Differences in vegetation and soil characteristics due to activity by rodents of the genus *Peromyscus* and ants of the genus *Formica*—possible implications for biodiversity maintenance in cattle-grazed land.

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Abstract:

The maintenance of landscape mosaics is an important way for conservation biologists to maintain biodiversity in areas that have been impacted heavily by human actions. This can be done either by combining areas of natural landscape with areas of varying land use, or by maintaining vegetation patches within a landscape. Both rodents and ants have been known to alter the vegetation composition around their burrows and mounds, thus increasing the heterogeneity of grasslands. Occasionally, rodents will burrow into mounds, potentially amplifying their impact within an area. This study focuses on the effects that rodents of the genus *Peromyscus* and ants of the genus *Formica* have on vegetation composition at the National Bison Range in Montana when found separately and when burrows are found underneath ant mounds.   Additionally, these effects are compared between cattle grazed and non-grazed habitats Based on soil moisture, soil compaction, and vegetation surveys at four distances from each treatment, cow grazing changed the effect that each landscape feature had on the surrounding vegetation and, all landscape features maintained a different vegetation composition from one another. The results suggest that the presence of *Peromyscus*, *Formica*, and the co-occurrence of the two increases variability among vegetation patches and could potentially hold implications for biodiversity maintenance in grasslands overgrazed by cattle.

Introduction

As human activity and therefore human impact on the environment increases, there is a search to find ways to lessen such impacts. Modern conservation biology focuses largely on the maintenance of species diversity (Lubchenco et al. 1991, Steffent et al. 1992). One of the most extensive forms of land use, livestock grazing encompasses 70% of the land in the western United States (Fleischner 1994). Being frequently mismanaged, livestock grazing often results in the loss of biodiversity in the region (Graetz 1994). Cooperlind (1991) has even gone so far as to cite grazing as "one of the primary threats to biological diversity." Therefore, it is important to identify and maintain factors that maximize biodiversity in grazed habitats. Forman (1995) proposed that this could be accomplished by maintaining a mosaic of landscapes by coupling areas of varied land use with areas of natural habitat features. One way of doing this is by maintaining less exploited natural areas such as grasslands that are located adjacent to economic areas such as rangelands (Forman 1995). The idea is that by maintaining such mosaics, species from the natural habitat could easily be incorporated into the cow-grazed habitat. Thus, the natural environment acts as a constant supplier of species to the cow-grazed site. Smaller scale mosaics such as patches of different vegetation increase biodiversity as well. Microenvironments can increase the biodiversity of plants as well as invertebrates and mammals (Folgarait 1988). Two organisms that have been known to create patches of vegetation that differ from their surroundings are ants and rodents.

Rodents alter soil composition through their burrowing activities thus indirectly affecting vegetation surrounding their burrows. Burrowing aerates the soil and changes the nutrient content of the soil through the mixing of soil layers (Scherba 1965). Rodents also directly influence vegetation surrounding their burrows through seed foraging, seed caching, and consumption. Although rodent foraging may hinder seed dispersal for some preferred plants (MacDougall and Wilson 2007), it has been shown that the seed preference of the deer mouse *Peromyscus maniculatus* benefits the survival of the favored plant species due to the mouse's foraging habits, seed caching, and consumption (Nowalk 2007; Vander Wall 2005). Many seeds are dropped and dispersed while foraging, and approximately 70% of the seeds that they handle are stored in caches, many of which are forgotten and left to germinate (Vader Wall et. al. 2005). These preferred plant species have been known to be most abundant in areas around rodent activity and comprise vegetation patches near burrows that differ from the surrounding environment.

Like rodents, particularly those of the genus *Peromyscus*, ants can also create vegetation patches directly around their shelters that differ from the surrounding environment. Sometimes considered 'ecosystem engineers,' ants often effect plants and are important in below ground processes through their chemical and physical alteration of soil (Brian 1978). Ants locally increase soil nutrients, especially in areas of poorer soils, and increase soil aeration and drainage through their tunneling and underground galleries (Brian 1978). This in turn affects the type of vegetation that grows at mounds. The short-lived, wind-blown plants that are characteristic of heavily grazed grasslands are more often found confined to mounds than they are found in other areas of the grassland (Farrow 1925, King 1977). King (1977) found that vegetation at active mounds also consists of a greater amount of rare species compared to the surrounding grassland. Because mounds are likely to have vegetation that is different from the vegetation structgure in the surrounding grassland, they are likely to increase the overall patchiness of grassland, thus contributing to the vegetation and microenvironment mosaic effect that is desired in biodiversity conservation methods.

Different vegetation patches can even exist at the same mound due to temperature variation throughout ant mounds. Temperatures generally reach greater extremes at ant mounds; temperature also changes at one mound depending on the orientation (King 1977). North facing slopes of mounds generally have more consistent temperatures than south-facing slopes. This is one more way in which the micro-environments of ant-hills are more heterogeneous than the grassland areas in which the mounds occur (King 1977) and could therefore potentially be used to increase the vegetation mosaic characteristic of a grazed area.

It is not uncommon for other insects or animals to temporarily use or inhabit ant mounds, even when the mounds are still active. The meadow vole, *Microtus montanus,* has been found to inhabit ant mounds in years of high abundance (Scherba 1965). On the National Bison Range, where *Peromyscus* spp. are the most commonly trapped small mammals in the grassland habitat, it is very likely that they are the rodents inhabiting mounds.

Although studies have focused on effects of both rodents and ants on soil and vegetation, few studies describe the changes in soil and vegetation that occur when mounds have rodents burrowing into them. The combined activities of both rodents and ants could perhaps create a combination of soil and vegetation characteristics that is different from those that are found when burrows and mounds occur separately. If this is the case, it would increase the patchiness of the grazed or non-grazed grassland and this resulting microenvironment could be useful in biodiversity maintenance, especially if these microenvironments are found in the cow grazed habitat.

I hypothesized that burrows which occur alone and in large clusters would have different vegetation combinations than a lone mound would and that all three types of shelters would have different vegetation combinations than that which would be found when a mound has burrows leading into it. I also hypothesized that this trend would be seen in both grasslands that are lightly grazed by deer ('non-grazed') and grasslands that are heavily grazed by cows ('grazed').

Materials and Methods

***Study Sites*:**

The National Bison Range was established in 1908. It consists of 18,500 acres that include habitats such as Palouse Prairie, forests, wetlands and streams (National Bison Range 2008). This study took place in the Palouse Prairie habitat of the National Bison Range which has been fenced off, causing many of the larger herbivores such as bison and elk to be excluded. The area is still grazed by deer, but could possibly be considered undergrazed and was therefore labeled lightly grazed or 'non-grazed' for this study. Adjacent to the non-grazed site of the Bison Range-maintained Palouse Prairie is private land that has been extensively grazed by cattle, which was used as the cow-grazed habitat in this study.

Within both the grazed and non-grazed habitats, 4 landscape features were chosen: lone mounds (mounds lacking any burrows within one meter), lone burrows (no more than 4 burrows), hotels (at least 8 burrows), and mounds with burrows either directly underneath them or within 10cm. Six replicates of each of these 4 landscape features were found for both grazed and non-grazed habitats.

Ant and Rodent Identification:

Ants were collected from every mound. To ensure that the ants were actually from the mound studied, each mound was poked and the ants that emerged were collected and identified. All mounds contained ants belonging to the genus *Formica* with some mounds also containing the obligate slave maker ant of the species *Polyergus.*

To determine what rodents were using the burrows and hotels involved in this study, traps were placed outside burrows for 3 nights for each of the 3 landscape features (lone burrows, mounds with burrows, and hotels) in both the grazed and the non-grazed grasslands. There was at least a 15-20% success rate for each trapping night and all rodents were identified as belonging to the genus *Peromyscus.*

Vegetation Surveys

Extending from the center of each treatment, vegetation surveys were conducted at four different distances: 0-0.5m, 0.5-1m, 1-2m, and 2-4m. As in King (1977), the percentage cover of each species of vegetation was estimated for each of these 4 distances. Species that were mostly seen throughout landscape features or were consistently found in one landscape feature were recorded so that the cover of 30 species could potentially be estimated for each landscape feature and distance. Separate controls were not chosen for the vegetation survey due to the difficulty in finding a large enough area unaffected by mounds or burrows. However, similar to the way in which King (1977) chose controls that were 3m from his study mounds, vegetation surveys extended to 4m so that it could be assumed that at least the outer-most distance transect was representative of the vegetation of the area and could therefore take the place of a separate control.

Of the 30 potential species for which cover was estimated, only eight species were chosen for statistical analysis based on their abundance, their effect on the percent grass and percent forbs in an area, and obvious trends observed in the field. The eight chosen species were crested wheatgrass (*Agropyron cristatum*), clasping pepperweed (*Lepidium perfoliatum*), tumbleweed mustard (*Sisymbrium altissimum*), smooth brome (*Bromus hordeaceus*), sulphur cinquefoil (*Potentilla recta*), prickly lettuce (*Latuca serriola*), species from the genus *Elymus* which consisted mainly of *Elymus smithii* (western wheatgrass) as well as some *Elymus repens* (quackgrass), and species from the genus *Polygonum*. Ideally, *Veronica* spp., which have been found to be especially abundant on ant-hills (King 1977), would have been included; however its abundance was too low in the majority of the transects for its presence to show any trends.

Soil Moisture:

Over the course of two consecutive days, soil samples were collected at the midpoint of each of the 4 distance transects used in the vegetation surveys so that a sample was collected for each of the 4 distances: 0.25m, 0.75m, 1.5m, and 3m. Soil was collected from 5-10cm below ground level, weighed, placed in a drying oven for 48 hours, and then reweighed to calculate the percent moisutre using the equation:

%moisture = (initial weight – final weight)/initial weight

Soil Compaction:

A relative measure of soil compaction was taken for comparison between distances, landscape features, and grazed and non-grazed habitats. Soil compaction was measured using a long screw firmly attached to a block of wood which was dropped from a set height, screw facing downward, through a piece of PVC piping. The distance that the screw went into the ground was measured and multiplied by negative one so that it would more accurately represent compaction during statistical analysis, and the compaction was compared across distances, landscape features, and grazed and non-grazed habitats so that it was a relative measure of compaction.

Statistical Analysis:

All of the data except for soil compaction was arc sin transformed. ANOVAs were run for soil compaction, soil moisture, bare ground, the percent of forb cover, and the percent of grass cover to see if there was a difference among the grazed and non-grazed sites, landscape features, and distances. A forward stepwise regression was run with grass species and total percent grass cover to find which species were most important in determining the percent grass cover. The same was done for forb species and percent forb cover. From the regression results, a total number of 5 species were chosen and ANOVA tests were run to see if there was a relationship of any of these species with grazing site, treatment, and distance from treatment. Similar ANOVA tests were also run on *Bromus hordeaceus*, *Polygonum* spp., and tumble mustard. *Bromus hordeaceus* was chosen based on its abundance observed in the field, and *Polygonum* spp., and tumble mustard were both chosen based on trends with landscape feature and distances observed in the field. To determine whether the farthest distance from the center of the landscape features could be considered the control for the study, ANOVA tests were repeated for the percent cover of grases, forbs, bare ground, and the 8 important plant species for only the farthest distance from the center of the landscape feature (2-4m). All ANOVAs were run with soil compaction as a covariate if it was significant, and much of the species data was log transformed before ANOVA tests were done so that the data were normally distributed.

Results:

ANOVA Results

ANOVA results indicated that the percent cover by forbs, grasses, bare ground, and 7 of the 8 chosen species did not differ between landscape features for both the grazed and the non-grazed habitat between 2-4m from the center of each landscape feature (Table 3). Only *Agropyron cristatum* showed any difference between landscape features; mounds with burrows did not increase in *Agropyron cristatum* cover in the grazed site like all of the other landscape features did (Table 3). ANOVA results also indicated that soil moisture was greater for the non-grazed site than it was for the grazed site but did not vary significantly between landscape features or distances (Table 1). For both grazing sites, soil compaction was least at the center of each landscape feature (Table 1, Fig 1). At the grazed site, lone mounds were more compact than both hotels and mounds with burrows, but at the non-grazed site they were less compact than both mounds with burrows and lone burrows (Table 1, Fig 2). Similar to the trend seen in soil compaction, only the center of the landscape feature had more bare ground than any of the other landscape features (Table 1, Fig 3). In the grazed site, mounds with burrows had significantly less bare ground than any of the other landscape features (Table 1, Fig 4); although they had less bare ground in the non-grazed than in the grazed, hotels still had more bare ground in the non-grazed site than any other landscape feature had (Table 1, Fig 4).

Percent cover by forbs was significantly greater in the non-grazed site for all landscape features and distances (Table 1, Fig 5). While the percent cover by forbs increased with distance for all of the other landscape features, it remained constant for hotels; hotels had significantly more forb cover than the other landscape features at the center of the landscape features but lone mounds had more percent forb cover than hotels at the farthest distance from the center of the landscape feature (Table 1, Fig 6). A distinct difference in percent grass cover could be seen between the first two and the last two distances for all landscape features and for both grazed and non-grazed, with the first two distances closest to the center of the landscape feature having significantly less percent cover by grass than the two farthest distances (Table 1, Fig 7). Only hotels had a significantly higher percent cover of grass in the grazed site than they did at the non-grazed site; at the non-grazed site, all other landscape features had a significantly greater percent cover by grass than the hotels had (Table 1, Fig 8).

Regression Analysis:

Regression analysis revealed that crested wheatgrass (*Agropyron cristatum*) and grasses from the genus *Elymus* had the greatest influence on the percent cover of grasses (R=0.664). A similar analysis for percent cover of forbs indicated that prickly lettuce (*Lactuca serriola*), clasping pepperweed (*Lepidium perfoliatum*), and sulphur cinquefoil (*Potentilla recta*) had the greatest influence (R=0.574).

ANOVAs for the Eight Most Relevant Plants:

Pepperweed had the most cover for the distance at the center of the landscape feature only for hotels. Pepperweed cover increased for both lone mounds and lone burrows as distance increased, and mounds with burrows had significantly more pepperweed between 0.5-1m from the center of the mound than lone mounds did (Table 2, Fig 9). Prickly lettuce was greater in the grazed than in the non-grazed for all landscape features and distances, hotels having the most prickly lettuce cover and lone mounds having the least (Table 2, Fig. 9). Sulphur cinquefoil (*Potentilla recta*) covered less area around lone mounds than any other landscape feature at the grazed site, and hotels had significantly less than any other landscape feature in the non-grazed site (Table 2, Fig 9). Grass species belonging to the genus *Elymus* had the greatest amount of cover by far around the mounds with burrows than around any of the other landscape features in the grazed section. For both grazed and non-grazed habitats, hotels had significantly less *Elymus* than any other landscape feature (Table 2, Fig 9). *Agropyron cristatum* covered much more of the lone mounds and lone burrows in the grazed habitat than hotels and mounds with burrows, and hotels had more cover than mounds with burrows; however, they all had the same amount of cover in the non-grazed section (Table 2, Fig 9). Only for mounds with burrows did *Polygonum* cover not change between grazing sites. All other landscape features showed an increase in the amount of *Polygonum* in the non-grazed site (Table 2, Fig 9). For tumble mustard, only lone mounds showed a decrease in cover for the grazed site (Table 2, Fig 9). For all landscape features and grazing sites, *Bromus hordeaceus* increased as distance from the landscape feature increased (Table 2, Fig 9). While hotels remained constant with *Bromus hordeaceus* cover throughout both grazing sites, all of the other landscape features increased so that they had more cover in the non-grazed site than hotels had. However, hotels had more *Bromus hordeaceus* cover than any of the other landscape features at the grazed site (Table 2, Fig 9).

Discussion:

The Effect of Grazing:

By both compacting soil and destroying much of the vegetation in an area through overgrazing, cows lower the soil's ability to retain water, thus contributing to the loss of grasslands via desertification (Forman 1995). Due to cow grazing, the pasture in this study that was once part of a Palouse Prairie is currently more compact and less moist than the non-grazed grassland adjacent to it. It is likely that this combination of cow grazing, increased compaction, and decreased moisture has caused the grazed habitat to have a greater percentage of bare ground and a smaller number of plant species than the non-grazed habitat. In accordance with (Damhoureye 2002) it appears as though cow grazing practices have decreased the biodiversity of the vegetation in the grazed habitat. However, it appears as though *Peromyscus* spp. and *Formica* spp. aid in the formation of mosaics through the different vegetation patches that are created surrounding their shelters.

Control Distance:

Because the percent cover by grasses, forbs, bare ground, as well as 7 of the 8 studied plant species were consistent over landscape features in grazed and non-grazed habitats for the farthest distance measured from the center of the landscape features (2-4m), it is fair to assume that that distance serves as a control and that the vegetation within that distance represents the vegetation composition of the grazed or non-grazed land that is unaffected by *Peromyscus* or *Formica* burrowing activity. This is in accordance with King (1977) who, when working with ants, chose controls that were 3m from study mounds.

Lone Mounds

In the non-grazed habitat, vegetation surrounding lone mounds did not differ much from the vegetation at the control distances. Vegetation around the lone mounds in the non-grazed habitat was comprised mainly of clasping pepperweed, *Elymus* spp., and

Bromus hordeaceus all of which were similar to if not slightly greater than the cover of those species in the control distance (Table 2, Fig. 9). Tumble mustard and *Potentilla recta* each represented about 10% of the vegetation cover in the area surrounding the lone mounds, and *Polygonum* spp. generally covered slightly less than that (Fig 9). The trace amounts of prickly lettuce and *Agropyron cristatum* found around lone mounds in the non-grazed habitat each comprised slightly less of the overall vegetation cover around lone mounds than they did at control distances.

Ant mounds tend to increase cause plants that are characteristic of over-grazed grasslands to increase in number (Farrow 1925, King 1977). This was seen in lone mounds in the grazed habitat, where the vegetation composition around the lone mounds consisted of only four of the studied species (half the amount it had in the non-grazed habitat) and was chiefly dominated by *Agropyron cristatum* which comprised over 50% of the vegetation cover (Fig 9). This was much greater for lone mounds than for the controls, hotels, and mounds with burrows. Because of its drought tolerance, ability to stabilize the soil and outcompete cheatgrass, and its palatability to all classes of livestock and wildlife, *Agropyron cristatum* is often recommended for forage production and (USDA 2008) and was very likely planted at one point in time in the grazed habitat. Lone mounds appear to increase the amount of *Agropyron cristatum* in a given area of the non-grazed habitat (Table 2, Fig 9). *Elymus* spp. provides approximately 20% of the vegetation cover around lone mounds, and pepperweed provides slightly less cover than that. Similar to the vegetation at the control distance, *Bromus hordeaceus* comprises around 10-15% of the total vegetation cover around mounds. Unlike the control or any of the other landscape features, lone mounds do not promote growth of *Potentilla recta* in the grazed habitat (Table 2, Fig. 9). Of the eight chosen species, lone mounds also lacked tumbleweed mustard, prickly lettuce, and *Polygonum.*

The number of chosen species was lower around lone mounds than it was for the control or any of the other landscape features in the grazed habitat (Fig 9). This could have been caused by soil compaction which was greater for lone mounds than it was for any other landscape feature in the grazed habitat. This increase in soil compaction probably caused the huge increase in bare ground in the grazed habitat which was greater than any of the other landscape features. Out of all four landscape features, lone mounds showed the most drastic increase in soil compaction between the non-grazed and grazed sites (Table 1, Fig 4) thus indicating that burrowing activity plays a role in regulating the degree of soil compaction.

Lone Burrows

In the non-grazed habitat, the vegetation around lone burrows was comprised mainly of *Elymus* spp., pepperweed, *Polygonum* spp., *Bromus hordeaceus,* and prickly lettuce—all of which represented a similar percentage of the vegetation cover (Fig. 9). Lone burrows increased the amount of *Polygonum* found in the non-grazed habitat. *Potentilla recta, Agropyron cristatum,* and tumbleweed mustard each comprised less than 5% of the vegetation cover around lone burrows (Fig 9).

In the grazed habitat, the amount of vegetation cover immediately surrounding lone burrows consisted of only 5 of the 8 studied species. Lone burrows lacked the tumbleweed mustard and prickly lettuce that comprised part of the vegetation cover at the control distances as well as at the mounds with burrows and hotels. This was most likely due to the high soil compaction that was found in lone burrows in the grazed habitat.

Potentilla recta, Bromus hordeaceus, Elymus spp., and clasping pepperweed each comprised about 10% of the vegetation cover. Similar to the vegetation around lone mounds, the vegetation surrounding lone burrows had much more compact soil in the grazed habitat than either hotels or mounds with burrows had which could likely account for the decrease in plant species relative to hotels and mounds with burrows. Similarly, lone burrows had a more drastic change in bare ground cover than hotels or mounds with burrows. Also similar to the vegetation surrounding lone mounds, the vegetation surrounding lone burrows had a greater amount of *Agropyron cristatum* cover (>50%) than the control distances or the hotels or mounds with burrows.

Hotels:

In the non-grazed habitat, vegetation cover surrounding hotels was dominated by pepperweed, which represented over 40% of the cover. *Peromyscus maniculatus* has been shown to prefer pepperweed seeds and to foster the growth of pepperweed plants through their foraging and seed caching habits (Nowalk 2007; Vander Wall et. al. 2005). Because numerous *Peromyscus* inhabit one hotel, this effect was likely multiplied, thus causing the concentration of pepperweed to be much greater around hotels than could be found in any other area of the study. Also, pepperweed grows well on disturbed soil (Sackschewsky and Downs 1992); since there are so many rodents, the area of disturbance covers a greater area in hotels than in the other landscape features. This is probably why the hotel was the only landscape feature to have a consistent number of forbs throughout all four distances. The larger area of disturbance found in the hotels most likely explains the larger amount of bare ground found around hotels than around lone mounds and lone burrows in the non-grazed habitat

In the non-grazed habitat, *Polygonum* spp. and prickly lettuce each comprised slightly less than 20% of the vegetation cover surrounding hotels. There was less *Bromus hordeaceus* around hotels (10% of the vegetation cover) than around the control distance or any of the other landscape features (Table 2, Fig 9). There were only trace amounts of *Elymus,* tumbleweed mustard, and *Potentilla recta*. Similar to lone burrows, hotels had a greater amount of *Polygonum* spp. and prickly lettuce than the control distance or either of the mounds (Table 2, Fig 9). However, hotels had much less *Elymus* and *Potentilla recta* than the control distance or any of the landscape features (Table 2, Fig 9).

Although it still represented the greatest amount of vegetation cover around hotels or anywhere else in the grazed habitat, there was less pepperweed cover in the grazed than in the non-grazed habitats (Table 2, Fig 9). Unlike forbs, grasses especially prairie grasses which evolved with numerous large herbivores and Agropyron cristatum, tend to have a high grazing tolerance (Damhoureye 2002) This could explain the decrease in pepperweed cover seen around hotels in the grazed habitat as well as the decrease that was seen in the overall percent cover of forbs for all landscape features and control distances. Because the amount of forbs decreased in the grazed habitat, the amount of grass cover increased for the hotels most of all. Even though there is less vegetation and more bare ground in the cattle grazed area, because there is less pepperweed, there is more room for grasses such as *Agropyron cristatum* and *Bromus hordeaceus* to grow (*Agropyron cristatum* comprised almost 30% and *Bromus hordeaceus* nearly 20%). Tumbleweed mustard*, Elymus*, *Potentilla recta*, and prickly lettuce were all under 10%. Overall, for both grazed and non-grazed habitats, hotels had the least amount of *Elymus* species.

Mounds with Burrows:

In the non-grazed habitat, pepperweed comprised the largest percent of vegetation cover around mounds with burrows (approximately 30% cover). Next was *Elymus* and *Bromus hordeaceus* at approximately 20% cover and prickly lettuce with approximately 15% cover. *Agropyron cristatum,* tumbleweed mustard, *Potentilla recta,* and *Polygonum* spp. all comprised less than 10% of the vegetation cover (Fig 9). Thus, the presence of mounds with burrows increased the amount of pepperweed in the non-grazed habitat, but to a lesser degree than hotels did (Table 2, Fig 9).

In the grazed habitat, pepperweed only comprised between 5-10% of the total vegetation cover around the mounds with burrows. Whereas *Agropyron cristatum* replaced pepperweed around hotels in the grazed habitat, *Elymus* spp. represented 35% of the vegetation cover surrounding mounds with burrows in the grazed habitat. *Agropyron cristatum,* along with *Potentilla recta* and tumbleweed mustard, each only comprised 10% of the vegetation cover around the mounds with burrows. *Bromus hordeaceus* represented 20% of the vegetation cover and prickly lettuce and *Polygonum* both provided only trace amounts of cover (Fig 9).

The mound with burrows was the only landscape feature to have all 8 study species make up its vegetation cover in the grazed habitat; even the control only had 7 species. In the grazed habitat, mounds with burrows had the least amount of bare ground. In the grazed habitat, mounds with burrows dramatically increased the amount of *Elymus* cover and decreased the amount of pepperweed cover in an area; they were also the only place where *Polygonum* could be found in the grazed habitat. With the exception of a perppperweed-*Elymus* switch in terms of the dominant vegetation cover, mounds with burrows appeared to maintain a relatively constant vegetation and soil composition between the grazed and non-grazed habitats; this was seen more in mounds with burrows than in any other treatment (Table 2, Fig 9). Because the mound with burrows was the only landscape feature to have more than one sutdy species burrowing or tunneling through the soil, these findings are in accordance with Tilman and Downing (1996) who claimed that "biodiversity begets stability."

Conclusion:

In conclusion, the data indicate that all four landscape features affect the vegetation differently so that each has a distinctive vegetation composition, and that they continue to have different vegetation compositions than one another regardless of grazing (Fig 9). The grazed site brought out sharper differences both among all of landscape features as well as between the landscape features and the vegetation that was typical of the grazed habitats. Because soil moisture was relatively constant within each grazing regimen, these findings are in accordance with Bestelmeyer et al (2001) that plant communities may co-vary with animal communities when soil composition is held fairly constant. This could potentially have implications regarding maintenance of biodiversity in cow grazed pastures, especially since the mounds with burrows had fairly consistent vegetation composition between grazed and non-grazed habitats relative to the other landscape features.

One important fact to note about the study sites in terms of the importance of landscape mosaics in biodiversity maintenance is the proximity of the cow grazed site to the non-grazed site. It has been suggested as a wise method of maintaining biodiversity is to keep natural sites close to sites for varying land use (Forman 1995). It is very possible, that some plants found in the grazed site such as pepperweed, which was mainly found in the non-grazed site and around hotels in the grazed, would not have remained in the cattle grazed site if the rodents had not been able to bring it over from the non-grazed site.

Possible Problems and Future Studies

Because the effects of anthills on vegetation depend on the age of the mound (Jakubczyk 1972), it is possible, but not likely, that all of the mounds with burrows were of a different age than all of the lone mounds. In order to test that this is the case, an improved version of this study should look into the possibility of aging mounds to ensure that all mounds are the same age. Also soil temperature should be measured to see the differences in soil temperature between each landscape feature since ant mounds have been found to increase the temperature of their mounds and to have that temperature vary depending on the side of the mound (Folgairt 1988). Because rare plant species have been found either confined to ant mounds or to be more abundant around ant mounds in grasslands (King 1977), ideally a mosaic map should be created in which all 30 species surveyed for vegetation cover are represented. It would be expected that this would show an even greater difference in the composition of vegetation patches around landscape features.

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Table 1: Results of ANOVA test for soil data.
The independent variables were grazing site, mound or burrow type (treatment), distance from center of type (treatment).
When it was significant, soil compaction was used as a covariate.

TREATMENT	Moisture			Compaction			Bare Ground			% Grass			% Forb		
	f stat	df	p-value	f stat	df	p-value	f stat	df	p-value	f stat	Df	p-value	f stat	df	p-value
Grazed	5.044	1	0.026	176.703	1	0	119.391	1	0	1.711	1	0.193	191.213	1	0
Type	0.481	3	0.696	1.444	3	0.232	5.554	3	0.001	3.522	3	0.016	0.832	3	0.478
Distance	0.241	3	0.867	2.782	3	0.043	13.273	3	0	9.505	3	0	13.185	3	0
Grazed* Type	0.584	3	0.627	2.52	3	0.06	7.46	3	0	2.623	3	0.052	1.048	3	0.373
Grazed * Distance	0.359	9	0.782	0.124	3	0.946	2.186	3	0.092	0.249	3	0.862	2.037	3	0.111
Type* Distance	0.819	9	0.6	0.897	9	0.529	1.044	9	0.408	0.69	9	0.717	1.935	9	0.05
Type*Dis*Grazed	0.495	1	0.876	1.113	9	0.356	0.737	9	0.675	0.238	9	0.988	0.743	9	0.669
Covariate (Compaction)	—	—	—	—	—	—	—	—	—	9.956	1	0.002	—	—	—

Table 2: Results of ANOVA tests on the 8 most 'important species' across all of the landscape features, distances and grazing sites. The independent variables were grazing site, type (treatment) of burrow or mound, and distance from the center of each treatment. When it was significant, soil compaction was used as a covariate.

TREATMENT	Pepperweed			Tumble mustard			Elymus			A. cristatum		
	f stat	df	p-value	f stat	df	p-value	f stat	df	p-value	f stat	Df	p-value
Grazed	10.113	1	0.002	1.825	1	0.179	0.001	1	0.980	90.585	1	0
Type	15.106	3	0	1.394	3	0.247	8.557	3	0	7.602	3	0
Distance	4.436	3	0.005	2.005	3	0.115	1.11	3	0.347	2.178	3	0.093
Grazed* Type	2.892	3	0.037	3.8	3	0.011	4.274	3	0.006	10.741	3	0
Grazed * Distance	2.96	3	0.034	1.531	3	0.209	0.061	3	0.980	0.113	3	0.952
Type* Distance	3.026	9	0.002	0.347	9	0.957	0.48	9	0.886	0.528	9	0.852
Type*Dis*Grazed	1.184	9	0.309	0.335	9	0.962	0.273	9	0.981	0.352	9	0.956
Covariate (Compaction)	4.49	1	0.036	—	—	—	10.615	1	0.001	—	—	—

TREATMENT	Polygonum			Bromus			Potentilla recta			Prickly lettuce		
	f stat	df	p-value	f stat	df	p-value	f stat	df	p-value	f stat	Df	p-value
Grazed	128.21	1	0	26.866	1	0	11.488	1	0.001	93.097	1	0
Type	4.145	3	0.007	1.422	3	0.238	1.511	3	0.214	7.14	3	0
Distance	1.323	3	0.269	3.488	3	0.017	2.329	3	0.076	1.218	3	0.305
Grazed* Type	9.243	3	0	5.37	3	0.002	7.088	3	0	1.465	3	0.226
Grazed * Distance	1.833	3	0.143	0.266	3	0.85	0.747	3	0.526	0.329	3	0.805
Type* Distance	0.784	9	0.631	0.141	9	0.998	0.409	9	0.929	0.213	9	0.992
Type*Dis*Grazed	0.78	9	0.635	0.476	9	0.889	0.826	9	0.593	0.282	9	0.979
Covariate (Compaction)	—	—	—	—	—	—	—	—	—	—	—	—

Table 3: ANOVA results for the effect of landscape features and grazed habitats on the percent cover of bare ground, forbs, grasses, and all eight plant species at a distance between 2 and 4 meters from the center of each treatment. The independent variables were the amount of grazing and the type of landscape feature.

TREATMENT	Pepperweed			tumble mustard			Elymus			A. cristatum		
	f stat	df	p-value	f stat	df	p-value	f stat	df	p-value	f stat	df	p-value
Grazed	13.31	1	0.001	4.174	1	0.048	4.546	1	0.039	20.347	1	0
Type	0.62	3	0.606	0.067	3	0.977	2.012	3	0.128	3.419	3	0.026
Grazed* Type	0.861	3	0.469	1.536	3	0.22	2.301	3	0.092	3.354	3	0.028
TREATMENT	Polygonum			Bromus			Potentilla recta			Prickly lettuce		
	f stat	df	p-value	f stat	df	p-value	f stat	df	p-value	f stat	df	p-value
Grazed	43.756	1	0	3.292	1	0.077	6.633	1	0.014	20.479	1	0
Type	1.109	3	0.357	0.453	3	0.717	1.697	3	0.183	0.633	3	0.598
Grazed* Type	1.109	3	0.357	1.409	3	0.254	1.093	3	0.363	0.289	3	0.833
TREATMENT	Bare Ground			% Grass			% Forb					
	f stat	df	p-value	f stat	df	p-value	f stat	df	p-value			
Grazed	1.381	1	0	0.245	1	0.623	4.693	1	0			
Type	1.05	3	0.381	1.708	3	0.181	0.128	3	0.1			
Grazed* Type	1.525	3	0.223	0.736	3	0.536	0.017	3	0.829			

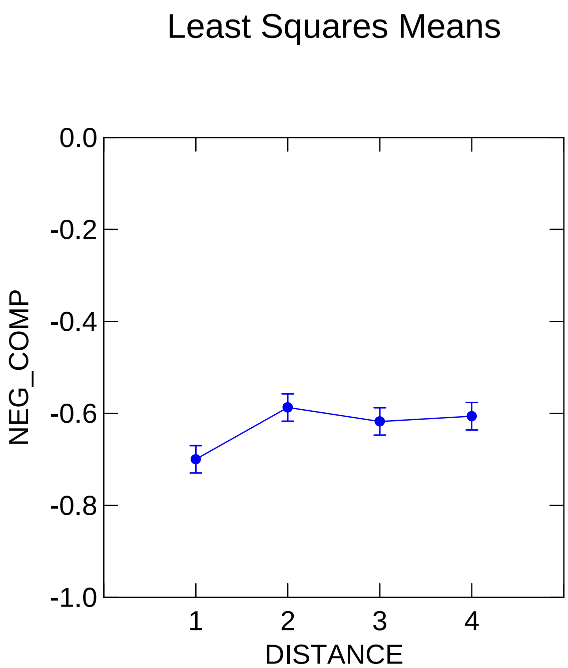


Fig 1: Effects of Distance from Landscape featureon Soil compaction

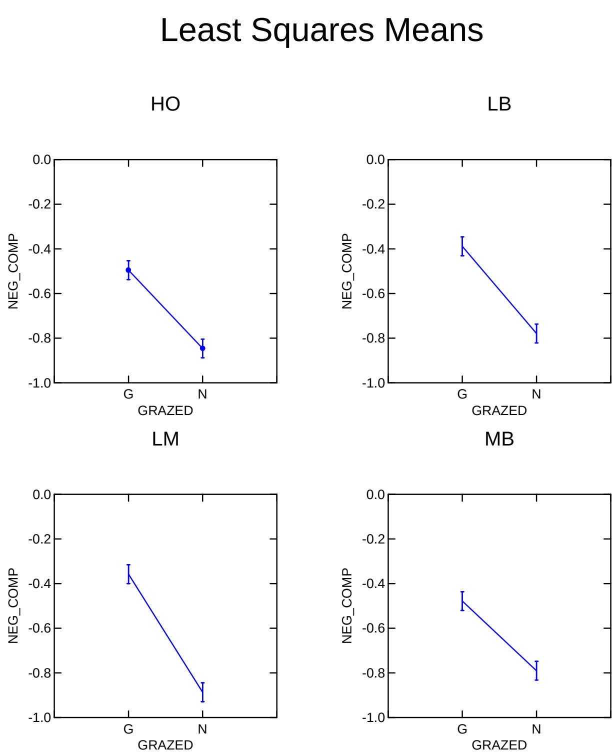


Fig 2: Soil Compaction: Interaction Between Grazing and Treatment

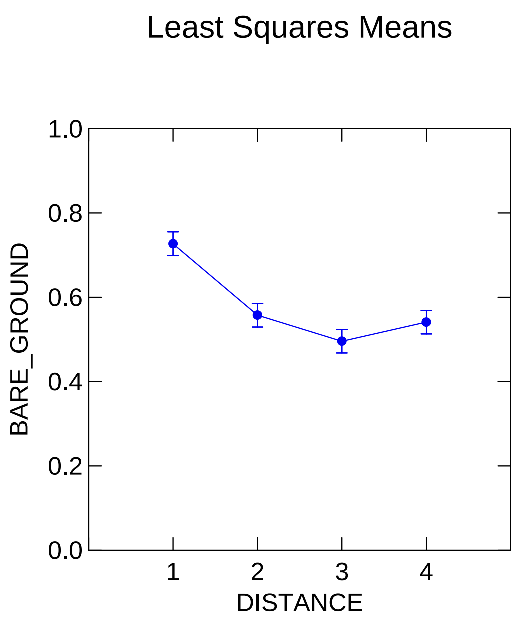


Figure 3: The Effect of Distance from the Center of Each Landscape feature on Bare Ground

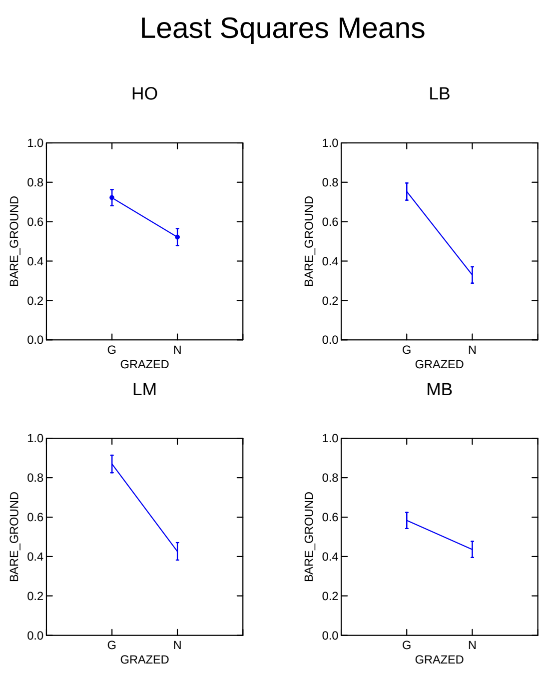


Figure 4: The interaction between landscape feature and grazing on bare ground.

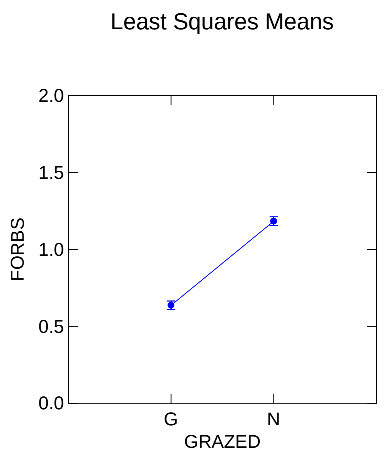


Figure 5: The effect of grazing on the percent cover by forbs

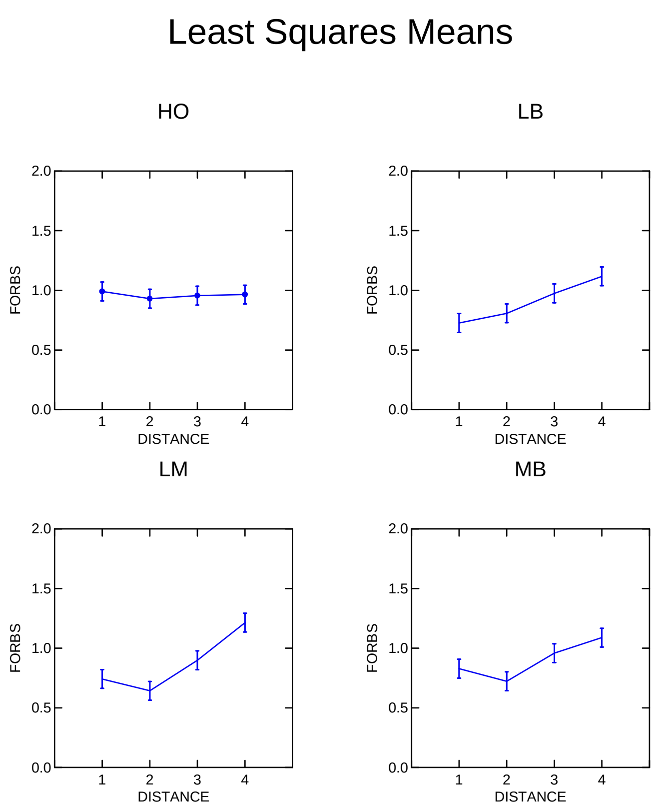


Figure 6: Interaction between the effect of distance and landscape feature on the percent cover by forbs

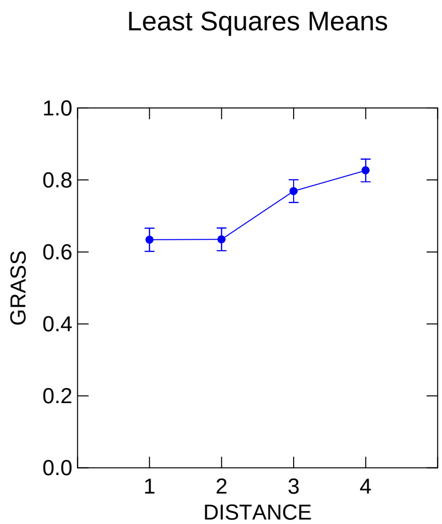


Figure 7: The effect of the distance from the center of each landscape feature on the percent cover by grass.

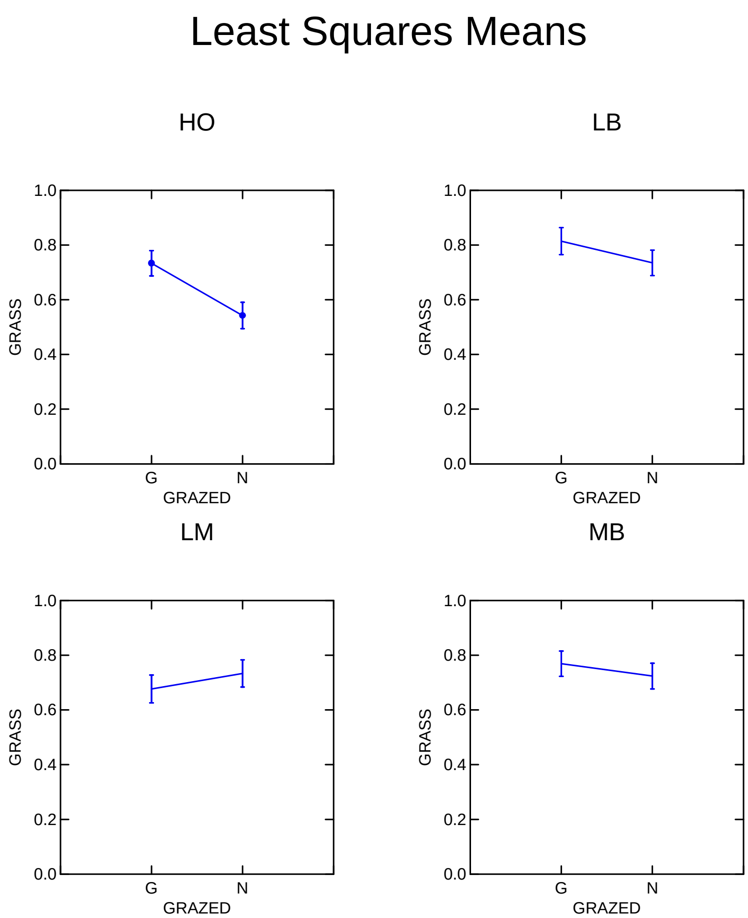
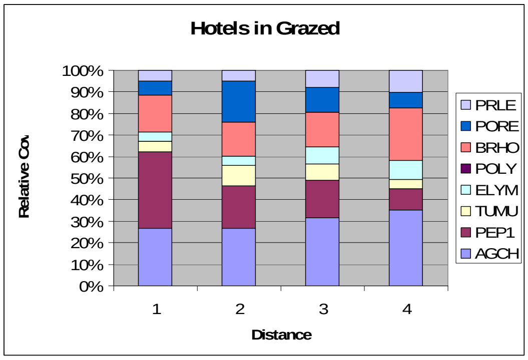
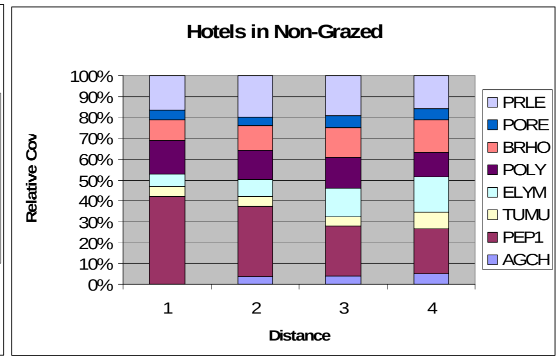


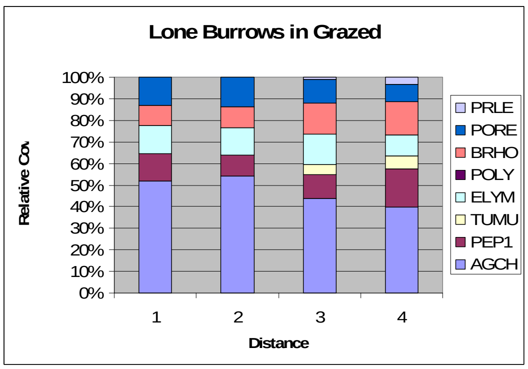
Figure 8: Interaction between the effect of grazing and landscape feature on the percent cover by grass.


Hotels in Grazed
100%
90%
80%
70%
60%
50%
40%
30%
20%
10%
0%
Relative Cov
1
2
3
4
Distance
PRLE
PORE
BRHO
POLY
ELYM
TUMU
PEP1
AGCH

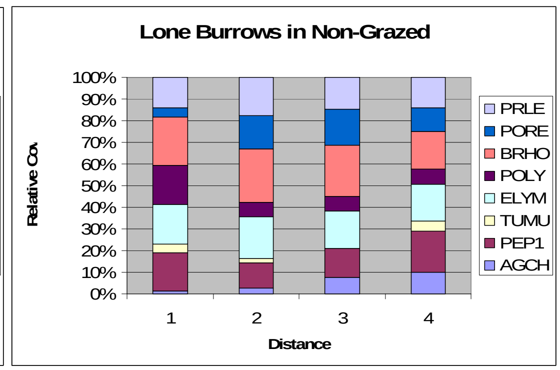
(a)


Hotels in Non-Grazed
100%
90%
80%
70%
60%
50%
40%
30%
20%
10%
0%
Relative Cov
1
2
3
4
Distance
PRLE
PORE
BRHO
POLY
ELYM
TUMU
PEP1
AGCH

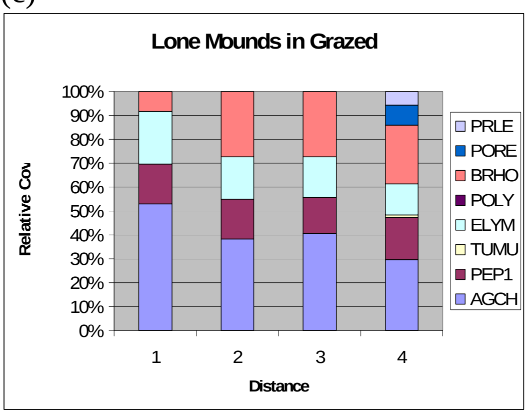
(b)


Lone Burrows in Grazed
100%
90%
80%
70%
60%
50%
40%
30%
20%
10%
0%
Relative Cov
1
2
3
4
Distance
PRLE
PORE
BRHO
POLY
ELYM
TUMU
PEP1
AGCH

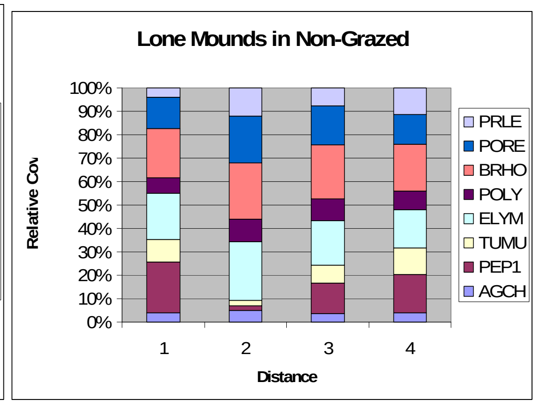
(c)


Lone Burrows in Non-Grazed
100%
90%
80%
70%
60%
50%
40%
30%
20%
10%
0%
Relative Cov
1
2
3
4
Distance
PRLE
PORE
BRHO
POLY
ELYM
TUMU
PEP1
AGCH

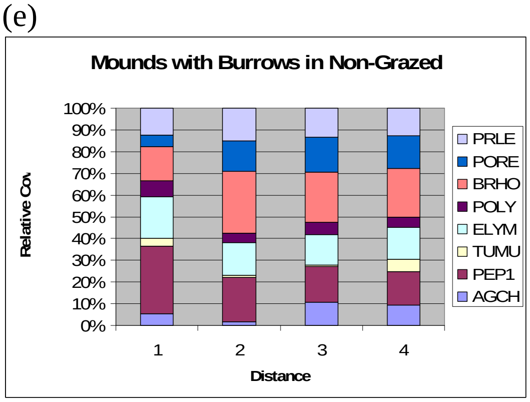
(d)


Lone Mounds in Grazed
100%
90%
80%
70%
60%
50%
40%
30%
20%
10%
0%
Relative Cov
1
2
3
4
Distance
PRLE
PORE
BRHO
POLY
ELYM
TUMU
PEP1
AGCH

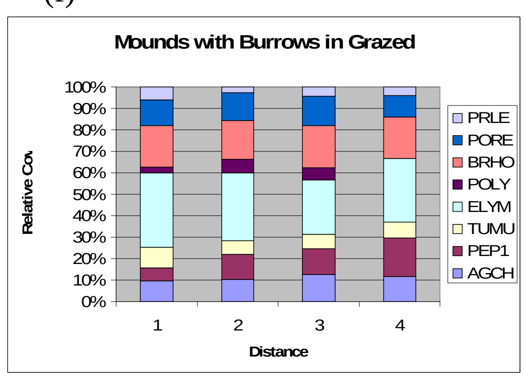
(e)


Lone Mounds in Non-Grazed
100%
90%
80%
70%
60%
50%
40%
30%
20%
10%
0%
Relative Cov
1
2
3
4
Distance
PRLE
PORE
BRHO
POLY
ELYM
TUMU
PEP1
AGCH

(f)


Mounds with Burrows in Non-Grazed
100%
90%
80%
70%
60%
50%
40%
30%
20%
10%
0%
Relative Cov
1
2
3
4
Distance
PRLE
PORE
BRHO
POLY
ELYM
TUMU
PEP1
AGCH

(g)


Mounds with Burrows in Grazed
100%
90%
80%
70%
60%
50%
40%
30%
20%
10%
0%
Relative Cov
1
2
3
4
Distance
PRLE
PORE
BRHO
POLY
ELYM
TUMU
PEP1
AGCH

(h)

Figure 9: Relative cover of 8 different plant species separated according to grazed, treatment, and distance. (a) hotels at the cow-grazed site (b) hotels at the non-grazed site (c) lone burrows in the cow-grazed site (d) lone burrows in the non-grazed site (e) lone mounds in the cow-grazed site (f) lone mounds in the non-grazed site (g) mounds with burrows at the cow-grazed site (h) mounds with burrows in the non-grazed site.