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CHAPTER 19

Fire and Fuel Management

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> The only alternative to planned and managed vegetation patterns in Southern California appears to be the acceptance of great economic damage, threat to human life, and the unpleasant aesthetic and environmental effects of unmanageable wildfire.
>
> CLIVE COUNTRYMAN, 1974

> Even though fire is itself an inexorable force of nature, we need not view its worst effects as inevitable.
>
> STEPHEN F. ARNO AND STEVEN ALLISON-BUNNELL, 2002

The complex set of tasks we now characterize as *fire management* evolved from the single-minded pursuit of fire control. The management of wildland fuel has become one of the more important aspects of fire management (Biswell 1989, Carle 2002). In the last 20 years, fuel management has come to play a leading role in managing ecosystems and natural resources. Scientists and managers have improved their shared understanding of the importance of natural processes in ecosystem function. Attempts to exclude fire events merely delay, alter, and intensify subsequent fires. The build-up of fuel in some California ecosystems has contributed to the destructive power of recent fires. To be effective at protecting social values and natural resources, California land managers have focused attention on the manipulation of wildland fuel. Toward this end, fuel management is the most significant land management activity in many parts of California.

As a society, we recognize the necessity of managing the effects of wildland fire on both humans and natural resources. We have learned from experience that we cannot simply eliminate fire from fire-adapted ecosystems, nor can we ignore it. We have the responsibility to manage the range of fire patterns and fire effects that occur on wildlands. Although fuel management is not limited to the reintroduction of fire as an ecosystem process, prescribed fire remains a critical component of responsible management.

Fuel management is important simply because it gives us the opportunity to modify the pattern of future fire by modification of today's fuel. Climate and topography cannot be changed although fuel management can effect some local weather characteristics (van Wagtendonk 1996). This leaves fuel and ignitions as the two main means by which wildfires can be affected (Martin et al. 1989). Hence, fuel management and fire prevention have joined fire suppression as key components of fire management programs.

This chapter builds on the concepts and processes developed in Part I and described for the bioregions in Part II of this book. The historical, social, and political considerations in the other chapters in Part III define the management setting in which fuel management operates. This chapter first provides an overview of basic fuel management concepts. We then describe the setting in which fuel management programs operate within the various land management agencies and fire departments in California's diverse wildfire environment.

Fuel Management Objectives

The direct goal of any fuel treatment is the modification of potential fire behavior or fire effects to achieve a defined condition. Federal and state fuel management programs have the purpose of reducing risks to human communities and improving ecosystem health. To ensure these programs are coordinated, common priorities for fuel treatments have been established that follow the guidelines and policies under the National Fire Plan (USDA and USDI 2004).

Common goals are reducing potential fire intensity and rate of spread, reducing the severity of fire effects, and restoring historic fuel quantity and structure. Achieving these goals creates the potential for reestablishing presettlement fire regimes. Manipulation of fuel is the most common and effective way to influence future wildland fires.

The land management objectives requiring management of fuel are diverse and often complex. Reestablishing or restoring historic fire regimes can be, but are not always, the objective of fuel management. Modified or redefined fire regimes that accept currently occurring fire regimes or a fire regime distribution that differs from the historic pattern are often the objective of wildland management. These goals may be driven by the need to manage for habitat for individual species (see Chapter 23), or as part of an effort to exclude wildland fire from an ecosystem for public safety purposes.

Fuel Management Basics

Fuel is accumulated live and dead plant biomass. Chapter 3 discusses in detail how the characteristics of fuel influence its potential to burn. Fuel moisture, chemical composition, surface area to volume ratio, size, and structural arrangement of the fuel in the stand and on the landscape influence the conditions under which fuel will burn, as well as help characterize the resulting fires.

Fuel management is the planned manipulation of the amount, composition, and structure of the biomass within wildland ecosystems for the purpose of modifying potential fire behavior and effects (NPS 2004). Fuel has several characteristics that can be manipulated to influence its potential to burn, and the characteristics of the potential wildland fire. Fuel management includes the manipulation of a number of different fuel characteristics to achieve a defined modification of future fire behavior (Pyne et al. 1996, Stephens and Ruth 2005). Table 19.1 explains how different fuel characteristics are modified by fuel treatment. Fuel characteristics that are typically manipulated are as follows:

Fuel Quantity The overall amount of fuel in the ecosystem is an important factor determining the character and impact of fires. The metric used to describe the quantity of fuel is oven dry weight per unit area (tons per acre). This dry weight is often subdivided into size classes. The size classes are based on the time the fuel takes to reach equilibrium with moisture in the air. Small fuels, such as pine needles, respond to changes in relative humidity more rapidly than do large, dense fuels, such as logs. Fuel can be removed from a site by a variety of means, thereby reducing fuel quantity.

Fuel Size The sizes of fuel particles are very important in determining fire behavior and effect. Fine fuels—less than a quarter inch in diameter—have the greatest influence on the ignition and spread of fires. Removal of fine fuel is a primary focus of many fuel management projects.

Packing Ratio Packing ratio is a measure of how densely packed the fuel particles are. Fuel may be compacted through a variety of mechanical treatments including mastication, chipping, and shredding. Compact fuel burns more slowly because the oxygen required for combustion is not available to the fuel away from the surface.

Surface Fuel Surface fuel is composed of small shrubs, grasses, and plant debris lying on the surface of the ground. Surface fuel is necessary for fire to spread continuously across landscapes. Surface fuel continuity can be interrupted to achieve fuel management goals.

Crown Fuel The branches and foliage of the trees and large shrubs (over 6 feet in height) make up crown fuel. Continuous crown fuel is required for fire to spread through the crowns of trees. Crown fires may also occur in discontinuous stands of trees if supported by surface fire. Wind speed and, to a lesser extent, foliar moisture are important to propagation of crown fires. Crown fire risk reduction may be accomplished through removing trees and ladder fuel, treating surface fuel, or a combination of the above. Such treatments reduce the continuity and bulk density of crown fuel and increase the separation between crown fuel and surface fuel.

Horizontal Fuel Continuity Within any ecosystem, horizontal fuel continuity is necessary to allow fire to spread laterally across a surface or through crowns. Surface fuel discontinuities act as barriers to fire spread under most conditions. Fires can spot across bare areas, especially under dry, hot, windy conditions. Fuel treatments designed to interrupt fuel continuity include fuel breaks and strategically placed area treatments.

Vertical Fuel Continuity Vertical fuel continuity is necessary for surface fire to spread into the crowns of trees within forested ecosystems. Vertical fuel continuity can be reduced to increase the separation between the surface fuel and the crown fuel. Fuel treatments are often designed to separate surface fuel and crown fuel to reduce the probability of crown involvement.

Ladder Fuel Intermediate-sized trees or shrubs provide a fuel conduit that can allow a surface fire to “climb” into the crown fuel. Fuel treatments can remove shrubs and small trees or the lower branches of trees to reduce ladder fuel.

Types of Fuel Treatments

The term *fuel management* is a new term, not found even as recently as the second edition of the classic text by Brown and Davis (1973), *Forest Fire Control and Use*. Fuel management as a concept first appeared about the same time fire *control* became fire *management*—1977—and is now ubiquitous in discussions of fire management.

Fuel treatments take on a wide assortment of forms but can generally be divided into two categories—fire treatments and mechanical treatments. Fire treatments are the application, use, or management of wildland fire to modify fuel. Mechanical treatments rely on a variety of methods to manually modify or remove fuel. Fuel treatment programs often include the use of mechanical treatments to restore the fuel to a condition where fire can be used to maintain the desired range of conditions over a longer period of time.

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TABLE 19.1

Fire and non-fire treatment effects on fuel and potential fire

	Non-fire Treatments			*Fire Treatments*		
	Thinning	Grazing	Mastication	Surface Fire	Mixed Severity Fire	Crown Fire
Total fuel quantity	Reduced	Reduced	No effect	Reduced	Removes fuel, may create new dead fuel	Removes fuel, may create new dead fuel
Fuel size	Reduces aerial (crown) fuel of all sizes	Reduces fine fuel Browsing may remove twigs and branches	Increases the percentage of small-sized fuel particles	Reduces fuel of all sizes depending on moisture content of fuel and duration of burning	Reduces fuel of all sizes depending on moisture content of fuel and duration of burning	Reduces fuel of all sizes depending on moisture content of fuel and duration of burning
Packing ratio of surface fuel	Not directly influenced	Increases packing ratio because fine fuels are decreased	Increases packing ratio because of compaction	Variable effect	Variable effect	Variable effect
Surface fuel continuity	Can be used to decrease surface fuel continuity	Can be used to decrease surface fuel continuity	Can be used to decrease surface fuel continuity	Reduces surface fuel continuity	Reduces surface fuel continuity	Reduces surface fuel continuity
Crown fuel continuity	Can be used to reduce crown fuel continuity	No effect	No effect on mature canopy	Can reduce crown fuel continuity	Reduces crown fuel continuity	Reduces crown fuel continuity
Surface fuel	Increases surface fuel if branches or debris are left on site after thinning	Reduces total surface fuel	Compacts surface fuel, can increase total surface fuel if brush or small trees are converted to surface fuel	Reduces total surface fuel	Reduces total surface fuel	Reduces total surface fuel

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Crown fuel	Reduces crown fuel	Miinimal impact from browsing	No effect on mature canopy	Minimal effect from scorching or tree mortality in sensitive species	Reduces crown fuel through mortality and scorching	Reduces crown fuel through consumption of leaves and small twigs
Horizontal fuel continuity	Can be used to reduce horizontal fuel continuity, primarily in aerial fuels	Can be used to reduce horizontal fuel continuity	Can be used to reduce horizontal fuel continuity through rearrangement	Reduces horizontal fuel continuity	Reduces horizontal fuel continuity	Reduces horizontal fuel continuity
Vertical fuel continuity	Can be reduced by removal of ladder fuel, increasing the separation of surface and crown fuel	Browsing can reduce ladder fuel	Can be reduced by removal of ladder fuel, increasing the separation of surface and crown fuel	Can be reduced by removal of ladder fuel, increasing the separation of surface and crown fuel	Can be reduced by removal of ladder fuel, increasing the separation of surface and crown fuel	Can be reduced by removal of ladder fuel, increasing the separation of surface and crown fuel
Ladder fuel	Can be used to reduce ladder fuel	Browsing can reduce ladder fuel	Can be used to reduce ladder fuel	Reduces ladder fuel	Reduces ladder fuel	Reduces ladder fuel
Potential for surface fire	Not directly influenced	Reduces potential for surface fire	Can reduce potential for surface fire	Reduces potential for surface fire	Reduces potential for surface fire	Reduces potential for surface fire
Potential for crown fire	Reduces potential for crown fire	Reduces potential for crown fire by decreasing surface fire potential	Can reduce potential for crown fire by decreasing surface fire potential and increasing height to live crown base	Reduces potential for crown fire by decreasing surface fire potential	Reduces potential for crown fire by decreasing surface fire potential and crown fuel continuity	Reduces potential for crown fire by decreasing surface fire potential and crown fuel continuity

FIGURE 19.1. Prescribed burning in Yosemite Valley is used to reduce fire hazard, maintain meadows, and to open vistas. (National Park Service photo.)

Fire Treatments

Fire treatments may include prescribed fires purposely ignited to achieve established objectives, or naturally caused fires allowed to burn in designated locations under specific conditions. Both types of fire treatments maintain the presence of fire as an ecological process, but prescriptions may or may not be designed to mimic the historic influences of fire.

PRESCRIBED FIRE

Civilizations around the world have used prescribed fire for millennia to accomplish a wide array of objectives. Pyne (1982) notes, "To discriminate between influences of climatic change, biotic migrations, natural fire, and aboriginal firing of the landscape is all but impossible." Prescribed fire has often been a supplement to natural sources of ignition or, in some areas, a replacement for such ignitions.

The uses and purposes of prescribed fire in California are widely varied. A general differentiation can be made between *restoration* burns, in which the current ecological condition is modified, and *maintenance* burns, in which existing conditions are maintained within a specified range. Modifications may include the reduction of hazardous amounts of dead and down fuel, the stimulation of fire-dependent species, the control or removal of non-native species, improvement of range condition, or the creation of wildlife habitat.

Prescriptions for burning consider the variables that influence fire behavior, the ecological role of fire, and the ability to control the fire and minimize the potential for escapes. Site considerations include slope, aspect, topographic position, and role of fire in the project area. Prescribed conditions at the time of burning include the season, weather, fuel conditions, and the availability of qualified personnel.

Methods for ignition can greatly influence the intensity and severity of prescribed fires. Ignition patterns are used to modify and control fireline intensity and fire severity patterns. A wide variety of hand-held, mechanized, and aerial ignition methods are used to accomplish the desired fire patterns. The most effective method for a given project will depend on the terrain, fuel type, prescribed conditions, type and pattern of fire, and the scale of the project.

Whether for restoration or maintenance purposes, the establishment of measurable objectives, and monitoring methods to measure them, are critical. The value of prescribed fire to land managers decreases with the inability to quantify the purpose of the fire and its accomplishments (or lack of them). Prescribed burning within an adaptive management context is critical to each agency (Fig. 19.1).

WILDLAND FIRE USED FOR RESOURCE BENEFITS

The concept of allowing lightning fires to burn originated in 1968 in Sequoia and Kings Canyon National Parks, followed by other agencies and other units (Kilgore 1974). Much like maintenance prescribed fires, areas in which wildland fires are allowed to burn are generally considered to be within historic or natural ranges of variability. The original justification for such areas is that they were sufficiently remote to have been unaffected by fire suppression activities.

Following the 1988 Yellowstone Area fires, additional requirements for planning, approving, and implementing the wildland fire use program were established. With greater emphasis in federal fire policy on the restoration of fire to its more natural role and the revision of fire management plans that this entailed, the program in California has grown (Fig.19.2). Smoke from these fires is a concern to air quality

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FIGURE 19.2. The Bluff wildland fire use project was successfully managed in Lassen Volcanic National Park in the summer of 2004. (Photo by Mike Lewelling, Lassen Volcanic National Park.)

regulators, and land managers will continue to balance the importance of clean air with the reality that wildland fires will occur. Representatives from the National Parks, National Forests, state air regulators, and local air districts developed protocols in 2004 for implementation of the wildland fire use program. All recognize that smoke from these fires is transported throughout the state and across jurisdictions from areas with relatively clean air to other areas where visibility and human health are already at risk from elevated levels of particulate matter and other pollutants.

Mechanical Treatments

Many kinds of vegetation management remove, rearrange, or modify biomass. Mechanical fuel treatments must also include the objective of modifying potential fire behavior. Many vegetation management strategies have multiple objectives. The question of which mechanical vegetation management treatments reduce hazardous fuel and which do not is a contentious issue in California and throughout the West (Agee and Skinner 2005, Stephens and Moghaddas 2005a). This has been the subject of much debate, intellectual discourse, and some legal action focused on timber salvage and forest management. Land management agencies, the fire service, large landowners, elected representatives, and the public need improved fire behavior models, analysis, research, and, especially, monitoring, to resolve this issue. A long-term study is underway to compare the efficacy, the economics, and the effects of prescribed fire, mechanical thinning, and a combination of the two on a series of linked study sites in fire-adapted ecosystems throughout the country (Knapp et al. 2004).

Removal of both live and dead woody fuel can utilize equipment such as feller bunchers, skidders, and grapplers. Trees may also be thinned to a variety of densities. Crushing, chipping, shredding, chopping, and other mechanical methods of changing the fuel characteristics are commonly used. Woody material can be chipped or burned in piles. Mechanical treatments can be more precise than prescribed fire. Smoke impacts and damage from scorching are avoided when mechanical methods are used instead of fire. In some cases, the fuel can be removed from the area and used to produce wood products or to generate electricity, as described in Sidebar 19.1. However, removal of organic material reduces the amount of carbon and nutrients on the site. The application of mechanical methods on a scale matching the fuel problem in California is dependent on continued partnerships with research and industry to find uses of the material and cost-effective methods of removing it. Work remains to be done on use of these methods in remote or steep locations.

Other mechanical methods may include grazing to remove fine fuel and type conversions such as brush to grass. In many cases, however, the need for prescribed fire to maintain the conditions once established mechanically still remains. Although the risk of wildland fire may be reduced through mechanical means, these treatments rarely prove a perfect surrogate for fire (Stephens and Moghaddas 2005b,c). The presence of heat and smoke, as well as the recycling of specific nutrients are fire-specific cues that cannot be simulated by mechanical treatments.

FOREST THINNING

Thinning is used as a treatment to modify the fuel structure in forests that have become denser due to fire exclusion. Thinning projects that reduce ladder fuel or crown fuel continuity can be effective at moderating crown fire behavior. Thinning is often proposed as a fuel management treatment because it can provide economic returns and produce some commercial timber products. In most cases, thinning projects

SIDEBAR 19.1. BIOMASS REMOVAL

FIGURE 19.1.1. Mechanized harvest of sawtimber and biomass from the Wrights Creek burn plantation. (Photo by Dave Horak, Stanislaus National Forest.)

In forest management, biomass removal commonly refers to the mechanical removal of small trees, branches and tops of larger trees, and portions of down woody material from the forest floor. It can provide for substantial reductions of hazardous fuel. Forest thinning may remove a wide range of tree sizes, with trees smaller than 25 cm in diameter at breast height and 1.5 m above the uphill ground line providing the majority of biomass yield. This practice is regarded as a valuable component of the forest management toolkit, especially where fuel hazard reduction is a major management objective.

Like other ground-based mechanical operations, biomass removal is generally limited to slopes less than 40%; however, recently designed equipment now provides for access to steeper slopes (Fig. 19.1.1). In some cases, a skyline-yarder aerial harvesting system is used to collect woody material from steep slopes. Numerous strategies exist for cutting, collecting, and transporting biomass from the stump to a roadside landing. Equipment type, size, and capability vary widely. One common strategy uses a rubber-tired feller-buncher, to cut and concentrate the biomass, and a grapple skidder, to transport the concentrated material to the landing. At the landing site, the biomass is fed into a chipper and blown into a van for transport to a local power generation facility.

Economic considerations play a substantial role in biomass removal projects. The material is commonly chipped at roadside landings and hauled to wood-fired electrical generation plants. Harvesting and transportation costs are substantial and are not always offset by the value of the delivered chips. When forest thinning includes valuable saw timber products, the connected costs of biomass harvest and transportation may be absorbed more easily. In some cases, Forest Service fuel reduction projects often provide additional funding to cover expenditures beyond those covered by the value of the chips. In other cases, subsidies from governmental agencies can play an important role in providing for cost-effective projects. There are several other promising end uses of biomass material; however the use as fuel is the most common at this time. —*Joseph W. Sherlock* are only effective as a fuel management technique when fine surface fuel is also reduced (Agee and Skinner 2005).

Thinning can remove trees to create specified stand densities, patterns, distributions, and species compositions. Thinning is an effective fuel management method if it reduces the likelihood that a surface fire will transition into a crown fire by breaking up vertical and horizontal fuel continuity. The thinning specifications, by density and by diameter classes of trees, are important characteristics of thinning prescriptions. Considerable progress has been made in developing guidelines to implement fuel reduction goals through thinning projects as summarized by Peterson et al. (2004).

MASTICATION

Mastication is the mechanical grinding, crushing, shredding, chipping, and chopping of fuel that can reduce fireline intensity and the rate of fire spread. Mastication and some other mechanical modifications of the fuel are used to reduce potential fire behavior by reducing fuelbed depth and thereby increasing packing ratio. An ever-increasing selection of mechanical equipment is available to accomplish these tasks.

Mastication can effectively accomplish the modification of potential fire behavior with a great deal of precision. It can be applied to specific areas and fuel and can be effective without the need to remove fuel or soil cover from the site. Ladder fuel, specific fuel sizes, or shrub layers can be the specific target for projects. These mechanical treatments differ greatly from historical fire in ecological effects. They do not replace the biological role of fire and can create a significant impact on the site by the presence of equipment. Mastication, like other mechanical treatments is most commonly applied in the restoration rather than in maintenance of wildland ecosystems.

GRAZING

Prior to the arrival of domestic livestock, native grazers undoubtedly had a great influence on herbaceous fuel. Domestic livestock have been effective at modifying fuel in California since the establishment of the missions as described in Chapter 18. Concentrated livestock grazing is still used to reduce surface fuel loads and the rate of fire spread. Grazing or browsing for the specific purpose of reducing fuel is applied on a limited scale, mostly on the wildland-urban interface in shrublands or grasslands. Its use is growing as a maintenance tool on fuel breaks and other linear fuel reduction projects. Nonetheless, the impact of grazing on vegetation and fire regimes in present-day California should not be discounted. Grazing of cattle influences fire regimes on the Northeastern Plateaus and Southwestern Desert bioregions, especially on lands administered by the Bureau of Land Management. The removal of fine fuel by domestic animals shortens the fire season and reduces fire potential.

Owners of large tracts of private land have used fire to improve forage and grazing throughout the twentieth century (Biswell 1989). The Vegetation Management Program (VMP), administered by the California Department of Forestry and Fire Protection (CDF), was established in 1983 to provide a means to share the cost of mechanical treatment and prescribed burning on private land in California. VMP has enabled CDF and landowners to conduct safe and effective prescribed burns on ranchlands throughout the state. A second objective was wildlife habitat improvement in cooperation with the California Department of Fish and Game. The number of acres burned under the VMP program has declined somewhat in recent years, but at its peak, more than 24,000 ha (60,000 ac) were burned each year.

Fuel Management Phases: Restoration and Maintenance

The restoration and long-term maintenance of ecosystems for a defined set of desired conditions including the range of variability for wildland fuel requires knowledge about fire regimes. These fire regimes may or may not have persisted on the same landscapes in the past, or even exist there currently. The desired condition is typically a manifestation of society's needs from that wildland landscape. Establishment or restoration of a changed fire regime will often require both an initial restoration phase and a long-term maintenance phase. The importance of analyzing the costs and the frequency of restoration and maintenance has been highlighted by federal agencies' current efforts to define condition class and fire regime on a spatial basis. These concepts are designed to assist fire managers and the public in setting priorities for fuel management based on the frequency and severity of fire under pre- European conditions (fire regime) and departure from these regimes that has occurred during the fire suppression era (condition class) (Schmidt et al. 2002). The growing availability of spatial data describing fuel characteristics allows managers to use these data to set priorities for fuel treatments and to quantify the extent of the fire hazard problem at a variety of scales.

The *restoration phase* is designed to re-establish the fuel structure and composition before prescribed fires can be introduced or reintroduced. During this phase, the techniques that are used are not necessarily the ones that occurred historically or the ones that will be prescribed for a long-term program. Mechanical treatments such as thinning of overly dense forest stands are important tools. These treatments must maintain the desired focal characteristics of the landscape while accelerating the progress toward desired fuel conditions. Duration of the restoration phase can range from a single treatment to several decades of treatments. The restoration will effectively and efficiently set up the landscape for fire to operate as an ecosystem process, enabling continuance during the maintenance phase. In some cases, prescribed fire alone can be used in the restoration and maintenance phases (Stephens and Moghaddas 2005b).

The *maintenance phase* is the long-term application of prescribed fire or other fuel management techniques to the landscape. The maintenance phase can be accomplished once the restoration phase is completed. If the landscape is already in a condition that can support the desired prescribed fire regime, restoration is not necessary. Maintenance phase treatments are characterized by greater variability and "more random" fire applications within normal ranges of fire regime attributes for given ecosystems. In many cases, application of herbicides, scraping, chopping, or other methods are used to maintain mechanical fuel treatments. There are many challenges to completing maintenance treatments on thinned areas and fuel breaks. The costs of developing the initial treatments can sometimes be defrayed by the economic value of the trees that are removed. As more areas are restored, the cost of completing maintenance on previously treated areas multiplies. Fire managers must choose between doing restoration work on new areas and maintaining areas that have received initial restoration treatments. The challenge of following through on maintenance has come up repeatedly in California (Cermak 1988). Perhaps the most striking example of this is the Ponderosa Way and Truck Trail, a 1,047-km (650-mi) long fuel break completed in the 1930s to stop the spread of fire from the foothills into forested areas. It stretched from the Pit River to the southern end of the Sierra Nevada near Kernville (Green 1977). The Truck Trail persists as a street name in many foothill communities, but the fuel break is gone, due to lack of maintenance.

Choosing Management Methods on Complex Landscapes

The primary objective of fuel management is the reduction of potential fire behavior and effects. We know how to monitor and evaluate the effects of individual fuel treatments (Brown et al. 1982, Miller 1996, Lutes et al. 2006, NPS 2003, Agee and Skinner 2005, Stephens and Moghaddas 2005b). It is far more challenging to design and monitor treatments on a landscape scale. This requires the application of large numbers of treatments over entire watersheds and the development of measures to evaluate the interaction of wildfires with these treatments over long periods of time. Such data are essential in making the most efficient use of scarce funds and setting priorities and schedules for treatment. Essential questions, including how to arrange fuel treatments, how often to maintain them, how much of the landscape must be treated, and how these treatments interact with critical wildlife habitat and riparian areas, require both complex tools and difficult trade-offs.

Reducing surface fuel will limit the potential intensity of fires, provide a higher probability of controlling wildfires, and allow more of the forest to survive when it does burn (Agee 2003). Thinning treatments can be directed to effectively reduce ladder and crown fuel. Prior to 1990, the majority of fuel management treatments on forested areas in California were aimed at removing debris generated by forestry activities. These treatments were funded by the Forest Service under the Brush Disposal program. The Brush Disposal (BD) Fund was created in 1916 to burn the excess brush and slash resulting from logging operations. The BD Fund requires timber purchasers to pay a brush disposal fee in addition to the timber sale price. Fuel treatments funded by these fees consisted primarily of piling and burning residue left after timber harvest or fire salvage. These deposits were also used to conduct broadcast burning of large areas that had been thinned as well as to burn clear-cut blocks. The BD program is still an important part of the Forest Service fuel management program, but its use has declined from its peak in the 1980s. The gradual decline of the BD program can be attributed to two things: first, the decline of timber program sales on national forests in California, and second, the loss of revenues on individual timber sales as the cost of harvest increased and the size, and therefore value, of the material being harvested declined. Little usable data exist on the extent and distribution of treatments conducted historically under the program in California, although we do know that thousands of acres were treated and millions of dollars spent. The distribution of these treatments in the landscape was not designed to influence wildfires.

Today, the focus of fuel treatments in many public and private forests is the removal of dense trees and modification of surface fuel. The purpose of these treatments is to reduce the risk of crown mortality during wildfires, to increase the probability of successful fire suppression, and to improve forest health. The Healthy Forest Restoration Act of 2003 establishes these as high priorities for federal agencies and gives stewardship authority to the Forest Service and the Bureau of Land Management.

It is important to note that logging residues (activity fuels) that are left on site can result in potential fire behavior that is more extreme or similar to an untreated forest (van Wagtendonk 1996, Stephens 1998). Fuel treatments in forests that once experienced frequent, low- to moderate-intensity fire regimes should focus on surface first and then ladder and crown fuel (Stephens 1998, Agee 2003, Stephens and Ruth 2005).

One method of establishing priorities and arrangements of fuel treatments on a landscape scale is to link them to past fire causes. Strategically placed area treatments may be an effective strategy to reduce landscape fire behavior in large, heterogeneous areas (Finney 2001). These treatments are a system of overlapping-area fuel treatments designed to minimize the area burned by high-intensity head fires in diverse terrain.

Human-caused fires commonly occur near highways, roads, trails, campgrounds, and urban areas, making it possible for fire managers to forecast areas of higher ignition potential. Defensible fuel profile zones placed near areas of high human-caused ignitions can be used to decrease the probability of large, high-severity fires by improving suppression efficiency (Agee et al. 2000, Stephens and Ruth 2005). The defensible fuel profile zone idea originated on the Lassen National Forest (Olson et al. 1995). The proposal was further developed by Weatherspoon and Skinner (1996) as a fuel management strategy. The concept was popularized by the Quincy Library Group, a grassroots community group centered in Quincy, California. This group sought to influence the Forest Service to reduce the risk of large damaging wildfires and improve the local economy by putting local people to work and revitalizing the declining forest products industry. The Quincy Library Group succeeded in convincing the federal government to plan and finance fuel management efforts on three national forests in northern California. Their original proposal was funded by Congress in 1999 to plan and construct a network of wide, shaded, fuel breaks on the Lassen, Plumas, and Tahoe National Forests. These networks differ from traditional fuel breaks by being wider and emphasizing retention of overstory trees. The purpose of these networks was to provide an area with road access where firefighters could take action safely on wildfires. One of the primary goals of the program was to implement the network of fuel breaks and monitor the effect that they had on this fire-prone ecosystem over the long term (Quincy Library Group 1994).

Fuel breaks have a long history California. The chaparral management program in Southern California reached its peak in the 1970s, and was supported by extensive research conducted at the Forest Service Riverside Fire Lab (Green and Shmimke 1971, Green 1977). According to Green (1977), there were 2,977 km (1,850 mi) of fuel break wider than 30 m (100 ft) in California in 1972. The original management plans for the Angeles, Cleveland, San Bernardino, and Los Padres National Forests proposed ambitious programs to maintain a complex network of fuel breaks extending from national forests into the adjoining cities and suburbs. These plans also proposed management of age classes in chaparral through a mosaic of prescribed burning. Countryman (1974) discussed the short intervals needed for effective rotational burning, as well as the high costs, and risks of escaped prescribed burns. Debate continues today on whether such strategies are effective under the worst-case weather conditions that typify Southern California wildfires (Keeley et al. 2004, Moritz et al. 2004). Concerns have been raised over the effects of out-of-season burning and increased fire frequency on biodiversity (see Chapters 15 and 22).

In forested areas, installation and maintenance of fuel breaks, strategically placed fuel treatments, and defensible fuel profile zones at appropriate spatial scales (Finney 2001) should reduce wildfire area and severity. Defensible fuel profile zones and fuel breaks will only be effective in reducing losses in the urban–wildland intermix if they are used in combination with combustion-resistant homes that are surrounded by a defensible space free of flammable vegetation and fuel.

Several California forest types are currently experiencing elevated levels of high-intensity, high-severity wildfire, and active management is necessary to slow or reverse this trend. Prescribed fire can be used to reduce fuel hazards but constraints can severely limit operation periods. It is common for many fire managers to have a single week or less when constraints (e.g., air quality, wildlife, weather, crew availability) actually allow burning. It is not possible to restore and maintain hundreds of thousands of hectares of forests with high fire hazards within these constraints (Stephens and Ruth 2005).

The social and political aspects of fuel management, although always factors in land management, are of even greater consequence today. It is of increasing importance for land managers to articulate and quantify the nature of the fuel hazard issue and the rationale behind the selection of tools and programs to mitigate it.

Within the context of fuel management, several social and political issues predominate. One set of issues revolves around the changing ecological role of fire. In some areas, the use of fire may make a situation worse ecologically, while in others, fire may be a useful tool to restore and maintain ecosystems in a desired state. In still other areas, the volume of fuel is so great that some fuel should be removed mechanically before fire can be safely restored.

Fire managers determine which situations exist on the land in question. Each situation will be affected by many ecological effects, such as the vulnerability of soil to erosion caused by prescribed versus wildland fire, and therefore the likelihood of erosion impacting watersheds. Air quality regulators want land managers to consider the use of mechanical fuel reduction methods before the use of prescribed fire. The use of mechanical methods to reduce fuel, and the threat of wildland fire, will cause controversy over which fuel should be removed; if live trees, then how many? Of what diameter? To what density? And mechanical treatment methods will have their own ecological impacts. Although the issues can be displayed fairly easily, the acquisition and analysis of data to arrive at the best combination of fuel techniques is not such an easy process. The Forest Service has recently completed work on analytical tools to assist fire and land managers in laying out fuel treatments in watersheds and across multiple jurisdictions. This tool, known as FIRESHED analysis (Bahro and Barber 2004), makes use of spatial data layers to allow the design of treatments and the testing of these tools using fire modeling methods (Sidebar 19.2).

The fuel manager must make candid evaluation of the wildland fire and fuel situation, including an assessment of the ecological impact of various fuel-reduction techniques and their influence on wildland fire behavior. This evaluation is the fundamental explanation to the public and to those who appropriate funds so that the program will be both effective and efficient. The amount of controversy that arises in fuel programs is proportional to the degree to which evaluation is not done, or explained, well. Clear description of the consequences of fuel management action—or inaction—will also help managers comply with air quality, cultural resource, threatened and endangered species, and other laws and regulations.

SIDEBAR 19.2. FIRESHED ASSESSMENT

Fireshed assessment is an interdisciplinary and collaborative process for designing and scheduling fuels and vegetation management treatments across broad landscapes to meet goals for changing outcomes associated with large, severe wildland fires (Fig. 19.2.1). The fireshed assessment process is based on the premise that management actions (in the form of fuels treatments located to modify fire behavior) can affect the outcome of a wildland fire (how large it gets, where it burns, and how severely it affects communities, habitats, and watersheds).

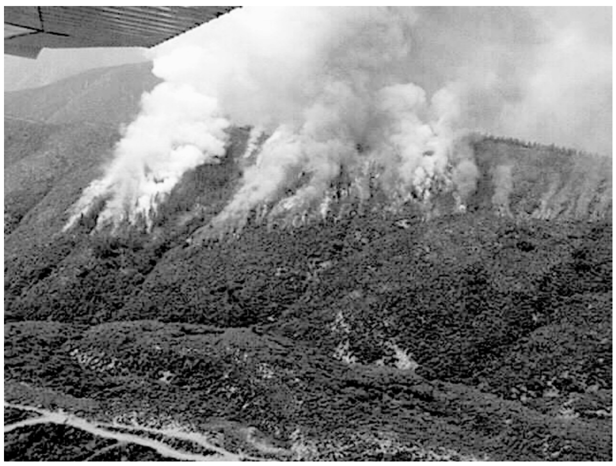

FIGURE 19.2.1. Fire behavior at the landscape scale.

The approach for modifying landscape-scale fire behavior is anchored in the concept that, by using a carefully designed pattern of treatment areas, managers can treat a fraction of the landscape to achieve intended modifications in wildland fire behavior. The design of treatment area patterns is based on the premise that disconnected fuels treatment areas overlapping across the general direction of fire spread are theoretically effective in changing fire spread. Research conducted by Dr. Mark Finney (2001) suggests that fire spread rates can be reduced, even outside of treated areas, if a fire is forced to flank areas where fuels have been reduced or otherwise modified. Hence, treated areas function as "speed bumps," slowing the spread and reducing the intensity of oncoming fires, thereby reducing damage to both treated and untreated areas, and ultimately reducing the size and severity of wildland fires. Two criteria must be met for this strategy to be effective: (1) the pattern of area treatments across the landscape must interrupt fire spread, and (2) treatment prescriptions must be designed to significantly modify fire behavior within the treated areas. As landscape-scale wildfire behavior is modified over time, fire suppression opportunities are enhanced, leading to smaller fires that are less damaging and less costly. Treatments for modifying wildfire behavior can also be designed to meet multiple resource objectives, such as improving forest health and providing habitats for at-risk species over the long-term.

During fireshed assessment, interdisciplinary natural resource teams, working with partners from government agencies, stakeholders, and other collaborators, use the following process to design fuels treatments and assess their performance in changing outcomes of potential large "problem" fires.

Step 1: Determine Wildfire Threats by Identifying "Problem" Fires. "Problem" fires are the potential wildfires of greatest concern based on impacts to lives, property, forests, and watersheds. Such fires occur when suppression resources are unable to contain them under initial attack. Problem fires are the 2% of wildfires that escape initial attack, and are the most costly and damaging fires. Problem fires (along with data from historical large fires) are used to identify and delineate firesheds during Step 2.

Step 2: Frame the Analysis Area (Fireshed) for Assessment. Firesheds are large (thousands of acres) landscapes that share similar historical large wildland fire characteristics as well as potential fire behavior

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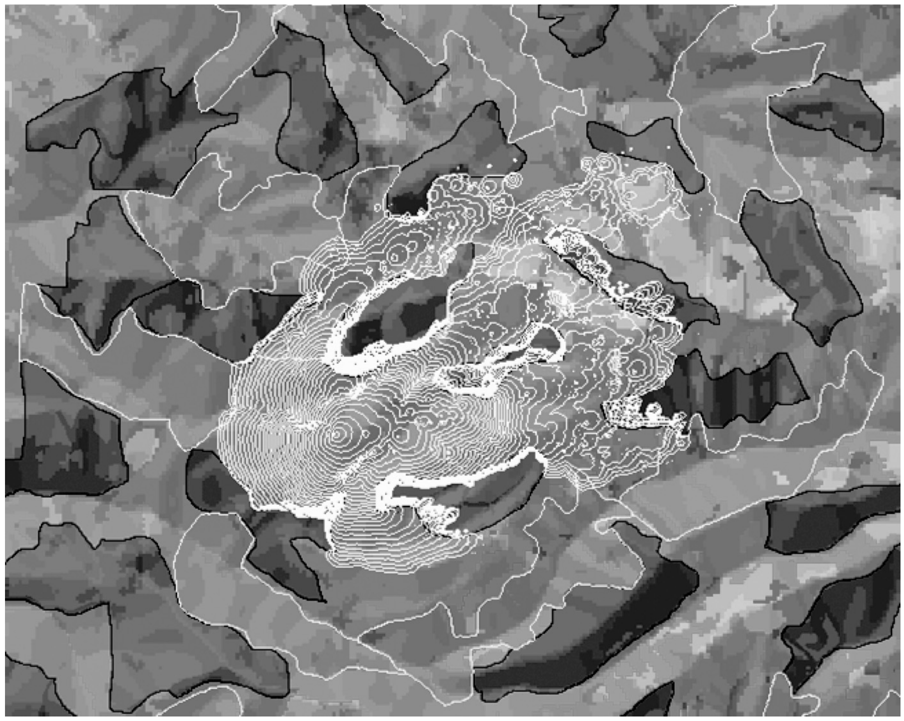

FIGURE 19.2.2. A modeled example of wildland fire moving across a treated landscape *(white lines)*. Note the reduced rate of fire spread in treatment areas *(dark-shaded areas in the fire perimeter)*.

characteristics. The purpose of delineating firesheds is to identify areas that are sufficiently large to assess the effectiveness of fuels treatment at changing the outcome of a large wildland fire.

Step 3: Characterize the Likely Behavior of the Problem Fire(s) Within the Fireshed. The problem fire defines the weather conditions of concern (wind directions, wind speeds, fuel moistures, and expected fire behavior) under which fuels treatments in the fireshed must perform. The location, size, and severity of the problem fire provide the baseline for assessing the extent to which various treatment scenarios change potential large wildfire outcomes. Spatial modeling tools, such as FARSITE and FLAMMAP, are used to analyze, display, and game multiple iterations of the problem fire's behavior.

Step 4: Develop a Treatment Pattern and Prescriptions Aimed at Changing the Outcome of the Problem Fire. First, a pattern of treatment areas is laid out across the fireshed to interrupt potential fire spread. Each treatment area is then assigned a prescription or prescriptions. Treatment prescriptions must be designed to significantly modify fire behavior within each treated area by removing sufficient material to cause a fire to burn at lower intensities and slower rates of spread. Prescriptions focus on removing fuels in a sequential manner, starting with surface, then ladder, and finally crown fuels to achieve desired effects on fire behavior. Prescriptions also consider existing vegetation and fuels conditions; for example, in previously treated areas, a maintenance treatment may be prescribed. Treatment methods can include prescribed burning, hand treatments, and/or mechanical treatments.

This step also involves demonstrating how the combination of treatment area patterns and prescriptions (referred to collectively as *the treatment scenario*) modifies wildland fire spread, resulting in a smaller potential fire with less severe effects (Fig. 19.2.2). The performance of Step 4's treatment scenario in changing the outcome of the problem fire is assessed by comparing the potential fire in the treated landscape with the problem fire in the untreated landscape based on fire location, size (acres), and type (acreages experiencing surface fire, passive crowning, and active crowning). As in Step 3 above, FLAMMAP and FARSITE are useful tools for displaying these outcomes.

Step 5: Adjust Treatments from Step 4 to Incorporate Landscape-Scale Desired Outcomes for Other Resources Where Possible While Still Meeting the Intended Effect of Changing the Outcome of the Problem Fire. Treatment patterns and prescriptions from Step 4 are adjusted and refined to incorporate multiple resource objectives, such as reducing stand densities, maintaining habitats, making treatments cost effective, and mitigating potential impacts to watershed conditions and landscape visual character. The primary goal, however, is to continue to maintain a treatment scenario that meets the primary objective of changing the outcome of the problem fire. As in Step 4, performance in changing wildfire outcomes is assessed.

Step 6: Adjust and Refine the Treatment Scenario Developed in Step 4 Based on Information from the Field and Other Relevant Sources. During this step, some potential treatment areas as well as past treatments are reviewed in the field, especially those that have been affected by wildland fire. Information from past treatments and fire impacts inform the current fireshed assessment process in making coarse-scale refinements or adjustments to treatment designs, analysis assumptions, or both. *—Bernhard Bahro, Laurie Perrot*

Focusing fuel management funds on the wildland–urban interface may preclude or hinder the use of prescribed fire because of safety or air quality concerns. Fuel buildup near communities may require mechanical fuel reduction before prescribed fire can be safely used, if it can be used at all. Although prescribed fire managers have effectively worked for years with impacts on air quality (see Chapter 21), sensitive species (see Chapter 23), cultural resources, and other environmental issues, many of these projects were in remote areas away from the public. With the current emphasis on fuel reduction projects in the wildland-urban interface, there is greater likelihood of public interest, concern, and involvement. Controversy can arise when smoke blows into neighborhoods or concerns arise about mechanical treatments, particularly with regard to thinning being a pretext to allow logging.

Choosing the methods to be used for fuel management is becoming a more complex process with more choices available and more considerations necessary. As fire and fuel management become a greater focus of the land managers and the public, more information and scientific understanding are needed to answer the public's questions. Public acknowledgment of the scope and scale of the fire and fuel issues in California wildlands brings with it increased levels of scrutiny and accountability.

History of Fuel Management: The Evolution of a Fuel Emergency

As detailed in Chapter 17, Native Americans used fire to modify fuel for several thousand years prior to the arrival of European settlers. Some Native American fire practices were continued in modified forms by the early European settlers. Ironically, one of the first widespread modifications of Native American fuel patterns came with the introduction of large numbers of domestic livestock, which eliminated most of the surface fuel over large areas during the late 1800s. This was unintentional fuel management, but did result in widespread modification of fire patterns. The effort to exclude fire from ecosystems during the 1900s has resulted in additional fire pattern changes (see Chapter 18). We now know that the effect of these management efforts was to maximize fuel loads by allowing the uninterrupted accumulation of fuel.

A fuel condition emergency has been developing over the past 200 years and is now manifesting. From 2002 to 2004, four states—California, Arizona, Oregon, and Colorado—have experienced their largest wildland fires ever recorded. Additionally, Montana had thousands of acres burn during the 2003 fire season. The annual cost of suppression and rehabilitation are exceeding a billion dollars.

These catastrophic situations were foreseen decades ago by the pioneers in prescribed fire use in California. As noted by Carle (2002), government advocates of fire protection overrode ranchers, loggers, and other practitioners of "light burning." Interestingly, many of the arguments used against the practice of light burning are as valid today as they were in 1924: Fire damages young trees, is expensive, and is difficult to adapt to variations in fuel and topography. Fire suppression was viewed as more straightforward and practical. The difference today is the understanding we now have about the effects on both ecosystems and fire behavior that result from the accumulation of understory vegetation and fuel in the absence of fire.

The research and teaching of Dr. Biswell remains the cornerstone of the use of fire in California. His work and the work of his students, such as Bruce Kilgore, James Agee, Jan van Wagtendonk, Tom Nichols, and Ron Wakimoto, were instrumental in the establishment of prescribed fire and wildland fire use programs at Sequoia and Kings Canyon and Yosemite National Parks. Similar programs were established in national forests, refuges, and parks throughout California.

Therefore, it is useful to examine in some detail the techniques that Dr. Biswell and others used to support the transition of policy. The translation of Dr. Biswell's techniques from small demonstration burns to large prescribed burn units to landscape or drainage-sized prescribed fire projects has continued to be a challenge. The teachings of Dr. Biswell, however, contain the solution to this transition: patience and public education.

Dr. Biswell's lesson of patience has two elements. One is the more obvious technique of conducting prescribed burns slowly and carefully, not exceeding the holding capacity of the personnel present, as well as not exceeding the capacity of the ecosystem to absorb heat with undesirable amounts of damage or mortality. The other is bringing along the public, agency administrators, and cooperators slowly enough that their comfort level with the use of prescribed fire is not exceeded. It is often said that it has taken a century of fire suppression to cause the fuel condition of ecosystems we see today, and it might take a century of prescribed fire to restore these ecosystems.

The difficult task of the modern fire manager is to increase the size and magnitude of fuel management programs so that the fuel can be reduced and ecosystems can be restored at a significant rate while also building public support. Many land management agencies conduct prescribed fires, but at a rate and size trivial when compared to the size of the unit and scale of the wildland fire risk. It is the advancement of the size of prescribed fire programs from small research burns to ecologically significant landscape burns that requires skill and patience. This also requires a concomitant public education effort, which was the critical element of Dr. Biswell's methods, as well as those of the other early researchers in the successful use of prescribed fire.

Fire policy itself has become more complex, and in particular the measurement and mitigation of risk associated with prescribed fire operations. Although very few prescribed fires escape and cause damage to structures or property, the few that do cause such damage receive much media attention and result in even more risk mitigation policies to be written and managers to become more risk adverse and cautious. Escaped prescribed fires in California have had a profound impact on interagency cooperation in the implementation of prescribed programs. In 1957, the 202-ha (500-ac) Bogus Burn on the Klamath National Forest escaped and was controlled at 5,192 ha (12,831 ac) (Cermak 1988). After the Bogus Burn escape, prescribed burning on National Forests in California was severely reduced until the 1970s. The 1990 Bedford Canyon fire, an escaped prescribed burn on the Cleveland National Forest, burned onto private land into a subdivision and destroyed a dozen homes. This fire prompted state legislation that led to the development of the Cooperative Prescribed Fire Agreement between California and the federal agencies. The agreement formalized the multi-agency coordination to implement prescribed burns on multiple jurisdictions.

In 1999, the Lowden Ranch Fire escaped and burned through part of the town of Lewiston, destroying 23 homes. This escape served to increase public anxiety about the use of prescribed fire adjacent to towns and homes and increased northern California communities' interest in finding mechanical alternatives to prescribed fire in the urban-wildland interface. The Lowden Ranch escape also had significant impacts on fire management professionals. In the years following this fire, managers and prescribed burn bosses have become much more risk averse and concerned about both personal liability and the risk associated with performance of their jobs.

Air quality and smoke management policies frequently limit agencies' abilities to conduct fire management programs—ironically so because one of the purposes of prescribed burning is to *reduce* wildfires, which emit much more smoke than do prescribed fires (Agee 1989). The 1997 Beaver Creek prescribed fire on the Stanislaus National Forest was a turning point regarding prescribed fire and smoke management. Prior to this time, many county burn rules exempted all prescribed burns above 1,500 meters (6,000 feet) elevation in the Sierra Nevada. Counties frequently approved these exemptions to allow fire managers to burn on "no burn" days. The Beaver Creek burn and a number of other burns on adjacent parklands, CDF management units, and forests were approved simultaneously. An unforecasted weather pattern caused the smoke from these fires to impact most of the Sierra Nevada, the Central Valley, and the Reno and Lake Tahoe areas. This event precipitated the revision of the state burning regulations and heralded a new era in regulation of smoke from prescribed burns. Public concerns about smoke put air quality regulators in the difficult position of trying to both protect the public from unhealthful air and support fire managers in their use of fire.

The issues of invasive plants, which may take advantage of prescribed fire or mechanical fuel treatment to become established, is a growing concern (see Chapter 22). This problem is particularly severe in the deserts and chaparral of California and is thoroughly discussed in Chapter 16. The effects of prescribed fire on sensitive species are often poorly understood; managers are often reluctant to allow prescribed fires that may have deleterious effects on sensitive species or their habitats (Knapp et al. 2005, Stephens and Moghaddas 2005c) (see Chapter 23). Because of these and many other issues, the responsibilities of state and federal fuel managers have become increasingly more rigorous. Considerable time and effort are spent addressing technical issues such as burn plan development and approval, acquisition of permits, budget formulation and tracking, and the mobilization of sufficient fire resources to conduct burns or implement treatments.

Too often lost in the effort to conduct fuel management has been the more qualitative issue of public education, the same issue that was so important in the original public promotion of the need for prescribed fire to the public. One of the most encouraging developments of the last few years is the cooperative education and planning efforts of fire managers and the public. The California Department of Forestry and Fire Protection, in trying to develop community involvement at the local level through the state's California Fire Plan, encouraged the development of fire-safe councils throughout the state. These councils have sprung up in both rural and suburban communities. The primary objective of the councils is involving citizens in creating defensible space around their homes and in working together to design protection strategies for their communities. These groups are increasingly interested, as they should be, in influencing fuel management priorities on areas adjacent to their communities and are influencing the design of projects and the expenditures of funds by federal, state, and local government fuel managers.

Another interagency group, the California Fire Alliance, created a one-stop grants application web site for National Fire Plan grants in California. The purpose of this clearinghouse is to provide a California-wide view of community-based fuel treatment projects to estimate funding needs and to evaluate the capacity of communities and organizations to conduct fuel treatment, education, and fire hazard reduction planning.

These are encouraging trends in a state that clearly needs a force to galvanize interagency cooperation and cohesion in development of fuel management strategies. The continued implementation of fuel management in California absolutely requires the involvement of the public in issues such as smoke management that require cooperation between a variety of agencies and regulators. The ability of land managers to educate the public and gain their support for prescribed fire programs is directly linked to the survival of these programs.

Managing Fuel in Twenty-First–Century California

Recent fire history in California is characterized by what have been come to be called "fire sieges" (CDF and USDA Forest Service 2004). These are periods when multiple, large fires briefly overwhelm the considerable fire-suppression capability of federal, state, and local government fire departments. These events are costly and large enough to capture the attention of media, government, and the people of California. Such fires directly impact the cities and towns in the paths of the fires. Homes, businesses, and lives are lost. Closed highways, electrical power disruptions, and large-scale evacuations impact the economies of large areas of the state. During a 13-day period in 1970, wildfires in Southern California burned 230,000 hectares (580,000 acres), destroyed 772 homes, and killed 16 people. The most recent of these sieges occurred in Southern California in late October of 2003 when wildfires burned 303,514 hectares (750,000 acres), destroyed 3,652 residences, and killed 22 people.

California's forested mountain ranges have also been affected by fire sieges. These sieges are characterized by multiple, large, lightning fires burning under very dry conditions (Weatherspoon et al. 1992). Numerous fires start in remote or rural areas and burn large areas in the national forests, parks, and rangelands of the Klamath Mountains, Coastal Ranges, Cascades, and Sierra Nevada. The most notable recent sieges were in 1977 and 1987. Throughout the course of the twentieth century, such events in the Sierra Nevada have shown an increased *percentage* of the area burned being impacted by crown fire and exhibiting tree mortality, even though the *number* of hectares burned in the Sierra Nevada range and California has not increased significantly (McKelvey and Busse 1996, Stephens 2005).

Each of these fire sieges has had a profound impact on the fuel management program in the state, stimulating fact-finding reviews and investigations. Reports, commissions, and local government bodies uniformly recommend that fuel management be expanded to protect communities, improve the efficiency of fire suppression, and lessen impacts on natural resources. There is a surge of public and government support for fuel management programs in the wake of these events. This support translates into increases in funding for all types of fuel treatment. A task force on California's wildland fire problem was convened after the severe fires of 1970 and made a number of recommendations that still ring true today: require hazardous fuel abatement adjacent to structures, strengthen research efforts, improve fuel management planning efforts, expand the prescribed burning program in chaparral, and create a network of fuel breaks and greenbelts (Anonymous 1972). The requirement for defensible space subsequently became part of the state code. And the other recommendations were implemented, but only for a time. Funding gradually decreased, treated acres declined, and fuel breaks were left unmaintained. More importantly, the initial efforts failed because the treatments were not monitored, and we learned little about the effects of those treatments on fire hazard and fire regimes. In every case, there has been a marked increase in treated acres subsequent to these sieges, but a failure to carry through on the recommendations over the longer term and gather vital landscape-level data to adapt and improve programs in the future.

It has been said that the wildland–urban interface is a defining fire management issue of the twenty-first century. Pyne (1982) noted, however, that these interface issues have been a part of fire management as long as fires have burned from wildlands into communities. The 1991 Oakland Hills fire, for example, had a precedent in the 1923 Berkeley fire. What was new was the number of homes and communities that have been, and continue to be, constructed in the interface, greatly increasing the number of people and amount of property at risk. Many of these homes are at risk not so much because of the build-up of fuel, but because homes and towns are constructed in vegetation types that naturally burn with high intensity and rapid spread. Comparisons of structure density in the footprint of the Laguna fire of 1970—an area burned again in the Cedar fire of 2003—showed that the number of structures has increased fivefold (Husari et al. 2004). Fire management in the interface is clearly one of the major natural resource issues for California as the twenty-first century begins.

Continuing development in the interface area is reorienting fire resources and funding for fuel management programs. Allocating firefighting resources to protect homes and communities, rather than to suppress the fire itself, is one reason for increasing costs and size of wildfires. Simultaneously, the increased threat of wildland fire to the public has also influenced the magnitude and pattern of allocation of fuel management funding appropriations at the national level.

Increasing loss of homes in the interface has spurred Congress to allocate more fuel management funds to treat more acres at risk. Congress has accepted the argument made by land managers that expanding fuel treatment to work in concert with suppression resources is an important part of the solution to the escalating costs of wildland fires.

The Risk of Fuel Management Projects

It is important to recognize that fuel management, particularly prescribed fire, involves inherent risk to both natural resources and communities. Changes in the federal policy emphasizing the importance of the restoration of the natural role of fire have led to a greater use of prescribed fire. This, in turn, has led to an increased potential for escaped prescribed fires or for smoke episodes from larger or multiple burns.

The 2000 Cerro Grande prescribed fire, which escaped from Bandelier National Monument and burned into the community of Los Alamos, New Mexico, led to a number of refinements to increase control of prescribed fire by federal agencies, including an emphasis on the availability of fire suppression resources should weather conditions deteriorate. Prescribed fire does carry inherent risk with it, but the risk can be analyzed, mitigated, and reduced with better identification of the nature of the risk.

Similarly, health impacts from smoke continue to be a source of liability. Planning, modeling, and mitigation of the volume and extent of smoke impacts are needed to anticipate and avoid those impacts. As with other aspects of prescribed fire, the use of monitoring equipment to show what health standards have, or have not, been violated is a basic part of the program.

Even without the risk of escaped fire, fuel management brings additional risks. Fuel management in forested ecosystems commonly seeks to reduce the potential for catastrophic, high-intensity crown fires. This is accomplished by reducing the overall fuel loads and reducing the continuity of crown fuel. Over time, this is a transition from a high-severity crown fire regime to a low-severity surface fire regime. It is important to understand that this does not usually mean less fire, but rather more frequent fire. Although surface fires are certainly more easily controlled by suppression efforts, the amount of fire over time often increases.

The Cost of Not Implementing Fuel Treatments

Since the 1940s, many wildfire experts have warned of the effects of allowing fuel to accumulate far beyond natural levels. Harold Weaver, Harold Biswell, Roy Komarek, Ed Komarek, and Bruce Kilgore all stressed the need for the restoration of fire to the ecosystem and for the need to manage fuel loads to mitigate the occurrence of high-intensity, destructive wildland fires. Their predictions have proven all too accurate. The cost of *not* doing fuel management projects, therefore, is increasing damage to cultural and natural resources, higher suppression costs, degraded air quality, loss of revenue to communities, and, of paramount importance, increased risk to firefighter and public safety.

The cost of not doing fuel treatments is larger and more damaging fires, because incident commanders and fire chiefs will not put firefighters in harm's way to bring more-intense fires under control under worst-case fire conditions. Changing climates may further escalate the fire management problem (Fried et al. 2004).

The Future of Fuel Management in California

The future of fuel management in California, and its implementation at a level of activity that significantly reduces hazardous amounts of wildland fuel and restores and maintains healthy ecosystems, will require state, local, and federal fire managers to work more closely with the citizens of California. This will require the ability to make the highly technical field of fuel management intelligible to the citizens of California and greater efforts by fire managers to understand the public's point of view. It requires a balance of treatment types and careful decisions concerning priorities for use of mechanical fuel reduction methods, prescribed fire, and wildland fire use based on monitoring treatments and adapting programs (Sidebar 19.3).

Communities and fire management agencies must cooperate in the development of risk reduction fire and fuel management programs. It is this cooperation between the public and the government agencies in the reduction of wildfire damage, and the restoration of fire to a more beneficial ecological influence, that is the cornerstone of the new fire policies.

Beyond these efforts to inform and communicate, there is an even greater need to educate, which brings us back full circle to the lessons taught by Dr. Biswell and others. Support for and understanding of fuel management programs should be a year-round activity—and not limited to fire season. The future of fuel management, which must include the increased use of mechanical treatment and prescribed fire, depends on not only the acquisition of funding, personnel,

SIDEBAR 19.3. PRESCRIBED FIRE AND FUELS MANAGEMENT IN SEQUOIA AND KINGS CANYON NATIONAL PARKS

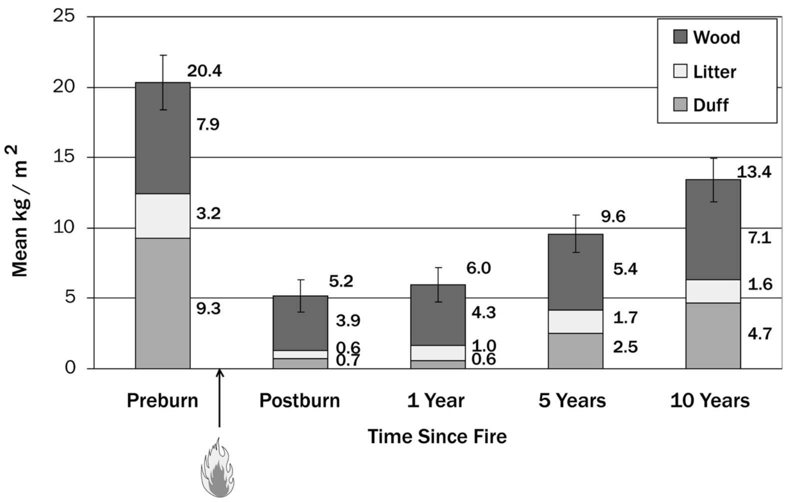

FIGURE 19.3.1. Fuel accumulation in the Giant sequoia-mixed conifer forest type (n = 26 plots). Error bars indicate 80% confidence interval.

Early studies in the giant sequoia forests of the Sierra Nevada demonstrated that a long period of fire exclusion had created heavy accumulations of fuels and an increased density of young trees. Scientists recognized that these conditions, if left unchecked, might promote uncharacteristically intense and/or extensive fires with potentially undesirable effects. In response, National Park Service managers at Sequoia and Kings Canyon National Parks began a prescribed fire program in 1969 (Fig. 19.3.1). Although early observations and limited short-term data indicated that these prescribed fires seemed to be effective, consistent, reliable data to demonstrate program success and long-term trends were lacking (Keifer et al. 2006).

How to Burn

The Sequoia-Kings Canyon National Park fire effects monitoring program was started in 1982 to provide feedback to help guide the prescribed fire management program (National Park Service 2003). Monitoring efforts are designed to determine if fuel reduction and other objectives are being met, to help detect unexpected consequences of prescribed burning, and to provide this information to fire managers, other park staff, and the public.

To most efficiently monitor fire effects, the mixed-conifer forest is stratified into three different types based on species composition and physiographic characteristics: the giant sequoia–mixed conifer, white fir–mixed conifer, and low-elevation–mixed conifer forest types. The fuels portion of the monitoring program measures dead and down organic matter on the forest floor (surface fuels) including litter, duff, and woody fuel using a planar intercept method (Brown 1974, Brown et al 1982). Surface fuels are measured in plots before and after the area is burned under a specified range of environmental conditions (temperature, relative humidity, wind, and fuel moisture).

The objective for fuel reduction in all forest types is a 60%–95% removal of total surface fuel load. Postburn monitoring results have revealed that the fuel reduction objective is met or exceeded in all

TABLE 19.3.1
Reduction in total surface fuels immediately after prescribed fire by forest type

Forest Type	*Fuel Reduction: 80% Confidence Interval (Mean)*
Giant sequoia-mixed conifer (n = 28 plots, 18 fires)	71%–81% (76%)
White fir-mixed conifer (n = 10 plots, 6 fires)	62%–85% (73%)
Low-elevation mixed conifer (n = 5 plots, 3 fires)	75%–93% (84%)

FIGURE 19.3.2. The prescribed fire program at Sequoia and Kings Canyon National Parks treats undesirable fuel conditions. (Photo by MaryBeth Keifer, National Park Service.)

three mixed-conifer forest types (Table 19.3.1), indicating that the range of burning conditions are appropriate for the desired fuel reduction.

When to Burn

Tens of thousands of acres of mixed-conifer forest in the parks were in need of prescribed fire treatment to reduce fuels and restore fire. It has taken decades to attempt to apply fire over such a large area, and returning to areas for repeat prescribed burns was not a priority early in the management program. More recently, managers have begun to apply repeat treatments; therefore, making decisions about the timing of second (and subsequent) prescribed burns is necessary to prioritize areas for treatment.

Results from long-term monitoring provide managers with critical data that track the accumulation of fuels over time in areas burned and thus can provide insight into when future fuels treatments are needed. In the giant sequoia-mixed conifer forest, fuel load had reached 66% of pre-burn levels by 10 years post-burn (Fig. 19.3.2). This result means that reburns for fuel reduction should be considered after 10 years following the initial burns if managers want to avoid a return to heavy pre-burn fuel load conditions in this forest type. By 10 years post-burn in the white fir–mixed conifer forest type, mean total fuel load was 83% of pre-burn levels, indicating that reburns for fuel reduction should be more strongly considered after 10 years in this forest type.

In the low-elevation–mixed conifer forest, total fuel load accumulated to 58% of pre-burn levels by five years post-burn, faster than in other forest types. Much of this accumulation is woody fuel due to the high amount of post-burn tree mortality that occurred in this forest type. While the sample size is limited (five plots), data from these five-year post-burn plots indicate that reburning may be warranted sooner than in other forest types to prevent fuels from accumulating to pre-burn levels.

The timing of reburns based on fuel accumulation also corresponds to historic fire return intervals (time between fires) and the differences in return intervals by elevation. Historic fire return intervals in the giant sequoia–mixed conifer and white fir–mixed conifer forests ranged from 2 to 30 years, with a mean of 10 years (Kilgore and Taylor 1979, Swetnam 1993, Stephens and Collins 2004, Moody et al. 2006). Fire return intervals decrease with decreasing elevation (Caprio and Swetnam 1995), therefore, the more xeric low-elevation–mixed conifer forests are likely to have had more frequent fires than the other mixed conifer types. The correspondence of fuel accumulation patterns with historic fire return intervals demonstrates that park managers may be able to achieve the simultaneous goals of reducing fuel hazard and restoring natural fire regimes.

Long-term fuel monitoring may also have important implications for smoke management and emissions modeling. For example, the dominant component of the pre-burn fuel complex is duff, while woody fuel, which produces less smoke than smoldering duff, tends to make up a greater proportion of the post-burn fuelbed (Fig. 19.3.2). Monitoring results from seven giant sequoia–mixed conifer plots show lower total fuel reductions for second treatments (48%) than in the initial burns (76%). In addition, a smaller proportion of duff was consumed in the reburns (47%) than in the initial prescribed fires (89%). It seems likely that the amount of smoke produced by individual burn units will be reduced after multiple treatments are implemented.

Integrating Results into Management Actions

Fuel and fire effects monitoring has become a critical component of Sequoia and Kings Canyon National Parks' fire management program and results from the monitoring program demonstrate the usefulness of long-term information. The ecology of fire and fuels management is often not simple. The issues are made even more complex by agency missions and political mandates that may present managers with multiple goals such as reducing fuel hazards while at the same time restoring and maintaining natural processes. Understanding fuel dynamics through long-term monitoring in these systems is an important part of helping managers to answer critical questions that will better address complex goals and continually improve the way that public lands are managed. *—MaryBeth Keifer* and technology, but also the construction of a base of public support for the program. This base of support will help cushion the program from incidents that may occur, such as smoke episodes, changes in scenic resources, and even escapes. The building of support is a year-round process, and its success or lack of success will directly affect the activity and acceptance of the fuel management program. This is the lesson we can learn from Dr. Biswell and the other prescribed fire pioneers, and was the key to their success in convincing agencies to change from fire control to fire management.

Conclusion

Fuel management programs in California do not suffer from a lack of public interest. However, they consistently have lacked a clear focus that could carry across the multiple jurisdictions, varied fire regimes, and political and demographic landscapes of California in a way that could truly influence large fires and sustain biodiversity and ecosystem health. Every fire siege, expensive fire season, and escaped prescribed fire generates new fuel management policies and initiatives before previous decisions have been tested or evaluated. There is an increasing call for fire management strategies and programs that are developed and monitored in a consistent and cohesive manner (USDI 2001). The National Fire Plan of 2001 kicked off efforts to establish a single federal fire policy rather than a set of loosely coordinated agency approaches to fire management. The National Fire Plan has been expanded to do a better job of considering the needs of state and local fire departments, as reflected in the Western Governors' Association's 10-Year Strategy (www.westgov.org/wga/initiatives/fire/final_fire_rpt.pdf). The California Fire Plan, released by the CDF in 1999, takes a collaborative and iterative approach to involving citizens in designing fuel management strategies and aggregating these up into a statewide approach to fuel management and fire protection.

Priority setting for fuel management will always be a difficult task in California. The sheer number of vegetation types and fire regimes described in the preceding chapters illustrates the difficulty of sorting out fuel management techniques appropriate to each of these assemblages of fire-adapted plants and animals. The selection of fuel management techniques is further complicated by how the land is used and how many people live nearby. Is it wilderness or is it private land? Is it allowable or practical to use mechanical treatment methods to reduce accumulated fuel? These factors also influence how fuel treatments are distributed in the landscape. With all the barriers to implementation, it is clear that we should use every tool available to us, including—and especially—decision support tools, which help us in distributing fuel treatments in the most efficient way, and monitoring, which helps us understand what works and what does not. There may come a time when mechanical treatments are the dominant fuel treatment available to managers for reducing fuel. Prescribed fire and wildland fire use may only be possible in a few areas that we designate, where fire is absolutely essential to preserve a few of the best examples of fire-adapted ecosystems. That time has not arrived—yet. We must work together to make sure that we delay, rather than hurry, that day into existence. The alternative is that we lose much of what we have worked so hard to describe in this book, in all its beauty, variety, and complexity.

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