WILDFIRE MANAGEMENT ON A HUMAN-DOMINATED LANDSCAPE

California Chaparral Wildfires

Jon E. Keeley, Ph.D., and CJ Fotheringham

Catastrophic wildfires are an outcome of the California vegetation and climate. These fires are driven by severe weather, and fire management is unable to prevent or stop them. Unlike many western forests, where fire restoration is needed to reduce fire hazard and return natural processes, California shrublands need greater protection from an increasing onslaught of fires. Fuel modification at the wildland-urban interface and better land planning are important future needs.

Jon E. Keeley *is a research scientist with the U.S. Geological Survey and a professor of biology at the University of California, Los Angeles. He has authored over 250 research papers dealing with the ecology, evolution, physiology, and taxonomy of California plants. His current research is on historical patterns of burning and their effect on alien plant invasions. Jon resides near Sequoia National Park in the community of Three Rivers, California.*

CJ Fotheringham *is a doctoral student in the Department of Ecology and Evolutionary Biology at the University of California, Los Angeles. Her research is focused on the evolutionary patterns of species response to fires in Mediterranean-climate shrublands of California and South Africa and in non-Mediterranean-climate shrublands of the Southwest. She has published papers in* Science, Ecology, *the* Journal of Ecology, *and various other international journals. CJ resides in Los Angeles.*

Chaparral covers sandstone formations in the Hurricane Deck region of the San Rafael Wilderness, Los Padres National Forest, California. Chaparral—a mixture of shrubby plants adapted to dry summers—is "made to burn," containing volatile oils that help to spread the fire.

Since 1970, 12 of the nation's 15 most destructive wildfires have occurred in California, costing the insurance industry $4.8 billion,[1] the most destructive being the firestorms of October 2003 (see Box 1). That California leads the nation in fire losses is not surprising since, with more than 33 million people, it is the most populous state in the nation. Almost all of these fires have occurred in shrublands rather than in forests, which should also not be surprising since chaparral is the most extensive vegetation type in California, covering over 8.8 million acres (3.6 million hectares),[2] or one-twelfth of the state, and is a highly flammable plant community. Relative to the national focus on western forests, there is need for greater attention on the California wildfire problem, not just because it accounts for most of the losses in property and lives in the nation, but also because fire management practices appropriate for other parts of the country often are inappropriate for this region.

Fire Regimes and Fire Management Options

The term *fire regime* refers to the types of fuels consumed (surface or canopy fuels) and the intensity, frequency, and seasonality of fires in an area; the fire regime in any particular place is dictated by climatic factors, the fuel characteristics of the vegetation, and the pattern of natural lightning and human ignitions. Understanding the fire regime of an area is critical to developing an effective management policy, and the diversity of fire regimes over the North American landscape means that there can be no single model of how fire managers should approach fire hazard. Two examples illustrate this point: the ponderosa pine forests of the southwestern United States and California's chaparral shrublands. Historically, fires in southwestern ponderosa pine forests typically burned in frequent, low-intensity surface fires that, because of widely spaced canopies and sparse, patchy understory fuels, burned only as high-intensity crown fires on a limited spatial scale.[3] In contrast, chaparral shrublands always burn in high-intensity crown fires that typically kill all aboveground biomass, and low-intensity chaparral surface fires are unknown.

One critically important difference between these extremes is that a century of fire suppression policy has been very effective at excluding fires from many forests in the western United States, but not from southern California shrublands (see Box 2). Before we consider chaparral, however, it will be instructive to understand the factors contributing to fire suppression impacts in forests.

Certain attributes of western forests allow rapid fire suppression: mountain climates have a much shorter fire season; ignitions are commonly from lightning, under weather conditions not usually conducive to rapid fire spread; and fires typically spread by surface fuels, which produce lower flame lengths. Over much of the 20th century, these characteristics have led to highly successful fire suppression, equivalent to fire exclusion, over much of the West.

Consequently, western forests now have an unnatural accumulation of surface fuels, and an increased density of young, shade-tolerant trees. Increased density of young trees is perhaps the more serious problem because these saplings act as ladder fuels that change fire behavior from surface fires to lethal crown fires. In addition to fire suppression, heavy livestock grazing has also contributed to fire exclusion by reducing herbaceous fuels in some forest types.[4] While fire exclusion has contributed to these dangerous fuel conditions throughout the western United States, other land use practices such as logging have also played a role. Logging encourages the dense ingrowth of young trees and increases surface fuels from slash left on the site. In fact, one recent study of factors determining fire severity after a large northern California fire attributed more fire damage to past timber practices than to fire exclusion.[5] In contrast to the situation in western forests, California shrublands have not experienced fire exclusion,[6] nor are fuel levels outside the historical range of variability.[7]

SHRUBLAND FIRES

In California, most large and deadly fires are chaparral fires, and we must understand their causal factors if we are to reduce the losses from such catastrophic events. The solution is not simply to allocate more resources to fire management activities. Indeed, for the latter half of the 20th century, every decade has been followed by a decade of increased expenditures on fire suppression activities, yet each decade has also been followed by one of increased losses in property and lives.[8]

One of the major reasons for the inability of fire managers to stop losses from chaparral fires is that for most of the last several decades, both scientists and managers have approached chaparral management with a one-size-fits-all model. It seemed intuitive that if fire suppression had excluded fires from ponderosa pine forests and had created a dangerous fuel buildup, other landscapes with a similar fire suppression policy would experience the same unnatural fuel buildup. However, we now know that in coastal California's chaparral landscapes, fire suppression policy cannot be equated with fire exclusion (see Box 2), and that for most of the 20th century, California's chaparral shrublands have burned at close to or higher than natural frequencies.[9]

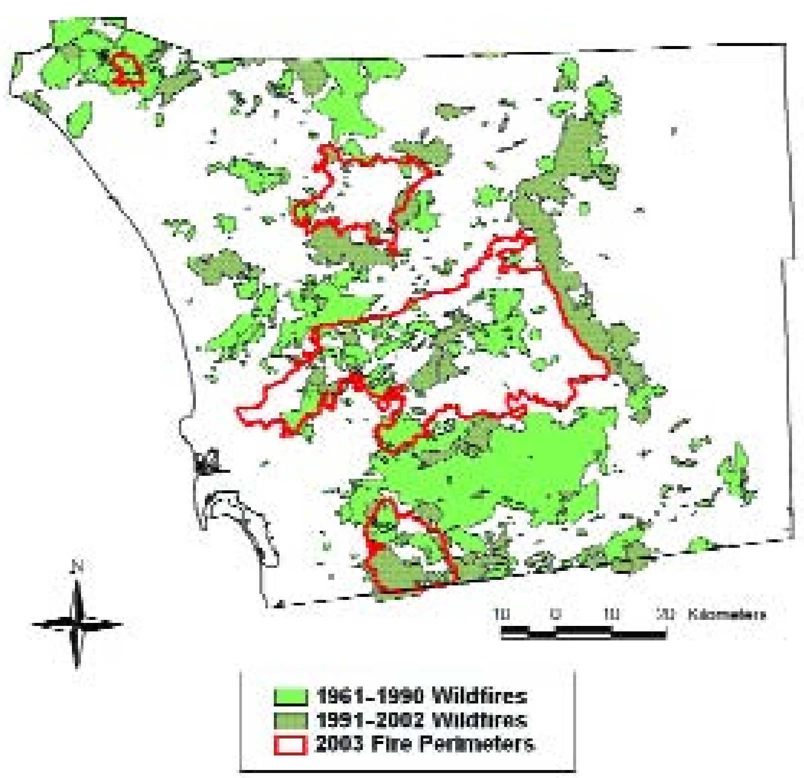
Box 1. October 2003 wildfires in southern California

The southern California fires of late October 2003 were the largest fire event in California's recent history. In over a half-dozen separate fires, more than 742,000 acres (364,000 hectares) of wildlands burned, in many cases through a complex mosaic of urban and wildland fragments, as well as across the well-defined and extensive wildland-urban boundary. A total of 3,361 homes and 26 lives were lost in this event, which stands as one of the costliest disasters in California, exceeding previous fires, earthquakes, and other natural disasters.

The October 2003 fires burned through diverse plant communities, but the proportion of different vegetation types burned was not reflected in the media coverage, which made it appear as though most were forest fires. This mistaken image was undoubtedly due to the fact that some of the fires burned in unnaturally intense and spectacular crown fires in forests with important recreational value and relatively high-density housing. However, coniferous forests made up only about 5 percent of the total acreage burned.[1] Most of the burned landscape was chaparral shrublands, and nearly all of the loss of property and lives was due to these shrubland fires. Nonetheless, this important fact did not prevent exploitation of the disaster by timber advocates as further justification for extensive forest thinning or clearcutting.[2]

San Diego County suffered the most from these shrubland fires, especially the Cedar Fire (center red outline, Figure 1), which at 273,230 acres (110,620 hectares) is the largest fire in official California records dating back to circa 1910.[3] The fires burned through a mosaic of young and old fuel classes, and the behavior of the fires was largely dictated by the powerful Santa Ana winds. Despite extreme fire conditions, the public expected fire suppression forces to directly attack these infernos. Illustrative of the misunderstanding associated with the causes of these fires was the claim by one major insurance company that policyholders who lost property did so, not because of unavoidable aspects of weather, fuels, or other attributes of the fire, but because of mishandling of the fire by agencies with firefighting jurisdiction.[4]

Figure 1. Fuel ages burned by Santa Ana wind-driven fires in San Diego County, California, October 2003



Red outlines, from top to bottom: Roblar Fire, Paradise Fire, Cedar Fire, Otay Fire.

Source: Adapted from J. E. Keeley, CJ Fotheringham, and M. Moritz, "Lessons from the 2003 Wildfires in Southern California," *Journal of Forestry* 102, no. 7 (2004): 26–31.

It is now becoming clear that the age and spatial pattern of fuels are minor factors controlling the ultimate size of chaparral fires (see Box 1 and Figure 1). Indeed, fire frequency analysis in chaparral from northern Baja California to Monterey has shown no strong relationship between fuel age and fire probabilities.[10] Instead, in nearly all areas, the hazard of burning increases only moderately with time since the last fire. A more localized investigation of historical burning patterns in Los Angeles County found a similar pattern, but with an increasing probability of burning during the first two decades after the last fire.[11] However, the apparent resistance to burning by young age classes exhibits a strong interaction with fire weather conditions; although the probability that fires will burn out in young age classes during moderate weather is high, under severe winds, fires readily spread through young stands of chaparral.[12]

The reason fuels play only a minor role in controlling large fires in southern California chaparral is because this region has the worst fire climate in the country, with extreme winds capable of overcoming any potential fuel limitation (see Box 3). These winds, known as Santa Anas in southern California and as Diablo winds in the San Francisco area, result in stormlike conditions producing wildfires commonly referred to as "firestorms." Under these conditions firefighters are forced into defensive actions until the weather changes. In the Santa Monica National Recreation Area northwest of Los Angeles, the 12 largest wildfires in recorded history ranged in size from 16,000 to 43,000 acres (6,700–17,400 hectares), and all were autumn fires driven by Santa Ana winds.[13] In other parts of southern California, large fires are usually associated with Santa Ana wind conditions, and the very destructive ones nearly always are (see Table 1).

Further illustrative of the overriding importance of these winds is the relationship between large fires and drought. Throughout the western United States, large fires are usually restricted to periods of extreme drought.[14] However, in southern California, Santa Ana winds are just as likely to cause a large fire during a wet year as during a dry year.[15] Antecedent climate does appear to play a role in that it increases the length of the fire season, because large fires over 5,000 hectares that occur outside the Santa Ana season take place only during drought.

Three Key Points About Chaparral Fire Management

- Large, high-intensity wildfires are a natural feature of chaparral landscapes. They occurred prior to Euro-American settlement and will take place again in the future.
- Twentieth-century fire management practices have been ineffective in preventing chaparral wildfires.
- We need to view chaparral fires as we do other uncontrollable natural disasters and to focus on developing human infrastructure capable of minimizing their damage.

History of Large Chaparral Fires

The 2003 firestorms (see Box 1) were natural events that have been repeated on the California landscape for eons. Studies of charcoal depositions extracted from ocean bottom sediment cores off the coast of Santa Barbara have found that the frequency of large fires has not changed in the past 500 years.[16] Indian legends from tribes in the vicinity of the current San Diego County also describe a mass migration of local tribes due to a massive wildfire.[17]

Although the October 2003 Cedar Fire (see Box 1) was the largest in California since official fire records have been kept, historical accounts portray even larger fire events. A *Los Angeles Times* article on September 27, 1889, described a fire near Santa Ana three times larger than the recent Cedar Fire: "The fire which has been burning for the past few days still continues in the canyons. The burned and burning district now extends over 100 miles north to south, and is 10 to 18 miles in width." In fact, collectively, fires in southern California during late September 1889 exceeded all of the October 2003 acreage burned; another fire ignited that same week in September 1889 in

Box 2. Contrasting fire regimes

Western U.S. conifer forests have had a long history of mostly low-severity fires, as revealed in studies relating annual tree rings to fire scars embedded in the wood. Such fire records are possible wherever low-severity fires scar but do not kill trees.

Throughout the western United States, researchers have investigated literally thousands of tree records, which have revealed a remarkably similar pattern from New Mexico to California. Prior to the 20th century, forest fires were frequent, occurring every 10 to 20 years, but since the beginning of fire suppression activities in the early 1900s, tree rings show almost no fire scars.[1] In these forests, a century of fire suppression has succeeded in excluding fire.

In contrast, shrubland fires are always lethal crown fires that eliminate any records of past fires. The U.S. Forest Service and other agencies, however, have very good written records that are relatively accurate indications of 20th-century shrubland burning patterns. Those records show that in coastal California, substantial acreage has burned every decade throughout the century, indicating that fire suppression policies have never excluded fire from these landscapes. The written records also demonstrate a fire rotation interval in coastal California shrublands of 30 to 40 years for much of the 20th century.[2] It is doubtful that fires were ever much more frequent, since 20 to 30 years is near the limit of fire tolerance for many of the dominant native shrubs.

Box 3. Santa Ana wind-driven fires

Southern California has the worst fire climate in the country, largely because of the regular autumn foehn winds, known as Santa Anas.[1] Although massive wildfires anywhere in the world are usually driven by severe fire weather, such conditions are generally not annual events. Southern California is an anomaly, and severe fire weather conditions occur every autumn. Lasting from a few days to a week or more, a high-pressure cell over the Great Basin, coupled with a low-pressure trough off the Pacific Coast, leads to very high offshore winds (60–100 km/hr) with a relative humidity of below 10 percent. Under these conditions firefighters are forced into defensive action that includes evacuating homes ahead of the fire front and protecting property on the periphery. Fire containment does not occur until the weather changes.

San Diego County, near Escondido, and in two days the same Santa Ana winds blew it all the way to downtown San Diego,[18] a distance roughly equal to the long axis of the 2003 Cedar Fire. Other large 19th-century fires are known from other counties in coastal California.[19]

While large wildfires were reported throughout southern California during the 19th and early 20th centuries, it was only in the latter half of the 20th century that they routinely resulted in major loss of property and lives.[20] The primary reason for this development was not a change in fire behavior but rather the fact that California's population had grown exponentially.[21] As a consequence, urban sprawl placed huge populations adjacent to watersheds of dangerous fuels. In addition, because 95 to 99 percent of all fires on these chaparral landscapes are started by people, as populations grew, fire frequency increased (see Figure 2), which in turn increased the chances of ignitions during Santa Ana wind events. Prior to entrance of Native Americans into North America, lightning was a potential source of ignition for Santa Ana wind-driven fires since there is significant overlap in their seasonal distribution; thus such fires were likely a natural feature of this landscape, albeit at a lower frequency than observed today.[22]

The key point here is that massive fires have occurred at periodic intervals in the past and likely will occur again in the future. It may be more useful from a planning and management perspective to see these events as we currently view 100-year flood events or other such cyclical disasters.

Twentieth-Century Shrubland Fire Management Practices

For the past several decades, southern California shrubland fire management has been based on the philosophy that prefire fuel management practices can control the ultimate size of these massive fire events. On California shrubland landscapes, the preferred treatment has long been prescription burning, applied on a rotational basis so that a mosaic of different-age fuels is created. These fuel modification treatments were expected to prevent large wildfires by creating mosaics that included patches of young fuel, which theoretically were expected to act as barriers to fire spread. However, over the past several decades, this management philosophy has not been effective at eliminating large, catastrophic fires.

Some would argue that the failure to eliminate catastrophic shrubland fires is due to inadequate funding of fuel treatments, coupled with restrictions on prescribed burning related to strict air quality standards and the danger of burning in wildland-urban mosaics. While these concerns are real,[23] nothing about the future economic outlook or environmental restrictions suggests that these limitations are likely to change, and we have good reason to believe that even if greater fuel modifications were possible, the hazard of catastrophic fires would not diminish.

The extent to which landscape-level fuel treatments are effective in shrubland fire is mainly a function of weather conditions during the fire event. The evidence is overwhelming that under extreme fire weather conditions such as the autumn Santa Ana winds, young fuels (Figure 1), or even fuel breaks, will not act as barriers to fire spread.[24] This is quite evident for southern California's October 2003 wind-driven wildfires (see Box 1). Crossing nearly the entire width of San Diego County's east-west burning Cedar Fire were substantial swaths of vegetation less than 10 years of age, not just in one, but in two parts of that fire (Figure 1).[25] Burning in San Diego County at the same time was the Otay Fire, which exhibited the same phenomenon: the fire burned through thousands of acres on which the vegetation was only 7 years of age. The primary reason young fuels cannot act as a barrier to fire spread under such severe weather conditions is that if high winds do not drive the fire through the fuels, the winds will spread the fire around them, or lift and carry firebrands over them to spread the fire a half-mile or more beyond the active front.

Table 1. Recent major fires in San Diego County

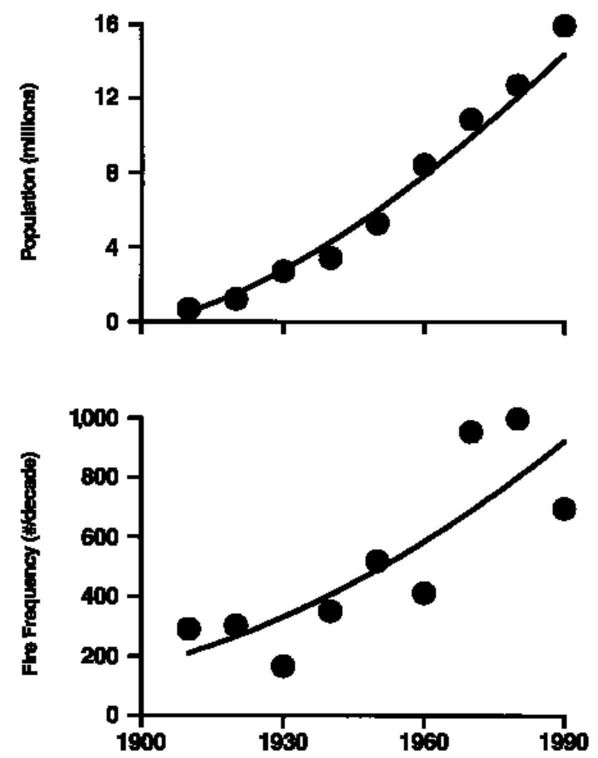
Most destructive fires occur during severe autumn Santa Ana wind conditions. Even in non–Santa Ana wind conditions, however, weather is still a contributing factor—for example, the July 2002 Pines Fire occurred during a heat spell and was accompanied by gusting winds.

Fire	Month/Year	Acres	LOST Structures	LOST Lives
*Cedar	Oct. 2003	281,000	2,232	14
*Laguna	Oct. 1970	190,000	382	5
*Paradise	Oct. 2003	56,600	169	2
*Harmony	Oct. 1996	8,600	122	1
Pines	July 2002	61,690	45	0
*Gavilan	Feb. 2002	6,000	43	0
*Viejas	Dec. 2001	10,350	23	0
La Jolla	Sept. 1999	7,800	2	1

Source: U.S. Forest Service fire records for the Cleveland National Forest, California. Acreage approximate.

*Santa Ana wind-driven fires.

Figure 2. Fire frequency and population growth in southern California, 1910–1990



Source: J. E. Keeley and CJ Fotheringham, "Historic Fire Regime in Southern California Shrublands," *Conservation Biology* 15 (2001): 1536–1548; J. E. Keeley and CJ Fotheringham, "Impact of Past, Present, and Future Fire Regimes on North American Mediterranean Shrublands," in *Fire and Climatic Change in Temperate Ecosystems of the Western Americas*, ed. T. T. Veblen, W. L. Baker, G. Montenegro, and T. W. Swetnam (New York: Springer, 2003), pp. 218–262.

What Is the Appropriate Future Fire Management Strategy?

Prefire fuel modifications will undoubtedly remain an important part of the southern California fire management arsenal, but their application needs to be carefully considered if they are to be effective and provide benefits equal to or exceeding their cost.[26] For example, fires burning under moderately calm wind conditions and high humidity have been observed to burn out when the fire encounters young fuels, and such fires are less likely to spread firebrands beyond these barriers. These fires, however, seldom present major problems for firefighting crews and do not pose a major threat to the loss of property and lives (see Table 1). Thus, serious attention needs to be paid to whether or not fuel treatments are cost-effective for these fires.

The key to effective use of prefire fuel modifications in crown fire ecosystems such as chaparral is their strategic placement. Under severe weather, lower fuel loads will not stop the spread of fire, but they do reduce fire intensity and thus provide defensible space for fire suppression crews. The chief benefit of prefire fuel manipulations in crown fire ecosystems is the enhancement of firefighter safety, and strategic placement is therefore critical to the success of these measures. However, much of the southern California shrubland landscape is far too steep to provide defensible space regardless of fuel structure, and thus fuel manipulations in these areas are unlikely to provide economically viable benefits. We suggest that fuel manipulations will be most cost-effective when focused on the wildland-urban interface. Homes are often lost during severe fire weather because firefighters refuse to enter areas that lack a buffer zone of reduced fuels sufficient to provide defensible space.

HOW DO WE MEASURE FIRE MANAGEMENT SUCCESS?

In terms of management goals, the metric for fuels treatments on these shrubland landscapes needs to change from simply measuring "acres treated" to consideration of their strategic placement. This change in management philosophy is being recommended by the Santa Monica Mountains National Recreation Area, the largest National Park Service unit in southern California.[27]

To accurately measure the success of fuel treatments, studies need to take a close look at the role of prefire fuel treatments versus weather during the fire. For example, in the Cedar Fire (see Box 1), fuel breaks were not effective at preventing major structural losses in adjacent subdivisions (see Table 1) because of the severe weather conditions during the early stages of the fire. In contrast, prefire fuel treatments northwest of the town of Pine Valley in eastern San Diego County may have saved that community from destruction by the Cedar Fire. However, the fire front threatened Pine Valley after the Santa Ana winds had died down and after the onshore breezes had brought cooler temperatures and higher humidity. If weather conditions had not improved, the fuel treatment area would have provided less of a barrier to fire spread into the community; that particular fuel treatment prescription therefore may not be an adequate standard for other fires threatening Pine Valley.

One justification for rotational prescription burning is that maintaining a large fraction of the landscape in young fuel-age classes reduces fire severity and thus enhances vegetation recovery. However, extensive studies of postfire recovery following the 1993 fires in southern California found that the impact of high-severity fires was variable, with both positive and negative effects on postfire recovery.[28] Five years postfire, researchers could find little discernable difference in chaparral recovery between high- and low-severity burn sites.[29] It would therefore be premature at this point to conduct expensive fuel treatments with the expectation of producing major improvements in postfire recovery of vegetation.

Another resource benefit of fuel treatments has long been thought to be their ability to reduce postfire flooding and sediment loss.[30] Presumably, if watersheds in proximity to urban environments were to receive prescription burning on a rotational basis, only a small portion of each watershed would lose excessive amounts of debris at any given time, and thus flooding and debris flow hazards would be reduced. However, any such patchwork of age classes is still vulnerable to large-scale Santa Ana wind-driven wildfires.[31] (See Box 1 and Figure 1.)

Alternatively, it has been suggested that, regardless of the size of burned patches, burning watersheds on a 5-year rotational interval would greatly reduce the immediate postfire sediment loss.[32] In the long run, however, this approach may not be cost-effective for several reasons. One critical determinant of sediment loss is the magnitude of precipitation in the first postfire year.[33] If rainfall is light, sediment loss is minimal, regardless of prefire stand age. But when burning is followed by a winter of high rainfall, sediment losses are considerable. Prescription burning at 5-year intervals greatly increases the probability of a fire being followed by an El Niño year of high rainfall, as contrasted with the probability of an El Niño year following a fire at its more natural return interval of 35 years. Cumulative sediment loss over the long term would also be much greater for 5-year burn intervals since such intervals would mean multiple peak discharges, as opposed to a single peak discharge over a 35-year burn interval. More important than any of these factors is that burning at 5-year intervals will almost certainly result in type conversion of native shrublands to alien grasses and forbs,[34] which would greatly increase the chances of slope failure in these steep watersheds.[35]

RESOURCE DAMAGE FROM FIRE MANAGEMENT PRACTICES

Fire management decisions often have negative effects on natural resources, but agencies differ in their ability to integrate fire and resource issues. Many local California fire departments as well as the California Department of Forestry and Fire Protection have reducing fire hazard as an overriding mandate; resource issues are often not primary concerns. Even in federal agencies more directly concerned with resource management, such as the U.S. Forest Service and the National Park Service, because of the complexities of modern management practices, fire management decisions are not always closely linked to resource management. As a consequence, fire managers are sometimes unaware of resource threats posed by fire management practices.[36]

Fire suppression and prefire fuel manipulations are management practices that have ecological equivalents in the roles played by equilibrium and disequilibrium processes in natural ecosystems. Fire suppression attempts to maintain ecosystem equilibrium by preventing disturbance, whereas prefire fuel manipulations introduce disequilibrium. Understanding how our management practices might simulate natural ecosystem processes may be an important step toward more effective adaptive management.

In forested environments such as ponderosa pine ecosystems, some of the dominant species have a reproductive cycle dependent on disturbance, and therefore the equilibrium conditions created by successful fire suppression have very negative impacts on the long-term sustainability of these forests.

In contrast, for many shrubland ecosystems, fire suppression policy, despite valiant efforts, has been unable to keep up with the ever-increasing frequency of fires on these human-dominated landscapes (see Figure 2). As a result, shrubland ecosystems have been exposed to an unusually high frequency of disturbance. Most casual observers see little problem with this kind of disturbance because shrublands are classically described as "fire-type" or "fire-adapted" ecosystems. However, it is a misnomer to describe the species in these communities as "fire adapted." Species are not adapted to fire per se, but rather are adapted to a fire regime that includes a particular range of fire frequencies, seasonality, and fire intensities. Deviations from this regime can threaten the persistence of many native species.

The primary threat to native species comes from the fact that fires create an ecological disequilibrium that can be exploited by many aggressive alien weeds. The dense canopy cover of undisturbed shrublands readily shades out herbaceous alien plants; after a fire, the extent to which aliens invade is dependent on a race between alien seeds reaching the site and shrub canopy recovery.[37] Following every fire, shrublands undergo a developmental period in which native plant populations recover dormant seed banks and transport photosynthetic products to tubers, bulbs, and corms. Repeat fires with insufficient recovery periods between them will result in limited native shrub recovery, creating an ecological vacuum rapidly filled by alien weeds. This "type conversion" from native shrubs to alien herbaceous vegetation can have a profound impact on many ecological processes.

Such type conversion has already occurred over a quarter or more of the current wildland landscape in coastal California, beginning with the earliest human occupation of the region.[38] While fire suppression activities have failed to exclude fire from this landscape, they almost certainly have prevented massive landscape changes that might have occurred if the exponentially increasing rate of human-ignited fires during the 20th century had been left unabated.[39] Although the rate of type conversion is not currently being monitored, it appears to the authors of this essay that it is happening at an ever-increasing rate in southern California. These landscapes are currently challenged with far too much fire, and any management practices that create disequilibrium conditions, such as fuel reduction projects, must evaluate the potential negative impacts of these practices—particularly alien plant invasion.

Changing Our Perspective on Fire

Californians need to embrace a different model of how to view fires on chaparral landscapes. Our response needs to be tempered by the realization that fires are natural events that cannot be eliminated from California shrublands. We can learn much from the science of earthquake or other natural disaster management: no one pretends we can stop earthquakes—rather, we engineer infrastructure to minimize their impact.

We need to closely evaluate human development practices that place people at serious risk to destructive wildfires. The primary shortcoming of California's fire management agencies has been the failure to adequately convey to the public their inability to stop massive Santa Ana wind-driven fires. For much of the past half-century, public agencies have held the false belief that how or where they allowed new developments to be built was irrelevant to fire safety—largely because of assurances that fire managers could prevent fires from burning across the wildland-urban interface. Undoubtedly there has been substantial pressure on fire managers to convey an overly confident image, and not to highlight their limitations.

Future development in California needs to closely involve fire managers at the planning stage. In addition, communities need to take greater responsibility for creating defensible fire-safe zones through placement of greenbelt infrastructure, such as golf courses and parks, between wildlands and homes.

Top: Urban sprawl has contributed to increasingly higher fire suppression costs as firefighters try in vain to protect homes in fire-prone landscapes such as California chaparral.

Bottom: Regrowth of chaparral following a wildfire near Arroyo Seco, Agua Tibia Wilderness, Cleveland National Forest, California.