THE ECOLOGICAL IMPORTANCE OF MIXED-SEVERITY FIRES

NATURE'S PHOENIX

Edited by Dominick A. DellaSala and Chad T. Hanson

Chapter 7

High-Severity Fire in Chaparral: Cognitive Dissonance in the Shrublands

Richard W. Halsey[1] **and Alexandra D. Syphard**[2]

[1]*Chaparral Institute, Escondido, CA, USA,* [2]*Senior Research Ecologist, Conservation Biology Institute, Corvallis, OR, USA*

7.1 CHAPARRAL AND THE FIRE SUPPRESSION PARADIGM

The conflict between facts and beliefs concerning fire in California's native shrublands is an example of cognitive dissonance—the psychological discomfort caused when an individual is confronted with new facts or ideas that are in conflict with currently held opinions (Festinger, 1957).

The most characteristic native shrubland in California is chaparral, a drought-hardy plant community composed of such iconic species as manzanita (*Arctostaphylos* sp.) and ceanothus (*Ceanothus* sp.) (Figure 7.1). Once the preferred habitat of the California grizzly bear (*Ursus arctos californicus*), chaparral covers many of the state's hills and mountains with rich biodiversity that reaches its peak on the central coast. Chaparral is also the most extensive vegetation characterizing the California Floristic Province and extends north to southern Oregon, south into Baja California, and as disjunct patches in central and southeastern Arizona and northern Mexico (Keeley, 2000). Although often portrayed as a fire-adapted ecosystem, a more accurate description is one adapted to a particular fire pattern or regime that is characterized by large, infrequent, and high-intensity fires (Keeley et al., 2012). Increase the frequency, reduce the intensity, or change the seasonality of fire and chaparral species can be eliminated, often replaced by nonnative weeds and grasses. As ignitions have increased as a result of human activity, chaparral is being threatened by too much fire in much of its range, particularly in southern California.

The role fire plays in chaparral is often misunderstood by policymakers, land and fire managers, forest scientists, and the public (Keeley et al., 2012). The primary cause of this misunderstanding is a powerful belief system that has formed around what can be characterized as the *fire suppression paradigm*,

FIGURE 7.1 Chaparral is a unique plant community characterized by large, contiguous stands of drought-hardy shrubs, a Mediterranean-type climate, and infrequent, high-intensity/high-severity crown fires (photo: R.W. Halsey).

resulting in cognitive dissonance as new scientific information has emerged. The fire suppression paradigm asserts that a century of fire suppression policy has eliminated fires and allowed vegetation (fuels) to accumulate to unnatural levels so that today when wildfires begin they burn uncontrollably, often producing catastrophic effects (Keeley et al., 1999). For many plant communities, especially chaparral, little could be further from the truth. Data for the past 100 years show that despite a policy of fire suppression, wildfires have not been able to be eliminated in most southern California landscapes; in fact, fires are more common today than historically. Because of this misconception about fire suppression, managers have been trained to believe that wildfires are fuel-driven events and, as a consequence, can be controlled by modifying vegetation.

Deeply embedded in the paradigm is the preconception that small, low-intensity/low-severity surface fires are natural and large, high-intensity/high-severity crown fires are not. When a high-severity fire burns more than ~40 ha (100 acres), it is often considered a direct result of past fire suppression. The paradigm was originally developed to describe the surface fire regime found in lightning-saturated, dry ponderosa pine (*Pinus ponderosa*) forests of the Southwest, where it is a relatively accurate representation (Steel et al., 2015).

Because the fire suppression paradigm is forest-centric, understory shrubs and small trees are viewed as fuel rather than important components of habitat. This has led to a set of values, facilitated by lumber and ranching interests, that view chaparral as "worthless brush," an "invader" of forests and rangeland, and an "unsightly menace" (Halsey, 2011). The bias has led to other pejorative characterizations such as the erroneous claim that chaparral plants are so pyrogenic that they are literally "oozing combustible resins" (Shea, 2008). The paradigm has effectively demonized a native ecosystem that supports significant biodiversity.

The key point is that chaparral fires are unlike forest fires, yet forest fire ecology has been misapplied to explain how fire should burn in chaparral.

Clearing up this confusion is one of the reasons this chapter was written. The basic facts about chaparral fires can be summarized as follows:

- Fire suppression has not caused excessive amounts of chaparral to accumulate (Keeley et al., 1999).
- Fire suppression has played a critical role in protecting many chaparral stands from ecological damage resulting from excessive fire.
- Infrequent, large, high-intensity crown fires are natural in chaparral (Keeley and Zedler 2009).
- There are few, if any, justifiable ecological/resource benefits in conducting prescribed burning or other vegetation treatments in chaparral (Keeley et al., 2009a).

Research over the past two decades has rejected the fire suppression paradigm when applied to ecosystems subject to crown fires, especially shrublands like chaparral. Not surprisingly, the cognitive dissonance caused by this research (e.g., Conard, S.G. and Weise, D.R., 1998, Mensing et al., 1999, Keeley et al., 1999, Keeley and Zedler, 2009, Lombardo et al., 2009) has fostered resistance by the supporters of the challenged paradigm (e.g., Minnich 2001). Consequently, it continues to influence public policy and opinion about chaparral specifically and wildfire in general. But, as the evidence has accumulated, the fire suppression paradigm is slowly shifting to a new one that acknowledges that infrequent, large, high-intensity crown fires do in fact represent the natural fire regime for chaparral and that weather, not fuel type, is the most important variable controlling fire intensity, spread, and size (e.g., Moritz et al., 2004, Keeley and Zedler, 2009).

7.2 THE FACTS ABOUT CHAPARRAL FIRES: THEY BURN INTENSELY AND SEVERELY

The natural, physical structure of chaparral shrubs (contiguous cover, dense accumulation of fine leaves and stems, and retention of dead wood) and the seasonal pattern of drought that includes low humidity, high temperatures, and low live fuel moistures create conditions favoring high-intensity crown fires (Figure 7.2).

Crown fires are those that burn into the canopies of the dominant vegetation. These are opposed to surface or understory fires that burn vegetation close to the ground. *Surface fires* are common in certain forested ecosystems where there is a distinct separation between understory vegetation and the tree canopy. Chaparral creates a contiguous fuel bed from the ground up that makes high-intensity crown fires inevitable.

Fire intensity represents the energy released during various phases of a fire. High-intensity fires typically consume most of the living, aboveground plant material, leaving behind only charred stems and branches.

Fire-severity is also used to describe wildland fire but in relation to how fire intensity affects ecosystems. It is typically measured by the amount of organic material consumed by the flames (above- and belowground), or plant mortality. The manner in which fire intensity and severity are used interchangeably by

FIGURE 7.2 The natural, physical structure of chaparral shrubs (contiguous fuel from the ground to the crown) and the seasonal pattern of drought create conditions favoring high-intensity/high-severity crown fires (photo: R.W. Halsey).

different authors sometimes leads to considerable confusion (Keeley, 2009). For chaparral, however, severity measures may not be particularly helpful because high-intensity chaparral fires typically burn all the aboveground living material, leaving behind only dead, charred shrub skeletons. Fire severity has been measured by the twig diameter remaining on the terminal branches of shrub skeletons and has been shown to correlate with one measure of fire intensity (Moreno and Oechel, 1989). Even though the mature, aboveground forms of some plant species are killed, the belowground portions remain alive as lignotubers that resprout vigorously within a few weeks after the fire. In the first year after fire, massive numbers of seeds from fire-killed obligate seeding shrubs and fire-following annuals are stimulated by fire cues to germinate in the postfire environment (Keeley, 1987, Keeley and Keeley, 1987). Obligate seeding shrubs are nonsprouting species, like many Ceanothus and manzanita species, that require a fire cue for seed germination. As long as fire arrives above the lower limit of the natural fire return interval of 30-40 years, the severely burned postfire chaparral ecosystem is extraordinarily resilient and vibrant (Figure 7.3).

The size of chaparral fires varies, but the seasonal occurrence of high winds, usually from September through December at the end of California's drought period, nearly guarantees periodic large, high-intensity fire events across the shrubland landscape. The historical, natural occurrence of such large crown fires two to three times per century has been confirmed by multiple investigators studying charcoal sediments (Mensing et al., 1999), tree rings of big-cone Douglas-fir (*Pseudotsuga macrocarpa*) that occur in small populations on steep slopes within the chaparral (Lombardo et al., 2009), and historic records (Keeley and Zedler, 2009).

Large crown fires that have historically burned with high intensity characterize all Mediterranean-type climate shrublands around the world (California,

FIGURE 7.3 A large variety of chaparral plant species quickly resprout from underground lignotubers after a fire. In addition, the germination of seeds of obligate seeding (non-respouting) shrubs is stimulated by heat, charred wood, or smoke. Resprouting species shown include chamise (*Adenostoma fasciculatum*; front right), two laurel sumac (*Malosma laurina*; center left), and three mission manzanita (*Xylococcus bicolor*). Obligate seeding *Ceanothus tomentosus* seedlings are pictured in the middle of the photo. Note the diameter of the burned stems. The lack of small twigs indicates a high-severity fire (photo: R.W. Halsey).

central Chile, South Africa, southwestern Australia, and the Mediterranean Basin) (Keeley, 2012). In particular, the likely scenario for chaparral-dominated wildfires in California before human settlement was one of large, infrequent fires (once or twice per century) that were ignited by lightning in forested areas at higher elevations during the moderate summer monsoon period between August and September. Remnants of the fire, such as smoldering logs, persisted into the fall. When extreme weather variables coincided, for example, several years of drought, low humidity, high temperature, and strong winds, the fire would have reignited and rapidly spread. Fires stopped when they reached the coast or when the weather changed. Today fires ignited at higher elevations during monsoonal storms are extinguished, and at lower elevations fires are vastly more frequent as a result of human-caused ignitions (Keeley, 2001).

Although counterintuitive, chaparral plant communities are much more resilient to infrequent, high-intensity fires than they are to cooler, more frequent, lower-intensity fires (Keeley et al., 2008). If chaparral does not have sufficient time to replenish the soil seed bank, accumulate the biomass necessary to produce fires hot enough to successfully germinate fire-cued seeds, or allow resprouting species time to restore starch supplies in underground lignotubers, a cascading series of events begins that can significantly change or completely eliminate the plant community. If the fire return interval is less than 10 to 20 years, biodiversity is reduced and nonnative weeds and grasses typically invade, ultimately type-converting native shrubland to nonnative grassland (Brooks et al., 2004).

Today the average fire rotation interval (time between fires) for wildlands in southern California is 36 years, but this varies widely among different locations.

Fire return intervals can vary from fires every few years in some locations to fires every 100 years or more at others (Keeley et al., 1999).

7.3 FIRE MISCONCEPTIONS ARE PERVASIVE

In conflict with ecological facts is the presumption of the fire suppression paradigm that large, high-intensity fires in chaparral are unnatural. Popularized versions of the paradigm as characterized by public opinion, the press, and Congressional testimony claim these fires are so hot that they destroy plant communities and leave behind lifeless moonscapes that are prone to mudslides that occur because of cooked soils. It is concluded that this is the direct result of twentieth-century fire suppression that allowed the chaparral to become overgrown with dense shrubs, creating massive amounts of fuel. Also, the fact that postfire recovery is so dramatic has likely reinforced the false notion of a fire-adapted community that "needed" fire to "rejuvenate" itself. These conclusions are clearly not supported by a plethora of studies (reviewed in Keeley et al., 2012).

Following the logic of the fire suppression paradigm is that chaparral fires should be allowed to burn without efforts to suppress them. In fact, some have used the paradigm to support artificially igniting fires to the landscape. The reality of the situation, however, makes such an approach both dangerous and ecologically damaging.

First, fire is suppressed for a reason: When near human communities it can destroy property and kill people. No responsible fire manager is going to allow a wildland fire to burn anywhere near a community. The much maligned US Forest Service's "10 a.m. policy," whereby all possible resources are thrown at the fire with the intention of suppressing it by 10 a.m. the next day, or the California Department of Forestry and Fire Protection's goal of keeping all fires confined to less than 4 ha, are critical public safety policy objectives near homes. "We're protecting private lands and public lands where there's many lives at stake and homes at stake, [and] infrastructure," Duane Shintaku, California Department of Forestry and Fire Protection's Deputy Director for Resource Protection said. ". . . [A]nd you can't tell someone 'You know what? We're just going to see what would happen if we wait to see if it gets big.'" (Goldenstein, 2015).

Second, as we discuss later, too much fire—rather than not enough—is threatening many native shrubland ecosystems. The overgeneralization and misapplication of the fire suppression paradigm is the underlying cause of many of the misconceptions about wildland fire in chaparral. Ironically, fire suppression often is criticized by the very agencies responsible for doing it and by citizens who have been misled by the publicity supporting the fire suppression paradigm, yet whose lives and property are being protected.

Confusing Fire Regimes

In forests, the idealized behavior of frequent, low-intensity fire caused by lightning has been characterized as the "good" kind of fire because it is considered controllable, typically burning 40 ha or less and only “pruning plants” rather than “consuming” them (Sneed, 2008, Kaufmann et al., 2005; also see Chapter 13). However, such a fire is physically impossible in vegetation with the characteristics of chaparral (Figure 7.4).

Emblematic of the impact caused by the misapplication of the forest-centric fire suppression paradigm is a statement made by the chair of the Santa Barbara County Fish and Game Commission, who criticized a proposal to designate chaparral as a protected, environmentally sensitive habitat (Giorgi, 2014):

> *Fire in our local ecosystems is one of the best ways to achieve the goal of good biodiversity. The local Native Americans burned almost every year. Early Spanish explorer records prove this to be true. There are many lightning-caused fires in our area, but we routinely put them out, creating an unnatural condition of heavy, dense fuel loading and harming our ecosystem in the process.*

The chair’s statement would have been supportable if it had only referred to the region’s few higher-elevation pine forests or the mixed-conifer forests on the western slopes of the Sierra Nevada (see Chapters 1 and 2). Extending it to the chaparral ecosystem that dominates the surrounding Los Padres National Forest, however, is inappropriate. In addition, unlike high-elevation forests where lightning is common, the south coastal region of southern California does not experience sufficient lightning frequency to sustain the kind of fire imagined by the board’s chair. In fact, the region has one of the lowest lightning frequencies in North America (Keeley, 2002).

This information was provided to the Fish and Game Commission through testimony before and during the hearing. The commission voted to reject the proposal that chaparral be designated as a sensitive habitat.

Native American Burning

The burning of landscapes by Native Americans has become an integral part of the fire suppression paradigm because it supports the practice of prescribed burning to reduce fuel loads. While it is true Native Americans burned the landscape along the central coast of California, there is strong evidence that such burning led to the elimination of shrublands near population centers, rather than maintaining them in a healthy condition (Keeley, 2002). The assumption that anthropogenic burning is important to maintain healthy vegetation communities in North America is in conflict with the fact that these communities existed as functioning ecosystems for millions of years before human settlement.

The important point is that Native American burning practices were performed to modify selected parts of the landscape in an artificial manner to support a hunter-gatherer existence. We cannot afford to emulate this pattern today. Most shrubland ecosystems already experience more fire than they can tolerate (e.g., Keeley et al., 1999). In addition, Native Americans did not

FIGURE 7.4 The 2007 Zaca Fire burned more than 97,200 ha in the Los Padres National Forest, the third-largest recorded fire in California after the 1889 Santiago Canyon Fire and the 2003 Cedar Fire. Although there are unburned patches within the perimeter (note vegetation strips at the lower right, along the central ridge, and the unburned area to the left), wherever the flames burned, they did so at high intensity/high severity. The fire burned over the entire scene shown in the photo (photo: R.W. Halsey).

need to be concerned with the spread of combustible, non-native weeds and increased ignitions caused by millions of additional people on the landscape.

Some have also speculated that Native Americans used "controlled burning" to prevent large wildfires (Anderson, 2006, SBCFWC, 2008). Evidence of Native American burning shows it was for localized management within a half-day's walk from villages (Keeley, 2002), not that they were able to reduce the severity and frequency of uncontrolled wildfires. There is little reason to believe Native Americans could prevent the occurrence of large wildfires on the broader landscape. Indeed, one ethnographic report describes a massive wildfire in San Diego County before European contact that resulted in a significant migration of Native American residents to the desert (Odens, 1971).

Succession Rather Than Destruction

The notion that high-intensity fires "destroy" the natural environment is a common theme in media stories after nearly every wildland fire (see Chapter 13). The concept is so pervasive it makes its way from public media to professional reports for decision makers. For example, Los Angeles City Council staff reported that the 2007 Griffith Park Fire "... caused significant damage to the vegetation, destroying the majority of the mixed chaparral and mixed shrub plant communities" (LACC, 2007).

As long a fire is within the parameters of the natural fire regime, a more accurate view is that large, high-intensity fires are part of a natural successional process for chaparral. Interestingly, chaparral is "autosuccessional," meaning that after chaparral burns, chaparral returns (Hanes 1971). The first year or two after a fire, ephemeral fire-following annuals and short-lived perennials dominate but then begin to be replaced by shrub seedlings and resprouts. The shrubs continue to grow and eventually re-form the chaparral canopy within 10 to 15 years. This confounded early ecologists and foresters who were trained in traditional ecology to value trees over shrubs. Their response during the 1920s was to plant over a million conifers, a substantial share of which were nonnative in the San Gabriel Mountains in Los Angeles County. Most were soon killed by drought or eventually by fire, convincing most foresters that chaparral, not forest, was the most sustainable plant community in the area (Halsey, 2011).

Although postfire ecological succession stories do sometimes make the news, they are generally overwhelmed by sensationalized reports of flames, destruction, and blackened landscapes. As remarkable as the postfire chaparral environment is—with hills covered with colorful wildflowers, resprouting shrubs, and large clusters of seedlings emerging from the dark soil—the perception that the environment has been destroyed by fire remains a pervasive image.

Decadence, Productivity, and Old-Growth Chaparral

When discussing the impact of fire, one must take care not to fall into the trap of anthropomorphizing a wild ecosystem like chaparral and thinking fire is needed to "refresh" or "clean out" old, "decadent" or "senescent" growth (Hanes, 1971). These characterizations of older chaparral stands have not been supported by subsequent research (see, e.g., Moritz et al., 2004, Keeley, 1992).

Multiple studies have demonstrated the ability of old-growth chaparral, nearly a century old or more, to maintain productive growth and recover with high biodiversity after a fire (Hubbard, 1986, Keeley and Keeley, 1977, Larigauderie et al., 1990). In fact, long fire-free periods are required for many species to properly regenerate (Odion and Tyler, 2002, Odion and Davis, 2000, Keeley, 1992).

With legacy manzanitas having waist-sized trunks, a rich flora of lichens rarely found anywhere else (Lendemer et al., 2008), and a dense canopy forming a protective watershed, old-growth chaparral provides an important habitat for a wide array of species and valuable ecosystem services to surrounding human communities. As such, old-growth chaparral represents a crucial component in the preservation of California's biodiversity (Keeley, 2000) (Figure 7.5).

Sometimes, a trailside sign or textbook description of chaparral includes the specter of "undisturbed climax chaparral" eventually becoming so thick that it will either "choke itself," "die out," or be replaced by woodland (Ricciuti,

FIGURE 7.5 Old-growth chaparral in San Diego County, California. A big-berry manzanita (*Artctostaphylos glauca*) has wrapped itself around an Engelmann oak (*Quercus engelmannii*). The manzanita is estimated to be over a century old (photo: R.W. Halsey).

1996). While trees will overtop and shade out chaparral in areas with higher annual rainfall and richer soil conditions than exist in the vast majority of chaparral sites, the general belief that chaparral will eventually disappear because of age is not supported by data (Keeley, 1992).

The imagined fate of old-growth chaparral illustrates the common genesis of many misconceptions where anecdotal evidence has replaced scientific investigation—observations that may have merit in a limited, specific instance but have been broadly misapplied to support a binary, black-and-white paradigm. The remarkable nuances of nature as revealed by science are ignored.

Unfortunately, with increasing fire frequency, old-growth stands of chaparral (in excess of 75 years old) are becoming increasingly rare (Knudsen, 2006). And, while biodiversity does temporarily increase after a fire, because of the germination of ephemeral fire-following species, there is no danger that this biodiversity is threatened by long fire-return intervals. The soil seed bank can likely remain viable for a significant amount of time. Shrublands burned after approximately 150 years respond with a rich array of seedlings (Keeley et al., 2005b) (Figure 7.6). Considering the number of human-caused ignitions, there is no need to be concerned over the lack of fire. The flames will come.

Allelopathy

Another factor mentioned to support the notion that fire is "needed" in chaparral is allelopathy, the theorized phenomenon of plants releasing chemicals to suppress the growth or germination of neighboring competitors. It was suggested that such chemical inhibition explained the lack of plant growth under the canopy of mature chaparral stands in southern California (Muller et al., 1968). When the chaparral burned, the theory suggested, flames denatured the toxic

FIGURE 7.6 A large number of fire-following annuals and short-lived perennials emerge from the soil seed bank after a high-intensity chaparral fire. In addition, geophytes emerging from underground tubers, like this brodiaea (*Dichelostemma capitatum*), are likely stimulated to flower by additional sunlight provided by the removal of the chaparral canopy by fire (photo: R.W. Halsey). *(Tyler and Borchert (2007))*.

substances in the soil, thereby releasing the seeds from inhibition and suggesting the need for fire. One problem with this explanation is that the soil chemicals suspected of suppressing growth actually increase after a fire (Christensen and Muller, 1975).

The seeds of most chaparral plants are innately dormant before they make contact with the ground because of their dependency on fire cue-stimulated germination. In addition, the presence of herbivores has been demonstrated to be a major factor in eliminating seedlings that do germinate (Bartholomew, 1970). Therefore, the lack of seedlings under the canopy and the postfire seedling response in chaparral can be easily explained without considering chemical inhibition (Halsey 2004). Despite the research, however, allelopathy in chaparral is still presented as fact in college courses and texts (SBCC, 2002, George et al., 2014).

Fire Suppression Myth

Quickly to follow most fire stories are attempts to explain why the fire happened in the first place."Fuel build-up," as per the fire suppression paradigm, is invariably blamed despite the science that has demonstrated otherwise.

In analyzing the California Statewide Fire History Database since 1910, Keeley et al. (1999) concluded that for shrub-covered landscapes of southern and central coastal California, "there is no evidence that fire suppression has altered the natural stand replacing fire regime in the manner suggested by others." In fact, fire suppression in California's Pacific south coast has played an important role in *protecting* much of the chaparral from too much fire. The authors of a comprehensive summary of the literature about fires in the region concluded the following (Keeley et al., 2009a):

> *The fire regime in this region is dominated by human caused ignitions, and fire suppression has played a critical role in preventing the ever increasing anthropogenic ignitions from driving the system wildly outside the historical fire return interval. Because the net result has been relatively little change in overall fire regimes, there has not been fuel accumulation in excess of the historical range of variability, and as a result, fuel accumulation or changes in fuel continuity do not explain wildfire patterns.*

Unfortunately, fire suppression in shrublands has not been completely successful in protecting chaparral and sage scrub habitats from too much fire. Shrublands in areas surrounding the San Diego, Los Angeles, and Santa Barbara metropolitan areas have some of the most negative fire return interval departures in California, meaning they are experiencing more fire than they have historically, threatening the chaparral's resilience (Safford and Van de Water, 2014). The problem seems to be spreading north into the northern Santa Lucia Range and may likely continue to spread as climate change and population growth increase the potential for ignitions.

Too Much Fire Degrades Chaparral

Chaparral is highly resilient to periodic fire, within the natural range of variability, and postfire communities are remarkable in their capacity to return to prefire composition within a decade or so after fire, with the community assembly finely balanced with resprouting and seeding species. Nevertheless, given increases in fire frequency, this resiliency can be interrupted. "Type conversion" is the term given to changes in vegetation type caused by changes in the external environment, and one of the most common disturbances is accelerated fire frequency. When keystone, non-resprouting (obligate seeding) shrub species, like most *Ceanothus* species, experience closely spaced fires, their populations often are decimated and effect a type conversion to a less diverse, resprouting-dominated chaparral (Zedler et al., 1983). Such stands become more open and often are subsequently invaded by nonnative herbaceous species. Fire return intervals of less than 6 years have been shown to be highly detrimental to the persistence of non-resprouting chaparral species (Jacobsen et al., 2004); in fact, multiple fires within a 6-year interval have even reduced resprouting species, further opening the chaparral environment (Haidinger and Keeley, 1993).

That this type conversion has been an ongoing process since the arrival of humans in California is apparent (Wells, 1962). The process is complex, dependent on fire history, community composition, and site factors. The loss of shrub cover and the invasion of combustible grasses creates a positive feedback process (Keeley et al., 2005a) whereby the community assembly changes, further increasing fire frequency and causing further type conversion away from the original stand composition. The speed of the type conversion process can be increased dramatically by numerous variables such as drought, cool-season fires (Knapp et al., 2009), livestock grazing, soil type, soil disturbance, and mechanical clearance activities (Bentley, 1967).

During extended periods of drought, seedling success of obligate seeding shrubs, like many *Ceanothus* species, is reduced after fire. In fact, excessive soil temperatures resulting from drought-induced canopy reduction after adult die back between fires has been shown to cause the premature germination of *Ceanothus megacarpus* seedlings just before the seasonal drought period (Burns et al., 2014). Seedling survival under such conditions is questionable, and the process depletes the seed bank.

Record drought conditions after fire also increase the mortality of resprouting chaparral shrubs like chamise (*Adenostoma fasciculatum*) and greenbark (*Ceanothus spinosus*). Resprouting shrub species likely deplete their carbohydrate reserves during the resprouting process, making them particularly vulnerable to drought because of the need to transpire water to acquire carbon dioxide that is used to supply energy to a large, respiring root system (Pratt et al. 2014). An additional fire within a 10-year window adds even more stress to resprouting species.

That type conversions occur and that severe type conversion from evergreen chaparral to alien-dominated grasslands has significantly altered the Californian landscape in the past are beyond question (Wells, 1962, Keeley, 1990), but an important issue is the extent of this contemporary threat. Talluto and Suding (2008) found that, over a 76-year period, 49% of the sage scrub shrublands in one southern California county had been replaced by annual grasses and that a substantial amount of this could be attributed to fire frequency.

In recent years, southern California has experienced some rather extensive reburns at anomalously short intervals (Keeley et al., 2009b), potentially setting the stage for the disruption of natural ecosystem processes and type-converting these shrublands to a mosaic of exotic and native species. This has already been documented clearly for a number of sites (Keeley and Brennan, 2012), where short-interval fires have extirpated some native species and greatly enhanced alien species. As discussed above, within the four southern and central/coastal national forests in California, most of the shrublands—the dominant plant communities within these federal preserves—are threatened by excessive fire, whereas the mountain forests of southern California have an overall fire deficit (Figure 7.7).

Quantifying how much chaparral has been compromised or completely type converted is a challenging research question because much of the damage likely was accomplished before accurate records of plant cover were kept. Based on interesting relic patches of chamise and historical testimony, Cooper (1922) speculated that extensive areas of chaparral have been eliminated and converted to grasslands, including the floor of the Santa Clara Valley, large portions of the

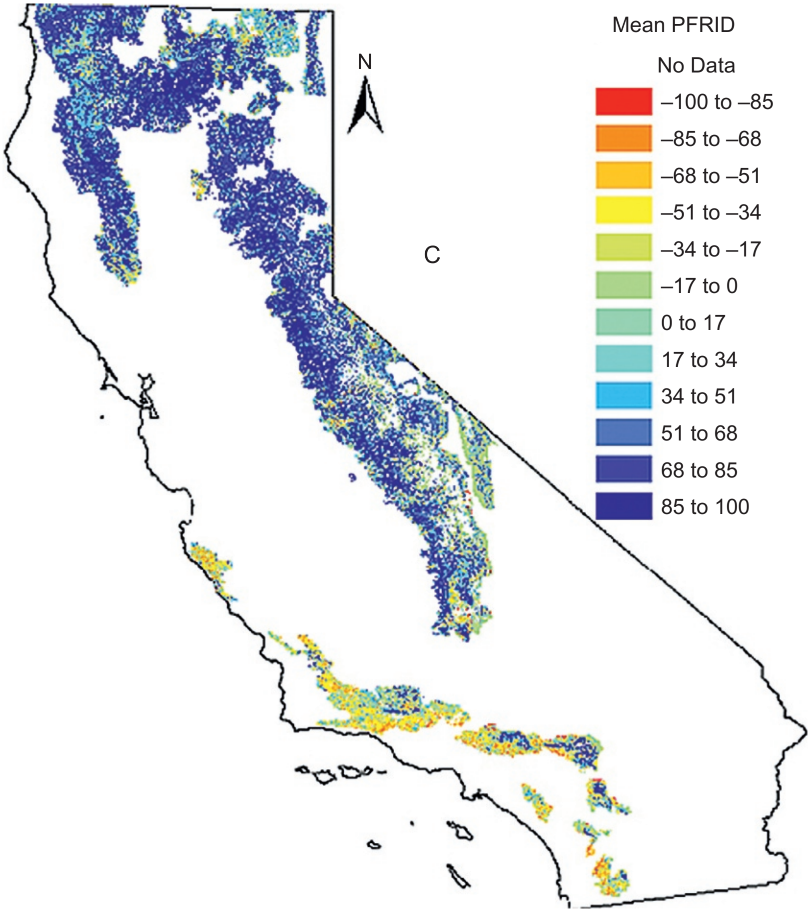

FIGURE 7.7 Most chaparral in California is threatened by too much fire, as shown by the map's color variations representing the fire return interval departure (PFRID) percentages for national forest lands in California. Note the color differences between the southern California national forests, which are dominated by chaparral (yellows), and the conifer-dominated forests in the Sierra Nevada (blues). The warm colors identify areas where the current fire return interval is shorter than that before European settlement (negative PFRID percentages). Cool colors represent current fire return intervals that are longer than those before European settlement (positive PFRID percentages) (photo: R.W. Halsey). *(From Safford and Van de Water (2014)).*

Sacramento and San Joaquin Valleys, and many of the grassy regions in the Coast Ranges and the western Sierra foothills. Large areas along Interstate 5 in the Cajon Pass region, the foothills above San Bernardino, and the Chino Hills south of Pomona also appear to be type-converted landscapes.

The focus on complete type conversion to grassland has led some to ignore the beginning stages of the process: the simplification of habitat by the loss of biodiversity (Keeley, 2005). For example, in a comment letter on the draft 2010

FIGURE 7.8 The impact of excessive fire on chaparral. The entire area shown was burned in 1970. The middle/left area burned again in 2001 and is returning with a full complement of native chaparral species. In the right portion, which burned again in 2003, obligate seeding species are absent, the number of resprouting species has been reduced, and nonnative weeds have invaded. The interval between the last two fires was too short, causing a dramatic reduction in biodiversity and leading to type conversion. The location pictured is near Alpine, San Diego County, California (photo: R.W. Halsey).

California Fire Plan, San Diego County claimed that chaparral burned in both the 2003 and 2007 wildland fires "remained chaparral and is recovering" (Steinhoff, 2010). In fact, much of the chaparral in question was not recovering well at all because of the loss of several keystone shrub species, and it was showing significant invasion by nonnative grasses (Keeley and Brennan, 2012) (Figure 7.8).

Meng et al. (2014) recently raised some skepticism about the ability of repeat fire to effect type conversion by pointing out the difficulty early twentieth-century range managers experienced when using fire to "improve" ranges that were supposedly plagued by chaparral. These managers typically relied on herbicides and mechanical destruction for thorough replacement of shrubs to create more useful grazing lands. As pointed out by Keeley and Brennan (2012), however, managers utilize fire only under narrow prescription conditions, which are generally not capable of carrying repeat fires at short fire return intervals—hence their difficulty in meeting their objective. By contrast, wildfires typically burn outside prescription, often with 100 km/h (about 60 mile/h) wind gusts and relative humidity less than 5%.

Using remote sensing, Meng et al. (2014) attempted to answer the question of how extensive type conversion is caused by repeat fires occurring in the past decade. While the technique cannot address changes in diversity and species composition that are known to occur with short-interval fires, it has some potential for viewing more gross changes in functional types such as shrubs and annual plants. Although these authors concluded that widespread type conversion is not an immediate threat in southern California, this conclusion deserves closer scrutiny because documenting fire-related vegetation change across large landscapes over just a 25-year period using remote sensing is fraught with potential errors and cannot serve as an effective proxy for field data.

One reason for error is that numerous spatially and temporally different human and biophysical factors can influence the process of postfire recovery; these factors should be controlled for before attribution can be determined. In the paper by Meng et al. (2014), the control and overlap areas were located on somewhat adjacent, but very different, parts of the landscape that varied by factors such as aspect, terrain, or soil type. The areas also could have experienced different landscape disturbance histories. This is especially possible given the topographic complexity of the region and researchers' use of the California's Fire Resource and Assessment Program's Fire History Database (FRAP) for discerning precise stand ages. This database is broadly useful for management planning but must be used carefully in a research context. For example, Keeley et al. (2008) found that across 250 sites the FRAP database did not accurately portray stand age (as determined by ring counts) for 47% of the sites, presumably because of the scale at which fires are mapped and by generally ignoring fires less than 40 ha.

Another concern is that the method of documenting vegetation change used by Meng et al. (2014) may not be sensitive enough to resolve gradual shifts in composition that would likely occur after only one repeat fire event. They used a vegetation index derived from imagery sensed remotely from a satellite as a way of assessing vegetation "cover," or the "greenness," of each 30-m image pixel. Because different pigments are stimulated by different parts of the light spectrum, this index essentially assesses chlorophyll content, which is correlated with biomass and assumed to represent the relative cover of evergreen shrubs. It does not, however, account for differences among chaparral species, whose composition in the plots was unknown. In addition, different species of chaparral have varying sensitivities to repeat fires, and thus multiple repeat fires of differing intervals might be required to discern enough vegetation change to be detected by this index.

Given that vegetation change is likely a gradual, cumulative process, the results reported by Meng et al. (2014) are actually consistent with a potential for widespread chaparral conversion—contrary to their conclusions. Over half of the area that burned twice in their study did have lower cover, as defined by the index, than the control area. Given enough fire on the landscape over a long enough period of time, gradual shifts may result in significant change and impact.

Type Conversion and Prescribed Fire

Unfortunately, the priorities of land management agencies have led some to deny the existence of chaparral type conversion. For example, in the same comment letter mentioned above, San Diego County wrote that it "strongly disagreed" with the draft 2010 California Fire Plan because it contained the following statement:

> *. . . fires have been too frequent in many shrublands, especially those of southern California, which are then at risk of type conversion from native species to invasives that can pose a fire threat every fire season.*

The county explained that recognizing the threat of chaparral type conversion in the Fire Plan would impact its ability to obtain funding to carry out vegetation clearance activities.

Prescribed burning—one of the clearance activities that San Diego County was hoping to conduct—has been shown to seriously compromise chaparral plant communities. In a study that simulated the effect of frequent fire on southern California coastal shrublands, Syphard et al. (2006) concluded that, "Due to this potential for vegetation change, caution is advised against the widespread use of prescribed fire in the region."

One of the problems with prescribed burning in chaparral is that there is a narrow window when such burns can occur: in the cool season (late spring). Plants have too much moisture in their tissues in the winter and early spring months to carry a fire. In the summer and fall, the risk of wildfire is too high because of low moisture levels and weather conditions. As a consequence, prescribed burns are conducted when the chaparral ecosystem is most vulnerable. The plants are growing, the soil is still moist, many animal species are breeding, and some birds are occupying the chaparral during their annual migrations. Thus significant ecological damage can occur as a result of a prescribed burn (Knapp et al., 2009).

The exact mechanisms are not clearly understood, but cool-season burns likely cause significant damage to plant growth tissues and destroy seeds in the soil as soil moisture turns into steam. A prescribed burn conducted in the 1990s in Pinnacles National Park, California, led to immediate type conversion of chaparral to nonnative grassland (Keeley, 2006). An escaped prescribed burn in 2013 consumed more than 1090 ha of fragile desert habitat in San Felipe Valley, California, much of which was chaparral that was recovering from a fire 11 years before. The fire seriously compromised one of the last old-growth desert chaparral stands in the region (CCI, 2013) (Figure 7.9).

Combustible Resins and Hydrophobia

There is no question that the loss of vegetation after a fire exposes more soil surface and increases the kinetic force of precipitation on the soil, which can increase the flow of water on the surface. The result can be significant erosion, flash flooding, and large debris flows. However, a factor that seems to get more attention than its proven influence justifies is water repellency, or "hydrophobic soils."

The observation that heat during a fire can change or intensify the water repellency of soil depending on temperature and other factors has been studied

FIGURE 7.9 Photo shows an escaped, 40 ha prescribed fire in the San Felipe Valley Wildlife Area, San Diego County, California, that ultimately burned more than 1000 ha, most of which was 11-year-old desert chaparral. Considering the ecological fragility of the area because of its age and the multiple fires that have burned much of the valley over the previous decade, there likely will be a significant reduction of biodiversity in the region (photo: R.W. Halsey).

extensively (DeBano, 1981, Hubbert et al., 2006) and was first identified after chaparral fires. The hydrophobic soils theory suggests that because of the gas released by burning plants and soil litter, hot fires create an impermeable "waxy layer" a few inches below the surface. According to popular accounts, this layer then prevents water from permeating the ground, causing large chunks of topsoil to break loose during rain storms and slide down the hill (LAT, 2014). Warnings about the hazards of such waterproof layers are commonly raised by the media after fires.

However, the actual impact hydrophobic soils have on erosion is questionable. Contrary to the impression often left by popular accounts, water repellency is not like a layer of plastic wrap under the surface; instead it is quite patchy and transient, abating once soils are wetted. Water repellency is also a natural condition of many unburned soils. In fact, high-severity fires have been found to destroy repellency (Doerr et al., 2006). In a review of the literature, Busse et al. (2014) concluded the following:

> *Most studies have only inferred a causal link between water repellency and erosion, and have failed to isolate the erosional impacts of water repellency from the confounding effects of losses in vegetation cover, litter cover, or soil aggregate stability.*

Unfortunately, the theorized role hydrophobic soils play in erosion has been repeated so many times that it has taken on the power of myth and is used to justify questionable, and sometimes expensive, land management decisions. The chaparral has been especially targeted for blame.

FIGURE 7.10 Postfire treatments in chaparral are costly and often of questionable value. Strips of mulch were dropped by aircraft on the side of the Viejas Mountain in San Diego County after the 2003 Cedar Fire (photo: R.W. Halsey).

To justify the clearance of native chaparral habitat, the Arizona Game and Fish Department claimed that "… catastrophic wildfire in the chaparral type can burn intensely enough to create hydrophobic soils, reducing soil productivity, increasing erosion, and causing severe downstream flooding" (AGFD, 2007). The City of Los Angeles spent $2 million to spread mulch after the 2007 Griffith Park Fire in part because "… chaparral vegetation has a natural tendency to develop water repellent or hydrophobic soils due to their natural high wax content. As a result, burned watersheds generally respond to runoff faster than unburned watersheds…" (LACC, 2007).

More than $1.25 million was spent laying down strips of mulch on Viejas Mountain in San Diego County after the 113,473 ha, high-intensity 2003 Cedar Fire, ostensibly to control erosion (Figure 7.10). However, Viejas Mountain is composed of gabbro-type soils that are not typically prone to extensive erosion (Halsey, 2008). Hydrophobic soils also have been used to justify postfire "salvage" logging after the 2013 Rim Fire in the Stanislaus National Forest (USFS, 2013).

7.4 REDUCING COGNITIVE DISSONANCE

Despite clear research that disproves many of the commonly held misconceptions about fire in chaparral that are fostered by the fire suppression paradigm, misconceptions persist. Many have found their way into land management plans that advocate landscape-scale "fuel treatments" or vegetation management projects for the stated purpose of "returning" California's chaparral ecosystem to a more "natural" and supposedly less dangerous fire regime. How the media, policymakers, and managers have responded to the cognitive dissonance that occurs when their assumptions about fire are challenged by science provides insight into the difficulties encountered when new ideas confront embedded paradigms.

Festinger (1957) suggested there are several ways an individual can reduce the tension caused by facts or ideas that conflict with their own opinions. Individuals can respond with cognitive competence by accepting the new data point or idea and change their opinions accordingly. Alternatively, individuals can respond incompetently by rejecting the new data point or idea either by ignoring or denying it or by justifying their opinion with new information or beliefs, occasionally using logical fallacies in the process.

For example, as mentioned earlier, when the chair of the Santa Barbara County Fish and Game Commission cited Native American burning as an argument for why we should not suppress fires in chaparral, he was using the common logical fallacy of appealing to antiquity. Such an appeal assumes older ideas or practices are better than newer ones because they have been around for a long time.

Local Agency

In an attempt to alter the natural fire regime, San Diego County tried to establish a chaparral clearance program that targeted more than 780 square kilometers of back country habitat with "prescribed fire, mechanical or biochemical fuel treatments" (SDCBS, 2009). This effort was based on a report issued earlier by the county. In misapplying the fire suppression paradigm to native shrublands, the report claimed that, "A fire regime of smaller, more frequent fires was being replaced by one of fewer, larger, and more intense fires" because of an unnatural density of "fuel" as a result of past fire suppression (SDCBS, 2003).

Despite volumes of data submitted by reviewing scientists over a period of more than 4 years indicating the county was basing its policies on incorrect assumptions, the county's Planning and Land Use Department repeatedly issued new drafts of its vegetation management plan without correcting the errors (Halsey, 2012).

In a comment letter by the Conservation Biology Institute, scientists wrote (Spencer, 2009):

> *Although this fourth draft is an improvement over previous drafts, it reflects partial and piece-meal updating based on various submitted comments and the workshop discussions rather than the comprehensive re-write that is necessary. This results in the report being internally inconsistent, confusing, and often self-contradictory. Moreover, despite scientific facts and logic presented to the county by numerous individuals, the report continues to perpetuate disproved myths about fires and fire management in southern California.*

In addition to ignoring information contrary to its position, the county misinterpreted the science in a manner that justified its viewpoint. One of the scientists whose work was the subject of the county's misinterpretations in the 2003 report wrote:

> *We were disturbed by the way our research findings were completely mischaracterized in this report on page 8. Not only are the specific statements about our findings completely false, but also, more generally, our research does not support the claims and recommendations of this section of the report.*
>
> Schoenberg and Peng (2004).

The San Diego County Board of Supervisors eventually adopted a final vegetation management plan in 2009, with most of the inaccurate information removed but with some of the questionable ecological assumptions about chaparral remaining. Within a month of the plan's adoption, the county attempted to implement the report's first clearance project without conducting the appropriate environmental review as required by the California Environmental Quality Act. The county claimed an "emergency exemption."

However, the California Chaparral Institute (CCI), an environmental nonprofit organization based in San Diego County, successfully challenged the project in court. The court rejected the county's position that a 3- to 4-year, $7 million vegetation management project was a "short-term project" addressing an immediate, emergency occurrence. In an attempt to influence the judge, county counsel used the logical fallacy of appealing to emotion by warning of death and destruction during future fires if the court ruled against the county. Since the hearing was considering a point of law, not evaluating emotional pleas, the judge was not swayed. The court ordered the county to follow the proper procedures under the law.

The county ultimately produced a full environmental impact report (EIR) on the project after being challenged again by CCI when it attempted to avoid the review process a final time through a negative declaration. The EIR was certified and the county completed the initial site-specific clearance project in 2012. The county later dropped the larger regional effort that had been so severely criticized.

State Agency

The California Board of Forestry and Fire Protection proposed in 2012 a statewide Vegetation Treatment Plan (VTP) that targeted more than one-third of the state for potential vegetation clearance operations. The VTP stated that large-scale wildland treatments should focus on areas "... up to the watershed scale, or even greater, that are treated to reduce highly flammable or dense fuels, including live brushy plants in some vegetation types (such as chaparral), a buildup of decadent herbaceous vegetation or, dead woody vegetation." One of the rationales for the VTP was that "[p]ast land and fire management practices (fire suppression) have had the effect of increasing the intensity, rate of spread, as well as the annual acreage burned on these lands" (CSBF, 2012).

As with the San Diego County example, there is no scientific support for this conclusion in chaparral, where most of California's largest wildland fires occur. Commenting on the VTP's stated intent to "reintroduce fire into (natural) communities where fire has been excluded through past fire suppression efforts," the California Department of Fish and Wildlife (CDFW, 2013) wrote the following:

> *There is substantial evidence that the frequency of fires continues to increase in coastal southern California (USDI NPS, 2004; Keeley et al., 1999). Fire management of California's 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 accumulations (Keeley, 2002). There is also considerable evidence that high fire frequency is a very real threat to native shrublands in southern California, sometimes leading to loss of species when fire return intervals are shorter than the time required to reach reproductive maturity (Keeley, 2002).*

In contrast to San Diego County's reluctance to accept new scientific research, the state responded with cognitive competence. After the state board received criticism from fire scientists that the VTP did not reflect the most current research, the California State Legislature asked the California Fire Science Consortium, an independent network of fire scientists and managers, to review the proposal. The Consortium recommended that the VTP "undergo major revision if it is to be a contemporary, science-based document" (CFSC, 2014). The board then began the process of rewriting the document in 2014, with assurances they would be modifying their plan by incorporating the new information and offering opportunities for the original reviewers to provide input on the developing draft.

Media

The popular media poses a particular problem because reporters often do not specialize in one topic long enough to become familiar with contrary data that question prevailing paradigms. When confronted with new information, however, the media outlet has several options. It can provide time or space for an editorial response, publish another story on the subject, or make a concerted effort to incorporate the new information into its editing process for future stories.

For example, significant cognitive competence has been demonstrated by one of California's most influential newspapers, the *Los Angeles Times*. The paper has become familiar with the science and has helped its readers understand that too much fire is threatening the chaparral (LAT, 2009), recommended the California Board of Forestry withdraw its original vegetation management plan and produce a new one using the best available science (LAT, 2013), and commonly describes the state's characteristic ecosystem as chaparral rather than using the older, pejorative term "brush."

A San Francisco Bay-area publication, on the other hand, provides an example of how older, inaccurate information was allowed to persist. In an article about fires in the chaparral-dominated Ventana Wilderness area of the Los Padres National Forest, Rowntree (2009) wrote:

> *Because of fire suppression policies and strategies put into place in 1907, fires became relatively infrequent. But when fires happened, and Marble Cone is a prime example, the immense accumulated fuel led to hotter, more intense fires compared to those associated with a more natural fire regime.*

There is no scientific evidence to support the claim that chaparral fires are burning hotter or more intensely than they have historically. The Marble Cone Fire cited in the article burned approximately 72,000 ha in 1997. In 1906, however, before the fire suppression era was said to have begun, approximately 60,700 ha burned with equal intensity in the same area. Other large, intense fires in the region were recorded even earlier (J. Keeley, unpublished data).

In southern California, the 2003 Cedar Fire in San Diego County, which burned 113,473 ha, is often referred to as California's largest fire. But in 1889, the Santiago Canyon Fire burned an estimated 125,000 ha (and possibly as much as 200,000 ha, depending on the estimates used) in San Diego, Orange, and Riverside Counties (Keeley and Zedler, 2009). Although the capacity for large fires has not changed, the number of people and homes in the way of the flames certainly has increased. Over the past century, high-intensity chaparral-related wildfires have continued to be some of the largest and most devastating conflagrations in the United States in terms of property and lives lost (Halsey, 2008).

The author of the aforementioned article on the Marble Cone Fire reinforced the misconception that large, high-intensity fires are unnaturally destructive because they roar across the landscape, "destroying oak, madrone, chamise, manzanita, and all other shrubs and trees in its path." The impression made was that if the Marble Cone Fire had been natural, it would have been a low-intensity surface fire that "smolders as it slowly works its way through grasslands and chaparral." The presumed destructive nature of hydrophobic soil also was cited in the article as being responsible for creating "the slippery foundation for the mud-flows that caused havoc on Highway 1. . . ."

After receiving a critique from the CCI citing the errors, the publisher decided, after consulting with the author, that the article was accurate and stood by its perspective. Although a website-based opportunity was offered for a short critique of the story, the publisher rejected publishing a follow-up article or comment letter because there was not enough room in the magazine for an additional discussion of an issue as complex as fire (D. Loeb, personal correspondence, 2010).

7.5 PARADIGM CHANGE REVISITED

In his seminal work on the structure of scientific revolutions, Thomas Kuhn (1962) wrote ". . .the proponents of competing paradigms practice their trades in different worlds." For the proponents of the fire suppression paradigm, wildfire is primarily a fuel-driven event. Thus controlling fuels controls fires, as the thinking goes, and native vegetation is viewed not as habitat but rather merely as unwanted fuel.

Alternatively, an increasingly common paradigm shift is framing wildfire in context of the entire environment, whereby other variables such as weather can play more important roles than fuel and whereby vegetation is viewed as wildlife habitat. The first paradigm is embedded in a controllable world where nature can be tamed, whereas in the second one, nature will ultimately defeat control. One sees nature as fuel; the other sees nature as providing important habitat in both its pre- and postburned conditions (also discussed in the Preface and Chapters 1–6 and 13). One focuses on manipulating wildlands to control wildfire, the other on community retrofits and planning to make them more fire-safe (Penman et al., 2014). As Kuhn explains, the two groups:

> *. . . see different things when they look from the same point in the same direction. Again, that is not to say that they can see anything they please. Both are looking at the world, and what they look at has not changed. But in some areas they see different things, and they see them in different relations one to the other. That is why a law that cannot even be demonstrated to one group of scientists may occasionally seem intuitively obvious to another.*

The feeling one may have during an argument that the other party is operating in another universe can in fact be an accurate description of what is happening.

Although other drivers of fire behavior are sometimes acknowledged, the practical implementation of policies resulting from the fire suppression paradigm is an exclusive focus on fuels (wildland vegetation). In this view, any fuel is too much fuel. Such a viewpoint was offered by a timber industry advocate during congressional testimony after the 2003 chaparral-dominated wildfires in southern California (Bonnicksen, 2003):

> *Some people believe that horrific brushland fires are wind-driven events. They are wrong. Science and nearly a century of professional experience shows that they are fuel driven events. Wind contributes to the intensity of a fire, but no fire can burn without adequate fuel, no matter how strong the wind.*

Besides the logical fallacy of appealing to unnamed authorities, this argument sets up the classic straw man fallacy. By misrepresenting the science that challenges the fuel-centric position and then refuting it, the congressional witness concludes that the science itself has been refuted. This is a fallacy because the science that is claimed to be refuted is actually being misrepresented.

Clearly, fire needs fuel to burn. Excepting extreme situations, all terrestrial environments have some kind of fuel, be it grass, shrubs, trees, or houses; all can provide adequate fuel for a fire under the right conditions. The science that challenges the fire suppression paradigm does not hold that fire can burn without fuel.

As the ~365,000 ha East Amarillo Complex grassland fire in Texas demonstrated in 2006, fine, grassy fuels also can also cause horrific fires. Twelve people died and 89 structures were destroyed in a fire that moved 72 km in just 9 h and had flame lengths >3.5 m (Zane et al., 2006).

While fuel reduction projects can help fire suppression efforts and reduce fire intensity, they have been shown to be ineffective when it matters most: during extreme fire weather. During such conditions, the fire is not controllable because it will burn through, over, or around fuel treatments (Keeley et al., 2004, Keeley et al., 2009b). Many fuel breaks never intersect fires, but those that do nearly always require the presence of a fire crew to be effective, demonstrating the importance of a fuel break's strategic location (Syphard et al., 2011). An extensive study of chaparral fires throughout central and southern California showed that there is not a strong relationship between fuel age and fire probabilities (Moritz et al., 2004). Even in fuels-reduced forests, burning under extreme weather conditions can produce large areas of high-severity fire (Lydersen et al., 2014). Extensive fuel treatments in a forest can also fail to prevent extensive damage to a community, such as Lake Arrowhead during the 2008 Grass Valley Fire, if the structures themselves are not fire-safe (Rogers et al., 2008).

Paradigms have a challenging intellectual duality because not only can they guide productive research, they can also blind. Proponents of an older paradigm can ignore overwhelming, contrary evidence or force it to fit their model. As Thomas Chamberlin (1890) wrote in his paper concerning the value of multiple working hypotheses, "There is an unconscious selection and magnifying of the phenomena that fall into harmony with the theory and support it, and an unconscious neglect of those that fail of coincidence."

In addition to the force of paradigm, financial pressure can be involved in propelling an idea beyond its proven effective value. When the 2003 Healthy Forests Restoration Act was passed by Congress, a significant source of money was made available for fuel treatments on public and private land. Shortly after the passing of the act, a US Forest Service supervisor summit was held in Nebraska, where forest supervisors were asked to sign a pledge to meet their forests' hazardous fuel targets. A clear signal was being sent from Washington, DC, that clearing vegetation was going to be a primary goal. The act codified the fire suppression paradigm and encouraged the perspective of habitat as hazardous fuel, regardless of the natural fire regime.

Don G. Despain, one of the original scientists who advocated allowing fire to perform its natural role in ecosystems, met with other wildland fire pioneers like Les Gunzel, Robert Mutch, and Bruce Kilgore in Missoula, Montana, in 1972 to discuss ways they could change how fire was viewed. "We were a pretty lonely bunch back then," Don explained in a 2006 interview (D. Despain, personal communication). But as time went on and attitudes about fire began to shift, Don began to notice that the impact of past fire suppression was being taken too far. Alternative variables that may have influenced fire behavior in the West were being ignored. "So many assumptions about fire were being made that had never been observed," Don said. "I came to think I was the only person to watch a fire actually burn. People need to get out and observe and apply natural curiosity with what is going on instead of running to the legislature."

7.6 CONCLUSION: MAKING THE PARADIGM SHIFT

In the 1990s the predominate view of chaparral within region 5 (California, mostly) of the US Forest Service was that the ecosystem represented primarily fuel, needed more fire, and that large chaparral wildfires were a direct product of twentieth-century fire suppression. Although there are Forest Service managers who still hold these views, the agency has demonstrated cognitive competence by accepting new information, rejecting the fire suppression paradigm as it had been applied to chaparral, and adjusting its official policies accordingly.

The shift began in 2000, after three papers that seriously questioned the prevailing views were published (Keeley et al., 1999, Mensing et al., 1999, Zedler and Seiger, 2000). These papers stimulated a significant volume of research, confirming that the fire suppression paradigm was not applicable to California's chaparral ecosystem.

John Tiszler (2000) wrote a white paper questioning the use of prescribed fire in the chaparral-dominated Santa Monica Mountains National Recreation Area (SMMNRA) within the National Park system. After the 2000 Cerro Grande Fire in Colorado, the National Park Service established a moratorium on prescribed fire and began a reexamination of its parks' fire management policies. New fire ecologists reexamined the SMMNRA's approach to fire and rejected the fire suppression paradigm. By 2005, a new fire management plan was formalized for the park (SMMNRA, 2005). The new approach is summarized on the park's website (SMMNRA, 2015):

> *In the last forty years fire managers have promoted the idea that prescribed fire is necessary to protect ecosystems and communities by restoring fire's natural role in the environment to thin forest stands and to reduce hazardous fuels. This is true for western forests where the natural fire regime was frequent, low intensity surface fires started by lightning . . . However, this is not true for the shrubland dominated ecosystems of southern California and the Santa Monica Mountains.*

After the 2003 Cedar Fire in San Diego County, California, the California Chaparral Institute was established for the purpose of protecting and raising awareness about the value of native shrublands. Through publications, public outreach, and occasional legal challenges, the organization helped to communicate the new science to both the public and government agencies.

By 2013, the paradigm shift occurred and the US Forest Service published a guiding document that redefined their view of chaparral and recognized how excessive fires were threatening the ecosystem (USFS, 2013):

> *There is an additional crisis taking place in our Southern California Forests as an unprecedented number of human-caused fires have increased fire frequency to the extent that fire-adapted chaparral can no longer survive and is being replaced with non-native annual grasses at an alarming rate ... Only an environmental restoration program of unprecedented scale can alter the direction of current trends.*

On June 18, 2013, during an important US Forest Service symposium at the headquarters of the Angeles National Forest, Martin Dumpis, the coordinator for a new Forest Service initiative focusing on the protection and restoration of chaparral, summarized the new approach well. Standing at the podium and speaking with his characteristically disarming midwestern accent, he said, "Chaparral should be seen as a natural resource, rather than a fire hazard."

We still have a long way to go for a complete paradigm shift—from one that views mature chaparral as no more than an unnatural fuel load to one that recognizes expansive, contiguous stands of old-growth chaparral as natural and valuable. However, we are seeing the process of change accelerate. We believe that the recent forward progress with which the shift is occurring is not only the result of solid, compelling science but also constructive citizen involvement, persistence, and especially relationships based on trust and respect. While comment letters and lawsuits can speed up the process, we have found that relationships fuel change in the most productive, lasting way.

For example, when CCI won its lawsuit against San Diego County, its efforts to expand its educational programs were stymied by informal resistance from bureaucrats whose vegetation treatment programs were curtailed (Halsey, 2012). However, relationships developed through volunteer work, professional interactions, and sincere efforts to collaborate by environmental organizations like CCI and the Endangered Habitat League persisted and ultimately outlasted the resistance. The lawsuit was critical in protecting habitat, but it was relationships that implemented successful solutions. Such relationships also likely shaped legislative action on defensible space regulations and vegetation treatment programs, Forest Service policy shifts concerning chaparral, and the successful implementation of new public outreach efforts involving wildland preserves in San Diego County.

We have learned that, in the long run, science, involvement, and relationship building are all vital to ensure that the policies affecting our lives are based on the latest facts from paradigm shifts, rather than from unproductive responses to cognitive dissonance.

REFERENCES

AGFD, 2007. South Mowry Habitat Improvement Project. Arizona Game and Fish Department. Habitat Partnership Program. Habitat Enhancement and Wildlife Management Proposal. Project N. 07-521. Tucson, Arizona.

Anderson, M.K., 2006. Tending the Wild. University of California Press, Berkeley, 256 p.

Bartholomew, B., 1970. Bare zone between California shrub and grassland communities: the role of animals. Science 170, 1210–1212.

Bentley, J.R., 1967. Conversion of Chaparral Areas to Grassland: Techniques used in California. Agriculture Handbook No. 328. US Department of Agriculture, Washington, DC, 35 p.

Bonnicksen, T., 2003. Testimony to the Subcommittee on Forests and Forest Health of the Committee on Resources, U.S. House of Representatives. In: One Hundred Eighth Congress, First Session. December 5, 2003, Lake Arrowhead, California.

Brooks, M.L., D'Antonio, C.M., Richardson, D.M., DiTomaso, J.M., Grace, J.B., Hobbs, R.J., Keeley, J.E., Pellant, M., Pyke, D., 2004. Effects of invasive alien plants on fire regimes. Bioscience 54, 677–688.

Burns, A., Homlund, H.L., Lekson, V.M., Davis, S., 2014. Seedling survival after novel drought-induced germination in Ceanothus megacarpus. In: Abstract. Berea College Research Symposium, Kentucky.

Busse, M.D., Hubbert, K.R., Moghaddas, E.E.Y., 2014. Fuel reduction practices and their effects on soil quality. Gen. Tech. Rep. PSW-GTR-241, U.S. Department of Agriculture, Forest Service, Pacific Southwest Research Station, Albany, CA, 156 p.

CCI, 2013. Escaped Cal Fire Prescribed Burn, San Felipe Valley Wildlife Area in a letter from the California Chaparral Institute to the South Coast Region. Department of Fish and Wildlife, California, July 8, 2013.

CDFW, 2013. California Department of Fish and Wildlife Memorandum on the California Board of Forestry and Fire Protection Draft Vegetation Treatment Program Environmental Impact Report. Attachment A.

CFSC, 2014. Panel Review Report of Vegetation Treatment Program Environmental Impact Report by California Board of Forestry and Fire Protection in Association with CAL FIRE Agency. Coordinated by California Fire Science Consortium, August 2014.

Chamberlin, T.C., 1890. The method of multiple working hypotheses. Science Feb 7. Also reprinted in 1965. Science 148, 754–759.

Christensen, N.L., Muller, C.H., 1975. Effects of fire on factors controlling plant growth in Adenostoma chaparral. Ecol. Monogr. 45, 29–55.

Conard, S.G., Weise, D.R., 1998. Management of fire regimes, fuels, and fire effects in southern California chaparral: lessons from the past and thoughts for the future. Tall Timbers Ecology Conference Proceedings 20, 342–350.

Cooper, W.S., 1922. The Broad-Sclerophyll Vegetation of California. An Ecological Study of the Chaparral and its Related Communities. Carnegie Institution of Washington, Washington, DC, Publication No. 319. 124 p.

CSBF, 2012. Draft Programmatic Environmental Impact Report for the Vegetation Treatment Program of the California State Board of Forestry and Fire Protection. The California Department of Forestry, Sacramento, CA. October 30, 2012.

DeBano, L.F., 1981. Water repellent soils: a state-of-the-art. United States Department of Agriculture Forestry Service General Technical Report, PSW-46. Berkley, California.

Doerr, S.H., Shakesby, R.A., Blake, W.H., Chafer, C.J., Humphreys, G.S., Wallbrink, P.J., 2006. Effects of differing wildfire severities on soil wettability and implications for hydrological response. J. Hydrol. 319, 295–311.

Festinger, L., 1957. A Theory of Cognitive Dissonance. Stanford University Press, Stanford, CA.

George, M.R., Roche, L.M., Eastburn, D.J., 2014. Ecology. Annual Rangeland Handbook, Division of Agriculture and Natural Resources, University of California, Davis, CA.

Giorgi, W.T., 2014. Testimony at the Santa Barbara County Fish and Game Commission, November 20, 2014.

Goldenstein, T., 2015. Water Stress Takes Toll on California's Large Trees, Study Says. Los Angeles Times, Los Angeles, CA, January 19, 2015.

Haidinger, T.L., Keeley, J.E., 1993. Role of high fire frequency in destruction of mixed chaparral. Madrono 40, 141–147.

Halsey, R.W., 2004. In search of allelopathy: an eco-historical view of the investigation of chemical inhibition in California coastal sage scrub and chamise chaparral. J. Torrey Bot. Soc. 131, 343–367.

Halsey, R.W., 2008. Fire, Chaparral, and Survival in Southern California. Sunbelt Publications, San Diego, CA.

Halsey, R.W., 2011. Chaparral as a natural resource. In: Proceedings of the California Native Plant Society Conservation Conference, January 17-19, 2009, pp. 82–86.

Halsey, R.W., 2012. The politics of fire, the struggle between science & ideology in San Diego County. Serialized from The Chaparralian 40 (3/4), 6–20. Independent Voter Network, May 15, 2013. http://ivn.us/2012/05/15/the-politics-of-fire-the-struggle-between-science-ideology-in-san-diego-county/May 1, 2012.

Hanes, T.L., 1971. Succession after fire in the chaparral of southern California. Ecol. Monogr. 41, 27–52.

Hubbard, R.F., 1986. Stand Age and Growth Dynamics in Chamise Chaparral. Master's thesis, San Diego State University, San Diego, CA.

Hubbert, K.R., Preisler, H.K., Wohlgemuth, P.M., Graham, R.C., Narog, M.G., 2006. Prescribed burning effects on soil physical properties and soil water repellency in a steep chaparral watershed, southern California, U.S.A. Geoderma 130, 284–298.

Jacobsen, A.L., Davis, S.D., Fabritius, S.L., 2004. Fire frequency impacts non-sprouting chaparral shrubs in the Santa Monica Mountains of southern California. In: Arianoutsou, M., Papanastasis, V.P. (Eds.), Ecology, Conservation and Management of Mediterranean Climate Ecosystems. Millpress, Rotterdam, Netherlands.

Kaufmann, M.R., Shlisky, A., Marchand, P., 2005. Good fire, bad fire: how to think about forest land management and ecological processes. U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station, Fort Collins, CO.

Keeley, J.E., 1987. Role of fire in seed germination of woody taxa in California Chaparral. Ecology 68 (2), 434–443.

Keeley, J.E., 1990. The California valley grassland. In: Schoenherr, A.A. (Ed.), Endangered Plant Communities of Southern California. Southern California Botanists, Fullerton, California, pp. 2–23.

Keeley, J.E., 1992. Demographic structure of California chaparral in the long-term absence of fire. J. Veg. Sci. 3, 79–90.

Keeley, J.E., 2000. Chaparral. In: Barbour, M.G., Billings, W.D. (Eds.), North American Terrestrial Vegetation, second ed. Cambridge University Press, Cambridge, UK, pp. 203–253.

Keeley, J.E., 2001. We still need Smokey bear! Fire Manage. Today 61 (1), 21–22.
Keeley, J.E., 2002. American Indian influence on fire regimes in California's coastal ranges. J. Biogeogr. 29, 303–320.
Keeley, J.E., 2005. Fire as a threat to biodiversity in fire-type shrublands. Gen. Tech. Rep. PSW-GTR-195: 97-106, USDA Forest Service.
Keeley, J.E., 2006. Fire management impacts on invasive plant species in the western United States. Conserv. Biol. 20, 375–384.
Keeley, J.E., 2009. Fire intensity, fire severity and burn severity: a brief review and suggested usage. Int. J. Wildland Fire 18, 116–126.
Keeley, J.E., Brennan, T.J., 2012. Fire-driven alien invasion in a fire-adapted ecosystem. Oecologia 169, 1043–1052.
Keeley, J.E., Keeley, S.C., 1977. Energy allocation patterns of a sprouting and nonsprouting species of *Arctostaphylos* in the California chaparral. Am. Midl. Nat. 98, 1–10.
Keeley, J.E., Keeley, S.C., 1987. Role of fire in the germination of chaparral herbs and suffrutescents. Madrono 34, 240–249.
Keeley, J.E., Zedler, P.H., 2009. Large, high-intensity fire events in southern California shrublands: debunking the fine-grain age patch model. Ecol. Appl. 19, 69–94.
Keeley, J.E., Fotheringham, C.J., Morais, M., 1999. Reexamining fire suppression impacts on brushland fire regimes. Science 284, 1829–1832.
Keeley, J.E., Fotheringham, C.J., Moritz, M., 2004. Lessons from the 2003 wildfires in southern California. J. For. 102, 26–31.
Keeley, J.E., Keeley, M., Fotheringham, C.J., 2005a. Alien plant dynamics following fire in Mediterranean-climate California shrublands. Ecol. Appl. 15, 2109–2125.
Keeley, J.E., Pfaff, A.H., Safford, H.D., 2005b. Fire suppression impacts on postfire recovery of Sierra Nevada chaparral shrublands. Int. J. Wildland Fire 14, 255–265.
Keeley, J.E., Brennan, T.J., Pfaff, A.H., 2008. Fire Severity and ecosystem responses from crown fires in California shrublands. Ecol. Appl. 18 (6), 1530–1546.
Keeley, J.E., Aplet, G.H., Christensen, N.L., Conard, S.C., Johnson, E.A., Omi, P.N., Peterson, D.L., Swetnam, T.W., 2009a. Ecological foundations for fire management in North American forest and shrubland ecosystems. Gen. Tech. Report PNW-GTR-779. USDA, USFS PNW Research Station, Portland, OR, 92 p.
Keeley, J.E., Safford, H., Fotheringham, C.J., Franklin, J., Moritz, M., 2009b. The 2007 southern California wildfires: lessons in complexity. J. For. 107, 287–296.
Keeley, J.E., Bond, W.J., Bradstock, R.A., Pausas, J.G., Rundel, W., 2012. Fire in Mediterranean Climate Ecosystems: Ecology, Evolution and Management. Cambridge University Press, Cambridge, UK. 528 p.
Knapp, E.E., Estes, B.L., Skinner, C.N., 2009. Ecological effects of prescribed fire season: a literature review and synthesis for managers. Gen. Tech. Report PSW-GTR-224, USDA, Forest Service. PSW Research Station, 80 p.
Knudsen, K., 2006. Notes on the Lichen Flora of California # 2. Bull. Calif. Lichen Soc. 13 (1), 10–13.
Kuhn, T.S., 1962. The Structure of Scientific Revolutions. The University of Chicago Press, Chicago, IL.
LACC., 2007. Griffith park fire recovery plan/expenses. Council File Number 07-0600-S38, Los Angeles City Council, Los Angeles, CA, August 1, 2007.
LAT, 2009. A Burning Problem. Los Angeles Times editorial, Los Angeles, CA, April 22, 2009.

LAT, 2013. Cal Fire's Flawed Fire Plan. Critics Say It's Outdated, Contains Many Inaccuracies and Could Cause Major Environmental Damage. Los Angeles Times editorial, Los Angeles, CA, March 11, 2013.

LAT, 2014. Flash Floods after Fires. Los Angeles Times, Los Angeles, CA, December 18, 2014.

Larigauderie, A., Hubbard, T.W., Kummerow, J., 1990. Growth dynamics of two chaparral shrub species with time after fire. Madrono 37, 225–236.

Lendemer, J.C., Kocourkov, J., Knudsen, K., 2008. Studies in lichens and lichenicolous fungi: notes on some taxa from North America. Mycotaxon 105, 379–386.

Lombardo, K.J., Swetnam, T.W., Baisan, C.H., Borchert, M.I., 2009. Using bigcone Douglas-fir fire scars and tree rings to reconstruct interior chaparral fire history. Fire Ecol. 5, 32–53.

Lydersen, J.M., North, M.P., Collins, B.M., 2014. Severity of an uncharacteristically large wildfire, the Rim Fire, in forests with relatively restored frequent fire regimes. For. Ecol. Manag. 328, 326–334.

Meng, R., Dennison, P.E., D'Antonio, C.M., Moritz, M.A., 2014. Remote sensing analysis of vegetation recovery following short-interval fires in southern California shrublands. PLoS One 9, e110637.

Mensing, S.A., Michaelsen, J., Byrne, 1999. A 560 year record of Santa Ana fires reconstructed from charcoal deposited in the Santa Barbara Basin, California. Quat. Res. 51, 295–305.

Minnich, R.A., 2001. An integrated model of two fire regimes. Conservat. Biol. 15, 1549–1553.

Moreno, J.M., Oechel, W.C., 1989. A simple method for estimating fire intensity after a burn in California chaparral. Acta Oecol. 10, 57–68.

Moritz, M.A., Keeley, J.E., Johnson, E.A., Schaffner, A.A., 2004. Testing a basic assumption of shrubland fire management: how important is fuel age? Front. Ecol. Environ. 2, 67–72.

Muller, C.H., Hanawalt, R.B., McPherson, J.K., 1968. Allelopathic control of herb growth in the fire cycle of California chaparral. Bull. Torrey Bot. Soc. 95, 225–231.

Odens, P., 1971. The Indians and I. Imperial Printers, El Centro, CA, 80 p.

Odion, D.C., Davis, F.W., 2000. Fire, soil heating, and the formation of vegetation patterns in chaparral. Ecol. Monogr. 70, 149–169.

Odion, D., Tyler, C., 2002. Are long fire-free periods needed to maintain the endangered fire-recruiting shrub *Arctostaphylos morroensis* (Ericiaceae)? Conserv. Ecol. 6, 4.

Penman, T.D., Collins, L., Syphard, A.D., Keeley, J.E., Bradstock, R.A., 2014. Influence of fuels, weather and the built environment on the exposure of property to wildfire. PLoS One 9 (10), e111414.

Pratt, R.B., Jacobsen, A.L., Ramirez, A.R., Helms, A.M., Traugh, C.A., Tobin, M.F., Heffner, M.S., Davis, S.D., 2014. Mortality of resprouting chaparral shrubs after a fire and during a record drought: physiological mechanisms and demographic consequences. Global Change Biol. 20, 893–907.

Ricciuti, E.R., 1996. Chaparral. Biomes of the WorldBenchmark Books. Marshall Cavendish, New York, 64 p.

Rogers, G., Hann, W., Martin, C., Nicolet, T., Pence, M., 2008. Fuel Treatment Effects on Fire Behavior, Suppression Effectiveness, and Structure Ignition. US Department of Agriculture, Forest Service, Region 5, Vallejo, CA, R5-TP-026a. 35 p.

Rowntree, L., 2009. Forged by Fire. Bay Nat. 9 (4), 24–29.

Safford, H.D., Van de Water, K.M., 2014. Using fire return interval departure (FRID) analysis to map spatial and temporal changes in fire frequency on national forest lands in California.

Res. Pap. PSW-RP-266, U.S. Department of Agriculture, Forest Service, Pacific Southwest Research Station, Albany, CA, 59 p.

SBCC, 2002. Biology 100. Concepts in Biology. Introduction to Chaparral. Santa Barbara City College, Santa Barbara, CA. Summary on college website, Retrieved December 18, 2014, http://www.biosbcc.net/b100plant/.

SBCFWC, 2008. Draft resolution to the Santa Barbara County Board of Supervisors from the Santa Barbara County Fish and Wildlife Commission, February 26, 2008.

Schoenberg, F.P., Peng, R.D., 2004. Letter to the San Diego Board of Supervisors, January 26, 2004.

SDCBS, 2003. Mitigation Strategies for Reducing Wildland Fire Risks. San Diego County Wildland Fire Task Force Findings and Recommendations, San Diego County Board of Supervisors, San Diego, CA, August 13, 2003.

SDCBS, 2009. County of San Diego Vegetation Management Report. Final Draft, 2/11/09. San Diego County Board of Supervisors.

Shea, N., 2008. Under Fire. National Geographic Magazine, Washington DC. July, 2008.

SMMNRA, 2005. Final Environmental Impact Statement for a Fire Management Plan, Santa Monica Mountains National Recreation Area. US Department of the Interior, National Park Service, Washington, DC.

SMMNRA, 2015. Why This Park Does Not Use Prescribed Fire. US Department of the Interior, National Park Service, Washington, DC. Santa Monica Mountains National Recreation Area website: http://www.nps.gov/samo/parkmgmt/prescribedfires.htm.

Sneed, D., 2008. Fires in California Devastate Wildlife, Sensitive Habitats. The Tribune, San Luis Obispo, July 12, 2008.

Spencer, W.D., 2009. Letter to the County of San Diego Planning Commission. Conservation Biology Institute, San Diego, CA, January 5, 2009.

Steel, Z.L., Safford, H.D., Viers, J.H., 2015. The fire frequency-severity relationship and the legacy of fire suppression in California forests. Ecosphere 6 (1), 8.

Steinhoff, 2010. San Diego County comment letter on the draft California Fire Plan.

Syphard, A.D., Franklin, J., Keeley, J.E., 2006. Simulating the effects of frequent fire on southern California coastal shrublands. Ecol. Appl. 16 (5), 1744–1756.

Syphard, A.D., Keeley, J.E., Brennan, T.J., 2011. Comparing the role of fuel breaks across southern California national forests. For. Ecol. Manag. 261, 2038–2048.

Talluto, M.V., Suding, K.N., 2008. Historical change in coastal sage scrub in southern California, USA in relation to fire frequency and air pollution. Landsc. Ecol. 23, 803–815.

Tiszler, J., 2000. Fire Regime, Fire Management, and the Preservation of Biological Diversity in the Santa Monica Mountains NRA. Report for the Santa Monica National Recreation Area, Thousand Oaks, CA, May, 2000.

Tyler, C.M., Borchert, M.I., 2007. Chaparral geophytes: fire and flowers. Fremontia 35 (4), 22–24.

USFS, 2013. Ecological Restoration Implementation Plan. R5-MB-249. US Department of Agriculture. Forest Service. Pacific Southwest Region, Vallejo, CA, 154 p.

USDI NPS, 2004. Draft Environmental Impact Statement Fire Management Plan, Santa Monica Mountains National Recreation Area. United States Department of the Interior, National Park Service, Washington, DC.

Wells, P.V., 1962. Vegetation in relation to geological substratum and fire in the San Luis Obispo quadrangle, California. Ecol. Monogr. 32, 79–103.

Zane, D., Henry, J.H., Lindley, C., Pedergrass, P.W., Galloway, D., Spencer, T., Stanford, M., 2006. Surveillance of Mortality during the Texas Panhandle Wildfires (March 2006). Regional and Community Coordination Branch, Public Health Preparedness Unit, Texas Department of State Health Services.

Zedler, P.H., Seiger, L.A., 2000. Age mosaics and fire size in chaparral: a simulation study. In: 2nd Interface between Ecology and Land Development in California, pp. 9–18, USGS Open-File Report 00-02.

Zedler, P.H., Gautier, C.R., McMaster, G.S., 1983. Vegetation change in response to extreme events: the effect of a short interval between fires in California chaparral and coastal scrub. Ecology 64, 809–818.