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Fire Management of California Shrubland Landscapes

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ABSTRACT / Fire management of California shrublands has been heavily influenced by policies designed for coniferous forests, however, fire suppression has not effectively excluded fire from chaparral and coastal sage scrub landscapes and catastrophic wildfires are not the result of unnatural fuel accumulation. There is no evidence that prescribed burning in these shrublands provides any resource benefit and in some areas may negatively impact shrublands by increasing fire frequency. Therefore, fire hazard reduction is the primary justification for prescription burning, but it is doubtful that rotational burning to create landscape age mosaics is a cost effective method of controlling catastrophic wildfires. There are problems with prescription burning in this crown-fire ecosystem that are not shared by forests with a natural surface-fire regime. Prescription weather conditions preclude burning at rotation intervals sufficient to effect the control of fires ignited under severe weather conditions. Fire management should focus on strategic placement of prescription burns to both insure the most efficient fire hazard reduction and to minimize the amount of landscape exposed to unnaturally high fire frequency. A major contributor to increased fire suppression costs and increased loss of property and lives is the continued urban sprawl into wildlands naturally subjected to high intensity crown fires. Differences in shrubland fire history suggest there may be a need for different fire management tactics between central coastal and southern California. Much less is known about shrubland fire history in the Sierra Nevada foothills and interior North Coast Ranges, and thus it would be prudent to not transfer these ideas too broadly across the range of chaparral until we have a clearer understanding of the extent of regional variation in shrubland fire regimes.

Mediterranean-climate shrublands of southern and central-coastal California are one of the most fire hazardous landscapes in North America (Schroeder and others 1964). The combination of dense contiguous fuels, summer drought, autumn foëhn winds, and an extensive urban/wildland interface all contribute to this situation. Since at least the middle of the twentieth century property losses from wildfires have increased every decade, despite concomitant increases in fire suppression expenditures, and in recent years there have been several wildland fires that have exceeded $1 billion in losses each (FRAP 1999).

Many have assumed that this fire hazard is unnatural and has developed because of fuel accumulation arising from a century of fire suppression policy (Dodge 1972, Bonnicksen and Lee 1979, Minnich 1983, Pyne 1995). This reasoning is a logical extension of the well-documented fire hazard in western coniferous forests resulting from a century of fire exclusion (Agee 1993). Reduction of fire hazard in coniferous forests requires the reintroduction of fire through prescription burning and other fire management policies (e.g., Parsons and DeBenedetti 1979, Stephenson 1999). Likewise, for shrubland ecosystems it has been proposed that there is an urgent need for massive prescribed burning, in order to reintroduce fire into the California shrubland-dominated landscape (Minnich and Dezzani 1991). Further, it has been suggested that a strategic reintroduction of fire by rotational burning, which maintains the landscape in a mosaic of different age classes, can prevent large catastrophic wildfires (Countryman 1974, Minnich 1995, 1998). These ideas are reflected in fire management plans on all of the southern and central-coastal California national forests (Conard and Weise 1998), and thus deserve serious consideration.

The initial support for fire restoration in chaparral shrublands was from modeling studies by Philpot (1974), which predicted that as stand age increases due to fire suppression, fire size increases. These models were interpreted to mean that prescription burning of small patches would create a landscape age mosaic capable of acting as a barrier to the spread of large catastrophic wildfires. The primary support for this fuel age model has been a comparison of burning patterns north and south of the U.S. border (Minnich 1983,

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1989, 1995, 1998, Minnich and Cho 1997). These studies reported a coarse grain pattern of large fires north of the border and a fine grain pattern of smaller fires south of the border. Although the conclusion that differences exit has been challenged (Strauss and others 1989, Keeley and Fotheringham 2001a), the primary problem is how to interpret burning patterns north and south of the border.

Minnich (1983, 1989, 1995, 1998) has assumed that the pattern of burning north of the border is the result of highly effective fire suppression activities, which have excluded fire and allowed an unnatural aging of chaparral. This assumption has largely gone unchallenged because countless fire history studies in western U.S. forests have shown fire suppression policy commonly results in fire exclusion. However, recent studies of California shrublands have shown that fire suppression has failed to exclude fire and as much or more area burns now than prior to active fire suppression (Moritz 1997, 1999, Conard and Weise 1998, Keeley and others 1999, Weise and others in press, Keeley and Fotheringham 2001a, 2001b). These studies call into question the basic assumption behind the border comparison studies and make it doubtful that any differences in burning patterns north and south of the border can be held up as an illustration of the consequences of a fire suppression policy.

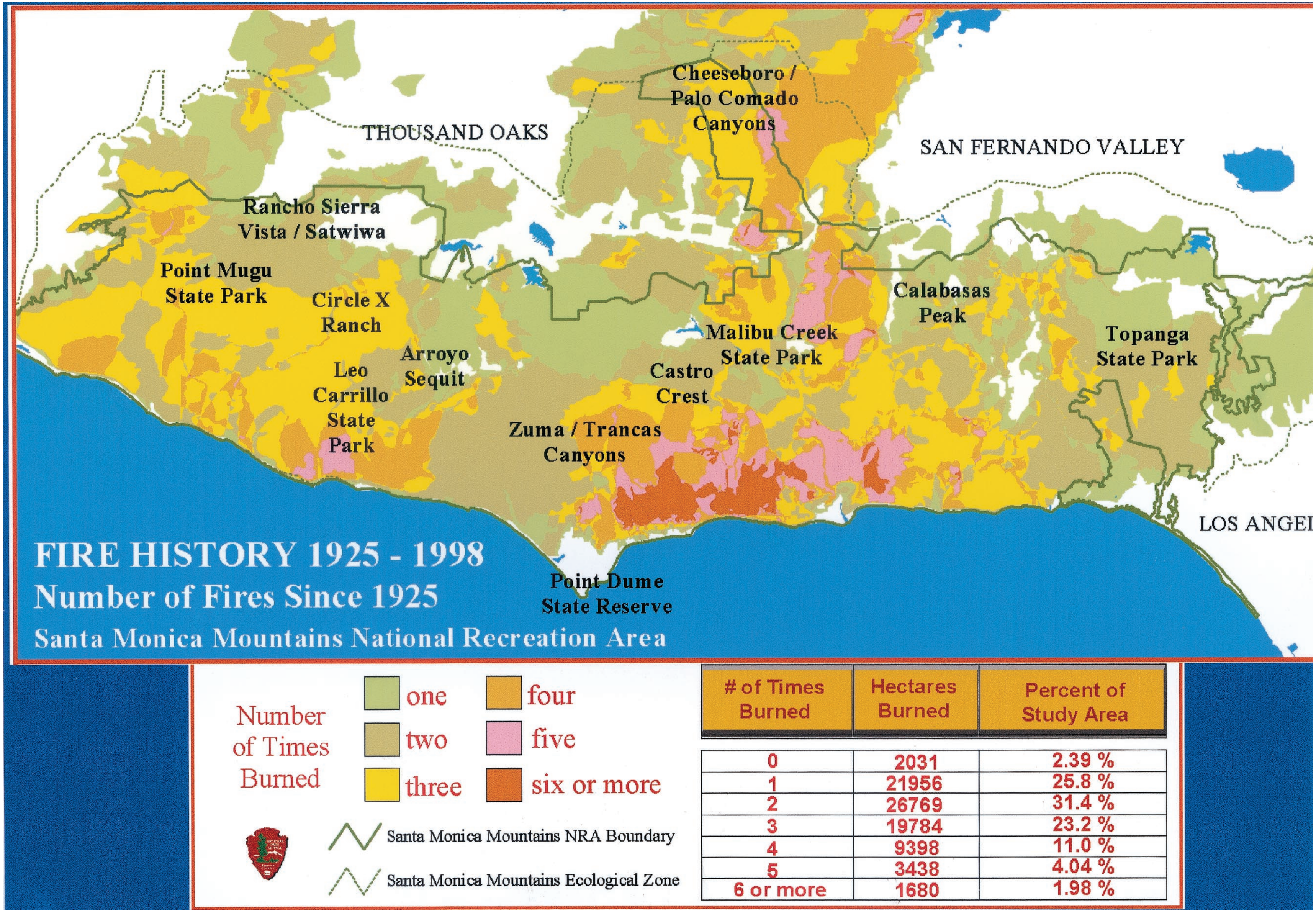
Likewise, two broad conclusions from the border comparison studies are doubtful. One conclusion is that large destructive crown fires are a modern phenomenon, unknown on the California landscape prior to active fire suppression (Minnich 1989, 1995, 1998, Minnich and Dezzani 1991, Minnich and Cho 1997). There are, however, countless reports throughout this region of large crown fires during the nineteenth century and earlier (Kinney 1900, Barrett 1935, Brown and Show 1944, Brown 1945, Greenlee and Moldenke 1982, Greenlee and Langenheim 1990, Keeley and others 1999, Mensing and others 1999, Keeley and Fotheringham 2001a).

Another conclusion drawn from the border comparison studies is that shrubland fire regimes are largely immune to external forcing functions such as severe fire weather, but rather are constrained by the rate of fuel accumulation and the constraint is sufficient to account for a natural fire return interval of 60–80 years (Minnich 1989, 1995, 1998, Minnich and Dezzani 1991, Minnich and Cho 1997). However, recent studies north of the U.S. border have shown that fire hazard is either independent of age (Moritz 1999) or only weakly dependent up to 20 years (Schoenberg and others 2001, Peng and Schoenberg in press). Other evidence that fire behavior is not a deterministic function of fuel age is the fact that large catastrophic fires will readily burn through young stands less than 20 years of age and do not require old vegetation (Dunn 1989, Keeley and others 1991, Keeley and Fotheringham 2001b). Also, modeling studies predict that fuel age alone can not constrain fire size (Zedler and Seiger 2000).

These findings call into question fire management strategies that include widespread prescribed burning designed to create age mosaics in southern California shrublands. Reexamination of the policy is particularly warranted in ranges that border large urban centers, such as the Los Angeles Basin, because these are the areas currently subjected to the highest fire frequencies (Keeley 1982, Rogers 1982, Conard and Weise 1998, Keeley and others 1999, Weise and others in press), and are the areas where most human resources are at risk. Illustrative of the situation is the fire history for the Santa Monica Mountains, which forms the northwestern boundary of the Los Angeles Basin. These mountains have been repeatedly burned this century (Figure 1), and the bulk of vegetation that burns in the largest wildfires are less than 20 years of age (Figure 2); a pattern that has persisted for half a century (Shantz 1947, McBride and Jacobs 1980, Radtke and others 1982). The situation is similar in other southern California mountain ranges (Conard and Weise 1998, Weise and others in press). In these human-dominated landscapes, people maintain a significant presence of fire, both through the shear numbers of fires ignited as well as the very wide seasonal window of ignitions, many of which coincide with severe fire weather conditions (Schroeder and others 1964).

Prescribed Burning

In light of these findings, there is a need to reevaluate prescribed burning and the appropriate fire management policy for shrubland-dominated landscapes. Such policy analysis is invariably complicated by the fact that there are multiple motivations for use of prescribed burning. Most commonly it is justified as a means of reducing fire hazard, but it is also an appropriate technique for enhancing natural resource values. Agencies differ in their motivation, e.g., the California Department of Forestry and Fire Protection consider fire hazard reduction to be their primary objective (CDF 1996), whereas the National Park Service places as much or more emphasis on the use of fire to improve resources (Parsons and van Wagtendonk 1996). Of particular importance is the reality that prescriptions reducing fire hazard may not always enhance resource values and sometimes may detract (Johnson and Miyanishi 1995, Bradstock and others 1998). Thus, there is



# of Times Burned	Hectares Burned	Percent of Study Area
0	2031	2.39 %
1	21956	25.8 %
2	26769	31.4 %
3	19784	23.2 %
4	9398	11.0 %
5	3438	4.04 %
6 or more	1680	1.98 %

Figure 1. Fire frequency between 1926-1997 for the Santa Monica Mountains, Los Angeles, and Ventura counties (U.S. National Park Service, Santa Monica Mountains National Recreation Area, Thousand Oaks, CA).

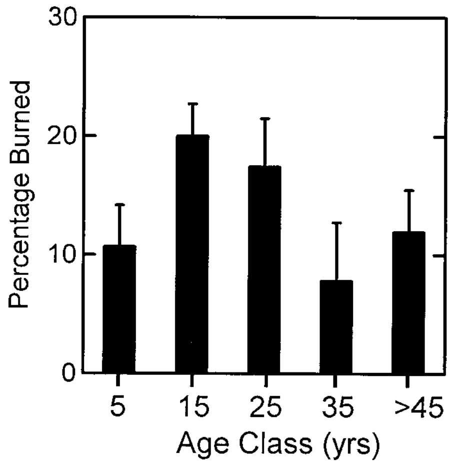


Figure 2. Vegetation age burned in the eight largest fires during the 30 year period (1967–1996) in the shrub dominated Santa Monica Mountains (Ventura and Los Angeles counties, California) (data from Keeley and others 1999). Incident reports on these fires all note the severe fire weather conditions as a causal factor in these catastrophic events.

great potential for disagreement over the appropriate fire management policy.

A primary resource value in this region is the shrubland ecosystem, comprising chaparral and coastal sage communities, which have long been touted for their watershed value (Kinney 1900, Clar 1959) and more recently as a repository of biodiversity (Davis and others 1994, Keeley and Swift 1995, Stephenson and Calcarone 1999). These ecosystems are resilient to a wide range of fire regimes, but there are two potential threats presented by the extreme conditions of total fire exclusion or very frequent repeat fires. These have been termed "senescence risk" (loss of fire-dependent species during long fire-free periods) and "immaturity risk" (loss of species when fire return intervals are shorter than the time required to reach reproductive maturity), respectively (Zedler 1995). Due to the resilience of these communities to century long fire-free intervals (Keeley 1992), and the high incidence of fire in the coastal ranges of central and southern California, senescence risk appears to be unimportant at this point in time. However, there is abundant evidence that high fire frequency is a very real threat to native shrublands, sometimes extirpating species sensitive to short fire return intervals (Zedler and others 1983, Haidinger and Keeley 1993, Keeley 1995).

Other potential resource benefits from prescription burning include invasive plant control, but the primary invasive problems largely involve herbaceous species, which are favored by increased frequency of disturbance (Keeley in press). Thus, it is not likely that prescription burning would displace these invasive species, unless the target was vulnerable to a particular seasonal window of burning, which did not also inhibit native species. Prescription burning to knock out certain invasives, coupled with active restoration of natives, may be one way fire could be used to enhance resource values in these shrublands.

In general, there are no examples where fire-dependent shrublands are threatened by lack of fire and few instances where prescription burning would have natural resource benefits. The primary justification for prescription burning in southern and central coastal California shrublands is fire hazard reduction, and this is commonly accomplished by reducing fuels with prescription burning on a rotational basis. Because of limited information on the fire history of chaparral shrublands in northern California and the foothills of the Sierra Nevada it would be prudent at this time to not include them in this generalization.

Prescription Burn Plans

Key to the use of prescribed burning is the prescription plan, which requires integration of both scientific and social aspects of intentional burning. Critical scientific parameters to be considered are the weather, fuels and topography. One of the social parameters that plays a key role in setting limits on the use of prescription burning is economics; indeed, Conard and Weise (1998) contend that this alone precludes the widespread use of prescription burning as proposed for southern California forests. Other issues such as air quality will greatly limit the window of opportunity for use of this tool, particularly in the Los Angeles Basin (Miller 1984).

In selecting the rotational interval, three factors must be balanced: (1) Foremost is the ability of trained personnel to safely contain the fire within pre-determined boundaries, (2) critical to a successful burn is the ability of the vegetation to ignite and spread fire, and (3) the ultimate test is how effective the burn is at reducing fire hazard. Balancing these factors has been done quite successfully in a wide range of coniferous forest types in both the east (Cumming 1964) and the west (Parsons and van Wagtendonk 1996). These forests have a natural surface-fire regime and prescription burning is largely undertaken to burn understory vegetation. However, different problems arise when applying prescription burning to crown-fire ecosystems such as California chaparral (Countryman 1974, Leisz and Wilson 1980), where balancing these three factors is perhaps more challenging:

Factor 1. In order to ensure successful containment of a prescribed burn there are strict limitations on the acceptable wind speed, air temperature, relative humidity, and fuel moisture. Failure to adhere to the prescription conditions (e.g., the northern California Lewiston Burn in 1999) or a change in weather conditions (the southern California Bedford Burn in 1990) can result in escape and major property damage. In general, prescription burning is done at wind speeds below 17 kph (10 mph), relative humidities above 30%, air temperature below 32°C (95°F) and fuel moisture above 75% (Fenner and others 1955, Green 1981). However, the range of acceptable conditions varies with the fuel load and landscape, and as one parameter (e.g., air temperature) improves, less desirable levels in another parameter (e.g., relative humidity) will combine to form acceptable prescriptions (Paysen and others 1998).

One approach to safely expanding the prescription limits is through spring burning, where the area to be burned is pretreated by mechanical crushing and drying (Wolfram 1962). High fuel moisture in surrounding vegetation acts as an effective barrier to fire escaping the designated prescription burn area. However, this approach is expensive and has the potential for disrupting the soil mantle and producing resource damage. Also, this unseasonable application of fire appears to inhibit postfire vegetation recovery (Rundel and others 1980, Florence 1985, Parker 1990) and is correlated with increased soil erosion (Turner and Lampinen 1983).

Factor 2. Because prescriptions are designed for safety, they are often sub-marginal for burning. Under prescription weather conditions, fire spread is markedly influenced by fuel structure and stands less than 20 years of age often will not carry fire successfully (Green 1981, Paysen and Cohen 1990, Conard and Regelbruge 1994). This is largely due to the lack of sufficient dead fuels required to spread fire to live foliage, plus the lack of fuel continuity between the ground and the shrub canopy and between adjacent canopies, factors that are extremely critical to fire spread under low wind and high humidity. Controlled burning of younger stands requires either, prescriptions with risky weather conditions, or pretreatment with biodegradable herbicides, which increase dead material, coupled with seeding of alien herbaceous plants that increase flashy (readily-ignitable) fuels.

Factor 3. Evaluating the effectiveness of prescribed burning at reducing fire hazard is complicated by the fact that such fuel management practices are never going to be fully effective against all fires. Wildfires ignited under weather conditions that approximate prescription weather conditions will be more readily contained when they encounter young stands of vegetation because fire spread is blocked due to limited fuels or the lower fire intensities allow for safer access by fire crews (Countryman 1974). However, wildfires ignited under severe weather conditions, such as those driven by Santa Ana foëhn winds or other severe weather conditions (e.g., see Schroeder and others 1964), present a different case. Landscape age mosaics created by rotational burning will not pose a barrier since the high winds readily push fires through young age classes (e.g., Figure 2). Under these conditions, young vegetation is of minimal value in halting the forward spread because of the danger of placing people in the path of such fires, and also because fire brands are capable of spreading the fire kilometers beyond the front (Dunn and Piirto 1987, Dunn 1989). Young stands of vegetation may assist fire crews in preventing lateral spread, but generally only assist in stopping the advancing front of large fires when coincident with a significant change in weather (Rogers 1982, Dunn and Piirto 1987).

Therefore, prescription burning can only be done safely under weather conditions that require mature chaparral, 20 years of age or more, but stands this age and younger will not form effective barriers to fire spread under severe weather conditions. Landscapes managed by such rotational burning may contribute to easier containment of fires burning under moderate weather conditions (e.g., prescription burn weather), but are of limited help under severe weather conditions (e.g., the annual autumn Santa Ana foëhn winds). However, it is these latter fires that become truly catastrophic and are responsible for the greatest losses of property and lives (Schroeder and others 1964, Countryman 1974). Thus, prescription burning in chaparral crown-fire ecosystems is most efficient at inhibiting the least threatening fires, and least effective at inhibiting the most threatening fires.

On Balance is Prescription Burning a Viable Tool?

These considerations should not be interpreted to mean that prescription burning has no place in fire management of shrubland ecosystems, but only to emphasize the limitations to its effectiveness. Landscape scale rotational burning is unlikely to ever be a viable management strategy, both because it is ineffective against the most dangerous fires, and because it is neither economically feasible nor possible within the temporal window of burning opportunity constrained by air quality restrictions (Conard and Weise 1998). Although of minimal value in stopping fires under severe conditions, prescription burning may aid fire suppression under other conditions. However, it is important to recognize that the primary advantage to rotational burning is to create young age classes that provide access to fires, and thus strategic location of prescription burns is more critical than the sheer number of hectares burned. Therefore, widespread prescription burning to create landscape age mosaics should be replaced with strategic placement of prescription burns that focus on well known fire corridors and expose the least amount of landscape to the risk of unnaturally high fire frequency.

Conard and Weise (1998) and Reggelbrugge (2000) recommended a two-prong prefire fuel management strategy, which includes low intensity management over much of the landscape, coupled with intensive management along strategic buffer zones. Low intensity management is largely centered around establishment and maintenance of strategically placed fuel breaks that provide access for attacking fires before they reach the urban/wildland interface. Strategic buffer zones would recognize those landscape features known as predictable corridors for bringing fire into urban interface areas and create an intensive fuel management zone.

Fuel Breaks

A fuel break is a strategically located, pre-constructed control line where vegetation is manipulated to produce a permanent strip of low volume fuel. In southern California they (or the closely related "fire break") represent one of the earliest attempts at fire management and were the primary state funded form of fire control practiced during the early days of the California Board of Forestry around the turn of the last century (Clar 1959). Fuel breaks are larger and more permanent than firebreaks and typically provide a 30 to 200 m (sometimes 400 m) wide break in dense fuels (Omi 1979). Their purpose is to provide access for fire suppression activities—in and of themselves they are often not effective barriers to fire spread (Davis 1965). Construction of fuel breaks began in earnest in the 1930s and their effectiveness has been debated ever since (Clar 1969, Lee and Bonnicksen 1978, Biswell 1989, Agee and others 2000).

Fuel breaks are of questionable value in preventing the spread of fire under severe fire weather conditions (Omi 1977, Dunn and Piirto 1987). However, these zones of reduced fuels provide safe access to fires ignited under more moderate weather conditions (Anonymous 1962, Davis 1965, Salazar and González-Cabán 1987) and may contribute to reducing the size of fires ignited under such conditions, as inferred by Moritz (1997).

Historically, fuel breaks have been evaluated largely in terms of their financial impact and fuel hazard reduction benefits (Davis 1965, Gutiérrez 1979, Agee and others 2000) or wildlife habitat value (Adams 1976). Minimal consideration has been given to their potentially negative impacts on the landscape. Negative impacts include the aesthetic detraction of distributing the human imprint across the wildland landscape, maintaining a presence of "flashy" herbaceous fuels within the mature shrublands, and their contribution to non-native plant invasion. In shrubland landscapes these "invasive highways" are nearly always dominated by non-native herbaceous species, and have the potential for introducing exotics into remote wildland areas. Reduced fuels in fuel breaks results in lower fire intensities that exacerbate the invasive problem by increasing survivorship of alien seed banks (Keeley in press). In addition, fuelbreaks also alter the natural dispersion patterns of small mammals (Stavert 1976).

There are strategies for reducing these impacts and yet still provide effective fire protection. For example, associating fuel breaks with roadways would minimize the total landscape impact since roads share many of the same negative landscape features with fuel breaks (Magill 1992), yet provide the benefits of fuel discontinuity. There is value added to this scheme in that the vast majority of fires are ignited along roadways (Gee 1974, Conard and Weise 1998). Also, reducing the fire hazard along roadsides increases the safe use of roads during fires.

Buffer Zone Fuel Management

The most cost effective strategy for reducing catastrophic losses from wildfires is to minimize the management effort spent on the bulk of the chaparral landscape and focus on strategic locations. The worst fires predictably follow landscape features (Weide 1968, Franklin 1987). Buffer zones involve intensive management at the urban/wildland interface and would represent more than just "defensible space." Buffer zones have two objectives: to prevent wildland fires from entering and disrupting urban ecosystem processes and to limit ignitions arising from urban populations, which may spread and disrupt wildland ecosystem processes (Conard and Weise 1998). Historically, fires moving in both directions have been highly destructive to property (Lillard 1961). The extent to which fires diffuse across this buffer zone represents the "permeability" of the buffer zone, a parameter important in other types of management such as ecological reserve design (e.g., Kelly and Rotenberry 1993).

Management in this buffer zone will be necessarily complex, as it will involve multiple stakeholders with disparate goals, incentives, and available resources. These include local governments, homeowners, environmentally aware citizens, and resource management agencies. Cooperation between these groups would be essential to effective management.

Local and state governments play key roles in developing effective land planning aimed at managing the limits of the urban-wildland interface. Minimum fire risk planning is critical since the urban-wildland interface is already so extensive that even strategically focused intensive management will have enormous ecological impacts. Of particular concern is the increasing pattern of the classic urban-wildland interface being replaced by the "mixed interface," where development is embedded in a wildland matrix (Davis 1989). In this regard, education of homeowners, and local politicians, to the potential "costs" associated with residence at the urban/wildland interface is essential; "fire suppression is no more capable of preventing all catastrophic fires at this interface, than flood control can prevent disaster for those living in flood plains" (Frank Davis personal communication, 1999). Unfortunately, adequate planning is not the whole answer since development plans are often altered due to political pressure, and commonly in manners that enhance fire risk (Miller 1998).

The size, shape, and placement of a buffer zone would vary with the particular mode of fuel management. For urban environments juxtaposed with highly flammable shrublands, several types of buffer zones have been tried: (1) rotational burning to maintain younger age classes, (2) type conversion to less hazardous fuel types through high frequency prescription burning or mechanical or biodegradable herbicide treatment, (3) creation of artificial "green belts" of less flammable vegetation around developments, and (4) denuding the buffer zone by mechanical removal and disking. These alternatives have different trade-offs:

1. Seeming to work within the natural system is the use of repeated prescription burning to maintain the shrubland vegetation in a less flammable successional stage. Under most weather conditions this type of buffer is effective in providing fire suppression crews safe access to the fire and increases the chances of containment before spreading to the urban environment. However, prescription burning at urban/wildland interface has important limitations because the litigation threat from escaped prescribed burns is high (Rogers 1982). Also, this sort of buffer zone has not proven successful under extreme fire weather conditions such as foëhn winds.
2. Type conversion of the buffer zone vegetation can provide further reductions in fire hazard and may take various forms (Bentley 1967), although due to increased erosion hazard, this is not a viable option on steep slopes (Figure 3). Least destructive is the thinning of the natural shrubland, coupled with pruning of remaining shrubs (State of California 1993). This may be successful in stopping fires under moderate fire conditions but is not fail-safe under extreme fire weather conditions. While portending to work within the natural system, such buffer zone manipulations are always accompanied by invasion of non-native grasses and forbs. In addition to enhancing the spread of invasive plants, these herbs pose an additional fire hazard due to their high flammability throughout most of the year. Coupled with the high probability of incendiary fires adjacent to human habitation, herbaceous fuels greatly increase the chances for movement of fire from the urban to the wildland environment, and to other urban areas. This hazard can be reduced by annual cropping of these grasses and forbs, but this is expensive when conducted across the urban/wildland interface. Herbicidal treatment has been used to eliminate the herbaceous component, but this is environmentally undesirable and eliminating this herbaceous component leads to erosion problems. Use of goats for fuelbreak maintanance is problematical and can be expensive (Sidahamed and others 1982). Finally, such "type conversion" may be undesirable to some people because it diminishes the wildland experience, which is why many people choose the urban/wildland setting. This aesthetic component is a particular concern since the buffer zone often needs to be wide enough (100 to 400 m) to reduce the chances for airborne fire brands from the unmanaged shrubland zone.
3. Greenbelts are a much more extreme type conversion that makes no pretense at working within the natural system (Younger and others 1976). Recommendations include use of low volume and slow-burning drought tolerant plants (Nord and Green 1977) Such greenbelts require water subsidies and thus are expensive, plus they change the entire ambiance from a urban/wildland setting to a city park atmosphere, something that both attracts and repulses, depending upon the person. The primary repulsion is from the environmentally aware, who know the answer to Krieger's (1973) question "What's wrong with plastic trees?,"-namely, they are not part of the natural environment and thus detract from the experience of living at the urban/

Figure 3. Experimental conversion of chaparral to alien-dominated grassland on the San Dimas Experimental Forest of southern California. These slopes were sufficiently steep that soil slumps resulted from this type conversion project.

wildland interface. Long term ecological impacts of "green belts" are unknown.

4. The more extreme treatment of mechanically denuding the site (Roby and Green 1976) is effective in preventing the spread of fire both into and out of the urban environment, except under the more severe fire conditions where fire brands may spread fire long distances. This technique often involves annual disking and has many of the same economical and esthetic problems as the other alternatives, including potential for extreme erosion. In addition, it is not always legally possible because of the impacts of extreme habitat modification on associated rare or endangered species (GAO 1994).

Watershed Considerations

One limitation to the focus on prefire buffer zone management is that it may not adequately address the impact of postfire flooding and debris flows that derive from fires in watersheds somewhat removed from the urban/wildland interface (Wells and Brown 1982). For these reasons fire managers will need to maintain their landscape scale perspective and consider strategically important watersheds that affect the urban environment. This is increasingly difficult as some critical watersheds have themselves been fragmented by urbanization, causing unforeseen problems in hydrology (Wells 1991).

Despite the millions of dollars spent on postfire manipulations, there is a lack of widespread agreement on their effectiveness. Compelling evidence has been presented that postfire grass seeding is often neither effective nor desirable (Conard and others 1995, Robichaud and others 2000), however, there are mechanical manipulations (e.g., hay bales) that provide a level of protection from flooding with minimal negative impacts on the biotic resources (Collins and Johnston 1995).

Prefire watershed management through prescription burning is predicated on the belief that postfire

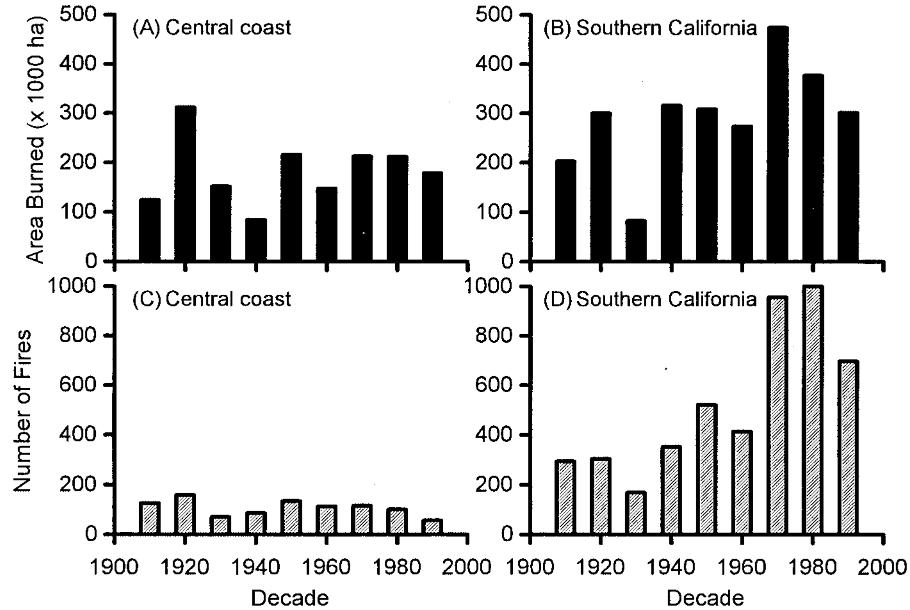


Figure 4. Change in fire frequency and area burned this century for central coastal California (including Monterey, San Luis Obispo, Santa Barbara, and Ventura counties) and southern California (including Los Angeles, San Bernardino, Riverside, Orange, and San Diego counties). Total shrubland area for these regions is 1.05 and 1.23 million hectares for central and southern California, respectively. Fire data from the California Fire History Data Base, California Department of Forestry and Fire Protection and shrubland area from Callaham 1985).

flooding and erosion are affected by fire intensity and fire size (Rogers 1982). Controlled burning is done under prescriptions that generate lower intensity and burns are planned for small portions of a watershed (e.g., Riggan and others 1994). The potential for small burns to reduce massive erosion and debris flows is high, however, there is little compelling evidence that lower fire intensity plays a crucial role in reducing postfire soil losses. In general, the relationship between prefire fuel treatments and postfire flooding and debris flows is complex and in need of more research (Spittler 1995).

Regional Variation

One important lesson learned from historical fire data is that there is the potential for extraordinary spatial variation in patterns of burning, even within the shrubland regions considered here. For example, historical patterns of fire ignitions and area burned may be quite different between the central coast and southern California, despite roughly similar sized shrubland areas (Figure 4). The lack of autumn foëhn winds in the foothills of the Sierra Nevada, coupled with higher lightning fire incidence and fewer human-ignited fires (Keeley and Fotheringham in press) suggest that this region may also differ from the patterns observed in southern California. Considering the spatial variation in climate and human demography it is likely that over the range of shrubland habitats in California there is need for differing fire management approaches. Rather than a statewide strategy there is need for more localized management strategies that recognize differences in fire regime, population distribution, as well as infrastructure development, in particular the distribution of roads where most human ignited fires originate.

Conclusions

Southern California shrublands are just one of a number of vegetation types that typically burn in stand-replacing crown fires, driven more by severe fire weather than by unnatural fuel accumulation (Bessie and Johnson 1995, Agee 1997, Keeley and Fotheringham 2001b, Johnson and others 2001). Although the interface problem is one of national scope, and not restricted to fire (Bailey 1991), it is of particular concern when crown fire ecosystems are juxtaposed with the urban environment. The urban/wildland interface is of course one important reason why, nationwide, fire suppression costs are increasing at a higher rate than inflation (Husari and McKelvey 1996).

Despite increasing expenditures on fire suppression, property losses associated with shrubland fires in California have been steadily increasing (Bonnicksen and Lee 1979, Kinney 1984, FRAP 1999). Over two decades ago Bonnicksen (1980) noted that in southern California shrublands there was no relationship between fire control expenditures and area burned and proposed that this clearly indicated that the fire-exclusion policy was in error. However, this conclusion rests on the assumption that the policy of fire suppression has actually worked to exclude fire and cause an unnatural accumulation of hazardous fuels, but in reality, fire suppression has not effected fire exclusion on this landscape (Moritz 1999, Conard and Weise 1998, Keeley and others 1999, Schoenberg and others 2001, Keeley and Fotheringham 2001b, Peng and Schoenberg in press). Increased expenditures are tied to increasing numbers of incendiary fires, which are tied to the ever increasing population growth. Increasing losses are the direct result of expansion of urban development into the high fire hazard wildland environment, something noted in the initial stages of urban sprawl in southern California (Zivnuska and Arnold 1950, Davis 1965).

Despite the likelihood that large wildfires will remain a feature of this landscape, there are management strategies that could limit its impact on the loss of property and lives. In addition to "hazard reduction" methods involving prescription burning and other fuel treatments, there are many other pre-fire management strategies, including those focused on fire ignition reduction (FRAP 1999). Indeed, fire suppression activities are barely staying ahead of the increasing human ignitions on this landscape (Keeley 2001). There is a marked need for continued fire prevention to reduce the likelihood of ignitions during the annually-predictable severe fire weather known as Santa Ana winds (Schroeder and others 1964).

Another obvious approach would be better land planning that manages for limited human use in high-risk areas and reduces risky urban/wildland interface configurations. It is important to impress upon the public, and politicians, that there are inevitable costs associated with development in or adjacent to these wildland areas. Tacit acceptance of this inevitable cost is the fact that several decades ago the U.S. Forest Service altered their vocabulary by replacing the term "fire control" with the term "fire management" (Loeher 1983). In the future the situation is likely to deteriorate rather than improve since rural population growth is expected to exceed urban growth (Bradshaw 1987), thus expanding the interface perimeter. It seems logical that constraining the rapidly expanding urban/wildland interface is critical to keeping the fire hazard situation from worsening.

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