The 2007 Southern California Wildfires: Lessons in Complexity

Jon E. Keeley, Hugh Safford, C.J. Fotheringham, Janet Franklin, and Max Moritz

ABSTRACT

The 2007 wildfire season in southern California burned over 1,000,000 ac (~400,000 ha) and included several megafires. We use the 2007 fires as a case study to draw three major lessons about wildfires and wildfire complexity in southern California. First, the great majority of large fires in southern California occur in the autumn under the influence of Santa Ana windstorms. These fires also cost the most to contain and cause the most damage to life and property, and the October 2007 fires were no exception because thousands of homes were lost and seven people were killed. Being pushed by wind gusts over 100 kph, young fuels presented little barrier to their spread as the 2007 fires reburned considerable portions of the area burned in the historic 2003 fire season. Adding to the size of these fires was the historic 2006–2007 drought that contributed to high dead fuel loads and long distance spotting. As in 2003, young chaparral stands and fuel treatments were not reliable barriers to fire in October 2007. Second, the Zaca Fire in July and August 2007 showed that other factors besides high winds can sometimes combine to create conditions for large fires in southern California. Spring and summer fires in southern California chaparral are usually easily contained because of higher fuel moisture and the general lack of high winds. However, the Zaca Fire burned in a remote wilderness area of rugged terrain that made access difficult. In addition, because of its remoteness, anthropogenic ignitions have been low and stand age and fuel loads were high. Coupled with this was severe drought that year that generated fuel moisture levels considerably below normal for early summer. A third lesson comes from 2007 conifer forest fires in the southern California mountains. In contrast to lower elevation chaparral, fire suppression has led to major increases in conifer forest fuels that can lead to unnaturally severe fires when ignitions escape control. The Slide and Grass Valley Fires of October 2007 occurred in forests that had been subject to extensive fuel treatment, but fire control was complicated by a patchwork of untreated private properties and mountain homes built of highly flammable materials. In a fashion reminiscent of other recent destructive conifer fires in California, burning homes themselves were a major source of fire spread. These lessons suggest that the most important advances in fire safety in this region are to come from advances in fire prevention, fire preparedness, and land-use planning that includes fire hazard patterns.

Keywords: fuel-driven fires, southern California, terrain-driven fires, wind-driven fires, urban fuels, wildland–urban interface

As is evidenced year after year, the nature of the "fire problem" in southern California differs from most of the rest of the United States, both by nature and degree. Nationally, the highest losses in property and life caused by wildfire occur in southern California, but, at the same time, expansion of housing into these fire-prone wildlands continues at an enormous pace (Safford 2007). Although modest areas of conifer forest in the southern California mountains experience the same negative effects of long-term fire suppression that are evident in other western forests (e.g., high levels of forest fuel accumulations, increasing stand density, and more), fire suppression has had no demonstrable effect on fuels, fire size, or fire severity in the extensive chaparral systems of the southern California foothills, where most of the damaging wildfires occur (Conard and Weise 1995, Keeley and Fotheringham 2003, Safford 2007). In these highly flammable shrublands, human ignitions are now so frequent in some parts of the landscape that the very survival of natural vegetation is dependent on strict and total fire suppression policies (Halsey 2005).

In southern California, 2007 was another headline year for destructive wildfires, evoking unpleasant memories of the historic 2003 "firestorm" (Keeley et al. 2004). The first 2007 fire to capture national attention was the Windy Ridge Fire in Orange County, which threatened thousands of homes in mid-March, when fire activity is

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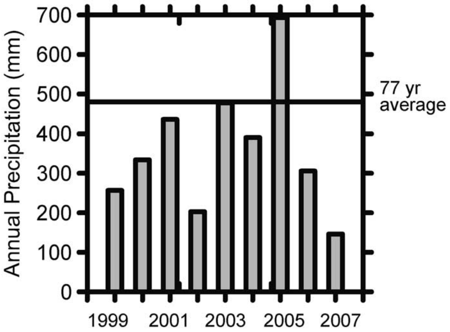

Figure 1. Southern California precipitation, 1999–2007. Average from National Oceanic and Atmospheric Administration station in San Diego, Orange, Riverside, San Bernardino, Los Angeles, Ventura, and Santa Barbara counties (www.ncdc.noaa.gov/oa/climate/normals/usnormalsinv.HTML).

usually at its nadir. Although the media attributed this to "unusual" spring Santa Ana winds, such winds are normal at this time of year. What was unusual was the low moisture content of live fuels for this early date, because of the historic drought southern California had experienced in 2007 and in 6 of the 8 years previous (Figure 1). In midsummer, as the drought continued, we witnessed one of the largest fires in California's history, the Zaca Fire in Santa Barbara County. This was followed a few months later by multiple large fire events during the autumn Santa Ana wind season. The largest of these fires and most losses were in the chaparral dominated foothills, but some smaller fires in the montane coniferous forests did considerable damage to local communities as well. The total property losses from the autumn 2007 firestorm are estimated at $1.8 billion (Karter 2008). In all, the 2007 fire season for southern California, from Santa Barbara south, consumed more than 400,000 ha (1,000,000 ac), and this included several megafires of extraordinary size (Table 1; Figure 2).

Like the 2003 southern California fires (Keeley et al. 2004), the 2007 fires provide lessons for those willing to learn from them. In this contribution, we use the 2007 fires to illustrate the complexity of the fire problem in southern California and to draw three lessons about the behavior of large, destructive fires in this densely populated and highly flammable region.

Autumn Shrubland Fires: The Santa Ana Effect

Between Oct. 20 and 23, 2007, more than two dozen major fires broke out across southern California, driven by dry, gale-force Santa Ana winds. Large fires were experienced from the Mexican border in southern San Diego County northward to Ventura County (Table 1; Figure 2). Such autumn fires are generally the largest fires in the region (Figure 3A). Although drought contributed to seasonal anomalies in live fuel moisture during the summer Zaca Fire (see later in this article), live fuel moisture in October 2007 was not outside the typical autumn range (Figure 4) and thus does not explain the immense size of some of these fires. However, severe drought in 2006 and 2007 (and in 5 other years since 1999; Figure 1) had contributed to extensive vegetation dieback (NOAA 2007). These dead fuels are hypothesized to have been a major factor in fire spread through enhanced spot

Table 1. Southern California fires over 300 ha during the 2007 wildfire season.

Fire	County	Size (ha)	Start date	Duration (days)	Santa Ana wind (days)	Structures lost	Lives lost	Cost ($ millions)	Dominant vegetation	Previously burned (%)	Burned last 5 yr (ha)	Burned last 10 yr (ha)
Alessandro	Riverside	337	Mar. 4	1	1	0	0		Shrublands	98.4	0	301
Sierra	Riverside	315	Mar. 11	1	1	0	0		Shrub and grass	7.6	0	0
Windy Ridge	Orange	655	Mar. 11	2	2	3	0	1.5	Shrublands	100	5	5
Las Flores	San Bernardino	1,659	Mar. 31	2	0	1	0		Shrublands	1.1	0	0
Dawson	Riverside	389	May 8	1	0	0	0		Grasslands	52.5	22	22
Griffith Park[a,b]	Los Angeles	283	May 8	1	0	0	0		Shrublands	58.1	0	0
Island	Los Angeles	1,911	May 10	5	0	6	0	4.8	Shrub and grass	0	0	0
Gorman	Los Angeles	961	May 19	3	0	0	0	1	Shrublands	59.3	0	0
Zaca[a]	Santa Barbara	94,462	July 4	58	0	1	0	122.3	Shrublands	58.3	17	360
Canyon	Los Angeles	301	July 7	2	0	0	0	0.5	Shrublands	35.3	0	0
North	Los Angeles	859	Sept. 2	2	0	0	0		Shrub and grass	100	0	0
Pine[a]	San Diego	794	Sept. 12	4	0	0	0	4.3	Shrublands	100	0	0
Butler 2[a]	San Bernardino	5,664	Sept. 14	6	0	3	0	15.2	Conifer forest	9.5	0	240
Angel 3	San Diego	337	Sept. 15	3	0	0	0		Shrub, oak, conifer	68.8	231	231
Ranch[a]	Los Angeles, Ventura	21,994	Oct. 20	13	3	10	0	9	Shrublands	98.4	8,539	9,928
Witch[a]	San Diego	56,796	Oct. 21	10	3	1,650	2	18	Shrublands	90.8	17,960	18,168
Harris 2	San Diego	36,717	Oct. 21	10	3	548	5	21	Shrublands	88	9,168	11,097
Buckweed[a]	Los Angeles	12,506	Oct. 21	3	3	63	0	7.5	Shrublands	97.2	1,849	2820
Santiago[a]	Orange	9,365	Oct. 21	18	3	24	0	21.7	Shrublands	78.8	4	576
Malibu Canyon[a]	Los Angeles	1,483	Oct. 21	5	3	16	0	7.1	Shrublands	100	0	0
Sedgwick	Ventura	327	Oct. 21	2	2	0	0	1.1	Shrublands	0	0	0
Slide[a]	San Bernardino	5,055	Oct. 22	9	2	271	0	27.1	Conifer forest	27.1	221	427
Rice	San Diego	3,833	Oct. 22	6	2	248	0	6.6	Shrubland	20	21	35
Grass Valley[a,b]	San Bernardino	485	Oct. 22	7	2	200	0	7.5	Conifer forest	51.7	0	0
Magic	Los Angeles	1,143	Oct. 22	3	2	0	0		Shrublands	49	17	17
Ammo[a]	San Diego	7,385	Oct. 23	6	1	0	0	0.7	Shrublands	27.4	0	0
Poomacha[a]	San Diego	16,494	Oct. 23	10	1	217	0	20.7	Shrublands	81.4	3,487	4,169
Corral[a]	Los Angeles	1,664	Nov. 24	3	2	86	0	7.1	Shrublands	100	0	0

All fires except the Dawson were ignited directly or indirectly (e.g., power lines) by humans. The median size of fires >300 ha occurring under Santa Ana wind conditions was 3,833 ha; the median for fires that occurred through the rest of the year was 859 ha.

[a] Fire areas have been updated by subtracting unburned areas within the fire perimeter, using remotely sensed measures of fire severity.

[b] Griffith Park and Grass Valley Fires included because original fire size within geographic information system (GIS) perimeter (i.e., before subtraction of unburned patches) was greater than 300 ha.

fire ignitions far ahead of the fire front (Keeley and Zedler 2009).

Autumn fires typically last longer than fires at other times of the year (Figure 3B) and although Santa Ana winds play critical roles in the initial stages, most fires persist after the offshore flow subsides. The October 2007 fires are a good example of this pattern. Most damage occurred during the initial Santa Ana winds, but many of the October 2007 fires persisted for a week to 10 days after the Santa Ana winds had subsided (Table 1). Another example of this effect was observed in the 2003 Cedar Fire in San Diego County, where, after the offshore Santa Ana winds died down, strong onshore flow drove the fire inland through the Cuyamaca Mountains, burning large expanses of montane forest in a high severity crown fire (Franklin et al. 2006). We hypothesize that one reason these fires persist after the winds have subsided is because post–Santa Ana onshore flow initially returns hot, dry air displaced over the ocean back on to land, thus extending the period of abnormally low humidities and high temperatures beyond the period of the Santa Anas themselves. This is illustrated by the weather conditions during the 2007 Witch Fire (Figure 5), which began on October 21 and burned for 10 days. The Santa Ana wind event was relatively brief, persisting for 3 days; however, the humidity and temperature did not return to conditions more typical of westerly flow until the end of the month. In addition to weather, there are also logistic problems that affect the total length of the fire period; e.g., fighting these fires requires major adjustments in the spatial deployment of firefighting resources as winds shift from offshore to onshore flow.

The October 2007 fires are noteworthy not only for their size, but also because they followed so closely on the extraordinary fires of October 2003, in many cases burning through and around the same communities affected by the 2003 fires. Most striking, however, is the fact that the October 2007 fires reburned extensive portions of the 2003 fire scars, as well as other areas burned in 2002 and even 2004 (Table 1). In San Diego County the Harris, Witch, and Poomacha fires reburned over 30,000 ha of 4-year-old fuels (Figure 6). In Ventura County the Ranch Fire reburned 8,500 ha of the 2003 Piru and Verdale fires and in Los Angeles County the Buckweed Fire reburned 1,800 ha of the 2002 Bouquet and Copper fires (Table 1). In all, the 2007 Santa Ana fires burned more than 40,000 ha (100,000 ac) of "young" fuels (less than 5 years old), further demonstrating (as did the 2003 fires themselves) that recently burned shrublands do not reliably impede the spread of Santa Ana wind-driven fires (Dunn 1989, Conard and Weise 1995, Keeley and Fotheringham 2003, Keeley et al. 2004, Safford 2007).

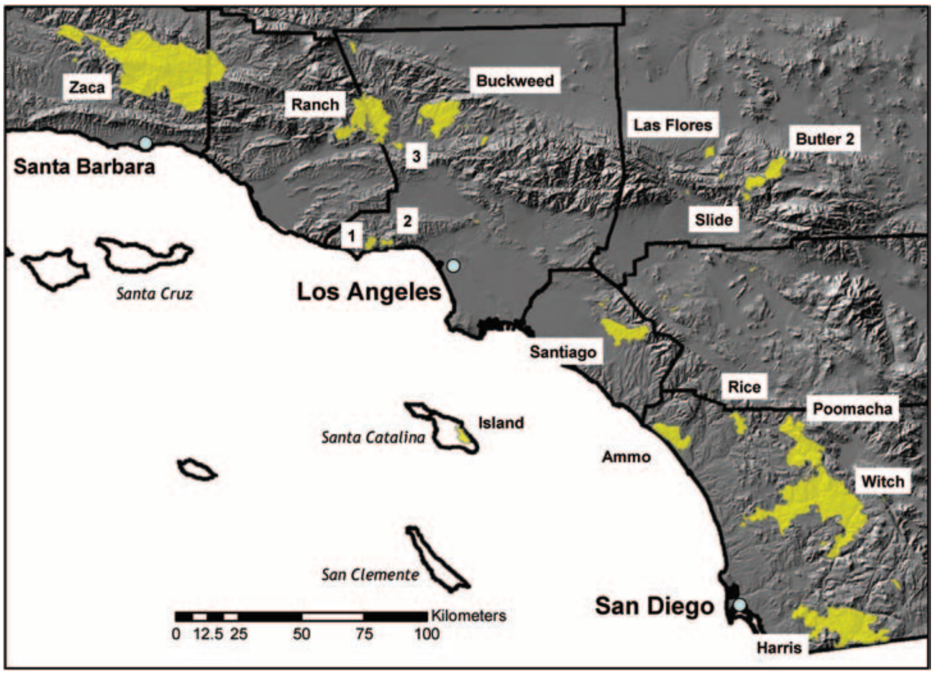

Figure 2. Southern California and locations of fires referred to in this study. Fires greater than 1,000 ha in size are identified. Numbers refer to (1) Corral Fire, (2) Malibu Canyon Fire, and (3) Magic Fire. Los Angeles is at 34°03.510′N latitude, 118°14.653′W longitude.

These patterns provide additional evidence that "fuel mosaics" in southern California shrublands (Minnich and Franco-Vizcaino 1999)—whether manmade or fire caused—are not an efficient barrier to fire spread during the severe weather that drives most of the large fires in the region (Dunn 1989, Conard and Weise 1995, Keeley et al. 2004, Moritz et al. 2004). This should not be interpreted to mean that fuel modification treatments have no role on these landscapes, but only that they need to have clearly defined goals that do not include the expectation that they will stop fast-moving Santa Ana wind-driven fires (note that, for the most part, fire management personnel do not have this expectation, but it remains common in the press, the public, and political circles). Under these conditions fuel modification largely has value as a means of reducing flame lengths and producing defensible space for firefighting activities, including anchor points for backfires and other burnouts. Fuel treatment location in the southern California landscape is thus inherently a strategic proposition. Much effort is currently being expended by federal land and fire management agencies in southern California to develop spatially and temporally explicit strategies for fuel treatment location and maintenance (e.g., see USDA 2005 and NPS 2006).

A further issue is that fuel treatments add disturbance to an already highly disturbed landscape and can lead to ecological degradation. Many southern California ecosystems are sensitive to frequent disturbance and once their fire frequency threshold is reached, there can be negative ecological consequences, including type conversion to exotic vegetation (which also increase fire spread rates), soil erosion, decrease in groundwater recharge, and loss of wildlife habitat (Spittler 1995, Keeley et al. 2005, Merriam et al. 2006, Syphard et al. 2006). For resource protection, fuel modification in areas subject to frequent large fires should be performed in judicious fashion. Beyond the wildland–urban interface (WUI), we continue to lack a clear understanding of where fuel treatments are most cost-effective, both economically and ecologically. That is not to say that there are not strong opinions, but data remain insufficient to bring all stakeholders to common levels of understanding and agreement.

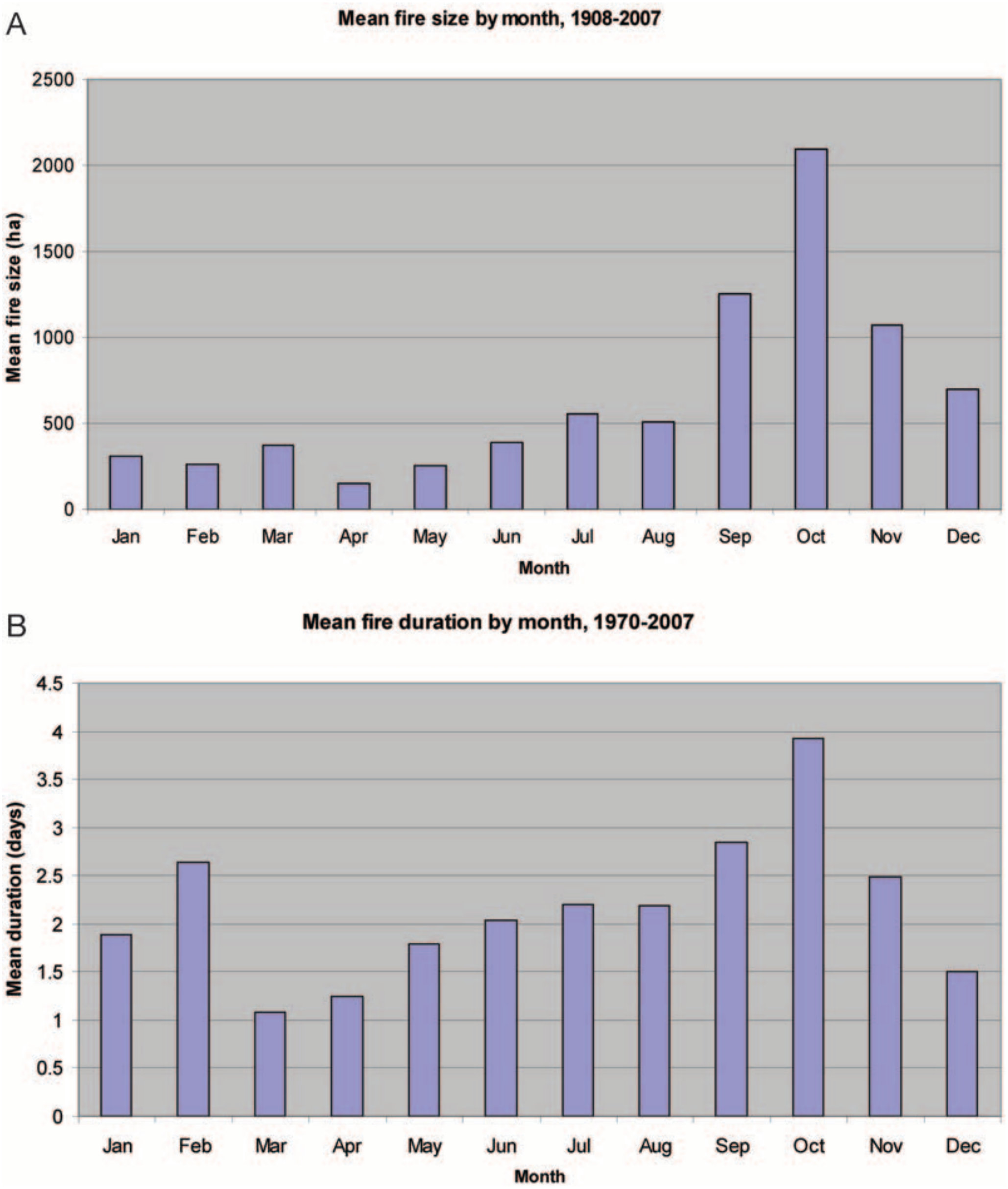

Figure 3. (A) Mean fire size by month, 1908–2007, for fires occurring in southern California (excluding desert habitat). Counties include Santa Barbara, Ventura, Los Angeles, San Bernardino, Riverside, Orange, San Diego, and Imperial. (B) Mean fire duration for fires from the same area, 1970–2007. Data are generally not available for duration of earlier fires. Data from California State fire history database (Cal Fire 2008). This data set contains all federal fires more than 4 ha and Cal Fire fires more than 40 ha, but few fires below these size thresholds; i.e., most fires are not included in this data set. Were smaller fires included, our inspection of the fire reports from federal fire agencies suggests that the values in the graphs would decrease but the relative patterns would not change. Fires more than 3 standard deviations from the mean for the month were removed from the data set.

Short fire cycles (5–10 years or less) put the sustainability of woody ecosystems at serious risk, as reburning occurs before shrubs have developed sufficient stored carbohydrate reserves and/or soil seed banks to maintain their dominance. In general, the grassland physiognomy can survive such short fire return intervals, but these short intervals are marginal for coastal sage scrub and are clearly destructive to chaparral (Keeley 2006b). Large areas in the southern California foothills (especially in Los Angeles and San Bernardino counties) have experienced 4–10 (or even more) fires over the last 100 years and what was originally chaparral or sage scrub is now alien grasses peppered with scattered remnants of the former shrub cover (Jacobson et al. 2004). This appears to be a problem associated with autumn fires and less likely to occur earlier in the season (Figure 7). As shown in Table 2, chaparral comprised between 25 and 85% of the landscape reburned by the 2007 fires. Given the sensitivity of this vegetation type to high fire frequency, thousands of hectares—especially in San Diego County—are apt to be invaded by alien grass species, which is likely to lead to even higher fire frequencies. Restoration of shrub communities to such landscapes is difficult to impossible (Allen 1993). One probable result of the October 2007 wildfires in southern California is thus a heightened risk of repeated fires. A major fire management challenge for these landscapes will be the effective suppression of fires for at least the next couple of decades.

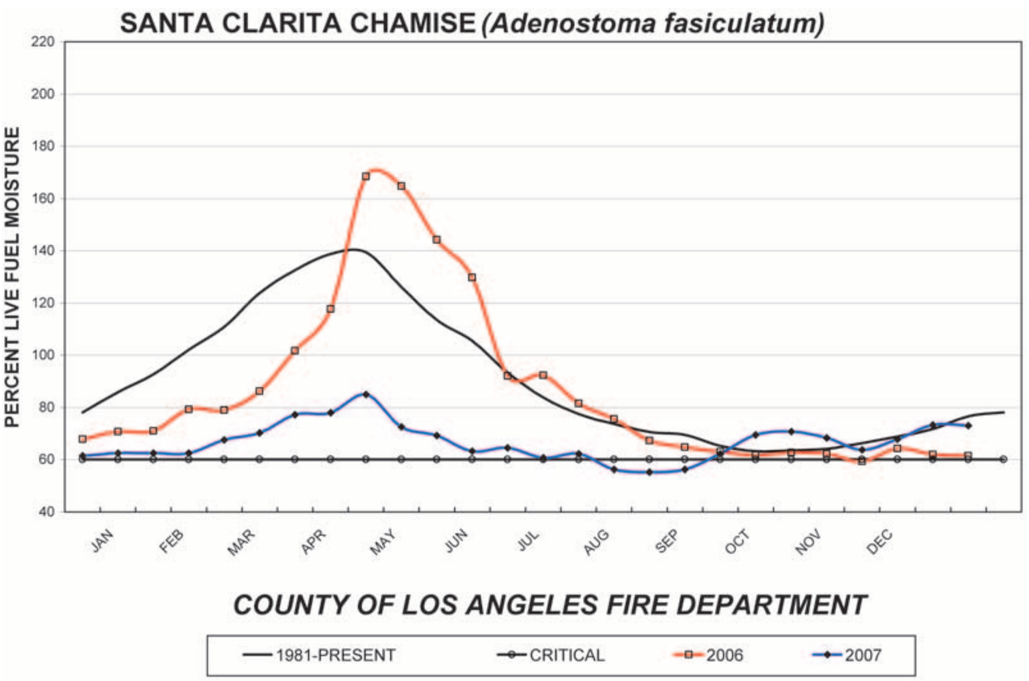

Figure 4. Live fuel moisture in the widespread chaparral shrub *Adenostoma fasciculatum* from Santa Clarita in northern Los Angeles County for 2006, 2007, and the 27-year average. The critical threshold line at 60% indicates the point where tissue is susceptible to mortality (County of Los Angeles 2008).

Summer Shrubland Fires: The Zaca Fire

Although best known for the catastrophic effects of Santa Ana wind-driven fires in the autumn, southern California is also subject to fires earlier in the season. In fact, most ignitions in southern California occur in the June–September period (Keeley 2006a). However, in most cases spring and summer fires are quickly contained (Figure 3B) and cause little damage, largely because of higher fuel moisture and the absence of Santa Ana winds. On rare occasions, however, summer fires can become large and difficult to control. The best all-time example of this relatively rare phenomenon was the 2007 Zaca Fire, which began near the western boundary of the Los Padres National Forest on July 4 (Figure 2; Table 1) and by the end of August had surpassed in size even the famous 1932 Matilija Fire, which burned 89,100 ha just east of this area (Keeley and Zedler 2009). Containment of the Zaca Fire took 2 months, longer than for any southern California fire on record.

The ultimate size and duration of the Zaca Fire were the result of multiple factors. Although not driven by the offshore flow of dry Santa Ana winds, control of the fire was complicated by periodic and erratic onshore winds and high temperatures. There were only six “red flag” days over the duration of the fire (a red flag day is an officially declared “high fire hazard” day, defined primarily by high winds and warm, dry temperatures), but maximum daily wind speeds just east of the fire averaged 20–40 km/hour throughout July and August, and daily temperature maxima averaged over 36°C (range, 30.6–43.3°C; Ozena RAWS station, 34°40′, 119°21, 1,118 m [Desert Research Institute 2009].

The Zaca Fire burned in very remote chaparral-dominated landscapes (Figure 8). It spent more than 3 weeks burning through parts of the San Rafael Wilderness, and in the end, almost 70% of the fire area occurred in wilderness and other roadless areas. As with the Matilija Fire 75 years earlier (Keeley and Zedler 2009), inaccessibility strongly limited aggressive suppression tactics on the Zaca Fire and was a major contributor to the fire’s unusual size and duration. Even where roads and fuel breaks allowed access into the backcountry, high local relief and complicated topography made direct attack on the fire extremely risky. The steep, complex terrain also drove erratic fire behavior even on days with only moderate winds (Anthony Escobar, Los Padres National Forest, pers. comm. June 2008; McDaniel 2007).

Another factor contributing to this being an unusually large summer fire is that the extreme drought of 2006–2007 resulted in markedly lower live fuel moisture (Figure 4). The lack of spring rains and lower fuel moisture appears to be a prerequisite for large fires at such an early date (Dennison et al. 2008).

Additionally, the remoteness of the area burned by the Zaca Fire has led to many fewer anthropogenic ignitions over the last 100 years than in most of coastal southern California, and thus much older vegetation (Figure 8). For example, the interior 40,000 ha of the fire area had only 8 fires recorded since 1911, 1 of which was caused by lightning, in contrast to a comparable area outside the fire perimeter that recorded 69 fires during that time period, all of which were human caused (Cal Fire 2008). Consequently, large areas within the Zaca Fire perimeter had not burned for an unusually long time (Figure 8); 41% of the landscape had not burned since 1911 (when record-keeping began), and another 46% had not burned in over 50 years (Cal Fire 2008). It is surmised that this led to generally denser and older fuels than firefighters normally encounter in southern California fires, and this was likely exacerbated by the general observation that older chaparral stands typically support a higher dead/live fuel load ratio than younger stands (Conard and Weise 1995).

Some observers have suggested that

burning these very old stands provided resource benefits; however, this landscape was still largely within the range of historical variation for chaparral fire frequency (Schmidt and Safford 2007). Contrary to being a resource benefit, one of the major resource challenges is preventing this area from burning again during the next 10 years, because this could stress the natural ecosystems to the point where alien grasses invade (Keeley 2006b).

One factor mentioned by fire managers as important in preventing the Zaca Fire from becoming even larger than it did were the young age classes along the southwestern perimeter (Figure 8). However, further details would be required to know if this was because limited fuels caused the fire to die down or these areas provided anchor points for backburning or there was a serendipitous shift in wind direction at that point on the fire perimeter. The fact that more than 50% of the fire perimeter stopped at vegetation more than 70 years of age (Figure 8) makes it clear that more than fuel age needs to be considered when interpreting such static fire-perimeter maps. In summary, although the Zaca Fire burned primarily under fire weather conditions less extreme than fall Santa Ana conditions, inaccessibility, steep and complex terrain, drought, fuel loads, and fuel conditions all combined to create conditions for an immense fire (McDaniel 2007).

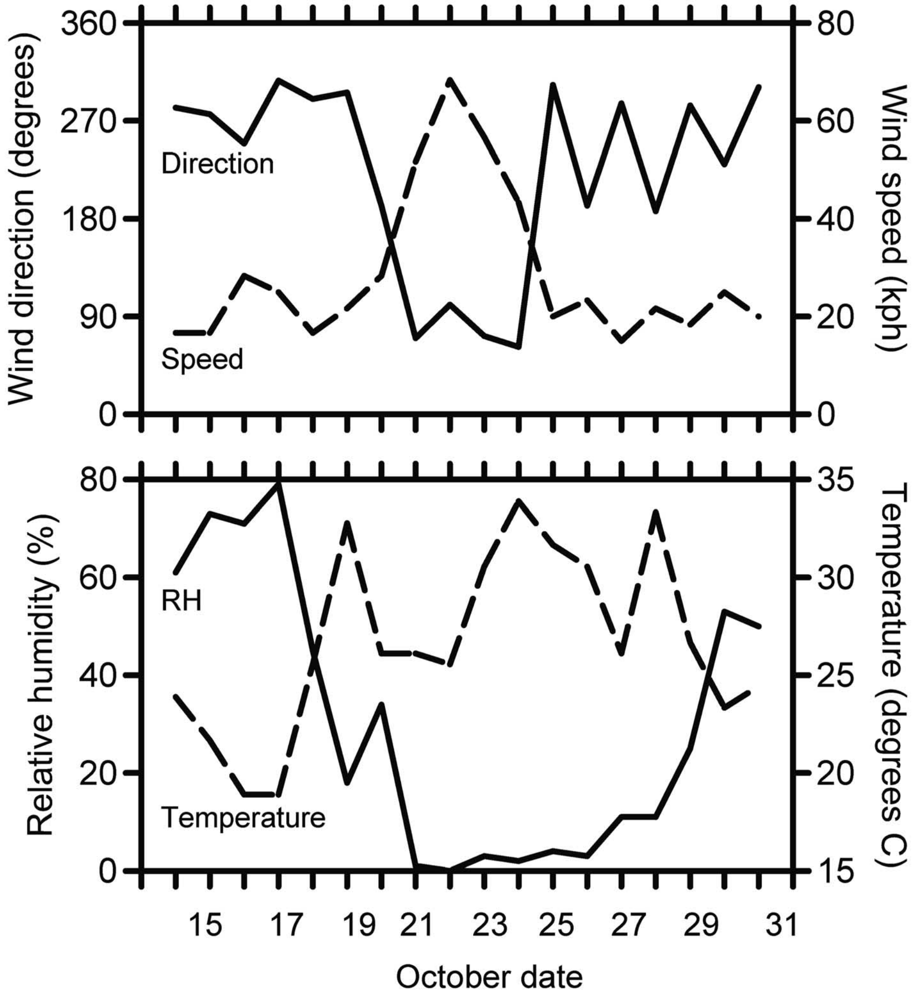

Figure 5. Midday (11 am–12 pm) wind direction, wind speed, relative humidity (RH), and temperature before, during, and after the Santa Ana wind event that initiated the Witch Fire (Table 1; Valley Center RAWS station; Desert Research Institute 2009). Valley Center, California is near the northern perimeter of the Witch Fire at 33°13′34″ 116°59′32″, 418 m.

Urban Forest Fires in the Mountains

In southern California, conifer forests comprise less than 10% of the landscape, primarily as widely disjunct patches in the higher mountains. The first major montane fire in 2007 was the Butler 2 Fire in San Bernardino County, which burned high elevation Jeffrey pine and mixed conifer forests under strong maritime winds (Table 1). The Butler 2 Fire miraculously missed nearby communities, but caused large-scale evacuations. This was followed a month later by the nearby Slide and Grass Valley fires, which were Santa Ana driven and destroyed nearly 500 homes in mountain communities (Table 1). An important lesson from these fires was that despite a herculean effort by the federal government and property owners to reduce forest fuel loads, the urban fuels were sufficient to lead to uncontrollable fire losses.

In contrast to the October 2007 Santa Ana fires that burned through lower elevation chaparral, the majority of the higher elevation forest area burned by the Butler 2, Slide, and Grass Valley fires had not seen a fire since at least the beginning of the last century (Table 1). In addition, the combination of drought and massive bark beetle infestation resulted in extensive dieback of trees (Jones et al. 2004). In the mountaintop forests of San Diego, Riverside, and San Bernardino counties it is estimated that by 2007, 4.6 million trees had died from drought stress and beetles (Rosenberg 2007). Dead forest fuels were major factors in the 2003 fires in Cuyamaca State Park in San Diego County (Hawkins and Petit 2007). To address this double-whammy of heavy fuel accumulation and catastrophic forest mortality, mountain communities and the US Forest Service engaged in a series of strategic forest thinning projects (Mountain Area Safety Task Force 2008, Rogers et al. 2008). By 2007, fuel treatments had already been implemented surrounding the communities affected by the Grass Valley and Slide fires; thus, dead fuel loads were not a major factor in fire spread.

Fuel treatments on the Grass Valley and Slide fires had some effect on fire behavior, where less than 10% of the fire burned at high severity (Rogers et al. 2008). In contrast, untreated forests in the Butler 2 Fire had nearly complete canopy mortality over 50–60% of the fire area (H. Safford, pers. obs., Sept. 2007).

However, the lesson to be learned from the Grass Valley and Slide fires is that even with extensive forest thinning and subsequent ameliorated fire behavior, there was still major property loss; nearly 500 homes

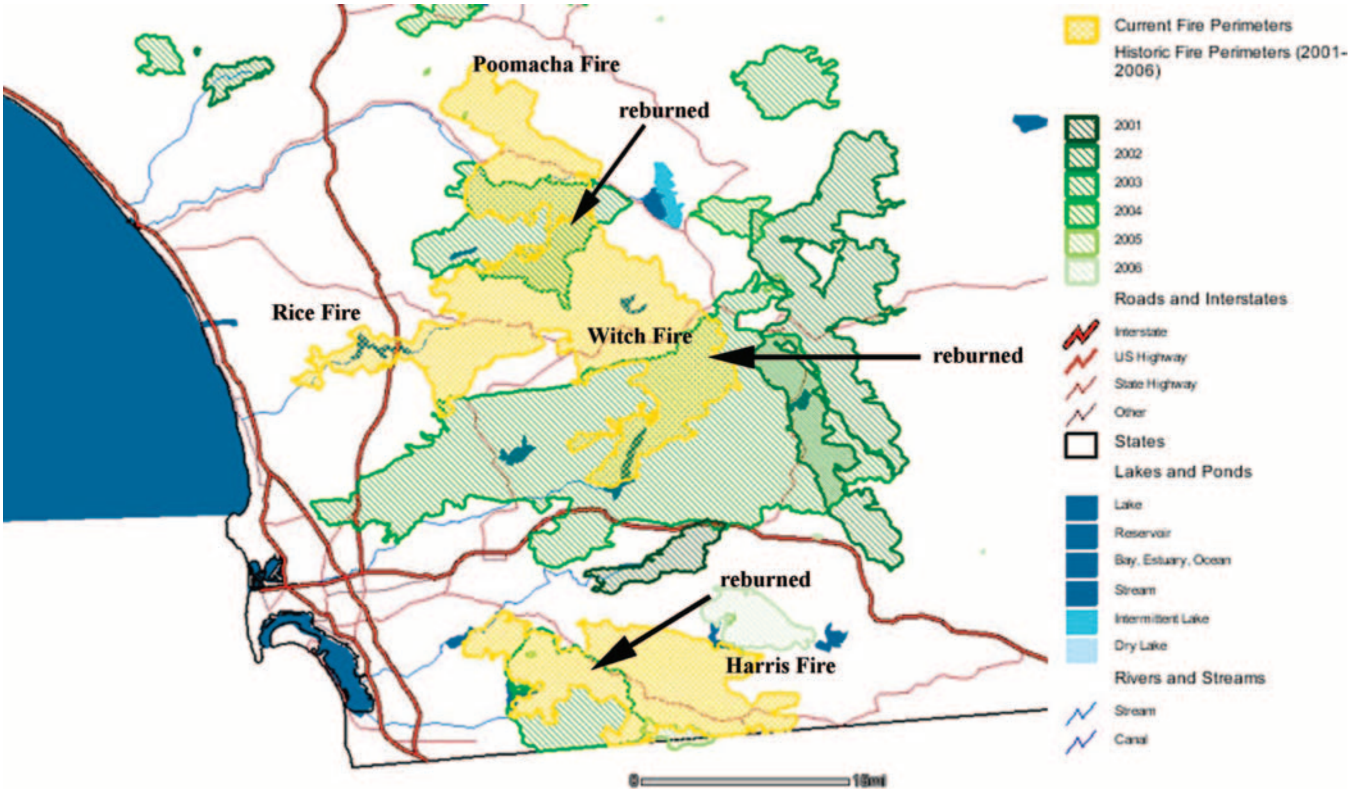

Figure 6. Extensive overlap of fire perimeters for major fires in 2003 and 2007 fires in San Diego County, California; from north to south the 2003 fires (green shading) were the Paradise Fire, Cedar Fire, and Otay Fire and the 2007 fires (yellow shading) are labeled.

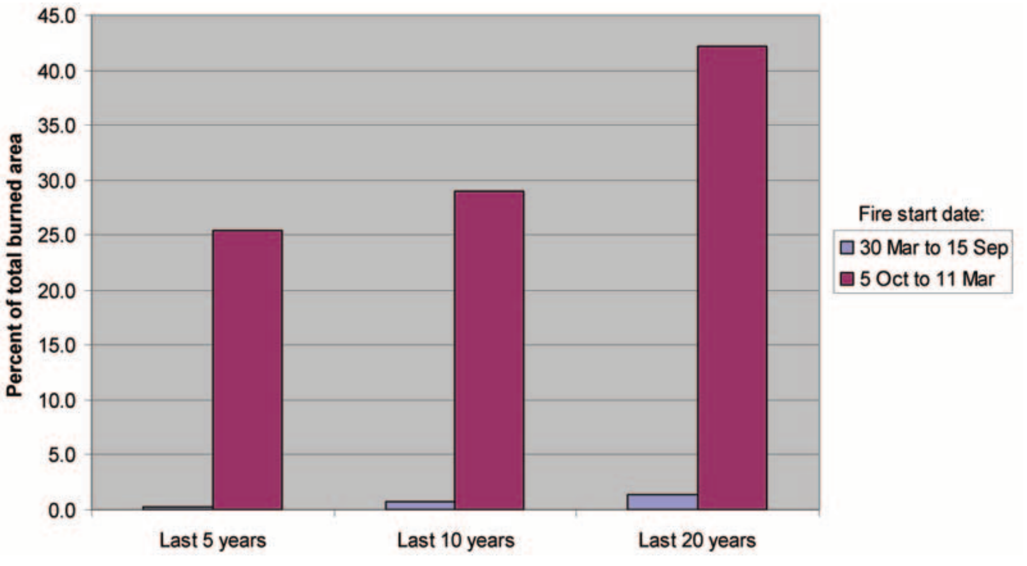

Figure 7. Percentage of the area burned by the 2007 fires in Table 1 that was previously burned within the last 5, 10, and 20 years. Fires from October 5 to March 11 (red bars) occurred during the Santa Ana season; fires from March 30 to September 15 (blue) occurred during the time of year when Santa Ana winds are rare or altogether absent.

were destroyed (Table 1). Detailed study of the destruction from the Grass Valley Fire showed that high intensity forest fire was not a direct factor in igniting the vast majority of homes (Cohen and Stratton 2008). Many private properties had not been adequately treated for fuels, and a high number of homes in the area were constructed from highly flammable materials, including wooden decks and shake roofs. Rogers et al. (2008) concluded that "homes, not the vegetation, were the primary fuel by which the fire spread." The common pattern was that homes ignited from flying embers carried by high winds, and a "domino-effect" ensued, where urban fuels played the major role in fire spread. Urban tree removal and adjacent forest fuel treatments did play a role in containing the level of property loss by changing fire behavior, reducing smoke levels, and enhancing visibility, which provided firefight-

Table 2. Areas burned in 2002 and 2003 reburned in 2007 by vegetation type shown as a percentage of the 2002/2003 burned area (e.g., 45% of the chaparral area burned in the Paradise Fire was reburned in the Poomacha Fire).

	2007 Fires:	Harris	Witch	Poomacha	Ranch	Buckweed
Vegetation	2002/3 fires:	Otay	Cedar and Paradise	Paradise	Piru/Verdale	Bouquet/Copper
Chaparral		25	55	45	27	85
Sage scrub		67	25	33	41	8
Grass		5	5	3	10	3
Woodland		1	13	13	20	4
Conifer		0	0	0	<1	0
Misc.		2	3	6	2	<1

Areas calculated based on fire perimeters, but similar results found using burn severity maps (details not shown).

ers greater access to the area (Rogers et al. 2008). However, dense urban fuels simply overwhelmed firefighters in their attempt to prevent residential fire spread (Cohen and Stratton 2008). These patterns are similar to those described for the Angora Fire that burned earlier in the year near Lake Tahoe; fuel treatments were implicated in saving some homes but were not entirely effective because fire spread from home to home was driven by urban fuels (Murphy et al. 2007).

The lesson from these fires is that in a forest setting, appropriate management of wildland fuels can assist in fighting fires, but more attention needs to be paid to urban fuels if homeowners are to feel secure. Additionally, greater care in planning, so that spacing between houses is safer, construction of houses and associated structures is more fire resistant, and greater care in designing and maintaining urban landscape vegetation is needed.

Forest fuel treatments are also likely to have provided resource benefits during the Poomacha Fire. Although this was largely a foothill shrubland fire, it threatened conifer forests on Palomar Mountain. Mechanical fuel treatments along a roadway allowed firefighter access for backfire operations that are thought to have prevented crown fires in Palomar State Park, which contains some of the last remaining old-growth mixed conifer forest in San Diego County (M. Wells, California State Parks, pers. comm., Jan. 2008).

Additional Lessons from the 2007 Fires

The Island Fire (Table 1; Figure 2) occurred on Santa Catalina Island, one of the California Channel islands, and reflects changes in land-management practices not typical of the mainland situation. Two hundred years of intensive livestock grazing have greatly altered this landscape (Brumbaugh 1980). Until about 10 years ago feral goats were responsible for denuding much of the native vegetation (Schoch 2007). Recently, The Catalina Island Conservancy has worked to remove the feral grazers and restore the island from exotic grassland to native shrublands. Consequently, fuels have accumulated and greatly increased fire frequency and fire hazard on Catalina Island; similar changes are underway on adjacent Channel Islands as well (Klinger 2007, Knapp 2005). In some respects this is similar to the situation associated with wildfires stemming from land-use changes in Spain and other parts of the Mediterranean Basin (Pausas 2004).

The Corral Fire (Table 1) illustrates that fire size is not the ultimate determinant of how destructive a fire becomes: point of origin relative to wind direction and urban development are far more critical factors. The Malibu area of Los Angeles County consists of north–south canyons that feed Santa Ana winds directly into highly developed coastal communities. High population density in the region coupled with a well-developed road system has resulted in countless ignitions during wind events. This area has suffered extensive property damage in at least a dozen fires since the original Malibu Colony was destroyed by fire in 1929 (Malibu Fires 2008).

Summary and Conclusions

Most "problem fires" in southern California are driven by autumn Santa Ana winds, but big fires can occur at other times of the year. Other factors such as terrain, drought, fuels, and accessibility interact with wind to make simple categorization of the southern California "fire problem" difficult. However, one factor that is common across the overwhelming majority of large fires is that they are largely the result of anthropogenic ignitions. Differences in their causal factors aside, almost all southern California fires are potentially preventable. Better fire prevention is of paramount importance throughout southern California. This includes consideration of better restrictions on use of machinery in wildland areas during severe fire weather (cause of the Zaca Fire), placement of power lines underground in corridors of known Santa Ana winds (cause of the Witch Fire), more conspicuous arson patrols during Santa Ana wind events (cause of the Santiago Fire), or barriers along roadsides (ignition site for many of the 2007 fires). Fires in southern California require strategic thinking that links causal factors with necessary fire management responses. In many cases the most likely factors altering future fire impacts and outcomes are under community control and require greater attention to zoning and planning decisions.

The three lessons we can draw from the 2007 fires can be summarized as follows:

1. Most large fires in southern California occur after the long summer dry period and are driven by high winds under hot and dry conditions (Santa Ana winds). The largest of these fires burn through chaparral fuels under conditions that defy efforts at control. Increasing housing density in the southern California foothills is escalating the complexity and danger of fire control efforts under these challenging conditions. During Santa Ana wind events such as those that drove the autumn 2007 fires, chaparral fires are not constrained by previous fire boundaries. Stated another way, young fuels in chaparral are not a reliable barrier to fire spread under Santa Ana conditions. The extreme frequency of fire in the southern California foothills is driving large-scale vegetation-type conversion, as shrub-dominated landscapes cede to more fire-resilient (largely exotic) grasses.
2. Although it is a major factor in driving

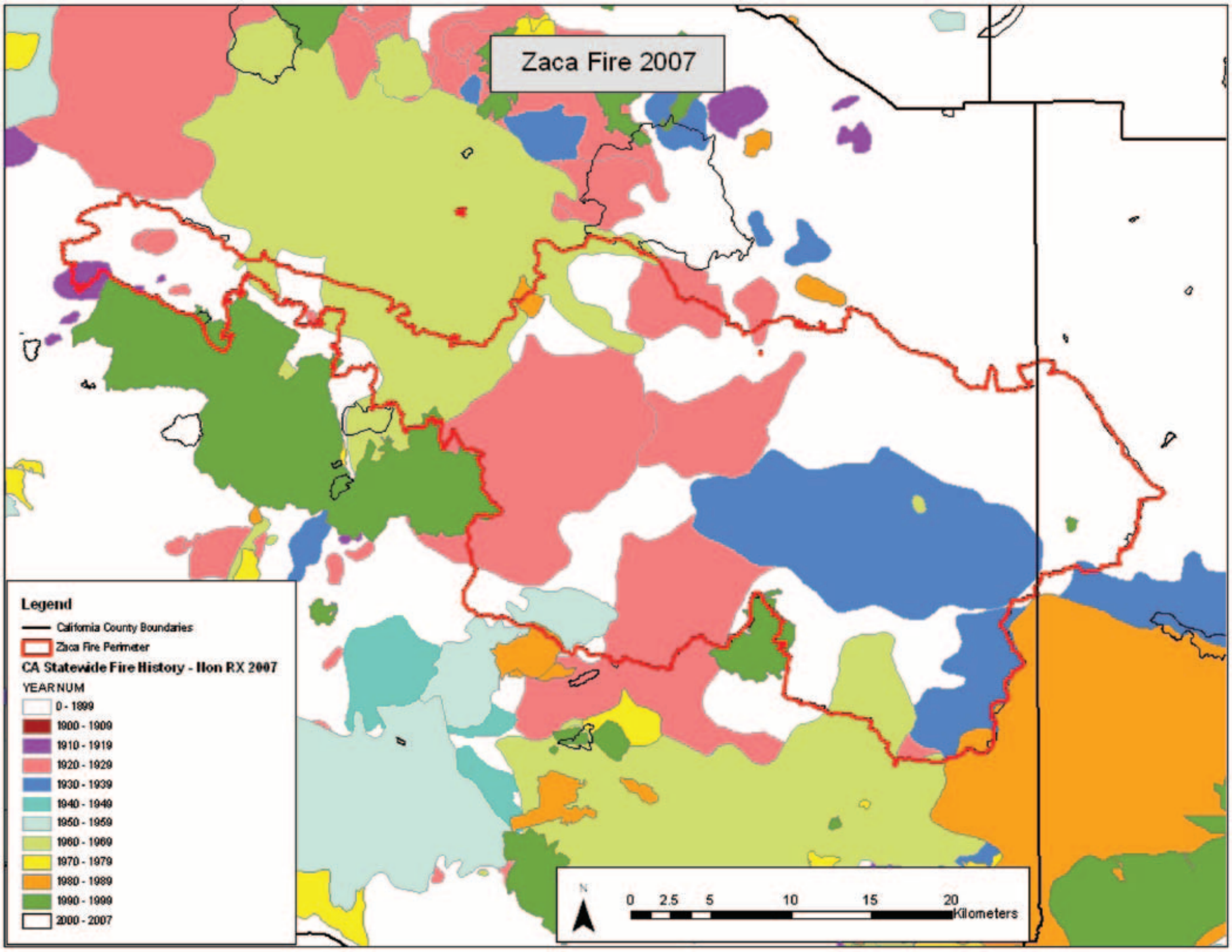

Figure 8. Fire perimeter of the 2007 Zaca Fire and time since last fire for areas inside and outside of the perimeter; distance across panel image is 71 km (data from the Cal Fire FRAP Fire History database).

fire size, wind does not cause all large fires in southern California. Using a 2007 example, the immense Zaca Fire burned for 2 months with only 6 days of high winds. Factors responsible for the size and duration of the Zaca Fire included historically low fuel moistures due to the 2006–2007 drought; steep, inaccessible terrain that both limited fire control options and fueled "topographic" fire runs; and large areas of old chaparral that supported high levels of dead fuels. Spring and summer fires in southern California chaparral are usually easily contained because of the general absence of high wind events. Both WUI and non-WUI fuel treatments can be fundamental to control of these events, but strategic location of these treatments is important, as is a transparent assessment of their relative economic and ecological costs.

3. The fire problem in the conifer-dominated southern California mountains is of a different nature than in the shrub- and grass-dominated foothills. In contrast to the foothill environment, where anthropogenic fires are occurring with unnerving frequency, fire suppression efforts in southern California conifer forests have been largely successful. The long-term lack of fire in these once fire-rich habitats has resulted in a fuels-heavy environment that may burn at unnaturally high severity when a wildfire does escape control. The Butler 2, Slide and Grass Valley fires were montane forest fires in a patchwork of small communities and housing subdivisions, and despite being relatively small, they were especially destructive to property. These fires occurred in forests that had had extensive fuel treatments, but fire control in two of the three fires was complicated by the density of housing and exceptional flammability of building materials used in many mountain homes. In a fashion reminiscent of other recent destructive conifer fires in California, burning homes themselves were a major source of fire spread.

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