

SEASONAL AND HABITAT-BASED PREY DIVERSITY
OF BOBCATS, *LYNX RUFUS*, IN BIG BEND
NATIONAL PARK, TEXAS

by

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Dedication

I dedicate this work to my daughter,

Emory Marie Browning.

May she always follow her dreams,

let nothing stand in her way,

and endeavor to make a difference in the world.

And, may she grow to love

the Big Bend, spending time in the

Chisos and climbing her namesake,

Emory Peak.

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Abstract

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The bobcat (*Lynx rufus*) population in Big Bend National Park (BIBE) provides an excellent opportunity for study due to the varied arid habitat in which they exist, the dynamic nature of their environment, and the paucity of scientific documentation on this unexploited population. As an abundant carnivore, the bobcat is crucial to BIBE's community ecology and trophic structure, emphasizing the need to investigate, in depth food habits in relation to environmental factors. Bobcats feed on a variety of small vertebrates, primarily lagomorphs and rodents, and are also known to take down large prey, such as mule deer and white tailed deer. Previous research found bobcat diet within BIBE in relation to a reduction in the mule deer abundance in the park from 1972-74 to 1980-81. Their findings suggest that bobcats increase consumption of lagomorphs, a primary prey item when mule deer populations decline. However, they did not address habitat type or seasonality. Taking into account the five major ecosystems of BIBE (floodplain arroyo, desert scrub, sotol grassland, pinion-juniper-oak forest, cypress-pine-oak forest) and seasonal variation from winter to summer, I investigated differences in bobcat diet based on time of year and habitat type. I hypothesized that while lagomorphs and rodents would make up the majority of bobcat diet, ratios and species would vary by

season and location, with significant differences between 1) cooler months following monsoon season (January) and the hottest, driest time of year (May/June) and 2) high elevation woodland/grassland, low desert, and riparian floodplain. My findings support the assumption that bobcats in BIBE primarily consumed lagomorphs and rodents, with lagomorphs consumed at a higher percentage for all samples combined (44%). Rodents comprised 28% of prey found in scat collected. Differences between seasons included an increase in number of taxa from May/June to January, including carnivores and deer. Seasonal changes also included a reduction in lagomorph occurrence (51% - 39%) and an increase in rodent occurrence (26% - 33%). Prey diversity did not differ significantly across ecosystem type and was quite low; May/June $H' = 0.22$, January $H' = 0.20$ ($P > 0.1$), and increasing sample size by combining both seasons resulted in a lower diversity measure ($H' = 0.18$) in other words, a lower evenness in prey species. Dietary niche breadth was higher in the summer ($B_s = 0.53$) than in the winter ($B_s = 0.35$), and overall dietary niche breadth was $B_s = 33$. Both diversity and niche breadth measures followed a similar trend, with summer being the highest and combined measures being lowest. Because diversity and dietary niche breadth are measures of the relationship between species richness and relative abundance, an increase in species diversity alone does not increase diversity, especially if those species exist in low relative abundance.

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Chapter 1

Introduction

Felidae and the North American Bobcat, *Lynx rufus*

Many North American populations of wild cats (Carnivora: Felidae) continue to decline due to anthropogenic causes, specifically alteration of habitat and human interaction (IUCN 2011, Harrison 2010, Anderson & Lovallo 2003). Of the seven felid species found in North America, jaguar, *Panthera onca*; mountain lion, *Puma concolor*; jaguarundi, *Puma yagouaroundi*; Canada lynx, *Lynx canadensis*; bobcat, *Lynx rufus*; ocelot, *Leopardus pardalis*; and margay, *Leopardus wiedii*, four are listed as Endangered throughout a significant portion of their range: jaguar, jaguarundi, ocelot, and margay (FWS 2012). Of the remaining three, Canada lynx is listed as Threatened and both the mountain lion and bobcat hold federal Endangered status on the population level. The Florida panther, *P. concolor coryi*, of southern Florida, the Eastern cougar, *P. concolor cougar*, of the Northeastern U.S., and the Mexican bobcat, *L. rufus escuinapae*, in central Mexico are listed as Endangered by the Environmental Protection Agency (FWS 2012). Additionally, bobcat populations are listed as endangered by New Jersey and have been extirpated in Delaware; they are considered Rare, Threatened, or of Special Concern in the Midwest where they receive protection at the state level (Woolf & Hubert 1998). The International Union for Conservation of Nature (IUCN) lists five of the seven North American felid species as decreasing, with only Canada lynx and bobcats as stable (2011). The Convention on International Trade in Endangered Species of Wild Fauna and Flora (CITES) lists the bobcat in Appendix II as a species not currently threatened with extinction, but that could be at risk if trade is not closely monitored. Appendix II includes not only species that are of legitimate conservation concern, but also species considered to look similar to endangered or threatened species (e.g. furbearers such as the bobcat

that may resemble other spotted felids). With so many felid species registering concern, research is ongoing in an effort to document population size, genetic diversity, individual home ranges, suitable habitat, dispersal corridors, and food habits.

Small size, elusive nature, and generalist capabilities (habitat and prey) likely enable bobcats to fare better than other North American felids in the face of habitat destruction, fragmentation, and human persecution (Hansen 2007, Woolf & Hubert 1998). Additionally, with its Least Concern/Stable status at the federal level, and its decline and ongoing recovery in the Midwest, the bobcat offers a unique opportunity to study, in depth, natural history and differences in prey consumption in a range of habitats under varying environmental and anthropogenic pressures. Investigating trends in bobcat food habits in relation to dynamic environmental factors may answer questions or prompt new mitigation strategies regarding not only bobcat management, but also new conservation approaches for endangered and threatened feline species confronted with a growing human population, continued fragmentation and loss of habitat, and a changing climate.

Felid Predation

Felidae is considered to be the most carnivorous family of Carnivora, consuming almost exclusively vertebrate prey. Thus, their trophic status as secondary or higher (tertiary, quaternary) consumers is vital to every ecosystem they inhabit. While small cats, subfamily Felinae, are not likely to fill an apex predator niche similar to that of larger relatives within the Pantherinae, they nevertheless play a crucial predatory role (Hansen 2007). Many of the organisms felids consume are primary consumers that could overrun an ecosystem, lowering biodiversity, if not kept in check by predation. Predation strategies in felids range from solitary generalism (with respect to prey items) in species such as the bobcat to solitary specialization in species such as the Canada lynx. Additionally, the African lion, *Panthera leo*, is the only truly social felid and obligate group

hunter and is a generalist predator. Female cheetahs, *Acinonyx jubatus*, are solitary specialists, however males form hunting coalitions. The diversity of felid strategies and varying levels of specialty allow them to adjust to changes in changes in prey abundance in various communities with dynamic and differing environmental factors.

Bobcat Characteristics

Morphology

Medium-sized cats, bobcats are known for their short tails, ear tufts, and facial ruffs (Figure 1-1). Their color range is light brownish to grayish with a white ventral region and variation in the amount and intensity of black spots throughout their pelage. The posterior of each ear is also distinctly marked with a white spot under the black tuft and the tip of the tail is distinctly marked with a black spot (Hansen 2007, Anderson & Lovallo 2003). Body size varies based on sex and habitat type with males being larger, on average, than females, and cats in more northern and temperate regions being larger than cats in more southern and arid regions (Dobson & Wigginton 1996). Bobcat height ranges from 43-58 cm at the shoulder and length ranges from 63-104 cm nose to tail; weights of males range from 7-13 kg, females from 4.5-8 kg (Hansen 2007, Anderson & Lovallo 2003, Dobson & Wigginton 1996).

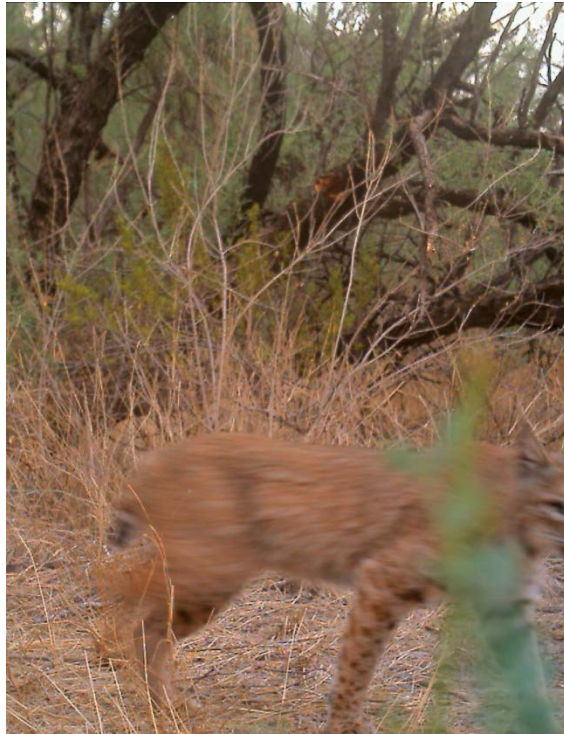


Figure 1-1 A Big Bend bobcat, *Lynx rufus*, on the move 4km east of Santa Elena Canyon, 5/5/2008. This photograph was taken by a wildlife trip camera (Cuddeback Trail Camera 1217) mounted on a tree in the river floodplain. Bobcats are typically crepuscular, and more nocturnal than diurnal, but it is not unusual to see one during the day.

Phylogeny

Bobcats evolved in North America following the migration of a felid ancestor that crossed the Bering Land Bridge during the Late Miocene epoch, between 8.5 to 8.0 MYA, that later gave rise to the *Lynx* genus in addition to other felid genera over time with subsequent emigration and immigration (Johnson *et al.* 2006). During the Pleistocene epoch, approximately 1.8 MYA, a basal split occurred within the genus *Lynx* that gave rise to the bobcat lineage and a lineage that later differentiated into the other *Lynx* species, *L. canadensis*, *L. lynx*, and *L. pardinus*, respectively (Johnson *et al.* 2006). Due to historical events, such as glaciation, and modern-day anthropogenic effects, the

bobcat exhibits complex genetic structure throughout its geographic range (Reding *et al.* 2012.)

Geographic Range

The bobcat's range extends from far southern Canada to southern Mexico (Figure 1-2). Barriers to expansion of this historic range include low temperatures on the northern border and competitive restrictions with sympatric felids at the Isthmus of Tehuantepec in southern Mexico (Sánchez-Cordero *et al.* 2008). Bobcats had been nearly extirpated from both their northeastern and midwestern ranges near the turn of the last century. Populations in midwestern states declined due to loss of habitat from deforestation and agriculture, as well as excessive harvest for pelts (Woolf & Hubert 1998). Although current distribution maps typically show bobcats to be absent from the midwest, patchily distributed populations are present; these are protected and in recovery, with some delisted from state Endangered status (Johnson *et al.* 2010).

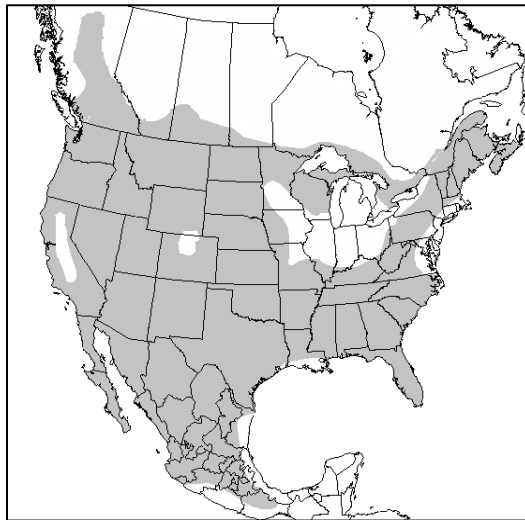


Figure 1-2 Geographic range of the bobcat, *Lynx rufus*

Map adapted from the Smithsonian Institute, NatureServe, The Nature Conservancy, Conservation International, World Wildlife Fund, and Environment Canada.

Reproduction

Similar to most felids, bobcats have a polygynous mating strategy. Mating usually occurs in early spring, followed by a 60-70 day gestation period with an average of three offspring produced per litter. Kittens are typically weaned by eight weeks of age, but stay with their mother, learning to hunt before dispersing at approximately one year of age. Females reach sexual maturity by one year, but can reproduce earlier. Males reach sexual maturity at approximately two years of age (Hansen 2007, Anderson & Lovallo 2003).

Population Structure and Dispersal

Bobcats are crepuscular, solitary predators with established home ranges that vary in size, possibly due to resource availability (Lawhead 1984). While female home ranges typically do not overlap each other, male home ranges often overlap those of other males. For mating purposes, neighboring males and females typically overlap home ranges (Bailey 1974, Benson et al. 2004). It is difficult for transient bobcats to settle in areas already claimed as territories by other individuals (Bailey 1974). Additionally, bobcats appear to only breed successfully when they have a well-established home range (Janečka et al. 2006). Sub-adults may disperse up to 100km or more from their natal ranges when establishing home ranges in unoccupied territory that offers adequate cover and prey (Johnson et al. 2010). While bobcats are found in diverse habitats with varying resource availability, they appear to favor microhabitats with thick vegetative cover and dense understory, likely due to the need for diurnal sleeping areas (Kolowski and Woolf 2002).

Mortality

Wildlife mortality due to highways is an ongoing conservation concern for many terrestrial animals, including bobcats. Lovallo and Anderson (1996) found that bobcats in

northwestern Wisconsin appear to prefer home ranges with fewer paved roads and higher densities of wildlife trails. Their data also suggested that bobcats avoid crossing paved roads, particularly in high traffic areas. This avoidance may in part be a function of lack of preferred habitat near highways. Additionally, Millions and Swanson (2007) investigated natural and artificial barriers, such as roadways, to bobcat movement using analysis of genetic diversity and gene flow. Their findings suggested that roadways do not fragment bobcat populations genetically, despite evidence of roadway avoidance. In south Texas, however, research suggests that highways profoundly impact bobcat mortality rates (Cain et al. 2003). Twenty-five bobcats were found dead, due to collision with highway vehicles, in a two year period along a 32.2 km stretch of road. Cain *et al.*'s (2003) findings suggested that roadways were a significant factor in bobcat population fragmentation. Riley *et al.* (2006) also used genetic techniques to study bobcat dispersal across a freeway in Los Angeles. They found that not only do roads present a real barrier to dispersal, but bobcats that do cross the freeway rarely reproduce due to "territory pile-up" near highways and their intensive territorial nature. Therefore, bobcats that did cross the highway, likely in an attempt to establish home ranges, were unable to do so due to the lack of available space. As a result, they were unable to successfully reproduce. Riley et al.'s (2006) study reflected a loss of gene flow due to a significant anthropogenic barrier.

Food Habits

Bobcats consume primarily lagomorphs and rodents, common prey items that could overrun a community, exhaust resources, and reduce biodiversity if not limited by predation. However, this vital ecosystem service tends to be undervalued for felids and other small carnivores (Anderson & Lovallo 2003, Hansen 2007). Bobcats also prey upon a variety of other small mammals, birds, and reptiles, occasionally taking larger prey such

as mule deer, *Odocoileus hemionus*, and white-tailed deer, *Odocoileus virginianus* (Leopold & Krausman 1986, Delibes & Hiraldo 1987). Consequently, the bobcat is a prime example of an important small/medium sized predator and an essential component of local food webs.

Bobcat diet has been studied in various ecosystems throughout its geographic range, which includes temperate forests and grasslands, arid and desert grassland, scrub desert, coastal chaparral, riparian zones, and mountainous regions. Consumption of lagomorphs and rodents as a high percentage of their annual diet is well-documented. However, prey species may vary seasonally, geographically, and due to effects of extreme weather events. In southern Iowa, an area of interspersed forests, grassland, and agricultural crops, Brockmeyer and Clark (2007) found bobcat diet to be consistent with documented findings throughout most of its range. Eastern cottontails, *Sylvilagus floridanus*, made up 60% of diet in their study with mice and voles, *Peromyscus* sp. and *Microtus* sp., comprising ~20% and fox squirrels, *Sciurus niger*, less than 15%. Jones and Smith (1979) found Sonoran Desert bobcats in the ecotone region between low desert scrub and high desert chaparral to consume primarily rodents (67% of prey) regardless of season and variation in prey species abundance of lagomorphs and rodents. In Pennsylvania, 41% of bobcat diet consisted of white-tailed deer, 22% lagomorphs, including eastern cottontail and Appalachian cottontail, *S. obscurus*, and 18% rodents, *Peromyscus* sp., identified in the stomachs they dissected (McClellan *et al.* 2005). These findings are consistent with previous studies suggesting that bobcats in the northern extent of their geographic range prey more on deer than lagomorphs and rodents (Anderson & Lovallo 2003, Hansen 2007). In the Cape Region of Baja California, Mexico, a subtropical arid ecosystem, Delibes *et al.* (1997) found lagomorphs to dominate bobcat diet (74%) with rodents much less prevalent (40%). An interesting

aspect of bobcat diet in this region was a reliance on non-avian reptiles (15%) and birds (12%), levels not documented in any other ecosystem. The bobcat's broad dietary niche within and across regions and adaptability to varied vertebrate prey likely add to its ability to successfully inhabit a wide array of ecosystems that vary in prey type and abundance, and environmental pressures.

Harrison (2010) assessed diet in a protected population of Chihuahuan Desert bobcats in southern New Mexico. His findings of approximately 58% lagomorph prey, and 21% rodents are consistent with the results of most dietary studies in other southern regions (but see exceptions above). Leopold and Krausman (1986) studied bobcat diet within BIBE in relation to a reduction in mule deer abundance in the park from 1972-74 to 1980-81. Their findings suggest that bobcats increased consumption of lagomorphs specifically when mule deer populations declined. However, they did not address habitat type or seasonality. Taking into account the five major ecosystems of BIBE (river floodplain-arroyo, scrub desert, sotol grassland, pinion-juniper-oak woodland, cypress-pine-oak woodland) and seasonal variation from winter to summer, I investigated differences in bobcat diet based on time of year and habitat type.

Chapter 2

Hypotheses

In Big Bend National Park, the bobcat is sympatric with another felid, the mountain lion (*Puma concolor*). While the ecology of the Big Bend lion population has been studied within the park (Waid 1990, Ruth 1991), the bobcat population has not been formally investigated, with the exception of a dietary study in the 1980's (Leopold & Krausman 1986). Due to the paucity of scientific documentation, the bobcat within BIBE provided an excellent opportunity for study, both to understand the behavior and ecology of the species itself and its role in the ecological communities of the region. As an abundant carnivore, the bobcat is crucial to BIBE's biodiversity and trophic structure, emphasizing the need to investigate its food habits in relation to environmental factors and prey availability. The protected status of the bobcat within the park in addition to the diversity of habitats found in BIBE provide a unique opportunity to answer prey consumption questions regarding minimally disturbed populations in varied arid habitats.

Bobcats feed on a variety of small vertebrates, primarily lagomorphs and rodents, and are also known to feed on large prey such as mule deer and white tailed deer (Leopold & Krausman 1986, Delibes & Hiraldo 1987, Anderson & Lovallo 2003, Hansen 2007). Leopold and Krausman (1986) studied bobcat diet within BIBE in relation to a reduction in the mule deer abundance in the park from 1972-74 to 1980-81. Their findings suggested that bobcats increase consumption of lagomorphs, a primary prey species, specifically when mule deer populations decline. However, they did not address habitat type or seasonality. Taking into account the five major ecosystems of BIBE (floodplain arroyo, scrub desert, sotol grassland, pinion-juniper-oak forest, cypress-pine-oak forest) and seasonal variation from winter to summer, I investigated differences in bobcat diet based on time of year and habitat type. I hypothesized that while lagomorphs and rodents

would make up the majority of bobcat diet, the importance of these prey types would vary by season and location, with substantial differences between 1) cooler months following the monsoon season (January specifically) and the hottest, driest time of year (May/June) and 2) the high elevation woodland/grassland, low desert, and riparian floodplain ecotones.

Chapter 3

Study Area

Big Bend National Park encompasses 324,219 hectares in the “big bend” region of the Rio Grande River, which occurs between the Mexican state of Chihuahua and the southwestern border of Texas in Brewster County (Figure 3-1). The park was founded in 1944, enclosing the largest protected area of the Chihuahuan Desert within the United States. Despite its arid environment, BIBE exhibits a high level of species richness for a desert. The diversity of species found in this region is due to an elevation range of 548m at the eastern most edge of Boquillas Canyon to 2385m at Emory Peak in the Chisos Mountains, and the presence of reliable and semi-reliable water sources (Wauer and Fleming 2002). Variation in elevation, soil type, water availability, exposure, and human activity impact species distribution throughout the park and provide the basis for the five major ecosystems found in BIBE: river floodplain-arroyo, scrub desert, sotol grassland, and two mountain woodland formations, pinyon-juniper-oak and cypress-pine-oak (Wauer and Fleming 2002) (Figure 3-2). Each ecosystem varies not only in elevation, but also in average temperature and rainfall, influencing significant differences in species diversity and vegetation cover throughout the park. Additionally there are major differences in species composition across many taxa within the scrub desert (low-, mid-, high-elevation desert) due to a range in elevation from 548 m to 1066 m and the resulting differences in temperature (average decrease 6.4°C/km) and rainfall (12 cm – 40 cm) as elevation increases (J. Kuban, unpublished data, plus my own unpublished data, Browning, compilation of field studies in BIBE comparing biodiversity at low-, mid-, high-elevation scrub desert and sotol grassland).

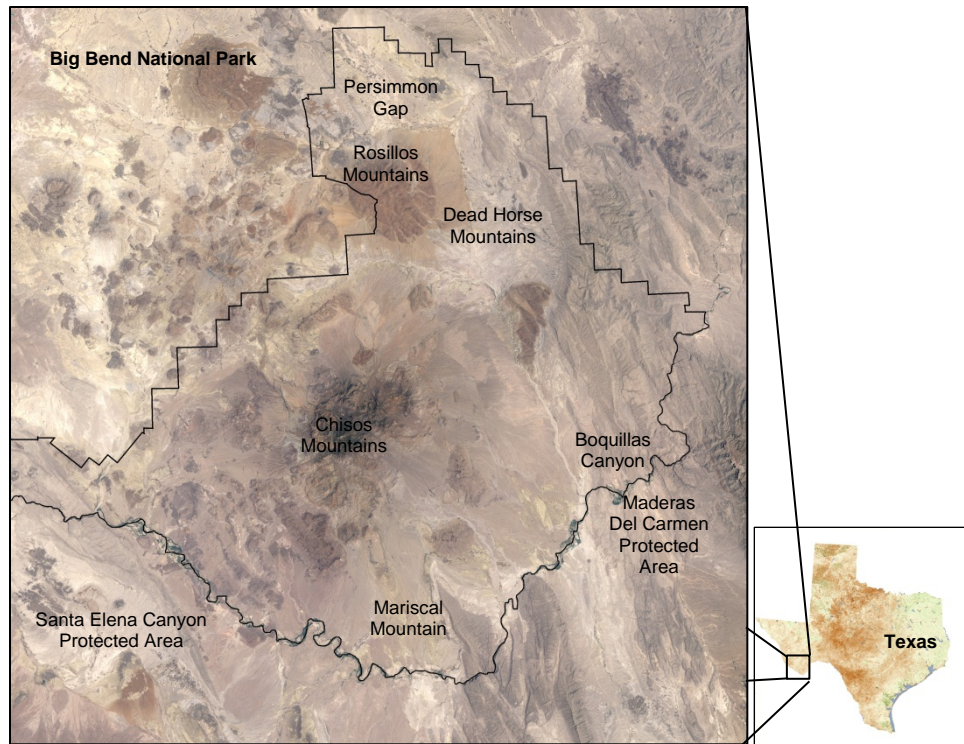


Figure 3-1 Big Bend National Park (BIBE); adapted from NASA satellite imagery, 2010. BIBE is located in the southern portion of Brewster County along the Rio Grande River. The Chisos Mountains occur near the middle of the park, with minor mountain formations throughout the park such as the Rosillos Mountains, Dead Horse Mountains, and Mariscal Mountain. Canyons along the river include Santa Elena, Mariscal, and Boquillas Canyon. The area of the park in the lower Rosillos Mountains is private land owned by the neighboring Rosillos Ranch.

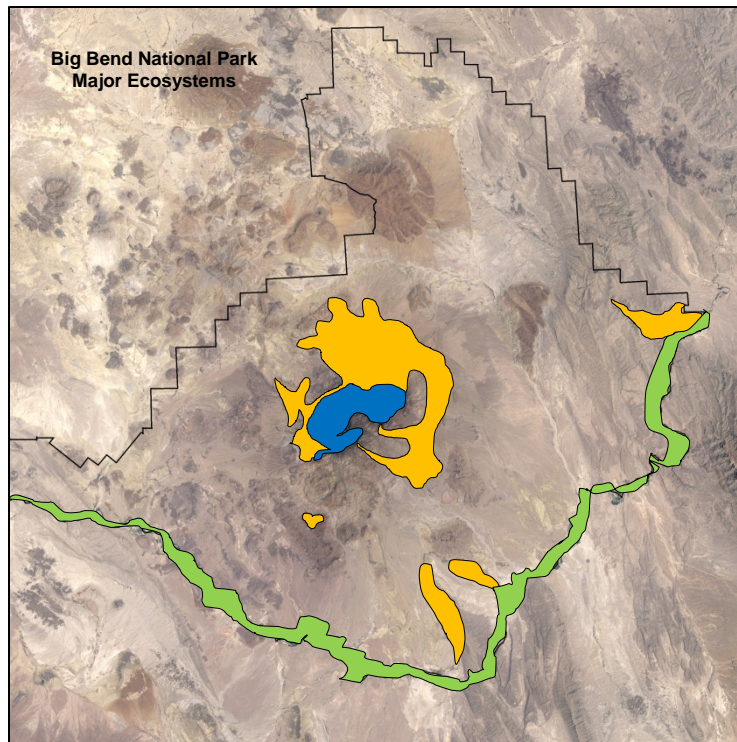


Figure 3-2 Big Bend National Park major ecosystems: river floodplain = ■
 scrub desert = ■ , sotol grassland = ■, and the woodland formations = ■

Major Ecosystems

River Floodplain-Arroyo

The River Floodplain-Arroyo formation is located along the Rio Grande River, spanning BIBE's 291 km southern border with a range in elevation from 548 m to 1219 m. The floodplain adjoins the river's tributaries, reaching deeper into the scrub desert, providing access to water in some of the hottest locations in the park. The mesic soils of this formation support the growth of large producers not found in most desert ecosystems, providing a reliable trophic foundation for primary consumers in addition to valuable cover and for wildlife. Trees observed within the floodplain include two species of cottonwood, *Populus fremonti* and *P. deltoies*; mesquite, *Prosopis juliflora*; huisache,

Acacia farnesiana; Gooding's willow, *Salix gooddingii*; desert willow, *Chilopsis linearis*; and cat claw mimosa, *Mimosa aculeaticarpa*. Common reed, *Phragmites australis*, can also be found immediately adjacent to the river (Wauer & Fleming 2002, Joseph Kuban Jr., personal communication). Unfortunately, as is the case along much of the Rio Grande, invasive salt cedar or tamarisk, *Tamarix pentandra*, can be found in the river floodplain of the park, negatively impacting native vegetation, arthropods, and birds (Moore 2010).

Scrub Desert

The Scrub Desert formation in BIBE comprises 49% of the park and is the largest protected expanse of Chihuahuan Desert in the United States (Figure 3-3). Rainfall averages between 12 and 25 cm, increasing with elevation, which ranges from 548 m to 1066 m in the high desert. The indicator plant of the Chihuahuan Desert is the lecheguilla, *Agave lecheguilla*. It is found exclusively within the boundaries of the Chihuahuan Desert, primarily in the scrub desert and higher elevation grassland ecosystems. Other important plants found in this formation include the creosote bush, *Larrea tridentata*, mesquite, *Prosopis juliflora*, and the tarbush, *Flourensia cernua*, in addition to many species of prickly pear cactus (*Opuntia*) and candelilla, *Euphorbia antispyhilitica*. The lower expanse of the scrub desert formation extends to 609m in elevation and exhibits the characteristics found in the Chihuahuan Desert in Mexico. This portion of the desert is the harshest environment in the park. Lecheguilla dominates this landscape as well as candelilla, red-spined prickly pear, *O. spinosibacca*, and Torrey yucca, *Yucca torreyi*. Important plant species found in mid-elevation desert (609-731 m) include Torrey yucca and creosote as well as Engelmann's prickly pear, *O. engelmannii*. Ocotillo, *Fouquieria splendens*, can be found in the desert from the lowest elevations to higher than 1066 m in the sotol grassland. High elevation desert occurs near the base of

foothills beneath sotol grassland. Shrubs such as creosote grow larger at this elevation range, as do trees such as honey mesquite, *P. glandulosa*, and *Acacia* species (Wauer & Fleming 2002, Joseph Kuban Jr., personal communication).



Figure 3-3 Expanse of mid-elevation scrub desert dominated by creosote, *Larrea tridentata*, leading to the Chisos Mountains. Torrey yucca, *Yucca torreyi*, can be seen in the background. Notice short bunches of grasses in the foreground, which are also dispersed throughout the rest of the scrub desert. The foothills that lead into sotol grassland can be seen faintly between the desert scrub and the Chisos.

Sotol Grassland

At approximately 1066 m, a cline exists between scrub desert and the sotol grassland formation, which extends to approximately 1524 m. Sotol grassland is a transitional ecosystem between the desert and the woodland ecosystems of the Chisos Mountains and associated canyons. Rainfall in this formation averages 20 to 38 cm

annually. The increased precipitation combined with deeper, richer soils allows the sotol grasslands to support a variety of grasses in addition to vegetation not found in lower elevations. The dominant plants in this formation include woody perennials such as sotol, *Dasyllirion leiophyllum* and Texas bear-grass, *Nolina texana*, in addition to annual grasses such as chino grass, *Bouteloua brevifolia*, blue grama, *B. gracilis*, and tobosa grass, *Hilaria mutica*, (Patrick *et al.* 2007, Wauer & Fleming 2002). Creosote also occurs in this ecosystem, as it does through much of the park. Many shrubs are common such as catclaw mimosa and various species of *Acacia* (Joseph Kuban Jr., personal communication).

Pinion-Juniper-Oak Woodland

The pinion-juniper-oak woodland formation (PJO) begins gradually with an ecotonal change from the sotol grassland formation at 1128 m, extending to 2194 m in the Chisos Mountains. Rainfall in this ecosystem ranges from 30 – 40 cm, allowing enough soil moisture to support an extensive forest system. The mountain ecosystems surrounded by desert create a biogeographic island in BIBE, adding to the overall biodiversity of the park and containing species that are found nowhere else in the area. Trees in this formation include both conifers and broadleaf (some deciduous broadleaf) and are much denser on the north and east facing slopes of the Chisos than the west and south facing slopes. Dominant coniferous trees in the PJO woodland include the Mexican pinion pine, *Pinus cembroides*; Arizona yellow pine, *P. arizonica*; weeping juniper, *Juniperus flaccida*; and alligator juniper, *J. deppeana*. Broadleaf trees common in the Chisos Mountains include the Texas madrone, *Arbutus xalapensis*, as well as several species of oak: gray oak, *Quercus grisea*; Emory oak, *Q. emoryi*, and Chisos red oak, *Q. gravesii*. quaking aspen, *Populus tremuloides*, is also found in the PJO woodlands below the highest point in the park, Emory Peak (Wauer and Fleming 2002, Blanche and

Ludwig 2001, Joseph Kuban Jr., personal communication). The mountains and resulting woodland ecosystems provide prime habitat for wildlife not found elsewhere in the park, such as the eastern cottontail and the Carmen Mountains white-tailed deer, *Odocoileus virginianus carminis*. Additionally, the Chisos Mountains provide prime habitat for both mountain lion and black bear, *Ursus americanus*.

Cypress-Pine-Oak Woodland

The cypress-pine-oak woodlands (CPO) are found only in two mountain canyons: Boot Canyon and Pine Canyon. This formation represents the wettest ecosystem in the park, with more than 50 cm of precipitation each year and 100% humidity during the park's rainy season, late July through September. This unusual habitat surrounded by desert is home to trees found nowhere else in the region. The Arizona cypress, *Cupressus arizonica*, is the largest tree in the park and is found only in Boot Canyon, its only location in Texas. The lateleaf oak, *Q. tardifolia* is also found in the CPO woodlands, its only location in the United States. Big tooth maple, *Acer grandidentatum*, is also found in the high canyons of the Chisos Mountains, providing fall color in the park, an unusual site in the desert (Wauer & Fleming 2002, Blanche & Ludwig 2001, Joseph Kuban Jr., personal communication).

Minor Ecosystems

There are several minor ecosystems within BIBE. Most important to this study are the desert springs and mountain waterfalls, as they provide a reliable to semi-reliable source of water for wildlife, bobcats in particular (Raymond Skiles, NPS biologist, personal communication). Major springs include Oak Spring, Dugout Wells, Croton Springs, Mule Ear Springs, and Glenn Springs. Important waterfalls include the Window Pour-off, the pour-off above Pine Canyon, and Cattail Falls (Wauer & Fleming 2002, Joseph Kuban Jr., personal communication).

Potential Prey Base

A variety of vertebrate prey suitable for bobcat consumption inhabit BIBE. Three lagomorph species, eastern cottontail, *Sylvilagus floridanus*, desert cottontail, *S. audubonii*, and black-tailed jackrabbit, *Lepus californicus* are found within park boundaries. Jackrabbits can be found throughout the majority of the park year round up to about 1646 m (Wauer and Fleming 2002). They typically feed on large amounts of grasses and reproduce in response to the combination of increasing photoperiod and the monsoon season (Portales *et al.* 2004). Jackrabbits, while frequently observed in the park during this study, existed in lower numbers than the desert cottontail. Desert cottontails are abundant throughout the riparian and desert scrub formations of the park, but typically are not found higher than 1432 m. They prefer dense vegetation and consume a combination of forbs, grasses, cacti, and mesquite leaves and beans (Phillips and Comus 2014). The eastern cottontail is found in the higher elevations of BIBE, primarily the Chisos Mountains and the sotol grasslands above 1432 m. Eastern cottontails also consume a variety of plant species including grasses, forbs, woody species, and succulents (Chapman *et al.* 1980).

Fifteen species of mice and rats are found in varying abundance throughout the park, including pocket mice (*Chaetopidus* and *Perognathus* sp.), kangaroo rats (*Dipodomys* sp.), deermice (*Peromyscus* sp.), harvest mice (*Reithrodontomys* sp.), wood rats (*Neotoma* sp.), and cotton rats (*Sigmodon* sp.). Squirrels are also found in major ecosystems within the parks. Rock squirrels (*Spermophilus variegatus*) inhabit rocky areas and are typically seen during the day at higher elevations. I observed them frequently in the Chisos Mountains and along the trail to Cattail Falls during both summer and winter field seasons. Ground squirrels are also commonly seen at lower elevations and were observed frequently during both field seasons including: Texas antelope squirrel

(*Ammosperophilus interpres*), Mexican ground squirrel (*S. mexicanus*), and spotted ground squirrel (*S. spilosoma*). Two species of pocket gopher partition spatial niches in the park: Botta's pocket gopher (*Thomomys bottae*) inhabits desert, grassland, and mountain woodland formations while the yellow-faced pocket gopher (*Cratogeomys castanops*) inhabits sandy soils near the river floodplain (Wauer and Fleming 2004).

The most abundant ungulates found within the park are mule deer (*Odocoileus hemionus*) and Carmen Mountains white-tailed deer (*O. virginianus carminis*) plus the porcine species, javelina or collared peccary (*Tayassu tajacu*). Mule deer inhabit the lowland areas near the river and throughout the scrub desert and grassland, they typically do not venture higher than 1524 m in elevation. White-tailed deer are found only in the Chisos Mountains and are a common sight on mountain hikes and in the Basin. They are rarely seen below 1524 m. Javelina inhabit all major ecosystems in the park and are true omnivores and scavengers (Wauer and Fleming 2004). I observed all three species frequently during both field seasons.

Chapter 4

Methods

Field Methods

I collected bobcat scat during two-week long field seasons in BIBE during the hottest time of year, May/June, 2005, and the coolest time of the year, January, 2006 (permit # BIBE-2005-SCI-0034). Scats were identified by size, distinctive shape, and presence of fur (Murie & Elbroch 2005) (Figure 4-1). During both field seasons, I surveyed travel corridors such as trails, back roads, and washes throughout the park in all of the five major ecosystems for scat and tracks (Figures 4-2, 4-3). I hiked >61 km of trails throughout the park, not including washes and wildlife trails off the main trails. I drove >165 km of unpaved and unmaintained back roads in search of scat, and additional wildlife trails and washes to hike in search of scat and other feline sign (tracks, scratch marks, kills sites).

I focused on trails because bobcats typically defecate in two location types: 1) trails or pathways as a communication mechanism for other bobcats (neighbors, transients, potential mates) and 2) latrines near den sites of females with offspring (Kight 1962, Delibes & Hiraldo 1987, Hansen 2007). In areas with adequate cover and water, I searched for bobcat latrines and located two, one near Santa Elena Canyon on the southwestern border of the park and the other near Daniel's Ranch near the river on the eastern side of the park. Moreover, females may use feces to mark territorial boundaries and/or important locations within their home ranges (Provost *et al.* 1973, Bailey 1974).



Figure 4-1 Bobcat scat collected along a wildlife trail near Old Maverick Road, 1/2006. Bobcat scat can be identified by the shape with notable segments, pointed ends, and the presence of copious amounts of fur.



Figure 4-2 Wildlife tracks proceeding through a dry wash in foothills west of the Chisos Mountains, 1/2006. Washes are common corridors for animals in the park and a variety of tracks can be observed.



Figure 4-3 Bobcat pugmarks (forepaws) in the mud along the Rio Grande River at Santa Elena Canyon, 1/2006. Note the absence of claw marks due to the bobcat's retractable claws and the uneven alignment of the two middle toes. Toes are tear-drop shaped and slightly spread out. Two lobes are present along the leading edge of the heel pad, while three lobes are present along the hind edge.

All bobcat scat encountered was collected using small paper bags, which were labeled and placed in sealed plastic bags, which were also labeled. GPS waypoints were taken for each scat collected (Figure 4-4). It was not necessary to dry samples; no fresh scat was encountered and all samples were desiccated upon detection due to the arid conditions of the Chihuahuan Desert. Additionally, all bobcat tracks encountered were photographed, measured, and GPS waypoints recorded in an order to further document presence.

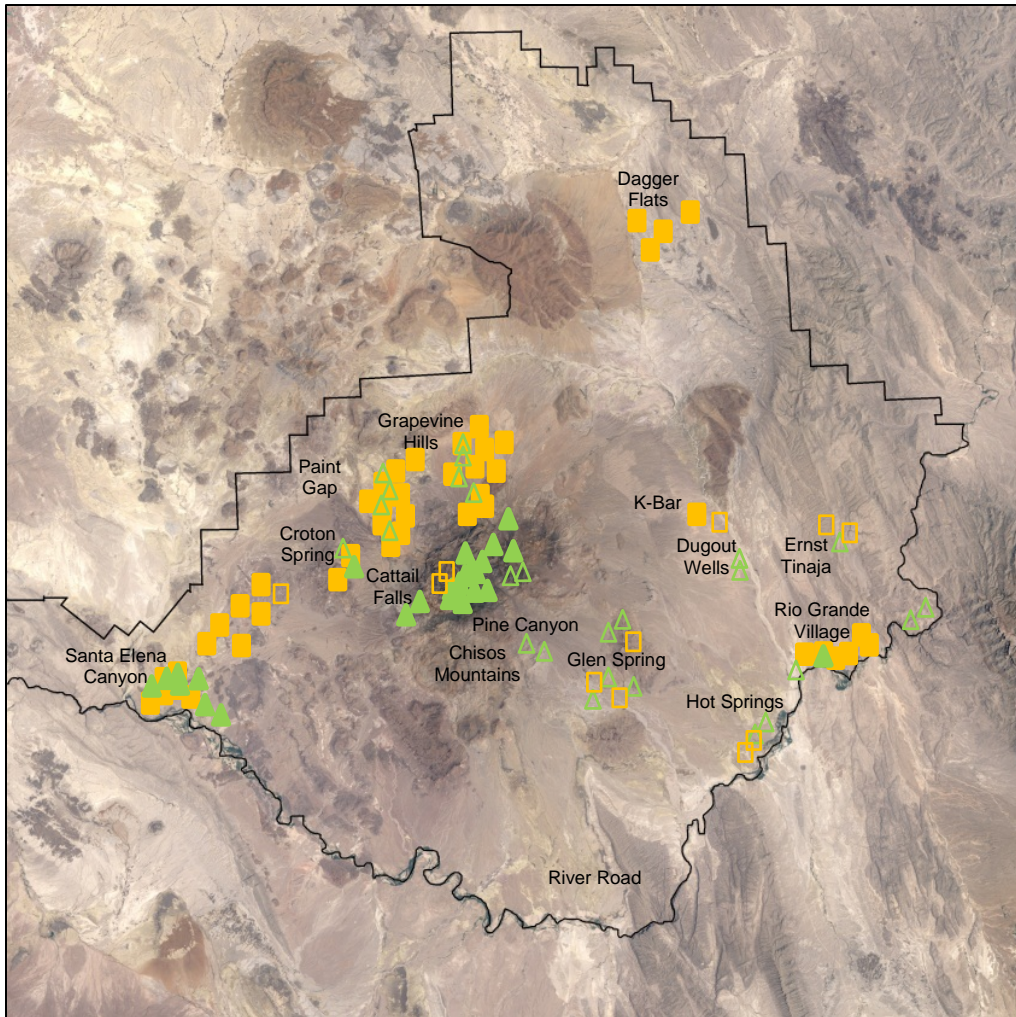


Figure 4-4 Bobcat scats collected per season:

▲ = May/June 2005, not analyzed = △

■ = January 2006, not analyzed = □

Abundances of possible prey species were not quantitatively surveyed due to the number of prey taxa in the park and difficulty in accurate assessment (e.g. trapping was neither practical nor permitted). However, cottontails, jackrabbits, antelope squirrels, ground squirrels, kangaroo rats, deer, javelina, whiptail lizards, and various avian species were sighted regularly on daily and/or nightly outings. The abundance of lagomorphs

and rodents alone created hazardous conditions while driving as they often were alongside or crossing the roadways (personal observation and personal communication, Raymond Skiles, NPS biologist). More desert cottontails were observed than any other species.

Laboratory Methods

All scat samples collected in BIBE were returned to the laboratory at the University of Texas, Arlington for analysis and stored in five gallon buckets at ambient temperature. Each sample was carefully pulled apart while separating hair, bone, and solid matter. I used a lighted magnifying glass and forceps to separate each scat and the prey remains. I sorted and grouped the different hair types in each scat sample and placed groupings of each hair type on slides for microscopic identification. Prey species were then identified by hair using medulla patterns and cuticle scale impressions of guard hairs and underfur (Sessions et al. 2009). The medulla is the central portion of the hair shaft and varies by pattern within and between taxonomic groups. Medulla types vary from simple to compound and homogeneous, to fragmental and nodose (Figure 4-5 – 4-7). Cuticle scales vary in shape and length from imbricate to coronal.

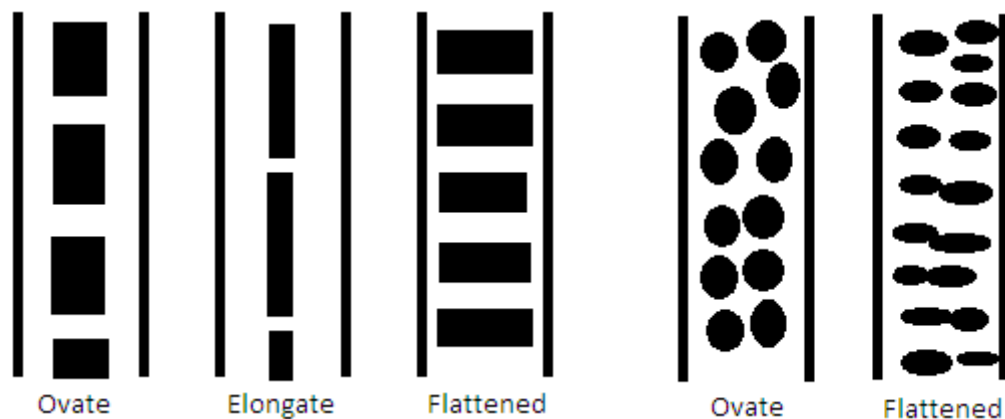


Figure 4-5 Simple medulla patterns, ovate, elongate, and flattened and compound medulla patterns, ovate, and flattened.

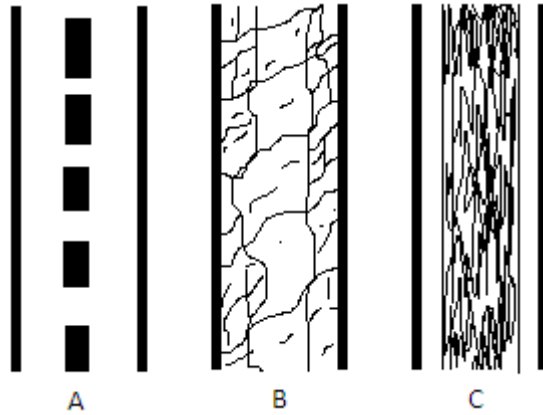


Figure 4-6 Fragmented medulla patterns, A, B, and C.

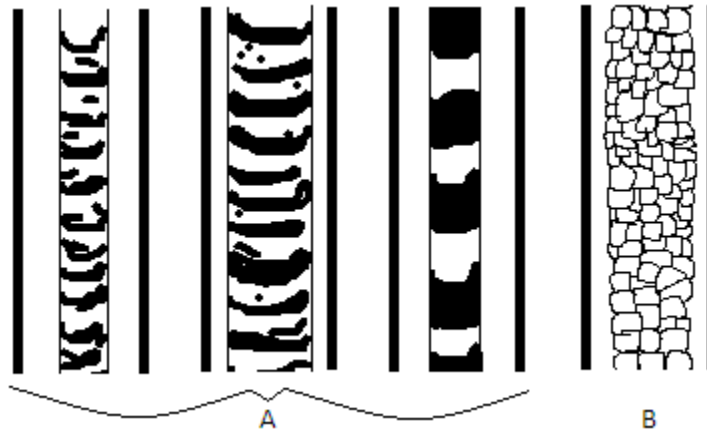


Figure 4-7 Nodose medulla types A and B.

I made cuticle impressions of hair samples using microscope slides and clear nail polish, and then viewed cuticle and medulla patterns through a light microscope at 100x – 400x magnification (Figure 4-8). I identified hair specimens to genus and species in most cases using a dichotomous key for terrestrial mammals in Texas (Debelica and Thies 2009) and comparison to published micrographs and museum specimens (Appendix A).

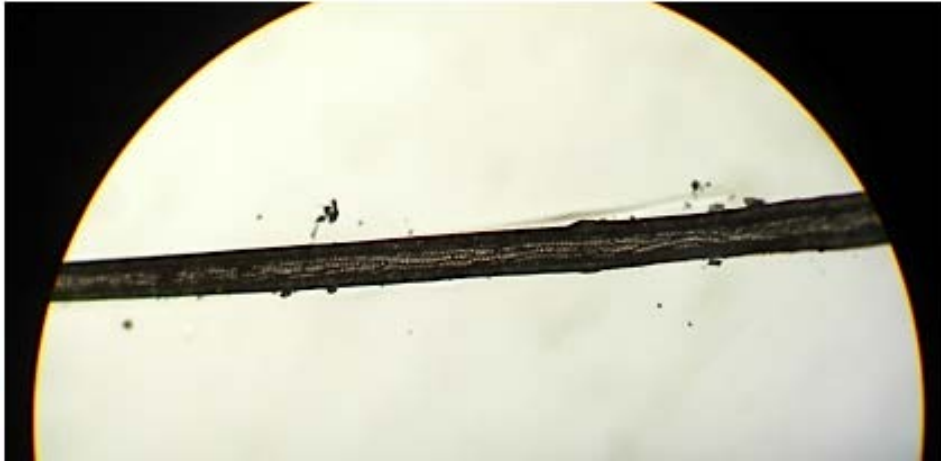


Figure 4-8 Light micrograph (100x) of eastern cottontail, *Sylvilagus floridanus*, fur collected in bobcat scat along Green Gulch in the Chisos Mountains, May 2005.

Note the continuous medulla that occupies the entire hair shaft,
nodose type B, with <6 wavy columns.

Chapter 5

Analysis

A total of 121 scat specimens were collected over the course of both field seasons, of which 42 were lost due to unforeseen circumstances. Of the specimens that remained, 32 were collected during the May field season and 47 were collected during the January field season (Table 5-1). Two samples from the May/June field season were disqualified from analysis; one was mountain lion and the other was coyote, *Canis latrans*. Nine samples were disqualified from analysis during the January field season: two were mountain lion, two were coyote, two could not be confirmed as bobcat during prey analysis, and three did not have GPS points and trail names clearly recorded. Interestingly, the lion scat sample collected in May near the Window Trail in the Chisos Basin contained bobcat claws and hair. The total number of bobcat scats included in analysis was 68; 30 during May/June and 38 during January.

Table 5-1 Number of bobcat scat samples by ecosystem and season.

Ecosystem	May/June	January
Riparian	12	11
Desert	1	27
Sotol	2	-
Woodland	15	-
Total	30	38

Percent and Frequency of Occurrence

Percent occurrence of prey items was calculated by dividing the total number of occurrences of a prey species by the total number of prey species observed, then multiplying by 100. Percent occurrence measures the relative frequencies of prey in the total sample. I calculated frequency of occurrence by multiplying the number of scats that contained a particular prey species by 100 and dividing the result by the total number of

scats I examined. Frequency of occurrence measures the degree of occurrence of individual species in the total sample.

Prey Diversity and Dietary Niche Breadth

I calculated prey species diversity with the Shannon Diversity Index (H'):

$$H' = - \sum p_i (\ln p_i)$$

for May/June, January, and total combined. The index calculates the diversity of a sample where the population size of each species is not known. H' = index of diversity (between 0 and 4, with 4 being the most diverse) and p_i = the proportion of individuals of prey species i (relative abundance) in the sample. Bobcat dietary niche breadth (B_s) was calculated for each season and the total year using the formula:

$$B_s = ((\sum p_i^2) / n - 1)$$

where p_i = the proportion of individuals of prey species i and n is the total number of prey species. B_s ranges between 0 and 1; 0 representing the highest level of specialization and 1 representing the highest level of generalization (Levins 1968, Hurlbert 1978).

Mean Weight of Vertebrate Prey

Mean weight vertebrate prey (MWVP) was calculated as the geometric mean. Average weight for each prey species was obtained from Myers *et al.* (2014). Because large prey items (mule deer, mountain lion) were likely scavenged and not eaten whole, they were not included in MWVP due to potential bias.

Chapter 6

Results

Percent Occurrence and Relative Abundance

Lagomorphs comprised 51% of bobcat diet in May/June with a reduction to 39% in January while other prey increased in frequency from May/June to January: rodents (26% - 33%), birds (3% - 6%), cervids (0 – 2%), javelina (0 – 2%), and chiropterans (0 – 4%). Squirrels/gophers also decreased in occurrence from May/June to January (11% - 4%). Lagomorphs decreased in frequency from May/June to January (60% - 53%), as did squirrels/gophers (13% -5%). Carnivores (Mephitidae and Procyonidae in addition to scavenged coyote and mountain lion) and birds increased slightly (10% -13%, 7% -8%) while cervids, javelina, and chiropterans appeared in scat samples for the first time in January (3%, 3%, and 5% respectively) (Table 6-1). Regarding relative abundance of individual species, desert cottontail ($ra = 0.14$ summer, $ra = 0.29$ winter) and jackrabbit ($ra = 0.17$ summer, $ra = 0.80$ winter), were the most abundant species both seasons. Cactus mouse, *Peromyscus eremicus*, also increased, $ra = 0.80$ in winter.

Table 6-1 Percent and frequency of occurrence of prey groups in May/June and January field seasons.

Species Group	% occurrence		Freq. occurrence	
	May/June N = 30	January N = 38	May/June N = 30	January N = 38
Lagomorphs	51	39	60.00	52.63
Small rodents	26	33	26.67	44.74
Squirrel/Gopher	11	4	13.33	5.26
Carnivores	9	10	10.00	13.16
Birds	3	6	6.67	7.89
Cervids	-	2	-	2.63
Javelina	-	2	-	2.63
Chiropterans	-	4	-	5.26
Total	100%	100%	116.67	135.20

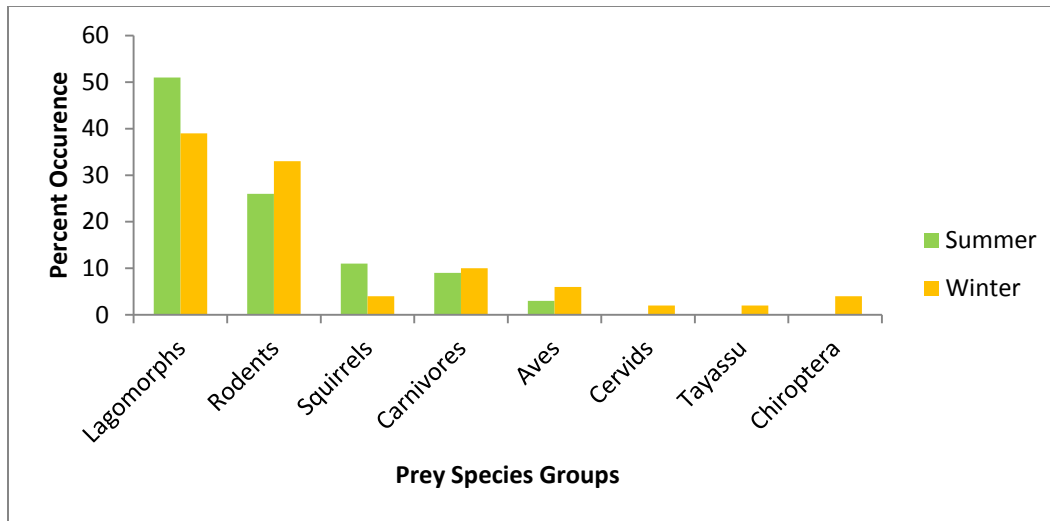


Figure 6-1 Proportions of species groups found in bobcat scat during May/June and January collection periods, May/June 2005 = Summer and January 2006 = Winter.

Table 6-2 Prey Species matrix and key with relative abundance of species during each season in each ecosystem type.

Species	Key	Riparian		Desert		Sotol		Woodland	
		Summer	Winter	Summer	Winter	Summer	Winter	Summer	Winter
<i>Lepus californicus</i>	Lc	0.36	-	-	0.08	-	-	0.06	-
<i>Sylvilagus auduboniia</i>	Sa	0.36	0.14	-	0.16	-	-	-	-
<i>Sylvilagus floridanus</i>	Sf	-	-	-	0.02	-	-	0.41	-
<i>Ammospermophilus interpres</i>	Ai	-	-	0.04	-	-	-	-	-
<i>Spermophilus variegatus</i>	Sv	-	-	-	-	-	-	0.06	-
<i>Thomomys bottae</i>	Tb	-	-	-	-	0.67	-	0.06	-
<i>Chaetodipus species</i>	Cs	-	-	-	0.02	-	-	-	-
<i>Dipodomys merriami</i>	Dm	0.07	-	-	0.02	-	-	-	-
<i>Mus musculus</i>	Mmu	-	-	-	0.02	-	-	-	-
<i>Neotoma albagula</i>	Na	-	-	1	-	-	-	-	-
<i>Peromyscus eremicus</i>	Pe	0.07	-	-	0.08	-	-	0.06	-
<i>Peromyscus maniculatus</i>	Pm	0.02	-	0.04	-	-	-	-	-
<i>Peromyscus pectoralis</i>	Pp	-	-	-	0.02	0.33	-	-	-
<i>Peromyscus species</i>	Ps	-	-	-	0.04	-	-	-	-
<i>Sigmadon hipsis</i>	Sh	0.07	0.06	-	-	-	-	-	-

Table 6-2 -continued.

<i>Sigmadon ochrognathus</i>	So	-	-	-	-	-	0.06	-	-
<i>Odocoileus hemionus</i>	Oh	-	0.02	-	-	-	-	-	-
<i>Tayassu tajacu</i>	Tt	-	-	-	0.02	-	-	-	-
<i>Bassariscus astutus</i>	Ba	-	-	-	-	-	-	0.06	-
<i>Canis latrans</i>	Cla	-	0.02	-	-	-	-	-	-
<i>Conepatus leuconotus</i>	Cle	-	-	-	0.06	-	-	0.06	-
<i>Mephitis mephitis</i>	Mm	-	-	-	-	-	-	0.06	-
<i>Procyon lotor</i>	Pl	-	-	-	0.02	-	-	-	-
<i>Puma concolor</i>	Pc	-	-	-	-	-	-	0.02	-
<i>Myotis</i>	M	-	-	-	-	0.02	-	-	-
Unknown Aves 1	A1	-	-	-	0.02	-	-	-	-
Unknown Aves 2	A2	-	0.02	-	-	-	-	-	-
Unknown Aves 3	A3	-	-	-	0.02	-	-	-	-
Unknown Aves 4	A4	0.07	-	-	-	-	-	-	-
Unknown Chiroptera	Uc	-	0.02	-	-	-	-	-	-
Unknown rodent	Ur	-	-	-	-	-	-	0.06	-

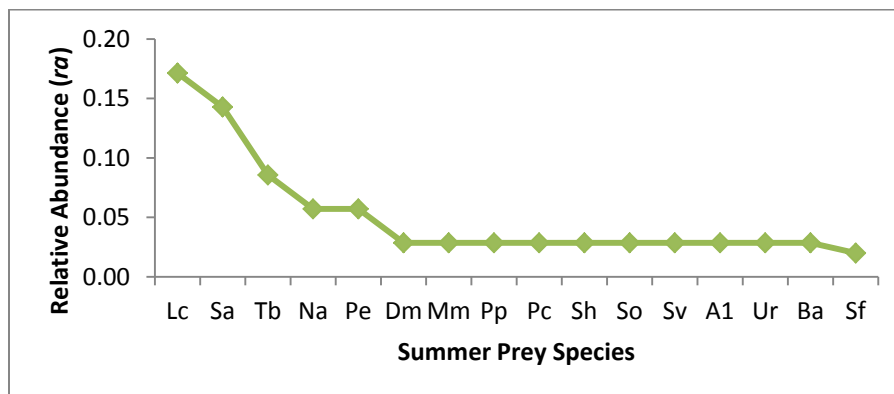


Figure 6-2 Prey species curve by relative abundance for the May/June Summer field season, all ecosystems combined. *Lepus californicus* (Lc) ra = 0.17, *Sylvilagus audubonii* (Sa) ra = 0.14, *Thomomys bottae* (Tb) ra = 0.09, *Neotoma albigula* (Na) and *Peromyscus eremicus* (Pe) ra = 0.06, *Dipodomys merriami* (Dm), *Mephitis mephitis* (Mm), *P. pectoralis* (Pp), *Puma concolor* (Pc), *Sigmadon hispidus* (Sh), *S. ochrognathus* (So), *Spermophilus variegatus* (Sv), unknown birds (A1), unknown rodents (Ur), and *Bassariscus astutus* (Ba) ra = 0.03, *S. floridanus* (Sf) occurred once ra = 0.02.

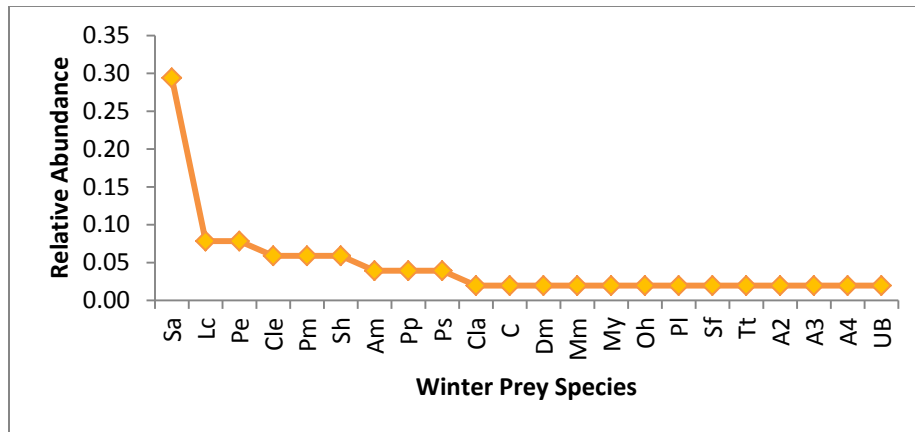


Figure 6-3 Prey species curve by relative abundance for the January Winter field season. *Sylvilagus audubonii* (Sa) $ra = 0.29$, *Lepus californicus* (Lc) and *Peromyscus eremicus* (Pe) $ra = 0.08$, *Onychomys leucogaster* (Cl), *P. maniculatus* (Pm), and *Sigmodon hispidus* (Sh) $ra = 0.06$, *Ammospermophilus interpres* (Ai), *P. pectoralis* (Pp), and *Peromyscus* sp. (Ps) $ra = 0.04$, *Canis latrans* (Cl), *Chaetodipus* sp. (Cs), *Dipodomys merriami* (Dm) *Mephitis mephitis* (Mm), *Myotis* sp. (Ms), *Odocoileus hemionus* (Oh), *Procyon lotor* (Pl), *S. floridanus* (Sf), *Tayassu tajacu* (Tt), unknown birds 2, 3, 4, (A2, A3, A4) and unknown Chiroptera (UB) $ra = 0.02$.

Prey Diversity and Dietary Niche Breadth

For May/June bobcat prey, $H' = 0.22$. For January bobcat prey diversity, $H' = 0.20$. Combined H' for summer and winter was $H' = 0.18$. Differences in prey diversity were not significant between summer and winter (T-test, $P > 0.1$). During the May/June field season, dietary niche breadth was $B_s = 0.53$ (95% CI ± 0.01). In January $B_s = 0.35$ (95% CI ± 0.01). Total $B_s = 33$ (95% CI ± 0.01). Mean weight of vertebrate prey (MWVP) was calculated as the geometric mean. Average weight of each species was obtained from Myers *et al.* (2014). Because large prey items were likely scavenged or not eaten whole, they were not included in MWVP due to bias. MWVP prey in May/June was 94.70g (95% CI ± 0.61), January MWVP = 127.35g (95% CI ± 0.93).

Chapter 7

Discussion

Bobcats are considered to be prey generalists, preying primarily on a variety of lagomorph and rodent species, in addition to deer, birds, non-avian reptiles, and mesocarnivores. In BIBE, bobcats primarily consumed lagomorphs and rodents, as expected, with a higher percentage of lagomorphs consumed for all samples combined (44%). The desert cottontail was the most abundant lagomorph in bobcat scat ($ra = 0.23$), followed by the black-tailed jack rabbit ($ra = 0.12$) and eastern cottontail ($ra = 0.09$). Rodents comprised 28% of scat collected, the cactus mouse, *Peromyscus eremicus*, was the most abundant rodent in combined scat samples, $ra = 0.07$. *Peromyscus* species (*P. eremicus*, *P. maniculatus*, *P. pectoralis*) combined to a total occurrence of 15%, $ra = 0.15$. Other rodents observed included cotton rats, *Sigmodon* species, wood rats, *Neotoma* species, kangaroo rats, *Dipodomys*, species, pocket mice, *Chaetodipus*, and the house mouse, *Mus musculus*. The bobcat's generalist prey strategy is unusual among felids, as most felids are considered to be prey specialists with one or two preferred prey species and one or two secondary prey species, such as the bobcat's close relatives Canada lynx, and Eurasian lynx, *L. lynx* (Molinari-Jobin *et al.* 2007, Squires and Ruggiero 2007). However, even specialist felids may alter prey strategies when faced with reduced abundance of the primary choice. Canada lynx, a snowshoe hare, *Lepus americanus*, specialist, will shift to include squirrel species, *Tamiasciurus hudsonicus* and *Glaucomys sabrinus*, a variety of grouse, least weasel, *Mustela nivalis* and cervids in the most northern and southern parts of their range when hare densities are low (Apps 2000, Mowat *et al.* 2000). The bobcat's lagomorph and rodent preference is evident, and the generalist prey strategy serves them well in an impressive variety of habitats. Diet variation has been documented within and between habitat types over the expanse of

their geographic range. Therefore, my findings are not surprising compared to studies of other Chihuahuan Desert bobcats that show considerable flexibility in choice of prey (likely a consequence of prey abundance and accessibility by habitat and season) (Leopold and Krausman 1986, Harrison 2010).

Prey Variation by Season

From May/June to January, I documented an increase in range of taxa consumed (Table 6-1, Figure 6-1). While bobcats consumed mostly lagomorphs and rodents, they also consumed other carnivores, birds, mule deer, javelina, *Tayassu tajacu*, and bats. Single or low occurrences of mesocarnivore prey such as raccoon, *Procyon lotor*, skunks, *Mephitis mephitis* and *Conepatus leuconotus*, and ringtail, *Bassariscus astutus*, were not surprising and have been observed in other diet studies (McClellan *et al.* 2005, Haas 2009, Harrison 2010). Other small/medium felids are also known to opportunistically take mesocarnivore prey such as Canada lynx (Squirres and Ruggerio 2007). However, mountain lion and coyote, *Canis latrans*, were unexpected and likely scavenged.

Over half of bobcat diet during the May/June field season contained lagomorphs (51%), with a 12% reduction during January (39%). Rodents comprised 26% of May/June diet with an increase to 33% in January. The shift in lagomorph/rodent percentages from summer to winter may have been due to several factors, the two most obvious being rainfall and temperature. A strong possibility is the annual monsoon season in BIBE during August and September. Additional rainfall from late summer into fall has been linked to rodent population growth in the Chihuahuan Desert (Lima *et al.* 2008). An increase in abundance of rodent prey species likely influences overall biodiversity, differences in prey availability, and food webs from the bottom up, which may explain the shift I detected from summer to winter. Temperatures change dramatically in this region

from summer to winter and day to night. The low desert can reach up to 49° during mid-afternoon in May and June while temperatures can drop as low as 4° in the desert and mountains overnight in winter months (typically, the most extreme fluctuations in daily temperature occur in the low desert). However, a shift in both daily and nocturnal temperatures may not be likely to influence bobcat activity in BIBE. Elizalde-Arellano *et al.* (2012) documented that Chihuahuan Desert bobcats in Mexico do not alter their activity patterns based on harsh temperatures.

Prey Variation by Habitat

Also interesting, are the differences in presence/absence in major ecosystems (Table 6-1). During field seasons, scats were collected in every major ecosystem within the park. However, only one scat was detected in Desert Scrub and two in Sotol Grassland during May/June, with the majority of scats collected in riparian and woodland systems. It is unlikely that scat ecosystem abundance is linked to summer temperatures and is likely linked to collection error or lost samples (Elizalde-Arellano *et al.* 2012). The intricate spring system throughout BIBE enables bobcats, and other wildlife, to remain active in throughout the harsher regions of the park (Raymond Skiles, NPS Biologist, personal communication). However, to truly understand bobcat movement, landscape use, and seasonal activity within the park, a study utilizing GPS collars is necessary.

Prey diversity did not differ significantly across ecosystem type and was quite low; May/June $H' = 0.22$, January $H' = 0.20$ ($P > 0.1$). Increasing sample size by combining both seasons resulted in a lower diversity measure ($H' = 0.18$). Despite the increased number of species in January, relative abundance for most species was low, resulting in lower diversity measures. While the low level of diversity was somewhat surprising, it is not entirely unexpected. Although bobcats are prey generalists, they are generalists within a specific predatory niche that is composed almost exclusively of

vertebrate prey. Assessing dietary niche breadth gives a more accurate picture of the bobcat's role as an unexploited predator. My data suggested that dietary niche breadth was higher in the summer ($B_s = 0.53$) than in the winter ($B_s = 0.35$), with the overall dietary niche breadth of $B_s = 33$, being similar to bobcats in Arizona (Hass 2009). Similar to diversity, the low relative abundance of many prey species lowers the overall size of niche breadth. Both diversity and niche breadth measures follow a similar trend, with summer being highest and combined measures being lowest. Additionally, the bobcat's broad niche breadth and ability to capture and consume a variety of vertebrate prey are likely to allow it to survive better when prey resources are scarce than can other felids with narrower foraging niches.

Conclusions

While my data suggest a primary preference for lagomorphs closely followed by rodents, it appears that bobcats may increase consumption of rodents as they become more available following monsoon season (Lima *et al.* 2008). Leopold and Krausman (1986) found BIBE bobcats to include more lagomorphs as mule deer prey became less available. Prior to my study, mule deer density in far west Texas averaged 2.4 mule deer per km^2 (Brunjes *et al.* 2006). This estimate is less than estimated by Leopold and Krausman (1986) 3 – 7/ km^2 depending on site during the latter half of their study when mule deer densities dropped significantly and lagomorphs increased in bobcat diet. It is logical to hypothesize that lagomorphs also become more abundant following monsoon season (Browning personal observation before and during this study and Raymond Skiles, NPS biologist, personal communication). However, the relationship between rainfall and lagomorph abundance is not consistent in the literature. Sowls (1957) found no correlation between rainfall amounts and reproduction rates in desert cottontails in Arizona, while studies that pre-date his work suggest a relationship between rainfall and

reproductive rates of Audobon cottontails and brush rabbits in central California (Mossman 1955, Fitch 1947). The composition of bobcat diets varies both seasonally and spatially. This flexibility is likely to be beneficial as prey type and abundance may be dynamic due to environmental pressures. Therefore, this ecosystem service should not be undervalued by wildlife managers.

Future Work

Four years after data collection, the park began to experience an extreme drought, as did the rest of the region. If prey availability and therefore consumption are linked to rainfall in the park, then it is reasonable to hypothesize that there has been a dramatic impact on bobcat diet during the current drought. More research is needed to determine current food habits of bobcats in the region, changes in dietary niche breadth, long-term effects of the current drought, and implications due to climate change.

Appendix A
Specimens Used for Comparison

Museum specimens used for comparison (hair samples) for prey species in bobcat scat.

Sigmodon hispidus, Hispid Cotton Rat, Male

Arlington State College Vertebrate Museum

Texas, Palo Pinto Co. 15 mi W of Graford

234x98x31.6x17.6

26 Mar 1960, W.F. Pyburn #37

M-173: *Procyon lotor*, Raccoon, Male

Arlington State College Vertebrate Museum

Texas, Tarrant Co. 2 mi E of Fort Worth

760x295x125x67.4

21 Jan 1961, A.G. Cleveland #48

M-82: *Sylvilagus floridanus*, Eastern Cottontail, Male

Arlington State College Vertebrate Museum

Texas, Palo Pinto Co. 5 mi N of dam at Possum Kingdom

400x59x93x55

6 Jan 1962, R.E. Jones, # 2

M-778: *Neotoma albigula*, White-throated woodrat, Male

Texas, Jones Co. 10 mi E of Stamford

386x162x37x51 3777.7

15 Nov 1969, W. Pratt #556

M-1109: *Tayassu tajacu*, Javelina a/k/a Collared Peccary

University of Texas, Arlington, Merriam Museum

Texas, Starr Co. F.M. 2098, 2 mi E of Falcon State Park

13 Mar 1973, S.R. Wylie, J.F. Barrett

M-1544: *Mephitis mephitis*, Striped Skunk, Female

University of Texas, Arlington, Merriam Museum

Texas Bend, Lampasas Co. 2 mi NE

695x319x69.3x29.5 1825

13 Oct 1974, M.W. Rogers, J.R. Glidewell #81

1908: *Neotoma micropus*, Southern Plains Woodrat, Female

University of Texas, Arlington, Merriam Museum

Texas, Corpus Christi

337x146x44x28, 274.6

7 Feb 1977, J.E. Lovell, R.M. Delliings

Appendix B

Micrographs of Medulla Patterns by Species

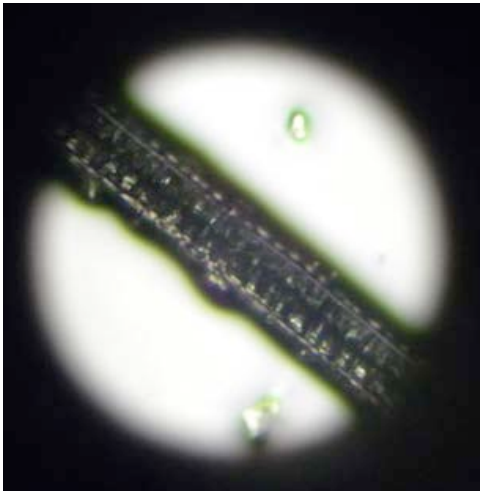
Medulla patterns of prey species observed in bobcat scat specimens.



Canis latrans, Coyote



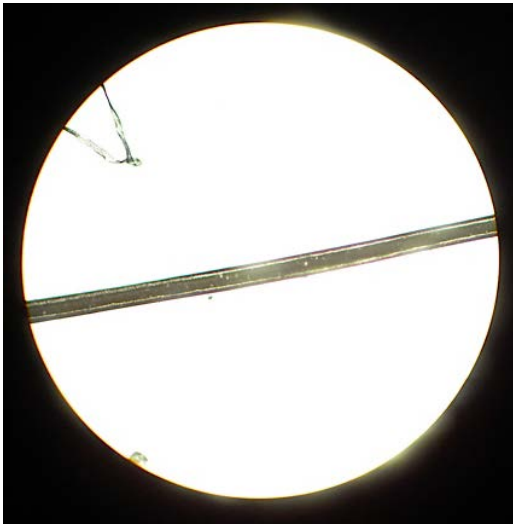
Sylvilagus floridanus, Eastern Cottontail



Sigmodon hispidus, Hispid Cotton Rat



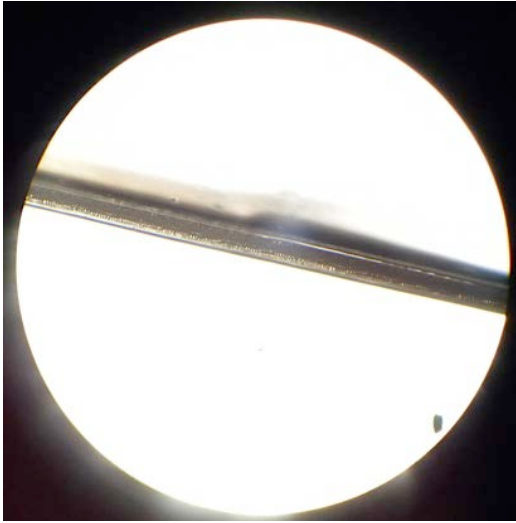
Peromyscus eremicus, Cactus Mouse



Procyon lotor, Common raccoon



Peromyscus pectoralis, White-ankled Mouse



Puma concolor, Mountain Lion

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Biological Information

Ellen Stringer Browning originally began her academic career in the fine arts, earning a Bachelor of Fine Arts degree from Stephen F. Austin State University. Shortly after completion of her BFA, a reassessment of priorities and goals led her to pursue a longtime interest in behavioral ecology academically and professionally. Browning returned to the undergraduate classroom to lay a solid foundation for study in biology, ecology, and behavior. Additionally, she began working as a feline zookeeper to gain hands-on experience with species she intended to study long-term. With two years of science-based undergraduate scholarship behind her, Browning commenced work on her Master of Science degree in Biology with Daniel R. Formanowicz, Jr. at the University of Texas, Arlington (UTA). She completed her M.S. in May of 2004 after finishing her thesis on foraging latencies of captive slender-tailed meerkats, *Suricatta suricatta*, with regards to novel food and natural vs. artificial foraging enrichment regimes at the Dallas Zoo.

A fervor for field biology, the Chihuahuan Desert, and felids led Browning to her doctoral research of bobcats, *Lynx rufus*, in the Big Bend. Two years into her doctoral work, Browning met Dr. Joseph F. Kuban, Jr., a fellow Big Bend researcher and enthusiast who had recently been diagnosed with amyotrophic lateral sclerosis (ALS). While a student in Kuban's Ecology of the Big Bend course at UTA, Browning was asked to take over his Scientific Research & Design: Honors Ecology program at Nolan Catholic High School. Nolan is a college preparatory school in Fort Worth, Texas that boasts the longest running high school ecology program in the United States. Kuban founded the program in 1974, which includes extensive field work and data collection in a variety of ecosystems. Browning accepted this honor and spent six years at the helm of Nolan's nationally and internationally recognized ecology program. In 2013, Browning made the

decision to return to UTA in order to complete her dissertation project on bobcats in the Big Bend.

Future research interests include the effects of drought on bobcat food habits in Big Bend and differences between pre- and post- drought prey selection, bobcat food habits and movements in moderately disturbed habitats, particularly along urban green belts and in minimally developed areas, and bioaccumulation of pollutants in terrestrial carnivores and how pollutants enter and travel through terrestrial food webs.



Gray fox, *Urocyon cinereoargenteus*, near Santa Elena Canyon,
Big Bend National Park 2/2/2008.