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Native Species Response to Goat Foraging in a Shrub-invaded California Coastal Grassland

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NATIVE SPECIES RESPONSE TO GOAT FORAGING IN A SHRUB-INVADED CALIFORNIA COASTAL GRASSLAND

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Native species response to goat foraging in a shrub-invaded California coastal grassland

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Abstract

California coastal grasslands have been frequent targets of preservation efforts due to the habitat they provide for native perennial bunchgrasses, such as purple needlegrass (*Stipa pulchra*), which have been nearly completely replaced by non-native annual grasses in much of the state. Once protected from ecological disturbance, however, these grasslands become subject to invasion by coyote brush (*Baccharis pilularis*), potentially resulting in permanent loss of habitat. Goats have successfully been used to control woody vegetation in other contexts but to date there have been no studies published on using goats to restore ecological disturbance in coyote brush-invaded coastal grasslands. Land managers at Fort Ord in the central coast region of California conducted a field study to measure the groundcover responses of six taxa to repeated bouts of goat foraging in dense stands of coyote brush in an invaded grassland. There was decisive evidence that repeated bouts of goat foraging coincided with a 24% net decrease of coyote brush groundcover and a 37% net increase of annual grass groundcover in foraged plots relative to control plots, but no clear evidence of this relationship for other taxa. These results indicate that goat foraging is effective at reducing coyote brush groundcover but its ability to directly facilitate corresponding increases in bunchgrass is uncertain. Foraging should continue in areas of rapidly invading coyote brush while future research should examine how the intensity, duration, and seasonality of foraging can be managed to favor native species.

Keywords: coastal grassland, coyote brush, goats, bunchgrass, grassland restoration, ecological disturbance

Introduction

California coastal grasslands (coastal grasslands) have better withstood the consequences of European settlement than their valley counterparts. Coastal grasslands have nearly twice the species richness as valley grasslands (Stromberg et al. 2001, Stohlgren et al. 1999) due in part to the presence of perennial bunchgrass species such as purple needlegrass, California oatgrass, and other native forbs (Ford and Hayes 2007, Munz and Keck 1959) that have been largely replaced by non-native annual grasses elsewhere in the state (Bartolome et al. 2007, Barbour 1996, Heady 1977, Burcham 1956). Compared to other, proximal plant communities such as coastal scrub and Monterey Pine, species richness in coastal grasslands is more than three times greater (Stromberg et al. 2001, Vogl et al. 1977). Coastal grasslands support 80 endemic plant species, 18 of which are special-status, and a handful of special-status wildlife species, including the Pt. Arena mountain "beaver", American badger, San Francisco garter snake, California red-legged frog, and several invertebrate species (Ford and Hayes 2007, Howell 1970). For these reasons, coastal grasslands are regarded as biodiversity hotspots with high conservation value (Stromberg et al. 2001).

Coastal grasslands were, perhaps, first distinguished from other types by Burcham (1957), who described them as having developed under much cooler temperatures and higher rainfall than valley grasslands (Ford and Hayes 2007). North to south, coastal grasslands occur patchily from the Oregon border to San Luis Obispo county and from west to east, coastal grasslands transition to valley grasslands as one moves from the coastal terraces and bald hills in the west toward the inland ridges and valley bottom in the east (Ford and Hayes 2007, Stromberg et al. 2001).

Coastal grasslands have been greatly altered from their original state by the consequences of European settlement beginning in the 17th century. The causes can be summarized as 1) the introduction of non-native annual grasses, 2) continuous overgrazing of livestock, 3) conversion of grassland habitat to agricultural use, and 4) fire suppression (Bartolome et al. 2007, Heady 1977). The result is that native perennial grasslands are an endangered ecosystem (Stromberg et al. 2001, Peters and Noss 1995), with remaining perennial grasslands rarely having more than 15% cover of native perennial grass species (Ford and Hayes 2007). California grasslands of all types face continuing threats from development—between 1984 and 2008 approximately 500,000 acres were converted to residential, commercial, or agricultural use (Cameron et al. 2014).

Due to the ecological, historical, and cultural value of coastal grasslands and the continued threats that they face, there has been sustained interest in their conservation and restoration (Barry et al. 2006, Bartolome et al. 2004, D'Antonio et al. 2002). Purple needlegrass (*Stipa pulchra*) has officially been designated the state grass of California. Purple needlegrass grasslands are considered sensitive plant communities by the California Department of Fish and Wildlife (2015). Today, much of the most intact coastal grassland is on protected lands.

Perennial bunchgrasses, the indicator species of coastal grasslands, were long thought to be the dominant species of climax grassland communities throughout their range (Heady 1977, Burcham 1957, Clements 1934). However, this paradigm has shifted. A critical reevaluation of the evidence suggests that the extent and species composition of grasslands encountered by the earliest European arrivals was the result of centuries or millennia of anthropogenic fire with a fire return interval of 2–10 years (Stromberg et al. 2001, Hamilton 1997, Greenlee and Langenheim 1990). This fact went largely unnoticed by European settlers, whose extensive use of domestic livestock functioned as a substitute for fire by maintaining a disturbance regime. Now it is generally recognized that in the absence of fire and grazing, coastal grasslands are vulnerable to invasion by native shrubs, namely coyote brush (*Baccharis pilularis*) (Zavaleta and Kettley 2006, McBride and Heady 1968).

Significant portions of coastal grassland are protected by Fort Ord National Monument (Fort Ord) in the southern Monterey Bay area. The Fort Ord Reuse Plan Environmental Impact Report identifies 4,240 acres of annual grassland and 475 acres of perennial grassland on Fort Ord (EMC Planning Group Inc and EDAW Inc 1997), which approximates the distinction between valley and coastal grasslands. Fort Ord has been managed as public lands by the Bureau of Land Management (BLM) since 1993. In the early 2000s BLM land managers familiar with the area noticed a steady invasion of Coyote brush into a coastal grassland in the southeastern portion of what is now Fort Ord, resulting in nearly 100% groundcover in some places (Fig. 1). Concerned that this invasion could permanently reduce remaining bunchgrass habitat, BLM land managers began developing conservation and restoration strategies.

The consensus of the literature on grazing for biodiversity in California is that results are highly varied and that further research should be conducted within the context of specific goals (Bartolome et al. 2014, Hopkinson and Bartolome 2009, D'Antonio et al. 2002). Some studies have reported on the effectiveness of goat foraging for controlling woody or invasive vegetation (Ingham 2008, Hart 2001, Thomsen et al. 1993) and one study has tangentially reported on the potential of goats to control coyote brush in the context of fuel load reduction (Tsiouvaras et al. 1989). However, there have been no studies published to date on the effectiveness of goat foraging to control coyote brush in the context of native grassland conservation and restoration.

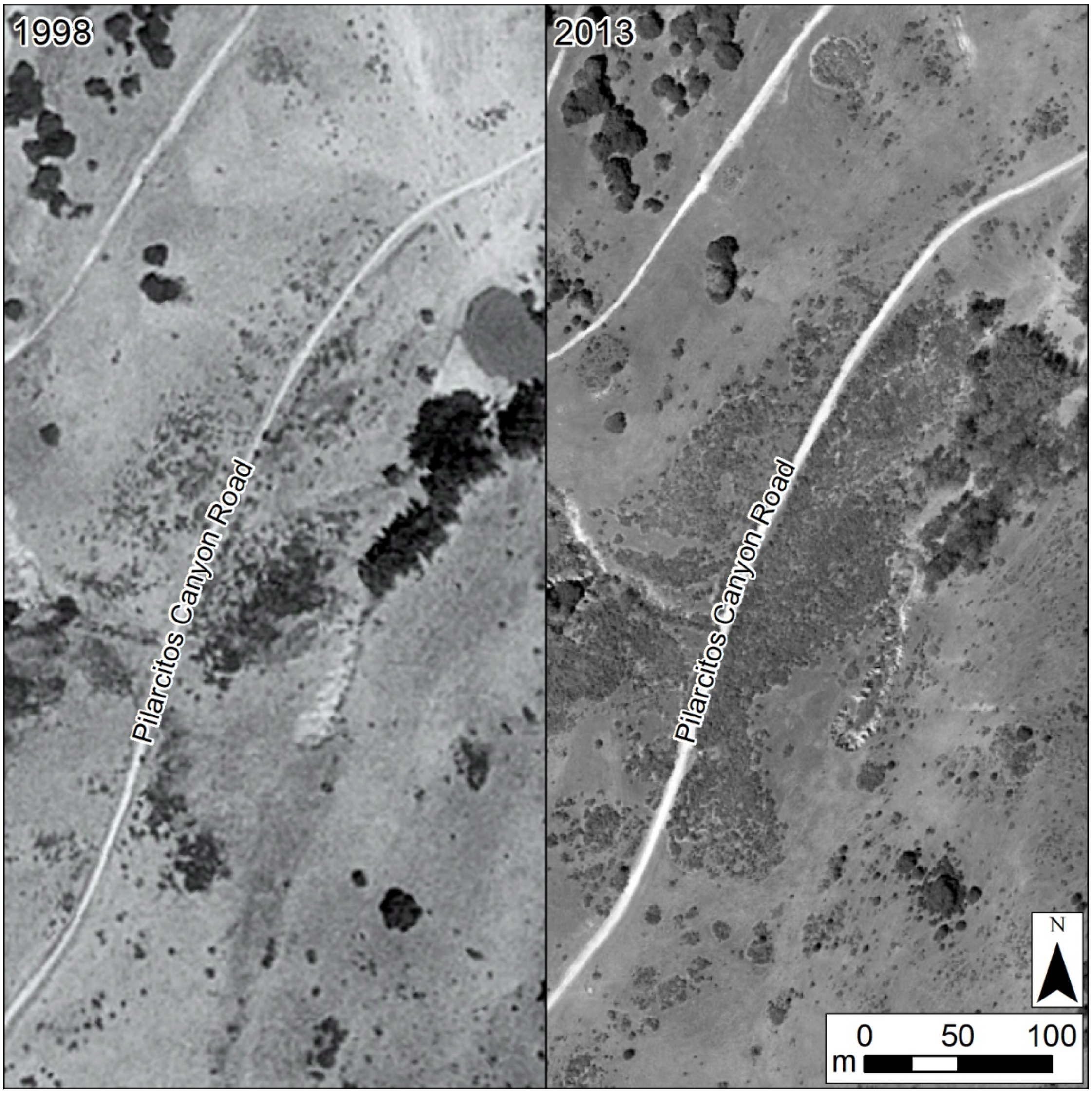

Figure 1: Time-series of aerial photos of a California coastal grassland in the Fort Ord National Monument (Fort Ord). Aerial photos were taken in 1998 (left) and 2013 (right) of a grassland located in Pilarcitos Canyon in the south-central portion of Fort Ord. The area in the center of the frame filled in to form a dense stand of coyote brush with nearly 100% canopy cover and no understory in some areas. Equally concerning is the southeastern hillside where scattered coyote brush recruits appear to be establishing and filling in.

In late December 2013, BLM land managers began using controlled goat foraging to reduce coyote brush groundcover in heavily invaded portions of coastal grassland. In order to quantify the response, a collaborative field study was established between BLM staff and

California State University Monterey Bay faculty and students. The study was designed to address the following research questions:

1. Can goats foraging be used to effectively control and reduce coyote brush groundcover?
2. Does goat foraging facilitate the recovery of native bunchgrass populations?

Methods

Study Area

FONM is an approximately 15,000-acre protected area located four miles southeast of the Monterey Bay near the Cities of Marina, Seaside, and Salinas in Monterey County, California (Fig. 2). The topography consists of gently rolling vegetated dunes in the west and moderate to steeply sloped canyons in the east, ranging in elevation from just above sea level to over 200 meters above sea level. Vegetative communities include maritime chaparral, coast live oak woodland, annual grassland, valley needlegrass grassland, coastal sage scrub, vernal pools, and freshwater marsh. The area has a Mediterranean climate, typified by 36 cm (14 in.) of rainfall that falls between the months of November and April. Land use history of the site includes ranching and military training.

The study area comprised two sites situated within south to north running canyons: Pilarcitos Canyon in the south-central portion of Fort Ord and Barloy Canyon immediately to the west (Fig. 2). At the onset of the study, the sites consisted of dense patches of coyote brush situated along transition zones between hillsides and valley bottoms.

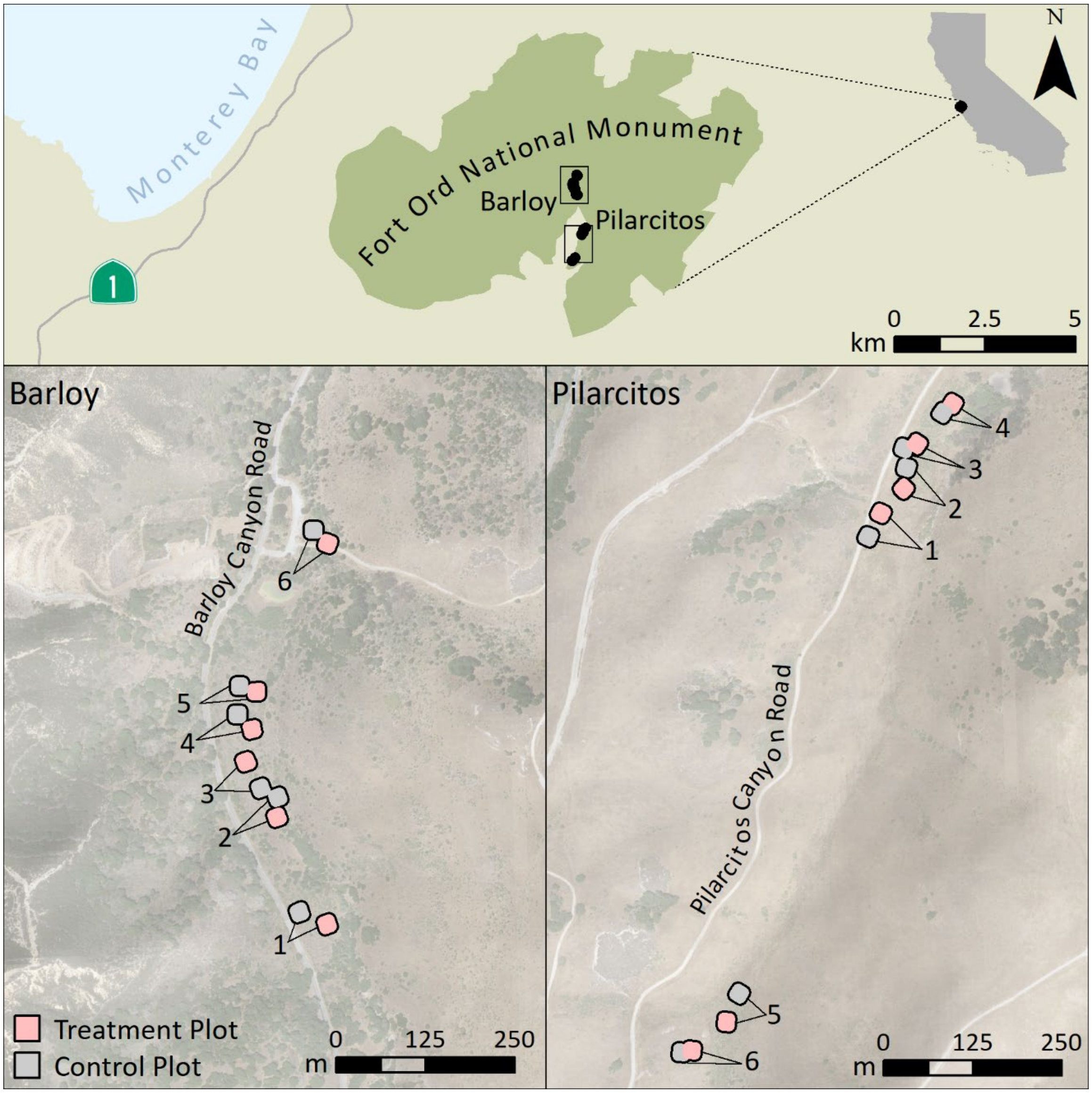

Figure 2: Study Area. Fort Ord is a 15,000-acre protected area located a few miles inland from the Monterey Bay near the city of Marina, California. 24 experimental plots were established in Pilarcitos and Barloy Canyons, areas with relatively dense populations of native perennial grasses threatened by expanding patches of Coyote brush. Plot pairs comprised an open 10-by10-meter foraged plot and an exclusion-fenced 12-by-12-meter control plot, each with two parallel 10-meter permanent transects. Species occurrence data were collected along the transects using the point-intercept method at 25-cm intervals each spring.

Experimental Design and Data Collection

We collected groundcover data within patches of grassland dominated by coyote brush over a period of six years. In late December 2013, a team of BLM staff , volunteers and Suzy Worcester established 6 pairs of 10-by-10-meter treatment and control plots with each pair randomly placed within an approximately 2.5-acre area of dense coyote brush in Pilarcitos Canyon. The following year 6 additional pairs of plots were established in neighboring Barloy Canyon resulting in 24 plots total. Within each plot, the team installed two randomly-placed, permanent 10-meter south-to-north transect lines within the plots using t-posts to define the beginning and end points of each transect. The transects were separated by a distance of at least one meter. To protect the control plots from goat foraging, the team used electric net fencing during the first year of grazing and installed permanent fencing the following year. Both types of fencing were setup to provide a one-meter buffer around the control plots to provide extra protection from foraging.

Vegetative groundcover along transects was collected using the point-intercept method. Vertical space was divided into an understory layer (0 to 40 cm) and a shrub layer (above 40 cm). The team held a 1.5-meter wooden dowel in a vertical position at each point along the transects to represent the intercepting point. An interception was defined as physical contact between the vertically positioned dowel and a plant. Data were collected at 25-cm intervals. Intercepted plants were recorded to species level when possible; when species-level identification was not possible due to plant immaturity the team recorded the category of the plant (i.e. “annual grass”, “other native herbaceous”, etc.). Parts of mature shrubs that intercepted the dowel in the understory layer but primarily occupied the shrub layer were recorded as intercepted in the shrub layer; immature shrubs that intercepted the point in the understory layer and were entirely under 40 cm tall were recorded as intercepted in the understory layer. In contrast, tall forbs and grasses that intercepted the point in the shrub layer were recorded in the understory layer such that forbs and grasses plants were never recorded as being intercepted in the shrub layer.

Goat foraging was instituted as a series of annual targeted grazing episodes (Table 1). We refer to each episode and its associated data as a “Bout”; pre-foraging data are referred to as Bout 0. Bout 1 foraging commenced on December 31, 2013, in Pilarcitos Canyon, and in November of the following year in Barloy Canyon. Subsequent bouts of foraging were conducted annually from November through April. Foraging intensity and duration varied over the course of the study; the goats were managed to target dense stands of coyote brush more intensely during the first two bouts of foraging but were allowed to forage more freely during subsequent bouts. Intense bouts of foraging had 600 to 1400 goats in approximately 2.5 acre electrified pens for approximately 24 hours surrounding each pair of grazed and control plots. Lower intensity grazing had a similar number of goats foraging over a larger area.

Bout 0 data were collected in winter just before foraging commenced. Subsequent bouts of data were collected at the peak of spring. Due to this difference in seasonality, Bout 0 data were not analyzed except for coyote brush, whose groundcover does not fluctuate annually to the same degree as understory taxa.

During Bout 2 data collection, the team defined a coyote brush intercept differently: an intercept was any point at which any part of a coyote brush plant was within 10 cm of the vertically positioned dowel. This rule was introduced during special bouts of winter data collection (used to report preliminary findings) in anticipation of spring growth and was inadvertently carried forward through the second bout of data collection the following spring.

This rule was applied only during Bout 2 data collection and due to this inconsistency Bout 2 groundcover data for coyote brush were not used in the analysis.

We collected groundcover data from a total of 24 plots. However, data were not collected from every plot every year (Table 1). The dataset comprises seven bouts of data collection beginning with Bout 0 for coyote brush and Bout 1 for all other taxa. Species level data were aggregated into six groundcover categories, consisting of coyote brush, bunchgrass, other native herbaceous, annual grass, other non-native, and invasive (Appendix A).

Data Analysis

We applied an information-theoretic approach to the analysis of binned transect data. Because data were collected at 25-cm intervals they could not be considered spatially independent, however, we did not want to discard useful information by averaging all data collected within a plot into single datum. Therefore, we averaged adjacent data points into bins. The appropriate bin width, i.e. how many adjacent transect points were averaged into each bin, was identified by examining the spatial autocorrelation of transects at varying lag distances, or distances between points. We quantified spatial autocorrelation using Moran's I, a measure of the spatial autocorrelation. We ranked the Moran's I value of each transect-bout at each lag-distance against a distribution of Moran's I values of randomly resampled transect-bouts (n = 500) at corresponding lag-distances. The appropriate bin width was identified as the distance at which the median observed Moran's I values became generally similar to the resampled Moran's I values. This bin width also defined the minimum acceptable distance between transects within plots; data from transects that were within this distance from another transect would not be used.

We developed a suite of random-intercept generalized linear mixed effects models to examine the relationship between goat foraging and groundcover. Using the notation of Zuur (2016), the full model equation was:

$$Y_{ijk} \sim \mathrm{B}(n, \pi_{ijk})$$

$$\mathrm{logit}(\pi_{ijk}) = \beta_{0i} + \beta_T T_j + \beta_B B_k + \beta_X B_k T_j \qquad \textbf{[1]}$$

$$\beta_{0i} \sim \mathrm{N}(0, \sigma^2)$$

where Y_{ijk} is absolute groundcover of a plant group at location i, under treatment j, after bout k, which is distributed binomially with n points per bin and probability $\pi_{i,j,k}$; β_T, β_B, β_X are fixed effect parameters for a treatment, i.e. foraged vs. control, effect, T, bout effect, B, and treatment-bout interaction effect, X; and β_{0i} is the group-level random intercept, which is distributed normally with variance σ^2.

We developed a total of six models comprising every functionally distinct subset of the fixed effects of the full model, including a null model with no fixed effects (Table 2). We conducted a balanced model comparison for each taxon using Akaike's Information Criterion (AIC) as described by Burnham and Anderson (2004). We measured the relative importance (RI) of each parameter by summing the AIC-weights of all models containing that parameter; evidence for RI was expressed in log evidence ratios (LER). We described the strength of evidence as follows: LERs between 0 and 0.5 were "equivocal", between 0.5 and 1 were "substantial", between 1 and 2 were "strong", and over 2 was "decisive".

We considered the treatment-bout interaction effect to be of primary interest. We interpreted evidence for this effect as evidence that groundcover changed due to repeated bouts of goat foraging. We considered the non-interactive treatment and bout effects (T and B) to be of secondary interest. Evidence for an effect associated with variable T alone was not interpreted as evidence of the effect of foraging, but rather that groundcover of would-be foraged areas was different from that of would-be control areas at the outset of the study i.e. at bout $B = 0$. Evidence for an effect associated with variable B alone was interpreted as evidence that groundcover changed over course of the study but not in a way that was necessarily associated with foraging.

We reported net changes in groundcover in cases where there was substantial or greater evidence for a treatment-bout interaction effect. Net change in groundcover was defined as the total groundcover change in foraged areas less that of control areas. For example, if a taxon's groundcover decreased by 10% in foraged areas between Bout 0 and 6, increased by 10% in control areas between Bout 0 and 6, and evidence for a treatment-bout interaction effect was at least substantial, then we would report a net foraging-associated decrease in groundcover of 20% for that taxon.

We used the R programming language, version 3.6.1, to conduct all analyses. We used the "ape" package to calculate Moran's I and the "blme" package to fit models with maximum a posteriori parameter estimation. We applied normally distributed Bayesian priors to the fixed effects (with a standard deviation of 0 for the intercept and 2.5 for all other parameters) to encourage model convergence.

Results

Visual interpretation of the correlograms suggests that spatial autocorrelation between transect points is indistinguishable from ambient levels at distances of 2.5 meters or greater for all taxa except invasive (Fig. 3). Transect data were therefore binned at 2.5 meters. Invasive data were severely zero-inflated and were not considered in this interpretation. Data from transects less than 2.5 meters from another transect were discarded, resulting in 92 bins in Pilarcitos Canyon and 80 bins in Barloy Canyon for a total of 172 bins.

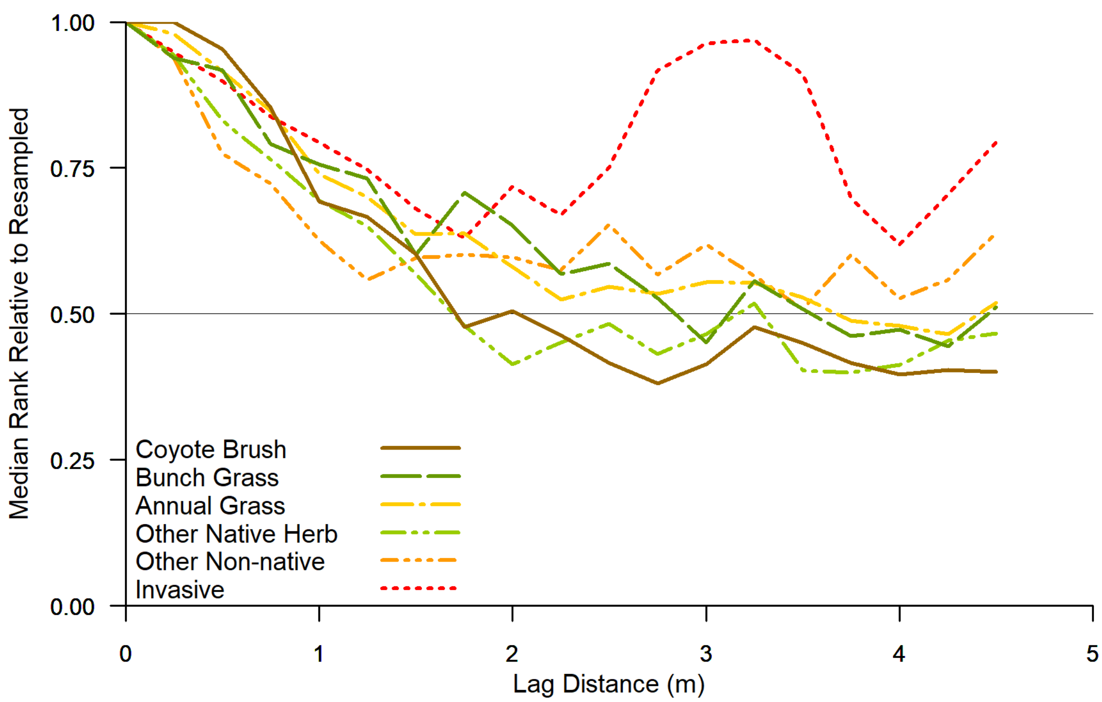

Figure 3: Spatial autocorrelation along transects relative to randomly resampled data. We identified the distance along transects at which points were not correlated with one another by comparing the correlation of observed data to distributions of randomly resample data. As lag distance increases, spatial autocorrelation between transect points decreases. Spatial autocorrelation between points becomes indistinguishable from randomness when the measured correlation of the median transect approximates that of randomly resampled data. Visual interpretation of the plot suggests that this occurs at lag distances greater than 2 meters for all categories, with the possible exception of invasive. The elevated correlation of invasive data may be due to a preponderance of zeros. Based on this analysis we binned transect data at two-and-a-half meters.

There was decisive evidence that a treatment-bout effect was associated with a net decrease in coyote brush groundcover of 24% (LER 6.0) and a net increase in annual grass groundcover of 37% (LER 5.1) in foraged plots relative to control plots (Tables 3 and 4, Fig. 4). There was strong evidence against an association between a treatment-bout effect and change in invasive groundcover (LER -1.0), but further interpretation of this result is of little consequence due to a preponderance of zeros in the dataset. Though there was substantial evidence for change in bunchgrass groundcover (LER 0.7) and decisive evidence for change in other non-native groundcover (LER >10) associated with a bout effect, there was no clear evidence for a treatment-bout interaction effect for either bunchgrasses or other non-native groundcover. There was no clear evidence of any change in other native herbaceous groundcover over the course of the study.

A total of 100 species were identified during the transect surveys, comprising 1 coyote brush, 6 bunchgrass, 11 annual grass, 47 other native herbaceous, 31 other non-native, and 4 invasive species (Appendix A).

Discussion

We can answer research question 1 (Can goat foraging be used to effectively control and reduce coyote brush groundcover?) with a decisive "yes". Furthermore, by substituting model-weighted parameter estimates for coyote brush (Table 3) into a logistic function we can predict how many repeated bouts of foraging it would take to achieve an arbitrarily selected groundcover target. For example, the model predicts that it would take 7 bouts of foraging to achieve a groundcover target of less than 25% for this study area. Visual interpretation of Figure 3 suggests that this is a reasonable prediction, though overreliance on this prediction should be avoided given between-bout variability.

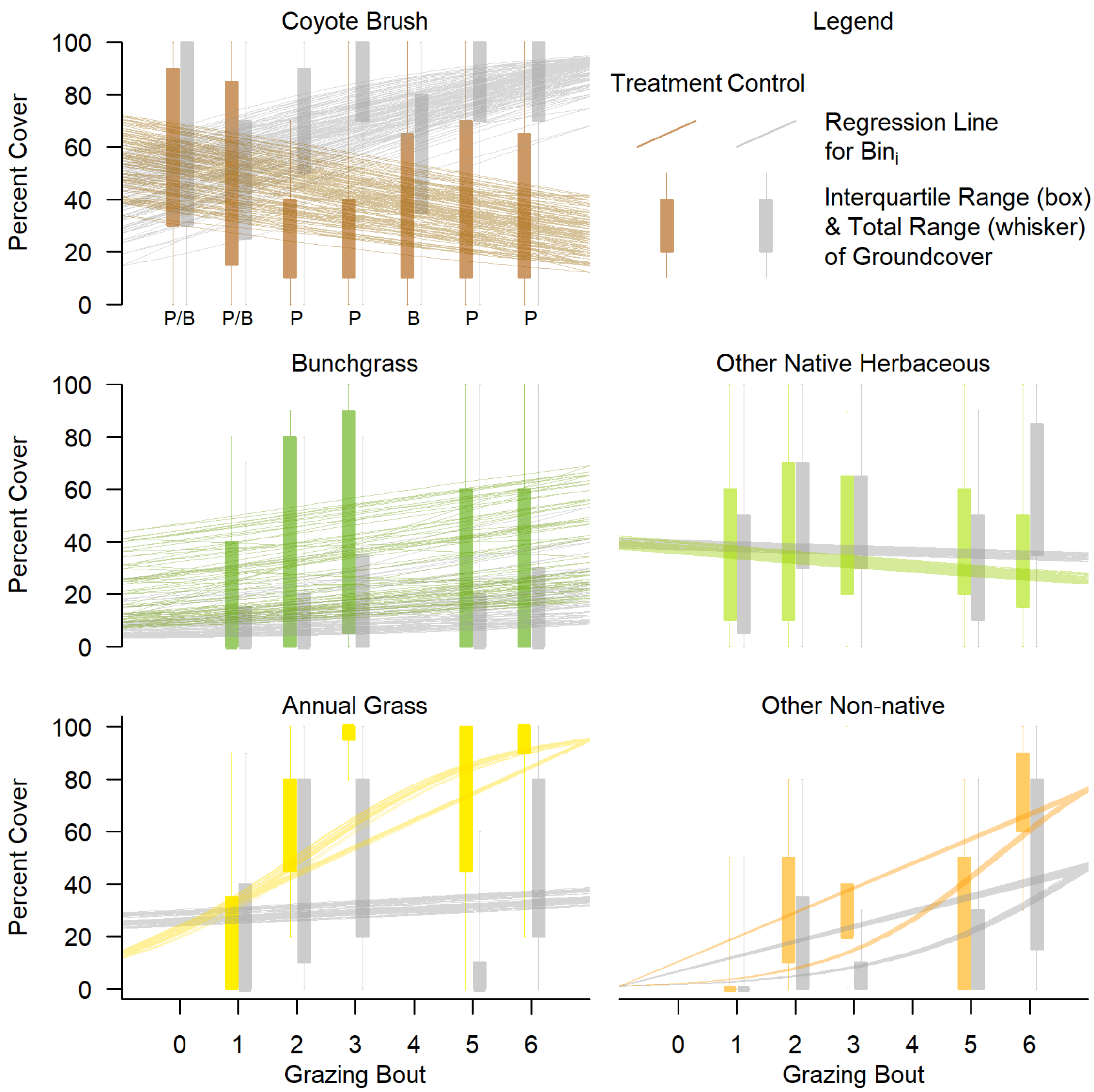

Figure 4: Summary of groundcover data with fitted regression lines. Bout 0 represents baseline data collected before goat foraging commenced. Colored and gray boxes and lines represent treatment and control plots respectively. Groundcover data are represented as box and whisker plots where boxes encompass the 25th through 75th percentile values and whiskers extend through the total range of values. Regression lines were fitted for each bin using evidence-weighted averages of parameter estimates. Coyote brush was the only category with data collected from both canyons, though data were not collected in both canyons every bout; which canyons were surveyed for a given bout is indicated by "P" for Pilarcitos, "B" for Barloy, or "P/B" for both. Boxes and regression lines for Invasive were all 0 and are not shown.

For research question 2 (Does goat foraging facilitate the recovery of native bunchgrass populations?), we must give a more circumspect response. There was precisely zero evidence for or against a direct treatment-bout effect on bunchgrass groundcover (Table 3). This lack of evidence may be due in part to the fact that bunchgrass groundcover was higher in treatment plots than control plots at the outset of the study and remained so throughout the study, potentially masking any increases in treatment plots due to foraging. This unfortunate circumstance may have been further exacerbated by the absence of Bout 0 data collected at the peak of spring, which would have allowed a comparable direct measurement of the pre-foraging bunchgrass groundcover in treatment and control plots. These gaps may eventually be compensated for with additional bouts of springtime data collection, especially in Barloy Canyon. Currently, only Bout 1 data were collected in springtime in Barloy Canyon; a subsequent bout of springtime data collected in Barloy Canyon would allow the same time-series analysis conducted for all taxa in Pilarcitos Canyon to be conducted for all taxa in Barloy Canyon.

Based on these data, it is easier to make the argument that goat foraging is indirectly supportive of bunchgrass populations since a) coyote brush invasion is a local threat to bunchgrass populations, and b) goat foraging is effective at controlling coyote brush groundcover but c) not demonstrably harmful to existing bunchgrass populations. Since bunchgrass groundcover was higher in treatment plots at the outset of the study we would have been more likely to detect a negative treatment-bout effect if one existed. The lack of evidence for such an effect is reassuring.

There is no evidence for a statistically significant increase in invasive groundcover, though fluctuations between 0% and 5% groundcover were observed. Given that the goat herd is relocated to foraging grounds throughout the state on an annual basis there is reasonable concern that the herd may introduce or exacerbate invasive weed populations in Fort Ord. Anecdotally, there have been reports of an association with yellow starthistle. Though there is no evidence for goats bringing invasive weeds to Fort Ord and though goats have been shown to be effective at controlling yellow starthistle (Thomsen et al. 1993), land managers must be sensitive to the perception of such an association. Currently, BLM land managers require incoming goats to feed exclusively on alfalfa for four days prior to arrival on Fort Ord to remove invasive seeds from their digestive tract. Another strategy for managing this perception—maintaining an on-site herd year-round—is discussed below.

Less reassuring, but not surprising, is the decisive evidence for a positive treatment-bout effect for annual grass. This result affirms the consensus of the literature, which is that annual grasses successfully outcompete native vegetation in becoming established in bare or disturbed soil. (Barry et al. 2006, Dyer et al. 1996, Stromberg and Kephart 1996). Their ubiquitous presence throughout the state gives indication of this ability. This is not to say that native species are entirely replaced in areas where annual grasses dominate (Keeler-Wolf et al. 2007). Indeed, 54 of the 100 species identified during the survey were native, a testament to the biodiversity of coastal grasslands. Nevertheless, land managers interested in favoring the response of native species may need to investigate tuning the intensity, duration, and seasonality of foraging as well as more direct interventions such as mulching and reseeding, as discussed below.

It is worth discussing between-bout variation in groundcover and its potential sources. Between-bout changes in groundcover were not unidirectional. For example, coyote brush groundcover in treatment plots declined 29% between Bouts 0 and 2 but then rose 18% by Bout

5. Proposed sources for such variation are 1) changes in treatment application, 2) observer bias, and 3) fluctuations in annual precipitation.

Treatment application evolved over the course of the study as land managers balanced the needs of the goat herd, changing landscape, and long-term research project in real-time. These changes in intensity, duration, and available forage probably explains much of the between-bout variation in groundcover. While this variation makes it difficult to predict the number of bouts necessary to reach a defined target, it does not preclude our ability to make binary, yes or no statements about the effectiveness of goat foraging.

Observer bias may explain some variation as well since data collectors changed year to year and data collectors' identification ability ranged from expert to novice. The abilities of even the most accomplished team members improved over time. Involvement of students and volunteers in data collection provided invaluable opportunities for citizen science, community outreach, and education but probably introduced some variation into the dataset. This variation may be most pronounced in bunchgrass observations, where early or late season bunchgrasses and bunchgrass seedlings could be misidentified as annual grasses.

Fluctuation in annual precipitation is also a likely driver of between-bout variation. The unintuitive groundcover increase in control plots of both coyote brush and two understory taxa (other native herbaceous and other non-native, Appendix B) is likely due to increased precipitation. While one would generally expect understory groundcover to decline with increases in coyote brush, Bouts 5 and 6 happened to be wet years ending the driest period in recent California history, indicating that sunlight is not the only limiting factor in control plots but that soil moisture also plays an important role in groundcover. The especially large groundcover increases in Bout 6 (2019) may be a result of greater seed production in 2018, the first non-drought year of the study.

Future research should both continue and expand. Additional bouts of foraging may compensate for the variation present in the current dataset. The benefits of citizen science should be considered and balanced against the need for precision when selecting data collectors. Foraging intensity, duration, and seasonality should be held as constant as possible for the remainder of the study to allow as accurate predictions as possible about the long-term effects of foraging. As additional bouts of data are collected researchers must decide how to incorporate these data into the current dataset. Foraging and data collection commenced a year earlier in Pilarcitos Canyon than in Barloy Canyon. This introduces the confounding variable of precipitation as it fluctuates between calendar years. This issue was avoided in the current analysis because Barloy Canyon data were only used for coyote brush groundcover, which were not expected to be unduly sensitive to fluctuations in precipitation. The most straightforward approach to accounting for fluctuations in precipitation would be to add either calendar year or precipitation as a variable to the model.

In addition to future bouts of data, researchers may consider analyzing existing data that were not used in the analysis. In addition to the repeated measurements of permanent transects that were used in this analysis, researchers collected groundcover from a third, randomly placed transect in each plot each year. While this data structure does not lend itself to a repeated-measures analysis, it does contain valuable groundcover information waiting to be analyzed.

Research should also be expanded to attempt to relate specific levels of foraging intensity, duration, and seasonality to the groundcover responses of bunchgrasses and other native herbaceous species relative to annual grasses and other non-native species. This would be an ambitious undertaking but is not beyond the opportunities afforded by Fort Ord National Monument and its foraging as a grassland management tool program.

Implications

Goat foraging is an effective tool for reducing coyote brush groundcover. Over the course of the study coyote brush groundcover in foraged plots decreased from 55% to 40% in Pilarcitos Canyon and from 63% to 41% in Barloy Canyon while groundcover of control plots increased from 62% to 79% in Pilarcitos Canyon and decreased from 62% to 55% in Barloy Canyon.

There was a positive trend in bunchgrass groundcover over the course of the study, particularly in foraged plots. Bunchgrass groundcover increased from 18% to 35% in foraged plots and from 10% to 19% in control plots. While the statistical analysis did not provide substantial evidence linking this relative increase directly to goat foraging, goat foraging was compatible with increasing bunchgrass populations.

Annual grasses increased greatly, increasing from 21% to 90% in foraged plots and from 21% to 53% in control plots. These results were expected given annual grasses ability to colonize bare areas and the species composition of the surrounding grasslands.

Other native herbaceous remained flat in foraged plots, going from 38% to 37%, and increased in control plots from 31% to 55%. This increase in control plots is unexpected given that most native grassland forbs are not shade tolerant, but soil moisture may have been a limiting factor prior to high precipitation in 2018 and 2019.

Other non-native increased from 4% to 76% in foraged plots and from 5% to 49% in control plots. As with annual grasses these results are not surprising: non-native plants are here because they are good at becoming established in new areas. Specific species driving a sudden increase in Bout 6 were four seeded vetch (*Vicia tetrasperma*), crane's bill geranium (*Geranium* *molle*), and hairy vetch (*Vicia hirsuta*). A complete break down of other non-native occurrences by bout is given in Appendix B.

Ground cover of invasive species, comprising Italian thistle *(Carduus pycnocephalus),* Bull thistle *(Cirsium vulgare),* Poison hemlock *(Conium maculatum),* and Harding grass *(Phalaris aquatica)*, fluctuated between 0% and 5% for both foraged and control plots over the course of the study. Occurrences were too few to make reliable statistical inferences but we observed no concerning increase in invasive groundcover.

Goat foraging should be focused on areas where coyote brush is rapidly filling in rather than on dense stands with hard edges. That land managers have already implemented this strategy within the study area makes it no less an important implication of this work and one that is supported by the data. Dense stands of coyote brush are likely to be old enough that few viable bunchgrass seeds remain in the underlying seed bank. As canopy is opened in these dense stands the bare or litter-covered ground favors recruitment of annual grasses and other non-natives. Focusing on rapidly filling areas will prevent these dense coyote brush stands from forming, thereby protecting existing bunchgrass populations. When targeted foraging of dense stands does occur, it may be possible to ameliorate the relatively high recruitment of annual grasses and other non-native species by mulching the resulting areas of bare or almost bare soil and seeding with seeds of bunchgrasses and other native species. This, of course, would obscure measurement of a treatment-bout effect if it were applied to treatment plots of an active study.

Finally, there are two reasons to consider maintaining a year-round on-site herd if financial and land resources allow. Foraging systems are complex and tuning them for native species recruitment requires subtle changes in intensity, duration, and seasonality. Maintaining a year-round herd will allow the degree of control necessary to optimize foraging for specific land management objectives which must otherwise be balanced against other uses of the herd, such as off-site fuel load reduction. Maintaining an on-site herd would also prevent the transport and introduction, real or apparent, of invasive and non-native seeds and species into protected grasslands.

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Tables

Table 1. Timeline of foraging and surveying bouts for Pilarcitos and Barloy Canyons. Bout 0 represents baseline data collected before foraging commenced. Bout 1 foraging and Bout 0 surveying were conducted concurrently such that later plots were surveyed as goats foraged in earlier, already surveyed plots.

<table>
<tr><th></th><th></th><th colspan="2">Pilarcitos</th><th colspan="2">Barloy</th></tr>
<tr><th></th><th></th><th>Forage</th><th>Survey</th><th>Forage</th><th>Survey</th></tr>
<tr><td>2013</td><td>Dec</td><td rowspan="5">Bout 1</td><td rowspan="3">Bout 0</td><td></td><td></td></tr>
<tr><td rowspan="7">2014</td><td>Jan</td><td></td><td></td></tr>
<tr><td>Feb</td><td></td><td></td></tr>
<tr><td>Mar</td><td></td><td></td><td></td></tr>
<tr><td>Apr</td><td rowspan="2">Bout 1</td><td></td><td></td></tr>
<tr><td>May…</td><td></td><td></td><td></td></tr>
<tr><td>Nov</td><td rowspan="6">Bout 2</td><td></td><td rowspan="6">Bout 1</td><td rowspan="2">Bout 0</td></tr>
<tr><td>Dec</td><td></td></tr>
<tr><td rowspan="7">2015</td><td>Jan</td><td></td><td></td></tr>
<tr><td>Feb</td><td></td><td></td></tr>
<tr><td>Mar</td><td></td><td></td></tr>
<tr><td>Apr</td><td rowspan="2">Bout 2</td><td rowspan="2">Bout 1</td></tr>
<tr><td>May…</td><td></td><td></td></tr>
<tr><td>Nov</td><td rowspan="6">Bout 3</td><td></td><td rowspan="6">Bout 2</td><td></td></tr>
<tr><td>Dec</td><td></td><td></td></tr>
<tr><td rowspan="7">2016</td><td>Jan</td><td></td><td></td></tr>
<tr><td>Feb</td><td></td><td></td></tr>
<tr><td>Mar</td><td></td><td></td></tr>
<tr><td>Apr</td><td></td><td></td></tr>
<tr><td>May…</td><td></td><td>Bout 3</td><td></td><td></td></tr>
<tr><td>Nov</td><td rowspan="6">Bout 4</td><td></td><td rowspan="6">Bout 3</td><td></td></tr>
<tr><td>Dec</td><td></td><td></td></tr>
<tr><td rowspan="6">2017</td><td>Jan</td><td></td><td></td></tr>
<tr><td>Feb</td><td></td><td></td></tr>
<tr><td>Mar</td><td></td><td></td></tr>
<tr><td>Apr</td><td></td><td></td></tr>
<tr><td>Nov</td><td rowspan="6">Bout 5</td><td></td><td rowspan="6">Bout 4</td><td></td></tr>
<tr><td>Dec</td><td></td><td></td></tr>
<tr><td rowspan="9">2018</td><td>Jan</td><td></td><td></td></tr>
<tr><td>Feb</td><td></td><td></td></tr>
<tr><td>Mar</td><td></td><td></td></tr>
<tr><td>Apr</td><td></td><td></td></tr>
<tr><td>May</td><td></td><td rowspan="2">Bout 5</td><td></td><td></td></tr>
<tr><td>June…</td><td></td><td></td><td></td></tr>
<tr><td>Oct</td><td></td><td></td><td></td><td>Bout 4</td></tr>
<tr><td>Nov</td><td rowspan="4">Bout 6</td><td></td><td rowspan="4">Bout 5</td><td></td></tr>
<tr><td>Dec</td><td></td><td></td></tr>
<tr><td rowspan="2">2019</td><td>Jan</td><td></td><td></td></tr>
<tr><td>Feb</td><td></td><td></td></tr>
</table>

Mar			
Apr		Bout 6	
May			

Table 2: Summary of AIC model comparison. Models were summarized by degrees of freedom (*K*), AIC score (AIC, lower is better), the difference between model AIC score and the lowest scoring model for each taxon (ΔAIC), and the proportion, or weight, of evidence for each model (w_i).

Model	***K***	**AIC**	**ΔAIC**	w_i	**Model**	***K***	**AIC**	**ΔAIC**	w_i
Coyote Brush					*Other Native Herbaceous*				
B + T×B	4	788.6	0.0	0.701	B + T×B	4	551.1	0.0	0.269
Full	5	790.4	1.7	0.299	T	3	552.0	0.9	0.172
T + B	4	816.8	28.2	0.000	Null	2	552.0	0.9	0.170
T	3	817.0	28.3	0.000	B	3	552.4	1.3	0.143
Null	2	844.7	56.0	0.000	T + B	4	552.4	1.3	0.142
B	3	844.7	56.1	0.000	Full	5	553.0	1.9	0.104
Bunchgrass					*Other Non-native*				
Full	5	379.1	0.0	0.481	B + T×B	4	347.9	0.0	0.514
T + B	4	379.8	0.6	0.348	T + B	4	349.0	1.1	0.294
T	3	381.2	2.1	0.170	Full	5	349.9	2.0	0.190
B + T×B	4	391.6	12.5	0.001	B	3	358.7	10.9	0.002
B	3	395.7	16.6	0.000	T	3	426.7	78.8	0.000
Null	2	397.4	18.2	0.000	Null	2	434.9	87.1	0.000
Annual Grass					*Invasive*				
B + T×B	4	503.5	0.0	0.635	Null	2	5.5	0.0	0.502
Full	5	504.6	1.1	0.365	B	3	7.6	2.1	0.174
T + B	4	526.3	22.8	0.000	T	3	7.6	2.1	0.172
T	3	551.5	48.0	0.000	B + T×B	4	9.6	4.1	0.064
B	3	568.3	64.8	0.000	T + B	4	9.6	4.1	0.064
Null	2	593.1	89.6	0.000	Full	5	11.6	6.1	0.024

Table 3: Relative importance of predictors and model-weighted coefficients. The balanced model comparison comprised all possible permutations of three predictors: number of foraging bouts (B), treatment (T), and an interaction effect between B and T. LERs indicating substantial, strong, and decisive evidence are bolded, underlined and boxed respectively and cumulatively.

	T			**B**			**T × B**		
Category	**RI**	**LER**	β_T	**RI**	**LER**	β_B	**RI**	**LER**	β_X
Coyote B.	0.299	-0.4	-0.02	1.000	**6.3**	0.08	1.000	**6.0**	-0.25
Bunchgrass	0.999	**3.0**	0.68	0.830	**0.7**	0.05	0.482	0.0	-0.05
Annual Grass	0.365	-0.2	-0.05	1.000	**>10**	0.02	1.000	**5.1**	0.26
Other Native	0.418	-0.1	-0.03	0.658	0.3	-0.01	0.373	-0.2	-0.02
O. Non-nat.	0.483	0.0	0.09	1.000	**>10**	0.15	0.704	0.4	0.07
Invasive	0.260	**-0.5**	-0.02	0.326	-0.3	-0.06	0.088	**-1.0**	-0.01

Table 4: Summary of changes in groundcover report as groundcover mean and standard deviation. Forage and control rows are formatted according to the strength of evidence for an interaction effect and a bout effect, respectively. Bolded, underlined and boxed text represents substantial, strong, and decisive evidence, respectively.

	Percent Groundcover (Mean ± SD)						
Treatment	**Bout 0**	**Bout 1**	**Bout 2**	**Bout 3**		**Bout 5**	**Bout 6**
Coyote Brush							
Pilarcitos							
Foraged	**55 ± 30**		**26 ± 21**	**32 ± 25**		**44 ± 33**	**40 ± 32**
Control	**62 ± 33**		**65 ± 26**	**80 ± 25**		**79 ± 22**	**79 ± 27**
Barloy							
Foraged	**63 ± 36**	**51 ± 35**			**41 ± 32**		
Control	**62 ± 38**	**48 ± 30**			**55 ± 32**		
Bunchgrass							
Foraged		18 ± 25	35 ± 38	51 ± 41		30 ± 34	35 ± 32
Control		10 ± 17	13 ± 22	20 ± 23		15 ± 24	19 ± 29
Annual Grass							
Foraged		**21 ± 21**	**65 ± 23**	**97 ± 5**		**69 ± 33**	**90 ± 20**
Control		**21 ± 31**	**45 ± 38**	**50 ± 34**		**8 ± 12**	**53 ± 35**
Other Native Herbaceous							
Foraged		38 ± 31	42 ± 32	40 ± 28		40 ± 24	37 ± 26
Control		31 ± 28	54 ± 29	48 ± 25		34 ± 27	55 ± 33
Other Non-native							
Foraged		4 ± 9	31 ± 26	33 ± 25		29 ± 27	76 ± 21
Control		5 ± 12	23 ± 23	8 ± 9		17 ± 21	49 ± 34
Invasive							
Foraged		0 ± 0	0 ± 2	2 ± 5		2 ± 5	5 ± 10
Control		1 ± 6	2 ± 8	2 ± 9		0 ± 1	5 ± 13

Appendix A: Species List

Scientific Name	Common Name	Category
Aira caryophyllea	Silvery hairgrass	Annual grass
Anagalis arvensis	Scarlett pimpernel	Other non-native
Anthriscus caucalis	Bur chervil	Other non-native
Artemisia californica	California sagebrush	Other native herb
Artemisia douglasiana	Mugwort	Other native herb
Avena barbata	Slender wild oats	Annual grass
Baccharis pilularis	Coyote bush	Coyote brush
Brassica nigra	Black mustard	Other non-native
Briza minor	Little quakinggrass	Annual grass
Bromus carinatus	California brome	Bunchgrass
Bromus diandrus	Ripgut brome	Annual grass
Bromus hordeaceous	Softchess	Annual grass
Bromus madritensis	Spanish brome	Annual grass
Camissonia ovata	Suncup	Other native herb
Carduus pycnocephalus	Italian thistle	Invasive
Carex barbarae	Santa Barbara sedge	Other native herb
Centaurea melitensis	Tocalote	Other non-native
Cerastium glomeratum	Large mouse ears	Other non-native
Chenopodium californicum	Goosefoot	Other native herb
Chlorogalum pomeridianum	Soap plant	Other non-native
Cirsium vulgare	Bull thistle	Invasive
Claytonia perfoliata	Miner's lettuce	Other native herb
Conium maculatum	Poison hemlock	Invasive
Conyza canadensis	Canadian horseweed	Other native herb
Dichelostemma capitatum	Blue dicks	Other native herb
Elymus glaucus	Blue wildrye	Bunchgrass
Elymus triticoides	Creeping wildrye	Other native herb
Erodium botrys	Broadleaf filaree	Other non-native
Erodium cicutarium	Coastal heron's bill	Other non-native
Festuca bromoides	Six-week fescue	Annual grass
Festuca myuros	Rattail sixweeks grass	Annual grass
Festuca octoflora	Sixweeks fescue	Annual grass
Festuca perennis	Italian rye grass	Annual grass
Galium aparine	Goose grass	Other non-native
Galium porrigens	Climbing bedstraw	Other native herb
Geranium dissectum	Cut-leaved geranium	Other non-native
Geranium molle	Dovesfoot geranium	Other non-native
Pseudognaphalium californicum	California everlasting	Other native herb
Hirschfeldia incana	Mustard	Other non-native
Hordeum brachyantherum	Meadow barley	Other native herb

Scientific Name	Common Name	Category
Hordeum murinum	Foxtail barley	Annual grass
Horkelia cuneata	Wedgeleaf horkelia	Other native herbaceous
Hosackia stipularis	Stipulate lotus	Other native herbaceous
Hypochaeris glabra	Smooth cats-ear	Other non-native
Juncus balticus	Wire rush	Other native herbaceous
Juncus occidentalis	Western rush	Other native herbaceous
Juncus patens	Spreading rush	Other native herbaceous
Juncus phaeocephalus	Brownhead rush	Other native herbaceous
Juncus tenuis	Path rush	Other native herbaceous
Leymus triticoides	Creeping wild rye	Other native herbaceous
Logfia gallica	Narrowleaf cottonrose	Other non-native
Lupinus arboreus	Yellow bush lupine	Other native herbaceous
Lupinus bicolor	Bicolored lupine	Other native herbaceous
Lupinus nanus	Sky lupine	Other native herbaceous
Madia gracilis	Grassy tarweed	Other native herbaceous
Madia sativa	Coast tarweed	Other native herbaceous
Marah fabaceous	California man-root	Other native herbaceous
Medicago polymorpha	Burclover	Other non-native
Melica californica	California melic	Bunchgrass
Melilotus indica	Yellow sweet clover	Other non-native
Mimulus aurantiacus	Sticky monkey flower	Other native herbaceous
Pentagramma triangularis	Goldback fern	Other native herbaceous
Phacelia malvifolia	Stinging phacelia	Other native herbaceous
Phalaris aquatica	Harding grass	Invasive
Plantago coronopus	Buckhorn plantain	Other non-native
Plantago lanceolata	English plantain	Other non-native
Pogogyne serpylloides	Thyme leaf mesa mint	Other native herbaceous
Pseudognaphalium californicum	Ladies tobacco	Other native herbaceous
Pseudognaphalium luteoalbum	Jersey cudweed	Other non-native
Pterostygia drymarioides	Woodland threadstem	Other native herbaceous
Ranunculus californicus	California buttercup	Other native herbaceous
Rumex acetosella	Sheep's sorrel	Other non-native
Rumex crispus	Curly dock	Other non-native
Rumex salicifolius	Willow dock	Other native herbaceous
Salvia mellifera	Black sage	Other native herbaceous
Sanicula crassicaulis	Gamble weed	Other native herbaceous
Sidalcea malviflora	Checkerbloom	Other native herbaceous
Silene gallica	Flycatch	Other non-native
Sisyrinchum bellum	Blue-eyed grass	Other native herbaceous
Solanum umbelliferum	Blue witch	Other native herbaceous
Sonchus asper	Prickly sow-thistle	Other non-native
Sonchus oleraceus	Sowthistle	Other non-native
Stachys bullata	Wood mint	Other native herbaceous

Scientific Name	Common Name	Category
Stellaria media	Chickweed	Other non-native
Stipa cernua	Nodding needlegrass	Bunchgrass
Stipa lepida	Foothill needlegrass	Bunchgrass
Stipa pulchra	Purple needlegrass	Bunchgrass
Toxicodendron diversilobum	Poison oak	Other native herbaceous
Trifolium angustifolium	Narrow leaf clover	Other non-native
Trifolium aureum	Golden clover	Other non-native
Trifolium gracilentum	Pinpoint clover	Other native herbaceous
Trifolium hirtum	Rose clover	Other non-native
Trifolium microcephalum	Small head clover	Other native herbaceous
Triteleia crocea	Yellow brodiaea	Other native herbaceous
Triteleia ixioides	Pretty face	Other native herbaceous
Verbena lasiostachys	Common verbena	Other native herbaceous
Vicia hirsuta	Hairy vetch	Other non-native
Vicia ludoviciana	Slender vetch	Other native herbaceous
Vicia stiva	Spring vetch	Other non-native
Vicia tetrasperma	Four seeded vetch	Other non-native

Appendix B: Other Non-native Occurrences by Bout