# Fire and Landscapes: Patterns and Processes[1]

## Jan W. van Wagtendonk[2]

Fire has been a pervasive influence on the Sierra Nevadan landscape for millennia. Lake sediments containing charcoal and pollen indicate that fires have occurred for at least the past 13,000 years. Brunelle and Anderson (2003) found that charcoal accumulation varied with vegetation and temperature, increasing during warm periods dominated by oaks *(Quercus* spp.*)* and sagebrush (*Artemisia tridentata)* and decreasing during cool periods dominated by subalpine species, such as mountain hemlock (*Tsuga mertensiana*). They concluded that the lake sediment record was consistent with other long-term records of climate and vegetation in the Sierra Nevada and with records of fire and climate for the past 1,000 years as determined from tree-ring studies (Graumlich 1993). Although it is not possible to determine whether the frequency of lightning strikes varied during the period covered by the sediment record, the number of ignition sources was obviously sufficient to produce fires across the landscape.

Predictions of increased temperatures with global warming indicate that fire could become even more prevalent in the future than it is today (Knox 1992). Higher temperatures might double the frequency of lightning strikes (Price and Lind 1994). As fuels accumulate because of fire exclusion and as more and more new homes are built in wildlands, the situation becomes even more severe. In order to reduce fire hazards and risks, land managers and private landowners must take into account the natural role of fire. This paper discusses the conditions essential for fire to be a component of the landscape and the patterns and processes that occur as these conditions interact. The evolution of the current hazardous situation in the Sierra Nevada is described, and a management program is suggested that would encompass the natural role of fire and allow humans to live harmoniously in a fire-adapted environment.

## Conditions Essential for Fires

For fire to play an ecological role on a landscape, three conditions must occur simultaneously and frequently during the evolution of that landscape. First, a source of ignitions must be present, for example, lightning or anthropogenic activities. Second, the ignitions must encounter a receptive fuel bed with sufficient fuel to burn. Finally, the weather conditions must be conducive for fire spread. These conditions are all met frequently in the Sierra Nevada, and fires occur annually throughout the range. Since the early 1900s, nearly 5,000 fires have burned more than 20,000 $km^2$ in the 67,000-$km^2$ region *(fig. 1).*
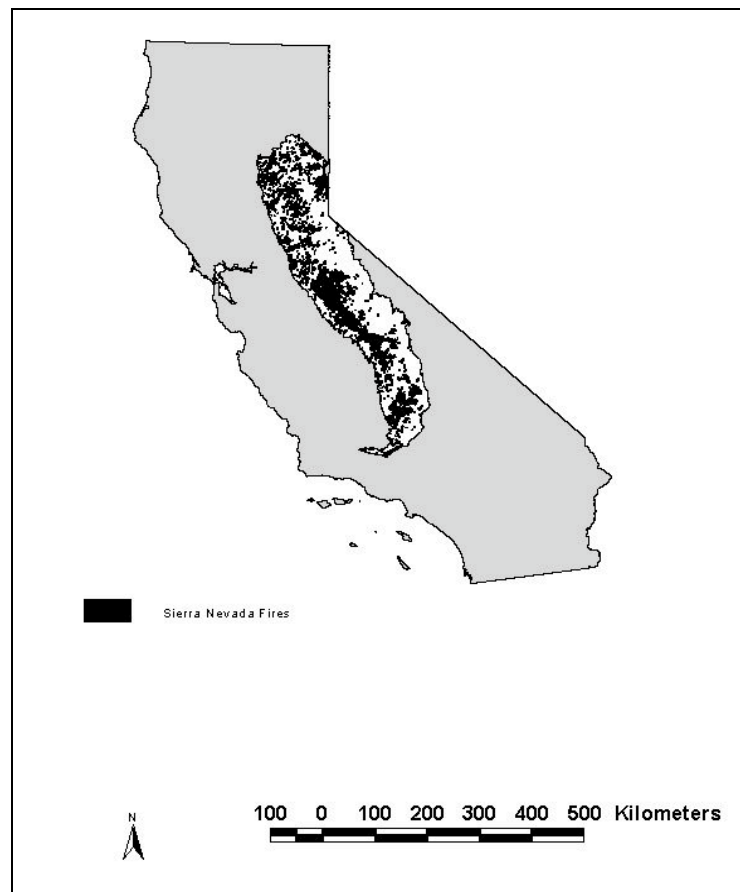
### Ignition Sources

Without an ignition source, fire cannot be a factor in an ecosystem. Lightning and ignitions by Native Americans were the principal sources of fires in the past. Although it is difficult to

**Figure 1**— Fires from all causes in the Sierra Nevada bioregion, 1908–2001.

quantify the extent of burning by native people, ethnographers believe their use of fire was extensive (Anderson 1994). Regardless of the contribution of Native Americans to the number of ignitions, lightning is so prevalent that it alone can account for the evolution of fire regimes in the Sierra Nevada (Vale 1998). With the advent of automated lightning detection systems, information regarding the location, date, and time of each strike can be recorded. *Figure 2* shows the annual variation in number of strikes in the Sierra Nevada from 1985 through 2000. Not all of these strikes resulted in a fire because many of them did not land in receptive fuels or during adequate burning conditions. Moreover, it is estimated that less than 70 percent of the strikes exhibited long-continuing currents associated with ignitions (Anderson 2003). In a study of lightning strikes and fires in Yosemite National Park, van Wagtendonk (1994) found that an average of 1,208 strikes per year started only 42 fires per year.

The role fire plays is also affected by the location of the lightning relative to the landscape. *Figure 3* shows the geographic distribution of lightning strikes per year per 100 $km^2$ in the Sierra Nevada from 1985 through 2000. The density of strikes increases from west to east, reaching a maximum of just under 50 strikes per year per 100 $km^2$ just east of the crest. Elevation accounts for much of this increase. *Figure 4* shows the number of strikes occurring in 1999 for the Sierra Nevada per 500-ft contour interval. The strike density reached a maximum between 8,500 and 9,000 feet on both sides of the crest and was lowest in the foothills.
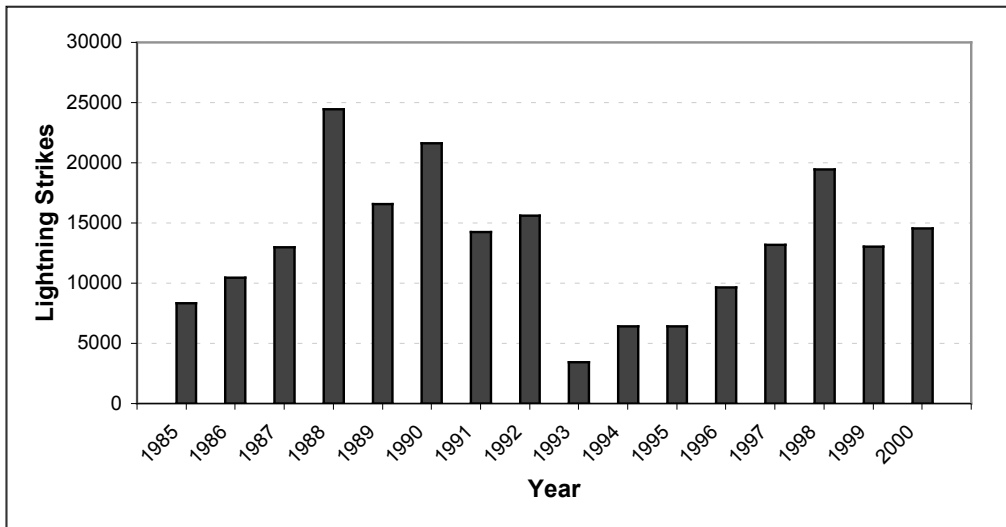
**Figure 2––** Number of lightning strikes per year from 1985 through 2000 in the Sierra Nevada bioregion.
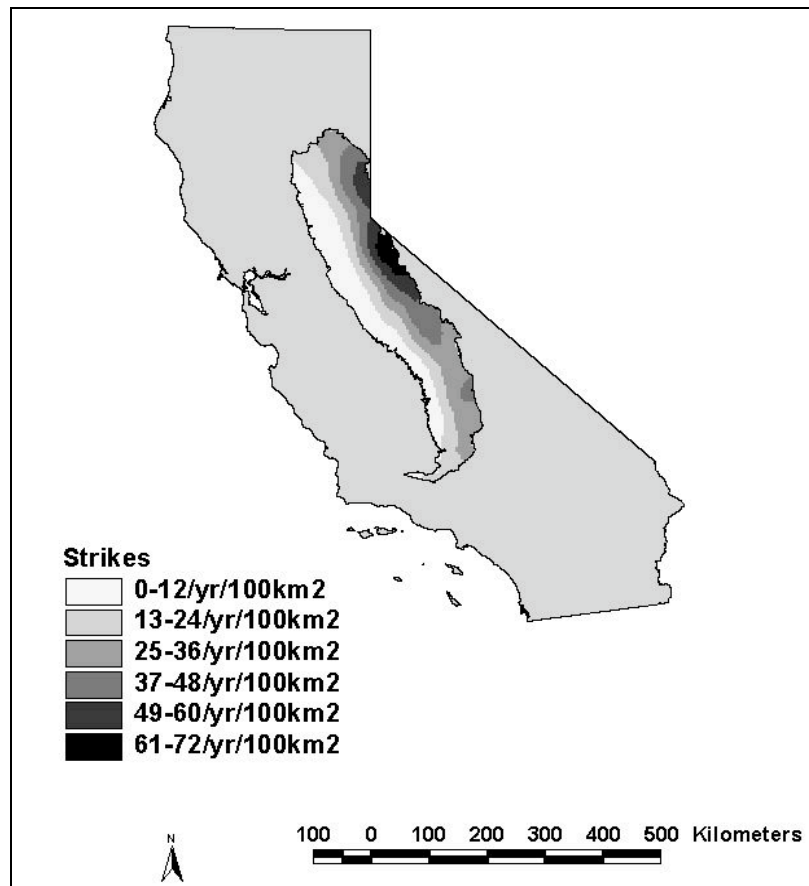


**Figure 3—** Number of lightning strikes per year per 100 km$^2$ in the Sierra Nevada bioregion, 1985–2000.
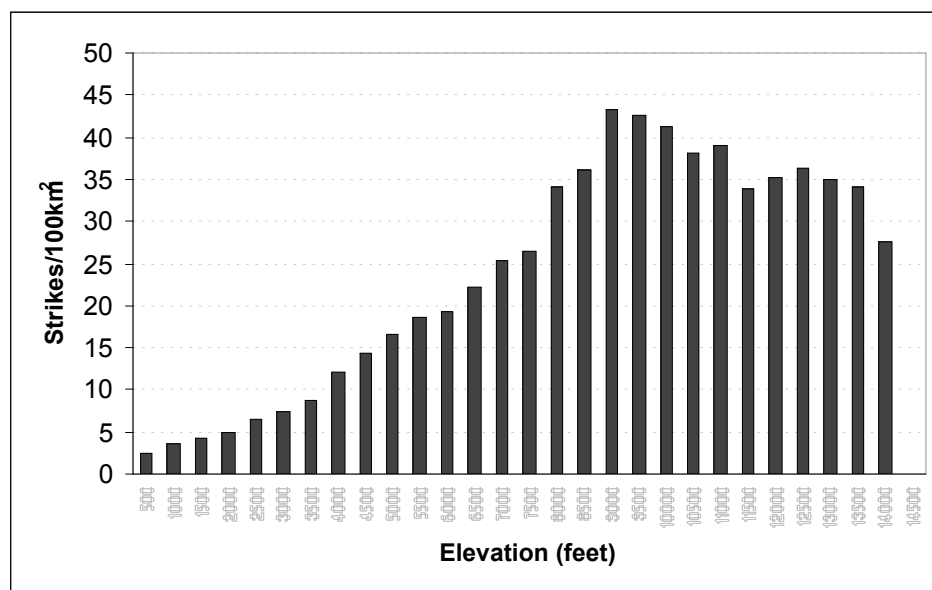
**Figure 4—** Number of lightning strikes per 100 km$^2$ by 500-ft contour intervals in the Sierra Nevada bioregion, 1999.

## *Fuels*

Fuels vary in amount, type, and distribution over space and time. For example, van Wagtendonk and others (1998) found that the weight of woody surface fuels of Sierra Nevada conifers ranged from 0.22 kg m$^{-2}$ for foothill pine (*Pinus sabiniana*) to 2.34 kg m$^{-2}$ for giant sequoia (*Seqoiadendron giganteum*) and increased as trees grew older and larger. Fuelbed bulk density ranged from 12.41 kg m$^{-3}$ for foothill pine to 40.21 kg m$^{-3}$ for limber pine (*Pinus flexilis*). These variations in fuel characteristics result in dramatic differences in fire behavior under similar weather and topographic conditions. Similar variation can be found in crown fuels. Although no data are available for the Sierra Nevada, Brown (1978) found that crown bulk densities in the Rocky Mountains ranged from 0.6 kg m$^{-3}$ for western red cedar (*Thuja plicata*), a species similar in crown structure to incense cedar (*Calocedrus decurrens*), to 2.24 kg m$^{-3}$ for whitebark pine (*Pinus albicaulis*).

Fuel maps based on satellite imagery show that the spatial distribution of fuels is very heterogeneous (van Wagtendonk 1998). The Sierra Nevada landscape is a mix of fuel types interspersed with water and barren areas. This pattern is influenced by the response of vegetation to the available water and also reflects climate, elevation, aspect, and soil properties. Fires burning over this landscape exhibit a similar degree of spatial heterogeneity.

## *Weather*

Weather patterns in the Sierra Nevada are influenced by its topography and geographic position relative to the Central Valley, the Coast Ranges, and the Pacific Ocean. The primary sources of precipitation are winter storms that move from the north Pacific and cross the Coast Ranges and Central Valley before reaching the Sierra Nevada. As the air masses move up the gentle western slope, precipitation increases and, at the higher elevations, falls as snow. Once across the crest, most of the moisture has been driven from the air mass and precipitation decreases sharply. Precipitation also decreases from north to south, with nearly twice as much falling in the northern Sierra Nevada as in the southern region. Sierra Nevadan temperatures are generally hot in the summer and cold in the winter. Temperatures

decrease as latitude and elevation increase. Wind speeds are variable, averaging up to 10 km hr$^{-1,}$ but speeds of more than 100 km hr$^{-1}$ have been recorded out of the north during October.

The burning index for a given area is calculated by combining data on fire weather (temperature, relative humidity, cloudiness, and wind speed) with information about topography and fuels, to provide an indicator of fire behavior conditions. *Figure 5* shows the variation in the average maximum burning index across an elevational transect through the Yosemite region from the foothills to the Great Basin. At Buck Meadows, located at the upper edge of the foothills at 917 m, the 10-year average maximum burning index reaches 82. As elevation increases, the average maximum burning index decreases, reaching 68 at Crane Flat at 2,023 m and falling to only 21 at Tuolumne Meadows at 2,614 m. Across the crest of the Sierra Nevada at Crestview (2,310 m), the burning index rises to an average maximum of 41.
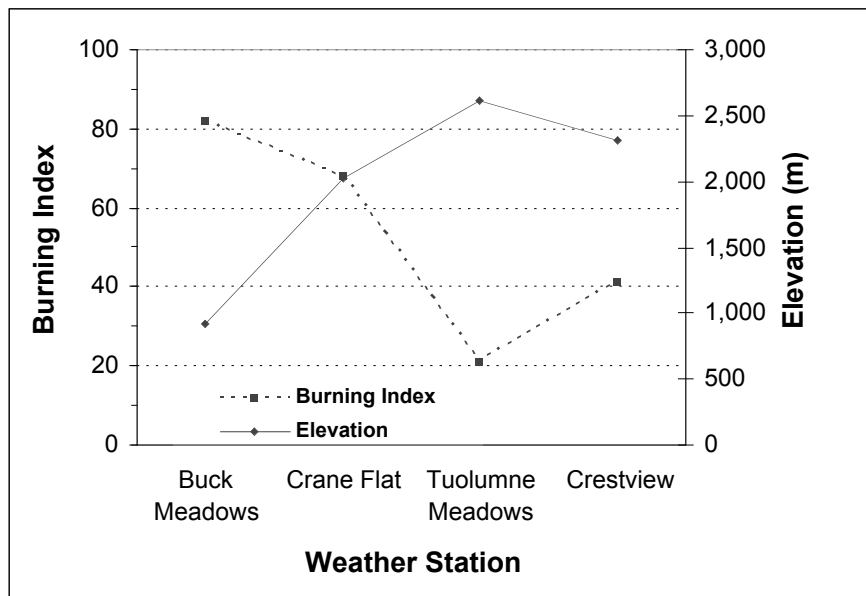


**Figure 5—** Average maximum burning index at sites of weather stations along an elevational transect of the Sierra Nevada, 1993–2002.

## *Landscape Mosaic*

A very complex landscape mosaic results from fires burning under variable conditions of ignition, fuels, and weather. In the absence of anthropogenic influences, the simultaneous occurrence of lightning strikes, flammable fuels, and weather conducive for burning determines the frequency, size, and intensity of a fire. The resulting variation in fire effects (including fire severity) influences subsequent vegetation succession and fire behavior. Interrupting this burning cycle by excluding fire leads to homogenization of the landscape, resulting in large continuous forest stands with tangled understory vegetation and accumulated dead woody debris.

## **Fire and Landscape Interactions: The Illilouette Basin Example**

To understand how primeval forests developed with the influence of fire, it is instructive to look at an area where fires have been allowed to burn with minimal interference. For the past three decades, Yosemite National Park has had a program of wildland fire use, which prescribes the conditions necessary for allowing lightning-caused fires to run their course. The U.S. Army suppressed all fires in the park between 1890 and 1916, at which point the

National Park Service was established. The Park Service continued to suppress all fires until 1973 when it began implementing the wildland fire use program.

The Illilouette Creek Basin, just south of Yosemite Valley, is an ideal place to examine patterns that emerge from fires freely interacting on a landscape (*fig. 6*). From 1930 (when fire records were first kept) through 1972, only 26.7 ha were burned by 100 fires. Between 1973 and 1979, the area burned increased by 1,885.7 ha, with 1,467.9 ha burned in the 1974 Starr King Fire. An additional 1,941.1 ha burned between 1980 and 1986. The 1981 Fat Head Fire burned up to the Starr King Fire area before going out.
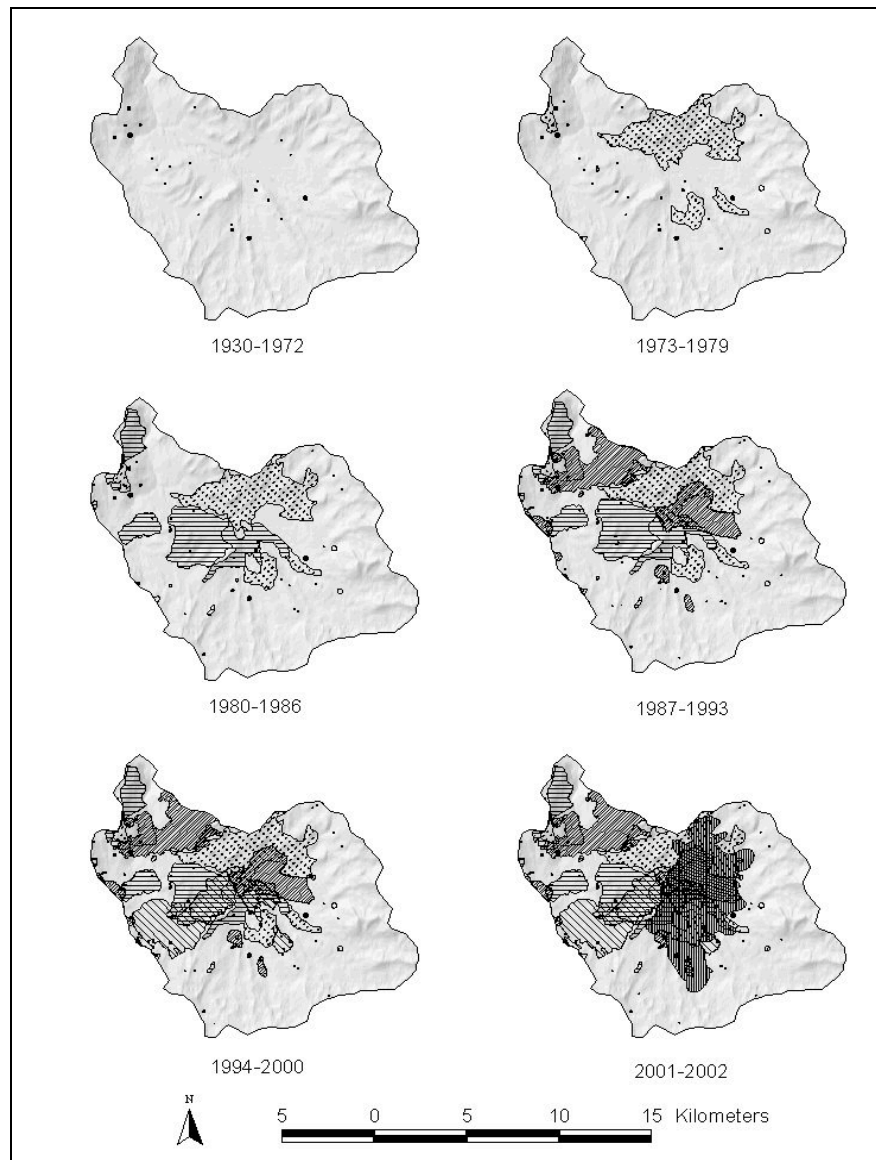
**Figure 6—** Fires in the Illilouette Creek Basin before and after the wildland fire use program was initiated in 1973, Yosemite National Park, 1930–2002.

Not until the period between 1987 and 1993 did reburning occur: in 1988 when the Alaska Fire burned into portions of the Starr King Fire and the 1980 Buena Vista Fire. In both cases, fire intensity was greatly reduced in the reburned areas. Out of the total of 1,996.5 ha that burned during this period, 759.7 ha burned in the Alaska Fire and 791.2 ha in the 1991 Ill Fire. Interestingly, the Ill Fire did not reburn the Starr King fire because the fires were separated by several granite domes. The next period (from 1994 through 2000) saw extensive reburning during the 1994 Horizon Fire before it was suppressed when prescribed conditions were exceeded. The Horizon Fire burned 1,316.6 ha out of the 2,007.3 ha that burned during this period. By 2001, enough fuel had accumulated on the older fires for the 2,135.1-ha Hoover Fire to reburn large areas. However, very little reburning occurred on the 6-year-old Horizon Fire. The Ottoway Fire burned an additional 25.3 ha in 2002.

Reburns are only part of the process that creates diverse landscapes. Fine-scale patterns of fire severity within a fire perimeter add to the heterogeneity already exhibited at landscape level. Recalculating the perimeter of the Hoover Fire based on a severity analysis excludes many areas thought to be burned. *Figure 7* shows fire severity levels within the new perimeter of the Hoover Fire. The unburned areas were either barren, previously burned (as recently as 1994), or were too moist to burn. As severity data become more widely available, it will be possible to examine the intricacies of fire interactions and develop a more detailed understanding of landscape patterns.
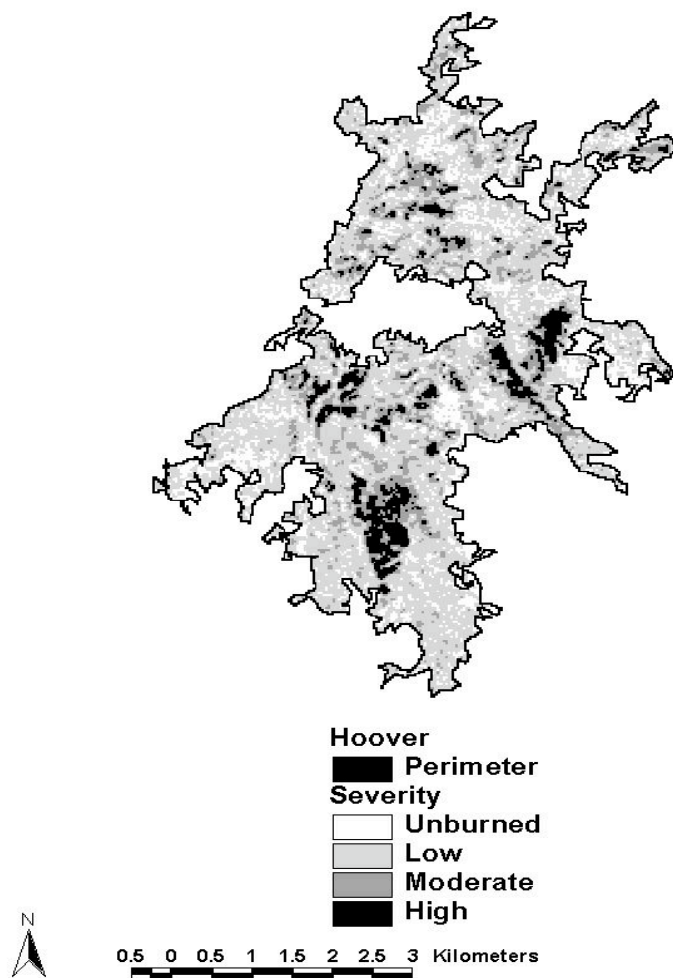


**Figure 7—** Fire severity on the Hoover Fire, Yosemite National Park, 2001.

## Sierra Nevada Landscapes Today

Years of resource-extraction activities and fire exclusion have disrupted ecological patterns and processes on the landscape (McKelvey and others 1996). Accumulations of dead woody debris and dense stands of shade-tolerant understory trees and shrubs have made the fuel and vegetation complex nearly homogeneous. The inevitable fire that cannot be suppressed becomes larger and burns more intensely than would have occurred without this history of fire exclusion. Some believe these conditions are a result of natural succession: even without human intervention, Sierra Nevada forests would have become denser and fuels would have increased. Others believe that environmental groups have contributed to the problem because they have sued to prevent activities that might reduce fuels, such as prescribed burning and thinning. The environmental community, in turn, blames the timber industry for removing the larger trees and leaving the small, unmerchantable debris. The truth is probably somewhere in between these contrasting viewpoints, and, rather than placing blame, the key is to take action to solve the problem.

## A Landscape-Level Fire Management Program

To allow fire to play a more natural ecological role, management must take a landscape-level approach. Such an approach requires large blocks of land with single ownership, or multiple owners with compatible objectives. Examples of a single-owner program can be found in large national parks. In Yosemite National Park, an integrated fire management program includes fire suppression, prescribed fire, and wildland fire use. The program is based on analysis of natural fire return intervals—the number of years between naturally occurring fires—and the magnitude of departures from these for each vegetation type (van Wagtendonk and others 2001). Areas where departures are generally two or fewer have been categorized as wildland fire use zones. In these areas, lightning fires that meet specific prescriptions are allowed to burn to meet land management objectives. Human-caused fires are extinguished immediately using the appropriate management response. Approximately 85 percent of the park is in this zone. Areas where fire return intervals are three or more times greater than normal are managed to reduce fuel hazards and restore natural conditions. Prescribed fires and mechanical treatments are used for this purpose. Mechanical treatments are restricted to areas immediately surrounding structures or other developments requiring protection from fire.

The 2002 fire season illustrates the results achieved with this program. A total of 53 fires burned 2,722.1 ha *(fig. 8)*. Thirty-two of the fires were caused by humans or exceeded the prescription, and these fires were suppressed. The largest two of these fires burned 49.0 ha out of the total of 62.0 ha burned by this type of fire. Thirteen lightning-caused fires were allowed to burn 1,124.1ha under prescribed conditions. The Wolf Fire burned 725.6 ha between July and October around the development at White Wolf. Eight prescribed fires, the largest of which was the Gin Flat Fire at 1,350.8 ha, treated 1,536.0 ha. In addition to the burning program, 124.2 ha were mechanically treated. Our results to date confirm that landscape-level fire management objectives can be met through a program that combines aggressive suppression, active prescription burning, and wildland fire use.

## Conclusion

The patterns and processes of landscape-level fire are a product of the interactions between ignitions, fuels, weather, and topography. Interruption of these processes results in changes to the patterns and, subsequently, the behavior of future fires. Attempts to ameliorate the negative results of past practices will be most successful if they mimic the natural role of fire. Hazard reduction methods must focus on modifying the amount and continuity of surface fuels to reflect the conditions of the pre-suppression era. In order to restore the natural role of fire, fire itself must be one of the tools used. Fire cannot be reintroduced without fire.
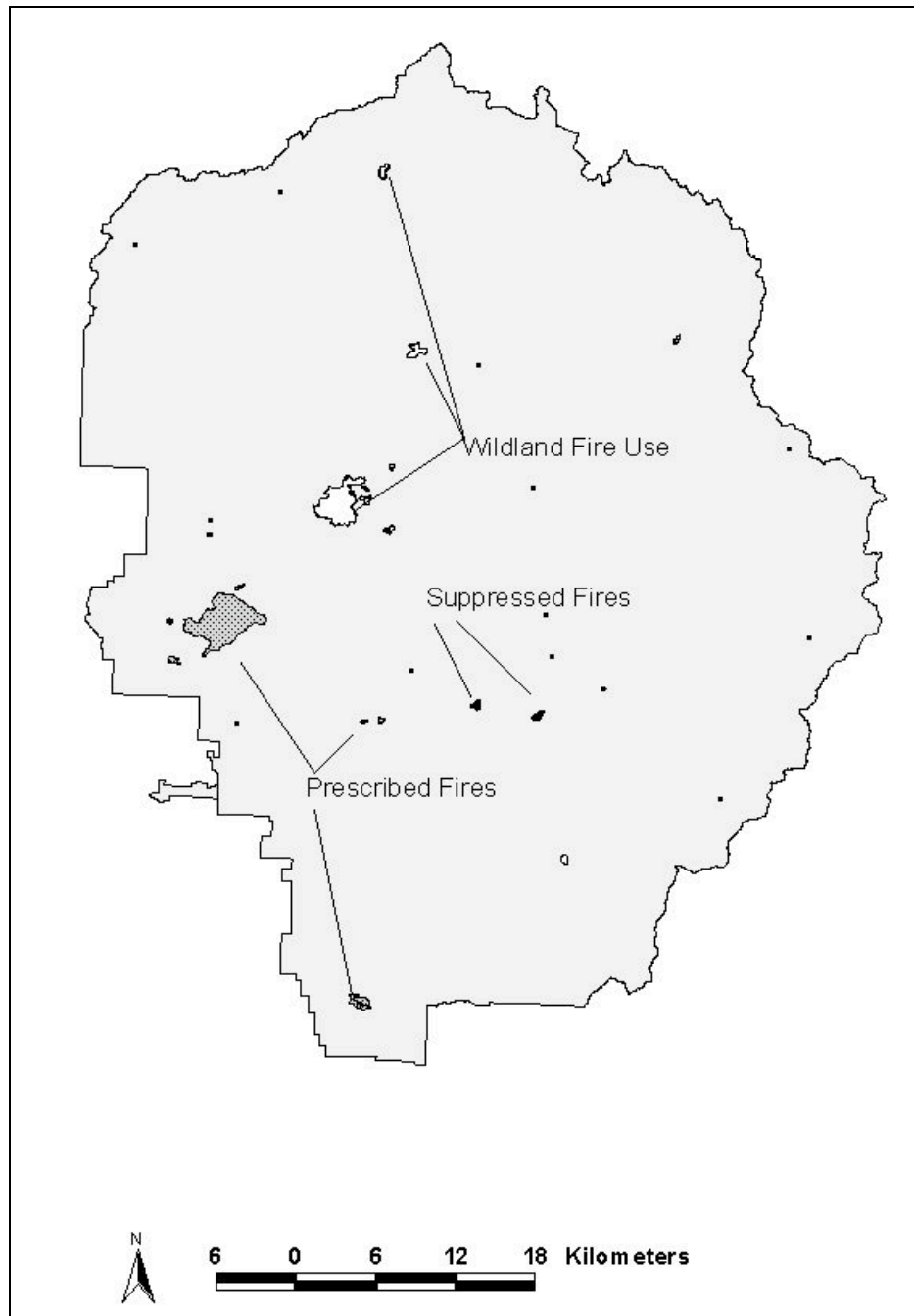
**Figure 8—** Landscape level fires in Yosemite National Park, 2002.

# References

Anderson, M.K. 1994. **Prehistoric anthropogenic wildland burning by hunter-gatherer societies in the temperate regions: A net source, sink, or neutral to the global carbon budget?** Chemosphere 29: 913-934.

Anderson, R.S.; Smith, S.J. 1994. **Paleoclimate interpretations of meadow sediment and pollen stratigraphies from California.** Geology 22: 723-726.

Brown, J.K. 1978. **Weight and density of crowns of Rocky Mountain conifers.** Res. Paper INT-197. Ogden, UT: Intermountain Forest and Range Experiment Station, USDA Forest Service; 56 p.

Brunelle, A.; Anderson, R.S. 2003. **Sedimentary charcoal as an indicator of late-Holocene drought in the Sierra Nevada, California, and its relevance to the future.** The Holocene 13(1): 21-28.

Graumlich, L.J. 1993. **A 1000-year record of temperature and precipitation in the Sierra Nevada.** Quaternary Research 39: 249-255.

Knox, Joseph B. 1992. **Global climate change: Impacts on California.** In: Knox, Joseph B., Shearing, Anne F., eds. Global climate change in California: Potential impacts and responses. Berkeley, CA: University of California Press; 1-25.

McKelvey, K.S.; Skinner, C.N.; Chang, C.; Erman, D.C.; Husari, S.J.; Parsons, D.J.; van Wagtendonk, J.W.; Weatherspoon, C.P. 1996. **Fire in the Sierra Nevada, an overview.** In: Sierra Nevada Ecosystem Project: Final Report to Congress, Vol. II. Report No. 37. Davis, CA: Wildland Resources Center, University of California; 1528 p.

Price, C.; Rind, D. 1994. **Lightning fires in a 2xCO$_2$ world.** Proceedings of the 12th conference on fire and forest meteorology; 1993 October 26-28; Jekyll Island, GA. Bethesda, MD: Society of American Foresters; 77-84.

Swetnam, T.W. 1991. **Fire history and climate change in giant sequoia groves.** Science 262: 885-889.

Vale, T.R. 1998. **The myth of the humanized landscape: An example from Yosemite National Park.** Natural Areas Journal 18: 231-236.

van Wagtendonk, J.W. 1994. **Spatial patterns of lightning strikes and fires in Yosemite National Park.** Proceedings of the 12th conference on fire and forest meteorology; 1993 October 26-28; Jekyll Island, GA. Bethesda, MD: Society of American Foresters; 223-231.

van Wagtendonk, J.W. 1998. **Use of thematic mapper imagery to map fuel models.** Proceedings of the 13th conference on fire and forest meteorology; 1996 October 27-31; Lorne, Australia. Moran, WY: International Assoc. Wildland Fire 13: 215-224.

van Wagtendonk, J.W.; Benedict, J.M.; Sydoriak, W.M. 1998. **Fuel bed characteristics of Sierra Nevada conifers.** Western Journal of Applied Forestry 13(3): 73-84.

Van Wagtendonk, J.W.; Kent A.; Meyer, J.B.; Paintner, K.J. 2002. **The use of geographic information for fire management planning in Yosemite National Park.** The George Wright Forum 19(1): 19-39.