ECOLOGICAL EFFECTS OF FUEL MODIFICATION ON ARTHROPODS AND OTHER WILDLIFE IN AN URBANIZING WILDLAND

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ABSTRACT

Fire protection ordinances mandate clearing of large areas of native vegetation around new and existing structures in southern California. Such destruction of wildlife habitat is an inevitable result of development, but the damage to habitat is underestimated because of the piecemeal manner in which development occurs. Fire clearance and concomitant irrigation transform terrestrial arthropod communities, which serve many ecosystem functions. By comparing terrestrial arthropods at disturbed and undisturbed coastal sage scrub sites, the effects of fire clearance can be extrapolated, including interaction of invasive exotic arthropods, elimination of top predators and other sensitive arthropod species, and an overall reduction in native arthropod diversity. Such changes in the arthropod community are likely to have resonating effects on wildlife diversity that extend beyond the area of fire clearance itself. For urbanizing wildlands such as the Santa Monica Mountains, the legal context and rate of development make fuel modification a significant threat to ecosystem health.

keywords: arthropods, brush clearance, California, chaparral, coastal sage scrub, fire clearance, fuel management, Santa Monica Mountains, wildfire.

Citation: Longcore, T. 2003. Ecological effects of fuel modification on arthropods and other wildlife in an urbanizing wildland. Pages 111–117 *in* K.E.M. Galley, R.C. Klinger, and N.G. Sugihara (eds.). Proceedings of Fire Conference 2000: The First National Congress on Fire Ecology, Prevention, and Management. Miscellaneous Publication No. 13, Tall Timbers Research Station, Tallahassee, FL.

INTRODUCTION

Removal of vegetation is one of many management strategies to reduce the risk of structures burning during wildfires on the urban–wildland interface. The practice of fuel modification or vegetation management has widespread application along with structural design (i.e., roofing, chimneys, siding) and local infrastructure (i.e., access routes, water supply) in minimizing fire danger for homes (Vicars 1999). Perhaps because fuel-modification activities are spread across the landscape, the ecological effects of policies requiring extensive clearance of native vegetation are generally not considered by either fire-prevention professionals or fire ecologists. However, the cumulative effects of fuel-management practices on ecosystems are likely to be significant. This paper reviews the effects of fuel-modification practices on native plants and animals, with special attention given to terrestrial arthropods. Effects of these practices are weighed against the benefits of vegetation removal for fire prevention with a discussion of the potential for reducing clearance area if it is accompanied by other fire-prevention techniques.

The Santa Monica Mountains in southern California provide a case study on the effects of fire clearance on native ecosystems. The east–west mountain range extends from near downtown Los Angeles westward to Ventura County, bisecting much of urban Los Angeles. The vegetation is a diverse mix of wetlands, riparian forests, oak woodlands, chaparral, and coastal sage scrub. Because of the proximity of the mountain range to dense urban occupation, it is a favorite site for those seeking a rural retreat or commuter home. This intense urbanization pressure adds to the potential future of fuel modification that perforce accompanies development. The *Fuel Modification Plan Guidelines* (http://www.lacofd.org/Forestry_folder/fuel.htm) were developed to help reduce the threat of fire in high hazard areas in this region (County of Los Angeles Fire Department 1998).

FUEL-MODIFICATION LAWS

Fire-clearance ordinances are found in all jurisdictions in the Santa Monica Mountains. The Los Angeles County guidelines (County of Los Angeles Fire Department 1998) apply to the majority of the undeveloped portion of the range. These guidelines were prepared pursuant to the Los Angeles County Fire Code for buildings in very high fire hazard zones, a classification that applies to the entire area of the mountains. Additionally, there are California statutes that require fire clearance (California Public Resources Code § 4291), as do ordinances in the City of Los Angeles and City of Malibu. These laws are extremely powerful, trumping even private property rights. Because native vegetation is deemed to be a hazard, a property owner with no structures can be forced, at his or her own expense, to clear native vegetation from his or her property to provide protection for a structure on an adjacent property. Current regulatory standards do not recognize the ecological value or ecosystem services of native vegetation in high fire danger areas; rather they treat such vegetation as if it were potentially explosive. The only properties in the Santa Monica Mountains that are not subject to strict enforcement of fire-clearance standards are federal and state parklands, which thus far have not been legally obligated to destroy native habitat for the sake of fire protection. However, parkland managers are under intense political pressure to clear vegetation surrounding the properties of adjacent landowners (Pool 2000).

Within this regulatory context, I evaluate the ecological effects of the predominant fire-clearance standards established by the County of Los Angeles and implemented in the Santa Monica Mountains. These guidelines provide the basis for fuel-modification plans for new and remodeled structures in the mountains, and effectively mimic the standards enforced by the Los Angeles County Fire Department for all structures. A fuel-modification plan must establish four zones surrounding structures (County of Los Angeles Fire Department 1998:4–5). Zone A, the Setback Zone, extends 6 m (20 feet) around all structures. Most vegetation in this zone is limited to "ground covers, green lawns, and a limited number of selected ornamental plants." Within this zone, the guidelines require "[i]rrigation by automatic or manual sprinkler systems to maintain healthy vegetation with high moisture content." Zone B, the Irrigation Zone, allows that "[s]ome native or existing vegetation may remain if spaced . . . and maintained free of dead wood . . ." but where "[a] large percentage of existing vegetation may be removed and replaced with appropriate irrigated fire resistant and drought tolerant plant material." Zone C, the Thinning Zone, requires that native vegetation be heavily thinned and selectively replaced by ornamental species. Certain native plant species are prohibited in this zone because of their flammability. All dead vegetation must be removed and fine fuels reduced to 7.6 cm (3 inches) above the ground. Zone D, the Interface Thinning Zone, consists of native vegetation thinned to reduce total mass. While the guidelines provide for some flexibility of implementation of the size of these four zones, they are almost uniformly implemented where the first three zones are in the first 30.5 m (100 feet) from the structure, and the fourth zone is an additional 30.5 m, with total fuel modification of 61 m (200 feet) surrounding each structure. By comparison, the City of Los Angeles brush-clearance guidelines require 61 m of clearance in high fire-hazard areas, whereas in the thinning zone (30.5–61 m) shrubs must be spaced at a minimum of 5.5 m (18 feet) apart.

The insurance industry has greatly influenced the application of fuel-modification guidelines. For properties with high fire hazard, the insurer of last resort is the California Fair Access to Insurance Requirements (FAIR) Plan. For properties within designated "brush areas" (so designated by the Insurance Services Office), the FAIR Plan assesses a surcharge based on the amount of clearance surrounding a property. Since the most recent revision of these charges in 1999, all structures with less than 61 m of brush clearance are assessed surcharges, ranging from $0.13 to $2.52 per hundred dollars of insurance, based on clearance distance and other hazard factors, including distance to fire station, roof type, and type of coverage. Prior to these revisions, surcharges were assessed in some areas if clearance was less than 122 m (400 feet). Combined with the county regulations, the FAIR Plan surcharge system guarantees that all structures in the Santa Monica Mountains have at least 61 m of fuel modification. In 2000, a legislative bill introduced by California State Senator Sheila Kuehl (AB 1983) established that if a property owner failed to provide brush clearance for a structure on an adjacent property, the owner (not the neighbor owning the structure) is assessed the FAIR Plan surcharge (California Insurance Code § 10100.2).

The area affected by fire clearance depends on the distance from the structure that requires modification. This area increases geometrically with the increasing radius of the circle of clearance required. For example, assuming that a home has no area, 30.5 m of clearance would affect 0.29 ha (0.72 acres) of vegetation, 45.75 m (150 feet) affects 0.66 ha (1.62 acres), and 61 m affects 1.17 ha (2.88 acres). Assuming a reasonably sized home, 61 m of fire clearance results in the destruction of 1.21 ha (3 acres) of surrounding habitat. These habitat modifications have profound effects on the flora and fauna of the immediate area and have the potential to cause significant landscape-level effects.

LOCAL EFFECTS OF FUEL MODIFICATION

Arthropods

Although arthropods represent over 65% of Earth's described taxa and play many important ecological roles (Wilson 1987, Samways 1990:56), they receive little attention in discussions of fire management, except as pests that may promote fire. However, as a group, arthropods have received increasing attention as useful monitors of ecological conditions (Kremen et al. 1993, Abensperg-Traun et al. 1996, Jansen 1997, Rykken et al. 1997, Williams 1997, Mattoni et al. 2000). Arthropods have short generation times, respond quickly to environmental perturbations, and are easily collected for environmental monitoring. Relatively little has been written about the arthropods of coastal sage scrub and chaparral (Force 1981, Prentice et al. 1998, Longcore 1999, Bolger et al. 2000). However, my study (Longcore 1999) and the extensive work completed by others on the spread of exotic arthropods in California and elsewhere (Holway 1995, 1998*a,b*, 1999; Human and Gordon 1996; Way et al. 1997; Human et al. 1998; Kennedy 1998; Suarez et al. 1998, 2000) allow for sufficient detail to predict the effects of fire clearance on arthropod communities.

I analyzed the results of a 5-year survey of the terrestrial arthropods in coastal sage scrub habitats on the Palos Verdes Peninsula in southwestern Los Angeles County (Longcore 1999). Undisturbed, disturbed, and restored coastal sage scrub habitats were continuously trapped with pitfall traps from 1994 to 1998. The coastal sage scrub of the Palos Verdes Peninsula is similar to that of the Santa Monica Mountains, and the general patterns observed there can be

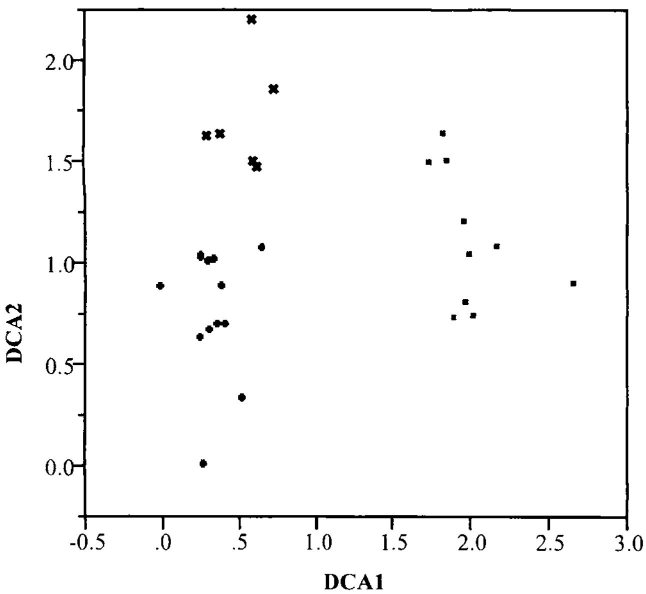

Fig. 1. Detrended correspondence analysis (DCA) of arthropod communities sampled at undisturbed (+), disturbed (×), and restored (■) coastal sage scrub habitats on the Palos Verdes Peninsula, California (modified from Longcore 1999).

extrapolated to the chaparral, riparian forests, and oak woodlands of the Santa Monica Mountains. Arthropod communities in cleared areas are likely to be similar to those at both disturbed and restored sites. First, the removal of native vegetation and concomitant invasion of annual grasses typical of fire-clearance areas in the Santa Monica Mountains produce conditions similar to the disturbed coastal sage scrub at Palos Verdes. Both have low, regenerating shrub cover, but are drastically simplified in terms of structural diversity and total shrub cover compared to mature shrublands. Second, sites that undergo fuel modification have some similarities to sites that have been restored. In this respect, both restored sites and sites subject to fuel modification are mechanically disturbed and are subject to artificial irrigation.

To detect differences and similarities among arthropod communities at disturbed, native, and restored sites in Palos Verdes, I performed detrended correspondence analysis using log-transformed arthropod abundance (Longcore 1999). The resulting ordination (Figure 1) showed a clear distinction between restored sites and all other sites on the first axis. This axis is negatively associated with arthropod diversity ($r^2 = 0.46$, $P < 0.0001$). On the second axis, habitats are separated by vegetation height with disturbed habitats scoring higher and native habitats with more structural complexity scoring lower. The restorations also showed the same pattern with younger restoration areas scoring higher on the second axis. The effect of vegetation height on the second axis is quite clear, with 56% of the variation in this axis explained by a height index of vegetation calculated for each site.

Fire-clearance activities will also substantially affect arthropod community composition by reducing the complexity of vegetation. Relating the first axis to fire-clearance practices requires further information. The axis is also correlated with increased abundance of the invasive Argentine ant (*Linepithema humile*), which explains 56% of the variation in diversity at all sites ($P < 0.001$). The deleterious effect of Argentine ants on native arthropods is well documented, with numerous studies reporting a decrease in arthropod diversity as Argentine ant abundance increases (Erickson 1971; Cole et al. 1992; Human and Gordon 1996, 1997; Holway 1998*a*; Kennedy 1998). Fuel modification increases the abundance of Argentine ants by providing two conditions that increase invasion: a water source (Holway 1998*b*, Human et al. 1998) and increased disturbance (Human et al. 1998). Water sources are provided by the mandatory irrigated zone, and disturbance is an ongoing result of vegetation removal. Argentine ants invade far beyond the water sources and into surrounding undisturbed habitats, with increased abundance documented to a distance of up to 200 m (656 feet) (Suarez et al. 1998).

Community-level analysis indicates that the species composition will change and overall diversity will decrease when habitats are subjected to fuel modification. Disturbed sites have fewer predators such as scorpions (Scorpiones) and trap-door spiders (Ctenizidae), and are dominated by exotic arthropods, such as Argentine ants, European earwigs (*Forficula auricularia*), pillbugs and sowbugs (*Armadillidium vulgare* and *Porcellio* spp.), and the sowbug killer spider (*Dysdera crocata*) (Longcore 1999). These changes in arthropod species diversity will have resonating impacts on vertebrates that consume arthropods as prey species. Suarez et al. (2000) showed that coastal horned lizards (*Phrynosoma coronatum*) prefer native ants (*Pogonomyrmex* spp. and *Messor* spp.) as their food source, and populations decline when these species are eliminated by invading Argentine ants.

Birds

Fuel-modification practices by definition decrease the structural diversity of chaparral and coastal sage scrub habitats. Resident and migratory bird species will respond to these changes in predictable ways. Stralberg (2000) identified three categories of birds in the Santa Monica Mountains: local and long-distance migrants, chaparral-associated species, and urban-associated species (Table 1). Her study showed that abundance of migrants and chaparral-associated birds decreases closer to edges with urban developments, while abundance of urban-associated species increases. The effects of urbanization itself will increase edges across the mountains, and fire clearance greatly exacerbates the effect. Stralberg's (2000) explanatory model shows that the increasing percentage of urban area on a landscape scale explains variation in bird communities not explained by site variables. Similarly, Bolger et al. (1997*b*) found decreased densities of sensitive species in response to increased edge and fragmentation in southern California chaparral.

Many of the urban-associated bird species are also nest predators (e.g., western scrub jay [*Aphelocoma californica*], American crow [*Corvus brachyrhyn-*

Table 1. Suites of bird species in the Santa Monica Mountains, California (Stralberg 2000).

Suite	Species
Local and long-distance migrants	Ash-throated flycatcher, *Myiarchus cinerascens*
	Pacific-slope flycatcher, *Empidonax difficilis*
	Phainopepla, *Phainopepla nitens*
	Black-headed grosbeak, *Pheucticus melanocephalus*
Chaparral-associated species	Bewick's wren, *Thryomanes bewickii*
	Wrentit, *Chamaea fasciata*
	Blue-gray gnatcatcher, *Polioptila caerulea*
	California thrasher, *Toxostoma redivivum*
	Orange-crowned warbler, *Vermivora celata*
	Rufous-crowned sparrow, *Aimophila ruficeps*
	Spotted towhee, *Pipilo maculatus*
	California towhee, *Pipilo crissalis*
Urban-associated species	Mourning dove, *Zenaida macroura*
	American crow, *Corvus brachyrhynchos*
	Western scrub-jay, *Aphelocoma californica*
	Northern mockingbird, *Mimus polyglottos*

chos]). As edges and abundance of these species increase, nest predation on chaparral-associated species will increase (Langen et al. 1991, Hogrefe et al. 1998, Söderström et al. 1998), which may reduce populations of chaparral-associated bird species (Schmidt and Whelan 1999).

While I do not discuss mammals and reptiles in detail, similar patterns of decreasing diversity and increasing dominance by exotic species would result from fire clearance (Dickman 1987, Bolger et al. 1997*a*).

Plants and Cryptobiotic Crust

Fuel-modification activities result not only in the removal of native vegetation but in the active promotion of exotic species surrounding structures. The *Fuel Modification Plan Guidelines* (County of Los Angeles Fire Department 1998) provide a list of recommended plant species for the first three fuel-modification zones (Zones A–C). Of 369 species listed, only 33 (9%) are native to Los Angeles County, and at least 8 are recognized as noxious weeds in California (County of Los Angeles Fire Department 1998). For example, capeweed (*Arctotheca calendula*) and Chinese tallow tree (*Sapium sebiferum*) are recommended by the county in fuel-modification zones, but are listed as "Red Alert" species with the potential to spread explosively by the California Exotic Pest Plant Council (1999). Other weedy plant species recommended by the county include *Acacia* spp., *Gazania rigens, Lonicera japonica, Echium fastuosum, Cotoneaster* spp., *Eucalyptus* spp., and *Verbena* spp.

In addition to the purposeful introduction of invasive species, the disturbance associated with fire clearance promotes the invasion of plant species already associated with residential development. Over half of the nonnative species in the Santa Monica Mountains are associated with disturbed areas, including cleared areas (Rundel 2000). This relationship between invasive exotics and disturbance is found throughout California and in other Mediterranean regions (Kotanen 1997, Rundel 1998). The understory areas subject to fuel modification are rapidly dominated by invasive exotic grasses and forbs. As discussed extensively elsewhere (e.g., Mooney et al. 1986, Minnich and Dezzani 1998, Rundel 1998), invasive plant species can profoundly affect ecosystem structure and function by modifying fire regimes, nutrient cycling, and erosion patterns. As fuel modification increases the disturbed area across the landscape, invasive species, aided by ongoing disturbance and irrigation, will continue to invade adjacent native habitats. Invasive species are of special concern to federal land managers, in light of the Executive Order (13112) on Invasive Species (3 February 1999) requiring federal agencies to prevent invasive species introductions and to restore habitats invaded by invasive species, while prohibiting funding of any activities that would promote the spread of invasive species unless "the benefits of such actions clearly outweigh the potential harm caused by invasive species" (Section 2a(3)).

Beyond promoting the invasion of vascular plants, fuel modification disrupts the cryptobiotic crusts that form on soils in arid environments. Soil crusts composed of lichens, mosses, algae, fungi, and bacteria are common in arid and semiarid regions of the world (Belnap 1993, St. Clair and Johansen 1993, Lesica and Shelley 1996). The adhesive qualities of mucilaginous polysaccharides exuded by blue-green algae and fungi reduce erosion by increasing soil cohesion (Belnap and Gardner 1993). Crusts also increase essential mineral availability (N, P, K, Ca, Mg, Fe) and promote mycorrhizal associations (Harper and Pendleton 1993). However, crusts are easily disturbed and recover slowly from disruption (Johansen et al. 1997).

LANDSCAPE EFFECTS OF FIRE CLEARANCE

The local ecological effects of fire clearance are clearly deleterious to native plants, arthropods, birds, and other wildlife. The cumulative effect of these practices poses a risk to landscape connectivity and watershed health.

The California Coastal Commission recently completed an assessment of cumulative impacts to key resources in the area under its jurisdiction in the Santa Monica Mountains (California Coastal Commission 1999). Their study area, which encompassed the majority of the Santa Monica Mountains, included 33,124 ha (81,850 acres) in Los Angeles and Ventura counties in which there were 9,352 dwellings. The Commission estimated the potential for between 5,522 and 8,396 additional structures, depending on whether or not further subdivision is allowed. The fuel-modification area required for these structures will depend on how they are dispersed across the landscape. At the extreme, if one assumes no clustering and a fuel-modification area of 1.21 ha (3 acres) per structure and full subdivision, then the potential new development would destroy roughly 9,700 ha (24,000 acres), or 30% of the entire region. If one assumes the likely scenario of moderate clustering, with total average clearance of 0.4–0.6 ha (1–1.5 acres) per structure, then new development would consume 3,200–4,800 ha (8,000–12,000 acres) of habitat through fire clearance (10%–15%). Of the potential new structures, 470 are close enough to state and federal parklands to create pressure for clearance of these public lands (California Coastal Commission 1999).

While explicit geographic analysis of the distribution of existing fire clearance and future development remains to be completed, the magnitude of wildlife habitat currently and potentially subjected to clearance has a significant adverse effect on ecosystem health. For example, the denudation from fuel modification results in increased stormwater flow, higher peak flows, and more suspended solids in the streams that drain into the Pacific Ocean from the mountains (Radtke 1983), decreasing water quality for rare and endangered fishes. Transformation of vegetative cover from chaparral to annual grasses increases erosion and landslides in watersheds (Pitt et al. 1978). As more development occurs along roads, fire clearance extends the divisive effect of roads to create a barrier of inhospitable habitat for native birds and mammals that is close to 305 m (1,000 feet) across. The cumulative effect of this will be landscape fragmentation greater than now experienced, even in areas designated as wildlife corridors.

POTENTIAL FOR POLICY CHANGE

If the negative environmental effects of fuel modification are accepted, what latitude exists for changes in the current policies? Protection of human life and property is the top priority of fuel management, so the challenge is for policies to ensure the safety of firefighters and residents while minimizing ecological harm. One way is to minimize construction in high fire danger zones, which would keep both property and firefighters out of harm's way. In analyzing the environmental impacts of development in high fire danger areas, the ecological destruction wrought by fire clearance should be considered fully.

A second way to minimize ecological damage is to change the fuel-modification standards themselves. This is likely to be difficult because of the public perception that such clearance is necessary and the financial pressure exerted by insurers to clear vegetation around homes. The 61-m clearance required by the California FAIR plan exemplifies this pressure. However, this standard is not based on any published scientific study; rather, the published literature on fire clearance shows that more than 30.5 m clearance is not necessary.

Table 2. Structure loss from the 1961 Bel Air fire, California, by brush clearance and roof type (from Howard et al. 1973).

	Structure loss	
Brush clearance	Approved roofs	Unapproved roofs
0–9 m (0–30 feet)	67/275 = 24.3%	158/319 = 49.5%
9–20 m (30–60 feet)	13/239 = 5.4%	104/363 = 28.6%
20–32 m (60–100 feet)	2/118 = 1.6%	28/195 = 14.4%
32+ m (100+ feet)	1/151 = 0.7%	31/310 = 14.8%

As reviewed by Cohen (2000*a*), structures can ignite in two ways during a wildfire. First, firebrands (burning pieces of material) can be blown onto the structure and its immediate surroundings, causing them to ignite. This ignition depends largely on the flammability of the structure and the (ornamental) vegetation immediately around it. Fire clearance does little to reduce this type of ignition because firebrands can be blown onto a structure from a significant distance.

Second, structures can be heated by a fire to the point of combustion, which is influenced by fire-clearance distance. Cohen has investigated this type of ignition through models and experiments and shown that 10–30 m (33–100 feet) is the clearance needed to prevent ignition (Cohen 2000*a,b*). This clearance distance is supported by retrospective studies of structure survival following fire, which show 90% structure survival with 10–20 m (33–66 feet) of clearance and nonflammable roofs. This is illustrated in the pattern of loss from the 1961 Bel Air fire in the eastern portion of the Santa Monica Mountains (Howard et al. 1973) (Table 2) and the 1990 Santa Barbara "Paint" fire (Foote 1996). In the Bel Air fire, the probability of loss for structures with fire-resistant roofs was only 0.7% (1 of 151) with 30.5 m of clearance. By contrast, structures with flammable roofs had at least a 14.4% chance of loss no matter how much clearance was provided (Howard et al. 1973). Howard et al. (1973) therefore recommended brush clearance of 30.5 m and enforcement of fire-resistant roofs to minimize losses. It seems to be poor public policy to require 61 m of clearance in the absence of evidence that it reduces structure loss or increases safety. While 30.5 m of clearance is clearly supported, the additional 30.5 m of clearance quadruples the loss of habitat while providing no additional structure protection. Furthermore, predictive models of structure loss show that brush clearance is less important to structure safety than removing flammable objects near the structure, having a tile roof, having a low pitch roof, or having brick, stone, or block walls (Wilson 1984).

Fuel-modification guidelines could also be changed to make the practices more amenable to biological resource values. First, landscaping beyond the first 6 m surrounding structures should be limited to native vegetation occurring in the local area. This would eliminate the invasive species currently planted in many fuel-modification zones, and keep the benefits of the deep and extensive root systems characteristic of Mediterranean plants. Second, the irrigation zone could be eliminated to minimize the invasion of exotic arthropods into fuel-modification areas. These changes must be accompanied by strict enforcement of fire-resistant construction (both for new development and existing structures), and close attention to vegetation immediately adjacent to structures.

Any changes to current fuel-modification guidelines must be considered carefully and discussed with firefighters and insurance industry representatives to ensure that structures remain adequately protected and firefighter safety is maintained. While the solutions may require long negotiation and political will to implement, it is appropriate to begin a public policy discussion on the effects of fuel modification. Such efforts must be accompanied by public education about the science of structure protection, dispelling the myth that more clearance always guarantees a safer structure. Rather, property owners must be taught to accept responsibility for the flammability of their structures and immediate surroundings—a home with a wood shingle roof is just as vulnerable with 61 m of clearance as with 30.5 m of clearance.

Acknowledgment of the significant impacts to biological resources discussed in this paper should also lead to more careful environmental review of policy decisions establishing fuel-modification requirements to allow for full disclosure of impacts and formulation of appropriate mitigation measures. For example, an Environmental Impact Report could have been prepared to disclose and analyze the impacts of the County of Los Angeles Fire Department (1998) *Fuel Modification Plan Guidelines*. Such full and open policy discussions may result in different fuel-modification practices, incentives to avoid construction in fire danger zones, or other mechanisms to maintain life and property while protecting the beauty and biological diversity of our remaining wildlands.

ACKNOWLEDGMENTS

I thank Anya-Kristina Kroeger for research assistance, Kevin Shaffer for encouraging my participation in the conference, and Catherine Rich for constructive editorial comments. All remaining errors are my own.

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