SECTION VI

Building Strategies for the Future Sierra Nevada

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C. PHILLIP WEATHERSPOON
Pacific Southwest Research Station
U.S. Forest Service
Redding, California

CARL N. SKINNER
Pacific Southwest Research Station
U.S. Forest Service
Redding, California

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Landscape-Level Strategies for Forest Fuel Management

ABSTRACT

As a result largely of human activities during the past 150 years, fires in Sierra Nevada forests occur less frequently and cover much less area than they did historically but are much more likely to be large and severe when they do occur. High-severity wildfires are considered by many to be the greatest single threat to the integrity and sustainability of Sierra Nevada forests. The continuing accumulation of large quantities of forest biomass that fuel wildfires points to a need to develop landscape-level strategies for managing fuels to reduce the area and average size burned by severe fires. Concurrently, more of the ecosystem functions of natural fire regimes—characterized in most areas by frequent low- to moderate-severity fires—need to be restored to Sierran forests. This chapter reviews past and current approaches to managing fuels on a landscape basis and, based on a synthesis of many of these approaches, proposes an outline for a potential fuel-management strategy for Sierra Nevada forests.

INTRODUCTION

Prior to concentrated Euro-American settlement in the middle to late 1800s, low- and middle-elevation forests in the Sierra Nevada were characterized by relatively frequent low- to moderate-severity fires (Skinner and Chang 1996). These frequent fires performed important ecological functions (Kilgore 1973). As a result largely of human activities during the past 150 years, including but not limited to fire suppression, fires now occur less frequently and cover much less area but are much more likely to be large and severe when they do occur (Husari and McKelvey 1996; McKelvey and Johnston 1992; Skinner and Chang 1996; U.S. Forest Service 1995; Weatherspoon et al. 1992). In aggregate, such high-severity fires are well outside the natural range of variability for these ecosystems and are considered by many to be the greatest single threat to the integrity and sustainability of Sierra Nevada forests. In addition, related human-induced changes in forest structure, composition, and processes (including many of the functions once performed by frequent fires) are in many areas so profound that they jeopardize ecosystem diversity and viability even without reference to severe fire (Skinner and Chang 1996; U.S. Forest Service 1995).

These concerns are prominent among the issues confronting those interested in the well-being of the Sierra Nevada. This chapter addresses potential landscape-level strategies intended to reduce the extent of severe fires in Sierra Nevada forests and to restore more of the ecosystem functions of frequent low- to moderate-severity fires. As a byproduct, these strategies offer tools that could contribute significantly to improving the health, integrity, and sustainability of Sierra Nevada ecosystems.

To keep the scope of the chapter manageable, we focus on the low- to middle-elevation coniferous forests of the Sierra Nevada, on both west and east sides of the crest. Our reasons include the following:

- These forests rank at or near the top among Sierran vegetation zones in terms of overall richness and diversity of resources and values.

- Twentieth-century fire occurrence in these forests has been much greater than in higher-elevation forests (McKelvey and Busse 1996). High-severity wildfires are much less a concern in the higher-elevation forests.

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- Based on records of twentieth-century fire occurrence, the probability of wildfire in low- to middle-elevation coniferous forests is somewhat less than in the lower elevation foothill woodland and chaparral vegetation types (McKelvey and Busse 1996). However, the negative effects of severe wildfire on the dominant vegetation—and by extension on numerous other resources—generally are more profound and more long lasting in the coniferous forests.
- The composition and structure of the dominant vegetation in low- to middle-elevation coniferous forests probably have been affected more adversely by removal of the natural fire regime (and thus potentially could benefit more from its partial restoration) than in higher or lower vegetation types.

We recognize the problems associated with the threat of wildfires to lives and property in the urban-wildland intermix areas in the Sierran foothills. Management of foothill vegetation is mentioned in our discussion of these intermix areas. Many of the same general principles and approaches for fuel-management strategies that we discuss for the coniferous forests apply also to the foothill vegetation types.

A CAUTIONARY TALE OF FOREST BIOMASS

A simplified, qualitative accounting of production and disposition of biomass may help to clarify the problem of fuel accumulation in many Sierra Nevada forests. As indicated earlier, low- and middle-elevation forest types—west-side pine, west-side pine–mixed conifer, and east-side pine—are emphasized. It is appropriate here to consider only aboveground biomass, both for simplicity and relevance to the topic at hand. While we recognize the importance to today's forests of events in the latter half of the nineteenth century (McKelvey and Johnston 1992), we focus here on contrasts between the periods before 1850 and after 1900.

Biomass Production

Sierra Nevada forests produce a great deal of biomass. While considerable variation exists in terms of the site and climatic variables that largely determine net primary productivity, in general terms Sierra Nevada forests are quite productive (Helms and Tappeiner 1996). For the forest types indicated earlier, the west-side types are substantially more productive than east-side pine. The average rate of biomass production during most of the twentieth century probably has exceeded that which occurred from, say, 1650 to 1850 because this century generally has been warmer and wetter than the earlier period (Graumlich 1993). More complete site occupancy, in the form of denser forests in many areas (Gruell 1994), also may have contributed to greater production now than then. Allocation of total biomass production apparently has differed considerably between the two periods. A much greater percentage of biomass historically was stored in the boles of large trees and in herbaceous vegetation in relatively open stands, whereas now much more goes into small trees in dense stands.

Biomass Disposition

The main factors accounting for disposition or removal of forest biomass are decomposition (oxidation), fire (oxidation), and herbivores and humans (utilization).

Decomposition

In California's Mediterranean climate, decomposition rates generally are low, limited by low temperatures in the winter and inadequate moisture in the summer. In some portions of the Sierra Nevada mixed conifer forest type, however, sufficient moisture may be retained well into the summer to support fairly high rates of decay (Harmon et al. 1987). Decomposition rates in Sierra Nevada forests probably have been greater during this century than during the period 1650–1850 because (1) this century has been warmer and wetter (Graumlich 1993), (2) the generally denser stands during this century have provided more mesic microclimates that favor decomposition, and (3) more forest floor biomass has been available for decomposition because it has not been removed regularly by fire during the twentieth century. Neither historically nor now, however, has decomposition been the primary remover of biomass in Sierra Nevada forests.

Presettlement Fire

In presettlement forests most biomass ultimately was oxidized by frequent low- to moderate-severity fires. High-severity fires more than a few acres in size were unusual (Kilgore 1973; Skinner and Chang 1996; Weatherspoon et al. 1992). Across much of the landscape, dead biomass on the forest floor was kept at low levels, and most small understory trees were killed and subsequently consumed by fire. While small areas of high-severity fire killed patches of large trees (Stephenson et al. 1991), most large trees survived the fires and were consumed at some point after their death by subsequent fires. The longevity of large snags and downed logs under presettlement fire regimes is a subject of debate. It seems likely, however, that relatively few downed logs reached advanced stages of decay on xeric sites before being consumed by fire, whereas a greater proportion could last for longer periods (and also decay faster) on more mesic sites. Physical removal from the site was a minor component of total biomass disposition, although harvest of biomass by Native Americans, especially for firewood, may have been a significant factor locally (Anderson and Moratto 1996).

Twentieth-Century Fire

If we skip now to the twentieth century, the relative roles of fire and biomass removal have changed drastically. As fire suppression was initiated and took effect early in the century, the proportion of biomass consumed by fire dropped precipitously, as did annual burned area. During the course of the twentieth century, however, annual burned area for the Sierra Nevada has shown no overall time trend, even though it has fluctuated considerably from year to year. Large fires have composed an increasing proportion of that burned area as the century has progressed (McKelvey and Busse 1996). In recent years, large fires have become less controllable and more severe, evidently reflecting in part increased fuel loadings.

Another possible indicator of changing fuel conditions is a shift in the distribution of fires between human and lightning ignitions over the course of the twentieth century. We observed this shift as part of an evaluation of twentieth-century fire records for Sierran national forests. We used records for fires greater than 40 ha (100 acres) within the twenty-four core SNEP river basins. Because of the extraordinary extent of the 1987 and 1990 lightning fires, we present the summaries for two intervals of time so as to exclude and include these two years: 1910 through 1986 (table 56.1) and 1910 through 1993 (table 56.2). We arbitrarily split each interval into two time periods for these summaries.

These summaries suggest some conspicuous differences between human-caused fires and lightning fires. Whether the extraordinary years of 1987 and 1990 occurred simply by chance we cannot say based on these limited data. However, whereas the fire-suppression organization does appear to have reduced total area burned by, and number of, large human-caused fires, it has not been effective in reducing either the area burned by or the number of large lightning fires.

In table 56.3 we summarize fire characteristics for each of the three years of greatest burned area for each time period. All six of these years were quite dry. The summaries show that total area burned was similar in these years. However, lightning fires contributed only small proportions of total area burned for the first four years but very large proportions for the last two years—1987 and 1990. It is interesting to note that the total number of fires also differs considerably between the earlier years and 1987 and 1990. Those two years had fewer and much larger fires contributing most of the area burned.

The pattern of fire starts and the necessary response of the fire-suppression organization differ considerably between the two types of ignition. Human-caused fires generally occur as a singular event or occasionally a few simultaneous events. This allows the fire-suppression organization to respond to individual fires with a relatively large body of fire-suppression resources. Lightning fires, in contrast, usually occur as simultaneous multiple ignitions. In unusually dry years, resource requirements necessary to deal with simultaneous

TABLE 56.1

Summary of fire characteristics for 1910–47 compared with 1948–86.

	Total Annual Burned Area (ha)		Maximum Annual Fire Size (ha)		Total Annual Number of Fires	
Years	**1910–47**	**1948–86**	**1910–47**	**1948–86**	**1910–47**	**1948–86**
All Fires Greater than 40 ha						
Minimum	882	125	283	66	5	2
1st quartile	3,990	1,257	1,260	559	12	6
Median	14,483	4,295	3,324	2,026	19	9
3rd quartile	21,285	11,443	8,421	6,599	35	14
Maximum	95,126	43,330	21,234	18,100	82	23
Total for entire period	685,880	319,806			983	395
Human-Caused Fires Greater than 40 ha						
Minimum	882	125	283	66	5	2
1st quartile	3,732	1,182	1,022	553	11	5
Median	14,202	3,781	3,324	1,333	17	8
3rd quartile	20,708	8,690	8,421	6,599	33	11
Maximum	93,588	39,402	21,234	18,100	65	20
Total for entire period	651,801	273,526			890	318
Lightning-Caused Fires Greater than 40 ha						
Minimum	0	0	0	0	0	0
1st quartile	12	21	12	21	0	1
Median	324	217	175	197	2	1
3rd quartile	901	1,233	550	708	3	4
Maximum	9,738	7,356	5,748	7,238	18	6
Total for entire period	34,079	46,280			93	77

TABLE 56.2

Summary of fire characteristics for 1910–51 compared with 1952–93.

	Total Annual Burned Area (ha)		Maximum Annual Fire Size (ha)		Total Annual Number of Fires	
Years	**1910–51**	**1952–93**	**1910–51**	**1952–93**	**1910–51**	**1952–93**
All Fires Greater than 40 ha						
Minimum	828	44	283	44	5	1
1st quartile	3,990	1,178	1,260	526	12	6
Median	13,856	4,537	3,654	2,107	18	9
3rd quartile	20,110	12,125	8,880	6,144	34	13
Maximum	95,126	81,887	21,234	53,011	82	23
Total for entire period	730,131	454,861			1039	403
Human-Caused Fires Greater than 40 ha						
Minimum	828	0	283	0	5	0
1st quartile	3,732	1,120	1,022	481	11	4
Median	13,585	3,108	3,654	1,099	17	7
3rd quartile	19,585	6,993	8,880	4,434	32	9
Maximum	93,588	39,402	21,234	18,100	65	20
Total for entire period	692,170	267,879			934	306
Lightning-Caused Fires Greater than 40 ha						
Minimum	0	0	0	0	0	0
1st quartile	12	44	12	44	0	1
Median	324	347	175	272	2	1
3rd quartile	902	2,625	550	1,960	3	4
Maximum	9,738	80,704	5,748	53,011	18	13
Total for entire period	37,960	186,982			105	97

multiple ignitions can quickly exceed those available (e.g., 1977, 1987, 1990). Show and Kotok (1923) recognized early, on the basis of the 1917 fire season, that general regional lightning events have the potential to strain the fire-suppression organization severely.

The period of record is insufficient to conclude that there is a definite trend toward larger severe lightning fires or that a threshold has been crossed. However, we suggest that the potential influences of changing fuel mosaics, stand conditions, and landscape patterns on the fire environment logically would begin to show up first in dry years under lightning situations.

Utilization

In contrast to the changed role of fire in removing biomass, utilization of biomass has increased by orders of magnitude over the levels that prevailed before Euro-American settlement. The components of biomass removed by logging have changed dramatically from those that previously were removed by fire. Fire-resistant large trees have been harvested and replaced by much more fire-susceptible small trees. Dead biomass in the form of logging slash and natural (i.e., not produced by management activities) fuels has built up on the forest floor because of lack of fire and inadequate or nonex-

TABLE 56.3

Fire characteristics in the three major fire years (years of greatest burned area) during 1910–51 compared with those during 1952–93.

	1910–51			1952–93		
Year	**1924**	**1926**	**1931**	**1959**	**1987**	**1990**
Fire size (ha)						
1st quartile	95	101	119	155	182	120
Median	305	222	249	673	277	606
3rd quartile	1,307	572	1,095	3,268	785	3,405
Maximum	15,054	10,252	17,715	7,710	53,011	38,624
Total burned area	95,126	57,527	52,540	43,330	81,887	57,099
Lightning percentage[a]	2	17	2	9	99	95
Total number of fires	56	80	40	23	18	11

[a]Percentage of total area burned.

istent fuel treatment. Total decomposition probably has accelerated, but at a rate not nearly sufficient to compensate for the increasing fuel load. Together, surface fuels and dense understories have greatly increased the risk of crown fires (Kilgore and Sando 1975; Parsons and DeBenedetti 1979). Heightened stress from overly dense stands, often dominated by shade-tolerant species no longer kept in check by frequent fires, also has increased mortality from insects (Ferrell 1996), further adding to dead biomass available as fuel.

Fuel Management

As managers began to see the consequences of increased fuel loads, they undertook a variety of fuel-management activities. These activities have included a range of treatments that mimic or facilitate the natural processes of biomass disposition: (1) burning on site (with or without prior piling or rearrangement), (2) accelerating decomposition (and reducing flammability) by rearranging the fuel bed closer to the ground, and (3) physical removal from the site. Adequacy of slash treatment following timber harvest or other vegetation management activity has varied from quite good to nonexistent.

For the Sierra Nevada as a whole, however, vegetation management activities have produced considerably more new fuels than they have eliminated. Furthermore, the increasing problem of live understory fuels has been addressed inadequately in silvicultural or fuel-management activities. Efforts to treat accumulating amounts of natural fuels, often with prescribed fire, also have fallen far behind rates of fuel accretion, due in large part to inadequate funding and various concerns about the use of prescribed fire. Even the active prescribed burning programs in Sierran national parks over the past twenty-five years, utilizing both natural and management ignitions, have restored fire to the forests at rates well below presettlement levels (Botti and Nichols 1995; Husari and McKelvey 1996; Parsons 1995). Consequently, these burns have been unable even to keep up with new biomass accumulation, let alone to consume all the excess biomass generated by decades of fire suppression. The basic problem is the same outside the parks: current quantities of flammable biomass—primarily small trees and surface fuels—in low- to middle-elevation Sierran forests are unprecedented during the past several thousand years and are continuing to accumulate at a much faster rate than they are being removed.

The Fuel Problem and the Need for a Strategy

Given current federal and state budget climates, increasing suppression costs, and attrition of skilled firefighters, reductions in suppression forces seem more likely than substantial increases (Husari and McKelvey 1996; U.S. Department of the Interior and U.S. Department of Agriculture 1995). According to a growing consensus among fire managers, more suppression capability is not the solution anyway. This idea is reinforced, we believe, by the data presented earlier on distributions of lightning and human ignitions. History tells us that periodic dry years are inevitable and that regional-scale lightning events that limit the effectiveness of suppression forces are not unusual.

If more suppression is not the answer, and if flammable biomass continues to accumulate at current rates, and if we do nothing substantive to arrest that accumulation, simple physics and common sense dictate that the area burned by high-severity fires will increase. Losses of life, property, and resources will escalate accordingly. This conclusion is strengthened by the fact that recent "drought" years, during which many large, severe fires burned (McKelvey and Busse 1996), appear to be relatively common when viewed on a time scale of centuries (Graumlich 1993).

Therein lies the rationale for large-scale fuel management. Given the massive scope of the problem and budget constraints, brute force is likely to be neither feasible nor adequate. A carefully considered strategy is required. Treatments need to begin in the most logical, efficient, cost-effective places. Specific components of biomass—mostly small trees and surface fuels—need to be targeted. We must devise ways to pay for the needed treatments. At least on public lands, treatments conducted to reduce the hazard of severe wildfires should be compatible with overall desired conditions for sustainable ecosystems. In general, conditions need to be moved away from dense, small-tree-dominated forests toward more open, large-tree-dominated forests. And the rate of treatment needs to be carefully planned: in the short term, rates of biomass removal may well need to exceed rates of production in order to return these forests to a more sustainable, fire-resilient condition. The remainder of this chapter displays and discusses various considerations for developing such a landscape-level fuel-management strategy.

A REVIEW OF FUEL-MANAGEMENT STRATEGIES

Our use of the term *fuel-management strategies* here refers to methods for prioritizing or locating fuel treatments on a landscape scale in such a way as to increase their overall effectiveness for reducing the extent of severe wildfires. Most past fuel management in the Sierra Nevada has taken place in the national forests. Most of that has not been characterized by strategic planning: management emphasis and funding have directed fuel management primarily toward treatment of activity fuels following timber sales, and sales usually were not located with strategic fuel considerations in mind. In fact, timber sales often were dispersed—thereby reducing overall effectiveness of fuel treatments—intentionally in an attempt to meet various management objectives, such as minimizing cumulative watershed impacts of harvest-related activities. In recent years, however, innovative fire and fuel managers have begun to think much more strategically and to collaborate with foresters and silviculturists to address landscape-level forest health concerns. This change has been stimulated and supported by the general move toward ecosystem management and by new capabilities for spatial, landscape-level planning provided by geographical information system (GIS) technology.

Some of these evolving ideas are included in the following sections, which provide a sampling of various types of fuel-management strategies that have been proposed and, to varying degrees, implemented. Also incorporated here are some of the ideas discussed by a group of experts in a Fuels Management Strategies Workshop sponsored by SNEP in March 1995 (Fleming 1996). Three somewhat distinct but certainly overlapping approaches have been used: (1) identifying fuel-management approaches appropriate within each of several landscape zones defined by general characteristics, uses, or emphases; (2) setting priorities based on various combinations of risk, hazard, values at risk, and suppression capabilities; and (3) employing a fuelbreak-type concept intended to interrupt fuel continuity on a landscape scale and to aid in limiting the size of fires by providing defensible zones for suppression forces. A fourth "approach" that has received explicit emphasis recently, although it is implicit to some degree in the other approaches, is rate or timing of implementation.

Strategies Based on Zones

Arno and Brown (1989) proposed three landscape zones. In Zone I, wilderness and natural areas, the emphasis would be on prescribed natural fire (PNF), augmented by management-ignited prescribed fires (MIPF) as necessary to restore much of the natural role of fire to these ecosystems. In Zone II, the general forest management zone, well-planned and well-implemented fuel management, both in conjunction with and in addition to proper timber harvests, would contribute significantly to good overall management. In Zone III, the residential forest, education of homeowners and local officials about the realities of fire hazards in the wildland-urban interface would go hand in hand with effective, esthetically pleasing manipulation of fuels. The authors suggested that shaded fuelbreaks around homes and developments could be an effective measure. They recommended concentrating most efforts in Zone III and adjacent portions of Zone II.

A somewhat different zone approach provides the basis for fire-management direction in Sequoia–Kings Canyon National Parks (Manley 1995) . Zones are defined by estimated proximity of current conditions to the natural range of variability. In Zone 1, areas essentially unaffected by postsettlement activities (mostly higher elevations), natural processes, including PNF, are permitted to operate with little restriction. In Zone 2, areas significantly modified by postsettlement activities, corrective actions, including conservative use of PNF and MIPF, are required before permitting resumption of all natural processes. In Zone 3, built-up areas with highly flammable fuel types near park boundaries, full suppression is combined with mechanical fuel treatments and conservative use of MIPF.

Greenwood (1995) described a land classification system based on structure density (presumably closely related to population density) plus appropriate fire-related buffers. While his analysis was done for the entire state of California, the subset of Sierra Nevada data could easily be analyzed separately, and most of his general conclusions probably would still apply. He labeled the classes wildland, intermix, and developed, corresponding to increasing structure densities, and noted the surprisingly high percentage of land in the intermix category, even on public lands. He emphasized that the presence of people and their structures constrains many of the options available for both fuel management and fire suppression. Approaches suggested ranged from reestablishment of presettlement conditions and processes in some wildland areas to reliance on fire-safe regulations, public education, aggressive initial attack, and only minimal vegetation manipulation in more densely settled developed areas.

Strategies Based on Risk, Hazard, Values at Risk, and Suppression Capabilities

To provide a common frame of understanding for the discussion that follows, definitions of "risk," "hazard," and "values at risk" (McPherson et al. 1990) are given here.

> FIRE RISK: (1) The chance of fire starting, as affected by the nature and incidence of causative agents . . . (2) Any causative agent. (P. 45)
>
> FIRE HAZARD: A fuel complex, defined by volume, type, condition, arrangement, and location, that determines the degree of ease of ignition and of resistance to control. (P. 42) "Resistance to control" is related both to fire behavior and resistance to line construction.
>
> VALUES-AT-RISK: Any or all natural resources, improvements, or other values which may be jeopardized if a fire occurs. (P. 131)

A number of authors have reported the use of decision analysis to aid in fuel-management decision making (Anderson et al. 1991; Cohan et al. 1983; Radloff and Yancik 1983). Decision analysis became the cornerstone of the National Activity Fuel Appraisal Process (Hirsch et al. 1981; Radloff et al. 1982), which was intended to provide a consistent means of evaluating the important factors affecting fuel-treatment decisions. The Fuel Appraisal Process provided probabilities of various-sized fires by intensity class, based on information about topography, historical weather, historical fire occurrence (risk), suppression capability, and hazard (measured or projected based on alternative fuel treatments).

Biehl (1995) described an "all risk management" strategy in use on the Stanislaus National Forest. Fuel profiles, expected ignitions, and suppression resources are used in conjunction with management-defined acceptable resource loss to determine whether, where, and what kind of fuel treatment is needed. The Stanislaus National Forest is combining the most active prescribed burning program of all California national forests—concentrated mainly in natural (i.e., nonactivity) fuels—with considerable biomass thinning. Fuelbreaks are employed, but only as anchor lines to facilitate initiation of areawide fuel treatments using prescribed fire.

Perkins (1995) has devised a similar fire-analysis system for use on the Klamath National Forest as part of the forest's landscape-analysis system. Risk, fire behavior potential (based on fuel classification, slope class, and ninetieth-percentile summer wildfire weather conditions), and resource values (based on forest plan direction) are the primary factors used to determine fuel-management treatment priorities. Fuels information is derived from vegetation classification, modified by management history and large-fire history.

James (1994) developed a simple system for estimating a "catastrophic fire vulnerability rating," based on a point total derived from separate qualitative assessments of risk, hazard, value, and suppression capability. The system includes three sets of "fire/fuel treatment standards" corresponding to fire vulnerability ratings of high, moderate, or low. Finally, it provides a straightforward feedback mechanism for adjusting the posttreatment vulnerability rating. All vulnerability factors are weighted equally, but local managers should be able to modify weightings fairly easily to account for their assessment of the relative importance of various factors.

Strategies Based on Fuelbreaks or Similar Landscape-Level Interruptions of Fuel Continuity

> FUELBREAKS: Generally wide (60–1,000 feet) strips of land on which native vegetation has been permanently modified so that fires burning into them can be more readily controlled. (McPherson et al. 1990, 56)

Early Experiences with Fuelbreaks

Green (1977) traced the long history of fuelbreaks and their predecessors, firebreaks (narrower strips usually cleared to mineral soil), in California. Perhaps surprisingly, a recommendation to the State Board of Forestry for blocking out the forest with strips of "waste" land wide enough to prevent fire from crossing was made as early as 1886. The Sierra Nevada was a part of early firebreak history. S. B. Show, District Forester, proposed in 1929 that a firebreak be constructed along the entire length of the western slope of the Sierra Nevada at the interface of the chaparral and the pine forest. Depression-related federal funding, especially for the Civilian Conservation Corps, permitted work to begin in 1933 on what came to be known as the "Ponderosa Way and Trucktrail." The intent of this strip, which when completed was about 1,050 km (650 mi) long and generally 45–60 m (150–200 ft) wide (Green 1977), was to help prevent fires from burning from the chaparral up into the more valuable Sierran timber (Green and Schimke 1971).

The transition from firebreaks to fuelbreaks came about as part of preattack planning in the early 1950s (Green 1977). Most early fuelbreak construction was in southern California chaparral. The Duckwall Conflagration Control Project on the Stanislaus National Forest, initiated in 1962, extended the fuelbreak concept into the Sierra Nevada mixed conifer forest type (Green and Schimke 1971). Green and Schimke (1971), Pierovich and colleagues (1975), and Green (1977) provided a number of guidelines for planning, constructing, and maintaining fuelbreak systems. Among their recommendations: The number and location of fuelbreaks, along with the size of blocks to be separated by the fuelbreak network (1,000 ha [2,500 ac] for the Duckwall program), should be determined by fire-control objectives as part of the preattack planning process. Needs for protecting populated areas or high resource values should be given high priority in fuelbreak location. Planned management projects—in range, wildlife, recreation, timber, watershed, and forest roads and trails—should be reviewed to see how they might contribute to the fuelbreak network. Ridges usually are preferred for locating fuelbreaks, although other locations can be used. Locating fuelbreaks along existing roads where possible was recommended to facilitate access by suppression forces. Suggested fuelbreak widths varied from about 60 to 120 m (200 to 400 ft). The necessity of maintaining reduced-fuel conditions on fuelbreaks, through a combination of appropriate vegetation (e.g., low volume and/or low flammability) and periodic treatments, was emphasized.

A number of anecdotal accounts of the effectiveness of fuelbreaks (or lack thereof) during wildfire incidents, mostly during the 1960s and early 1970s, were summarized by Pierovich and colleagues (1975) and Green (1977). Although experiences were mixed, fuelbreaks were found to be effective much of the time in stopping wildfires except under the most extreme conditions. Success was most likely when fuelbreaks were properly installed, properly maintained, and adequately staffed by suppression forces during wildfires.

The same authors (Pierovich et al. 1975; Green 1977) discussed existing economic analyses of fuelbreak effectiveness, which differed in their conclusions but for the most part found that a fuelbreak system could be justified economically as part of a well-integrated fire-management system. A subsequent study of fuelbreak investments in southern California, using a linear programming model, predicted that increasing fuelbreak widths could substantially reduce area burned and fire-related damages if initial investments were concentrated in a specific "damage-potential zone" (Omi 1979). Although potential corollary—i.e., nonfire—benefits of fuelbreaks have been recognized (Green 1977), such benefits generally have not been considered in evaluations of their efficacy or cost effectiveness. In a study of three forested fuelbreaks in the central Sierra Nevada, however, Grah and Long (1971) found that fuelbreak construction increased timber values within the fuelbreaks by reallocating site resources to larger, faster growing, and more valuable trees. A portion of fuelbreak costs, therefore, was offset by the benefit to the timber resource.

Recent Experiences and Recommendations for Using Fuelbreaks

Fuelbreak construction and maintenance have retained some emphasis in southern California. Salazar and Gonzalez-Caban (1987) found that in a large 1985 wildfire in chaparral on steep terrain, the fuelbreak system apparently influenced the location of the final fire perimeter. Except during the most extreme burning conditions, fuelbreaks functioned as intended.

In contrast, most forested areas in the state have seen little attention given to fuelbreaks over the past twenty years. Fuel management in Sierra Nevada national forests has been dominated by support of the timber management program during most of that period. Budgets for other fuel activities have been quite limited. Furthermore, many fire and fuel specialists have viewed fuelbreaks as being of little value for a variety of reasons, including the following: (1) to be effective for stopping fires, fuelbreaks need to be staffed by suppression forces, which often have been unavailable when needed, frequently because of demands for protecting structures in urban-wildland intermix areas; (2) in general, recommended fuelbreak widths of 60–120 m (200–400 ft) (Green and Schimke 1971; Green 1977) have been considered too narrow to be effective under many conditions, especially with extensive spotting (ignition of new fires outside the perimeter of the main fire by windborne sparks or embers); (3) fuelbreaks often have been viewed as standalone measures that competed with more effective areawide fuel treatments; and (4) fire control has been viewed as the sole beneficiary of fuelbreaks, with little thought given to other potential resource benefits.

Over the past ten years or so, a number of large, severe fires in California and elsewhere in the western United States have emphasized the seriousness and the enormity of the wildland fuel problem. Fuelbreaks have begun to receive renewed attention as one part of the solution. Arno and Brown (1989) suggested their use around homes and developments in the wildland-urban interface. In the recovery plan for the northern spotted owl, Agee and Edmonds (1992) recommended the use of fuelbreaks along with underburning to reduce the probability of catastrophic wildfires in “designated conservation areas” within the Klamath and East Cascades subregions. Weatherspoon and colleagues (1992) suggested a two-stage fuelbreak strategy to help reduce the occurrence of severe fires in California spotted owl habitat in Sierra Nevada mixed conifer forests. Known owl sites first would be “isolated” using a broad band of prescribed burns, followed by a more general program of breaking up fuel continuity on a landscape scale. Fites (1995) proposed a similar approach to help protect “areas of late-successional forest emphasis” and to restore more sustainable, fire-resilient conditions across the landscape. Arno and Ottmar (1994, 19) pointed out the need for “an interconnected network of natural fire barriers and treated stands as zones of opportunity for controlling wildfires.”

In the draft Environmental Impact Statement (EIS) for managing California spotted owl habitat in Sierra Nevada national forests (U.S. Forest Service 1995), Alternatives C and D included an upper slope/ridge zone that would be dominated by large, widely spaced shade-intolerant trees. These alternatives were viewed as creating conditions in this zone closer to those thought to have existed before Euro-American settlement. In addition, the zone would provide many of the fire-management benefits of a wide shaded fuelbreak. Alternative F incorporated some of the fuelbreak-related concepts of the Quincy Library Group (QLG) proposal (summarized later) for the northern Sierra Nevada.

LaBoa and Hermit (1995) presented a number of ideas for strategic fuel planning and treatment, based on their recent work as members of the California spotted owl EIS Team (sufficiently recent that these ideas were not included in the draft EIS). They included the use of fuelbreaks; however, they stressed the need not to stop with a fuelbreak network but to build from it to accomplish large-scale fuel modification on a landscape level.

The most detailed fuel-management strategies to date have been proposed for the northern end of the Sierra Nevada—the Lassen and Plumas National Forests and the Sierraville Ranger District of the Tahoe National Forest. The two strategies, which were developed semi-independently by the QLG and the U.S. Forest Service, have much in common and build on many of the ideas cited earlier. Rapid implementation of a network of broad fuelbreaks is key to both proposals.

QLG is a community-based group whose members represent a wide range of interests, including fisheries and environmental groups, timber industry, and county government. The group has made strategic fuel management a central focus of its land management proposal (Quincy Library Group 1994). QLG proposes that an intensive four-year effort be focused on installing a network of strips approximately 0.4 km (0.25 mi) in width, mostly along existing roads, that break up fuel continuity across the landscape and provide defensible zones for suppression forces. During this period, essentially all forest management activities, including biomass and other thinnings, salvage activities, and treatment of surface fuels, would be focused on implementing this fuelbreak network. Each year 1/32 of the total forest acreage would be treated, so that at the end of the four-year period 1/8 of the forest would be a part of these strips. The strips would have reductions in stand density, lower canopy ladder fuels, and surface fuels, and they would have relatively low levels of snags and large downed woody debris. After the initial period, a longer term fuel-management strategy would add some strips to isolate areas of high value and/or high risk, but the emphasis generally would shift to areawide treatments.

The Technical Fuels Report, prepared by fire/fuel specialists from the Lassen, Plumas, and Tahoe National Forests (Olson et al. 1995), is similar in several respects to the QLG proposal. The "defensible fuel profile zone" (DFPZ), a concept first described by Olson (1993), is central to the strategy outlined in the report. Much like a broad fuelbreak, a DFPZ is a low-density, low-fuel zone averaging 0.4 km (0.25 mi) in width, located mostly along roads, and designed to support suppression activities. Like the strips in the QLG proposal, DFPZs are intended to be installed over a period of just a few years. The authors point out that DFPZs are intended not to take the place of widespread fuel treatment but rather to increase the effectiveness of initial fuel treatment and to facilitate subsequent treatment of adjacent areas. Olson et al. (1995) describe the "community defense zone" (CDZ) as another component of their strategy concerned with urban interface areas within or near national forest boundaries. Similar in concept to a DFPZ, a CDZ is designed to reduce the threat of wildfire spreading onto national forest land from private land, or vice versa. Like DFPZs, CDZs would have a high priority for completion within a short period of time. The authors stress the importance of the involvement and cooperation of local communities in implementation of CDZs. A third type of zone, the "fuel reduction zone" (FRZ), refers to general area fuel treatment that would take place mainly after the high-priority system of DFPZs and CDZs is in place. The Technical Fuels Report (Olson et al. 1995) emphasizes the importance of site-specific considerations and local decision making in setting priorities and implementing the details of the broad fuel-management strategy outlined.

A POTENTIAL FUEL-MANAGEMENT STRATEGY FOR SIERRA NEVADA FORESTS

The approaches summarized in the previous section, along with the discussion at the SNEP Fuels Strategies Workshop (Fleming 1996), seem to point to some degree of convergence of thinking about the fuel problem and some components of a strategy to deal with it. In this section we attempt to synthesize many of the previously mentioned approaches into an outline for a potential fuel-management strategy for Sierra Nevada forests.

The ideas presented here are necessarily general in nature. The Sierra Nevada is enormously complex and diverse. Landowners and ownership objectives vary widely. While agencies and large landowners may choose to set some priorities on a regional or subregional scale, any attempt on our part to recommend or prescribe specific management practices rangewide would be naive, counterproductive, and contrary to the SNEP charter. Readers should view this "strategy" as a set of principles and ideas to consider as they develop their own landscape-specific strategic plans. (Additional ideas can be found in cited references.) Such plans will be greatly facilitated and improved by developing and maintaining good GIS databases. Later in this chapter we discuss the nature and role of such databases for supporting fire and fuel-management decision making in the context of adaptive ecosystem management (Everett et al. 1994; Walters and Holling 1990).

Although landscape-specific planning is focused on a small portion of the entire Sierra Nevada, it nevertheless requires thinking on a much broader scale than often has occurred in the past. 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. Dealing with fuels on only a local, piecemeal basis will be inadequate.

Goals of the Fuel-Management Strategy

The strategy has three general goals, ranging from short to long term and from relatively narrow to broad. Each goal can be viewed as nesting within the following one. The goals are consistent and complementary, as are the means to work toward their accomplishment. For example, the strategy provides that short-term approaches to reducing hazard be compatible with longer-term goals of ecosystem sustainability (Arno and Ottmar 1994).

The first goal—the immediate need from a fire-management standpoint—is to reduce substantially the area and average size burned by large, severe wildfires in the Sierra Nevada. Ideally this will be a short- to medium-term goal, whose urgency will lessen as the fuel-management strategy becomes increasingly effective. A second, longer-term goal should be to restore more of the ecosystem functions of frequent low- to moderate-severity fire. The two goals are closely linked. They could be met simultaneously by replacing most of the high-severity acreage with the same, or preferably much greater, acreage of low- to moderate-severity fire. A third, overarching goal is to improve the health, integrity, and sustainability of Sierra Nevada ecosystems. This goal certainly goes beyond fire considerations. Progress toward achieving the first two goals, however, is critical to the third.

Management actions to progress toward these three goals should be occurring concurrently. Often it will be possible for a single treatment or project to address all three goals simultaneously. In fact, opportunities for such congruence should be sought. In this chapter, however, we spend the most time addressing the first goal—not because it is most important in the long run but because it is the most urgent in the short run to reduce losses of lives, property, and resources, and to make it possible to work more effectively toward achieving the second and third goals. Stated in another way, the fuel-management strategy has joint themes of protection and restoration of ecosystems, and, in many portions of the Sierra Nevada, protection is a prerequisite to restoration. In a longer term context, strategies geared specifically toward reducing losses from large, severe wildfires should gradually become less important; restoration in turn should provide a more fundamental level of protection along with improved ecosystem health.

Goal 1: Reduce Substantially the Area and Average Size Burned by Large, High-Severity Wildfires

Large, high-severity fires were unusual historically in most Sierra Nevada forests. Fire regimes in the Sierra Nevada generally were characterized by relatively frequent, low- to moderate-severity fires (Skinner and Chang 1996). Changes in low- and middle-elevation forests and their associated fuel complexes, brought about largely by human activities since Euro-American settlement (including but not limited to fire suppression), have made these forests much more prone to large, severe fires (Chang 1996; Husari and McKelvey 1996; McKelvey and Johnston 1992; Skinner and Chang 1996; U.S. Forest Service 1995). Such fires, in aggregate, are well outside the natural range of variability and thus can be considered detrimental to Sierra Nevada ecosystems (Manley et al. 1995). Furthermore, the current prevalence of such fires is unacceptable socially. The rapidly increasing population of the Sierra Nevada increasingly places people's houses at risk of loss to severe wildfires and makes potential solutions to the problem much more difficult.

In pursuing goal 1, it is essential for the wildland fire agencies to continue support for suppression and prevention activities. These fire-management efforts alone, however, cannot resolve the problems of fire in the Sierra Nevada. Aggressive, strategically logical fuel-management programs, compatible with overall desired conditions for sustainable ecosystems, are necessary to address the basic problem of excessive fuel accumulation.

Goal 2: Restore More of the Ecosystem Functions of Frequent Low- to Moderate-Severity Fire

The frequent low- to moderate-severity fires that occurred throughout much of the Sierra Nevada until about 150 years ago performed many important ecological functions (Kilgore 1973; Chang 1996). Wildfires of this type, however, have been virtually eliminated from Sierra Nevada ecosystems (as measured by annual area burned by such fires), because these are the fires that are suppressed most easily. As a result, the ecological functions historically performed by such fires have been largely lost, with some known and many unknown consequences. It is highly unlikely that fires will ever burn as much area as often and with the same distribution of severities as they once did. Nevertheless, it makes sense to try to restore fire to a more nearly natural role in those parts of the landscape where it is practical to do so. Where fire alone cannot be used practically, fire surrogates such as silvicultural techniques and mechanical fuel reduction methods (Helms and Tappeiner 1996; Weatherspoon 1996) can be employed—either by themselves or in conjunction with prescribed fire—as appropriate to mimic some of the functions of fire and to move landscapes toward desired conditions (Manley et al. 1995). Over time, adaptive management (Everett et al. 1994; Walters and Holling 1990) should help us to determine which ecosystem functions of fire can be emulated satisfactorily by surrogates, which may be irreplaceable, and the implications for management.

Goal 3: Improve the Health, Integrity, and Sustainability of Sierra Nevada Ecosystems

The third goal is consistent with the first two and is central to overall SNEP goals. It should be achievable (1) by reducing the incidence of high-severity fires, which are detrimental to ecosystem sustainability in natural fire regimes characteristic of most of the Sierra Nevada; and (2) by moving ecosystems closer to pre-European-settlement conditions and processes, assumed by many to be a useful first approximation of sustainable ecosystems (e.g., Manley et al. 1995; Swanson et al. 1994), at least on public lands. We cannot define those presettlement conditions with any great precision, but we do know enough to be reasonably confident that this strategy would move us in the desired direction.

Components of the Strategy

The strategy we discuss here has three basic components: (1) networks of defensible fuel profile zones (DFPZs) (the term adopted from Olson 1993 and Olson et al. 1995) created and maintained in high-priority locations; (2) enhanced use of fire for restoring natural processes and meeting other ecosystem management goals; and (3) expansion of fuel treatments to other appropriate areas of the landscape, consistent with desired ecosystem conditions. We also discuss possible institutional changes that might increase the effectiveness of the strategy. This strategy builds upon and draws freely from the various strategies cited elsewhere in this chapter.

Defensible Fuel Profile Zones

Given the massive scope of the problem that goal 1 is intended to address, a carefully considered strategy is required for prioritizing fuel treatments. Such a strategy should permit managers to multiply the benefits of treatments in order to make the most rapid and most efficient progress toward achieving goal 1. We focus our discussion in this section on DFPZ networks. Multiple benefits of DFPZs may include (1) reducing severity of wildfires within treated areas (as with any fuel-management treatment), (2) providing broad zones within which firefighters can conduct suppression operations more safely and more efficiently, (3) effectively breaking up the continuity of hazardous fuels across a landscape, (4) providing "anchor" lines to facilitate subsequent areawide fuel treatments, and (5) providing various nonfire benefits. We are aware of no other strategy with as great a potential in the short term to progress reasonably rapidly toward achieving goal 1.

Rationale

The basic purposes of fuelbreaks were summarized earlier. These stated purposes generally do not include some of the potential benefits we envision for DFPZs, however. We offer an expanded rationale here, including the reasons for our choosing not to use the term fuelbreak as part of the strategy we describe.

Fuel-management activities in forested ecosystems normally involve some combination of (1) removing or modifying surface dead fuels to reduce their flammability; (2) removing or modifying live fuels to reduce their horizontal and/or vertical continuity, thereby reducing the probability of crown fire; and (3) felling excess snags that could be safety hazards and sources or receptors of firebrands.

The kind of protection afforded by fuel-management treatments depends not only on the localized nature of the treatments but also on their scale and spatial relationships. If you do a good job of treating fuels on a 1-acre (0.4 ha) patch of forest but do nothing in the surrounding forest, the edge effects probably will overwhelm the treatment in the event of a severe fire, and the small patch will be lost as well as everything around it. (There is a lesson here for group selection cuttings [Helms and Tappeiner 1996; Weatherspoon 1996]: it makes little sense to do fuel treatments in only the small regeneration openings and ignore the rest of the forest [Weatherspoon and Skinner 1995].) If you treat fuels to the same standard in a square 40-acre (16 ha) stand, edge effects are relatively much less important. Fire intensity will be much lower than in the surrounding (untreated) forest, and under most conditions the majority of the stand probably will survive. However, that 40-acre stand probably will have only a limited effect on fire damage in the untreated forest downwind. If you now treat the fuels on n 40-acre stands scattered randomly across the landscape, essentially the same result is expected, times n—i.e., the treated stands probably will not suffer excessive damage from a fire, but their intensity-reducing effect will not extend much beyond the treated areas. This last scenario, incidentally, approximates most of our past fuel treatments, which were not planned with strategic fuel management in mind.

If you take that same total treated acreage (40n) and string it together into a broad zone (DFPZ) that makes sense strategically, you have still protected those treated acres, with even less edge effect. In addition, however, you now have a reasonable chance of putting suppression forces into that zone and stopping the fire, thereby protecting areas on the downwind side of the DFPZ.

The term fuelbreak or shaded fuelbreak has been used to describe some of the same ideas. We do not use either term in describing this strategy, however, because they tend to carry some undesirable connotations:

- A shaded fuelbreak is often envisioned as a strip of land too narrow (60–120 m [200–400 ft] [Green and Schimke 1971; Green 1977]) to be effective for stopping a fire under many conditions. In contrast, 0.4 km (0.25 mi) has been suggested as a nominal width for DFPZs (Olson et al. 1995; Quincy Library Group 1994). Use of the term zone (the Z in DFPZ) suggests a broader treated area than fuelbreak.
- A shaded fuelbreak is usually considered to have a single purpose—a relatively safe, accessible location in which suppression forces can initiate suppression actions. A DFPZ also serves this suppression function, almost certainly more effectively (because of its greater width) than a normal shaded fuelbreak. In addition, however, the DFPZ represents a substantial portion of the landscape—perhaps 10 to 25 percent for a completed network—within which fire damage is likely to be much reduced in the event of a wildfire. Furthermore, a DFPZ network may represent a number of potential additional benefits, including improved forest health, greater landscape diversity, increased availability of open forest habitat, and probably greater proximity to the historic range of variability and desired conditions.
- A shaded fuelbreak is often envisioned as “an alternative”—i.e., a standalone option for dealing with fuels. The DFPZ incorporates the notion that landscape treatment of fuels must start somewhere, so it makes sense to begin in strategically logical locations. The DFPZ is a place to start—a place from which to build out in treating other appropriate parts of the landscape—not an end in itself.

General Location, Description, Creation, and Maintenance

For the most part, DFPZs should be placed primarily on ridges and upper south and west slopes. All else being equal, DFPZs should be located along existing roads to simplify construction and maintenance and to facilitate use by suppression forces. Where roads do not follow ridges, road locations in relatively gentle terrain—e.g., along broad valley bottoms—are usually suitable for DFPZs. Roads that follow side slopes and canyon bottoms in steep terrain should be avoided except where they might facilitate stream crossings by DFPZs.

A network of DFPZs that define discrete blocks of land would require some DFPZ segments to cross drainages. Decisions about how best to deal with stream crossings should be based upon site-specific analyses. In most cases, however, we anticipate that the function of a DFPZ network would not be seriously jeopardized by limiting any treatments within the riparian zone portion of a DFPZ to those treatments (if any) deemed acceptable elsewhere in the riparian zone. Prescribed burning might be particularly appropriate as a treatment. Because of their relatively moist environment, untreated or minimally treated riparian zones normally should not present an undue risk of serving as a “fuse” to spread fire across a DFPZ adequately staffed with suppression forces.

A reasonable nominal width for DFPZs is probably 0.4 km (0.25 mi) (Olson et al. 1995; Quincy Library Group 1994) until experience indicates otherwise. It seems logical, however, to vary the width based on strategic importance, topography, or other conditions. For example, a broad, major ridge with a main road might warrant a considerably wider DFPZ than a spur ridge with steep side slopes. Using the fire-growth model FARSITE to model various fuel-treatment alternatives, van Wagtendonk (1996) found that fires burning under ninety-fifth-percentile weather conditions spotted across 90-m (300 ft) fuelbreaks under most fuel treatment scenarios but did not spot across 390-m (slightly less than 0.25 mile) fuelbreaks under any of the scenarios.

The Quincy Library Group (1994) proposed that DFPZs be used to break up the land into blocks averaging 4,000–5,000 ha (10,000–12,000 ac). We have no reason to argue with that as a first approximation, but the appropriate area certainly will vary among landscapes as a function of topography and the various factors discussed later. In many cases it may be logical to implement an initial high-priority "low-density" DFPZ network—e.g., along major ridges and main roads and in the vicinity of forest communities. Subsequent efforts would be a combination of maintaining existing DFPZs, constructing new ones to break up the landscape into smaller blocks, and broadening existing DFPZs in conjunction with areawide fuel treatments.

Treatment of DFPZs should result in a fairly open stand, 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. Similarly, edges of DFPZs need not be abrupt but can be "feathered" into the adjacent forest. Posttreatment canopy closure usually should be no more than 40%, although adjustments in stand density based on local conditions certainly are appropriate. In some areas, for example, greater canopy closure may be desirable to slow encroachment by highly flammable shrubs or other understory vegetation, so long as tree crowns are high enough that a sustained crown fire in the denser canopy is very unlikely.

Available treatment techniques for DFPZs include silvicultural cutting methods, prescribed fire, mechanical fuel-reduction techniques, and combinations of these. In most cases, cuttings of various kinds will be the most effective initial treatments to accomplish needed adjustments in stand structure and composition (Helms and Tappeiner 1996; Weatherspoon 1996). Thinning from below often will be a desirable technique to move DFPZs from overly dense, small-tree-dominated stands toward more open, large-tree-dominated stands. Prescribed fire frequently will be the treatment of choice following a cutting. In some areas, prescribed fire alone may be the preferred approach because existing stand conditions are near desired conditions or because cuttings are precluded or otherwise inappropriate. Generally, however, prescribed fire is not likely to be a suitable standalone technique for bringing about major changes in stand structure on the large scale necessary for timely implementation of DFPZ networks in Sierra Nevada coniferous forests. Factors that argue against massive and rapid increases in standalone prescribed burning include lack of adequate funding (initial burns in unthinned stands may be quite expensive), air-quality restrictions, competition for trained personnel during active wildfire seasons, and risk of escapes. Moreover, needed reductions in stand density using fire alone could require a number of successive burns spanning several decades. Failure to utilize biomass in the process would generate large quantities of smoke from consumption of excess biomass and would forgo opportunities to generate income to finance treatments. Opportunities for economic and social benefits would be forfeited as well. Furthermore, effects of initial burns probably would not closely approximate "natural" fire effects because of fuel complexes that differ greatly from those of the presettlement era (Skinner and Chang 1996; Weatherspoon 1996).

To ensure effectiveness of a DFPZ, basic adjustments in stand structure must be followed by reduction in surface fuels to a low-hazard condition using prescribed fire or mechanical methods, or both. In some cases, adequate mechanical "treatment" may result from crushing of fuels during harvest operations, especially where whole trees are removed from the stand. Prescribed fire was the best choice among van Wagtendonk's (1996) modeled scenarios from the standpoint of reducing surface fuels, and it also can raise the bases of live crowns (by killing lower branches) to increase vertical discontinuity of live fuels. Where feasible economically, removal and utilization of cut trees are preferable to treating them in place as fuels. Densities of snags and downed logs should be kept relatively low and compensated as appropriate by higher densities outside DFPZs.

From a fire standpoint, ridges and upper southerly slopes generally should benefit more than average from thinning and hazard reduction: they tend to dry out faster and without treatment would support severe fires a higher proportion of the time than other aspects and slope positions. The heavy thinning also would promote faster growth of trees into large size classes less susceptible to fire damage. Their low-fuel character, low density of snags, and resistance to sustained crown fires should make DFPZs substantially safer for suppression personnel than most other locations. Furthermore, the efficiency and productivity of suppression forces in building and holding firelines and in backfire operations should be significantly enhanced in DFPZs, especially in those containing roads. Aerial retardant drops should be considerably more effective in DFPZs as well because of the open canopy and relative ease of getting retardant to the forest floor.

To retain their effectiveness, DFPZs should be maintained in low-fuel conditions with periodic retreatments, targeting especially accumulated surface fuels and new growth of understory vegetation. Retreatment with prescribed burns should be relatively easy and inexpensive in the open environment of DFPZs. (It should be noted in this regard that

DFPZs are not unique in their need for maintenance. Fuel treatments anywhere require maintenance to retain their effectiveness. A DFPZ should cost less to maintain than an equal area of comparable fuel treatment elsewhere, however, because of its contiguity and relative accessibility.) Burns may be required about once every ten years or more often depending on rate of encroachment by shrubs and other understory fuels. DFPZ retreatment may be combined with broadened area treatment, using the DFPZ as an "anchor line." Appropriate vegetative ground covers, including perennial grasses and low-volume shrubs (e.g., bear clover), can reduce maintenance needs (Green 1977).

As main canopy trees grow and increase in crown area, they will need to be thinned periodically to maintain desired crown spacing. A few may be left to become snags, but snag density generally should be lower than elsewhere in the forest. In addition, long-term maintenance of a large-tree-dominated DFPZ will require periodic regeneration of portions of the zone. Long-rotation, low-density versions of group selection (Weatherspoon 1996) might be the best silvicultural method for this purpose, because it provides for regeneration of shade-intolerant (generally fire-tolerant) species and permits the maintenance of single canopy layers in any given location, thereby discouraging crown fires. With long rotations, a DFPZ could have sustainable age-class structures and still be occupied mostly by fire-resistant large trees.

Potential Nonfire Benefits

A range of benefits not directly related to fire would be expected to accrue from having more open stand conditions along ridges and upper southerly slopes. In general, such open conditions probably would be somewhat similar to those that dominated the same topographic positions in presettlement forests (Skinner and Chang 1996)—on average more open than other sites because of more xeric conditions and more frequent fires. A probable reduction in total evapotranspiration could lead to increased water yield from these sites. Probability of adverse watershed effects from harvesting and other management activities should be reduced because of greater-than-average distances from streams (Kattelmann 1996). These areas should contribute to overall habitat diversity and esthetic variety in landscapes that currently tend to be deficient in open, large-tree-dominated structures (Graber 1996; U.S. Forest Service 1995). Forage conditions should be improved in more open forest areas, especially with prescribed fire (Menke et al. 1996), and conceivably could help to reduce livestock grazing pressure in riparian areas. From a timber standpoint, total production of woody biomass might be reduced but would be concentrated in larger, more valuable trees (e.g., Grah and Long 1971). Lower stand density should reduce stress on trees and make them less susceptible to insect attack (Ferrell 1996). It is possible, though unproved, that broad zones of relatively low susceptibility to insects could reduce "contagion" effects of insect activity, thus perhaps slowing movement of outbreaks (Mason and Wickman 1994). If found to be true, this idea would provide an interesting parallel to the effect of a low-hazard DFPZ on fire movement.

The concept that DFPZs may have multiple nonfire benefits emphasizes the point that strategic fuel management is an integral component of overall ecosystem management. It also argues for focusing a large proportion of overall management efforts in the short term on planning and implementing a sound DFPZ network.

Factors to Be Considered in Prioritizing DFPZ Locations

In the next sections we present a number of factors that should be considered in designing a DFPZ network. We do not attempt to set priorities among these factors—to presume, for example, that values should be weighted more heavily than historical fire occurrence or that one value is more important than another value. Such prioritization is best left to local managers using local fire planning and other information.

"Biggest Bang for the Buck." This concept says, in essence, "All else being equal, do the cheapest, easiest areas first."

Some stands already may be in an open, low-fuel condition because of recent management activities. Other areas, such as rocky outcrops and relatively bare ridges, may provide natural barriers to the spread of fire. Where it makes sense strategically to do so, such areas should be incorporated into a DFPZ network.

For areas requiring some degree of treatment to be suitable as a DFPZ, we suggest that those areas sometimes considered "most in need of treatment"—i.e., dense stands and heavy fuels—should not necessarily be given high priority. Their costs per unit area may be quite high. This subject can, and should, be debated. Our feeling, however, is that from a strategic standpoint, it seems advisable to treat first those areas that currently would not function effectively as a DFPZ but that could be brought to acceptable standards most quickly and inexpensively. Thus a greater total length of effective DFPZ could become functional for a given cost or in a given period of time. That larger treated area of DFPZ also would be more likely itself to survive in the event of a severe fire.

Some areas may be acceptably open but require surface fuel treatment. Prescribed burning may be the most desirable and cost-effective option. More often, some thinning is likely to be necessary. Except in areas where they are precluded for various reasons, cuttings (preferably with utilization of cut trees) generally provide a more efficient route to desired forest structures than prescribed burns. Where thinning is needed, the "biggest bang for the buck" principle may translate to giving priority to multiproduct sales that are economically self-sustaining by removing some sawtimber to pay for the removal of smaller trees.

Other examples of locations or conditions that might be given priority under this principle include (1) accessible areas with relatively gentle terrain and (2) areas with a significant component of relatively large pine or Douglas fir trees.

An additional benefit of the "biggest bang for the buck" principle may be in more quickly developing demonstration areas or other examples of successful implementation of DFPZs. Such areas may be valuable for building and sustaining trust and support for strategic fuel management.

Historical Fire Occurrence and Risk. A major consideration in locating DFPZs on the landscape should be the broad zones within the Sierra Nevada that have experienced the highest occurrence of large fires during this century—reflecting a combination of relatively high risk and high hazard. McKelvey and Busse (1996) found a strong elevational trend in the occurrence of twentieth-century fires in Sierran national forests. The frequency (percentage of area burned at least once) of large fires was highest below 1,000 m (3,300 ft) elevation and dropped fairly rapidly at higher elevations. This elevation zone corresponds generally with the foothill vegetation types and lower coniferous forests. It is consistent with observations by others that the highest twentieth-century fire occurrence in Sierra Nevada forests has been in the west-side pine and pine–mixed conifer types and in the east-side pine type (LaBoa and Hermit 1995; U.S. Forest Service 1995; Weatherspoon et al. 1992).

This information suggests a fairly simple guideline for accounting for historical fire occurrence: all else being equal, and in the absence of more site-specific fire-occurrence information, begin establishing a DFPZ network at the lowest elevations of ponderosa or Jeffrey pine forests and work upward into the mixed conifer type. In the general forest zone—i.e., away from settlements or other high-value areas—true fir and other upper montane types probably have low priority for a DFPZ network from the standpoint of wildfire control. Certainly other management objectives, however, may call for zones of more open forest conditions than those common in most locations today.

Where managers have good "landscape-specific" data on fire-occurrence, it of course should be weighed more heavily than regionwide trends. Local fire data also may indicate the direction of prevailing winds that accompany extreme weather events and/or large fires; this information should be used in planning DFPZ locations. Current and projected information on risk—i.e., ignition sources—should be considered as well. For example, DFPZs should have a role in isolating heavily traveled transportation corridors and other areas where ignitions historically have been high. This certainly applies to urban-wildland intermix areas, which are discussed next.

Urban-Wildland Intermix Areas. DFPZs have a potential benefit as protective buffers around high-value locations. Urban-wildland intermix areas are prominent in this regard. A protective buffer should help reduce the incidence of fires moving from wildlands into these high-value areas and (from the risk standpoint) also reduce the movement into wildland areas of fires initiating in intermix areas. These reasons, along with the fact that most populated areas in the Sierra Nevada lie within the elevation zone most frequently burned during the twentieth century (Greenwood 1995; McKelvey and Busse 1996), give a high overall priority to strategic fuel management in urban-wildland intermix areas.

As compared with DFPZs elsewhere, in forested intermix areas it may be desirable to focus more on nonfire silvicultural treatment methods in order to minimize concerns about smoke and potential escapes. In woodland and chaparral vegetation types, however, prescribed burning may be the most practical treatment approach except for limited areas of mechanical treatment. Opportunities may exist for the California Department of Forestry and Fire Protection's Vegetation Management Program (Husari and McKelvey 1996) to develop DFPZs near urban-wildland intermix areas in conjunction with some of its prescribed burning in foothill vegetation types.

The need to deal with fire and fuel issues in intermix areas is confounded by the considerable complexity of those issues. The physical problems associated with the juxtaposition of people, personal property, and wildlands are compounded by an array of problems linked to political and institutional conditions, multiple and diverse ownerships, and a wide range in understanding and attitude.

Any overall fuel strategy for urban-wildland intermix areas must begin with the use of appropriate fire-safe practices by individual property owners. Prominent among those practices are adequate clearance between structures and flammable vegetation and the use of fire-resistant roofing and other fire-safe construction practices (Davis 1990). Part of the process of achieving better compliance with fire-safe regulations is simply education of property owners—necessarily an ongoing task. Another part may involve stronger incentives, including significant fines for noncompliance, revision of insurance premiums and insurability requirements (Davis 1990), and possibly increased tax rates, to reflect more accurately the risk of fire loss in wildland settings as modified by personal fire-safe practices.

Cooperative efforts to reduce hazard within and around communities represent another critical component of fuel management in intermix areas. Partnerships that include local governments, local landowners, community groups, bioregional councils, and, as appropriate, state and federal agencies could be effective. Fostering such cooperative efforts is a high priority for the recently formed California Fire Strategies Committee. Sponsored by the California Resources Agency, the committee consists of representatives of a wide array of government and private entities with a common interest in dealing effectively with California's wildfire problems. Members have adopted an ambitious set of action items in support of the committee's mission "to reduce the risk of catastrophic fire for the protection of Californians and the natural environment."

Fuel-management activities in urban-wildland intermix areas should be coordinated with similar activities on nearby national forest or other public land and with activities of large private landowners. In a recent strategic assessment of fire management in the U.S. Forest Service, Bacon and colleagues (1995) proposed that priority for hazard mitigation on national forests in intermix areas be placed on areas where adjacent landowners agree to participate with the U.S. Forest Service in fuel management and other fire-safety projects. While designing and implementing an effective DFPZ network in and around complex intermix areas often will not be easy, it will be greatly facilitated by effective cross-ownership cooperative efforts.

Concerns about intermix areas do not stop with current conditions. Population in Sierran foothill areas is projected to continue rapid growth (Duane 1996). An important potential set of solutions related to fire issues rests with state and local officials, including legislators and county planning and zoning commissioners, who should implement appropriate limitations and disincentives for new construction in high-fire-hazard areas.

Fire-related connections between urbanized areas and nearby wildlands go beyond the potential spread of fire from one area to the other. Increasingly in recent years, federal wildland fire-control agencies have been put into the position of having to assume responsibility for structure protection during major wildfires (Bacon et al. 1995; Husari and McKelvey 1996). This imposes costs on other landowners and the general public in two ways: (1) Taxpayers at large pay for these fire-protection services, and (2) losses to natural resources on public lands increase when these forces are diverted to structure protection (Davis 1990). Bacon and colleagues (1995, 4) proposed a redefinition of responsibilities: "(1) fire protection on State and private lands is the responsibility of State and local governments, (2) homeowners have a personal responsibility to practice fire safety, (3) the role of the Forest Service is stewardship of adjacent National Forests, cooperative assistance to State and local fire organizations, and cooperative suppression during fire emergencies." They suggested two general approaches for the U.S. Forest Service in response to these responsibilities: (1) The U.S. Forest Service would phase out of responsibility for direct initial attack in urbanized areas. Existing protection agreements would be renegotiated to reflect this change. Cooperative fire-protection programs would be expanded to facilitate state efforts to take on the additional work. (2) Protection priorities would be changed from the present order of life first, property second, and resources third, to life first, followed by property and resources valued on a par. These recommendations are consistent with policy changes for federal agencies proposed in the Federal Wildland Fire Management Policy and Program Review (U.S. Department of the Interior and U.S. Department of Agriculture 1995). Bacon and colleagues (1995) also recommended that opportunities be sought for land exchanges that would improve the ability to manage fire in urban-wildland intermix areas.

Other High-Value Areas. A number of other kinds of high-value areas may warrant buffering with DFPZs—e.g., areas of late-successional emphasis (Franklin et al. 1996), biodiversity management areas (Davis et al. 1996), and plantations (Wilson 1977). Such protection may be particularly useful when fuel reduction within the high-value area itself is undesirable or infeasible because of the nature of the value being emphasized and/or high costs of treatment. It might be desirable to treat a high-value area with prescribed fire, for example, but appropriated funds might be inadequate, especially since initial reintroduction of fire without mechanical pretreatment can be rather expensive in some places. In contrast, a DFPZ outside the high-value area could be self-financing through removal of a product. It also could aid in the subsequent reintroduction of fire into the area.

DFPZs need not be placed immediately adjacent to a high-value area. In most cases it probably is desirable to back off to a location that makes sense for other reasons, as discussed earlier—e.g., a ridge or an upper south slope, along a road, relatively cheap to treat.

Using a DFPZ to provide a buffer between adjacent areas may also be useful where management emphases or intensities, rather than values per se, differ. For example, it might be desirable to provide such a separation between an area managed primarily for natural values, including use of PNF, and an adjacent area managed primarily for commodities. This might or might not be associated with an ownership boundary.

Fire Hazard. Hazard is another factor that needs to be considered in locating DFPZs. All else being equal, a landscape dominated by continuous heavy fuels is in greater need of zones of fuel discontinuity than one with light fuels. Insofar as possible, however, actual DFPZ location should favor relatively open, low-fuel sites in order to treat more area with the available funds. In other words, DFPZs should separate high-hazard areas but not necessarily be built through them.

It is reasonable to assume that high-hazard areas may be relatively more of a concern with respect to the potential for high-severity wildfires in drier years. In such years, a higher percentage of the total fuel profile (including live fuels) becomes readily available for combustion. Drier fuels and drier microclimate near the forest floor favor easier ignition and faster fire spread. The significance of such changes in dry years is increased by the preponderance of dry years in the past ten years and by the fact that such years may be more nearly the norm when viewed on a time scale of centuries (Graumlich 1993).

Professional and Public Support. Many forest-management activities are controversial, among resource professionals as well as various segments of the public. We believe that creating and maintaining DFPZs may offer multiple benefits, including reduced wildfire hazard, improved forest health, and utilization of excess forest biomass, which in most cases should outweigh potential ecosystem damage. Adequately explained and understood, therefore, DFPZs should be reasonably well supported. Nevertheless, some areas proposed for DFPZs may be controversial. All else being equal, we suggest that, at least initially, creation of DFPZ networks be concentrated in areas where professional and public support are relatively high and disagreement relatively low. In most cases, more than enough work will need to be done to permit activities to be focused in these areas and to defer more controversial work. Well-designed and properly implemented early DFPZs may generate additional support for further development of a strategic fuel-management program.

Rate of Implementation and Practicability

We believe that, in the short term, planning and implementing DFPZ networks should have a high priority for management of low- to middle-elevation Sierran forests and appropriate portions of foothill woodland and chaparral types. Ideally, these networks should be in place within ten years. Implementing these networks will require a great deal of concentrated and cooperative effort. It also may well require “departures” from nondeclining even flow of timber volume under the National Forest Management Act. Potential benefits could be substantial, however, in terms of strategic reduction of wildfire hazard, improvement in forest conditions, and increases in economic and social well-being in forest-based communities.

By any measure, implementing a rangewide system of DFPZs within ten (or even twenty) years is a formidable undertaking. Responsible managers must be concerned with the feasibility and potential value of such a task compared with alternative management actions. Given the high priority of fire-protection and restoration issues in Sierran forests and the multiple benefits (cited earlier) that might be anticipated from DFPZ networks, a number of managers may judge such networks to have a high overall priority for management.

To be achievable, implementation of a DFPZ system cannot be viewed simply as a fire function or goal. Rather, it should be considered a multiresource or ecosystem management goal, with much of the overall activity of the management unit in the short term being integrated with and focused on planning and implementing a sound DFPZ network. Similarly, multifunction funding would improve the feasibility of accomplishing this task.

How will we pay for all the silviculture and fuel management that will be necessary to implement DFPZ networks, given the large areas that need to be treated? Considering historical levels of funding and current directions of federal budgets, it seems highly unlikely that federal appropriated funds—even from multiple functions—will be adequate. And managers may decide that most of the limited appropriated funds for fuel treatment are best spent to support prescribed burning of natural fuels in areas with special emphases on reestablishing natural processes (see the following section). Thus, truly significant progress on DFPZs and other large-scale fuel treatments will have to be the result of economically self-sustaining activities. Yet much of the needed treatment involves removal of small trees that often have marginal or negative market value. Part of the solution may come from multiproduct sales, in which sawtimber and other high-value products subsidize the removal of lower value material. One of the challenges for managers will be to locate and design multiproduct or other sales in ways that make them economically viable. In addition, however, it probably will be important to support the establishment of particleboard or other plants capable of generating value from small trees. Public land managers and private entrepreneurs need to discuss whether and how it may be possible to provide sufficient assurances of a continuing supply of biomass from public lands (e.g., for several decades) to warrant the capital investment in such plants. Research and development efforts also are needed to develop more efficient technology for harvesting and processing small material and new markets for utilizing it (Lambert 1994).

Most resource professionals would agree that fuel reduction and thinning of overly-dense stands are high-priority needs in most pine and mixed-conifer forests of the Sierra Nevada. These are precisely the kinds of activities envisioned for DFPZs, with the added proviso that they be placed in strategically logical locations. It is important to note, therefore, that the major barriers to DFPZ implementation—e.g., economic viability of small trees and maintenance of treated areas—are not unique to DFPZs: they apply much more widely. Thus, these barriers must be resolved in any case if large-scale thinning and fuel management are to be implemented. The contiguous nature and relative accessibility of DFPZs, however, may help to lessen the severity of these problems in DFPZs.

Enhanced Use of Fire

Restoring the many functions of fire as an ecosystem process can be accomplished fully only by using fire. Alternative and supplementary methods must play a large part in needed restoration, but they can substitute only partially for fire (Weatherspoon 1996). In the context of goal 2, therefore, we believe that a considerably expanded use of prescribed fire can and should play an important role in the management of Sierra Nevada ecosystems (Husari and McKelvey 1996; Mutch et al. 1993).

In some portions of the Sierra Nevada, especially higher elevation areas, large high-severity fires are not much of a concern. Thus neither goal 1 nor DFPZs are particularly applicable. Many such areas are located in national parks and wilderness areas, but substantial additional acreage of red fir and other high-elevation vegetation types fits in this category. Our suggestion in these areas would be to extend the use of prescribed natural fire (PNF) as much as possible (including appropriate areas outside parks and wildernesses) and to augment PNF with management-ignited prescribed fires

(MIPF) as needed to reestablish a near-natural distribution of fire frequencies.

MIPF also should become a key part of the management of other areas in which restoration of natural processes is a major management objective. Examples of such areas might include areas of late-successional emphasis (Franklin et al. 1996), biodiversity management areas (Davis et al. 1996), and research natural areas.

As indicated earlier, DFPZs require periodic maintenance to retain their effectiveness, and prescribed fire often will be the treatment of choice. Since the structure and composition of DFPZs are intended to be closer to presettlement conditions than most other areas of the landscape, it would seem logical for fire to assume a dual role there—maintenance of the low-fuel nature of DFPZs and restoration of natural processes.

A number of practical and political considerations constrain the use of both MIPF and PNF on a large scale. Constraints include risk of escapes, lack of adequate funding, competition for trained personnel during active wildfire seasons, and air quality restrictions (Husari and McKelvey 1996; Parsons 1995). The difficulties of applying prescribed fire on a significant scale are illustrated by the inability of the prescribed fire program at Sequoia and Kings Canyon National Parks—certainly among the most active in the Sierra Nevada—even to begin to approach the presettlement fire frequency for the giant sequoia groves. A National Interagency Fire Center study to be undertaken beginning in 1996 will test the feasibility of and constraints on landscape-scale application of prescribed fire in the Kaweah River drainage of Sequoia National Park.

In addition to prescribed burning, significant benefits related to goal 2 could be achieved by allowing low- and moderate-intensity wildfires to burn. Potentially, many more burned acres could be achieved by this means than with prescribed fire. The vast majority of ignitions in the Sierra Nevada are suppressed using fast, aggressive control. The flexibility already existing in present federal fire-management policy to use alternative suppression responses is rarely exercised outside the national parks and a few wilderness areas in the Sierra Nevada (Husari and McKelvey 1996). Fire managers currently are required to select the most economically efficient suppression option without considering potential resource benefits of wildfires. Fires that would produce results most similar to those that occurred under presettlement conditions are regularly suppressed while small, because they are easy and inexpensive to put out. Proposed new federal policies (U.S. Department of the Interior and U.S. Department of Agriculture 1995) would permit wildfires to be "managed" if they meet resource objectives.

More flexible use of appropriate suppression responses, possible use of managed wildfires to meet resource objectives, and expanded use of both MIPF and PNF jointly offer considerable opportunities for managers to restore more of the ecosystem functions of fire to the Sierra Nevada. All of these opportunities should be enhanced as forest and fuel conditions are improved over time. It should be recognized that in those areas from which fire continues to be excluded, for whatever reasons, some ecosystem components and processes will depart significantly from their natural range of variability, with unknown consequences.

Areawide Fuel Treatments

The development of DFPZs described in this chapter is a logical place to begin, but it is intended to be only a first step toward achieving the three goals of the fuel-management strategy discussed earlier. DFPZs should help to limit the spatial extent of severe fires (van Wagtendonk 1996; Sessions et al. 1996); however, they will not reduce the susceptibility of the intervening landscape areas to severe fire effects, nor will they improve forest health or restore more nearly natural processes in those intervening areas. Landscape mosaics and vegetative profiles will need to be managed on broader scales, using mainly silvicultural cuttings and fire, to achieve desired forest conditions and processes (Mutch et al. 1993).

The implementation of areawide landscape treatments should be significantly facilitated by using previously established DFPZ networks as anchor lines from which to build out. Factors considered in prioritizing DFPZ locations, discussed earlier, may also be useful as guides for prioritizing areawide treatments. From the standpoint of topography, for example, middle and upper south and west aspects on relatively gentle (machine-operable) slopes may be logical locations for early work.

RESEARCH AND ADAPTIVE MANAGEMENT NEEDS

The Role of Adaptive Management

Ecosystem management is increasingly espoused as a guiding concept for managing public lands (Jensen and Bourgeron 1994; Manley et al. 1995; Salwasser 1994). Managing for ecosystem integrity and sustainability, however, is more difficult and fraught with more uncertainties than managing for a set of specific outputs. We have much to learn. For many reasons, including the complexity and variability of forested ecosystems and the broad spatiotemporal scale that provides the context for ecosystem management, traditional research cannot provide all the answers. Scientists, managers, and interested members of the public must work together as partners in a process of learning by doing—i.e., adaptive ecosystem management (Everett et al. 1994; Mutch et al. 1993; Walters and Holling 1990).

A key concept of adaptive management is that we cannot wait for perfect information, because we will never have it. Despite the uncertainties, we must move forward with managing for sustainable ecosystems using the best information we have, knowing that with time we will learn more and be able to manage more intelligently.

The subject of landscape-level fuel-management strategies is certainly appropriate to address through adaptive management. For example, we can make educated assumptions about how a network of DFPZs might help to reduce high-severity fires and contribute to desired conditions and landscape diversity. Only through monitoring, experience, and time, however, will we know the validity of those assumptions. Only through adaptive management will we learn what locations, target conditions, and treatment schedules for implementing a DFPZ network will work for what kinds of landscapes—or whether a DFPZ network makes sense in the first place.

Similarly, we know that the ecosystem functions of frequent low- to moderate-severity fire have been largely lost from Sierran forests. Restoring these functions can be accomplished fully only by using fire. Yet in many areas silvicultural techniques and other fire "surrogates" are needed in addition to or in lieu of fire to accomplish needed restoration (Weatherspoon 1996). The extent to which natural fire regimes can or should be emulated, and the consequences for long-term ecosystem viability of alternative approaches to using fire versus fire surrogates on large scales, will become clear only through carefully designed research and adaptive management.

A GIS Database in Support of Fuel-Management Strategies and Adaptive Ecosystem Management

Good information is essential to intelligent planning of specific fuel-management strategies in the short term, and to assessing the effectiveness of those strategies (and adjusting subsequent management as appropriate) in the mid to long term. An integrated GIS database can provide a good focus for this information. The concept is quite simple and logical, given the increasingly GIS-oriented world in which we operate. Actually accomplishing the monitoring and other data collection necessary to make it fully functional may be another matter. From a fire standpoint, it probably makes sense to use the same general priorities for this data collection as discussed earlier for locating DFPZs.

In the following sections we indicate some thoughts about the directions in which we should be moving with GIS databases. We are not suggesting a standalone fire and fuel GIS. Rather, the following kinds of data needed to support fire and fuel decision making would be integrated into a larger database to inform overall land management.

Management Direction

Management objectives and guidelines, including those specific to fire and fuel management, should be indicated by area.

Vegetation and Fuels Data

The need for data on vegetation and fuels is basic and well recognized. (Much of the living vegetation is fuel, of course, but to simplify the discussion here we list vegetation and fuels separately.) Mapping should utilize the best sampling strategies combining remote sensing imagery (perhaps at several scales) and ground truthing. The reliability of existing vegetation maps should be verified before they are incorporated into the database. Fire-relevant attributes of vegetation (including understory composition and structure, and vertical and horizontal continuity) need to be characterized adequately. Similarly, surface fuels should be described, utilizing field-verified vegetation/fuels correlations to the extent feasible.

Since vegetation and fuels change over time, the dynamics occurring naturally through succession and growth must be dealt with using models combined with periodic field evaluations. Natural and human-caused disturbances also change vegetation and fuels, from a little to a lot. The database must be updated as needed to reflect these disturbance-induced changes. To account for these dynamics adequately, we need to go beyond traditional spatial GIS to incorporate new concepts in spatiotemporal GIS (Peuquet 1994; Skinner et al. 1992).

Management Activities and Other Disturbances

For our land management activities (including prescribed fire and fuel management) that significantly alter vegetation and fuels, monitoring must be carried out to determine the extent to which management objectives were met and the effects on vegetation, fuels, and other key ecosystem components. The GIS database should be updated to indicate the nature, date, spatial extent, and costs of the activity and the resulting spatially referenced vegetation and fuels. "Natural" or unplanned disturbances—especially wildfires—must also be incorporated into the database. Wildfires should be mapped by severity classes and key fire effects. To the extent allowed by available data, burning conditions at different times and places on a fire, along with suppression actions and costs, also should be entered. After postfire activities are completed, the new vegetation/fuel complex should become part of the database. To permit long-term evaluation of fires and management activities, however, it is important to maintain—not discard—prefire vegetation and fuel data. A spatiotemporal GIS would serve this purpose more efficiently than the systems generally available today (Peuquet and Niu 1995; Peuquet et al. 1992).

Other Fire-Related Data

Risk (historical fire occurrence and historical and projected ignition patterns), values at risk (for both populated and wildland areas), suppression capabilities, and any other spatially relevant fire-planning data should be included in the database. It may well be advisable for public and private landowners to cooperate in establishing data standards and protocols applicable to fire and fuels, thereby permitting data sharing, cross-ownership analyses, and the like when mutually desirable.

Benefits of the GIS Database

This kind of database, in even a rudimentary form, certainly will permit better planning for fuel-management strategies. As data are improved and accumulated over time, moreover, its value will increase. We will begin to have the data necessary to relate wildfire severity and effects to prior management activities (including fuel treatments), fuel conditions, and site and stand characteristics (e.g., Weatherspoon and Skinner 1995). Over time, as more wildfires are documented, our ability to assess the efficacy and cost-effectiveness of various fuel-management strategies in terms of both behavior and effects of subsequent wildfires and suppression costs will grow. We also will be able to evaluate trade-offs involving environmental effects of the treatments themselves. We will be much better able to learn by doing and monitoring—the essence of adaptive management (Everett et al. 1994; Mutch et al. 1993; Walters and Holling 1990).

Establishing and maintaining an accurate GIS database of this kind will require considerable effort and commitment on the part of managers and landowners. It will be a long-term, ongoing process. Many other resource benefits will accrue, however, and in fact it is difficult to see how real ecosystem management in a fire-prone region such as the Sierra Nevada will be feasible without such a database.

CONCLUSIONS

Fire has been an important component of most Sierran ecosystems for thousands of years (Skinner and Chang 1996). However, human activities since European settlement, along with variation in climate, have profoundly altered fire regimes, leading to anomalous vegetation and fuel conditions throughout much of the range. Two major fire-related "problems" have developed in the Sierra Nevada: (1) too much high-severity fire and the potential for much more of the same and (2) too little low- to moderate-severity fire, along with a variety of ecological changes attributable at least in part to this deficiency. 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.

Given the realities of our modern civilization, we must recognize that the changes in ecosystem conditions and in the role of fire are only partially reversible. We can and should reduce the extent of large, severe wildfires. However, such fires will continue at an appreciable level (almost certainly at a higher level than in the presettlement period) into the foreseeable future. We can and should restore more of the ecosystem functions of low- and moderate-severity fire, utilizing such fire to the extent feasible. It is inconceivable, however, that fire in its presettlement extent and frequencies could be restored fully to the Sierra Nevada.

Nevertheless, a partial solution is far better than no solution at all or than a continuing deterioration of Sierran forests from a fire standpoint. There is much that we as land stewards can and should do. The two fire-related problems cited earlier can be translated into the three strategic goals that have been discussed in this chapter. 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 period of time, and they certainly cannot be solved overnight. Progress also will require landscape-scale strategic thinking, planning, and implementation. This chapter has provided some ideas for managers to consider as they develop their own landscape-specific plans.

We have much to learn as we move more fully into an era of ecosystem management, including strategic fuel management. Adaptive management must be an integral part of our management activities, as discussed earlier. It is important to note in this regard that we do not have to have all the answers before beginning needed restoration work. We know enough at this point to recognize that current conditions in most low- to middle-elevation forests of the Sierra Nevada are unacceptable in terms of wildfire hazard, diversity, and sustainability. Regardless of the extent to which presettlement conditions are used as a guide to desired conditions, most informed people would agree that these forests generally should be less dense, have less fuels, and have more large trees. Even if we have not precisely identified target conditions, we certainly know the direction in which we should begin moving. That beginning alone will require a large measure of commitment and hard work. We can adjust along the way as we learn more and become better able to define desired conditions for Sierran forests.

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