COMMUNITY COMPOSITION OF SMALL MAMMALS IN RELATION TO ENVIRONMENTAL DISTURBANCES ON TALLGRASS PRAIRIE

By

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PRAIRIE

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Chapter I

INTRODUCTION

Prairie Development and Maintenance—Grasslands once covered over 400 million hectares of land on the North American continent, encompassing approximately 50% of the land surface area (Joern and Keeler 1995). Approximately 162 million hectares of these grasslands lay in the Great Plains region, running from Indiana in the east, spreading north-south from Manitoba to Texas, and continuing westward all the way to the Rocky Mountains (Samson and Knopf 1994). This extensive North American prairie system often is divided into three major grassland types: tallgrass or true prairie, mixed- or mid-grass prairie, and shortgrass prairie. The tallgrass prairie system was the dominant vegetation type and covered between 60 and 70 million hectares of the eastern portion of the Great Plains (Samson and Knopf 1994). Tallgrass prairie generally is dominated by species that are typically 1-2 meters high, especially big bluestem (*Andropogon gerardi*), Indiangrass (*Sorghastrum nutans*), and switchgrass (*Panicum virgatum*; Joern and Keeler 1995). These plants are supported by a higher amount of rainfall (60-100 cm) than occurs on prairies to the west (Steinauer and Collins 1996).

The rise of extensive grasslands began during the Miocene-Pliocene transition, 5-7 million years ago (Axelrod 1985). During this time, the area east of the Rocky Mountains became drier, causing the retreat of forests and woodlands as more drought-tolerant grasses took over. During the glacial cycles of the Pleistocene, forests and grasslands shifted in relation to glaciers. Grasslands were pushed south as glaciers advanced and forests occupied the cooler, wetter areas closer to the glacier. As the last glacier retreated 10,000-12,000 years ago, a gradual warming period allowed grassland species to return to the central plains (Collins and Glenn 1995). As grasslands became established, three main elements—climate, grazing, and fire—allowed prairies to prevail and kept forests and woodlands at bay. The change in climate after the last glacial retreat allowed grasses and forbs to flourish where trees and shrubs could not. Decreased rainfall in the rain shadow of the Rocky Mountains and great year-to-year and within year variability of precipitation forced forests to retreat to more mesic areas. Dry conditions of the prairies also allowed for periodic fires at return intervals of 2-5 years (Steinauer and Collins 1996). These fires kept trees from becoming established and allowed the prairies to remain open. This was especially important in the eastern tallgrass prairies where precipitation was high enough to support tress. In addition, mid- to late-spring fires increased productivity of tallgrass prairie (Bragg 1995). Large numbers of grazers, such as bison (*Bison bison*), concentrated grazing in these newly burned and highly productive areas of the prairie. This intensive grazing helped block encroachment by trees and allowed fuels to build up in the much more lightly grazed unburned areas. These relatively ungrazed areas became prone to fire as litter accumulated, especially in dry years, and any trees trying to become established in the area soon became victim to fire. This interaction between grazing, drought, and fire is believed to be the most important factor in development and maintenance of the prairie ecosystem in the Great Plains of North America.

Today grasslands are among the most completely altered ecosystems in North America (Joern and Keeler 1995), with only about 4% of presettlement tallgrass prairie remaining (Steinauer and Collins 1996). Since 1830, the decline in area of tallgrass prairie, estimated to be 82-99%, has exceeded that of any other major ecosystem in North America (Samson and Knopf 1994). Most of this once abundant grassland system has been converted for agriculture, resulting in the loss of native grasses and forbs due to plowing and planting of exotic crops. However, steep terrain and rocky soils have made the Flint Hills of Kansas and Oklahoma unsuitable for agriculture. In this region the prairie has been converted to highly productive cattle ranches where native grasses and forbs have remained with cattle replacing the once abundant native herbivores of the Great Plains; however, even this land has not escaped alteration. Ranching practices such as exclusive spring burning and suppression of autumn and winter fires have resulted in dominance of warm season grasses. In addition, the higher proportion of forbs in the diets of cattle as opposed to bison (Plumb and Dodd 1993) has resulted in the decrease in abundance of forbs (Smith 1996).

Oil Production—In addition to conversion and fragmentation of tallgrass prairie, oil production in the southern plains has contributed to the decline of this ecosystem. In Oklahoma, oil was discovered in 1859, although steady production did not begin until the late 1800s and early 1900s. The great oil boom of 1900-1935 resulted in more than 8.8 billion barrels of crude oil being pumped from the Mid-Continent Oil Region, which included Texas, Oklahoma, and Kansas (Franks et al. 1981). As people flooded to Oklahoma in search of this new form of wealth, drilling derricks and oil rigs began to dot the landscape; roads were constructed to make traveling easier; storage tanks were built to hold the extracted oil; and pipelines were laid to move crude oil to refineries in Texas and Kansas. However, the building of storage tanks and pipelines could not keep up with the production of oil. As a result, many producers created open-pit earthen reservoirs or dammed rivers and streams to store their excess oil, resulting in lakes of petroleum (Tyson et al. 1977). These large lakes left scars devoid of vegetation on the prairie. Although lakes of petroleum no longer exist and most of the scars have healed, oil spills still occur today through breaks or leaks in pipelines, storage tanks, and pumpjacks.

In normal production practices, oil brought up from deposits is accompanied by formation brine water (saltwater), which can contain chloride concentrations up to seven times that of sea water (Simmons 1985). During the early years of production, saltwater was left to drain over the land surface or placed in large earthen evaporation pits. In the 1920s, it was discovered that pumping the brine water down a dry or abandoned hole increased production in nearby wells. Although re-injection, which is still in use today, soon became a profitable means of disposing of oil field brine and increasing production, earthen evaporation pits were still utilized through the 1960s. Re-injection was accomplished by pumping the oil/brine mixture to a processing facility where oil and brine were separated (Hallman 1957). Via pipelines, crude oil would then be sent to storage tanks or oil refineries, and brine was sent to wells where it would be injected back underground. This process results in 3 types of spills that can occur when a pipeline breaks—oil, brine, or an oil/brine mixture—all having different effects on the surrounding ecosystem. All 3 types of spills will kill any vegetation present on the spill site, although the length and severity of the effect can vary. Hydrocarbons, a component of crude oil, can be degraded by bacteria in the soil in a matter of years (Wilson and Jones 1993), allowing the spill site to recover in a short time. Brine, however, has a much more lasting effect. High concentrations of salt in brine water can remain in the soil for decades, causing topsoil to erode away due to the absence of vegetation cover.

Problem Statement—The tallgrass prairie once existed as a contiguous ecosystem extending from Indiana in the east and north-south from Manitoba to Texas in the west. Disturbance, namely drought, fire, and grazing, has historically been an important factor in the development and maintenance of tallgrass prairie. Unfortunately, much of the tallgrass prairie ecosystem was extirpated prior to extensive ecological study (Steinauer and Collins 1996) and has become increasingly fragmented over the last century. Today, studies must be done on the small fragments of tallgrass prairie remaining in order to understand the importance of disturbance in maintaining the function of the ecosystem. However, not all functional elements are always present on these fragmented plots of prairie. In most of the historic tallgrass prairie region, many native large mammals including the grizzly bear (*Ursus arctos*), wolf (*Canis lupus*), elk (*Cervus elaphus*), bison, and pronghorn (*Antilocapra americana*) have been extirpated. In addition, historic fire regimes have been removed or controlled in remaining fragments. This has resulted in removal of two functional elements involved in the maintenance of tallgrass prairies: grazing and periodic fire. Recently, however, anthropogenic disturbances have increased and become a major factor in the tallgrass prairie ecosystem. In the southern Great Plains, oil production has resulted in the introduction of disturbances such as roads, oil facilities, and spills. It is important to understand how these anthropogenic disturbances affect the tallgrass prairie ecosystem and how these disturbances interact with more natural disturbances.

On tallgrass prairie fragments, the small mammal community provides an excellent study group due to a typically small home range and because most native species are still abundant, thus allowing community-wide analysis. An extensive long-term study of small mammals on tallgrass prairie has been conducted on the Konza Prairie, Kansas; however, this study has been conducted mainly on ungrazed prairie with rigid burning schedules (Reichman 1987), mainly restricted to spring. In addition, other studies of small mammals on tallgrass prairie have been conducted on small remnants or areas of restored prairie on which few natural elements, such as grazing by native bison and fire, are present. As a result, there is a need for small mammal studies on more natural, functional ecosystems. In addition, there have been many studies conducted on the toxicological effects of oil on plants and animals; however, few studies have been done on how oil and brine spills change the ecology of the effected area through the removal of vegetation, or how oil and brine contamination interact with other forms of natural habitat disturbance such as fire. As a result, the response of the small mammal community to oil and/or brine spills (which completely alter the plant community through the direct killing of all plants in the affected area) remains unknown. Therefore, the purpose of this study is to investigate: 1) how the small mammal community in a bison-grazed tallgrass prairie responds to autumn burning, oil spills, and brine spills; and 2) if and how these responses differ among various types of natural and human-created disturbance.

Chapter II

Community Composition of Small Mammals in Relation to Environmental Disturbances on Tallgrass Prairie

ABSTRACT

Historically, disturbance has been an important factor in the development and maintenance of the tallgrass prairie ecosystem. Fire has played a major role in tallgrass prairies for thousands of years; however, in the last 200 years Europeans have changed the types of disturbance occurring on the Great Plains of North America. Oil production on the southern prairies has resulted in occasional oil and brine (saltwater brought up during the normal production of oil) spills, which can drastically change the vegetation characteristics at a site. I compared small mammal communities on disturbed sites and undisturbed sites on tallgrass prairie grazed by bison. Small mammals were trapped monthly for 1 year on 2 autumn burned sites, 2 unburned sites, 2 oil spill areas (consisting of 2 oil spill sites and 2 adjacent oil reference sites) and 1 brine spill area (consisting of 1 brine spill site and 1 adjacent brine reference site). Deer mice (*Peromyscus maniculatus*) were significantly more abundant on burned, oil spill, and disturbed sites than unburned, oil reference, and undisturbed sites, respectively. Least shrews (*Cryptotis parva*) were significantly more abundant on unburned, oil reference, brine reference, and undisturbed sites than burned, oil spill, brine spill, and disturbed sites, respectively. Prairie voles (*Microtus ochrogaster*) were significantly more

abundant on unburned, oil reference, and undisturbed sites than burned, oil spill, and disturbed sites, respectively. Cotton rats (*Sigmodon hispidus*) were significantly more abundant on unburned and undisturbed sites than burned and disturbed sites, respectively. Species diversity was higher on unburned, oil reference, and undisturbed sites than burned, oil spill, and disturbed sites. Species composition and diversity were similar on burned and spill sites. These results show that disturbance can drastically change the animal community existing on a site. Species can be categorized as either disturbance-positive or disturbance-negative depending upon their response to disturbance. Species overlap on undisturbed and disturbed sites was not complete; therefore both disturbed and undisturbed sites are needed to maximize small mammal diversity on tallgrass prairie.

INTRODUCTION

The tallgrass prairie ecosystem is a disturbance-driven system. Maintenance of ecosystem processes and native plant and animal communities of the tallgrass prairie are dependent upon these disturbances, especially drought, grazing, and frequent fire (Steinauer and Collins 1996). These disturbances interact with each other to create a mosaic of patches across the landscape and allow diverse plant and animal species to interact within the ecosystem. Historically, presettlement natural disturbances interacted with vegetation characteristics across a wide range of temporal and spatial scales. Interaction among disturbances, and between disturbances and abiotic factors, resulted in a checkerboard of patches with a complex history of disturbance (Steinauer and Collins 1996). In general, drought and fire, which could occur during any time of the year, would influence movement and grazing patterns of large herbivores, especially bison (*Bison bison*). Most grassland species, including small mammals, evolved within this complex interaction of elements and have become dependent upon or specialized within this constantly changing ecosystem.

Species responses to fire in tallgrass prairie have been studied extensively. Most post-fire changes in the small mammal community can be attributed to changes in vegetation following fire. Small mammals generally are separated into three categories relative to their response to fire (Kaufman et al. 1990). Fire-positive species, such as the deer mouse (*Peromyscus maniculatus*), are attracted to recently burned areas and are found in higher densities following a burn. Elliot's short-tailed shrew (*Blarina hylophaga*) and prairie vole (*Microtus ochrogaster*) are fire-negative species (Kaufman et al. 1989, Clark et al. 1995, McMillan et al. 1995) and prefer more heavily vegetated areas or more dense litter layers and are found in lower densities following a burn. Fire-neutral species show no response to fire and are often found in similar numbers on burned and unburned sites. Most studies on the response of small mammals to fire in tallgrass prairie have been conducted on ungrazed prairie with a majority of fires occurring during the spring season within a rigid burning program (Schramm and Willcutts 1982, Kaufman et al. 1983, Clark et al. 1995, Clark and Kaufman 1990). However, this was not the historic disturbance pattern present in tallgrass prairie prior to European settlement. Only a few studies have been conducted on small mammals following an autumn fire (McMillan et al. 1995, Chance 1984) or with a grazing and burning interaction (Clark et al. 1989, Matlock et al. 2001). To fully understand complex interactions between small mammal communities and disturbance, studies need to be conducted in more natural settings that include autumn and/or summer fires and grazing.

Fire, grazing, and drought, have always been important disturbances in the tallgrass prairie ecosystem. In the last 200 years, however, anthropogenic disturbances have increased and become a major factor in the tallgrass prairie ecosystem. In the late 1800s, oil production began in the southern Great Plains of North America. Since then, disturbances related to oil production, such as roads, oil facilities, and spills, have been introduced. In normal production practices, oil brought up from deposits is accompanied by formation brine water (saltwater), which can contain chloride concentrations up to seven times that of sea water (Simmons 1985). In the early years of oil exploration, both oil and brine often were diverted into large open-pit reservoirs. Although those practices are no longer used, scars from old saltwater pits are still present on the landscape. In addition, new oil and brine spills are still occurring throughout oil fields in the southern Great Plains. An extensive number of studies have been conducted on direct effects of exposure to environmental contaminants on small mammals (see McBee and Bickham 1990, Talmage and Walton 1991 for reviews); however, few studies have been conducted on the effect oil and brine spills have on the ecology of the small mammal community. Studies have indicated changes in the small mammal community on land strip-mined for coal (Sly 1976, Hansen and Warnock 1978), mine waste sites (Kirkland 1976), radioactive waste disposal areas (Groves and Keller 1983), hazardous waste disposal sites (Flickinger and Nichols 1990), and polychlorinated biphenyls contaminated sites (Linzey and Grant 1994). However, all of these studies were on sites where there had been time for regrowth of vegetation. I have found no studies that have been conducted on contaminated sites where vegetation had not regrown following the contamination.

In this study, the small mammal community was sampled in tallgrass prairie grazed freely by bison to determine differences in community composition among various site types. The objectives of this study were to look at differences in the small mammal community among 1) autumn burned prairie and unburned prairie, 2) oil spill sites and adjacent reference sites, and 3) a brine spill site and an adjacent reference site. Burned sites and spill sites were grouped together as disturbed sites, and unburned sites and reference sites were grouped together as undisturbed sites to determine overall community differences between disturbed and undisturbed sites. In addition, burned sites and spill sites were compared to each other to determine if small mammal community composition was different between an historic natural disturbance and an anthropogenic disturbance.

STUDY AREA AND METHODS

Study Area—The Tallgrass Prairie Preserve (TPP), owned and operated by The Nature Conservancy, is located approximately 19 km north of Pawhuska within Osage Co. in northeastern Oklahoma. It is situated at the southern end of the Flint Hills (Hamilton 1996) near the western boundary of the tallgrass prairie system (Sampson and Knopf 1994). The approximately 15,200-ha preserve consists mainly of tallgrass prairie dominated by big bluestem (*Andropogon gerardi*), little bluestem (*Schizachyrium scoparium*), switchgrass (*Panicum virgatum*), and Indiangrass (*Sorghastrum nutans*; Hamilton 1996). Streamside gallery forests and cross-timber woodlands consisting of post oak (*Quercus stellata*) and black-jack oak (*Quercus marylandica*) also are present on the preserve. Historically, this land was used for cattle grazing and has never been plowed, which has allowed native vegetation to remain. In addition, oil production has been present historically, with 107 working pumpjacks currently present on the TPP (R. G. Hamilton, pers. comm.). As a result of this oil production, numerous oil and brine spills of various sizes and ages are scattered around the preserve.

The Nature Conservancy's goal for the preserve is to restore a functioning tallgrass prairie landscape (Hamilton 1996). As a result, a natural ecosystem is being restored through implementation of a randomized burning regime and reintroduction of native bison. During the study, the bison unit covered 4197 ha of the TPP. At the beginning of the study there were approximately 1200 bison inhabiting the unit, with the herd growing to about 1600 by the end of the study. The randomized burning pattern used in the bison unit consisted of a 3-year return interval (33% of the unit burned in one calendar year; R. G. Hamilton, pers. comm.) with 40% burned during the dormant spring season (March/April), 20% during the late growing season (August/September), and 40% during the dormant autumn season (October through December; Hamilton 1996). Prior to each burn season, the entire bison unit was surveyed to determine the fuel load available across the landscape. Burn units were chosen randomly from areas above the minimum fuel load threshold. This randomized burning resulted in a more natural and complex patchwork of burning across the preserve. Reintroduction of bison to the preserve also returned a major element of native grasslands and allowed for studies to be conducted in the presence of the bison-fire interaction historically present in tallgrass prairie.

Data Collection—The small mammal community was sampled by placing snap traps on 7 separate areas of the TPP (Fig. 1). All trapping areas were located within the bison unit and were freely grazed. Each area was trapped for at least 12 months. The 7 areas were split into 2 groups with both groups trapped separately every month. Traps were baited with a mixture of peanut butter and oats and were checked on 3 consecutive mornings and the 2 intervening afternoons every month, except when inclement weather limited trapping to 2 nights. No corrections were made for sprung traps or traps missing bait, and all occupied and sprung traps were reset at each check.

The 7 trapping areas consisted of 2 autumn burned areas, 2 unburned areas, 2 oil spill areas, and 1 brine spill area (Table 1). Trapping was scheduled to run on all areas from October 2000 to September 2001; however, due to a burn ban in the area, scheduled burning was not accomplished until late November (Table 1). Therefore, burned areas were trapped beginning in December 2000 until November 2001, unburned areas were trapped from October 2000 to November 2001, and spill areas were trapped from October 2000 to September 2001 (Table 1). Due to the randomization of the burning pattern, unburned areas with burn histories similar to the burned areas did not exist. Therefore, areas were considered unburned after 3 growing seasons following a burn. All 3 spill areas were split into spill sites and reference sites. Spill sites were those sites that were directly affected by the spill and were not yet vegetated (Fig. 2). Reference sites were those sites adjacent to spill sites but not obviously affected by the spill (Fig. 2). This resulted in a total of 6 site types: burned, unburned, oil spill, oil reference, brine spill, and brine reference. All site types except the brine spill and the brine reference had 2 replicates—B1 and B2 for burned sites, U1 and U2 for unburned sites, O1 and O2 for oil spill sites, R1 and R2 for oil reference sites, S1 for the brine spill site, and R3 for the brine reference site.

The oil spills were both part of 1 large continuous spill that occurred on 6 January 1999. The 2 spill areas were separated by a stretch of road along which the spill ran for approximately 130 m. This resulted in different levels of contamination at the 2 sites (S. L. Coughlin, pers. comm.). Sizes of the 2 individual spills were rather small with O1 approximately 0.16-ha, and O2 approximately 0.09-ha. The source of the brine spill, estimated to be over 70 years old, is unknown. This site still contains elevated levels of salt in the soil (S. L. Coughlin, pers. comm.) and covers 65-ha with part of the spill located on a ranch bordering the preserve. Due to the randomization of the burning pattern, unburned site U1 was burned in March 2001 (Table 1) after trapping had been concluded for the month on that site. For analyses, data from this site were split into preburn (U1U) and postburn (U1B) data.

In each area, there were 2 transect lines of 20 stations each at intervals of 8 m. Each station consisted of 1 museum special trap and 1 large snap trap attached to a stake by wire, which was used to reduce loss of specimens and traps by predators. Each trap was placed approximately 1 m from the stake at an angle perpendicular to the trap line. On burned and unburned sites, there were 2 trap lines in each area at a 90° angle to each other with the beginning of one line placed at the end of the other line (Fig. 3A). Modifications of this design were made for the spills to maximize the number of stations on the spill. On the brine spill, 1 complete line was placed in the reference site directly adjacent to the spill, and the second line was placed completely within the spill (Fig. 3B). For the oil spills, however, this arrangement was not possible due to their small sizes. Therefore, 1 line ran through the middle of the spill with the first station placed near the inner edge of the spill and the rest of the line running the length of the spill and into the unaffected prairie (Fig. 3C). The second line was placed in the same manner running the width of the spill perpendicular to the first line (Fig. 3C).

Upon capture of a specimen, date, time, trap number, trap type, species, sex, reproductive condition (scrotal or non-scrotal for males, lactating or not lactating for females), and weight were recorded. Specimens were deposited into the Oklahoma State University Collection of Vertebrates.

Analyses—Analyses were based on capture rates, which were calculated as captures/100 trap nights, and were used to account for the variation in trapping effort among sites (Table 1). One trap night was considered to be equal to 1 trap set for 1 24-hr period. Capture rates were calculated by site for each species and all species combined. In analyses involving capture rates, only data from December 2000-November 2001 for unburned sites were used to correlate trapping results from these sites to trapping results from burned sites. For site comparisons, burned sites were compared with unburned sites, oil spill sites were compared to oil reference sites, and the brine spill site was compared to the brine reference site. For some analyses, sites were grouped into disturbed (spill and burned) and undisturbed (unburned and reference) sites. In addition, oil spill sites and the brine spill site were combined and compared to the burned sites in order to determine if there were differences between a "natural" disturbance and an anthropogenic disturbance.

Diversity patterns of small mammals were analyzed by calculation of species richness and diversity. Species richness was calculated as the total number of species caught on a site. Diversity was determined by the Shannon Diversity Index (SDI), which was calculated with the equation (Brower et al. 1998):

$$H' = \frac{N \log N - \sum n_i \log n_i}{N}$$

where N is the total number of individuals captured on a site, and n_i is the number of individuals of the i^{th} species captured on a site. SDI is a popular measure of diversity because it takes into account both species richness and evenness. A high SDI indicates a community with many equally or nearly equally abundant species present, whereas a low SDI indicates a community composed of a few species or only a few abundant species (Brower et al. 1998). Data for all months were pooled to calculate SDI. In addition, normality tests were run to determine if the data for capture rates of each species and SDI were normally distributed. All capture rates for species were not normally distributed, thus the non-parametric Kruskal-Wallis test was performed to determine whether capture rates of individual species differed among sites. Diversity values were normally distributed among sites, so an analysis of variance (ANOVA) was run to determine if SDI differed among sites. All preceding statistical tests were run using SAS (SAS 2001).

Ordination techniques were used to determine differences in small mammal community composition among sites. Ordination techniques allow a summary of patterns in species composition among samples (in this case sites; Collins 2000). Specifically, correspondence analysis (a form of ordination) is commonly used in the analysis of species data at different sampling sites (Legendre and Legendre 1998). Results of this ordination consist of sites and/or species arranged along an environmental gradient (Palmer 1993). Due to the arch or horseshoe effect that can be produced by correspondence analysis (see Hill and Gauch 1980), I used detrended correspondence analysis (DCA), which does not produce this side effect. DCA is an indirect gradient analysis where environmental gradients are inferred from species composition data (Palmer 1993). The data used in this analysis consisted of capture rates of each species at each site. I used capture rates as a measure of abundance because this allowed differences in species abundances and trapping effort to be taken into account.

RESULTS

Thirteen species of small mammals (418 individuals) were caught over a total of 19,680 trap nights from October 2000 to November 2001 (Appendix). Four species—the deer mouse, prairie vole, cotton rat (*Sigmodon hispidus*), and least shrew (*Cryptotis parva*)—collectively represented 89.2% of the total number of individuals captured. Rare species, species which individually comprised less than 5% of captures, included Elliot's short-tailed shrew, hispid pocket mouse (*Chaetodipus hispidus*), eastern woodrat (*Neotoma floridana*), marsh rice rat (*Oryzomys palustris*), white-footed mouse (*Peromyscus leucopus*), fulvous harvest mouse (*Reithrodontomys fulvescens*), eastern harvest mouse (*Reithrodontomys humulis*), plains harvest mouse (*Reithrodontomys montanus*), and thirteen-lined ground squirrel (*Spermophilus tridecemlineatus*). Captures of these species were too low for statistical comparisons among site types, but were included in total species capture rates, diversity indices, and ordination analyses. Individuals were caught in both the morning and evening trap checks with 12 of 13 species caught in overnight sessions and 5 species caught in daytime sessions. Species caught in the daytime included cotton rat (25/56 total captures), Elliot's short-tailed shrew (3/15), least shrew (4/38), prairie vole (18/69), and thirteen-lined ground squirrel (3/3).

Data given for rare species are for captures on all sites from October 2000 to November 2001. Rare species were caught on all site types (Table 2; Appendix). Species with only 1 capture each were the plains harvest mouse caught on the brine reference site, eastern woodrat caught on a burned site, and the marsh rice rat caught on an unburned site. The fulvous harvest mouse and Elliot's short-tailed shrew were caught only on undisturbed sites, and the hispid pocket mouse was only caught on disturbed sites. The thirteen-lined ground squirrel was caught twice on burned sites and once on a reference site. The white-footed mouse was caught mostly on disturbed sites with only 2 captures on undisturbed sites. The eastern harvest mouse was caught mostly on undisturbed sites with the only capture on a disturbed site being that of an individual on a burned site only 5 days after the burn occurred.

Severe weather—Three separate severe winter storms hit Oklahoma in December 2000 resulting in the state's coldest month since 1983 and culminating in the coldest November-December on record (NOAA 2000a). The first storm hit Osage Co. on December 12th, dropping temperatures into the teens and 20s for the next three days and dumping 30.5 cm of snow in Pawhuska on December 13th (NOAA 2000a). A second storm two weeks later brought another 14 cm of snow and ice to Pawhuska, with the third storm leaving an additional 7.6 cm of snow on the ground on the last day of the month (NOAA 2000a, NOAA 2000b). All trapping for December was completed before these weather events occurred. Following this severe weather, capture rates of small mammals dropped significantly and did not recover by the end of the study (Fig 4). Several species were common in the 3 months previous to the severe weather, but became rare in the months that followed. A total of 56 cotton rats and 37 least shrews were captured in October, November, and December of 2000; however, no additional cotton rats and only 1 additional least shrew (March 2001) were caught through the end of the study in November 2001 (Fig. 4). Elliot's short-tailed shrews also declined following the storms with 12 animals caught prior to the severe weather and only 3 caught afterwards (2 in

January 2001, 1 in August 2001; Fig. 4). Prairie voles and deer mice showed no major decline in captures in the 3 months following the storms, although captures of prairie voles dropped after April. Deer mice were caught during every trapping session and showed no drop in captures following the storms.

Fire—For comparisons of capture rates between burned and unburned sites, only data from December 2000 to November 2001 were used. All 4 common species showed a response to fire when capture rates were compared between these 2 site types. The deer mouse had higher capture rates on burned sites than unburned sites ($P = 0.02$), whereas capture rates were higher on unburned sites than burned sites for the least shrew ($P = 0.005$), prairie vole ($P < 0.001$), and cotton rat ($P = 0.04$).

Burned sites and unburned sites showed differences in small mammal community structure as well. There were 6 different species caught on burned sites (Table 2) with deer mice dominating the community (90% of captures; Fig. 5). Unburned sites had a species richness of 8 species (Table 2) with prairie voles and cotton rats being the most common (72% of captures combined; Fig. 5). Only the deer mouse, white-footed mouse, and eastern harvest mouse were found on both site types. Mean SDI was higher on unburned sites than burned sites (Table 2; $P = 0.005$). In addition, community structure for site U1, which was burned part way through the study, was substantially altered after the burn. Six species were caught on this site prior to the burn, but only 3 species were caught following the burn. There were no species caught on this site both prior to and after burning. Elliot's short-tailed shrew, least shrew, prairie vole, marsh rice rat, eastern harvest mouse, and cotton rat were caught prior to burning, and hispid pocket mouse, deer mouse, and thirteen-lined ground squirrel were caught after the site was burned.

Oil—Three of the 4 common species showed significant differences in capture rates between oil spill and oil reference sites. Deer mice had higher capture rates on oil spill sites than oil reference sites ($P = 0.003$), whereas the least shrew ($P = 0.002$) and prairie vole ($P < 0.001$) were caught more often on oil reference sites than oil spill sites (Table 2, Appendix). Although 13 cotton rats were caught on oil reference sites and only 1 on an oil spill site (Appendix), mean capture rates were not significantly different between these 2 site types ($P = 0.27$).

Oil spill sites and oil reference sites also differed in community structure. Species richness was higher on oil reference sites (8) than oil spill sites (4; Table 2). Deer mice dominated the small mammal community on oil spill sites (94% of captures), but oil reference sites were dominated by prairie voles and least shrews (65% of captures combined; Fig. 5). Only the white-footed mouse, deer mouse and cotton rat were found on both site types. In addition, mean SDI was higher on oil reference sites than oil spill sites ($P = 0.001$; Table 2).

Brine—Only 1 species, the least shrew, showed a difference in capture rates between the brine spill and brine reference sites. This species had a higher capture rate on the brine reference site than the brine spill site ($P = 0.04$; Table 2). The deer mouse was caught on both the brine reference and brine spill sites and showed no difference in capture rates ($P = 0.34$; Table 2). No prairie voles or cotton rats were caught on either site (Table 2; Appendix).

The brine spill and brine reference sites did not show any difference in community structure. Species richness on the two sites was similar with 2 species being caught on the spill site and 3 species on the reference site (Table 2; Appendix). Only the deer mouse was found on both sites and represented 94% of captures on the spill and 83% of captures on the reference site (Fig. 5). Mean SDI did not differ between the two sites ($P = 0.27$; Table 2).

Disturbance—Spill sites were compared to burn sites to determine if there were differences in small mammal communities on sites disturbed by a "natural" disturbance versus an anthropogenic disturbance. Species richness was similar on both site types, although more species were caught on burned sites (6) than spill sites (4; Table 2). In addition, deer mice dominated the small mammal community on both site types (94% on spill sites, 90% of captures on burned sites; Fig. 5), and SDIs did not differ between spill and burned sites ($P = 0.46$; Table 2). Only deer mice showed a difference in capture rates among burned sites compared to spill sites, with higher capture rates on spill sites ($P = 0.04$; Table 2).

All 4 species showed differences in capture rates between disturbed and undisturbed sites. Prairie voles and least shrews were caught only on undisturbed sites, and cotton rats were caught more often on undisturbed sites ($P = 0.05$). Deer mice, however, were caught more often on disturbed sites than undisturbed sites ($P = 0.008$).

Community structure differed between disturbed and undisturbed sites. Disturbed sites had a species richness of 7 species with deer mice comprising 92% of captures. Undisturbed sites had higher species richness (10) and SDI (0.734) than disturbed sites (0.175; $P = 0.003$), with captures on undisturbed sites dominated by 4 species: prairie vole, least shrew, cotton rat and deer mouse.

Detrended correspondence analysis showed that sites grouped into 2 distinct groups along DCA axis 1 (Fig. 6). This axis explained 68% of the variance in species composition, and can be interpreted as a gradient of disturbance. The group of sites closest to the origin of axis 1 included all burned sites and spill sites; all considered disturbed sites. Although considered an undisturbed site, the brine reference site (R3) also was included in this group. The second group of sites included all unburned sites and both oil reference sites. These were all considered undisturbed sites. In general, disturbed sites grouped together and undisturbed sites grouped together based upon small mammal community composition.

DISCUSSION

Severe weather—Numbers of cotton rats, Elliot's short-tailed shrews, and least shrews declined following the severe weather events that occurred in Oklahoma in December 2000, whereas deer mice populations seemed to be unaffected. Other studies have shown substantial reductions in cotton rat populations following periods of severe cold and/or unusual amounts of snowfall (Dunaway and Kaye 1961, Goertz 1964, Fleharty et al. 1972, Sauer 1985, Langley and Shure 1988). Dunaway and Kaye (1961) reported cotton rat populations from two areas at Oak Ridge National Laboratory in Tennessee had completely vanished following a winter of severe cold and record snowfall. Goertz (1964) also reported the complete disappearance of a cotton rat population following a winter of severe cold and two weeks of snow cover over a layer of ice in Payne Co., Oklahoma. He suggested that cotton rats, a recent Neotropical migrant, cease foraging in extremely cold weather (Goertz 1964). Cotton rats generally build grass nests above ground (Cameron and Spencer 1981), and because cotton rats are not known to store food (Schendel 1940) this period of inactivity can result in death from starvation or exposure. In the current study, the severe winter weather was preceded by a severe drought during the late summer and autumn (NOAA 2000a). This may have caused the cotton rat population to be already under stress before the cold weather and snow arrived, causing the population to crash.

Deer mouse populations, on the other hand, did not change following the cold weather. This species normally builds nests underground and will consistently cache food (Eisenberg 1968). This would allow deer mice to be insulated from the cold and have food readily available, thus the loss of a few days of foraging would not be fatal. The population crash of prairie voles, which did not occur until several months after the severe weather, may have been due to normal population cycles that have been found in this species. In Kansas, populations of prairie voles tended to crash in the spring, with some recovery during the breeding season (Gaines and Rose 1976). No documentation on population changes due to weather for least shrews or Elliot's short-tailed shrews could be found, although Merritt (1986) found high winter survivorship of northern short-tailed shrews (*Blarina brevicauda*) in eastern deciduous forests of North America due to the ability of this species to incorporate behavioral, anatomical, and physiological adjustments to adapt to seasonal changes.

Fire—Least shrews had a negative response to fire and were significantly more abundant on unburned sites compared to burn sites. Unburned sites had at least 3 growing seasons since the last burn and therefore had a significant amount of growth, cover, and litter present on the sites (pers. obser). This is consistent with habitat preferences for this species, which is generally found in grassy, weedy, and brushy fields, with the presence of dense herbaceous ground cover being an important factor (Whitaker 1974). The only other study on the response of least shrews to fire in tallgrass prairie reported no response by this species to burning (Clark et al. 1995).

The prairie vole also responded negatively to fire with no individuals caught on burned sites. This species is found mostly in prairie habitat where there is suitable cover to construct runways and nests (Kaufman and Fleharty 1974, Stalling 1990). Clark and Kaufman (1991) found that prairie voles foraged selectively in patches with moderate amounts of litter, but avoided patches with compacted litter. Burned sites would be unsuitable for prairie voles until enough cover and litter had developed for proper runways and construction of nests. Other studies have found this species to have varying responses to fire. Cook (1959) found that *Microtus* did not respond to a fire in ungrazed grassland in California due to the rapid growth of grasses and buildup of cover following the fire. A fire-positive response was found on a restored prairie in Illinois (Schramm and Willcutts 1982). However, other studies have found prairie vole populations to decrease following fire in ungrazed prairie (Clark 1989; Clark and Kaufman 1990) and grazed prairie (Clark et al. 1989), mostly due to emigration of prairie voles from burned to unburned prairie.

Cotton rats also had a negative response to fire with no individuals caught on burned sites. Cotton rats generally are found in habitats that have well-developed litter layers and a complex vertical structure (Kaufman and Fleharty 1974, Clark et al. 1998). Grasses generally dominate these areas, and grass height and density are considered important components of their preferred habitat (Cameron and Spencer 1981). Cotton rats are found in similar habitats as prairie voles and often use the same runway systems (Clark et al. 1998). In this study, cotton rats were found in the same habitats as prairie voles and both showed a fire negative response. Unburned sites had at least 3 growing seasons since the last burn and had suitable grass growth and dead litter for cotton rat habitat. Burned sites provide unsuitable habitat for cotton rats due to the absence of litter and lack of cover. Few studies have reported on the response of cotton rats to burning in tallgrass prairie; however, Brillhart et al. (1995) reported cotton rats showed no response to fire history in an ungrazed prairie in Kansas.

Deer mice were found to be fire-positive with significantly higher abundance on burned than unburned sites. In a long-term study at Konza Prairie in Kansas, Kaufman et al. (1990) found densities of deer mice were higher in burned areas than unburned areas in 18 of 19 censuses. This species is granivorous and tends to favor low cover areas where movement is not hindered and seeds can be found easily. In ungrazed tallgrass prairie this species occurs more frequently in burned areas, where there is less litter and more open areas, than unburned areas in Kansas (Clark 1989; Clark et al. 1989, Kaufman et al. 1983, Kaufman et al. 1998) and Illinois (Schramm and Willcutts 1982). Deer mice had a delayed response to an autumn fire in Kansas where differences in abundance between unburned and burned areas did not occur until spring. In my study, 8 deer mice were caught on burned sites less than 2 weeks following the fire. Although trapping was not conducted on the burned sites prior to burning, only 3 deer mice had been caught on unburned sites the 2 months prior to burning. In addition, only 1 deer mouse was caught on unburned sites during the 2 weeks following the fire on burned sites. This shows a possible near immediate response of deer mice to burning. High amounts of litter appear to have a negative impact on deer mice (Clark et al. 1989) and the low amounts of standing and dead material on burned sites provide suitable habitat for deer mice. Deer mice would respond to the removal of litter and cover following the burn by moving onto the more open burned areas following fire.

Overall, small mammal community structure differed between burned and unburned sites. Species richness and diversity were lower on burned sites than on unburned sites. The most abundant species on burned sites was the deer mouse, whereas cotton rats and prairie voles were the most abundant species on unburned sites. In addition, least shrews and Elliot's short-tailed shrews were found on unburned sites but not on burned sites. The decreased species richness and diversity on burned sites is due to the fact that the 3 most abundant species on unburned sites (Elliot's short-tailed shrew, prairie vole, and cotton rat) were never caught on burned sites, and the dominant species on burned sites (deer mouse) was uncommon on unburned sites. Data from site U1 (burned during the study) support these findings. Species caught on this site prior to burning included the cotton rat, prairie vole, and least shrew. After burning, none of these species were caught on this site, and deer mice were caught for the first time. Burning on this site made the site unsuitable for cotton rats and prairie voles and more suitable for deer mice due to the removal of both a deep litter layer and high amounts of standing cover.

Oil—Oil spill sites proved to be a barrier to many species. Least shrews and prairie voles were never captured on oil spill sites, although they were abundant on the oil reference sites surrounding the spills. In addition, only 1 cotton rat was caught on an oil spill, and this individual was caught less than 1 m from the edge of the spill. The lack of any herbaceous ground cover on the spill sites caused these species to avoid the spill sites and remain in the areas surrounding the spill where more suitable habitat could be found. The fact that a total of 61 least shrews, prairie voles, and cotton rats were caught off the spill and only 1 was caught on the edge of the spill (Appendix) demonstrates how important dense vegetation and cover are to these species. On the other hand, deer mice were caught more often on oil spill sites than oil reference sites with 60 deer mice caught on oil spills and only 7 caught on adjacent reference areas (Appendix). There were no small mammal burrows found on the oil spills (pers. obser.), so it is likely this species was nesting in the vegetated areas surrounding the spills and using the spills for foraging excursions. The presence of wind blown seeds and invertebrates (pers. obser.) on the oil spills may have provided easy foraging for these mice.

Species richness and diversity were lower on oil spill sites than oil reference sites. This decreased species richness and diversity on oil spill sites was due to the dominance of deer mice on the spills with few other species present. Oil reference sites, however, had higher species richness, and species dominance was more even with least shrews being the most dominant and prairie voles and cotton rats also very common. This difference in small mammal community composition and structure between these 2 site types shows how drastically disturbance can affect an ecosystem. Only a few studies have been done on changes in the rodent community on petrochemical contaminated sites. McMurry (1993) reported on the small mammal community structure on toxic sites and reference sites in Oklahoma. He reported differences in community structure between sites contaminated with complex mixtures of heavy metals and organic hydrocarbons and uncontaminated reference sites. Differences in the small mammal community between the two types of sites was primarily due to the large numbers of house mice (*Mus musculus*) and the general lack of shrews and voles on toxic sites (McMurry 1993). In addition, both cotton rats and *Peromyscus* species were found in higher abundance on reference sites (McMurry 1993). Another study from Oklahoma reported low numbers of voles and greater abundance of house mice and pocket mice on sites contaminated with petrochemicals when compared to reference sites (Lochmiller et al. 2000). Both of these studies were conducted on sites where extensive regrowth of vegetation had occurred. I have found no other published studies of small mammal communities on bare soil contaminated sites.

Brine—There was no difference in community structure between the brine spill site and brine reference site. Species richness and diversity were similar, and deer mice were the dominant species on both sites. Similarity between sites may be explained by the area surrounding the brine spill having been burned in the spring prior to the start of trapping (Table 1). In a grazed environment, this would cause suitable habitat for cotton rats, prairie voles, and least shrews to decrease; however, due to intense grazing by bison resulting in reduced cover and an increase in bare ground, suitable habitat for deer mice would increase. This would cause the reference area for the brine spill to have a species composition similar to that of burned sites. SDI was not different between the brine reference site and burned sites, no cotton rats or prairie voles were found on either site, and capture rates of deer mice were similar. Therefore, the brine reference site is more similar to a disturbed site than an undisturbed site, most likely due to the recent burning.

Twice as many deer mice were caught on the brine spill site than the brine reference site, although they comprised a similar percentage of the population—94% on the spill site, and 83% on the reference site. Rustiati and Kaufman (1994) reported a positive response by free-living deer mice to seeds with various sodium concentrations. Mice chose control seeds (no sodium added) and low sodium seeds (0.05M) more than medium (0.10M) or high (0.50M) sodium seeds (Rustiati and Kaufman 1994), showing a mild positive response to low levels of sodium. Therefore, deer mice may be attracted to the brine spill in order to utilize salt from the spill site. However, deer mice also were common on the oil spill site, where there was no brine present. Results showed there were no differences in capture rates of deer mice between the oil spill anc ($P = 0.41$). In addition, there was no difference in overall species diversit spill sites and the brine spill site ($P = 0.84$). Therefore, this species may l more to the lack of cover and dominance of bare ground on both of these presence of a salt source on the brine spill.

The fact that twice as many deer mice were caught on the brine sp brine reference site may be due to the increased cover on the brine referen Following the burning of the reference site in spring 2000, bison concentr grazing on this site during summer 2000. This kept the amount of standin a minimum, and provided suitable habitat for deer mice. However, after a been burned in autumn 2000 and spring 2001 began to grow new grass in bison began to concentrate their grazing on these newly burned areas. Th increase in the standing live and dead vegetation on the brine reference sit decrease in grazing pressure on this site (pers. obser.). Suitable habitat fo decreased on this site, making the brine spill more suitable than the refere supported by the fact that after May 2001 only 1 deer mouse was caught o reference site and 10 were caught on the brine spill site.

Disturbance—Burned sites and spill sites were similar in species c structure. Only deer mice showed a difference in capture rates with more spill sites than burned sites. There were no differences in all other parame the two site types. Species that were found on burned sites were also gene spill sites. Species found on both site types were responding to similar veg characteristics at these sites—little grass cover, no litter present, and a larg open space and bare ground. These characteristics would not be suitable for species dependant upon dense vegetation. Therefore it is reasonable to see that species structure on burned and spill sites would be similar.

Disturbed sites and undisturbed sites showed differences in species composition. Undisturbed sites had a higher species richness and diversity with 4 species sharing dominance, while disturbed sties had lower species diversity and richness with the community dominated by deer mice. Only 5 of the 13 species caught were found on both disturbed and undisturbed sites. Although undisturbed sites were more species rich and diverse, they did not provide suitable habitat for all species present in a tallgrass prairie ecosystem. Thus, both disturbed and undisturbed sites must be present in tallgrass prairie in order to provide suitable habitat for the entire small mammal community.

Ordination analyses organize communities on a graph so that communities that are the most similar in species composition and abundance appear closest together, while communities that differ in the relative importance of a similar set of species, or has a different set of species altogether, appear farther apart (Begon et al. 1996). Detrended correspondence analysis demonstrated that, based on species composition, sites grouped into disturbed and undisturbed sites along axis 1. Species composition on oil spill sites (O1, O2) and burned sites (B1, B2, U1B) were clearly different from reference (R1, R2) and unburned sites (U1U, U2), respectively. In fact, site U1 split between the two groups with site U1U (unburned) grouping with the undisturbed sites, and site U1B (burned) grouping with the disturbed sites. Species composition on this site changed significantly between before burning and after burning. In addition, species composition on the brine reference site (R3) was more similar to the brine spill site (S1) and other disturbed sites than it was to undisturbed sites. This agrees with the community structure results that showed the brine reference site to have similar species composition and abundance as burned sites. Therefore, species composition of individual undisturbed sites was more like that of other undisturbed sites than disturbed sites, with no significant difference appearing among undisturbed sites. Similarly, species composition of individual disturbed sites was more like that of other disturbed sites than undisturbed sites, with no significant difference among disturbed sites. Therefore, small mammal species are responding more to the results of the disturbance (decrease in standing live cover, removal of litter, increase in bare ground) than to the specific disturbance itself.

Conclusions—Kaufman et al. (1990) separated small mammal species into 3 categories according to their response to fire. Fire-positive species are found at higher densities on burned sites than unburned sites, fire-negative species are found at higher densities on unburned than burned sites, and fire-neutral species tend to be found on both areas. However, this study shows that species are responding more to disturbance in general than to fire specifically. I found that species caught more often on burned sites than unburned sites were also caught more often on spill sites than reference sites, and generally on disturbed sites than undisturbed sites (deer mouse). Also, species that were found on unburned sites more often than burned sites were also found more often on reference sites than spill sites, and more often on undisturbed sites than disturbed sites (least shrew, prairie vole, and cotton rat, although cotton rat only approached significance for spill versus reference sites). Small mammals in this study can be categorized into more generalized categories of disturbance-positive (deer mouse) and disturbance-negative (least shrew, prairie vole, and cotton rat) species.

On a localized scale, disturbance can drastically change the small mammal community present on a site. Sites that may have a mix of many species of small mammals can become dominated by a single species over a short time span as a result of disturbance. Burning a site can change a community dominated by cotton rats and inhabited by other small mammal species into a community dominated by deer mice with few other species present (U1U and U1B, for example). The same can be seen on sites impacted by oil spills. Most species found off the spill were not found on the spill, but deer mice were found mostly on the spill and infrequently off the spill. Disturbance changes the vegetation characteristics of a site, and small mammals respond to those changes. Providing a mosaic of burned and unburned patches of various ages on tallgrass prairie will allow a high diversity of species to be present on a landscape. Both disturbance-positive and disturbance-negative species will have adequate habitat within this mosaic. Although oil spill and brine spill sites have small mammal communities similar to those on burned sites, spill sites, especially brine spill sites, have a much longer lasting effect on the ecosystem. Burned sites can have a completely different small mammal community only 3 years post burning. However, spill sites can have an effect on the small mammal community for up to 70 years. In addition, in this study, spill sites were relatively small in size. As a result, small mammals could continue to live outside the spill and visit the spill site for foraging excursions. More extensive studies need to be conducted on spills of varying sized to determine the impact of spill size on community composition and structure, as well as to determine how these animals are using the spills and if any sublethal effects result from the continued use of these bare soil sites.

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Table 1—Descriptions of trapping sites on the Tallgrass Prairie Preserve, Oklahoma. Data for the number of growing seasons since the last burn refer to the beginning of the study. All sites except U1 had 1 additional growing season by the end of the study.

Disturbance Site type Site*	Date last burned	No. of growing seasons since last burn	Date of spill	No. of traps set per night	Trapping dates
Disturbed					
Fall burn					
B1	27-Nov-2000	0	---	80	Dec. 2000-Nov. 2001
B2	29-Nov-2000	0	---	80	Dec. 2000-Nov. 2001
Oil spill					
O1	22-Mar-1999	2	6-Jan-1999	22	Oct. 2000-Sep. 2001
O2	22-Mar-1999	2	6-Jan-1999	14	Oct. 2000-Sep. 2001
Brine spill					
S1	31-Mar-2000	1	Approx. 1930	40	Oct. 2000-Sep. 2001
Undisturbed					
Unburned					
U1	29-Jan-1998 (7-Mar-2001)	3	---	80	Oct. 2000-Nov. 2001
U2	22-Mar-1997	4	---	80	Oct. 2000-Nov. 2001
Oil reference					
R1	22-Mar-1999	2	---	58	Oct. 2000-Sep. 2001
R2	22-Mar-1999	2	---	66	Oct. 2000-Sep. 2001
Brine reference					
R3	31-Mar-2000	1	---	40	Oct. 2000-Sep. 2001

*See Fig. 1 for locations of trap sites.

Table 2—Capture rates (# captures/100 trap nights), species richness, and species diversity of small mammals trapped on 6 site types on the Tallgrass Prairie Preserve, Oklahoma. Capture rates were calculated using total captures and total number of trap nights for a given site type. Data are from trapping dates listed in Table 1.

	Site type						
Measure	Burned	Unburned	Oil spill	Oil reference	Brine spill	Brine reference	All sites
Species							
Blarina hylophaga	0.000	0.329	0.000	0.000	0.000	0.000	0.076
Chaetodipus hispidus	0.043	0.000	0.076	0.000	0.000	0.000	0.025
Cryptotis parva	0.000	0.154	0.000	1.036	0.000	0.152	0.193
Microtus ochrogaster	0.000	1.096	0.000	0.679	0.000	0.000	0.351
Neotoma floridana	0.014	0.000	0.000	0.000	0.000	0.000	0.005
Oryzomys palustris	0.000	0.022	0.000	0.000	0.000	0.000	0.005
Peromyscus leucopus	0.043	0.022	0.038	0.036	0.152	0.000	0.041
Peromyscus maniculatus	1.293	0.132	2.273	0.250	2.348	1.136	1.070
Reithrodontomys fulvescens	0.000	0.000	0.000	0.071	0.000	0.000	0.010
Reithrodontomys humulis	0.014	0.132	0.000	0.071	0.000	0.000	0.046
Reithrodontomys montanus	0.000	0.000	0.000	0.000	0.000	0.076	0.005
Sigmodon hispidus	0.000	0.044	0.038	0.464	0.000	0.000	0.285
Spermophilus tridecemlineatus	0.028	0.000	0.000	0.036	0.000	0.000	0.015
All species	1.435	2.807	2.424	2.643	2.500	1.364	2.124
Effective trap nights	7040	4560	2640	2800	1320	1320	19680
Species richness	6	8	4	8	2	3	13
Mean Shannon Diversity Index	0.196	0.548	0.106	0.652	0.099	0.242	0.322

Fig. 1—The Tallgrass Prairie Preserve is located in Osage Co. in northeastern Oklahoma. Two oil spill areas, 2 burned areas, 2 unburned areas, and 1 brine spill area were trapped within the bison unit (dark shaded area).

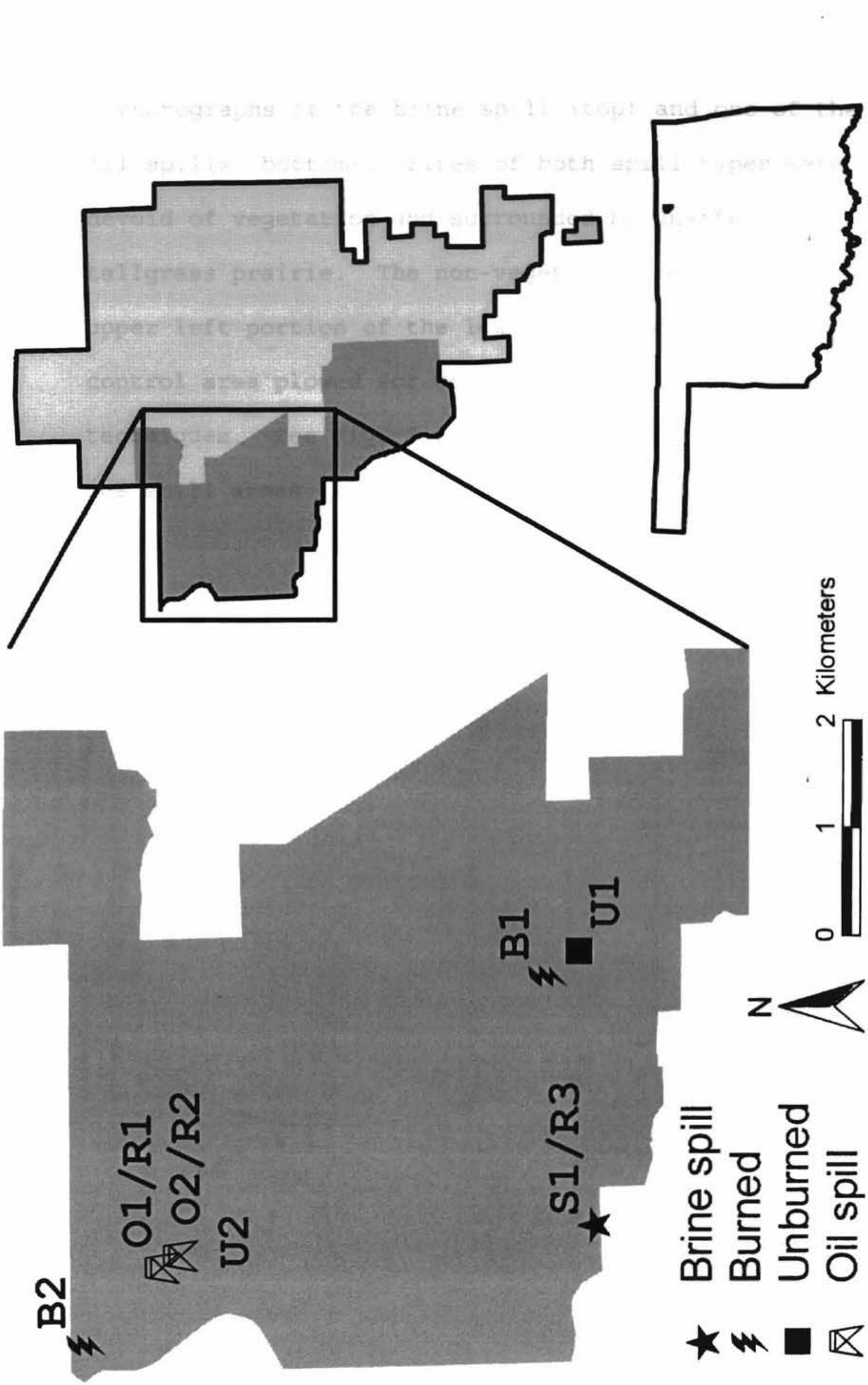

B2
O1/R1
O2/R2
U2
S1/R3
B1
U1
N
0
1
2
Kilometers
Brine spill
Burned
Unburned
Oil spill

Fig. 2—Photographs of the brine spill (top) and one of the oil spills (bottom). Sites of both spill types were devoid of vegetation and surrounded by unaffected tallgrass prairie. The non-vegetated area in the upper left portion of the lower photograph is a control area plowed for comparison of remediation techniques. See Fig. 3 for configuration of traps at the spill areas.

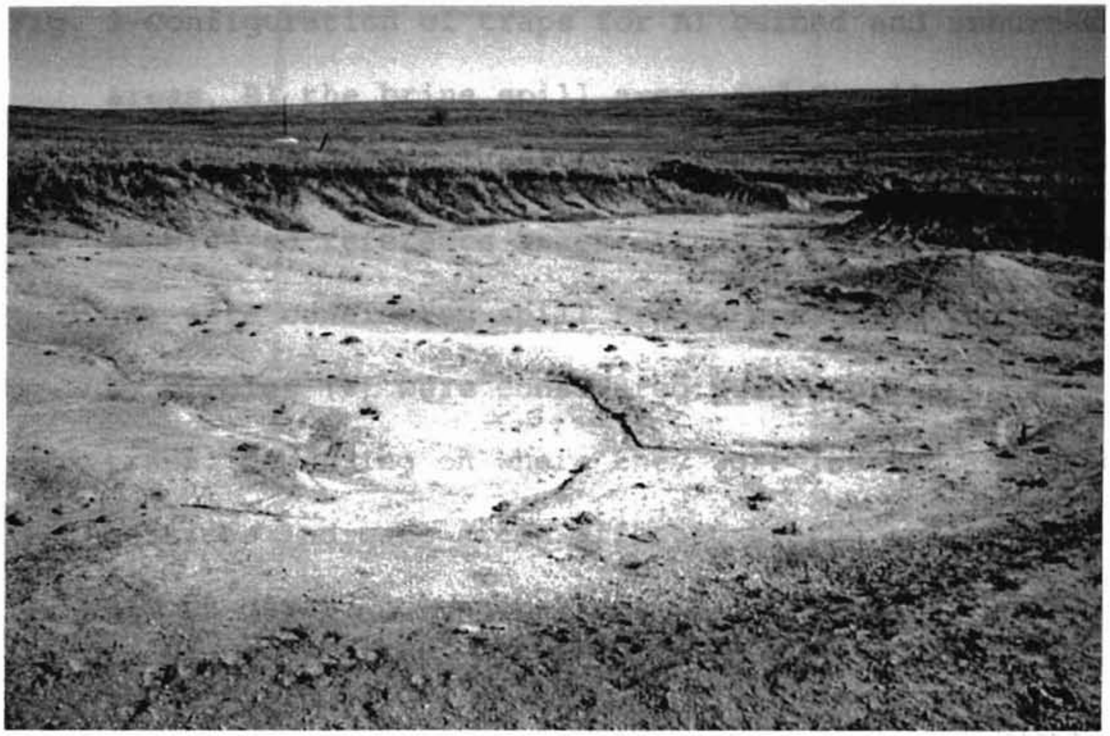


Fig. 3—Configuration of traps for A) burned and unburned areas, B) the brine spill area, and C) oil spill areas. Traps indicated by triangles (▲) were considered reference traps, traps indicated by squares (■) were considered spill traps, and traps indicated by circles (●) were considered burned or unburned traps, depending on where they were located. Shaded portions indicate areas affected by the spills and almost devoid of vegetation.

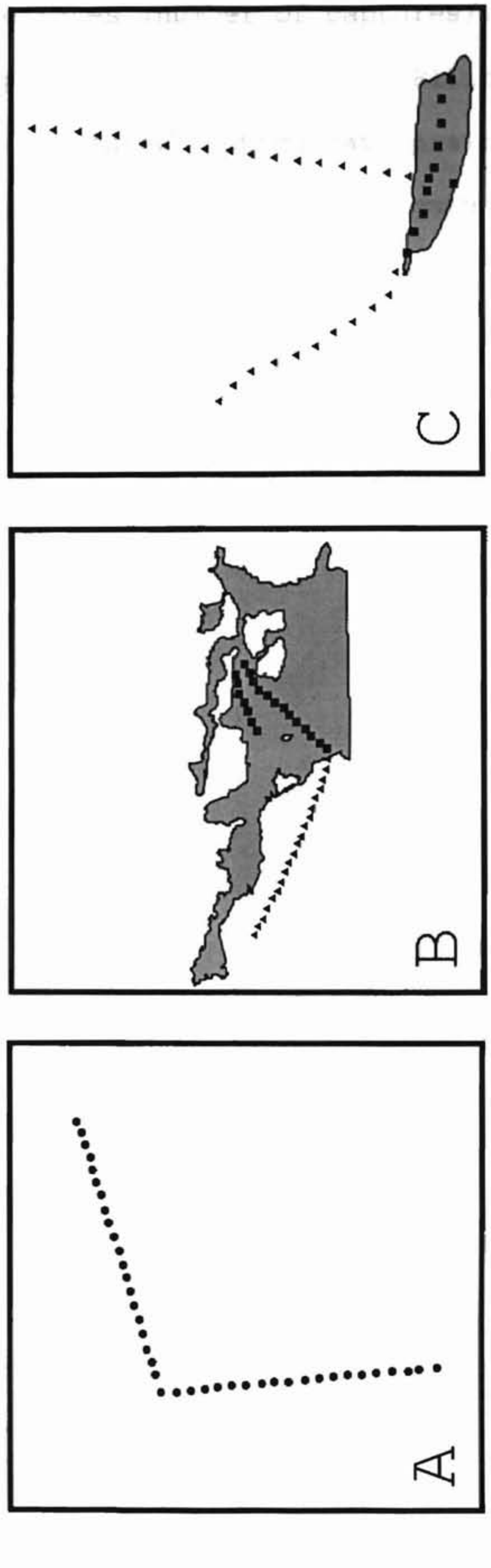

C
B
A

Fig. 4—Capture rates (number of captures/100 trap nights) pooled across sites for Elliot's short-tailed shrew, least shrew, cotton rat, prairie vole, deer mouse and all species for each month of trapping on the Tallgrass Prairie Preserve, Oklahoma. The vertical dotted line indicates the timing of the occurrence of severe weather.

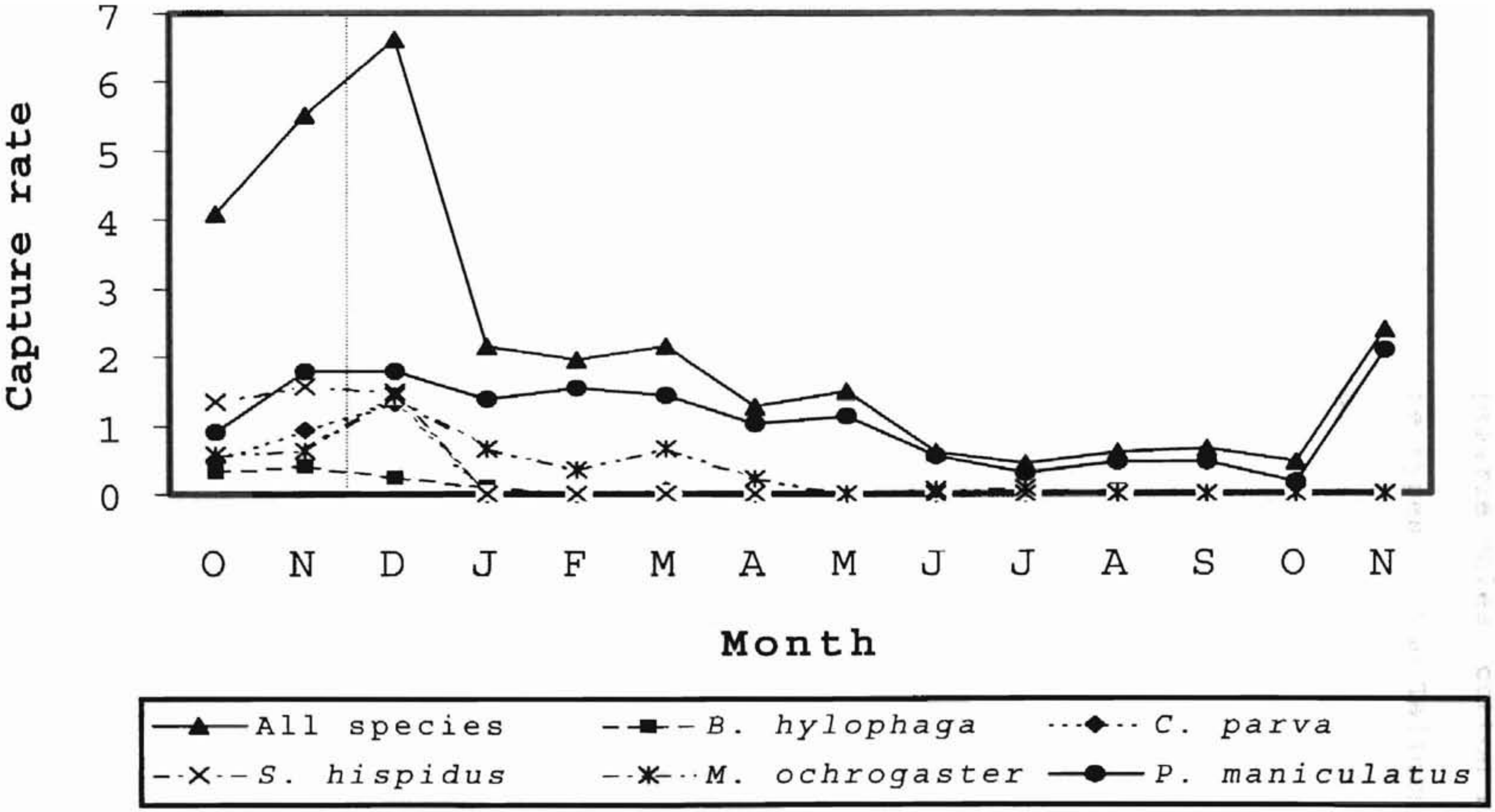

Capture rate
0
1
2
3
4
5
6
7
O
N
D
J
F
M
A
M
J
J
A
S
O
N
Month
All species
B. hylophaga
C. parva
S. hispidus
M. ochrogaster
P. maniculatus

Fig. 5—Capture rates (number of captures/100 trap nights) of least shrews, prairie voles, cotton rats, and deer mice on the 6 site types on the Tallgrass Prairie Preserve, Oklahoma.

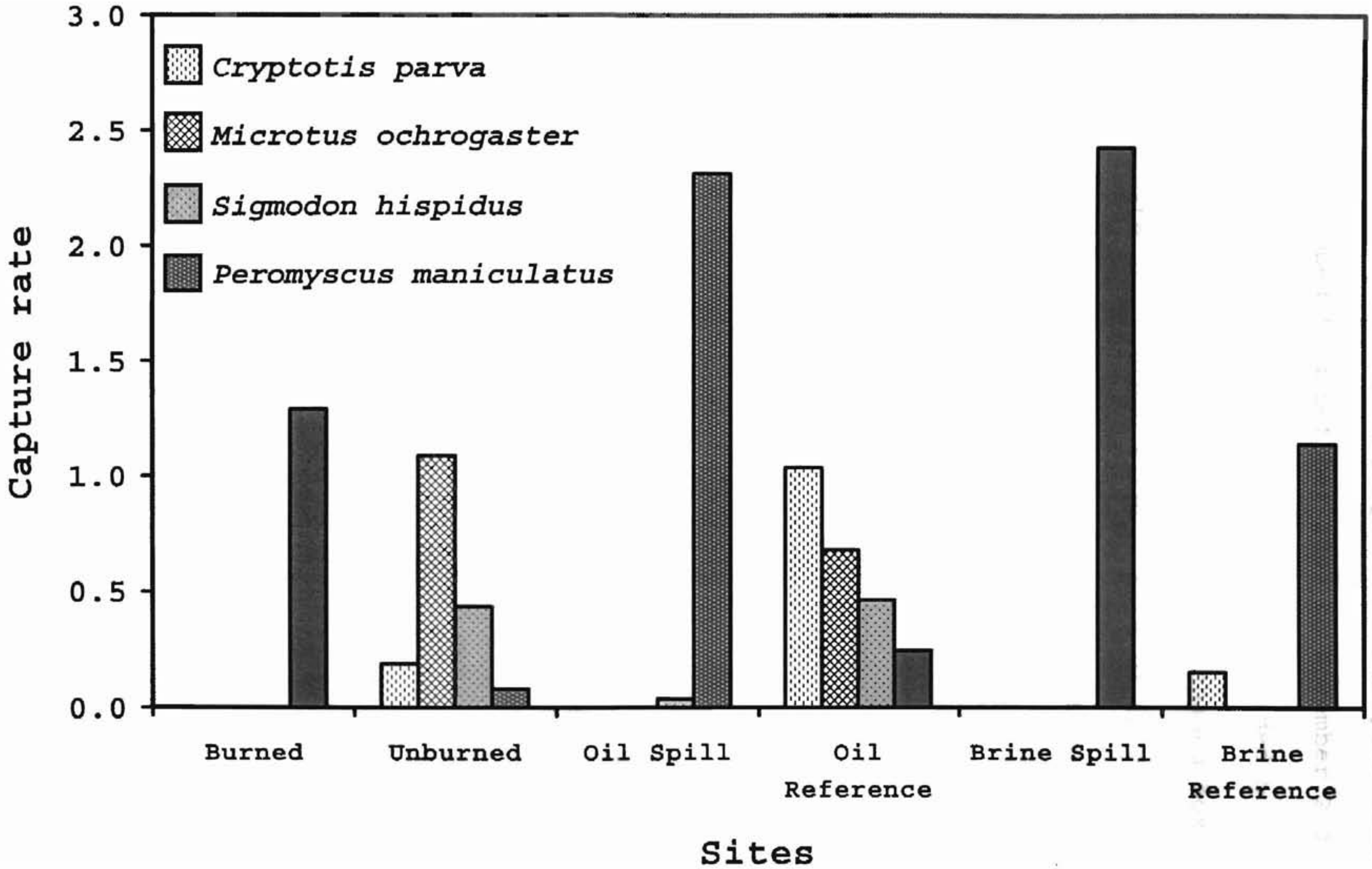
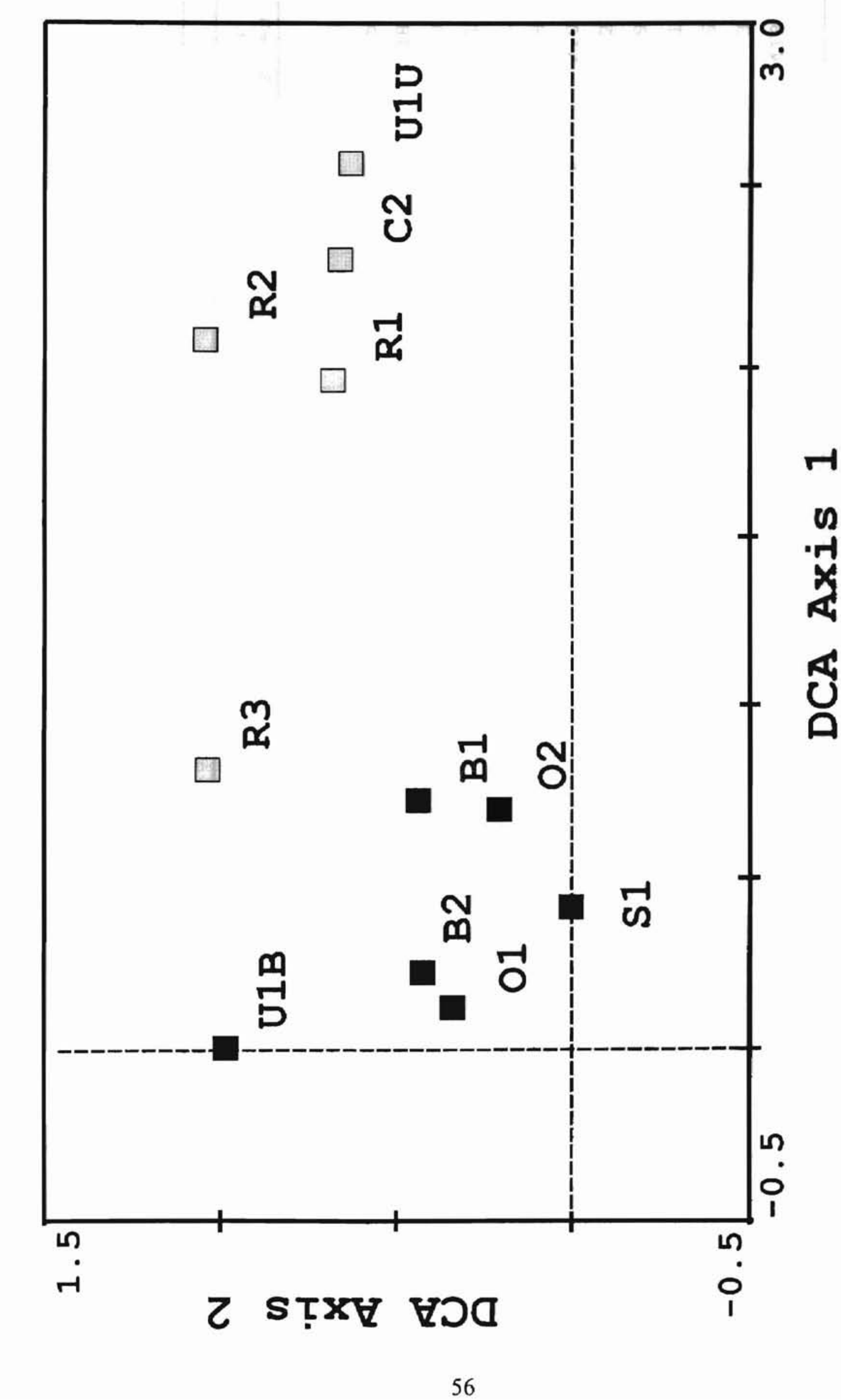

Cryptotis parva
Microtus ochrogaster
Sigmodon hispidus
Peromyscus maniculatus
Capture rate
3.0
2.5
2.0
1.5
1.0
0.5
0.0
Burned
Unburned
Oil Spill
Oil Reference
Brine Spill
Brine Reference
Sites

Fig. 6—Results of detrended correspondence analysis (DCA) of sites trapped from October 2000 to November 2001 at the Tallgrass Prairie Preserve. Black shaded boxes (■) indicate disturbed sites, and gray shaded boxes (□) indicate undisturbed sites. Site U1 is divided into sites U1U (before burning) and U1B (after burning).



DCA Axis 1
DCA Axis 2
-0.5
3.0
1.5
-0.5
U1U
C2
R2
R1
R3
B1
O2
B2
S1
O1
U1B

APPENDIX

Total number of individuals caught on each site type for each species, and the total number of effective trap nights for each site type.

Measure	Site type						
	Burned	Unburned	Oil spill	Oil reference	Brine spill	Brine reference	All sites
Species							
Blarina hylophaga	0	15	0	0	0	0	15
Chaetodipus hispidus	3	0	2	0	0	0	5
Cryptotis parva	0	7	0	29	0	2	38
Microtus ochrogaster	0	50	0	19	0	0	69
Neotoma floridana	1	0	0	0	0	0	1
Oryzomys palustris	0	1	0	0	0	0	1
Peromyscus leucopus	3	1	1	1	2	0	8
Peromyscus maniculatus	91	6	60	7	31	15	210
Reithrodontomys fulvescens	0	0	0	2	0	0	2
Reithrodontomys humulis	1	6	0	2	0	0	9
Reithrodontomys montanus	0	0	0	0	0	1	1
Sigmodon hispidus	0	42	1	13	0	0	56
Spermophilus tridecemlineatus	2	0	0	1	0	0	3
All species	198	100	126	100	66	34	418
Effective trap nights	7040	4560	2640	2800	1320	1320	19680

VITA

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