

**Effects of grazing on native plant abundance and diversity in a
California grassland invaded by *Phalaris aquatica***

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ABSTRACT

California grasslands have been heavily invaded by European annual and perennial grasses, but remnant populations of native vegetation still exist on coastal grasslands. Livestock grazing can be an effective tool for managing invasive species and promoting diversity, but grazing disturbance may be detrimental to native plant species. I examined a grassland that has been historically grazed by cattle and assessed how the plant community has responded to grazing exclusion at locations that have been fenced for more than 20 years. I conducted vegetation surveys on the grazed and ungrazed sides of five sites along the cattle fences in order to determine differences in native and exotic cover and diversity. I also assessed differences in cover and fitness of Harding grass, an invasive perennial grass. Overall, I found that grazing reduced the cover and fitness of Harding grass but had no significant effect on native and exotic cover or diversity. However, grazing did significantly increase exotic forb cover. Average differences in native and exotic cover and diversity were insignificant for the study system as a whole, but I did find large differences at some sites. Grazing response of total species richness and Shannon diversity index also varied substantially between study sites. These results suggest that other unknown factors are influencing how the community responds to the presence or absence of grazing. Further research is needed to determine the role of factors such as productivity and species composition in determining grazing response.

KEYWORDS

native plants, invasion, grassland ecology, Harding grass, disturbance

INTRODUCTION

California grasslands are among the most heavily invaded ecosystems in the world (Gea-Izquierdo, Gennet & Bartolome, 2007). Prior to the arrival of European settlers in the 18th and 19th centuries, much of the state was dominated by native perennial bunchgrasses which have now been displaced by Mediterranean annual grasses and forbs (Hatch, Bartolome, Fehmi & Hillyard, 1999; Seabloom, Harpole, Reichman & Tilman, 2003). Many northern California grasslands have also been invaded by European perennial grasses (Thomsen, Corbin, & D'Antonio, 2006). This invasion poses a significant threat to native plant diversity and can have serious implications for ecosystem functioning (Hobbs & Huenneke, 1992). Because exotic species must out-compete existing natives to become established, disturbance is often instrumental in allowing invasion to take place (Seabloom et al., 2003). Some of the most important disturbances in California grasslands include natural disturbances such as fire and drought, as well as anthropogenic disturbances such as soil disturbance, nitrogen addition, and livestock grazing (Hobbs & Huenneke, 1992).

Grazing creates disturbance in plant communities. Livestock can facilitate the establishment of invasive plants by trampling and defoliating established species, thereby reducing their competitive ability and creating bare patches, and by disrupting nutrient cycles (Kimball & Schiffman, 2003; Dorrough, Ash, & McIntyre, 2004). In this way, the introduction of livestock to California by European settlers may have been a primary cause of widespread invasion by exotic species (Hatch et al., 1999; Corbin & D'Antonio, 2004). However, grazing removal also represents a disturbance (Hayes & Holl, 2003). Moderate grazing has been shown to promote community diversity (Fujita, Yamada, Matsui, Sakai & Yamamura, 2009; Papanastasis, 2009), and livestock exclusion can result in diversity loss by allowing certain species out-compete other species and establish dominance (Schultz, Morgan & Lunt, 2011).

Grazing disturbance has different effects on native and exotic plants, and on various plant functional groups. Because the history of intensive human use of livestock in California is short compared to the history of livestock in Europe, European plant species may be better-adapted to grazing than California natives (Kimball & Schiffman, 2003; Bartolome, Fehmi, Jackson & Allan-Diaz, 2004; HilleRisLambers, Yelenik, Colman & Levine, 2010). Grazing introduction may therefore provide an advantage in allowing European species to invade beyond merely

creating opportunities for colonization. Grazing also often favors exotic annual grasses, which have higher growth rates and seed dispersal rates than perennials (Holmes & Rice, 1996). Annuals therefore sustain populations by rapidly dispersing and colonizing open patches, while perennial recruitment is more severely limited by defoliation and trampling (Holmes & Rice, 1996; Seabloom et al., 2003). Grazing is almost always detrimental to perennial grasses (Milchunas & Lauenroth, 1993), but little research has been done on the difference in effect between native and exotic species in California. Many exotic perennial species have been shown to be superior competitors than natives, and this competitive advantage may be amplified under grazing pressure (Thomsen et al., 2006; Corbin & D'Antonio, 2009). Exotic perennials have also been shown to be able to colonize more rapidly after disturbance than native perennials (Cushman, Tierney, & Hinds, 2004). Additionally, grazing is often detrimental to native forb species (Hayes & Holl, 2003). Livestock may be effectively used to control exotic invasive perennial grasses, but it may also have a detrimental effect on native species.

The purpose of my study was to assess the impact of cattle grazing on the vegetation community of a coastal California grassland. I also determined the effectiveness of grazing in controlling invasive Harding grass (*Phalaris aquatica*), a Mediterranean perennial bunchgrass species. I examined the effects of long-term grazing exclusion at Pepperwood Preserve in Santa Rosa, Sonoma County, California, by surveying vegetation at adjacent grazed and ungrazed sites that had been fenced for more than 20 years. My objectives were to determine the effect of grazing exclusion on 1) native and exotic species abundance and diversity, 2) overall diversity, and 3) Harding grass abundance and fitness. In accordance with the hypothesis that exotic species are generally better-adapted to grazing than natives, I expected grazing to reduce native cover and species richness. However, because grazing is generally detrimental to perennial species (Milchunas & Lauenroth, 1993), I expected Harding grass abundance and fitness to be lower on grazed sites. I expected that grazing would also promote overall diversity by reducing competitive dominance of Harding grass.

METHODS

Study System

Sonoma County is characterized by a Mediterranean climate and is intermediate between California's wet, foggy coastal region and the hotter, drier Central Valley. Grasslands in this region are categorized as coastal prairie ecosystems (Corbin & D'Antonio 2004). Vegetation is dominated by non-native Mediterranean annual grasses such as wild oat (*Avena fatua*), soft brome (*Bromus hordeaceus*), and Italian ryegrass (*Lolium multiflorum*), with some remnant native perennial grasses including purple needlegrass (*Nassella pulchra*) and California oatgrass (*Danthonia californica*). The site is also highly invaded by Harding grass, a widespread invasive species in California grasslands. Harding grass stands displace native vegetation and can pose a fire hazard during summer months (California Invasive Plant Council, n.d.).

The pastures where I established my field sites are located on former ranching homesteads which have been grazed since the late 1800's. Presently, cattle are permitted to graze from December through May to promote diversity and suppress woody species. Harding grass has been present since 1964, when it was seeded as part of a re-vegetation effort after a fire (M. Gillogly, pers. comm., March 25, 2011). Several cattle fences have been constructed on the preserve since the mid-1980's, providing adjacent grazed and ungrazed areas with comparable soil, slope, aspect, and plant communities.

Data Collection

Site selection

I selected five replicate sites along cattle fences to compare grazed and ungrazed plant communities. The sites were within 0.5km of one another and contained comparable vegetative communities and soil conditions, but were spread so that I could determine whether grazing effects were consistent on a local scale. Sites 1-3 were located along the same fence following a slope gradient, with Site 1 (N 38.5757, W 122.7045) near the top of the slope, Site 2 (N 38.5754, W 122.7045) further down the slope, and Site 3 (N 38.5750, W 122.7045) at the bottom. Sites 4

(N 38.5771, W 122.7021) and 5 (N 38.5792, W 122.7028) were each located along separate fences on separate slopes. I selected sites randomly, but restricted my selection to areas where Harding grass was present. There was no Harding grass in my sample plots at Site 2, but the site was adjacent to Harding grass-invaded areas and contained the native grass *N. pulchra*.

Vegetation census

All the replicate sites were divided into grazed and ungrazed sub-sites by cattle fences. I sampled vegetation on either side of the fence by laying out six evenly spaced 1m² frames at each sub-site (Fig. 1). Minimum distance to the fence was 3m. In each sample plot, I visually estimated percent cover of all plant species present, as well as bare ground and litter cover. I identified species using the herbarium at Pepperwood, following Jepson Manual nomenclature. I classified species by origin (native or exotic), by functional group (grass or forb), and by life-history guild (annual or perennial) according to the Calflora online database (Calflora n.d.). I categorized the rush *Juncus tenuis* as a grass.

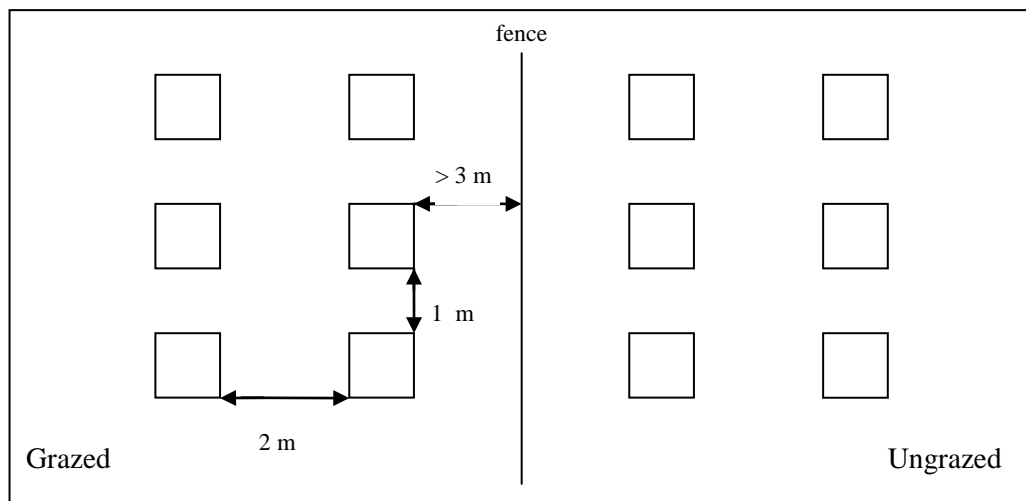


Figure 1. Each site was divided by a cattle fence and contained a grazed and ungrazed treatment. Six evenly-spaced 1m² plots were set up on either side of the fence. I visually estimated percent cover of all species present in the sample plots.

Diversity metrics

I measured diversity in my plots by counting the number of species per m². I calculated total species richness values for each plot, as well as separate native and exotic species richness values. I used species cover data to calculate Shannon-Wiener index: $H' = -\sum p_i \ln p_i$, where p_i was the estimated cover of the i th species in each plot.

Harding grass individual measurements

Because Harding grass individuals are large (diameter ~1m) and are distributed in a clumped pattern, they could not be accurately sampled using 1m² plots. I sampled individuals along a 10m transect at each sub-site. Site 2 did not include significant levels of Harding grass, and was therefore excluded. I marked a plant every 2m, so that a total of five individuals per sub-site were measured. I measured the height, bunchgrass diameter, and seed count of each plant and calculated average values for each sub-site.

Analysis*Log response ratios*

I calculated native cover, exotic cover, native species richness, exotic species richness, total species richness, Shannon-Wiener index, and Harding grass cover for each sample plot. Plot-level data were used to calculate a mean value and standard error for each sub-site. I also calculated sub-site means for individual Harding grass height, diameter, and seed count. For each variable, I calculated a log response ratio [LRR= $\ln(\text{mean grazed}/\text{mean ungrazed})$] (Hedges, Gurevitch, & Curtis, 1999). The sign of LRR indicated whether the variable responded positively or negatively to grazing. I then combined data from all sites to calculate overall grazed and ungrazed means and overall LRR for each variable. I used the same formula to calculate individual species response, using cover data summarized from all study sites.

Statistical Analysis

To determine the effect of grazing on each of my variables, I compared grazed and ungrazed means using ANOVA in R Commander (Fox et al., 2009; R Development Core Team, 2009). Native and exotic cover data were ln-transformed to fit normal distributions. Because sample plots were grouped by site and therefore were not independent replicates, I tested grazing effects against the interaction between site and grazing to determine statistical significance. I used the same ANOVA method to compare mean height, diameter, and seed count between grazed and ungrazed Harding grass individuals. Diameter data were square-root transformed, and seed count data were ln-transformed to fit a normal distribution. Because Harding grass cover data could not be transformed to fit a normal distribution, I compared means between grazing treatments using a nonparametric Kruskal-Wallis test.

RESULTS

Native perennial species in the system consisted of the grasses *N. pulchra* and *D. californica*, as well as the rush *J. tenuis*. I identified one native annual grass species, five native forb species, six exotic annual grass species, and fifteen exotic forb species. Harding grass was the only exotic perennial grass species. Both grazed and ungrazed plots were dominated by exotic annual grasses, and there was no significant difference in exotic annual grass cover between grazing treatments. The major differences between grazed and ungrazed plots were in exotic forbs and Harding grass, with exotic forb cover higher in the presence of grazing and Harding grass cover higher in the absence of grazing (Fig. 2). The individual species with the strongest responses to grazing were primarily exotic forbs, most of which responded positively to grazing. *N. pulchra* did not respond significantly, and *D. californica* and *J. tenuis* responded negatively to grazing. No native forbs responded significantly. Responses of exotic annual grasses were mixed (Fig. 3).

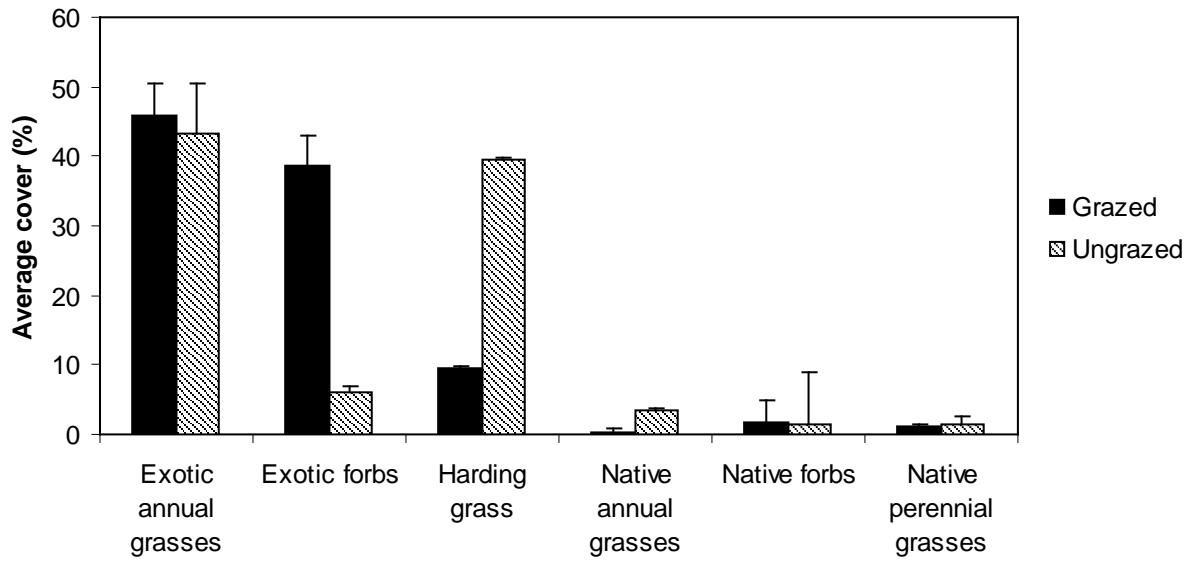


Figure 2. Mean cover of major vegetation categories on 1m² plots at grazed and ungrazed sites at Pepperwood Preserve. Harding grass is the only exotic perennial grass in the system.

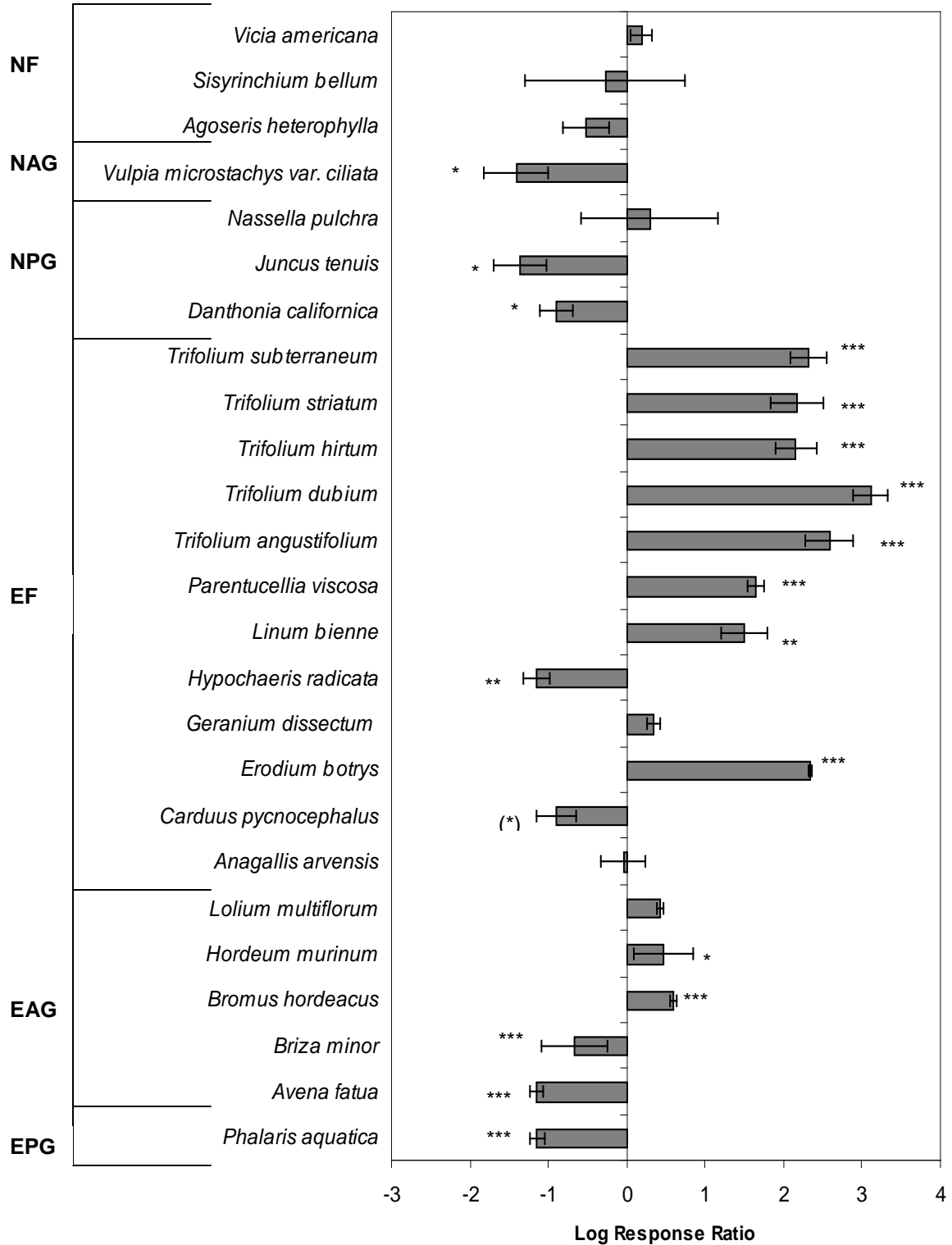
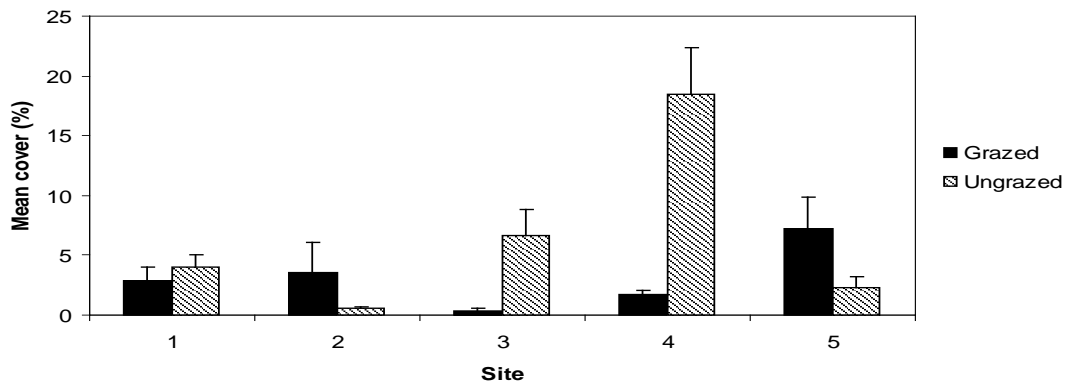


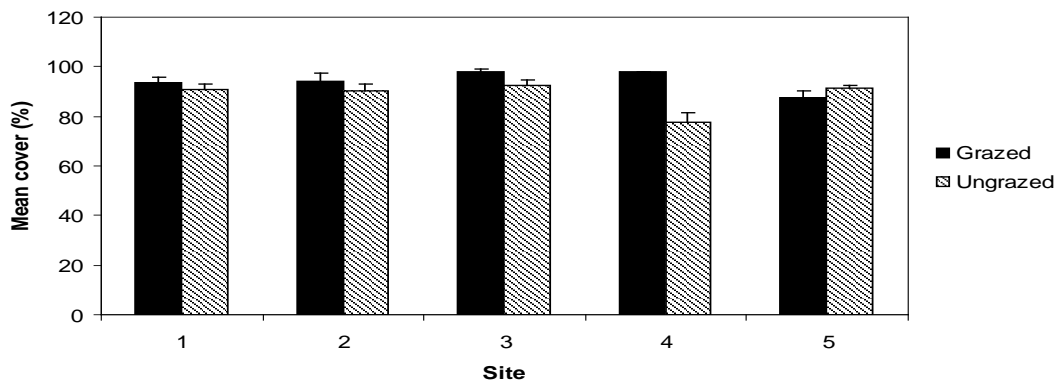
Figure 3. Log response ratios of individual species in each vegetation category. NF= native forbs, NAG= native annual grasses, NPG= native perennial grasses, EF= exotic forbs, EAG= exotic annual grasses, EPG= exotic perennial grasses. Species that only occurred on one side were not included. Error bars represent standard error. Significance was tested using ANOVA. *** $p < 0.001$ ** $p < 0.01$ * $p < 0.05$ (*) $p < 0.05$.

Native/Exotic Cover and Richness

On average, native species made up (3 ± 0.8)% of total cover on grazed plots and (6 ± 0.1)% of total cover on ungrazed plots. Exotic cover was (94 ± 1.2)% on grazed plots and (88 ± 1.4)% on ungrazed plots. The difference in native cover between grazed and ungrazed plots was not statistically significant ($F_{1,4}=4.43$, $p=0.52$). The difference in exotic cover was also not significant ($F_{1,4}=13.79$, $p=0.24$). Each site had similar levels of exotic cover on both the grazed and ungrazed sides (Fig. 4b), but native cover response was large at some sites (Table 1, Fig. 4a). Native cover was significantly higher on the ungrazed sides of Sites 3 and 4, but was higher on the grazed sides of Sites 2 and 5. Native species richness was roughly proportional to native cover (Fig. 5a). Grazing slightly increased exotic species richness at four of five sites, but the difference was only significant at Site 5 (Table 1, Fig. 5b). Neither native nor exotic species richness was significantly different between grazing treatments (native SR: $F_{1,4}=3.50$, $p=0.52$; exotic SR: $F_{1,4}=15.67$, $p=0.13$).



a.



b.

Fig. 4. a) Mean native species cover and b) mean exotic species cover on 1m^2 plots between grazed and ungrazed treatments across study sites. Error bars represent standard error.

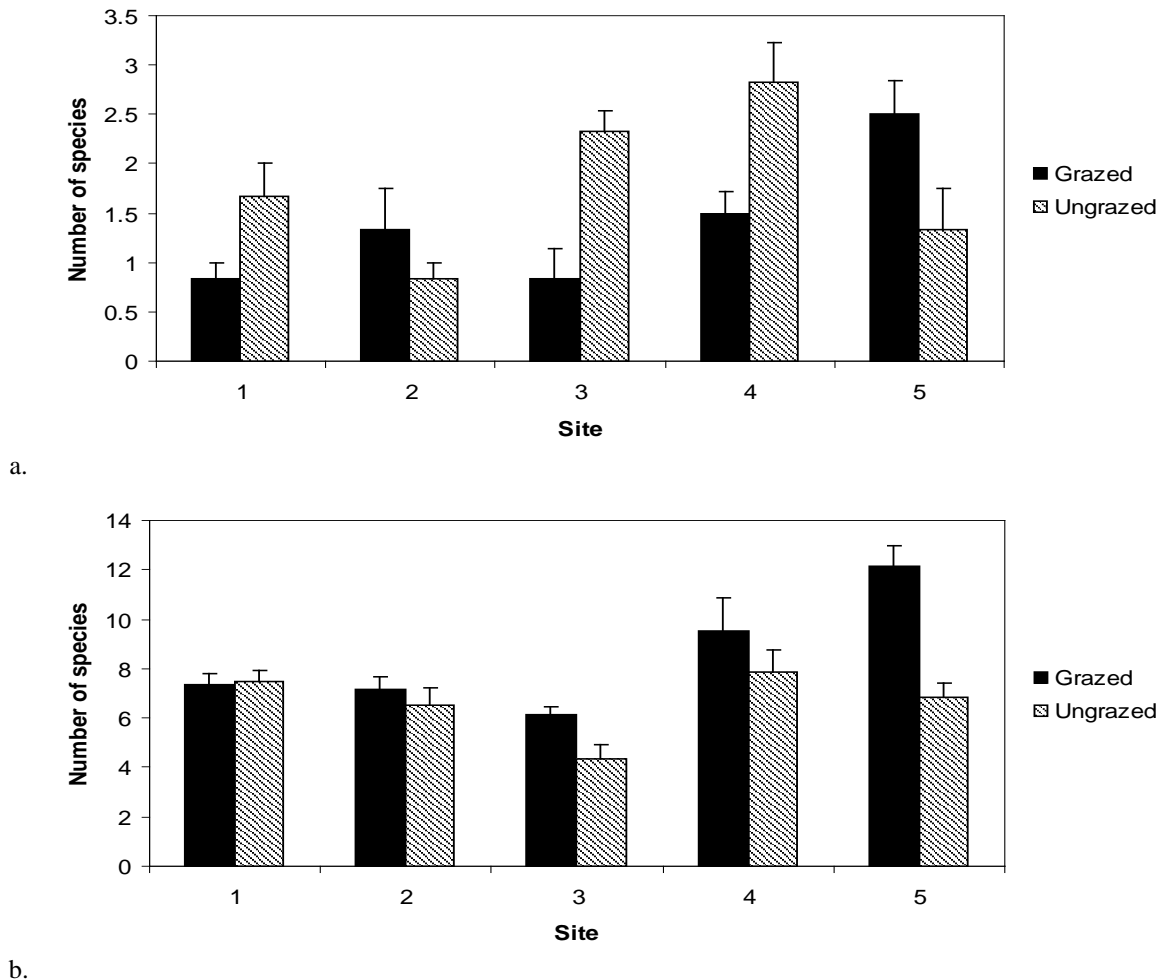
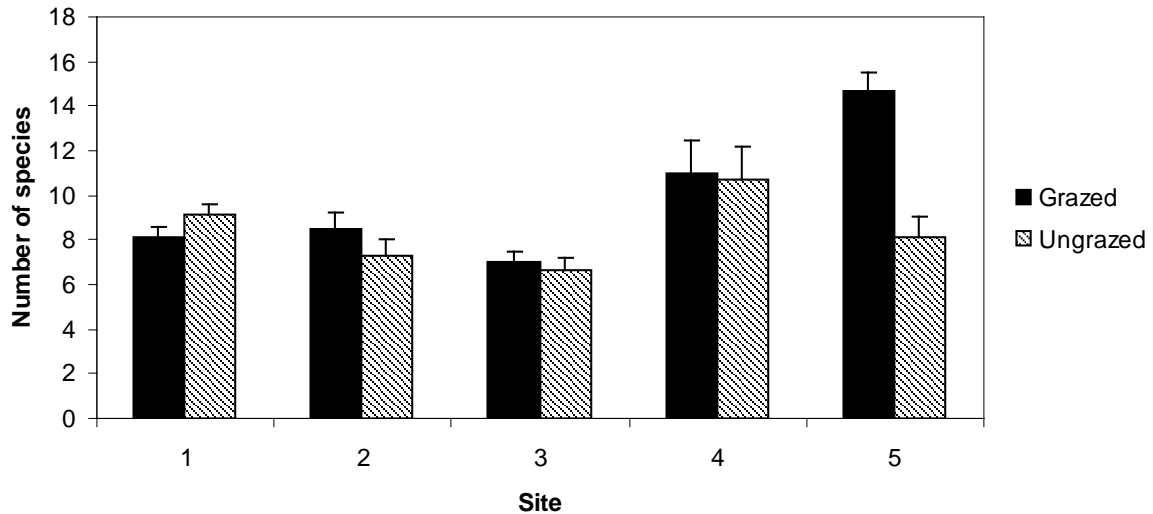


Fig. 5. a) Mean native species richness and b) mean exotic species richness across study sites. Number of species are per m². Error bars represent standard error.

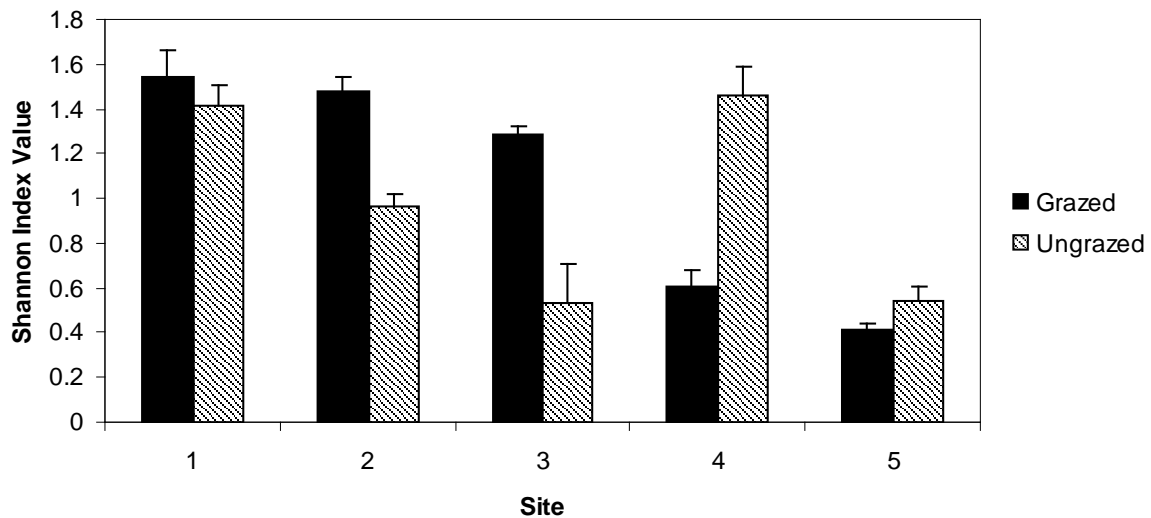
Total Diversity

I found that mean total species richness was reduced by 1.5 ± 0.52 species per m² on ungrazed plots, and mean Shannon index was reduced by 0.079 ± 0.064 . Neither total species richness nor Shannon index was significantly different between grazing treatments (total SR: $F=6.44$, d.f.=4, $p=0.30$; Shannon index: $F_{1,4}=1.82$, $p=0.79$). Sites 1-3, which were each located along the same slope, had similar species richness values to one another. Sites 4 and 5 were located on separate slopes and each had a greater number of species than Sites 1-3 (Table 1, Fig. 6a). With the exception of Site 5, there was little difference in species richness between grazing treatments (Fig. 6a). There were large differences in Shannon index values between grazing

treatments at Sites 2, 3, and 4, but these differences were not consistent in direction (Table 1, Fig. 6b). Shannon index was higher on the grazed sides of Sites 1-3, but was higher on the ungrazed sides of Sites 4 and 5. Total species richness response did not necessarily correspond to Shannon index response, since some sites that had small differences in total species richness between grazing treatments had large differences in Shannon index. Additionally, Site 5 had a large difference in total species richness but a relatively small difference in Shannon index.



a.



b.

Fig. 6. a) Mean species richness and b) mean Shannon index across sites. Number of species and Shannon index values are per m². Error bars represent standard error.

Harding Grass Cover and Fitness

Harding grass made up (40 ± 7.4)% of total cover on ungrazed plots. Grazing reduced Harding grass cover by (30 ± 5.2)% (Kruskal-Wallis $\chi^2_{1,3}=10.10$, $p=.017$). Cover was lower on the grazed side at three of four sites (Fig. 7a). At Sites 3 and 5, where Harding grass made up over 80% of cover on the ungrazed sides, grazing reduced cover by $\sim 70\%$. Though mean plant height and diameter were generally lower on the grazed sides of each site (Table 1, Fig. 7b-c), the overall difference between grazing treatments was not statistically significant ($F_{1,3}=22.01$, $p=0.088$; $F_{1,3}=19.15$, $p=0.24$). Grazing significantly reduced mean seed count by 22 ± 4.4 seeds per plant, a factor of ~ 0.75 ($F_{1,3}=26.01$, $p=0.020$). This reduction was consistent across sites, but differences were not significant at all sites (Table 1, Fig. 7d).

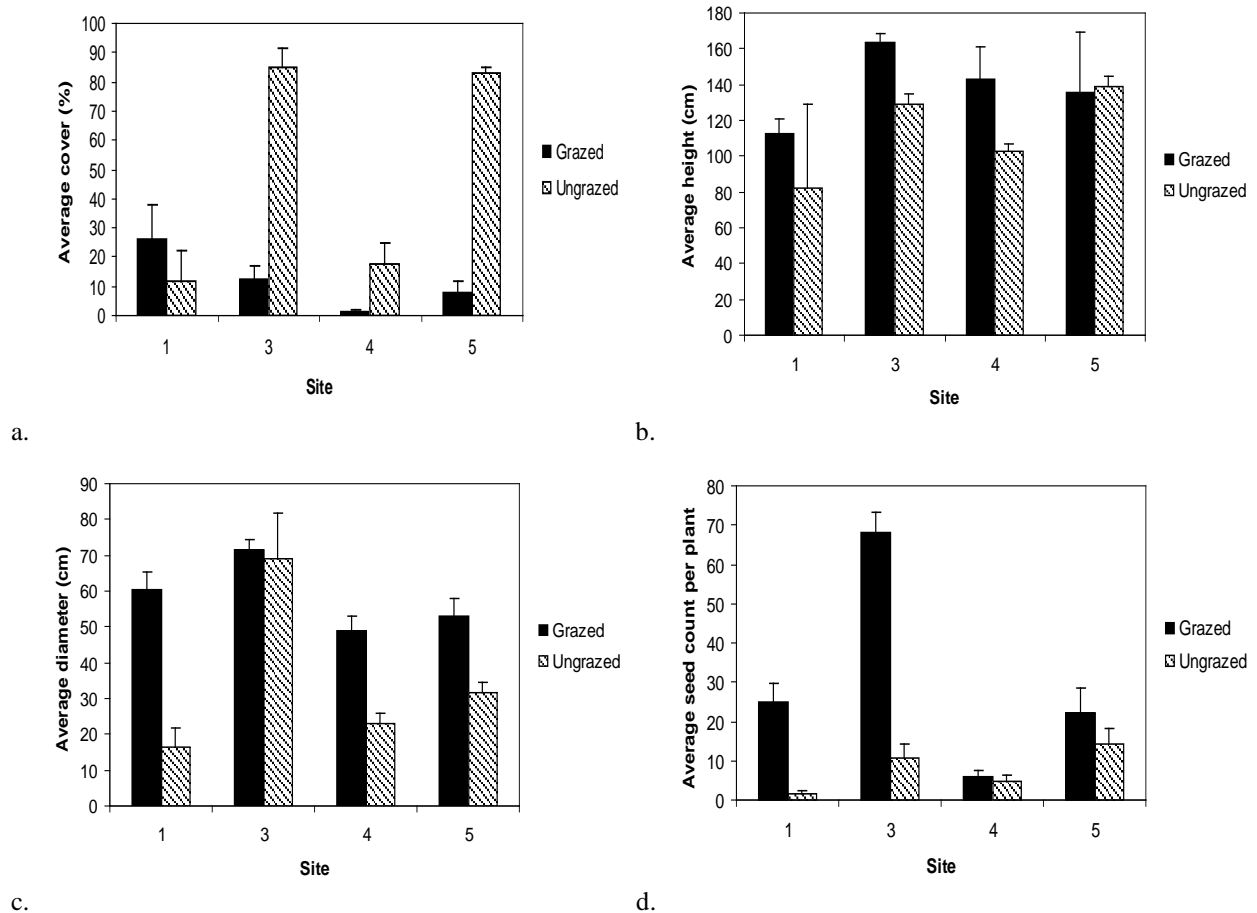


Fig. 7. Mean Harding grass a) cover, b) height, c) diameter, and d) seed count per plant by site. Error bars represent standard error.

Table 1. I compared means of each variable on either side of a grazing fence on a California grassland. Values given are grazing log response ratios [LRR= $\ln(\text{mean grazed}/\text{mean ungrazed})$] at each study site and overall for all sites combined. I tested the significance of differences between grazed and ungrazed means using an ANOVA. * $p < 0.05$

	Site 1	Site 2	Site 3	Site 4	Site 5	Overall
Native Cover	-0.316	1.94	-2.86	-2.39	1.13	-0.705
Exotic Cover	0.0298	0.0400	0.0606	0.227	-0.0429	0.0618
Native species richness	-0.693	0.470	-1.03	-0.636	0.629	-0.251
Exotic species richness	-0.0225	0.0976	0.353	0.193	0.577	0.249
Total species richness	-0.116	0.147	0.0488	0.0308	0.586	0.161
Shannon Index	0.0821	0.431	0.873	-0.880	-0.285	0.0773
<u>Harding grass measurements</u>						
Cover*	0.808	-	-1.94	-2.64	-2.36	-1.43
Height	-0.375	-	0.0501	-0.102	-0.487	-0.224
Diameter	-0.169	-	-0.0876	-1.44	-0.329	-0.419
Seed count*	-1.01	-	-1.30	-1.89	-1.13	-1.13

DISCUSSION

My study assessed the effect of grazing exclusion on native vegetation, on overall diversity, and on invasive Harding grass in a northern California grassland. I determined grazing effect by comparing plant communities at adjacent grazed and ungrazed sites divided by a cattle fence. I hypothesized that exclusion would increase the cover and fitness of Harding grass, thereby decreasing both native and exotic diversity, but would also increase native cover. I found that Harding grass cover and fitness were significantly reduced in the presence of grazing. While the overall patterns for native vs. exotic abundance and diversity supported my hypotheses, there were large variations in grazing response between individual study sites. This variation suggests that unknown factors may be playing an important role in shaping the plant community's response to grazing.

Native/Exotic Cover

Grazing exclusion slightly increased native species cover in my study system while decreasing exotic cover. However, the overall difference was not large in magnitude or statistically significant. It is likely that, because ungrazed sites were grazed prior to being fenced, exotic species were able to invade during the period of grazing and maintain dominance after livestock were excluded. If native, grazing-intolerant species cover becomes sufficiently reduced, these species may be unable to become re-established even in the absence of grazing pressure (Seabloom et al., 2003; Dorrough et al., 2004). While established stands of native perennial grasses can successfully compete with exotic annual grasses after being invaded (Corbin & D'Antonio, 2004), it is possible that these native species were too infrequent in my system to become re-established. Additionally, the fact that exotic annual grass cover was roughly equal in grazed and ungrazed plots indicates that grazing does not have a substantial effect on the competitive ability of these species. Grazing disturbance may be a crucial factor in allowing exotic annual grasses to invade, but may be less important once they become established (HilleRisLambers et al., 2010).

Although grazing did not significantly affect total native or exotic cover, it did have significant effects on certain plant species and guilds. Cover of the native perennials *D. californica* and *J. tenuis* was higher on ungrazed plots, indicating that grazing exclusion may assist in the restoration of these species. However, the fact that *N. pulchra* did not respond significantly to grazing suggests that this strategy may not be applicable to all native species. Furthermore, previous studies have shown that grazing exclusion alone does not necessarily result in a reversion to native perennial dominance (Hatch et al., 1999). By contrast, there was a very large difference in exotic forb cover between grazed and ungrazed plots. Most of this difference was due to a few clover species (genus *Trifolium*), which are characteristic of grazed pastures (Sotoyome Resource Conservation District, 2006). Another exotic forb with a strong positive grazing response was *Erodium botrys*, which is also highly tolerant of grazing (Kimball & Schiffman, 2003). While I cannot conclude that all exotic species are favored by grazing, a few well-adapted exotic forb species have been able to dominate the system and displace native vegetation. No native forbs in the system responded significantly to grazing, but previous studies have found that grazing is generally detrimental to native perennial forbs and beneficial

to native annual forbs (Hayes & Holl, 2003). *Vulpia microstachys* var. *ciliata*, the one native annual grass in the system, responded negatively to grazing. However, the response of one species is not sufficient to generalize the effect of grazing on all native annual grasses.

Diversity

Overall, grazing did not have a significant effect on either total species richness or Shannon diversity index. Species richness appears to be more closely associated with spatial variation in plant community composition than with grazing, since Sites 1-3, which are relatively close to one another, had similar richness values while Sites 4 and 5, which are located further from Sites 1-3, had different values. With the exception of Site 5, I found little difference in total species richness between grazing treatments. Because grazing can significantly impact species richness by preventing one species from establishing dominance (Fujita et al., 2009; Schultz et al., 2011), the large difference at Site 5 may have been due to Harding grass being dominant on the ungrazed side. However, I would expect to find a similar difference at Site 3, where Harding grass was also dominant on the ungrazed side. Harding grass cover was similar on the grazed sides of both sites.

The difference in diversity response between sites may be caused by productivity differences or by differences in grazing frequency according to the Dynamic Equilibrium Model, which predicts greater differences in species richness as a result of higher levels of disturbance at sites with greater productivity (Huston, 1979; Kondoh, 2001). Because Site 3 was located at the bottom of a valley while Site 5 was located on a moderate slope, I might expect Site 3 to retain more soil moisture and thus be more productive. However, this would cause a greater species richness response at Site 3 than at Site 5. It is possible therefore that Site 5 is grazed more frequently than Site 3. Mean bare ground cover was roughly 3% on the grazed side of Site 5 as opposed to 2% at Site 3, possibly indicating a higher level of disturbance at Site 5.

Shannon index response was also inconsistent between study sites. Results for Sites 1-3 follow the pattern found by Fujita et al. (2009), which predicts a greater response in species diversity going downhill along a slope gradient as a result of increasing soil moisture and increasing productivity. These results also support my prediction that Shannon diversity would be higher on grazed plots (Harrison et al., 2003; Schultz et al., 2011). However, I observed the

opposite result at Sites 4 and 5. Because grazing promotes diversity by preventing competitive exclusion, I would expect Shannon index to respond most positively to grazing at both Sites 3 and 5, where Harding grass was the most dominant (Schultz et al., 2011). If I assume that Site 3 was more productive than Site 5, for the reasons stated above, the fact that Shannon index had a strong positive grazing response at Site 3 but not at Site 5 is in accordance with the Dynamic Equilibrium Model. However, the Shannon index response does not correspond to the expected species richness response.

Harding Grass Cover and Fitness

I found that grazing significantly reduced Harding grass cover in the system. This finding agrees with previous studies that have found that lack of disturbance can allow exotic perennial grasses to establish dominance (Gonzalez & Clements, 2010). Fitness of Harding grass in terms of plant height and diameter was not significantly different between fenced and unfenced areas, though these results are somewhat limited by my small sample sizes. Because standard deviations were large for plant height and diameter, sampling more individuals may have resulted in stronger statistical significance. However, I did find that grazing dramatically reduced the number of seeds per plant. This result was consistent across all study sites. Although mature Harding grass plants seem to be resistant to livestock disturbance, grazing has a negative effect on seed development and dispersal. Grazing during the spring, when seeds are developing, would therefore likely be an effective management strategy for controlling the spread of Harding grass (Virgona, Avery, Graham & Orchard, 2000).

One concern with using grazing to manage exotic perennial grasses is that this strategy may also be harmful to native grasses (Corbin & D'Antonio, 2009). However, negative effects of grazing on native grasses can be counteracted by the suppression of competitors. I observed that *D. californica* responded negatively to grazing, but that *N. pulchra* had no significant response. Grazing generally reduces the fitness of *N. pulchra* (Kimball & Schiffman, 2003), but *N. pulchra* has also been shown to be an inferior competitor to several exotic perennial grasses, including Harding grass (Thomsen et al., 2004). It is possible that the benefits of reducing competition from Harding grass are in balance with the negative effects of grazing.

Future Directions

Future studies should aim to identify factors that cause variation in grazing effects within a system. It is possible that variations in species composition between sites were responsible for differing results; it may therefore be necessary to examine species-specific interactions rather than plant guild differences. This approach may reveal which native species have the potential to be restored to grazed pastures. Future research should also examine the effects of small, local-scale variations in productivity and disturbance levels on diversity response to grazing.

Limitations

My study provided a snapshot of the plant community at Pepperwood during a single growing season, and a number of limitations must be taken into account. First, yearly climate variation can cause large changes over short timescales in a system where grazing creates a long-term change in plant community (Fuhlendorf, Briske & Smeins, 2001). Continuing my study over several years may reveal variations in grazing response between wetter or drier years. My study also covered a specific geographic area. However, because the system was dominated by common species such as *Avena fatua*, *Bromus hordeaceus*, and *Lolium multiflorum* (Hatch et al., 1999; Corbin & D'Antonio, 2004), the results should be applicable to a wide range of California coastal grassland. Another limitation is the relatively small number of sites used in my study. Because many results varied between sites, a larger sample size may have helped to reveal more consistent patterns. However, strong variations in native cover and diversity results between my sites indicate that the community response to grazing was influenced by other factors. Unfortunately, the data I collected was insufficient to identify those factors.

Broader Implications

Grazing can be an effective method for controlling the spread of Harding grass and other exotic perennial grass invaders, but managers should be mindful of the effect of livestock on remnant native plants. While grazing may be detrimental to native perennial grasses, it may be less damaging than competitive exclusion by exotic perennial invaders. My study shows that the

grazing response of native plant species, as well as the response of community diversity, can be variable even on highly similar sites. Managers should monitor changes in community diversity when implementing a grazing management scheme, and incorporate adaptive strategies.

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