INFLUENCE OF LANDSCAPE VARIABLES ON THE DIET

OF BURROWING OWLS (*ATHENE CUNICULARIA*)

IN THE TEXAS PANHANDLE

by

Annalisa Browning

A Thesis Submitted in Partial Fulfillment

Of the Requirements for the Degree

MASTER OF SCIENCE

Major Subject: Biology

West Texas A&M University

Canyon, Texas

August 2016

ABSTRACT

Prairie dogs (*Cynomys* spp.) were once prolific on the Great Plains of North America. As keystone species, many organisms rely upon prairie dogs. One species in particular is the burrowing owl (*Athene cunicularia*), which nests in the burrows created by prairie dogs. Burrowing owls live in a wide variety of habitats and are opportunistic predators, consuming a diverse array of prey items. There are many factors that may influence the diet of burrowing owls. I evaluated the influence of land use, as well as season and precipitation on the diet of burrowing owls. Regurgitated pellets (n = 654) were collected from 6 prairie dog towns from April-October of 2014 and 2015 in the Texas Panhandle. Canonical correspondence analyses as well as multiple regression analyses were used to determine the association of landscape variables, season, and precipitation on the diet of burrowing owls. Burrowing owls in this study consumed mostly invertebrates, with short-horned grasshoppers (Acrididae) being the most significant prey item. Season had the greatest influence on the diet of burrowing owls, followed by class-level and landscape-level variables, and then precipitation. This information may be useful for future management plans dealing with relocation and reintroduction, by allowing managers to focus on areas that provide a suitable mosaic of patchiness for these birds.
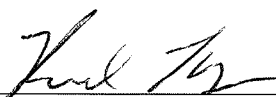
ACKNOWLEDGMENTS

Approved:

_____   12 Aug 2016

Richard T. Kazmaier, PhD   Date
Chairman, Thesis Committee

_____   12 Aug 16
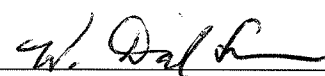
Rocky Ward, PhD   Date
Member, Thesis Committee

_____   12 Aug 2016

W. David Sissom, PhD   Date
Member, Thesis Committee

_____   12 Aug 2016

Head, Department of Life, Earth   Date
And Environmental Sciences

_____   _____

Dean, College of Agriculture and   Date
Natural Sciences

_____   _____

Dean, Graduate School   Date

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

CHAPTER I

INFLUENCE OF LANDSCAPE VARIABLES ON THE DIET OF BURROWING OWLS (*ATHENE CUNICULARIA*) IN THE TEXAS PANHANDLE

LITERATURE REVIEW

The Great Plains

Ecosystems that are dominated by herbaceous plant species are referred to as 'grasslands' (Coupland 1979). Grasslands make up 40% of the global land surface area and 42% of the earth's plant cover (White et al. 2000). Grasslands cover over 4.6 billion ha and account for 24% of the planet's vegetation (Shantz 1954). Also referred to as rangeland and prairie, grasslands take up around 50% of the land surface area in North America (Sims et al 1978). Historically, out of the 770 million ha that make up the United States, 300 million ha were once considered grasslands (Küchler 1964). Presently, grasslands now cover approximately 125 million ha, but are still considered to be the largest of the natural biomes in North America (U.S. Forest Service 1980).

The North American Great Plains began developing around 70 million years ago with the receding of the Western Interior Seaway, a vast inland sea, caused by a gradual uplift of the continent which exposed a relatively flat sea floor (Kauffman 1977). The end of the Cretaceous was also marked by a decline in the high temperatures that had prevailed during that era. This reduction in temperature did not last and by the mid

Paleocene, temperatures were once again on the rise. This warm period continued into the early Oligocene, and also coincided with a time of rapid evolution of modern animal and plant species (Brooks 1951). At this point in time the Rocky Mountains were not the vast mountain chain we see today, allowing moist Pacific air to flow freely onto the Great Plains, creating a warm and humid climate. This climate allowed for the temperate forest belt of the north to shift even farther north, while the tropical forest belt of the south also extended farther north (Dorf 1960). However, by the late Oligocene, the uplift of the Rocky Mountains began again in earnest, cutting off the flow of moist Pacific air and a gradual shift towards the present arid to sub-humid climate began. Fossil records from the late Oligocene to the early Miocene suggest that the eastern Rockies and the Great Plains were beginning to develop open woodland shrub and grasslands (Dorf 1960). During the late Oligocene and Miocene, there was an increase in aridity on the Great Plains, caused by the rain shadow of the rising Rocky Mountains (Dix 1964).

The grassland biome really began to develop in the Miocene. Sand deposits from the middle to late Miocene and Pliocene contain over thirty different grass species. It was also during the Miocene that fossil records show a change in mammalian teeth, shifting position and becoming more effective for harvesting grasses with high levels of silica (Kurten 1972). Fossil records during this time shift to an increase in grass pollen and a decrease in tree pollen, showing a reversal in forest migration and a gradual spread of savannahs and open grasslands in place of forests (Axelrod 1985). The Pleistocene followed the Pliocene and with it came dramatic changes in climate and vegetation. Beginning in the early Pliocene, temperatures began to drop and within the Pleistocene, 4 massive glaciations occurred in the northern portion of North America (Dorf 1960). The

last of the ice sheets that covered what is now known as the Great Plains, retreated around 10,000 years ago (Kupsch 1960). From climate data and fossil records, it has been surmised that the grassland biome of the Great Plains completely replaced the deciduous forest around 8,000-9,000 years ago (Wright 1970).

Modern man arrived in western North America at the end of the Pleistocene and have since had a substantial impact on the environment (Kurten 1972). The extinction of mammalian herbivores of the time has been attributed to man and man is thought to have had some type of impact on the flora of the time (Bohrer 1975). Native Americans have been in North America for as long as 30,000 years (Bragg 1995) and have used fire as a tool for many aspects of their lives including hunting, vegetation management, and insect control (Stewart 1956, Anderson 1990). Frequent fires, both natural and man-made, played a significant role in shaping and maintaining the North American grasslands (Stewart 1956). Suppression of fires began sometime after European settlement on the Great Plains (Umbanhower 1996), largely because of town development, agriculture, continuous cattle grazing, and recommendations against burning (Bragg and Hulbert 1976). Without frequent fires, much of the grasslands have been taken over by woody shrubs. In Texas, the lack of fire has allowed mesquite and shrub oak to encroach onto the grasslands (Axelrod 1985). Along with frequent fires, periodic drought and grazing mammals are also features of grasslands (Risser et al. 1981, Anderson 1982, Anderson 1990) and have played a significant role in shaping and maintaining the vegetation of those grasslands (Gleason 1922, Anderson 1990).

The decline of mammalian herbivores stabilized before the arrival of the Europeans, with the grasslands now supporting pronghorn (*Antelocapra americana*), bison (*Bison bison*), deer (*Odocoileus* spp.), elk (*Cervus canadensis*), and bighorn sheep (*Ovis canadensis;* Shelford 1963). Coronado made his first venture into western North American in 1539 and with his explorations came sheep, cattle, and horses (Schickendanz 1980). The Great Plains remained largely unsettled until around 1865. The United States Homestead Act of 1862 allowed around 1.5 million people to obtain roughly 800,000 km^2 of land, most of which was located on the Great Plains (Ostlie et al 1997). By the late 1800s, cattle numbered 7.6 million head in the 11 western states (U. S. Senate 1936). Loss of prairie began, mostly with the conversion of prairie to agriculture. This loss of prairie to agriculture increased dramatically in the 1920s with changes in farming practices, as well as federal agriculture policies (Barnes 1993). Forty-seven percent of the Great Plains now consists of cropland (Reiners 1995).

Moisture on the Great Plains decreases from east to west, creating changes in dominant vegetation (Weaver 1954) and separating the plains into 3 distinct regions: Tall-grass, mixed-grass, and short-grass prairie. Out of those 3 regions, tall-grass prairie, which lies to the eastern part of the region, receives the most rainfall (Risser et al. 1981). The dominant vegetation of the region is big bluestem (*Andropogon geradii*) and little bluestem (*Schizachyrium scoparium*), followed by Indian grass (*Sorghastrum nutans*) and switchgrass (*Panicum virgatum*). Tall-grass prairie is now mostly cultivated (Sims 1988) and only 1% of its historical range remains intact (Samson and Knopf 1994).

Mixed-grass prairie lies to the west of the tall-grass prairie and consists of a mixture of tall-grass and short-grass prairie. Dominant vegetation includes little bluestem, needlegrass (*Stipa* spp.), wheatgrass (*Agropyron* spp.), grama grass (*Bouteloua* spp.), dropseed (*Sporobolus* spp.), buffalo grass (*Bochloë dactyloides*), muhly (*Muhlenbergia* spp.), and three-awn (*Aristida* spp.; Sims 1988). Only 20% of the historical range of the mixed-grass prairie remains (Samson and Knopf 1994).

The last region, short-grass prairie, expands east of the Rocky Mountains from Nebraska, Wyoming, Colorado, and Kansas, down through the High Plains of Oklahoma, New Mexico, and Texas. Dominant vegetation of the short-grass prairie includes, blue grama (*Bouteloua gracilis*), buffalo grass, western wheatgrass (*Agropyron smithii*), sand dropseed (*Sporobolus cryptandus*), ring muhly (*Muhlenbergia torreyi*), needle-and-thread grass *(Stipa comata*), and prairie Junegrass (*Koeleria cristata*). Much of the short-grass prairie of the Texas High Plains has been converted into irrigated farming. Long-term disturbance of short-grass prairie has caused native grasses to decline and has propagated the spread of perennials like cactus (*Opuntia* spp.), snakeweed (*Gutierrezia* spp.), and yucca (*Yucca* spp.), as well as weedy annuals such as brome grass (*Bromus* spp.), Russian thistle (*Salsola kali*), barley (*Hordeum* spp.) and fescue (*Festuca* spp.; Sims 1988). Short-grass prairie has seen a less dramatic range decline than the other regions, with 30% of the historical range remaining intact (Samson and Knopf 1994). In the United States, 42% of the Great Plains is comprised of rangeland and 33% is comprised of cropland, while 95% is privately owned (Natural Resources Conservation Service 1992).

Prairie Dogs

Two groups of mammalian herbivores helped to fundamentally shape the grasslands: Large migratory herbivores and small-medium sized burrowing mammals (Whicker and Delting 1988, Davidson et al. 2010, Delibes-Mateos et al. 2011). These herbivores evolved with each other as well as with the grasslands they have relied upon for millions of years, shaping the grassland ecosystems along the way (Jones et al. 1994, Power et al. 1996).

Prairie dogs (*Cynomys* spp.) were once prolific in the grasslands of western North America, colonizing up to 100 million ha at their peak (Anderson et al. 1986). There are 5 species of prairie dog: Gunnison's prairie dog (*Cynomys gunnisoni*), Utah prairie dog (*Cynomys parvidens*), white-tailed prairie dog (*Cynomys leucrus*), Mexican prairie dog (*Cynomys mexicanus*), and the black-tailed prairie dog (*Cynomys ludovicianus*). There are 2 recognized subgroupings within the genus *Cynomys*: the white-tailed subgroup, including Gunnison's, Utah, and white-tailed prairie dog, and the black-tailed subgroup which contains the Mexican prairie dog and the black-tailed prairie dog. There are some noticeable differences between the 2 subgroups. True to the subgroup names, Mexican and black-tailed prairie dogs have a long black-tipped tail, while Gunnison's, Utah, and white-tailed prairie dogs have a shorter white- or gray-tipped tail (Hall 1981). The black-tailed subgroup does not hibernate (although they will spend days underground during inclement weather [Koford 1958]), while the white-tailed subgroup will remain underground during late fall and winter for around 4 months. The white-tailed subgroup live at elevations between 1,500-3,000 m, while the other subgroup tends to reside at

lower elevations (200-700 m; Hollister 1916). Out of the 5 species of prairie dog, the black-tailed prairie dog is the most widespread, historically stretching across 11 states in the U. S., Canada, and Mexico within the Great Plains (Hall 1981). The black-tailed prairie dog is highly social, forms the largest colonies, and achieves the highest densities (Knowles and Knowles 1994). Unless otherwise stated, the term prairie dog will refer to the black-tailed prairie dog from this point forward.

Historically believed to number over 5 billion individuals during the latter part of the 19th century (Meriam 1902), plague, eradication programs, unregulated shooting, and habitat loss has led to a staggering 98% decline in prairie dog numbers since 1919 (Summers and Linder 1979, Van Putten and Miller 1999). Extensive poisoning began around 1880 by livestock operators and in 1915, the government provided programs to assist with the poisoning effort (Dunlap 1988). Eradication programs continue today, even though control programs are ineffective and costly (Collins et al. 1984). Toxicants used to control prairie dog populations often negatively affect non-target species, such as passerines, small mammals, and ground-dwelling invertebrates (Deisch et al. 1989, 1990, Apa et al. 1991, McCaffrey et al. 2009). Studies have also concluded that competition between cattle and prairie dogs is not what it was once thought.

Merriam (1902) estimated that prairie dogs compete with cattle by reducing range productivity by 50-75%. However, modern research suggests, at most, a 4-7% reduction in range productivity (Uresk and Paulson 1988), while other studies have found that cattle coexisting with prairie dogs have no significant difference in market weight (Hansen and Gold 1977, O'Melia et al. 1982). Miller et al. (1994) concluded that 300 prairie dogs

7

consume as much forage as 1 cow and calf. Within short-grass prairie, Hansen and Gold (1977) concluded that prairie dogs decrease suitable grazing habitat for cattle. Although prairie dogs reduce forage for cattle, the vegetation found on prairie dog towns often has a higher nutritional level and may be the reason why there was no decline in weight gains and no net loss of weight observed in cattle grazing on these areas (O'meilia et al 1982). Much of the range of the prairie dog coincides with lands that are used for livestock grazing and prairie dogs are heavily persecuted in these regions (Lauenroth et al. 1994).

Reading (1993) conducted a survey within 2 counties in Montana and found that 97% of ranchers believed in controlling prairie dog numbers and 91% thought that they should not suffer losses attributed to prairie dogs. Rural residents had roughly the same view, showing no inclination towards conservation and seeing little value in prairie dogs, while urban residents believed prairie dogs had ecological worth and favored protection. Environmentalists believe that prairie dogs play a unique and important role in the prairie ecosystem and refer to the prairie dog as a keystone species (Reading 1993, Miller et al. 1994, Kotliar et al. 1999, Reading et al.1999, Kotliar 2000).

The term "keystone species" was first coined by zoologist Robert T. Paine in 1969 in reference to the ochre sea star (*Pisaster ochraceus*) and its ecological role in increasing species richness by its selective predation on common mussels (*Mytulis edulis*). Later, 3 criteria where suggested when considering a species for keystone status: the species must have a large impact on its ecosystem or community, that impact must be excessively large relative to the abundance of the species (Power et al. 1996), and the functions it provides must be unique and not performed by other processes or species

8

(Kotliar 2000). Nine species rely directly on prairie dogs, while another 137 species are associated with prairie dogs in some way (Kotliar et al. 1999). Reading (1993) suggested that at some level, as many as 170 species may rely on prairie dog activity. Clark et al. (1982) found 107 vertebrate species on or near prairie dog towns.

Not everyone agrees that prairie dogs fit the role of keystone species, Stapp (1998) while agreeing that prairie dogs do play an important role in the grassland ecosystem, summarized that the effects of prairie dogs on other species is poorly understood. Stapp believed that a more complete understanding of prairie dogs and their role in the Great Plains is needed, especially in short-grass prairie. Miller et al. (2000) responded by stating that while more studies would be beneficial, prairie dogs absolutely fit all the qualifications for a keystone species and as a result should be protected and properly managed. Another argument came from Kotliar et al. (1999), who also agreed that prairie dogs play an important role and did conclude that prairie dogs are a keystone species, but cautioned against over-exaggerating the degree of that role in the literature.

Prairie Dogs and Their Impact on Other Species

Vegetation and soil. — Koford (1958) believed western wheatgrass, blue grama, buffalo grass, and Russian thistle to be the most important food sources to prairie dogs. Grazing pressure by prairie dogs usually favors an increase in blue grama and buffalo grass, while decreasing western wheatgrass. A few species seem to be resistant to grazing pressure by prairie dogs: needleleaf sedge (*Carex duriuscula*), six-weeks fescue (*Festuca octoflora*), and scarlet globemallow (*Sphaeralcea coccinea*; Koford 1958).

When comparing colonized sites with mixed-grass sites that were not colonized or grazed, Agnew et al. (1986) found that there was a higher number of plant species on non-colonized sites. The same was observed by Weltzin et al. (1997), finding live herbaceous biomass to be 3-4 times greater in non-colonized areas. Conversely, other studies on native shortgrass prairie sites in Colorado suggested that prairie dog towns had a greater number of plants (Bonham and Lerwick 1976, Koford 1985). Prairie dog colonies exhibit higher levels of soil nitrogen and support higher numbers of nematodes than sites without prairie dogs (Ingham and Detling 1984). Vegetation on colonies tends to have higher digestibility and nutritional content, and there are more live plants than dead plants (Wydeven and Dahlgren 1985, Krueger 1986, Knowles 1986, Detling and Whicker 1988, Whicker and Detling 1993). Prairie dogs create an increase in the abundance of forbs (Koford 1958, Bonham and Lerwick 1976, Hassien 1976, O'Meilia et al. 1982), as well as an increase in vegetation production (Ursek and Bjugstad 1983), soil nutrients (Hassien 1976), and nitrogen concentration in plants (Coppock et al. 1983a).

Prairie dogs like to maintain a clear view of any potential predators and generally clip vegetation that is over 15 cm tall (Koford 1958). Prairie dog grazing and clipping helps to maintain grasslands and slow the invasion of shrubs. A study in Texas found that when prairie dogs were poisoned off or eradicated, mesquite (*Prosopis* spp.) spread from 27% to 61% of ground cover (Weltzin et al. 1997).

Invertebrates. — Over 36 families of invertebrate fauna may utilize prairie dog towns (Deisch et al. 1989). Prairie dog colonies provide habitat and resources to beetles (Coleoptera) and grasshoppers (Orthoptera; Russell and Delting 2003, Bangert and

Slobodchikoff 2004). On mixed grass prairie, prairie dog colonies supported a higher number of terrestrial arthropods, but had a lower total diversity (Olson 1985). Agnew et al. (1988) and O'Meilia et al. (1982) found higher densities of arthropods in uncolonized areas. The burrows created by prairie dogs may help to increase the overall abundance and diversity of arthropods (Davidson and Lightfoot 2007). After excavating 13 prairie dog burrows, Wilcomb (1954) found several beetles and their larvae, crickets (Orthoptera), and mites (Astigmata). Four-fifths of the 33,000 arthropods taken from the excavated burrows were mites. Black widow spiders (*Latrodectus hesperus*) are also commonly found at the entrance of unused burrows (Koford 1958).

Herpetofauna. — Shipley and Reading (2006) found that prairie dogs had both a positive and negative affect on herpetofauna. Species that require dense or tall vegetation were negatively affected, while others benefit from the clipped vegetation and burrows created by prairie dogs. Tyler (1968) reported that barred tiger salamanders (*Ambystoma mavortium),* woodhouse's toads (*Bufo woodhousii*), Texas toads (*Bufo speciosus*), Great Plains narrow-mouth toads (*Gastrophryne olivacea*), western diamondback rattlesnakes (*Crotalus atrox*), prairie rattlesnakes (*Crotalus viridis*), bullsnakes (*Pituophis catenifer*), Texas spotted whiptails (*Cnemidophorus gularis*), six-lined racerunners (*Cnemidophorus sexlineatus*), fence lizards (*Sceloporus undulatus*), and ornate box turtles (*Terrapene ornata*) utilized vacant prairie dog burrows, and several species of herpetofauna that were commonly associated with prairie dog colonies. Lomolino and Smith (2003) found that barred tiger salamanders, plains spadefoot toads (*Spea bombifrons*), Great Plains toads (*Bufo cognatus*), Woodhouse's toads (*Bufo woodhousii*), prairie rattlesnakes, western

plains garter snakes (*Thamnophis radix*), Texas horned lizards (*Phrynosoma cornutum*), and ornate box turtles were closely associated with prairie dog colonies in Oklahoma.

Mammals. — Most small mammals seem to benefit from living on a prairie dog town. Shipley and Reading (2006) found a greater abundance and higher species diversity and richness on colonies. When compared to ungrazed mixed-grass prairie, prairie dog colonies were found to have a higher abundance of rodents, while sites without colonies supported great species richness (Agnew et al. 1986). Unoccupied burrows provide shelter for deer mice (*Peromyscus maniculatus*) and grasshopper mice (*Onychomys leucogaster*; Koford 1958). Tyler (1968) found that vacant burrows were utilized by coyotes (*Canis latrans*), kit foxes (*Vulpes mactrotis*), raccoons (*Procyon lotor*), badgers (*Taxidea taxus*), striped skunks (*Mephitis mephitis*), thirteen-lined ground squirrels (*Spermophilus tridecemlineatus*), Southern Plains woodrat (*Neotoma micropus*), and desert cottontails (*Sylvilagus audobonii*).

Prairie dogs have coexisted with massive herds of bison, pronghorn, and elk for many thousands of years. Ungulates have a preference for grazing on prairie dog colonies (Coppock et al. 1983*b*, Whicker and Detling1988). Sierra-Corona et al. (2015) found that in the Chihuahuan desert grasslands, cattle preferentially grazed and rested on prairie dog colonies during fall and winter months. The colony may have provided an important forage resource during those months. Bison and pronghorn preferentially feed on prairie dog colonies, although they utilize different areas of the colonies. Bison prefer to feed on grass-dominated areas, while pronghorn select for forb-shrub dominated areas. A high dietary overlap does occur between bison and prairie dogs and between pronghorn and

prairie dogs. It was observed that the feeding relationship between bison and prairie dogs was mutually positive, while the feeding relationship between pronghorn and prairie dogs was neutral (Krueger 1986).

Birds. — The Great Plains supports a wide variety of grassland avian species and those that breed in this region are also considered to be one of the fastest declining groups of birds (Knopf 1994, 1996, Brennan and Kuvleskey 2005). There has been a steady decline in endemic avian species in recent decades (Knopf 1996, Peterjohn and Sauer 1999). Prairie dogs create unique habitat which supports breeding bird populations more than areas without prairie dogs. Along with supporting breeding birds, prairie dog towns may support more avian diversity than ecosystems lacking prairie dogs (Augustine and Baker 2013). Agnew et al. (1986) found significantly higher bird species diversity on prairie dog colonies when compared to mixed-grass prairie sites in South Dakota. In the Texas Panhandle, Ray et al. (2015) found a higher abundance of endemic birds on prairie dog towns, but off colony sites supported a higher abundance of Nearctic-Neotropical and Nearctic-temperate migrants. Non-colony sites also supported a greater total abundance and species richness. This contrasts what most other studies found (Agnew et al. 1986, Barko et al. 1999). One explanation for the contrasting results may have been the relatively small size of the prairie dog town on which this study took place.

Prairie dog towns also seem to have a varying impact on avian species resulting from many factors such as climate, vegetation, and size of the colonies (Ray et al 2015). Changes in vegetation by prairie dogs in shortgrass prairie may not be distinctive enough to influence bird populations. Colony size positively impacts avian abundance, but not

13

necessarily avian diversity. Avian abundance was significantly higher on short-grass prairie with prairie dog colonies than on sites without colonies (Barko et al. 1999). Unlike Barko et al. (1999), Reading et al. (1989) found that avian richness increased significantly with increased prairie dog colony size. The difference between the 2 studies may be contributed to drought and sample size. Prairie dog colonies may also become more important to birds at different times.

Barko et al. (1999) found that avian populations utilized prairie dog colonies more during April, May, and June, which coincides with the breeding season for most birds. Similarly, Smith and Lomolino (2004) found that avian association with prairie dogs was more dependent upon season than year, with summer months having a higher rate of association than fall and winter. Prairie dog towns are also important during other times of the year. Colonies are often an important overwintering resource, with burrows that provide refuge (Butts 1976) and prairie dogs providing an important food source (Allison et al. 1995).

Burrowing Owl

One of the many birds associated with prairie dog towns is the burrowing owl (*Athene cunicularia*). The burrowing owl historically ranged from southern regions of Canada all the way down the western half of the United States into Mexico and South America, with disjunct populations forming unique subspecies in Florida and the Bahamas (AOU 1957). This small owl is typically found in open level habitats, and often selects areas where vegetation has been reduced in coverage and height (Butts and Lewis 1982, Green and Anthony 1989, Plumpton 1992), which may increase their ability to

detect predators, as well as prey items (Green and Anthony 1989). In the Great Plains, a majority of burrowing owls are associated with prairie dog colonies, where they use burrows as their homes and nest sites (Butts and Lewis 1982, MacCracken et al. 1985, Plumpton and Lutz 1993a, Desmond et al. 2000, Sidle et al. 2001), as well as eavesdropping on the alarm calls of prairie dogs (Bryan and Wunder 2014).

In most species of owls, the females are larger than the males. It is believed that this difference in sizes promotes differential niche exploitation and reduces intersexual competition (Cade 1960), and the female is better able to protect young from potential predation by the male, as well as from other predators (Amadon 1959). Burrowing owls actually exhibit the opposite trend, with males tending to be slightly larger than the female in weight and wing length (Earhart and Johnson 1970, Martin 1973). Size and food habits may largely influence the degree of sexual dimorphism in North American owls. Earhart and Johnson (1970) found that larger owls tend to have a greater degree of sexual dimorphism than smaller species of owls. They also found that owls that feed on vertebrates seem to have a greater degree of dimorphism than those owls that fed primarily on insects. It is also curious to note that burrowing owls are one of the only species of owl in which cannibalism has been most commonly reported (Bent 1938, Robinson 1954, Thomsen 1971, Marti 1974).

Burrowing owls are opportunistic predators (Gleason and Craig 1979, Tyler 1983, Green et al. 1993, Haug et al. 1993), feeding on invertebrates, birds, rodents, lizards, snakes, and frogs (Bent 1938). Burrowing owls forage in a wide variety of locations, such as pasture, cropland, prairie dog colonies, and fields (Butts and Lewis 1982), as long as

the vegetation is not overly thick or above 1 m in height, which impedes their ability to track and take down prey items. Burrowing owls tend to stay around their burrows during daylight hours, venturing out between dusk and dawn (Haug and Oliphant 1990). Insects are generally hunted during the day while mammals, scorpions, and sun spiders are taken at night (Plumpton and Lutz 1993*b*, Restani et al. 2001, Hall et al. 2009). Burrowing owls forage and utilize a wide array of habitats such as, grasslands (Poulin et al. 2011), grazed pasture (Wingert 2012), agricultural fields (Rich 1986, Leptich 1994, Moulton et al. 2005, 2006), golf courses, airports (Thomsen 1971), military facilities (Plumpton and Lutz 1993*a*), university campuses (Poulin et al. 2011), vacant lots within residential areas (Millsap and Bear 2000, Poulin et al. 2011), and roadways (Coulombe 1971).

In the U.S., burrowing owl populations are in decline (White 1994), and have been listed as a Species of National Conservation Concern (U. S. Fish and Wildlife Department 2008). The eradication of burrowing mammals, especially prairie dogs, is thought to be the main factor attributed to the recent decline in populations of burrowing owls (Grant 1965, Butts and Lewis 1982, Pezzolesi 1994, Desmond and Savidge 1996, Desmond et al. 2000). Habitat loss from urban development (Konrad and Glimer 1984) and the conversion of pasture and grassland to cropland (Grant 1965, Konrad and Glimer 1984) has also played an extremely significant role in their decline. The burrowing owl has been listed as a species of concern in California, Montana, Oklahoma, Oregon, Utah, Washington, and Wyoming. The species is listed as threatened in Colorado and endangered in Minnesota. There is no federal status for the burrowing owl in Arizona, Idaho, Kansas, Nebraska, Nevada, New Mexico, North Dakota, South Dakota, and Texas (Klute et al. 2003). There have been significant declines in burrowing owl populations

documented in the Trans-Pecos region of Texas and western areas of the Texas

Panhandle (Haug et al. 1993).

INTRODUCTION

The arrival of humans to the Great Plains brought many changes to the landscape.

The study of landscape ecology focuses on the idea that habitat patches have the

capability of strongly influencing many aspects of a species' life (McGarigal and Marks

1995). The changing of natural habitat to urbanization and conversion of grasslands to

cropland have created a mosaic of landscapes (Collins and Glenn 1988, Vinton and

Collins 1997). All these changes have also led to fragmentation of habitat on the Great

Plains. Fragmentation leads to a decline in biodiversity, increasing edge habitat while

decreasing patch size and creating isolated areas of natural habitat (Forman 1995, Murcia

1995). Because of these issues, I evaluated how landscape variables, as well as season

and precipitation, influence the diet of burrowing owls in the Texas Panhandle.

STUDY SITES

This study took place from March through October of 2014 and April through

October of 2015. My study sites included 6 prairie dog towns located throughout the

Texas Panhandle (Figure 1). My first site was located on the Rita Blanca National

Grasslands in Dallam County, north of Dalhart, Texas. This particular part of the

Grasslands prohibited hunting and poisoning of prairie dogs, and was part of a relocation

project. The site was occasionally used for grazing by cattle. This was a very large town

(~ 38 ha) with intermittent prairie dog and burrowing owl activity.

17

Site 2 was located on a private ranch in Hartley County, west of Channing, Texas. This site was located on grazed pasture land. Agricultural fields were located across the road from the prairie dog town and burrowing owls were commonly seen perched on fence line on the agricultural side. Prairie dog populations were occasionally controlled by hunting on this property. At ~36 ha, this prairie dog town was similar in size to site 1.

Site 3 was located on private property just off of Interstate 40, west of Vega, Texas, in Oldham County. This site was poisoned in 2014 during the study, and although there was a reduction in prairie dog activity, there was never an absence of prairie dogs. This site was bordered by agricultural fields and a major highway system. This prairie dog town was moderate sized at ~29 ha.

Site 4 was located on private property within the city limits of Canyon, Texas, in Randall County. This site was on pasture land that was grazed by horses and cattle a couple times per year. This site was generally unsuccessful and had little prairie dog activity as the seasons continued. For unknown reasons, burrowing owls completely disappeared from the site midway through the 2015 season. This prairie dog town covered ~ 113 ha.

Site 5 was located within Gene Howe Wildlife Management Area in Hemphill County, just outside of Canadian, Texas. Although, large numbers of prairie dogs and burrowing owls were always found on this site, this prairie dog town was the smallest of my sites (~ 9 ha). This area was often grazed by cattle.

Site 6 was located on a ranch, east of Wellington, Texas in Collingsworth County. This site was located on rangeland and usually had cattle grazing on site. Agricultural fields were located nearby. Prairie dogs were not controlled on this site. At ~10 ha, this was my second smallest prairie dog town.

METHODS

Once prairie dog towns were located, I scanned towns from my vehicle for burrowing owls, as well as on foot for signs of use (white wash, pellets, "decorations", etc.). I attempted to collect pellets during the first 2 weeks of each month by revisiting previously occupied burrows. Collection was either delayed or canceled because of rain, which often caused the pellets to disintegrate. For each site, I attempted to collect 20 pellets, although that was not always the case because sites varied depending upon season, weather events, and other unforeseeable events (poisoned town, disappearance of owls, etc.). Pellets collected were stored individually in labeled whirl-packs and placed in bags labeled with date, location, and number of pellets collected. The pellets were then stored in the freezer until ready to be dissected.

In the lab, pellets were measured (length and width) using a caliper and then broken apart in a petri dish and examined under a dissection microscope (magnification 7-30X; Leica ZOOM 2000, Leica Microsystems, Buffalo, New York, USA) to identify prey items down the lowest taxonomic level possible. The minimum number of individual arthropod prey items per sample was determined using paired appendages (generally mandibles), heads, and elytra. A compound microscope (40-400X; Olympus CH-2, Olympus Corporation, Center Valley, Pennsylvania, USA) was used to identify

19

guard hairs from mammals and scales from snakes and lizards. Bones were used to

identify amphibians and reptiles, and feathers (once determined feathers did not belong to

burrowing owl) and bones were used to identify bird remains. If available, paired

mandibles were used to determine number of individuals present in pellet.

Within ArcView version 3.3 (Environmental Systems Research Institute,

Redlands, California, USA), boundaries were created around prairie dog towns (using

burrows as reference) by digitizing over 2015 aerial photography. A buffer of 5 km was

created around the outline of the prairie dog town at each site. These polygons were used

to clip existing USGS land use-land cover (LULC) layers within the GIS. The Patch

Analyst extension was then used to calculate FRAGSTATS for each buffered LULC area

(McGarigal and Marks 1995).

FRAGSTATS is a program that helps to quantify landscape structure.

FRAGSTATS calculates several statistics for the landscape as a whole and for each patch

or class variable. Each of these groups is then looked at on a different scale: area metrics,

patch metrics, edge metrics, shape metrics, core area metrics, nearest neighbor metrics,

and diversity metrics. I evaluated landscape and class variables within the area metrics,

patch metrics, edge metrics, shape metrics, and diversity metrics.

Area metrics look at the area of each patch that makes up the landscape. This

metric quantifies landscape composition, which quantifies the amount and presence of

each patch type within a landscape, but not the placement or location of the patches

within the landscape. There are 2 types of variables that are classified as area metrics,

class area and total landscape area. Class area looks at how much landscape is made up of

a particular patch type and can be an important tool for quantifying the extent of fragmentation in an area. Total landscape area helps to define the extent of a landscape (McGarigal and Marks 1995). McGarigal and Marks (1995) believed the area of each patch that makes up a landscape mosaic to be the single most important and useful piece of information pertaining to the landscape.

FRAGSTATS computes statistics looking at patch density, patch size, and variability metrics. Within this section of metrics is the number of patches, mean patch size, and patch size standard deviation. These types of metrics generally represent landscape configuration, which looks at the spatial characteristics, as well as the physical distribution of patches within a landscape. These metrics can also determine the extent of habitat fragmentation in a given landscape (McGarigal and Marks 1995).

Another classification of metrics is edge metrics. Edge metrics represent landscape configuration. Total edge and edge density are both helpful edge metrics. Total edge measures the total edge length of both the landscape level (all patch types) and of a particular patch type (McGarigal and Marks 1995).

Shape metrics also represent landscape configuration. Mean shape index measures the average patch shape, while mean-perimeter-area ratio is the sum of each patch perimeter/area divided by the number of patches. Both area measure of patch shape complexity.

Diversity metrics represent landscape composition. Shannon's diversity index (SDI) is the most popular diversity index and represents the amount of 'information' per patch (McGarigal and Marks 1995).

21

Each of the metrics listed above was looked at on a landscape scale. The class variables used were agriculture, rangeland, and urban with the following metrics: class area, number of patches, mean patch size, patch size standard deviation, total edge, edge density, mean patch edge, mean shape index, and mean-perimeter-area ratio.

Other variables included monthly rainfall during pellet collection season which was acquired from nearby National Oceanic and Atmospheric Administration [NOAA] land-based weather stations (NOAA 2016; Figure 2) and months and years of collection.

I categorized dietary results into taxonomic families for all analyses (Milne and Milne 1980, Schmidly 1994, Conant and Collins 1998). From these family level data, I calculated dietary diversity using a modified Simpson's Index ($1-\sum p_i^2$) and Shannon's Index ($H' = -\sum p_i \ln p_i$), where p_i is the proportion of the ith taxa in the sample. I also calculated dietary evenness ($H'/\ln S$, where S is dietary richness; Magurran 1988). I then used multiple regression to compare dietary diversity, evenness, family richness, and total number of food items to landscape and precipitation variables. I set $\alpha = 0.1$ for all analyses.

I then used the family-level dietary information to represent species space (Figure 3) and the FRAGSTATS output, seasons, and precipitation variables to represent environmental space within a Canonical Correspondence Analysis (CCA; ter Braak 1986, Palmer 1993) using CANOCO version 4.5. This CCA was performed on untransformed data to determine the influence of environmental, seasonal, and climate variables on the diet of burrowing owls. For this analysis, I used forward selection to determine which environmental variables were significant for explaining variation in burrowing owl diet.

RESULTS

Field Results

I collected 654 pellets, with 256 pellets collected in 2014 (Table 1) and 398 pellets collected in 2015 (Table 2). I identified 6,550 prey items representing 41 different families across all pellets. Invertebrates consisted of roughly 94% of the total food items consumed, while vertebrates made up around 6%. Short-horned grasshoppers (Acrididae) were by far the most consumed prey item, accounting for approximately 46% of all food items, with a 77% frequency of occurrence (Table 3). The hispid pocket mouse (Heteromyidae: *Chaetodipus hispidus*) was the most commonly consumed small mammal with an 8% frequency of occurrence (Table 4).

Multiple Regressions

The relationship between landscape variables and total number of food items was important ($F_{652} = 3.454$, $p < 0.001$). Class area of agriculture, class area of rangeland, patch size standard deviation, total edge, mean patch edge, and monthly precipitation were all positively associated with total number of prey items found in pellets. Total land area had a negative association with total number of food items. Landscape variables did not seem to significantly affect family-level richness. Mean shape index was negatively associated with the family-level richness of the pellets ($F_{652} = 2.853$, $p < 0.001$). Landscape variables significantly affected the diversity and evenness of food items. Modified Simpson's Index was positively influenced by edge density and negatively influenced by class area of rangeland, mean shape index, and monthly precipitation ($F_{652} = 4.999$, $p < 0.001$). Shannon's Index was negatively influenced by class area of

rangeland, mean shape index, and monthly precipitation ($F_{652} = 4.142$, $p < 0.001$).

Evenness was positively influenced by edge density, but negatively influenced by class area of rangeland, mean shape index, and monthly precipitation ($F_{652} = 4.559$, $p < 0.001$; Table 5).

On a broad range scale of prey items, invertebrates were significantly influenced by landscape variables and rainfall ($F_{653} = 4.189$, $p < 0.001$). Class area of rangeland, class area of agriculture, patch size standard deviation, total edge, mean patch edge, and monthly precipitation positively influenced invertebrates in the diet, while total land area had a negative influence. Amphibians in the diet were influenced by monthly precipitation ($F_{653} = 1.746$, $p < 0.05$). Mammals in the diet were positively influenced by total land area and edge density, and negatively influenced by class area of agriculture, class area of rangeland, patch size standard deviation, total edge, mean patch edge, mean shape index, and monthly precipitation ($F_{653} = 10.636$, $p < 0.001$). Birds in the diet were negatively influenced by mean shape index ($F_{653} = 3.387$, $p < 0.001$; Table 6).

Canonical Correspondence Analysis

Total inertia, which measures the amount of variance explained by the data set, was 7.463. The first eigenvalue was 0.265 and the second eigenvalue was 0.221. The first 2 axes explained 59.2% of variance in the data. After that, the eigenvalues drop dramatically (third eigenvalue = 0.076, fourth eigenvalue = 0.061), suggesting that the axes beyond the second have a much weaker explanatory power. Based on this, only the first 2 axes were examined. The sum of all canonical eigenvalues, which is the total amount of variation that can be explained by the environmental variables, was 0.820. Out

24

of the 50 environmental variables tested, 13 variables were significance, including

seasons (April, May, June, July, August, and September), the year 2014, landscape level

mean shape index, class level mean perimeter area ratio of agriculture, mean patch size of

rangeland, number of patches of rangeland, urban class area, and monthly precipitation.

The position of the centroids suggested that months were the most important

variable influencing diet in this analysis (Figure 4). April, May, and June centroids

suggested these months had a strong positive influence on the presence of small

mammals and invertebrates in the diet, while July, August, and September positively

influenced the presence of invertebrates and reptiles in the diet (Table 7).

Landscape variables and precipitation suggested a positive association with

invertebrates in this analysis. The position and length of the biplot arrows indicated that

mean shape index had a high association with nearly all taxa, except for a few

invertebrate groups, such as long-horned grasshoppers (Tettigonidae), cicadas

(Cicadidae), and scorpions (Buthidae). The length of the biplot arrows for mean patch

shape of rangeland and number of patches of rangeland had the highest influence of class

variables. Mean perimeter area ratio of agriculture had a slight influence. While still

significant, monthly precipitation was weakly associated with invertebrates.

DISCUSSION

Season appeared to have a greater influence on the diet of burrowing owls than

the landscape variables I examined. Marti (1974) found that burrowing owls in Colorado

consumed a greater variety of prey items in spring and early summer as compared to late

summer and fall. In Nevada, Hall et al. (2009) observed more vertebrate prey items in the

spring months (Mar-May). In this study, small mammal prey items were highly associated with spring and early summer, showing little association during other months. This increase in vertebrate consumption, especially mammal prey items, may be directly related to the breeding season of burrowing owls (Thomsen 1971, Maser et al. 1971, MacCracken et al. 1985, Hall et al. 2009).

After migrating in, courtship and pair formation generally begin in March and April (Grant 1965, Butts 1973). Vertebrates are an important nutritional source, providing nutrients to females during a critical time when high levels of calcium and protein are required during egg production (St. Louis and Breebaart 1991). After laying, the female burrowing owl remains in the nest throughout the incubation and brooding process, rarely leaving the burrow (Thomsen 1971, Martin 1973). Although the female may occasionally forage nearby for invertebrates (Poulin and Todd 2006), it is almost completely up to the male to provide food to the female during incubation and eventually to both the female and owlets (Martin 1973, Baicich et al. 1997, Poulin et al. 2011).

In New Mexico, Martin (1973) observed that the males were responsible for providing all food items until the owlets reached 3-4 weeks of age. Wingert (2012) observed larger mammal prey items, such as pocket gophers (Geomydiae) and ground squirrels (Sciuridae), being taken during the breeding season, while smaller rodents were more likely to be taken during the non-breeding season. I observed this as well, with larger species such as pocket gophers, woodrats (*Neotoma* spp.), hispid cotton rats (*Sigmodon hispidus*), and cottontails (*Sylvilagus* spp.) occurring more frequently in April,

May, and June. Poulin (2003) found that nearly 98% of the biomass being delivered to chicks during their first 10 days of life consisted of vertebrate prey items.

The life cycles of the mammalian prey items may also play an important role in influencing the diet of burrowing owls. Most of these prey items exhibit year-round breeding in Texas when conditions are favorable (Choate 1970, Armstrong and Jones 1972, Judd et al. 1978, Webster and Jones 1982, Schmidly 1994). There also appears to be a peak in reproduction during spring months for most small mammals (Blair 1941, Cameron 1977, Schmidly 1994). Although burrowing owls are opportunistic predators and generalists, if overall prey availability is high, burrowing owls may be more selective of those prey items. Silva et al. (1995) found that as small mammal densities increased, invertebrate prey items decreased, suggesting that small mammals may be a preferred prey item. A multitude of small mammals breeding in the spring in Texas, could increase the availability of mammals for harvest by owls in my study area, especially during a critical time when burrowing owls are breeding.

There was a transition from a mixture of small mammals and invertebrates to mostly invertebrates in late summer and early fall. This may be related to the fact that the breeding season is coming to a close and the owlets have fledged and started foraging for their own food. Owlets emerge from the burrows at around 14 days old (Baicich et al. 1997). They are able to fly in about 26 days (Thomsen 1971) and are fully fledged and begin utilizing satellite burrows after 40-45 days (Baicich et al. 1997). Around 60 days, the owlets disperse (King and Belthoff 2000). An increase in invertebrates during late

summer, could be related to inexperienced newly fledged owlets, who may find invertebrates prey items easier to capture and consume.

Shyry (2005) believed that juvenile burrowing owls may be almost strictly insectivores between the time they fledge and migration. Adults may also shift to invertebrate prey after the breeding season for similar reasons (Errington and Bennett 1935, Wingert 2012). Errington and Bennett (1935) conducted a study in Iowa and concluded that vertebrate prey items were found June to early August, while invertebrates were found from mid-August to September. In central Utah, Smith and Murphy (1973) found a heavy reliance of invertebrates in the late summer diet of burrowing owls, with vertebrates being taken less frequently. Poulin (2003) found that female burrowing owls tended to be the primary invertebrate hunters, while males primarily hunted vertebrates. A transition to more invertebrates influencing the diet in summer, may be related to the fact that females are no longer tending to the owlets and are out hunting invertebrate prey items.

In northern parts of their range, grasshoppers remain inactive during the cooler weather of spring, but become more populous with the warmer temperatures that summer brings (Poulin 2003). Although vertebrate prey items play an essential role in the productivity of burrowing owls, insects may play a more crucial role as the summer progresses, especially in the condition of the young burrowing owls as they begin migration (Poulin 2003). In a study conducted in southern Saskatchewan, Canada, Poulin and Todd (2006) observed more beetles being captured in the spring, while grasshoppers

were consumed more as summer progressed. They concluded that insects begin to play a larger role in the diet of burrowing owls in late summer (Poulin and Todd 2006).

Reptiles slightly increase in the diet of burrowing owls as the summer progressed. Landscape variable and precipitation had no important significance on the influence of reptiles in the diet. Selection of reptiles must then come down to season and life cycles. Bednarz (1987) observed an increased consumption of insect and reptiles in the summer diet of Harris' hawks (*Parabuteo unicinctus*). Breeding seasons of snakes and lizards may play an important in the diet of burrowing owls. Juvenile snakes and lizards emerge in late summer and fall (Force 1931, Carpenter 1952, Milstead 1957, Kassing 1961, Howard 1974) and may be easy targets for foraging burrowing owls.

October was the only month that did not have significance in influencing prey items. This may be a result of less diversity of prey items during this time. Seasonal shift in breeding of prey items, prey activity, and the effects of climate could have impacted availability of prey items for burrowing owls in October of both years.

Prey items representing 8 families were found only in 2014 (Stenopelmatidae, Cerambycidae, Trogidae, Mutillidae, Mantidae, Scolopendridae, Geomyidae, and Scincidae) and 8 families only found in 2015 (Buprestidae, Pompilidae, Scoliidae, Vespidae, Ctenizidae, Theriidae, Teiidae, and Ambystoma). Although there was an equal number of year specific prey items, a total of 37 individuals from those families occurred in 2014, while only 9 individuals occurred in 2015. It is unclear why 2014 was significant to the diet of burrowing owls, but 2015 was not considered significant. Seasonal cycles, rainfall, as well as a multitude of other factors could have contributed to the significance

of 2014. Access to better climate data may have helped to understand why this trend occurred.

Patch shape can have significant impacts on ecological processes. Buechner (1989) found that patch shape influenced small mammal migration. In California, Collinge and Palmer (2002) found that beetles were more abundant and more likely to move into rectangular-shaped patches instead of square-shaped patches. O'Connor et al. (1999) observed that the occurrence of grassland bird species was influenced more by patch-level variables than the composition of the landscape as a whole. Larger patch sizes also tend to support more species of birds, providing more food sources than surrounding smaller patches (McIntyre 1995). Burrowing owls are found in abundance on both large patches and small patches, but are generally associated with high landscape heterogeneity (Pezzolesi 1994, Biddle 1996, Warnock and James 1997, Orth and Kennedy 2001). In my study, invertebrates were the most consumed prey items and many landscape variables were positive associated with invertebrates in the diet.

Burrowing owls preferentially select heavily grazed grasslands whether by livestock and/or prairie dogs (Butts 1973, MacCracken et al. 1985) and termination of grazing has a negative impact on owls in those areas (Dechant et al. 2002). Hayward et al. (1997) found that cotton rats, western harvest mice (*Reithrodontomys megalotis*), and Taylor's pygmy mice (*Baiomys taylori*) had a higher abundance within livestock exclosures, while heteromyids had a higher abundance on grazed plots. Deer mice are the most generalized and widespread North American rodent (Baker 1968) and can be found in both grazed and ungrazed habitats (Bock et al. 1984). Grazing negatively impacted

30

abundance and species richness of lizards (Jones 1981), while beetle abundance and richness increases with disturbance caused by grazing (Abensperg-Traun et al. 1996). Debano (2006), on the other hand, found less richness in beetles and less richness and diversity in Hymenoptera on grazed sites, while Hemiptera diversity increased on grazed sites. Thus, there may be less diversity of species on rangeland/grazed habitat, but burrowing owls may be more selective of prey items that may be abundant in these areas.

Agricultural lands have the ability to create different types of habitat, such as cultivated fields, shelter belts, and hedge rows. Moulton et al. (2005) found that owls nesting near agricultural fields in Idaho had access to more invertebrates than those owls nesting near nonagricultural lands, although there were more rodents on non-agricultural lands. Other studies indicate that small mammal populations are higher in agricultural areas as compared to native grasslands (Butts 1973, Gleason 1978, Poulin 2003, Sissons 2003, Hennin 2010). This increase in available prey items may allow owls nesting near agricultural fields to consume a more specialized diet, as compared to owls nesting near nonagricultural fields (Moulton et al. 2005). If there is a high availability of prey items and the search time for those prey items is low, a species may have the ability to become more specialized, the opposite holds true for areas with low prey availability and a high search time (MacArthur and Pianka 1966).

Burrowing owls have adapted to living in many urbanized areas as mentioned previously. Owls living in urban environments may have access to different prey items than rural owls. Blair (1996) found that moderate development in urban areas in California increases species diversity, but has a negative effect on native species

31

diversity. Heavy development had a negative impact on native species diversity, as well as total species diversity. Abundance of native grassland rodents seems to decline in proximity to suburban edges (Bock et al. 2002).

The presence of invertebrates in the diet was positively related to total edge and mean patch edge, while the presence of small mammals in the diet was positively related to edge density. Food availability may increase with the habitat edge created in fragmented areas and small patches (Haug and Oliphant 1990, Biddle 1996, Orth and Kennedy 2001). Arthropod and rodent abundance is often higher in both disturbed areas and in areas with more edge habitat (Webb and Hopkins 1984, Deulli et al. 1990). In Colorado, Orth and Kennedy (2001) found that burrowing owls may prefer edge habitat and select for fragmented areas. These areas are heavily utilized by burrowing owls as foraging habitat (Rich 1986, Haug and Oliphant 1990, Rosenberg and Haley 2004).

Association of mammals in the diet was positive correlated with increasing total landscape area. This may be because burrowing owls tend to stay closer to their burrows during the daytime and search for invertebrates within close proximity to their burrows. Mammals are mostly hunted at night and burrowing owls stray farther from their burrows during this time. Increased total landscape area corresponds to larger prairie dog towns. Burrowing owls select areas with a greater number of active prairie dog burrows (Hughes 1993) and towns (Butts 1973; Butts and Lewis 1982; Desmond 1991; Desmond and Savidge 1996; Sidle et al. 2001). Reproductive success of burrowing owls is also higher on larger colonies as compared to smaller colonies (Desmond et al. 2000). Clark et al.

(1982) found that larger prairie dog colonies supported higher vertebrate diversity than smaller colonies in New Mexico.

Monthly precipitation positively influenced invertebrates and amphibians in the diet of burrowing owls. Grasshopper abundance and growth rates have been linked to precipitation and temperature. Their numbers increase with spring and summer precipitation and warm spring and summer temperatures (Nenery and Hamilton 1969, Capinera and Horton 1989, Fielding and Brusven 1990). Dunham (1978) found that there was a significant positive correlation between precipitation and arthropod abundance. On tropical islands, arthropod abundance significantly increased with rainfall, but species diversity did not (Tanaka and Tanaka 1982). Owen (1989) found that rainfall was the single most important predictor for salamander, frog, toad, and turtle populations in Texas. However, rainfall was more weakly significant as a predictor for snakes, and lizards were negatively associated with increased rainfall (Owen 1989). Although precipitation positively influenced invertebrates and amphibians in this study, monthly rainfall negatively influenced the diversity and evenness of the diet of burrowing owls. This may be that burrowing owls are most likely selecting for prey items whose abundance is positively correlated with precipitation, resulting in a less diverse diet. Total number of food items in pellets was positively associated with precipitation. Although they are focusing on fewer individual species, there seemed to be an abundance of those particular prey items.

Landscape factors may play a greater role in a larger scaled study. Variables that were not significant in this study may actually play a role in a larger scale study, as well

as in different environments. More success collecting pellets in the field would have been helpful, potentially adding more to my results. Collecting climate data at each site would have been an interesting variable to add to this study. I was only able to collect rainfall data from nearby weather stations.

The burrowing owl is ranked the 2nd most economically beneficial bird in North America, behind the barn owl (Fisher et al. 2007). It receives this ranking because of the vast numbers of agricultural pests (rodents and insects) it consumes (Green et al. 1993, Plumpton and Lutz 1993b, York et al. 2002). This study suggests that although landscape and class variables have some influence on the diet of burrowing owls, season played the most important role. This information may be useful for future relocation and reintroduction projects within the Texas Panhandle. A variety of different habitat patches is beneficial, but season seems to play the biggest role in the diet of burrowing owls. However, these seasonal effects on diet suggest that burrowing owl diets might be dramatically altered if global climate change has significant effects on the seasonality of this region. Burrowing owls are only a small portion of the big picture. The decline in burrowing owls has been linked to a decline in prairie dog numbers. Eradication and the conversion of natural habitat in the Great Plains has severely reduced the population of prairie dogs. Conservation of burrowing owls requires a greater scale of management, conserving areas of the Great Plains, and protecting and maintaining population of prairie dogs.

LITERATURE CITED

Abensperg-Traun, M., G. T. Smith, G. W. Arnold, and D. E. Steven. 1996. The effects of habitat fragmentation and livestock-grazing on animal communities in remnants of gimlet *Eucalyptus salubris* woodland in the western Australian wheatbelt. I. Arthropods. Journal of Applied Ecology 33:1281-1301.

Agnew, W., D. W. Uresk, and R. M. Hansen. 1986. Flora and fauna associated with prairie dog colonies and adjacent ungrazed mixed-grass Prairie in western South Dakota. Journal of Range Management 39:135-139.

Agnew, W. D., W. Uresk, and R. M. Hansen. 1988. Arthropod consumption by small mammals on prairie dog colonies and adjacent ungrazed mixed grass prairie in western South Dakota. Pages 81-87 *in* Proceedings of the Eighth Great Plains Wildlife Damage Control Workshop. D.W. Uresk, G. L. Schenbeck, and R. Cefkin, coordinators. U. S. Forest Service General Technical Report RM-154, Washington, D. C., USA.

Allison, P. S., A. W. Leary, and M. J. Bechard. 1995. Observations of wintering ferruginous hawks (*Buteo regalis*) feeding of prairie dogs (*Cynomys ludovicianus*) in the Texas panhandle. Texas Journal of Science 47:235-237.

Amadon, D. 1959. The significance of sexual differences in size among birds. Proceedings of the American Philosophical Society 103:531-536.

American Ornithologists' Union (AOU). 1957. Check-list of North American birds. Fifth

    edition, Baltimore, Maryland, USA.

Anderson, R. C. 1982. An evolutionary model summarizing the roles of fire, climate, and

    grazing animals in the origin and maintenance of grasslands. Pages 297-308 *in* J.

    Estes, R. Tyrl, and J. Brunken, editors. Grasses and grasslands: systematics and

    ecology. University of Oklahoma Press, Norman, Oklahoma, USA.

Anderson, E., S. C. Forrest, T. W. Clark, and L. Richardson. 1986. Paleo-biology,

    biogeography, and systematics of the black-footed ferret, *Mustela nigrips*

    (Audobon and Bachman), 1851. Great Basin Naturalist Memoirs 8:11-62.

Anderson, R. C. 1990. The historic role of fire in the North American Grassland. Pages 8-

    18 *in* L. Wallace and S. Collins, editors. Fire in tallgrass prairie ecosystem.

    University of Oklahoma Press, Norman, Oklahoma, USA.

Apa, A. D., D. W. Uresk, and R. L. Linder. 1991. Impacts of black-tailed prairie dog

    rodenticides on nontarget passerines. Great Basin Naturalist 51:301-309.

Armstrong, D. M. and J. K. Jones Jr. 1972. Mammalian species: *Notiosorex crawfordi*.

    The American Society of Mammalogists 17:1-5.

Augustine, D. J. and B. W. Baker. 2013. Associations of grassland bird communities with

    black-tailed prairie dogs in the North American Great Plains. Conservation

    Biology 27:324-334.

Axelrod, D. I. 1985. Rise of the grassland biome, central North America. Botanical

    Review 51:163-201.

Baker, R. H. 1968. Habitats and distribution. Pages 98-126 *In* Biology of *Peromyscus*. J. A. King, editor. American Society of Mammalogy. Special publication 2.

Baicich, P. J. and C. J. O. Harrison. 1997. A guide to the nests, eggs, and nestlings of North American birds. Second Edition. Academic Press, San Diego, California, USA.

Bangert, R. K. and C. N. Slobodchikoff. 2004. Prairie dog engineering indirectly affects beetle movement behavior. Journal of Arid Environments 56:83-94.

Barko, V. A., J. H. Shaw, and D. M. Leslie, Jr. 1999. Birds associated with black-tailed prairie dog colonies in southern shortgrass prairie. The Southwestern Naturalist 44:484-489.

Barnes, R. L. 1993. The U. C. C.'s insidious preference for agronomy over ecology in farm lending decisions. University of Colorado Law Review 64: 457-512.

Bednarz, J. C. 1987. Successive nesting and autumnal breeding in Harris' hawks. Auk 104:85-96.

Bent, A. C. 1938. Life histories of North American birds of prey, Part 2. Dover Publications Inc., New York, New York, USA.

Biddle, P. B. 1996. Do land-use patterns influence Burrowing Owl nest site selection in northeastern Colorado? Thesis, Colorado State University, Fort Collins, Colorado, USA.

Blair, W. F. 1941. Observations on the life history of *Baiomy taylori subater*. Journal of Mammalogy 21:223.

Blair, R. B. 1996. Land use and avian species diversity along an urban gradient.
Ecological Applications 6:506-519.

Bock, C. E., J. H. Bock, W. R. Kenney, and V. M. Hawthorne. 1984. Responses of birds,
rodents, and vegetation to livestock exclosure in a semidesert grassland site.
Journal of Range Management 37:239-242.

Bock, C. E., K. T. Vierling, S. L. Haire, J. D. Boone, and W. M. Merkle. 2002. Patterns
of rodent abundance on open-space grasslands in relation to suburban edges.
Conservation Biology 16:1653-1658.

Bohrer, V. L. 1975. The prehistoric and historic role of the cool-season grasses in the
Southwest. Economic Botany 29:199-208.

Bonham, C. D. and A. Lerwick. 1976. Vegetation changes induced by prairie dogs on
shortgrass range. Journal of Range Management 29:221-225.

Bragg, T. B. 1995. The physical environment of Great Plains grassland. Pages 49-81 *in*
A. Joern and K. Keeler, editors. The changing prairie North American grassland.
Oxford University Press, New York, New York, USA.

Bragg, T. B. and L. C. Hulbert. 1976. Woody plant invasion of unburned Kansas
bluestem prairie. Journal of Range Management 29:19-24.

Brennan, L. and W. Kuvleskey 2005. North American grassland birds: an unfolding
conservation crisis? Journal of Wildlife Management 69:1-13.

Brooks, C. E. P. 1951. Geological and historical aspects of climate change. Pages 1004-1018 *in* T. R. Maline, editor. Compendium of Meteorology. American Meteorological Society, Boston, Massachusetts, USA.

Bryan, R. D. and M. B. Wunder. 2014. Western burrowing owls (*Athene cunicularia hypugaea*) eavesdrop on alarm calls of black-tailed prairie dogs (*Cynomys ludovicianus*). Ethology 120:180-188.

Buechner, M. 1989. Are small-scale landscape features important factors for field studies of small mammal dispersal sinks? Landscape Ecology. 2:191-199.

Butts, K. O. 1973. Life history and habitat requirements of Burrowing Owls in western Oklahoma. Thesis, Oklahoma State University, Stillwater, Oklahoma, USA.

Butts, K. O. 1976. Burrowing owls wintering in the Oklahoma panhandle. Auk 93:510-516.

Butts, K. O and J. C. Lewis. 1982. The importance of prairie dog colonies to burrowing owls in Oklahoma. Proceedings of the Oklahoma Academy of Sciences 62:46-52.

Cade, T. J. 1960. Ecology of the peregrine and gyrfalcon populations in Alaska. University of California Publications in Zoology. 63:151-290.

Cameron, G. N. 1977. Experimental species removal: demographic responses by *Sigmodon hispidus* and *Reithrodontomys fulvescens*. Journal of Mammalogy 58:488-506.

Capinera, J. C. and D. R. Horton. 1989. Geographic variation in effects of weather on grasshopper infestation. Environmental Entomology 18:8–14.

Carpenter, C. C. 1952. Comparative Ecology of the Common Garter Snake (*Thamnophis s. sirtalis),* the Ribbon Snake (*Thamnophis s. sauritus*), and Butler's Garter Snake (*Thamnophis butleri*) in Mixed Populations. Ecological Monographs 22:235-258.

Choate, J. R. 1970. Systematics and zoogeography of middle American shrews of the genus *Cryptotis*. University of Kansas Publication, Museum of Natural History 19:195-317.

Clark, T. W., T. M. Campbell III, D. G. Socha, and D. E. Casey. 1982. Prairie dog colony attributes and associated vertebrate species. The Great Basin Naturalist 42:572-582.

Collinge, S. K. and T. M. Palmer. 2002. The influences of patch shape and boundary contrast on insect response to fragmentation in California grasslands. Landscape Ecology 17:647-656.

Collins, A. R., J. P. Workman, and D. W. Uresk. 1984. An economic analysis of black-tailed prairie dog (Cynomys ludovicianus) control. Journal of Range Management 37:358-361.

Collins, S.L. and S.M. Glenn. 1988. Disturbance and community structure in North American prairies. Pages 131-143 *in* H.J. During, M.J.A. Werger, and J.H. Willems, editors. Diversity and pattern in plant communities. SPB Academic Publishers, The Hague.

Conant, R. and J. T. Collins. 1998. Peterson's Field Guide: Reptiles and Amphibians of Eastern/Central North America. Third Edition. Houghton Mifflin Company, New York, New York, USA.

Coppock, D. L., J. K. Detling, J. F. Ellis, and M. I. Dyer. 1983*a*. Plant herbivores interactions in a mixed grass prairie: effects of black-tailed prairie dogs on intraseasonal aboveground plant biomass and nutrient dynamics and plant species diversity. Oecologia 56:1-9.

Coppock, D. L., J. K. Detling, J. F. Ellis, and M. I. Dyer. 1983*b*. Plant herbivores interactions in a mixed grass prairie II: Responses of bison to modification of vegetation by prairie dogs. Oecologia 56:10-15.

Coulombe, H.N., 1971. Behavior and population ecology of the burrowing owl, *Speotyto cunicularia*, in the Imperial Valley of California. Condor 73:162-176.

Coupland, R. T., editor. 1979. Grassland Ecosystems of the World: Analysis of Grasslands and Their Uses. Cambridge University Press, Cambridge, UK.

Davidson, A. D. and D. C. Lightfoot. 2007. Interactive effects of keystone rodents on the structure of desert grassland arthropod communities. Ecography 30:515-525.

Davidson, A. D., E. Ponce, D. C. Lightfoot, E. L. Fredrickson, J. H. Brown, and J. Cruzado. 2010. Rapid response of a grassland ecosystem to an experimental manipulation of a keystone rodent and domestic livestock. Ecology 91:3189-3200.

Debano, S. J. 2006. Effects of livestock grazing on aboveground insect communities in semi-arid grasslands of southeastern Arizona. Biodiversity and Conservation 15:2547-2564.

Dechant, J. A., M. L. Sondreal, D. H. Johnson, L. K. Igl, C. M. Doldade, P. A. Rabie, and B. R. Euliss. 2002. Effects of management practices of grassland birds: burrowing owl. Northern Prairie Wildlife Research Center, Jamestown, North Dakota, USA.

Deisch, M. S., D. W. Uresk, and R. L. Linder. 1989. Effects of two prairie dog rodenticides on ground-dwelling invertebrates in western South Dakota. Pages 164-170 *in* Ninth Great Plains wildlife damage control workshop proceedings. A. J. Bjugstad, D. W. Uresk, and R. H. Hamre, editors. United States Department of Agriculture Forest Service, General Technical Report RM-171, Ft. Collins, Colorado, USA.

Deisch, M. S., D. W. Uresk, and R. L. Linder. 1990. Effects of prairie rodenticides on deer mice in western South Dakota. Great Basin Naturalist 50:347-353.

Delibes-Mateos, M., A. T. Smith, C. N. Slobodchikoff, and J. E. Swenson. 2011. The paradox of keystone species persecuted as pests: a call for the conservation of abundant small mammals in their native range. Biological Conservation 144:1335-1346.

Desmond, M. J. 1991. Ecological aspects of burrowing owl nesting strategies in the Nebraska panhandle. Thesis, University of Nebraska, Lincoln, Nebraska, USA.

Desmond, M. J. and J. A. Savidge. 1996. Factors influencing burrowing owl (*Speotyto cunicularia*) nest densities and numbers in western Nebraska. American Midland Naturalist 136:143-148.

Desmond, M. J., J. A. Savidge, and K. M. Eskridge. 2000. Correlations between burrowing owl and black-tailed prairie dog declines: a 7 year analysis. Journal of Wildlife Management 64:1067-1075.

Detling, J. K. and A. D. Whicker. 1988. A control of ecosystem processes by prairie dogs and other grassland herbivores. Pages 23-29 *in* Proceedings of the eighth Great Plains wildlife damage control workshop, Rapid City, South Dakota. U.S. Forest Service, Washington, D. C., USA.

Dix, R. L. 1964. A history of biotic and climatic changes within the North American grasslands. Pages 71-90 *in* D. J. Crisp, editor. Grazing in Terrestrial and Marine Environments. Blackwell Scientific Publishing, Oxford, UK.

Dorf, E. 1960. Climatic changes of the past and present. American Scientist 48:341-364.

Duelli, P., M. Struder, I. Marchand, and S. Jakob. 1990. Population movement of arthropods between natural and cultivated areas. Biological Conservation 54:193-207.

Dunham, A. E. 1978. Food availability as a proximate factor influencing individual growth rates in the Iguanid lizard *Sceloporus merriami*. Ecology 59:770-778.

Dunlap, T.R. 1988. Saving America's Wildlife. Princeton University Press, Princeton, New Jersey, USA.

Earhart, C. M. and N. K. Johnson. 1970. Size dimorphism and food habits of North
American owls. Condor 72: 251-264.

Errington, P. L. and L. J. Bennett. 1935. Food habits of burrowing owls in northwestern
Iowa. Wilson Bulletin 47:125-128.

Fielding, D. J. and M. A. Brusven 1990. Historical analysis of grasshopper (Orthoptera:
Acrididae) population responses to climate in southern Idaho, 1950–1980.
Environmental Entomology 19:1786–1791.

Fisher, J. B., L. A. Trulio, G. S. Biging, and D. Chromczak. 2007. An analysis of spatial
clustering and implications for wildlife management: a burrowing owl example.
Environmental Management 39:403-411.

Force, E. R. 1931. Habits and birth of young of the lined snake (*Tropidoclonion
lineatum*). Copeia 2:51-53.

Forman, R. T. T 1995. Land Mosaics: The Ecology of Landscapes and Regions.
Cambridge University Press, New York, New York, USA.

Gleason, H. A. 1922. Vegetational history of the Middlewest. Annals of the American
Association of Geographers 12:39-86.

Gleason, R. L. 1978. Aspects of the breeding biology of Burrowing Owls in southeastern
Idaho. Thesis, University of Idaho, Moscow, Idaho, USA.

Gleason, R. L. and T. H. Craig. 1979. Food habits of Burrowing Owls in southeastern
Idaho. Great Basin Naturalist 39:273-276.

Grant, R. A. 1965. The Burrowing Owl in Minnesota. Loon 37:2-17.

Green, G. A. and R. G. Anthony. 1989. Nesting success and habitat relationships of
    burrowing owls in the Columbia Basin, Oregon. Condor 91:347-354.

Green, G. A., R. E. Fitzner, R. G. Anthony, and L. E. Rogers. 1993. Comparative diets of
    Burrowing Owls in Oregon and Washington. Northwest Science 67:88-93.

Hall, E. R. 1981. The mammals of North America. Second Edition. John Wiley & Sons,
    New York, New York, USA.

Hall, D. B., P. D. Greger, and J. R. Rosier. 2009. Regional and seasonal diet of the
    western burrowing owl in south central Nevada. Western North American
    Naturalist 69:1-8.

Hansen, R. M. and I. K. Gold. 1977. Black-tailed prairie dogs, desert cottontail, and cattle
    trophic relations on shortgrass range. Journal of Range Management 30:210-214.

Hassien, F. D. 1976. A search for black-footed ferrets in the Oklahoma panhandle and
    adjacent area and an ecological study of black-tailed prairie dogs in Texas
    County, Oklahoma. Thesis, Oklahoma State University, Stillwater, Oklahoma,
    USA.

Haug, E. A. and L. W. Oliphant. 1990. Movements, activity patterns, and habitat use of
    burrowing owls in Saskatchewan. Journal of Wildlife Management 54:27-35.

Haug, E. A., B. A. Millsap, and M. S. Martell. 1993. Burrowing owl (*Speotyto cunicularia*). *In* A. Poole and F. Gill, editors. The Birds of North America, No. 61. Ithaca: Cornell Lab of Ornithology; retrieved from the Birds of North American Online. http://bna.birds.cornell.edu/bna/species/061. Accessed 1 March 2016.

Hayward, B., E. J. Heske, and C. W. Painter. 1997. Effects of livestock grazing on small mammals at a desert Cienaga. Journal of Wildlife Management 61:123-129.

Hennin, H. L. 2010. Ecological impacts of converting cropland to permanent-cover for four native prairie taxa. Thesis. University of Regina, Regina, Saskatchewan, Canada.

Hollister, N. 1916. A systematic account of the prairie dogs. North American Fauna 40:1-37.

Howard, C. W. 1974. Comparative Reproductive Ecology of Horned Lizards (Genus *Phrynosoma*) in Southwestern United States and Northern Mexico. Journal of the Arizona Academy of Science 9:108-116.

Hughes, A. J. 1993. Breeding density and habitat preferences of the burrowing owl in northeastern Colorado. Thesis, Colorado State University, Fort Collins, Colorado.

Ingham, R. E. and J. K. Detling. 1984. Plant herbivore interactions in a North American mixed grass prairie. III. Soil nematode populations and root biomass on *Cynomys ludovicianus* colonies and adjacent uncolonized areas. Oecologia 63:307-313.

Jones, K. B. 1981. Effects of grazing on lizard abundance and diversity in western Arizona. Southwestern Naturalist 26:107-115.

Jones, C. G., J. H. Lawton, and M. Shachak. 1994. Organisms as ecosystem engineers. Oikos 69:373-386.

Judd, F. W., J. Herrera, and M. Wagner. 1978. The relationship between lipid and reproductive cycles of a subtropical population of *Peromyscus leucopus*. Journal of Mammalogy 59:669-676.

Kassing, E. F. 1961. A life history study of the Great Plains ground snake, *Sonora episcopa episcopa* (Kennicott). Texas Journal of Science 13:185-203.

Kauffman, E. G. 1977. Geological and biological overview: Western Interior Cretaceous basin. Mountain Geologist 14:75-99.

King, R. A. and J. R. Belthoff. 2000. Post-fledging dispersal off burrowing owls in southwestern Idaho: characterization of movements and use of satellite burrows. Condor 103:118-126.

Klute, D. S., L. W. Ayers, M. T. Green, W. H. Howe, S. L. Jones, J. A. Shaffer, S. R. Sheffield, and T. S. Zimmerman. 2003. Status assessment and conservation plan for the western burrowing owl in the U. S. U. S. Fish and Wildlife Service Biological Technical Publication BTP-R6001-2003.

Knopf, F. L. 1994. Avian assemblages on altered grasslands. Studies in Avian Biology 15:247-257.

Knopf, F. L. 1996. Prairie legacies-birds. Pages 135-148 *in* F. Samson and and F.L. Knopf, editors. Prairie conservation: preserving North America's most endangered ecosystem. Island Press, Washington, D. C., USA.

Knowles, C. 1986. Some relationships of black-tailed prairie dogs to livestock grazing. Great Basin Naturalist 46:198-203.

Knowles, C. J. and Knowles, P. R. 1994. Review of Black-tailed Prairie Dog: Literature in Relation to Rangelands Administered by the Custer National Forest. Custer National Forest, Billings Montana, USA.

Koford, C. B. 1958. Prairie dogs, whitefaces, and blue gramma. Wildlife Monograms No. 3:3-78.

Konrad, P. M. and D. S. Glimer. 1984. Observations on the nesting ecology of burrowing owls in central North Dakota. Prairie Naturalist 16:129-130.

Kotliar, N. B., B. W. Baker, A. D. Whicker, and G. Plumb 1999. A critical review of assumptions about the prairie dog as a keystone species. Environmental management 24:177-192.

Kotliar, N. B. 2000. Application of the new keystone-concept to prairie dogs: How well does it work? Conservation Biology 14:1715-1721.

Krueger, K. 1986. Feeding relationships among bison, pronghorn, and prairie dogs: an experimental analysis. Ecology 67:760-770.

Küchler, A. W. 1964. Potential natural vegetation of the conterminous United States. American Geographical Society Special Publication 36.

Kupsch, W. O. 1960. Radiocarbon-dated organic settlement near Herbert, Saskatchewan. American Journal of Science 258:282-292.

Kurten, B. 1972. The Age of Mammals. Columbia University Press, New York, New York, USA.

Lauenroth, W. K., D. G. Milchunas, J. L. Dodd, R. H. Hart, R. K. Heitchmidt, and L. R. Rittenhouse. 1994. Effects of grazing on ecosystems of the Great Plains. Pages 69-100 *in* M. Vavra, W. A. Laycock, and R. D. Pieper, editors. Ecological implications of livestock herbivory in the West. Society for Range Management, Denver, Colorado, USA.

Leptich, D. 1994. Agricultural development and its influences on raptors in southern Idaho. Northwest Science 68:167-171.

Lomolino, M. V. and G. A. Smith. 2003. Terrestrial vertebrate communities at black-tailed prairie dog (*Cynomys ludovicianus*) towns. Biological Conservation 115:89-100.

MacArthur, R. H. and E .R. Pianka. 1966. On optimal use of a patchy environment. American Naturalist 100:603-609.

MacCracken, J. G., D. W. Ursek, and R. M. Hansen. 1985. Vegetation and soils of burrowing owl nest sites in Conata Basin, South Dakota. Condor 87:152-154.

Magurran, A. E. 1988. Ecological Diversity and its measurement. Princeton University Press, Princeton, New Jersey, USA.

Marti, C. D. 1974. Feeding ecology of four sympatric owls. Condor 76:45-61.

Martin, D. J. 1973. Selected aspects of burrowing owl ecology and behavior. Condor 75:446-456.

Maser, C., E. W. Hammer, and S. H. Anderson. 1971. Food habits of the burrowing owl in central Oregon. Northwest Science 45:19-26.

McCaffrey, R. E., M. C. Wallace, and J. D. Ray. 2009. Small mammals and ground-dwelling invertebrates associated with active and controlled colonies of black-tailed prairie dogs (*Cynomys ludovicianus*). The Southwestern Naturalist 54:300-306.

McGarigal, K. and B. J. Marks. 1995. FRAGSTATS: spatial pattern analysis program for quantifying landscape structure. USDA Pacific Northwest Research Station. General Technical Report PNW-GTR-351, Portland, Oregon, USA.

McIntyre, N. E. 1995. Effects of forest patch size on avian diversity. Landscape Ecology 10:85-99.

Merriam, C. H. 1902. The prairie dog of the Great Plains. Pages 257-270 *in* Yearbook of the U.S. Department of Agriculture 1901. U.S. Government Printing Office, Washinton, D. C., USA.

Miller, B., G. Ceballos, and R. P. Reading. 1994. The prairie dog and biotic diversity. Conservation Biology 8:677-681.

Miller, B., R. Reading, J. Hoogland, T. Clark, G. Ceballos, R. List, S. Forrest, L. Hanebury, P. Manzano, J. Pacheco, and D. Uresk. 2000. The role of prairie dogs as a keystone species: response to Stapp. Conservation Biology 14:318-321.

Millsap, B. A. and C. Bear. 2000. Density and reproduction of burrowing owls along an urban development gradient. Journal of Wildlife Management 64:33-41.

Milne, L. and M. Milne. 1980. National Audubon Society: Field Guide to North American Insects and Spiders. Random House Inc., New York, New York, USA.

Milstead, W. W. 1957. Observations on the Natural History of Four Species of Whiptail Lizard, *Cnemidophorus* (Sauria, Teiidae) in Trans-Pecos Texas. The Southwestern Naturalist 2:105-121

Moulton, C. E., R. S. Brady, and J. R. Belthoff. 2005. A comparison of breeding season food habits of burrowing owls nesting in agricultural and nonagricultural habitat in Idaho. Journal of Raptor Research 39:429-438.

Moulton, C. E., R. S. Brady, and J. R. Belthoff. 2006. Association between wildlife and agriculture: underlying mechanisms and implications in burrowing owls. Journal of Wildlife Management 70:708-716.

Murcia, C. 1995. Edge effects in fragmented forests: implications for conservation. Trends in Ecology and Evolution 10:58-62.

National Oceanic and Atmospheric Administration [NOAA]. 2016. Monthly climatological summary 2014, 2015. http://www.ncdc.noaa.gov/data-access/land-based-station-data Accessed on 8 May 2016.

Natural Resources Conservation Service 1992. National resources inventory data files. U. S. Department of Agriculture, Washington, D. C., USA.

Nenery, N. J. and A. G. Hamilton. 1969. Effects of rainfall on range forage and

populations of grasshoppers, San Carlos Apache Reservation, Arizona. Journal of

Economic Entomology. 62:329-333

O'Connor, R. J., M. T. Jones, R. B. Boone and T. B. Lauber. 1999. Linking continental

climate, land use, and land patterns with grassland bird distribution across the

conterminous United States. Studies in Avian Biology 19:45-49.

Olson, S. L. 1985. Mountain plover food items on and adjacent to a prairie dog town.

Prairie Naturalist 17:83-90.

O'Meilia, M. E., F. L. Knopf and J. C. Lewis. 1982. Some consequences of competition

between prairie dogs and beef cattle. Journal of Range Management 35:580-585.

Orth, P. B. and P. L. Kennedy. 2001. Do land-use patterns influence nest-site selection by

burrowing owls (*Athene cunicularia hypugaea*) in northeastern Colorado?

Canadian Journal of Zoology 79:1038-1045.

Ostlie, W. R., R. E. Schneider, J. M. Aldrich, T. M. Faust, R. L. B. McKim, and S. J.

Chaplin. 1997. The status of biodiversity in the Great Plains. The Nature

Conservancy, Minneapolis, Minnesota, USA.

Owen, J. G. 1989. Patterns of Herpetofaunal Species Richness: Relation to Temperature,

Precipitation, and Variance in Elevation. Journal of Biogeography 16:141-150.

Paine, R.1969. A note on the trophic complexity and community stability. American

Naturalist 103:91-93.

Palmer, M. W. 1993. Putting things in even better order: the advantages of canonical correspondence analysis. Ecology 74:2215-2230.

Peterjohn, B. G. and J. R. Sauer. 1999. Population status of North American grassland birds from the North American Breeding Bird Survey, 1966-1996. Studies in Avian Biology 19:27-44.

Pezzolesi, L. S. W. 1994. The western Burrowing Owl: increasing prairie dog abundance, foraging theory, and nest site fidelity. Thesis, Texas Tech University, Lubbock, Texas, USA.

Plumpton, D. L. 1992. Aspects of nest site selection and habitat use by burrowing owls at the Rocky Mountain Arsenal, Colorado. Thesis, Texas Tech University, Lubbock, Texas, USA.

Plumpton, D. L. and R. S. Lutz. 1993*a*. Nesting habitat use by burrowing owls in Colorado. Journal of Raptor Research 27:175-179.

Plumpton, D. L. and R. S. Lutz. 1993*b*. Prey selection and food habits of burrowing owls in Colorado. Great Basin Naturalist 53:299-304.

Poulin, R. G. 2003. Relationships between burrowing owls (*Athene cunicularia*), small mammals, and agriculture. Dissertation, University of Regina, Regina, Saskatchewan.

Poulin, R. G. and L. D. Todd. 2006. Sex and nest stage differences in the circadian foraging behaviors of nesting burrowing owls. Condor 108:856-864.

Poulin, R. G., L. D. Todd, E. A. Haug, B. A. Millsap and M. S. Martell. 2011. Burrowing owl (*Athene cunicularia*), The Birds of North America Online (A. Poole, Ed.). Ithaca: Cornell Lab of Ornithology; retrieved from the Birds of North American Online: http://bna.birds.cornell.edu/bna/species/061. Accessed 1 June 2016.

Powers, M. E., D. Tilman, A. Estes, B. A. Menge, W. J. Bond, L. S. Mills, J. Daily, C. Castilla, J. Lubchenco, and R. T. Paine. 1996. Challenges in the quest for keystones. BioScience 46:609-620.

Ray, J. D., M. C. Wallace, and R. E. McCaffrey. 2015. Avian use of black-tailed prairie dog colonies in shortgrass prairie. Great Plains Research 25:75-82.

Reading, R. P. 1993. Toward an endangered species reintroduction paradigm: a case study of the black-footed ferret. Ph.D. dissertation. Yale University, New Haven, Connecticut, USA.

Reading, R. P., B. J. Miller and S. R. Kellert. 1999. Values and attitudes toward prairie dogs. Anthrozoös 12:43-52.

Reiners, W. A. 1995. Ecosystems of the Great Plains: scales, kinds, and distribution. Pages 11-32 *in* S. R. Johnson and A. Bouzaher, editors. Conservation of Great Plains Ecosystems. Kluwer Academic Publishers, Dordrecht, Holland.

Restani, M., L. R. Rau, and D. L. Flath. 2001. Nesting ecology of burrowing owls occupying black-tailed prairie dog towns in southeastern Montana. Journal of Raptor Research 35:296-303.

Rich, T. 1986. Habitat and nest-site selection of burrowing owls in the sagebrush steppe of Idaho. Journal of Wildlife Management 50:548-555.

Risser, P. G., E. C. Birney, H. D. Blocker, S. W. May, W. J. Parton, and J. A. Wiens. 1981. The true prairie ecosystem. Hutchison Ross Publishing, Stroudsburg, Pennsylvania, USA.

Robinson, T. S. 1954. Cannibalism by a burrowing owl (*Speotyto cunicularia*). Wilson Bulletin 66:72.

Rosenberg, D. K. and K. L. Haley. 2004. The ecology of burrowing owls in the agroecosystems of the Imperial Valley, California. Studies in Avian Biology 27:120-135.

Russell, R. E. and J. K Delting. 2003. Grasshoppers (Orthoptera: Acrididae) and black-tailed prairie dogs (Sciuridae: *Cynomys ludovicianus* (Ord)): associations between two rangeland herbivores. Journal of the Kansas Entomology Society 76:578-587.

Samson, F. and F. Knopf. 1994. Prairie conservation in North America. Bioscience 44:418-421.

Schickedanz, J. G. 1980. History of grazing in the southwest. Pages 1-9 *In* Grazing management systems for Southwest rangelands, a symposium. The Range Improvement Task Force New Mexico State University, Las Cruces, New Mexico, USA.

Schmidly, D. J. 1994. The Mammals of Texas. University of Texas Press, Austin, Texas, USA.

Shantz, H. L. 1954. The place of grasslands in the earth's cover of vegetation. Ecology 35:143-145.

Shelford, V. E. 1963. The ecology of North America. University of Illinois Press, Urbana, Illinois, USA.

Shipley, B. K. and R. P. Reading. 2006. A comparison of herpetofauna and small mammal diversity on black-tailed prairie dog (*Cynomys ludovicianus*) colonies and non-colonized grasslands in Colorado. Journal of Arid Environments 66:27-41.

Shyry, D. 2005. Western burrowing owls (*Athene cunicularia*) in southeast Alberta: juvenile survivorship from fledgling to migration effects of tags and late-season diets. Thesis, University of Alberta, Edmonton, Alberta.

Sidle, J. G., M. Ball, T. Bear, J. J. Chynoweth, G. Foli, R. Hodoroff, G. Moravek, R. Peterson, and D. N. Svingen. 2001. Occurrence of burrowing owls in black-tailed prairie dog colonies on Great Plains National Grasslands. Journal of Raptor Research 35:316-321.

Sierra-Corona, R., A. Davidson, E. L. Fredrickson, H. Luna-Soria, H. Suzan-Azpiri, E. Ponce-Guevara, and G. Ceballos. 2015. Black-tailed prairie dogs, cattle and the conservation of North America's arid grasslands. PloS One 10:1-15.

Silva, S. I., I. Lazo, E. Silva-Aranguiz, F. M. Jaksic, P. L. Meserve, and J. R. Gutierrez.1995. Numerical and functional response of burrowing owls to long-term mammal fluctuations in Chile. Journal of Raptor Research 29:250-255.

Sims, P. L. 1988. Grasslands. Pages 265-286 *In* M. G. Barbour and W. D. Billings, editors. North American Terrestrial Vegetation. Cambridge University Press, New York, New York, USA.

Sims, P. L., J. S. Singh, and W. K. Lauenroth. 1978. The structure and function of ten western North American grasslands. I. Abiotic and vegetational characteristics. Journal of Ecology 66:251-285

Sissons, R. A. 2003. Food and habitat selection of male burrowing owls (*Athene cunicularia*) on southern Alberta grasslands. Thesis. University of Alberta, Edmonton, Alberta, Canada.

Smith, D. G. and J. R. Murphy. 1973. Late summer food habits of adult burrowing owls in central Utah. Journal of Raptor Research 7:112-115.

Smith, G. A. and M. V. Lomolino. 2004. Black-tailed prairie dogs and the structure of avian communities on the shortgrass plains. Oecologia 138:592-602.

St. Louis, V. L. and L. Breebaart. 1991. Calcium supplements in the diet of nestling tree swallows near acid sensitive lakes. Condor 93:286-294.

Stapp, P. 1998. A reevaluation of the role of prairie dogs in Great Plains grasslands. Conservation Biology 12:1253-1259.

Stewart, O. C. 1956. Fire as the first great force employed by man. Pages 115-133 *in* W. L. Thomas, editors. Man's role in changing the face of the earth. University of Chicago Press, Chicago, Illinois, USA.

Summers, C. A. and R. L. Linder. 1979. Food habits of the black-tailed prairie dog in

      western South Dakota. Journal of Range Management 31:134-136.

Tanaka, L. K and S. K. Tanaka. 1982. Rainfall and Seasonal Changes in Arthropod

      Abundance on a Tropical Oceanic Island. Biotropica 14:114-123.

ter Braak, C. J. F. 1986. Canonical correspondence analysis: a new eigenvector technique

      for multivariate direct gradient analysis. Ecology 67:1167-1179.

Thomsen, L. 1971. Behavior and ecology of burrowing owls on the Oakland Municipal

      Airport. Condor 73:177-192.

Tyler, J. D. 1968. Distribution and vertebrate associates of the black-tailed prairie dog in

      Oklahoma. Dissertation, University of Oklahoma, Norman, Oklahoma, USA.

Tyler, J. D. 1983. Notes on the burrowing owl food habits in Oklahoma. Southwestern

      Naturalist 28:100-102.

Umbanhowar, Jr., C. E. 1996. Recent Fire History of the Northern Great Plains.

      American Midland Naturalist 135:115-121.

Uresk, D. W. and A. J. Bjugstad. 1983. Prairie dogs as ecosystem regulators on the

      northern High Plains. Pages 91-94 *in* USDA-Forest Service, Rapid City, South

      Dakota, USA.

Uresk, D. W. and D. B. Paulson. 1988. Estimated carrying capacity for cattle competing

      with prairie dogs and forage utilization in western South Dakota. Pages 387-390

      In Symposium on management of amphibian, reptiles, and small mammals in

North America, Flagstaff, Arizona. July 19-21, 1988. GTR RM-166. U. S. Forest Service, Washington, D. C., USA.

U. S. Fish and Wildlife Service. 2008. Birds of conservation concern 2008. U. S. Department of Interior, Fish and Wildlife Service, Division of Migratory Bird Management, Arlington, Virginia, USA.

U. S. Forest Service. 1980. An assessment of the forest and range land situation in the United States. USDA publication FS-345.

U. S. Senate 1936. The Western Range. Senate Document 199. *In* 74th Congress, 2nd Session US Government Printing Office, Washington*,* D. C.

Van Putten, M. and S. D. Miller. 1999. Prairie dogs: the case for listing. Wildlife Society Bulletin 27:113–120.

Vinton, M.A. and S.L. Collins. 1997. Landscape gradients and habitat structure in native grasslands of the central Great Plains. Pages 3-19 *in* F.L. Knopf and F.B. Samson, editors. Ecology and Conservation of Great Plains Vertebrates. Springer-Verlag, New York, New York, USA.

Warnock, R. G. and P. C. James. 1997. Habitat fragmentation and Burrowing Owls (*Speotyto cunicularia*). Pp. 477–486 *in* Duncan, J. R., D. H. Johnson, & T. H. Nicholis, editors. Biology and conservation of owls of the northern hemisphere. USDA Forest Service General Technical Report NC-190. North Central Research Station, Forest Service, U.S. Department of Agriculture, St. Paul, Minnesota, USA.

Weaver, J. E. 1954. North American prairie. Johnsen Publishing Company, Lincoln, Nebraska, USA.

Webb, N. R. and P. J. Hopkins. 1984. Invertebrate diversity on fragmented *Calluna* heathland. Journal of Applied Ecology 21:921-933.

Webster, W. D. and J. K. Jones Jr. 1982. Mammalian species: *Reithrodontomys megalotis*. The American Society of Mammalogists 67:1-5.

Weltzin, J. F., S. L. Dowhower, and R. L. Heitschmidt. 1997. Prairie dog effects on plant community structure in southern mixed-grass prairie. The Southwestern Naturalist 42:251-258.

Whicker, A. D. and J. K. Detling. 1988. Ecological consequences of prairie dog disturbances. Bioscience 38:778-785.

Whicker, A. D. and J. K Detling. 1993. Control of grassland ecosystem processes by prairie dogs. Management of prairie dogs complexes for the reintroduction of the black-footed ferret. U. S. Fish and Wildlife Service Biological Report 13:18-27.

White, C. M. 1994. Population trends and current status of selected western raptors. Studies in Avian Biology 15:161-172.

White, R., S. Murray, and M. Rohweder. 2000. Pilot analysis of global ecosystems: Grassland ecosystems. World Resource Institute, Washington, D.C., USA.

Wilcomb, M. J. 1954. A study of prairie dog burrow systems and the ecology of their arthropod inhabitants in central Oklahoma. Dissertation, University of Oklahoma, Norman, Oklahoma, USA.

Wingert, C. M. 2012. Seasonal food habits of burrowing owls (*Athene cunicularia*) in

    human-altered landscapes. Thesis. California Polytechnic State University, San

    Luis Obispo, California, USA.

Wright, Jr. H. E. 1970. Vegetational history of the Central Plains. Pleistocene and Recent

    Environments of the Central Great Plains 3:157-172.

Wydeven, A. P. and R. B. Dahlgren. 1985. Ungulate habitat relationships in Wind Cave

    National Park. Journal of Wildlife Management 49:805-813.

York, M.M., Rosenberg, D.K. and Sturm, K.K., 2002. Diet and food-niche breadth of

    Burrowing Owls (Athene cunicularia) in the Imperial Valley, California. Western

    North American Naturalist 62:280-287.

Table 1: Numbers of burrowing owl pellets obtained from 6 prairie dog towns within the Texas Panhandle during 2014.

Site	March	April	May	June	July	August	September	October	Total
Canyon	6	X	X	6	4	7	0	X	**23**
Channing	X	X	17	15	0	10	X	0	**42**
Dalhart	X	X	0	8	2	14	X	1	**25**
Gene Howe	X	19	X	16	6	4	0	0	**45**
Vega	X	14	X	8	8	15	7	17	**69**
Wellington	X	X	21	1	7	8	X	15	**52**
Total	**6**	**33**	**38**	**54**	**27**	**58**	**7**	**33**	**256**

X= unable to collect

Table 2: Numbers of burrowing owl pellets obtained from 6 prairie dog towns within the Texas Panhandle during 2015.

Site	March	April	May	June	July	August	September	October	Total
Canyon	X	17	7	0	0	X	X	X	24
Channing	X	20	X	8	8	14	12	8	70
Dalhart	X	20	X	16	6	5	X	0	47
Gene Howe	X	13	X	6	16	21	20	8	84
Vega	X	20	20	22	15	15	10	20	122
Wellington	X	16	X	3	12	5	9	6	51
Total	**0**	**106**	**27**	**55**	**57**	**60**	**51**	**42**	398

X= unable to collect

Table 3: Total number of and percent frequency of occurrence of invertebrate prey items in burrowing owl pellets from the Texas Panhandle, 2014-2015.

Prey Item	Total Number of Individuals	% Frequency
Orthoptera		
Acrididae	3041	77.06
Tettigoniidae	141	20.95
Gryllotalpidae	486	19.88
Stenopelmatidae	4	0.61
Coleoptera		
Buprestidae	2	0.31
Cerambycidae	22	3.63
Chrysomelidae	10	1.53
Cicindelidae	120	12.08
Curculionidae	39	3.82
Elateridae	7	0.92
Scarabaeidae	746	41.60
Silphidae	57	5.96
Tenebrionidae	1013	53.36
Trogidae	1	0.15
Unknown beetle	3	0.31
Unknown beetle larvae	1	0.15
Hemiptera		
Cicadidae	19	2.60
Pentatomidae	7	0.76
Reduviidae	2	0.31
Hymenoptera		
Formicidae	219	8.56
Mutillidae	2	0.15
Pompilidae	1	0.15
Scoliidae	1	0.15
Vespidae	1	0.15
Apidae	88	6.88
Mantodea		
Mantidae	3	0.46
Unknown insect	1	0.15
Scolopendromorpha		
Scolopendridae	1	0.15
Anareae		
Ctenzidae	1	0.15
Lycosidae	56	7.49
Salticidae	9	1.38
Theridiidae	1	0.15
Solifugae		
Eremobatidae	74	7.80
Scorpiones		
Buthidae	3	0.46

Table 4: Total number and percent frequency of occurrence of vertebrate prey items in burrowing owl pellets from the Texas Panhandle, 2014-2015.

Prey Item	Total Number of Individuals	% Frequency
Lagomorpha		
Leporidae		
Sylvilagus floridanus	4	0.61
Rodentia		
Muridae		
Mus musculus	1	0.15
Neotoma micropus	2	0.31
Baiomys taylori	39	5.81
Onychomys leucogaster	19	2.75
Peromsycus spp.	33	4.89
Reithrodontomys megalotis	27	3.82
Sigmodon hispidus	48	7.34
Heteromyidae		
Chaetodipus hispidus	54	8.26
Dipodomys ordii	19	2.91
Perognathus flavescens	25	3.82
Geomyidae		
Geomys bursarius	3	0.46
Insectivora		
Soricidae		
Cryptotis parva	9	1.22
Notiosorex crawfordi	2	0.31
Unknown Mammal	2	0.31
Squamata		
Teiidae		
Cnemidophorus sp.	1	0.15
Scincidae		
Plestiodon obsoletus	1	0.15
Phrynosomatidae		
Phrynosoma cornutum	4	0.61
Sceloporus spp.	6	0.92
Unknown lizard	3	0.46
Colubridae		
Sonora semiannulata	1	0.15
Thamnophis marcianus	1	0.15
Thamnophis proximus	1	0.15
Tropidoclonion lineatum	1	0.15
Unknown snake	1	0.15
Caudata		
Ambystomatidae		
Ambystoma tigrinum	1	0.15
Unknown anurans	29	4.28
Unknown birds	34	4.43

Table 5: P-values from multiple regression relating landscape variables to characteristics of burrowing owl diets in the Texas Panhandle, 2014-2015.

Landscape Variables	Total Number of Prey Items	Family Richness	Modified Simpson's Index	Shannon's Index	Evenness
Class Area (Agriculture)	0.004	0.960	0.221	0.330	0.245
Class Area (Rangeland)	0.003	0.389	0.039	0.066	0.074
Total Landscape Area	0.004	0.961	0.222	0.331	0.246
Patch Size Standard Deviation	0.004	0.932	0.282	0.410	0.293
Total Edge	0.004	0.945	0.274	0.399	0.287
Edge Density	0.668	0.588	0.043	0.121	0.015
Mean Patch Edge	0.004	0.992	0.238	0.352	0.259
Mean Shape Index	0.600	0.001	0.001	0.001	0.009
Monthly Precipitation	0.003	0.177	0.017	0.024	0.049

Table 6: P-values from multiple regression relating landscape variables to the abundance of major taxa in the diet of burrowing owls in the Texas Panhandle, 2014-2015.

Landscape Variables	Invertebrates	Amphibians	Mammals	Reptiles	Birds
Class Area (Agriculture)	0.002	0.371	0.002	0.617	0.394
Class Area (Rangeland)	0.002	0.253	0.001	0.372	0.783
Total Landscape Area	0.002	0.371	0.002	0.617	0.394
Patch Size Standard Deviation	0.003	0.396	0.003	0.666	0.346
Total Edge	0.002	0.393	0.003	0.660	0.352
Edge Density	0.432	0.968	0.001	0.743	0.447
Mean Patch Edge	0.002	0.378	0.002	0.631	0.380
Mean Shape Index	0.433	0.266	0.012	0.106	0.033
Average Monthly Precipitation	0.001	0.070	0.044	0.348	0.743

Table 7: Percent frequency of occurrence per month of prey items found in burrowing owl pellets in the Texas Panhandle, 2014-2015.

|	Apr	May	June	July	Aug	Sept	Oct
Acrididae	56.12	53.85	66.06	84.52	97.46	100	96
Gryllotalpidae	2.88	7.69	11.01	34.52	38.14	34.48	29.33
Tettigonidae	2.88	6.15	5.5	22.62	37.29	56.9	26.67
Stenopelmatidae	0	0	0	0	0.85	5.17	0
Buprestidae	1.44	0	0	0	0	0	0
Cerambycidae	0	0	0	2.38	4.24	0	0
Chrysomelidae	0	0	3.67	5.95	0	1.72	0
Cicindelidae	2.88	6.15	7.34	21.43	24.58	6.9	16
Curculionidae	7.91	9.23	2.75	1.19	2.54	1.72	0
Elateridae	0	1.54	0.92	1.19	0	5.17	0
Scarabaeidae	42.45	46.15	48.62	55.95	33.05	25.86	37.33
Silphidae	6.47	7.69	5.5	5.95	7.63	6.9	1.33
Tenebrionidae	56.83	58.46	55.05	60.71	51.69	41.38	41.33
Trogidae	0	0	0	1.19	0	0	0
Cicadidae	0	0	0	14.29	3.39	0	1.33
Pentatomidae	0	0	0.92	0	2.54	1.72	0
Reduviidae	0	0	0.92	0	0.85	0	0
Formicidae	7.19	7.69	9.17	15.48	6.78	12.07	4
Mutillidae	0	0	0.92	0	0	0	0
Pompilidae	0	0	0	0	0.85	0	0
Scoliidae	0	0	0	0	0	1.72	0
Vespidae	0.72	0	0	0	0	0	0
Apidae	14.39	12.31	5.5	4.76	2.54	3.45	0
Mantidae	0	0	0	2.38	0.85	0	0
Ctenizidae	0.72	0	0	0	0	0	0
Lycosidae	10.07	18.46	7.34	3.57	0.85	8.62	5.33
Salticidae	2.16	0	3.67	1.19	0	0	1.33
Theridiidae	0	0	0	0	0	1.72	0
Eremobatidae	1.44	3.08	11.01	14.29	15.25	3.45	4
Buthidae	0	1.54	0	1.19	0	0	1.33
Scolopendridae	0	0	0	0	0	0	1.33
Leporidae	0.72	0	0.92	0	0.85	0	0
Muridae	45.32	46.15	29.36	5.95	2.54	5.17	12
Heteromyidae	27.34	23.08	28.44	3.57	2.54	3.45	4
Geomyidae	0	0	0.92	0	0	3.45	0
Soricidae	2.88	1.54	0.92	1.19	0.85	0	2.67
Teiidae	0	0	0	1.19	0	0	0
Scincidae	0	0	0.92	0	0	0	0
Phrynosomatidae	0.72	0	0.92	4.76	1.69	1.72	1.33
Colubridae	0	1.54	0.92	0	0.85	0	2.67
Ambystomatidae	0	1.54	0	0	0	0	0
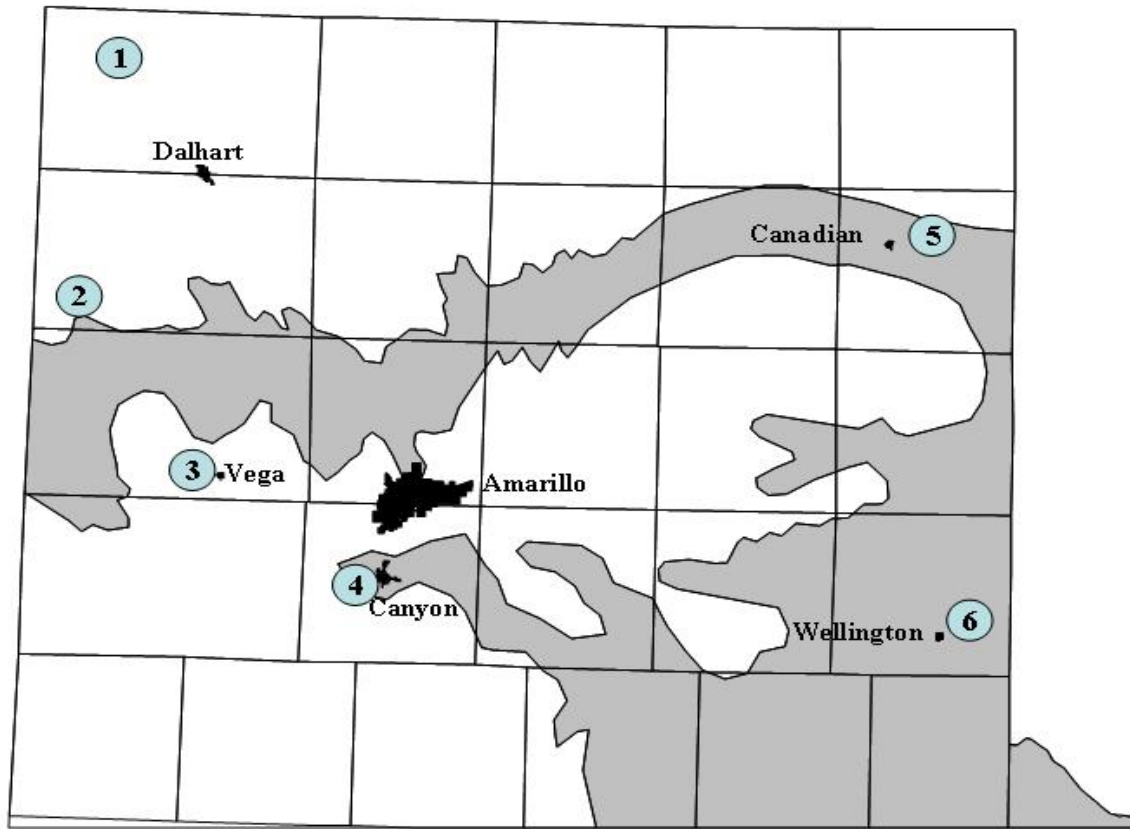
Figure 1: Map of the Texas Panhandle showing study sites where collections occurred in 2014 and 2014. (1) Dalhart site, (2) Channing site, (3) Vega site, (4) Canyon site, (5) Gene Howe site, and (6) Wellington site. The gray area represents the Rolling Plains ecoregion, while the white area represents the High Plains ecoregion. Black areas represent nearby population centers.
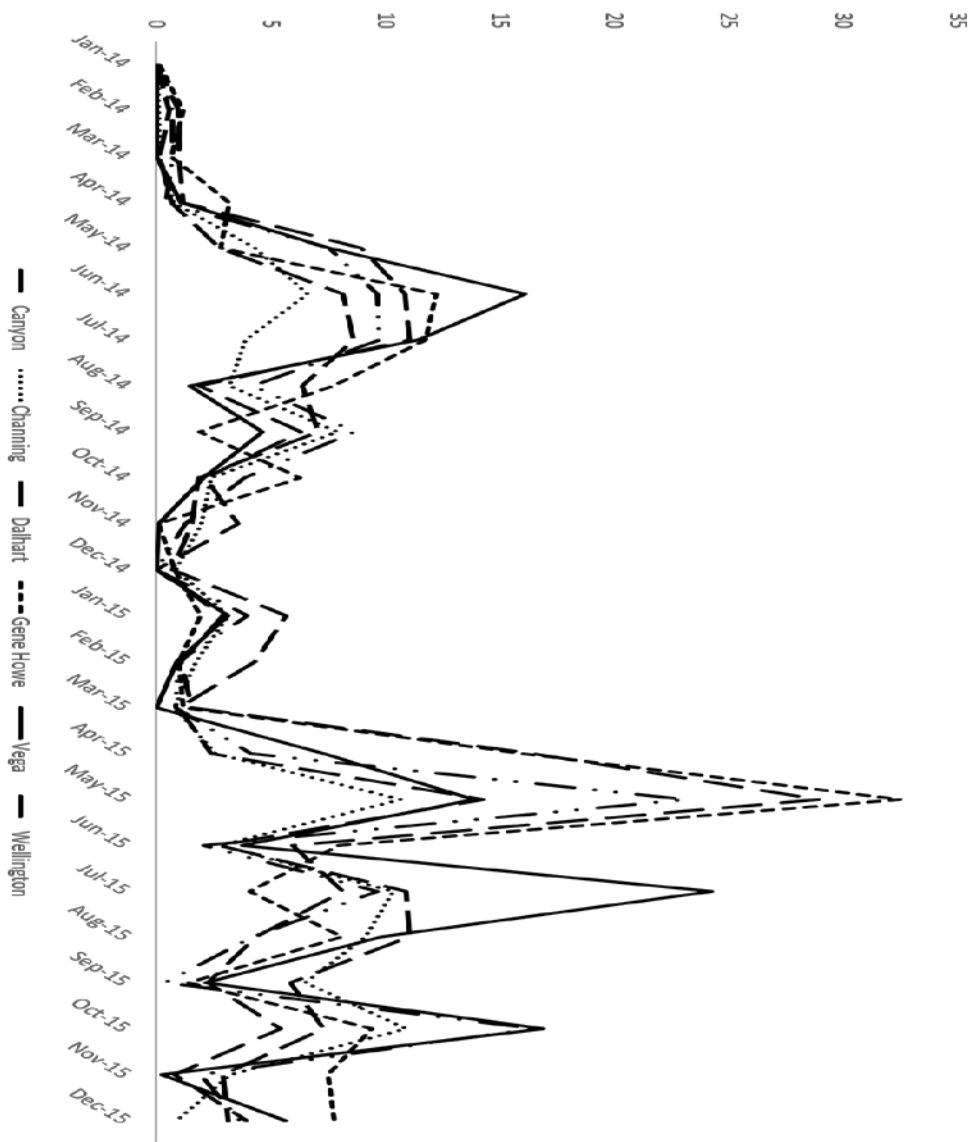
Figure 2: Monthly rainfall patterns from weather stations throughout the Texas Panhandle, 2014 – 2015
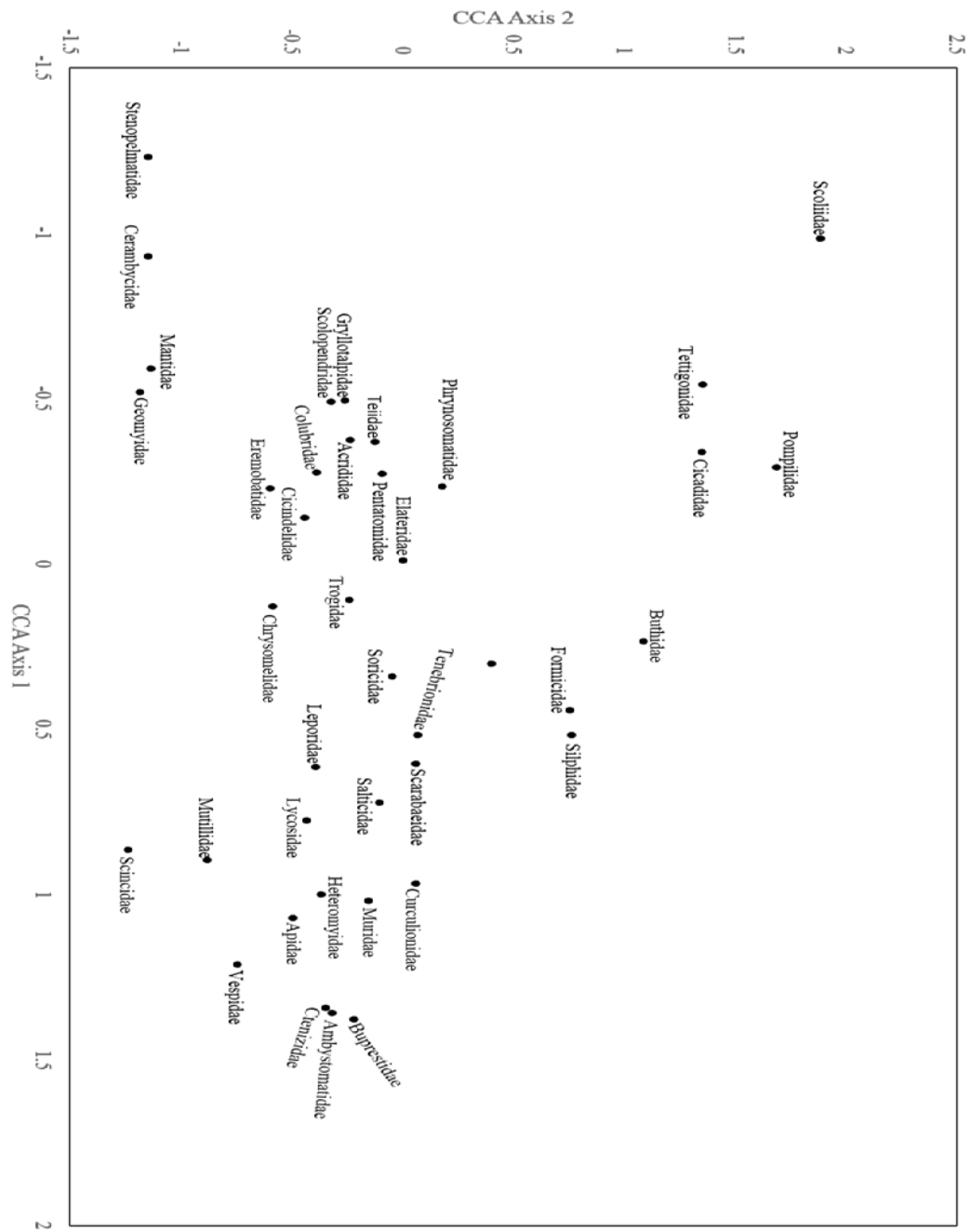
Figure 3: Canonical Correspondence Analysis species space representing family level

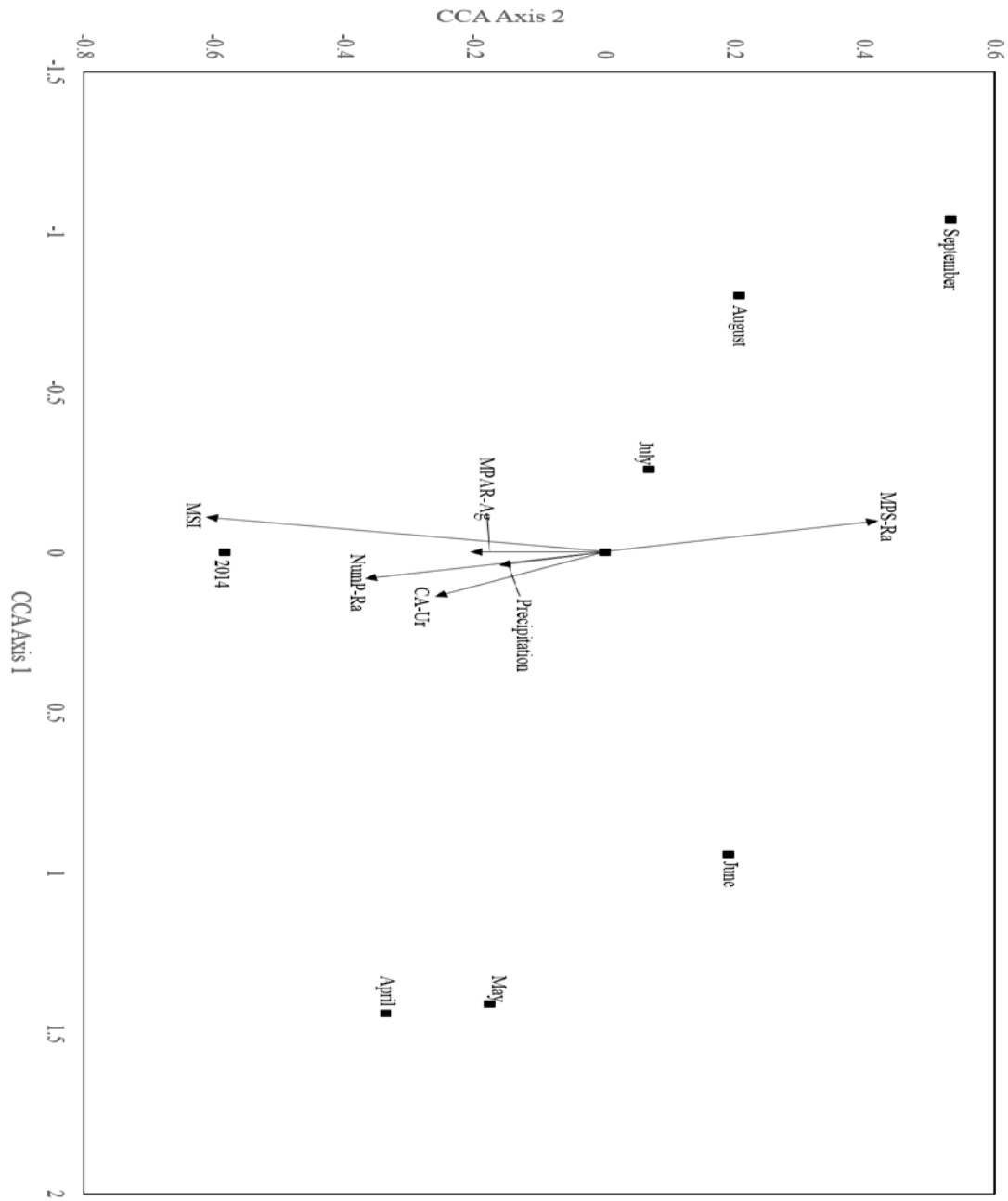prey items found in burrowing owl pellets from the Texas Panhandle, 2014-2015.

Figure 4: Canonical Correspondence Analysis biplot graph with biplot arrows representing association of landscape variables (Mean Shape Index [MSI], Mean Patch Size-Rangeland [MPS-Ra], Mean Perimeter Area Ratio-Agriculture [MPAR-Ag], Number of Patches-Rangeland [NumP-Ra], and Class Area-Urban [CA-Ur]) and precipitation on family level prey items found in burrowing owl pellets. Centroids represent months and years that had a significant influence on family level prey items.