BEETLE RESPONSE TO SEASONAL PRESCRIBED FIRE IN BLUE OAK *(Quercus douglasii)* WOODLANDS OF BIG CHICO CREEK ECOLOGICAL RESERVE

A Thesis

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in

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by

Mark Louis Lynch

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ABSTRACT

BEETLE RESPONSE TO SEASONAL PRESCRIBED FIRE IN BLUE OAK *(Quercus douglasii)* WOODLANDS OF BIG CHICO CREEK ECOLOGICAL RESERVE

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Fire is an integral component of terrestrial ecosystem processes. The timing, intensity and frequency of fires influence ecosystem responses throughout the world. Prescription burns have been widely reintroduced into fire-adapted systems in order to restore natural processes, control exotic species, and other unwanted vegetation. The majority of studies examining the effects of prescribed fire have predominately focused on vascular vegetation; largely ignoring species in higher trophic levels. Beetles occupy multiple trophic levels as consumers, serving as decomposers, herbivores, predators, and scavengers. In order to improve our understanding of arthropod responses to seasonal variation in prescribed fire, I examined the effects of spring (late wet-season) and fall (early wet-season) prescribed fires on ground cover structure (bare ground, leaf litter, plant stem density) and ground-dwelling beetle guilds in blue oak (*Quercus Douglassii*) woodlands of Big Chico Creek Ecological Reserve (BCCER), Butte County, California. The study was conducted on twelve quarter hectare (50 m x 50 m) sites. Ground cover and beetles were sampled pre-treatment in April and early May 2007, followed by burning four sites (spring treatment) in late May 2007. Four more sites were burned (fall treatment) in early November 2007, with the four remaining sites left unburned (control). Post treatment sampling of ground cover and beetles occurred in April and early May 2008. Burn Severity was similar between spring and fall burn treatments, but fall burns experienced the highest variability in burn severity between sties. Bare ground increased and leaf litter decreased significantly in both spring and fall burn sites. Plant stem density decreased in fall burns, but did not change in spring burns. Overall beetle density decreased in fall and spring burn sites, but the differences were not significant between treatments. Beetle density in fall burn treatments tended to be lower than spring sites, but the response may have been complicated by temporal recovery between fall and spring treatments. With respect to guilds, seed eaters showed a strong negative correlation to burn severity and bare ground but a positive correlation to leaf litter, suggesting bare ground was associated with vital resource losses. Fire prescription studies conducted in California most often implement fire treatments with the support of professional private/government fire crews allowing burns to take place in drier conditions than allowed by burn permits issued to the public. The differences in prescription timing between public burn periods and that allowed by professional fire crews may affect plant and animal species differently due to the phenology and activity of species present at the time of burn prescriptions. Although fires decreased beetle density, results of the study did not show wet-season burn timing (spring and fall burn prescriptions) to have a negative effect in ground-dwelling beetle assemblages. The decrease in plant stem density in fall burns but not in spring burn sites suggests burn timing influenced plant stem density response and could prove useful in land management planning. Thus, burn timing appears to have significantly affected plant response, but had minimal influence on beetle response; suggesting spring and fall burn prescriptions can be utilized as a management tool without a dramatic impact on beetle guild assemblages present.

CHAPTER I

INTRODUCTION

Prescribed fire is a process by which humans ignite fires intentionally under weather conditions that promote safe control of burn behavior and achieve pre-determined management objectives (e.g., fuel reduction, exotic species control, natural processes). Prescription burns have been widely reintroduced into fire-adapted ecosystems to reduce the frequency of catastrophic fires (Niwa and Peck 2002) and have been documented to aid in the preservation and management of plant and animal communities (Kilgore 1973; Tester 1989; Siemann et al. 1997; Peterson and Reich 2001). Most prescription burns are conducted before or after the natural fire season because of reduced fire intensity, allowing for safer control of prescription burns. However the temporal differences between prescription burns and natural occurring fires can influence ecosystem responses differently depending on the timing, intensity and frequency of the burns and life stage of species present at the time of burning (Howe 1994; Chang 1996; Sackmann and Farji-Brener 2006).

Following an extremely active fire season of 1910, fire suppression efforts were employed to decrease the frequency of fires as settlement of the western United States increased (Hann and Bunnell 2001). The era of wildfire prevention began with an overall decrease in the number and size of fires until the 1950's, then the trend reversed and wildfires began to increase with intensity and frequency. Fire suppression efforts altered natural fire regimes by lengthening the time between fires, which led to substantial increases in forest fuel loads. The accumulation of volatile biomass promoted a rise in large catastrophic fires that negatively effected ecosystem health (Pyne 1982; Stephens 1998; Hann and Bunnell 2001; Six and Skov 2009). Increasingly severe wildfire seasons raised concern about ecosystem health across the west. The catastrophic fires of Yellowstone in 1988 spurred the evaluation of fire policies across the country (Hann and Bunnell 2001), ranging from National Park fire plans to statewide reviews.

In California, with vast areas of fire-prone habitat, the California Fire Plan was created in the 1990s (California Department of Forestry and Fire Protection 1996), subsequent to review of wildland fire policies. The plan recommended the use of prescribed fire to reduce burn severity in habitats carrying excess fuel loads. A main goal of the plan was to reduce the overall cost of fire suppression that had grown exponentially over the past century. It was believed that lighter fuel loads, created with controlled burns, would lead to lower intensity burns and ultimately cost less to manage wildfire activity (California Department of Forestry and Fire Protection 1996). As a result of this policy, fire prescriptions have greatly increased over the last decade on both private and public lands. As projected, fuel loads and burn severity on lands treated with prescribed fire declined and certain plant species suffering recruitment losses successfully began to regenerate (Kilgore 1973; Niwa and Peck 2002; Fulé et al. 2004).

Among California's fire adapted ecosystems, endemic blue oaks (*Quercus douglasii*) constitute the most abundant hardwood type across the state, covering over three million acres of Sierra and Coastal Foothill Ranges (Swiecki and Bernhardt 1998). They are characterized by an understory dominated by exotic annual grasses and occasional native perennial grasses, mixed with a sparse cover of shrubs (Standiford et al.

1997). California oak woodlands provide habitat for more vertebrate wildlife species than any other vegetation type in California (Ohmann and Mayer 1987), qualifying them as critically important to California wildlife. Fire studies examining vegetation in blue oak woodlands have demonstrated potential benefits to seedling recruitment and sapling development by removing vegetation that competes for light, soil moisture, and nutrient availability (McClaran and Bartolome 1989).

Blue oak woodlands in California exist in a Mediterranean climate where precipitation almost exclusively falls between mid-autumn and mid-spring, creating extreme wildland fire conditions in the dry season, unsuitable for safe prescription burning. In order to burn safely, prescription fires are conducted during the early and late wet season, but this has potential implications for vegetation and wildlife species that may be vulnerable to mortality, depending on their phenology at the time of burning (Howe 1994).

Plant species subjected to fire treatments before seed maturation and senescence can suffer dramatic seed losses and possible population declines. If fire prescriptions are implemented too early when fuel moisture is high, fires typically fail to consume seed sets having a minimal impact on seed production. However, when seeds senesce from parent plants they receive critical protection in the soil medium from fire events, often resulting in minimal effects on plant species response (Platt et al. 1988; Howe 1994; DiTomaso et al. 1999; Meyer and Schiffman 1999). Habitat structure often significantly alters following fire (McCoy 1986; Siemann et al. 1997; Underwood and Quinn 2010), most notably in the composition of ground cover: leaf litter, bare ground, vegetation density, exposed rock and downed wood (Siemann et al. 1997; Niwa and Peck

2002; Pausus et al. 2008). The extent of change and compositional makeup following burns is contingent upon burn intensity and habitat type, leading to heterogeneous responses around the world.

Beetles are one of the most diverse taxa, with more than 400,000 species recorded world-wide (Hyvarinen et al. 2009). They span all trophic levels as predators, herbivores, decomposers and pollinators, serving integral roles in nutrient cycling and energy flow within terrestrial ecosystems (Crowson 1981; Orgeas and Anderson 2001). They can be grouped into guilds based on their relationship to habitat type and food source requirements. For example, phytophagous beetle species feed on plant material and the plant cover also provides protection from potential predation. Phytophagous beetles can influence plant species composition by feeding on selected species and in some cases assist competing plant species ability to increase their populations (Crawley 2009). While phytophagous species can reduce plant fitness, other guilds like detritivores that are decomposers indirectly help stimulate plant growth through nutrient cycling. They are associated with leaf litter, obtaining nutrients from organic matter. Wood boring beetles are also decomposers, and together with leaf litter detritivores, play a vital role in nutrient cycling and ecosystem functions (Lattin 1993; Yang 2006). Wood boring beetles are also often attracted to injured and dead trees caused by fires (Bradley and Tueller 2001; Perrakis and Agee 2006), but some species are known for outbreaks and will target healthy trees, potentially causing large-scale forest devastation (Wermelinger 2004). The seed-eater beetle guild can have beneficial as well as detrimental effects on vegetation. They can assist with seed dispersal by transporting seeds away from parent plants to caches that may germinate later under favorable environmental conditions (Vernon

1972). Vegetation can also be negatively affected by seed consuming beetle guilds that reduce seed banks through seed consumption (Zhang et al. 1997). Predatory beetles improve overall ecosystem health by reducing the abundance of injured and diseased arthropods (Gullan and Cranston 2010), also assisting in population control of phytophagous insects that have potential to decimate target plant species (Symondson et al. 2002).

Arthropods have potential to be suitable biological indicators of ecosystem health in terrestrial habitats (Kremen et al. 1993). In particular, interest has increased utilizing beetles as indicators that represent arthropod responses to environmental change such as that caused by fire (Stork 1990; Orgeas and Anderson 2001; Nunes et al. 2006; Michaels 2007). In addition, it has been documented that analyses focused at the beetle species level are not always necessary for monitoring general habitat quality, thus coarser taxonomic identification at the functional level is suitable (Orgeas and Anderson 2001). This offers a cost-effective means to monitoring ecosystem health and affords conservation managers the ability to perform analyses without specialized training required by professional taxonomists.

Studies on arthropod responses to prescribed fire have been few compared to vascular plant examinations (Harris and Whitcomb 1974; Peterson and Reich 2001; Underwood and Quinn 2010). However, studies that have focused on beetles have shown alterations in habitat can influence the response of beetles to fire events (Evans 1984; McCoy 1986; Gandhi et al. 2001; Pausus et al. 2008). Timing has been demonstrated to impact arthropod responses, but it is dependent on the life stage of arthropods at the time of burning (Siemann et al. 1997). In some instances fire has enhanced arthropod diversity as a result of increased habitat heterogeneity caused by the burn (Orgeas and Andersen 2001; Villa-Castillo and Wagner 2002; Apigian et al. 2006). Increases of dead wood following fires attract pyrophilous (fire-dependent) beetle species to the area, taking advantage of newly formed habitat (Bradley and Tueller 2001). Fires have also contributed to increases in predatory beetle species due to a reduction of protective cover and increases of injured prey (Niwa and Peck 2002; Underwood and Quinn 2010).

In some studies, significant declines in beetle density and other arthropods directly following fires have been recorded (Harris and Whitcomb 1974; Andersen and Muller 2000; Saint-Germain et al. 2005; Underwood and Quinn 2010), but populations often return to pre-treatment densities within one year, demonstrating minimal, short term effects (Abbott 1984; Andersen and Muller 2000; Niwa and Peck 2002; Underwood and Quinn 2010). Immediate population declines subsequent to fire events have been attributed to multiple factors including direct mortality, predation, loss of resource availability (*e.g., food and cover*) and emigration from resource depleted burn zones (Majer 1984; Curry 1994; Blanche et al. 2001; Niwa and Peck 2002).

With respect to guild responses to fire, phytophagous species dramatically declined following fire due to the loss of foliage, but populations stabilized by the middle of the next growing season (Cancelado and Yonke 1970). Gillon (1972) documented a high percentage of phytophagous species were able to escape the fire, then recolonize burn areas when conditions were suitable. Similar to phytophagous insects, seed eaters declined due to fire events because of reduced seed availability (Underwood and Quinn 2010).

This study aimed at understanding the implications and differences between spring and fall prescribed fire for vegetation and ground beetles in blue oak (*Quercus douglassii*) woodlands. The study was designed to examine ground beetle responses to temporal variations in prescribed fire seasons and to relate this response to habitat changes induced by the fire events. I hypothesized that spring burns would burn cooler than fall burns because of anticipated higher moisture levels common in late spring burning. I also hypothesized that both spring and fall burns would have a negative impact on beetles and vegetation, but the timing of spring burns would have a greater impact on vegetation and beetle assemblages because of the developmental stage of seed production and high activity level of beetles in the late wet-season of spring, leaving them vulnerable to mortality.

CHAPTER II

METHODS

Study Area

Big Chico Creek Ecological Reserve (BCCER) is part of the Sacramento River Watershed, located ten miles northeast of Chico, CA in the northern Sierra Nevada foothills (Figure 1). BCCER is the largest tract of land (3,995 acres) owned and managed by the CSU, Chico Research Foundation and encompasses approximately four miles of Big Chico Creek, ranging in elevation from 700 to 2,160 feet (California State University, Chico 2003a). Located in a Mediterranean Climate, the area experiences moist, cool winters and hot dry, summers (Critchfield 1983). Temperatures often reach above 100 ºF in the summer and occasionally drop below freezing in the winter, with variable rainfall averaging about 40 inches annually (California State University, Chico 2003a). Precipitation almost exclusively falls between mid-autumn and mid-spring, creating extreme wildland fire conditions in the dry season. The Reserve is characterized by canyon and ridge habitats, dominated by blue oak, mixed oak and chaparral plant communities (California State University, Chico 2003a).

Sampling Protocol

Twelve sites each 2500m^2 were distributed throughout the Reserve. Sites were selected in locations composed of dominant blue oak overstories and herbaceous

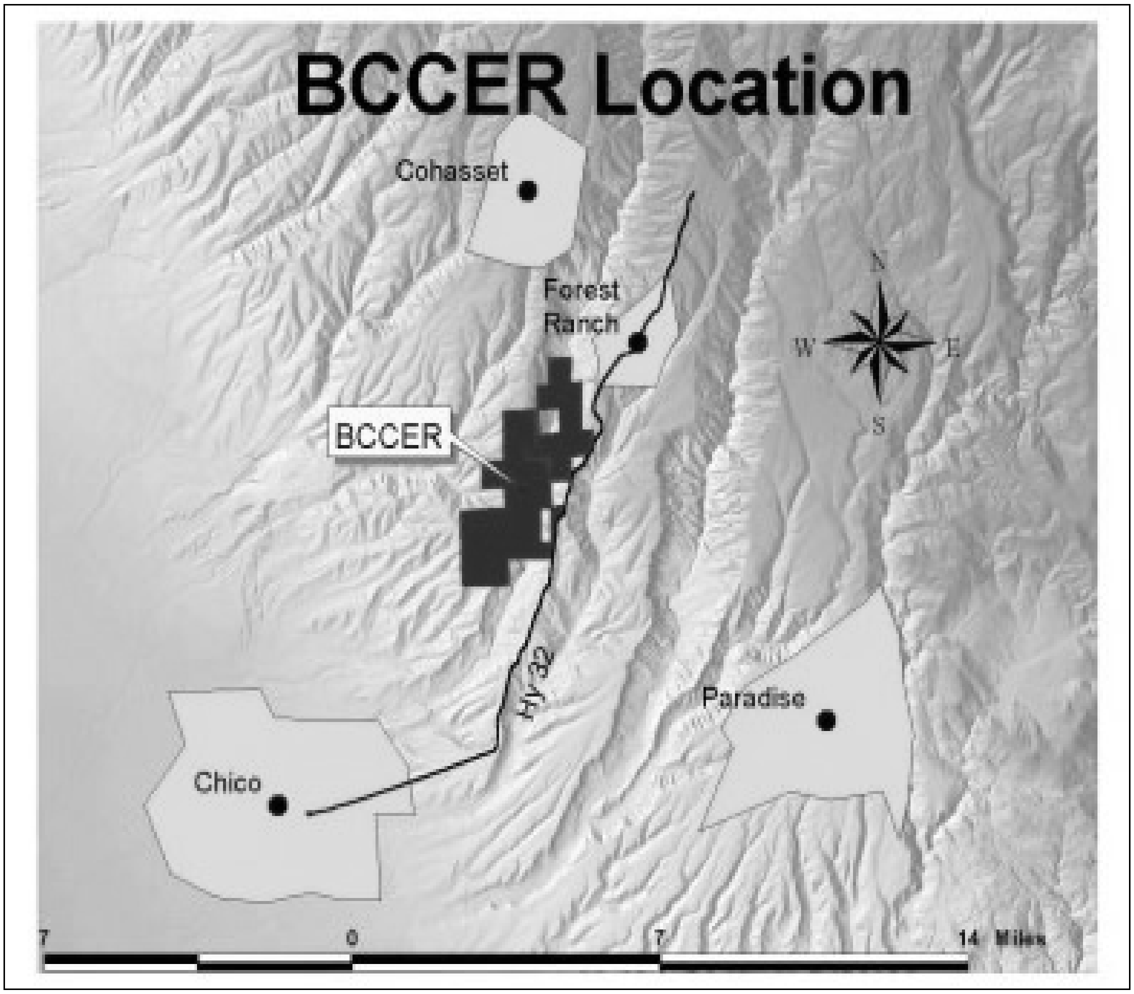

Figure 1. Big Chico Creek Ecological Reserve located ten miles east of Chico, CA.

Source: California State University, Chico. 2003b. Big Chico Creek Ecological reserve maps. Available from: http://www.csuchico.edu/bccer/Ecosystems/maps/maps.html. Reproduced with permission.

understories, predominantly composed of exotic annual grasses and occasional native shrubs. Randomly selected, each site was assigned one of three treatments (spring burn, fall burn, control) and distributed evenly between the east and west canyon aspects (Figure 2). To account for the potential edge effect from adjacent vegetation communities, a buffer (25 m) of blue oak woodlands extended beyond the perimeter of each site.

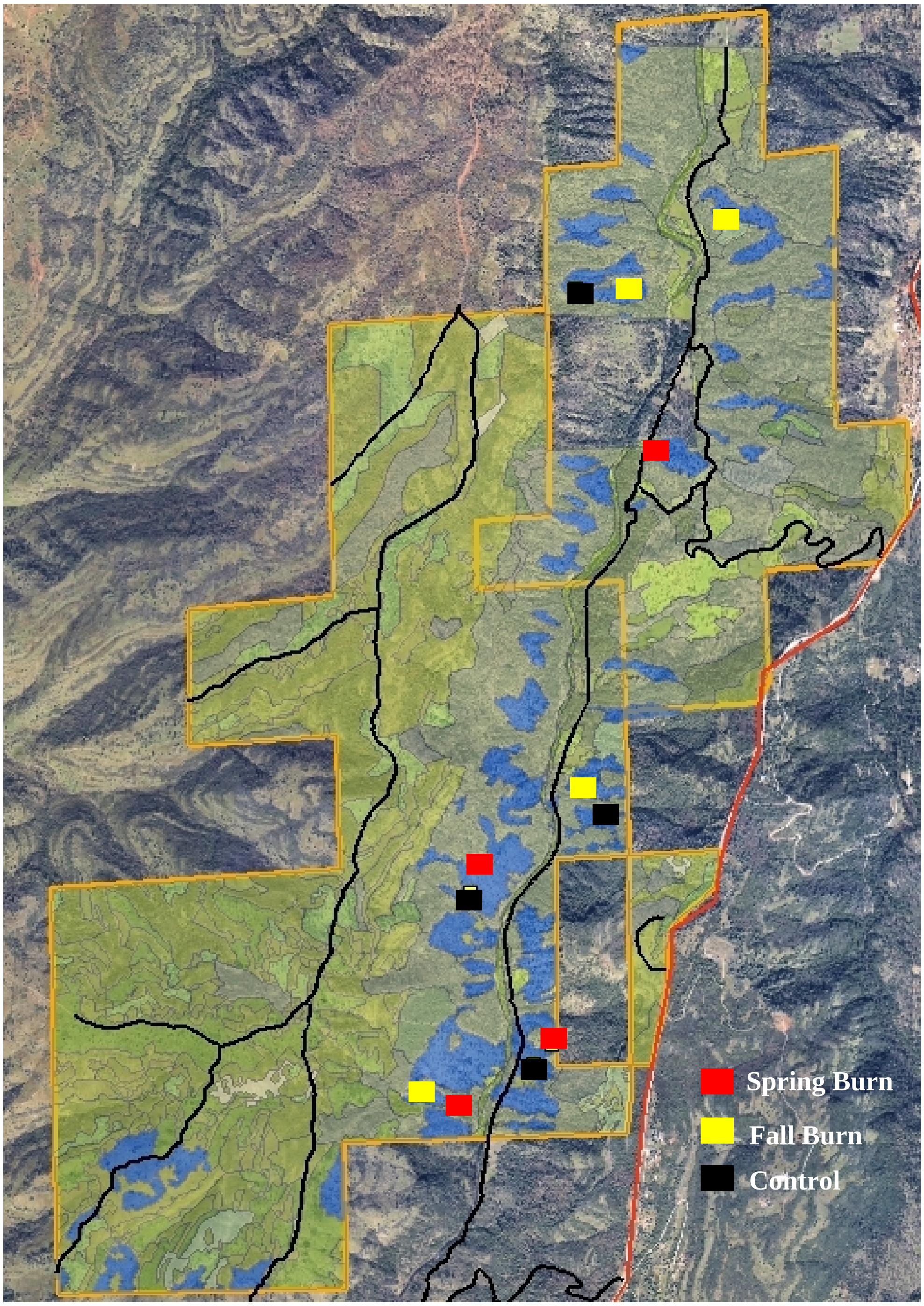

Figure 2. Study sites in blue oak woodlands(highlighted in blue) of Big Chico Creek Ecological Reserve.

Source: California State University, Chico. 2003b. Big Chico Creek Ecological Reserve maps. Available from: http://www.csuchico.edu/bccer/Ecosystems/maps/maps.html
National Agricultural Imagery Program (NAIP). 2005. NAIP imagery. Washington (D.C.): U.S. Department of Agriculture, Farm Service Agency. Reproduced with permission.

Pre-treatment sampling included vegetation and beetle data collection at all twelve plots in April and early May 2007. In late May 2007 four sites were burned (spring treatment), followed by prescription burning at four additional sites in November 2007 (fall treatment), with the remaining four plots untreated (control). Post-burn sampling of vegetation and beetles occurred in the fall of 2007 and spring of 2008.

The original study design focused on small mammal response to fire, however small mammal capture rates during pre-treatment sampling (<.0001%) were too low for examining fire influences. Inversely ground dwelling beetles were common in pitfall and funnel traps, serving as suitable alternatives to small mammals in examining ecosystem responses to fire.

Beetle Sampling

Beetles were sampled in spring 2007 (pre-treatment), fall 2007 and spring 2008 (post-treatment). Each site was sampled for 15 total days per season. Traps were open in five day intervals, followed by seven closed days prior to the subsequent sampling cycle.

At the conclusion of each five day sampling cycle, beetles were collected and frozen, preserving specimens for later examination. Beetles were collected from drift fence arrays each composed of four dry pitfall traps (5 gallon buckets) and three funnel traps (30cm wide x 45 cm long x 28 cm high). Each array was composed of three drift fences each measuring 14 m long and 0.5 m tall (Figure 3). During organismal sampling at each site, specimens gathered from traps were consolidated to one collection, resulting in all analyses related to beetle response focused at the site level. Sampling was

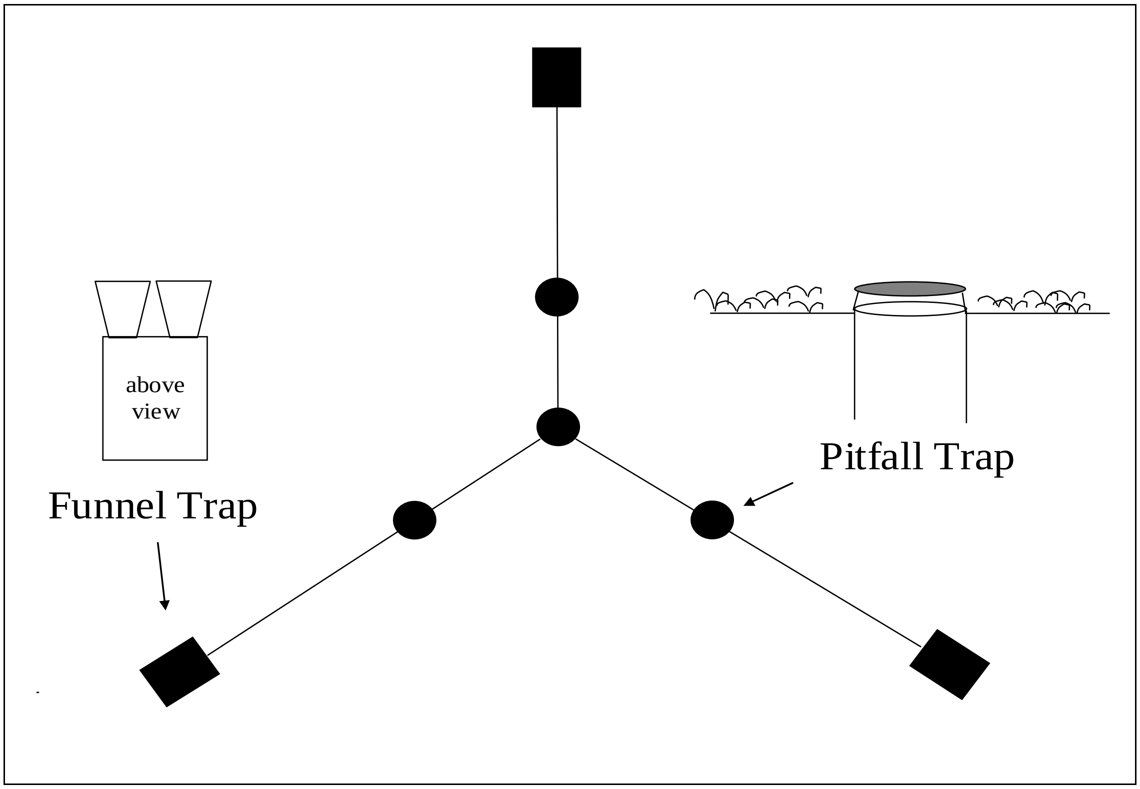

Figure 3. Drift fence array oriented upslope within a study plots with views of each trap type (funnel and pitfall).

conducted in collaboration with another graduate student (John Rowden) utilizing the same trap arrays to examine herpetofauna response to fire.

Specimens were initially sorted by morphology (Oliver and Beattie 1996) then identified to guild using reference texts (Borror, Triplehorn and N.F. Johnson 1989; Evans and Hogue 2006). The ground beetle guilds were composed of phytophagous, seed eaters, detritivores, predators and wood borers; voucher specimens were identified by a taxonomist (Kirby Brown) to ensure specimens were identified correctly.

Vegetation Sampling

Pre-treatment sampling of vegetation was conducted in spring 2007 and re-sampled the following spring of 2008, using a method derived from the Modified Whittaker (Stohlgren et al. 1995). Sites were sampled using three nested vegetation plots measuring 20 m x 8 m. Each vegetation plot contained 1 m^2 and 0.25 m^2 quadrats (Figure 4). Two permanent rebar markers were installed at diagonal corners of each vegetation plot. A metric survey tape was run around the perimeter of each plot then nested vegetation sampling points were located and surveyed.

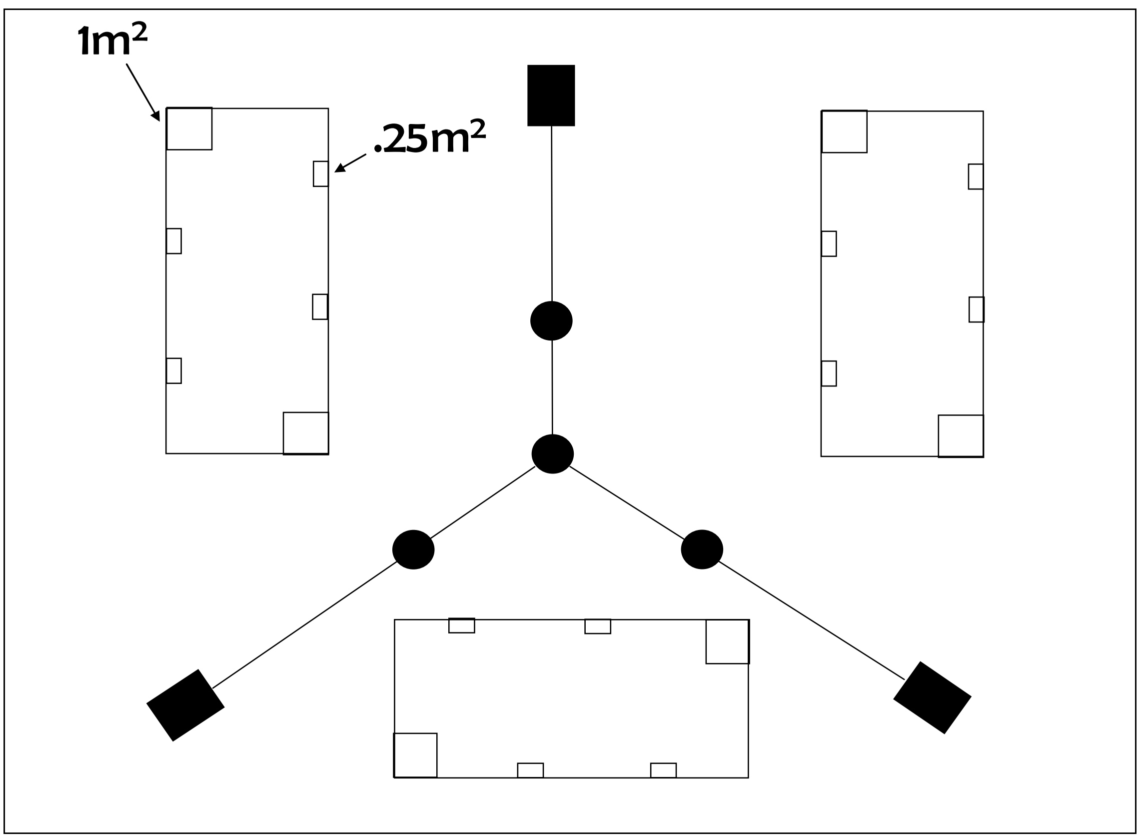

Figure 4. Study plots with drift fence arrays and vegetation plots. Each vegetation plot consisted of four .25m^2 and two 1m^2 quadrats. Each vegetation plot was oriented in the same position at each site.

In each quadrat (1 m^2 and 0.25 m^2) the method and sample variables measured were the same. Measurements were collected on litter depth, ground cover composition (bare ground, rock, organic litter, plant stem density, downed wood) and individual species canopy cover (herbaceous and woody). The percentage sum of all ground cover categories in a quadrat equaled 100%. Ground cover was measured by the percentage of area occupied at ground level by each cover type. Ground cover estimates for vegetation were measured by estimating the combined plant stem density of vegetation in a quadrat, excluding above ground canopy coverage. All the vascular plants present in a quadrat were identified to species or lowest taxonomic level possible, when diagnostic characters were not present because of early or late phenology. Plant form, native or exotic and canopy cover were also recorded for each species. Total canopy coverage in a quadrat could exceed 100% because each species was treated as an individual canopy layer independent of other species present. To ensure sub-sampling in the site was representative of actual species present, the 20 m x 8 m vegetation plots were surveyed for any species not represented in the 1 m^2 and 0.25m^2 quadrats. At the site level, overstory canopy was measured with a spherical densitometer at each permanent rebar marker and the center pitfall trap of the site (7 points).

Prescription Burns

Spring burns were prescribed for four sites in mid-May 2007, following flora and faunal sampling. In order to implement the fire treatments, a LE-5 burn permit and site inspection was required by California Department of Fire. In addition to a LE-5 permit, permissive burn treatments required adequate air quality by Butte County Air

Quality Control Board and low winds on burn days. A two-meter fuel break was developed around each 2500m^2 burn site to help control the fires. Fifty gallon barrels of water were stationed on the upslope end of each plot, providing gravity fed water to fill backpack sprayers used to control the fire. Sites were first ignited with a drip-torch along the upslope edge of the sites allowing for a slow downslope burn through the site. Once the fire had burned 5 meters downhill, the bottom side of the sites were ignited with a drip-torch and allowed to burn towards the center of the plot, meeting the fire burning downslope into the site. Volunteers assisted in preventing the fires from jumping the fuel breaks, burning large fallen logs and/or spreading into the tree canopy. The process was replicated during the fall burn treatments in November 2007 subsequent to the dry season burn ban being lifted by CalFire. The date burn bans are lifted each year vary, contingent upon adequate moisture levels in the local area that allow for safe controllable prescription burning.

Following each fire, burn severity was assessed in each vegetation quadrat. Burn severity was assigned a numerical value: 0 – no burn, 1 – leaf litter burn, 2- herbaceous canopy burn or 3 – complete burn. Burn severity was assigned based on the dominant burn category present in each quadrat.

Data Summary and Statistical Analysis

Beetle guild assemblages, burn intensity and vegetation were all analyzed at the site level. P-value level of significance was set at (0.10) due to small sample sizes and non-parametric statistics were used due to lack of normality in the data. All three beetle sampling periods per season were combined to one sample then averaged to determine the number of beetles/m^2 at the site level. Spring burn site S2E was an extreme outlier, with beetle bloom events uncharacteristic of all other sites, resulting in removal of the site from beetle analyses, but remained in all other analyses. Beetle guild assemblages, vegetation and burn severity were all analyzed at the site level. Burn severity values recorded from quadrats at each site were summed then divided by the highest burn severity possible at a site, resulting in a percentage burn severity value. Burn severity in each site was summed for all sampled quadrats, then converted to average percent area burned for each site. To test differences between burn treatments in seasonal burn severity, I used the Wilcoxin Rank-Sum Test. Percent cover estimates were summed for each ground cover variable (bare ground, rock, organic litter, plant stem density, downed wood) recorded in the quadrats then averaged for the entire site. Rock and downed wood were removed from analyses because of extremely low presence in the study sites. All site averages were summed for each treatment then averaged to obtain an average percent cover per treatment. All ground cover vegetation data were converted to proportionate values then arc-sine square root transformed. Spring 2007 (pre-treatment) differences in ground cover variables between the treatments (spring burns, fall burns and controls) were summed for each treatment then analyzed using the Kruskal-Wallis Test. Post-treatment ground cover data was then analyzed by quantifying the difference of percent cover for each ground cover variable between spring 2007 and spring 2008 in each treatment. Total beetle density and guild density were analyzed from the beetle data at each site. The total number of beetles and individual guilds captured at each site per season were first averaged to number of beetles per m^2. Spring 2007 (pre-treatment) beetle data was tested for differences in beetle density between treatments (spring burns, fall burns and controls). Post-treatment beetle data was then analyzed by quantifying the difference in beetle density between spring 2007 and spring 2008 in each treatment. The differences were summed for each treatment and tested using the Kruskal-Wallis Test to analyze the difference in change of beetle density between fall burns, spring burns and controls. To test the difference in change of beetle density between two treatments, I used the Wilcoxin Rank-Sum Test. I compared total beetle abundance and individual guilds to ground cover types and burn intensity by performing a Spearman’s rank correlation procedure. The study was conducted in a canyon that site aspect could influence the results. To test aspect influences on guild assemblages and vegetation, I ran a Wilcoxin Rank-Sum Test. All statistical analyses were performed in JMP 6.0.3 (SAS Institute Inc.).

CHAPTER III

RESULTS

Burn Severity

On average, a slightly greater percentage of the fall plots burned (77.4%) compared to the spring burn plots (72.6%) though the pattern was not significant (Wilcoxin Rank Sum, p = 0.31, Figure 5. The range of variability was greater for fall burn plots, ranging 48.6% between plots, in contrast to spring burn plots ranging 26.4%. For both fall and spring burn treatments, burn severity was higher on east aspects of the canyon than west aspects, but there was not a significant difference between the two (Wilcoxin Rank Sum, p = 0.38, Figure 6) though the western aspects were more variable.

Vegetation

Characteristic of oak savannas, leaf litter was the dominant cover type, followed by plant stem density and bare ground (Figure 7). Bare ground accounted for the smallest percentage of cover type prior to treatment. Analysis of spring 2007 pre-treatment data showed that ground cover types (bare ground, plant stem density and leaf litter) were similar between treatments (Table 1, Table 2). Exposed rock and downed wood contributed less than 1% ground cover across all sites and were removed from analyses.

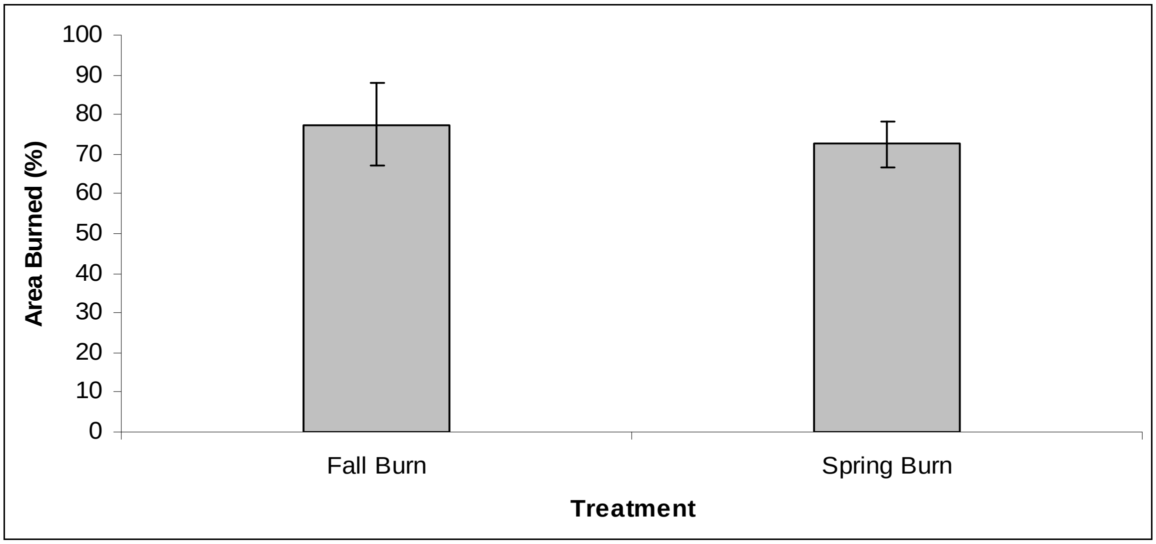

Figure 5. Burn severity measured as average area of site burned between spring and fall burn treatments (±SE).

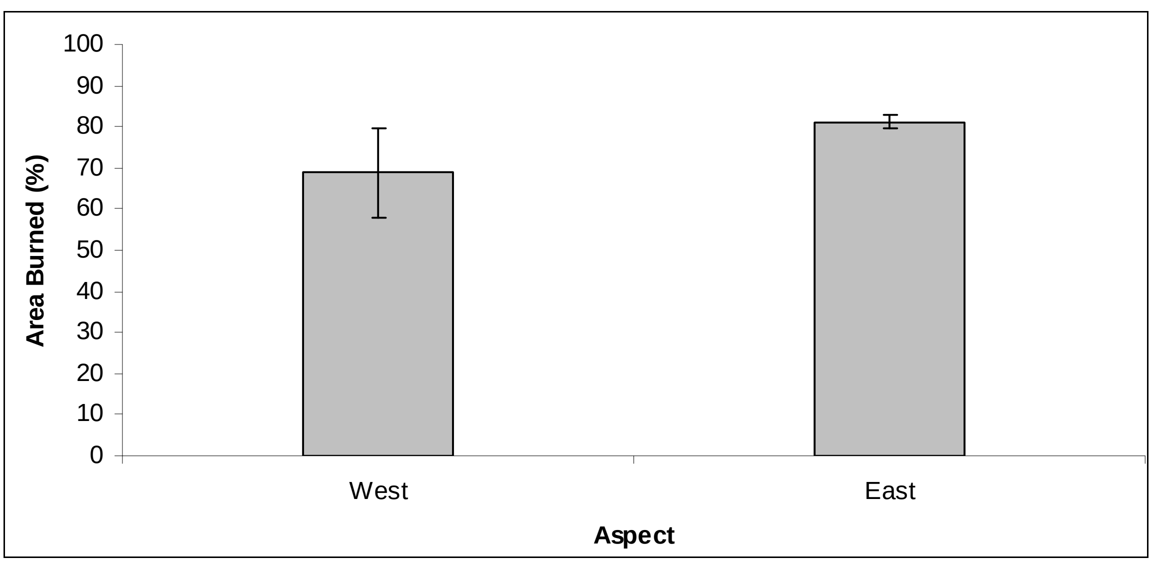

Figure 6. Comparison of average area burned (±SE) for west and east canyon aspect sites. Sites with an east aspect tended to consistently have a higher burn severity but the difference was not significant.

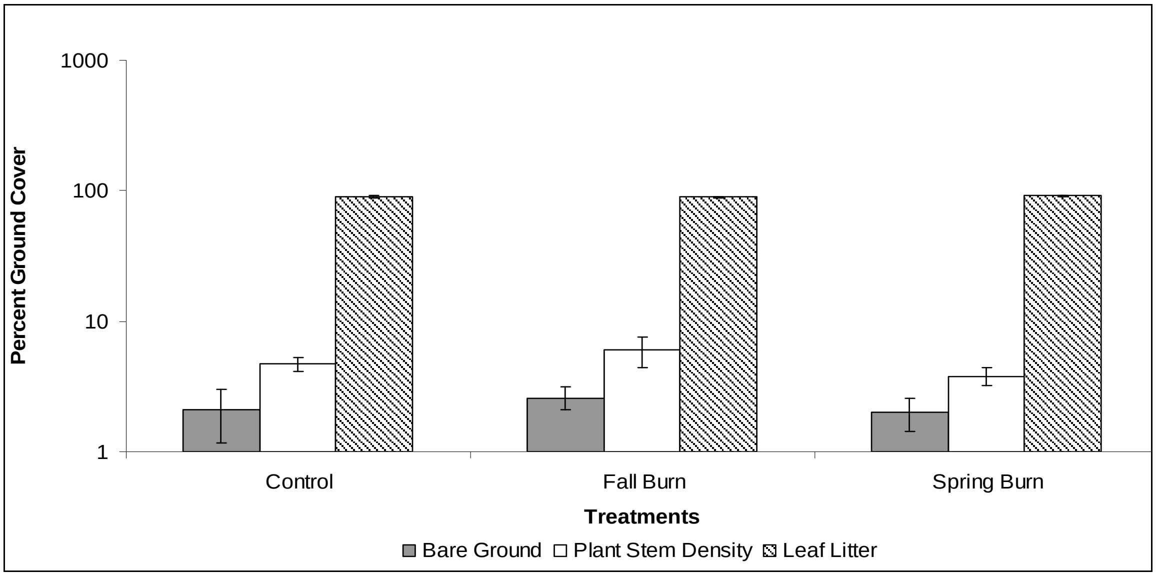

Figure 7. Average pre-treatment ground cover (±SE). Percent data logarithmic transformed graphically to illustrate the relationships between ground cover categories.

Table 1. Average percent ground cover for bare ground, plant stem density and leaf litter for all treatments before (2007) and after (2008) burns. Sample size was 4 for each treatment

Year	Bare Ground			Plant Stem Density			Leaf Litter		
2007	Spring	Fall	Control	Spring	Fall	Control	Spring	Fall	Control
Mean	2.0	2.2	2.1	3.8	5.9	4.7	91.9	89.3	90.1
Standard Deviation	1.4	1.0	1.9	1.5	3.3	1.1	2.4	1.1	2.5
Range	2.9	2.4	3.7	3.6	6.2	2.2	5.2	2.3	5.3
2008									
Mean	27.1	34.8	4.4	2.7	1.4	4.6	68.6	60.2	88.2
Standard Deviation	11.9	16.0	3.9	1.4	0.8	1.1	11.2	16.2	5.1
Range	29.0	37.2	8.6	2.9	1.6	2.7	26.2	36.9	11.5

Following both spring and fall burns there was a significant difference ($p \leq 0.10$) between burn treatments and the controls (Table 2). The percentage of bare ground

Table 2. Statistical comparison of percent cover for ground cover types for 2007 pre-burn and 2008 post-burn. Kreskal Wallis Test for comparing all treatments and Wilcoxin Rank Sum Test used for pair-wise analyses for 2008 data, * $p \leq 0.05$, ** $p \leq 0.1$

Cover Type	2007	2008		
	All Treatments	All Treatments	Spring Burn/Control	Fall Burn/Control
Bare Ground	0.93	0.03*	0.03*	0.03*
Plant Stem Density	0.49	0.08**	0.38	0.03*
Leaf Litter	0.47	0.03*	0.05*	0.05*

and leaf litter significantly changed in spring burn plots compared to the control plots (Table 2) whereas plant stem density did not significantly vary. In contrast, all three cover types were significantly different from controls in the fall burn treatment. Bare ground increased on average by 30% in both burn treatments and leaf litter decreased by a comparable percentage between spring and fall sites (Figure 8) however, leaf litter remained the dominant cover type in all treatments (Table 1).

For fall and spring burn treatments combined, burn severity was highly correlated with ground cover response to prescription fire. The Spearman's correlation coefficient for burn severity and bare ground showed a positive correlation (rho = 0.89), inversely plant stem density (rho = -0.88) and leaf litter (rho = -0.82) showed negative correlations with burn severity.

Beetle Sampling

A total of 1,370 beetles were collected in the study from the families: Carabidae (Ground Beetles), Coccinellidae (Lady Beetles), Curculionidae (Weevils), Dascillidae (Soft-Bodied Plant Beetles), Elateridae (Click Beetles), Hydrophilidae (Water Scavenger Beetles), Scarabaeidae (Scarab Beetles), Silphidae (Carrion Beetles), and

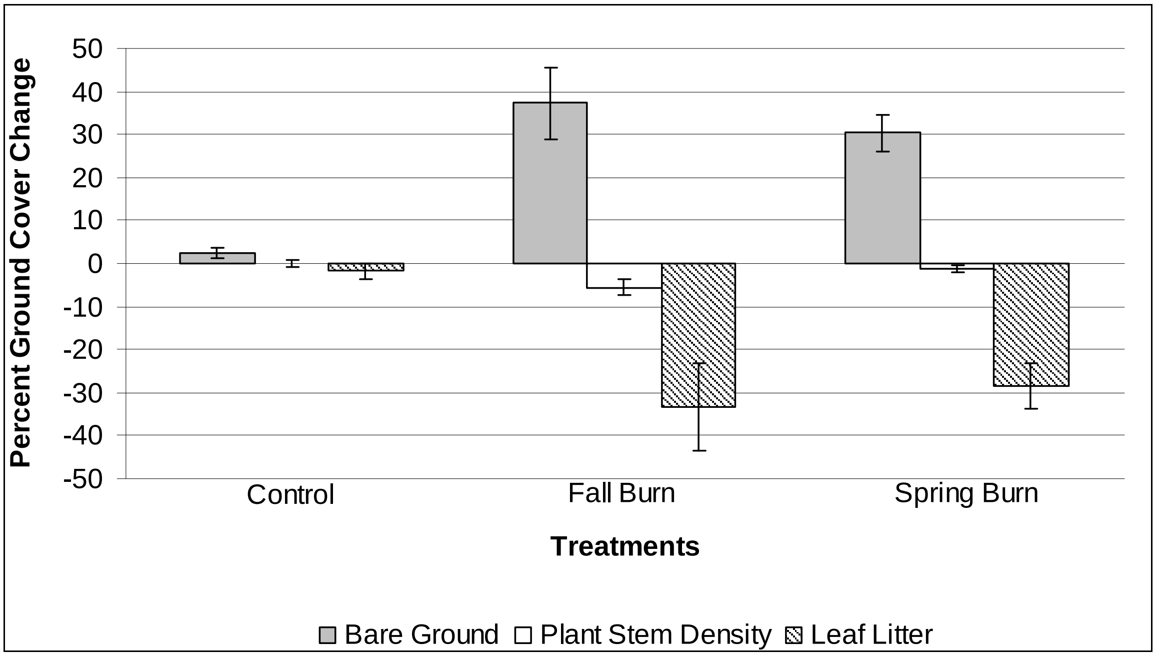

Figure 8. Average (±SE) percent ground cover change between treatments in spring 2008.

Tenebrionidae (Darkling Beetles). The families were comprised of the guild types: phytophagics, detritivores, seed eaters, predators and wood borers (Table 3).

Overall beetle density during pre-treatment conditions was not statistically different between treatments (Kruskal-Wallis, p = 0.92 Table 4, Figure 9). Pre-treatment beetle density for all sites combined was somewhat negatively correlated with bare ground (rho = -0.4) and positively correlated with plant stem density (rho = 0.4) but the correlations were not significant (Table 5).

In the post-burn treatments in general fewer beetles were captured (Table 3), but beetle density did not significantly change between treatments following prescription burns (Table 4), though there was a noticeably greater change in burn treatments compared to the control plots (Figure 10). For example, control sites were comparable with little change between pre and post-burn sampling whereas fall burn plots

Table 3. Total sum and average density of beetles (m^2) by feeding guilds by burn treatment for pre-burn and post-burn sampling

Year	Average/Total Beetles			Phytophagous			Detritivores			Seed Eaters			Predators			Wood Boring		
2007	Spring	Fall	Control	Spring	Fall	Control	Spring	Fall	Control	Spring	Fall	Control	Spring	Fall	Control	Spring	Fall	Control
sum	221	302	253	1	17	2	11	32	14	146	160	142	56	76	83	7	17	12
Mean	0.0295	0.0302	0.0264	0.0001	0.0017	0.0002	0.0015	0.0032	0.0014	0.0195	0.016	0.0142	0.0075	0.0076	0.0083	0.0009	0.0017	0.0012
Standard Deviation	0.0204	0.0177	0.0089	0.0002	0.0024	0.0002	0.0016	0.0015	0.0019	0.0165	0.0186	0.0085	0.0069	0.0024	0.0018	0.0008	0.0017	0.0014
Range	0.0392	0.0404	0.0216	0.0004	0.0052	0.0004	0.0032	0.0036	0.004	0.0328	0.0412	0.0204	0.0136	0.0052	0.004	0.0016	0.0036	0.0028
sample size	3	4	4	3	4	4	3	4	4	3	4	4	3	4	4	3	4	4
2008																		
sum	159	166	269	4	8	5	29	29	21	82	21	83	23	69	102	21	39	58
Mean	0.0212	0.0166	0.027	0.0005	0.0008	0.0005	0.0039	0.0029	0.0021	0.0109	0.0021	0.0083	0.0031	0.0069	0.0102	0.0028	0.0039	0.0058
Standard Deviation	0.0163	0.0082	0.0137	0.0002	0.0016	0.0008	0.0026	0.0043	0.0008	0.0162	0.0026	0.0064	0.0009	0.0037	0.0076	0.0007	0.0033	0.0022
Range	0.0296	0.0184	0.032	0.0004	0.0032	0.0016	0.0052	0.0092	0.0016	0.0288	0.0056	0.0152	0.0016	0.008	0.0172	0.0012	0.0072	0.0064
sample size*	3	4	4	3	4	4	3	4	4	3	4	4	3	4	4	3	4	3

*Sample size varies due to removal of a spring burn site that had excessive beetle blooms

Table 4. Statistical comparison of beetle density between treatment types for total beetles and guild groups. Kreskal Wallis Test for comparing all treatments and Wilcoxin Rank Sum Test used for pair-wise analyses for the 2008 data, * significant correlation at level $p \leq 0.05$, ** $p \leq 0.1$

	2007	2008		
	All Treatments	All Treatments	Spring Burn/Control	Fall Burn/Control
All Beetles	0.92	0.57	0.92	0.31
Phytophagous	0.19	0.07**	0.86	0.08**
Detritivores	0.7	0.27	0.22	0.56
Seed Eaters	0.94	0.58	0.86	0.67
Predators	0.89	0.45	0.28	0.67
Wood Borers	0.69	0.16	0.05*	0.31

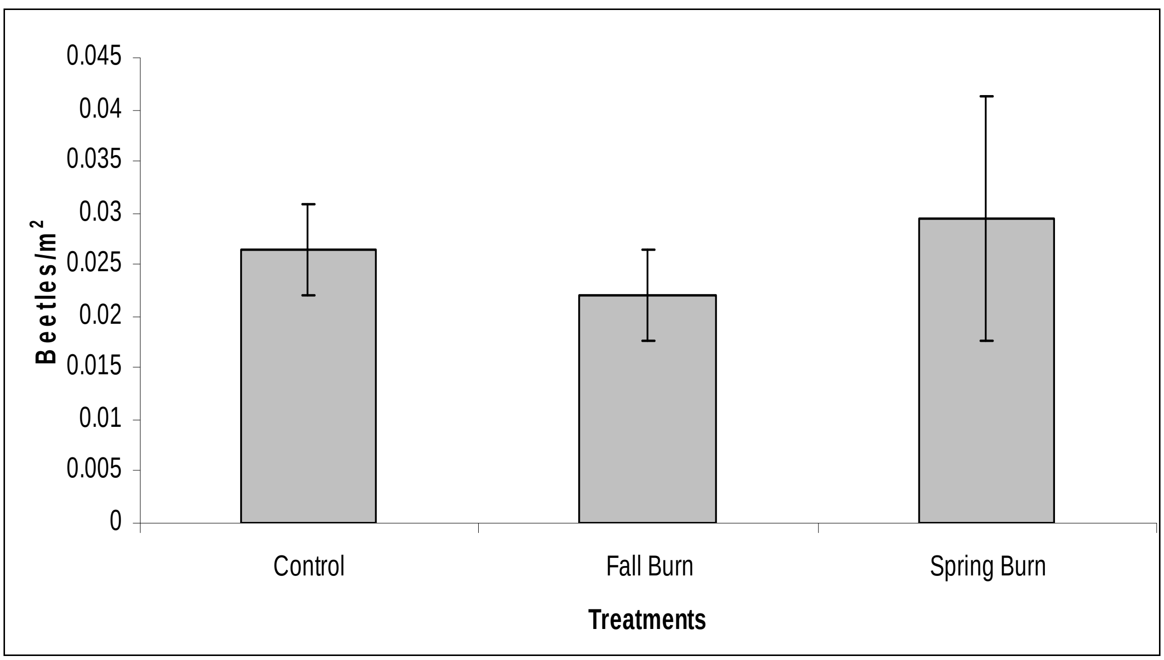

Figure 9. Average pre-treatment beetle density (±SE) for fall burns, spring burns and controls.

Table 5. Spearman's Correlation Coefficient comparing beetle density to ground cover percent at all sites for pre-treatment spring 2007, * significant correlation at level $p \leq 0.05$, ** significant correlation at level $p \leq 0.1$

Guilds	Bare Ground	Leaf Litter	Plant Stem Density
All Beetles(m^2)	-0.4	-0.05	0.41
Phytophagous	0.13	-0.31	0.5
Detritivores	0.5	-0.33	-0.06
Seed Eaters	-0.5	-0.03	0.30
Predators	-0.03	-0.08	0.25
Wood Borers	-0.02	-.06	-0.02

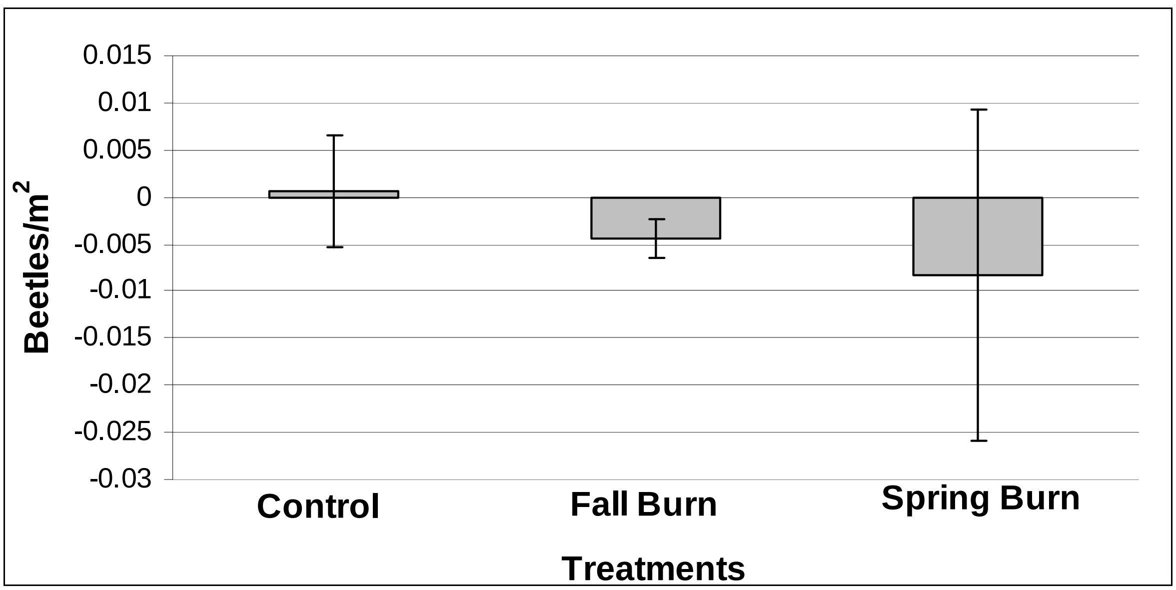

Figure 10. Comparison of average change in beetle density (±SE) between treatments following burn prescriptions.

experienced the greatest different in beetle density between pre and post-burn treatments. In general, the high variability between plots resulted in the lack of this trend being significant.

Both treatments were combined for correlation tests because treatment sample sizes were too small to test correlations for fall and spring burns independently. Overall, beetle density did not demonstrate a significant correlation with ground cover types or burn severity in post-treatment conditions for fall and spring burn sites combined (Table 6).

Table 6. Spearman's Correlation Coefficient comparing beetle density to ground cover percent and burn severity for spring and fall burn sites in spring 2008, * significant correlation at level $p \leq 0.05$, ** $p \leq 0.1$. Spring and fall burn treatment sites were combined due to small sample size

Guilds	Burn Severity	Bare Ground	Leaf Litter	Plant Stem Density
All Beetles (m^2)	-.17	-.38	.13	-.11
Phytophagous	-.09	.04	-.07	-.13
Detritivores	.38	.54	-.71	-.41
Seed Eaters	-.83*	-.92*	.74**	.60
Predators	-.06	-.40	.49	-.21
Wood Borers	.68**	.67	-.52	-.34

Guild-Level Analyses

In descending order, seed eaters were the most abundant guild type in pre-treatment sampling, followed by predators, detritivores, wood borers and phytophagics (Table 3, Figure 11). Although seed eaters had the highest density, they were also the most variable group, demonstrating population booms during the sampling effort. There were no significant differences in guild density between treatments in spring 2007 (Table 4), though there was high variability between plots in each guild. Pre-treatment guild

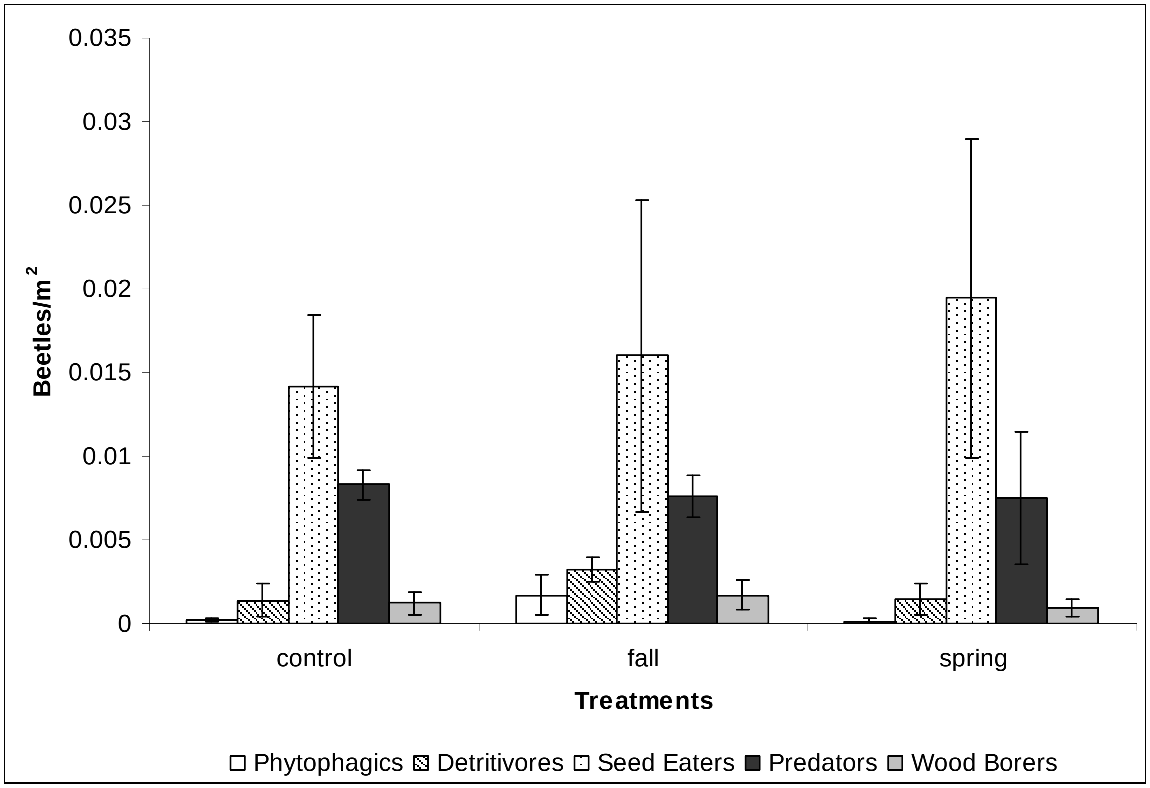

Figure 11. Pre-treatment average beetle guild densities (±SE) between treatments.

densities were not significantly correlated with any ground cover types (Table 5), though bare ground was somewhat positively correlated with detritivores (rho = 0.5) and negatively correlated with seed eater (rho = -0.5). Stem density was weakly correlated with phytophagics (rho = 0.5).

Multiple guild groups showed correlations to burn severity and ground cover types (Table 6). Seed eaters showed a strong negative correlation (-0.83) to burn severity whereas wood borers showed a moderate positive correlation (0.68). Seed eaters responded negatively to increases of burn severity (-0.92) and positively to increases of leaf litter (0.74). Though not significant, there were also weak correlations between detritivores and cover type with a positive association with bare ground (0.54) and a stronger negative correlation (-0.71) with leaf litter. Wood borers were somewhat positively associated with bare ground and negatively associated with leaf litter.

Post-burn treatment guild level analyses did not reveal a significant difference in beetle density between treatments, except for marginal differences in phytophagous beetles (Table 4). In pair-wise treatment analyses phytophagous beetles in the fall treatment decline significantly compared to control sites, but spring burn site phytophagous beetles did not differ from control sites. Pair-wise analysis also showed a significant difference in wood boring beetle density between spring burn sites and controls (Table 4).

Changes in guild density between treatment replicates were quite variable which contributed to non-significant changes (Figure 12). However trends in the control

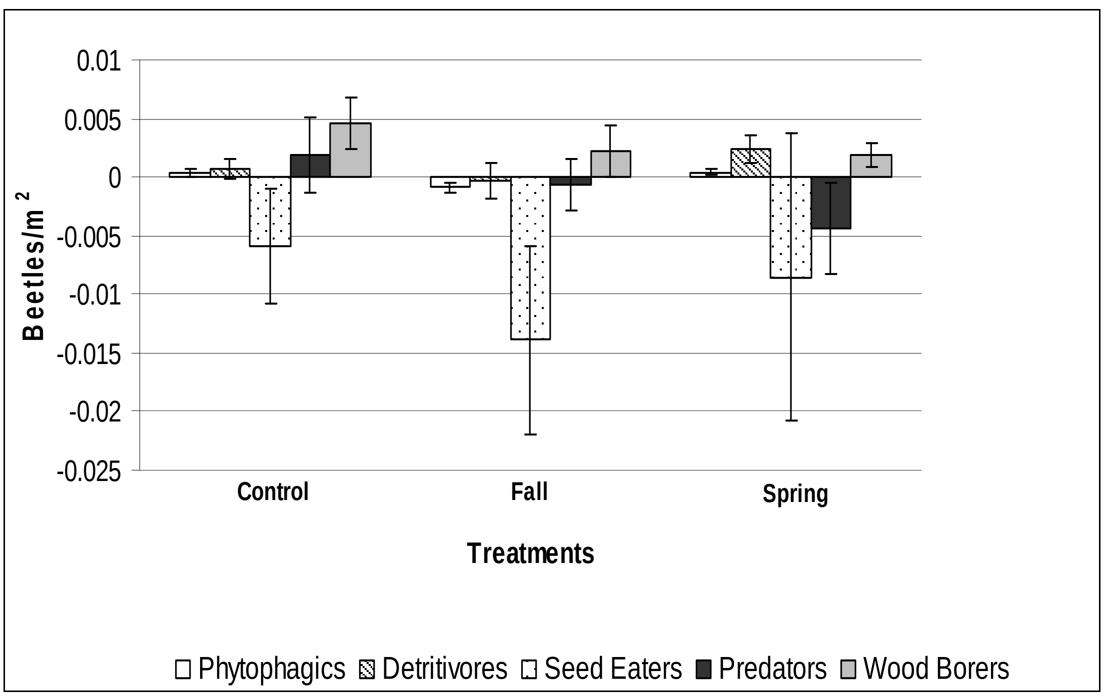

Figure 12. Post-burn treatment comparison of average change in beetle guild density (±SE) between treatments.

sites between years provides a basis for comparing treatment responses. For example, in the control sites seed eaters density decreased on average by 43% between 2007 and 2008 whereas wood borers increased by over four-fold (Table 3). In contrast, there was a markedly greater change in seed eaters in the fall burn treatments compared to the controls (Figure 12). There was also an increase in wood borers but not as great as in the controls. In the spring burn treatment, the decrease on seed eaters was intermediate between the control and fall burn treatment sites. The most notable difference for the spring burn sites was the decline in predatory beetles which contrasts with the control sites which saw an increase in this guild between years. The spring burn sites were also the only treatment that had an increase in detritivores between years (Figure 12).

CHAPTER IV

DISCUSSION

Prescription burning in a Mediterranean climate is logistically challenging and results may be difficult to predict because of considerable inter-annual climatic variability (common droughts and years of abnormally high rainfall inherent with Mediterranean climates). Plant and animal species have patterned their activity to follow the wet and dry cycles of the Mediterranean climate; consequently, their activity levels can fluctuate annually. Many species including plant and beetle species decrease activity and growth during the hot and dry seasons. In the wet season, particularly the early and late periods experience highest plant and animal activity. These transitional periods between wet and dry seasons are also the most common and safest times to conduct prescription burns, creating possible implications for species during their peak activity.

Public burn restrictions are generally lifted in the early wet season of fall when fuel moisture increases and then burn restrictions enforced in spring when fuel moisture decreases leading into the dry season. In contrast, many fire prescription studies conducted in California most often implement fire treatments with the support of professional private/government fire crews allowing burns to take place in drier conditions than allowed by burn permits issued to the public. In addition to any differences in burn coverage and intensity, the differences in prescription timing between public burn periods and that allowed by professional fire crews may affect plant and animal species differently due to the phenology and activity of species present at the time of burn prescriptions.

In this study overall burns were cool and patchy, leaving islands of unburned ground cover in fall and spring burn sites. Sites burned in a heterogeneous mosaic, leaving islands of leaf litter and standing dead biomass within the sites that fire did not penetrate. Differences in seasonal burn timing did not influence change in burn severity between spring and fall sites, even though plant phenology was quite different between treatments. I expected fall burns to be hotter than spring burns, but predictions were based on burning in drier conditions similar to larger scale operations supported by fire crews. Because of the elevated moisture levels present during public burn periods, it most certainly influenced the burn patterns and likely to have affected species differently than burns implemented during drier conditions.

Vegetation Response

Leaf litter was the most abundant fuel type present in sites prior to burning. Deciduous over-story blue oaks and annual herbaceous plant species contribute substantial amounts to leaf litter composition annually, maintaining it as the dominant ground cover type. In the spring of 2008 following burn treatments both fall and spring burn sites changed significantly in habitat structure, with large decreases in leaf litter that led to increases in bare ground. Decreases in leaf litter can lead to losses of soil moisture through exposed bare ground and increases of light availability, potentially having an influence on plant seed germination (Rathcke and Lacey 1985).

Studies have demonstrated burn timing can influence the response of vegetation in grasslands (Parson and Stohlgren 1989; Howe 1994; DiTomaso et al. 1999; Meyer and Schiffman 1999). In a study conducted by Howe (1994), annual plant species subjected to fire treatments prior to complete seed maturation and senesce, experienced population declines the subsequent year. Losses were attributed to seed loss caused by the fire events. Fire prescriptions implemented post-seed maturation and senescence often fail to affect the viable seed bank because seeds are protected from fire by favorable conditions in the soil medium beneath the leaf litter (Platt et al. 1988; Howe 1994; D'Antonio et al. 2003), which was an anticipated result of this study.

However, burns in this study were implemented during the public burn period, different than the timing of the study conducted by Howe (1994) and other fire studies. Typically with fall burns, the vegetation is still relatively dry and seeds have not yet germinated with the wet late fall rains. However, in this study prior to prescribing the fall burns, early rains triggered seed germination and sprouting of annuals in the herbaceous understory. Dry weather following the early rains allowed the ground and standing dead fuel to dry sufficiently for broadcast burning and the fall fires burned through treatment sites, but it also killed the majority of early emergent annual growth (personal observation) and led to an overall decrease in fall burn treatment plant stem density in the following spring. The unexpected results are potentially due to plant phenology at the time of burning.

Plant stem density at spring burn sites only changed marginally from control plots, also most likely due to prescription timing and plant phenology. Contrary to my expected results, spring fires crept around standing green vegetation predominantly burning leaf litter, failing to consume maturing seeds sets and reduce the seed bank for the following grow season. Consequently one year after the fires, vegetation stem density approached pre-burn densities.

Native Plant Response (Personal Observations)

Blue oak seedlings that were burned appeared to be tolerant of the burns, commonly re-sprouting following burns (Appendix A). Native grasses that occasionally occupied burn zones also demonstrated resiliency to the fires, quickly re-sprouting fresh vegetative growth (Appendix B).

Beetle Response

There was high variance in beetle density within treatments. Ground dwelling beetles are influenced by biotic and abotic factors at a regional level, but also at a small local scale that can lead to varied results within treatments (Wiens et al. 1995). The high variance influenced the significance level of difference between treatments, but trends were evident in the response of beetles to burn treatments, suggesting there was a level of influence fire timing had on beetle density.

Several studies have documented a decline in beetle density and other arthropods directly following fires (Harris and Whitcomb 1974; Andersen and Muller 2000; Saint-Germain et al. 2005; Underwood and Quinn 2010), but stabilization often occurring within one year, demonstrating minimal, short term effects (Abbott 1984; Andersen and Muller 2000; Underwood and Quinn 2010). In some studies, rapid recoveries have been attributed to relatively low intensity burns leaving patches of unburned habitat that could potentially provide refuge for arthropods escaping direct fire exposure and supply vital resources typically consumed by fire events (Hughes 1943; Sackmann and Farji-Brener 2006).

In this study beetle density in both fall and spring burn sites remained lower than control sites one year after the spring burns and 6 months following the fall burns, revealing trends that suggest fire treatments influenced beetle response. It is possible beetle density in fall and spring burn sites was returning to pre-treatment levels because the differences in beetle density were relatively minor, but I did not begin sampling until one year following burn treatments, lacking data collection on early-response to fire immediately following treatments.

Beetle densities in fall burn sites decreased and remained lower than spring sites during post-treatment sampling, possibly a function of the differences in recovery time between spring and fall burns before post-treatment sampling occurred. Beetle assemblages had almost one year to recover following spring burns before post-treatment sampling occurred, where as beetles utilizing fall burn sites had about half the time to recover before post-treatment sampling. However, habitat structure was significantly altered following the seasonal fires, which has been demonstrated to influence beetle response (McCoy 1986; Holliday 1992; McCullough et al. 1998). Bare ground tended to increase more in fall sites and showed negative correlation trends in overall beetle density. Bare ground is void of many resources important to ground beetles, such as protective cover, food availability and moisture retention that are more common in areas covered in organic matter. This may have impacted beetle density in post-treatment sampling.

Beetle Guild Response

In general heterogeneous habitats support diverse beetle assemblages, conversely beetle diversity is lower in habitats with fewer vegetation layers (i.e., blue oak savannas) that have fewer specialized niches available to occupy (Sackmann and Farj-Brener 2006). Beetles that occupy complex habitats have shown more susceptibility to fire than species that prefer less complex structure (York 1999; Sackmann and Farji Brener 2006) and may explain why beetle response to fire is varied across different ecosystems (Sackmann and Farj-Brener 2006). Most of the beetle assemblages in my study appeared to be resilient to seasonal fire treatments even though habitat structure was altered significantly. Seed eaters and predators declined in density, but the changes were minimal and may have been a function of decreases in vegetation and limited availability of prey species.

Overall, phytophagous beetle captures were extremely low compared to other guild groups and were likely undersampled. Phytophagous beetle are predominately leaf-layer beetles, sampled using sweep nets, but in this study I used ground pitfall traps focusing the capture effort on ground dwelling beetles. Phytophagous beetle density declined in fall burn sites whereas it increased in spring and control plots. The fall decline may reflect the loss of plant stem density following fall fires. Inversely phytophagous density remained unchanged in spring sites where plant stem density did not change either. However capture rates were too low to make valid inferences about the influence fire had on phytophagous beetle response.

The seed eater guild was the most abundant guild pre-burn treatment and also the guild that changed the most post-treatment. Overall seed eating beetle density declined more in fall and spring sites than control sites, but high variance in each treatment prevented the results from being significant. Seed eating beetle species commonly experienced population blooms during the study that skewed results and made it difficult to determine the effect of burn severity and habitat alterations on guild response. Considering control sites declined as well, there may have been a regional environmental factor that triggered a decline in this guild other than the burns. However, the decline was most notable in the fall burn treatments. Positive correlations to plant stem density for spring and fall burns, suggest a loss of plant stem density and seed mortality due to the fires may have influenced a decrease in seed availability for seed eaters (Niwa and Peck 2002). Seed eaters were negatively correlated with burn severity, demonstrating susceptibility to burning. Seed eaters preferred areas containing leaf litter opposed to bare ground in fall and spring burns, possibly because of a loss of protective cover, leaving them susceptible to potential predation.

In several studies, pyrophilous species such as wood boring beetle populations dramatically increased following fires, attracted to heat and smoke from the burns (Bradley and Tueller 2001). Overall, the wood borer guild exhibited relatively low densities pre and post-fire treatment at all sites. Wood borer densities in controls increased more than fall or spring burn sites, suggesting increases were attributed to some environmental factor other than burning. The understory of the blue oaks was dominated by herbaceous vegetation and contained less than 1% dead wood and the low wood boring beetle density might be a reflection of the low amount of dead wood in the study sites. Blue Oaks are fire tolerant, rarely falling victim to burn events (Plumb and Gomez 1983; Arévalo et al. 2009) that would attract wood boring beetles. Corroborated with low intensity fires, post-treatment conditions were not comparable to other studies that have documented substantial increases in wood borers. Burn severity was positively correlated with increases in wood boring beetle density in spring and fall burn sites. Also wood borers tended to favor bare ground over leaf litter, but overall wood borer density was too low to make valid inferences about potential factors that may have influenced beetle response.

Detritivores and predators showed minor changes in density. Detritivores showed resiliency to fall and spring fires and may have benefited from their versatility in resource use and the ability to withstand changes in habitat. It would have been expected that detritivore density would have decreased with loss of leaf litter, but detritivores correlated negatively with leaf litter. Overall detritivore density was quite low in the study and correlations were insignificant, suggesting results were implicated by sample size.

Predatory beetle density on average declined for fall and spring treatments but increased in control sites, suggesting burns influenced density change. Contrary to my results, predatory beetles often benefit from increases of injured and exposed prey, due to direct fire events and loss of protective cover (Underwood and Quinn 2010; Niwa and Peck 2002). It is possible that populations of prey species declined after the fires and negatively affected predatory beetles, but without sampling prey species it is difficult to suggest factors that contributed to declines in density.

Conclusion

The available literature on grassland responses to fire that are based on treatments issued during drier conditions in both, fall and spring seasons revealed different results than mine. Overall fires tended to decrease beetle density, even though spring burns proved to be ineffective for broadcast burning due to the burn timing and plant phenology. Most published spring burn studies are assisted by government fire crews and are issued later in the dry season, timed with maturing seed sets and lower moisture conditions, yielding substantially different results. If the desired effect is to reduce herbaceous plant density, then early wet-season fall burning after annual seeds have germinated is the suggested time to burn, but early wet weather can complicate fall burn opportunities by substantially reducing the seasonal burn window or eliminating it all together when rainfall is high. This potentially has profound implications for land managers conducting small-scale prescription burns during the public permissible burn period of Northern California, similar to burn activities at Big Chico Creek Ecological Reserve. Future studies that examine fire timing in blue oak woodlands should subdivide each prescription burn season into finer categories, in order to effectively capture ecosystem responses. The study aimed at informing reserve managers of the implications associated with seasonal burning, demonstrating a need for the development of a burn plan and reduction of ad hoc prescription burning, common at Big Chico Creek Ecological Reserve.

Study Limitations and Logistical Considerations

Big Chico Creek Ecological Reserve contains highly heterogeneous vegetation communities and varied topography, making it difficult to select sites over .25 hectares of comparable vegetation and environmental conditions. Accessibility is also a major factor navigating the rugged terrain of the Reserve. Potentially high water flows in Big Chico Creek and limited vehicle access can heavily influence the implementation of a study, deeming it important to consult reserve management during the project designing phase.

We were concerned with the potential of bears destroying drift fence arrays. Bears were problematic in sites during the fall when they were foraging for mature blue oak acorns (Appendix C). John Rowden developed a concentrated pepper spray that he applied to the drift fences twice a week that successfully repelled bears from continuing to destroy sites.

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APPENDIX A

Blue oak seedling re-sprouting subsequent to burning over in fire treatment. Photo credit M. Lynch 2007.

APPENDIX B

Blue wildrye (*Elymus glaucus*) re-sprouting following fire treatment. Photo credit M. Lynch 2007.

APPENDIX C

Bear damaged drift fences lacking detouring pepper spray treatment. Photo credit M. Lynch 2007