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# Research on the Effects of Wildland Fire and Fire Management on Federally Listed Species and Their Habitats on San Clemente Island, Southern California

Open-File Report 2015–1194

**U.S. Department of the Interior**
**U.S. Geological Survey**

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By Jon E. Keeley and Teresa J. Brennan

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## Conversion Factors

Inch/Pound to International System of Units

| Multiply | By | To obtain |
|---|---|---|
| | Length | |
| millimeter (mm) | 0.03937 | inch (in.) |
| meter (m) | 3.281 | foot (ft) |
| meter (m) | 1.094 | yard (yd) |
| kilometer (km) | 0.6214 | mile (mi) |
| kilometer (km) | 0.5400 | mile, nautical (nmi) |
| | Area | |
| square meter ($m^2$) | 0.0002471 | acre |
| square meter ($m^2$) | 10.76 | square foot ($ft^2$) |
| hectare (ha) | 2.471 | acre |
| square hectometer ($hm^2$) | 2.471 | acre |
| hectare (ha) | 0.003861 | square mile ($mi^2$) |
| | Volume | |
| milliliter (mL) | .033814 | ounce, fluid (fl. oz) |
| | Mass | |
| gram (g) | 0.03527 | ounce, avoirdupois (oz) |

Temperature in degrees Celsius (°C) may be converted to degrees Fahrenheit (°F) as °F = (1.8 × °C) + 32.

## Datum

Horizontal coordinate information is referenced to the World Geodetic System 1984 (WGS 84).

## Abbreviations

| | |
|---|---|
| ANOVA | analysis of variance |
| BO | Biological Opinion |
| DI | distilled |
| SHOBA | Shore Bombardment Area |
| TZ | 2,3,5-triphenyltetrazolium chloride |

# Research on the Effects of Wildland Fire and Fire Management on Federally Listed Species and Their Habitats on San Clemente Island, Southern California

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## Executive Summary

This project was initiated to address potential impacts to federally listed species from expanded military operations that have contributed to fires on San Clemente Island, southern California, and implementation of the San Clemente Island Wildland Fire Management Plan, as described in the U.S. Fish and Wildlife Service issued Biological Opinion (BO) FWS-LA-09B0027-09F0040 in 2008. The BO identifies non-native annual grasses as threats to all of San Clemente Island plant species because of competition and potential effects on the fire regime. In addition to effects on native plant species, annual grass thatch is thought to negatively affect habitats for listed bird species. The BO included conservation measures proposed by the U.S. Navy to:

1. Study the effectiveness of prescribed fire in controlling non-native annual plants,
2. Evaluate the response of the California boxthorn (*Lycium californicum*) community to fire, and
3. Study the effect of fire on *Delphinium kinkiense* (San Clemente Island larkspur).

The study also identified the need to study the effects of fire on *Malacothamnus clementinus* (San Clemente Island bush-mallow) and *Sibara filifolia* (Santa Cruz Island rock cress). Thus, to address these needs and related issues, research projects 1–4 were undertaken:

**Project 1.** The purpose was to understand the potential impact of fires on recovery of boxthorn scrub vegetation because it is important habitat for numerous endangered species. Because of the very limited amount of remaining intact boxthorn scrub, we were restricted from doing prescribed burns in this plant community, but we were given permission to burn highly degraded boxthorn scrub. We concluded that the dominant shrub, boxthorn, is able to tolerate fire by resprouting. Although this species is resilient to fire, there are no obviously fire-dependent species in this community, as evidenced by the lack of postfire seedling recruitment of boxthorn or any other species. An additional goal of this study was to evaluate the extent to which burning might impact non-native grasses. Our studies showed little reduction in these annual grasses, presumably because these open degraded sites lacked sufficient fuel to generate lethal temperatures for non-native "seed banks" (which refer to mature seed stored in canopies, litter, and soil).

**Project 2.** The purpose was to determine the impact of burning in native grasslands on the relative composition of native and non-native grasses. These studies indicated that burning in these grasslands generated sufficient temperatures to have a highly significant impact on reducing non-native annual grasses. Native grasses, which recover from resprouts, were minimally impacted and, thus, the balance between native and non-native grasses shifted in favor of natives 2 years after the burn treatments. Because of the population dynamics of non-native annual grasses, we anticipate that this change is temporary, but the literature is unclear on how long it should last. In order to more fully understand the management implications of fire, we recommend continuing to monitor the plots until the effect has ceased. We anticipate that this will be from 1 to 3 years. Once the effect is no longer significant, it may prove useful to do a follow-on prescribed fire experiment with unburned controls, 2012 burned controls, and plots burned twice to evaluate if there is a synergistic effect of multiple fires in fostering increases in native species.

**Project 3.** The purpose was to evaluate the impacts of fire on three listed plant species on San Clemente Island. These are *Delphinium variegatum* ssp. *kinkiense* (San Clemente Island larkspur), *Malacothamnus clementinus* (San Clemente Island bush-mallow), and *Sibara filifolia* (Santa Cruz Island rock cress) (*Delphinium variegatum* ssp. *kinkiense* is an herbaceous perennial, *Malacothamnus clementinus* is a subshrub, and *Sibara filifolia* is a short-lived annual. Based on these different life histories, we might expect differences in their response to fire. We outline here the general responses to fire known from the literature on life history types in coastal California. These patterns are used to make predictions about the fire response of each of the listed species and to make predictions of how their seed germination will respond to fire-type cues such as heat shock and smoke. This approach was necessitated because of the rarity of these species, which prevented us from being given permission to do field studies of their fire response; however, we were able to do limited experimentation on seed germination responses to fire-related cues. Seed germination results were consistent with the patterns expected based on life-history studies in these fire-prone ecosystems.

*Delphinium variegatum* ssp. *kinkiense* is an herbaceous perennial distributed in the remnants of native grassland persisting on the island. Although we have relatively few studies of how fires impact native grasslands in California, the limited understanding we have at this point suggests that herbaceous perennials, including *Delphinium variegatum* ssp. *kinkiense*, are resilient to fires at relatively short intervals because of the fact that recovery involves normal winter sprouting and recovery is not dependent on accumulation of seed banks or fire-stimulated seed germination. This is borne out by seed germination results from this study. *Malacothamnus clementinus* is a subshrub present in low-growing scrub. Based on earlier seed germination results of the closely related *M. fremontii*, we expected heat shock and not smoke to stimulate germination. Although our germination results seemed to support this prediction, results were not statistically significant. Viability tests suggested that the seed pool was viable, although the tetrazolium test is only an indicator of potential viability. Also, it is clear from abundant seed studies that for species with deeply dormant seeds, as predicted for *M. clementinus*, complete germination often require months of incubation. *Sibara filifolia* is an ephemeral annual present on severe sites such as rock outcrops or thin soils. It is to be expected that on such sites, fire is not an important ecosystem process because fuels are lacking that could carry fire. Of course, for all species that occur in such refugia, between fires the species may colonize other sites subject to fire. As a general rule, they are extirpated from such sites but survive fires in these refugia sites. Seed germination experiments are consistent with this hypothesis.

**Project 4.** The purpose was to evaluate the impact of a Phos-Chek® application to the affected ecosystems. This powdery fire retardant is mixed with water and typically is applied by aircraft during a fire event to reduce the rate of fire spread. On San Clemente Island, it was applied as a pre-fire treatment to create a perimeter around the military training zone of highest fire potential. This was applied annually for a decade, and there was interest in understanding the impact of this concentrated application on native plant growth. During the initial examination of the Phos-Chek® area, we discovered an unexploded ordinance and were not allowed to continue the field studies on Phos-Chek® impact. We have done a literature search of Phos-Chek® to make inferences about impact and to make suggestions on potential experimental means of addressing this issue.

## Introduction

Fire and herbivory are major factors influencing biological diversity worldwide, and potentially have both positive and negative impacts (Olff and Ritchi, 1998; Bond and Keeley, 2005). On fire-prone landscapes where species have had a long evolutionary association with fire, it is common to view such taxa as fire adapted. However, it is important to recognize that species are not adapted to fire per se but to a particular fire regime. Divergence from the natural disturbance regime—for example, more intense or less intense fires, shorter or longer fire intervals—introduces the risk of ecosystem degradation; vegetation may be too young to produce propagules if disturbance occurs too frequently or intensely, or so old that short-lived species drop out (Zedler and others, 1983; Olff and Ritchi, 1998).

Coastal southern California shrublands (for example, sage scrub and chaparral) are more likely to have too much disturbance than not enough, as human-caused ignitions are common and natural ignitions are rare (Keeley, 2005) and herbivory has intensified with the introduction of livestock (Westman, 1983). In these ecosystems, short intervals between disturbances cause woody species to drop out; shrublands may be type-converted to annual grasslands (Dunn and others, 1988; Keeley, 2006), decreasing the diversity of native species (Keeley, 2005). Coastal sage tends to drop out with fire return intervals of less than 3 years; chaparral is even more sensitive to shortened frequencies, dropping out when fire return intervals decrease to less than 10–20 years (Keeley, 2000); therefore, fires could reduce woody native plant cover if frequent or when shrublands are recovering from severe disturbances. A feedback cycle occurs with frequent disturbance, such as fire, overgrazing, and non-native grasses:

- When closed canopy chaparral stands burn, non-native grasses and forbs populate openings,
- These grasses compete directly with native species and form continuous fine fuels that perpetuate the short fire return interval,
- Obligate seeders are lost and degraded chaparral is dominated by resprouters, and finally
- Frequent fires or intense grazing cause fewer shrubs and perpetuate annuals (Vogl, 1981; Keeley, 2006).

However, at least one native perennial grass common to California, *Stipa pulchra* (plant nomenclature according to Baldwin and others, 2012) tends to increase as a result of fire (Bartolome and Gemmill, 1981; Resnick, 1988; Hatch and others, 1999). This species also produces more culms and grows larger when competing annual grasses are removed (Dyer and Rice, 1999); therefore, carefully timed burning could promote this native grass if annual grass seeds were killed by an early season fire.

On the Channel Islands of southern California in general and on San Clemente Island in particular, grazing and browsing by non-native herbivores, and fire have profoundly affected the balance between native and non-native vegetation (Westman, 1983). Disturbances throughout the island in all vegetation types include a century of grazing and browsing by domestic sheep, cattle, and goats, and military training exercises with associated wildfires. Livestock likely were introduced in the mid-1800s, or if they were introduced earlier, their abundance remained low until that time (Bruce, 1994). Sheep and cattle were removed in 1935. Goats and pigs were eradicated over a period of two decades, beginning in 1972. Until the island became a military training area in 1934, as many as 40,000 sheep, 1,000 cattle, plus untold numbers of goats and pigs occupied the island (28,381 goats and 2,195 pigs were removed in the 1970s–1990s) (U.S. Navy, 2002). Long-term overgrazing also may have affected the interception of water by reducing the woody plant cover (U.S. Navy, 2002); this may have caused a feedback cycle that favors non-native grasses. Soil texture and depth also could be important factors affecting the abundance of these grasses. Today, perennial grasses seem to be more common in the areas mapped as “fine loamy grasslands” and the annual grasses are more common in the areas mapped as “clay grasslands”, indicating that the differences may be attributed to soil texture-moisture interactions.

The five most common non-native annual grasses on San Clemente Island toward the end of the goat grazing period were *Avena barbata*, *Bromus madritensis* ssp. *rubens, B. hordeaceus*, *B. diandrus*, and *Hordeum murinum* (Resnick, 1988). Although these grasses were ubiquitous on the island, *B. hordeaceus* and *H. murinum* were more common in low elevations, and *A. barbata* and *B. diandrus* were more common at high elevations. A sixth species, *Lamarckia aurea*, was rarely present in grassland areas and was common in amongst succulent scrub (Resnick, 1988).

Characteristic of island biogeography, San Clemente has several endemic species that are adapted to pre-human settlement conditions and are adversely impacted by unnaturally high levels of disturbance (MacArthur and Wilson, 1967; Westman, 1983). Considering the fact that disturbances in southern California shrublands cause an increase of non-native grasses at the expense of native diversity, fires and grazing on San Clemente Island could have a profound effect, because of the island’s high endemism and low diversity (Westman, 1983). Because of overgrazing on San Clemente Island, six plant, four bird and one reptile taxa are considered threatened or endangered by the U.S. Fish and Wildlife Service (U.S. Navy, 2008).

As is the case in coastal mainland mountains, natural fires are rare in the Channel Islands (only three lightning fires have been documented in 140 years of record-keeping) (U.S. Navy, 2002). On San Clemente Island, there is no evidence that Native Americans ever burned on the island and there were no large native grazers; therefore, burning and mammalian grazing seem to be new phenomena to island ecosystems. Fire was used by sheep ranchers to kill woody plants (that is, *Rhus integrifolia* and *Artemisia californica*) and to stimulate the growth of grasses and forbs for feed (U.S. Navy, 2002). The combined effects of intensive grazing, burning, and drought resulted in the type of conversion of much of the southern plateau to non-native annual grasses that readily burn. Comparing aerial photographs from 1943, 1971, and 1985, much of the shrubland communities on the southern part of the island continued to degrade as a result of goats, whose population exploded after they were abandoned by sheep ranchers (Kellogg and Kellogg, 1994).

Today, although there are no more large grazers on the island (ranching ended when the military took control of the island in 1935; goats and pigs were eradicated in the 1970s–1990s), localized disturbance continues, particularly on the dry southern end of the island. This part of the island is designated the Shore Bombardment Area (SHOBA), where fires ignite from explosions and are generally allowed to burn themselves out. Unexploded ordinance makes it too risky to fight the fires with hand crews, but in certain instances, a helicopter is used to extinguish these fires. To prevent the spread of these fires into habitat for threatened and endangered plants and animals, the U.S. Navy sprays the fire retardant Phos-Chek® between SHOBA and the rest of the island. The U.S. Navy has proposed increasing the frequency and area of its training activities and, in consultation with the U.S. Fish and Wildlife Service, it was decided that the effects of both fire and fire retardant need to be studied (U.S. Navy, 2008). The study areas in the current plan were selected for these purposes.

## Goals and Objectives

The overarching goal of this study was to provide information necessary for sustainable management of endangered fauna and flora on San Clemente Island. The objectives were to evaluate the impacts of fire and fire management practices on federally listed species and their habitat on San Clemente Island (see appendix I). These potential impacts are of particular concern in the dominant shrubland known as boxthorn scrub, the main habitat for the endangered *Amphispiza belli* ssp. *clementeae* (San Clemente Island sage sparrow).The grasslands are also of concern; they are habitats for endangered fauna and flora, including two plants that were a focus of this study, *Sibaria filifolia*, and *Delphinium variegatum* ssp. *kinkiense*. The island has both non-native annual grasslands and native perennial-dominated grasslands. Specific goals were to provide information on the impacts of unplanned escaped fires on island ecosystems and the potential for strategic application of prescribed burning to control non-native species. An additional goal was to provide information on the impacts of long-term applications of Phos-Chek® , which has been used repeatedly on the same sites to limit the spread of fire. Although not a specific goal of this project, the study indicated numerous potential limitations of studying fire-prone ecosystems on San Clemente Island.

## Study Area and Plant Communities

Located in the Pacific Ocean near the Mexican border, San Clemente Island is the southernmost Channel Island in the United States and is located 100 km west of San Diego, California (fig. 1). The climate is subtropical, with February lows of about 4 °C and August highs of about 35 °C (U.S. Navy, 2002). Annual rainfall is highly variable (1996–2006 mean was 169 mm, and during this decade it ranged from less than 50 mm in 2001–2002 to greater than 400 mm in 1997–1998) (Turner, 2009), but additional moisture comes from fog precipitates, which frequently blanket the island in the springtime. During the postfire recovery period of this study, precipitation was relatively low (fig. 2). San Clemente Island has a unique vegetation that has been shaped by Tertiary volcanic substrates, mild marine climate, and isolation from the mainland. Many of the plant communities have been degraded by at least 8,000 years of human habitation (and probably longer), more than 85 years of intensive livestock grazing, and 75 years of military training and weapons testing.

Soils (vertisols and alfisols) are derived from volcanic substrates and marine sediments (U.S. Navy, 2008). Until *Microtus californicus* was introduced by Euro-Americans, San Clemente Island did not have any fossorial animals such as earthworms, burrowing rodents, or salamanders affecting soil porosity and herbivory (U.S. Navy, 2002). There are several vegetation types on the island; this study was located in maritime desert scrub (including 1,465 ha of boxthorn association), maritime sage scrub, annual grassland, and perennial grassland. Over the entire 34-km, north-to-south length of the island, including most of the central plateau, disturbance has resulted in type conversion to annual grasslands, mixed with native forbs and grasses. The east and west slopes maintain extensive native plant cover dominated by shrubs.

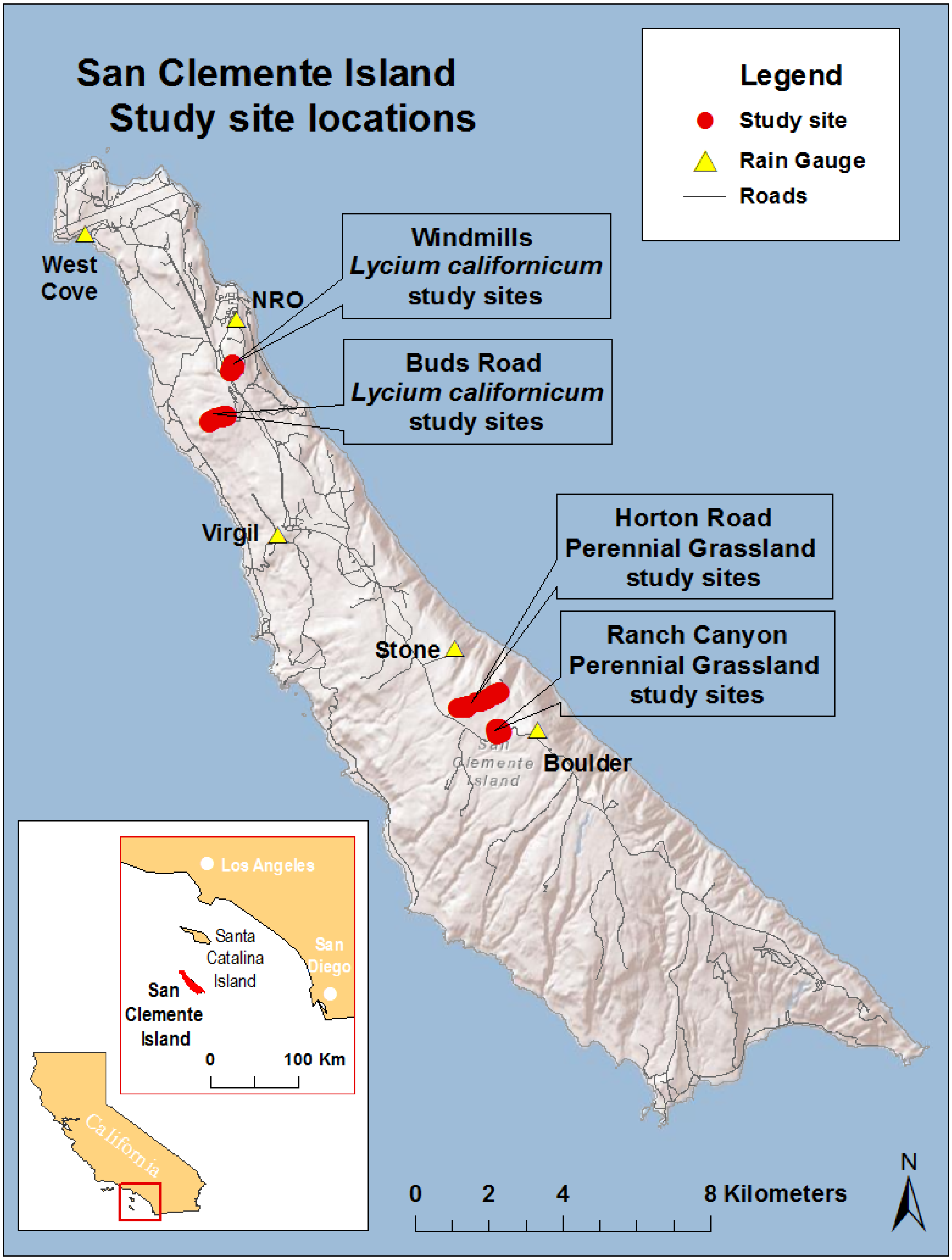



**Figure 1.** Study sites and climate stations (modified from the San Clemente Island Integrated Natural Resources Management Plan [U.S. Navy, 2002]) and relationship to the mainland (from www.alertdiver.com), San Clemente Island, southern California.

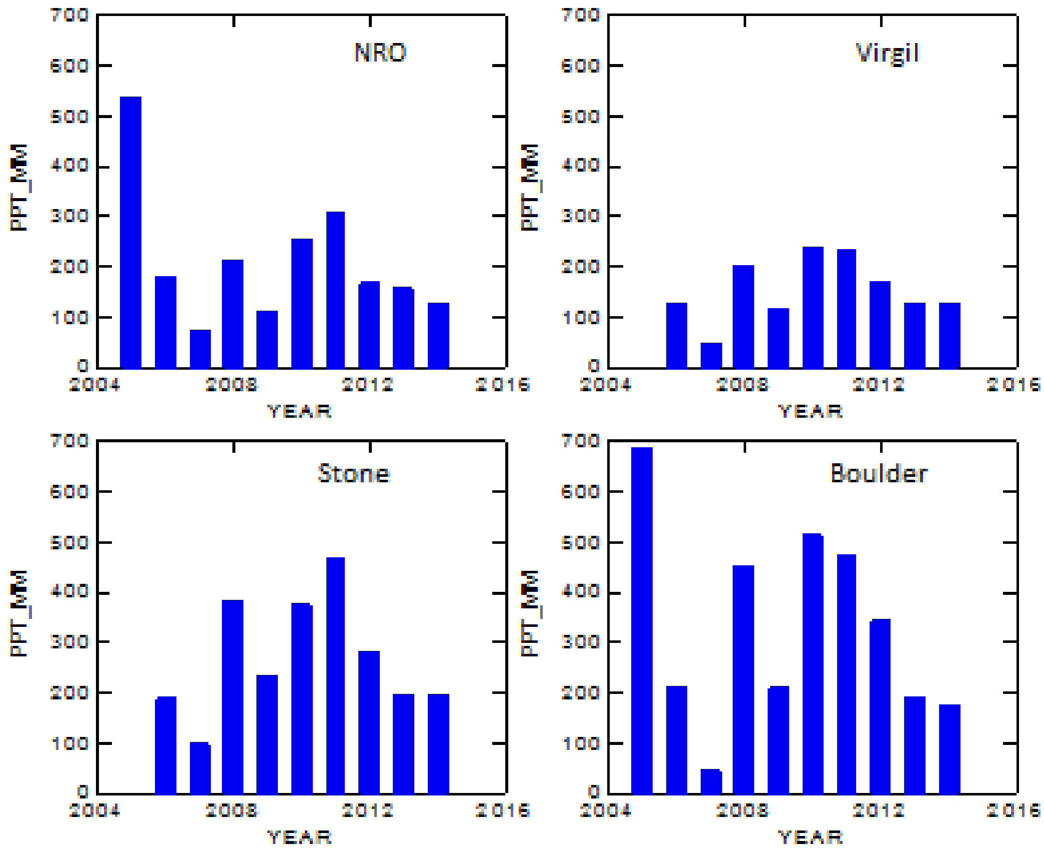



**Figure 2.** Annual precipitation (October–September) at four climate stations, San Clemente Island, southern California (see fig. 1). Data from MESOWEST. PPT_MM, precipitation, in millimeters.

## Project 1—Boxthorn Scrub Sensitivity to Fire

The purpose of this project was to understand the potential impact of fires on recovery of boxthorn scrub vegetation.

Because the community comprises a significant amount of succulent cactus and semi-succulent *Lycium californicum*, which act as a heat sink that could potentially inhibit fire spread, it is likely that fires would only spread in this community at certain times of the year. Based on seasonal patterns of fuel moisture recorded from associated species (fig. 3), we infer that fires are most likely in late summer and early autumn, except during anomalous drought years. We were unable to determine the extent to which fires would be carried by vegetation in the intact system because of restrictions on burning in undisturbed boxthorn scrub. However, prescribed burns may not have been very informative in answering this question because they are conducted under conditions of moderate relative humidity and low wind speed. Semi-succulent vegetation that fails to carry fire under prescribed conditions often will burn during wildfires that ignite outside prescribed burns when temperatures and wind speed are high and relative humidity is low.

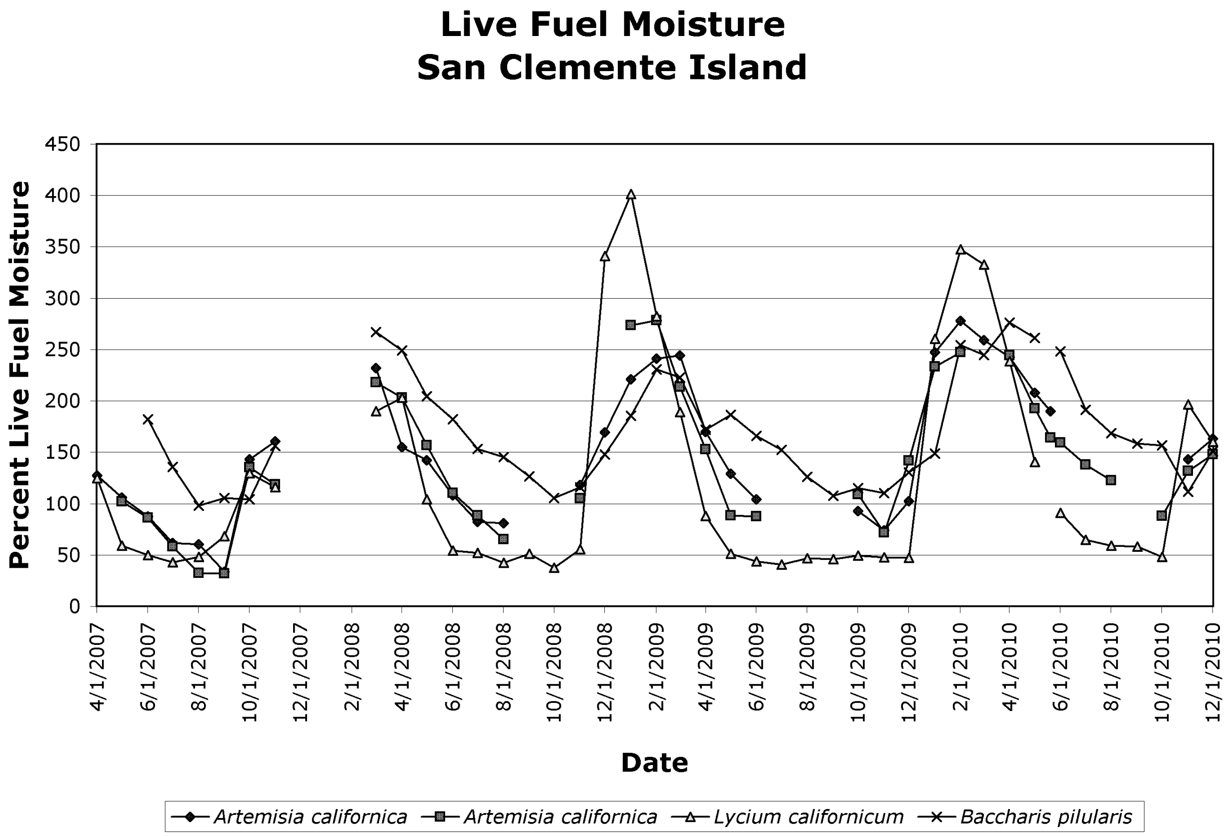



**Figure 3**. Live woody fuel moisture, San Clemente Island, southern California. Data from Emily Howe, Soil and Ecology Restoration Group, San Diego State University.

One factor that will affect both fire behavior and postfire community recovery is the extent of invasion of non-native grasses before fires. Annual grasses comprise flashy fuels that may alter fire spread and intensity, sometimes in ways that favor further non-native invasion (Keeley, 2006). Additionally, prefire grass populations embedded with scrub vegetation establish non-native seed banks that play a critical role in determining the size of populations of non-native species after fire. Therefore, we had initially planned on burn treatments that would be stratified by the level of prefire non-native grasses and forbs. We had planned on including relatively intact boxthorn scrub with very limited non-native plant cover prior to burning, and more open boxthorn with one-quarter or more of surface area currently occupied by non-native grasses and forbs. However, this research design, which had been devised to answer the specific questions posed at the outset, could not be conducted because of restrictions on burning intact boxthorn scrub.

Restrictions on burning in intact boxthorn scrub also limited our ability to measure the resilience of all components of this community to fire. However, we were able to answer a more limited set of questions by burning in highly degraded thorn scrub vegetation. We were able to conduct prescribed fires in highly degraded boxthorn scrub and thus obtain some information on the recovery of *Lycium californicum,* the dominant species in this community.

Our objectives were to conduct late spring prescribed burns in small plots distributed in the native boxthorn scrub. It would have been most informative to burn under conditions conducive to moderate-to-high fire intensity and high canopy mortality. However, the degraded boxthorn scrub lacked sufficient fuels to produce high-intensity burning. In spite of this, the prescribed burns succeeded in producing nearly complete canopy removal of grasses and shrubs. As a result of subsequent monitoring during the next 2 years, we were able to determine the potential postfire recovery of the dominant shrub *Lycium californicum* by resprouts and the extent to which this species indicated postfire seedling recruitment. We also were able to assess the resilience of these open degraded shrublands to return to prefire composition and the impact of burning on the ratio of native shrubs to non-native grasses.

## Project 1—Methods

At two separate sites, Buds Road and Windmills (fig. 1), 20 plots (10 × 10 m) were selected within highly degraded boxthorn/annual grass landscapes. Site selection for controls and burning treatments was based on the criteria that the sites were adjacent and to the west of the main coastal dirt road and represented the appropriate balance of native shrub to non-native grass cover. Specifically, there was less than 50 percent cover by boxthorn scrub, thus presumably making the sites unsuitable for endangered bird species of concern. Although this imposed bias did not provide conditions for drawing general conclusions about how the boxthorn scrub community type would respond to fire, it contained sufficient representation of the dominant shrub to allow conclusions on how this species, *Lycium californicum,* responded to fire.

Prescribed fires for Projects 1 and 2 were set in late spring 2012 (fig. 4. see appendix II for an after-action report for the 2011–2012 Prescribed Fire Grass Plots Project, appendix III for Google Earth views of selected sites for Projects 1 and 2, and appendix IV for video coverage of prescribed burns). Ten of these plots were selected for prescribed burning and a 2.5-m-wide border around the plot also was burned. To the outside of the burned area, a 2-m band was cleared and soaked with Phos-Chek® (see appendix II) to prevent the spread of fire beyond the plots. Fireline intensity was determined with methods described in Keeley and McGinnis (2007); specifically, during the prescribed fires we visually monitored flame length and rate of spread.

Postfire monitoring of vegetation recovery was conducted in spring 2013 and 2014. Each 10 × 10-m plot was subdivided into four equal-size subplots (fig. 5). In the middle of each subplot, a 1 × 1-m quadrat was intensively sampled by recording density, an ocular estimate of cover and height of each species, and whether or not these species were present as seedlings or resprouts. In the remaining part of the subplot, additional species not encountered within the quadrat were recorded and the number of prefire shrubs, as indicated by the burned skeletons, were recorded, and also whether or not they were resprouting,.

Mixed effects analysis of variance (ANOVA) models were used to compare the composition and structure of vegetation in burned compared to unburned controls. For all analyses, the four quadrats were averaged to give a total for each 10 × 10-m plot, so in each statistical test the sample size was n=10 burned and n=10 control plots.

**Figure 4.** Burning in the degraded boxthorn (*Lycium californicum*) scrub showing uneven consumption of vegetation, San Clemente Island, southern California. Photograph by J.E. Keeley, June 2012.

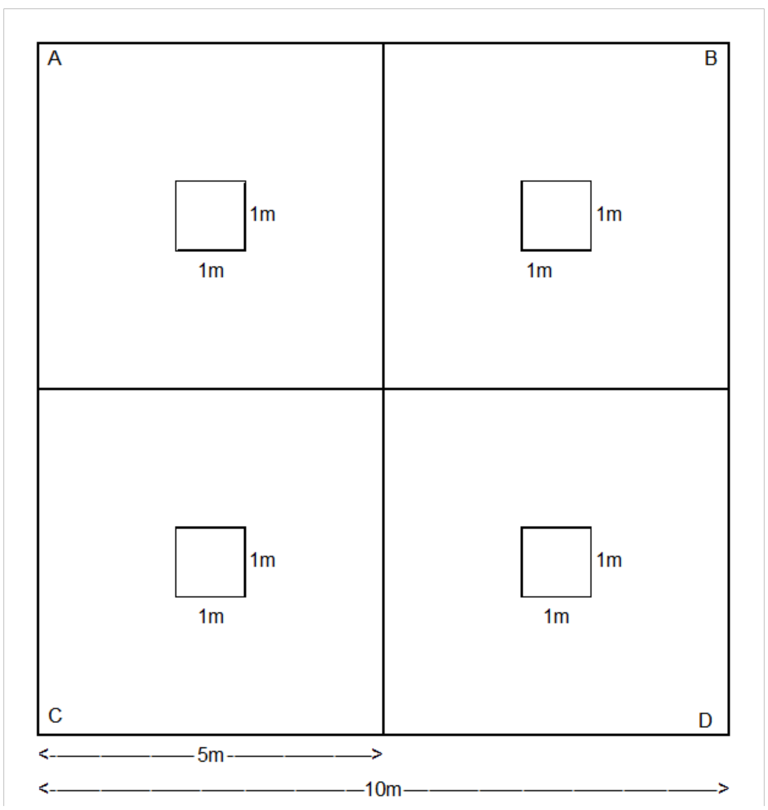



**Figure 5.** Vegetation sampling layout for treatments and controls. Each 10 × 10-meter (m) plot is subdivided into four equal subplots with 1 × 1 m quadrats in the center of each.

## Project 1—Results and Discussion

### Community Response

Total cover in control plots was roughly 50 percent of the ground surface covered and at least one-half of the cover comprised non-native herbaceous species (fig. 6), indicating the highly degraded nature of these boxthorn communities. In the first year after fire, native cover declined relative to controls and non-native species cover stayed about the same (fig. 6. By the second year, native cover was still substantially less than controls. Clearly, fire favored non-native species at the expense of native species, although the effect was not substantial.

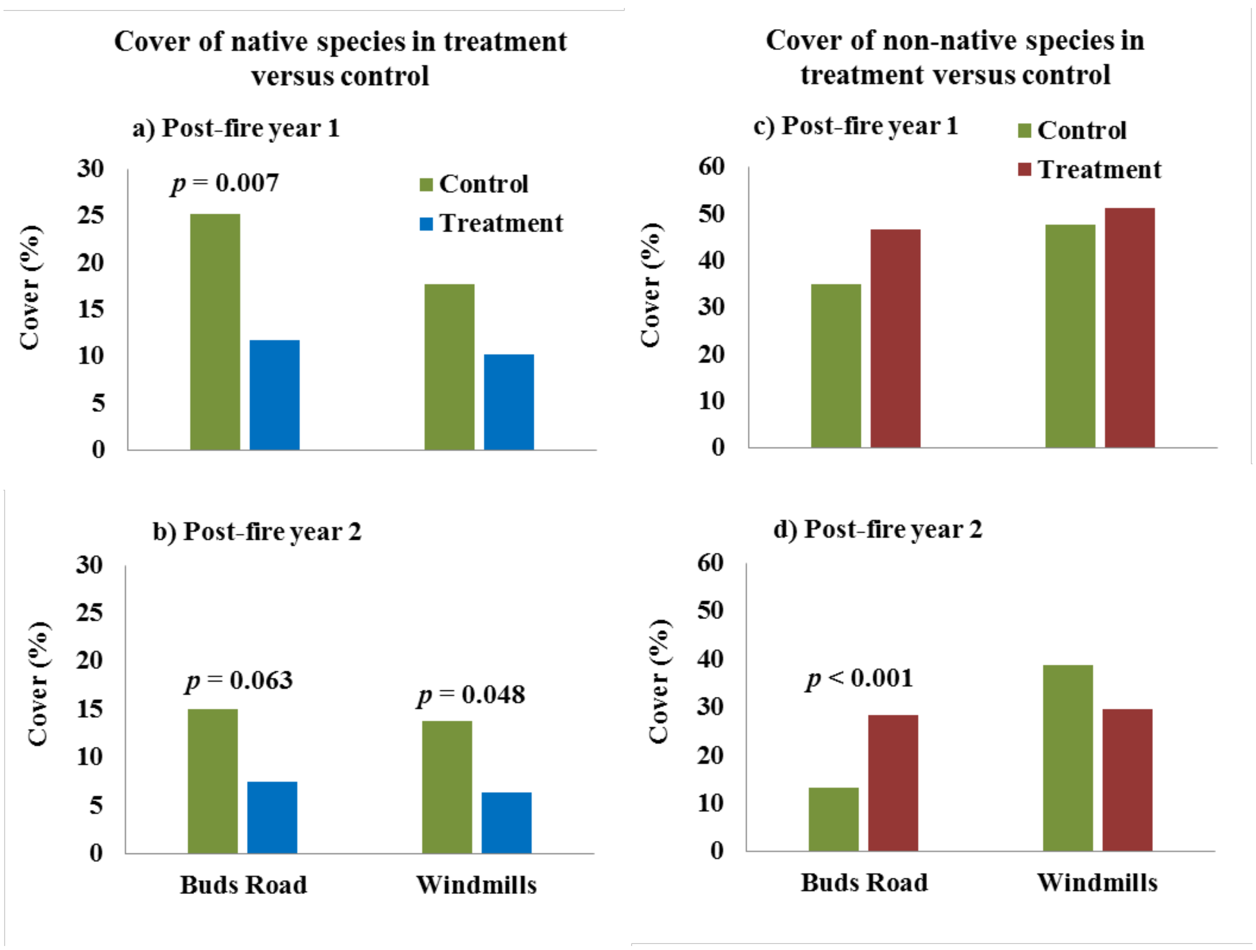



**Figure 6.** Percentage (%) of cover of native and non-native species in degraded California boxthorn (*Lycium californicum*) scrub between prescribed burn treatments and unburned controls at the two boxthorn sites (*p* values for paired t-test), San Clemente Island, southern California.

The dominant shrub in this scrub community is *Lycium californicum* and, thus, a measure of community resilience to fire is the capacity for this shrub to recover after fire. Two specific questions addressed in this study were:

1. After fire, does *Lycium californicum* resprout from the base?
2. Does it have a dormant seed bank that is triggered to germinate in a single group?

Observations after the burning treatments showed that nearly all *Lycium* were top-killed, but it is apparent from comparison with the controls that some of those shrubs likely were dead before the fire (fig. 7a). This species has the capacity to resprout after fire, as shown in figure 7b. In the first postfire year (2013), there were as many or more resprouts in the burned plots as in the controls; however, it is hard to interpret these numbers because of the growth characteristics of this shrub. After burning, what seemed to be a single shrub would resprout from more than one part of the plant and, often where branches had rooted, resprouts would occur, and often the connecting branches made it difficult to ascertain if it was a single small shrub or a rooted branch of a larger shrub. Regardless of these observations, the results show that *Lycium* is a vigorous resprouter after fire. Not all resprouting was realized in the first season, as there was an increase in resprouting individuals in 2014; at the Buds Road site, there was a 70 percent increase in postfire resprouting individuals, and at the Windmills site a 28 percent increase.

Cover of *Lycium* decreased markedly in the first year after fire (fig. 8). In the second year, cover of this species increased slightly at one site but was unchanged or declined at the other site. How long it would take to recover the former cover is not derived from these data, but with an assumption of a constant rate of recovery, we estimate it would be several years or more.

One of the fundamental characteristics of fire-adapted vegetation is the ability to recover after fire with massive seedling recruitment from a dormant seed bank. A breakdown of *Lycium* by growth form indicates that this species does not show postfire seedling recruitment (fig. 9). Two seedlings were found, in total, across all treatment plots. No seedlings were observed in controls.

The response to fire by the two dominant plant families in 2014 is indicated in the subsequent figures that show cover in 2014 for native (fig. 10a) and non-native species (fig. 10b). For native species, the primary increase in cover after fire was for the Asteraceae Family, including *Amblyopappus pusillus, Deinandra fasciculata, Lasthenia gracilis, Logfia filaginioides,* and *Malacothrix foliosa.* For non-native species, *Erodium* increased most at all sites.

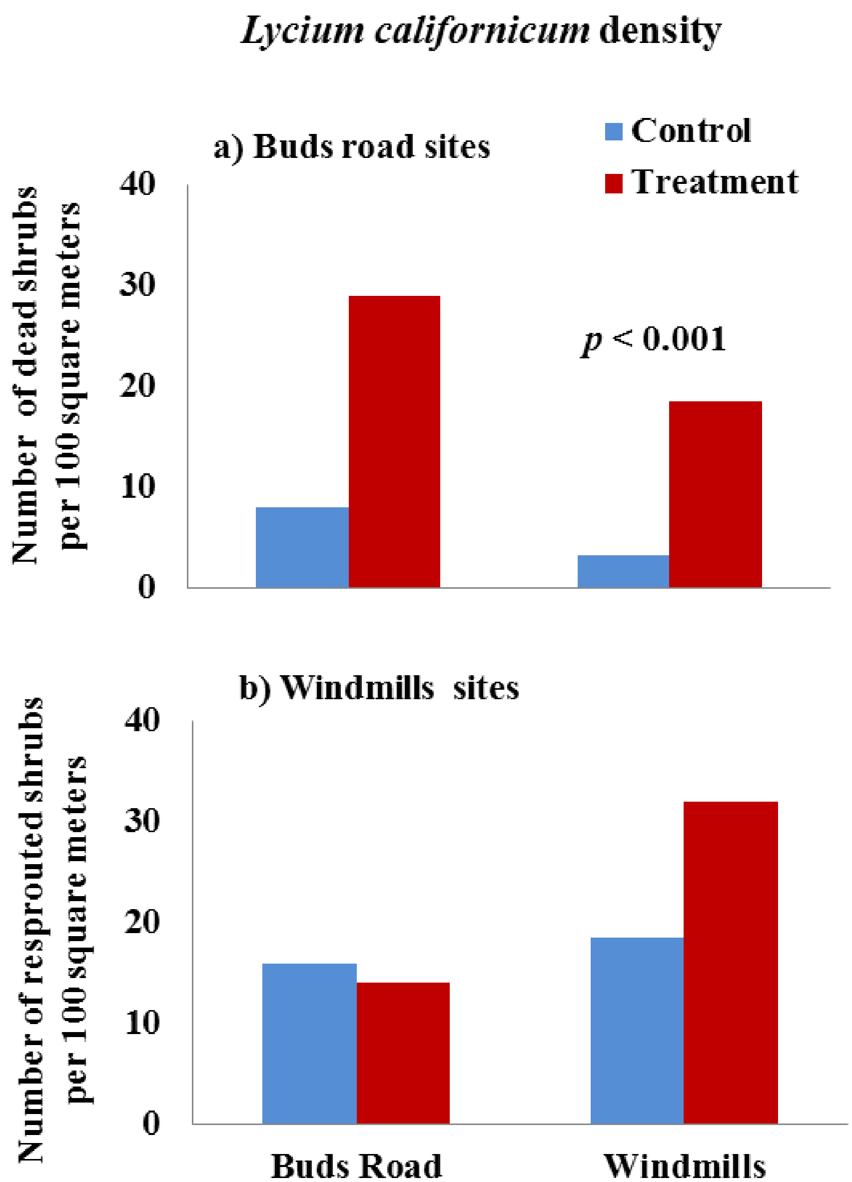



**Figure 7.** Densities of dead California boxthorn (*Lycium californicum*) shrubs (top panel) and resprouting *Lycium californicum* shrubs (bottom panel) in 2013 for first-year burned treatments and unburned controls at the two boxthorn sites (*p* values for paired t-test), San Clemente Island, southern California.

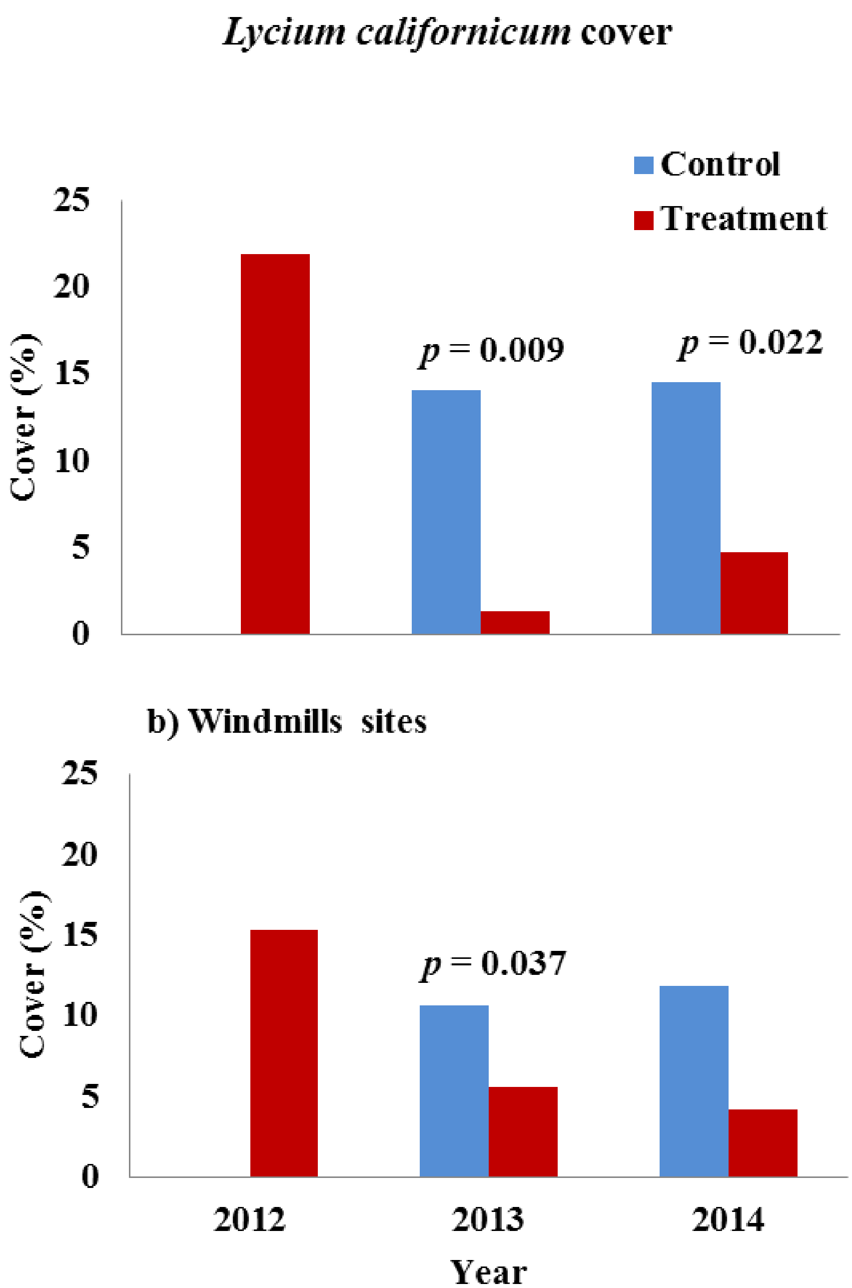



**Figure 8.** Percentage (%) of cover of California boxthorn (*Lycium californicum*) shrubs at the Buds road site (top panel) and Windmills sites (bottom panel) (p values for paired t-test) in 2012 prior to prescribed burns and in the first and second postfire years 2013 and 2014, San Clemente Island, southern California.

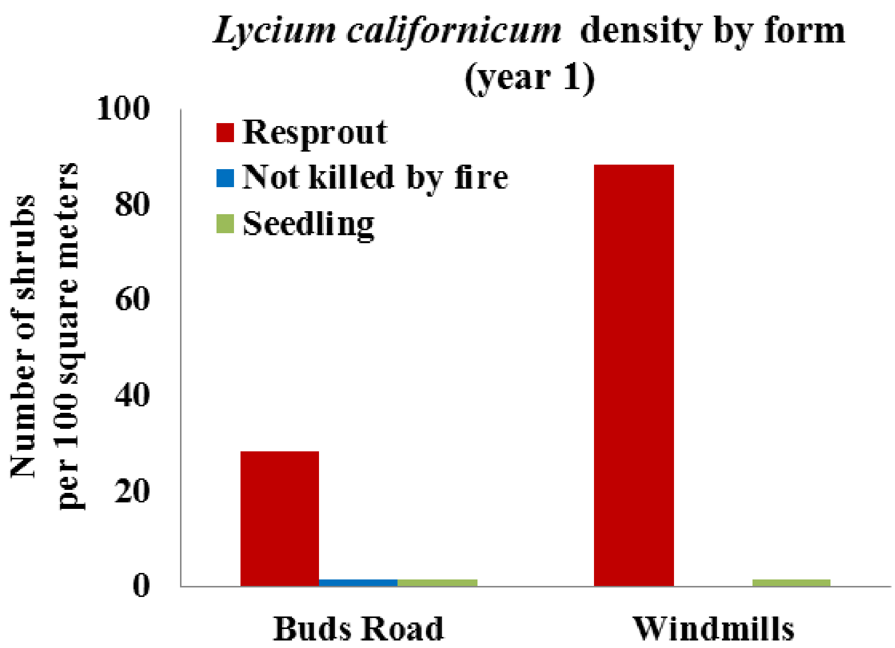
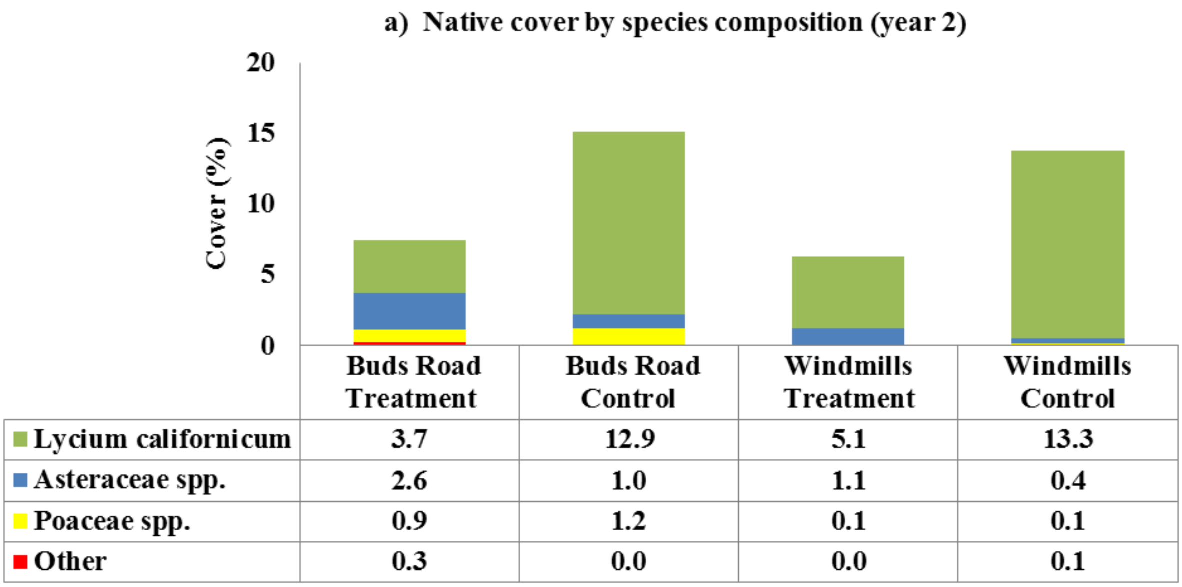
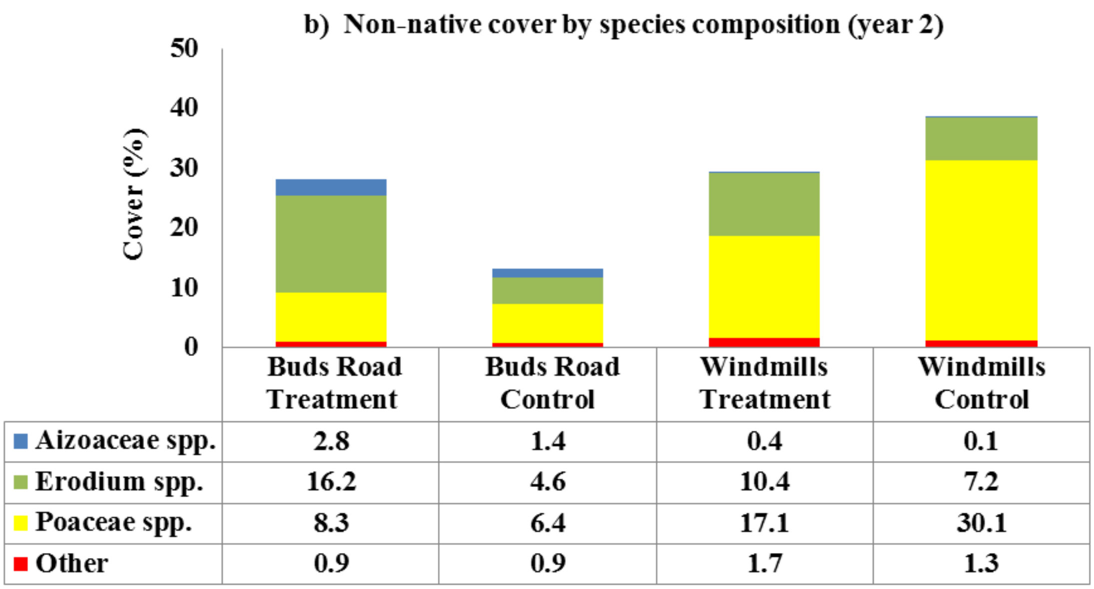



**Figure 9.** Resprouts and seedlings of California boxthorn (*Lycium californicum)* at the two sites in the first year after fire, San Clemente Island, southern California.




| | Buds Road Treatment | Buds Road Control | Windmills Treatment | Windmills Control |
|---|---|---|---|---|
| Lycium californicum | 3.7 | 12.9 | 5.1 | 13.3 |
| Asteraceae spp. | 2.6 | 1.0 | 1.1 | 0.4 |
| Poaceae spp. | 0.9 | 1.2 | 0.1 | 0.1 |
| Other | 0.3 | 0.0 | 0.0 | 0.1 |




| | Buds Road Treatment | Buds Road Control | Windmills Treatment | Windmills Control |
|---|---|---|---|---|
| Aizoaceae spp. | 2.8 | 1.4 | 0.4 | 0.1 |
| Erodium spp. | 16.2 | 4.6 | 10.4 | 7.2 |
| Poaceae spp. | 8.3 | 6.4 | 17.1 | 30.1 |
| Other | 0.9 | 0.9 | 1.7 | 1.3 |

**Figure 10.** Family distribution of cover for native and non-native species between prescribed burn treatments and unburned controls at the two sites, San Clemente Island, southern California.

## Project 2—Native Grassland Response to Fire and Impact on Non-Natives

Multiple goals included determining the impact of prescribed fire on native grassland recovery and the impact of fire on non-native grasses. Although one of the focal species, *Delphinium variegatum* ssp. *kinkiense*, does occur in native grasslands, we were directed to burn plots that did not contain this species. Our specific objective was to determine the recovery of native and non-native grasses for 2 years after prescribed burns. Additionally, we evaluated how the community composition varied in response to different burning conditions.

## Project 2—Methods

Prescribed burns were conducted as described in section, "Project 1—Methods." Our initial objective in these mixed native and non-native grasslands was to burn at a time when non-native grass plants were dry in order to carry fire but the seed not yet dispersed (fig. 11). We hypothesized that this would maximize the lethal effects of the fire on seed viability and produce the greatest reduction in these non-native annual grasses. However, constraints on the timing of prescribed burns (appendix II) resulted in several postponements, so at the time of the burns, significant seed dispersal had already occurred. Plot selection and sampling were the same as in section, "Project 1—Methods"; one exception was that, in the 5 ×5-m subplots outside the 1 × 1-m quadrats, the only additional data recorded were presence of species not occurring in the quadrats.


**Figure 11.** Typical flame lengths and even consumption of biomass in grassland plots, San Clemente Island, southern California. Photograph by J.E. Keeley, June 2012.

## Project 2—Results and Discussion

Burning had a very different impact on native compared to non-native grasses (fig. 12). Non-native grasses, which included species of *Avena, Bromus,* and *Hordeum*, declined substantially after fire, and this difference persisted into the second postfire year. The proportional decrease in native grasses was much smaller and not significant at all sites. At all three sites, *Stipa pulchra* was the only native grass present in our plots, although a few other native grasses occur in this grassland.

Thus, prescribed burning clearly altered the proportions of native and non-native grasses, favoring natives. The gap left by the loss of non-native grasses was largely filled by a large increase in certain non-native forbs—in particular, species of *Erodium*—and this was consistent across all sites (fig. 13).

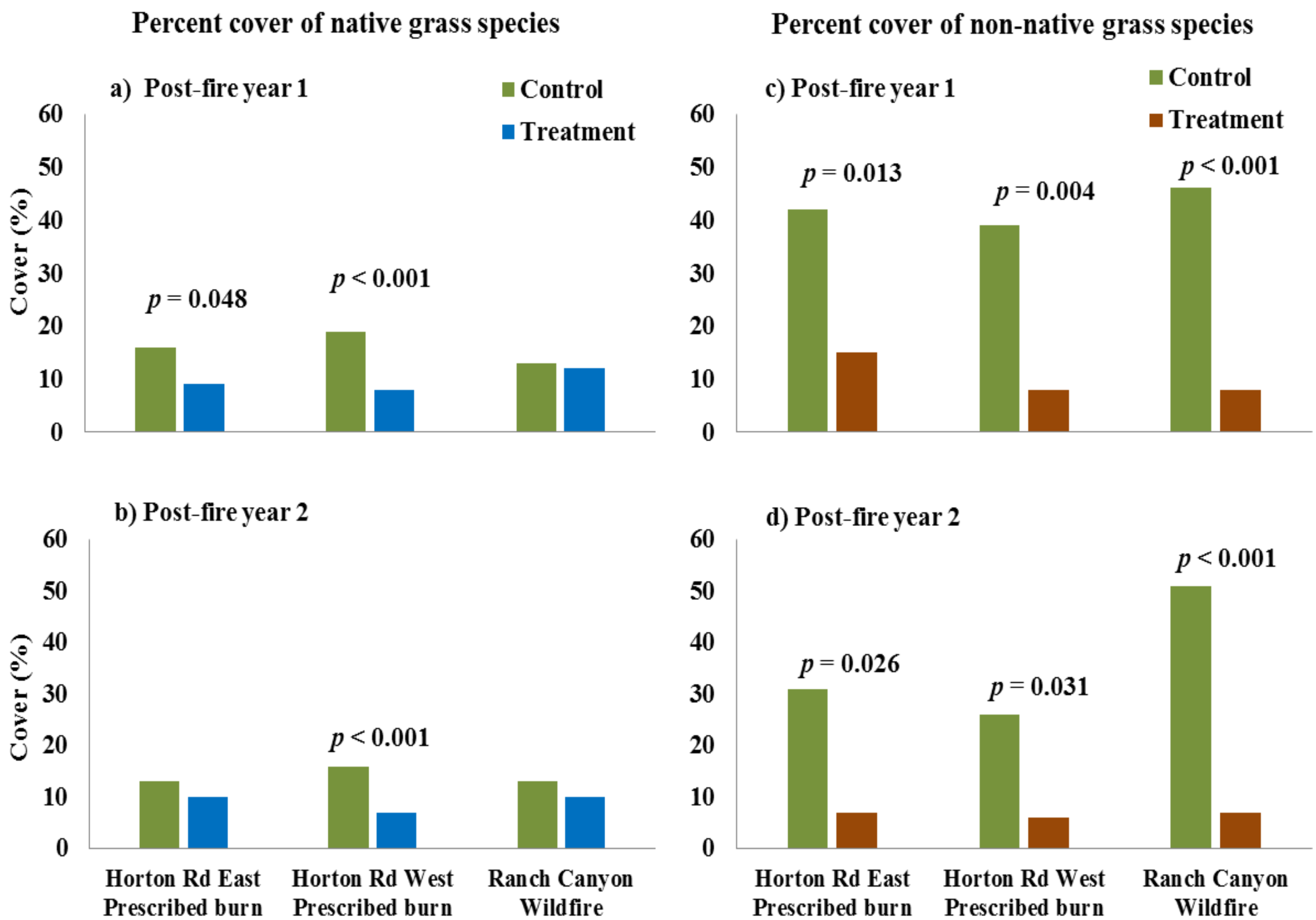



**Figure 12.** Percentage (%) of cover of native and non-native grass cover for controls and prescribed burns in the first and second postfire years at the grassland sites. *P* values indicate significance associated with change in cover between controls and burns for native and non-native grasses separately (with two-tailed t-test).

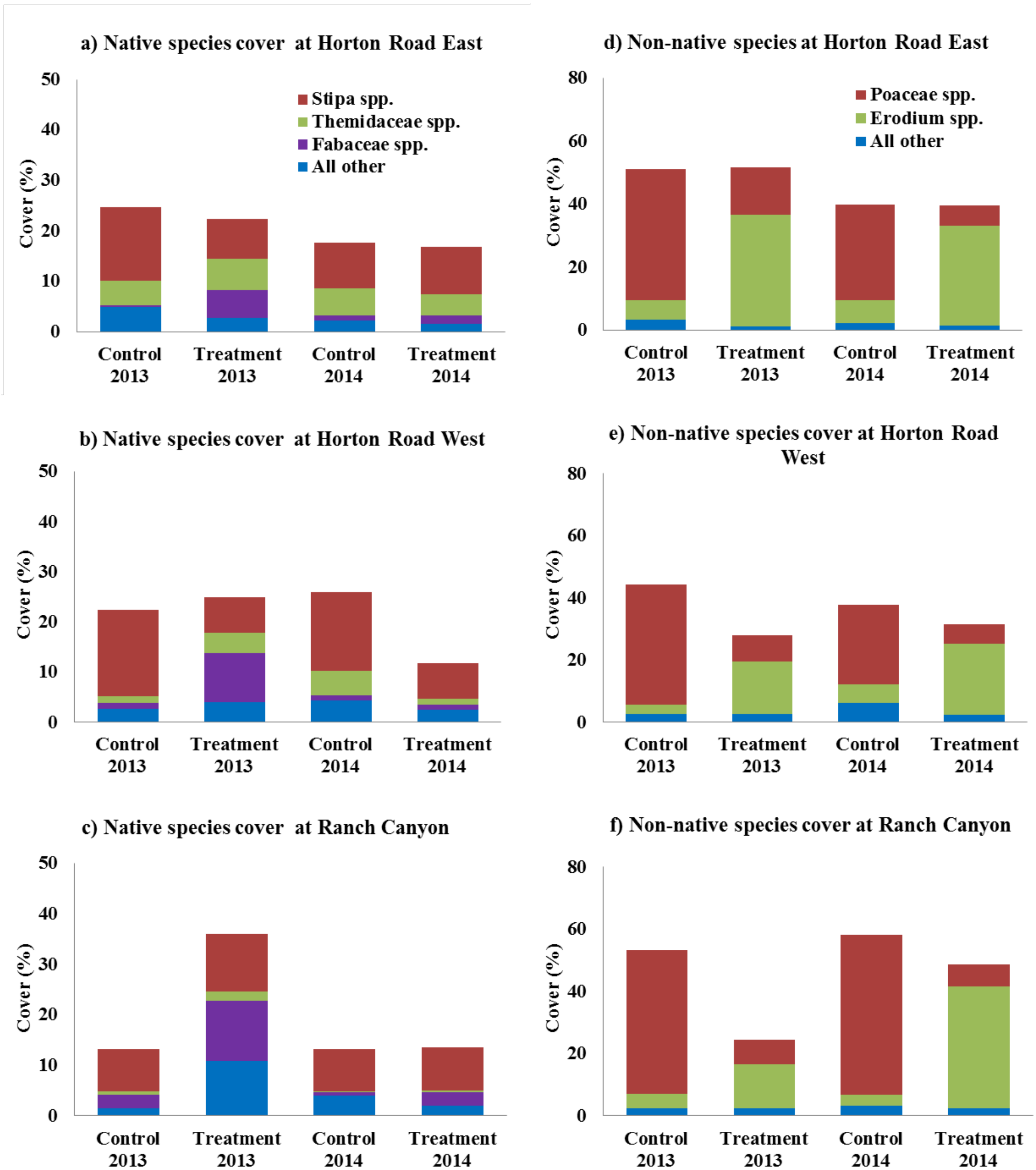



**Figure 13.** Percentage (%) of native and non-native cover of all species at the three grassland sites for controls and prescribed burns in the first and second postfire years, San Clemente Island, southern California.

Looking across all sites, we see a diversity of responses in native and non-native species (table 1). Not surprisingly, geophytes and suffrutescent species that survive fire from underground parts and resprout are not significantly impacted by fire. Herbaceous perennials such as *Stipa pulchra* depend on some part of the aboveground plant surviving fire and reduced in cover by intense burning. Native annuals such as *Lupinus bicolor* and *Trifolium* spp. are hard-seeded species with heat-stimulated germination, as are many species in the Fabaceae family (Keeley and Fotheringham, 2000), and increased after burning. Non-native annuals are dependent on their short-lived transient seed banks surviving fire and, thus, it is not surprising that many of these species were greatly reduced relative to the values present prior to fire,, in particular species of *Bromus*. Somewhat surprising is the opposite response of *Erodium* species, and this may be tied to the unusual seeds that have a hygroscopic awn that allows the seed to self-bury and potentially escape destruction from high-intensity fire (Evangelista and others, 2011).

In the first postfire year, the burned sites had significantly higher diversity of native species at all three sites, but the diversity of non-native species was unchanged (fig. 14). We examined the extent to which fire characteristics might have influenced postfire recovery. Regression analysis of flame length and rate of spread failed to reveal any statistically significant relationships with native and non-native species diversity, total vegetation cover, or cover of just grasses.

**Table 1.** Cover of dominant native and non-native grassland species in controls and first postfire years (n=30), San Clemente Island, southern California.

| Species | Native | Form | 2013 | | | 2014 | | |
|---|---|---|---|---|---|---|---|---|
| | | | Control | Prescribed burn | *P* | Control | Prescribed burn | *P* |
| *Brodiaea kinkiensis* | Yes | Geo | 2.6 | 2.2 | 0.767 | 2.4 | 1.8 | 0.442 |
| *Calystegia macrostegia* | Yes | Suf | 1 | 1.7 | 0.581 | 2.8 | 0.8 | 0.253 |
| *Daucus pusilus* | Yes | Ann | 0.8 | 0.9 | 0.677 | 0.5 | 0.1 | **<0.001** |
| *Dichelostemma capitatum* | Yes | Geo | 0.8 | 1.2 | 0.313 | 0.5 | 0.3 | 0.485 |
| *Lupinus bicolor* | Yes | Ann | 0.4 | 3.5 | **<0.001** | 0.5 | 1.1 | **0.011** |
| *Stipa pulchra* | Yes | HP | 15.3 | 9.3 | **0.003** | 14.3 | 7.8 | **<0.001** |
| *Trifolium* spp. | Yes | Ann | 0.6 | 4.4 | **0.018** | 0.4 | 0.9 | **0.001** |
| *Avena* spp. | No | Ann | 3.7 | 2.1 | 0.075 | 4.2 | 2.7 | 0.11 |
| *Bromus diandrus* | No | Ann | 30.4 | 3.1 | **<0.001** | 29.5 | 2.3 | **<0.001** |
| *Bromus hordaceus* | No | Ann | 4.7 | 1.1 | **0.008** | 2.1 | 1 | 0.175 |
| *Bromus madritensis* | No | Ann | 2.4 | 1 | 0.126 | 0.7 | 0.6 | 0.61 |
| *Centaurea melitensis* | No | Ann | 1.8 | 1.3 | 0.068 | 2.6 | 1 | **0.009** |
| *Erodium* spp. | No | Ann | 5.5 | 22.4 | **<0.001** | 5.8 | 28.3 | **<0.001** |
| *Festuca* spp. | No | Ann | 6 | 4.1 | 0.303 | 1.3 | 1.6 | 0.248 |

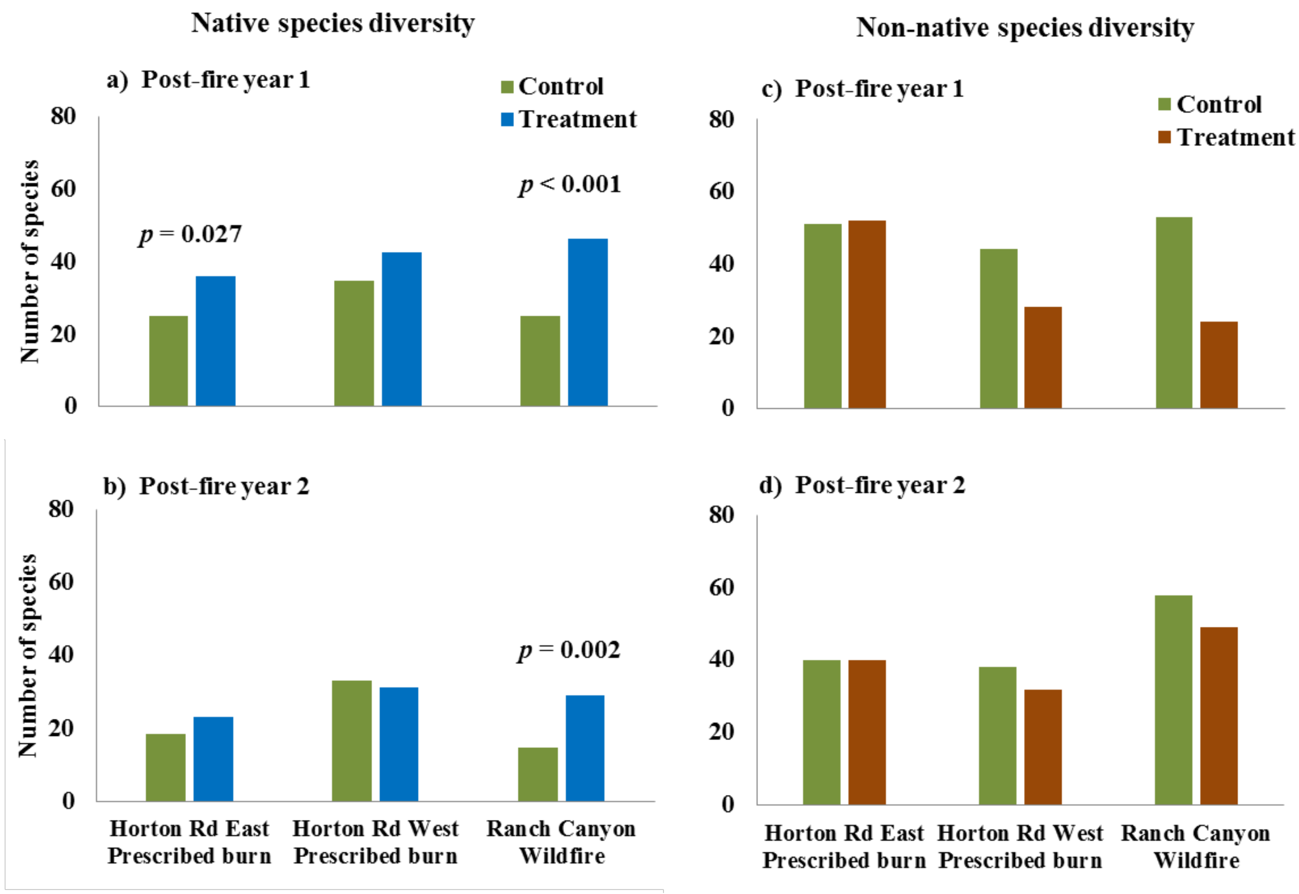



**Figure 14.** Diversity (number of species) of native and non-native species at the three sites for controls and prescribed burns in the first and second postfire years, San Clemente Island, southern California.

## Project 3—Impact of Fire on Three Listed Plant Species

The goal of this project was to evaluate the impact of fires on three listed plant species—*Sibaria filifolia* (Santa Cruz Island rockcress), *Malacothamnus clementinus* (San Clemente Island bush-mallow), and *Delphinium variegatum* ssp. *kinkiense* (San Clemente Island larkspur). Because of their federally listed status, direct measurements of fire impact on these species was not possible. Although bush-mallow occurs in undisturbed boxthorn scrub, it was not present in our degraded boxthorn sites and the effect of fire was not directly observed. The endangered larkspur does occur in native grasslands, but we were directed to select plots that did not have larkspur in them. Rockcress tends to occur in more open sites, and was not present in any of our burned sites. Our evaluation of the impact of fire on the persistence of these three species was based on their seed germination responses to fire cues such as heat-shock and smoke and a review of the literature (Keeley, 1987, 1991; Keeley and Fotheringham, 2000) on fire responses of similar functional types.

The larkspur is an herbaceous perennial, the mallow is a subshrub, and the rock-cress is a short-lived annual. Based on these different life histories, we might expect differences in their responses to fire. We outline here the general responses to fire known from different history types in coastal California. These patterns will be used to predict the fire responses of each of the listed species and to predict how their seed germination will respond to fire-type cues such as heat shock and smoke. This approach was necessary because of the rarity of these species, which prevented us from being given permission to do field studies of their fire response; however, we were able to do limited experimentation on seed germination responses to fire-related cues.

### Life-History Generalizations

There is much published information on postfire responses of a wide diversity of plants in chaparral and related shrublands in California (Keeley and others, 2012). Based on these data, there are numerous inferences one could make about the impact of fire on the three listed species.

### Annual Plants

Annual plants are ephemeral species that germinate in the winter and spring and grow for 1 to several months before setting seed and persisting as a dormant seed bank. This life form is well represented in the California flora and comprises diverse responses to fire. At one extreme are the “postfire endemics,” species that are largely restricted to the first couple of growing seasons after fire and then remain for decades as a dormant seed bank. Germination of these species often requires smoke or other chemicals from biomass combustion, and without such a stimulus they remain deeply dormant. Examples include *Emmenanthe penduliflora* (Boraginaceae, formerly Hydrophyllaceae), *Phacelia* spp. (Boraginaceae), *Allophyllum* spp. (Polemoniaceae), *Papaver californica* (Papaveraceae), *Silene multinervia* (Caryophyllaceae), and *Antirrhinum coulterianum* (Plantaginaceae, formerly Scrophulariaceae).

Many of the annuals associated with shrublands are “opportunistic.” Such species may establish in the absence of fire from non-dormant seeds that germinate during most years. Often they produce a polymorphic seed bank that includes a part that is non-dormant and a part that is deeply dormant and requires either heat or smoke to trigger germination. These species often dominate sites after fire, but persist in smaller numbers in openings within the shrubland as well as in adjacent grasslands. Examples include *Cryptantha intermedia* (Boraginaceae), *Gilia capitata* (Polemoniaceae), *Lotus salsuginosus* (Fabaceae), *Lupinus succulentus* (Fabaceae), and *Lepidium nitidum* (Brassicaceae).

Some annuals are restricted to barren sites such as rock outcrops or thin soils that have insufficient fuel to carry fire. They may be established in most years, and they sometimes colonize denser grasslands that can carry fire, but when burned, their seeds are sensitive to fire and the species “retreats” back to refugia of lower fuels. Examples include species of *Pectocarya* spp. (Boraginaceae), *Pterostegia drymarioides* (Polygonaceae), *Chorizanthe* spp. (Polygonaceae), and *Nemacladus ramosissimus* (Campanulaceae). The BO (FWS-LA-09B0027-09F0040 2008) identifies Saharan mustard (*Brassica tournefortii*) and non-native grasses (for example, *Schismus arabicus*) as invasives of particular concern for Santa Cruz Island rock cress because they can spread in the dry conditions that characterize the sites where the Santa Cruz Island rock-cress is located. The BO raises concerns that these species might increase fuel loads in this low-fuel habitat and increase the risk of fire burning through the area. These habitats have very low primary productivity; given this fact and the results of the non-native annual grassland studies reported in this study, it is unlikely that fuel loads in Santa Cruz Island rock cress habitat could be high enough or continuous enough to adversely affect this species.

Adverse effects of fire on annual plants occur through destruction of the seed bank. It is unlikely that soil temperatures would be high enough to kill soil-stored seed, and seed retained in the canopy only would be killed if there were sufficient biomass immediately surrounding the plant because Santa Cruz Island rock cress plants themselves have very low biomass.

California has a large flora of non-native weedy annuals that germinate with the first autumn rains and that are aggressive colonizers. Seeds generally are large and poorly buried, so they are sensitive to fire intensity. Fires in grasslands seldom reach intensities sufficient to kill these seeds, and so the seeds generally are established well after fires in these open habitats. Shrublands have sufficient fuel to create fire temperatures that are lethal to these invasive seed banks. Examples include *Bromus* spp. (Poaecae), *Avena* spp. (Poaceae), *Brassica* spp. (Brassicaceae), *Erodium* spp. (Geraniaceae), and *Salsola kali* (Chenopodiaceae).

### Herbaceous Perennials

The herbaceous perennial growth form produces herbaceous stems that live for less than 1 year, but the plant persists as perennial underground vegetative structures, including rhizomes, bulbs, corms, etc. In coastal southern California, sprouting from underground parts occurs in the winter and spring, and during summer, these stems die back. Thus, sprouting is a natural phenological stage that may occur annually, regardless of fire. Most fires occur during the time of year when the plants are dormant above ground and, thus, fire has a minimal impact on this life form. Such species typically flower most extensively after fire and; thus, they produce a pulse of seed that generally is non-dormant. Seed germination and seedling establishment is non-existent in the first year after fire because of limited soil seedbank and poor seed survival during fire. However, in the second postfire year, seedling recruitment may be abundant. Seeds generally lack dormancy, and once they are subject to the appropriate winter or spring temperature regime, they germinate readily without any fire-related cues. Examples include *Delphinium* spp. (Ranunculaceae), *Stipa* spp. (Poaceae), *Calochortus* spp. (Liliaceae), *Zigadensus* spp. (Liliaceae), and *Lomatium* spp. (Apiaceae).

### Suffrutescents

Suffrutescent species retain a woody base, but most of the annual growth dies back each year. They generally are short-lived (that is, they live for less than a decade) and, thus, they commonly are not present at the time of fire and, if they are present, they do not resprout to any extent. These species have dormant seed banks that are triggered by fire—either by heat shock or smoke. Examples include *Acmispon glaber* (formerly *Lotus scoparius*; Fabaceae), *Helianthemum scoparium* (Cistaceae), and *Dicentra chrysantha* (Papaveraceae, formerly Fumariaceae).

### Subshrubs

Weakly woody species comprise the dominants in sage scrub ecosystems and seral species in chaparral. Most of these subshrubs resprout to some extent after fire and recruit seedlings. None are obligate seeders. They typically produce polymorphic seeds, with a significant portion capable of germinating in the absence of fire and another portion remaining dormant until germination is triggered either by heat shock or smoke. Examples include *Artemisia californica* (Asteraceae), *Malachothamnus fremontii* (Malvaceae), *Eriogonum fasciculatum* (Polygonaceae), and *Salvia* spp. (Lamianceae). A few subshrubs, such as *Encelia californica* and *Hazardia squarrosa* (Asteraceae), are obligate resprouters immediately after fire, but resprouts flower prolifically in the first postfire growing season and non-dormant seeds recruit extensively in the second postfire year.

### Shrubs

Shrubs are obligate seeders, facultative seeders, or obligate resprouters. Obligate seeders and facultative seeders recruit seedlings ‘only’ in the first postfire year, and obligate resprouters recruit seedlings sporadically later in succession. All are resilient to high-intensity fires, and the primary impact of fire is when the return interval is shorter than the time required to build up sufficient soil seed banks.

### Life History Characteristics of the Three Listed Species

In this section, we predict how *Delphinium variegatum* ssp. *kinkiense, Malacothamnus clementinus*, and *Sibaria filifolia* will respond to the seed germination experiments, and we relate those results to expected responses to fire. *Delphinium variegatum* ssp. *kinkiense* is an herbaceous perennial, and we expect that seeds are largely non-dormant and will not be stimulated by fire type cues. *Malacothamnus clementinus* is similar in stature and ecology to *M. fremontii*, a species that has been studied extensively. Based on prior germination results for *M. fremontii* , we predict that *M. clementinus* germination will be stimulated by fire and will respond to heat shock but not to smoke. *Sibara filifolia* is a diminutive annual that generally is restricted to rock outcrops and other sites with thin soils and limited biomass. We predict that seeds will germinate without fire, and that neither heat-shock nor smoke will stimulate further germination.

### Seed Germination

To evaluate how fire might impact the three target species, we conducted laboratory germination experiments on wild-collected seeds in response to fire cues such as heat-shock and smoke. Direct effects of heat-shock and smoke on seed germination were assessed as in previous studies (for example, Keeley, 1987; Keeley and Fotheringham, 1998). As indicated in these published studies, a range of temperature treatments and smoke concentrations are necessary to determine stimulatory effects from lethal effects on seeds.

We tested germination of the three listed species of concern from San Clemente Island: the annual *Sibara filifolia* (Santa Cruz Island rock cress), the herbaceous perennial *Delphinium variegatum* ssp. *kinkiense* (San Clemente Island larkspur), and the subshrub *Malacothamnus clementinus* (San Clemente Island bush-mallow). Seeds were collected from the island, cleaned of fruit material and other debris, and supplied to the U.S. Geological Survey laboratory by Dr. Dawn Lawson. Direct effects of heat-shock and smoke on seed germination were assessed as in previous studies (for example, Keeley and Fotheringham, 1998).

## Project 3—Methods

### Viability Tests

A subset of seeds was assessed for viability with the standard tetrazolium test (Grabe, 1970). When applied directly to seed tissues, the dye responds to respiring tissues by turning red, and this is interpreted as an indication of viability. For this experiment, 10 seeds per species were placed on filter papers in glass petri dishes, about 2.5 mL of deionized water was added per dish, and seeds were left to hydrate overnight.

Seeds were then cut in one-half or nicked or punctured to expose the embryo or other vital tissue to the staining solution. All cutting was done under a microscope with the use of putty to stabilize the seeds. Seeds of the *M. clementinus* and *D. variegatum* ssp. *kinkiense* were cut in half longitudinally (both pre-conditioned and non-conditioned). The non-conditioned *S. filifolia* were halved. The pre-conditioned seeds, because of their softened tissue, were nicked or punctured.

A 0.1 percent solution of 2,3,5-triphenyltetrazolium chloride (TZ; 0.1 g/100 mL distilled [DI] water) was applied so it covered the seeds, and they were placed in the dark in a drawer overnight. The time needed for staining is species-specific, and some species required longer incubation periods. *S. filifolia* was left in TZ solution longer, owing to lack of staining after overnight treatment.

Embryos showing active respiration were considered "viable" and turned red. The darker the color, the greater the respiratory activity in the seed. Seeds with no visible staining were considered “non-viable”. The results from this TZ test were used to provide a basis for expressing germination results.

## Germination Experiments

Treatments were as follows:

Controls No treatment prior to incubating in distilled (DI) water

Heat: Dry heat at:
70 °C for 1 hour
100 °C for 5 minutes
Followed by incubation in DI water

Smoke: In place of DI water, dishes were supplied with liquid smoke diluted with DI water in the following ratios
1:100
1:500

Each treatment was replicated five times. Replicates comprised 15 seeds each for each species.

Seeds to be heat-treated were placed in glass petri dishes (lids removed). In both heat treatments, a heated metal rack from inside the oven was removed and the glass petri dishes were then quickly placed directly on the rack. The rack was placed back into the forced convection oven.

The brief heat treatment varied temporally because of the decrease in temperature when the oven door was opened and the dishes at room temperature were placed inside, although this was not a complication for the 1-hr treatment. To reduce this variation, the brief heat treatment was set at a higher temperature (103 °C), and ran at that temperature for several minutes until the temperature was correct. This increase in temperature was meant to ensure that the average temperature of the oven was within ±3 °C of the preferred temperature, and the timer started as soon as the seeds were placed inside the oven. Any slight variation in the temperatures was not meant to clearly define temperature optima, but, rather, to evaluate whether or not there was a germination response to heat-shock *per se*.

Germination was conducted in 60 × 15-mm polystyrene petri dishes with two pieces of 55-mm Whatman® No. 1 filter paper, and was initiated with the addition of 2.3–2.5 mL of deionized water for controls and heat-treated treatments. The same quantity of liquid smoke dilution was added to the smoke treated seeds. Petri dishes were separated by treatment, placed on plastic trays, and enclosed in heavy plastic bags to reduce evaporation and transfer of gases between treatments. Trays holding the smoke-treated dishes were double-bagged to ensure no transfer of smoke vapor to other trays.

Trays received a cold treatment by being stored for 3 weeks in a refrigerator set at about 4 °C. Trays were checked weekly to ensure that evaporation had not occurred and that the filter papers still seemed to be moist. Incubation followed with 12 hr in the light at 20 °C, alternating with 12 hr in the dark at 10 °C. Seeds were examined weekly for 6 weeks, and germinated seeds were recorded and removed. Germination was determined as the emergence of the radicle.

Final germination was expressed as a percentage of apparently viable seeds. Percentage germination was arcsine transformed prior to analysis. Treatments were analyzed with one-way ANOVA, and pairwise comparisons were made with the Bonferroni post hoc test. All analyses and graphics were run with SYSTAT® 10.2 (www.systat.com).

## Project 3—Results and Discussion

### Seed Viability—Tetrazolium (TZ) Test

Seeds of the annual *Sibaria filifolia* had less than 50 percent viability (table 2). No staining occurred on either pre-conditioned or non-conditioned treatments after the initial overnight soak. These were left in solution longer, and still no staining occurred after 48 hr. A higher percentage solution was used that included a 1 percent (1 g TZ/100 mL DI water), and seeds were soaked overnight. Very faint staining occurred, which may be a reasonable amount to consider viable or may show very low respiration activity that would not result in seed germination. There was a slight difference in possible TZ uptake with the pre-conditioned seeds, showing a slight increase in staining.

Seeds of the herbaceous perennial *Delphinium variegatum* ssp. *kinkiense* indicated high viability (table 3). There was no notable difference in staining between pre-conditioned and non-conditioned seeds. Staining varied between almost grayish/light pink to medium red. The grayish/pink seeds were considered to have reduced viability, and designated as "unsure."

The subshrub *Malacothanmnus clementinus* had high viability and conditioning had no effect on the viability test (table 4).

**Table 2.** Tetrazolium test results of viability for Santa Cruz Island rockcress (*Sibaria filifolia*).

| Number of pre-conditioned seeds | | Number of non-conditioned seeds | |
|---|---|---|---|
| Viable: | 0 | Viable: | 0 |
| Not viable: | 5 | Not viable: | 6 |

**Table 3.** Tetrazolium test results of viability for San Clemente Island larkspur (*Delphinium variegatum* ssp. *kinkiense*).

| Number of pre-conditioned seeds | | Number of non-conditioned seeds | |
|---|---|---|---|
| Viable: | 7 | Viable: | 7 |
| Not viable: | 1 | Not viable: | 0 |
| Unsure: | 2 | Unsure: | 3 |

**Table 4.** Tetrazolium test results of viability for San Clemente Island bush-mallow (*Malacothamnus clementinus*).

| Number of pre-conditioned seeds | | Number of non-conditioned seeds | |
|---|---|---|---|
| Viable: | 9 | Viable: | 9 |
| Not viable: | 1 | Not viable: | 1 |
| Unsure: | | Unsure: | |

## Germination

Germination of the annual Santa Cruz Island rock cress *(Sibara filifolia)* is shown in figure 15, germination of the herbaceous perennial San Clemente Island larkspur (*Delphinium variegatum* ssp. *kinkiense*) is shown in figure 16, and germination of San Clemente Island bush-mallow *(Malacothamnus clementinus)* is shown in figure 17. Statistical comparison of germination responses is shown in table 5.

Although germination of this ephemeral annual was not very high, it germinated under control conditions and certain fire cues resulted in significant decreases in germination. This herbaceous perennial showed nearly complete germination under control conditions and fire cues resulted in either no change in germination or significant decreases in germination. This subshrub had poor germination under all treatments and treatments showed no statistically significant effect.

**Table 5.** Analysis of Variance comparison of seed germination treatments shown in figures 15–17.

| Species | df | F | *P* |
|---|---|---|---|
| *Sibara filifolia* | 4 | 10.6 | <0.001 |
| *Delphinium variegatum* ssp. *kinkiense* | 4 | 42.0 | <0.001 |
| *Malacothamnus clementinus* | 4 | 1.8 | 0.167 |

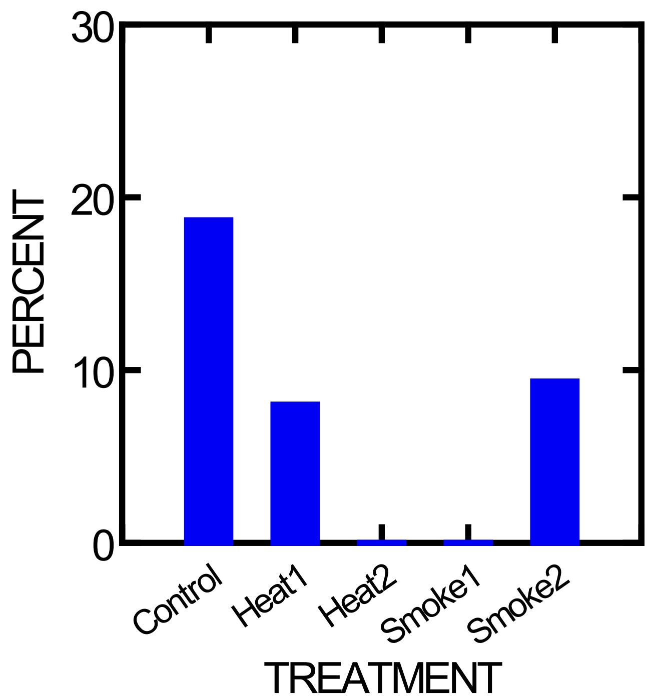



**Figure 15.** Germination of *Sibara filifolia* in response to heat shock and smoke treatments, San Clemente Island, southern California. See table 1 for statistical analysis.

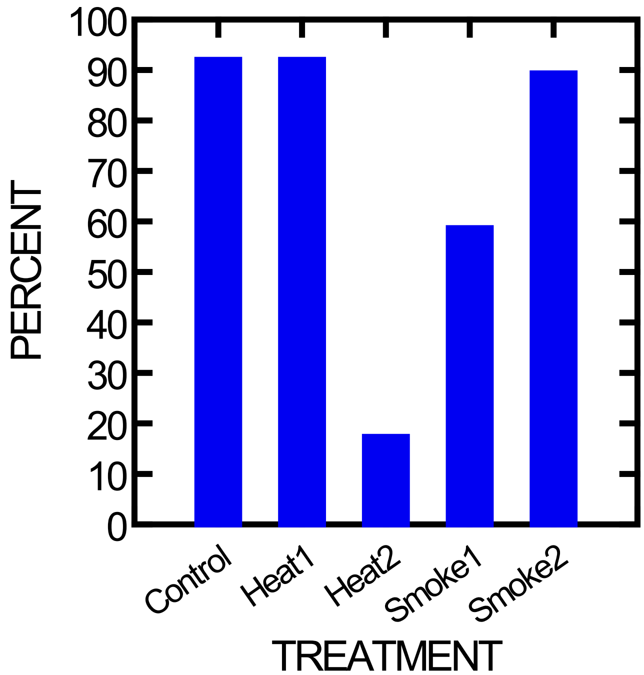



**Figure 16.** Germination of *Delphinium variegatum* ssp. *kinkiense* in response to heat shock and smoke treatments, San Clemente Island, southern California. See table 1 for statistical analysis.

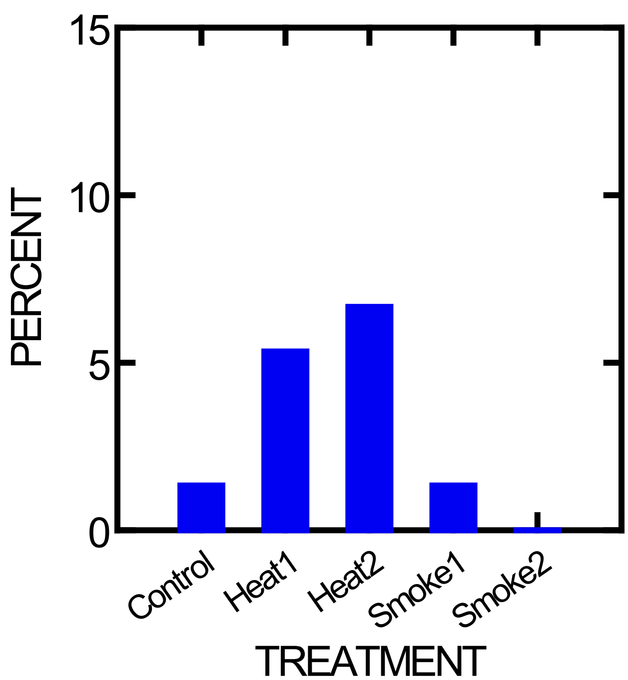



**Figure 17.** Germination of *Malacothamnus clementinus* in response to heat shock and smoke treatments, San Clemente Island, southern California. See table 1 for statistical analysis.

### Project 3—Conclusions

Seed germination results were consistent with the patterns expected based on life-history studies in these fire-prone ecosystems.

*Sibara filifolia* is an ephemeral annual present on severe sites such as rock outcrops or thin soils. It is to be expected that, on such sites, fire is not an important ecosystem process because fuels are lacking that could carry fire. Of course, for all species that occur in such refugia (for example, species of *Chroizanthe*), between fires the species may colonize other sites subject to fire. As a general rule, these species are extirpated from such sites, but survive fires in these refugia sites. Seed germination experiments (fig. 15) are consistent with this hypothesis.

*Delphinium variegatum* ssp. *kinkiense* is an herbaceous perennial distributed in the remnants of native grassland persisting on the island. Although we have relatively few studies of how fires impact native grasslands in California, the our limited understanding suggests that herbaceous perennials, including *Delphinium variegatum* ssp. *kinkiense*, are resilient to fires at relatively close intervals because recovery involves normal winter sprouting and is not dependent on accumulation of seed banks or fire-stimulated seed germination, as shown in figure 16. Although this species was not in any of our grassland burn plots, it has a life history similar to those of the *Brodiaea kinkiensis* and *Dichelostemma capitatum* that were present. As shown in table 1, these native perennials were not significantly affected by fire. It is unknown what frequency of fire represents a sustainable fire regime for these perennials that survive fire from underground vegetative structures. Fires occurring at intervals of less than 5 years likely will not be detrimental, but the *Delphinium* populations may tolerate much greater fire frequencies.

*Malacothamnus clementinus* is a subshrub present in low-growing scrub. Based on earlier seed germination results of the closely related *M. fremontii*, we expected heat shock and not smoke to stimulate germination (fig. 17). Although our germination results seemed to support this prediction, results were not statistically significant. Viability tests suggested the seed pool was viable, although the tetrazolium test is only an indicator of potential viability and not the final word on viability. Furthermore, it is clear from abundant seed studies that species with deeply dormant seeds, as predicted for *M. clementinus*, often may require months of incubation for full germination; therefore, our estimates may be low. This species also could benefit from a longer germination period.

### Project 4—Impact of Phos-Chek® Fire Retardant

Phos-Chek® is a powdery fire retardant that is mixed with water and typically applied by aircraft during a fire event to reduce the rate of fire spread. On San Clemente Island, it was applied as a pre-fire treatment to create a perimeter around the zone of highest fire potential (fig. 18). Phos-Chek® was applied annually for a decade, and there was interest in understanding the impact of this concentrated application to native plant growth. During the initial examination of the Phos-Chek® area, we discovered an unexploded ordinance and we were not allowed to continue the field studies in the Phos-Chek® impact area. Thus, this part of the project was terminated early on. However, we summarize in the following two paragraphs some of the potential impacts of Phos-Chek® on plants.

The active ingredients of Phos-Chek® are ammonium phosphate and diammonium sulfate—the same active ingredients in many agricultural fertilizers. Before use, Phos-Chek® is mixed into a liquid concentrate that includes thickeners, flow conditioners, corrosion inhibitors, and water. The end result is about 88 percent water and 12 percent retardant. Like fertilizer, retardant that is not removed from green vegetation after a fire has passed may cause its leaves to turn brown and wither. After heavy watering or substantial rain, the plants should return to normal and, much like fertilizer, growth should be enhanced by the added plant nutrients.


**Figure 18.** Fire retardant* (pink strips) applied annually on San Clemente Island to protect against the spread of fires that frequently ignite in the impact areas, San Clemente Island, southern California. (Source Google Earth™, USDA Farm Service Agency.) Some areas have been treated just once; others have been treated multiple times.

At 0.2-percent concentration, phosphate-based fire retardant increased germination of Mediterranean seed species and, at 2-percent concentration, was toxic to these species (Luna and others, 2007). A single application of a phosphate-based fire retardant in both California oak woodlands and Australian heathlands caused increases in the biomass of non-native plants (Larson and Duncan, 1982; Bell and others, 2005) and the death of certain species (Bell and others, 2005). Water and propagule abundance are key components of the equation. For example, in a Nevada shrub steppe community that had a low-to-moderate incidence of non-native plants in riparian areas and very few non-native plants in upland areas, the use of a phosphate-based fire retardant resulted in a flush of stems and species in more mesic riparian areas and no change in more xeric upland areas, compared to water alone as a retardant (Larson and others, 2000). In coastal sage scrub near Riverside, California, nitrogen fertilizer did not appreciably affect vegetation in unburned shrublands, but in burned areas during wet years, it significantly increased non-native grasses and non-nitrogen-fixing *Artemisia californica* and *Malacothamnus* shrubs and decreased nitrogen-fixing *Lotus* shrubs (Allen and others, 2005).

On San Clemente Island, the potential exists for continued application of Phos-Chek® to enhance the growth of non-native species that likely will displace native species in the area of application. This fertilizer effect also will have the potential for increasing the volume of flashy fuels in this localized area. It seems that the impact of this Phos-Chek® application may have significant but very localized impacts on the native biota.

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## Appendixes

Appendixes are available for download at http://dx.doi.org/10.3133/ofr20151194.

**Appendix I. U.S. Fish and Wildlife Service San Clemente Island Military Operations and Fire Management Plan, 2008.**

**Appendix II. After Action Report for the 2011–2012 Prescribed Fire Grass Plots Project.**

**Appendix III. Google Earth™ Image of Study Sites.**

III-A. Project 1 Buds Road Prescribed Burned and Control Sites.

III-B. Project 1 Windmills Prescribed Burned and Control Sites.

III-C. Project 2 Horton Road East Prescribed Burned and Control Sites.

III-D. Project 2 Horton Road West Prescribed Burned and Control Sites.

III-E. Project 2 Ranch Canyon Wildfire Burned and Control Sites.

**Appendix IV. Video Clips of Prescribed Burns.**

IV-A. Horton Road Prescribed Burns—June 6, 2012.

IV-B. Windmills Prescribed Burns—June 7, 2012.

IV-C. Buds Road Prescribed Burns—June 7, 2012.

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