Plant community response to fuel break and goat grazing in southern California

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Plant community response to fuel break and goat grazing in southern California

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Abstract

Background: California is a global biodiversity hotspot, yet increased urbanization of wildlands, warming temperatures, and invasion of nonnative species pose serious risks to these areas due to an increase in wildfire frequency. Fuel management is a tool for reducing fire risk to neighboring communities and natural resources that involves a two-step process requiring an initial reduction of woody vegetation followed by a repeated control of woody plants and reduction of herbaceous cover. To understand the compositional and structural changes resulting from fuel treatment methods in southern California chaparral, we evaluated the compositional and structural impacts of a recently created fuel break established around the Lake Morena community on the Cleveland National Forest. The area was initially treated with cut and pile burning, then treated with herbicide, and lastly grazed by 1,200 goats. The purpose of this study is to (1) evaluate the compositional and structural differences associated with the initial fuel break, and (2) quantify compositional shifts in herbaceous and woody vegetation caused by goat grazing over time.

Results: Plots on fuel breaks and in adjacent wildlands exhibited significantly different species assemblages. Total herbaceous cover (both native and nonnative) was 92 times greater on fuel breaks than in adjacent chaparral-dominated wildlands and native shrub cover was 55.3 times greater in adjacent wildlands than on fuel breaks. Goats had a significant impact on reducing native and nonnative herb cover (87% reduction in cover, 92% reduction in height), but were ineffective at reducing the cover and height of most woody species such as *Adenostoma fasciculatum, Eriogonum fasciculatum, Quercus berberidifolia,* and *Artemisia tridentata.* However, goats were found to be effective in controlling nonnative grasses including *Bromus diandrus* and *Bromus madritensis.*

Conclusion: Initial fuel break creation was effective at reducing wood biomass and height, simultaneously giving rise to an abundance and diversity of native and nonnative herbaceous species.

Although targeted goat grazing was successful at reducing herbaceous biomass, it was ineffective at reducing woody biomass which is often one of the most important goals for fuel management in chaparral ecosystems.

Abbreviations

WUI: wildland-urban interface

Introduction

California is a global biodiversity hotspot, largely centered in sage- and chaparral-dominated shrublands (Underwood et al. 2018). Yet, these ecosystems are threatened by an increase in wildfire frequency driven by increased urbanization of wildlands, warming temperatures, and invasion of nonnative species (Abatzoglou and Williams 2016; Bruegger et al. 2016; Keeley and Fotheringham 2001). Wildfire activity has increased exponentially in many parts of California as a result of increased flammable vegetation and a lengthened fire season. Increasing temperatures and reduced precipitation are likely to exacerbate the size and frequency of catastrophic fires by altering the amount and distribution of fuels and creating a shorter fire-return interval than historically present (Steel et al. 2015; Westerling and Bryant 2008).

To mitigate these large destructive wildfires, fuel reduction treatments are implemented to reduce fire risk to neighboring communities and natural resources by changing fire behavior and limiting fire spread (Hardy 2005; Mell et al. 2010; Simard 1991). A primary form of fuel management in shrublands is the construction of strategic fuel breaks at the wildland-urban interface (WUI). The main goal of fuel break creation is to reduce woody biomass; consequently, facilitating fire suppression activities that limit fire spread. Permanently converting a dense stand of chaparral to one of a lower fuel volume (e.g., cover, height) is often a multiple-step process that requires the initial removal of woody vegetation followed by periodic control of woody plants and reduction of herbaceous cover (Green 1977). Initial biomass removal may involve cut and pile burning (a form of vegetation removal where woody vegetation is manually removed above the root crown, placed in a pile, and burned), broadcast burning, or mastication. Herbicide use is one method for controlling regrowth after mature vegetation has been removed, but due to high costs and potential unintended consequences to other biota, there has been a need for alternative methods of controlling regrowth. Over the past few years, there is rising interest in controlling woody vegetation with domestic animals, such as goats. A limited number of studies have investigated goat grazing as a way of maintaining fuel breaks (Green and Newell 1982; Tsiouvaras et al. 1989). These studies have been mostly qualitative and have not quantified structural and compositional changes within chaparral dominated landscapes.

Despite the prevalence of fuel break treatments in southern California, there is little known about the ecological effects on vegetation structure and species composition in chaparral ecosystems. While the primary goal of fuel break creation and maintenance is to reduce woody vegetation, the removal of overstory woody species is likely to catalyze compositional and structural shifts in vegetation. We set out to evaluate these changes in response to initial fuel break creation and goat grazing. We specifically address the questions:

(1) How do vegetation composition and structure change in newly disturbed areas affected by fuel break creation?

(2) How does goat grazing, as a fuel reduction technique, affect the composition of herbaceous and woody vegetation?

Methods

Study Area: This study was conducted in a 116-acre fuel break system established in eastern San Diego County around the Lake Morena community in the Cleveland National Forest (32.69 °N, -116.52 °W). The study site experiences a Mediterranean climate, with subtropical high-pressure cells resulting in hot, dry summers and cool, wet winters. The chaparral plant communities at Lake Morena were dominated by shrub species, including *Adenostoma fasciculatum* Hook. & Arn., *Eriogonum fasciculatum* Benth., *Cercocarpus betuloides* Nutt., *and Quercus berberidifolia* Liebm. Two tree species, *Quercus agrifolia* Née and *Quercus engelmannii* Greene, were also present. A fuel break was initially created during fire suppression operations in the 1970s and was not disturbed again until October 2015 when the entire fuel break was treated with cut and pile burning. Herbicide was initially used to maintain the fuel break in May 2016, and two years later 1,200 goats were deployed at a rate of 10 goats per acre for two weeks in August 2018 within the fuel break to further reduce woody chaparral species. Initial vegetation surveys were conducted in July 2018 and vegetation plots were established in treated (cut and pile + herbicide, N=16) and untreated areas outside of the fuel break (untreated with no vegetation manipulation, N=8) (Fig. 1). Treated plots were subject to goat grazing in August 2018 and were re-sampled in October 2018 to capture the effects of grazing. Treatment plots that were surveyed before goat grazing are referred to as pre-grazing and those after goat grazing are referred to as post-grazing.

Experimental Design: The point line method (Heady et al. 1959) was used to quantify species composition, cover, and vegetation height. In total, 24 30-meter permanent line transects were established within the study site. All species, both dead and alive, in addition to the height of the tallest individual were recorded at 100 points along the 30-meter transect line. To calculate the effect of grazing on individual species, the cover of each species was summed across the entire transect and averaged for untreated, pre-grazing, and post-grazing treatment types. Cover estimates were also summarized by assigning individual species into five lifeform categories (tree, live shrub, dead shrub, native herbaceous (grasses and forbs), and nonnative herbaceous (grasses and forbs)). If multiple species of the same lifeform were present at the same point along the transect, the lifeform cover received a count of one at that point. Species richness, unlike lifeform cover, was calculated with overlapping species and the total count of species present within each lifeform was summed across each

30-meter transect line and averaged for untreated, pre-grazing, and post-grazing treatment types. Lifeform cover and species richness were summed across the entire transect and averaged for untreated, pre-grazing, and post-grazing plots. The tallest individual at each sampling point was recorded as part of the point-line intercept method. Lifeform height was calculated across each transect as the sum of herb or shrub height divided by the total number of transect points where that particular lifeform was the tallest.

To characterize ground cover and fuels, a one-square meter quadrat was used at five locations (5, 10, 15, 20, 25 meters) along the upslope side of the transect line. Within each quadrat, fuel height was measured at five points as the distance from the soil surface to the top of the tallest unrooted dead vegetation, and the ground cover (bare ground, litter, wood (above 6.35 mm diameter), live vegetation, and goat feces) was visually estimated. Ground cover and fuel height were pooled from the five quadrats to obtain a plot-level average.

Statistical Analysis: Non-metric multidimensional scaling (NMDS) was used to visualize compositional differences between treatment (fuel break and control) as a part of the '`vegan`' package in `R` (Oksanen et al. 2011). The ordination uses rank-order correlation and Bray-Curtis dissimilarities, with the `metaMDS` function, to model the differences among treatment and control plots based on species composition and abundance of all plant species. Two sample *t*-tests were used to evaluate differences in lifeform cover, richness, height, and ground cover between untreated (N=8) and treated plots (N=16). Data were checked for normality using QQ plots, and the equality of variances between the two groups were assessed using an F-test. Ground cover variables (bare ground, litter, and wood), shrub height, and shrub and herb cover and richness were square-root transformed to meet the assumptions of the *t*-test. Live tree richness and cover in addition to fuel and herb height were analyzed using a non-parametric Wilcoxon rank-sum test because they could not be adequately transformed to meet the assumptions of normality.

Paired *t*-tests were used to evaluate the effects of goat grazing on lifeform cover, richness, height, and ground cover. The observed differences from pre-grazing and post-grazing treatment plots were checked for normality with QQ plots. Variables were square-root (tree, wood, vegetation, native herb, nonnative herb, and feces cover, and native herb, nonnative herb and dead shrub richness) or sin (litter cover and live shrub richness) transformed to meet statistical assumptions. Live tree richness and average herb height were analyzed using a Wilcoxon rank-sum test because they did not meet assumptions of normality. All statistical analyses were done in `Rstudio` version 1.1.453 (Vienna, Austria) at $\alpha=0.05$ and we report means ± 1 standard error (SE).

Results

Compositional differences between treated and untreated areas.

Plots on (treated) and off (untreated) fuel breaks exhibit different species assemblages. The NMDS ordination of species composition resulted in a cluster of treated plots within the fuel break that contain more herbaceous species, while the untreated plots contain a greater abundance of shrub species (Fig. 2; final stress of two-dimensional solution = 0.191 with 20 iterations). Dead shrub cover was 89.6 times ($t(17)=-9.56$, $P<0.001$) greater and live shrub cover was 55.3 times ($t(9)=-4.92$, $P<0.001$) greater in untreated plots that lacked fuels management compared to treated plots (Fig. 3). Native herb cover was 88.1 times ($t(17)=6.52$, $P < 0.001$) and nonnative herb cover was 96 times ($t(21)=5.21$, $P < 0.001$) greater in treated plots compared to the control plots (Fig. 3). Nonnative grasses were the most abundant herbs in the treated plots (average cover: 26.83%) with a significantly higher cover of *Bromus tectorum* L. and *Bromus madritensis* L. (Table 1). Treated and untreated plots did not differ in tree cover (Wilcoxon sign-ranked test, $P = 0.92$). Total species richness at the 30-meter scale showed similar trends, with native herb richness 76.2 times (t(14)=4.77, $P < 0.001$) and nonnative richness 81.8 times (t(22)=3.23, $P < 0.001$) greater in the treatment compared to untreated plots (Fig. 3). Live shrub and tree richness were uniform across treatment types, while dead shrub richness was higher in untreated plots.

Fuel break creation elicited structural differences across the landscape by changing lifeform height and ground cover. Herb height was 97 times greater (Wilcoxon signed-rank test, $P < 0.001$) on treated plots than in control plots. Conversely, shrub height was 84.6 times greater (t(8.9)=-7.89, $P < 0.001$) and total fuel height was 31.5 times greater (Wilcoxon signed-rank test, P = 0.045) on plots that lacked fuels management (Fig. 4). There was a trend for bare ground cover to be greater on treated plots (t(22)=1.94, $P = 0.065$) with untreated plots having substantially more wood and litter (t(10.8)=-3.99, $P = 0.002$; t(22)=-2.62, $P = 0.016$; respectively) than treated plots.

Compositional and structural differences before and after goat grazing

To determine if goats were effective at reducing herbaceous and woody vegetation across the fuel break, we repeated our analysis of vegetation cover, richness, and height differences with a paired t-test on treatment areas inside the fuel break before and after grazing. We found an 87% reduction in herb cover due to grazing (t(15)=9.74, $P < 0.001$; Fig. 5). Grazing led to a decrease in native herb cover from 17.88 ± 2.6% to 2.38 ± 1.0% (t(15)=11.07, $P < 0.001$) and a decrease in nonnative herb cover from 25.25 ± 5.2% to 3.19 ± 0.9% (t(15)=14.30, $P < 0.001$). Generally, goats had a high preference for *Bromus madritensis* L. (100% reduction, t(15)=5.28, $P < 0.001$) and *Bromus diandrus* Roth (97% reduction, Wilcoxon rank-sum, $P = 0.281$) while *Bromus tectorum* L. (60% reduction, (t(15)=1.31, $P = 0.213$) was the only herbaceous species to persist with > 1% cover following goat grazing (Table 1). There was no significant decline in shrub cover (t(15)=1.70, $P = 0.114$) or tree cover (t(15)=0.68, $P = 0.509$) due to grazing, but generally, goats had a low preference for *Adenostoma fasciculatum*, *Eriogonum* *fasciculatum,* and *Ericameria* species while mostly targeting *Cercocarpus betuloides* and *Eriophyllum confertiflorum* (Table 2).

Grazing elicited similar trends in species richness at the 30-meter scale (Fig. 5). We found a 77.5% reduction in herb richness, with grazing decreasing native herb richness from 4.75 ± 0.6 to 1.00 ± 0.3 ($t(15)=7.32$, $P < 0.001$) and a decrease in nonnative herb richness from 2.75 ± 0.5 to 0.69 ± 0.2 ($t(15)=-3.08$, $P < 0.001$). Grazing did not cause a significant difference in live shrub ($t(15)=0.17$, $P = 0.869$), dead shrub ($t(15)=-0.08$, $P = 0.938$), or tree (Wilcoxon signed-rank test, $P = 1.00$) richness.

Grazing induced changes in vegetation structure across the landscape by both changing lifeform height and ground cover. There was a significant decrease in herb height from 17.1 ± 2.2 cm pre-grazing to 15.3 ± 2.6 cm post-grazing (Wilcoxon sign-ranked test, $P < 0.001$), but there was no significant difference in shrub height ($t(15)=0.075$, $p=0.491$) (Fig. 6). While we did not measure ground to the base of the crown height for trees, we observed that goats were effective at increasing this distance through the limbing and consumption of the lower branches (Fig. 7). A paired *t*-test showed a significant increase in bare ground cover ($p<0.001$) due to grazing but exhibited no change in wood or litter cover.

Discussion

This study demonstrates the complexity of fuel break creation and maintenance that involve a stepwise process in vegetation change. Initial fuel break creation has significant effects on vegetation cover and richness, as we expected. We found compositional differences driven by a decrease in the abundance of shrubs and a higher abundance and diversity of herbaceous species inside of the fuel break compared to non-disturbed areas. Chaparral shrublands are known for exhibiting unparalleled temporal diversity with substantial herbaceous richness (e.g. fire followers) being expressed following wildfire (Keeley et al. 2005). Herbaceous species can be triggered by various processes associated with shrub removal, such as heat, smoke, and chemical byproducts of the fire (Keeley and Fotheringham

2001). The process of fuel reduction may mimic some of the post-fire processes by increasing temperature at the soil surface or via scarification caused by ground disturbing fuels reduction activities. Shrub removal may also lead to light associated cues for germination (Le Maitre and Brown 1992, Stone 1957). It is important to note that this study was conducted on a relatively new fuel break and the difference in richness and cover for older fuel breaks are not likely to track our findings.

The fuel break complex at Lake Morena was recently opened in 2015 and we propose that fuel break creation promotes an increase in native and nonnative species initially, but repeated disturbances may lead to degradation that includes an increase nonnative annual species at the expense of native species. The dominance of nonnative annuals, especially grasses, may be reinforced in frequently disturbed areas through higher germination rates, competitive superiority, and accumulation of a persistent thatch layer (Molinari and D'Antonio 2020; Parendes and Jones 2000; Reynolds et al. 2001). Merriam et al. (2006) found that fuel break construction was strongly associated with moderately high nonnative abundance and showed that over time, with repeat disturbance, nonnatives can displace native species and become increasingly dominant. An increase in nonnative species on the landscape is detrimental as it not only changes soil nutrient cycling that is unfavorable to native species (Evans 2001), but it alters fuel characteristics such that fires become more frequent (D'Antonio and Vitousek 1992; Keeley 2001).More specifically, nonnative grasses are associated with increased fuel ignitability, fine-fuel loads, and fuel continuity, thus increasing fire occurrence and frequency at the regional scale (Fusco et al. 2019).

While the Lake Morena fuel break complex is currently exhibiting signs of increased herbaceous diversity, with repeated maintenance we suspect species diversity will decline and nonnative species will become the dominant vegetation type in this area. Alternatively, if this fuel break is not maintained and lacks future disturbance, herbaceous richness and cover are likely to decline due to the regrowth of shrubs and the exclusion of many nonnative and native annuals that were able to persist immediately after disturbance.

Controlling woody regrowth is vital to the functioning of fuel breaks in reducing fire risk to human-dominated landscapes. Therefore, understanding the effectiveness of alternative maintenance methods, such as goat grazing, is imperative. We found that targeted grazing was ineffective at reducing the height and cover of most woody vegetation, apart from *Eriophyllum confertiflorum* and *Cercocarpus betuloides*. Goats showed high selectivity when browsing shrubs and had a low preference for many of the dominant shrub species at Lake Morena. This selectivity should be considered when determining if goats are an economically feasible alternative to other methods of controlling regrowth.

Goat grazing strongly reduced both native and nonnative herbaceous cover and height, which may be desirable in areas where flashy fuels and ignition risk are a concern. It is important to note that goats also removed most of the nonnatives on the landscape (87% reduction) but tended to leave a higher cover of *Bromus tectorum* L.. Of the 3.2% of the nonnative herbaceous cover remaining after grazing, 3.0% was comprised of *B. tectorum.* Goats tended to avoid this species while eliminating other dominant nonnative species, such as *Bromus madritensis* L.. *B. tectorum* is palatable for six to eight weeks in the spring, however, when cheatgrass is grazed later in the summer, the long, straight awns can damage the eyes and mouth of grazers (Mosley et al. 1999). Although there is only 3.0% cover of *B. tectorum* cover at Lake Morena, this small amount may be sufficient for prolonged persistence which can displace native species, alter fire regimes, and modify hydrological properties (Arkle et al. 2014; Blank and Morgan 2013; Monaco et al. 2016). Land managers interested in using goats to control undesirable nonnative species should take into account the phenology and palatability of the target nonnative species.

Although goats successfully reduced herbaceous biomass, the reduction of woody biomass is often one of the most important goals for fuel management in chaparral ecosystems. Goats will eat a wide variety of species compared to most livestock but can be selective in targeting plants that are in a favorable growth stage (Green and Newell 1982). Qualitative observations of goat grazing have shown that goats prefer younger growth forms and become more selective as the shrubs mature. If grazing pressure is high or goats remain for a longer duration, they may begin to target less palatable species and growth forms (Green and Newell 1982). Due to the selectivity of goats in targeting woody plants, land managers should consider the seasonality, stage of regrowth, and species composition when deciding whether goats are an appropriate tool for fuel break maintenance.

Conclusions

With warming temperatures and continued development into the wildland-urban interface, chaparral-dominated shrublands are threatened by an increase in wildfire frequency. As pressure mounts to develop and maintain fuel breaks on the landscape, it becomes increasingly important to understand the effectiveness and consequences of various fuel reduction techniques on shrubland habitats. Initial fuel break creation through cut and pile and herbicide application at Lake Morena was effective at reducing woody biomass and height, while simultaneously giving rise to an abundance and diversity of native and nonnative herbaceous species. While this may superficially appear to be a win-win for fuels management and ecology, it is important to note that with repeated maintenance, fuel breaks are likely to become increasingly dominated by undesirable nonnative species. Goat grazing was ineffective at reducing height and cover of woody vegetation but was successful in reducing both native and nonnative herbaceous cover and height, which may be desirable in areas where flashy fuels and ignition risk are high. However, in areas where control of woody biomass is the primary goal, land managers should consider the seasonality, duration, and plant species composition when contemplating goats as a tool for fuel break maintenance.

Availability of data and materials

The datasets used and analyzed during the current study are available from the corresponding author upon reasonable request.

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Tables

Table 1: List of most abundant nonnative herbaceous species throughout study area. For each treatment, the average plant cover (%) is calculated across each 30-meter transect.

Nonnative herbaceous species	Cal-IPC rating	Pre-grazing cover	Post-grazing cover	Control (untreated) cover
Bromus diandrus Roth	Moderate	6.38 ± 3.5	0.19 ± 0.1	0.00 ± 0.0
Bromus madritensis L.	High	10.13 ± 2.8	0.00 ± 0.0	0.63 ± 0.42
Bromus tectorum L.	High	7.44 ± 2.9	2.63 ± 0.9	0.25 ± 0.3
Festuca myuros L.	Moderate	2.38 ± 1.2	0.00 ± 0.0	0.13 ± 0.4
Brassica tournefortii Gouan	High	0.50 ± 0.4	0.00 ± 0.0	0.00 ± 0.0
Avena sp. L.		0.50 ± 0.3	0.00 ± 0.0	0.00 ± 0.0

Table 2: List of most abundant shrub species throughout study area. For each treatment, the average plant cover (%) is calculated across each 30-meter transect.

Shrub species	Pre-grazing cover	Post-grazing cover	Control (untreated) cover
Adenostoma fasciculatum Hook. & Arn.	9.63 ± 2.3	9.25 ± 2.2	31.50 ± 5.12
Eriogonum fasciculatum Benth.	3.38 ± 1.5	2.81 ± 1.1	1.00 ± 1.0
Quercus berberidifolia Liebm.	2.38 ± 1.4	2.5 ± 1.6	4.25 ± 2.28
Cercocarpus betuloides Nutt.	1.50 ± 0.9	0.88 ± 0.5	5.63 ± 2.39
Rhus aromatica Aiton	1.31 ± 0.9	0.94 ± 0.6	1.00 ± 0.65
Artemisia tridentata Nutt.	1.00 ± 0.6	1.00 ± 0.6	0.00 ± 0.0
Eriophyllum confertiflorum (DC.) A. Gray	1.13 ± 0.4	0.00 ± 0.0	0.13 ± 0.1

Figure legends

Figure 1: Location of field plots indicated by green (fuel break) and blue (control) dots in relation to the Lake Morena fuel break (red polygon).

Figure 2: Non-metric multidimensional scaling plot (NMDS) of Bray-Curtis dissimilarity matrix of survey plots. Composition and species abundance differ among treatment plots inside the fuel created fuelbreak (blue triangles) and control plots outside the fuel break (pink circle). Species scores are shown in the same ordination space, with labeling priority given to more abundant and frequent species. All species codes correspond with the USDA Plants Database (USDA NRCS 2021). B(species) represents a dead branch of a live individual at the sampling point. Final stress of three-dimensional solution = 0.191 after 20 iterations.

Figure 3: Fuel break creation, through pile burning and herbicide, resulted in changes in plant lifeform cover (left) and species richness (right). Species richness is the number of species counted along a 30-meter transect line. The bold horizontal lines are the medians, the boxes represent 50% of the data, and each whisker represents 25% of the data. Dots represent outliers. When there are no outliers, the end of the whisker designates minimum and maximum values. Symbols above each category denote significant differences between treatment groups (ns: $p > 0.05$; ****: $p < 0.0001$; ***: $p < 0.001$; **: $p < 0.01$).

Figure 4: Fuel break creation, through pile burning and herbicide, resulted in changes to mean herbaceous height (left) and shrub height (right). The bold horizontal lines are the medians, the boxes represent 50% of the data, and each whisker represents 25% of the data. Dots represent outliers. When there are no outliers, the end of the whisker designates minimum and maximum values. Symbols above each category denote significant differences between treatment groups (****: $p < 0.0001$).

Figure 5: Goat grazing resulted in changes in plant lifeform cover (left) and species richness (right). Species richness is the number of species counted along a 30-meter transect line. The bold horizontal lines are the medians, the boxes represent 50% of the data, and each whisker represents 25% of the data. Dots represent outliers. When there are no outliers, the end of the whisker designates minimum and maximum values. Symbols above each category denote significant differences between treatment groups (ns: $p > 0.05$; ****: $p < 0.0001$; ***: $p < 0.001$; **: $p < 0.01$).

Figure 6: Goat grazing resulted in changes to mean herbaceous height (left) and shrub height (right). The bold horizontal lines are the medians, the boxes represent 50% of the data, and each whisker represents 25% of the data. Dots represent outliers. When there are no outliers, the end of the whisker designates minimum and maximum values. Symbols above each category denote significant differences between treatment groups (ns: $p > 0.05$; ****: $p < 0.0001$).

Figure 7: Goat grazing was effective at reducing the distance from ground to base of crown height on *Quercus agrifolia* Née. Photos taken by authors A. Grupenhoff and N. Molinari.

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Figures

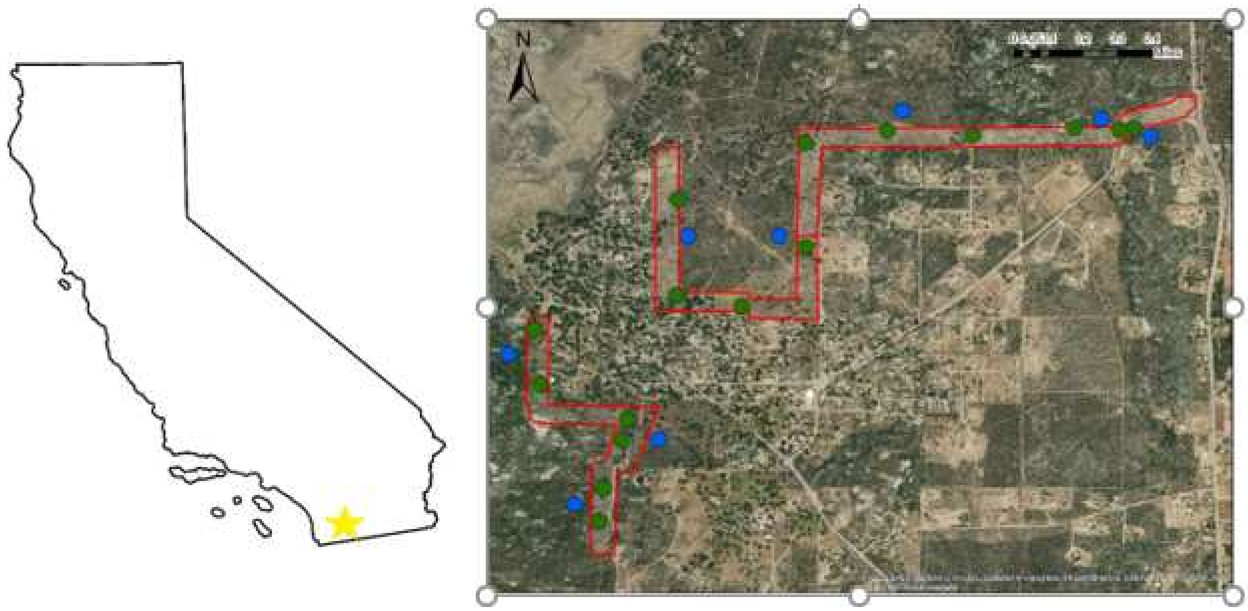

Figure 1

Location of field plots indicated by green (fuel break) and blue (control) dots in relation to the Lake Morena fuel break (red polygon).

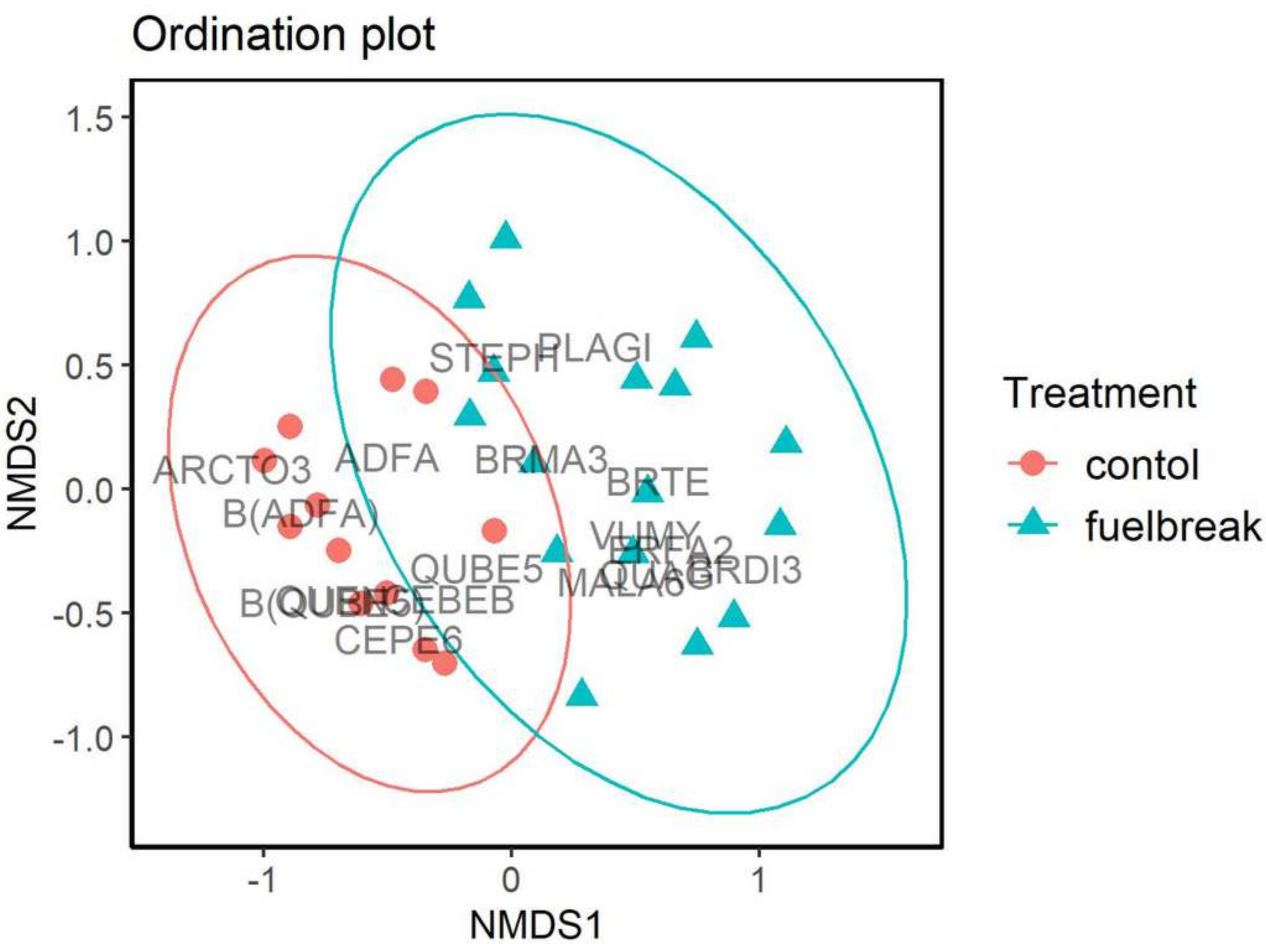

Figure 2

Non-metric multidimensional scaling plot (NMDS) of Bray-Curtis dissimilarity matrix of survey plots. Composition and species abundance differ among treatment plots inside the fuel created fuelbreak (blue triangles) and control plots outside the fuel break (pink circle). Species scores are shown in the same ordination space, with labeling priority given to more abundant and frequent species. All species codes correspond with the USDA Plants Database (USDA NRCS 2021). B(species) represents a dead branch of a live individual at the sampling point. Final stress of three-dimensional solution = 0.191 after 20 iterations.

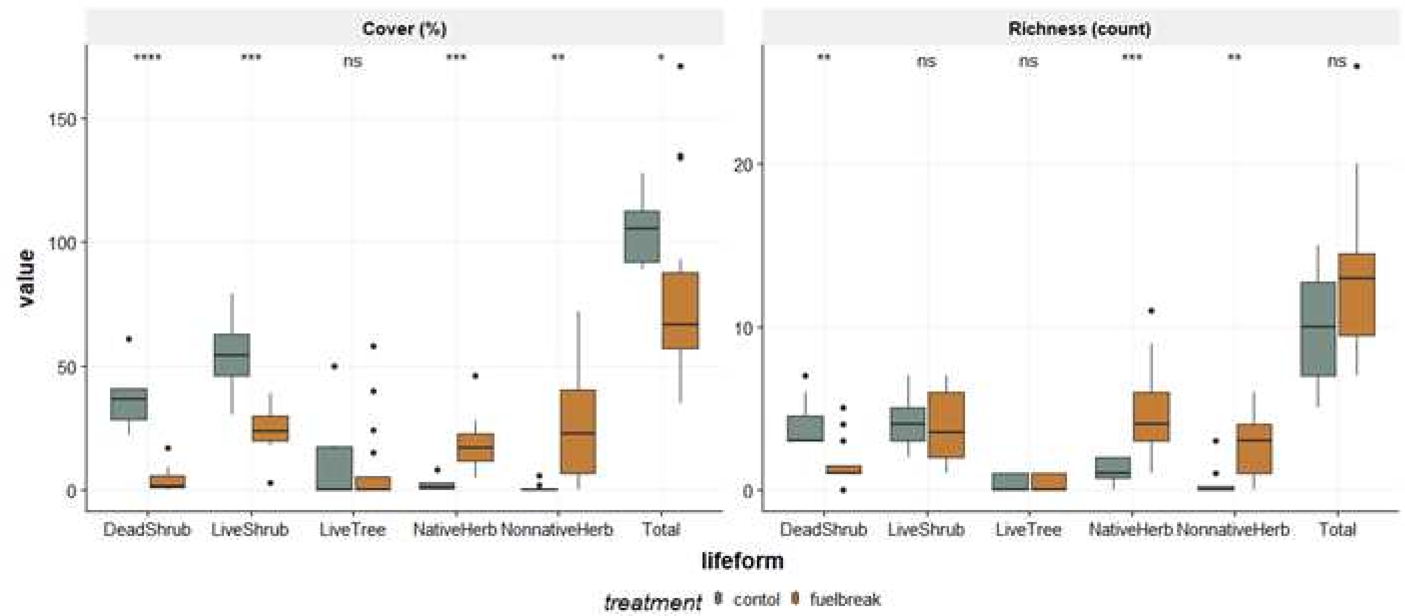

Figure 3

Fuel break creation, through pile burning and herbicide, resulted in changes in plant lifeform cover (left) and species richness (right). Species richness is the number of species counted along a 30-meter transect line. The bold horizontal lines are the medians, the boxes represent 50% of the data, and each whisker represents 25% of the data. Dots represent outliers. When there are no outliers, the end of the whisker designates minimum and maximum values. Symbols above each category denote significant differences between treatment groups (ns: $p > 0.05$; ****: $p < 0.0001$; ***: $p < 0.001$; **: $p < 0.01$).

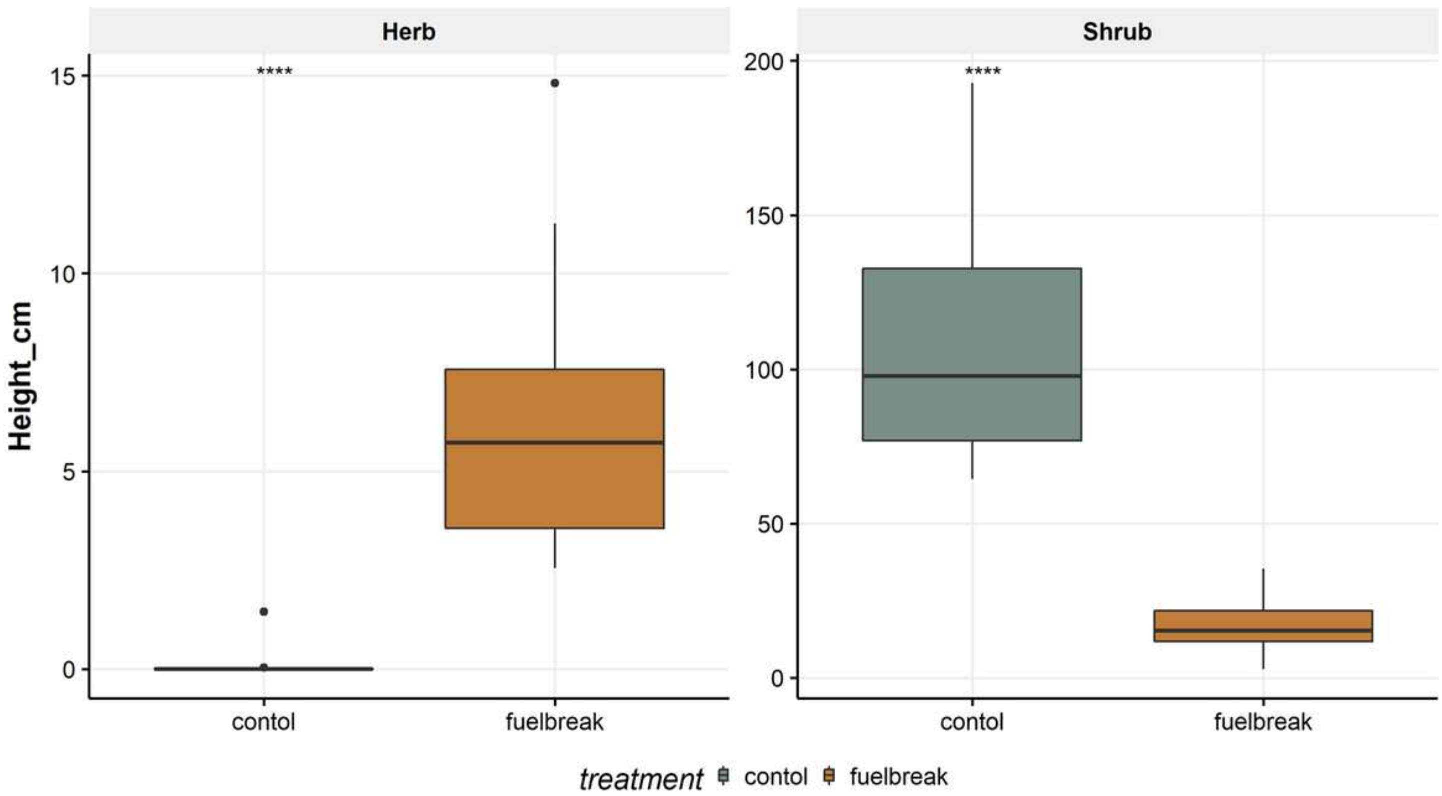

Figure 4

Fuel break creation, through pile burning and herbicide, resulted in changes to mean herbaceous height (left) and shrub height (right). The bold horizontal lines are the medians, the boxes represent 50% of the data, and each whisker represents 25% of the data. Dots represent outliers. When there are no outliers, the end of the whisker designates minimum and maximum values. Symbols above each category denote significant differences between treatment groups (****: $p < 0.0001$).

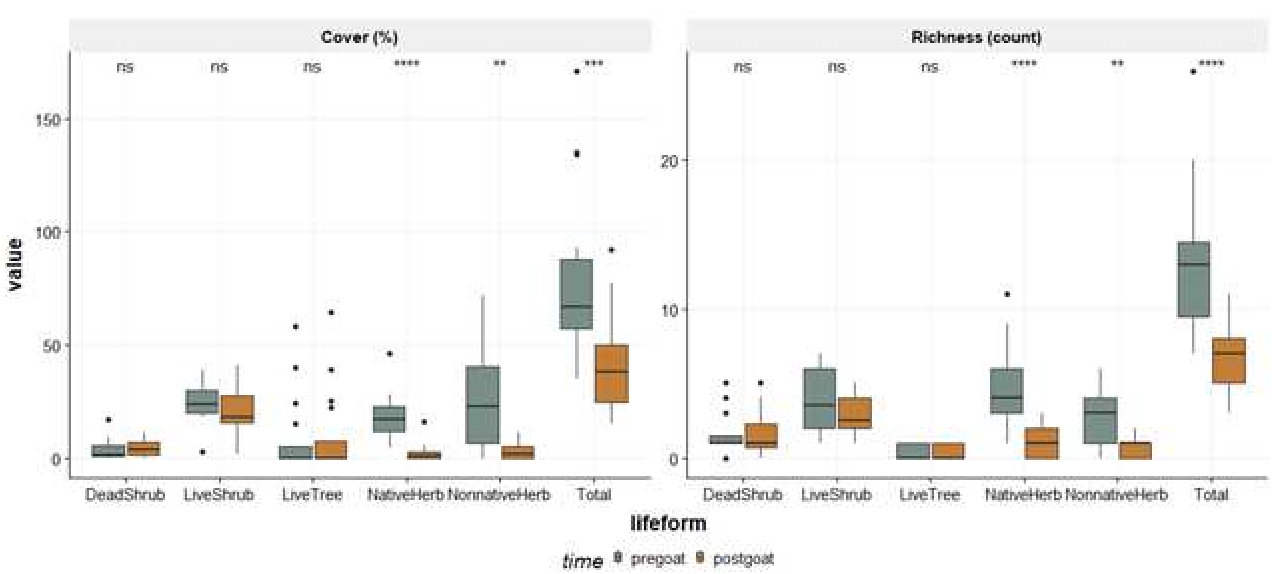

Figure 5

Goat grazing resulted in changes in plant lifeform cover (left) and species richness (right). Species richness is the number of species counted along a 30-meter transect line. The bold horizontal lines are the medians, the boxes represent 50% of the data, and each whisker represents 25% of the data. Dots represent outliers. When there are no outliers, the end of the whisker designates minimum and maximum values. Symbols above each category denote significant differences between treatment groups (ns: p > 0.05; ****: p < 0.0001; ***: p < 0.001; **: p < 0.01).

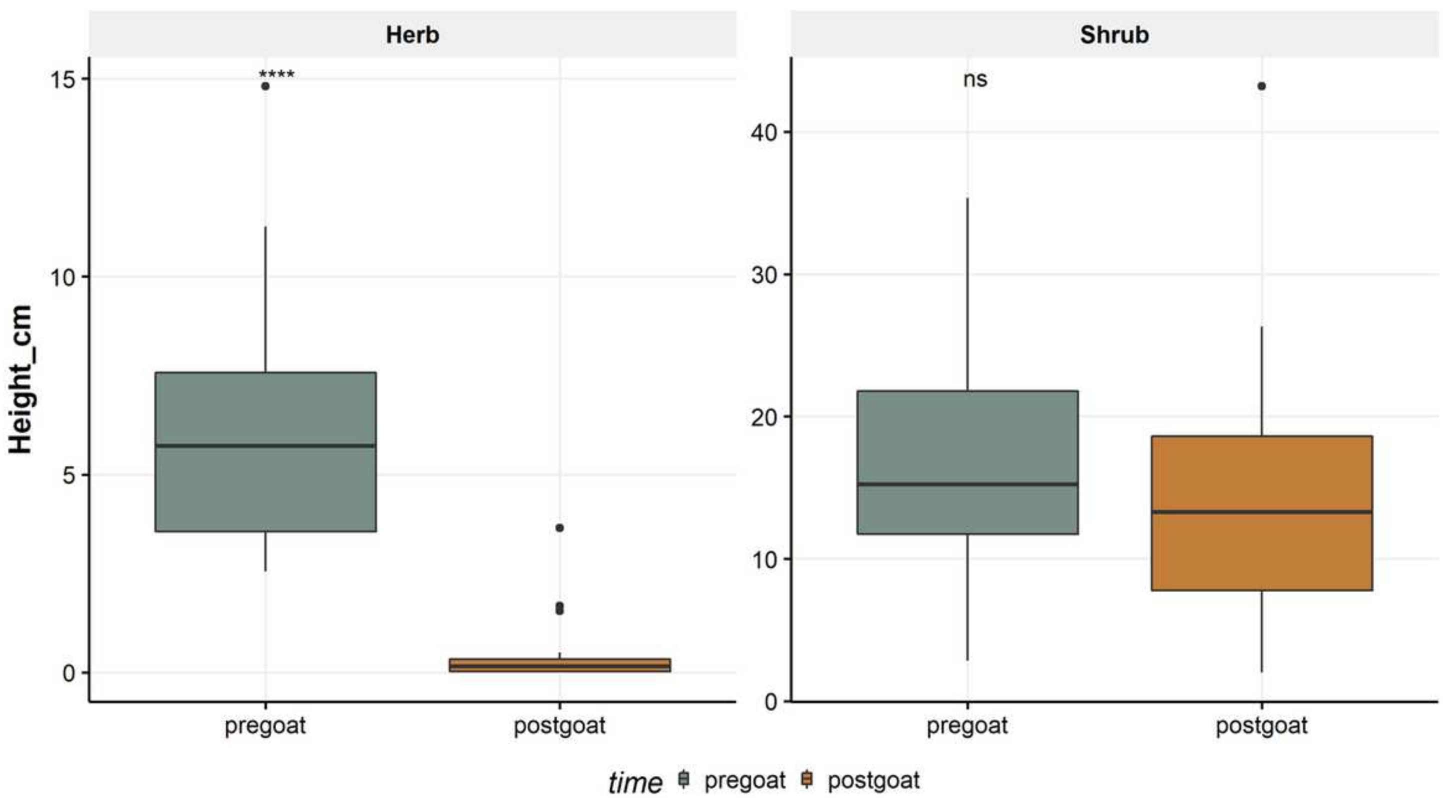

Figure 6

Goat grazing resulted in changes to mean herbaceous height (left) and shrub height (right). The bold horizontal lines are the medians, the boxes represent 50% of the data, and each whisker represents 25% of the data. Dots represent outliers. When there are no outliers, the end of the whisker designates minimum and maximum values. Symbols above each category denote significant differences between treatment groups (ns: p > 0.05; ****: p < 0.0001).

Figure 7

Goat grazing was effective at reducing the distance from ground to base of crown height on Quercus agrifolia Née. Photos taken by authors A. Grupenhoff and N. Molinari.