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Effects of prescribed burning on composition of serpentine grassland vegetation

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EFFECTS OF PRESCRIBED BURNING ON
COMPOSITION OF SERPENTINE GRASSLAND VEGETATION

A Thesis

Presented to

The Faculty of the Department of Biological Sciences

San José State University

In Partial Fulfillment

of the Requirements for the Degree

Master of Science

by

Debra Thornley Welch

May 2009

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EFFECTS OF PRESCRIBED BURNING ON
COMPOSITION OF SERPENTINE GRASSLAND VEGETATION

by
Debra Thornley Welch

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ABSTRACT

EFFECTS OF PRESCRIBED BURNING ON
COMPOSITION OF SERPENTINE GRASSLAND VEGETATION

by Debra Thornley Welch

Serpentine grasslands serve as refuges for native grassland plant species. Exotic

invasive plants increasingly displace even serpentine natives. Fire is a common tool used

by managers to control exotic vegetation. Controlled experimental burns were conducted

to evaluate the impacts of early summer burning on plant community species richness

and the abundance of *Leptosiphon ambiguus, Bromus hordeaceus, Lessingia micradenia*

var. *glabrata, Plantago erecta* and grasses in two kinds of patches: those with a high

abundance of *L. ambiguus* and little *B. hordeaceus*, and those with a moderate abundance

of both *L. ambiguus* and *B. hordeaceus*. This two-year study, conducted in Santa Clara

County, California, used a Randomized Block Repeated Measure design ($n = 10$) with the

treatments (burned, not burned) applied after the first year's data were collected.

From a management perspective there were three main benefits and one drawback

of burning. Increases in species richness in both types of patches and the increase in *L.*

ambiguus and reduction of *B. hordeaceus* in the *B. hordeaceus*-invaded patches were

beneficial outcomes. The reduction of *L. micradenia* in *L. ambiguus*-rich patches was a

drawback. Additionally, the study revealed that there was an increase in *P. erecta*

abundance with higher burn temperatures in *L. ambiguus*-rich quadrats; in *B. hordeaceus*-

invaded quadrats, there was a decrease in *P. erecta* abundance with higher burn

temperatures. Burning also decreased the abundance of all annual grasses combined.

Overall, prescribed burning at the grazed study site appeared to be beneficial.

ACKNOWLEDGMENTS

family members provided moral support and encouragement. I am grateful to my step-daughter, Brie, for enduring years in a home with only one income.

I dedicate my thesis to Jerry, my husband. Thank you, Jerry, for your emotional, technical, photographic, editorial and, not least of all, financial support, and for your patience during this challenge.

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Introduction

Historically, serpentine grasslands have served as refuges for native grassland plant species (McNaughton 1968; Kruckeberg 1984; Mooney et al. 1986; Murphy & Ehrlich 1989; Huenneke et al. 1990; Harrison 1997) and as habitat for endemic plants associated with serpentine soils (Kruckeberg 1984; Murphy & Ehrlich 1989; U.S. Fish and Wildlife Service [USFWS] 1998). Even in serpentine soils, though, endemic plants have increasingly been displaced by non-native, invasive grasses and forbs (Heady 1977; Mooney et al. 1986). Serpentine grasslands have resisted invasion because only plants that have evolved on serpentine soil are adapted to serpentine soils' low levels of nutrients such as nitrogen, phosphorus, and calcium combined with high levels of magnesium, iron, and other metals that are toxic to many plants (Kruckeberg 1984; Huenneke et al. 1990).

Recently, however, serpentine grasslands are being threatened by encroachment of non-native plants. This expansion of exotics onto serpentine soil may be due to new adaptations (Harrison et al. 2001) or to changes in the environment such as increased nitrogen deposits in soil from car and truck emissions (Weiss 1999). Some studies have shown that nutrient-poor ecosystems are especially vulnerable to nitrogen deposition (Aerts & Berendse 1988; Bobbink & Roelofs 1995; Power et al. 1995). Additional threats to serpentine grassland species include habitat shrinkage due to land development, habitat fragmentation and disjunction (USFWS 1998).

Prescribed burning is one method in which managers control weeds and increase germination and growth of desired plants (Menke 1989; Thomsen et al. 1993; Barry

1998; Bowcutt 1999; Pendergrass et al. 1999). Carefully executed burns can increase native plant cover or diversity (Menke 1989; Parsons & Stohlgren 1989; Meyer & Schiffman 1999). This shift in the community balance may result from a reduction in non-native plant biomass that results in increased space, light and nutrients (Vogl 1974; Parsons & Stohlgren 1989; Whelan 1995; DiTomaso et al. 1999). Another possible mechanism is by slowing competitive displacement of native plants by exotic plants (McNaughton 1968; Noy-Meir 1995; Collins et al. 1998).

Following wildfires, Harrison et al. (2003) and Weiss and Wright (2005) conducted plant biodiversity studies in serpentine grasslands. These studies supported burning (and grazing) as a means of increasing native plant diversity and cover. Harrison's study, conducted in Yolo County, California, found that sites burned in an autumn wildfire contained greater species richness, particularly of native species, than unburned sites. Additionally, the burned sites had a less frequent occurrence of non-native annual grasses, with the exception of *Bromus hordeaceus* (Soft chess). Weiss' and Wright's (2005) study, conducted in San Mateo and Santa Clara Counties, took advantage of a spring wildfire. They found that biodiversity and *Plantago erecta* (California plantain) cover increased and *B. hordeaceus* cover decreased.

An additional mechanism for increasing native plant species diversity and cover in serpentine grasslands may be volatilization of nitrogen during fires (Gundale 2001). Nitrogen is volatilized at temperatures as low as 200°C; at 500°C and above, fifty percent or more of the nitrogen is volatilized (Neary et al. 1999). Nitrogen is most often volatilized in conditions with little organic matter or in very hot fires (Cilimburg & Short

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2005; U.S. Forest Service 2005). In contrast, fires that burn large amounts of organic matter are likely to release nitrogen into the soil.

Nitrogen removal, whether by burning or grazing, may also benefit individual species. Weiss (1999) found that variability in nitrogen deposition and grazing regime both affected plant communities. In San Mateo and Santa Clara Counties, California, study sites had varying amounts of nitrogen deposition. In ungrazed sites with high nitrogen deposition, there was more non-native invasive annual grass, less of the annual forb *P. erecta*, and fewer *Euphydrya editha bayensis* (Bay checkerspot butterflies) than in grazed sites with high nitrogen deposition. He proposed that high nitrogen leads to increased invasive grasses which grow tall and block *P. erecta* from detection by Bay checkerspot butterflies, a federally listed endangered species; *P. erecta* serves as the primary host plant for Bay checkerspot caterpillars (USFWS 1998).

In this controlled study, prescribed burning was investigated as a way of managing serpentine grasslands invaded by exotic grass. Two experiments were conducted: one investigated fire's impact on grassland patches rich with rare plant *Leptosiphon ambiguus* (Serpentine leptosiphon), the other examined effects on *L. ambiguus* patches invaded by exotic grass *B. hordeaceus*. Fire's impacts on species richness, key species, and grass abundance were examined by comparing pre- and post-burn parameters. Key species, (described in detail below) included rare plants *L. ambiguus* and *L. micradenia* var. *glabrata* (Smooth lessingia), exotic grass *B. hordeaceus*, and butterfly host plant *P. erecta*. These species are of particular importance in the study system that was investigated.

Study System

The study site is part of Rancho Cañada del Oro, located in California, U.S.A, approximately 11 km southeast of central San Jose (Fig. 1). Rancho Cañada del Oro is on the northeast (rain-shadow) side of the Santa Cruz Mountains, approximately 20 km northeast of the Pacific coast's Monterey Bay. The Santa Cruz Mountains were formed by tectonic action along the San Andreas Fault line. Serpentine outcrops, which are formed in fault zones, are found at Rancho Cañada del Oro. This serpentine soil is in the Montara series (United States Department of Agriculture 1974). Montara soil is a gray alkaline clay loam and is typically shallow, over greenish gray serpentine bedrock. Montara soils have low fertility and a low calcium:magnesium ratio (of 1:1 or less). The study site ranges in elevation from 365 m to 440 m.

Santa Clara County has a Mediterranean climate with summer high temperatures averaging 29°C and winter lows averaging 10°C in San Jose (National Resource Conservation Center 2009). Mean annual rainfall is approximately 57 cm per year and occurs almost exclusively between October and April. Rainfall data for Rancho Cañada del Oro itself are not available before the 2003-2004 season, but the mountains typically receive more rainfall than the City of San Jose. At Rancho Cañada del Oro, the 2004-2005 season had 60.7 centimeters of rain, with 7 centimeters falling in March. During the 2005-2006 winter, there were 108 centimeters of rain with 44 centimeters falling in March and April.

Rancho Cañada del Oro (1571 ha) is owned and managed by Santa Clara County Open Space Authority (SCCOSA), an entity whose chief objective is to purchase and

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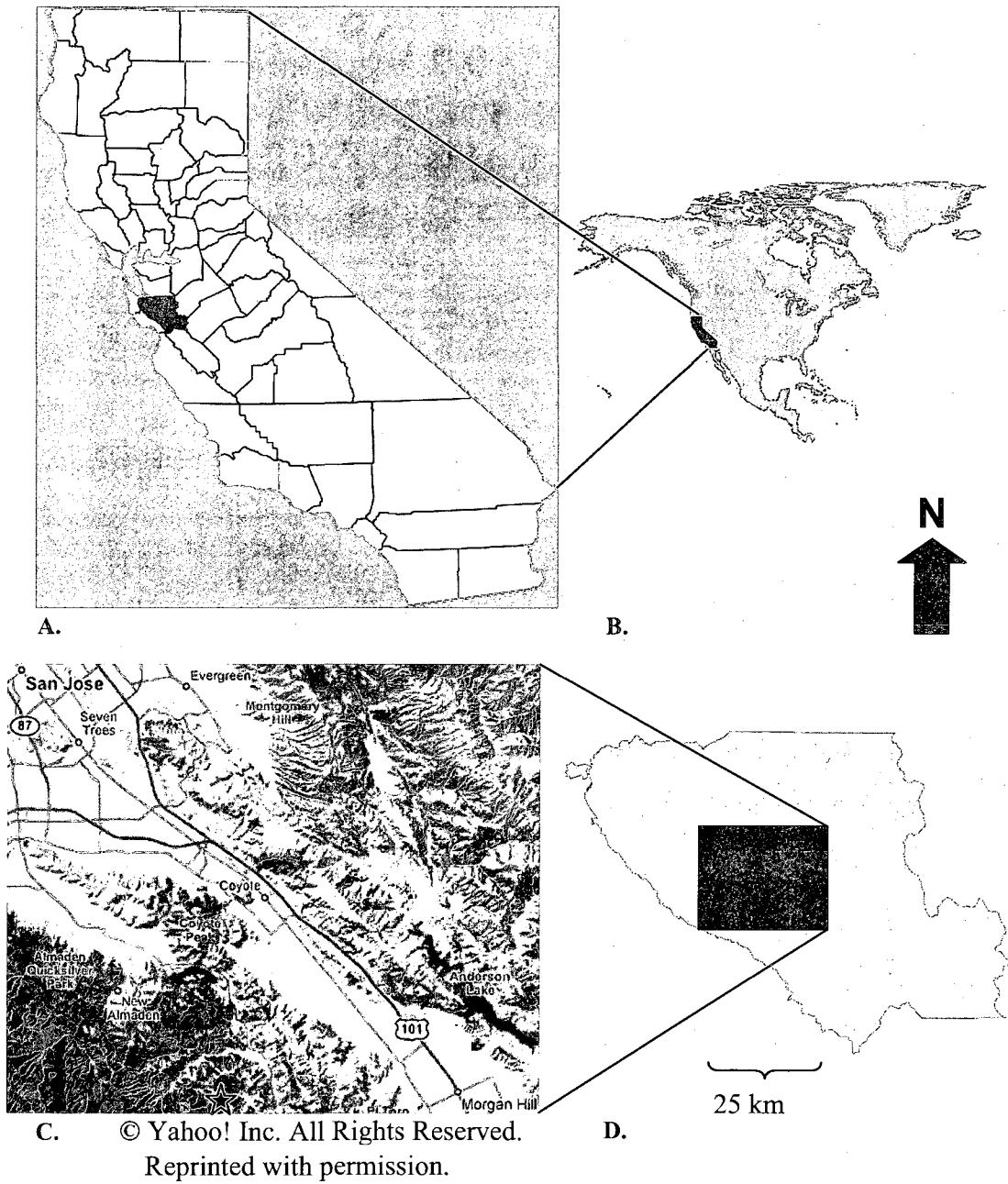
Figure 1. Location of study site at Rancho Cañada del Oro. **A.)** Santa Clara County, California. **B.)** California's position in North America. **C.)** Rancho Cañada del Oro (star), southeast of San Jose, CA in **D.)** Eastern Santa Clara County.

conserve undeveloped lands. In 2004, the Open Space Authority designated Rancho Cañada del Oro as a preserve and has opened two trails. The study site is on the south side of Llagas Creek and Casa Loma Road. Surrounding properties include Calero County Park (a 1,407-ha hiking, horse-back riding, and water-sports park), cattle ranches, and large private properties. One main dirt road has been developed on the property that goes from the bottom of the preserve, a valley floor, to the ridge. There are smaller dirt roads that have not been maintained and are only suitable for four-wheel drive vehicles when it is dry and grass is not too high.

The southern portion of Rancho Cañada del Oro has been grazed for over 100 years and has a stock pond. Prior to 2004, there were approximately 50 cows and calves on the property year round. (P. Congdon 2008, SCCOSA, San Jose, CA, personal communication). In 2004, SCCOSA started a formal grazing program. In an attempt to maintain 750 to 900 pounds/acre (840 to 1010 kg/ha) of residual dry vegetative matter, 28 to 32 cows and/or calves graze on the property for 7 to 9 months out of the year.

Study Site Fauna. Rare or threatened animals that are endemic to serpentine soils in California's San Francisco Bay Area include two species of blind harvestmen (harvestmen are commonly called daddy longlegs), five species of microblind harvestmen, a moth, and a butterfly. The study site is within the range of three of these species (USFWS 1998): *Adela oplerella* (Opler's longhorn moth), *Microcina homi* (Hom's microblind harvestman), and the Bay checkerspot butterfly. The longhorn moth and harvestman are species of concern, and the Bay checkerspot butterfly is federally

listed as a threatened species. The butterfly was observed during the course of this study (Fig. 2).

Study Site Flora. The plant communities found at Rancho Cañada del Oro are coast live oak woodland, manzanita and chamise chaparral, non-native annual grassland, perennial grassland, and riparian. These plant communities occur off serpentine and each appears to occur on serpentine as well.

The study site consists of patches of serpentine grassland on a small (approximately 8-ha) isolated outcrop of serpentine soil located on Rancho Cañada del Oro. Native plants that dominate the grassland patches are typical of California serpentine grasslands. Plants include perennial grasses such as *Nasella pulchra* (Purple needlegrass), *Melica torreyana* (Torrey's melicgrass), *Melica californica* (California melicgrass); perennial forbs such as *Dichelostemma capitatum* (Blue dicks); and annual forbs such as *P. erecta*, *Lasthenia californica* (California goldfields), and *Layia gaillardioides* (Woodland tidytips). As is typical of serpentine grasslands, study site vegetation is diverse and sparser than other grasslands (Bowcutt 1999) (Fig. 3).

Native species at the study site include serpentine grassland endemics. These plants are California Native Plant Society (CNPS) designated rare plants, but are not federally listed. The rare serpentine grassland endemics found at the study site are *Leptosiphon ambiguus* (List 4.2), *Lessingia micradenia* var. *glabrata*) (List 1B.2), and *Streptanthus albidus peramoenus* (Most beautiful jewelflower) (List 1B). *Dudleya abramsii setchellii* (Santa Clara Valley liveforever) was intentionally avoided

Figure 2. Federally listed Bay checkerspot butterfly, observed in 2006 at study site.

because it is a federally listed endangered plant. In any case, it did not occur in close

proximity to *L. ambiguus* (one of the primary species assessed in this study). None of the

study quadrats included *S. albidus* because there is only one small patch (<10 m^2) of it at

the study site.

At the study site, native-rich and native-depauperate patches occur within the

serpentine grassland area. Grasses are by far the most common invasive exotics at the

site (based on area covered). The grass *B. hordeaceus* is almost ubiquitous; however,

within the areas that are native-rich, it is much less dense. *Avena barbata* (Slender wild

oats*)* grows on the fringes of and within patches of the native-rich areas; *Lolium*

multiflorum (Italian ryegrass) is almost entirely restricted to the margins of the serpentine

Figure 3. Vegetation on the serpentine outcrop is sparser and more diverse than on surrounding grasslands. Serpentine grassland is in the background. Exotic annual grassland, off the serpentine outcrop, is in the foreground.

outcrop. At this site, *L. ambiguus* was restricted to native-rich areas, while *L. micradenia* var. *glabrata* grew in these areas and in the areas that were invaded by the wild oats.

Leptosiphon ambiguus (Rattan) J.M. Porter and L.A. Johnson is in the Polemoniaceae (Phlox) family (Hickman 1993). The name was recently changed from *Linanthus ambiguus* to *Leptosiphon ambiguus* as were most of the species in the genus *Linanthus* that are found in California. Reclassification was due to genetic studies by Bell, Patterson, Porter and Johnson (Porter 1998; Porter & Johnson 2000; Bell & Patterson 2000). The old generic name, *Linanthus*, comes from two Greek words: *linon*, meaning flax, and *anthos*, meaning flower because of the flower's likeness to flax. The new generic name comes from *lepto* which means thin, and *siphon* which means tube.

Leptosiphon ambiguus is an herbaceous (non-woody) annual dicot (Hickman 1993). The flower has a tubular corolla which usually has five lobes (petals). *Leptosiphon* ssp. ovules are self-pollinated or cross pollinated by wind or insects, especially the bee fly (*Bombylius* spp., Bombyliidae) (Schmidtt 1980; Murphy & Ehrlich 1989; Goodwillie 1999). Murphy and Ehrlich once observed Bay checkerspot butterflies visiting *L. androsaceus* when bee flies did not emerge until late in the season. Nectar had risen in the corolla to a level accessible to the butterfly's shorter proboscis. Bee flies were the only insects observed visiting *L. ambiguus* during the course of this study (Fig. 4). The flies have a long proboscis that extracts nectar from the long tubular flower. The *L. ambiguus* fruit is a capsule which dehisces (pops) when ripe to release seeds. Stems and leaves are thread-like, making it difficult to see when flowers are closed (Fig. 5.)

Figure 4. Bee fly visiting
L. ambiguus.
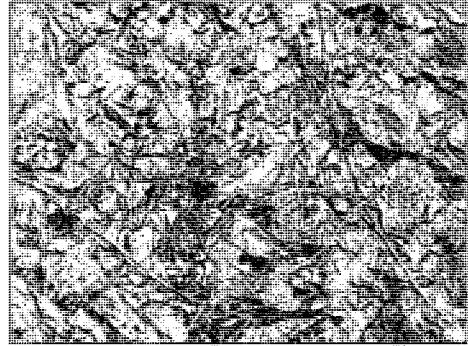
Figure 5. *Leptosiphon ambiguus* has thread-like stems and leaves. When flowers are closed, the plants are hard to see.

Leptosiphon ambiguus is found below 1000 meters above sea level in grassy areas, and is restricted to serpentine soils. Its affinity to serpentine soil is 5.8 on a scale of 1.0 to 6.25 with 6.25 showing the strongest affinity to serpentine (Safford et al. 2005). *Leptosiphon ambiguus* is endemic to California's San Francisco Bay Area and the Inner South Coast Ranges (Hickman, 1993) within nine counties (CNPS 2009), although it has been found, at least historically, in 14 counties (Calflora 2009) (Fig. 6). Because of its restriction to serpentine soils and limited range, it is on the CNPS watch list. Its state and global statuses are S3.2 and G3, respectively; it is "fairly endangered" and found only in California with an estimated 21-80 occurrences on 10,000-50,000 acres (4,047-20,234 ha) (California Native Plant Society 2009).
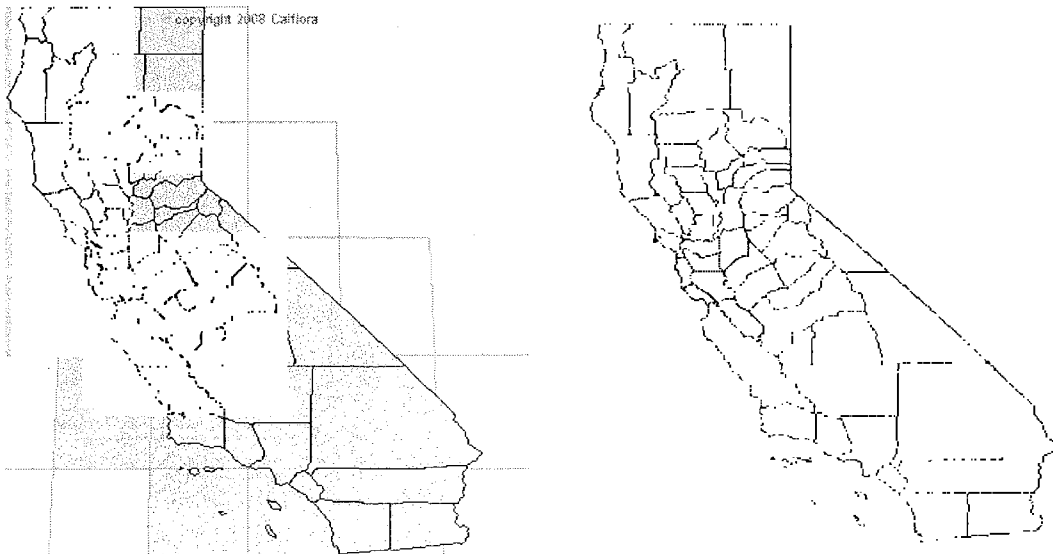
A.   Reprinted with permission from   B.   Reprinted with permission
      Calflora. © Calflora 2008   from CNPS. © CNPS 2009

Figure 6. Distribution of *Leptosiphon ambiguus*. **A.)** Historical accounts of *L. ambiguus*. Voucher specimens available for all 14 counties, from Calflora 2009. **B.)** Current counties containing *L. ambiguus*, from CNPS 2009.

Hypothesis and Goals

I chose to conduct my study in the less-invaded areas and to concentrate on

management of *L. ambiguus*. I targeted control of *B. hordeaceus*, which, in prime habitat

areas, seemed to be most competitive with native plants in general, and with

L. ambiguus in particular. I chose to do this because I thought that management of these

areas would most likely produce positive results partly because there would be an intact

native seed bank. Also, MacArthur and Wilson (1967) demonstrated that islands with

larger areas supported more species than a combined equal area of small but similar

islands. This island biogeography principle has been applied to patches of isolated habitat (islands) such as serpentine outcrops (Harrison et al. 2001). Employing this principle, it is better to enlarge a patch (of native serpentine grassland species) than it is to work from the edges to create several smaller but divided patches. Finally, habitat edges and small patches are more quickly invaded because of increased propagule arrival from the outside (Harrison et al. 2003).

In this study, I hypothesize that is that prescribed, early summer burning would enhance natives and reduce exotic invasive plant abundances in serpentine grasslands. One aim was to perform this study with randomly assigned controls; previous studies were conducted on sites where wildfires occurred. The two main goals were to determine if burning would affect the abundance of rare plant *L. ambiguus*, either positively or negatively, within its current habitat and to determine if burning will reduce non-native annual grass, *B. hordeaceus*. Another goal was to see if two other target species, *L. micradenia* var. *glabrata* and *P. erecta*, changed in abundance due to the burn. *Lessingia micradenia* was studied because of its rare status in California; *P. erecta* was studied because it is the primary host plant of the endangered checkerspot butterfly. Other objectives were to determine whether native and/or exotic species richness and/or grass abundance was affected by fire. The final goal was to determine whether or not burn temperature was correlated with the effects of burning on any of the vegetation parameters.

Methods

Experimental Design

Identifying and Pairing Quadrats. Serpentine grassland patches were identified in the study by the presence of serpentine grassland endemic plants (*Leptosiphon ambiguus*, *Lessingia micradenia* var. *glabrata*, and *Streptanthus albidus peramoenus*). In spring, serpentine patches that are *L. ambiguus*-rich are visually very different from patches that are invaded by *B. hordeaceus*. These "*L. ambiguus*" patches have a high percent cover of *L. ambiguus* throughout much of the quadrat. "*B. hordeaceus*" patches have a higher abundance of *B. hordeaceus* and less *L. ambiguus* (Fig. 7).

First, during quadrat selection, small (1 x 1-m or slightly larger) patches of *L. ambiguus* were identified and marked with flags. From these patches, ten 1 x 1-m *L. ambiguus*-rich master quadrats were chosen. A 1 x 1-m quadrat-marker made of PVC tubing, with 36 equal subplots marked off with monofilament line in a 6 x 6 grid, was laid down on the patch. Within master quadrats, 33-36 subplots contained *L. ambiguus*, with no more than four of the subplots containing 20 or more *B. hordeaceus* plants (these were counted by identifying culms or flowering stalks). Master quadrats were paired with quadrats that had approximately the same abundance (within 3 subplots, or 8.3%) of *L. ambiguus* and *B. hordeaceus*.

Quadrats were also paired by proximity; pairs were located within 10.5 m of each other. Where possible, they were also visually paired by presence and abundance of other dominant plant species. Where adequate matches could not be found, the quadrats
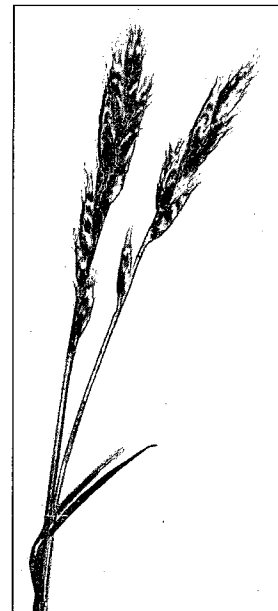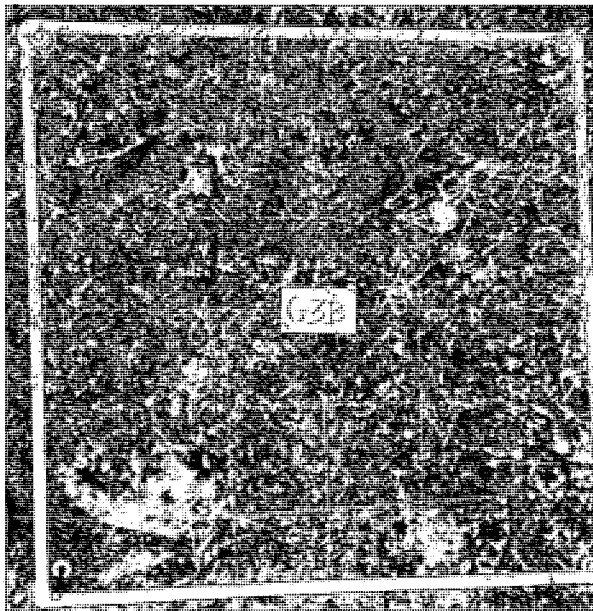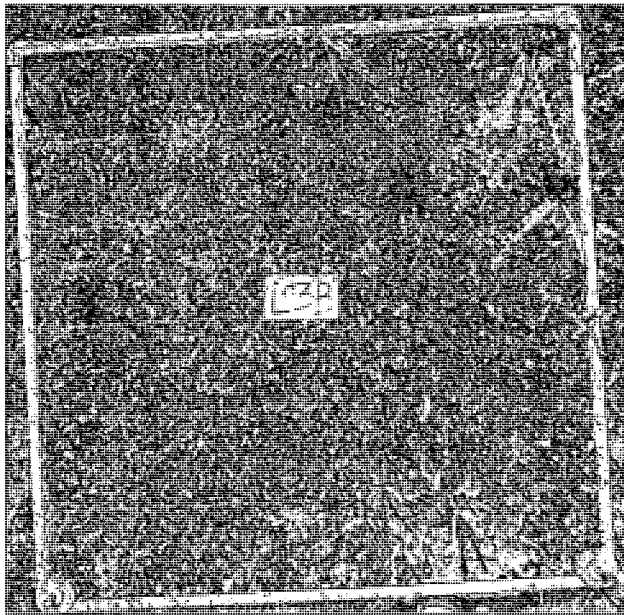
Figure 7. Patches identified in the *L. ambiguus*-rich experiment (top left photo) had more *L. ambiguus* (top right) and less *B. hordeaceus* (bottom right) than those in the "invaded" experiment (bottom left photo).

were discarded. New master quadrats were selected from among the previously identified small patches and these patches were subjected to the pairing criteria until ten pairs of *L. ambiguus*-rich quadrats were found (Fig. 8).

Similarly, ten *B. hordeaceus*-invaded master quadrats were chosen from flagged patches and paired with similar quadrats for a total of 40 quadrats. *Bromus hordeaceus* quadrats were identified and chosen on the fringes of *L. ambiguus*-rich areas, because patches close to *L. ambiguus*-rich areas were thought to be more likely to have a similar seed bank that would respond to the burns more than distant quadrats would. *Bromus hordeaceus* quadrats were chosen so that a similar number of subplots contained *L. ambiguus* as contained a high density of *B. hordeaceus*. Master quadrats had 15-28 subplots containing *L. ambiguus*, and 15-28 subplots that contained 20 or more culms of *B. hordeaceus*. Pairs were matched to within 3 subplots (8.3%) of *L. ambiguus* and to within 2 subplots (5.5%) of *B. hordeaceus*. Paired quadrats were within 7.5 m of each other (Fig. 8).

Quadrats were also paired by visually estimating percent cover of *L. ambiguus*. However, this measure was not recorded because of the difficulty of consistently and accurately estimating *L. ambiguus* cover. Percent cover was easy to estimate when *L. ambiguus* flowers were open, but when they were closed because of wind or senescence they were hard to see and still harder to distinguish from *L. linaflorus* and from other species that resemble *L. ambiguus*. This was especially true when estimating percent cover for the whole quadrat or even a quarter of a quadrat at a time. Even though
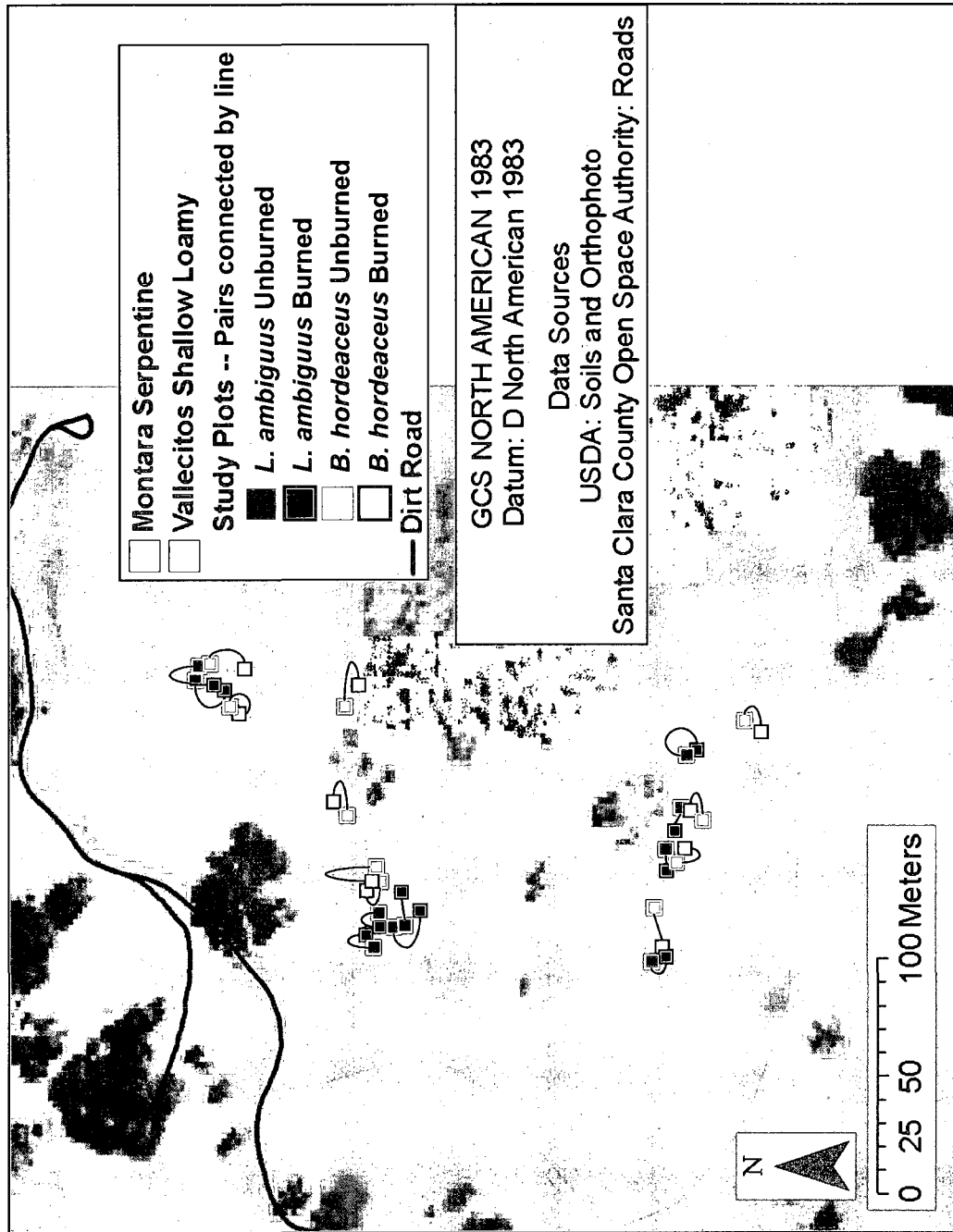
Figure 8. Distribution of quadrats on serpentine outcrop at Rancho Cañada del Oro study site. Quadrats are not to scale.

L. ambiguus cover was not measured in order to pair quadrats, percent cover appeared to be matched within pairs. Therefore, the abundance measure used (% subplots/quadrat) seemed to capture the difference in the amount of *L. ambiguus* within pairs prior to the burn.

After the burn, it was clear that the *L. ambiguus* frequency measure alone no longer accurately portrayed differences in *L. ambiguus* abundance within pairs. For each subplot relative cover was estimated on a scale from 0.0-4.0 with a precision level of 0.25. A value of "4" denoted that the entire subplot was dense with *L. ambiguus*. Maximum relative cover for a quadrat would be 144. This value was converted to a percentage.

Because quadrats were chosen to represent *L. ambiguus*-rich areas and *L. ambiguus* areas that are adjacent to *B. hordeaceus*, they are not distributed randomly throughout the grasslands. They are clumped in areas that meet these requirements (Fig. 8). Quadrats were marked with flags. Corners of quadrats were marked with 1-inch washers, held in place with 8-inch nails.

Treatment

Summary of Burn Protocol and Description of Burn Boxes. The burns were completed within burn boxes, 1.5-m square, 80-cm high metal frames, made from 24-gauge steel sheets and held together with bolts and wing nuts as described by Bruce Pavlik (2004, Department of Biology, Mills College, Oakland, CA, personal communication) (Fig. 9).
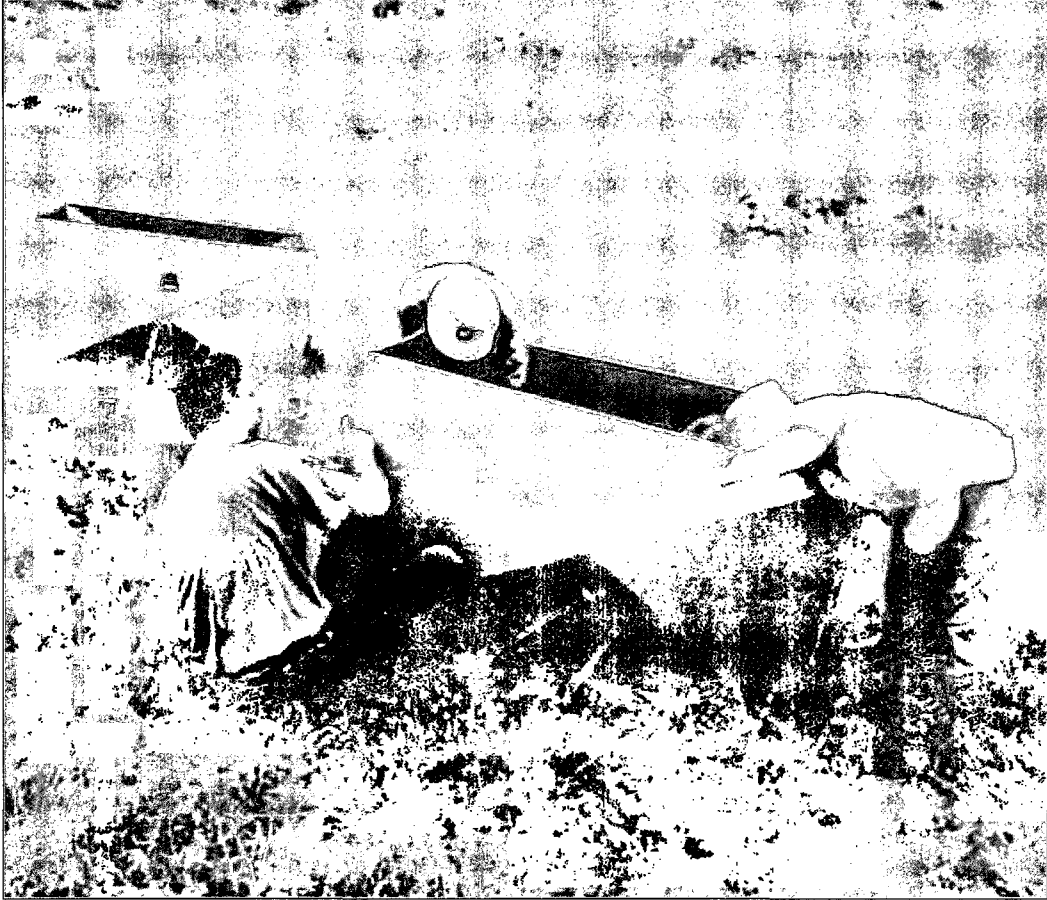
Figure 9. Photo of burn box assembly. Printed with permission from Chris Brinegar.

Buffer zone. In order to decrease edge effects, such as seeds falling into burned areas from outside the quadrats, 0.5-m buffer zones were created (Fig. 10). For "burned" quadrats, a 1.5 x 1.5-m area, with the sampled area in the center, was burned within the burn boxes. This created a 0.25-m burned buffer zone on each edge. The buffer zone was slightly increased to 0.5 m by mowing around the burn box to a 2 x 2-m-perimeter before performing the burns. The control quadrats had a 0.5-m buffer zone that was not burned or otherwise altered.

Unburned Quadrats—Control   **Burned Quadrats—Treatment**

0.25 m

1.00 m

▨ Sampled   ▧ Untreated buffer   ▦ Burned and sampled   ▨ Burned   ▨ Mowed
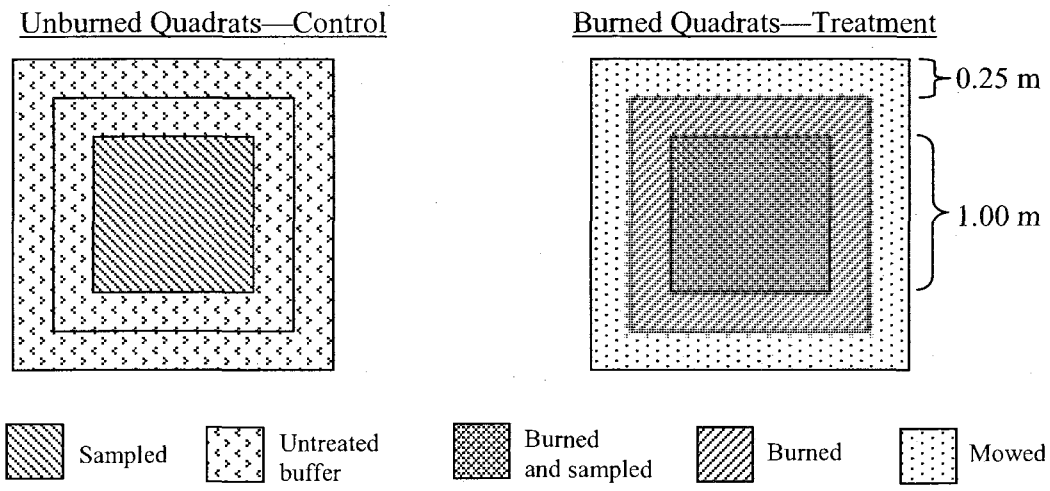
Figure 10. Diagrammatic representation of quadrats and buffer zones.

Timing and Burn Conditions. From each pair of quadrats, one was randomly chosen to be burned in early summer, when the grass was dry enough to burn, before *B. hordeaceus* and other exotic annual grasses had dropped their seeds, and after most *L. ambiguus* plants were senescent. The other quadrat from each pair was not burned. Santa Clara County Open Space Authority received permission from Santa Clara County to perform the burns on 28 June, 2005.

Weather conditions were monitored throughout the burn day in order to assess fire danger and burn conditions. The burn was performed on a calm morning between 8:20 and 11:15am; wind speeds varied between 0 and 3.5 mph (5.6 km/h). The temperature increased from 15 to 23°C, while relative humidity decreased from 88 percent to 57 percent. Radiant ground temperature, measured with an infrared thermometer (Extech,

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Inc., Waltham, MA, U.S.A.), generally increased during the morning from a low of 18.3°C to a high of 42°C. A test burn was performed in order to gauge the hazard of the fire's escaping the burn box and in order to assess and fine-tune the burn protocol.

Performing the Burn. Vegetation was ignited with a hand-held butane torch. In an attempt to more completely burn vegetation and to create conditions similar to prescribed burns performed in the open, we "back-burned" the quadrats. The vegetation at the top of the quadrat was ignited. We let the fire move down through the quadrat. The burn boxes seemed to block the air, and therefore the fire, from moving through the quadrat. The top-most unburned portion of the quadrat was re-ignited as needed. A backpack style pressurized water mister was used to extinguish flames that escaped beneath the burn box. Burn boxes were kept in place until each fire died out (Fig. 11).

Fire temperature was measured with the infrared thermometer held at arm's length by the same person in more or less the same position above each quadrat. A high temperature for each quadrat was recorded. These temperatures ranged from 276 to 646°C in *L. ambiguus*–rich quadrats and from 411 to 683°C in *B. hordeaceus* invaded quadrats. We attempted to measure ground-level burn temperature with temperature measuring crayons (Omega Engineering, Inc., Stamford, CT, U.S.A.) as described by Meyer and Schiffman (1999) without success.
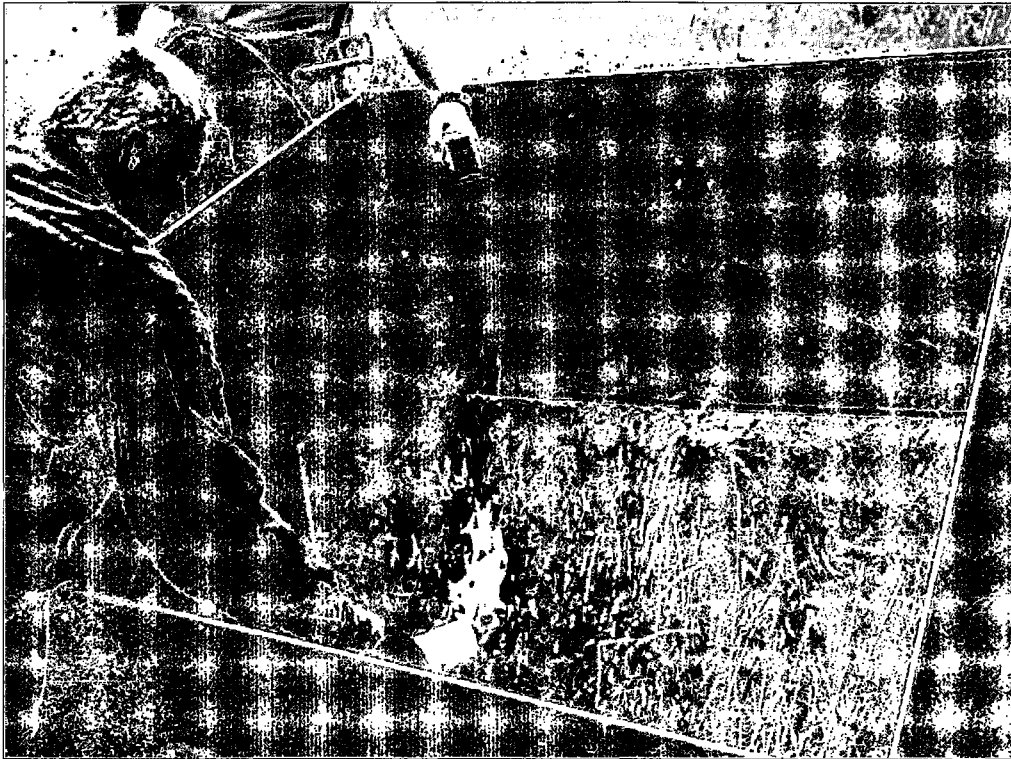
Figure 11. A grass-invaded quadrat is ignited with a butane torch while radiant heat is measured with an infrared thermometer. Printed with permission from Chris Brinegar.

Data Collection

Vegetation parameter data were collected (Table 1) by working from a data sheet with a list of plants previously found in local serpentine grasslands. Each species was recorded as it was found; species not on the original list were added to it. (Previously sampled quadrats were double-checked for these species). A specimen of each unrecognized species was collected. These species were temporarily recorded as "Species A," "Grass B," "Asteraceae C," etc. and were identified later.

Table 1. Vegetation Parameters.

<u>Target Species Parameters</u>

Leptosiphon ambiguus Abundance (/36)

Leptosiphon ambiguus Relative Cover (/144)

Bromus hordeaceus Abundance

Lessingia micradenia var. *glabrata* Abundance

Plantago erecta Abundance

<u>Grass Abundance Parameters</u>

Native Grass Abundance

Exotic Grass Abundance

Perennial Grass Abundance

Annual Grass Abundance

Total Grass Abundance

<u>Species Richness Parameters</u>

Native Species Richness

Native Grass Richness

Native Forb Richness

Exotic Species Richness

Exotic Grass Species Richness

Total Species Richness

Richness was determined by counting the number of species found in each quadrat; plants were grouped into life-form categories (grass or forb) and origin (native or exotic). For target species (*L. ambiguus, B. hordeaceus, L. micradenia,* and *Plantago erecta*) frequency, was also recorded; the number of subplots (out of 36) containing each target species was counted and converted to a percentage of the total number of subplots per quadrat. Frequency was considered to be an estimate of abundance for target plants because these species had relatively even densities in subplots where they occurred.

Grass abundance was measured by recording subplot frequency for each species of grass. In addition to grouping species together by origin, they were grouped together by habit (annual, perennial). The frequencies were added together and converted to a percentage for each group and for all grasses combined. (Grasses could add up to more than 100 percent since more than one type of grass could occur in each subplot.)

Two sets of vegetation parameter data were collected, one before, and one after the burn. In 2005, species data were collected between 15 April and 12 May. In 2006, data were collected between 19 April and 12 May.

Many of the quadrats were disturbed to a moderate degree by gophers, cows, or (in three cases) ATVs before data collection the second year. Because the quadrats were so small, there was a concern that the missing data would unduly influence the measured effect that would be attributed to burning. The estimated degree of disturbance was tested to see if burned quadrats were disturbed more or less than their paired controls. The two measures of disturbance were percent frequency of subplots that were disturbed and the percent cover of bare ground due to disturbance. It was not possible to determine the degree of disturbance for cattle, gophers, and ATVs separately, because rain or any of the disturbers erased underlying evidence. However, whatever the cause of the disturbance, it was still possible to identify areas of bare soil that were at one time disturbed to the point that they had little or no vegetation on them.

Data Analysis

In preliminary tests, initial mean species richnesses and abundances, "vegetation parameters," (Table 1) and mean disturbance were analyzed for differences between pairs

(blocks) for each experiment. The two experiments were on *L. ambiguus*-rich quadrats and *B. hordeaceus*-invaded quadrats. For each vegetation parameter, one-way Randomized Block ANOVAs (Zar 1984) were used to determine if mean richness or abundance in the paired treatment sites were similar prior to treatment. Pair and burn treatment were the independent variables. There were ten pairs and two treatments (pre-burn and control) in each experiment; $p < 0.10$ was considered to reflect differences between means. For each experiment, a one-way Randomized Block ANOVA (Zar 1984) was used to determine if the mean degree of disturbance was different ($p < 0.10$) in burned quadrats than controls. Independent variables were pair and treatment.

One-way Randomized Repeated Measure Block ANOVAs (Zar 1984) were used to determine if there was a treatment effect ($p < 0.05$) on mean species richness or abundance parameters. The independent variables were pair, treatment, and time. There were ten pairs, two treatments (burn and control) and two time-levels (spring 2005 and spring 2006) for each vegetation parameter. Each of the above analyses was run independently for the *L. ambiguus* experiment and the *B. hordeaceus* experiment.

Pearson correlation coefficients were determined (Zar 1984) to see if there were correlations between burn temperature and the change in each species richness or plant abundance between years ($|r| > 0.6$); *L. ambiguus* and *B. hordeaceus* experiments were tested both separately and together. Where one experiment showed a positive correlation between burn temperature and a given vegetation parameter, and the other experiment showed a negative correlation, there was further investigation.

In follow-up investigations, differences that might explain why a change in abundance was positively correlated with burn temperature in one experiment but negatively correlated in the other experiment were examined. Separate one-way Randomized ANOVAs tested for differences in mean pre-burn parameter values, change in parameter, and burn temperature between experiments. Correlation was tested between change in parameter and burn temperature using different burn temperature ranges designated as "cool" and "hot" in a combined *L. ambiguus* and *B. hordeaceus* experiment to see if there was a break in burn temperature where the parameter changed from a positive correlation to a negative correlation.

Further correlation tests were run to see if there were differences between experiments that would explain a positive correlation of burn temperature with a vegetation parameter in one experiment and a negative correlation in the other experiment. Pre-burn grass abundance seemed the most likely parameter to affect burn temperature, so it was tested for correlation with burn temperature for *L. ambiguus* and *B. hordeaceus* experiments separately and together. Correlation between change in parameter and pre-burn grass abundance and between change in parameter and change in grass abundance were also tested. Follow-up investigations were conducted on burned quadrats only, since only burned quadrats had associated burn temperatures. If there were significant results in tests that were relevant to control quadrats, they would have been further investigated as well.

Results

Overview of Study Quadrat Vegetation

Sixty-eight plant species were identified in study quadrats during the course of the study: 55 native species and 13 exotics (Appendix A). Initially the *Leptosiphon ambiguus* patches had 41 native and nine exotic plant species. Species richness for the *Bromus hordeaceus* patches was 47 native and 8 exotic plant species. Eight plants were found in 2006 that were not found in 2005. One plant that had occurred in 2005 was not found in 2006.

Although virtually the same numbers of exotic species were in both experiments the first year, they were present in significantly different quantities. The mean number of exotic species was higher in the *B. hordeaceus*-invaded experiment than in the *L. ambiguus* experiment. Exotic annual grasses were significantly more abundant in the *B. hordeaceus* experiment than in the *L. ambiguus* experiment ($p<0.001$). Native annual grass, *Vulpia microstachys* (Small fescue), was not significantly different in the two experiments ($p<0.001$). Native species richness and abundance parameters were not significantly different between the two experiments. The *B. hordeaceus*-invaded patches included more exotic plants, but the *L. ambiguus*-rich experiment did not include more natives (keeping in mind that abundance was not measured for most native species).

Preliminary Analyses: Initial and Disturbance Parameters

In *L. ambiguus*-rich quadrats, the Block ANOVAs showed that none of the initial parameters were significantly different in burned quadrats than in controls (Table 2, first column). Neither disturbance frequency ($p = 0.367$) nor disturbance cover ($p = 0.184$)

Table 2. ANOVA *p*-values for *L. ambiguus* experiment parameters. Significant *p*-values are <u>0.10</u> for pre-burn pairing and <u>**0.05**</u> for treatment effect.

	Pre-burn (Treatment)	Repeated Measure (Time x Treatment)	
Target Species			
L. ambiguus, % Subplot Frequency	0.168	0.454	
L. ambiguus, % Cover	n/a	0.531	◻
B.hordeaceus, % Subplot Frequency	1.000	0.285	
L. micradenia, % Subplot Frequency	0.746	**0.016**	
P. erecta, % Subplot Frequency	0.903	0.099	
Grass Abundance			
Native Perennial Grass Abundance, % Subplot Frequency	0.270	0.262	
Native Annual Grass Abundance, % Subplot Frequency	0.159	**0.027**	
Exotic Annual Grass Abundance, % Subplot Frequency	0.133	1.000	
Total Grass Abundance, % Subplot Frequency	0.166	0.129	
Species Richness			
Native Species Richness, no. spp.	0.688	0.207	
Native Grass Richness, no. spp.	0.705	0.322	
Native Forb Richness, no. spp.	0.759	0.124	
Exotic Species, no. spp.	0.260	0.743	
Exotic Grasses, no. spp.	0.496	0.853	
Total Species, no. spp.	1.000	**0.048**	

◻ Single measurement post-burn, not repeated

were significantly different in burned quadrats than in controls. In *B. hordeaceus* quadrats, initial parameters differed somewhat significantly between control and burned quadrats ($0.05 < p < 0.10$) (Table 3, first column). Neither mean disturbance frequency nor mean disturbance cover were significantly different ($p = 0.167$ and 0.446) in burned quadrats than controls. Because differences were not significant, neither disturbance measure was used as a covariate in the Repeated Measure ANOVA analysis of the vegetation parameters for either the *L. ambiguus* or the *B. hordeaceus* experiment.

Effects of Burning on *L. ambiguus* and *B. hordeaceus* Quadrats

In *L. ambiguus* quadrats three parameters were significantly affected by burning (Table 2, second column). In *B. hordeaceus* quadrats, six parameters were significantly dependent on treatment (Table 3, second column).

Species Richness. In *L. ambiguus* quadrats, burned quadrats had significantly more species (natives and exotics combined) than controls ($p = 0.048$) (Fig. 12). In the *B. hordeaceus* experiment, the mean number of exotic species increased with the burn treatment relative to controls ($p = 0.002$) (Fig. 13).

Target Species. In the *L. ambiguus* experiment, burning had a negative effect on mean *Lessingia micradenia* abundance ($p = 0.016$) (Fig. 14). In the *B. hordeaceus* experiment, *L. ambiguus* cover was significantly higher in burned quadrats than in controls ($p = 0.024$) (Fig. 15). Mean *B. hordeaceus* abundance greatly decreased in burned quadrats compared to controls ($p < 0.001$) (Fig. 16).

Table 3. ANOVA *p*-values for *B. hordeaceus* experiment parameters. Significant *p*-values are <u>0.10</u> for pre-burn pairing and **<u>0.05</u>** for treatment effect.

	Pre-burn (Treatment)	Repeated Measure (Time x Treatment)
Target Species		
L. ambiguus, % Subplot Frequency	0.343	0.711
L. ambiguus, % Cover	n/a	**<u>0.024</u>** ¤
B.hordeaceus, % Subplot Frequency	0.373	**<u>0.000</u>**
L. micradenia, % Subplot Frequency	0.788	0.523
P. erecta, % Subplot Frequency	<u>0.097</u>	0.408
Grass Abundance		
Native Perennial Grass Abundance, % Subplot Frequency	0.283	0.885
Native Annual Grass Abundance, % Subplot Frequency	0.342	**<u>0.015</u>**
Exotic Annual Grass Abundance, % Subplot Frequency	0.631	**<u>0.034</u>**
Total Grass Abundance, % Subplot Frequency	<u>0.063</u>	**<u>0.019</u>**
Species Richness		
Native Species Richness, no. spp.	<u>0.054</u>	0.693
Native Grass Richness, no. spp.	<u>0.051</u>	0.859
Native Forb Richness, no. spp.	0.193	0.612
Exotic Species, no. spp.	0.840	**<u>0.002</u>**
Exotic Grasses, no. spp.	1.000	0.297
Total Species, no. spp.	0.127	0.144

¤ Single measurement post-burn, not repeated
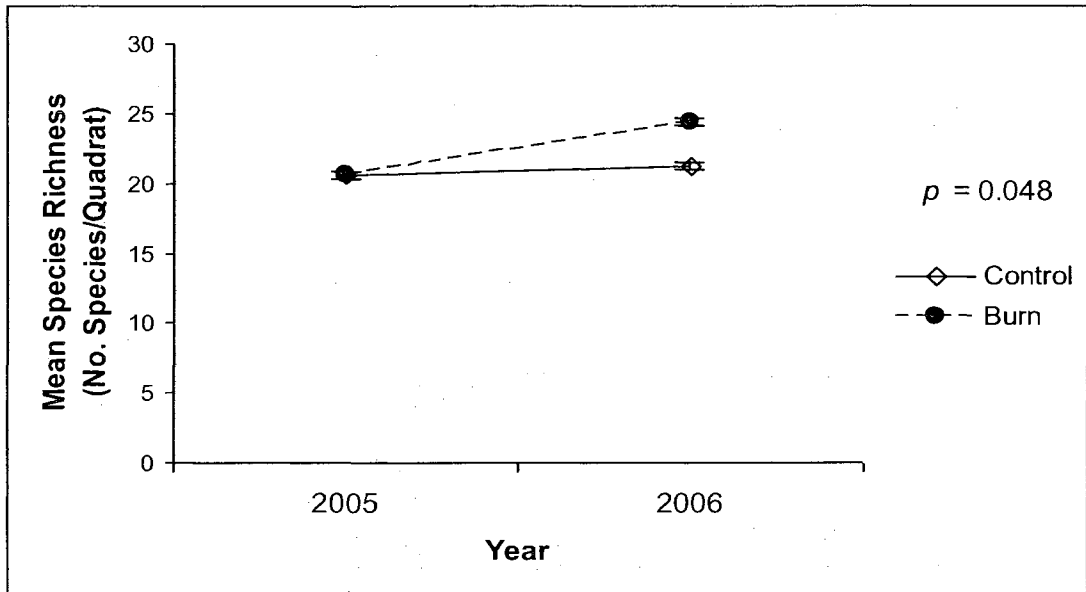
Figure 12. Effect of burning on total species number in *L. ambiguus*-rich experiment. Species number was enhanced in burned quadrats when compared to controls. Error bars represent ± SE.
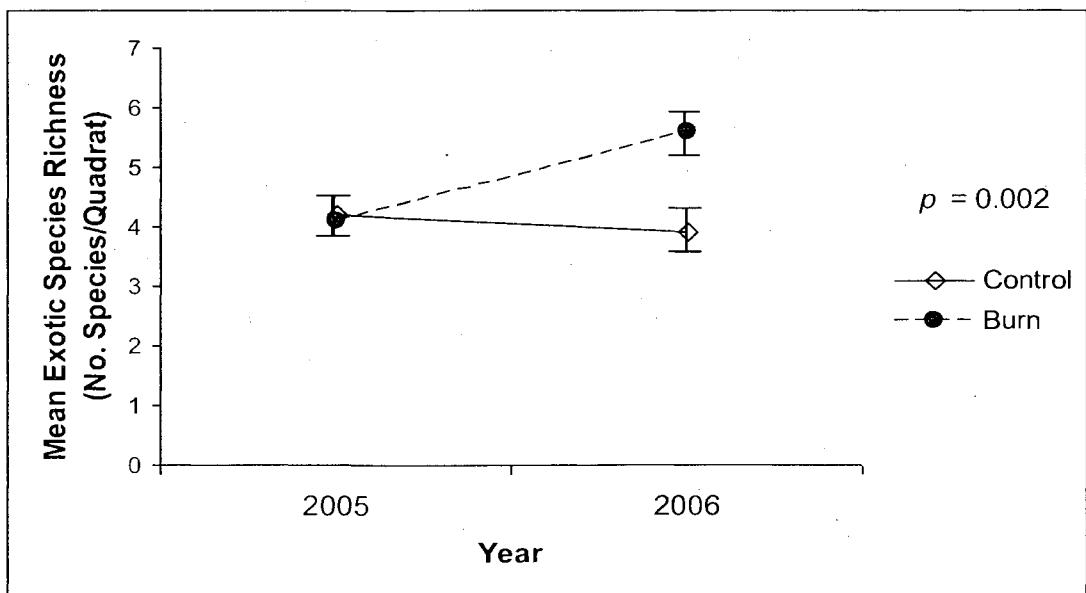
Figure 13. Effect of burning on exotic species richness in *B. hordeaceus* experiment. The number of exotic species increased in burned quadrats when compared to controls. Error bars represent ± SE.
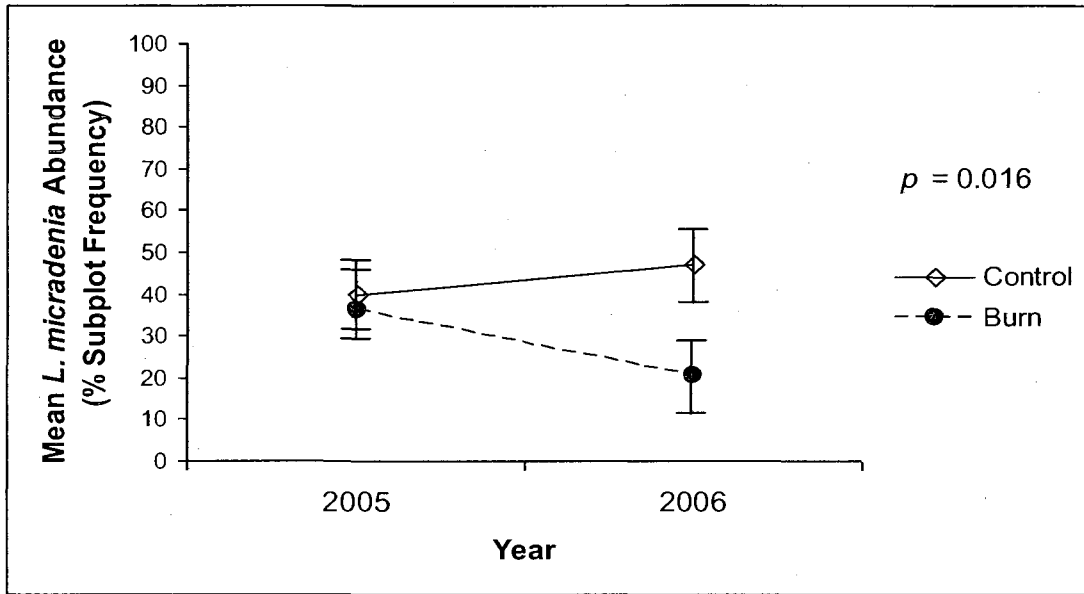
Figure 14. Effect of burning on *L. micradenia* var. *glabrata* abundance in *L. ambiguus* rich experiment. *Lessingia micradenia* was suppressed in burned quadrats when compared to controls. Error bars represent ± SE.
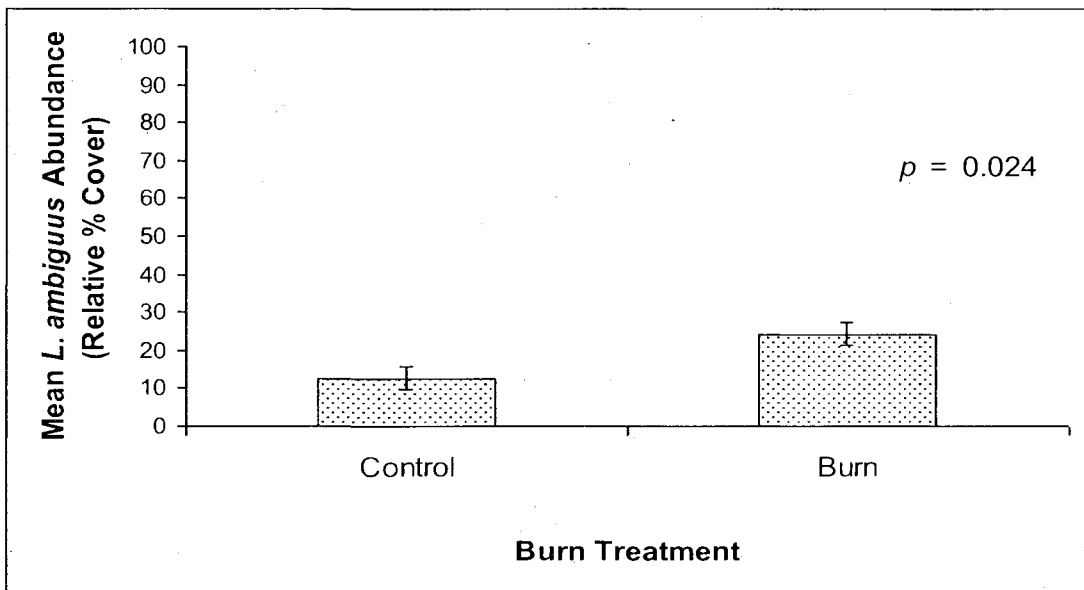
Figure 15. Effect of burning on *L. ambiguus* cover in 2006 in *B. hordeaceus*-invaded experiment. *L. ambiguus* cover increased in burned quadrats when compared to controls. Error bars represent ± SE.
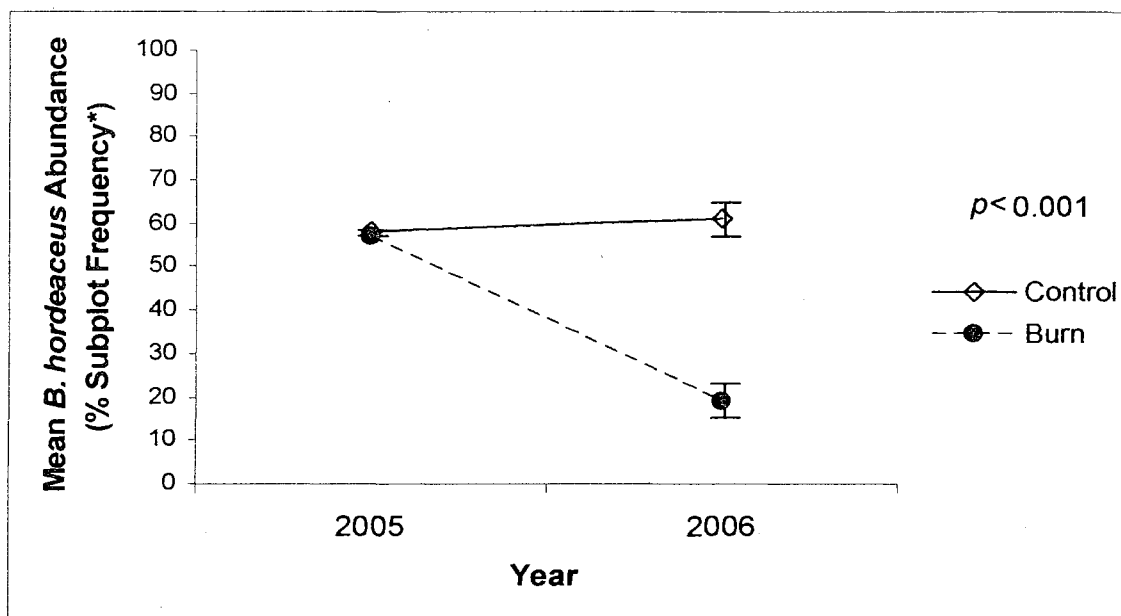
Figure 16. Effect of burning on *B. hordeaceus* abundance in *B. hordeaceus* invaded experiment. *B. hordeaceus* was suppressed in burned quadrats when compared to controls. *Frequency of subplots with ≥ 20 plants. Error bars represent ± SE.

Grass Abundance. Burning had a negative impact on grass abundance. In *L. ambiguus* quadrats native annual grass abundance decreased in burned quadrats compared to controls. In the *B. hordeaceus* experiment, mean grass abundance significantly decreased in burned quadrats compared to controls for all grass groupings (except perennial grass, which had no significant effect) (Fig. 17-20).
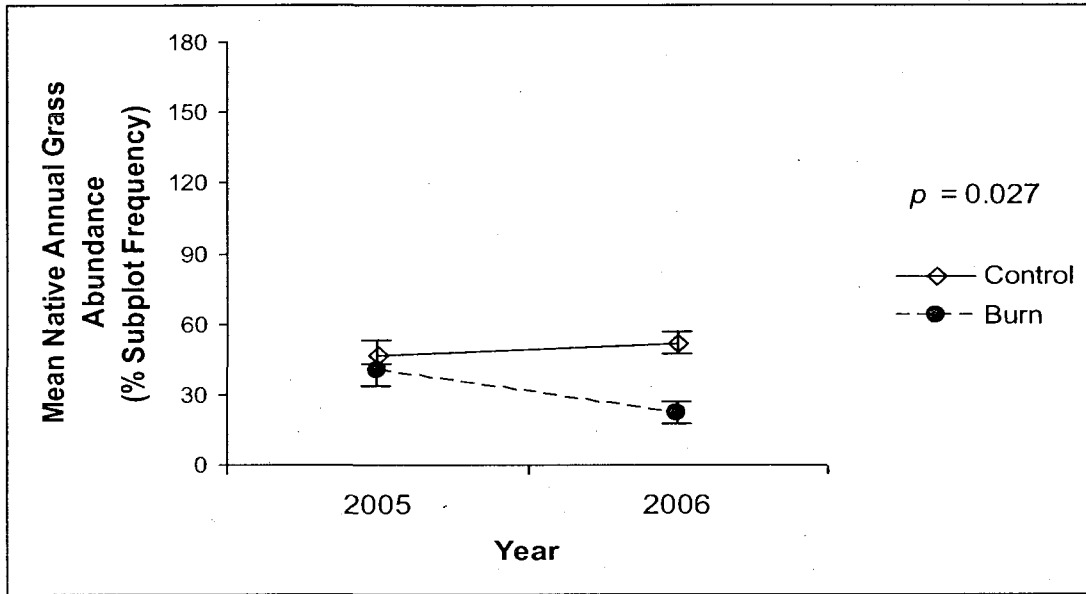
Figure 17. Effect of burning on native annual grass abundance in *L. ambiguus*-rich experiment. Error bars represent ± SE.
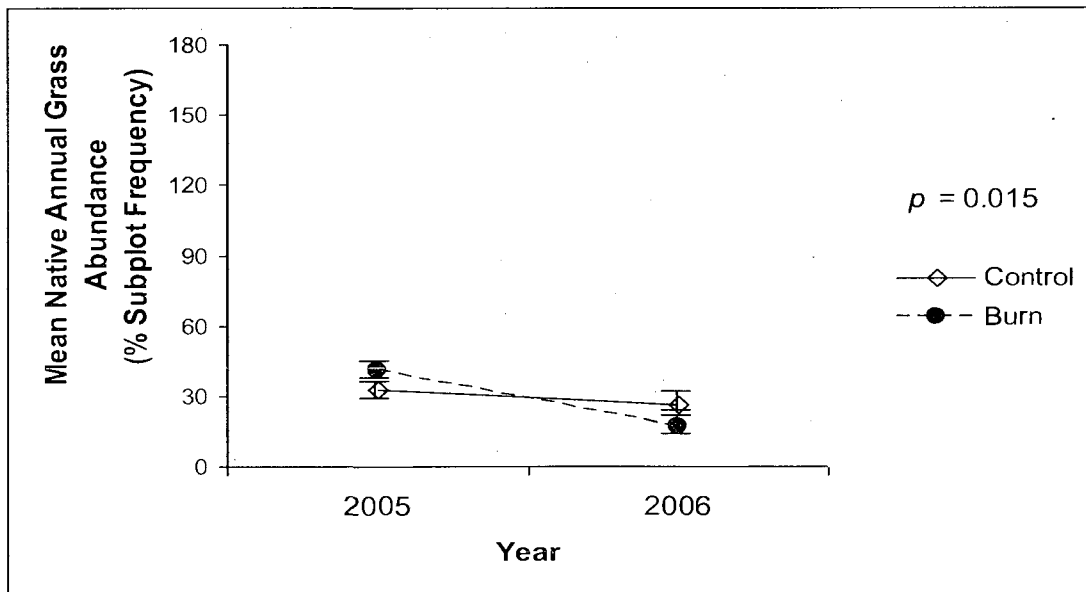
Figure 18. Effect of burning on native annual grass abundance in *B. hordeaceus*-invaded experiment. Error bars represent ± SE.
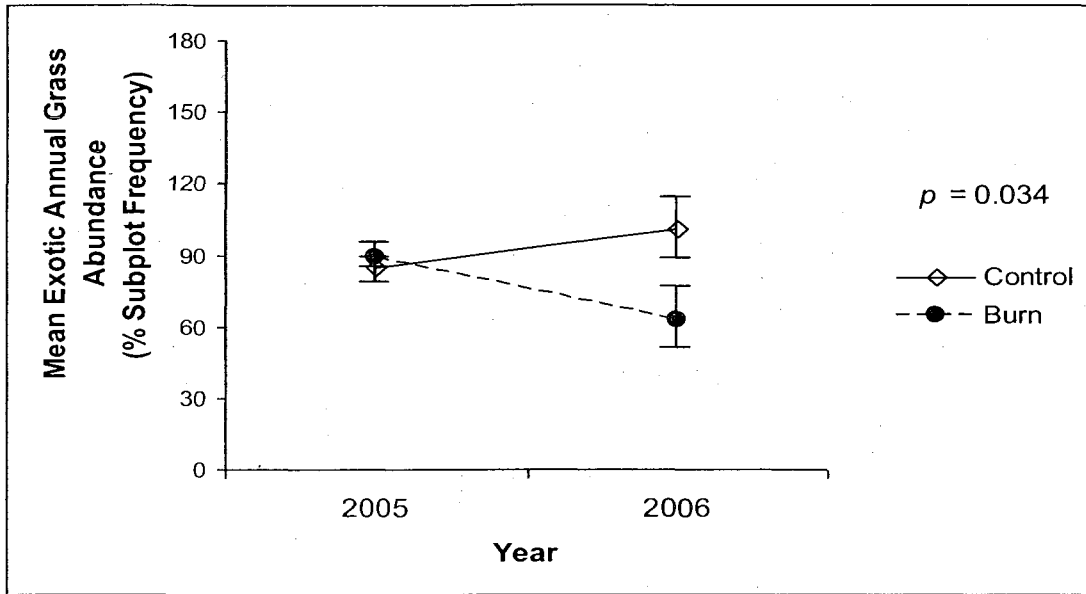
Figure 19. Mean exotic annual grass abundance in *B. hordeaceus*-invaded experiment. Error bars represent ± SE.
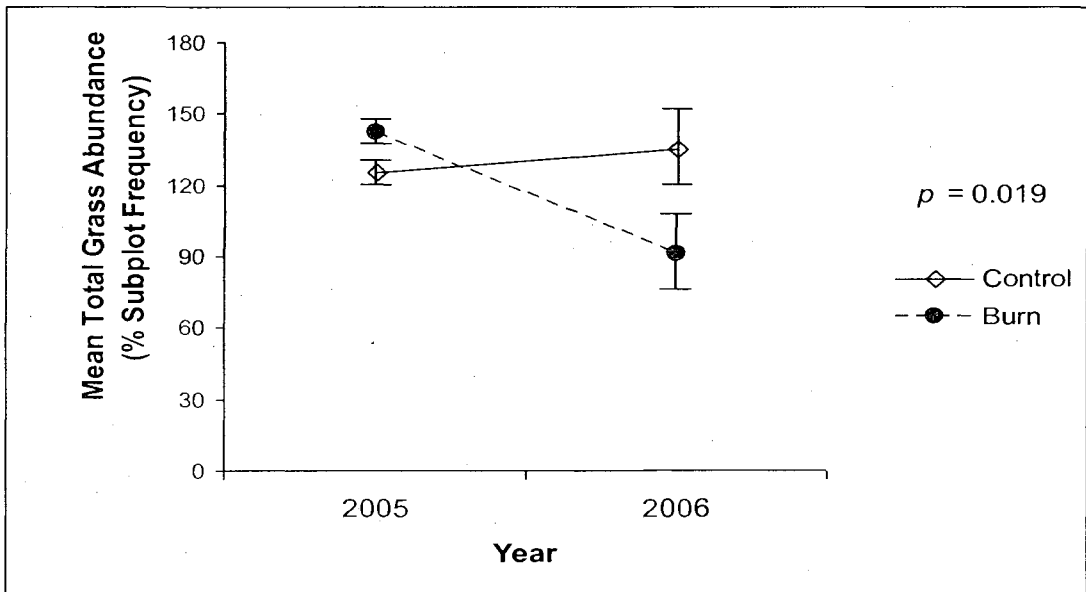
Figure 20. Mean total grass abundance in *B. hordeaceus*-invaded experiment. Error bars represent ± SE.

Burn Temperature Versus Vegetation Parameter Correlation and Follow-up

Change in *Plantago erecta* abundance was the only parameter with an effect that was correlated with burn temperature. In the *L. ambiguus*-rich experiment, *P. erecta* abundance was positively correlated ($r = 0.686$) with burn temperature (Fig. 21A), but in the grass experiment, *P. erecta* abundance and burn temperature were negatively correlated ($r = -0.855$) (Fig. 21B). When data from both experiments were combined, *P. erecta* abundance and burn temperature were not correlated ($r = 0.377$).

In follow-up analyses of burned quadrats, there were no significant differences in mean initial *P. erecta* abundance, mean change in *P. erecta* abundance or mean burn temperature between the *L. ambiguus* experiment and the *B. hordeaceus* experiment that might explain the opposing correlations between change in *P. erecta* and burn temperature ($p>0.05$) (Table 4).

Table 4. Some parameters likely to explain opposing correlations were not significantly different.

Vegetation Parameter	p-Value
Initial *P. erecta* Abundance, % Subplot Frequency	0.212
Change in *P. erecta* Abundance, % Subplot Frequency	0.675
Burn Temperature	0.064
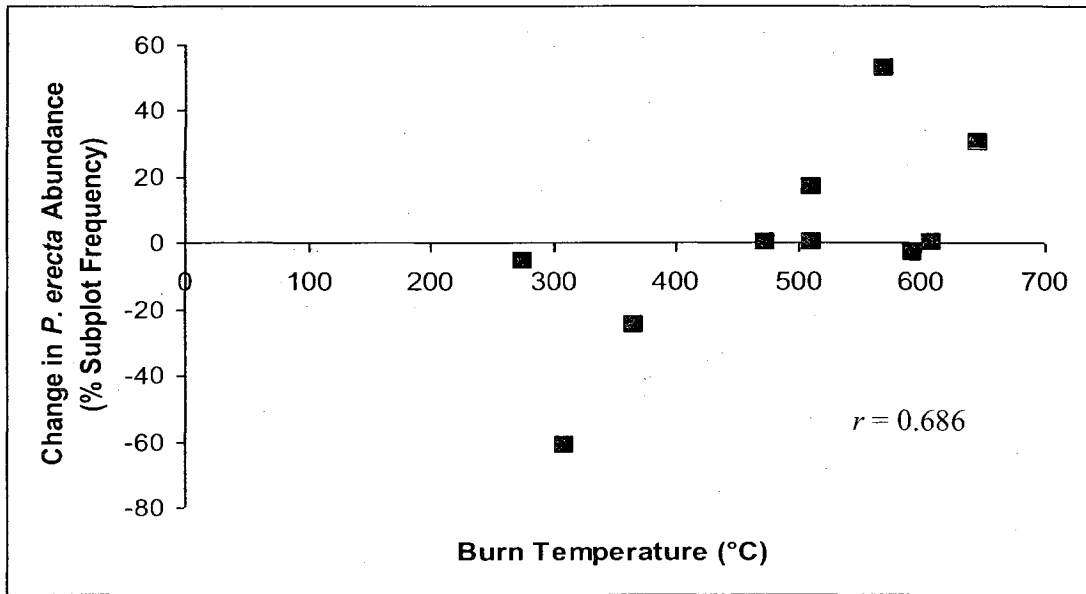
A. *Leptosiphon ambiguus* experiment.
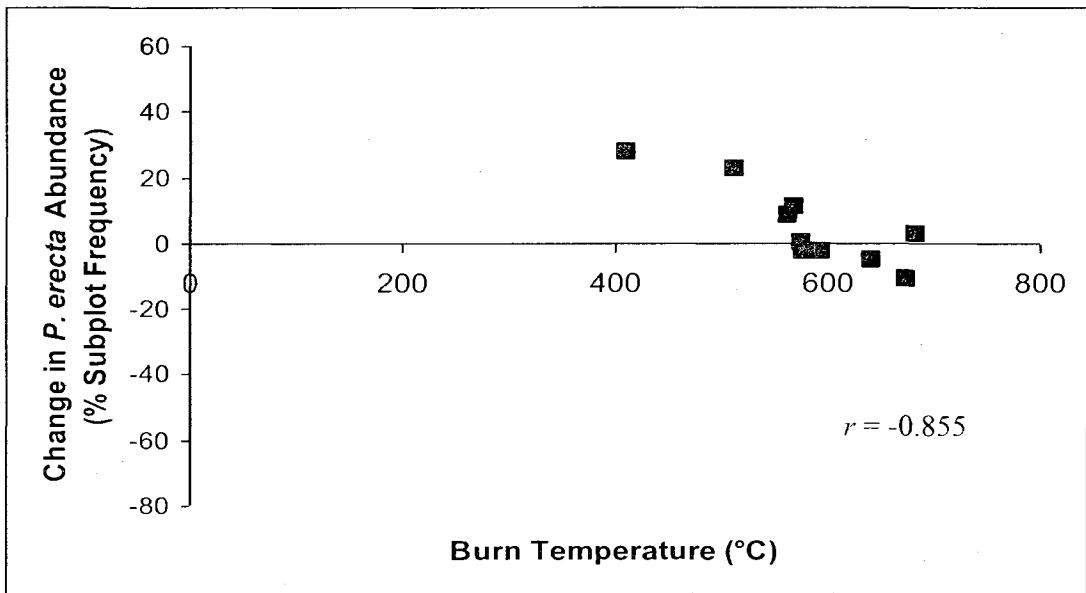
B. *Bromus hordeaceus* experiment.

Figure 21. *Plantago erecta* versus burn temperature correlation. **A.)** In *L. ambiguus*-rich quadrats, there was an increase in *P. erecta* abundance with higher burn temperatures. **B.)** In *B. hordeaceus*-invaded quadrats, the opposite occurred; there was a decrease in *P. erecta* abundance with higher burn temperatures.

There was no switch from a positive to negative correlation of burn temperature with change in *P. erecta* abundance ($|r| > 0.6$) based on temperature group divisions at 450, 500, 550 and 570°C (Table 5). (Note that three *L. ambiguus* plots burned below 400°C, no *B. hordeaceus* plots burned below 400°C and only one burned below 500°C.)

Table 5. Correlation of change in *P. erecta* versus burn temperature at different burn temperatures.

Temperature (°C)	Number of plots burning below Temp.	Correlation with change in *P. erecta* (*r* value)	Number of plots burning above Temp.	Correlation with change in *P. erecta* (*r* value)
450	4	0.532	16	-0.192
500	5	-0.505	15	-0.288
550	8	0.633	12	-0.271
570	11	0.676	9	0.124

In the *L. ambiguus* quadrats *P. erecta* decreased with higher pre-burn native grass abundance ($r = -0.797$) (Fig. 22). Burn temperature decreased with greater initial native perennial ($r = -0.780$) and native annual grass ($r = -0.705$) but increased with exotic annual grass ($r = 0.626$) (Fig. 23A-C). In the *B. hordeaceus* experiment, burn temperature increased with abundance of all grasses combined ($r = 0.701$), but not with any individual group of grasses. (Fig. 23D). None of these measurements were correlated when data from the *L. ambiguus* and *B. hordeaceus* experiments were combined.
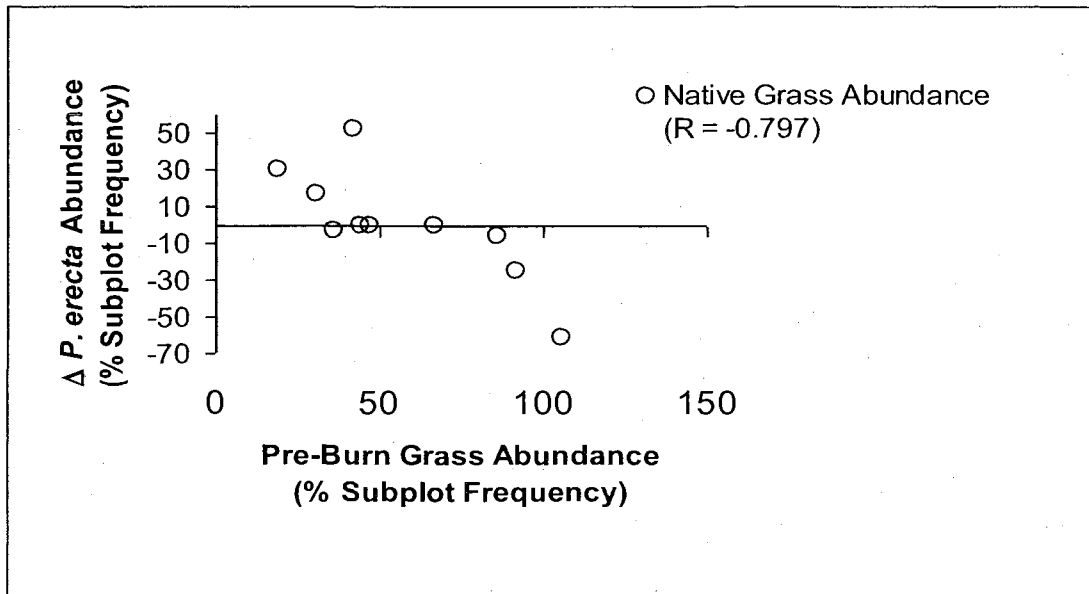
Figure 22. Change in *P. erecta* abundance in the *L. ambiguus*-rich experiment was correlated with pre-burn grass abundance of native grasses.

A. *Leptosiphon ambiguus* experiment

Burn Temp (°C)

○ Native Perennial Grass Abundance

r = -0.780

Pre-Burn Grass Abundance
(% Subplot Frequency)

700 600 500 400 300 200 100 0

0   20   40   60

B. *Leptosiphon ambiguus* experiment.

Burn Temp (°C)

× Exotic Annual Grass Abundance

r = 0.626

Pre-Burn Grass Abundance
(% Subplot Frequency)

700 600 500 400 300 200 100 0

0   20   40   60

C. *Leptosiphon ambiguus* experiment

Burn Temp (°C)

△ Native Annual Grass Abundance

r = -0.705

Pre-Burn Grass Abundance
(% Subplot Frequency)

700 600 500 400 300 200 100 0

0   50   100

D. *Bromus hordeaceus* experiment

Burn Temp (°C)

■ Total Grass Abundance

r = 0.701

Pre-Burn Grass Abundance
(% Subplot Frequency)

700 600 500 400 300 200 100 0

0   100   200   300

Figure 23. Significant correlations with pre-burn grass abundances. In the *L. ambiguus* experiment, native perennial grass (A) and native annual grass abundance (C) are negatively correlated with burn temperature, while exotic annual grasses are positively correlated with burn temperature (B). In the *B. hordeaceus* experiment, combined native and exotic grass abundance is positively correlated with burn temperature (D).

Discussion

Overview of Vegetation Parameters

Eight plants were found in 2006 but not in 2005 (Appendix A). For five of them [native forbs: *Camissonia graciliflora* (Hill suncup), and *Claytonia* spp. (Springbeauty), and exotic forb: *Capsella bursa-pastoris* (Shepherd's purse)], this may have been a sampling artifact because these species were all present early in the season but had shriveled and were indistinct later in the season (sampling was conducted earlier in the post-burn growing season than in the pre-burn season). Two of these species (both exotic forbs) should have been present late enough for the first year's sampling. They may have been stimulated by the fire; however, *Erodium* sp. (Filaree) occurred in both burned and control quadrats. It is likely that they were not found in the first year's sampling because they were uncommon in study quadrats [*Erodium* sp. occurred in four quadrats, and *Medicago polymorpha* (Bur clover) occurred in only one]. The one plant [exotic forb, *Trifolium hirtum* (Rose clover)] that occurred in 2006 in a burned quadrat, but not in 2005, may have been damaged by the fire. However, it occurred in only one quadrat the first year.

Species Richness

A beneficial outcome of burning is that species richness was enhanced in both experiments. The richness of all species increased in the *Leptosiphon ambiguus* experiment, although neither native nor exotic species numbers increased when analyzed separately. In the *Bromus hordeaceus* experiment, only exotic species richness increased. Noy-Meir (1995) reported that only grazed perennial grasslands consistently increased in

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species number. Vogl (1974), who reviewed several studies, also found that results of burning may be variable. Fire may either promote a mixture of annuals and enduring perennials or produce monocultures of fire-tolerant species. Seabloom et al. (2003) found that burning increased species diversity only when invaded grasslands were experimentally seeded. It is possible that the *B. hordeaceus*-invaded quadrats had limited seed banks of native species.

Target Species

Burning affected the two target species (*L. ambiguus* and *B. hordeaceus*) in ways that could be favorable from a management perspective. *Leptosiphon ambiguus* cover doubled and *B. hordeaceus* decreased to one-third its original value in the *B. hordeaceus*-invaded experiment. Because these effects occurred in the same experiment, *L. ambiguus* may have spread into areas invaded by *B. hordeaceus,* as postulated. Other possibilities are discussed below in the "Further Study" section.

A negative result of the burn was that a rare plant, *Lessingia micradenia* var. *glabrata*, was suppressed by fifty percent. This is a concern, but the effect may not be as severe as it first appears. Even though *L. micradenia* suppression was anticipated (since it had not yet set and dropped its seeds, and it was still quite green), the plots were intentionally burned thoroughly in order to detect negative effects. Even so, *L. micradenia* was not eliminated from any plots. In a prescribed burn on a larger scale, areas that were not invaded could be skipped over, while invaded areas could be targeted. A fire also would flow naturally through the areas that had dense dry fuel (primarily areas

invaded with annual non-native grasses) and might move around or incompletely burn green plants such as *L. micradenia.*

Both positive and negative results concur with Vogl (1974) who stated that native annuals are usually encouraged by fire when the burning occurs at the appropriate time. Fire provides exposed soil and full sun needed by most native annuals and provides heat that increases germination of others. In this study the burn occurred after *L. ambiguus* (and most of the native annuals) were senescent. *B. hordeaceus* was dry but had not dropped its seeds, and *L. micradenia* was still green. According to Vogl, some green annual plants, such as *Eschscholzia californica* (California poppy) can withstand "top removal" due to burning and produce seeds the following year. This phenomenon was not observed (nor looked for) in *L. micradenia* or other late-bloomers. Other late-bloomers, including perennials, at this site included *Eriogonum* spp. (Buckwheat), *Hemizonia congesta* (Hayfield tarweed), and *Calochortus argillosus* (Clay mariposa lily).

Grass Abundance

Burning significantly decreased native annual grass abundance in both the *L. ambiguus* and *B. hordeaceus* experiments. It also decre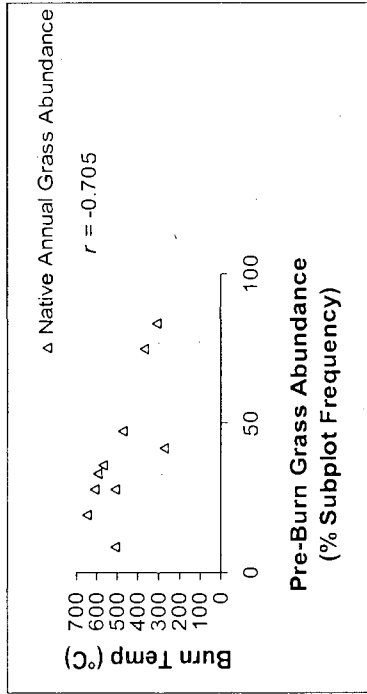ased exotic annual, native annual, and total grass abundance in the *B. hordeaceus* experiment. Native perennials were the only grasses not significantly affected by burning in the *B. hordeaceus* experiment. Looking at all the grass abundance graphs together, they appear very similar (Fig. 17-20). Early summer burning reduced annual grasses. This was anticipated as most of them were senescent and dry yet had not dropped most of their seeds.

Change in *Plantago erecta* Correlated with Burn Temperature

Although mean change in *P. erecta* abundance was not affected by burning in either experiment (the effect was marginally significant in *L. ambiguus* quadrats), change in *P. erecta* abundance was positively correlated with burn temperature in the *L. ambiguus*-rich experiment and negatively correlated with burn temperature in invaded quadrats. Initial *P. erecta* abundance did not account for the apparent difference in response. There are two possible biological explanations (initial differences in grass abundance and mycorrhizal communities) and two non-biological explanations (both involving burn temperature) for the opposing correlations. These are considered below.

Plantago erecta decreased in *L. ambiguus* quadrats with more native grass. It is possible that native grass abundance affected burn temperature. Burn temperature was lower in quadrats with more native grass and higher in quadrats with more exotic grass in the *L. ambiguus* experiment. Burn temperatures were also higher in quadrats with all grasses combined in the *B. hordeaceus* experiment.

It is logical that dry annual grass would burn at higher temperatures than perennial grass, which was still relatively moist. *B. hordeaceus* quadrats initially had more exotic annual grass than *L. ambiguus*. It would be expected that the exotic annual grass would drive the response (of increased burn temperature with more grass) in the *B. hordeaceus* experiment. However, native and exotic grasses appear to burn differently. It is not known why burn temperature would have been lower in *L. ambiguus* quadrats containing more native annual grasses. Initial native annual grass abundance represented a greater proportion of annual and total grass in the *L. ambiguus quadrats* than it did in

the *B. hordeaceus* experiment. It is possible that the native grasses are more abundant in *L. ambiguus* quadrats that were burned later in the day (when dew had evaporated) or that their abundance indicates some unknown parameter (with their location within at the study site) and that this in turn affected the change in *P. erecta* abundance.

The mycorrhizal fungal communities may have affected the change in *P. erecta* abundance with burn temperature. *Plantago erecta* has mycorrhizal associations (Chiariello et al. 1982) that may be altered by exotic grasses (Batten et al. 2006). Fire sometimes enhances, sometimes suppresses, and sometimes has no apparent effect on mycorrhizal communities (Bellgard et al. 1994).

Although mean burn temperatures were not significantly different between the two experiments, three *L. ambiguus* quadrats burned below 400°C, but none of the *B. hordeaceus* quadrats did. Therefore, there is no data for how *P. erecta* abundance is affected at lower temperatures in the *B. hordeaceus* experiment.

It is also possible that the radiant temperature measured did not reflect ground temperature, since the highest temperatures are usually produced well above the ground at the apex of the flames or higher (Vogl 1974) (the radiant heat measurement was taken approximately 0.5 m above the ground). This would be especially likely if flame height was different for different types of grass. It is also possible that perennial grass burned longer, exposing the ground to high temperatures for a longer period.

To understand the relationship between the change in *P. erecta* abundance and burn temperature, further study under more tightly controlled conditions and using more replicates would be required.

Management Considerations

Land managers must consider benefits and drawbacks of various management techniques and weigh them against taking no action at all. Benefits and risks to consider include feasibility, hazards, cost-effectiveness, and ecological management goals. Time of year, infrastructure (roads and fences already in place), proximity to man-made structures (homes), air quality, and community support can influence the balance. This study is primarily concerned with results to the environment, which are discussed in the conclusions. Each location must be considered independently.

Managers must consider effort and cost versus payback of different management methods. Rancho Cañada del Oro is fenced and therefore can be grazed by cattle, at a profit to land managers, when the land is leased to cattle owners. Cost may be prohibitive for grazing properties that are not fenced. Goats, which can be penned in small portable enclosures, require a goatherd where large predators are present. Burning can be an inexpensive management tool if performed outside the wildfire-danger season when minimal staff is needed (P. Congdon 2008, Santa Clara County Open Space Authority, San Jose, CA, personal communication).

Two drawbacks of burning as a management tool are the possibility of the fire spreading and the unpredictability of environmental conditions. It is not unusual for a scheduled fire to be cancelled due to fire danger or air quality issues. These two risks are minimized with burns performed before the surrounding environment dries out or after the first fall rains. The fact that most plants in serpentine grasslands mature and become senescent before the surrounding grasslands makes them candidates for earlier burns.

Further Study

Further study could be done on serpentine endemic plants' response to fire. None of the study plots contained the rare plants *Dudleya setchellii* or *Streptanthus albidus*. Weiss (2007) found that fires moved around *D. setchellii*, a succulent, without damaging it. In a fire allowed to move naturally through the grassland, green *L. micradenia* might not be damaged either. Further study could determine whether or not fire would be detrimental to *S. albidus*. Like *L. ambiguus*, *S. albidus* begins flowering in early spring. If it senesces in time, it would be likely to sustain little damage and could even benefit from a burn.

Studies could be done to try to explain why *L. ambiguus* cover increased in the *B. hordeaceus* experiment. Possible explanations are that *L. ambiguus'* reproductive capacity increased, seed germination was enhanced and/or that it spread into areas previously occupied by other plants (Vogl 1974; Pendergrass 1999). These quadrats had a relatively high *L. ambiguus* abundance, so they would not have been seed-limited as in the study performed by Seabloom et al. (2003).

Study Limitations

In this study serpentine grassland samples were limited to two types: *L. ambiguus* patches that were invaded by *B. hordeaceus*, and those that were not. This method of sampling was chosen in order to reduce variance and to increase the ability to detect changes in rare plant *L. ambiguus* and its ability to spread into *B. hordeaceus*-invaded areas. All conclusions are restricted to areas with these conditions. *Leptosiphon ambiguus*-rich experiments contained many of the species found in the least-invaded

zones in the serpentine grasslands and appeared to be fairly representative of these zones, except that *L. ambiguus* was more abundant in them. *Bromus hordeaceus* quadrats appeared to be fairly representative of mildly-invaded zones; once again *L. ambiguus* was over-represented. Although quadrats were not painstakingly paired for the other parameters, they were well-matched; only four out of 30 parameters were significantly different within pairs before the burn. So, it is not unreasonable that results would apply to the less-invaded serpentine grasslands in general.

Parts of the grassland that were notably missing were patches of dense perennial grasses (especially *Nasella pulchra*) and serpentine fringes invaded by *Avena fatua* or *Lolium multiflorum*. *Leptosiphon ambiguus* was not found in areas dense with either of these invasive grasses, but was found (the second year only) in the perennial grassland area. Previous studies indicate that *N. pulchra* responds favorably to burning but give no information about how *L. ambiguus* responds in *N. pulchra*-dominated grasslands.

Most abundance data were limited to frequency of subplots per quadrat. The assumption is that the number of subplots containing a species is indicative of the abundance in the entire quadrat. Percent cover, which is a more accurate and more common measure of abundance, was only collected for post-burn *L. ambiguus*. Percent subplot frequency was chosen in this study due to unfamiliarity with a number of species, difficulty in estimating *L. ambiguus* cover, and choosing to use a consistent measure of abundance among parameters that would (in addition) remain constant through most of the growing season.

Conclusions are limited to one site and to one year post-burn only. Conclusions can not be applied to sites with different species composition or soil type. Pendergrass et al. (1999) and Weiss et al. (2007) found that results may not be long-lasting. Increases in native species abundance and diversity and decreases in invasive exotics persist in some cases, but not in others.

Conclusions

Early summer burning appears to be an effective management tool in serpentine grasslands at Rancho Cañada del Oro even where grazing has occurred on a regular basis. There were three main benefits and one drawback as a result of burning at Rancho Cañada del Oro, a preserve that has been grazed for 100 years. The question is whether increased species richness, the reduction of an invasive grass, and an increase in abundance of one rare plant outweigh the reduction in abundance of another rare plant. Given *B. hordeaceus*' adaptation to serpentine grasslands (especially on small patches) (Harrison et al. 2001), benefits do appear to outweigh the one disadvantage. The best approach may be to combine grazing and burning. Collins (1992) found that biodiversity increased in grasslands with variable prescribed burning regimes. Grazing can be performed on a regular basis; the best burning regime can be investigated and carried out when fire hazard and air quality conditions permit.

Implications for Practice

- Refined pairing allowed treatment differences to be found that would otherwise have been lost due to variance in data.

- Results from this controlled study, with before and after data, showed similar benefits to those documented in wildfire studies.

- One rare endemic benefited from the burn and another was suppressed.

- Burn boxes provided a relatively safe way of testing the effects of prescribed fire on target species.

LITERATURE CITED

Aerts, R. and F. Berendse 1988. The effect of increased nutrient availability on vegetation dynamics in wet heathlands. Vegetatio **76:**63-69.

Barry, S. J. 1998. Managing the Sacramento Valley vernal pool landscape to sustain the native flora. Pages 236-240 in C.W. Witham, and E. T. Bauder, D. Belk, W. R. Ferren Jr., and R. Ornduff, editors. Ecology, conservation, and management of vernal pool ecosystems- proceedings from a 1996 conference. California Native Plant Society, Sacramento.

Batten, K. M., K. M. Scow, K. F. Davies, and S.P. Harrison 2006. Two invasive plants alter soil microbial community composition in serpentine grasslands. Biological Invasions **8:**217-230.

Bell, C. D., and R. W. Patterson 2000. Molecular phylogeny and biogeography of *Linanthus* (Polemoniaceae). American Journal of Botany. **87:**1857-1870.

Bellgard, S. E., R. J. Whelan, and R. M. Muston 1994. The impact of wildfire on vesicular-arbuscular mycorrhizal fungi and their potential to influence the re-establishment of post-fire plant communities. Mycorrhiza **4:**139-146.

Bobbink, R., and J. G. Roelofs 1995. Nitrogen critical loads for natural and semi-natural ecosystems: The empirical approach. Water Air and Soil Pollution **85:**2413-2418.

Bowcutt, F. 1999. A floristic study of Sugarloaf Ridge State Park, Sonoma County, California. Aliso **18:**19-34.

Calflora: Information on California plants for education, research and conservation, 2009. Berkeley, CA: The Calflora Database (a non-profit organization). URL http://www.calflora.org/ [accessed 18 February 2009].

California Invasive Plant Council (CalIPC), 2009. Berkeley, CA: Invasive plant profile. http://www.cal-ipc.org/ip/management/plant_profiles/index.php [accessed 28 February 2009].

California Native Plant Society (CNPS) 2009. Inventory of rare and endangered plants (online edition, v7-09a). California Native Plant Society. Sacramento, CA. URL http://www.cnps.org/inventory [accessed on 18 February 2009].

Chiariello, N., J. C. Hickman, and H. A. Mooney 1982. Endomycorrhizal role for interspecific transfer of phosphorus in a community of annual plants. Science **217:**941-943.

Cilimburg, A. C., and K. C. Short 2005. Forest fire in the US Northern Rockies: A primer. URL http://www.northernrockiesfire.org/effects/soilindi.htm [accessed 27 February 2009].

Collins, S. 1992. Fire frequency and community heterogeneity in tallgrass prairie vegetation. Ecology **73**:2001-2006.

Collins, S. 1998. Modulation of diversity by grazing and mowing in native tallgrass prairie. Science **280**:746-747.

DiTomaso, J. M., Kyser, M. S. Hastings 1999. Prescribed burning for control of yellow starthistle (*Centaurea solstitialis*) and enhanced native plant diversity. Weed Science **47**:233-242.

Goodwillie, C. 1999. Wind pollination and reproductive assurance in *Linanthus parviflorus* (Polemoniaceae), a self-incompatible annual. American Journal of Botany **86**:948–954.

Gundale, M. J. 2005. Nitrogen cycling and spatial heterogeneity following fire and restoration treatments in the ponderosa pine/Douglas-fir ecosystem. Dissertation. University of Montana, Missoula.

Harrison, S. K. Rice; and J. Maron 2001. Habitat patchiness promotes invasion by alien grasses on serpentine soil. Biological Conservation **100**:45-53.

Harrison, S., B. D. Inouye, and H. D. Safford 2003. Ecological heterogeneity in the effects of grazing and fire on grassland diversity. Conservation Biology **17**:837-845.

Heady 1977, H. F. 1977. Valley grassland. Pages 491-514 in M. G. Barbour and J. Major, editors. Terrestrial vegetation of California. California Native Plant Society, Sacramento.

Hickman, J. C. editor. 1993. The Jepson Manual, Higher Plants of California. University of California Press, Berkeley.

Hickman, J. C. editor 2009. The Jepson Manual, Higher Plants of California, (online edition). Jepson flora project: Jepson interchange for California floristics. The Jepson Herbarium Berkeley, CA. URL http://ucjeps.berkeley.edu/interchange/1_treat_indexes.html [accessed 19 February 2009].

California Native Plant Society (CNPS) 2009. Inventory of rare and endangered plants (online edition, v7-09a). California Native Plant Society. Sacramento, CA. URL http://www.cnps.org/inventory [accessed on 18 February 2009].

Huenneke, L. F., S. P. Hamburg, R. Koide, H. A. Mooney, and P. M. Vitousek 1990. Effects of soil resources on plant invasion and community structure in Californian USA serpentine grassland. Ecology **71**:478-491.

Kruckeberg, A. R. 1984. California serpentines: Flora, vegetation, geology, soils and management problems. University of California Press, Berkeley.

MacArthur, R. H. and E. O. Wilson. 1967. The theory of island biogeography. Princeton University Press, Princeton.

McNaughton, S. J. 1968. Structure and Function in California grasslands. Ecology **49**:962-972.

Menke, J. W. 1989. Grazing and fire management for native perennial grass restoration in California grasslands. Fremontia **20**:22-25.

Meyer, M. D., and P. M. Schiffman 1999. Fire season and mulch reduction in a California grassland: A comparison of restoration strategies. Madroño **46**:25-37.

Mooney, H. A., S. P. Hamburg, and J. A. Drake 1986. The invasion of plants and animals into California. Pages 250-272 in H. A. Mooney and J. A. Drake, editors. Ecology of biological invasions of North America and Europe. Springer Verlag, Berlin.

Murphy, D. D., and P. R. Ehrlich 1989. Conservation biology of California's remnant native grasslands. Pages 201-211 in Huenneke, L. F. and Mooney, H., editors. Grassland structure and function: California annual grasslands. Kluwer Academic Publishers, Dordrecht, the Netherlands.

Natural Resources Conservation Service, National Water and Climate Center, 1971-2000. ftp://ftp.wcc.nrcs.usda.gov/support/climate/taps/ca/06085.txt [accessed 26 February 2009].

Neary, D. G., C. C. Klopatek, L. F. DeBano, and P. F. Ffolliott 1999. Fire effects on belowground sustainability: A review and synthesis. Forest Ecology and Management **122**:51-71.

Noy-Meir, I 1995. Interactive effects of fire and grazing on structure and diversity of Mediterranean grasslands. Journal of Vegetation Science **6**:701-710.

Patterson, R. 1977. A revision of *Linanthus* section siphonella Polemoniaceae. Madroño **24**:36-48.

Parsons, D. J. and T. J. Stohlgren 1989. Effects of varying fire regimes on annual grasslands in the southern Sierra Nevada of California. Madroño **36**:154-168.

Pendergrass, K. L., P. M. Miller, J. B. Kauffman, and T. N. Kaye 1999. The role of prescribed burning in maintenance of an endangered plant species, *Lomatium bradshawii*. Ecological Applications **9**:1420-1429.

Porter, J. M. 1998. Nomenclature changes in Polemoniaceae. Aliso **17**:83-85.

Porter, J. M., and L. A. Johnson 2000. A phylogenetic classification of Polemoniaceae. Aliso **19**:55–91.

Power, S. A., M. R. Ashmore, D. A. Cousins, and N. Ainsworth 1995. Lon term effects of enhanced nitrogen deposition on a lowland dry heath in southern Britain. Water air and soil pollution **85**:1701-1706.

Safford, H. D., Viers, J. H. and Harrison, S. P. 2005 Serpentine endemism in the California flora: A database of serpentine affinity. Madroño, **52**:222-257.

Schmidtt, J. M. 1981. Pollinator foraging and evolution in flowering plant populations. Dissertation. Stanford University, Stanford.

Seabloom, Eric W., E. T. Borer, V. L. Boucher, R. S. Burton, K. L. Cottingham, L. Goldwasser, W. Gram, B. E. Kendall, and M. Fiorenza 2003. Competition, seed limitation, disturbance, and reestablishment of California native annual forbs. Ecological Applications **13**:575-592.

Thomsen, C., W. A. Williams, M. Vayssieres, F. L. Bell, M. R. George 1993. Controlled grazing on annual grasslands decreases yellow starthistle. California agriculture **47**:36-40.

U.S. Fish and Wildlife Service 1998. Recovery Plan for Serpentine Soil Species of the San Francisco Bay Area. Portland, Oregon.

U.S. Forest Service 2005. Wildland fire in ecosystems effects of fire on soil and water. http://www.fs.fed.us/rm/pubs/rmrs_gtr042_4.pdf [accessed Feb 27 2009].

United States Department of Agriculture 1974. Soil survey of the eastern Santa Clara area, California. USGPO, Washington.

Vogl, R. J. 1974. Effects of fire on grasslands. Pages 139-194 in T. T. Kozlowski and E. E. Ahlgren, editors. Fire and ecosystems. Academic Press, New York.

Weiss, S. 1999. Cars, cows, and checkerspot butterflies: Nitrogen-deposition and management of nutrient-poor grasslands for a threatened species. Conservation Biology **13**:1476-1486.

Weiss, S. B., and D. H. Wright 2005. Serpentine Vegetation Management Project Report (to US Fish and Wildlife Service). Creekside Center for Earth Observation. Menlo Park, CA. URL http://www.creeksidescience.com/files/weiss_et_al_2005_usfws_serpveg.pdf [accessed 20 February 2009].

Weiss, S. B., D. H. Wright, and C. Niederer 2007. Serpentine vegetation management project final report (to US Fish and Wildlife Service). Creekside Center for Earth Observation. Menlo Park, CA. URL http://www.creeksidescience.com/files/weiss_et_al_2007_usfws_serpveg.pdf [accessed 20 February, 2009].

Whelan, R. 1995. The ecology of fire. Cambridge University Press, Cambridge.

APPENDIX A. Plant Species List. Each species is listed by experiment (*L. ambiguus*-rich, *B. hordeaceus*-invaded), "Pre"- or "Post"-burn, treatment (Control, Burn), and no. of quadrats out of ten where species was present. (For *B. hordeaceus* # of quadrats where more than 20 plants/subplot in any subplot.)

Species Name	Common name	*L. ambiguus*-rich Control		*L. ambiguus*-rich Burn		*B. hordeaceus*-invaded Control		*B. hordeaceus*-invaded Burn	
		Pre	Post	Pre	Post	Pre	Post	Pre	Post
NATIVE FORBS									
Achillea millefolium	Yarrow	2	2	2	2		1	1	1
Achyrachaena mollis	Blow wives					1	3		
Agoseris heterophylla	Mountain dandelion	7	6	7	8	9	7	10	9
Allium serra	Jeweled onion				1	1			
Aphanes occidentalis	Western ladies' mantle	3	9	4	10	3	6	4	10
Astragalus gambelianus	Milkvetch	8	6	7	4	8	2	8	8
Calandrinia ciliata	Rednaids		1		6		2		3
Calochortus argillosus	Clay mariposa lily	7	3	5	2	3	2	4	
Calystegia subacaulis	Hill morning-glory	7	7	7	7	5	5	7	7
Camissonia graciliflora	Hill suncup		2		4		1		2

(Appendix A, continued)

| | | L. ambiguus -rich | | | | B. hordeaceus- invaded | | | |
| | | Control | | Burn | | Control | | Burn | |
		Pre	Post	Pre	Post	Pre	Post	Pre	Post
Castilleja attenuata	Cream owl's clover	6	4	3	1	3	3	2	2
Chlorogalum pomeridianum	Soap plant	2	1	2	2	3	2	2	2
Clarkia purpurea var. quadrivulnera	Winecup			1	1	1	1	1	2
Claytonia exigua	Serpentine springbeauty		1		3		1		2
Claytonia gypsophiloides	Gypsum springbeauty				1		1		
Claytonia perfoliata	Miner's lettuce		5		4		5		5
Cryptantha flaccida	Flaccid cryptantha	7	7	9	5	6	5	7	4
Dichelostemma capitatum	Blue Dicks	1		2	2	2		3	1
Epilobium brachycarpum	Annual fireweed	9	10	6	8	6	6	5	7
Eriogonum nudum	Naked buckwheat		2	3	4	4	4	4	4
Eriogonum roseum	Wand buckwheat	9	5	6	5	6	4	7	7
Eriophyllum confertiflorum	Golden yarrow	1	1		1		1		1
Eschscholzia californica	California poppy	6	6	7	8	9	8	9	9

(Appendix A, continued)

| | | L. ambiguus-rich | | | | B. hordeaceus-invaded | | | |
| | | Control | | Burn | | Control | | Burn | |
		Pre	Post	Pre	Post	Pre	Post	Pre	Post
Gilia achilleifolia	California gilia					2	2	1	
Gilia tricolor	Bird's eye gilia				3	4	4	2	3
Hemizonia congesta	Hayfield tarweed	8	9	10	9	10	7	10	7
Hesperevax sparsiflora	Erect evax	3	5	3	5	1	3	2	5
Lasthenia californica	California goldfields	5	6	6	8	5	6	4	4
Leptosiphon ambiguus	Serpentine leptosiphon	10	10	10	10	10	10	10	10
Leptosiphon liniflorus	Narrowflower flaxflower	1	1	1	1	1		2	1
Lessingia micradenia var. glabrata	Smooth lessingia	8	9	8	9	6	7	7	7
Linanthus dichotomus	Evening snow	1		1	2	1	1		1
Lomatium sp.	Lomatium	3	3	1		2	1	2	1
Lotus sp.	Trefoil	1					1	3	2
Lotus wrangelianus	Chilean bird's foot trefoil	3	3	1	4	3	3	2	4
Micropus californicus	Slender cottonweed	9	8	10	7	9	10	8	9

(Appendix A, continued)

| | | L. ambiguus-rich | | | | B. hordeaceus-invaded | | | |
| | | Control | | Burn | | Control | | Burn | |
		Pre	Post	Pre	Post	Pre	Post	Pre	Post
Microseris douglasii	Douglas' silverpuffs			1		1	1	1	
Plantago erecta	California plantain	8	9	9	8	9	9	7	9
Platystemon californicus	Cream cups	4	6	5	7	3	8	5	6
Sisyrinchium bellum	Western blue-eyed grass	2	4	4	4	6	3	4	3
Trifolium albopurpureum	Common indian clover	6	5	5	7	8	6	10	9
Trifolium bifidum	Notch leaf clover	4	3	1	2	2	4	5	3
Trifolium depauperatum var. truncatum	Dwarf sac clover							2	4
Trifolium gracilentum	Pinpoint clover			1	1			1	1
Trifolium willdenovii	Tomcat clover	8	7	8	9	9	8	8	8
Triphysaria pusilla	Dwarf orthocarpus	5	4	5	5	2	3	4	4
Uropappus lindleyi	Silver puffs	1		1		3	3	3	2
Total # Native Forbs		**33**	**34**	**35**	**40**	**36**	**42**	**40**	**41**

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(Appendix A, continued)

		L. ambiguus-rich				B. hordeaceus-invaded			
		Control Pre	Control Post	Burn Pre	Burn Post	Control Pre	Control Post	Burn Pre	Burn Post
Gilia achilleifolia	California gilia					2	2	1	
Gilia tricolor	Bird's eye gilia				3	4	4	2	3
Hemizonia congesta	Hayfield tarweed	8	9	10	9	10	7	10	7
Hesperevax sparsiflora	Erect evax	3	5	3	5	1	3	2	5
Lasthenia californica	California goldfields	5	6	6	8	5	6	4	4
Leptosiphon ambiguus	Serpentine leptosiphon	10	10	10	10	10	10	10	10
Leptosiphon liniflorus	Narrowflower flaxflower	1	1	1	1	1		2	1
Lessingia micradenia var. glabrata	Smooth lessingia	8	9	8	9	6	7	7	7
Linanthus dichotomus	Evening snow	1		1	2	1	1		1
Lomatium sp.	Lomatium	3	3	1		2	1	2	1
Lotus sp.	Trefoil	1					1	3	2
Lotus wrangelianus	Chilean bird's foot trefoil	3	3	1	4	3	3	2	4
Micropus californicus	Slender cottonweed	9	8	10	7	9	10	8	9

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(Appendix A, continued)

	L. ambiguus -rich				B. hordeaceus- invaded			
	Pre Control	Post Control	Pre Burn	Post Burn	Pre Control	Post Control	Pre Burn	Post Burn
EXOTIC FORBS								
Capsella bursa-pastoris Shepherd's purse		1		4		4		6
Erodium sp Filaree						1		3
Medicago polymorpha Bur clover								1
Silene gallica Windmill pink	5	5	7	6	7	2	6	7
Stellaria media Common chickweed								1
Trifolium hirtum Rose clover				1				
Total # Exotic Forbs	**1**	**2**	**2**	**2**	**1**	**3**	**1**	**5**

(Appendix A, continued)

| | | L. ambiguus-rich | | | | B. hordeaceus-invaded | | | |
		Pre Control	Post Control	Pre Burn	Post Burn	Pre Control	Post Control	Pre Burn	Post Burn
EXOTIC GRASSES									
Avena barbata	Slender wild oats	2	2	3	4	5		5	6
Bromus hordeaceus	Soft chess	4	5	4	4	10	10	10	10
Bromus madritensis ssp. rubens	Foxtail chess	4	5	5	5	8	6	7	6
Gastridium ventricosum	Nit grass	1				2		3	
Hordeum marinum	Farmer's foxtail	2	1	1	1	5	4	3	4
Lolium multiflorum	Italian rye grass		1	2	4	2	6	4	6
Vulpia bromoides	Brome fescue		1	1	1	3		3	
Total # Exotic Grasses		**5**	**6**	**6**	**6**	**7**	**4**	**7**	**5**
Total # Exotic Species		**6**	**8**	**8**	**8**	**8**	**7**	**8**	**10**

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