Chapter 15
Managing Chaparral Resources on Public Lands

Hugh D. Safford, Emma C. Underwood, and Nicole A. Molinari

Abstract Southern California supports some of the highest biodiversity in the United States, but it also suffers from very heavy visitor use, a large influx of non-native species, high levels of air pollution, steep and erosive slopes, and the most unpredictable precipitation regime in the nation. Wildland vegetation in southern California is dominated by highly flammable shrublands like chaparral. As a result, public lands in southern California are exceptionally fire-prone. Annually they experience more economic and environmental damage from wildfire than any other part of the US. Management in southern California shrubland ecosystems has traditionally focused heavily on fire and fuels, but degraded terrestrial and aquatic ecosystems and hundreds of rare, threatened, and endangered species require a more holistic approach, especially with growing human populations and their needs for ecosystem services, and the developing threat of climate change. In this chapter we categorize the major management priorities on public lands in southern California and explore their inter-relationships. We also identify a suite of ecosystem services provided by chaparral landscapes, and we assess how current management priorities interact with and impact these services. Major tensions exist between certain management focus areas, especially recreation and fuel management, and other management priorities and the ecosystem services we assessed. We show how an ecosystem service-based approach to chaparral management can help to better elucidate and resolve conflicts in chaparral management.

H. D. Safford (✉)
USDA Forest Service, Pacific Southwest Region, Vallejo, CA, USA

University of California, Davis, CA, USA
e-mail: hughsafford@fs.fed.us

E. C. Underwood
University of California, Davis, CA, USA

University of Southampton, UK

N. A. Molinari
USDA Forest Service, Los Padres National Forest, Goleta, CA, USA

E. C. Underwood et al. (eds.), *Valuing Chaparral*, Springer Series on Environmental Management, https://doi.org/10.1007/978-3-319-68303-4_15

Keywords Conservation · Ecosystem services · Fire · Fuel management · Recreation · Restoration

15.1 Introduction

Chaparral is one of most widely distributed terrestrial ecosystems in California, and it is found in some form on nearly every major federal conservation unit in the state (Fig. 1.1). Fully 60% (840,000 of 1.4 million ha) of the four southern California national forests support chaparral vegetation, and even the Mendocino National Forest, 650 km (400 miles) north of Santa Barbara, is almost one-quarter chaparral. Millions of Californians live in communities that are carved like islands from the chaparral sea, and tens of thousands reside in rural homes surrounded by chaparral on all sides.

Every year we are reminded that these are dangerous places to live. Chaparral vegetation is the principal fuel in the most fire-prone region in the United States (southern California), and the average year sees hundreds or thousands of homes and businesses burned, people killed or injured, and hundreds of millions of dollars in fire suppression costs and fire-related economic losses (Safford 2007; Halsey 2008; Rahn 2009). Yet people continue to pour into chaparral dominated landscapes and poor planning decisions continue to be made at the community and county level, decisions that have major implications for human economies and human lives (Halsey 2008). Ecological consequences of these planning decisions include direct ramifications, such as the loss of habitat, but also indirect ramifications, most consequentially related to fuel and fire management decisions designed to protect the community after it is built and inhabited.

Fire management has become a major industry in southern California at all jurisdictional levels. Within the US Forest Service, fire management now consumes >70% of the budget in southern California, compared to >50% nationally (USDA 2015a). Many, if not most, major management decisions made by US Forest Service units in southern California—which manage the vast bulk of chaparral habitat in the region—revolve around fire or fuels at some level. For example, suppressing fires to protect human lives and infrastructure; managing vegetation to reduce fuel; carrying out postfire rehabilitation and restoration work; or controlling non-native species in frequently burned areas. Other federal and state lands like the Santa Monica Mountains National Recreation Area (National Park Service), Camp Pendleton (Department of Defense) or Mount San Jacinto State Park (California State Parks) are experiencing similar situations (Table 15.1).

This myopic focus on the chaparral fire problem clouds and impoverishes people's understanding of the ecosystem values of chaparral. Indeed, given the major exposure Californians have to chaparral, it is extraordinary the extent to which it has been misunderstood and even reviled (see Chaps. 1, 5, and 11). This antipathy for chaparral has roots that go way back (see Chap. 5). Early settlers in southern California saw a troublesome brushland with trifling economic potential or value. It

Table 15.1 Major land management units (>5000 ha or 12,355 acres) in southern California in 2016 with large areas of chaparral[a]

Unit	Level	Agency	Size (ha)	Management plan and citation	Management focus areas[b]
Los Padres National Forest	Federal	US Forest Service	708,502	Southern California National Forests Land Management Plan, 2005 (USDA 2005)	Watershed protection, fire protection, conservation, recreation, flood protection, education
Angeles National Forest	Federal	US Forest Service	283,401	Ibid	Ibid
San Bernardino National Forest	Federal	US Forest Service	275,304	Ibid	Ibid
Cleveland National Forest	Federal	US Forest Service	186,235	Ibid	Ibid
Santa Rosa & San Jacinto Mtns. National Monument	Federal	Bureau of Land Management and Forest Service	113,360[c]	SRSJNM Final Management Plan, 2004 (USDI and USDA 2004)	Conservation, recreation
Channel Islands National Park	Federal	National Park Service	101,215	CINP Final General Management Plan, 2015 (USDI 2015)	Conservation, restoration, recreation, education
Santa Monica Mtns. National Recreation Area	Federal	National Park Service	64,777	SMMNRA General Management Plan, 2002 (USDI 2002)	Conservation, recreation, education
Camp Pendleton	Federal	US Marine Corps	50,607	CP Integrated Natural Resources Management Plan (USMC 2012)	Conservation, restoration, recreation
Vandenberg Air Force Base	Federal	US Air Force	40,486	VAFB Integrated Natural Resources Management Plan, 2011–2015 (USAF [US Air Force]. 2011)	Conservation, restoration, recreation
Cuyamaca Rancho State Park	State	CA Dept. of Parks and Recreation	10,121	CRSP General Plan, 2015 (State of California 2015)	Conservation, education, recreation
Hungry Valley State Vehicular Recreation Area	State	CA Dept. of Parks and Recreation	7692	HVSVRA General Plan, 1981 (State of California 1981)	Recreation, conservation, restoration

(continued)

Table 15.1 (continued)

Unit	Level	Agency	Size (ha)	Management plan and citation	Management focus areas[b]
Mount San Jacinto State Park	State	CA Dept. of Parks and Recreation	5668	MSJSP General Plan, 2002 (State of California 2002)	Conservation, recreation

[a]Since early 2016, two new national monuments (NM) have been proclaimed that contain large areas of chaparral (and US Forest Service and BLM lands): San Gabriel Mountains NM and Sand to Snow NM. These two National Monuments are too new to have approved management plans, thus they are not included here

[b]Management focus areas are ordered according to their emphasis in the plan

[c]Includes portions of San Bernardino National Forest

was a common misconception that chaparral represented a degraded, deforested condition and this belief led to widespread conifer planting in the late nineteenth and early twentieth centuries (Burns and Sauer 1992). Fire was used to clear land for home sites and crops, to open access for miners and livestock herders, and to improve forage (Plummer 1911; Patric and Hanes 1964; Keeley and Fotheringham 2003). By the end of the nineteenth century, such was the destruction of native vegetation in the San Gabriel and San Bernardino mountains that great vacillations in water supply—lower water delivery overall, punctuated by periodic devastating floods—and destructive landslides generated real economic harm in the valleys below, particularly to the croplands and large fruit orchards that characterized the greater Los Angeles Basin at the time (Plummer 1911). This galvanized public opinion and led to the establishment of the nation's second forest reserve (after Yellowstone) in the San Gabriel Mountains in 1892, and soon after other forest reserves in the neighboring mountains (e.g., Trabuco Canyon [Santa Anas] in 1893, San Jacinto in 1897). It is noteworthy that unlike most national forest lands, these landscapes were primarily protected to prevent watershed degradation (rather than to guard timber resources), principally through fire suppression (Plummer 1911).

Early conservationists and foresters like John Muir and Abbot Kinney (Kinney 1888; Muir 1918) were respectful of, if not enamored by chaparral, but as the southern California population grew, the respect turned largely to disdain. By the 1960s and 1970s, even scientific opinion had turned against chaparral, and the literature of the period is full of publications expounding the multiple benefits of clearing chaparral by whatever means necessary (e.g., Macey and Gilligan 1961; Bentley 1967; Corbett and Crouse 1968; Cable 1975; Riggan and Dunn 1982). These putative benefits included increasing runoff, generating better forage for livestock and game, making recreational and hunting use of the landscape easier, harvesting biomass for energy, and reducing fire-fighting costs. Even the pioneering and otherwise progressive fire ecologist Howard Biswell prefaced his 1974 study of chaparral fire ecology by suggesting that understanding the relationship between chaparral and fire would better serve the purposes of people who wanted to control and remove it (Biswell 1974).

Today we understand that chaparral has its own value. It is an important repository of biodiversity, and chaparral dominated counties like San Diego and Ventura are among the most biodiverse political jurisdictions in the nation (see Chaps. 2 and 3). Intact chaparral cover is an important component of the habitat required by hundreds of rare and endangered species, and the important but often forgotten ecosystem service of pollination is highly dependent on the proximity of healthy chaparral and other native vegetation to cropland and orchards (Kremen et al. 2004; Klein et al. 2012). Intact chaparral cover also protects soil from the direct impact of heavy rain, and live chaparral roots prevent soil erosion and overland flow (see Chaps. 7 and 8, Wohlgemuth et al. 2009) during both the dry and wet seasons. Chaparral sequesters much more carbon than the grass ecosystems that replace it when it is degraded (see Chaps. 6 and 12, Bohlman et al. in press) and intact chaparral may reduce fire ignitions during the high fire season due to high live fuel moisture and lower combustibility relative to the dried foliage of annual species. Intact chaparral with its characteristic dense cover and closed canopy is also relatively resistance to plant invasions.

Management of chaparral habitats is fraught with controversy (see Chaps. 5 and 11, Keeley 2002a; Halsey 2008). Many of these controversies find their roots in the different perspectives people and organizations have of the value of chaparral. Today, the extraordinary threat of fire and too many people, hundreds of threatened and endangered species, degraded watersheds, climate change, and water issues are re-focusing and intensifying the chaparral debate. More people are interested in conserving chaparral, at the same time that more people are exposed to the threat of fire; more people require water collected from chaparral dominated watersheds, at the same time that droughts are becoming more common and more pronounced; threats to rare species' survival are mounting at the same time that the housing market has recovered from the 2008 crash and subdivision growth is on the rise.

Sustainable management of chaparral will require that we balance these competing needs. Ideally, this is best done through a transparent process that considers proposed actions in the light of their impacts on a broad suite of ecosystem services. It is our thesis that much of the polemic in chaparral management can be resolved, or at least made less acute, by taking a more holistic view, and considering and integrating information on the range of ecosystem services provided by chaparral landscapes that are detailed in the chapters of this book. In this chapter we identify five major areas of public agency management focus in chaparral ecosystems, and summarize the inter-linked issues and controversies surrounding them. Along the way we highlight, through a series of case studies, progress that has been made in integrating multiple natural resources and ecosystem services in prioritizing, planning, and implementing management actions.

15.2 Areas of Management and Ecosystem Service Focus in Chaparral Ecosystems

To assess the overlap between areas of management focus and ecosystem services we perused the General Plans, or Land and Resource Management Plans, for the major federal and state conservation units and other designations in southern

California that included large proportions of chaparral, and some level of resource protection as a goal or mission (Table 15.1). We identified the overarching management focus areas for each unit, as outlined in each planning document (Table 15.1), and also the principal ecosystem services that each planning document identified as a good or service that could be enhanced or provided through management.

Generalized across the management plans, we found the principal management focus areas fall into six broad categories. In approximate order of their importance (i.e., either as directly identified in the management plans or based on their relative emphasis in the plan text [Table 15.1]) they are:

- Conservation
- Recreation management
- Fuel management
- Fire management
- Restoration
- Education

The principal ecosystem services acknowledged (either directly or indirectly) in the planning documents, also in approximate order of their importance (definition as above), are:

- Water provision
- Reduction of erosion and flooding
- Facilitation of recreation opportunities
- Protection of biodiversity
- Provision of aesthetic landscapes
- Carbon sequestration

Below, we describe the inter-relationships between the management focus areas highlighted in the general management plans and their connections to the six ecosystem services, and we provide a snapshot of the allocation of funding. These relationships (management priorities, ecosystem services, and budget) are highlighted within each of the management focus area subsections below to provide guidance for the reader. Note that we do not address education here, as it is discussed in depth in Chap. 11. Three case studies relating to these management priorities are presented in Boxes 15.1–15.3.

15.3 Major Chaparral Management Priorities, their Inter-relationships, and their Influences on Ecosystem Services

15.3.1 Conservation

By conservation, we refer both to biological conservation, which includes those human actions that seek to maintain genes, species, communities, and ecosystems that make up the earth's biological diversity (Soulé 1985), and natural resource

Box 15.1 Thinking Big in Chaparral Conservation

California is a national leader in collaborative efforts to protect large, interconnected landscapes for multiple species and ecosystems. The California Natural Community Conservation Act (1993, revised 2003) led to the Natural Community Conservation Planning (NCCP) Program. NCCP is managed by the California Department of Fish and Wildlife and, where there are federally listed species in question, the US Fish and Wildlife Service. NCCPs are focused on preserving intact ecosystems rather than single species, and became necessary in places like southern California where the single species focus and reactionary implementation of the national and California Endangered Species Acts were proving insufficient and controversial (Pollak 2001a). Although they are largely voluntary agreements, NCCPs bring stakeholders to the table by providing heightened predictability about the future regulatory environment, and more certitude about what can be developed and what must be conserved. Pollak (2001b) lists four major achievements of the NCCP program:

- A planning outlook that is more regional and longer term
- Development of large, interconnected networks of conservation reserves and corridors
- A setting for collaborative efforts by sometimes diametrically opposed groups
- Streamlining of regulatory processes and enhanced certainty regarding conservation and development actions

The original NCCP Act arose in response to conservation versus development controversies related to the potential listing of the California gnatcatcher in the late 1980s and early 1990s (Pollak 2001a). The primary focus of early NCCPs was the identification and protection, often through acquisition, of sage scrub habitat—a close relative of chaparral—which is key to gnatcatcher survival in southern California. Today NCCPs exist for species and habitats across California, centered in areas with extreme development pressures and multiple listed or potentially listed species, like southern California, the San Francisco Bay Area, and the central and southern Central Valley. Chaparral habitats are a focus of at least 16 NCCPs in California, 11 of them south of the Tehachapi Mountains (see map link on https://www.wildlife.ca.gov/Conservation/Planning/NCCP).

The NCCP process has provided major impetus to agencies, governments, businesses, private landowners, and conservation Non-Governmental Organizations (NGOs) to cooperate in developing workable compromises that attempt to balance development and conservation across large landscapes. For example, the Santa Rosa Plateau and lands draining to the Santa Margarita River were identified by animal tracking and corridor mapping (Luke et al. 2004; Beier et al. 2006) as key to maintaining ecological connectivity between the coast, the Santa Ana Mountains, and the Palomar Mountains (Fig. 15.1).

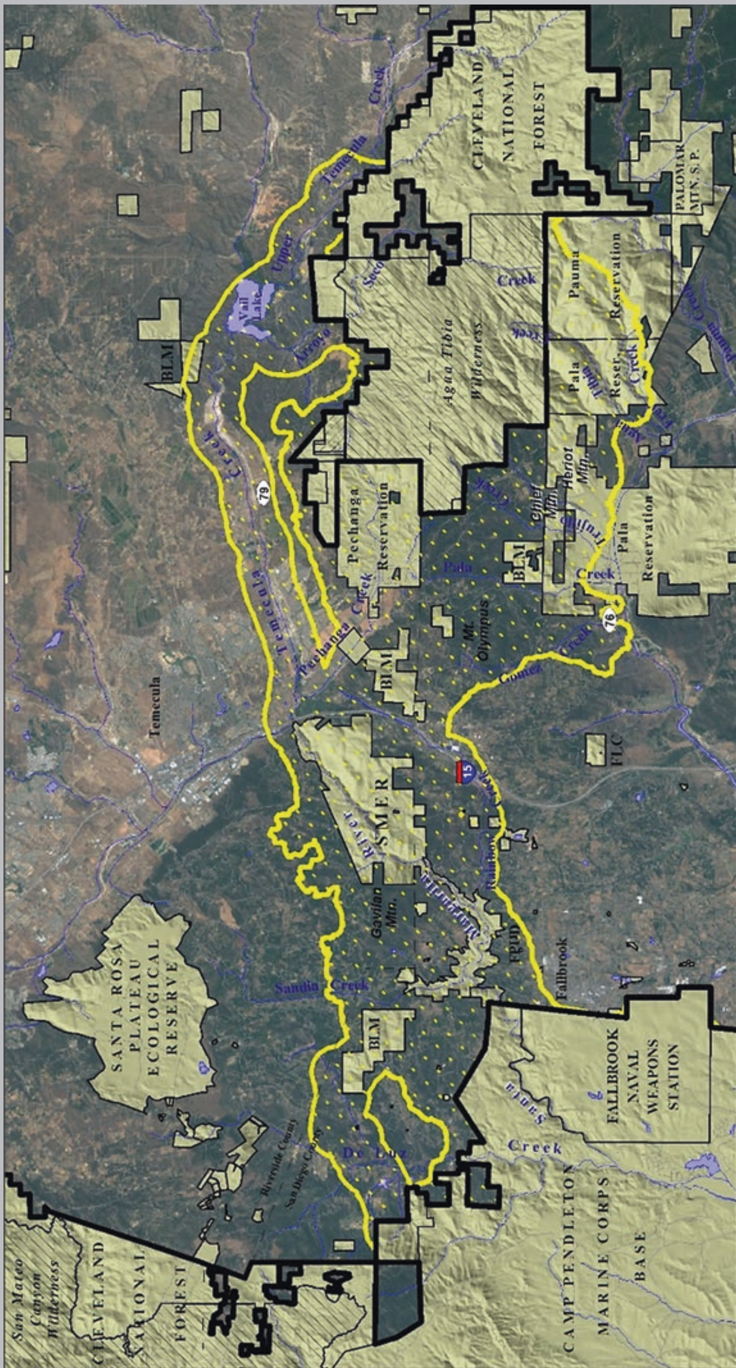

Fig. 15.1 Proposed Santa Ana Mountains-Palomar Mountain habitat corridor. Yellow perimeter indicates linkage design. From Luke et al. 2004

However, the logistical and political hurdles to saving this linkage corridor are daunting, which is further compounded by development pressures and increasing land prices. Two NCCPs in the area, the Western Riverside County Multiple Species Habitat Conservation Plan (County 2003), and San Diego North County Multiple Species Conservation Plan, have mapped proposed reserves, however the checkerboard of land ownership makes implementation extremely challenging. Large properties in the area belong to the US Forest Service, the US Marine Corps, the US Navy, a number of tribal reservations, Riverside County Parks, San Diego State University, the US Bureau of Land Management, The Audubon Society, and California State Parks, but there are thousands of smaller parcels as well, most privately owned. The I-15 freeway also represents a major barrier to connectivity. The Nature Conservancy and other NGOs have prioritized land acquisitions in the corridor (and other corridors on and adjacent to the Santa Rosa Plateau), but land prices and unwillingness to sell at the current time are proving to be major obstacles. The Santa Ana-Palomar linkage will be a test case of the NCCP process and its ability to conserve truly critical ecological landscapes in the face of overwhelming economic and development pressures (Morrison and Boyce 2008).

conservation, which is related but focuses more on the sustainability of resources necessary for human survival and well-being. Based on our management plan review, conservation is the principal management focus of most major public management units in southern California (Table 15.1). Southern California is overall the most biodiverse part of the United States, and it also supports the highest number of threatened, endangered, and sensitive (TES) species in the contiguous 48 states (Dobson et al. 1997; Stein et al. 2000).

High levels of habitat fragmentation constitute one of the paramount threats to biodiversity and TES species on chaparral lands throughout California. Chaparral and related shrubland types like sage scrub used to cover virtually uninterrupted swathes of millions of hectares along much of the California coast, but the rapid growth of human populations and associated urban and suburban areas have restricted natural habitat to numerous terrestrial islands that have lost much or all of their connectivity with nearby wildlands (Stephenson and Calcarone 1999). This has resulted in chaparral (and, even more so, sage scrub) dominated regions in California being major hotspots of species endangerment for multiple taxonomic groups (Dobson et al. 1997). As a consequence, the need for regional strategic conservation planning efforts has become paramount (Zedler 1996; Stephenson and Calcarone 1999), and over the last 25 years, southern California has become a national model for large scale, multiparty habitat and species conservation planning (see Box 15.1).

With respect to the other management priorities, conservation has an important influence on recreation (the second ranked management focus area), positively through the preservation of natural areas and open spaces that permit recreational use and educational opportunities, and in some cases negatively through the prohibition of certain kinds of recreational use (e.g., in wilderness areas or the Sespe Condor Sanctuary). Conservation has both positive and negative influences on fire and fuel management. Conserved areas are typically farther from urban areas and support low densities of access routes so human ignition densities tend to be lower, but the large areas of contiguous fuels in conserved areas can lead to greater fire spread and such areas are sometimes off-limits legally or logistically to fuel management activities, as well as certain fire management activities (USDA 2005; Syphard et al. 2008). Strategic land acquisition and conservation in areas of high fire hazard may be a valuable tool to reduce fire risk to homes while protecting biodiversity and other ecosystem services (Butsic et al. 2016). Conservation has a primarily positive influence on restoration, as conserved areas typically require less restoration, freeing restoration funds and efforts for more degraded habitats. Interestingly, although conservation is the primary focus of most chaparral dominated management units in southern California, it is not necessarily the top priority in terms of greatest spatial area in publicly owned chaparral. This is because the four national forests belong to the National Forest System, which is managed under a different set of laws and regulations than national, state, and county parks and is compelled to consider a wider swath of public uses (Wilcove 1989; Thomas 1996, Table 15.1).

Given the large and growing population in southern California and other chaparral areas, and the increasing occurrence of droughts and warmer, drier fire seasons, there are inevitably strong tensions between conservation and recreation and conservation and fuel management (see next section). At the present time, these tensions represent two of the most important resource management issues in California chaparral landscapes.

Of the general management priorities we identified in our review, conservation is the only one to have a primarily positive influence on all of the ecosystem service categories. For example, conserving native shrubland secures sediment on steep slopes, provides habitat for plant and animal species, increases the aesthetic value of the landscape, and stores carbon both above- and below-ground (the latter of which can be considerable for certain chaparral shrub species, especially postfire resprouters). Conservation also provides open space for many types of recreation, but strict conservation policies can have negative influences on opportunities for recreation, especially high-impact activities such as motorized recreation and suction mining.

It is difficult to determine exact budget numbers related to support of conservation on public lands in southern California or other areas dominated by chaparral. On some federal lands (e.g., US Forest Service), actual management of wildlife species falls to the California Department of Fish and Wildlife (DFW). In these cases, most actions carried out by the federal agency other than DFW are related to habitat management rather than direct species management (this is not the case with the National Park Service, which manages its own wildlife populations). Also, funds that are directly earmarked for conservation are a relatively small part of most agencies' budgets, and much conservation-related work is accomplished as part of projects funded by other areas of the budget or from trust-funds or partner funding. For example, federal agencies can purchase important private properties for conservation purposes with funds from the Land and Water Conservation Fund, which is derived by fees collected from offshore oil and gas drilling. State agencies carry out a large component of their conservation work through allocation of State bond funds. The long list of habitat, multi-species, and natural community conservation plans in California involves many public and private partners, with the bulk of funding often coming from bonds, foundations, or private donations. There is also a large area of overlap between restoration and conservation, which is the primary goal of most restoration projects, and most large scale restoration projects are funded through multi-party collaboratives.

15.3.2 Recreation

Recreation is the second most cited management focus area, which reflects the mandates of the public land management agencies, the proximity of the management units to the ~23 million residents of southern California, and the general lack of publicly accessible open space. The draft management plan for the new San Gabriel National Monument (USDA 2015b) is a good example of the difficult balancing act experienced by management agencies tasked with conserving species, ecosystems, and resources, while at the same time serving a huge clientele of recreational users whose cumulative actions comprise a major conservation threat. The plan notes that more than 15 million people live within 90 min of this national monument, but only 2% of the monument is suitable for recreational use, and within that 2% most use is concentrated at a handful of sites with water access (USDA 2015b) (see Chap. 10 for more information on recreational use and photo of water site use on the San Gabriel National Monument).

Other recreation issues for the public land management agencies in southern California include the high diversity of types of recreational use, some of which conflict (e.g., hikers versus mountain bikers versus horse riders; bird-watchers versus motorcycles; shooters versus hikers; fishermen versus suction miners, Moore 1994); ethnic differences in type of use (see Chap. 10, Baas et al. 1993); illegal recreational activities (e.g., unpermitted Off Highway Vehicle (OHV) use, unpermitted trail and campsite construction, illegal shooting) (Hartley 1986; McIntyre and Weeks 2002), and generally low budgets for recreation management.

With respect to management priorities, recreation has both direct and indirect effects associated with conservation (see Chap. 10 for a detailed study of recreation use on public lands). There is a direct negative relationship between conservation and recreation and this ranges from slightly to moderately negative in cases of low-impact recreation (non-motorized, low densities of users) to highly negative in cases of high-impact recreation, such as popular OHV trails (Havlick 2002; Reed and Merenlender 2008). However, there is also an indirect positive relationship, in that recreation is the principal connection for many users with natural ecosystems and such users are more likely to consider conservation an important goal (Lee 2011).

Recreationists can also have an important impact on fire management and fuel management, as areas with high recreational use are often major sources of ignitions and are more likely to require fuel reduction, not to mention enforcement of fire safety regulations (use of spark arresters, campfire restrictions, parking and road closures, etc.). Recreationist and recreational facility presence on the landscape can also greatly complicate fire operations (Bricker et al. 2008).

With respect to the ecosystem services, legal recreation itself has little relationship to water provision, however, excessive recreational use of streams can have major negative impacts on water quality. For example, short reaches of the East Fork of the San Gabriel River may see as many as 8000 people per day during the summer. The picnics and barbecues associated with this use generate over four hundred 122 L (32 gallon) bags of trash per day, according to US Forest Service estimates. Trash discarded in the streambed and river terrace area severely impairs the river and as a consequence a total maximum daily load (TMDL) has been established. In addition, roads and trails supporting recreation can be major sources of erosion and can impact soil retention. In terms of biodiversity, recreational use at the high levels common in southern California has negative influences, especially for larger animals like ungulates and predators (Knight and Gutzwiller 1995; Czech et al. 2000) and aquatic biota in heavily-used streams. The aesthetics of public lands can experience minor to moderate impacts from legal recreation, such as increased traffic and trash, but these escalate in high-impact recreation sites such as vehicular recreation areas or natural water features, or when recreationists are the ignition sources for wildfires (not an uncommon occurrence [Prestemon et al. 2013]).

In contrast, illegal recreational use has a variety of deleterious impacts on ecosystem services. These range from unpermitted OHV and other trail impacts on erosion, water quality, biodiversity, and aesthetics (Havlick 2002), to illegal shooting impacts on wildlife (direct mortality and indirect, through ingestion of lead ammunition), increased fire risk, and even human health (LPFW [Los Padres Forest Watch] 2016). Some of these impacts, such as OHV use, are often concentrated in areas where fuel management or fire clears dense vegetation from portions of the landscape.

Although recreation is a management priority—and public lands in southern California are among the most visited public lands in the US—the actual annual budgets allocated to recreation by most agencies are small (Kaczynski and Crompton 2006). For example, in 2016 the US Forest Service budget for "recreation, heritage and wilderness" was approximately 5% of the total budget (https://www.fs.fed.us/sites/default/files/media/2015/07/fy2016-budget-overview-update.pdf). For this reason, US Forest Service units in southern California have implemented (controversial) user fees to help pay the cost of, among other things, maintaining recreational facilities and dealing with resource damage by recreationists.

15.3.3 Fuel Management

Because chaparral landscapes are highly flammable and because human communities are so dispersed within these flammable landscapes, chaparral fuel management is a major focus for all public land managers in southern California. On southern California public lands, most ecosystem-disturbing activities carried out by management agencies relate in some fashion to fuel management. These can be either strategic prefire activities, such as prescribed fires or the removal of vegetation by bulldozers or masticators in fuelbreaks across the landscape, or tactical activities carried out in the heat of active fire control (which fall under fire management, below).

For decades, California land managers performed large scale fuel manipulations on chaparral landscapes with little public attention. However, advances in our understanding of the value and vulnerabilities of chaparral landscapes and the trade-offs associated with such work have led to increased public interest in the nature of and philosophy behind fuel manipulations. These advances include: (1) scientific information documenting the deleterious effects of reduced chaparral cover on a number of ecosystem properties and their function, (2) the development of a better understanding of the natural fire regime of chaparral vegetation, and (3) a growing recognition that reduced woody fuels do not act as a reliable barrier to fire spread under severe fire weather conditions, e.g., fires driven by Santa Ana winds.

In the first case, we now have a much better idea of the ecological trade-offs associated with the quasi-permanent removal of native vegetation cover that the fuelbreak system entails. Fuelbreaks do not cover a large portion of the southern California landscape, for example, the Cleveland National Forest fuelbreak network comprises less than 2.5% of the forest area (estimate based on draft Strategic Fuelbreak Analysis: 514 km (319 miles) of fuelbreaks at a maximum of 90 m (295 ft) width, T. Metzger, US Forest Service, pers. comm.), but they are very obvious to observers, and their environmental costs are high. These costs include increased non-native species invasion, higher soil loss rates, more variable runoff, and less groundwater recharge, enhanced access for unpermitted motorized vehicle entry, aesthetic impacts, and under certain circumstances higher local fire hazard (due to herbaceous fuels dominating where woody fuels have been reduced) (Corbett and Rice 1966; Merriam et al. 2006; Halsey 2008; Wohlgemuth et al. 2009).

In the second case, there is now broad agreement that the natural fire regime of most low- and mid-elevation chaparral ecosystems is characterized by infrequent (fire-return intervals between 30 and 100+ years), high severity fires (Minnich 2001; Van de Water and Safford 2011). Although chaparral is resilient to variability in fire frequency, we now know that persistent fires at return intervals of less than about 15 years reduce woody vegetation and enhance non-native grass invasion (especially in locations with high atmospheric nitrogen input, which is widespread in southern California) to the point that such sites eventually transform to quasi-permanent weedy grasslands (Zedler et al. 1983; Keeley 2006; Keeley and Brennan 2012). Today large areas of the mountain foothills of southern California been transformed from chaparral and sage scrub vegetation to non-native grasslands and weed fields. In turn, these sites are the major sources of non-native plant seeds that dominate the contemporary soil seed pool in southern California, and are also the major sources of human fire ignitions that define the modern southern California experience (see Chap. 12, Syphard et al. 2007a). It is also worth noting that application of prescribed fire on many chaparral landscapes represents a further increase in fire frequency on lands where the major source of degradation is already an overabundance of fire.

Table 15.2 Fuel and fire characteristics from 1970 to 2013 for two fire seasons on southern California's US Forest Service units (fire statistics from chaparral burning only)

Fire season	Name	Mean live fuel moisture (%)[a]	Mean monthly number of fires[b,c]	Mean fire size (ha)[b]	Median fire size (ha)[b]	Mean annual max fire size (ha)[b]	Absolute max fire size (ha)[b]	Mean annual burned area (ha)[b]	Mean monthly burned area (ha)[b]
May to Sept*	Spring–summer	93 (65–135)	2.9	2327	131	17,763	97,311	33,593	6719
Oct to Dec	Santa Ana	78 (65–90)	1.2	4858	335.4	8619	109,589	17,687	5896

[a](County of Los Angeles 2016). Mean of mid-month shrub live fuel moisture measurements, 1981–2016

[b]Fire perimeter data (FRAP 2014) only include fires reaching at least 4 ha (10 acres) in size on US Forest Service lands. The number of fires <4 ha is much higher than this number. Fire-return interval departure data (FRID) are from the USDA (2015c)

cThe Santa Ana season is tied to the development of cooler desert temperatures than coastal temperatures, and such a situation usually begins in October. Some years this occurs in late September however, so the boundary between September and October is necessarily artificial

In the third case, the historic fires of 2003 and 2007 made clear the limitations of southern California fuel reduction treatments in stopping fires under severe weather conditions (i.e., high winds, high temperatures, and conditions of drought, Keeley et al. 2004; Keeley et al. 2009). It should be noted that these limitations were understood in land management circles well before the 2000s (see, for example, Pillsbury 1963; Tyrrel 1982, and discussion in Cermak 2005), but these catastrophic events brought the issue into full focus.

A major debate has been ongoing for decades regarding the relative roles of fuels versus extreme weather in driving chaparral fire behavior (Minnich 1983, 2001; Conard and Weise 1998; Keeley et al. 1999; Keeley 2002a; Moritz et al. 2004; Keeley et al. 2009; Jin et al. 2014). In part, this is because of the different natures of the two fire seasons in southern California. The chaparral fire season in southern California stretches through much of the year, but it is best described as two distinct "subseasons", which occur back-to-back and are then separated by the (ever-shortening) rainy season in the winter and early spring. General characteristics of the two fire seasons are given in Table 15.2. Most fires in southern California occur in the late spring to late summer (Keeley and Fotheringham 2003), when air humidity and fuel moistures are higher, and winds are mostly maritime and moderate. In the second fire season, which lasts from early fall to early winter, there are fewer fires, but fuel moistures are lower than in the summer (the rainy season often does not arrive till December or January), and periods of high atmospheric pressure in the interior deserts bring strong winds from the east (föhn-type winds known as "Santa Anas") that carry hot, dry air into southwestern California (Keeley and Fotheringham 2003). The two fire seasons support similar monthly burned areas (although the longer length of the spring-summer season results in more overall burned area in this season [Jin et al. 2014]), but by far the most economic loss, destruction of homes, and fatalities are during the Santa Ana season (Safford 2007; Halsey 2008; Keeley et al. 2009). In the spring-summer fire season the fuel structure of chaparral is more likely to have important effects on fire spread and control. In the Santa Ana season, the windy conditions that make fire control difficult to impossible to control are more common and fuel structure is not a reliable barrier to fire spread (Keeley 2002a; Keeley et al. 2009; Syphard et al. 2011).

Recent work has made it clear that the gradual shift from the spring-summer season to the fall-winter season is characterized by changes in the relative balance between fuels and extreme weather driving fire behavior in chaparral (Keeley 2002a; Keeley et al. 2009; Jin et al. 2014). Of course there are fires, and portions of fires, that violate this rule in both fire seasons every year, but the overall pattern is well-understood by most managers and scientists. During fuel-driven fires in chaparral, fuel manipulations are valuable from a tactical standpoint, as long as they are strategically placed in areas safe enough to deploy firefighters (Syphard et al. 2011). Under extreme weather conditions, these fuel manipulations are less effective (and in many cases simply ineffective) because even very young chaparral vegetation is flammable under dry, hot conditions; winds carry embers far from the flaming front to jump over areas of fuel treatment; aerial attack is nearly impossible; and many firefighters are deployed in and adjacent to areas of human infrastructure to protect structures and lives (Keeley 2002a; Moritz et al. 2004). The understanding that fuel manipulations tend to be differentially effective in the two fire seasons has led to a focus on the characteristics of spring-summer fires for designing fuelbreaks (e.g., the ongoing US Forest Service strategic analysis of the southern California fuelbreak network), and a focus on fire prevention, community planning, and structure hardening (adapting homes to reduce vulnerability to fire) for the inevitable Santa Ana fires in the fall and winter (see Box 15.2).

Concerning the influence of the fuel management priority on the other management priorities: fuel management has the most strongly negative direct relationship with conservation, but for many spring-summer fires and some fall (Santa-Ana) fires fuel management is an important contributor to fire management success, so there is a very important spatial relationship to consider, namely that areas that are "sacrificed" for fuel reduction can act to conserve adjacent areas (Keeley 2002a; Keeley and Safford 2016). Effects of fuel management on legal recreation are probably minimal, except from the standpoint of aesthetics. Obviously, fuel reduction has important influences on fire management in conditions where fuels limit fire spread. As noted above, this is common in the spring-summer fire season, and less common in the fall fire season when most human infrastructure and lives are lost. Unlike fuel reduction in many semi-arid conifer forests in California (e.g., ponderosa pine or mixed conifer forest, Winford et al. 2015), fuel treatment implementation on chaparral landscapes is not a restorative treatment but rather a local resource sacrifice executed for the purpose of realizing benefits on adjacent lands. As such, its direct relationship to restoration—as with conservation—is negative. Indeed, abandoned fuelbreaks may require substantial restoration. Even so, fuelbreak construction may be necessary in some situations to provide at least a modicum of protection for adjacent chaparral (or other vulnerable vegetation) stands that have been restored.

Box 15.2 Reducing Fire Impacts on Natural Resources and Communities through Science-Based Collaboration

The Santa Monica Mountains National Recreation Area (SMMNRA) is embedded within the Los Angeles metropolitan area and provides recreation opportunities to over 12 million nearby residents (Fig. 15.2). The SMMNRA, like the majority of chaparral dominated landscapes in southern California, has deviated from historical fire-return intervals with some areas burning 5–11 times in the last 90 years. Repeated fires rank among the greatest threats to the park's natural resources, equal in importance to urbanization and fragmentation (NPS 2015). When coupled with concerns over community protection, reducing fire frequency has become a key issue for SMMNRA.

Most catastrophic wildland fires in the SMMNRA occur under extreme wind events (usually "Santa Ana" winds) that increase the rate of fire spread and impede control efforts. Between 1990 and 2009, 80% of economic losses occurred under Santa Ana winds (Jin et al. 2014). Under these conditions, landscape level fuel treatments are less effective at limiting the rate of fire spread. Consequently, the SMMNRA has refocused its efforts on two areas: (1) limiting fire frequency by reducing the number of ignitions during extreme weather conditions, and (2) encouraging the creation of defensible space around houses and retrofitting homes to reduce vulnerabilities to fire.

To accomplish these goals, the SMMNRA developed the Santa Monica Mountains Wildland Fire Resilient Landscape Collaborative (SMMWFRLC).

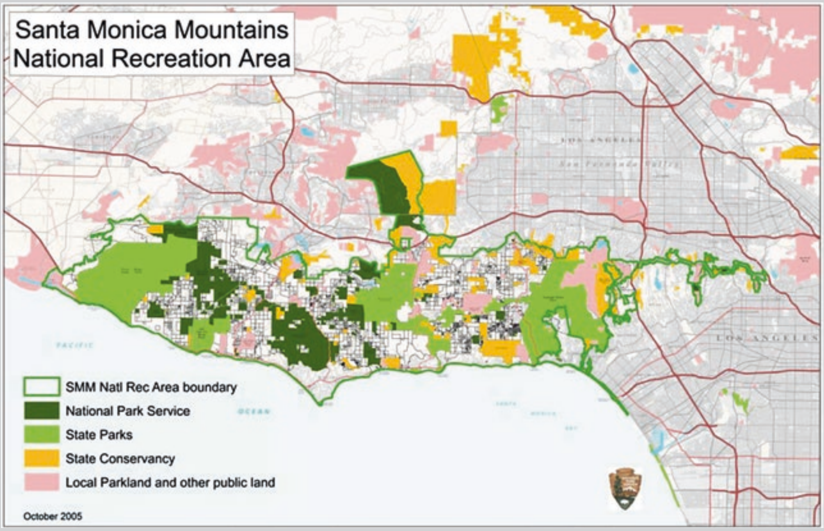

Fig. 15.2 SMMNRA comprises a diversity of ownership and an extensive wildland-urban interface. Gray and uncolored land is privately owned (image compliments of the National Park Service)

This collaborative brings together land management agencies, local fire departments, city and county governments, NGOs, fire safe councils, business and homeowner groups with a shared vision of "promoting a healthy, diverse, productive native landscape where local communities are safer and exposed to fewer major wildfires" (NPS 2015).

The SMMWFRLC has defined desired outcomes and measureable objectives for achieving their goals through coordination, communication, risk-based prioritization of treatments, and homeowner incentives across the SMMNRA. Examples of desired outcomes include:

- Improve resilience through fewer wildland fire ignitions and increased time between fires. A number of strategies will be employed to achieve this goal, including installation of concrete barriers to keep vehicles on the roadway within key ignition corridors, enhanced arson watch patrols during extreme weather events, closing parks and banning power tools during red flag weather, and relocation of powerlines under-ground in high wind corridors. Success will be measured as an increase in the average fire-return interval and a shift in the time-since-last-fire distribution for the SMMNRA.
- Improve ecosystem function through promoting native shrub cover and diversity. Actions include the control of non-native invading species, active restoration to enhance shrub recovery in disturbed or degraded areas, and reduction of fire ignitions to prevent type-conversion. Success will be measured through field monitoring and remotely sensed imagery.
- These actions will be guided by the emerging understanding that landscape resilience and maximization of ecosystem services in chaparral depends on reducing human fire ignitions and encouraging the establishment and persistence of native vegetation.

In relation to ecosystem services, chaparral fuel treatment has a necessarily negative direct effect on most of them. It removes native vegetation, reduces groundwater recharge and increases local runoff, increases erosion, and reduces landscape scenic quality. These negative effects are magnified as fuel treatments become larger. However, it is important to reiterate that the usefulness and importance of fuel treatments are not realized on the lands actually treated, but in those neighboring lands that are protected from fire. In addition, if a landscape has a high probability of burning in a large, severe event, strategically located and implemented fuel treatments and prescribed fires may increase erosion, runoff, and non-native plant invasion, but they may do so at a lower magnitude and in a more controlled fashion than a wildfire (or a series of wildfires) that burns a large area under severe weather conditions (Riggan et al. 1994; Regelbrugge 2001). It is also important to note that current-day fuel treatment practices are strongly constrained by the NEPA process and more mitigations are constantly being incorporated into these practices.

In terms of the budget devoted to fuel management, over the last 3 years (2014–2016) the southern California national forests have been allocated an average annual total of $7.26 million for wildland fuels management, which is approximately one-ninth of the budget (11.4%) allocated to wildland fire suppression (internal USFS budget numbers, G. Macias, US Forest Service, pers. comm.). Each national forest allocates these funds across a broad spectrum of activities which include salary, projects, travel, and training in addition to fuel management. This level of funding is far short of what is necessary to maintain the current fuelbreak network, and ongoing Forest Service assessments in southern California are considering how to consolidate the fuelbreak network to a set of strategically effective and defendable locations that can be adequately maintained under realistic budget scenarios (T. Metzger and S. Fillmore, US Forest Service, pers. comm.).

15.3.4 Fire Management

Fire management in chaparral vegetation is focused on immediate suppression of unplanned fires across all parts of the landscape. The number of human-caused ignitions in southern California, and other chaparral areas near urban areas in California, is extraordinary and the area of fire remains consistently high even as fire readiness and suppression budgets soar and associated staff dedicated to this task expand (Safford 2007). Although early researchers and managers believed that chaparral "needs" high frequencies of fire (e.g., Hanes 1971; Biswell 1974), the weight of evidence suggests that pre-EuroAmerican settlement fire-return intervals (FRIs) were in the range of 30–100 years (mean around 50–70 years, Minnich 2001; Van de Water and Safford 2011). Considerations of the natural history and regeneration strategies of chaparral shrub species also suggest that FRIs <15 years or so are sufficient to reduce most chaparral stands to grassland (Keeley 2006). Most chaparral dominated landscapes in California (but not all of them) occur in areas that support low densities of lightning ignitions (Keeley and Fotheringham 2001; Safford and Van de Water 2014), and the majority of pre-EuroAmerican fires would have been set by Native Americans, which probably had major influence on the distribution of grasslands and shrublands in coastal California (see Chap. 4, Keeley 2002b).

Today, many areas of chaparral in southern California, and some areas elsewhere in the State, support FRIs that are near or below 20 years (Safford and Van de Water 2014). These areas are all found adjacent to human communities, where human ignitions and flashy, herbaceous fuels interact to create zones of very high fire hazard (Syphard et al. 2007b) (Fig. 15.3).

Fire management has major influences on all of the other management focus areas and all of the ecosystem services. With respect to the management priorities: for much of southern California, fire management plays a major role in promoting conservation of unburned and infrequently burned areas. Although fire suppression has had a deleterious effect on many semi-arid conifer forests in the western US by removing a formerly important ecological process, full fire suppression is a man-

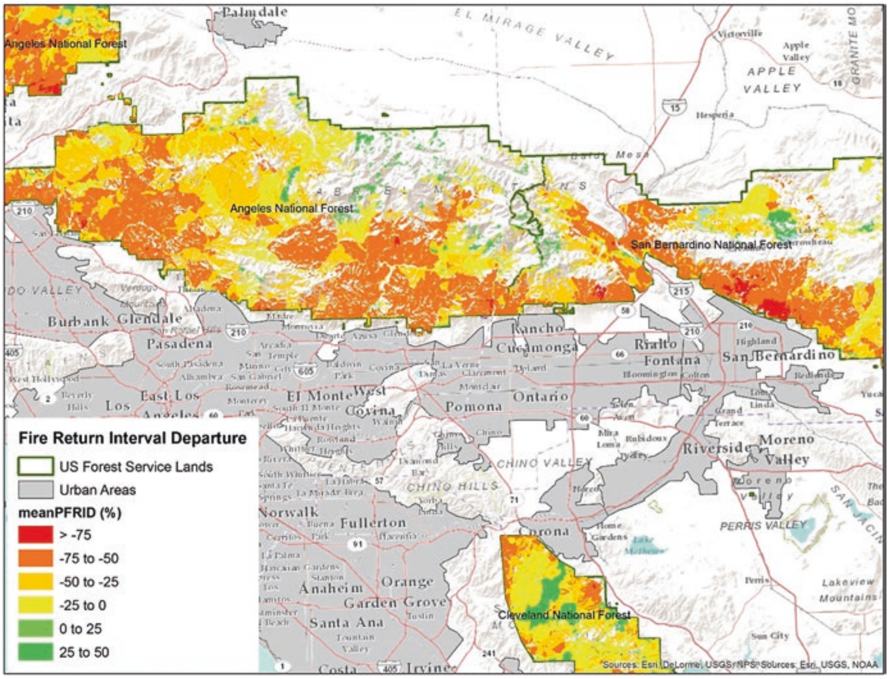

Fig. 15.3 Deviation from pre-European fire frequency in chaparral and coastal sage scrub vegetation types in southern California. MeanPFRID represents the percent by which the fire-return interval (FRI) over the last century differs from the presumed mean FRI before Euro-American settlement (55 years for chaparral, 76 for sage scrub, Van de Water and Safford 2011). Negative values indicate shrublands that are burning more frequently than under pre-EuroAmerican settlement conditions, positive values represent areas that are burning less frequently today than before settlement. As an example, the >−75% class includes those lands where the contemporary fire-return interval is <13.8 years (−[1−(13.8/55)])*100). See Safford and Van de Water (2014) for details

agement necessity in southern California chaparral, where fire frequencies are well above the natural range of variation on much of the landscape (Safford and Van de Water 2014; Keeley and Safford 2016, Fig. 15.3). Although the concept used to be derided, there is such a thing as chaparral old-growth, and it is rare and becoming rarer by the year. Such older stands support more intact soils, less stream sedimentation, more regular streamflows, fewer non-native species, and important recruitment sites for shade tolerant resprouting shrubs whose seeds are dispersed by animals (Keeley 1992).

There are some short- to medium-term negative influences of fire management on conservation, mostly at a local scale. These include soil disturbance caused by firelines created during firefighting, especially when bulldozers are used, creation of temporary roads and helispots, subsequent non-native species invasion, and illegal OHV use within these features. Fire retardant drops by aircraft also have impacts, particularly in riparian and aquatic habitats, and the burning of vegetation to reduce fuels in front of an oncoming fire will reduce vegetation cover and lead to the same impacts as fuel treatments.

In terms of recreation, fire management operations can pose hazards to people recreating in wildland areas (including increased vehicular traffic, air retardant drops, burnout operations, etc.), and sometimes such operations can also impact recreational facilities. In the sense that it impedes burning, fire suppression could be seen as having negative effects on certain postfire recreational uses of landscapes, such as postfire wildflower viewing. However, so much area burns in southern California in an average year that such impacts are more theoretical than real. Positive effects of reducing fire occurrence on the southern California landscape are myriad and these extend to recreation. Examples include protection of physical recreational infrastructure such as trails, roads, picnic and campgrounds, and avoidance of the often multi-year closures of such facilities that usually follow major fires.

Fire management effects on fuel management involve changes to chaparral fuel amounts and types. Fire occurrence will temporarily reduce fuels, while successful suppression will retain fuels. Suppression tactics can have important influences on postfire fuel management as well, i.e., temporary roads and unintentional invasion corridors as previously described. Finally, fire management influences on restoration include some negative impacts, such as the need to rehabilitate areas impacted by fire management operations, but overall the reduction of burned area and fire frequency in chaparral landscapes is the key, without which restoration success becomes nearly impossible.

Fire management in chaparral has major effects on the provision of ecosystem services. Reducing fire occurrence and burned area improves groundwater recharge and diminishes inter-seasonal and inter-annual variability in runoff; reduces flooding, soil erosion, and stream sedimentation; facilitates various recreational opportunities; protects native biodiversity; improves landscape aesthetics; and retains more carbon. At local spatial scales, and short- to medium-term temporal scales, fire management operations can also have negative effects on these services, primarily through direct impacts to vegetation, soil, and water through heavy machinery operation, fire retardant drops, and burnout operations (see Backer et al. 2004 for a more detailed discussion).

Of all of the management focus areas referenced in the management plans we reviewed, fire management is by far the most expensive priority. For example, the four southern California national forests all spend more than two-thirds of their annual budgets on fire-related expenses, and this does not include the funds that come from the national office to support the suppression of large fires that become regional or national emergencies. On the Los Padres National Forest, the percentage of the fiscal year 2015 allocated budget spent on fire relative to recreation and restoration was 74:6:2 (S. Shaw, US Forest Service, pers. comm.). Even so, in recent years fire management costs have been so high that the US Forest Service has had to routinely “borrow” funds from other management functions, a short-term fix that is creating medium- and long-term problems by diluting the agency’s capacities and accomplishments in areas other than fire suppression (USDA 2015b). In landscapes dominated by frequent-fire forest types (such as yellow pine and mixed conifer forests in the Sierra Nevada or the southern California mountains), shifting fire suppression funds to prefire fuel management and more wildland fire use is likely to pay off in lower overall cost, better ecological and ecosystem service outcomes, and less environmental damage due to severe fire (North et al. 2015). In chaparral landscapes, funding for fuel management needs to be sufficient to maintain strategically useful fuelbreaks (which it currently is not), but the very different relationship between fire and chaparral and the high level of fire risk to human lives and infrastructure means that fire suppression will necessarily remain a major focus. Enhanced focus on fire prevention and education, structure hardening and home retrofitting, and changes in community land planning are likely to have major payoffs in chaparral dominated landscapes as well (Keeley 2002a; Safford 2007; Halsey 2008).

15.3.5 Restoration

Although restoration is the management priority with the fewest mentions in the management plans we reviewed, its importance has been elevated in recent years. Current US Forest Service Region 5 guidance is to integrate principles of ecological restoration into all relevant facets of US Forest Service business (USDA 2011). In addition, California Proposition 84 (2006) provides hundreds of millions of dollars for restoration projects on state and federal lands, and restoration is an important focus area for the National Park Service, as well as on the two military bases included in our study (Table 15.1).

The growing focus on restoration is based on the understanding that ecologically intact chaparral landscapes are best for providing for and balancing the various ecosystems services that southern Californians desire from the wildlands that surround their communities. Although chaparral has historically been considered a resilient vegetation type able to quickly recover following disturbance, post-disturbance recovery of chaparral is increasingly compromised in contemporary southern California. Chaparral degradation—and loss of associated ecosystem services—is typically driven by repeat disturbance events like fire or grazing (see Chap. 12), and may be exacerbated by post-disturbance drought (Pratt et al. 2014) and atmospheric nitrogen deposition (Pasquini and Vourlitis 2010), among other things.

To illustrate the impact of some of these factors for managing chaparral resources, we combined data on climatic water deficit (Flint et al. 2013), nitrogen deposition (Fenn et al. 2010), and fire frequency (Safford et al. 2011) across three fires in the Santa Clara River watershed: the Copper (occurred in 2002), Piru (2003) and Ranch (2007) fires. In each of the input data layers (Fig. 15.4a–c) the higher the value, the more negative the conditions for chaparral. For example, higher values of climatic water deficit indicate greater stress on the vegetation, higher levels of nitrogen deposition are associated with non-native annual grass invasion and persistence, and

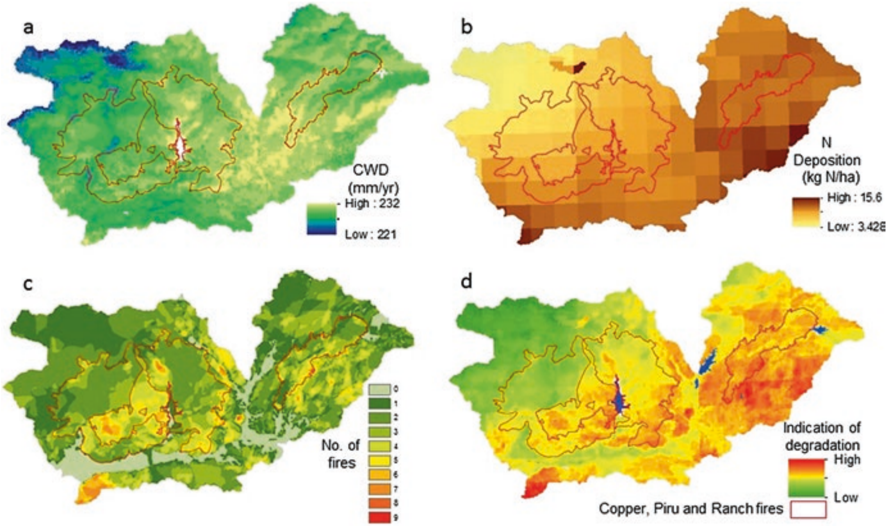

Fig. 15.4 Integration of (**a**) climatic water deficit (Flint et al. 2013), (**b**) Nitrogen deposition (Fenn et al. 2010), and (**c**) the number of fires since 1910 (Safford et al. 2011), to provide an indication of chaparral degradation (**d**) across three fires in the Santa Clara River watershed

high fire frequency has been linked with type-conversion of chaparral to non-native grasslands. The values in each of the input data layers were normalized by transforming from original units into deciles, and then summed to identify a range of degradation levels across the landscape (Fig. 15.4d). Higher degradation is indicated in the eastern part of the study area and within the southern, lower elevation regions of each of the fire perimeters, while areas in the northwest of the study area have relatively low levels of degradation.

The widespread nature of chaparral degradation and the importance of ecosystem services provided by chaparral landscapes to humans in southern California have prompted interest in chaparral restoration. While restoration of other California shrubland types, like coastal sage scrub or sagebrush steppe, has been well studied and broadly implemented, the viability of restoring chaparral is still in question (see Chap. 13). To this point, a few projects have demonstrated success in small, highly managed locations (e.g., Engel 2014), but success on the landscape scale is yet to come (see Chap. 13). To a great extent, the uncertainty in chaparral restoration comes from numerous difficult-to-control threats that thwart recovery. These include overly frequent fire, nitrogen deposition, recreational use, invasion by non-native species, and prolonged drought. Reducing the stressors that inhibit chaparral recovery is no small task, and support for this cause will require a broad understanding of the ecological, social, and economic value of chaparral ecosystems. This book is an effort in that direction.

Originally, restoration in the western United States tended to be narrowly seen as the restitution of ecosystem compositions and structures from before the period of

Euro-American settlement (Safford et al. 2012). In highly degraded landscapes like modern southern California however, such goals are unrealistic and unattainable for large portions of the landscape. Here, a landscape framework will need to be developed that permits identification of those places where traditional restorations are feasible, those places where novel conditions will need to be accommodated, and those places where a hybrid approach is most likely to succeed (Hobbs et al. 2014). In our opinion, moving forward with chaparral restoration will have more likelihood of success and gaining social support if it is approached through the lens of re-establishing ecosystem services (see Box 15.3).

With respect to the other management priorities, conservation is strongly positively influenced by restoration, except for local, largely ephemeral impacts that may result from ground-disturbing activities. Restoration has a largely positive medium- to long-term influence on recreation, since it restores aesthetic landscapes, but in the short-term it may require closure of recreation sites. The relationship between restoration and fuel and fire management is an important but complicated one. In many western US landscapes, ecological restoration is synonymous with the re-introduction of fire, but the reverse is the case in most of southern California, where fire frequencies are higher than the natural range of variation even under strict fire suppression policies (Safford and Van de Water 2014). Restoration in southern California thus requires the reduction of fire on the landscape, but this is much easier said than done. Probably the major conundrum in chaparral restoration is that most areas in major need of restoration are near human communities, which are the source of almost all fire ignitions as well as non-native, highly flammable annual grasses. In addition, restoration of tall, dense chaparral near areas of human habitation can increase fire risk, depending on the topography, weather patterns, and flammability of the local human environment. Restoration of older chaparral stands has unavoidable consequences for fire and fuel management in the form of changed fuel loading and structure.

Like conservation, restoration has primarily strongly positive influences on all of the ecosystem services referred to in the management plans we reviewed (see details of these services under Sect. 15.3.1). This is largely because the provision of many ecosystem services is generally maximized where there is intact native vegetation. These positive influences are the primary drivers behind the growing interest in chaparral restoration in southern California.

That said, like conservation and recreation, restoration receives only a small portion of the annual allocated budget in any of the management units we reviewed. The largest funding sources come from outside agency budgets, for example from California Proposition 84 funding, or funds acquired by the US Forest Service via negotiated settlements or litigation by the US Department of Justice against corporations or other entities who ignite costly wildfires. The latter source has resulted in some large allocations to select southern California watersheds, but to this point very little of the money has been spent in actually restoring chaparral, and the very short life-span of the funds (current US Forest Service policy is to use them within 3 years) means that real investment in restoration, which in highly degraded landscapes is a decades-long proposition, is nearly impossible.

15.4 Integrating Ecosystem Services into Chaparral Management

An understanding of ecosystem services, their quantity and value (see Chap. 9), can provide a framework to underpin the management of chaparral shrubland. This information can be provided by ecosystem service maps (see Box 15.3), detailing the pattern and quantity of ecosystem services across a landscape. Such maps can help spatially prioritize work, especially when there is overlap between multiple high value services and the management strategies needed to sustain them (Chan et al. 2006; Schroter and Remme 2016). This allows greater efficiencies to be achieved with limited resources, e.g., an area managed for carbon storage might also provide benefits for biodiversity and recreational use. Alternatively, maps of ecosystem services can illuminate trade-offs in natural resource management and policy decisions, for example in quantifying how vegetation removal during fuel management can impact carbon storage, biodiversity, or sediment erosion retention for a particular location.

Spatial maps of ecosystem services also provide a foundation for assessing the persistence of services under future conditions, for example, quantifying changing water runoff with a warmer, drier climate. Alternately, changes can be viewed from a demand perspective, for example the increased demand for water provision associated with growing populations and urbanized areas (Balvanera et al. 2001). Based on these findings, management decisions can be made as to what strategies will ensure the continued or increased provision of ecosystem services in the long-term.

15.4.1 Ecosystem Services and Restoration

From a broad perspective, the theory and principles of re-establishing key ecosystem components are relatively well-established, however an increasing focus on ecosystem services presents a shift in objectives in ecological restoration. Some fear an ecosystem services focus will undermine efforts to restore and conserve biodiversity, while others believe such a focus is necessary in order to guarantee human support for restoration endeavors, as well as to enable restoration efforts that occur at dimensions that are likely to actually make a difference at regional and global scales (Bullock et al. 2011; Safford et al. 2012; Alexander et al. 2016). In addition, strategies such as Payment for Ecosystem Services (PES) may present opportunities for funding conservation or restoration efforts. Despite the uncertainty and polemic in adopting a more ecosystem service-centric approach to restoration, evidence suggests an alignment between traditional principles of restoration and enhancement of ecosystem services. For example, a review of 89 studies across a range of ecosystem types showed that restoration increased biodiversity by an average of 44% while also increasing the provision of a suite of key ecosystem services (Benayas et al. 2009).

To this point, there has been minimal integration of information on ecosystem services in restoration planning and prioritization in chaparral landscapes. In general, focal areas for chaparral restoration have tended to be opportunistic and tied to habitat mitigation (see Chap. 13), stakeholder or academic/research interests, or specific funding sources, e.g., fire restoration funds allocated to a specific fire. However, integrating data on ecosystem services into decision making can contribute substantially to focusing, directing, and justifying restoration efforts.

The immediate impact of fire on chaparral and the ecosystem services it provides is substantial (see, for example, prefire compared to postfire sediment erosion in Box 15.3). However, relative to other ecosystems, healthy chaparral stands tend to be resilient to fire and recover relatively quickly. Some services, such as reduction of erosion, are greatly impacted in the first year postfire, but erosional loss of sediment from chaparral hillslopes can be down to prefire levels within 2 years of burning if vegetation recovery is normal (Wohlgemuth 2015). Postfire studies also show that chaparral shrublands generally recover their prefire biomass within about a decade (Black 1985; Bohlman et al. in press), much faster than forests burned at similar severity. With some ecosystem services, such as recreation, the rate of postfire recovery is less clear. Wildfires affect aesthetic values and recreational activities, with people tending to prefer vegetated, unburned landscapes (Hesseln et al. 1984). At the same time, the spectacular flush of wildflowers in the spring after a chaparral fire is a major attraction for botanically-inclined visitors.

In summary, when chaparral fires burn within the natural range of variation (NRV, 30–100+ years between fires), we can conclude that most ecosystem services provided by chaparral recover in a decade or less. The challenge is that much of the southern California landscape is experiencing fire at considerably higher frequencies than the NRV, and there are interacting stressors—such as nitrogen deposition and non-native plants—that further complicate the picture. Areas of degraded chaparral will necessarily provide attenuated ecosystem services. In Box 15.3 we use a recent fire from the Angeles National Forest to illustrate how data on prefire ecosystem services can be combined with information on postfire vulnerability and degradation to assist in the selection of restoration sites.

15.5 Conclusion

In this chapter we reviewed the relationships among five management focus areas on chaparral dominated public lands in southern California, as well as the relationships between these management focus areas and a suite of ecosystem services. Positive relationships among the focus areas and ecosystem services characterize situations where management actions can have multiple salutary outcomes, whereas negative relationships can help to identify situations where creative solutions are required.

Although some management focus areas have generally positive direct relationships with most other focus areas and ecosystem services (e.g., conservation and restoration), and some have generally negative direct relationships (e.g., fuel management and recreation), simple relationships were hard to find. Conservation and restoration do not benefit all segments of society, for example, and they certainly run afoul of certain economic interests.

Fuel management is a particularly complicated situation, and source of much of the tension that arises between managers and certain segments of the public in southern California and other chaparral areas. Management of chaparral fuels has negative direct effects on all of the ecosystem services we analyzed, and it runs counter to many of the other management focus areas. However, fuel management is absolutely necessary in chaparral landscapes that support human habitation, especially where such habitation has been spread across the landscape with little regard for human safety, and where the source of most fires is human ignitions. The real impact of chaparral fuel management needs to be assessed across landscapes and not in single localities, and through time and not at a given instant. From the ecological viewpoint, chaparral fuel management needs to be understood as a local resource sacrifice made in order to gain a benefit at the landscape scale. Because of its environmental impacts, such work must be carried out carefully and after comprehensive strategic analysis of the short- and long-term, local and regional impacts (Syphard et al. 2011). Careful, environmentally conscious fuel treatment planning and implementation is becoming progressively more common in chaparral landscapes. We describe one of these recent analyses in and around the Santa Monica Mountains National Recreation Area in Box 15.2.

Another, similar analysis—the so-called Strategic Fuelbreak Assessment—is underway on the four national forests in southern California. The overall objective of the analysis is to identify the fuelbreak system with "the highest probability of assisting fire suppression operations and maximizing the potential for long term maintenance." The desired outcome is a fuelbreak network that is as much meat and as little fat as possible, one that supports fuel treatments that are strategic and necessary for fire control and also maintainable in the long run. Current fuel treatments that are neither necessary nor maintainable will be allowed to revert to natural conditions. Although the analysis does not explicitly incorporate environmental variables, the process will provide an opportunity to employ the ecosystem service viewpoint in prioritizing and implementing restoration actions on those lands that will be removed from the network.

Recreation is the other area of major tension in chaparral management. Recreational use of chaparral lands, especially in southern California and the San Francisco Bay Area, is beginning to overwhelm both management agencies and ecosystems. Federal and state budgets for recreation management are small, and compounding the problem is the lack of philosophical coherence within the recreation community, where notable feuds exist between various subpopulations. The recent naming of two national monuments on lands of mixed US Forest Service and Bureau of Land Management jurisdiction in southern California (San Gabriel Mountains NM and Sand to Snow NM) was driven to a great extent by popular dismay at the inability of current recreational and educational opportunities to meet demand. Given that these lands are already heavily impacted by human use and

Box 15.3 Prioritizing Areas for Restoration in the Copper Fire
Emma C. Underwood and Allan D. Hollander

When the Copper Fire burned 7284 ha (18,000 acres) of chaparral in 2002 it had numerous impacts: it damaged recreation facilities, destroyed habitat for threatened and endangered plant species, and increased erosion from sub-catchments which impacted roads and aquatic habitats (Fig. 15.5). This case study illustrates how ecosystem service data can help prioritize sites for post-fire restoration efforts with the intent of maximizing the re-establishment of native chaparral while simultaneously enhancing the long-term provision of ecosystem services. We used a two-step process which first assessed the pre-fire quantity and pattern of four ecosystem services (water runoff, groundwater recharge, biodiversity, and carbon storage). Second, we assessed the postfire vulnerability of the landscape and the suitability for restoration by identifying: (1) locations where restoration efforts could help prevent high levels of sediment erosion, and (2) locations offering more suitable conditions for regeneration based on their fire history.

Identifying areas with high provision of ecosystem services

Data on each of the four ecosystem services were extracted from spatial data generated for a broader, southern California study area (see Chap. 9 for details of methods). Prefire patterns of water runoff were relatively high in the

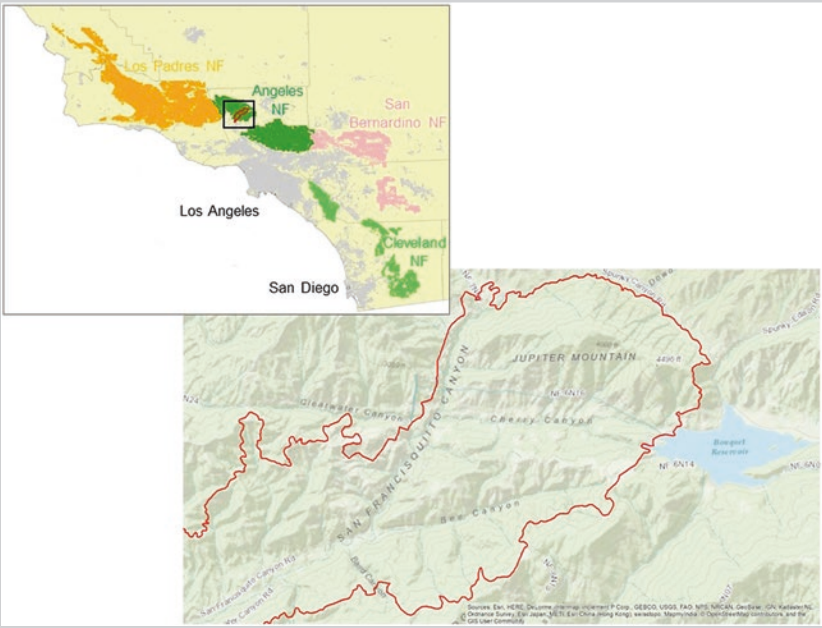

Fig. 15.5 Location of the Copper Fire in the Angeles National Forest (upper map) and topographic features of the upper Copper Fire perimeter referred to in the case study

upper northwestern corner of the Copper and lowest at the southern end (Fig. 15.6a). Prefire patterns of groundwater recharge were relatively high along the base of Bee Canyon and the perimeter on the western side of San Francisquito Canyon (Fig. 15.6b). The mean annual recharge within the fire perimeter was 66 mm/year and runoff was 54 mm/year. Patterns of biodiversity (Fig. 15.6c) represent an irreplaceability index with higher values indicating areas of greater importance for meeting conservation goals for each conservation target. These targets included sensitive species, natural vegetation types, landscape connectivity, Watershed Condition Class, and streams for the federally endangered, southern California steelhead trout. Locations with higher irreplaceability values were in the lower portion of the Copper Fire on the western side of San Francisquito Canyon. The prefire estimate of carbon storage for the Copper Fire used the Enhanced Vegetation Index (EVI)

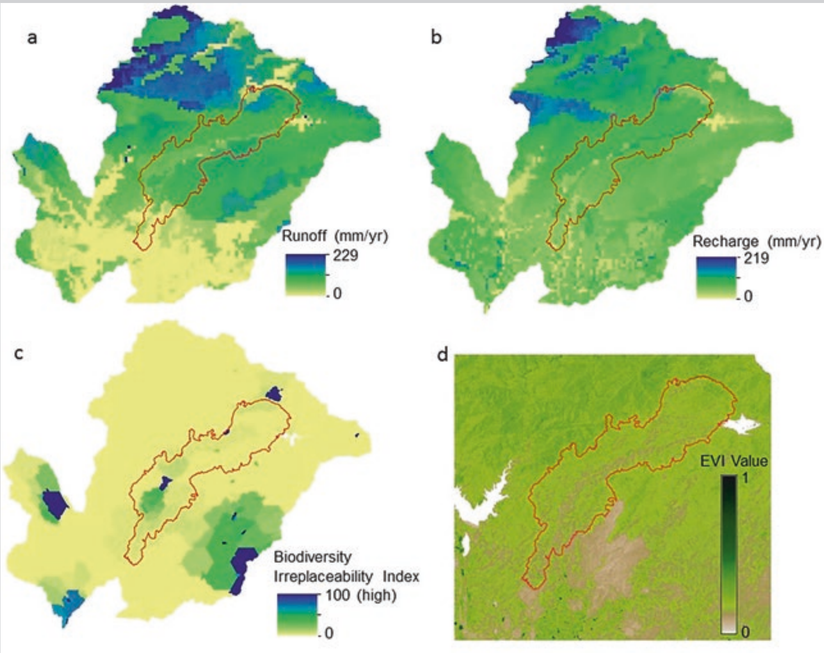

Fig. 15.6 Prefire patterns of ecosystem services in the hydrological units (HUC12) that intersect with the Copper Fire (red perimeter) shown in their original mapping units; (**a**) water runoff (270 m resolution [18 acres]), (**b**) groundwater recharge (270 m), (**c**) biodiversity (4.04-6475 ha [10–16,000 acre] polygons [minimum mapping unit 200 m]), and (**d**) the Enhanced Vegetation Index (30 m or 0.2 acres) from May 2002 used as a proxy for carbon storage (see Chap. 9 for details)

from Landsat TM imagery as a proxy. EVI values ranging from 0 to 1 prefire (May 2002) showed relatively uniform values within the fire perimeter, with lower values indicating less vegetation along Bee Canyon and San Francisquito Canyon Road, and slightly higher values in the northern tip of the fire perimeter associated with the higher elevations of Jupiter Mountain (1219 m or 4000 ft) (Fig. 15.6d).

We normalized the values in each of these services by converting from their original units to deciles, and then summed the four layers to identify prefire priorities for the provision of ecosystem services (Fig. 15.7). For the purposes of this case study, we assumed that areas with highest values of runoff, recharge, biodiversity, and biomass (carbon storage) contribute most to the provisioning of services and therefore should be priorities for restoration. High value areas of these four services combined are found in the northern, higher elevation end of the fire perimeter, around Jupiter Mountain, and along the western edge of the San Francisquito Canyon. The (summed) ecosystem service values decrease in the southern, lower elevation portion of the analysis area toward the city of Valencia.

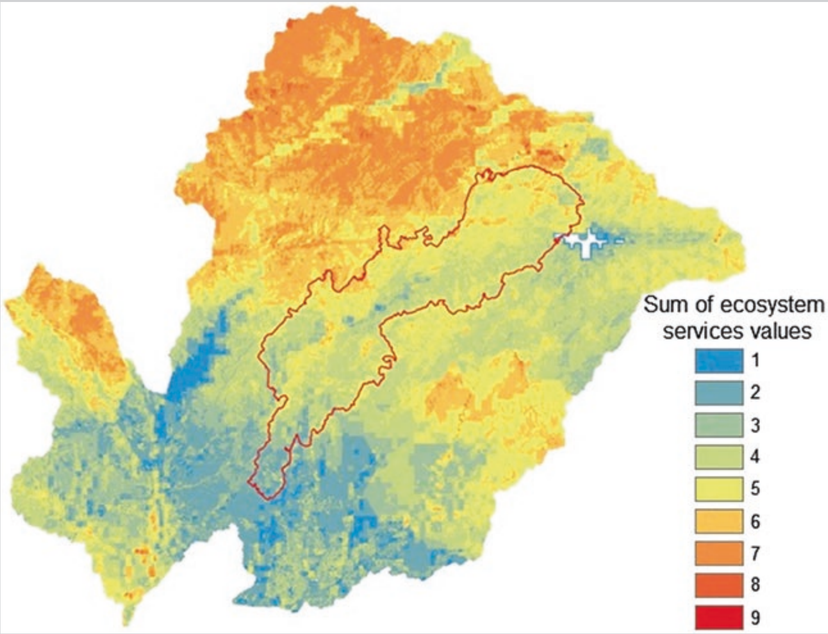

Fig. 15.7 Summation of the values of four ecosystem services across the Copper Fire (red perimeter)

Assessing Postfire Vulnerability

Evaluating the effects of fire on sediment erosion

To identify areas of high erosion vulnerability postfire we determined which subcatchments had the greatest change in sediment yield between prefire and immediately postfire. Sediment erosion was modeled using GeoWEPP software (Renschler 2003) under prefire and immediate postfire conditions. Prefire erosion was generally less than 5 tons/ha/year. (Fig. 15.8), compared to postfire where the majority of subcatchments ranged from 5 to 20 tons/ha/year. By visually inspecting the percent change between prefire and postfire sediment erosion we identified a threshold of 300% to provide a reasonably small area of the fire for the purposes of this case study. In practice, this threshold could be identified with resource managers familiar with the landscape. These areas of high erosion vulnerability were overlaid onto the map of ecosystem services provision (Fig. 15.9).

Assessing postfire regeneration suitability

Fire history was used to indicate sites within the Copper Fire that may be susceptible to degradation and type-conversion to annual non-native species. The current Fire-Return Interval (FRI) within the perimeter ranged from 8 to 53 years (Safford et al. 2011), while the natural range of variation in FRI for chaparral and serotinous conifer is 30–90 years (Van de Water and Safford 2011). For the purposes of illustration, we used a FRI of 21 years or less to indicate areas of low suitability for chaparral to recover postfire (Fig. 15.9). Other layers, like nitrogen deposition (which increases annual grass invasion) and climatic water deficit, could also be combined with FRI to help determine the likelihood of recovery postfire (see Fig. 15.4).

Combining ecosystem service values and data on vulnerability and suitable conditions can provide a valuable contribution to guiding the prioritization of chaparral restoration postfire, given limited resources and personnel. Determining how to weight the importance of these layers and assessing their

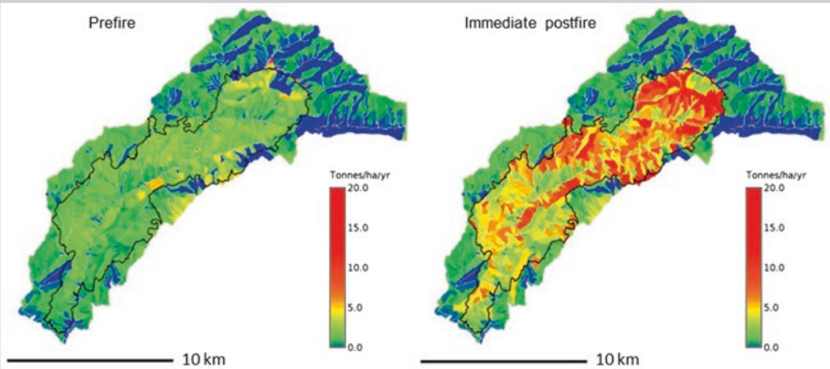

Fig. 15.8 Sediment erosion yield (tons/ha/year) by subcatchment within the Copper Fire under prefire and immediate postfire conditions

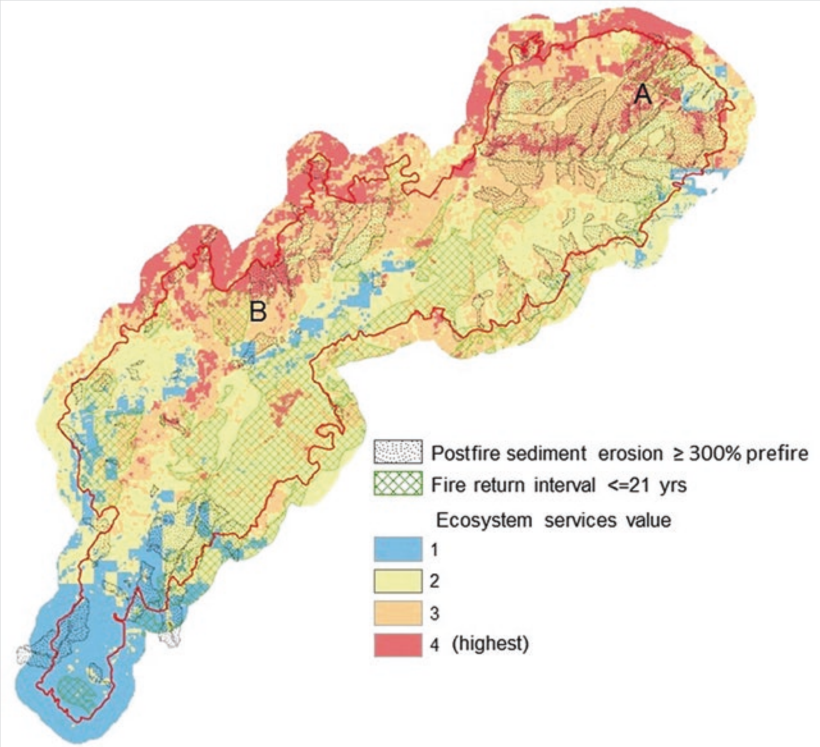

Fig. 15.9 Summation of the values of four ecosystem services condensed into four classes using natural breaks for ease of interpretation, overlain with areas where sediment erosion postfire is modeled to be ≥300% greater than prefire erosion, and areas where the fire-return interval is <=21 years. Label A (high service values and high erosion postfire) and Label B (high service values and high fire-return intervals) indicate possible locations for restoration activities that are discussed in the text

combined impact on the landscape depends on the restoration goals at the site and direction from the land management plan for the national forest, among other things.

In this illustration using the Copper Fire, we identified two locations with similar ecosystem service values but different erosion and fire characteristics. The first focused on the area around Jupiter Mountain (labelled 'A' in Fig. 15.9), where high levels of the four ecosystem services and high postfire erosion suggest a high potential payoff for restoration actions. The fire-return interval in this area is longer than the 21-year threshold, which suggests a greater probability of restored chaparral vegetation surviving long enough to develop into a resilient state. Area B is another area of high ecosystem service provision (Fig. 15.9), with some areas of high erosion, but successful restoration here could be threatened by higher fire frequencies given the current FRI

<21 years. In either site, some level of fire protection, fuels management, and non-native plant treatment is likely necessary if restoration is to be successful in the medium- to long-term.

Other data that could be included to prioritize areas for restoration include recreation values (e.g., trails, campsites), areas of cultural importance, or aesthetics. In addition, integrating maps of ecosystem services under future climate scenarios, or climatic data such as climatic water deficit, can indicate whether focal restoration areas selected today will support similar conditions for restored species in the long-term.

other anthropogenic stressors, an objective, ecosystem service-based approach will be best positioned to clearly compare the costs and benefits of different management alternatives.

Our case studies highlight the need to scale up restoration efforts from the local to the landscape level, as well as the need to better integrate ecosystem services into planning and prioritizing management actions. This is particularly important in southern California and the San Francisco Bay Area, where tens of millions of people live in close proximity to public lands, and there is huge (often unacknowledged) demand for the ecosystem benefits that these natural habitats provide, such as recreation and educational opportunities, water provision, protection from floods and debris flows, aesthetic landscapes, and the remarkable biodiversity for which coastal California is renowned. One of the key benefits of integrating ecosystem services into planning and management decision making is that it necessitates a broader perspective over longer timeframes and larger areas. For example, although fuel management negatively affects many ecosystem services at the location of the fuel treatment, under many conditions these features can help to stop undesired wildfires, protecting human lives and infrastructure but also ensuring continued provision of important ecosystem services in off-site habitats that are sensitive to frequent burning. The negative ecological impacts of a strategic fuelbreak network that is the product of a careful, holistic planning process are also likely to be much less in sum than the impacts of a large wildfire under severe weather conditions. The ecosystem service viewpoint also provides an impetus to develop multi-partner collaborations, and to integrate ecological and socio-economic aspects into chaparral management. This viewpoint will be particularly valuable in cases where management focus areas conflict—such as between conservation and recreation or conservation and fuel management—and budgets and resources are limited.

References

Alexander, S., J. Aronson, O. Whaley, and D. Lamb. 2016. The relationship between ecological restoration and the ecosystem services concept. Ecology and Society 21:34.

Baas, J. M., A. Ewert, and D. J. Chavez. 1993. Influence of ethnicity on recreation and natural environment use patterns: managing recreation sites for ethnic and racial diversity. Environmental Management 17:523-539.

Backer, D. M., S. E. Jensen, and G. R. McPherson. 2004. Impacts of fire suppression activities on natural communities. Conservation Biology 18:937-946.

Balvanera, P., G. C. Daily, P. R. Ehrlich, T. H. Ricketts, S. Bailey, S. Kark, C. Kremen, and H. Prereira. 2001. Conserving biodiversity and ecosystem services. Science 291:2047-2048.

Beier, P., K. L. Penrod, C. Lulke, W. D. Spencer, and C. Cabañero. 2006. South Coast missing linkages: restoring connectivity to wildlands in the largest metropolitan area in the USA. Pages 555-586 *in* K. R. Crooks and M. Sanjayan, editors. Connectivity conservation. Cambridge University Press, Cambridge, UK.

Benayas, J. M. R., A. C. Newton, A. Diaz, and J. M. Bullock. 2009. Enhancement of biodiversity and ecosystem services by ecological restoration: a meta-analysis. Science 325:1121-1124.

Bentley, J. R. 1967. Conversion of chaparral to grassland: techniques used in California. Agriculture Handbook 328. Washington, D.C., USA, USDA Forest Service.

Biswell, H. H. 1974. Effects of fire on chaparral. Pages 321-364 *in* T. T. Kozlowski, editor. Fire and ecosystems. Academic Press, New York, New York, USA.

Black, C. H. 1985. Biomass, nitrogen, and phosphorus accumulation over a southern California fire cycle chronosequence. Pages 445-458 *in* J. D. Tenhunen, F. M. Catarino, O. L. Lange, and W. C. Oechel, editors. Plant response to stress functional analysis in Mediterranean ecosystems. Springer-Verlag, Berlin, Germany.

Bohlman, G. N., E. C. Underwood, and H. D. Safford. Estimating biomass in California's chaparral and coastal sage scrub shrublands. Madroño, in press.

Bricker, K. S., D. J. Chavez, and W. W. Hendricks. 2008. Recreation and fire management in the urban National Forests: a study of manager perspectives. Pages 69-86 *in* D. J. Chavez, J. D. Absher, and P. L. Winter, editors. Fire social science research from the Pacific Southwest Research Station: studies supported by National Fire Plan funds. General Technical Report PSW-GTR-2009. USDA Forest Service, Pacific Southwest Research Station, Albany, California, USA.

Bullock, J. M., J. Aronson, A. C. Newton, R. F. Pywell, and J. M. R. Benayas. 2011. Restoration of ecosystem services and biodiversity: conflicts and opportunities. Trends in Ecology and Evolution 26:541-549.

Burns, C., and J. Sauer. 1992. Resistance by natural vegetation in the San Gabriel Mountains of California to invasion by introduced conifers. Global Ecology and Biogeography Letters 2:46-51.

Butsic, V., A. D. Syphard, A. Bar-Massada, and J. E. Keeley. 2016. Can private land conservation reduce wildfire risk to homes? A case study in San Diego County, California, USA. Landscape and Urban Planning 157:161-169.

Cable, D. R. 1975. Range management in the chaparral type and its ecological basis: the status of our knowledge. Research Paper RM-RP-155. Fort Collins, Colorado, USA, USDA Forest Service, Rocky Mountain Forest and Range Experiment Station.

Cermak, R. W. 2005. Fire in the forest. A history of fire control on the National Forests in California, 1898-1956. Publication R5-FR-003. USDA Forest Service, Pacific Southwest Region, Vallejo, California, USA.

Chan, K. M. A., M. R. Shaw, D. R. Cameron, E. C. Underwood, and G. C. Daily. 2006. Conservation planning for ecosystem services. PLoS Biology 4:1238-2152.

Conard, S. G., and D. R. Weise. 1998. Management of fire regime, fuels, and fire effects in southern California chaparral: lessons from the past and thoughts for the future. Pages 342-350 *in*

T. L. Pruden, and L. A. Brennan, editors. Tall timbers fire ecology conference proceedings, no. 20. Tall Timbers Research Station, Tallahassee, Florida, USA.

Corbett, E. S., and R. P. Crouse. 1968. Rainfall interception by annual grass and chaparral. Research Paper PSW-RP-48. Berkeley, California, USA, USDA Forest Service, Pacific Southwest Forest and Range Experiment Station.

Corbett, E. S., and R. M. Rice. 1966. Soil slippage increased by brush conversion. Research Note PSW-128. Berkeley, California, USA, USDA Forest Service, Pacific Southwest Forest and Range Experiment Station.

County of Los Angeles. 2016. Vegetation Management Program live fuel moisture 1981-2017, all areas, all fuels - chamise, ceanothus, sages, sagebrush. County of Los Angeles Fire Department, Forestry Division, Vegetation Management Unit, Pacoima, California, USA. http://www.fire.lacounty.gov/lfm/LFMAllArea1.pdf

Czech, B., P. Krausman, and P. Devers. 2000. Economic associations among causes of species endangerment in the United States. BioScience 50:593-601.

Dobson, A. P., J. P. Rodriguez, W. M. Roberts, and D. S. Wilcove. 1997. Geographic distribution of endangered species in the United States. Science 275:550-553.

Engel, M. D. 2014. The feasibility of chaparral restoration on type-converted slopes. Thesis. California State University, San Bernardino, California, USA.

Fenn, M. E., E. B. Allen, S. B. Weiss, S. Jovan, L. H. Geiser, G. S. Tonnesen, R. F. Johnson, L. E. Rao, B. S. Gimeno, F. Yuan, T. Meixner, A. Bytnerowicz. 2010. Nitrogen critical loads and management alternatives for N-impacted ecosystems in California. Journal of Environmental Management 91:2404-2423.

Flint, L. E., A. L. Flint, J. H. Thorne, and R. Boynton. 2013. Fine-scale hydrologic modeling for regional applications: the California Basin Characterization Model development and performance. Ecological Processes 2:25-46.

FRAP [Fire Resouce and Assesment Program], California Department of Forestry and Fire Protection. 2014. California fire perimeter geodatabase, calendar year 2013. http://frap.fire.ca.gov/data/frapgisdata-sw-fireperimeters_download

Halsey, R. W. 2008. Fire, chaparral, and survival in southern California. Second edition. Sunbelt Publications, San Diego, California, USA.

Hanes, T. L. 1971. Succession after fire in the chaparral of southern California. Ecological Monographs 41:27-52.

Hartley, M. S. 1986. An analysis of recreation management on southern California National Forests. USDA Forest Service, Pacific Southwest Region, California, USA. https://www.fs.fed.us/psw/publications/hartley/hartley_papers.pdf

Havlick, D. 2002. No place distant: roads and motorized recreation on America's public lands. Island Press, Washington, D.C., USA.

Hesseln, H., J. B. Loomis, and A. González-Cabán. 1984. Comparing the economic effects of fire on hiking demand in Montana and Colorado. Journal of Forest Economics 10:21-35.

Hobbs, R. J, E. Higgs, C. M. Hall, P. Bridgewater, F. S. Chapin III, E. C. Ellis, J. J. Ewel, L. M. Hallett, J. Harris, K. B. Hulvey, S. T. Jackson, P. L. Kennedy, C. Kueffer, L. Lach, T. C. Lantz, A. E. Lugo, J. Mascaro, S. D. Murphy, C. R. Nelson, M. P. Perring, D. M. Richardson, T. R. Seastedt, R. J. Standish, B. M. Starzomski, K. N. Suding, P. M. Tognetti, L. Yakob, and L. Yung. 2014. Managing the whole landscape: historical, hybrid, and novel ecosystems. Frontiers in Ecology and the Environment 12:557-564.

Jin, Y., J. T. Randerson, N. Faivre, S. Capps, A. Hall, and M. L. Goulden. 2014. Contrasting controls on wildland fires in southern California during periods with and without Santa Ana winds. Journal of Geophysical Research: Biogeosciences 119:432-450.

Kaczynski, A. T., and J. L. Crompton. 2006. Financing priorities in local governments: where do park and recreation services rank? Journal of Park and Recreation Administration 24:84-103.

Keeley, J. E. 1992. Recruitment of seedlings and vegetative sprouts in unburned chaparral. Ecology 73:1194-1208.

Keeley, J. E. 2002a. Fire management of California shrubland landscapes. Environmental Management 29:395-408.

Keeley, J. E. 2002b. Native American impacts on fire regimes of the California coast ranges. Journal of Biogeography 29:303-320.

Keeley, J. E. 2006. South Coast Bioregion. Pages 350-390 *in* N. G. Sugihara, J. W. van Wagtendonk, K. E. Shaffer, J. Fites-Kaufman, and A. E. Thode, editors. Fire in California's ecosystems. University of California Press, Berkeley, California, USA.

Keeley, J. E., and T. J. Brennan. 2012. Fire driven alien invasion in a fire-adapted ecosystem. Oecologia 69:1043-1052.

Keeley, J. E., C. J. Fotheringham, and M. Morais. 1999. Reexamining fire suppression impacts on brushland fire regimes. Science 284:1829-1832.

Keeley, J. E., and C. J. Fotheringham. 2001. Historic fire regime in southern California shrublands. Conservation Biology 15:1536-1548.

Keeley, J. E., and C. J. Fotheringham. 2003. Impact of past, present, and future fire regimes on North American Mediterranean shrublands. Pages 218-262 in T. T. Veblen, W. L. Baker, G. Montenegro, and T. W. Swetnam, editors. Fire and climatic change in temperate ecosystems of the western Americas. Springer, New York, New York.

Keeley, J. E., C. J. Fotheringham, and M. Moritz. 2004. Lessons from the October 2003 wildfires in southern California. Journal of Forestry 102:26-31.

Keeley, J. E., H. D. Safford, C. J. Fotheringham, J. Franklin, and M. A. Moritz. 2009. The 2007 Southern California wildfires: lessons in complexity. Journal of Forestry 107:287-296.

Keeley, J. E., and H. D. Safford. 2016. Fire as an ecosystem process. Pages 27-45 *in* H. A. Mooney and E. Zavaleta, editors. Ecosystems of California. University of California Press, Berkeley, California, USA.

Kinney, A. 1888. The forests of Los Angeles, San Diego, and San Bernardino counties, California. Report on the forest conditions in the Rocky Mountains and other papers. Government Printing Office, Washington, D.C., USA.

Klein, A. M., C. Brittain, S. D. Hendrix, R. Thorp, N. Williams, and C. Kremen. 2012. Wild pollination services to California almond rely on semi-natural habitat. Journal of Applied Ecology 49:723-732.

Knight, R. L., and K. J. Gutzwiller. 1995. Wildlife and recreationists. Coexistence through management and research. Island Press, Washington, D.C., USA.

Kremen, C., N. M. Williams, R. L. Bugg, J. P. Fay, and R. W. Thorp. 2004. The area requirements of an ecosystem service: crop pollination by native bee communities in California. Ecology Letters 7:1109-1119.

Lee, T. H. 2011. How recreation involvement, place attachment and conservation commitment affect environmentally responsible behavior. Journal of Sustainable Tourism 19:895-915.

LPFW [Los Padres Forest Watch]. 2016. Forest in the crosshairs: the environmental and health impacts of target shooting in the Los Padres National Forest. Los Padres Forest Watch, Santa Barbara, California, USA. http://lpfw.org/wp-content/uploads/2016/03/Forest-in-the-Crosshairs-Final-for-web.pdf

Luke, C., K. Penrod, C. R. Cabañero, P. Beier, W. Spencer, and S. Shapiro. 2004. A linkage design for the Santa Ana-Palomar Mountains connection. San Diego State University Field Stations Program, San Diego, California and South Coast Wildlands, Idyllwild, California, USA. http://www.scwildlands.org/reports/SCML_SantaAna_Palomar.pdf

Macey, A., and J. Gilligan. 1961. Man, fire and chaparral: a conference on southern California wildland research problems. University of California Conference Center at Lake Arrowhead, February 10-11, 1961. Agricultural Publication, Berkeley, California, USA.

McIntyre, D. L., and J. R. Weeks. 2002. Environmental impacts of illegal immigration on the Cleveland National Forest in California. The Professional Geographer 54:392-405.

Merriam, K. E., J. E. Keeley, and J. L. Beyers. 2006. Fuel breaks affect nonnative species abundance in Californian plant communities. Ecological Applications 16:515-527.

Minnich, R. A. 1983. Fire mosaics in southern California and northern Baja California. Science 219:1287-1294.

Minnich, R. A. 2001. An integrated model of two fire regimes. Conservation Biology 15:1549-1553.

Moore, R. L. 1994. Conflicts on multiple-use trails: synthesis of the literature and state of the practice. US Department of Transportation, Federal Highways Administration and National

Recreational Trails Advisory Committee, Washington, D.C., USA. http://ntl.bts.gov/lib/6000/6300/6341/Conflicts.pdf

Moritz, M. A., J. E. Keeley, E. A. Johnson, and A. A. Schaffner. 2004. Testing a basic assumption of shrubland fire management: how important is fuel age? Frontiers in Ecology and the Environment 2:67-72.

Morrison, S. A., and W. M. Boyce. 2008. Conserving connectivity: some lessons from mountain lions in southern California. Conservation Biology 23:275-285.

Muir, J. 1918. Steep trails. Houghton-Mifflin, Boston, Massachusetts, USA.

North, M. P., S. L. Stephens, B. M. Collins, J. K. Agee, G. Aplet, J. F. Franklin, and P. Z. Fulé. 2015. Reform forest fire management. Science 349:1280-1281.

NPS [National Park Service]. 2015. Foundation document Santa Monica Mountains National Recreation Area. May 2015. US Department of Interior, National Park Service, Santa Monica Mountains, Thousand Oaks, California, USA.

Pasquini, S. C., and G. L. Vourlitis. 2010. Post-fire primary production and plant community dynamics in chaparral stands exposed to varying levels of nitrogen deposition. Journal of Arid Environments 74:310-314.

Patric, J. H, and T. L. Hanes. 1964. Chaparral succession in a San Gabriel Mountain area of California. Ecology 45:353-360.

Pillsbury, A. F. 1963. Principles for the management of steep chaparral lands undergoing urbanization in the city of Los Angeles, City of Los Angeles Office of Civil Defense, Los Angeles, California, USA.

Plummer, F. G. 1911. Chaparral. Studies in the dwarf forests, or elfin-wood, of southern California. Bulletin 85, US Department of Agriculture, Forest Service. Washington, DC, USA.

Pollak, D. 2001a. Natural Community Conservation Planning. The origins of an ambitious experiment. California Research Bureau, Sacramento, California, USA.

Pollak, D. 2001b. The future of habitat conservation? The NCCP experience in southern California. California Research Bureau, Sacramento, California, USA.

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

Prestemon, J. P., T. J. Hawbaker, M. Bowden, J. Carpenter, M. T. Brooks, K. L. Abt, R. Sutphen, and S. Scranton. 2013. Wildfire ignitions: a review of the science and recommendations for empirical modeling. General Technical Report SRS-GTR-171. Ashville, North Carolina, USA, USDA Forest Service, Southern Research Station.

Rahn, M. 2009. Report. Wildfire impact analysis. San Diego State University, San Diego, California, USA. http://newscenter.sdsu.edu/sdsu_newscenter/images/rahn2009fireanalysis.pdf

Reed, S. E. and A. M. Merenlender. 2008. Quiet, nonconsumptive recreation reduces protected area effectiveness. Conservation Letters 1:146-154.

Regelbrugge, J. C. 2001. Role of prescribed burning in the management of chaparral ecosystems in southern California. Pages 19-26 *in* J. E. Keeley, M. B. Keeley, and C. J. Fotheringham, editors. Second interface between ecology and land development in California. Open-File Report 00–62, US Geological Survey, Sacramento, California, USA.

Riggan, P. J. and P. H. Dunn. 1982 Harvesting chaparral biomass for energy- an environmental assessment. General Technical Report PSW-GTR-58. USDA Forest Service, Pacific Southwest Forest and Range Experimental Station, Berkeley, California, USA.

Riggan, P. J., S. E. Franklin, J. A. Brass, and F. E. Brooks. 1994. Perspectives on fire management in Mediterranean ecosystems of southern California. Pages 140–162 *in* J. M. Moreno and W. C. Oechel, editors. The role of fire in Mediterranean type ecosystems. Springer-Verlag, New York, New York, USA.

Renschler, C. S. 2003. Designing geo-spatial interfaces to scale process models: the GeoWEPP approach. Hydrological Processes 17:1005-1017.

Riverside County. 2003. Western Riverside County multiple species habitat conservation plan. http://www.rctlma.org/Portals/0/mshcp/volume1/sec1.html#1.1

Safford, H. D. 2007. Man and fire in Southern California: doing the math. Fremontia 35:25-29.

Safford, H. D., G. Hayward, N. Heller, and J. A. Wiens. 2012. Climate change and historical ecology: can the past still inform the future? Pages 46-62 *in* J. A. Wiens, G. Hayward, H. D. Safford, and C.M. Giffen, editors. Historical environmental variation in conservation and natural resource management. John Wiley & Sons, New York, New York, USA.

Safford, H. D., K. Van de Water, and D. Schmidt. 2011. California Fire Return Interval Departure (FRID) map, 2010 version. USDA Forest Service, Pacific Southwest Region and The Nature Conservancy California. http://www.fs.fed.us/r5/rsl/clearinghouse/r5gis/frid/

Safford, H. D., and K. M. Van de Water. 2014. Using Fire Return Interval Departure (FRID) analysis to map spatial and temporal changes in fire frequency on National Forest lands in California. Research Paper PSW-RP-266, USDA Forest Service, Pacific Southwest Research Station, Albany, California, USA.

Schroter, M., and R. P. Remme. 2016. Spatial prioritisation for conserving ecosystem services: comparing hotspots with heuristic optimisation. Landscape Ecology 31:431-450.

Soulé, M. E. 1985. What is conservation biology? BioScience 35:727-274.

State of California. 1981. Hungry Valley State Vehicular Recreation Area general plan, Sacramento, California, USA, California Department of Parks and Recreation. http://www.parks.ca.gov/?page_id=21299

State of California. 2002. Mount San Jacinto State Park general plan. California Department of Parks and Recreation Southern Service Center, San Diego, California, USA. http://www.parks.ca.gov/?page_id=21299

State of California. 2015. Cuyamaca Rancho State Park general plan and environmental impact report. California Department of Parks and Recreation Southern Service Center, San Diego, California, USA. http://www.parks.ca.gov/?page_id=21299

Stein, B. A., L. S. Kutner, and J. S. Adams. 2000. Precious heritage: the status of biodiversity in the United States. Oxford University Press, New York, New York, USA.

Stephenson, J. R., and G. M. Calcarone. 1999. Southern California mountains and foothills assessment. General Technical Report PSW-GTR-175. Albany, California, USA, USDA Forest Service, Pacific Southwest Research Station.

Syphard, A. D., K. C. Clarke, and J. Franklin. 2007a. Simulating fire frequency and urban growth in southern California coastal shrublands, USA. Landscape Ecology 22:431-455.

Syphard, A. D., J. E. Keeley, and T. J. Brennan. 2011. Comparing the role of fuel breaks across southern California national forests. Forest Ecology and Management 261:2038-2048.

Syphard, A. D., V. C. Radeloff, J. E. Keeley, T. J. Hawbaker, M. K. Clayton, S. I. Stewart, and R. B. Hammer. 2007b. Human influence on California fire regimes. Ecological Applications 17:1388-1402.

Syphard, A. D., V. C. Radeloff, N. S. Keuler, R. S. Taylor, T. J. Hawbaker, S. I. Stewart, and M. K. Clayton. 2008. Predicting spatial patterns of fire on a southern California landscape. International Journal of Wildland Fire 17:602-613.

Thomas, J. W. 1996. Forest Service perspective on ecosystem management. Ecological Applications 6:703-705.

Tyrrel, R. R. 1982. Chaparral in southern California. Pages 22-26 *in* C. E. Conrad, and W. C. Oechel, technical coordinators. Proceedings of the symposium on dynamics and management of Mediterranean-type ecosystems. General Technical Report PSW-GTR-58. USDA Forest Service, Pacific Southwest Forest and Range Experiment Station, Berkeley, California, USA.

USAF [US Air Force]. 2011. Integrated natural resources management plan, plan period 2011-2015. US Air Force, Vandenberg Air Force Base, California, USA. www.dtic.mil/cgi-bin/GetTRDoc?AD=ADA550681

USDA [US Department of Agriculture]. 2005. Southern California National Forests land management plan. USDA Forest Service, Vallejo, California, USA. http://www.fs.usda.gov/Internet/FSE_DOCUMENTS/fsbdev7_007721.pdf

USDA [US Department of Agriculture]. 2011. Region 5 ecological restoration leadership intent. USDA Forest Service, Pacific Southwest Region, Vallejo, California, USA. https://www.fs.usda.gov/Internet/FSE_DOCUMENTS/stelprdb5351674.pdf

USDA [US Department of Agriculture]. 2015a. The rising cost of wildfire operations: effects on the Forest Service's nonfire work. USDA Forest Service, Washington, D.C., USA. https://www.fs.fed.us/sites/default/files/2015-Rising-Cost-Wildfire-Operations.pdf

USDA [US Department of Agriculture]. 2015b. San Gabriel National Monument draft land and resource management plan. USDA Forest Service, Angeles National Forest, Arcadia, California, USA.

USDA [US Department of Agriculture]. 2015c. Fire-return interval departure (FRID) geodatabase, calendar year 2014. http://www.fs.usda.gov/detail/r5/landmanagement/gis/?cid=STELPRDB5327836

USDI [US Department of the Interior]. 2002. Santa Monica Mountains National Recreation Area general management plan and environmental impact statement. US Department of the Interior, National Park Service, Calabasas, California, USA. https://www.nps.gov/samo/learn/management/gmp-general-management-plan-documents.htm

USDI and USDA [US Department of the Interior and US Department of Agriculture]. 2004. Santa Rosa and San Jacinto Mountains National Monument final management plan and record of decision, North Palm Springs, California, USA, US Department of the Interior, Bureau of Land Management, and USDA Forest Service. http://www.blm.gov/ca/st/en/prog/nlcs/SantaRosa_SanJacintoMtns_NM/management_plan.html

USDI [US Department of the Interior]. 2015. Channel Islands National Park final general management plan/wilderness study/environmental impact statement. US Department of the Interior, National Park Service, Ventura, California, USA. https://www.nps.gov/chis/learn/management/general-management-plan.htm

USMC [US Marine Corps]. 2012. Camp Pendleton integrated natural resources management plan. US Marine Corps, Camp Pendleton, California, USA. http://www.pendleton.marines.mil/Staff-Agencies/Environmental-Security/Natural-Resources-Management-Plan/

Van de Water, K. M., and H. D. Safford. 2011. A summary of fire frequency estimates for California vegetation before Euroamerican settlement. Fire Ecology 7:26-58.

Wilcove, D. S. 1989. Protecting biodiversity in multiple-use lands: lessons from the US Forest Service. Trends in Ecology and Evolution 4:385-388.

Winford, E. M., J. T. Stevens, and H. D. Safford. 2015. Fuel treatment impacts on the ecology of yellow pine and mixed conifer forests: a synthesis. California Agriculture 69:150-156.

Wohlgemuth, P. M. 2015. Hillslope erosion and small watershed sediment yield before and after fire in southern California. Pages 977-986 *in* Proceedings of the 3rd Joint Federal Interagency Conference (10th Federal Interagency Sedimentation Conference and 5th Federal Interagency Hydrologic Modeling Conference), Reno, Nevada, April 19-23, 2015. Washington, D.C., USA.

Wohlgemuth, P. M., K. R. Hubbert, J. L. Beyers, and M. G. Narog. 2009. Post-fire watershed response at the wildland/urban interface, southern California. Pages 137-142 *in* R. M. T. Webb and D. J. Semmens, editors. Planning for an uncertain future - monitoring, integration, and adaptation. Proceedings of the Third Interagency Conference on Research in the Watersheds, Estes Park, Colorado, September 8-11, 2008. Scientific Investigations Report 2009-5049, US Geological Survey, Estes Park, Colorado, USA.

Zedler, J. B. 1996. Coastal mitigation in southern California: the need for a regional restoration strategy. Ecological Applications 6:84-93.

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