# Terrestrial arthropod community responses to wildfire in Mediterranean forest ecosystems

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## ABSTRACT

Ground beetles are used as bioindicators of fire disturbance due to their ease of sampling and identification, ecosystem functions, and sensitivity to environmental change. In this study, I explored the relationship between ground beetle population abundance and species composition, and presence of wildfire over a nine-month period in Mt. Diablo, a Mediterranean ecosystem located in Contra Costa Co., CA. Using 60 pitfall traps along six transects, 274 beetle specimens belonging to 54 species were collected. I used analysis of variance and non-metric multidimensional scaling to determine the responses of ground beetles to fire. In terms of population abundance, I did not observe a significant difference between abundance of beetles between burned and unburned locations, or between vegetation types. However, I observed significant differences between the abundance of beetles in the dry and wet periods, in both burned and unburned locations, with the highest level of abundance in the wet months. Neither burn status nor differences in habitat were strongly correlated with species composition, suggesting that the terrestrial arthropod community in my study area had already recovered from wildfire by the time of my sampling. 24 species were found only in burned sites, 13 only in unburned sites, and 17 in both; however, many species had only a single representative specimen. The results suggest that understanding the effects of fire is crucial to preserving biodiversity in Mediterranean ecosystems, and further research is needed to understand the interaction of fire with beetle life cycles.

## KEYWORDS

beetles; biodiversity; Carabidae; community response; forest fire; pitfall trapping

## INTRODUCTION

Mediterranean forests are biodiversity hotspots; however, they are threatened by fragmentation, pests, and urban expansion. (Elia et al. 2012). Wildfires are a natural part of the Mediterranean ecosystem, but are met with caution from ecosystem managers because they can endanger surrounding urban areas (Huntsinger and Fried 1995). Forest management plans must understand wildfire's ecological importance and ability to reset succession and create new habitats (Whelan 1995), and balance this with the risk fire brings to human communities. Mt. Diablo State Park in California is one example of a Mediterranean ecosystem where management practices have led to intense wildfires, such as the one which occurred in September 2013. Grazing, which reduces understory fuel loads, has been banned on Park land since 1994 (Huntsinger and Fried 1995), and although controlled burns are part of the park's management plan, the last controlled burn was over 15 years ago (Cuff and Nardi 2013). Currently, the effect of the 2013 fire on the local environment is unknown. Assessing the impact of wildfire on a bioindicator taxon under these conditions will allow park managers to determine the effectiveness of their current management regime in preserving ecosystem health and biodiversity.

McGeoch (2007) defines three categories of bioindicators: environmental, ecological, and biodiversity. Environmental indicators respond predictably and quantifiably to environmental disturbances, and biodiversity indicators reflect the diversity of higher taxa in the same habitat. Ecological indicators contain elements of both of the first two classes, in that they are sensitive to environmental change, and their health as a community is reflective of the health of other taxa in the habitat (McGeoch 2007). There are three criteria for an ecological indicator: they must be functionally significant, feasibly sampled and reliably identified, and consistent in their response to disturbance (Pearce and Venier 2006).

Ground beetles fulfill the first two criteria of being an ecological indicator: they act as both predator and prey and contribute to maintaining soil structure, nutrient cycling and ecosystem decomposition (Seasteadt and Crossley 1984), and due to their short reproductive cycles and mobility, they respond to environmental changes more quickly than organisms with longer generation times (Kremen et al. 1993). In particular, ground beetles (Coleoptera:Carabidae) can be easily collected and identified (Spence and Niemelä 1994, Pearce and Venier 2006). However, little is known about the effects of fire on carabid community assemblages in Mediterranean ecosystems, as most studies on the impact of fire on ground beetles have been conducted in northern boreal ecosystems (Buddle et al. 2006, Cobb et al. 2007, Gandhi et al. 2001, Niwa and Peck 2002, Saint-Germain et al. 2005).

In northern boreal ecosystems, wildfires create unique habitats that contain diverse beetle assemblages and a large proportion of all rare species in the area (Gandhi et al. 2006, Buddle et al. 2006). Additionally, carabid species have been identified as ecological indicators for wildfire in pinyon-juniper woodlands (Higgins et al. 2014) as well as ponderosa pine forests (Chen et al. 2006). However, the body of research specifically focusing on carabid response to fires in Mediterranean climates is limited. The few available studies generally suggest that wildfires attract unique carabid species assemblages (Elia et al. 2012, Radea and Arianoutsou 2012), but their findings on the effect of wildfire on population abundance are varied. There is currently insufficient data to definitively determine whether carabid population abundance and species diversity respond consistently to wildfire in Mediterranean climates. For this reason, I decided to explore the knowledge gap in the population dynamics taking place within Mediterranean carabid communities.

Therefore, the principal objective of my study was to determine 1) the effects of wildfire on ground beetle population abundance and species richness in a Mediterranean climate, 2) how these effects vary over time and vegetation type, and 3) whether wildfire attracts unique species.

## METHODS

### *Study system description*

This study was located in Mt. Diablo State Park, in Contra Costa Co., California (37°52′54″N 121°54′51″W). Mt. Diablo's climate is Mediterranean and its vegetation types consist of mixed oak woodland, open grassland, and chaparral. The most recent wildfire, which burned a total of 1505 ha, occurred in Sep. 2013. I selected two areas with mixed pine/oak woodland and one with oak/grassland vegetation for my study, since ground beetles are rarely found in chaparral, and subdivided each into burned and unburned sites, for a total of six sites. (See Table 1 for GPS coordinates and Figure 1 for a map of pitfall trap sites.)

**Table 1.** Location and elevation of 4 pine woodland and 2 oak grassland sites in Mt. Diablo

| Site 1#- | Latitude | Longitude | Elevation |
|---|---|---|---|
| A {burned} | 37°53'45"N | 121 52' 40" W | 270m |
| B {unburned} | 37 53' 42"N | 121 52' 35"W | 230m |
| | | | |
| Malaise 1: | 37°53'45"N | 121°52'42"W | 287m |
| UV 1: | 37 53' 43"N | 121 52' 38"W | 270m |
| | | | |
| Site 2#- | | | |
| A {burned} | 37°53'40"N | 121°52'39"W | 238m |
| B {unburned} | 37°53'40"N | 121°52'36"W | 230m |
| | | | |
| Malaise 2: | 37°53'40"N | 121°52'39"W | 238m |
| UV 2: | 37°53'40"N | 121°52'41"W | 240m |
| | | | |
| Site 3#- | | | |
| A {burned} | 37°53'45"N | 121°52'26"W | 212m |
| B {unburned} | 37°53'43" N | 121°52'29"W | 214m |


**Fig. 1.** Location of sites in Google Earth.

*Pitfall trapping*

Although pitfall trapping can only be used to measure relative abundance (Spence and Niemelä 1994), they are commonly used in studies of epigaeic arthropod assemblages. To determine the relative abundance and diversity of ground beetle populations, I placed 10 pitfall traps in each site, for a total of 60 traps. I constructed the traps using 8" sections of PVC pipe (lathed to reduce thickness), each lined with a 16oz plastic cup. I dug in the traps so that the plastic cup's rim sat slightly below ground level (~1cm). The traps were spaced along linear transects ~5m apart, which is their effective trapping radius. Transects were roughly parallel to the direction of the burn, but mostly determined by ease of access. I set each trap with 1oz propylene glycol, a preservative and killing agent. Sheet roofing tiles were suspended above each trap with three nails to keep out rain and falling debris, and the entire trap was then covered with chicken wire to prevent disturbance from non-target animals.

*Malaise and UV traps*

In addition, I set one Malaise and one UV light trap in each of the two pine/oak burned sites, to capture rare flying species unable to be sampled by pitfall trapping. Due to a lack of resources, I was unable to set these traps in the oak grassland habitat. Malaise traps are large tents in which insects fly and are funneled into a jar of ethanol. UV light traps are buckets in which insects fly and are killed by cyanide. Both kinds of traps were purchased from BioQuip (Rancho Dominguez, CA).

*Sampling regime*

Pitfall and Malaise traps were set for three nights each month around the new moon, when ground beetle activity is highest, while light bucket traps were set for one night at the same time. I sampled for nine consecutive months, from July 2014-March 2015. This sampling period covers both the dry and wet seasons of the Mediterranean climate.

*Sample identification*

At the end of the trapping period, all ten cups from each pitfall transect were poured into one large container, resulting in six containers. Specimens were then removed from the propylene glycol and stored in 70% ethanol. Malaise specimens were transferred to a smaller container with the same 70% ethanol solution, and UV specimens were kept in refrigerated boxes. Both Malaise and UV specimens were sent to other labs for identification, since they contained many non-carabid species of interest to other researchers. I separated pitfall trap specimens into large taxa (Araneae, Coleoptera, non-Coleoptera Insecta, and misc. Arthropoda). I identified each Coleoptera specimen to morphospecies and eventually identified many to species level.

### *Data analysis methods*

Using R (R Core Team 2014), I conducted a Shapiro-Wilk test for normality, then used Kruskal-Wallace one-way analysis of variance to measure if population abundance and species richness were different between burned/unburned and woodland/grassland sites. Results were accepted as statistically significant at the 0.05 probability level. This method assumes independent samples, but not that data are normally distributed. I used non-metric multidimensional scaling (NMS), using PC-Ord (McCune and Mefford 2011) to measure how my communities differ across time, burn status, and vegetation type. This method requires relatively few assumptions.

## RESULTS

### *Collections from pitfall traps*

I collected a total of 274 individuals representing 54 species and 13 families during the sampling period: 201 individuals representing 28 species from the four pine-oak woodland sites, and 73 individuals representing 37 species from the two oak grassland sites. 24 species were specific to burned habitats, and 17 species to unburned habitats, while 17 were found in both (See Table 2). The most common families were Staphylinidae, Curculionidae, and Tenebrionidae. Due to the low number of specimens collected, I conducted my data analysis using all Coleopteran families, not Carabidae alone, as I had originally planned.

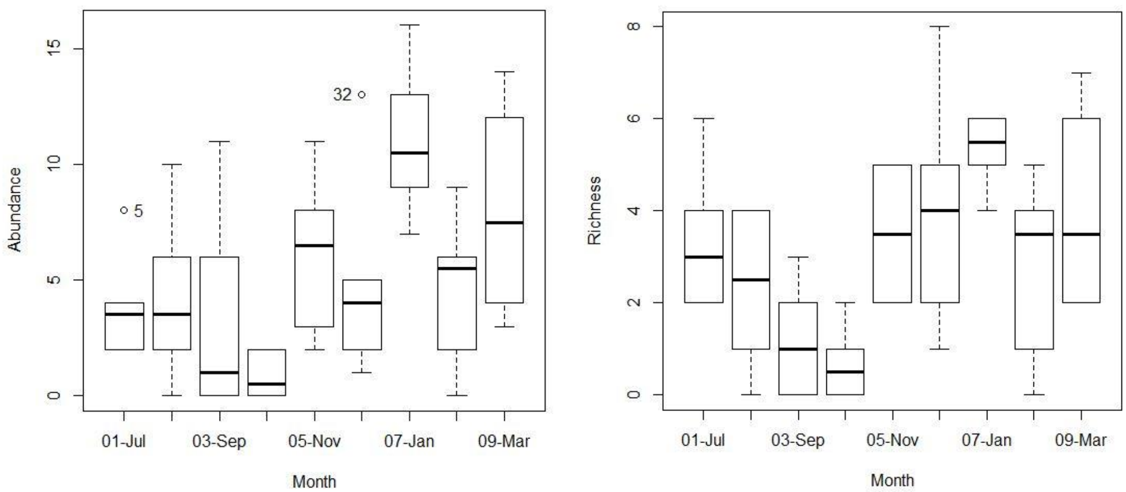
**Table 2. Total numbers per species for all beetles caught in pitfall traps**

| Species | Presence in sites | Total |
|---|---|---|
| *Amara sp.* | Unburned | 1 |
| *Apocrypha antiocoides* | Burned | 1 |
| *Blapstinus discolor* | Unburned | 1 |
| *Coelocnemis magma* | Burned | 1 |
| *Coniontis sp.* | Both | 20 |
| *Corticeus praetermissus* | Burned | 1 |
| *Cryptorhopalum sp.* | Burned | 1 |
| *Crysomelidae sp1.* | Burned | 1 |
| *Curculionidae sp1.* | Burned | 1 |
| *Curculionidae sp2.* | Burned | 3 |
| *Cymatodera sp.* | Burned | 1 |
| *Eleodes constrictus* | Burned | 9 |
| *Eleodes dentipes* | Burned | 2 |
| *Hylurgops porosus* | Both | 34 |
| *Lasconotus sp.* | Burned | 1 |
| *Latridiidae sp1.* | Unburned | 4 |
| *Latridiidae sp2.* | Unburned | 1 |
| *Leiodidae sp.* | Unburned | 5 |
| *Melanophthalma sp.* | Both | 3 |
| *Melyridae sp.* | Unburned | 2 |
| *Metophthalmus sp.* | Both | 12 |
| *Monotoma sp.* | Burned | 2 |
| *Nitidulidae sp1.* | Unburned | 1 |
| *Nitidulidae sp2.* | Burned | 1 |
| *Nyctoporis aequicollis* | Burned | 1 |
| *Phloeodes plicatus* | Burned | 1 |
| *Prionus californicus* | Burned | 1 |
| *Promecognathus laevissimus* | Both | 11 |
| *Pselaphinae sp.* | Both | 3 |
| *Pterostichus angustus* | Both | 8 |
| *Pterostichus californicus* | Both | 4 |
| *Pterostichus protensiformus* | Both | 6 |
| *Ptiliidae sp.* | Unburned | 5 |
| *Ptomaphagus sp.* | Both | 24 |
| *Scaphinotus interruptus* | Unburned | 2 |
| *Scaphinotus striatopunctatus* | Unburned | 2 |
| *Scolytinae sp.* | Unburned | 1 |
| *Staphylinidae sp1.* | Both | 4 |
| *Staphylinidae sp2.* | Both | 1 |
| *Staphylinidae sp3.* | Unburned | 1 |
| *Staphylinidae sp4.* | Both | 10 |
| *Staphylinidae sp5.* | Both | 42 |
| *Staphylinidae sp6.* | Both | 3 |
| *Staphylinidae sp7.* | Burned | 1 |
| *Staphylinidae sp8.* | Burned | 1 |
| *Staphylinidae sp9.* | Burned | 1 |
| *Staphylinidae sp10.* | Burned | 1 |
| *Staphylinidae sp11.* | Unburned | 3 |
| *Stentothorax sp.* | Burned | 1 |
| *Temnoschelia chlorodia* | Burned | 1 |
| *Thalycra sp.* | Both | 8 |

| | | |
|---|---|---|
| *Undetermined sp1.* | Both | 4 |
| *Undetermined sp2.* | Burned | 1 |
| *Zascelis irrorata* | Burned | 13 |

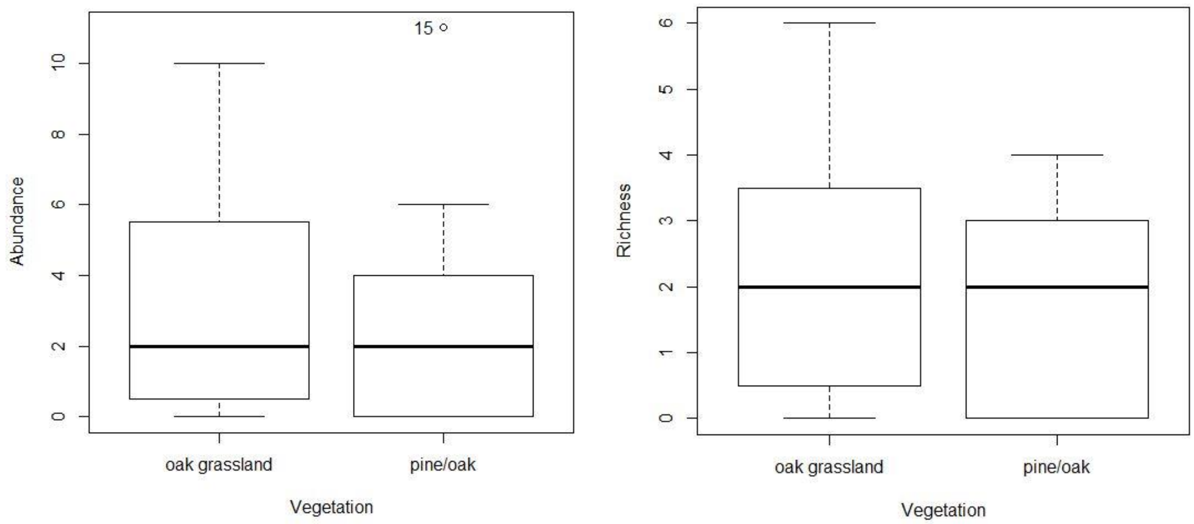
*Population abundance and species richness*

The result of the Shapiro-Wilks normality test showed my data to be not normally distributed (W = 0.921, P-value = 0.002). The results of Kruskal-Wallis tests showed no significant differences in population abundance between burned and unburned sites (P-values = 0.064) or between woodland and grassland (P-values = 0.184). However, there were significant differences in abundance and richness by month (P-values = 0.003 and 0.001 respectively), with both being lower in Jul-Oct than Nov-Mar, with the increase coinciding with the beginning of rainfall (see Figs. 2 and 3). I divided my dataset between these two dry and rainy periods, and repeated the analyses.



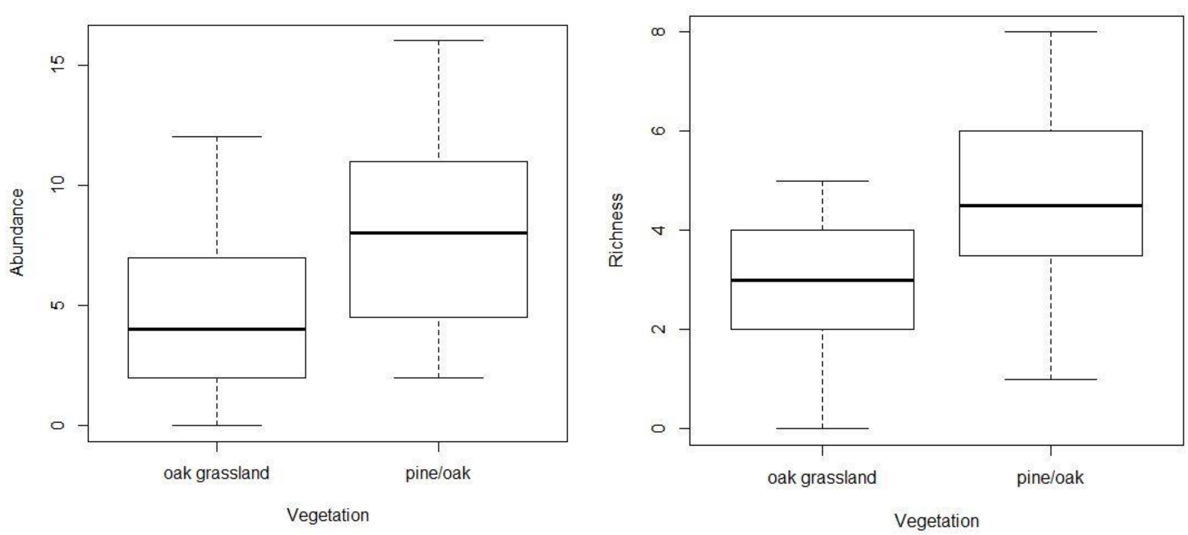

**Figs. 2 (L) and 3 (R).** Population abundance and species richness by month

In the dry season, there was no significant difference in abundance or richness between vegetation types (see Fig. 4 and 5). Because species richness is largely a function of population abundance, for simplicity I will report the P-values for abundance alone, which in this case is 0.975.



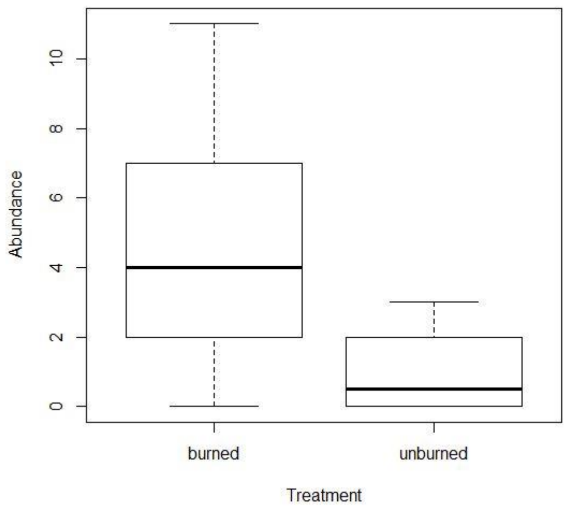

**Figs. 4(L) and 5(R).** Population abundance and species richness by vegetation type in the dry season

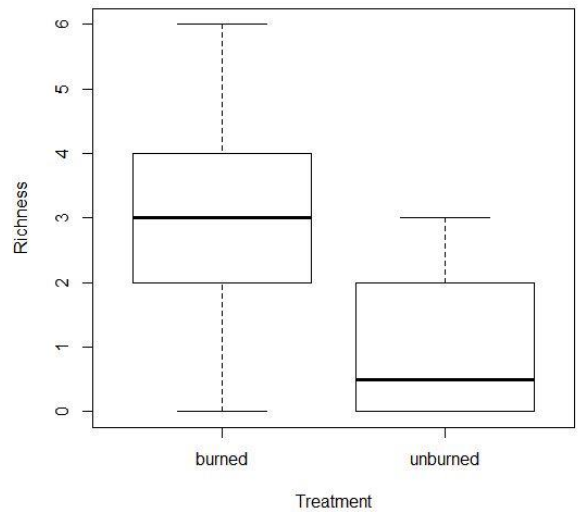
In the rainy season, there was a significant difference in abundance (P-value = 0.050) and richness between vegetation types (see Figs. 6 and 7).




**Figs. 6 (L) and 7 (R).** Population abundance and species richness by vegetation type in the rainy season

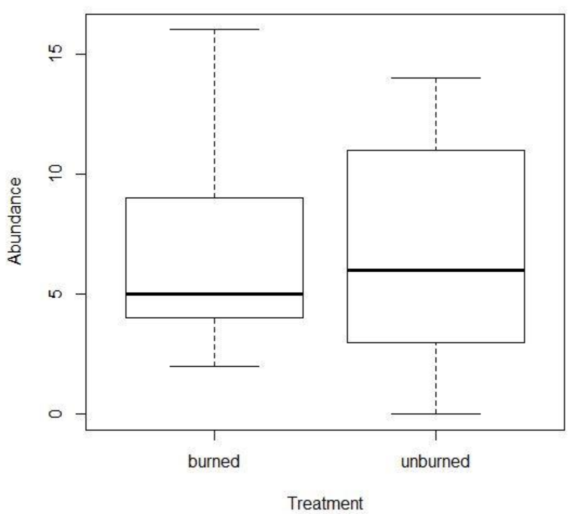
In the dry season, there was a significant difference in abundance (P-value = 0.002) and richness between treatments (see Figs. 8 and 9).

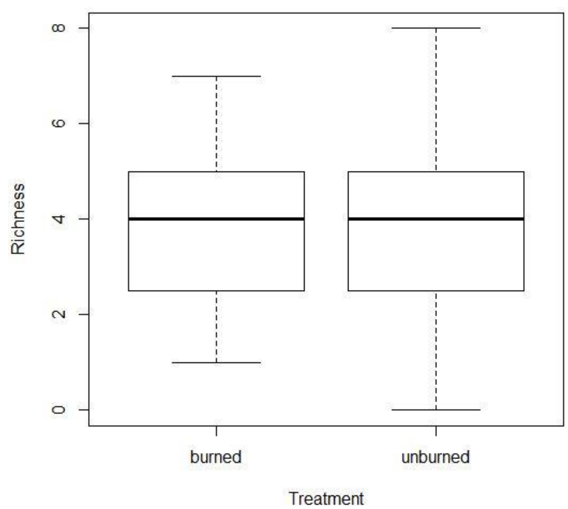



**Figs. 8(L) and 9(R).** Population abundance and species richness by burn treatment in the dry season

In the rainy season, there was no significant difference in abundance (P-value = 0.835) and richness between treatments (see Figs. 10 and 11).




**Figs. 10(L) and 11(R).** Population abundance and species richness by burn treatment in the rainy season

*Composition of arthropod communities and habitat*

NMS ordination (stress < 0.2) revealed no pattern with regard to community level responses to treatments (see Fig. 12). However, burned sites clustered independently from unburned sites in July and August (see Fig. 13).

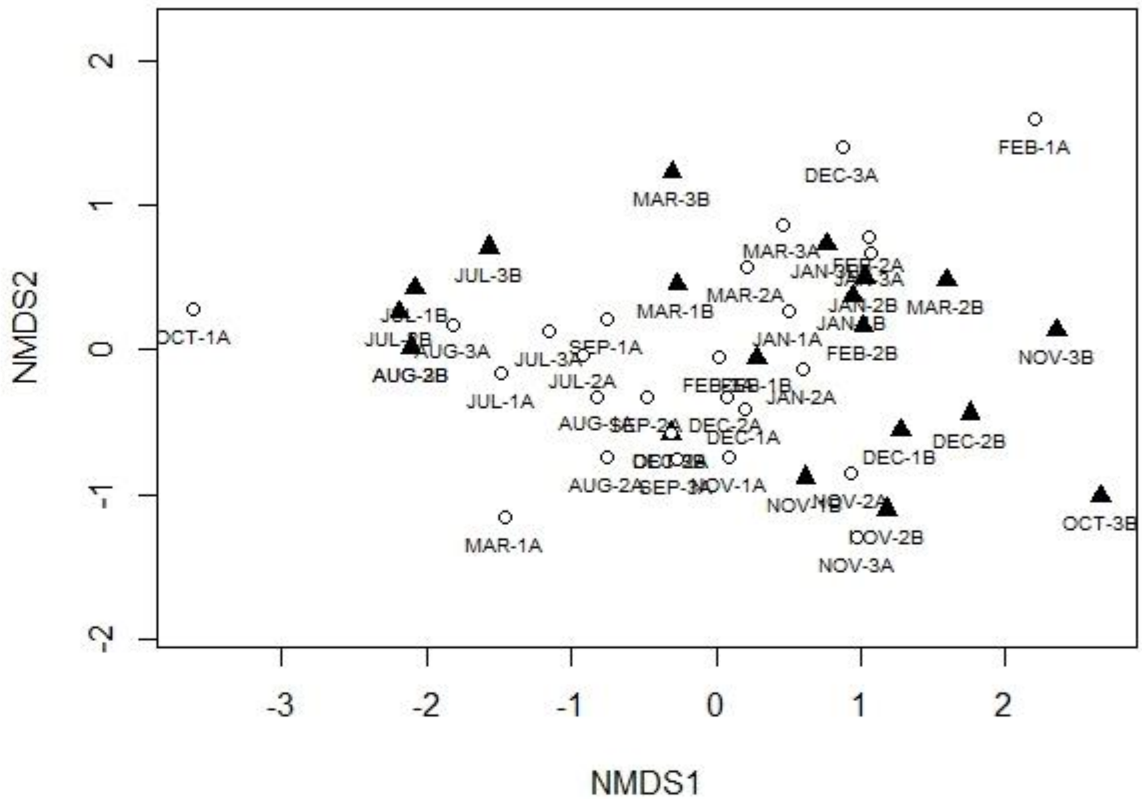



**Fig. 12** Nonmetric multidimensional scaling (NMS) based on Bray-Curtis's similarity index derived from beetle species presence/absence

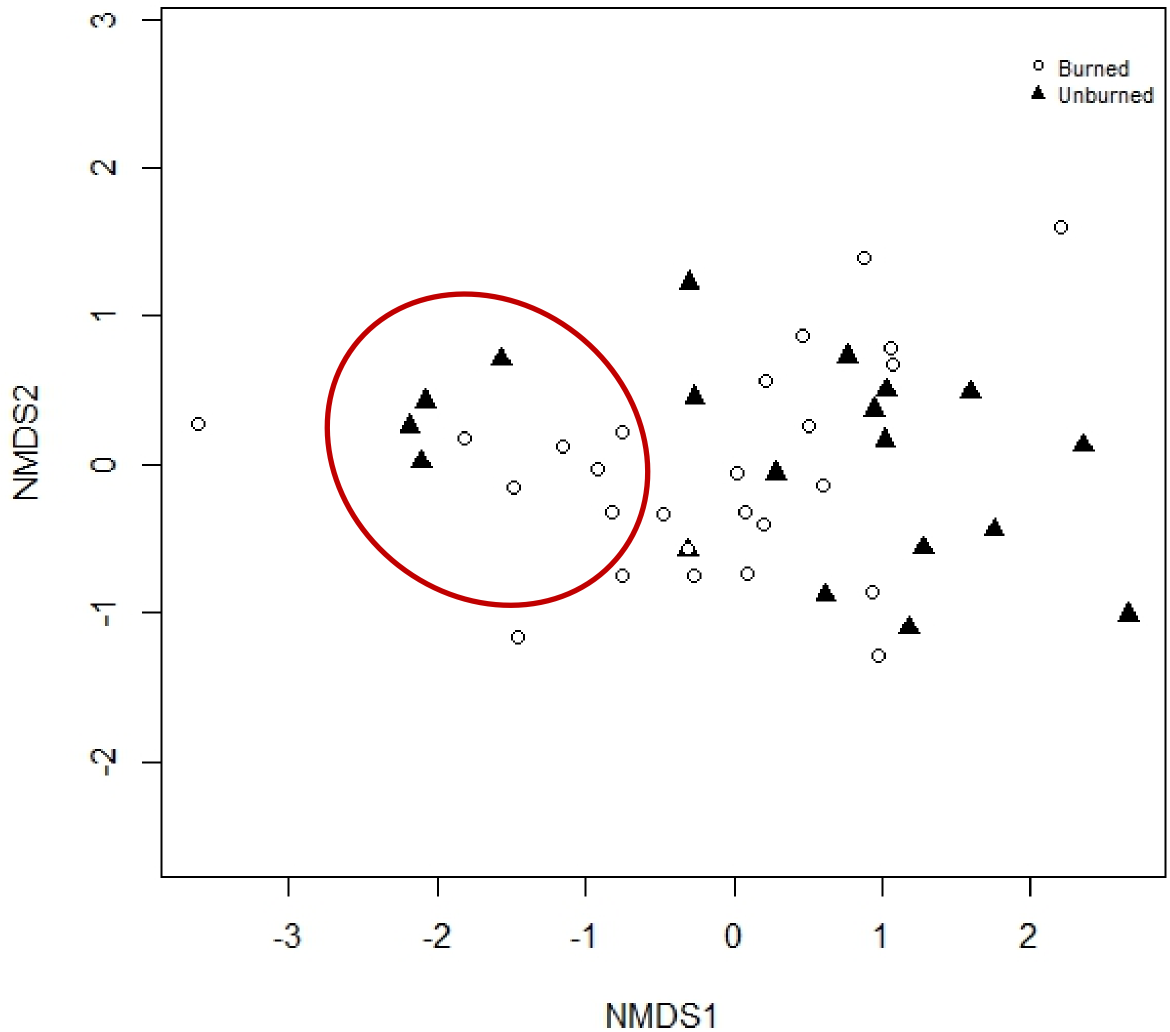



**Fig. 13** NMS plot with July and August communities circled

In terms of species with the highest levels of correlation with the ordination, *Coniontis sp., Eleodes dentipes, Pterostichus protensiformus, Ptomaphagus sp., and Staphylinidae sp5*. all had P-values < 0.1.

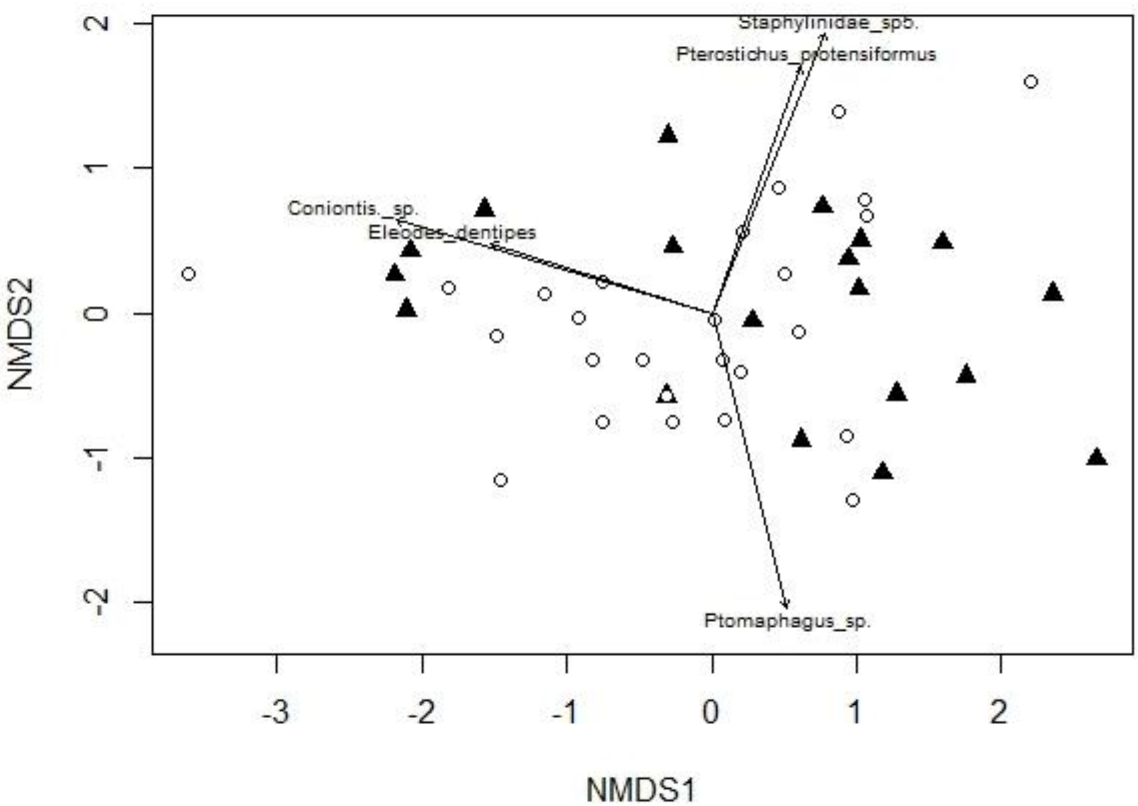



**Fig. 13** Species with the highest correlation with ordination

## DISCUSSION

*Key points of interpretation*

Seasonality and the beetle life cycle had the greatest influence on my results: population abundance and species richness varied by month, rather than treatment or environmental variables. Looking at the first few months alone, abundance and richness were higher in burned areas. This is supported by NMS ordination, which showed a significant difference in community structure between burned and unburned sites only in the first two months of my study. There were no indicator species closely associated with the treatment.

*Population abundance and species richness*

In all studies of fire effects on beetles I examined that took place in boreal forests, only one (Saint-Germain et al. 2005) reported a lower abundance of beetles in burned areas. However, the researchers only began sampling in the second year following the fire, so the peak occurrence of beetles could have been missed. All other boreal forest studies reported higher population abundance post-fire. In Mediterranean forests, Elia et al. (2011) reported abundance and richness to be higher in burned areas, and increasing along with proximity to the center of a burned area. In contrast, Radea and Arianoutsou (2012), in a survey of Mediterranean forest studies, found mixed results on population abundance. It is possible that in Mediterranean forest ecosystems, terrestrial arthropod assemblages recover more quickly from fire than in boreal forest ecosystems, making differences in abundance difficult to detect unless populations are sampled immediately. This would explain why, averaged over the nine months of my study, beetle population abundance and species richness were similar between burned and unburned areas.

However, when looking at the months closest to the fire, July to October, there is a significant difference in abundance and richness, with burned sites being higher in both. One factor explaining the observed response could be a correlation with predator species abundance (Higgins 2014). Since fire reduces ground cover for mammalian predators, and leaf cover for avian predators, it could create less predation pressure on beetles. Other factors could be the simplification of habitat structure due to burning, or the intersection of the fire with the beetle life cycle (Niwa and Peck 2002). Fire causes immediate mortality to beetles, but species with a below-ground life stage in the fall, when the fire occurred, may have been protected. Since the ground beetle species in Mt. Diablo are generally active in the spring, their mating season, and dormant in fall (personal correspondence, K. Will), the majority of beetles may have been unaffected by the fire, in which case, they would not be suitable as an indicator taxon. An examination of terrestrial spiders, which do not remain dormant underground, would shed light on these findings.

One possible explanation for why abundance and richness varied between vegetation types in the rainy, but not the dry season, is that rainfall resulted in more plants germinating in woodland than grassland, attracting more prey to woodland areas. Despite my sample size being small, these results indicate that studies in Mediterranean ecosystems should include both woodland and grassland areas, as beetle activity varies between them.

*Beetle assemblages*

NMS ordination showed little change in beetle assemblage structure in burned areas. Assemblage structure did not differ between habitats or between months, except for July and August. It could be the case that, since I was only able to begin sampling nine months following the fire, July and August were the tail end of the period in which the beetle assemblage was recovering from the fire. However, as more years of sampling result in additional collecting events, assemblages may group together according to some combination of burn status, habitat type, and season.

*Indicator species*

Of the species with the highest levels of correlation with the ordination, *Coniontis sp., Pterostichus protensiformus*, *Ptomaphagus sp., and Staphylinidae sp5*. were all among the most numerous, and found in both burned and unburned sites. *Eleodes dentipes* was found only in burned sites, suggesting it may be an indicator species for fire; however, only two specimens were collected, so the results are not meaningful. Currently, many of the species I found only have one or two representative specimens, so further sampling periods may reveal indicator species for fire.

*Limitations and future directions*

The major limitations of this study were time and sampling effort. Other studies of beetle assemblages used ~2000-6000 specimens; I only collected 274. More traps and sampling periods would have given my results greater statistical significance. Since this is the first year of a five-year study, it will be of interest whether further collecting will reinforce or contradict the patterns I have found. In addition, there remain to be completed a correlation of habitat variables with beetle assemblages, an examination of beetle species captured in Malaise and UV light traps, and statistical analyses using the spiders collected in the pitfall traps.

*Broader implications*

The results of this study indicate that terrestrial beetle assemblages do not differ between burned and unburned areas after about a year following a fire in Mediterranean ecosystems. Although beetles are numerous in these ecosystems, in terms of both individuals and species present, and they serve many functions as predators, prey, and decomposers, they may not be suitable as indicator species for wildfire recovery in Mediterranean forests, since the effect of fire on their assemblages varies depending on the incidence of the fire with their life cycles. However, based on my current results, it seems that Mt. Diablo's ecosystem, at least measured through the terrestrial beetle population, has made a rapid recovery from wildfire.

## ACKNOWLEGMENTS

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