are probably best spent to support prescribed burning in natural fuels where there is a special emphasis on reestablishing natural processes (goal 2). Existing cooperatively funded programs of the Forest Service and the California Department of Forestry and Fire Protection might be restructured to assist in funding some of the private landowner share. Significant progress on large-scale fuels treatments will have to be an economically self-sustaining enterprise, supported largely from the sale of forest products. Part of this can come from multiproduct sales, in which sawtimber and other high-value products subsidize the removal of lower-value material. Local property owners and communities may need to provide most of the support for treatments in the intermix areas.

In some portions of the Sierra Nevada, especially higher-elevation areas, including substantial acreage of red fir and other high-elevation vegetation types, large, high-severity fires are not as serious a concern. Thus neither goals 1, 3, and 4 nor DFPZs are particularly applicable. Many such areas are located in national parks and wilderness areas. The proposed strategy in these areas involves extending the use of prescribed natural fire (PNF) as much as possible (including appropriate areas outside parks and wildernesses) and augmenting PNFs with management-ignited prescribed fires (MIPFs) as needed to reestablish near-natural fire regimes. MIPF also should become a key part of the management of other areas in which restoration of natural processes is a major management objective. Recently approved new federal policies will permit wildfires to be "managed" if they meet resource objectives and if fire-hazard conditions elsewhere are not likely to require the deployment of suppression forces from the "managed fire" unit.

Implications

Continuation of current fire-management strategies (i.e., primarily fire suppression with spatially sporadic and limited fuels management) will have important implications in a number of areas. First, there will continue to be periods in many years, especially dry ones, when weather and fuels will combine to produce fire behavior beyond the technological capability of fire-suppression forces to respond effectively. The strategies described here are intended to modify the fuel conditions that support the severe events, thus reducing their magnitude and frequency of occurrence. However, fire suppression has been quite effective in limiting the total area burned in the Sierra Nevada during the twentieth century. Ecological considerations aside, continuing current management strategies might produce similar results, at least in the near term. The primary difference will be in the increasing threat to human lives, forest resources, and property as more people move into the wildland-urban intermix without adequate hazard reduction. This threat could probably be dealt with by treating the wildland-urban intermix areas, instituting economic incentives for stakeholders to take part, and continuing an aggressive suppression strategy.

However, there is strong evidence that fire once was a major ecological process in the Sierra Nevada with profound influences on many, if not most, Sierran ecosystems. The success of fire suppression has altered, and will continue to alter, Sierran ecosystems, with various consequences in regard to ecological function (e.g., nutrient cycling, successional pathways, forest structural development, biodiversity, hydrology). Many of the consequences probably have not yet been described. Regardless of what combinations of strategies are ultimately used, only wide-scale, extensive landscape treatments (e.g., prescribed fire, fuel treatments) can approach the level of influence that fire once had on the Sierran environment.

Ideally, work on all goals should progress concurrently. Where possible, opportunities should be sought that provide the greatest gain toward all goals. Where this is not possible, however, goals 1, 3, and 4 should generally be given higher priority in the short term, to reduce losses of lives, property, and resources and to make it possible to work more effectively toward achieving goal 2, thus improving the overall health and sustainability of Sierra Nevada ecosystems. Stated in another way, protection is a prerequisite to restoration in many areas. Regardless of what strategies and priorities are adopted, it is essential for the wildland fire agencies to continue strong support for suppression and prevention activities.

Fire-related evaluation criteria that can be used to monitor progress toward the goals presented include (1) area and distribution of burned areas by severity classes (e.g., high severity usually detrimental, low severity usually beneficial), (2) area and / or distribution of "desirable" fuel profiles, and (3) number of counties and communities adopting fuel-hazard reduction standards and participating in correcting hazardous fuel conditions in the wildland-urban intermix. The data required to apply these criteria should be part of a comprehensive temporal GIS database that would integrate, at a minimum, vegetation, fuels, fires, ecological and human values, and management activities.