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Socioecological Impacts of the Western Pine Beetle Outbreak in Southern California: Lessons for The Future

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Insects are important components of forest ecosystems representing most of the biological diversity and affecting virtually all processes. Some phytophagous species occasionally become so abundant that they threaten ecological, economic, social, and aesthetic values. The western pine beetle (*Dendroctonus brevicomis*) is a major disturbance in ponderosa pine (*Pinus ponderosa*) forests throughout much of the western United States. A notable outbreak, regarded by some as among the most severe for this species of bark beetle, occurred in southern California in the early 2000s. What is known about the socioecological impacts of the southern California outbreak is reviewed using the Millennium Ecosystem Assessment (2005) framework. Knowledge gaps of consequence to better understanding and anticipating the impacts of future outbreaks are identified.

Keywords: *Dendroctonus brevicomis*, *Pinus coulteri*, *Pinus ponderosa*, resilience, tree mortality

The western pine beetle (*Dendroctonus brevicomis*) is a major disturbance in ponderosa pine (*Pinus ponderosa*) forests throughout much of the western United States, particularly California (Miller and Keen 1960). Tree mortality attributed to western pine beetle can influence forest ecosystem structure and function by regulating certain aspects of primary production, nutrient cycling, ecological succession, and the size, distribution, and abundance of forest trees. Infestations may also impact timber and fiber production, water quality and quantity, fish and wildlife populations, recreation, grazing capacity, real estate values, biodiversity, carbon storage, cultural resources, and endangered

species, among other resources (Morris et al. 2018). The only other common host is Coulter pine (*P. coulteri*), a species indigenous only to the mountains of southern California and northern Baja California in Mexico (Fettig 2016). Western pine beetle generally exhibits a preference for colonizing larger diameter (>50 centimeters dbh) trees but under certain conditions, such as drought, may colonize and kill trees of all ages and size classes. Substantial basic and applied research has been devoted to western pine beetle dating back to the early 20th century (see Miller and Keen 1960 for review). Much is known about the ecology of this species, and several methods of management are available (Fettig 2016).

In the early 2000s, the mountain ranges of southern California began to experience increased levels of shrub and tree mortality attributed to severe drought (i.e., precipitation was the lowest in recorded history during 2001–2002, Minnich et al. 2016), and elevated populations of bark beetles and woodborers. Root diseases (USDA Forest Service 2003) and air pollutants, particularly nitrogen and ozone transported inland from urban and agricultural areas along the western slopes of the San Bernardino Mountains (Grulke et al. 1998, Jones et al. 2004), were important inciting and contributing factors. Although by 2004, mortality was dispersed across >259,000 hectares (ha), ~101,174 hectares were dominated by nonforest cover types (Walker et al. 2006), primarily chaparral and California (coastal) sage scrub. About 13% of conifers died between 2001 and 2004. Mortality was widespread and concentrated in several tree species, most notably ponderosa and Coulter pines (Figure 1, Table 1).

Western pine beetle populations were reported to be low in southern California in the late 1990s (USDA Forest Service 1997–1999). In 2000, western pine beetles were first noticed colonizing Coulter

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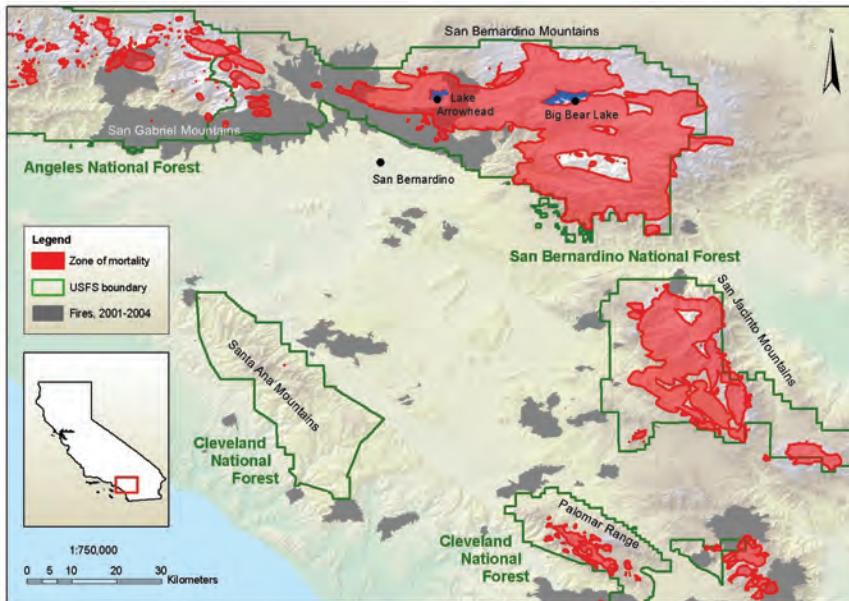


Figure 1. Areas impacted by the southern California outbreak during 2001–2004 based on aerial survey data provided by the USDA Forest Service. Red excludes mortality attributed to wildfire (depicted in gray) and areas occupied by nonhosts except for Jeffrey pine (*Pinus jeffreyi*), which is indistinguishable from ponderosa and Coulter pines during aerial surveys. Many areas adjacent to the zone of mortality are dominated by chaparral communities.

pinus at increased levels in the San Jacinto Mountains (USDA Forest Service 2000). Activity peaked in 2002–2003, when western pine beetle was reported to be the most common mortality agent associated with dead and dying pines throughout the San Bernardino and San Jacinto mountains ranges (USDA Forest Service 2002). Mortality of ponderosa and Coulter pines >43.2 centimeters dbh was 73.5% and 78% mortality, respectively (Walker et al. 2006). Despite continuing drought and an availability of susceptible hosts, western pine beetle populations rapidly declined in 2004 (Hayes et al. 2009). The southern California outbreak is considered to be among the most severe in recorded history for this species of bark beetle. Furthermore, San Bernardino National Forest, where most of the outbreak occurred (Figure 1), is one of the most heavily utilized national forests in the US (Blackwell 2003). Despite these factors, little has been written on this outbreak (USDA Forest Service 2000–2005). In this article, socioecological impacts are reviewed using categories identified in the Millennium Ecosystem Assessment (2005) (see McCollum and Lundquist 2018). The information provided is based on personal observations of the author, interviews and oral presentations, articles in the popular

press, and the few scientific publications that exist.

Provision Services

Fiber

At the beginning of the outbreak, southern California lacked the processing and milling capacities necessary to salvage large quantities of dead and dying trees. The mill nearest to heavily infested areas (e.g., Lake Arrowhead, California) was 320 kilometers away. Furthermore, mountain roads restricted the length of trailers commonly used to transport logs (Swan and Pattison 2007), and elevated transportation costs reduced the ability of most salvage to be economically viable without subsidy (California Department of Forestry and Fire Protection 2004). Through stimulus provided by low interest government loans

and grants, among other factors, small mills and new markets were slowly established to process beetle-killed timber (LeBlanc 2005) (Figure 2). By 2006, some 215 companies (some consisting of as few as one or two employees) were involved in utilizing or disposing of timber or fiber procured from areas impacted by the outbreak (Swan and Pattison 2007). Estimates of commercial sawlogs and other fiber (all trees) salvaged or harvested ranged from 115,312 to 566,788 green metric tons (mt) per year during 2004–2008, peaking in 2005 (Table 2).

Wildlife Habitat

Under normal circumstances, bark beetles create small gaps in the forest canopy by killing trees stressed by age, drought, defoliation, or other factors. In this context, few negative impacts are reported. However, this is not the pattern of mortality observed during the southern California outbreak where an abundance of large snags (average of ~30.5/ha, Stephens et al. 2018) was created at a landscape level in a short period of time. Presumably this was to the enrichment of snag-dependent species in the near-term. However, in a decade or two, all snags will have fallen to the forest floor (Keen 1955), increasing the amount of downed woody debris important to other wildlife species, but resulting in a paucity of habitat for snag-dependent wildlife. Conifer forests in the Sierra San Pedro Martir National Park in nearby northwestern Mexico that, unlike areas impacted by the southern California outbreak, have not experienced systematic fire suppression averaged 4.0 snags/ha (Stephens 2004). In 2002, during the same multiple-year drought observed in California, average snag density in the Sierra San Pedro Martir National Park increased to 5.1 snags/ha (Stephens 2004).

The San Bernardino Mountains are the highest and most extensively forested range in southern California (Stephenson and Calcarone 1999), and many unique

Management and Policy Implications

Impacts related to the southern California outbreak centered on regulating and cultural services. Concerns regarding hazard trees, fire risk, transportation and accessibility, and power line maintenance were paramount. The outbreak appeared to create a public awareness of forest health issues and concerns that was absent prior to the outbreak. The southern California outbreak provides important insight into what we might expect during and after future large-scale outbreaks of western pine beetle in California useful in planning management responses.

Table 1. Percentage of trees killed in southern California forests, 2000–2004.

Common name	Scientific name	Percentage of trees killed
Coulter pine ¹	<i>Pinus coulteri</i>	45
Incense cedar	<i>Calocedrus decurrens</i>	0
Jeffrey pine ²	<i>Pinus jeffreyi</i>	11
Lodgepole pine ²	<i>Pinus contorta</i>	2
Ponderosa pine ¹	<i>Pinus ponderosa</i>	55
Single-leaf pinyon ²	<i>Pinus monophylla</i>	7
Sugar pine ²	<i>Pinus lambertiana</i>	21
Western juniper	<i>Juniperus occidentalis</i>	1
White fir ²	<i>Abies concolor</i>	17

¹Species colonized by western pine beetle.

²Species colonized by other aggressive bark beetles (i.e., species capable of causing extensive levels of tree mortality) (Fettig 2016).

Based on data contained in Walker et al. (2006), defined here as >100,000 trees (≥12.7 centimeters dbh).



Figure 2. Salvage of trees killed by western pine beetle during the southern California outbreak, 2004. (Photo credit: C. Fettig, USDA Forest Service).

vegetation associations and rare species occur there. For example, this area contains the largest concentration of endemic herbaceous plants in California, several of which are federally listed as threatened or endangered (Stephenson and Calcarone 1999). Loss of canopy cover could be advantageous to some of these species. Given the magnitude and severity of the outbreak (Figure 1, Table 1), significant changes in forest structure, composition, and some type conversions have occurred (Walker et al. 2006). In San Bernardino County, for example, >2,833 ha of mixed conifer and hardwood converted to nearly pure hardwood, primarily interior live oak (*Quercus wislizeni*), California black oak (*Quercus kelloggii*), and canyon live oak (*Quercus chrysolepis*). Of note, California black oak is a cultural keystone species (Long et al. 2016) as its acorns are a preferred food

source for California's tribes and have an important role in tribal rituals, including dances, festivals, and ceremonies. About 607 ha of conifer forest converted to shrubland (Walker et al. 2006), representing a loss of resilience that is rarely observed in association with bark beetle outbreaks. This is partially attributed to the unique challenges of regenerating pines in southern California (Goforth and Minnich 2008). Loss of existing cover and structure associated with these conversions probably degraded the quality of habitat for some wildlife species, but studies evaluating impacts on terrestrial wildlife habitat are absent.

Aquatic Habitat

Areas impacted by the southern California outbreak contain several streams and lakes, which serve as important wintering grounds

for bald eagles (*Haliaeetus leucocephalus*) from the Greater Yellowstone Ecosystem (Harmata et al. 1999). In areas where the western pine beetle outbreak overlapped with recent wildfires (Figure 1), water yield, soil erosion, and sedimentation rates likely increased, which has been observed with other wildfires in the region (Stephenson and Calcarone 1999, Moody and Martin 2009). No studies have examined the impact of the southern California outbreak on aquatic resources; however, others have found important implications to municipal water supplies. For example, after a mountain pine beetle (*D. ponderosae*) outbreak in Colorado, elevated levels of dissolved organic carbon in surface waters promoted increases in carcinogenic compounds during municipal water treatments (Mikkelsen et al. 2013).

Regulating Services

Carbon

The many dead trees resulting from the southern California outbreak will gradually release carbon into the atmosphere as they decay over a period of ~100 years, or more immediately if consumed in wildfires. Based on tree mortality data provided by Walker et al. (2006), total carbon in all trees killed by all causes, except wildfire, is estimated to be ~1,698,558 mt (Table 3). Given the limitations of the data available, amounts attributable to western pine beetle cannot be determined specifically. However, 303,007 mt of carbon is estimated to be present in the pine component (Table 3), and much of this is larger-diameter trees, which are most vulnerable to western pine beetle (Fettig 2016). One way to compensate for carbon emissions is to lower the amount of biomass available for decay or burning by salvaging dead trees (Figure 2) and storing their carbon in solid wood products. Table 2 reports the biomass of fiber from salvage and fuels reduction projects; however, only a small portion of this material made it into solid wood products (Swan and Pattison 2007).

Fuels and Fire Danger

As documented in numerous press releases, considerable concern during and after the southern California outbreak was voiced regarding fire danger, especially for mountain communities with limited egress should a wildfire occur. Numerous wildfires swept through several areas of southern California in the fall of 2003 and 2007 and were

Table 2. Estimates of commercial sawlog and fiber biomass removals from salvage and fuel reduction projects in southern California forests, 2004–2008.

Category	2004	2005	2006	2007 ⁵	2008 ⁵
Commercial sawlogs ¹	60,675 ⁴	106,028	23,749	5,715	5,715
Other log markets ²	324,292	351,525	228,015	102,739	102,739
Biomass ³	26,090	109,235	49,866	6,858	6,858
Total	411,057	566,788	301,630	115,312	115,312

¹Defined locally as logs of ≥3.2 meters in length with a ≥25.4 centimeters small end diameter of sufficient economic value to be shipped profitably to an industrial sawmill. Board foot volumes converted using 5.443 mt per thousand board feet.

²Includes material sent to pallet manufacturers, re-manufacturers, firewood vendors, local portable sawmills, and specialty roundwood markets (Swan and Pattison 2007).

³Includes branches, tops, and sections of logs not economically viable to be shipped to other markets. It is likely that <50% of this material was actually removed from the forest (Swan and Pattison 2007).

⁴Based on Swan and Pattison (2007), values in green mt.

⁵Values are based on projections (Swan and Pattison 2007).

Table 3. Numbers, merchantable volume, and total (above and below-ground) carbon of trees killed in southern California forests, 2000–2004.

	Trees	Volume (m ³)	C (mt) ¹
<i>All trees</i>			
National forests	3,199,277	2,690,898	1,179,480
Non-federal	1,425,170	1,184,239	519,078
Total	4,624,447	3,875,137	1,698,558
<i>Pine only</i>			
National forests	439,926	474,990	208,199
Non-federal	236,754	216,298	94,808
Total	676,680	691,288	303,007

¹Factors for conversion of merchantable wood volumes obtained from Walker et al. (2006) (defined as ≥12.7 centimeters dbh to a 10.2 centimeters top) to total tree C included specific gravity = 0.38, merchantable wood volume to total tree biomass = 2.254, and proportion C in tree biomass = 0.512 (Birdsey 1996).

among the largest and most destructive in history in the region. In 2003, wildfires burned ~303,542 ha, killing 24 people and destroying 3,710 homes, but only ~8% of the area previously impacted by the western pine beetle outbreak burned (Figure 1). At the time of the 2003 wildfires, most of the dead trees were still retaining their needles.

Bond et al. (2009) used pre- and post-fire GIS data to examine how fire severity in southern California was affected by levels of tree mortality, among other factors. They found no evidence that prefire tree mortality levels influenced fire severity (Bond et al. 2009). However, the levels of mortality in their study seem low as they reported 50% of samples had no tree mortality above background levels. Furthermore, their study does not address potential changes in the risk of ignition or the strong temporal shifts in fuel characteristics that influence wildfire severity for decades after an outbreak has occurred.

Cultural Services

Hazard Trees

In response to threats posed by the numerous hazard trees, Governor Gray Davis

(D-California) signed a Declaration of State of Emergency on March 7, 2003 that covered San Bernardino, San Diego, and Riverside counties. A 2005 proclamation extended the declaration to Los Angeles County. Local emergencies were also declared and in some cases lasted for years; for example, one implemented in San Bernardino County was only terminated in 2013. Legal frameworks for sanitation and salvage were given through California Public Resources Codes 4712–4718, which provided that “every owner of timber or timberlands shall control or eradicate such insect pests or plant diseases on lands owned by him or under his control. If he does not do so the work may be performed as provided in this article.” Another statute (4716a) provided that “whenever the director determines that there exists an area that is infested or infected with insect pests or plant diseases injurious to timber or forest growth and that the infestation or infection is of such a character as to be a menace to the timber or timberlands of adjacent owners, the director, with the approval of the board, may declare the existence of a zone of infestation or infection, and describe and

fix its boundaries,” which permitted the state to appropriate resources to these areas. Several zones of infestation existed in the mountain ranges impacted by the southern California outbreak.

To help facilitate sanitation, salvage, and hazard tree removal efforts, the Mountain Area Safety Taskforce (MAST) was established in Riverside and San Bernardino counties, and the Forest Area Safety Taskforce (FAST) was established in San Diego County. The primary roles of MAST and FAST were to coordinate dead tree removal through increased interagency (county, state, and federal) communication and decision-making. In general, both taskforces were viewed as a success. To combat hazard trees, Congressman Jerry Lewis (41st District, R-California) initially secured \$3.3 million in early 2003. In September that year, Senator Dianne Feinstein (D-California) and Congressman Lewis helped secure an additional \$30 million in emergency supplemental funding. By 2010, more than \$200 million in public and private funds were spent on tree removal and fuels reduction (Edwards 2010). San Bernardino County alone removed 476,000 trees (Ghori 2013). In some cases, removal of hazard trees was costly and problematic for homeowners (Sahagun 2003). Residents who did not remove dead and dying trees within 30 days of receiving warning notices could face misdemeanor citations, which eventually could lead to liens against their properties for the cost of tree removals (Figure 3). Today, residents embrace the idea of thinning and fuels management around their homes (Ghori 2013).

Recreation and Spiritual Renewal

Chavez (2006) studied people’s beliefs and values pertaining to the management and use of natural areas in southern California.



Figure 3. In neighborhoods, hazardous tree removals negatively impacted aesthetics, 2004. (Photo credit: C. Fettig, USDA Forest Service).



Figure 4. During 2012–2015, much of California experienced a period of severe drought that incited a large western pine beetle outbreak. Like observed during the southern California outbreak, some areas have experienced >90% tree mortality (Photo credit: C. Fettig, USDA Forest Service).

Her work is not specific to areas impacted by the southern California outbreak but is relevant given the high visitation rates and recreational values of these forests. In order of importance, she reported individuals felt it was most important to manage natural areas for regulating services such as protection of water quality, protection of wildlife, improved air quality, and protection of plants, as well as cultural services such as camping, day hiking, educational purposes, scenic values, and wildlife viewing. These values are in agreement with

those expressed concerning the southern California outbreak during several meetings that the author attended.

Tourism and Property Values

About 56,000 people live in areas impacted by the outbreak; however, this number increases tenfold during the tourist season (Robinson and Harris 2006). Tourism is the lifeblood of many small communities affected by the southern California outbreak, but no studies examined the impact of the outbreak on tourism. During

interviews with real estate firms in 2004 in Lake Arrowhead—one of the most heavily impacted mountain communities—it became evident that the largest market segment affected was short-term (vacation) property rentals. In terms of real estate values, the outbreak had surprisingly little impact but, in some cases, changed how properties were sold during and immediately after the outbreak. Some homes were advertised at two prices, with and without hazardous tree removal.

Preserving Services

In terms of biodiversity, the mesic midelevation (1,372 to 2,134 meters) forests on the coastal side of the San Bernardino Mountains are of particular importance. These productive forests are key habitats for several forest-dependent wildlife species (Stephenson and Calcarone 1999). The California spotted owl (*Strix occidentalis occidentalis*) population in this area is critical to the continued viability of this species in southern California (Noon and McKelvey 1992). While no studies have examined the impact of the southern California outbreak on avian or small mammal populations, studies of other disturbances that have resulted in partial canopy removals (e.g., from fuels reduction) report subtle and site- and species-specific effects (McIver et al. 2013). Related to this, Lee et al. (2013) found no statistically significant effects of salvage logging on occupancy levels of California spotted owls in the San Bernardino and San Jacinto mountains ranges.

Conclusions and the Future

Since the southern California outbreak, levels of tree mortality attributed to western pine beetle peaked again in 2016 when 892,041 hectares were impacted, mostly in California following several years of severe drought (Fettig et al. 2018) (Figure 4). As a result, Governor Jerry Brown (D-California) declared a state of emergency on October 30, 2015, establishing a task force to help address the issue. In many ways, the 2016 outbreak and the southern California outbreak foreshadow future impacts of western pine beetle in the state as the intensity and duration of droughts—important inciting factors (Kolb et al. 2016)—are expected to increase as a result of climate change (Griffin and Anchukaitis 2014). Furthermore, the southern California outbreak provides some

insight into what socioecological impacts are likely to be of most concern in areas impacted by the 2016 outbreak, as well as future outbreaks, useful in bolstering our capacity to prepare and manage for such large-scale forest disturbances.

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