

INFLUENCE OF HABITAT HETEROGENEITY ON SMALL MAMMALS IN THE
CENTRAL PLATTE RIVER VALLEY, NEBRASKA

being

A Thesis Presented to the Graduate Faculty
of the Fort Hays State University
in Partial Fulfillment of the Requirements for
the Degree of Master of Science

by

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PREFACE

This thesis is written in the style of the Journal of Wildlife Management, to which a portion will be submitted for publication.

ABSTRACT

Although the loss of prairie is substantial across the extent of its historic range, large portions of native rangeland still remain throughout Nebraska. It is critical that resource managers and private landowners manage rangelands in a manner that will enhance ecosystem integrity by using techniques that provide disturbance regimes. Heterogeneity based management, such as patch-burn grazing and rest-rotation grazing, can be used as a conservation tool to increase biodiversity within management units and at a landscape level. Heterogeneity-based management has received much attention in the literature within the past decade, but there has been little focus on how these management systems influence small mammal communities. I trapped small mammals and surveyed vegetation structure among rangelands during 2009 and 2010 at the Platte River Whooping Crane Maintenance Trust in the Central Platte River Valley, Nebraska to determine the influence of structural heterogeneity on small mammals. Vertical height, litter depth, bareground, and standing dead vegetation were different among burn units during both years. My data indicated no difference in grasses, forbs, or litter cover among burn units for either year. I used the significant variables in a direct gradient analysis to identify which variables were critical in determining small mammal species presence. The species identified with vegetation variables for 2009 but not 2010 suggested there were other variables not considered in my study. Species diversity measurements indicated the recently disturbed burn units had the lowest small mammal diversity and the undisturbed burn units had the greatest diversity. Community similarity

was highest among similar burn units, which indicated that small mammal communities were similar among similar burn units during 2009 and 2010. Resource managers should recognize that alternative grazing systems that create a mosaic of vegetation structure can provide evolutionary processes necessary for prairie ecosystem function. Small mammals play a crucial role in grassland ecosystems and by using heterogeneity-based management, small mammal diversity increased which can lead to a healthier ecosystem.

ACKNOWLEDGMENTS

There are many people to thank for all the help and hard work that it took to accomplish this project. First, thanks to my advisor, Dr. Elmer J. Finck, for his insight, support, and encouragement. Dr. Finck's guidance has been invaluable in my development in the wildlife profession. Thanks to my committee members Dr. Robert B. Channell and Dr. Felipe Chavez-Ramirez, for their support with experimental design and technical analysis, the late Dr. Jerry Choate for his insight early on, and to Dr. Jordana J. LaFantasie for her input at such short notice on my graduate committee.

I thank the Platte River Whooping Crane Maintenance Trust, Inc. (the Trust) for the funding necessary to complete this project. A special thanks to Dr. Chavez-Ramirez, who played a major role in my decision to attend graduate school and in the development of my research. Without the funding and support of Dr. Chavez-Ramirez and the Trust my project would not have been possible. I also thank Dr. Dan H. Kim, and Dr. Luis Enrique Ramirez-Yáñez from the Trust who were always available for advice. Also, thanks to The Nature Conservancy's Chris Helzer and Chris Rundstrom for allowing me access to The Nature Conservancy's properties.

I thank everyone in the Department of Biological Sciences at FHSU. The graduate students and faculty provided a great environment to learn and grow as a professional. I especially thank my colleagues Alexander L. Galt, Chasen C. Gann, Justin V. Hamilton, and Zachary J. Schwenke, who were always available to provide insight and advice throughout my project

I thank everyone who volunteered to collect data in the field: Justin V. Hamilton, Ashlee Inslee, Zachary J. Schwenke, and the students from the Ciencias Forestales department at the Universidad Autonoma de Nuevo Leon. They were able to provide many hours of hard work in unfavorable conditions to help me reach my research goals. Special thanks go to my mother and sisters, Julie, Chelsea, and Samantha Aeschliman, and the rest of my family and friends for their encouragement throughout my academic career. Last but not least, I thank Stephanie Palmer for her love, encouragement, and understanding throughout this entire process.

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INTRODUCTION

The prairie ecosystem is one of the most endangered ecosystems on the planet (Samson et al. 2004). Nebraska was historically a landscape dominated by prairie vegetation; however, urbanization and agricultural practices have caused the destruction and degradation of this ecosystem leaving few unaltered native grasslands. Today, over half (53.8%) of Nebraska is used as rangeland (Brenner et al. 2001). Because of the endangered state of the prairie ecosystem throughout North America, the remaining prairies in Nebraska need to be managed with techniques that will conserve prairie ecosystem function by emulating historical disturbance regimes (Fuhlendorf and Engle 2004).

Traditionally, rangeland management has focused on the equilibrium paradigm (Fuhlendorf and Engle 2001). Under this paradigm, cattle (*Bos taurus*) are controlled to forage all burn units evenly, decreasing the historic variability of rangelands (Vermeire et al. 2004). This leads to homogenization of vegetation structure that does not vary over space and time. Heterogeneity of vegetation structure, or the variability in vegetation attributes, is thought to be the cause of biodiversity within rangelands (Fuhlendorf and Engle 2004). By using heterogeneity-based approaches that alter disturbances spatially and temporally, ecosystem function and biodiversity could be promoted in rangelands (Anderson 2006).

Many grasslands have been altered to accommodate livestock production. This includes prescribed fires in the spring to promote grass production for cattle forage. The

Platte River Whooping Crane Maintenance Trust, Inc (the Trust), located in the Central Platte River Valley, Hall County, Nebraska, has implemented 2 grazing systems: patch-burn grazing (PBG) and rest-rotation grazing (RRG). The purpose of these grazing systems is to create a heterogeneous landscape that increases biodiversity by providing the evolutionary pattern of the fire-grazing interaction (Fuhlendorf and Engle 2004). Furthermore, these systems provide cattle ranchers a grazing system that could improve forage quality for livestock while implementing wildlife conservation goals. While the topic of heterogeneity-based management has received much attention, there has been little investigation into its effects on small mammals in the Great Plains region especially in mesic prairie settings.

Vertebrates play a role in the evolution of prairie vegetation just as prairie vegetation plays a role in the evolution of its associated vertebrates. Small mammals contribute to overall prairie ecosystem health because they function on many trophic levels (Sieg 1987). Soil chemistry and structure are influenced by small mammals. Many rodents dig burrows, which influence water permeability, create microhabitats for other organisms, and deposit excrement adding nitrogen (Sieg 1987). Small mammals can affect vegetation directly in a variety of ways and many species play unique roles within the ecosystem. For example, the feeding ecology of *Reithrodontomys megalotis*, a granivore, and *Microtus pennsylvanicus*, an herbivore, can affect the species composition and distribution of grasses and forbs through seed caching and grazing, respectively (Fraser and Madson 2008). Voles (*Microtus* spp.) have been documented changing the

community structure of grasses over a relatively short time period (6 yrs) through selective herbivory when it is the dominant grazer (Howe et al. 2006). Feeding ecology also can be pivotal in mycorrhizal fungi and nitrogen-fixing bacteria dispersal, which play critical roles in grassland plant physiology (Maser et al. 1988). Population dynamics of small mammals impact populations of predators and prey within prairie ecosystems (Sieg 1987). Omnivorous and insectivorous species of small mammals have a regulatory effect on arthropod and other invertebrate populations (Churchfield et al. 1991). A species of shrew, *Blarina brevicauda*, is a predator of small mammal and insect species. Also, small mammals can serve as a prey base for mammalian, reptilian, and avian predators. Furthermore, management that impacts populations of small mammals could lead to undesired effects such as trophic cascades.

The grazing systems the Trust used might influence small mammal populations on the property they manage. For example, small mammal communities vary in species composition based on the successional stage of the vegetation (Grant et al. 1982, Clark and Kaufman 1991, Sietman et al. 1994, Rosenstock 1996, Matlack et al. 2001, Weir et al. 2007). Grazing large ungulates, such as cattle, is a technique common in range management. Cattle grazing can affect small mammals directly by trampling burrows, nests, and plant cover, compacting soil, and competing for food resources. Cattle can indirectly affect the prey base for insectivorous small mammals by attracting competitors such as the brown-headed cowbird (*Molothrus ater*), which forages for insects around grazing cattle herds.

Prescribed burning in spring is another technique used commonly in range management. Prescribed fires under the appropriate conditions can increase plant growth, stem density of grasses, and eliminate litter (Collins 1990). Spring burns have a large influence on small mammals (Kaufman et al. 1990). In previous studies, fire had a positive effect, increasing abundance of *Peromyscus maniculatus* while having a negative effect, decreasing abundance of *R. megalotis* (Clark and Kaufman 1991; Kaufman et al. 1988). This is likely due to the change in vegetation structure and the amount of available plant litter.

Time between fires is likely to be just as influential as the disturbance event. Structurally different habitats arise from patches that vary in fire intensity and fire return (Fuhlendorf and Engle 2004). The effect of the fire-grazing interaction in a prairie mosaic of rested patches needs to be further studied with regards to small mammals. This interaction can affect small mammals indirectly by creating patches with diverse vegetation structure, which influence habitat selection of small mammals (Matlack et al. 2001). Small mammals have distinct habitat requirements that must be met for a particular species to occupy an area. Fire and grazing that differ spatially and temporally can create a shifting mosaic of habitats that are necessary to support diverse small mammal communities across the landscape (Fuhlendorf and Engle 2004, Weir et al. 2007).

My study examined how small mammals were influenced by fire and grazing effects on vegetation structure. The objectives of my study were: 1) Small mammal

population characteristics: determine if small mammal population sizes varied over time, and if sex ratios were equal, 2) Vegetational attributes: determine if vegetation structure differed among burn units and seasons, 3) Microhabitat use: relate small mammal species abundances to the vegetation structure, and 4) Small mammal community assessments: measure alpha diversity within burn units and beta diversity among burn units. I hypothesized that vegetation structure will differ among grazing and fire treatments and small mammal species abundance and community structure will relate to the vegetation structure.

STUDY AREA

All sites were located in the Central Platte River Valley in Hall County, Nebraska. The majority of the study was conducted on land managed by the Trust and additional sites were provided by The Nature Conservancy (Figs. 1 and 2). This area experiences 160 frost free growing days. Average precipitation is 630 mm occurring between May and September. Soils consist of loamy or sandy alluvial deposits (Henszey et al. 2004).

Vegetative communities of the area are classified based on the ground water-level gradient (Henszey et al. 2004). Plant communities, along the ground water-level gradient, were emergent, sedge meadow, mesic prairie, and dry ridge along the Platte River (Henszey et al. 2004). The pastures used for the purpose of this study were characteristic of tallgrass prairie and were classified as sedge meadow or mesic prairie. Sedge meadows were dominated by sedges (*Carex* sp.), rushes (*Eleocharis palustris*, *Scirpus* sp., and *Juncus* sp.) and prairie cordgrass (*Spartina pectinata*). Mesic prairies were characterized by big bluestem (*Andropogon gerardii*), little bluestem (*Schizachyrium scoparium*), Indiangrass (*Sorghastrum nutans*), switchgrass (*Panicum virgatum*), Canada wildrye (*Elymus canadensis*), and prairie cordgrass. Common forbs include goldenrod (*Solidago* sp.), prairie clover (*Dalea purpurea*), sunflower (*Helianthus* spp.), woolly verbena (*Verbena stricta*), Baldwin's ironweed (*Vernonia baldwinii*), and milkweed (*Asclepias* sp.). Non-native cool season grasses included smooth brome (*Bromus inermis*), red top (*Agrostis stolonifera*), Kentucky bluegrass (*Poa pratensis*), and meadow fescue (*Schedonorus pratensis*).

In the past, The Trust has used many techniques to manage its land. Some of these included traditional grazing and haying. The Trust currently manages most of Wild Rose Ranch and Mormon Island for biodiversity by using the rest-rotation grazing system (Fig. 2). The Nature Conservancy and The Trust both used the patch-burn grazing system to manage portions of their properties (Fig. 1). Patch-burn grazing and rest-rotation grazing operates on the concept of focal grazing following a prescribed burn. Prescribed burning is used as a grazing distribution tool because post-fire growth attracts large herbivores (Vermeire et al. 2004). The patch-burn grazing system was comprised of 4 burn units in a single fenced in area. Each burn unit was burned once in a 4 year rotation. The cattle were placed on the PBG system and allowed to graze from 1 May until 15 October of each year. The patch-burn treatment promoted focal grazing because cattle spend the majority of their grazing time within recently burned units (Fuhlendorf and Engle 2004). The rest-rotation grazing system used 4 separately fenced burn units. Cattle were moved between current and 1 year post burn units in a given year. Like the PBG system, the RRG system was also rotated every 4 years to complete the cycle. For example, on the Trust's RRG system, burn unit A is burned in April of year 1, and is grazed from 1 May to 30 June before moving the cattle to the burn unit burned the previous spring (burn unit B). The cattle will then graze burn unit B from 1 July to 31 August before they are returned to burn unit A from 1 September until 15 October when they are removed. The other 2 burn units, C and D, will remain ungrazed during year 1. During year 2, burn unit A will be grazed during the summer (1 July to 31 August) while

in years 3 and 4 burn unit A will be rested. The burn units that required management were burned between late March to early May and underwent similar grazing intensity (1.2 to 1.5 animal unit months per ha).

METHODS

I focused trapping efforts primarily on the RRG system because cattle were restricted from the rested burn units. I sampled all 4 burn units of the RRG system and only 2 burn units within the PBG system (recently burned unit, and 1 year post burned unit). This gave me 6 burn units that was replicated 3 times (Table 1, Figs. 1 and 2). In 2009, 1 replicate of the PBG system was supplied by TNC (Fig. 1, TNC 1). In 2010, 1 of the Trust's PBG replicates did not get burned as scheduled (Fig. 1, Trust 2). The Nature Conservancy provided another replicate to replace it; therefore, 1 replicate of the PBG system was different from 2009 to 2010 (Fig. 1). All 3 replicates of the RRG system and 1 replicate of the PBG system for 2009 were managed by the Trust (Figs. 1 and 2). The remaining 2 replicates (1 in 2009, and 2 in 2010) of the PBG system were managed by TNC (Fig. 1, TNC 1 and TNC 2).

The selection of transect placement within the study area was based on standing water during the spring of 2009. Since these wet meadows experienced frequent flooding, I made sure the traps would not be inundated when it rained. All transects were at least 200 m from the nearest edge (fence, road, wooded edge, etc.) to eliminate edge effects. The locations for transects remained constant throughout this study. I used 190 m transects and a single transect was placed within each burn unit and was considered representative of the current stage (burn unit) of the grazing system. I sampled small mammals and vegetational attributes on each transect.

Small Mammal Trapping

Each transect was sampled 2 times during spring (April through May), summer (July through August), and fall of 2009-2010. The fall season varied between 2009 (October and November) and 2010 (September and October) due to inclement weather in 2009. The cold weather months, December through March, were excluded due to the probability of higher mortality while in the trap (Gannon et. al. 2007). Each trapping period lasted 3 consecutive nights. Trapping did not occur within 3 nights before or after a full moon, attributable to decreased surface activity by small mammals due to higher predation risk (Manson and Stiles 1998, O'Farrell et al. 1994). Traps were checked beginning 30 minutes after sunrise, and all trap checks were finished by 1030 hrs. Bait was replaced in traps as needed during the trapping period. Traps were closed after checking in the morning and re-opened in the late afternoon during hot weather months (temperature above 26° C). This decreased mortality from hyperthermia in diurnal species. During cold weather (temperature below 4° C), polyester filling was placed in each trap to act as nesting material to decrease mortality from hypothermia.

I sampled small mammals under the master permit number 1020 of the Nebraska Game and Parks Commission. I used folding Sherman live traps (7.6 x 8.9 x 22.9 cm) and baited them with a mixture of peanut butter and oats. Transects consisted of 20 trap stations placed at 10 m intervals, each trap station had 2 traps placed 1 m apart. For the burn units containing cattle, I constructed a temporary electric fence enclosure to prevent interference by cattle. Any traps found closed and empty were assumed to have been closed half the night and therefore were counted as half a trapnight. All methods for

handling live animals followed protocol from the American Society of Mammalogists' Animal Care and Use Committee (Gannon et al. 2007). A captured individual was removed from the trap by dropping it into a small mesh fabric bag and the following measurements and observations were taken: species, sex, reproductive stage, mass, alive or dead, age, identification number, and any other relevant observations. Toe clipping was used to give individuals a unique identifier until fall 2009 when Passive Integrated Transponder (PIT; Biomark, Boise, Idaho) tags were purchased for tagging. The PIT tags were Biomark 12 mm 134.2 KHz preloaded sterile needle packs. Upon capturing, each individual was scanned with a Biomark Pocket Reader (Biomark, Boise, Idaho). If no PIT tag was present, a new PIT tag was scanned and recorded, then implanted subdermally between the scapulae with a Biomark MK20 implant gun. These tags emit a unique, 15 digit radio signal identifier that can be read by the scanner to differentiate individuals. Any trap mortalities were prepared as voucher specimens and deposited at the Sternberg Museum of Natural History in Hays, Kansas.

Vegetation Sampling

I used a 20 x 50 cm Daubenmire frame to estimate the percent cover of grasses, forbs, litter, bareground, and standing dead (Daubenmire 1959). Also I measured average vegetation height and litter depth to the nearest cm with a tape measure within the frame for a total of 7 attributes. I dropped the frames in the 4 cardinal directions at a distance of 1 m around all trap stations. The vegetation attributes were measured once during the spring, twice during the summer (during times of greatest plant growth), and once during the fall for all transects.

Statistical Analyses

Small mammal population assessments.— I reported total numbers of individuals among species, trapnights, and capture success. I used chi-square test of independence to determine if numbers of individuals differed between years, and population sizes differed among seasons within years. A chi-squared test of independence was used to determine if the sexes of species were 1:1 ratios. I used chi-square test of independence for sex ratios among species for Rodentia only because I could not determine sex for Soricomorpha in the field. I used a chi-square with Yate's correction (χ^2_c) when the degrees of freedom were 1.

Vegetational attributes.— I used a repeated measures Multivariate Analysis of Variance (rmMANOVA) to determine if the vegetational attributes differed among burn units and over time (seasons) for 2009 and 2010. In this model, the burn unit (independent variable) was the between subjects effect, and season (repeated measure) was the within subjects effect. I was not as interested in the change in vegetation attributes over seasons but included season as a repeated measure to account for lack of independent samples. I reported Pillai's Trace test statistic because it is robust to violations of the assumptions of the MANOVA (Zar 2010). The assumption of sphericity was tested for the within subjects effects with Mauchly's Test of Sphericity, and the Greenhouse-Geisser measure was used where the assumption was violated. A statistically significant rmMANOVA was followed by a Tukey's post hoc analysis to determine where the differences among treatments occurred. I used SPSS statistical package (Version 12.0, Chicago, Illinois, USA) with an alpha level of 0.05 and reported

partial eta squared to indicate effect size where applicable. I used arcsine and log transformations to approximate normality (Zar 2010).

Small mammal microhabitat use.— I used a canonical correspondence analysis (CCA) to determine if the abundance weighted community was related more strongly to vegetation attributes than expected by chance as tested by Monte Carlo permutations. I calculated relative abundances for species among burn units on a per unit effort basis by dividing numbers of individuals by number of trap nights for each burn unit. The axes extracted by the CCA were linear combinations of known environmental variables (vegetation structure attributes). The predictive power of the variables was determined by how strongly they were related to the axes as determined by intra-set correlations of Ter Braak (Ter Braak 1986). For the CCA analyses I standardized rows and columns scores by centering and normalizing. Ordination scores were scaled to optimize sites, which allowed a direct spatial interpretation of the relationships between environmental and species points (McCune and Grace 2002). I graphed site scores as linear combinations of the environmental variables. I used 1,000 iterations for the Monte Carlo permutation tests to test the null hypotheses of no relationships between the species and environmental matrices. The Monte Carlo test calculated a p-value for the axis by determining what proportion of randomized runs had an eigenvalue greater than or equal to the observed eigenvalue. If 95% of the eigenvalues were less than the observed eigenvalue, then the axis could be viewed as statistically significant. The CCA was graphed and species were plotted in space created by the axes and the environmental variables were represented as vectors. The vectors visually represented the magnitude

and direction of environmental variables as they were weighted on the axes. Using this technique, I related small mammal community variation to environmental variation (Ter Braak 1986). Site rankings also were reported as a function of the CCA. Site rankings were assembled by ranking sites along the first axis of the CCA and plotting species to associate species with sites. I used PC-ORD (Version 4.41, MjM software, Gleneden Beach, Oregon, USA) for the CCA.

Small mammal community assessments.— I determined alpha diversity for each burn unit by calculating species richness, evenness, and diversity (Shannon-Wiener function, log base 10). Due to low sample sizes, I calculated these measures for 2009 and 2010 by pooling individuals across all replicates within a single year. I calculated beta diversity among burn units by using Sørensen's quantitative similarity measure (C_N). I calculated indices for 2009 and 2010 to report community similarities among burn units. I reported the similarity indices as a number between 0 and 1, where 0 indicates dissimilarity and 1 indicates similarity. Community similarity indicated the degree to which 2 burn units contained the same small mammal communities. Again, due to low sample sizes, these indices were calculated by pooling individuals across all replicates for a single year. I included all species when calculating species richness, species diversity, and evenness with the exception of *Mustela nivalis* (n = 1) in 2009.

RESULTS

Small Mammal Population Assessments

I captured a total of 699 individuals of 11 species during my study. Total trapping effort was 23,967.5 trapnights that yielded 1,175 captures (4.90% capture rate). A chi-square test indicated the number of individuals of all species trapped between years was not significantly different ($\chi^2_c = 0.01$, $df = 1$, $p > 0.05$). I summarized species captured by number of individuals per year and season (Table 2).

2009 sampling period.— During the 2009 seasons, I captured 348 individuals representing 9 species (Table 2). The trapping effort was 11,857 trapnights that yielded 588 captures (4.96% capture rate). A chi-square test indicated a 1:1 sex ratio among *Ictidomys tridecemlineatus* ($\chi^2_c = 0.84$, $df = 1$, $p > 0.05$), *Microtus pennsylvanicus* ($\chi^2_c = 0.11$, $df = 1$, $p > 0.05$), *Peromyscus maniculatus* ($\chi^2_c = 0.26$, $df = 1$, $p > 0.05$), and *Reithrodontomys megalotis* ($\chi^2_c = 3.32$, $df = 1$, $p > 0.05$).

During the fall season, I captured significantly more individuals of *B. brevicauda* ($\chi^2 = 14.60$, $df = 2$, $p < 0.05$), *P. maniculatus* ($\chi^2 = 29.08$, $df = 2$, $p < 0.05$), *R. megalotis* ($\chi^2 = 11.70$, $df = 2$, $p < 0.05$), and *Sorex cinereus* ($\chi^2 = 46.77$, $df = 2$, $p < 0.05$) than in the spring or summer. More individuals of *I. tridecemlineatus* were captured in the summer ($\chi^2 = 9.10$, $df = 2$, $p < 0.05$) than in the spring or fall. Due to low sample sizes, *Mus musculus* ($n = 1$), *Mustela nivalis* ($n = 1$), and *Onychomys leucogaster* ($n = 1$) were not considered in this analysis.

2010 sampling period.— During the 2010 seasons, I captured 351 representing 9 species (Table 2). The trapping effort was 12,110.5 trapnights that yielded 587 captures (4.90% capture rate). A chi-square test indicated a 1:1 sex ratio in *I. tridecemlineatus* ($\chi^2_c = 2.40$, $df = 1$, $p < 0.05$), *M. pennsylvanicus* ($\chi^2_c = 0.06$, $df = 1$, $p > 0.05$), but significantly more males than females among, *P. maniculatus* ($\chi^2_c = 7.85$, $df = 1$, $p < 0.05$), and *R. megalotis* ($\chi^2_c = 7.20$, $df = 1$, $p < 0.05$).

During the fall, I captured significantly more individuals of *B. brevicauda* ($\chi^2 = 20.00$, $df = 2$, $p < 0.05$), *M. pennsylvanicus* ($\chi^2 = 47.22$, $df = 2$, $p < 0.05$), *P. maniculatus* ($\chi^2 = 12.14$, $df = 2$, $p < 0.05$), *R. megalotis* ($\chi^2 = 13.22$, $df = 2$, $p < 0.05$), and *S. cinereus* ($\chi^2 = 107.20$, $df = 2$, $p < 0.05$) than in the spring or summer. I captured more *I. tridecemlineatus* in the summer ($\chi^2 = 19.60$, $df = 2$, $p < 0.05$) than in spring and fall. Due to low sample sizes, *Mus musculus* ($n = 3$), *P. leucopus* ($n = 2$), and *Zapus hudsonius* ($n = 3$) were not considered in this analysis.

Vegetational Attributes

The rmMANOVA indicated significant differences in vegetation characteristics among burn units for both 2009 ($F_{35, 27.7} = 2.27$, $p < 0.01$, $\eta p^2 = 0.61$) and 2010 ($F_{35, 50} = 2.28$, $p < 0.01$, $\eta p^2 = 0.62$). The burn units within RRG and PBG, their abbreviations, and burning and grazing efforts are shown relative to vegetation characteristics (Table 1).

2009 sampling period.— The between subjects effects indicated the percent of grasses, forbs, and litter did not differ significantly among burn units while vertical height, litter depth, bareground, and standing dead vegetation were significantly different

among burn units (Table 3). The within subjects effects indicated all vegetation characteristics except bareground were significantly different among seasons and the season \times burn unit interaction yielded no significant differences (Table 3). The between subjects effects were further analyzed by a Tukey's post hoc analysis for multiple comparisons and summarized with q-values and p-values (Table 4). Vertical height was significantly greater in RRG-3 than RRG -0, RRG-1, PBG-0, and PBG-1. Vertical height was greater in RRG-2 than RRG -0, PBG-0, and PBG-1 and was greater in RRG -1 than RRG -0. Litter depth was greater in RRG -3 than all other burn units. Litter depth was greater in RRG -2 than RRG -0, and PBG-0. There was less bareground in RRG -3 than RRG -0, and PBG-0. Standing dead vegetation was greater in RRG -3 than RRG -0, RRG -1, PBG-0, and PBG-1. Standing dead vegetation was greater in RRG -2 than RRG -0, and RRG -1.

2010 sampling period.— The between subjects effects for 2010 were similar to 2009 as they indicated the percent grasses, forbs, and litter did not differ significantly among burn units while vertical height, litter depth, and bareground and standing dead vegetation were significantly different among burn units (Table 5). Again, the within subjects effects indicated all vegetation characteristics except bareground were significantly different among seasons; however, season \times burn unit interaction yielded a significant difference with litter depth (Table 5). The between subjects effects were further analyzed by a Tukey's post hoc analysis for multiple comparisons and summarized with q-values and p-values (Table 6). Vertical height was significantly

greater in RRG-3 than RRG-0, PBG-0, and PBG-1. Vertical height was greater in RRG-2 than RRG-0 and PBG-0, and was greater in RRG-1 than RRG-0. Litter depth was greater in RRG-3 than all other burn units. Litter depth was greater in RRG-2 than RRG-0, RRG-1, PBG-0, and PBG-1. Bareground was greater in RRG-0 than RRG-1, RRG-2, RRG-3, and PBG-1. Bareground was greater in PBG-0 than RRG-2, and RRG-3. Standing dead vegetation was greater in RRG-3 than all other burn units. Standing dead vegetation was greater in RRG-2 than RRG-0 and greater in PBG-1 than RRG-0.

Small Mammal Microhabitat Use

The rmMANOVA indicated that percent grasses, forbs, and litter did not differ among burn units; therefore they were removed from the CCA. Also, I removed all species with < 4 individuals within a season from the analysis. I conducted a CCA for summer and fall of 2009 and 2010. The spring seasons were excluded from these analyses because the number of captures was low. The CCA identified 3 axes for each ordination; however, the third axis explained little variation in all instances (Tables 7 – 10). Thus, all interpretations will focus on the first and second axes.

Summer 2009.— For summer 2009 CCA, I included 5 species: *I. tridecemlineatus*, *M. pennsylvanicus*, *P. maniculatus*, *R. megalotis*, and *S. cinereus*. The CCA explained a cumulative of 50.5% of the variation in species composition with 2 axes (Table 7). Intra-set correlations were summarized for the first and second axes (Table 7). The ordination indicated *P. maniculatus* and *M. pennsylvanicus* were found in burn units characteristic of greater bareground and less litter depth and standing dead

vegetation (Fig. 3). *Ictidomys tridecemlineatus* was associated with greater standing dead vegetation (Fig. 3). *Reithrodontomys megalotis* was found in burn units with greater litter depth and standing dead vegetation (Fig. 3). *Sorex cinereus* was found in burn units characteristic of greater litter depth and vertical height and less bareground (Fig. 3). These data indicated a high species-environment correlation for the first axis ($r = 0.94$). I rejected the null hypothesis of no relationship between the small mammal and vegetation structure data. The eigenvalue for the first axis was at the maximum of the range expected by chance ($p < 0.01$, Table 7).

Fall 2009.— For fall 2009 CCA, I included 5 species: *B. brevicauda*, *M. pennsylvanicus*, *P. maniculatus*, *R. megalotis*, and *S. cinereus*. The CCA explained a cumulative of 44.9% of the variation of species composition with 2 axes (Table 8). Intra-set correlations were summarized for the first and second axes (Table 8). The ordination indicated *P. maniculatus* was associated with greater bareground and less litter depth, vertical height, and standing dead vegetation (Fig. 4). *Microtus pennsylvanicus*, *S. cinereus* and *B. brevicauda* were associated with greater litter depth, vertical height, standing dead vegetation, and less bareground (Fig. 4). These data indicated a high species-environment correlation for the first axis ($r = 0.80$). I rejected the null hypothesis of no relationship between the species and environmental data ($p < 0.01$, Table 8).

Summer 2010.— For summer 2010 CCA, I included 4 species: *I. tridecemlineatus*, *M. pennsylvanicus*, *P. maniculatus*, and *R. megalotis*. The CCA only explained a cumulative of 36.6 % of the variation of species composition with 2 axes

(Table 9). Intra-set correlations were summarized for the first and second axes (Table 9). *Peromyscus maniculatus* and *M. pennsylvanicus* associated with greater bareground and less litter depth, vertical height, and standing dead vegetation, which was the inverse of *I. tridecemlineatus*, *R. megalotis*, and *S. cinereus* (Fig. 5). These data indicated a high species-environment correlation for the first axis ($r = 0.70$); however, I retained the null hypothesis of no relationship between the species data and environmental data ($p = 0.36$). Therefore, the first axis might not differ from a random pattern.

Fall 2010.— For fall 2010 CCA, I included 5 species: *B. brevicauda*, *M. pennsylvanicus*, *P. maniculatus*, *R. megalotis*, and *S. cinereus*. The CCA only explained a cumulative of 35.5% of the variation of species composition with 2 axes (Table 10). Intra-set correlations were summarized for the first and second axes (Table 10). *Peromyscus maniculatus* and *R. megalotis* were associated with greater bareground (Fig. 6). *Blarina brevicauda* and *S. cinereus* were associated with greater litter depth, vertical height, standing dead vegetation, and less bareground (Fig. 6). *Microtus pennsylvanicus* was associated with greater litter depth (Fig. 6). Again, these data indicated a high species-environment correlation for the first axis ($r = 0.70$); however, I retained the null hypothesis of no relationship between the species data and environmental data ($p = 0.28$). Therefore, the first axis might not differ from a random pattern.

Site rankings were graphed for each season for 2009 and 2010. These graphs were used as another visualization of the CCA (Figs 7-10).

Small Mammal Community Assessments

In 2009, RRG-2 had the greatest species richness ($S = 7$) and RRG-3 had the greatest diversity and evenness of all burn units ($S = 5$, $H' = 0.60$, $J' = 0.86$). The 7 species I recorded in RRG-2 for 2009 were *B. brevicauda*, *I. tridecemlineatus*, *M. pennsylvanicus*, *M. musculus*, *P. maniculatus*, *R. megalotis*, and *S. cinereus*. Similarly, in 2010 RRG-3 had the greatest species richness, diversity, and evenness of all burn units ($S = 9$, $H' = 0.72$, $J' = 0.76$). The 9 species recorded in RRG-3 for 2010 were *B. brevicauda*, *I. tridecemlineatus*, *M. pennsylvanicus*, *M. musculus*, *P. maniculatus*, *P. leucopus*, *R. megalotis*, *S. cinereus*, and *Z. hudsonius*. The burn units with the lowest diversity were RRG-1 ($S = 4$, $H' = 0.21$, $J' = 0.36$) and RRG-0 ($S = 5$, $H' = 0.45$, $J' = 0.65$) for 2009 and 2010, respectively. Species richness (S), species diversity (H'), and evenness (J') are summarized by burn unit and year (Table 11).

Community similarities were summarized as pair-wise comparisons for 2009 and 2010 (Table 12). In 2009, PBG-0 and PBG-1 had the most similar small mammal communities ($C_N = 0.98$) while RRG-1 and RRG-3 had the least similar small mammal communities ($C_N = 0.24$). In 2010, PBG-0 and PBG-1 had the most similar communities ($C_N = 1.00$) while RRG-0 and RRG-3 had the least similar communities ($C_N = 0.46$).

DISCUSSION

Small Mammal Population Assessments

In 2009, sex ratios were 1:1 as expected, but in 2010 I captured more males than females in *I. tridecemlineatus*, *P. maniculatus*, and *R. megalotis*. I expected an even sex ratio but a male biased ratio in rodents might be the result of trapability, behavior, or even environmental phenomena. For instance, Havelka and Millar (1997) suggested differential physiological responses to climatic events between male and female *P. maniculatus* that lead to lower survivability in 1 sex depending on the conditions. High spring temperatures influences females to produce female biased litters while high temperatures in fall has lead to male biased litters (Havelka and Millar 1997).

I expected to see an increase in individuals from spring to fall because population sizes fluctuate annually, increasing from spring through fall after a large decline over winter. In 2009 and 2010, the numbers of *B. brevicauda*, *P. maniculatus*, *R. megalotis*, and *S. cinereus* increased from spring to fall. *Microtus pennsylvanicus* only showed an increase in captures in 2010, but this is likely due to an increase in captures from 2010 (n = 69) compared to 2009 (n = 19). My results indicated *I. tridecemlineatus* peaked during the summer instead of fall, which is likely because they are known to enter hibernation as early as July (Streubel and Fitzgerald 1978).

Vegetational Attributes

My data indicated similar results for 2009 and 2010. Vertical height, litter depth, percent bareground, and percent standing dead vegetation were different among burn

units in both years. My data indicated no difference in percent grasses, percent forbs, or percent litter for either year. However, the data did support my hypothesis that vegetation attributes differed among burn units. As expected, vertical height, litter depth, and standing dead vegetation were greater in undisturbed burn units, such as RRG-2 and RRG-3. Bareground was greater in recently disturbed burn units, such as RRG-0 and PBG-0. Similar results have been reported in tallgrass prairie (Fuhlendorf et al. 2006). Previous research indicates an increase in height and litter and a decrease in bareground in burn units that were >12 months since disturbances (Fuhlendorf et al. 2006). Although grass, forb, and litter cover in my study did not differ among burn units, previous research reports that vertical height and litter depth are determinants of habitat selection of rodents (Kaufman et al. 1990, Clark and Kaufman 1991). Based on the results of these analyses, burn units had distinct vegetative structure; therefore, I expected to see different small mammal communities in different burn units. Some species avoid areas with higher litter layers, such as *S. cinereus*, while others select for lower litter layers, such as *P. maniculatus* (Clark and Kaufman 1991). Therefore, vertical height and litter depth might be critical variables in species distribution. Burn units that contain more bareground and less litter depth were associated with recent disturbances and should contain species that require less structure, such as *P. maniculatus* and *I. tridecemlineatus*. Burn units that contain greater litter depth, vertical height, and standing dead vegetation were associated with undisturbed burn units and should contain species that require more structure, such as *B. brevicauda* and *S. cinereus*.

There was an unexpected result of these analyses. Because they were burned in the same year, I expected RRG-0 and PBG-0 to maintain similar attributes and I expected RRG-1 and PBG-1 to maintain similar attributes. However, RRG-0 was similar to PBG-1 in 2009 (Table 4) and RRG-1 was similar to PBG-0 in 2009 and 2010 (Tables 4 and 6). The departure from my expectations might be attributed to the nature of RRG and PBG systems. In the RRG system, cattle are confined to the burn unit for an allotted amount of time, whereas in the PBG system cattle can graze preferentially any burn unit at any time. The similarities between burn-year and 1-year post burn units are likely due to differential grazing of the units regardless of when it was burned.

Small Mammal Microhabitat Use

The CCAs indicated similar results for Soricomorpha. *Blarina brevicauda* and *S. cinereus* were associated with unburned, ungrazed burn units that were characteristic of higher litter depth, vertical height, standing dead vegetation, and less bareground (Figs. 3 – 6). The vegetation structure present in the older successional burn units within the RRG system provided a microhabitat that maintained water and temperature levels necessary for shrew survival.

Peromyscus maniculatus has been documented as a fire positive species that is found in high abundance in recently disturbed grasslands (Clark and Kaufman 1991). My results indicated *P. maniculatus* was associated with greater bareground cover and shorter vertical height, litter depth, and standing dead vegetation (Figs. 3 – 6). These attributes are indicative of recently disturbed burn units. Grazed and burned areas have less litter and standing vegetation and more forbs and bareground than ungrazed and unburned

areas (Vermeire et al. 2004). *Peromyscus maniculatus* is likely drawn to recently disturbed areas because of the lack of litter, its increasing vagility and making seeds more readily available for consumption (Kaufman et al. 1988).

Microtus pennsylvanicus is ubiquitous within prairie settings with documented multiannual population cycles. During 2009 I trapped only 19 individuals and the ordinations were conflicting from summer and fall possibly due to low sample size (Figs. 3 – 4). During 2010, I caught more *M. pennsylvanicus* (n = 69), but the ordinations for 2010 are not significant, perhaps given the breadth of niche voles use. Probably, the difference in captures between years was due to population cycles and not specifically habitat related. The rmMANOVA indicated grass cover did not differ among burn units. I hypothesize that since *Microtus* are herbivorous; their food source was in ample supply at the Trust leading them to be abundant in all burn units, confounding the ordination. Therefore, no specific habitat attributes that I measured could be assigned to this species. Other variables that were not measured in this study might explain the variation in this species population size and distribution.

My results for *R. megalotis* were conflicted. In summer 2009 there was a negative association with bareground and a positive association with standing dead vegetation and litter depth suggesting it was found in undisturbed burn units (Fig. 3). However, in fall 2009 *R. megalotis* was associated positively with bareground suggesting it was found in disturbed burn units (Fig. 4). Also, CCA rankings indicated this species was associated with *P. maniculatus* and *M. pennsylvanicus* in disturbed burn units (Figs. 7 – 10). Other research in tallgrass prairie is conflicted as well for *R. megalotis*. One

study reported *R. megalotis* is most abundant in plots that contained tall, lush vegetation of a recently burned patch (Kaufman et al. 1988). Differently, Kaufman et al. (1988) reported *R. megalotis* in stands that were 2-4 and 5+ years since fire. To gain a better understanding of habitat preference in *R. megalotis*, more research with more captures is needed.

In the summer 2009 CCA, *I. tridecemlineatus* did not have any clear vegetation associations (Fig. 3). However, when examining CCA rankings, this species was associated with disturbed burn units in 2009 (Fig.7). In 2010, *I. tridecemlineatus* was associated with undisturbed burn units (Fig. 9); however, the first axis in summer 2010 failed the Monte Carlo test. This suggested that the ordinations for 2010 might be unreliable. *Ictidomys tridecemlineatus* generally is found in highly disturbed areas such as grazed pastures (Streubel and Fitzgerald 1978).

The CCAs for 2010 showed how the species were arranged on the axes but the results of the Monte Carlo test suggested that the vegetation attributes did not influence abundances of small mammal species (Tables 9 and 10). Based on these results, variables, which were not considered, potentially were influencing the species distribution and abundances among burn units for 2010. CCA rankings for summer 2010 mixed burn units together along the first axis further demonstrating that the variables measured were not defining small mammal species abundance (Fig. 9). Climate variables should be considered in future studies such as landscape level climate (temperature and precipitation across all burn units) and microclimate (temperature and moisture within burn units). Other variables include amount and length of inundation by flooding events

and the juxtaposition of habitat types because of dispersal by small mammals.

Juxtaposition of burn units might be a critical variable given the proximity of ideal versus suitable habitat for small mammals to inhabit after a dispersal event.

Small Mammal Community Assessments

My results indicated the recently disturbed burn units had the lowest small mammal diversity and the undisturbed burn units had the greatest diversity. The greatest diversity occurred in burn units that had not been burned for 2 – 3 years and were rested from grazing. Without a system that provided fallow units, small mammal diversity would have been much lower.

I expected to find that similar burn units would yield similar small mammal communities. For example, recently disturbed burn units (RRG-0, RRG-1, PBG-0, and PBG-1) had high overlap indicating communities remained similar among these burn units for both 2009 and 2010. Also, undisturbed burn units (RRG-2 and RRG-3) had high overlaps indicating the communities were similar among these sites for both years. Disturbed and undisturbed burn units were the most dissimilar to each other. Furthermore, within the RRG system, 2 burn units had the most dissimilar communities (RRG-0 and RRG-3). These data further supported my hypothesis that communities were segregated based on the vegetation attributes unique to the successional stage of the burn unit. Without a system that provided for multiple habitat types, more diverse communities would not have occurred.

Management Implications

Prairies evolved with periodic fire and grazing disturbances; therefore, the organisms within the ecosystem require similar processes. With available prairie on the decline, remaining rangelands in the Great Plains should be managed to maximize habitat quality for biodiversity. This is best accomplished with heterogeneity-based management. In order to preserve the ecological integrity of the remaining prairie, managers should use heterogeneity-based management that mimics evolutionary processes or the historical disturbance regimes of prairie ecosystems (Fuhlendorf and Engle 2001). Small mammals can be a bioindicator of prairie ecosystem health where they influence soil, vegetation structure, and organisms among many trophic levels. By managing rangelands among a heterogeneous landscape many different small mammal communities can be supported. My research identified several variables that were significant determinants in species occurrence. If rangeland management does not promote heterogeneity, some species would not occur because their habitat requirements are not met. My research concluded that no burn unit contained all species but species were segregated among burn units by habitat characteristics. By providing a system that created a mosaic of habitat types small mammal diversity increased, which can influence the entire ecosystem. As a result of this research, I recommend that rangeland managers use management systems such as patch-burn grazing and rest rotation grazing. Given the large proportion of rangeland in Nebraska, promoting among patch heterogeneity would positively influence small mammal diversity and create an outcome that can favor livestock production and wildlife conservation.

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Table 1. Burn unit designation with burn and graze identity in the Central Platte River Valley
Nebraska, for A. 2009 and B. 2010.

A		
Burn unit ^a	Burn yr	Graze dates
RRG-0	2009	1 May - 30 June, 1 September - 15 October
RRG-1	2008	1 July - 31 August
RRG-2	2007	Ungrazed
RRG-3	2006	Ungrazed
PBG-0	2009	1 May - 15 October
PBG-1	2008	1 May - 15 October
B		
Burn unit ^a	Burn yr	Graze dates
RRG-0	2010	1 May - 30 June, 1 September - 15 October
RRG-1	2009	1 July - 31 August
RRG-2	2008	Ungrazed
RRG-3	2007	Ungrazed
PBG-0	2010	1 May - 15 October
PBG-1	2009	1 May - 15 October

^aRRG = Rest-rotation grazing, PBG = Patch-burn grazing. Number represents years since last burned.

Table 2. Small mammal individuals by year and season in the Central Platte River Valley, Nebraska, 2009-2010.

Species	2009				2010				Grand Total
	Spring	Summer	Fall	Total	Spring	Summer	Fall	Total	
<i>Blarina brevicauda</i>	0	1	9	10	0	0	10	10	20
<i>Ictidomys tridecemlineatus</i>	7	12	1	20	0	13	2	15	35
<i>Microtus pennsylvanicus</i>	7	4	8	19	4	16	49	69	88
<i>Mus musculus</i>	0	0	1	1	0	1	2	3	4
<i>Mustela nivalis</i>	0	0	1	1	0	0	0	0	1
<i>Onychomys leucogaster</i>	0	0	1	1	0	0	0	0	1
<i>Peromyscus maniculatus</i>	39	53	97	189	35	41	67	143	332
<i>P. leucopus</i>	0	0	0	0	0	0	2	2	2
<i>Reithrodontomys megalotis</i>	8	23	29	60	14	4	23	41	101
<i>Sorex cinereus</i>	0	10	37	47	1	3	61	65	112
<i>Zapus hudsonius</i>	0	0	0	0	0	2	1	3	3
Total	61	103	184	348	54	80	217	351	699

Table 3. Results for repeated measures MANOVA on vegetation attributes by burn unit, 2009.

Variable	Source of Variation								
	Between subjects			Within subjects					
	Burn unit			Season			Season x burn unit		
F	df	p	F	df	p	F	df	p	
Grasses ^a	0.50	5.00	0.77	25.93	1.89	< 0.01*	0.67	5.95	0.68
Forbs ^a	0.88	5.00	0.52	13.87	1.25	0.01*	0.70	6.24	0.66
Litter ^a	1.60	5.00	0.24	24.65	1.51	< 0.01*	1.23	7.54	0.34
Bareground ^a	4.88	5.00	0.01*	0.28	1.52	0.70	0.78	7.58	0.62
Standing dead ^a	13.30	5.00	< 0.01*	133.5	1.20	< 0.01*	3.25	6.00	0.31
Vertical height	20.93	5.00	< 0.01*	10.46	2.00	0.01*	0.53	10.0	< 0.01*
Litter depth	31.06	5.00	< 0.01*	16.92	2.00	< 0.01*	2.03	10.0	< 0.01*

^a Greenhouse-Geisser measure used because the assumption of sphericity was violated (within subjects).

* indicates significance.

Table 4. Tukey's pair-wise comparisons for vegetation attributes between burn units, 2009.

	RRG-0	RRG-1	RRG-2	RRG-3	PBG-0	PBG-1
RRG-0	-	vert (3.44, 0.04)	dead (4.39, 0.01) vert (6.45, 0.01) dpth (5.83, 0.01)	bare (4.29, 0.01) dead (6.86, < 0.01) vert (8.20, < 0.01) dpth (10.81, < 0.01)	not sig.	not sig.
RRG-1	-	-	dead (3.94, 0.02)	dead (6.41, < 0.01) vert (4.76, 0.01) dpth (8.10, < 0.01)	not sig.	not sig.
RRG-2	-	-	-	dpth (4.98, < 0.01)	vert (5.76, < 0.01) dpth (4.83, < 0.01)	vert (4.12, 0.01)
RRG-3	-	-	-	-	bare (3.60, 0.03) dead (5.01, < 0.01) vert (7.51, < 0.01) dpth (9.80, < 0.01)	dead (4.15, 0.01) vert (5.87, < 0.01) depth (8.01, < 0.01)
PBG-0	-	-	-	-	-	not sig.
PBG-1	-	-	-	-	-	-

RRG = Rest-rotation grazing, PBG = Patch-burn grazing. Number represents years since last burned. Variables listed are significantly different between column and row labels. bare = % cover bareground, dead = % cover standing dead, vert = vertical height, and dpth = litter depth. Numbers in parentheses are (q-value, p-value). **Bolded** values indicate the variable is greater for the row label.

Table 5. Results for repeated measures MANOVA on vegetation attributes by burn unit, 2010.

Variable	Source of Variation								
	Between subjects			Within subjects					
	Burn unit			Season			Season x burn unit		
F	df	p	F	df	p	F	df	p	
Grasses ^a	1.61	5.00	0.23	14.10	1.20	0.01*	0.68	5.98	0.67
Forbs ^a	1.29	5.00	0.33	14.34	1.17	0.01*	0.69	5.86	0.66
Litter ^a	2.36	5.00	0.10	18.36	1.10	0.01*	1.60	5.51	0.23
Bareground ^a	17.20	5.00	< 0.01*	2.90	1.28	0.10	1.64	6.41	0.20
Standing dead ^a	17.51	5.00	< 0.01*	207.2	1.38	< 0.01*	1.46	6.89	0.25
Vertical height	11.82	5.00	< 0.01*	10.72	2.00	< 0.01*	1.49	7.05	0.24
Litter depth	29.97	5.00	< 0.01*	63.53	2.00	< 0.01*	8.51	7.12	< 0.01*

^a Greenhouse-Geisser measure used because the assumption of sphericity was violated (within subjects).

* indicates significance.

Table 6. Tukey's pair-wise comparisons for vegetation attributes between burn units, 2010.

	RRG-0	RRG-1	RRG-2	RRG-3	PBG-0	PBG-1	
RRG-0	-	bare (5.09, < 0.01) vert (3.51, 0.04)	bare (6.92, < 0.01) dead (4.38, 0.01) vert (5.82, < 0.01) dpth (6.44, < 0.01)	bare (7.80, < 0.01) dead (9.00, < 0.01) vert (6.24, < 0.01) dpth (10.05, < 0.01)		not sig.	bare (5.37, < 0.01) dead (4.89, < 0.01)
RRG-1	-	-	dpth (3.82, 0.02)	dead (5.83, < 0.01) dpth (7.43, < 0.01)		not sig.	not sig.
RRG-2	-	-	-	dead (4.62, 0.01) dpth (3.60, 0.03)	bare (4.64, 0.01) vert (4.28, 0.01) dpth (6.01, < 0.01)	dpth (4.01, 0.02)	
RRG-3	-	-	-	-	bare (5.53, < 0.01) dead (6.09, < 0.01) vert (4.70, 0.01) dpth (9.61, < 0.01)	dead (4.11, 0.01) vert (3.67, 0.03) dpth (7.61, < 0.01)	
PBG-0	-	-	-	-	-	not sig.	
PBG-1	-	-	-	-	-	-	

RRG = Rest-rotation grazing, PBG = Patch-burn grazing. Number represents years since last burned. Variables listed are significantly different between column and row labels. bare = % cover bareground, dead = % cover standing dead, vert = vertical height, and dpth = litter depth. Numbers in parentheses are (q-value, p-value). **Bolded** values indicate the variable is greater for the row label.

Table 7. Axis summary statistics for canonical correspondence analysis, summer 2009.

Measure	Axis 1	Axis 2	Axis 3
Eigenvalue	0.64	0.38	0.14
Cumulative % variance explained	31.80	50.50	57.60
Pearson correlation ^a	0.94	0.80	0.56
Intra-set correlations ^b			
Bareground	-0.43	-0.35	0.34
Standing dead	-0.33	0.85	-0.33
Vertical height	0.54	0.16	-0.79
Litter depth	0.61	0.50	-0.56
Monte Carlo results			
Randomized eigenvalues (min-max)	0.10 – 0.64	0.02 – 0.38	0.00 – 0.27
p-value	< 0.01	^c	^c

^aSpecies-Environment, ^bTer Braak (1986), ^cP-values were not calculated for these axes because of possible bias by simple randomization tests (McCune and Mefford 1999).

Table 8. Axis summary statistics for canonical correspondence analysis, fall 2009.

Measure	Axis 1	Axis 2	Axis 3
Eigenvalue	0.36	0.09	0.01
Cumulative % variance explained	35.3	44.9	46.0
Pearson correlation ^a	0.80	0.62	0.27
Intra-set correlations ^b			
Bareground	0.86	0.29	-0.18
Standing dead	-0.69	0.61	0.35
Vertical height	-0.93	0.25	0.17
Litter depth	-0.98	0.07	0.04
Monte Carlo results			
Randomized eigenvalues (min-max)	0.04-0.45	0.00-0.15	0.00-0.07
p-value	0.01	^c	^c

^aSpecies-Environment, ^bTer Braak (1986), ^cP-values were not calculated for these axes because of possible bias by simple randomization tests (McCune and Mefford 1999).

Table 9. Axis summary statistics for canonical correspondence analysis, summer 2010.

Measure	Axis 1	Axis 2	Axis 3
Eigenvalue	0.15	0.09	0.03
Cumulative % variance explained	20.10	32.60	36.60
Pearson correlation ^a	0.70	0.67	0.36
Intra-set correlations ^b			
Bareground	0.59	-0.25	0.35
Standing dead	-0.44	0.86	-0.17
Vertical height	-0.19	0.47	-0.28
Litter depth	-0.42	0.47	0.13
Monte Carlo results			
Randomized eigenvalues (min-max)	0.04 - 0.26	0.00 - 0.18	0.00 - 0.06
p-value	0.36	^c	^c

^aSpecies-Environment, ^bTer Braak (1986), ^cP-values were not calculated for these axes because of possible bias by simple randomization tests (McCune and Mefford 1999).

Table 10. Axis summary statistics for canonical correspondence analysis, fall 2010

Measure	Axis 1	Axis 2	Axis 3
Eigenvalue	0.21	0.13	0.02
Cumulative % variance explained	22.20	35.50	38.20
Pearson correlation ^a	0.70	0.66	0.36
Intra-set correlations ^b			
Bareground	-0.76	-0.25	-0.23
Standing dead	0.76	-0.25	0.53
Vertical height	0.90	0.03	0.03
Litter depth	0.95	0.27	0.12
Monte Carlo results			
Randomized eigenvalues (min-max)	0.03 – 0.42	0.00 – 0.16	0.00 – 0.07
p-value	0.28	^c	^c

^aSpecies-Environment, ^bTer Braak (1986), ^cP-values were not calculated for these axes because of possible bias by simple randomization tests (McCune and Mefford 1999).

Table 11. Small mammal species richness (S), Shannon-Weiner function (H'), and evenness (J') by burn unit, 2009- 2010.

2009				2010			
Burn unit ^a	S	H'	J'	Burn unit ^a	S	H'	J'
RRG -0	4	0.46	0.76	RRG -0	5	0.45	0.65
RRG -1	4	0.21	0.36	RRG -1	6	0.54	0.69
RRG -2	7	0.59	0.70	RRG -2	7	0.63	0.75
RRG -3	5	0.60	0.86	RRG -3	9	0.72	0.76
PBG-0	6	0.51	0.66	PBG-0	7	0.61	0.72
PBG-1	6	0.57	0.74	PBG-1	8	0.60	0.67

^a RRG = Rest-rotation grazing, PBG = Patch-burn grazing system. Number signifies years since last burned.

Table 12. Community similarity as calculated by Sørensen's quantitative similarity measure for A. 2009 and B. 2010.

A. 2009						
	RRG -0	RRG -1	RRG -2	RRG -3	PBG-0	PBG-1
RRG-0		0.89	0.95	0.45	0.93	0.97
RRG -1			0.89	0.24	0.88	0.85
RRG -2				0.54	0.92	0.95
RRG -3					0.30	0.44
PBG-0						0.98
PBG-1						
B. 2010						
	RRG -0	RRG -1	RRG -2	RRG -3	PBG-0	PBG-1
RRG -0		0.91	0.60	0.46	0.96	0.96
RRG -1			0.83	0.60	0.86	0.84
RRG -2				0.86	0.60	0.55
RRG -3					0.56	0.54
PBG-0						1.00
PBG-1						

RRG = Rest-rotation grazing, PBG = patch-burn grazing. Number signifies years since last burned.

Figure 1. Patch-burn grazing system (3 replicates) along the Platte River in Hall County, Nebraska. Trust 1, Trust 2, and TNC 1 were replicates in 2009. In 2010, Trust 2 was replaced with TNC 2. Trust 1 and 2 were managed by The Platte River Whooping Crane Maintenance Trust, Inc. TNC 1 and 2 were managed by The Nature Conservancy.

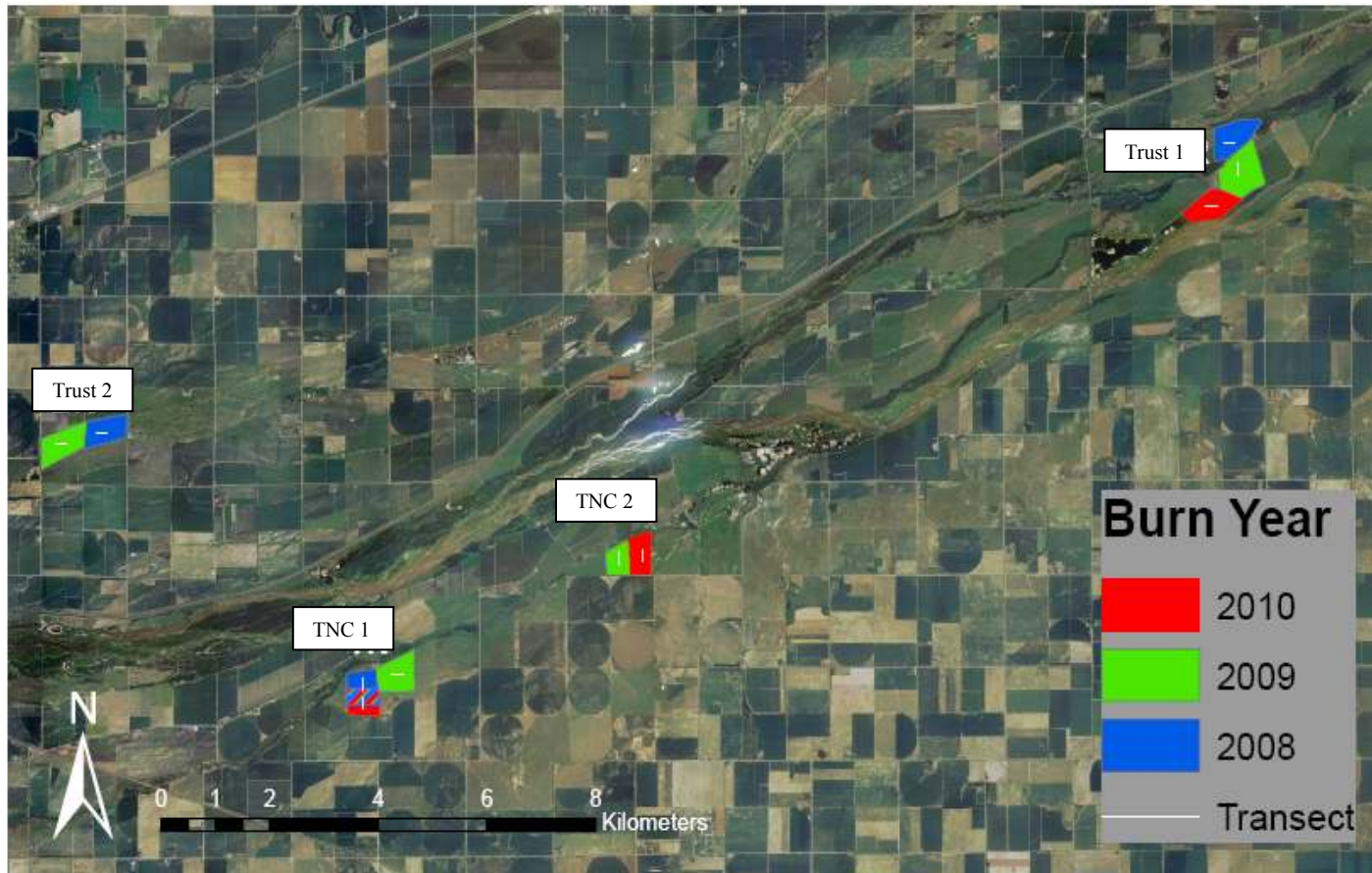


Figure 2. Rest-rotation grazing systems (3 replicates) along the Platte River in Hall County, Nebraska. Wild Rose Ranch and Mormon Island (separated by a channel of the Platte River) were both managed by The Platte River Whooping Crane Maintenance Trust, Inc.

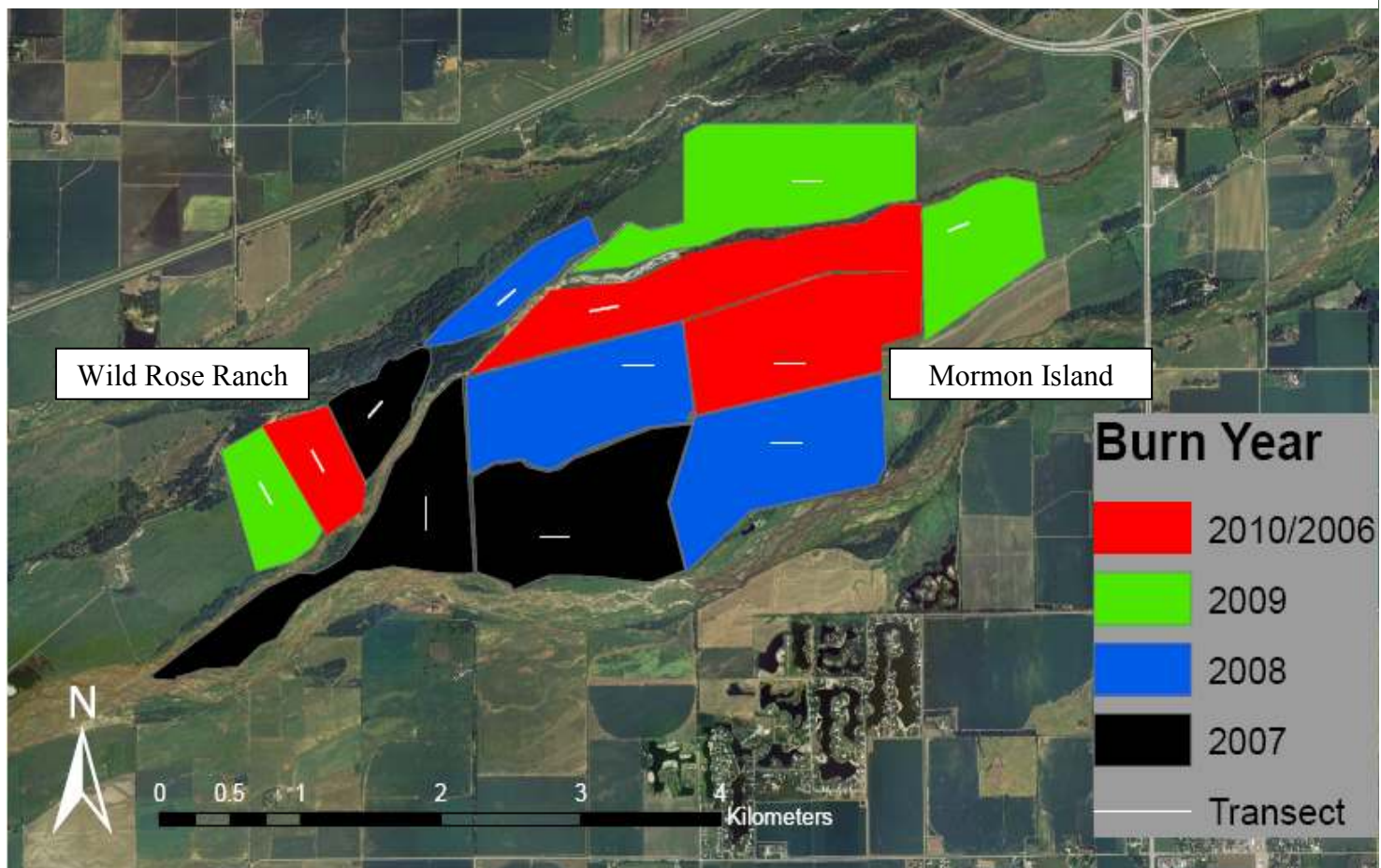


Figure 3. Summer 2009 ordination diagram of species in environmental space from canonical correspondence analysis for 5 species of small mammals. Ictr = *Ictidomys tridecemlineatus*, Reme = *Reithrodontomys megalotis*, Soci = *Sorex cinereus*, Mipe = *Microtus pennsylvanicus*, and Pema = *Peromyscus maniculatus*. Stdead = % cover standing dead, LDepth = litter depth, Vert = vertical height, and Bare = % cover bareground. Vectors represent direction and magnitude of vegetation variables on first and second axes.

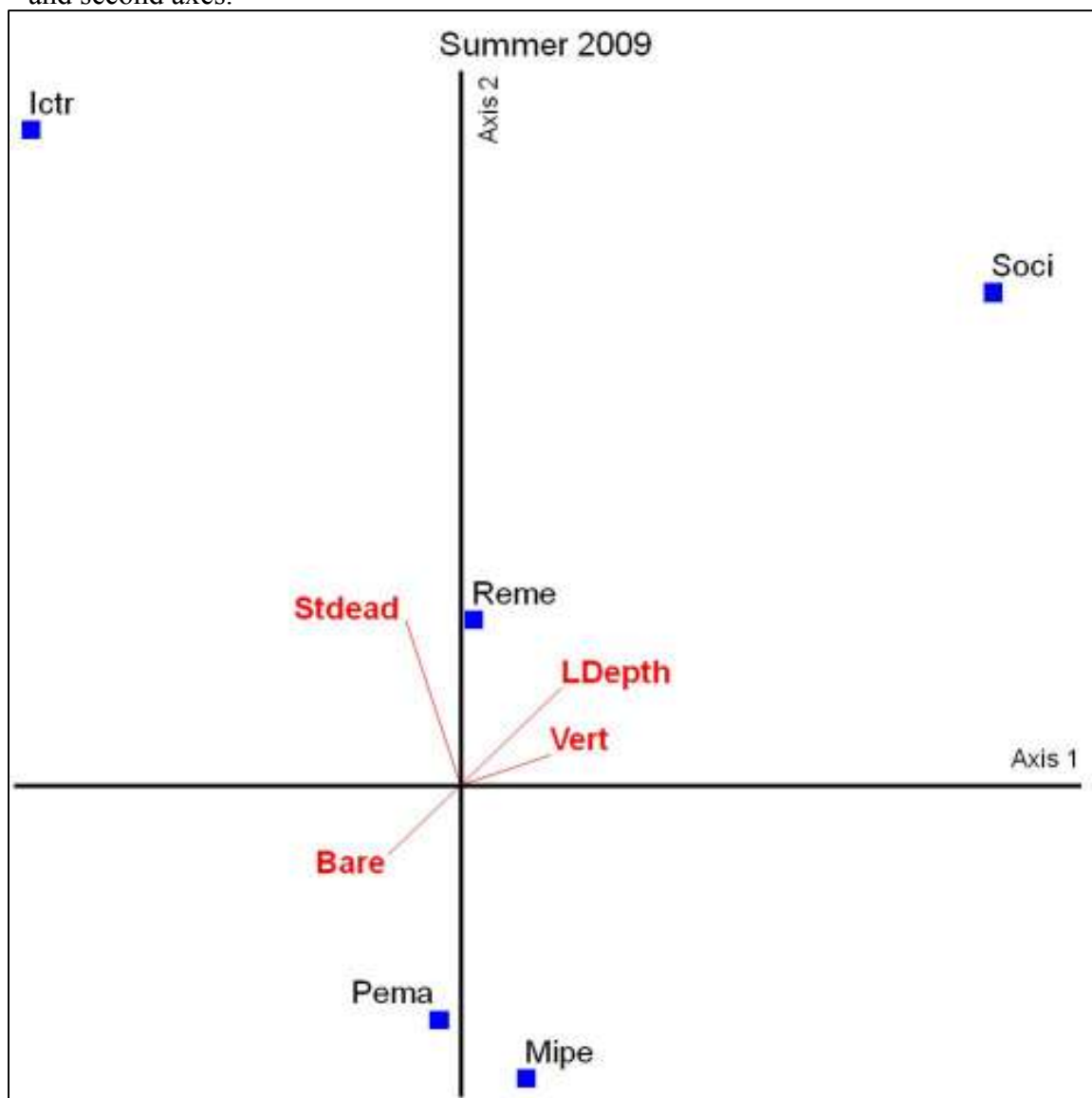


Figure 4. Fall 2009 ordination diagram of species in environmental space from canonical correspondence analysis for 5 species of small mammals. Reme = *Reithrodontomys megalotis*, Pema = *Peromyscus maniculatus*, Mipe = *Microtus pennsylvanicus*, Soci = *Sorex cinereus*, and Blbr = *Blarina brevicauda*. Stdead = % cover standing dead, LDepth = litter depth, Vert = vertical height, and Bare = % cover bareground. Vectors represent direction and magnitude of vegetation variables on first and second axes.

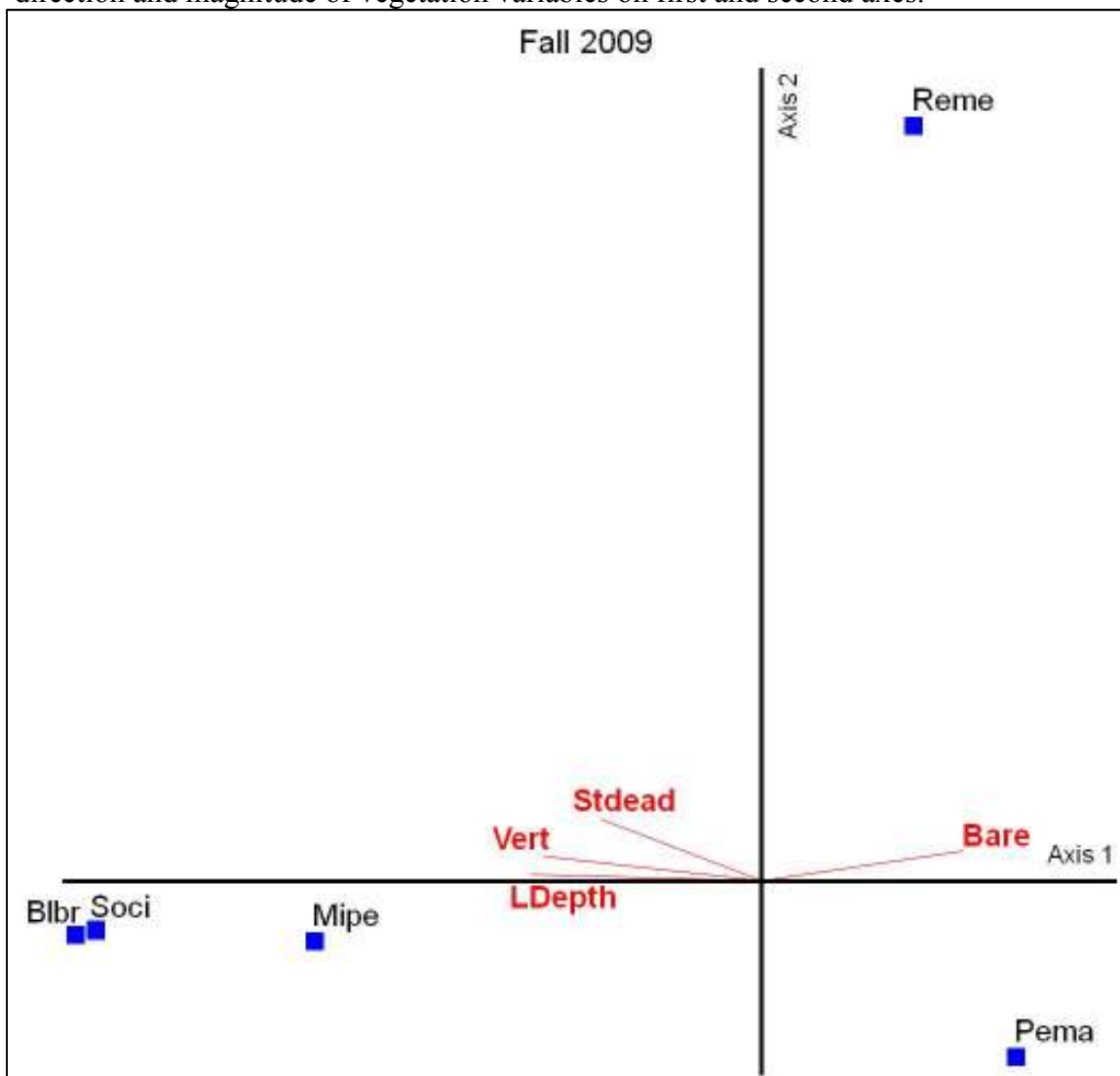


Figure 5. Summer 2010 ordination diagram of species in environmental space from canonical correspondence analysis for 4 species of small mammals. Reme = *Reithrodontomys megalotis*, Mipe = *Microtus pennsylvanicus*, Pema = *Peromyscus maniculatus*, and Ictr = *Ictidomys tridecemlineatus*. Stdead = % cover standing dead, LDepth = litter depth, Vert = vertical height, and Bare = % cover bareground. Vectors represent direction and magnitude of vegetation variables on first and second axes.

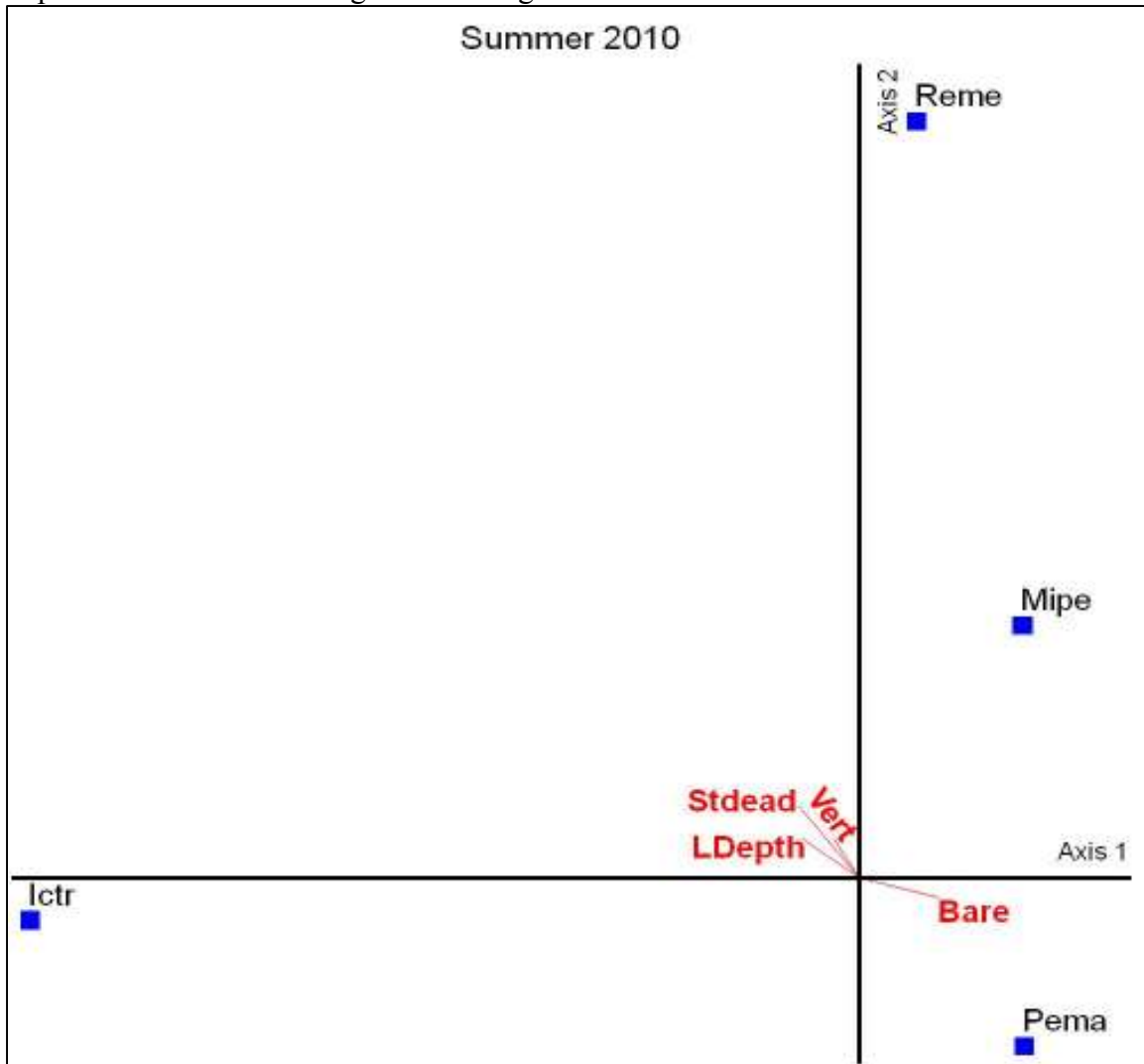


Figure 6. Fall 2010 ordination diagram of species in environmental space from canonical correspondence analysis for 5 species of small mammals. Mipe = *Microtus pennsylvanicus*, Soci = *Sorex cinereus*, Blbr = *Blarina brevicauda*, Reme = *Reithrodontomys megalotis*, and Pema = *Peromyscus maniculatus*. Stdead = % cover standing dead, LDepth = litter depth, Vert = vertical height, and Bare = % cover bareground. Vectors represent direction and magnitude of vegetation variables on first and second axes.

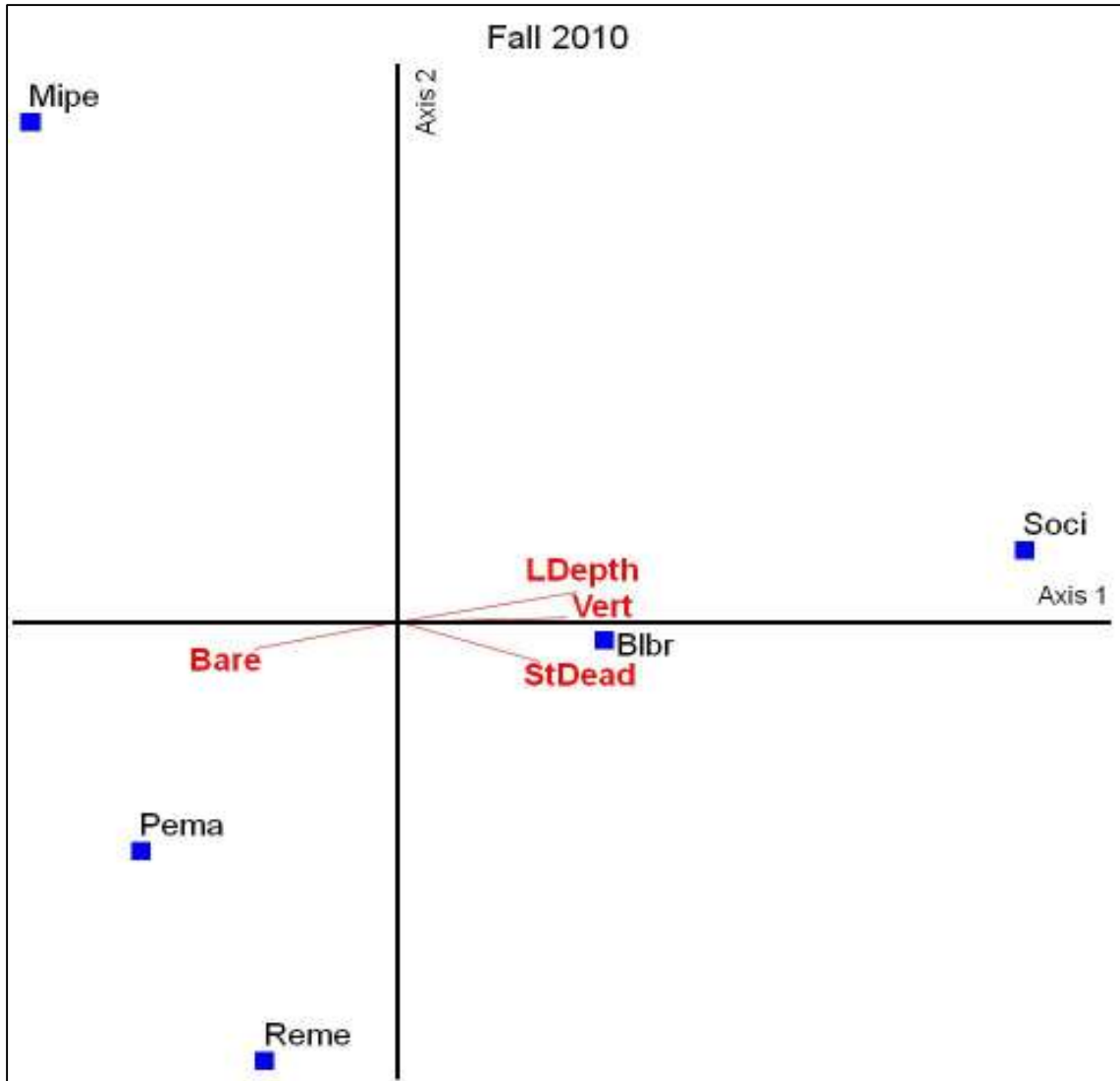


Figure 7. Site ranking along canonical correspondence analysis axis 1 for summer 2009. Species points associate with site points nearest above. Ictr = *Ictidomys tridecemlineatus*, Pema = *Peromyscus maniculatus*, Reme = *Reithrodontomys megalotis*, Mipe = *Microtus pennsylvanicus*, and Soci = *Sorex cinereus*. Axis 1 loadings are from Table 7.

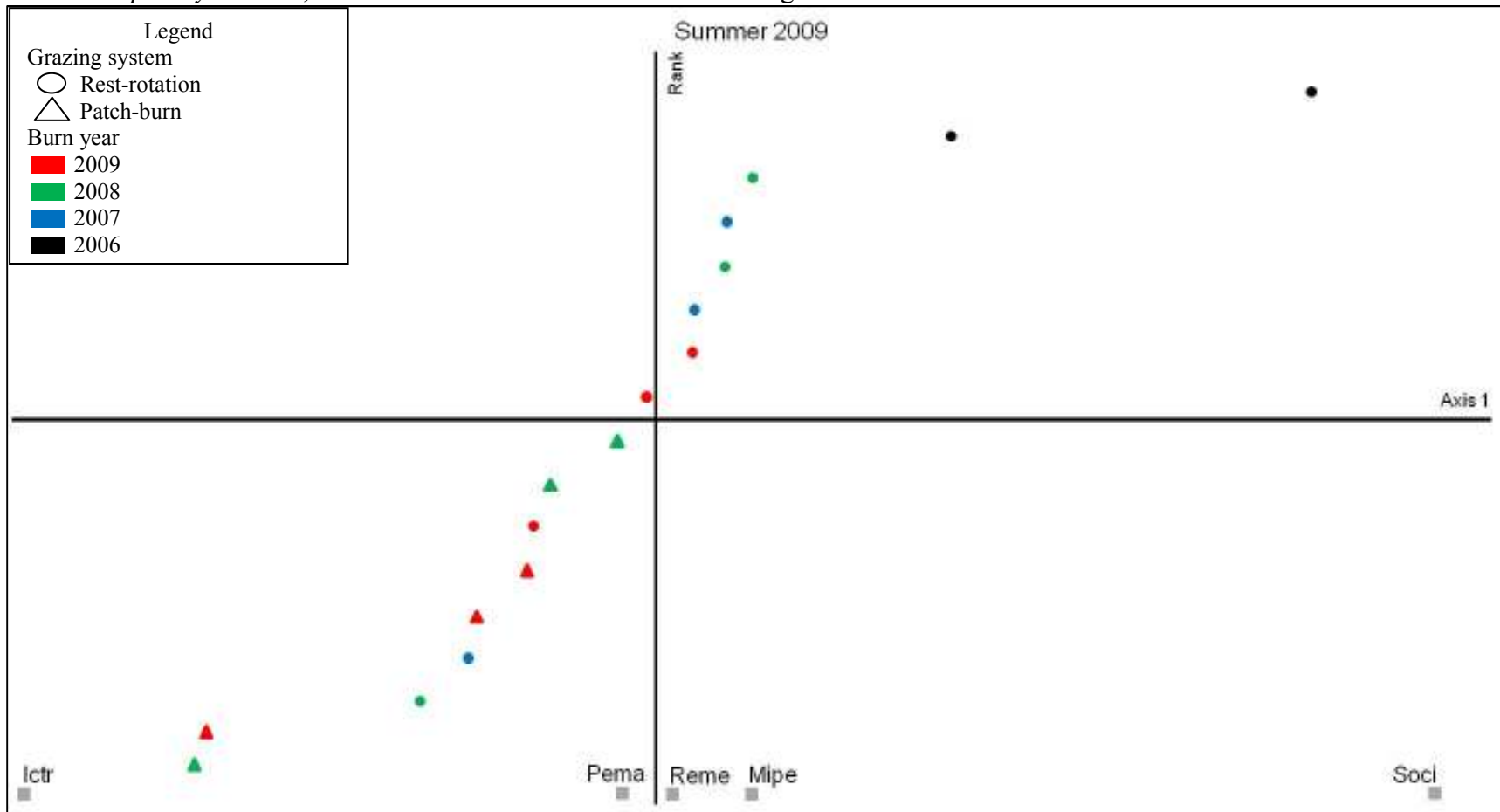


Figure 8. Site ranking along canonical correspondence analysis axis 1 for fall 2009. Species points associate with site points nearest above. Blbr = *Blarina brevicauda*, Soci = *Sorex cinereus*, Mipe = *Microtus pennsylvanicus*, Reme = *Reithrodontomys megalotis*, and Pema = *Peromyscus maniculatus*. Axis 1 loadings are from Table 8.

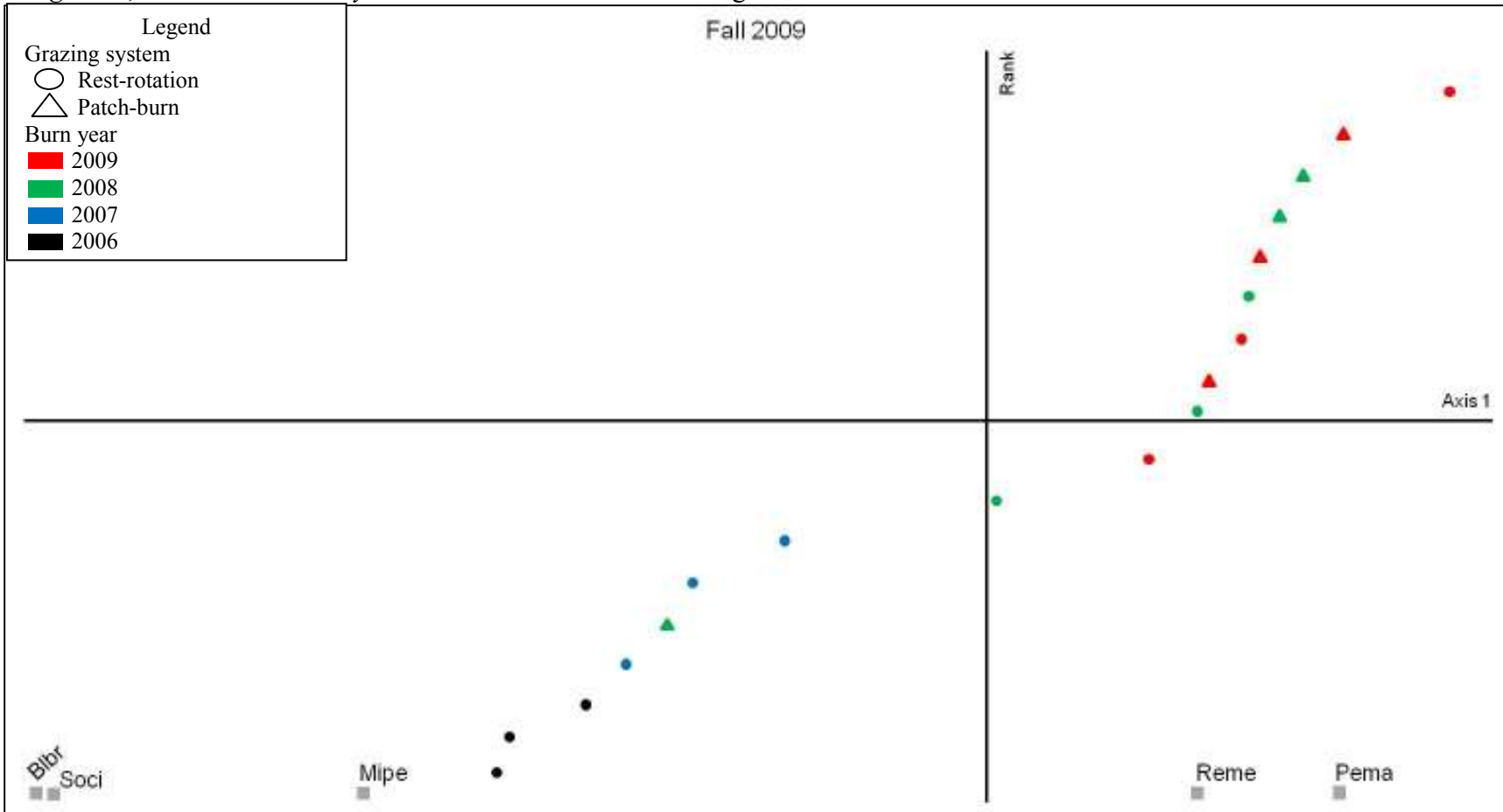


Figure 9. Site ranking along the canonical correspondence analysis axis 1 for summer 2010. Species points associate with site points nearest above. Ictr = *Ictidomys tridecemlineatus*, Reme = *Reithrodontomys megalotis*, Pema = *Peromyscus maniculatus*, and Mipe = *Microtus pennsylvanicus*. Axis 1 loadings are from Table 9.

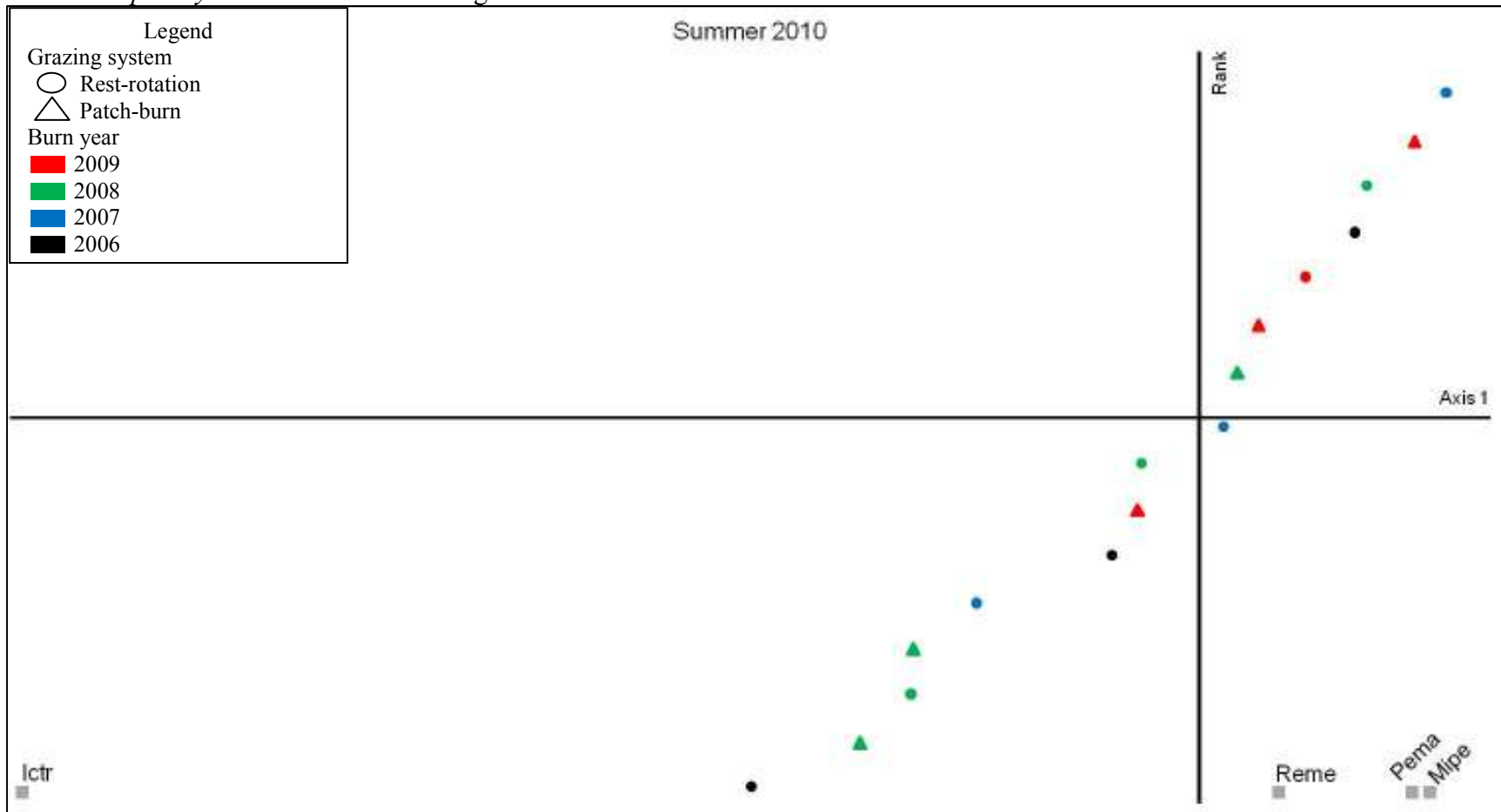
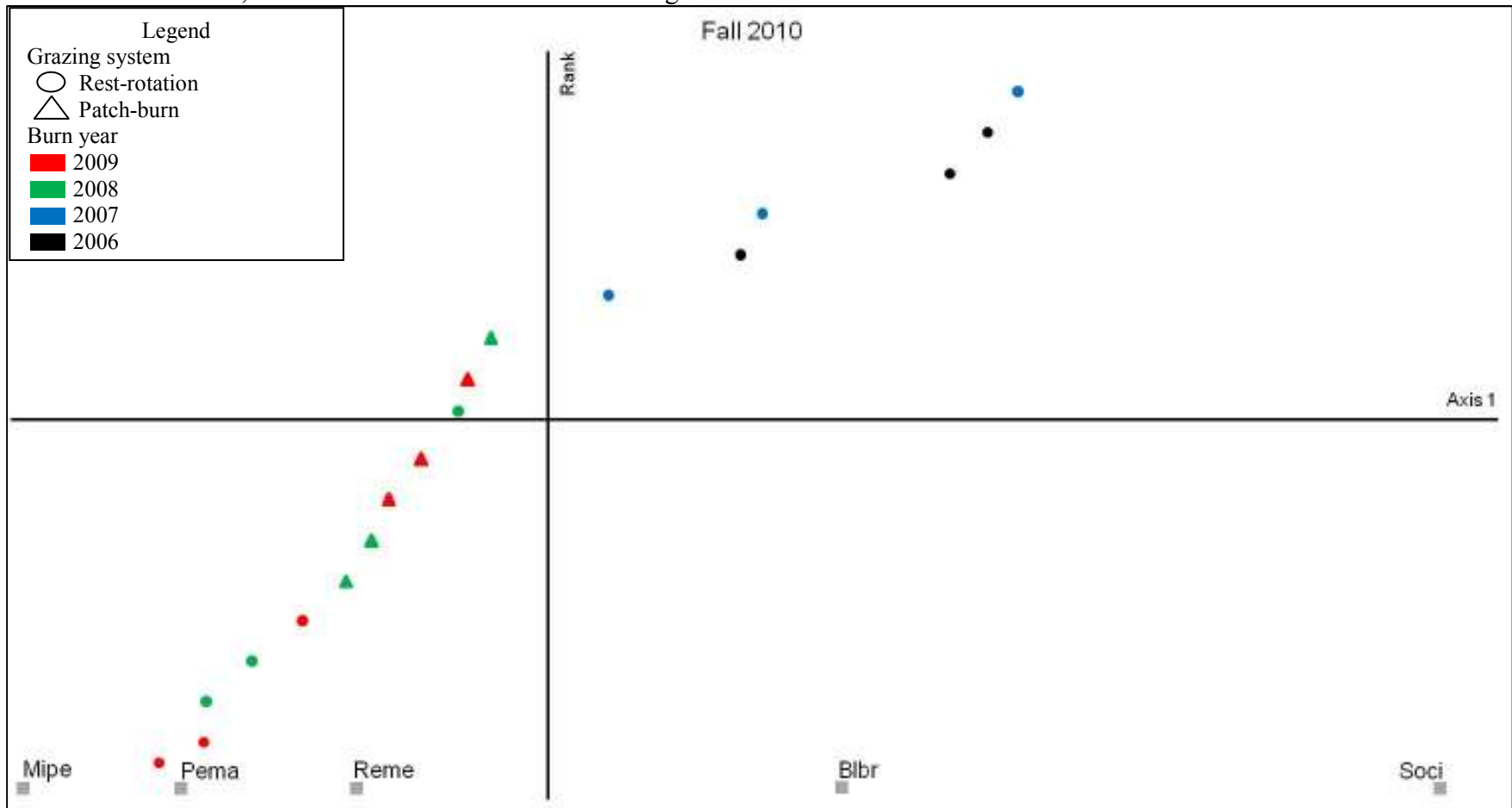


Figure 10. Site ranking along the canonical correspondence analysis axis 1 for fall 2010. Species points associate with site points nearest above. Mipe = *Microtus pennsylvanicus*, Pema = *Peromyscus maniculatus*, Reme = *Reithrodontomys megalotis*, Blbr = *Blarina brevicauda*, Soci = *Sorex cinereus*. Axis 1 loadings are from Table 10.



APPENDIX I

Mammal species observed in Hall County, Nebraska, 2009-2010.

Domain Eukaryota	
Kingdom Animalia	
Phylum Chordata	
Subphylum Vertebrata	
Class Mammalia	
Subclass Theria	
Infraclass Metatheria	
Order Didelphimorphia	
Family Didelphidae	
Virginia Opossum	<i>(Didelphis virginiana)</i>
Infraclass Eutheria	
Order Lagomorpha	
Family Leporidae	
Black-tailed Jackrabbit	<i>(Lepus californicus)</i>
Eastern Cottontail	<i>(Sylvilagus floridanus)</i>
Order Soricomorpha	
Family Soricidae	
Northern Short-tailed Shrew	<i>(Blarina brevicauda)</i>
North American Least Shrew	<i>(Cryptotis parva)</i>
Cinereus Shrew	<i>(Sorex cinereus)</i>
Order Carnivora	
Family Felidae	
Domestic Cat	<i>(Felis catus)</i>
Bobcat	<i>(Lynx rufus)</i>
Family Canidae	
Coyote	<i>(Canis latrans)</i>
Domestic Dog	<i>(Canis lupus familiaris)</i>
Family Mustelidae	
North American River Otter	<i>(Lontra canadensis)</i>
Least Weasel	<i>(Mustela nivalis)</i>
American Badger	<i>(Taxidea taxus)</i>
Family Mephitidae	
Striped Skunk	<i>(Mephitis mephitis)</i>
Family Procyonidae	
Raccoon	<i>(Procyon lotor)</i>
Order Perissodactyla	
Family Equidae	
Horse	<i>(Equus caballus)</i>
Order Artiodactyla	
Family Cervidae	
White-tailed Deer	<i>(Odocoileus virginianus)</i>

Family Bovidae	
Aurochs	<i>(Bos taurus)</i>
Order Rodentia	
Family Sciuridae	
Eastern Fox Squirrel	<i>(Sciurus niger)</i>
Woodchuck	<i>(Marmota monax)</i>
Thirteen-lined Ground Squirrel	<i>(Ictidomys tridecemlineatus)</i>
Family Castoridae	
American Beaver	<i>(Castor canadensis)</i>
Family Dipodidae	
Meadow Jumping Mouse	<i>(Zapus hudsonius)</i>
Family Cricetidae	
Meadow Vole	<i>(Microtus pennsylvanicus)</i>
Common Muskrat	<i>(Ondatra zibethicus)</i>
Northern Grasshopper Mouse	<i>(Onychomys leucogaster)</i>
White-footed Deermouse	<i>(Peromyscus leucopus)</i>
North American Deermouse	<i>(Peromyscus maniculatus)</i>
Western Harvest Mouse	<i>(Reithrodontomys megalotis)</i>
Family Muridae	
House Mouse	<i>(Mus musculus)</i>