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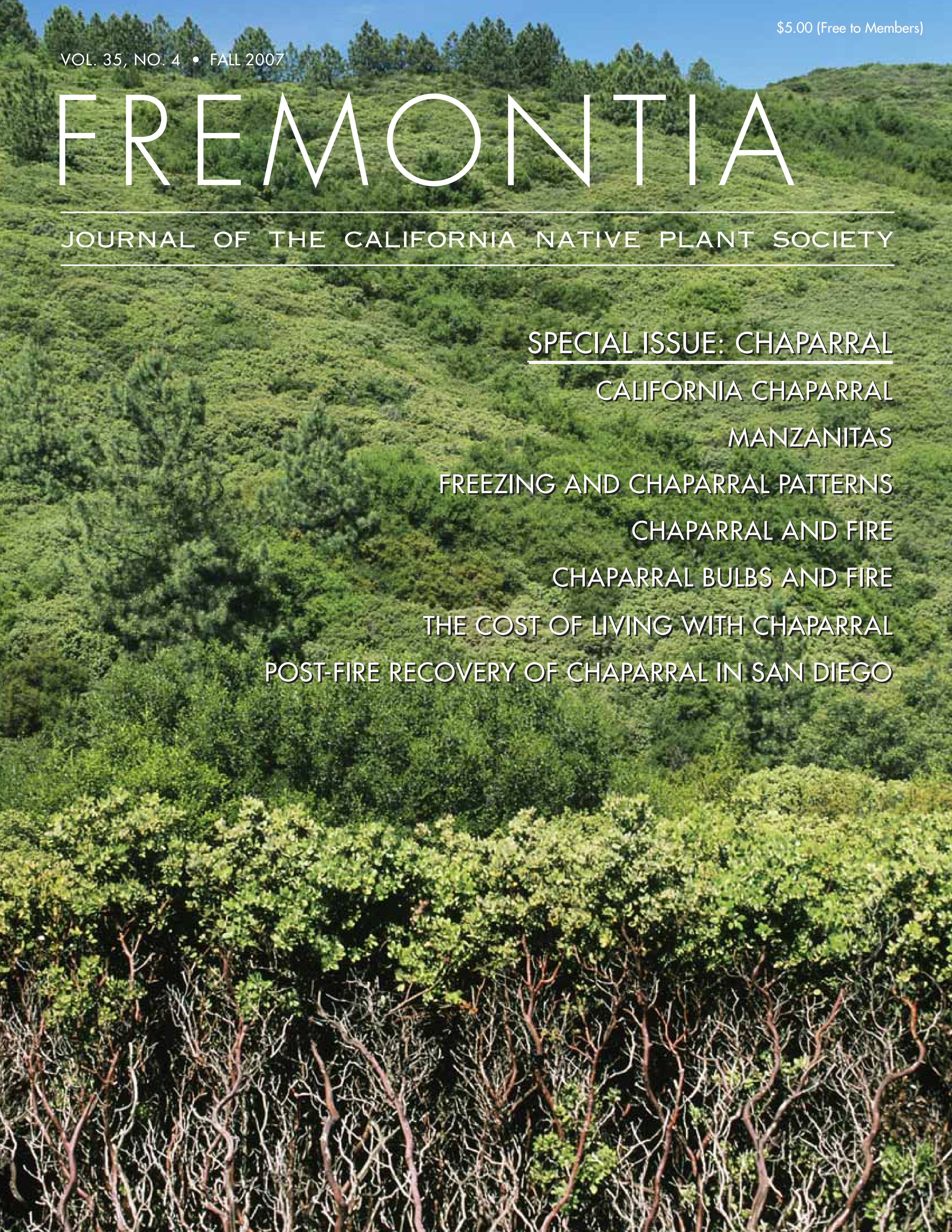

SPECIAL ISSUE: CHAPARRAL

Chaparral regrowth and ephemeral post-fire flora in the first spring after the 2002 Bouquet Fire, Los Angeles County (this area is in the fifth year of recovery as shown on page 20). All photographs by the author.

CHAPARRAL AND FIRE

by Jon E. Keeley

Large wildfires are an inevitable feature of chaparral. The moderate temperatures during winter promote growth of extensive stands of shrublands with contiguous fuels covering massive portions of the landscape. The summer-fall drought makes these fuels highly flammable over a relatively lengthy portion of the year. Because of widespread human influence, most fires today are anthropogenic; however, in wilderness areas lightning still accounts for some chaparral fires.

Wildfires in California shrublands pose a significant danger to humans but are usually not a threat to sustainability of this ecosystem. Most of the flora and fauna exhibit extraordinary resilience to fire. However, although one often hears that species in this community are "fire adapted," (indeed, I am sure I have written that many times), this is, strictly speaking, incorrect. None of the species in this fire-prone landscape are adapted to fire *per se*, but rather to a particular fire regime. Some fire regimes are destructive to chaparral species and will readily lead to their demise. The primary culprit is high fire frequency, and its impacts will be discussed later in this article.

The California chaparral crown-fire regime is characterized by high intensity fires that burn all above-ground shrub biomass. This is in contrast to the higher elevation ponderosa pine forest surface-fire regime, where fires typically burn as low intensity fires confined to surface litter and understory plants, resulting in survival of many of the dominant trees. This profound difference in fire regime leads to very different management needs, particularly with respect to fire. Management paradigms appropriate for forested ecosystems are often inappropriate for chaparral and other crown-fire ecosystems.

RISE OF THE FLORAL PHOENIX

Most chaparral fires occur in summer and fall and typically remain as blackened landscapes until the winter rains. Fires that occur following high rainfall seasons may still have sufficient soil moisture at the time of the fire to begin regeneration sooner; for example, shrub species sometimes initiate resprouts from underground roots or stems within weeks of summer fires. However, most regeneration is initiated following the first winter rains, both from resprouts and germination of the previously dormant seed bank. Chaparral is one of a handful of ecosystems in the world that responds to fire by initiation of a post-fire ephemeral flora, composed of species that are otherwise seldom seen. This post-fire flora comprises many life forms but is dominated by annual forbs. Commonly on a single slope face there may be a couple dozen different species and the composition often changes from one slope aspect to another. These post-fire species exhibit a range of specificities to fire, some being restricted to the first and second post-fire years, others lasting somewhat longer. The most specialized are known as "post-fire endemics" (Table 1).

These species spend most of their life cycle as dormant seed banks under the closed canopy of the chaparral. Sometimes this dormant period lasts a century or more, but that interval is getting increasingly shorter. Fire triggers germination of these species following winter rains and these species are often described as having "fire-dependent regeneration." When I was a student it was generally understood that heat from fire was the cue that triggered germination. It is now clear that for the vast majority of this ephemeral post-fire flora heat plays no role in their germination; rather it is chemicals produced by the combustion of organic matter that stimulates germination (Table 1). In 1997 a graduate student C.J. Fotheringham and I did research that showed that smoke could trigger germination in deeply dormant seeds, and this could happen either directly or indirectly by being transferred through the gas or aqueous phase long after the fire had passed. Further we demonstrated that one of the inorganic gases in smoke, nitrogen dioxide, could trigger complete germination in some species. Organic chemists have recently reported that an organic decomposition product found in smoke also can trigger germination. One of the fascinating stories in this ephemeral flora is that of members of the Papaveraceae, e.g., bush poppy (*Dendromecon rigida*) and species of *Dicentra*. Experiments show that these species are unresponsive to any fire cue if seeds are collected directly off the plant. Rather, they must first be allowed to "age" in the soil for perhaps as long as a year, after which they are still deeply dormant but now respond to smoke.

The ephemeral post-fire flora comprises other life forms such as geophytes and short-lived and slightly woody suffrutescent species. It is of interest that these two groups have radically different regeneration modes. Geophytes, including species of onion (*Allium*), *Brodiea,* mariposa lily (*Calochortus*), soap plant (*Chlorogalum*), blue dicks (*Dichelostemma*), and death camas (*Zigadenus*) are present at the time of fire as dormant bulbs and corms in the soil. They flower profusely after fire from resprouts and set weakly-dormant seed, which germinates after the subsequent winter rains. The suffrutescents such as deerweed (*Lotus scoparius*) and rock rose (*Helianthemum scoparium*) are present prior to fire, usually as dormant seed banks, which are heat stimulated and germinate in profusion after the first rains following fire.

Shrubs present prior to the fire are all represented in the first post-fire year, except when the interval

Burned shrub skeletons and post-fire annuals and short-lived perennials in the first spring after a fire.

Post-fire ephemeral flora. Top: California bells (*Phacelia minor*) after the Gujito Fire in 1997. • Bottom: Yellow-throated phacelia (*Phacelia brachyloba*).

between fires is unusually short. Many such as scrub oak (*Quercus berberidifolia*), coffeeberry (*Rhamnus californica*), redberry (*R. crocea*), chaparral cherry (*Prunus ilicifolia*), and mountain mahogany (*Cercocarpus betuloides*) return as vegetative re-sprouts. Their seedlings are nonexistent after fire. On the other hand, many species of ceanothus (*Ceanothus cuneatus* and *C. greggii*) and manzanita (*Arctostaphylos glauca* and *A. viscida*) are present after fire from germination of dormant seed banks that are either stimulated by heat (*Ceanothus*) or by combustion products (*Arctostaphylos*). Several species of these latter genera (e.g., *C. leucodermis* and *A. glandulosa*) both regenerate from resprouts and reproduce from seeds, as is the case for the ubiquitous chamise (*Adenostoma fasciculatum*).

The post-fire endemic story is interesting in that it is tied to chaparral and most of the taxa wear different hats in other communities, or in other words exhibit ecotypic variation. For example, whispering bells (*Emmenanthe penduliflora*) also is found in the Sonoran Desert where germination is tied to years of sufficient rainfall and fire plays no role in its life cycle. Lupine (*Lupinus succulentus*) and clover (*Trifolium wildenovii*) likewise are strictly tied to periodic post-fire environments in chaparral, but in adjacent grasslands, both may be annual components of the ecosystem showing little relationship to fire.

ALTERED FIRE REGIMES AND THE RISE OF ALIEN PLANTS

Ecologist Paul Zedler, formerly at San Diego State University, addressed the issue of threats to chaparral ecosystems due to altered fire regimes by proposing two potential risks. One was the "senescence risk," i.e., too little fire, which conceivably could lead to the local extirpation of species with fire-dependent regeneration. The other was "immaturity risk," arising due to repeat fires that occurred before fire-dependent species reached reproductive maturity, in which case soil seed banks would not be replenished at the time of fire, leading to localized extirpation.

Senescence risk does not represent a significant threat to chaparral persistence, as few areas escape fire for very long. On those occasions where chaparral stands escape fire for a century or more, studies show that they recover after fire as well as younger stands. However, immaturity risk is a very real threat because chaparral is not resilient to alterations in the fire regime that involve excessive fire frequency. This applies to both the resprouting and seeding shrubs as well as to the ephemeral post-fire flora.

Non-native grasses and forbs readily invade frequently burned shrublands and directly outcompete native herbs, perhaps favored by their early germination keyed to autumn rains. In addition, these annual alien species modify the environment to further favor their persistence. They commonly form a dense herb layer that produces highly ignitable fuels and extends the length of the fire season. Additionally, the fire regime switches to a combination of surface- and crown-fire with the alien grasses and forbs spreading fire to shrubs before the shrub canopies have closed in. Because surface fuels generate lower fire intensities, such fires favor survival of the alien seed bank, which would otherwise be destroyed in a crown-fire. Type conversion of native shrublands to alien grasslands has occurred over large portions of California. In the Coast Ranges roughly a quarter of the wildland landscape is grassland, and nearly all is dominated by alien annuals that have displaced shrublands.

ROOTS OF FIRE ADAPTATIONS

The fossil record is replete with evidence of wildfires beginning with the earliest evolution of land plants. This record shows that similar fire regime diversity of crown fires and surface fires has been present for hundreds of millions of years. It is likely that many of the fire response traits evident in chaparral have very ancient origins. This new emerging view of fire origins is in contrast to what many of us were taught early in our careers. For example, the now deceased paleontologist, Daniel Axelrod, formerly of the University of California, Davis, wrote that fire was a relatively recent phenomenon on our landscape and that it has played little role in the evolution of chaparral species. This is perhaps understandable because until the last couple decades ecologists and geographers were generally under the belief that climate and soils determined plant distributions. Fire was often not even mentioned in textbooks as an important ecological factor.

However, today there is a large body of evidence demonstrating that fire is a major ecosystem process on many landscapes throughout the world. In chaparral there is good reason to interpret smoke-stimulated germination, coalesced fruits in *Arctostaphylos* (see article by V.T. Parker in this issue), and lignotubers as evolutionary responses to the crown fire regime. Even more intriguing is the work of evolutionary ecologist Dylan Schwilk (formerly with U.S. Geological Survey, now at Texas Tech University) that supports the idea some chaparral species with fire-dependent reproduction have traits that are consistent with selection to enhance flammability.

TABLE 1. POST-FIRE SPECIALISTS IN CALIFORNIA CHAPARRAL FIRE-RELATED GERMINATION CUES

	Life Form	Germination
Asteraceae		
Chaenactis artemisiifolia	annual	smoke*
Malocothrix clevelandii	annual	smoke
Boraginacae		
Cryptantha micromeres, C. microstachys	annual	smoke
Brassicaceae		
Caulanthus heterophyllus	annual	smoke
Guillenia lasiophylla	annual	smoke
Caryophyllaceae		
Silene multinervia	annual	smoke
Cistaceae		
Helianthemum scoparium	annual	heat-shock**
Fabaceae		
Lotus salsuginosus, L. strigosus	annual	heat-shock
Lotus scoparius	suffrutescent	heat-shock
Lupinus hirsutissima, L. succulentus	annual	heat-shock
Trifolium wildenovii	annual	heat-shock
Hydrophyllaceae		
Emmenanthe penduliflora	annual	smoke
Eucrypta chrysanthemifolia	annual	smoke
Phacelia brachyloba, P. grandiflora, P. parryi, P. suaveolens, P. viscida	annual	smoke
Loasaceae		
Menzelia micrantha	annual	smoke
Onagraceae		
Camissonia micrantha, C. californica	annual	smoke
Papaveraceae		
Dendromecon rigida	shrub	smoke
Dicentra chrysantha, D. ochroleuca	suffrutescent	smoke
Papaver californicum	annual	smoke
Polemonianceae		
Allophyllum gilioides, A. glutinosum	annual	smoke
Gilia angelensis	annual	smoke
Scrophulariaceae		
Antirrhinum coulterianum	annual	smoke
Mimulus brevipes	annual	smoke
Solanaceae		
Nicotiana attenuata	annual	smoke

* smoke, charred wood, or other combustion products from fire

** heat-shock = brief exposure to high temperatures from fire

CALIFORNIA IS A BIG STATE

Many of the generalizations about chaparral are based on extensive studies in Southern California. However, chaparral is the dominant vegetation type in the state, and historically, fire activity has been very different in other regions.

For example, in Southern California, very little if any of the chaparral landscape has escaped burning since annual record keeping began in 1911, and throughout the latter half of the 20th century most counties have had a fire rotation interval between 30-40 years, which is at the lower threshold of tolerance for chaparral. In contrast, large portions of the chaparral in the southern Sierra Nevada have escaped burning for very long periods; over 40% has never had a recorded fire. In the mountains and valleys surrounding the East Bay of San Francisco a similar story unfolds where the fire rotation interval is estimated at about 100 years. Multiple factors account for these patterns. Differences in population density likely play a role since humans account for most fire ignitions in this vegetation. In addition, Santa Ana-type winds are rare in the southern Sierra Nevada foothills and the fire season is relatively short in the San Francisco Bay Area.

Chaparral five years after fire with resprouting evergreen chamise (*Adenostoma fasciculatum*) shrubs and seedlings embedded within a matirx of dried, but still alive, deerweed (*Lotus scoparius*) in Los Angeles County.

FIRE-PRONE YOUNG CHAPARRAL

Deer weed and other native perennials such as rock rose (*Helianthemum scoparium*) and morning glory (*Calystegia macrostegia*) are widespread in early seral stages. Their suffrutescent growth form has substantial dieback each year that provides more than enough fuel to make young chaparral highly susceptible to reburning. (Studies of similar stands show fine fuel loads are five to ten metric tons per hectare; Keeley and Halsey unpublished data.) Although these young fuels contribute to reduced flame lengths and produce fires more conducive to direct attack by fire fighters, they generally do not act as barriers to fire spread. This is one of the main reasons fire management aimed at producing "fuel mosaics" through rotational burning of chaparral has never worked in this vegetation type.

When young stands reburn they are much more susceptible to invasion by alien grasses, which in turn increases the risk of repeat fires. When fires occur multiple times within a 15- to 20-year period they can convert chaparral to alien-dominated grasslands.

THE ODD COUPLE: CHAPARRAL FIRES AND PEOPLE

Large chaparral wildfires have been a feature of this landscape for eons. Long before humans had a dominant influence, massive wildfires occurred here; records of them are embedded in ocean sediments and Native American legends. The earliest well documented large fire in Southern California was in 1878. The fire perimeter map (stored in the U.S. National Archives) shows this fire burned from west of Pasadena north through Tujunga, but not quite to Mt. Gleason peak, then west to beyond Pacifico Mountain and was estimated at 78,000 acres. In Orange County a huge fire pushed by Santa Ana winds was reported by the Los AngelesTimes in September 1889. The Riverside Enterprise (September 25, 1889) reported, "Never before have the people here witnessed such a natural pyrotechnic display. Looking eastward the entire heavens is one bright-red glare. Citizens in the entire [Santa Ana] valley are thoroughly aroused." The immensity of this fire is illustrated by the report that not only citizens on the western side of the range were impressed by the nighttime pyrotechnics but the fire was also clearly visible on the eastern side of the range: "Forest fires in the mountains east of Santa Ana raged all day and last night the light reflected upon the sky from the fire in that direction was plainly seen in this [Riverside] city." This was independently corroborated by Mr. L.A. Barrett in his 1935 book "*A Record of Forest and Field Fires in California from the Days of the Early Explorers to the Creation of the Forest Reserves.*" He was 15 years old and living in Orange County at the time of the fire, and his first-hand account written many years later notes that it was the largest fire he had ever seen in his 40 year USFS career (a career that spanned some noteworthy chaparral fires such as the Matilija Fire of 1932 that burned 220,000 acres). However, until the last half of the 20th century these large fires had minimal impact due to the low density of people in the region; for example, the Matilija Fire did not destroy any homes. With the increase in population there has been a concomitant increase in human infrastructure losses, and for the last 50 years, each decade has been followed by a decade of wildfires with increasing loss of property and lives. This is despite an increase each decade in state and federal expenditures for fire suppression.

A geographer at the University of California, Riverside, Richard Minnich, has argued for more than 20 years that the fire problem in Southern California chaparral is the same as for many conifer forest surface-fire regimes in the West. Namely, that highly effective fire suppression by fire fighters has excluded fires for over a century and caused anomalously high and contiguous stands of chaparral fuels. His solution to the problem is to allow "natural" wildfires to burn during moderate weather conditions and maintain the landscape in a mosaic of young and old fuels, which he contends will fire-proof the landscape (see Box 1). This is a testable hypothesis that has captured the attention of several investigators, including Susan Conard and David Weise at the U.S. Forest Service Fire Lab in Riverside, Max Moritz at the University of California, Berkeley, and myself and a Ph.D. student C.J. Fotheringham at University of California, Los Angeles. Multiple tests of this and related hypotheses have shown that in Southern California, fire suppression has not even come close to excluding fires, and that fuel age and landscape mosaics of different aged fuels, have little effect on fire behavior during our catastrophic autumn fire season.

Unfortunately the media have exploited these studies by personalizing them as grand debates and reducing them to opposing sides or "camps." This does an injustice to the scientific method and confuses the public. As a result there is a tendency to choose sides and pick the "expert opinion" of preference. These are serious fire management issues that deserve better. In the future, scientists and the media need to do a better job of explaining the alternative models and addressing issues of data in support of one model or another. We need to move away from presenting this as a squabble between alternative and equally supportable models.

A recent Government Accounting Office report pointed out that the USFS spends over 50% of its budget on fire suppression activities and more goes to California than all of the other western US states. Most of this money goes to protect private property, and this potentially diminishes their capacity for completing other resource stewardship objectives. The report further suggested that the federal government may need to consider mechanisms for recouping some fire suppression costs from local communities. While this will certainly meet strong resistance, it may lead to greater local attention on how new and innovative approaches to land planning can diminish community vulnerability to wildfires.

Californians need to embrace a different model of how to view fires on these landscapes. Our response needs to be tempered by the realization that these are natural events that cannot be eliminated from Southern California. In this respect we can learn much from the science of earthquake or other natural disaster management. No one pretends they can stop them, rather they engineer infrastructure to minimize impacts, and in this respect there is much that can be done at the local level.

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[For related papers see also: *http://www.werc.usgs.gov/seki/keeley.asp*]

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