THE EFFECTS OF LIVESTOCK GRAZING ON VEGETATION AND GROUND BEETLES (COLEOPTERA, CARABIDAE) IN A SEMI-ARID GRASSLAND

By

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IN A SEMI-ARID

GRASSLAND

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CHAPTER I

LITERATURE REVIEW OF THE EFFECTS OF LIVESTOCK GRAZING ON VEGETATION AND THE ROLE OF GROUND BEETLES AS INDICATORS OF DISTURBANCE

ABSTRACT

Cattle grazing plays an important role in the structure and function of many grasslands in the western United States. This is particularly true of the semi-arid grasslands of the southwest where limited soil moisture hinders the ability of vegetation to recover following a disturbance. In these systems, grazing often impacts a wide variety of variables such as soil moisture, soil compaction, soil erosion, rate of woody plant invasion, and plant species composition.

In addition to soils and vegetation, vertebrate and invertebrate grassland species are also affected as grazing alters their resource base. Grassland invertebrates in particular are highly responsive to changes in their immediate environment, making them potential indicators of changes in the environment due to grazing. Ground beetles (Coleoptera, Carabidae) have been studied as a group of insects that may reflect changes in the environment in a synergistic manner. Ground beetles therefore, may serve as indicators of a variety of changes due to livestock grazing in the semi-arid grasslands of the southwestern United States.

This review provides a framework for the following two chapters. The second chapter presents the results of the vegetation analysis portion of this thesis and the third chapter presents the results of ground beetle sampling. Chapter three integrates results from chapters one and two as a reference for describing environmental conditions faced by ground beetles.

GRAZING HISTORY

The grasslands of the southwestern United States have a natural history unlike the more expansive grasslands of the Midwest. While large native grazers have had an important role in shaping the Great Plains grasslands, the arid grasslands of the southwest have developed primarily without large populations of native herbivores (Mack and Thompson 1992). Only in recent history have these arid grasslands experienced substantial grazing pressure. The arrival of the Spaniards in the 1540s brought domestic livestock to the area for the first time (Bahre 1977, Bahre 1991). Columbus, Cortez, and Coronado supplied Mexico with livestock from Spain and these served as the progenitors of the herds that would later range northward into Texas, New Mexico and Arizona (Humphrey 1958). Livestock grazing reached its height around 1890, just before a severe drought reduced many of the herds. Despite the decrease in herd numbers, the area was still generally overgrazed and overstocked until the Taylor Grazing Act of 1934 set limits to stocking rates (Bahre 1977, Bahre 1991). Although stocking rates have decreased substantially since this time, livestock grazing continues to have a detrimental effect on the southwest ecosystem. In addition, new techniques such as short duration grazing (Holistic Resource Management) continue to generate an interest in the effects of livestock management on the vegetation dynamics of the arid grasslands of this region.

Our knowledge of presettlement conditions of the grasslands of southeast Arizona is unclear since much of the region has experienced livestock grazing and early Spanish explorers left few records of the state of the vegetation. Spanish Captain Juan Fernandez de la Fuente visited what is presently southeastern Arizona and described the west facing slopes of the Huachuca mountains as dominated by oak and the Babocomari drainage as thick with mesquite (Hidalgo del Parral 1695 in Bahre 1977). The Babocomari drainage is also described in 1851 as a wide stream dense with willows, cottonwoods, and abundant grass (Bahre 1977). Although the conditions of southwestern grasslands prior to Coronado remain largely unknown, present day research is important to determine recent shifts in plant community structure in response to grazing. Current ecological studies in these grasslands have focused on the vegetation's response to removal of domestic livestock instead of comparisons to pregrazed conditions (Bock and Bock 1995; Bock *et al*. 1984; Brady *et al* 1989; Chew 1982).

The grazing strategies used most commonly by ranchers in southeast Arizona include moderate, continuous (traditional) grazing and short duration grazing. Moderate continuous grazing is a traditional practice due to its relative ease as a management system. Cattle are usually maintained at moderate to light stocking densities and, in certain growing conditions, they may graze year-round. Grazing pressure is usually light during the growing season in order to provide enough vegetation to carry animals through the rest of the dormant season (Holecheck *et al*. 1989). The herd is not moved on a regular cycle through pastures. Livestock are allowed to selectively graze preferred plant species.

Short duration grazing, on the other hand, requires increased management input. Short-duration grazing is a relatively new concept developed by Allan Savory in the 1960s and has been modified into what is now referred to as Holistic Resource Management (HRM) (Holecheck 1989, Savory 1988). This is an adaptive management strategy that involves higher stocking rates than traditional grazing and herding of cattle through a system of pastures. Cattle are moved to different pastures frequently allowing the heavily grazed vegetation a period of rest and recovery. The benefits and drawbacks of both grazing systems with respect to soils and vegetation are discussed in the following sections.

GRAZING AND SOILS

Grazing systems can potentially affect several important soil parameters, such as compaction, infiltration, and erosion. Many studies have focused on these variables due to their direct relevance to changes in plant community structure following grazing (Abdel-Magid *et al.* 1987, Rietkert *et al.* 1997, and Naeth *et al.* 1991.). These three variables are often interrelated and may be viewed as a chain of events rather than independent processes.

Soil compaction, as measured by bulk density, often depends on the type of soil and the location or season (Abdel-Magid *et al.* 1987, Rietkerk *et al.* 1997). In general, sandy soils tend to suffer less from soil compaction than clayey soils. Northern locations with freeze-thaw cycles that provide soil break-up are able to compensate for soil compaction more than southern rangelands without freeze-thaw cycles. Southwestern grasslands are therefore more prone to chronic soil compaction following prolonged grazing. Abdel-Magid (1987) found no consistent connection between soil compaction and grazing system whereas, Van Haveren (1983) found that intensive early grazing over ten years resulted in compaction that effectively restricted water into the soil profile. In monsoon climates, such as in areas of the southwest, the ability of the soil to absorb water from sporadic and intense rainstorms is crucial to the existence of the native flora.

Proponents of short-duration grazing state that the high stocking rates of this system may increase water infiltration and reduce erosion and compaction (Savory 1980, Savory and Butterfield 1999). The increased hoof action apparently breaks up the soil surface of lichen, moss, and cryptobiotic crust and subsequently increases water flow to plants (Savory and Parsons 1980). This may also promote the succession of naïve range grasses because microsites are created for seed germination. Wood and Blackburn (1981) found no differences in infiltration rates in a comparison of short-duration and continuous grazing. Water infiltration was found to decrease under short-duration grazing when compared to continuous grazing (Thurow *et al.* 1986, Weltz and Wood 1986). Similar studies have found that water infiltration rates decreased almost linearly as grazing intensity increased (Rauzi and Hanson 1966, Rauzi and Smith 1973).

Hoof action can also contribute to soil erosion by making the soil surface more susceptible to water erosion during rainstorms (Trimble and Mendel 1995). This is especially true in arid lands where grazing can remove a large portion of the standing biomass and litter, leaving little structure to intercept rainfall. Compaction of soils reduces infiltration and increases runoff which subsequently accelerates soil erosion. In this respect, the three soil parameters are often interrelated in a cause and effect manner.

GRAZING AND VEGETATION

One of the predominant issues in the southwest with respect to grazing has been the proliferation of woody vegetation in areas that were historically grasslands. *Prosopis juliflora* (Swartz) DC (Mesquite), in particular, has been studied extensively as an aggressive invader following livestock grazing (Brown 1950, Buffington and Herbel 1965, Humphry 1958). Several factors have contributed to the spread of mesquite. Removal of vegetation by livestock tends to favor mesquite proliferation through reduction of grass species that compete with young mesquite seedlings. If a large percentage of the grass cover is removed, mesquite will benefit from a decrease in competition for soil water and nutrients. In addition, livestock grazing often results in a reduction in the amount of litter in a plant community and this may lead to fewer fine fuels to contribute to range fires which previously served to control the mesquite population. A third factor that contributes to mesquite proliferation is the spread of mesquite seeds through cattle. Cattle frequently ingest mesquite beans and the tough beans remain intact following digestion. In terms of trends in the current mesquite populations, studies have found that once mesquite is established it will continue to expand its range regardless of the grazing system (Brown 1950). Bogusch (1952) proposes that climate fluctuations between times of abundant rain and drought perpetuate rather than inhibit the invasion of mesquite. Although grasses are equally susceptible to drought, mesquite is a better long-term competitor for resources than grasses.

The influence of livestock grazing extends beyond the proliferation of woody species. Grasses and forbs also respond to livestock grazing, some in a semi-predictable manner according to their physiological traits (Bock and Bock 1995). In general, studies have found that grazing often favors short stature, rhizomatous or stoloniferous grass species over medium or tall bunchgrasses (Bock *et al.* 1984, Mack and Thompson 1982). Examples of short stature grasses that have been found to benefit from grazing are (blue grama) *Bouteloua gracilis* (H.B.K) Lag., *Bouteloua chondrosioides* H.B.K Benth. (sprucetop grama), and *Bouteloua eriopoda* Torr. (black grama) (Bock *et al.* 1984).

Stoloniferous species such as *Panicum obtusum* H.B.K. (vine mesquite) and *Buchloe dactyloides* (Nutt.) Engelm. (buffalo grass) are other common species that increase with grazing. Areas that have been allowed a rest from grazing support taller bunchgrass species such as *Eragrostis intermedia* Hitchc. (plains lovegrass), *Bouteloua curtipendula* (Michx.) Torr. (sideoats grama), and *Trichachne californicum* (Benth.) Chase (cane beardgrass) (Bock *et al.* 1984, Ellison 1960). These grasses are scarce on heavily grazed lands due to their lack of stoloniferous or rhizomatous tissues that aid in recovery following trampling or overgrazing (Bock and Bock 1995). However, some areas do not respond positively to a release from grazing, especially areas with little or unpredictable rainfall. In a study by Chew (1982), little directional change occurred in species composition over nineteen years of rest from grazing. Palatable grasses showed marginal increase and species adapted to grazing remained dominant in this study. Soils may also play an important role in response to, and recovery from, grazing as was indicated in a study by Buffington and Herbel (1965) where soil types shaped the responses of the vegetation community. This suggests that multiple environmental factors may work together to influence the response of the vegetation community to grazing management.

GRAZING AND INDICATORS

Given the complexity of evaluating the influence of environmental factors, some studies have suggested the use of indicator species as a measure of vegetation or habitat condition (Dufrene and Legendre 1997, Noss 1990, Rosenberg *et al.* 1986). Indicators are useful tools for evaluation of land management. Indicator species may serve as representatives of overall biodiversity in a given land management type or may serve as surrogates for a suite of environmental conditions or impacts (Noss 1990). In order to fulfill these roles, indicators need to be (1) particularly sensitive to given environmental conditions; (2) relevant to ecologically significant phenomena; (3) distributed over a wide geographic area; (4) and easy and inexpensive to measure or collect (Noss 1990).

Most recently, terrestrial arthropods have been studied as suitable indicators for evaluating land condition and the effects of various impacts, such as grazing management (Kremen *et al.* 1993). Often, insects will respond to a disturbance in characteristic manner which makes them useful in the assessment of changes in an ecosystem not immediately recognizable by changes in plant community structure (Rosenberg *et al.* 1986). Use of insects for assessing impacts may also address changes not accurately reflected by physical environmental variables. Physical and chemical measurements tend to provide data on environmental conditions at the time of measurements whereas sampling of the insect community generates information on conditions for a greater period of time (Rosenberg *et al.* 1986). In contrast, the short generation time of arthropods relative to other fauna allow for a quicker response to a disturbance than traditional mammalian and avian indicators. Insects may represent the interaction of several environmental variables thereby offering a more complete evaluation of grazing impacts than a single environmental variable. Terrestrial arthropods may respond to, and perhaps serve as important indicators of grazing management impacts.

Ground beetles are believed to be an insect family that occupies the role of an indicator of land condition in terrestrial ecosystems (Malfait and Desender 1990, Eyre and Luff 1990, Dufrene and Legendre 1997). Ground beetles are primarily predaceous arthropods that prey on other insects and occasionally consume seeds and grains.

Predaceous arthropods are argued to be a successful group of insects that are distributed over the total range of terrestrial habitats (Malfait and Desender 1990). Although cosmopolitan as a group, ground beetles have been found to be key components of desert communities (Polis and Yamashita 1991). Predaceous arthropods as a group account for a large percentage of the biomass of desert arthropods and exceed the biomass of desert vertebrates (Polis and Yamashita 1991). Ground beetle species are also typically specialized in their prey choice, and subsequently their habitat, which creates niche differentiation within the family. This leads to separation of ground beetles by habitat type. Grazing impacts may modify a habitat sufficiently to create altered micro-habitats that support different ground beetle assemblages. The combination of ground beetle niche differentiation and their large contribution to the biomass of desert ecosystems has contributed to their potential role as model organisms for the study of impacts or changes in management in arid habitats.

Studies have shown ground beetles to be highly influenced by changes in a variety of environmental conditions. Ground beetles have been found to be sensitive to amount of soil moisture (Luff *et al.* 1989, Thiele 1977), the type and amount of vegetative cover (Eyre and Luff 1990, Dennis *et al.* 1997), and other physical environmental factors such as humidity, temperature, and soil substrate type (Thiele 1977). Recent research on external impacts to ground beetles has focused on the effects of grassland management (Rushton *et al.* 1990), grazing regimes (Gardner *et al.* 1996), timber harvesting (Niemela *et al.* 1993), crop type (Dammer 1997), and habitat fragmentation (Vermeulen 1994). The study of grazing on ground beetle communities has occurred relatively recently and has focused primarily on European grasslands and pastures. Results from these studies have indicated several trends that have potential application to a variety of grassland types.

Studies of ground beetles have found species specific responses to grazing management. Often the ground beetle species responses are shaped by impacts to the plant community. In particular, ground beetles have been reported to be influenced by vegetation structure more than plant species composition (Gardner 1997, McFerran *et al.* 1994). A grazing study by Gardner (1997) indicated that the height of grasses and the shade they cast favored specific ground beetle assemblages. In a multivariate approach to grazing and ground beetles, Dennis *et al.* (1997) found ground beetles to be responsive to livestock stocking rate, mean vegetation height and botanical diversity. In this study, species were able to be grouped according to the grazing intensity and type of livestock in the pastures surveyed. In addition, larger bodied ground beetles were found in less intensively grazed treatments and smaller species found in greater grazing intensities, supporting previous findings (Blake *et al* 1994). Similar studies have been conducted that distinguish between ground beetles that prefer intensively managed versus unmanaged sites and often these stress a need for a better understanding of the natural history of individual ground beetle species (Rushton *et al.* 1990, Luff 1996).

Changes in specific environmental variables in response to grazing have been documented from many studies. In particular, the soil microclimate as influenced by disturbance is highly influential in the distribution of ground beetles (Thiele 1977). The soil microclimate may be influenced by soil compaction, reduced infiltration, and increased erosion following livestock grazing. Ground beetle distributions have been found to be affected by the amount of soil moisture present in the soil (Luff *et al.* 1989, Eyre and Luff

1990) which may be altered by grazing management. Soil compaction and the subsequent reduction in infiltration following intense grazing may reduce the amount of soil moisture available for ground beetles. Many ground beetle species deposit their eggs directly in the soil and the success of the developing larvae are dependent on both the amount of soil moisture and the temperature of the soil (Thiele 1977). It is also likely, that soil compaction may also inhibit the ability of the adult to emerge once fully developed. However, some opportunistic species may prefer the soil disturbance associated with trampling by livestock. In some cases, trampling opens up vegetation cover and allows species characteristic of sparsely vegetated areas to thrive (Malfait and Desender 1990). The effects of erosion have not been directly studied but may play a role in the development of soil inhabiting larvae. In general, ground beetle species exhibit a range of preferences for soil moisture and the degree of soil compaction (Dennis *et al.* 1997) which allows them to be used to characterize the degree of disturbance of a given grazing regime.

The importance of year to year variation in ground beetle assemblages is occasionally stressed in research findings (Luff 1996). While short-term sampling of ground beetle communities is useful for assessing habitat quality (Malfait and Desender 1990), year to year variation in species composition may be informative at a larger scale. In some studies, year to year variation was the most important factor shaping species composition (Luff 1996, Rushton *et al.* 1989). The sampling year may in some cases serve as an environmental variable for weather conditions of the past year (Luff 1996). The sensitivities of individual species to fluctuations in weather conditions may also be impacted by grazing intensity. Ground beetle assemblages of unmanaged areas have been found to be more stable over the years than intensively managed areas, which is possibly due to high recolonization rates of intensively managed sites (Rushton *et al.* 1989). Ground beetles must therefore be viewed as indicators within the context of natural variation in communities due to yearly meteorological factors.

The variety of environmental factors that are affected by livestock management provide important information on land conditions and habitat integrity. However, these variables indicate conditions at a single point in time. Indicator species, and ground beetles in particular, generate information on a variety of environmental conditions and over a longer span of time. Due to their sensitivities to biotic and abiotic conditions, ground beetles are frequently used as indicators of disturbances, such as livestock management.

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CHAPTER II

THE EFFECTS OF LIVESTOCK GRAZING ON PLANT COMMUNITY COMPOSITION IN A SEMI-ARID GRASSLAND IN SOUTHEAST ARIZONA.

ABSTRACT

The grasslands in southeast Arizona are located in a region that is believed to have evolved without grazing pressure by large herbivores. The relatively recent history of livestock grazing in the region has introduced a number of changes to plant communities and the environment in which they exist. In this study, I addressed some of the changes to plant species composition as a result of two different grazing strategies. I performed across the fence comparisons with different grazing methods to distinguish the effects of moderate and short duration grazing strategies on the plant community at the Appleton-Whittell Research Ranch in southeast Arizona. Multivariate methods such as Detrended Correspondence Analysis (DCA) and Canonical Correspondence Analysis (CCA) were used to evaluate patterns in plant species distribution. Plant species composition was significantly affected by grazing, soil moisture, and distance from the fence line. In general, soil moisture was a more influential variable on species composition at grazed sites than ungrazed sides of the fence. Distance from the fence was a more influential at ungrazed sides of the fence. The mean total vegetation cover was significantly higher on ungrazed situations across all sites and at short duration sites. The mean total vegetation cover was not significantly different across the fence at moderate sites indicating that short duration grazing has a more substantial impact on the plant communities in this study.

INTRODUCTION

Large native grazers, such as buffalo (*Bison bison*) have had an important role in shaping the grasslands of the Great Plains. However, the arid grasslands of the southwest United States have developed largely without large native herbivores (Mack and Thompson 1992). Only in recent history have these arid grasslands experienced substantial grazing pressure. The arrival of the Spaniards in the 1540s brought domestic livestock to the southwest for the first time and set the stage for subsequent grazing in this area (Bahre 1997, Bahre 1991). Grazing reached its maximum around 1890 before severe drought reduced many of the herds. However, the area was generally overgrazed and overstocked until the Taylor Grazing Act of 1934 set limits to stocking rates (Bahre 1977, Bahre 1991). Although stocking rates have decreased substantially, new practices such as short duration grazing (Holistic Resource Management) continue to drive an interest in determining the effects of these grazing practices have on vegetation of arid grasslands.

Several characteristics distinguish the two commonly used grazing practices in southeast Arizona. Short-duration grazing allows higher densities of cattle to graze an area for a limited time, often for only a few days. Cattle are moved to another pasture while the grazed pasture is deferred, or rested. Cattle continue to rotate through pastures, allowing each pasture to rest for approximately four weeks (Holecheck 1995) The increased stocking rate is believed to improve water infiltration, increase mineral cycling, and reduce dominance of undesirable species by evenly grazing all species (Holecheck 1995, Savory 1988). Moderate, continuous grazing, the more traditional method, permits cattle to graze without restrictions and at lower stocking rates. Cattle are also allowed to select plant species of greatest preference. It is often assumed that this will lead to excessive grazing of desirable forage plants (Holecheck 1995).

Knowledge of presettlement conditions of the grasslands of southeast Arizona is unclear since the entire area was grazed to some degree. Therefore, studies of grazing in these grasslands have instead focused on the response of vegetation to removal of domestic livestock (Bock and Bock 1995, Bock *et al.* 1984, Brady *et al* 1989, Chew 1982). The objectives of this study were to compare the effects of short duration and moderate, continuous grazing practices on plant species composition and cover on actively grazed ranches with a property where grazing has been removed. This study is the first part of a study to assess the effects of grazing intensity on ground beetles.

METHODS

DESCRIPTION OF STUDY SITE

I conducted this study at the National Audubon Society Appleton-Whittell Research Ranch in southeast Arizona (The Research Ranch). The Research Ranch is located 100 km southeast of Tucson on the Sonoita Plain (Figure 2.1). The Research Ranch, which comprises 3300 ha, was created in 1968 by the Appleton Family. Prior to 1968, The Research Ranch was the Elgin Hereford Ranch and was grazed using moderate continuous grazing methods similar to adjacent properties (Bock and Bock 2000). The Appletons removed livestock and transferred management responsibility to the National Audubon Society with the intent that the property be used for ecological research and as a preserve. The Research Ranch has been rested from livestock grazing since its creation and has been the setting of numerous studies that address recovery from grazing.

The Research Ranch lies within the semi-arid grasslands of southeast Arizona, an area characterized as the Chihuahuan Desert Province (Bailey 1995). The vegetation consists of perennial bunchgrass prairie with oak woodland at the higher elevations. Several drainages periodically flow following monsoon rains, including Post Canyon, O'Donnell Canyon, Turkey Creek, and Lyle Canyon. In the seasonally flooded lowlands *Sporobolous wrightii* Munro. (sacaton) can form dense stands and in other portions riparian woodlands are present and are dominated by *Platanus wrightii* Wats. (Wright's sycamore), *Populus fremontii* Wats. (Fremont's cottonwood) and *Salix* spp (willows). Uplands contain 19 different perennial grass species and include *Bouteloua gracilis* (Willd. ex Kunth) Lag. ex Griffiths (blue grama), *Eragrostis intermedia* Hitchc. (plains lovegrass), *Eragrostis lehmanniana* Nees. (Lehman's lovegrass), and *Lycurus phleoides* H.B.K. (wolftail). Woodlands are comprised of *Quercus emoryii* Torr. (Emory oak) and *Quercus arizonica* Sarg. (Arizona white oak) (McClaran 1995).

Elevation at The Research Ranch ranges from 1400 to 1560 meters. The yearly precipitation averages 43cm per year with 28cm falling in July, August, and early September (Bock and Bock 1984). The mean annual temperature is 12° C.

COLLECTION OF DATA

I conducted this study August 2 - 17, 1997. This time frame was within the summer monsoon season when the vegetation growth and beetle activity was expected to be greatest.

I selected two intense, short duration grazed sites (Post Canyon and East Gate) and two moderate continuous sites (Northwest and Northeast) from the ranches abutting

The Research Ranch (Figure 2.2). For each of these sites, I selected a site across the fence in the ungrazed sanctuary. In the short duration sites, 450 head of adult cows grazed for approximately four to five days per pasture in 1997 and 1998. Moderate continuous sites grazed 725 head of yearling steers in 1997 and 900 head in 1998. All sites had similar topography with a high grass component and little woody vegetation.

On each side of the fence, I placed three sets of transects perpendicular to the fence line. The transects started 10m from the fence in order to reduce edge effects. Each transect was 50m in length. At 10m intervals along the transect, I installed pitfall traps to capture insects. Adjacent to each trap a one-meter square vegetation quadrat was placed and percent cover and species composition were recorded. I also recorded percentages of rock, litter and bare ground. Plant species nomenclature follows Arizona Flora (Kearney 1970).

On the opposite side of the trap, I collected soil samples to determine the amount of soil moisture. I performed a simple gravimetric soil analysis on these samples to obtain percent soil moisture. A total of 15 vegetation quadrats and soil samples were collected from each side of the fence. Because the sample sites were located along transects, they are not spatially independent and therefore the sites may be at risk for pseudoreplication effects (Hurlbert 1984).

ANALYSIS OF DATA

The data obtained from these measurements were analyzed with CANOCO for Windows (ter Braak 1997). I performed an indirect gradient analysis, Detrended

Correspondence Analysis (DCA), to determine environmental gradients suggested by plant species distribution (Jongman *et al.* 1987). I then performed direct gradient analysis, Canonical Correspondence Analysis (CCA), to evaluate the relative influence of environmental factors on the distribution of plant species (Gauch 1982).

Input to the DCA and CCA analysis included plant species cover, and the amount of rock, bare ground, and litter in each quadrat. Environmental variables added to the CCA were soil water content (percentage) and distance from the fence line (meters). Nominal environmental variables (presence/absence) were also used for site identification and treatment (grazed/ungrazed). For both the DCA and the CCAs, species were square root transformed and rare species were downweighted. The percent cover of bare ground, litter, and rock were treated as passive species by categorizing them as supplementary environmental variables in the analyses.

In the CCA plant species and site data were analyzed in several sets. The initial analysis included all the environmental variables (soil moisture content, grazed or ungrazed, and site identification), excluding distance from the fence. Secondly, grazed and ungrazed sides of the fence were analyzed individually to determine the influence of soil moisture and distance from the fenceline. Thirdly, I performed a partial CCA. In this analysis sites served as covariables in order to factor out the effects of site differences on species distributions.

To evaluate overall and species specific differences in grazing strategies, I performed paired t-tests. Paired t-tests were used to 1) compare the amount of soil moisture in grazed and ungrazed situations at all sites, 2) compare differences in total vegetation cover across the fence, and 3) determine which common species showed significant across the fence differences in cover.

RESULTS

The indirect gradient analysis, DCA, revealed several patterns. First, the sites are generally clustered into two groups with one of the moderately grazed/ungrazed sites, the Northwest site, separated from the other sites (Figure 2.3a). I interpreted this separation to represent a soil texture gradient on axis 1. This is due to the rocky nature of the soils encountered at the Northwest site relative to the other sites. A soil map of The Research Ranch also confirms that a different soil type exists at the Northwest site from the other sites (Figure 2.2). The amount of rock was oriented towards the Northwest site and with woody species such as *Nolina microcarpa* S. Wats. (beargrass) and *Calliandra eriophyll*a Benth. var. eriophylla (fairyduster) (Figure 2.3a and 2.3b). Species associated with sandy soil conditions include *B. gracilis*, *Zinnia grandiflora* Nutt. (prairie zinnia), and *Baccharis pteronioides* D.C. (yerba de pasmo). Second, within these two groupings of sites, a pattern on axis 2 separates sites. A trend toward ungrazed sites located at the upper end of the axis and grazed sites located on the lower end of the axis suggests a grazing related gradient on axis 2. Third, sites which experience short duration grazing are grouped at the same distance on axis 1 but are on opposite ends of axis 2. Moderately grazed sites are separated on axis 1 due to their soil texture but are similarly placed on axis 2. There was a high amount of variation in species distribution explained by the axes in the DCA. Eigenvalues, which represent the amount of variance explained, were 0.592 for axis 1 and 0.474 for axis 2.

The first CCA analysis including both grazed and ungrazed sites indicated a strong association of species distribution with the measured environmental variables. Eigenvalues for axis 1 and 2 were 0.379 and 0.339 respectively. Results of the Monte Carlo permutation test indicated that the species data were significantly related to the environmental data ($p = 0.005$). The Northwest site, moderately grazed, exhibited the strongest relationship with water content (Figure 2.4). Several plant species were also correlated with water content (Figure 2.4). Plant species with high scores corresponding to water content were *Aristida* sp. (threeawn), *Eriogonum wrightii* Torr. ex. Benth (Wright's buckwheat), and *N. microcarpa*. There was also separation of species along the grazing axis. Species correlated with ungrazed situations included *Evolvulus sericeus* Sw. (silver dwarf morning-glory), *Hilaria jamesii* (Torr.) Benth. (galleta grass), and *E. intermedia* (Figure 2.4). Species correlated with grazed situations are *E. lehmanniana*, an unknown grass, and *Haplopappus tenuisecta* (Greene) Blake (burroweed).

Individual analyses of the grazed and ungrazed sites indicate more clearly the relationship between grazing, soil moisture and species composition. Results from the Monte Carlo analysis of ungrazed sites indicate that plant species distribution is significantly related to the measured environmental factors ($p = 0.005$). There was a relatively high degree of variation in species distribution explained by the environmental variables measured. Eigenvalues were 0.418 for the first axis and 0.267 for the second axis. The Monte Carlo analysis of the grazed sides of the fence also indicates that plant species distribution is significantly influenced by the measured environmental variables ($p = 0.005$). Eigenvalues for the grazed side of the fence were 0.609 for the first axis and 0.525 for the second axis.

The ungrazed sides of the Northeast and Northwest sites show high scores in relation to soil water content (Figure 2.5). This situation changes on the grazed sides where site scores for soil moisture are highest for East Gate and Northwest sites (Figure 2.6). The Northwest site had the highest soil moisture values and showed no significant difference in across the fence values (Table 2.1). East Gate is a short duration site that shows low soil moisture correlations on the ungrazed side of the fence and moderate to high soil moisture correlation on the grazed side of the fence. East Gate was the only site that showed significant differences in soil moisture across the fence, with higher soil moisture on the ungrazed side of the fence (Table 2.1). On the ungrazed side of the fence, species tend to show strong relationships with distance from the fence and soil moisture across most sites. However, on ungrazed sides of the fence soil water content appears to shape species distribution more than the distance from the fence. Mean soil moisture was generally greater on the ungrazed side of the fence in both grazing types but differences were not significant over the study area ($p = 0.162$) (Table 2.1).

In the fourth CCA, I performed a partial analysis, including percent soil moisture, distance from the fence line and grazed or ungrazed condition, but I factored out the effect of site differences. This allowed a closer look at the effects of grazing without the influence of the individual sites. The sites were entered as covariables. The results of the Monte Carlo permutation test indicated that the environmental variables are significantly related to the species composition ($p = 0.005$). Eigenvalues for the first axis were 0.209 and 0.018 for the second axis. These eigenvalues were lower than the CCA involving the sites, indicating a smaller degree of variation in species distribution that could be explained by the environmental variables than by the site locations. The use of the sites as covariables restricted the amount of species scatter, grouping most species in the center of the biplot (Figure 2.7).

Paired t-tests of mean total vegetation cover on grazed and ungrazed sides of the fence, irrespective of grazing type, indicate that total vegetation cover is significantly higher on the ungrazed side of the fence than the grazed side ($p = 0.02$) (Table 2.2). The mean vegetation cover on the grazed side was 42.9% and the mean vegetation cover on the ungrazed side of the fence was 49.9%. Short-duration sites responded similarly with significantly higher cover on the ungrazed side of the fence than the grazed side ($p = 0.03$) (Table 2.2). The mean vegetation cover for short-duration grazed sides was 43.1% and the mean for ungrazed sides was 52.5%. Moderately grazed sites did not show significant across the fence differences in total vegetation cover ($p = 0.16$) (Table 2.2). The mean vegetation cover for moderately grazed sites was 42.6% compared to 47.3% on the ungrazed sides of the fence.

The results from a paired t-test indicate differences in cover of common species in grazed and ungrazed sides of the fence (Table 2.3). Grass species that showed significantly higher cover on the ungrazed side of the fence include *B. gracilis* ($p = 0.00$) and *E. intermedia* ($p = 0.00$). *E. lehmanniana* ($p = 0.01$) and an unknown species of grass ($p = 0.03$) were significantly higher on the grazed side of the fence. Common grass species that showed no significant difference in cover across the fence included *H. jamesii* and *Aristida* sp.. One forb species, *Portulaca mundula* I.M. Johnson (kiss me quick), was significantly higher on the grazed side of the fence ($p = 0.001$). The amount of bare ground was significantly different across the fence with grazed areas comprised of significantly higher amounts of bare ground than ungrazed areas ($p = 0.014$).

DISCUSSION

GRAZING AND SPECIES COMPOSITION

Although the measured environmental variables significantly shaped plant species distribution, the location of the sampling sites appeared to exert a stronger influence on the plant community observed at each site. In particular, the Northwest site showed a stronger disparity in species composition compared to the other sites, in part because the soil type was different than the other sites. The variety of soil types and the subtle differences in plant communities present at The Research Ranch may partially be a result of the rolling and varied topography. While the vegetation sampling locations were selected to be similar superficially in vegetation type and slope, the study area was sufficiently diverse that the vegetation at each location had unique features specific to that portion of the property. This does not necessarily preclude any general conclusions on the vegetation response to grazing but suggests that some responses may be best observed by individual site or location studies over time.

The average total vegetation cover was higher on the ungrazed side of the fence at all sites but was not significantly greater at the moderate grazing type sites. Vegetation cover was significantly greater on ungrazed situations across all sites and at short duration sites suggesting that short duration grazing creates a more substantial and influential impact on the plant communities at The Research Ranch than does moderate grazing. Although the stocking rate was higher, the ability of livestock to disperse over a large area under moderate grazing appears to lessen the acute reduction of plant material observed at short duration sites. Although supporters of short duration grazing contend that the removal of vegetation is a short term affect with plants recovering rapidly (Savory 1988, Savory and Butterfield 1999), below average rainfall for an extended period could contribute to non-recovery and subsequent degredation of the plant community. An opening is therefore created for exotic species invasion or possible soil erosion. The effects of moderate grazing on vegetation may not be readily observed in averages of total cover but instead in long term shifts in species composition as livestock favor particular species over others. Some species specific responses to grazing are discussed as follows.

Species distributions in this study responded similarly to other studies documenting grazing tolerant/intolerant species in addition to some species that responded contrary to expectations. Species that are typically associated with grazing pressure that I observed more often in grazed situations included the grasses *Aristida* sp. and *E. lehmanniana*. In general, grass species were more common than forbs and shrubs and demonstrated significant across the fence differences more often. The most notable species associated with grazing pressure was *P. mundula*, a succulent leaved forb. *P. mundula* is not mentioned in previous studies at The Research Ranch and the surrounding area. This species was a relatively abundant forb which showed significantly higher cover in the grazed side of the fence than the ungrazed. The ability of the plant to conserve water in its' succulent leaves and low and spreading growth habit are factors that would enable it prosper in grazed situations. It is possible that this is a recent invader or has only recently reached significant numbers. Shrubs that showed slightly higher cover on the grazed sites include *H. tenuisectus* and *B. pteronoides*. With the exception of *P. mundula*, these are all species that have been documented as species that increase with grazing (Bock and Bock 1995, Brady *et al* 1989, Chew 1981, and Smith and Schmutz 1975).

Plants that were more abundant on the ungrazed Research Ranch than the surrounding ranches are *E. intermedia*, *B. gracilis*, *E. sericeus*, and *Malvastrum bicuspidatum* (S. Wats.) Rose (shrubby falsemallow). The significant decreases in cover of *B. gracilis* and *E. intermedia* on grazed sites can be attributed to their status as preferred plant material for cattle (Humphrey 1970). These grasses are preferentially eaten before other species such as *E. lehmanniana*. *B. gracilis*, the second most abundant grass on the ungrazed side of the fence, is considered one of the most important grasses on The Research Ranch (Bock and Bock 1986). However, it is also considered to be very grazing resistant (Humphrey 1970) and it is therefore surprising that cover is much lower on the grazed side of the fence. The association of *E. sericeus* with ungrazed situations may be explained by the palatability of this perennial forb (Martin 1973).

Species that performed contrary to expectations include several grasses and a forb species. Species of the genus *Aristida* have been found to generally decrease with grazing (Brady et al 1989, Smith and Schmutz 1975). This study indicates the opposite situation with *Aristida* increasing on the grazed side of the fence, although not significantly. Canopy cover of *H. jamesii* usually increases with grazing (Brady *et al* 1989) but instead decreased in this study. The amount of unknown grass cover is significantly higher on the grazed side of the fence, which may be an artifact of the early season sampling. I performed these vegetation surveys early in the monsoon season when the grasses were at an immature phenological stage and at times unidentifiable. Therefore, grasses labeled as unknown may actually belong with *H. jamesii*. The unknown grass had a similar growth habit to *Hilaria* but an identification could not be made without inflorescences. If the unknown belongs to *Hilaria*, the amount of cover on the grazed side of the fence would represent a substantially higher amount.

DISTANCE FROM THE FENCELINE AND SPECIES DISTRIBUTION

Distance from the fence is a stronger environmental variable in shaping species distribution in ungrazed sites than in grazed sites (Figures 2.5 and 2.6). It would seem more plausible that grazed sites would instead show a stronger response to distance from the fence. Factors that would be expected to influence this response include fence trailing by cattle and the increased trampling that occurs there. However, there appears to be little concentrated cattle activity near the fence lines of the ranch. The exception is the East Gate site, which has a dirt road along the fence line on the grazed side. The combination of increased disturbance near the road and the compaction of the soil may contribute to this sites' correlation with the short distance arrow (Figure 2.4).

On the ungrazed side of the fence, distance plays a much stronger role. Reasons for this are unclear at present. The likely explanation of invasion of weedy species from the grazed side of the fence does not appear to occur to any extent. The East Gate site is located near an encroachment of the exotic *Eragrostis chloromelas* Steud (Boers lovegrass). This species of lovegrass forms dense monocultures and the edge of this stand extends partially into the rear portion of the sampling area. This accounts for the high correlation of this species and the East Gate site with the distance arrow on the biplot (Figure 2.3).

SOIL MOISTURE AND SPECIES DISTRIBUTION

While increased soil moisture is a purported characteristic of short duration grazing (Savory 1988), much research suggests the opposite occurs, particularly in the western United States (McCalla *et al.* 1984, Thurow *et al.* 1986, and Weltz and Wood 1986). Grazing tends to reduce soil moisture due to reduced infiltration rates caused by trampling and subsequent soil compaction (Llacos 1962). Grazing can also reduce the amount of litter, which can lead to an increase in evaporation and reduced infiltration of precipitation (Tomanek 1969). However, in this situation, litter does not appear to be positively associated with an ungrazed situation, in fact, it tends to be slightly more correlated with grazing (Figure 2.2). This may account for the increased importance of soil moisture in short duration grazed sites. Some other explanations for this may be the effects of lower bulk density and penetration resistance in the short duration soils (Naeth *et al.* 1990). It is also possible that the time of year may have an influence on the importance of soil moisture. Early season growth, such as the beginning of a monsoon season, has been shown to increase the chances of lower bulk density and penetration resistance as influential factors since loss to evapotranspiration is less significant (Naeth *et al.* 1991). Therefore, the importance of soil moisture is possibly a short term effect. The soil moisture data were highly variable and across the fence differences were inconsistent between sites. The results of the data analysis indicate that no significant difference exists in percent soil moisture across all sites. Overall, the effects of soil moisture on the plant communities measured is probably not a critical factor shaping species distribution.

CONCLUSIONS

The Research Ranch contains plant communities that differ in species composition and cover with the surrounding grazed plant communities. The plant communities at The Research Ranch exhibit significantly higher mean total vegetation cover at all sites and at sites where short term grazing is practiced. Moderate grazed sites do not show significant differences in vegetation cover suggesting that short duration grazing has a more influential affect on plant communities in terms of cover. Species that showed significantly greater cover on the ungrazed side of the fence included *B. gracilis* and *E. intermedia*. Species that had significantly greater cover on the grazed side of the fence included *E. lehmanniana*, an unknown grass, and *P. mundula*.

The environmental variables measured were significant in shaping species distributions in all sample locations. In ungrazed situations the distance from the fenceline was the most important environmental variable. Grazed situations showed the percent of soil water to be the most important environmental variable. Overall, the location of the sample site was more influential in shaping species distribution than the measured environmental variables. The variety of landscape features and topography present at The Research Ranch create unique species assemblages and site specific responses to grazing pressure. In particular, the soil type appears to be important in shaping species composition at the sample sites.

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Table 2.1. Mean percent soil moisture and paired t-tests on grazed and ungrazed sites.

Site	Mean	Variance	p-value
East Gate Grazed	4.94	2.2	
East Gate Ungrazed	5.26	5.70	0.68
Northeast Grazed	3.26	0.96	
Northeast Ungrazed	5.05	3.93	0.006
Northwest Grazed	5.42	6.09	
Northwest Ungrazed	5.61	3.41	0.802
Post Canyon Grazed	4.63	9.5	
Post Canyon Ungrazed	4.61	1.33	0.976
Grazed overall	4.52	5.07	
Ungrazed overall	5.05	3.15	0.162

Table 2.2. Mean total percent vegetation cover and paired t-test of grazed and ungrazed sides of all sites, short-duration, and moderate continuous sites.

Sites	Mean grazed vegetation cover	Mean ungrazed vegetation cover	p-value
All sites	42.9	49.9	0.02
Short-duration sites	43.1	52.5	0.03
Moderate sites	42.6	47.3	0.16

Table 2.3. Results of paired t-tests of common grass, forb, shrub species and litter and bare ground at The Research Ranch.

Species	Grazed	Ungrazed	p value
Grasses			
Aristida sp.	4.3	3.3	0.601
Bouteloua gracilis	3.1	9.9	0.000
Eragrostis lehmanniana	2.9	0.7	0.008
Eragrostis intermedia	2.2	10.8	0.000
Hilaria jamesii	0.3	1.3	0.114
unknown grass	7.0	3.0	0.027
Forbs			
Convolvulus incanus	0.2	0.4	0.158
Malvastrum bicuspidatum	2.1	2.7	0.488
Portulaca mundula	2.6	0.4	0.001
Solanum eleagnifolium	0.2	0.1	0.741
Talinum aurantiacum	0.4	0.2	0.355
Shrubs			
Baccharis pteronioides	0.5	0.3	0.577
Haplopappus tenuisectus	4.1	2.1	0.133
Mimosa dysocarpa	0.9	1.3	0.185
Other			
Bare ground	46.1	35.1	0.014
Litter	6.0	7.8	0.071

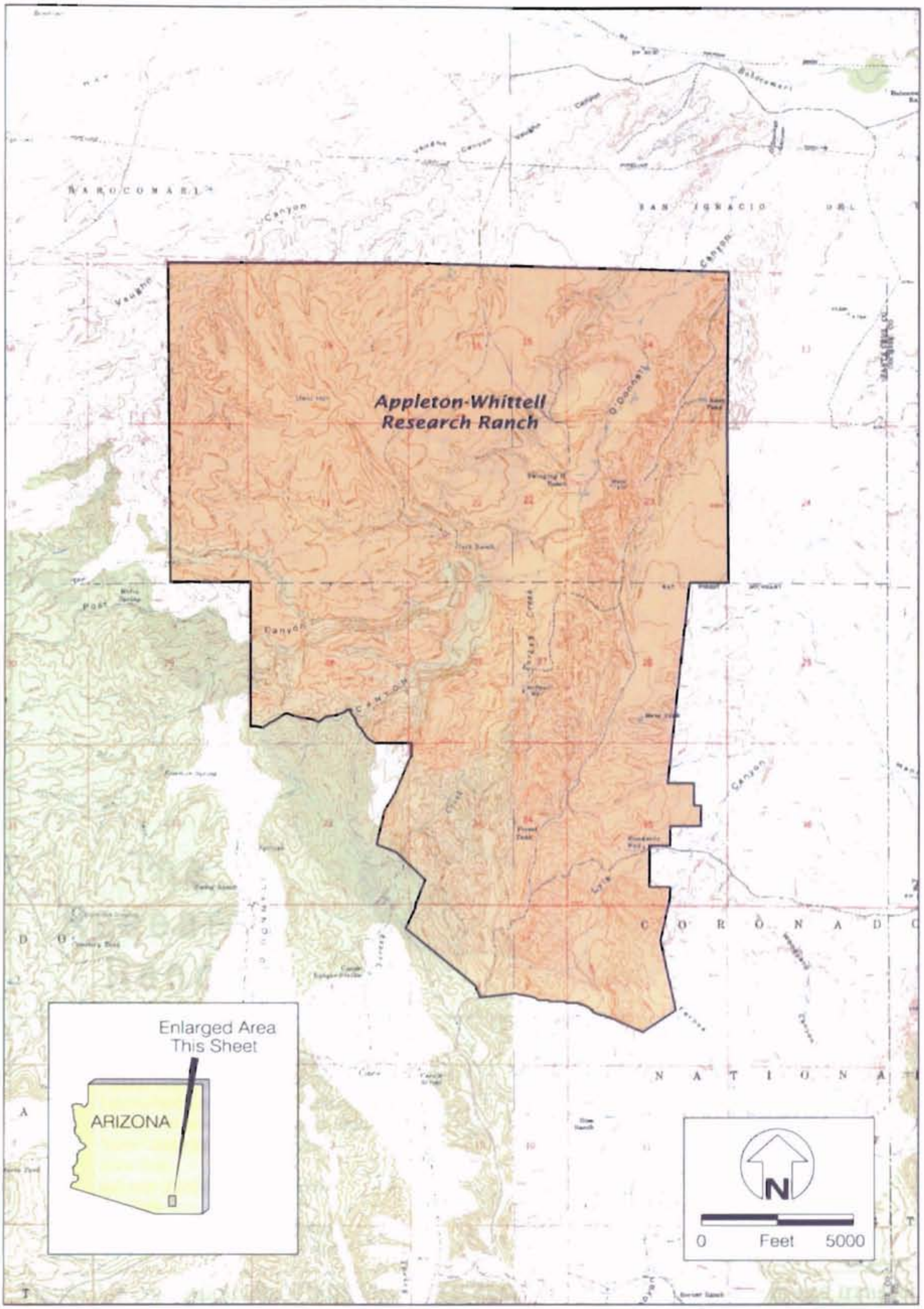

Figure 2.1 Location Map of the Appleton-Whittell Research Ranch, Santa Cruz Co., AZ

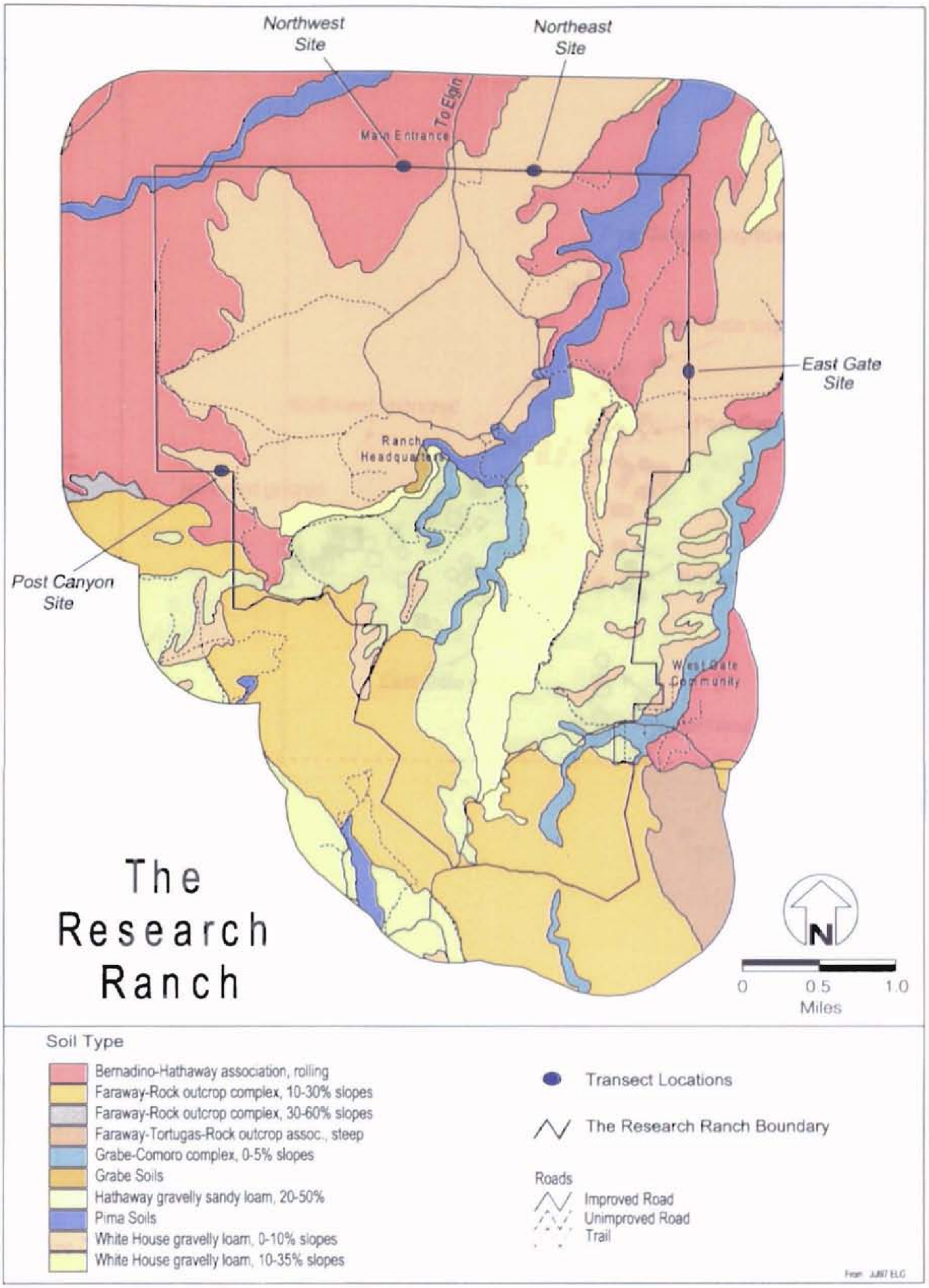

Figure 2.2 The Appleton-Whittell Research Ranch boundary with soil types and transect locations

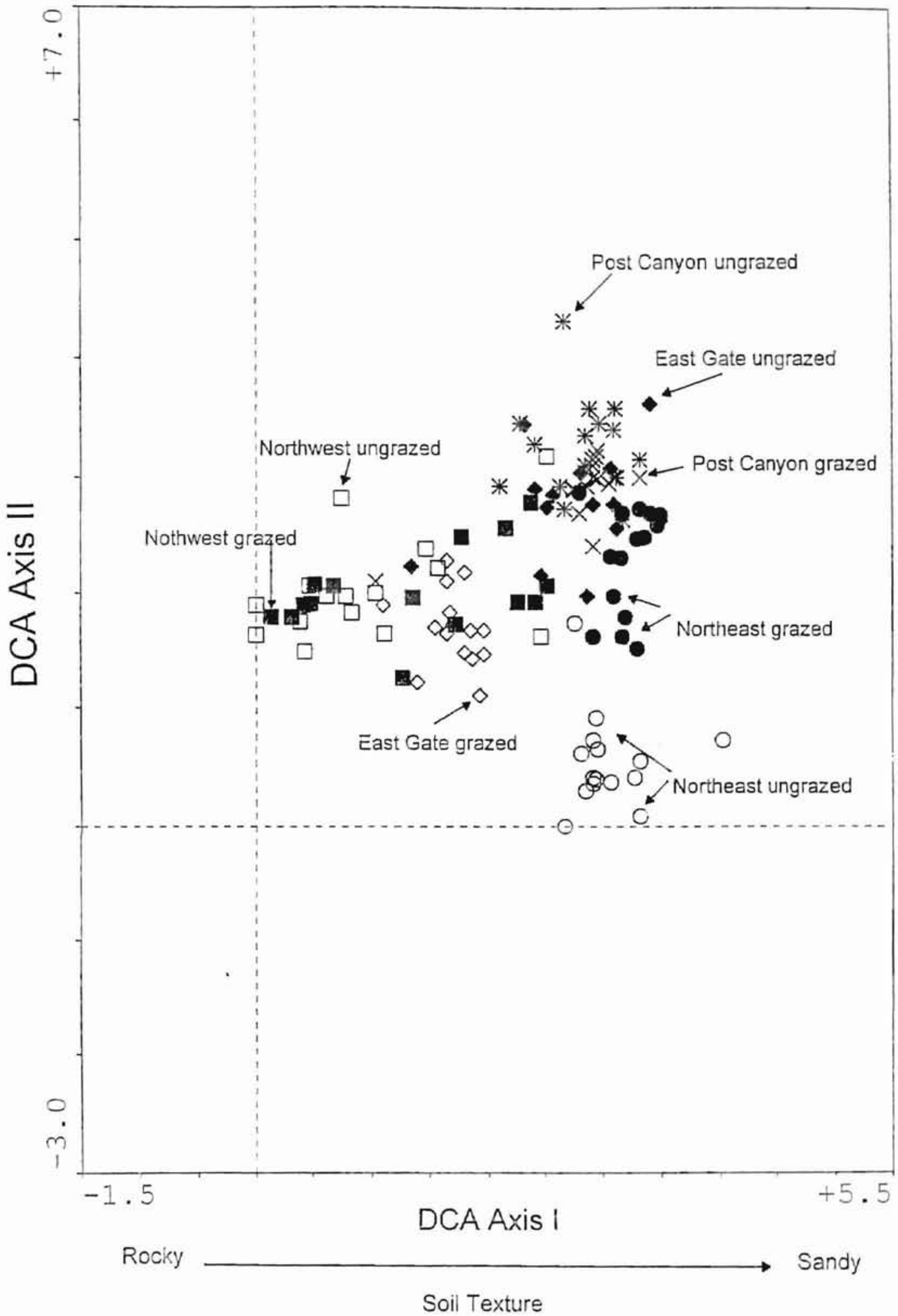

Figure 2.3a. Detrended correspondence analysis of the grazed and ungrazed sides of all sites with scatter of sites. Eigenvalues were 0.592 for the first axis and 0.474 for the second axis. Post Canyon and East Gate are short duration sites and Northeast and Northwest sites are moderate sites.

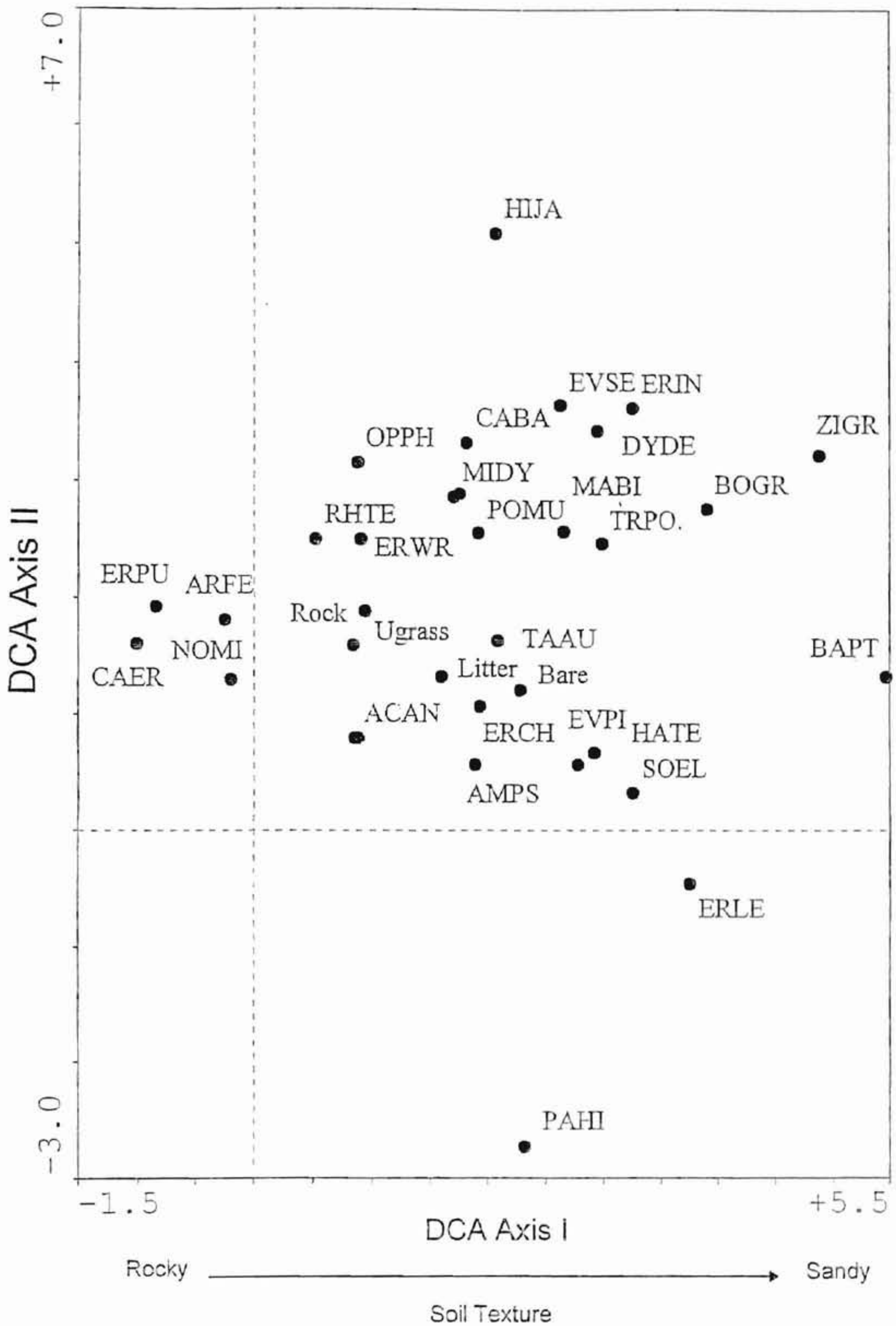

Figure 2.3b. Detrended correspondence analysis of the grazed and ungrazed sides of all sites with scatter of species. Eigenvalues were 0.592 for the first axis and 0.474 for the second axis. Four-letter codes are listed for species. A list of plant species codes is presented in Appendix A.

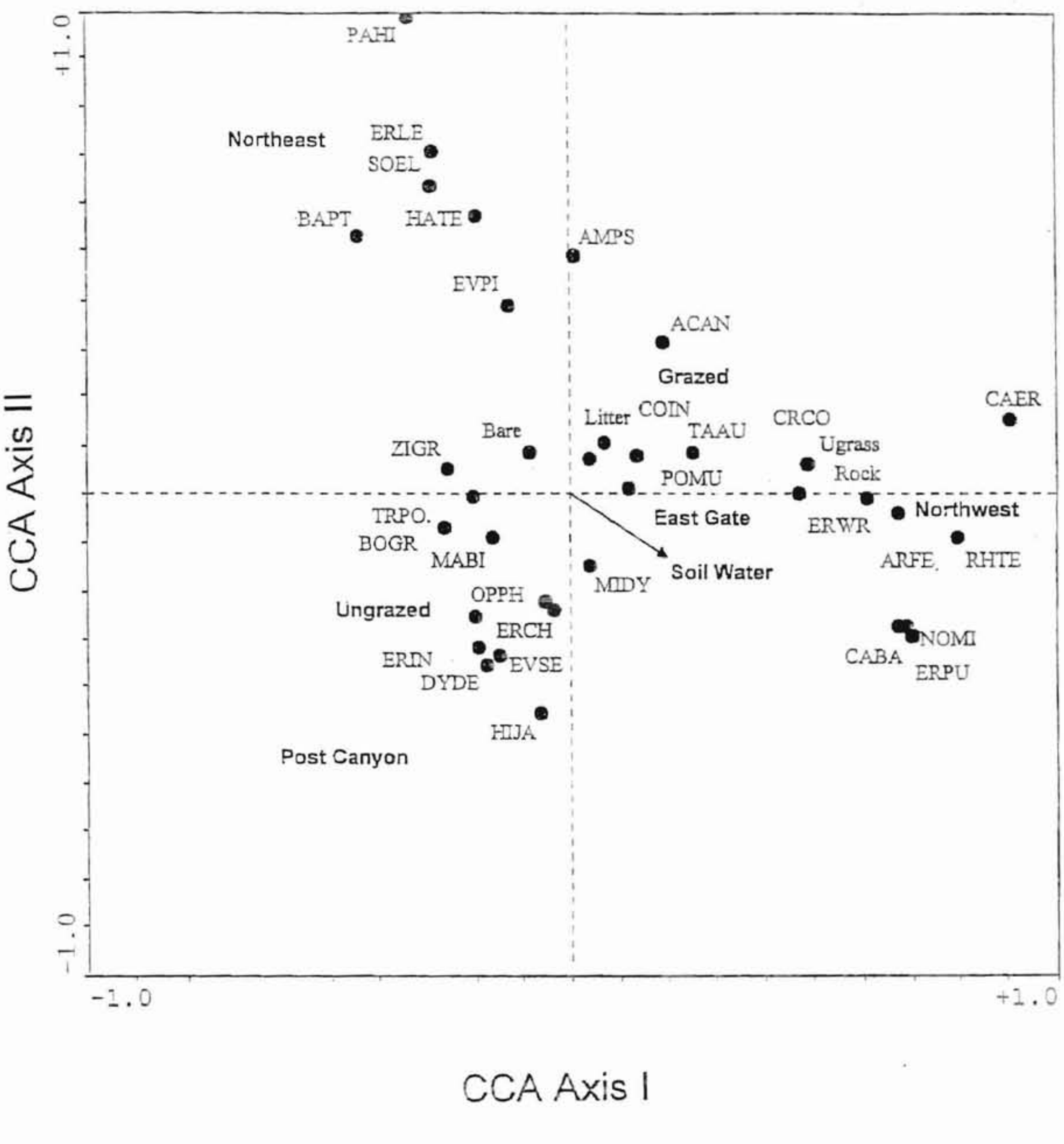

Figure 2.4. Canonical correspondence analyis of species composition and environmental variables for grazed and ungrazed sides of all sites. Eigenvalues were 0.379 for the first axis and 0.339 for the second axis. Four-letter codes for species are defined in Appendix A.

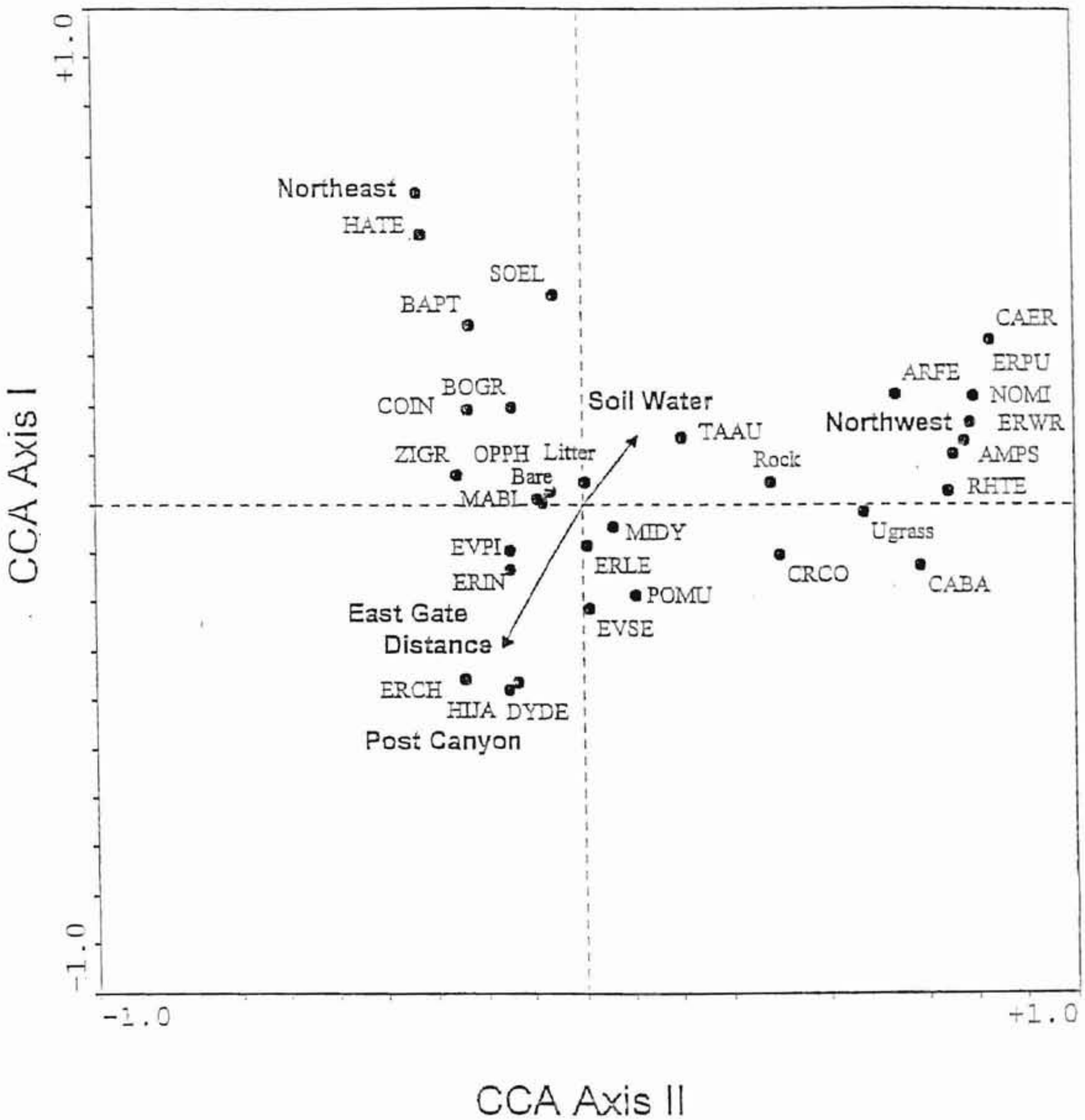

Figure 2.5. Canonical correspondence analysis of species composition and environmental variables on the ungrazed side of the fence at all sites. Eigenvalues were 0.418 for the first axis and 0.267 for the second axis. Four-letter codes for species are defined in Appendix A.

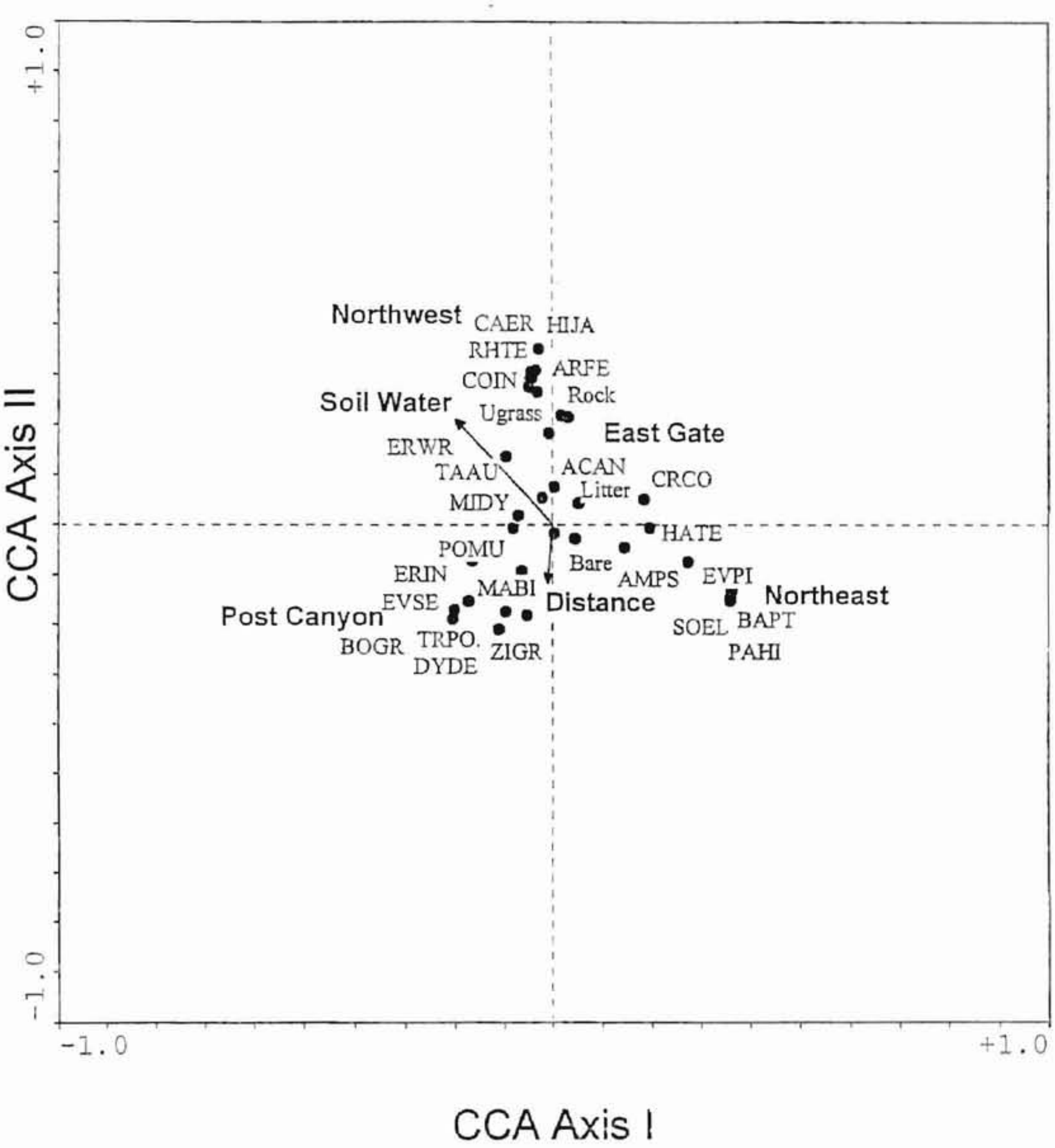

Figure 2.6. Canonical correspondence analysis of species composition and environmental variables on the grazed side of the fence at all sites. Eigenvalues were 0.609 for the first axis and 0.525 for the second axis. Four-letter codes for species are defined in Appendix A.

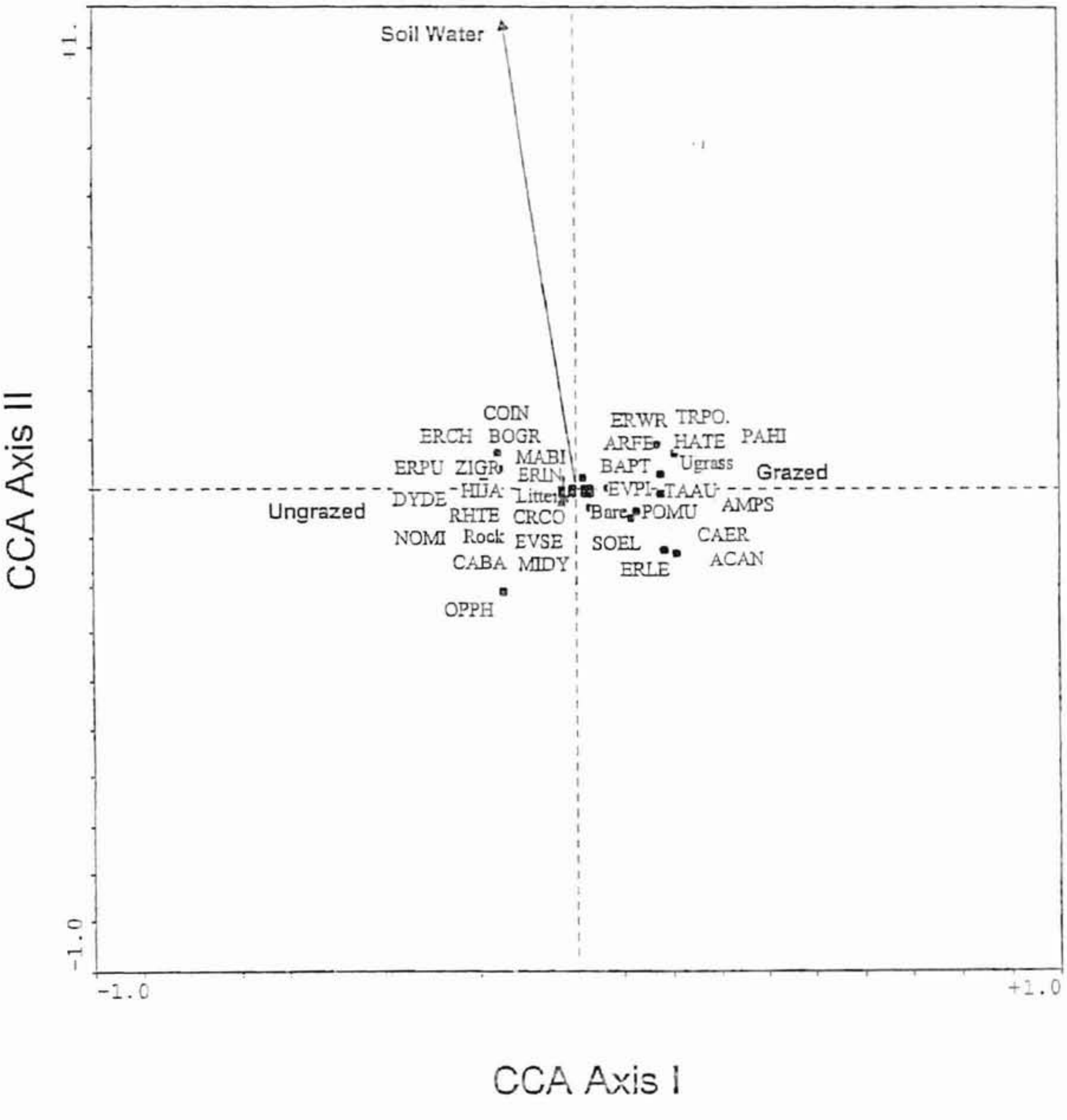

Figure 2.7. Partial canonical correspondence analysis of grazed and ungrazed sites with the sites entered as covariables. Eigenvalues were 0.209 for the first axis and 0.018 for the second axis. Four-letter codes for the species are defined in Appendix A.

Appendix A. Plant species code definitions for plants identified in vegetation sampling quadrats.

Plant Code	Scientific Name	Common Name
ACAN	*Acacia angustissima* (P.Mill) Kuntze	prairie acacia
AMPS	*Ambrosia psilostachya* D.C.	Western ragweed
BAPT	*Baccharis pteronioides* D.C.	yerba de pasmo
BOGR	*Bouteloua gracilis* (Willd. ex Kunth) Lag. ex Griffiths	blue grama
CABA	*Cassia bauhinoides* Gray	twinleaf
CAER	*Calliandra eriophylla* Benth. var *eriophylla*	feather duster
COIN	*Convolvulus incanus* auct non Vahl.	field bindweed
CRCO	*Croton corymbulosus* Engelm.	leatherweed
DYDE	*Dyschoriste decumbens* (Gray) Kuntz	spreading snake herb
ERCH	*Eragrostis chloromelas* Steud.	Boer lovegrass
ERIN	*Eragrostis intermedia* Hitchc.	plains lovegrass
ERLE	*Eragrostis lehmanniana* Nees	Lehmann lovegrass
ERPU	*Erioneuron pulchellum* (Kunth) Tateoka	fluffgrass
ERWR	*Eriogonum wrightii* Torr. ex Benth.	Wright's buckwheat
EVPI	*Evolvulus pilosus* Nutt.	shaggy dwarf morning-glory
EVSE	*Evolvulus sericeus* Sw.	silver dwarf morning-glory
HATE	*Haplopappus tenuisectus* (Greene) Blake	burroweed
HIBE	*Hilaria jamesii* (Torr.) Benth	galleta grass
MABI	*Malvastrum bicuspidatum* (S. Wats.) Rose	shrubby falsemallow
MIDY	*Mimosa dysocarpa* Benth.	velvetpod mimosa
NOMI	*Nolina microcarpa* S.Wats.	beargrass
OPPH	*Opuntia phaecantha* var. *discata* Engelm	cholla
PAHI	*Panicum hirticaule* J.Presl.	Mexican panicgrass
POMU	*Portulaca mundula* I.M. Johnson	kiss me quick
RHTE	*Rhynchosia texana* Torr. & Gray	Texas snoutbean
SOEL	*Solanum elaeagnifolium* Cav.	silverleaf nightshade
TAAU	*Talinum aurantiacum* Engelm.	orange fameflower
TRPO	*Trianthema portulacastrum* L.	desert horsepurslane
ZIGR	*Zinnia grandiflora* Nutt.	prairie zinnia

CHAPTER III

THE EFFECTS OF LIVESTOCK GRAZING ON GROUND BEETLE (COLEOPTERA, CARABIDAE) DISTRIBUTION IN A SEMI-ARID GRASSLAND

ABSTRACT

Ground beetles have been extensively studied as sensitive indicators of anthropogenic induced changes to the environment. Livestock grazing can cause changes to various environmental variables resulting in an indirect impact to ground beetle species composition through alteration of the plant community The goal of this study was to address the role of livestock grazing and grazing type (short duration and moderate continuous methods) on ground beetle species composition in a semi-arid grassland in southeastern Arizona. I collected ground beetles with pitfall traps at the National Audubon Society's Appleton-Whittell Research Ranch in 1997 and 1998. Significant across the fence differences in total ground beetle captures were observed only at one site, the East Gate short duration site. Vegetation cover appeared to affect the type and size of ground beetles with larger ground beetles more prevalent in high vegetation cover and small bodied species in low vegetation cover. A logistic regression analysis indicated that the amount of grass cover was a significant predictor variable for the presence of a large bodied ground beetle, *Pasimachus californicus*. High grass cover may be easier for *P. californicus* to negotiate and may provide areas for thermal escape and cover from predators. Predictive variables were also determined for the small bodied *Selenophorous sp.* and *S. planipennis*. The amount of forb cover predicted the presence of these two

species with densities highest at the grazed side of Post Canyon where forb cover was greatest. Overall, a high degree of site specificity was observed in ground beetle species compositions despite relatively similar landscape characteristics. Therefore, small differences in habitat may be highly influential in species distributions in addition to the role of livestock grazing.

INTRODUCTION

Livestock grazing often impacts a wide variety of environmental variables such as soil moisture, soil compaction, soil erosion, rate of woody plant invasion, and plant species cover and composition. These variables often act in a synergistic manner to effect the distribution and abundance of the organisms that rely on these resources for various life history requirements. Because of the complex dynamics of these environmental variables, the effects of grazing are often indirect, subtle, and difficult to determine. Many other types of disturbances are similarly complex which has generated an interest in indicator species, or species that are sensitive to a specific type of disturbance.

Ground beetle species distributions have been extensively studied because of their ability to respond to subtle changes in environmental variables due to a wide variety of impacts (Thiele 1977, Eyre and Luff 1990, Luff *et al.* 1992). In regions such as the temperate grasslands and forests in Europe, ground beetle species distributions have been found to be strongly correlated with different vegetation types and to changes in microhabitat due to disturbances (Luff 1990, Eyre and Luff 1990, Dennis *et al.* 1997). In this respect, they are often cited as environmental indicators, responding to particular changes in the environment before many other plant or animal species (Dufrene *et al.*

1990). Ground beetles have shown significant responses to vegetation structure, plant species composition, and type of grazing regime (Dennis *et al.* 1997). Ground beetle species richness is often representative of and correlated with species richness of other insect families therefore suggesting that they may be a surrogate for insect diversity within a given system (Oliver and Beattie 1996).

Ground beetles are successful in their role as environmental indicators for several reasons. Foremost is the large size of the family, which includes approximately 30,000 identified species (Arnett 1973). Ground beetles are primarily predaceous as both larvae and adults often with a narrow range of prey items (Arnett 1973). Predaceous arthropods, in general, comprise a large percentage of the biomass of desert arthropods and exceed the biomass of desert vertebrates overall (Polis and Yamashita 1991). Given the large number of ground beetle species and their often specialized prey choice, there is a subsequent high degree of niche differentiation in the family. These criteria often result in selectivity by ground beetles for specific habitat or vegetation types. Livestock grazing can alter a vegetation type by removing a substantial portion of the plant community, creating a dramatically different habitat than existed prior to grazing. In areas where a variety of grazing management strategies occur it is anticipated that the resulting plant communities would provide habitat for unique assemblages of ground beetles.

Comparatively little is known about the ground beetle communities in grazed or ungrazed vegetation in southeastern Arizona and this study provides important baseline information as well as a potential management tool for detecting multiple environmental changes in managed systems. The objectives of this study are to examine the effects of grazing on ground beetle species distribution on actively grazed ranches.

METHODS

DESCRIPTION OF STUDY SITE

The National Audubon Society's Appleton-Whittell Research Ranch (hereafter referred to as The Research Ranch) has been ungrazed by livestock since 1968 and is surrounded by actively grazed ranches. Prior to 1968, The Research Ranch was moderately grazed in a manner similar to properties that abut The Research Ranch boundaries. Two different grazing management strategies exist on the lands adjacent to The Research Ranch, continuous moderate grazing and short duration grazing (Holistic Resource Management) a method espoused by Allan Savory (Savory 1988, Savory and Butterfield 1999). Because The Research Ranch is not currently grazed, it serves as a benchmark for ecological studies addressing the effects of both the release from grazing and grazing method.

The Research Ranch comprises 3300 ha. and is located 100 km southeast of Tucson on the Sonoita Plain (Fig. 2.1). Elevation at The Research Ranch ranges from 1400 to 1560 meters. Precipitation occurs in a bimodal pattern with rain occurring during the winter and late summer. The yearly precipitation averages 43 cm with 28 cm falling during late summer monsoons in July, August, and early September (Bock and Bock 1986). The mean annual temperature is 12° C.

The Research Ranch lies within the semi-arid grasslands of southeast Arizona, an area characterized as the Chihuahuan Desert Province (Bailey 1995). The vegetation consists of perennial bunchgrass prairie with oak woodland at the higher elevations. Several drainages periodically flow following monsoon rains, including Post Canyon, O'Donnell Canyon, Turkey Creek, and Lyle Canyon. In the seasonally flooded lowlands *Sporobolous wrightii* Munro. (sacaton) can form dense stands and in other portions riparian woodlands are present and are dominated by *Platanus wrightii* Wats. (Wright's sycamore), *Populus fremontii* Wats. (Fremont's cottonwood) and *Salix* spp (willows). Uplands contain 19 different perennial grass species and include *Bouteloua gracilis* (Willd. ex Kunth) Lag. ex Griffiths (blue grama), *Eragrostis intermedia* Hitchc. (plains lovegrass), *Eragrostis lehmanniana* Nees. (Lehman's lovegrass), and *Lycurus phleoides* H.B.K. (wolftail). Woodlands are comprised of *Quercus emoryii* Torr. (Emory oak) and *Quercus arizonica* Sarg. (Arizona white oak) (McClaran 1995).

I conducted this study between August 2-17 1997 and September 21-26 1998. This time frame was coordinated to follow the summer monsoon season when the plant growth and beetle activity was expected to be highest. In 1997, I selected two short duration grazed sites and two moderate continuous grazed sites from the private ranches bordering The Research Ranch. For each of these sites, I selected a site directly across the fence in the ungrazed research ranch. The short duration sites had 450 head of adult cows in 1997 and 1998 and were moved among pastures every four to five days. The moderate continuous sites had 725 head of yearling steers in 1997 and 900 head in 1998. The four sites selected included Post Canyon, East Gate, Northeast, and Northwest (Figure 2.2). Sites were all roughly level with a high grass component and little woody vegetation. A total of four sites were established with eight trap arrays.

COLLECTION OF DATA

On each side of the fence I placed three transects lines perpendicular to the fence line. The transects were placed 10m from the fence in order to reduce any potential edge effects. Each of the three transects was 50m in length. Every 10m along each transect a pitfall trap was installed. Pitfall traps were installed with the lip of the pitfall cup flush with the ground surface and were equipped with funnels to reduce insect escape. Three sections of aluminum flashing were placed around the perimeter of the trap as guides to increase overall trap efficiency (Morrill 1975, Morrill *et al.* 1990). Traps were filled with 4% formalin as a killing agent and dish detergent to reduce evaporation. Traps were emptied every second day and the contents were transferred to alcohol filled vials. Ground beetles were sorted and specimens were identified using The Beetles of the United States (Arnett 1971). All species identifications were sent to Dr. George Ball at the University of Alberta for verification.

The vegetation quadrats were placed one meter from the pitfall traps in order to characterize the vegetation at the capture sites. Percent cover and species composition were recorded in each quadrat and were estimated to the nearest one percent. Plant species nomenclature follows Arizona Flora (Kearney 1970). In the first sampling year all three transects were used to collect beetles and measure vegetation for a total of 15 traps/vegetation quadrats on each side of the fence (120 traps total). In the second year, 1998, the trapping effort was reduced to one transect to collect beetles for a total of five traps/vegetation quadrats on each side of the fence (40 traps total). Because the sample sites were located along transects, they are not spatially independent and therefore the sites may be at risk for pseudoreplication effects (Hurlbert 1984).

ANALYSIS OF DATA

Ground beetle captures were summarized to show total number of species and individuals captured on grazed and ungrazed sides of the fence at each site and in the study area overall. Paired t-tests were conducted to detect significant differences in ground beetle captures in grazed and ungrazed sides of the fence. Vegetation data were summarized to present average vegetation cover at each site. The results of the multivariate analysis of vegetation from chapter two were also referenced.

I performed a logistic regression analysis using the enter method (SPSS for Windows Version 8.0, 1997) with p values of 0.05 to enter and 0.10 to exit the model. The following continuous independent variables were considered: percent composition of grass, forbs, litter, and bare ground. Categorical dependent variables included the presence or absence of ground beetles. I performed a separate logistic regression analysis for each ground beetle species captured in the study to determine the variables that best predicted the presence of each species. Only the 1997 sampling season generated adequate ground beetle captures to perform logistic regression analyses.

RESULTS

During the 1997 sampling season, a total of 23 ground beetle species and 214 individuals were captured (Table 3.1). The total number of individuals captured was higher on the ungrazed side of the fence at three of the four sites sampled. In each of the four sites, the number of species was higher on the ungrazed side of the fence than on the grazed side, regardless of grazing regime. The ungrazed sides of the fence contained between three to four more species than their grazed counterparts. In terms of between site differences, the East Gate and Post Canyon sites generally were more species rich than the Northeast and Northwest sites, although the number of total captures at each site was generally low. The total number of individuals was highest at the Post Canyon site and lowest at the Northeast site.

The captures from 1998 indicate that the number of individuals and species were very low (Table 3.2). Species richness values ranged from a high of three species at the Northeast ungrazed site to a low of zero species at the Northwest ungrazed and East Gate ungrazed sites. Numbers of individuals captured was slightly higher, showing a maximum of three individuals at the Northeast site and zero individuals at the East Gate ungrazed and Northwest ungrazed sites.

Table 3.3 indicates species' response to grazed or ungrazed conditions irrespective of the grazing type in 1997. Results suggest that ground beetles overall are found more frequently in ungrazed than in grazed conditions in this study. Approximately 65% of ground beetles were found more often on the ungrazed side of the fence. Most species were found more often in ungrazed situations with the exception of the following species: *Lebia bivittata; Lebia histrionica; Pseudomorpha angustata;* and *Selenophorus* spp.. Approximately 29% of the species captured were found more frequently in grazed than in ungrazed conditions. Roughly 17% of the species captured were found only in grazed situations and included *L. histrionica, L. bivittata*, and *P. angustata.* Approximately 33% of the species were captured in ungrazed situations only and included *Anisodactylus anthracinus, Bembidion rapidum, Brachinus elongatus, Calleida caerulea, Chlaenius pimalicus, Colliuris pennsylvanica, Harpalus* sp., and *Hellumorphoides ferrugineus.*

Captures from 1998 indicate that the numbers of ground beetles overall were equal on ungrazed and grazed situations (Table 3.4). Individual species responses varied with only one species found in both grazed and ungrazed situations, *Hellumorphoides latitarsus*. Species found only in grazed situations include *Notiobia mexicana*, and *Selenophorous* sp. Species found only in ungrazed situations include *A. anthracinus* and *Cymidis arizonsis*. *A. anthracinus* was captured in ungrazed situations only in both 1997 and 1998. *Selenophorous* sp. follows a similar trend as in 1997 with more individuals captured on the grazed side of the fence than the ungrazed side. *C. arizonensis* and *H. latitarsus* represent new species captures from 1997.

Table 3.5 depicts the distribution of species according to site and grazing regime. A large amount of variability was observed in captures in the four sites ranging from species captured only in one site/grazing regime to species captured in all sites/grazing regimes. In general, species tended to be limited to one site rather than captured at all sites. Fifty percent of the species captured were captured at only one site and 21% were captured in all sites. The East Gate and Post Canyon sites contained the highest number of species captured solely within one site, with totals of three and eight species respectively. One species, *Agonum cyclifer,* was unique to the Northwest site with no species unique to the Northeast site. Ubiquitous species captured during 1997 included *Selenophorous* sp., *P. californicus*, *A. tuckeri*, and *C. tomentosus*.

The most notable across the fence differences, in terms of species captured, were observed at the Post Canyon site. Post Canyon contained seven species that were captured only on the ungrazed side of the fence and three species that were captured only on the grazed side of the fence. Species consistently captured more often on the ungrazed side of the fence at several sites include *A. tuckeri, C. tomentosus, P. californicus,* and *S. conjunctus*. Species fidelity to grazed situations was generally site specific and did not span several sites.

In contrast to the 1997 captures, 1998 captures displayed less site specificity with only 2 species captured at only one site (Table 3.6). Capture rates were generally low ranging from three species captured at the Northeast ungrazed site to zero species captured at the East Gate ungrazed site. The low capture rates precluded detection of clear trends in species distribution. Differences in the capture frequency and new species captures are the most outstanding features of the 1998 capture data (Table 3.6).

Paired t-tests of the 1997 ground beetle captures on the grazed and ungrazed sides of the fence indicate that only East Gate site showed significant differences in total captures (Table 3.7). The East Gate site is managed with short duration grazing and contained significantly higher captures on the ungrazed side of the fence ($p = 0.004$).

The logistic regression analysis with four independent variables indicated that three of the 24 species analyzed contained significant predictive variables. *P. californicus*, *Selenophorous* sp., and *S. planinpennis* contained predictive variables that are listed in the following paragraphs.

Presence of one of the most frequently captured species, *P. californicus*, was predicted by the percent cover of grasses ($p = 0.031$). Sites where differences in grass cover were most apparent, Post Canyon and Northeast sites, *P. californicus* was captured exclusively on the side of the fence with the highest grass cover, the ungrazed side. The East Gate and Northwest sites showed more moderate across the fence differences in grass cover and captures here occurred on both sides of the fence, although more frequently on the ungrazed side of the fence.

Both *Selenophorous* sp. (p = 0.003) and *S. planipennis* (p = 0.046) presence were predicted by the percent cover of forbs. These two species were most abundant at the Post Canyon and East Gate sites where differences in forb composition was most distinctive and also the highest of all sites (Table 3.8). They were captured most frequently on grazed sides of the fence where the highest average percent cover of forbs was recorded.

DISCUSSION

SPECIES RICHNESS

Ground beetle species richness on the ungrazed side of the fence was higher than the grazed side at all sites which generally reflects the vegetation cover trend of higher cover on the ungrazed side of the fence. Although there appears to be a tentative relationship between species richness and grazing, an insufficient number of captures precludes any definitive conclusions or interpretations. Discussions presented here may be considered speculative and may be verified with additional sampling. Results from chapter two indicated that the mean vegetation cover was significantly higher on the ungrazed side of the fence.

Ground beetle species richness may be tied to total vegetation cover through several mechanisms. Increased vegetation cover provides more resources for plant dependent insect species and thermal cover for insects in general. This provides a wider array of prey species for ground beetles to choose from and subsequent niche differentiation by ground beetles. With a larger insect prey base, more ground beetle species may be able to exist in a given area. Higher cover may also allow for increased structural complexity, an area that ground beetles have been found to be sensitive (Coulson 1988). In this regard, diversity in plant architecture may significantly contribute to species richness and diversity.

Although structural complexity was not directly assessed in terms of plant height and canopy, variables such as the amount of litter and grass cover were measured and are likely the predominant structural components that influence species richness of ground beetles as they move through the grassland environment (Van Wieren 1991). The amount of litter and grass available influences the rate of beetle movement (Greenslade 1964), especially for small species (Luff 1990). For ground beetle species that showed distinct differences in abundance across the fence, size appeared to be a potential factor in site preference. Larger bodied species such as *Calasoma peregrinator*, *C. tomentosus*, and *P. californicus* were captured more frequently on the more densely vegetated ungrazed side of the fence. More diminutive species such as *L. bivittata*, *P. angustata*, *Selenophorous* sp., and *S. planipennis* were captured more frequently on the more sparsely vegetated grazed side of the fence. These results coincide with a study by Blake *et al.* (1994) that found ground beetles of small size were found under heightened grazing intensity. While the role of body size may be influential in determining species habitat preferences, it is not likely the only variable that influences species distribution.

Both the amount of grass and litter present may provide soil surface shading thereby reducing soil temperature extremes and preventing desiccation of both larvae and adults. A high grass component, which was generally found on the ungrazed sides of the fence, provides a year round structural component that contributes to soil shading and supports prey species, especially if not removed through grazing. Better reproductive sites may also be found on ungrazed sides of the fence because of reduced trampling of eggs deposited in the soil and on vegetation and more stable soil conditions in respect to soil moisture and temperature. More species may be able to exist and with better survival rates in ungrazed situations.

GRAZING AND GROUND BEETLE CAPTURES

Most ground beetle species were not captured throughout the study area and were instead restricted to one sampling location. The relative uniqueness of species captured in at the sampling locations may be the result of differences in microhabitat. Although sampling locations were selected for their similarity in topography and vegetation composition, distinctions were observed following vegetation sampling. Multivariate analyses presented in chapter two showed sampling locations to be somewhat separate spatially rather than grouped. A partial canonical correspondence analysis revealed that plant species composition was influenced more closely by the sample location itself than by the environmental variables measured, including the influence of grazing. Ground beetles may be governed by the same principal, responding more to local site specific factors.

Differences in species captured between the two sampling years indicates that a high degree of variability exists in species composition by year and with changes in temperature. The first sampling year occurred early in the monsoon season when temperatures were warmer and soil conditions were wetter. The second sampling year occurred later in the monsoon season when temperatures were cooler and soils drier. The higher temperatures and wetter conditions during the first sampling year yielded far more species and individuals than the second year. These results concur with a study by Luff (1996) where year to year variation was greater than the differences between sites and management regimes. The cool nights of the second years' sampling period may have reduced beetle activity considerably. Ground beetles, and insects in general, were more active during the first year sampling when monsoon rains were just beginning to cause vegetation to green up and less active during the second sampling when vegetation was setting seed. Results indicate that species composition may not be predictable or reliable year to year in a highly variable environment unless sampling occurs in similar climatological conditions. Therefore, any use of ground beetles for environmental monitoring must take into consideration seasonal timing when designing and analyzing study results.

The total number of ground beetle captures during 1997 was generally higher on ungrazed sides of the fence with the exception of the Post Canyon site. The number of captures was higher at the Post Canyon site partially due to the high concentration of *Selenophorous* sp., a small bodied ground beetle that was particularly abundant on the grazed side of the fence. Total captures were only significantly different at the East Gate site where the number of individuals captured was higher on the ungrazed side of the fence. The East Gate site is managed with short duration grazing and also showed significant across the fence differences in vegetation cover, showing higher cover on the ungrazed side of the fence. This grazed side of this site had the highest amount of bare ground measured and the second lowest measured grass cover which may have favored the ungrazed side for ground beetle occupation. Physical factors may have also influenced the number of captures between the two sides of the fence. A gravel road runs along the fenceline on the grazed side of the fence which may limit the movement of ground beetles from the ungrazed side of the fence to the grazed side. Roads also expose individuals to predation, particularly for a fenceline that doubles as bird perch sites parallels the road, as is the case at the East Gate site. Roads also fragment landscapes, particularly for species with limited mobility, such as ground beetles.

GROUND BEETLES AND PREDICTIVE VARIABLES

While the sampling sites were not very far apart, unique species compositions were found in most of the sites. Sites that appeared superficially similar in vegetation and aspect had widely differing species compositions which is likely due to conditions in the immediate vicinity such as, proximity to water, trees, rocks, and the site elevation. The uniqueness of the captures from Post Canyon may be due in part to the relatively diverse surroundings of the site. The site is surrounded by a relatively diverse group of soil types (Figure 2.2) and subsequently diverse vegetation types. While the site is similar to other sampling sites, it is not far from a canyon that holds water and supports riparian vegetation. It is also surrounded by oak trees, and higher elevation areas outside the preserve boundaries. In contrast, the Northwest and Northeast sites are not situated in similarly diverse surroundings and contain fewer endemics and lower species richness.

Ground beetle species that responded in a consistent manner to grazing were deemed the most representative of grazing impacts. Within this group, species that were found more often on the ungrazed side of the fence were more consistent in their fidelity than those that were found more often on the grazed side of the fence.

Species that responded to grazing characteristically by occurring on the ungrazed side of the fence in most or all sites included *A. tuckeri*, *C. tomentosus*, *P. californicus*, and *S. conjuctus*. Of these species, only *P. californicus* contained a significant predictor variable, the amount of grass cover.

Members of the *Pasimachus* genus are a primarily southern group endemic to Central and North America. Species in this genus have been found to prefer dry open prairies with sparse vegetation (Arnett 1973). Given their preference for dry conditions, it is likely that other factors such as body size and suitable prey availability are also influential factors in their distribution. Because of its larger size, it is more likely to be able to maneuver among the more densely vegetated ungrazed areas. It also may have a better opportunity of finding more abundant prey items. The amount of grass cover was a predictive variable for *P. californicus* presence which is possibly related to the ability of the grass to support prey species and provide thermal regulation. *P. californicus* was only captured in grazed areas that supported higher cover of grasses than their ungrazed counterparts. The larger size of *P. californicus* could contribute its conspicuousness in areas of low vegetation cover, such as grazed sites, and may cause it to be susceptible to predation by birds or mammals. In general, *P. californicus* may be considered more likely to occur in ungrazed conditions unless grass cover in an adjacent grazed area is greater than the ungrazed area.

The presence of *S. planipennis* and an unknown species of *Selenophorous* was predicted by the amount of forb cover in the sites where they were captured. These species were most abundant at the Post Canyon site where forb cover was highest. They were captured in high numbers on both sides of the fence, but appeared to prefer, although inconsistently, the grazed side of the fence. The numerous captures on the grazed side of the Post Canyon site may indicate that these small species prefer the low amount of litter found there and the subsequent easy access to possibly abundant forb specific prey. In general, these species appear to prefer grazed situations but may use them opportunistically or irregularly enough that they should not be considered species that prefer grazed situations.

Other ground beetle species that did not exhibit significant predictor variables but appeared to respond to the grazing treatment are discussed as follows:

S. conjunctus captures indicated that many more individuals occurred on ungrazed than grazed areas. Species of this genus typically inhabit areas in the vicinity of water and under a layer of detritus composed of dead vegetation (Arnett 1973). Litter was not a significant predictive variable for this species, although all the capture sites contained higher litter percentages on the ungrazed sides of the fence. The site with the greatest across the fence differences in plant litter also demonstrated the greatest differences in *S. conjunctus* captures. *S. conjunctus* was captured only once on a grazed side of the fence suggesting that this species is fairly specific to ungrazed situations. In light of the somewhat low number of captures (15 across all sites), designating this species grazing intolerant may be premature.

C. tomentosus was captured more often on the short duration sites and on the ungrazed side of the fence in general. However, because it was captured on both sides of the fence at the short duration sites, it is not likely responding directly to management type but instead to other environmental cues present at short duration regime sites. While sites were selected to be similar in topography and general plant community type, some differences were observed. Soils at the Northeast and Northwest trap site (moderate, continuous regime) were generally more rocky than soils in the Post Canyon and East Gate sites (short duration regime). *C. tomentosus* may not be as responsive to changes in vegetation cover but more sensitive to differences in soil type. *C. tomentosus* was captured more often on the ungrazed side of the fence overall, but when captures are considered at each site no strong consistent differences are observed. A possible explanation for this may be that the gregarious nature of the species. *C. tomentosus* tends to feed more often on dead or injured insects and individuals have been observed working in numbers to tear apart a prey item too large for one individual (Arnett 1973). Therefore, members of this species may congregate in areas depending on the location of an injured insect which would result in highly variable densities as is shown in this study. *C. tomentosus* has been documented to occur under vegetation in dry grass areas and eggs are typically deposited in mud cells on the underside of leaves or twigs (Arnett 1973). This would suggest that the species would favor the generally higher vegetation cover found in the ungrazed areas for reproduction and resting. Although *C. tomentosus* exhibited a tendency to occur more often in ungrazed conditions overall, and short duration sites specifically, its' feeding behavior may preclude it from being considered a species that reliably occurs in ungrazed situations.

A. tuckeri was captured more often on ungrazed sides of the fence and occurring more frequently at short duration sites. Because *A. tuckeri* was captured on both sides of the fence, it is likely not responding directly to the grazing regime but instead to site specific environmental factors. Members of the *Apristus* genus typically inhabit sandy soil areas among rocks and often close to stream margins (Arnett 1973). These species tend to run swiftly and fly steadily, making them difficult to capture. Their high mobility and tendency towards flight may in part explain their distribution at all sites within the study and their relatively low capture rates. It is unclear why *A. tuckeri* was captured more frequently on the short duration sites. The Post Canyon site has proximity to water in its favor but the East Gate site, where most of the captures were recorded, does not have water in close proximity or any other unusual or easily discernable site characteristics. Higher captures of this species through a longer trapping effort may indicate that this species is more specific in its' habitat requirements than can be inferred from this study.

Due to low captures or inconsistencies, the following species were evaluated only in terms of their uniqueness or site specific habitat preferences and not in terms of species generally responsive to grazing at a larger scale. Site specific attributes influencing the captures of these species are discussed below.

C. pennsylvanica presence was predicted by the amount of litter also, with captures limited to one individual at the East Gate site. Adult members of *C. pennnsylvanica* are typically found on vegetation and the larvae are often found near wet ground around marshes or cultivated fields (Arnett 1973). The single capture of this species likely represents a tourist or vagrant species from more a mesic location.

L. bivittata appeared to prefer the grazed treatment of the Post Canyon Site. This was the only site the species was captured and no captures were made on the ungrazed side of the fence Members of the genus *Lebia* are known to be primarily arboreal, climbing on plants during the daylight (Arnett 1973). Given the lack of vertical structure on this side of the fence, it is possible that *L. bivittata* is attracted to this side of the fence because of suitable prey. The abundant forb cover, with some species flowering at the time of captures, may have attracted prey species for *L. bivittata*. Another possibility is that this species typically inhabits the oaks in the vicinity and forages in open areas if prey is abundant. The small size of the species likely influence its preference to forage in areas of abundant bare ground and sparse litter. Overall, it appears that *L. bivittata* prefers the suite of environmental conditions present at the short duration grazed Post Canyon site. It may also be a species that, when present, is a short duration grazing specific.

P. angustata was captured exclusively on the grazed side of the fence at two sites where it was captured, Northwest and Northeast sites. Members of the genus *Pseudomorpha* have been found to prefer gravelly soil in *Pinus edulis* Engelm. (pinyon pine), *Juniperus* sp. (juniper), and *Quercus turbinella* Greene (live oak) woodland areas where they occur in Texas. Similar vegetation does not exist where these species were most abundantly captured although soils are rockier than most of the study area and *Nolina microcarpa* S. Wats. (beargrass) is uniquely abundant. However, it is interesting to note that while strong across the fence differences in captures were observed at the Northwest site, few obvious differences in vegetation, litter, or bare ground were noted. It is therefore, likely that either captures are too low to indicate a environmental based trend or that unknown factors such as competition or predation are more influential.

CONCLUSIONS

Results from this study have revealed several characteristics of the ground beetle community at The Research Ranch. General observations on the richness of the ground beetle community suggest that species richness may be tied to the amount of vegetation cover and therefore to the grazing treatment. Increases in species richness on the ungrazed side of the fence are likely based on the role of vegetation in providing resources for prey items, areas of thermal cover, and resources for reproduction. Grass and litter components are likely important in respect to the differential mobilities of species based on their size. Smaller species are likely more affected by structural components such as the amount of grass and litter with larger species more suited to negotiate "clutter" in their environment. Results indicate that the small bodied species were, in general, more variable in their response to grazing treatment. This may indicate that these species are more opportunistic, feeding in grazed areas that may be temporarily rich in prey and that provide easy movement. Blake *et al*. (1994) also found that ground beetles of smaller size were more abundant in areas that were intensively grazed seeded grasslands. The larger bodied ground beetles, such as *C. tomentosus*, *P. californicus*, and *C. peregrinator* were more reliably found on the ungrazed side of the fence. This suggests that their larger size enables them to negotiate more complex and abundant vegetation on the ungrazed side of the fence and therefore remain more specific to the ungrazed side of the fence. In this respect, the larger ground beetles were overall more responsive to the effects of grazing treatment than smaller species. However, some small bodied ground beetles, such as *S. conjunctus* and *A. tuckeri,* were consistently responsive to grazing treatment in a variety of sites. Overall, species that were observed to respond most reliably to grazing treatment and were therefore good indicators included *P. californicus*, *S. conjunctus*, and *C. tomentsus*.

While some general conclusions on species responses across the study area may be made, low captures of many species precludes a firm conclusions of habitat preference and grazing tolerance or intolerance. Many species were trapped at one location only and in low numbers indicating that species distributions may be more sensitive to site specific variables than grazing treatment or regime overall. Trapping arrays placed in relatively discreet habitat types at The Research Ranch may enable a more refined estimation of the habitat preferences of the ground beetle species captured in this study. Climate likely also play a strong role with species assemblages varying widely between different yearly rainfall patterns. All of these circumstances are very important to consider when evaluating species responses to a given environmental variable. Given the narrow and often unpredictable window when climatic conditions are optimal, future ground beetle research in this region may require multiyear sampling or a more extensive trapping effort. The role of differential mobilities may also be influential and warrants additional studies.

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Table 3.1. Species richness and total number of individuals at each sampling location during 1997.

Site/Type	Richness	Total Individuals
East Gate Short Duration Grazing	8	23
East Gate Ungrazed	11	33
Post Canyon Short Duration Grazing	8	59
Post Canyon Ungrazed	12	45
Northeast Moderate Continuous Grazing	3	5
Northeast Ungrazed	6	18
Northwest Moderate Continuous Grazing	4	12
Northwest Ungrazed	7	19

Table 3.2. Species richness and total number of individuals at each sampling location during 1998.

Site/Type	Richness	Total Individuals
East Gate Short Duration Grazing	1	2
East Gate Ungrazed	0	0
Post Canyon Short Duration Grazing	1	1
Post Canyon Ungrazed	1	2
Northeast Moderate Continuous Grazing	1	1
Northeast Ungrazed	3	3
Northwest Moderate Continuous Grazing	1	1
Northwest Ungrazed	0	0

Table 3.3. Total number of individuals of each species captured in grazed versus ungrazed sides of the fence in 1997.

Species	Ungrazed	Grazed
Agonum cyclifer	1	1
Anisodactylus anthracinus	2	0
Apristus tuckeri	9	2
Bembidion poculare	3	1
Bembidion rapidum	3	0
Calleida caerulea	1	0
Calasoma peregrinator	6	1
Chlaenius pimalicus	1	0
Chlaenius tomentosus	19	9
Clivina postica	2	1
Colliuris pennsylvanica	1	0
Discoderus robustus	1	1
Harpalus sp.	4	0
Hellumorphoides ferrugineus	1	0
Lebia bivittata	0	8
Lebia histrionica	0	1
Notiobia mexicana	1	1
Pasimachus californicus	18	2
Pseudomorpha angustata	0	9
Selenophorous sp.	26	49
Selenophorous concinnus	0	1
Selenophorous planipennis	1	11
Stenolophus conjunctus	14	1
Ground beetles - total	115	99

Table 3.4. Total number of individuals of each species captured in grazed versus ungrazed sides of the fence in 1998.

Species	Ungrazed	Grazed
Anisodactylis anthracinus	3	0
Cymidis arizonensis	1	0
Hellumorphoides latitarsis	1	1
Notiobia mexicana	0	1
Selenophorous sp.	0	3
Ground beetles - total	5	5

Table 3.5. Species occurrence and abundance by trapping site and grazing type in 1997.

Species	East Gate ungrazed	East Gate grazed *SD	Post Canyon Ungrazed	Post Canyon Grazed *SD	Northeast Ungrazed	Northeast Grazed *MC	Northwest Ungrazed	Northwest Grazed *MC
Ground beetles	33	23	45	59	18	5	19	12
Agonum cyclifer	0	0	0	0	0	0	1	1
Anisodactylus anthracinus	0	0	2	0	0	0	0	0
Apristus tuckeri	5	1	1	1	1	0	2	0
Bembidion poculare	0	0	3	1	0	0	0	0
Bembidion rapidum	2	0	0	0	1	0	0	0
Brachinus elongatulus	0	0	3	0	0	0	0	0
Calleida caerulea	1	0	0	0	0	0	0	0
Calosoma peregrinator	0	0	5	1	0	0	1	0
Chlaenius pimalicus	0	0	1	0	0	0	0	0
Chlaenius tomentosus	6	5	5	2	5	0	3	2
Clivina postica	2	1	0	0	0	0	0	0
Colliuris pennsylvanica	1	0	0	0	0	0	0	0
Discoderus rubustus	0	1	0	0	0	0	1	0
Harpalus sp.	0	0	4	0	0	0	0	0
Helluorphoides ferrugineus	0	0	1	0	0	0	0	0
Lebia bivittata	0	0	0	8	0	0	0	0
Lebia histrionica	0	0	0	1	0	0	0	0
Notiobia mexicana	1	0	0	0	0	1	0	0
Pasimachus californicus	4	1	5	0	5	0	4	1
Pseudomorpha angustata	0	0	0	0	0	1	0	8
Selenophorus sp.	1	11	15	35	3	3	7	0
Selenophorous concinnus	0	1	0	0	0	0	0	0
Selenophorous planipennis	1	1	0	10	0	0	0	0
Stenolophus conjunctus	9	1	1	0	4	0	0	0

* SD = Short duration grazing type, MC = Moderate continuous grazing type

Table 3.6. Species occurrence and abundance by trapping site and grazing type in 1998

Species	East Gate ungrazed	East Gate grazed *SD	Post Canyon Ungrazed	Post Canyon Grazed *SD	Northeast Ungrazed	Northeast Grazed *MC	Northwest Ungrazed	Northwest Grazed *MC
Ground beetles	0	2	2	1	3	1	0	1
Anisodactylus anthracinus	0	0	2	0	1	0	0	0
Cymidis arizonensis	0	0	0	0	1	0	0	0
Hellumorphoides latitarsus	0	0	0	0	1	0	0	1
Notiobia mexicana	0	0	0	0	0	1	0	0
Selenophorus sp.	0	2	0	1	0	0	0	0

* SD = Short duration grazing type, MC = Moderate continuous grazing type

Table 3.7 Paired t-tests of across the fence differences in total captures of ground beetles during 1997.

Site/Type	Number of Captures		p value
	Grazed	Ungrazed	
East Gate Short duration grazed	23	33	0.0038
Post Canyon Short duration grazed	59	45	0.4063
Northeast Moderate continuous grazed	5	18	0.0598
Northwest Moderate continuous grazed	12	19	0.1694

Table 3.8. Average percent vegetation cover, litter, and bare ground at each site during 1997.

Site/Type	Total Vegetation	Grass	Forbs	Litter	Bare
East Gate ungrazed	48.1	28.2	13.9	9.0	42.4
East Gate grazed - SD	38.5	18.8	9.3	4.0	61.1
Post Canyon ungrazed	50.6	35.9	11.2	6.1	38.7
Post Canyon grazed -SD	43.8	19.5	24.3	2.7	53.4
Northeast ungrazed	45.5	26.5	7.0	9.5	45.1
Northeast grazed - MC	29.0	11.8	5.7	7.9	58.5
Northwest ungrazed	73.8	25.2	7.46	6.0	14.0
Northwest grazed - MC	81.3	28.7	6.4	9.2	11.26

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