# FOOD HABITS AND SELECTIVE FORAGING BY THE TEXAS TORTOISE

# (*GOPHERUS BERLANDIERI*)

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Jonathan L. Scalise, B.A.

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FOOD HABITS AND SELECTIVE FORAGING BY THE TEXAS TORTOISE

(*GOPHERUS BERLANDIERI*)

Committee Members Approved:

Thomas R. Simpson, Chair

Francis L. Rose, Co-chair

John T. Baccus

Approved:

J. Michael Willoughby
Dean of the Graduate College

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**ABSTRACT**

FOOD HABITS AND SELECTIVE FORAGING BY THE TEXAS TORTOISE

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Jonathan Leon Scalise, B.A.

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SUPERVISING PROFESSOR: THOMAS R. SIMPSON

The Texas tortoise (*Gopherus berlandieri*) is a state threatened species occurring in southern Texas. Dietary specifics for this species are not known and are needed for appropriate management and conservation. I collected 51 Texas tortoise fecal samples from 5 different sites from across the distribution during summers of 2007 and 2008. Vegetative analysis was performed at each site using the Daubenmire method (Daubenmire, 1959) to estimate percent cover of each plant species. Later, each species was categorized by forage class (cactus, forb, grass, or woody vegetation) and percent

cover estimates were summed for each forage class. Dietary analysis was performed on fecal material using a microhistological approach. My results varied by study site, but some trends were evident. Forb fragments were identified from 100% of fecal samples, cactus in 98.0 %, grass in 96.0 %, woody vegetation in 92.2%, and animal fragments in 56.9 %. Analysis of data from all sites suggests Texas tortoises forage selectively ($\chi^2_3$ = 875.8, $p < 0.001$) and consume cacti more than expected and grasses less than expected. Male tortoise diets differed significantly ($\chi^2_4$ = 42.1, $p < 0.001$) from female tortoises as males consumed more cacti than females. Adult and juvenile tortoise diets also differed significantly ($\chi^2_4$ = 30.3, $p < 0.001$) where juveniles consumed less grass and more forbs than adults. This information is very valuable as invasive grass species could potentially out-compete native flora. Land management practices by landowners providing forage for Texas tortoises should be considered.

# CHAPTER I

## INTRODUCTION

The Texas tortoise (*Gopherus berlandieri*) occurs south of a line from Del Rio east to San Antonio and north to Rockport in Texas and then south into northern Mexico (Judd and McQueen, 1980). It is the smallest (maximum carapace length = 219 mm) and most sexually dimorphic member of the genus (Judd and McQueen, 1980; Judd and Rose, 1989). Home range estimates for the Texas tortoise vary from 0.45-2.38 ha for males and 0.22-1.40 ha for females (Rose and Judd, 1975). Female Texas tortoises have an average of 3 eggs per clutch and only 1 clutch per season, which is a smaller clutch size than other *Gopherus* species (Judd and Rose, 1989). The life span of Texas tortoises is assumed to be 30-50 years with known individuals living up to 70 years (Judd and Rose, 2000).

The Texas tortoise is listed as state threatened due to low reproductive rates and loss of habitat to agricultural land uses (Rose and Judd, 1982) and has a Global/State rarity ranking of G4/S3 (Texas Parks and Wildlife, http://www.tpwd.state.tx.us/publications/pwdpubs/pwd_pl_w7000_1187a/media/IV.pdf). Judd and Rose (2000) noted the effect of habitat alteration via farming and grazing on Texas tortoise distribution and abundance in the lower Rio Grande Valley of Texas. The desert tortoise (*G. agassizii*) and the gopher tortoise (*G. polyphemus*) are both listed as threatened (U. S. Fish and Wildlife Service, http://ecos.fws.gov/tess_public/pub/listedAnimals.jsp) for similar reasons (Diemer, 1986; Ross, 1986).

Understanding food habits is especially important for conservation and management of at risk species (Huygens et al., 2003; Hernandez et al., 2006). Dietary studies determine which food items an organism consumes and prefers (Ford and Moll, 2004) and the nutritional needs of an organism. Such ecological knowledge assists in understanding life history components such as breeding population fluctuations (Mindell et al., 1987) and species productivity (Bjorndal, 1985). Dietary studies also assist in delineating occupied habitat for target species (Jones et al., 1998) and describe vegetative factors within the organism's habitat (Clark et al., 2001). Many dietary studies have examined the roles of birds (Wutherich et al., 2001), rodents (Compton et al., 1996), monkeys (Clark et al., 2005), and box turtles (Braun and Brooks, 1987) as seed dispersers; and thus, their influence on habitat.

Dietary study methods used for herbivores include direct observation, gross analysis of digestive tract contents, and microhistological analysis of gut contents or fecal material (Moskovits and Bjorndal, 1990). Microhistological analysis was often used for mammalian herbivores such as white-tailed deer (Zyznar and Urness, 1969), cattle (Free et al., 1970), and brush-tailed opossums (Fitzgerald and Waddington, 1979). Similar methods were used to analyze diets of desert tortoises (Van Devender et al., 2002), suggesting this method can also be used to assess the diet of Texas tortoise with equal effectiveness. Auffenberg and Weaver (1969) identified several plant species from Texas tortoise droppings in Cameron County. Holechek et al. (1982) provided a summary of strengths and weaknesses of several of the most common techniques used in dietary analysis.

Little information is available on the free roaming diet of Texas tortoises. Developing knowledge of their dietary habits and food preferences is an important step in understanding ecological and nutritional needs of the species (Jennings, 2002). Ultimately, this will lead to improved management for this state designated threatened species on private lands. This is extremely important because > 97% of Texas lands are privately owned (Texas Center for Policy Studies, http://www.texascenter.org/almanac/Land/LANDCH3P1.HTML). Land management practices such as livestock grazing, brush removal, and tillage practices in farming extensively alters plant communities and might produce negative impacts on tortoise populations. However, Kazmaier et al. (2001a) found no significant effects of livestock grazing on the Texas tortoise population at Chaparral Wildlife Management Area (Chaparral WMA).

My objectives were: 1) collect fecal samples from tortoises; 2) identify food items present in fecal samples; and 3) determine if tortoises foraged selectively and, 4) to determine if there were differences in food habits and forage selection between sexes. I predict Texas tortoises forage selectively.

# CHAPTER II

## METHODS

### Study Area

My study sites were distributed across the distribution of the Texas tortoise within Texas. Sites included privately owned ranches as well as publically owned lands such as the Chaparral WMA (28°19'47.49"N 99°25'2.41"W) in Dimmit and La Salle counties and Las Palomas WMA (26° 7'18.76"N 97°57'25.62"W) in Cameron County (Fig. 1). These areas represent widely disparate habitats inhabited by the Texas tortoise such as the Prosopis-Acacia dominated thornscrub of the Chaparral WMA (Kazmaier et al., 2001a; Kazmaier et al., 2001b) to the coastal grassland prairies and lomas of the Lower Rio Grande Valley (Johnston, 1963). Privately owned ranches included Jones Ranch (28°38'59.40"N 99°30'12.84"W), Dos Venados Ranch (26°36'20.20"N 98°38'47.66"W), and Chaney Lake Ranch (28°56'8.88"N 100° 6'24.47"W) (Fig. 1).

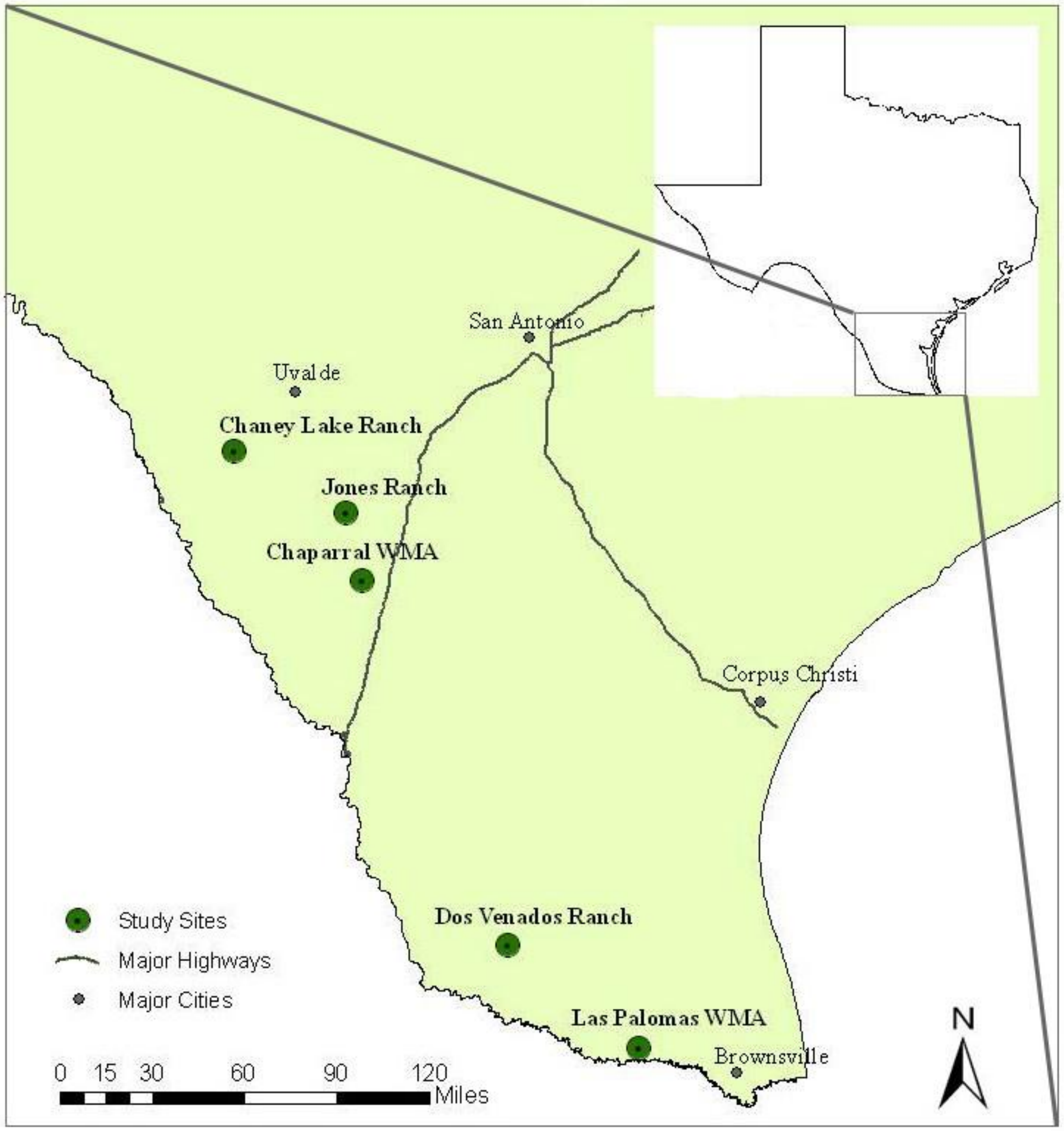


Figure 1. Map of South Texas with locations of five study sites used to collect Texas tortoise fecal material in summers 2007 and 2008. Map created by Melissa D. Fuechec.

## Tortoise Fecal Sample Collection

I searched for Texas tortoises by road cruising ranch roads (Kazmaier et al., 2001b) and incidental searches during summers of 2007 and 2008. I recorded location GPS coordinates, sex, and standard measurements for each tortoise including carapace and plastron lengths, carapace width, shell height, and mass. Males were identified by concave plastrons and more pronounced gular projections and chin glands and it was not possible to identify sex of juveniles. Tortoises were held in individual 1-5 gallon plastic buckets for no more than 24 h in temperature controlled environments until they defecated. I placed fecal samples in zip-lock bags for transport to the lab where they were dried under a ventilation hood to prevent mold. I returned and released tortoises at sites of capture in a shaded area to prevent stress and dehydration.

Handling of tortoises was performed under Texas Parks and Wildlife Scientific Permit # SPR-0993-638 and Texas State University IACUC Permit # 0720_0611_07.

## Fecal Analysis

I washed dried fecal samples through a fine meshed sieve to remove dirt and mucus and to tease apart larger undigested fragments such as seeds or grass blades. I preserved washed fecal samples in glass specimen jars with 70% EtOH. For analysis, I randomly dispersed a preserved fecal sample evenly across a 12.7 x 19.05 cm plastic tray. I used a 5 x 10 line grid with 50 intersecting points beneath the clear plastic tray in a manner similar to the point frame method (Chamrad and Box, 1964). The point frame technique is accurate and more time efficient compared to hand separation (Johnson and Hansen, 1977). I removed plant fragments and other material at each of the 50 line intersections, cleared them with bleach if necessary, and made a slide of the plant materials. I identified the first identifiable epidermal fragment on each slide to the lowest possible taxon with a compound light microscope at up to 400 x magnification (Zyznar and Urness, 1969). I then categorized fragments into one of five forage classes (cactus, forb, grass, woody, or animal). I prepared reference slides of plant fragments by first rehydrating dried plant samples for 24 h in water. I removed epidermal cells by scraping with a razor blade, used bleached to clear remaining interstitial cells, and wet mounted them on a glass slide. I maintained detailed notes on cellular features and digital photomicrographs of epidermal cells for use as a reference alongside a publication with similar plant cell details (Green et al., 1985).

## Vegetative Survey

I surveyed vegetation at each study site using a non-permanent variation of the Daubenmire method (Coulloudon et al., 1999). At randomly selected tortoise capture points, I placed two 50 m transects perpendicular to the road and in opposite directions. When roads were along a property fence line, I placed the two 50 m transects in the same direction and 20-25 m apart. At every 10 m on the 50 m transect, I systematically placed a rectangular, 25 x 100 cm Daubenmire frame (Daubenmire, 1959) on the center line of the transect and estimated percent cover of each species of plant < 1 m in height within the quadrat. Later, I categorized each species as one of four forage classes (cactus, grass, forb, or woody vegetation) and summed the percent cover values for each forage type at each site.

## Use vs. Availability Analysis

I used Pearson's chi-square goodness of fit test to determine if Texas tortoise consumption of plants was selective or used disproportionately to availability (Johnson, 1980). First, I excluded data pertaining to animal fragments from this analysis because there were no comparable measurements made on availability for this forage class. I calculated the proportion of all other forage classes by dividing the percent cover of the forage class by the total percent cover of all forage classes. This was also done individually for Chaparral WMA and Jones Ranch, but not for the other sites due to small sample sizes. Next, I multiplied these proportions by the total number of fragments from all four vegetative forage classes to calculate the expected number of fragments from each forage class. I used Pearson's chi-square goodness of fit test in program R (R Development Core Team, Vienna, Austria) to compare the expected number of fragments for each forage class to the total observed number of each forage class (Neu et al., 1974) to test the null hypothesis that usage is not different from availability.

I calculated individual confidence intervals for each forage type found in the fecal material to determine if forage types were used in proportion to their availability at each study site. Neu et al. (1974) suggested using Bonferroni adjustment to the z statistic when estimating significance for more than one parameter simultaneously. Bonferroni adjusted 95% family of confidence intervals were calculated to determine if individual forage types were used more or less at each study site. If the expected proportion of fragments of forage type fell within the confidence intervals of the used proportion of fragments, then that forage type was used as expected. However, if the expected proportion fell below the confidence intervals, the forage type was used more than expected and if the expected proportion was greater than the confidence intervals then the forage type was used less than expected. Since I needed to maintain a 95% family of confidence intervals and estimate four parameters simultaneously, I adjusted my significance level of $\alpha = 0.05$ using $\alpha/k$, where $k$ is the number of simultaneous estimates being made. The corrected $\alpha$ was 0.0125 which means my adjusted z statistic was 2.5.

I also calculated Manly's alpha preference indices for each forage class observed at each study site (Krebs, 1999). I then compared $\alpha$ to $1/m$ where $m$ is the number of forage classes to determine if a forage class was preferred or avoided. According to Manly's alpha, if alpha is larger than $1/m$ then that forage class is preferred and if smaller then it was avoided (Krebs, 1999). I used four forage classes so any forage class with an alpha > 0.25 was considered preferred and < 0.25 was considered avoided.

## Differences by Sex and Age Class

I used a chi-square goodness of fit test to determine if use was significantly different between males and females. I also used a chi-square goodness of fit test on all male and female usage data compared to juvenile usage data to determine if use between adults and juveniles was significantly different.

# CHAPTER III

## RESULTS

### Fecal Analysis

I collected and analyzed 51 tortoise fecal samples (Table 1). The combined data from all tortoises showed forbs occurred most often (36.7% of all identified fragments), followed by cactus (28.0%), grass (20.8%), and finally woody vegetation (8.71%) in the diet (Table 2). Non-plant material including mammal hairs, insect pieces, snail shells and even a small feather made up 5.76% of the identified fragments from fecal material. These were documented but excluded from the analysis. Of the 51 fecal samples analyzed, 29 had at least one fragment identified as animal origin (Table 3) but generally in low amounts, as only four of those 29 made up for 38.8% of animal fragments documented in Texas tortoise fecal samples.

Use by site at Chaparral WMA, Jones Ranch, and Chaney Lake Ranch was generally consistent with the overall results (Table 3). At Dos Venados Ranch, grass was observed more often than cactus (23.0% to 13.4%) (Table 3) and at Las Palomas Ranch grass was observed more than forbs and cactus (48.7% to 28.0% and 14.7%, respectively) (Table 3).

Table 1. Summary of the number of Texas tortoise fecal samples collected by study site in 2007 and 2008 and categorized by sex and age.

| Study Site | Female | Male | Juvenile | Total |
|---|---|---|---|---|
| Chaparral WMA | 13 | 7 | 4 | 24 |
| Jones Ranch | 9 | 5 | 2 | 16 |
| Chaney Lake Ranch | 1 | 1 | 1 | 3 |
| Dos Venados Ranch | 1 | 1 | 3 | 5 |
| Las Palomas WMA | 1 | 2 | 0 | 3 |
| | | | | |
| All Sites | 25 | 16 | 10 | 51 |

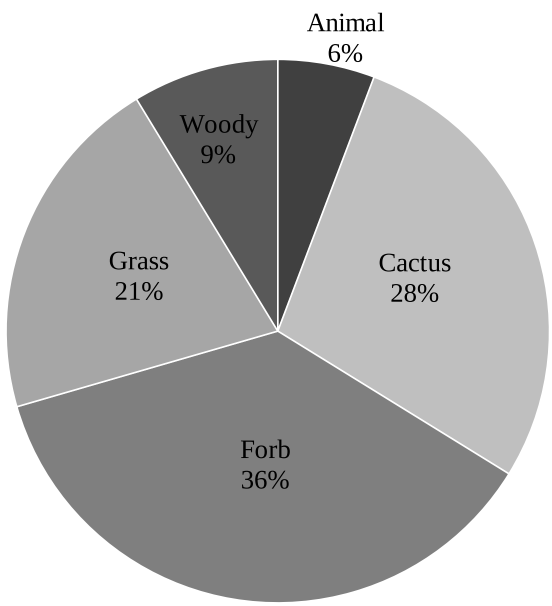


Figure 2. Percent composition of forage classes found in Texas tortoise fecal material at all study sites combined in 2007 and 2008.

Table 2. Proportions of forage classes observed in fecal samples of Texas tortoises and forage class availabilities by study site. With 95% confidence intervals forage classes were defined as used more than expected (M), less than expected (L), or as expected (-).

| Study Site | Forage Class | Observed Use (In Diet) | Observed Use Proportions | Expected Use Proportions | Expected Use (Availability) | 95% Family Confidence Interval of Observed Proportion | Used More or Less than Expected |
|---|---|---|---|---|---|---|---|
| Chaparral | Cactus | 387 | 0.337 | 0.011 | 13.01 | $0.302 < p < 0.372$ | M |
| WMA | Forb | 439 | 0.382 | 0.418 | 480.56 | $0.346 < p < 0.418$ | L |
| | Grass | 200 | 0.174 | 0.566 | 650.0 | $0.146 < p < 0.202$ | L |
| | Woody | 123 | 0.107 | 0.005 | 5.42 | $0.084 < p < 0.130$ | M |
| | Total | 1149 | | | 1149 | | |
| Jones Ranch | Cactus | 242 | 0.318 | 0.020 | 15.5 | $0.276 < p < 0.361$ | M |
| | Forb | 280 | 0.368 | 0.318 | 241.6 | $0.325 < p < 0.412$ | M |
| | Grass | 176 | 0.232 | 0.575 | 437.1 | $0.193 < p < 0.269$ | L |
| | Woody | 62 | 0.082 | 0.087 | 65.8 | $0.057 < p < 0.106$ | - |
| | Total | 760 | | | 760 | | |
| Chaney Lake | Cactus | 35 | 0.276 | 0.034 | 4.31 | $0.176 < p < 0.375$ | M |
| Ranch | Forb | 51 | 0.402 | 0.387 | 49.2 | $0.293 < p < 0.510$ | - |
| | Grass | 31 | 0.244 | 0.491 | 62.4 | $0.149 < p < 0.339$ | L |
| | Woody | 10 | 0.079 | 0.088 | 11.2 | $0.019 < p < 0.138$ | - |
| | Total | 127 | | | 127 | | |
| Dos Venados | Cactus | 29 | 0.134 | 0.003 | 0.57 | $0.076 < p < 0.191$ | M |
| Ranch | Forb | 124 | 0.571 | 0.687 | 149.2 | $0.487 < p < 0.655$ | L |
| | Grass | 50 | 0.230 | 0.126 | 27.4 | $0.159 < p < 0.302$ | M |
| | Woody | 14 | 0.065 | 0.184 | 39.9 | $0.023 < p < 0.106$ | L |
| | Total | 217 | | | 217 | | |
| Las Palomas | Cactus | 22 | 0.147 | 0.027 | 4.02 | $0.075 < p < 0.219$ | M |
| WMA | Forb | 42 | 0.280 | 0.384 | 57.6 | $0.188 < p < 0.372$ | L |
| | Grass | 73 | 0.487 | 0.563 | 84.4 | $0.385 < p < 0.589$ | - |
| | Woody | 13 | 0.087 | 0.027 | 4.02 | $0.029 < p < 0.144$ | M |
| | Total | 150 | | | 150 | | |
| All Sites | Cactus | 715 | 0.298 | 0.014 | 33.7 | $0.274 < p < 0.321$ | M |
| | Forb | 936 | 0.390 | 0.409 | 983.0 | $0.365 < p < 0.414$ | - |
| | Grass | 530 | 0.221 | 0.495 | 1189.8 | $0.199 < p < 0.242$ | L |
| | Woody | 222 | 0.092 | 0.082 | 196.5 | $0.078 < p < 0.107$ | - |
| | Total | 2403 | | | 2403 | | |

Table 3. Percent occurrence of forage classes found in Texas tortoise fecal samples at five study sites in south Texas in 2007 and 2008.

| Study Site | Forage Type | Occurrence | Samples Analyzed | Percent Occurrence |
|---|---|---|---|---|
| Chaparral WMA | Animal | 13 | 24 | 54.2 |
| | Cactus | 25 | 24 | 104.2 |
| | Forb | 24 | 24 | 100.0 |
| | Grass | 22 | 24 | 91.7 |
| | Woody | 23 | 24 | 95.8 |
| Jones Ranch | Animal | 8 | 16 | 50.0 |
| | Cactus | 16 | 16 | 100.0 |
| | Forb | 16 | 16 | 100.0 |
| | Grass | 16 | 16 | 100.0 |
| | Woody | 15 | 16 | 93.8 |
| Chaney Lake Ranch | Animal | 3 | 3 | 100.0 |
| | Cactus | 3 | 3 | 80.0 |
| | Forb | 3 | 3 | 100.0 |
| | Grass | 3 | 3 | 100.0 |
| | Woody | 3 | 3 | 80.0 |
| Dos Venados Ranch | Animal | 5 | 5 | 100.0 |
| | Cactus | 4 | 5 | 100.0 |
| | Forb | 5 | 5 | 100.0 |
| | Grass | 5 | 5 | 100.0 |
| | Woody | 4 | 5 | 100.0 |
| Las Palomas WMA | Animal | 0 | 3 | 0.0 |
| | Cactus | 3 | 3 | 100.0 |
| | Forb | 3 | 3 | 100.0 |
| | Grass | 3 | 3 | 100.0 |
| | Woody | 2 | 3 | 66.7 |
| All Sites | Animal | 29 | 51 | 56.9 |
| | Cactus | 50 | 51 | 98.0 |
| | Forb | 51 | 51 | 100.0 |
| | Grass | 49 | 51 | 96.1 |
| | Woody | 47 | 51 | 92.2 |

## Forage Availability

Grasses and forbs made up 91% of available forage cover at all sites combined (Fig. 3). Forbs and grasses also had the largest percent cover at all sites excluding Dos Venados Ranch, where grass (13%) was less than woody vegetation (18%) (Table 3). Woody vegetation had a higher canopy cover than cactus at all sites except Chaparral WMA, where cactus (1.1%) was more abundant than woody vegetation (0.5%) and Las Palomas WMA, where cactus and woody vegetation were equal in coverage (3%) (Table 3).

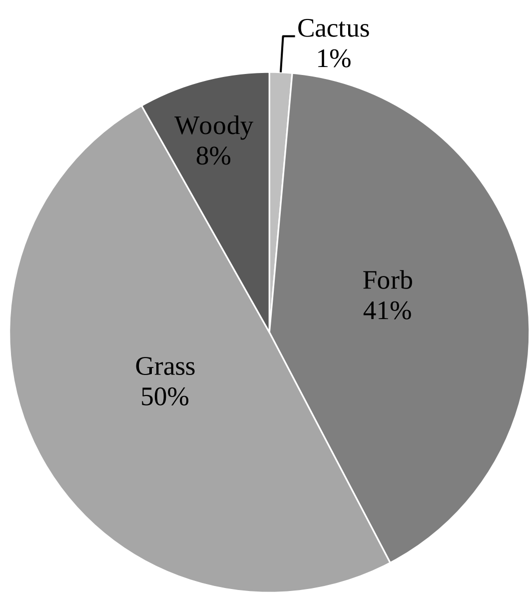


Figure 3. Percent cover of forage classes available at all study sites combined.

## Use vs. Availability Analysis

I compared Texas tortoise use of forage classes to the availability of each forage class to determine if they fed selectively. Pearson's chi-square analysis showed that use and availability were significantly different (Table 4). The null hypothesis of proportional use and availability was rejected for all sites combined and for both sites individually analyzed.

Texas tortoises from all sites combined used cactus significantly more than expected, grass significantly less than expected, and forbs and woody plant species were used as expected ($\chi^2_3 = 875.8$, $p < 0.001$) (Fig. 4). Results of Pearson's chi-square test of independence showed used and availability differed significantly at Chaparral WMA ($\chi^2_3 = 697.5$, $p < 0.001$) and Jones Ranch ($\chi^2_3 = 313.4$, $p < 0.001$). At every individual site cactus was used more than expected (Table 3, Fig. 5-9). Grass, however, was only used as expected at Las Palomas WMA, slightly less than expected at Dos Venados Ranch, and more than expected at the other sites (Table 3, Fig. 5-9). Observed use of woody vegetation did not vary significantly from expected use at Jones and Chaney Lake Ranches, slightly more than expected at Chaparral WMA and Las Palomas WMA, and less than expected at Dos Venados Ranch (Table 3, Fig. 5-9).

Results of the Manly's α preference index were generally consistent with the inference of 95% confidence intervals. The Manly's α preference index did disagree on the use of forbs at Jones Ranch suggesting forbs were avoided (Table 4); whereas, the confidence intervals of the observed use for this forage class were above availability which would suggest it was used more than expected (Table 3). Manly's α preference index also indicated avoidance of several other forage classes (Table 4) when considered used in proportion to availability by the confidence intervals (Table 4).

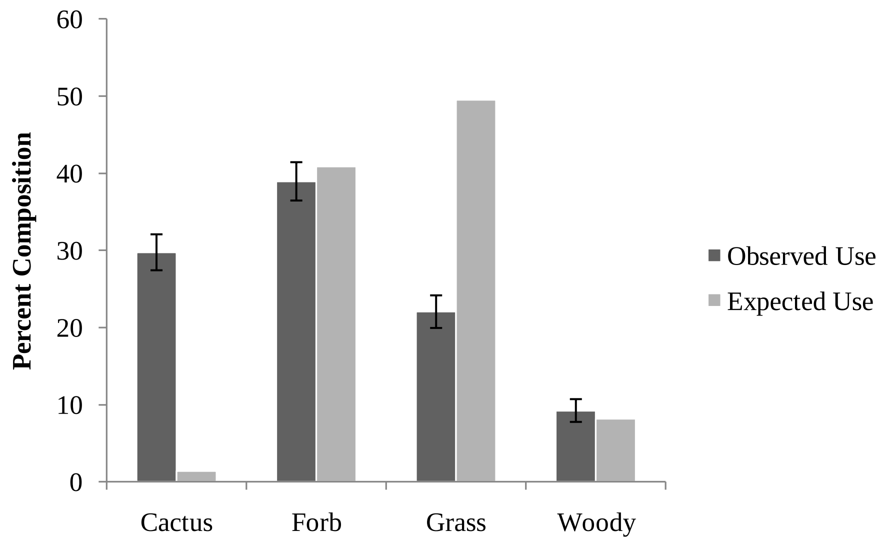


Figure 4. Percent composition of used and available forage classes at all study sites combined shown with Bonferroni adjusted 95% family of confidence intervals.

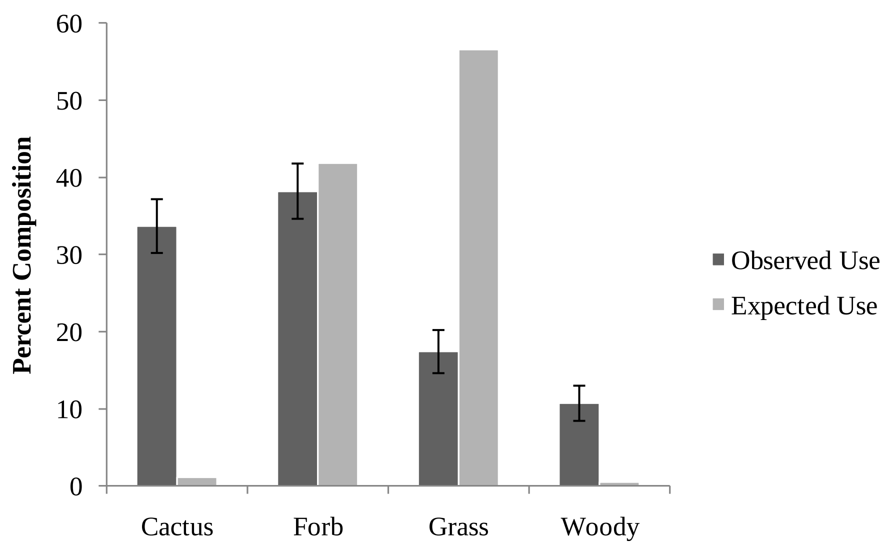


Figure 5. Percent composition of used and available forage classes at Chaparral WMA shown with Bonferroni adjusted 95% family of confidence intervals.

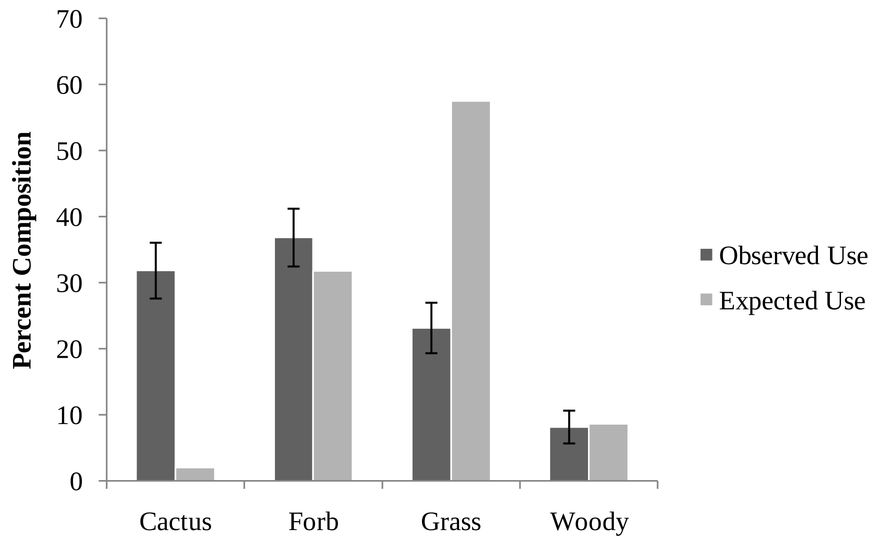


Figure 6. Percent composition of used and available forage classes at Jones Ranch shown with Bonferroni adjusted 95% family of confidence intervals.

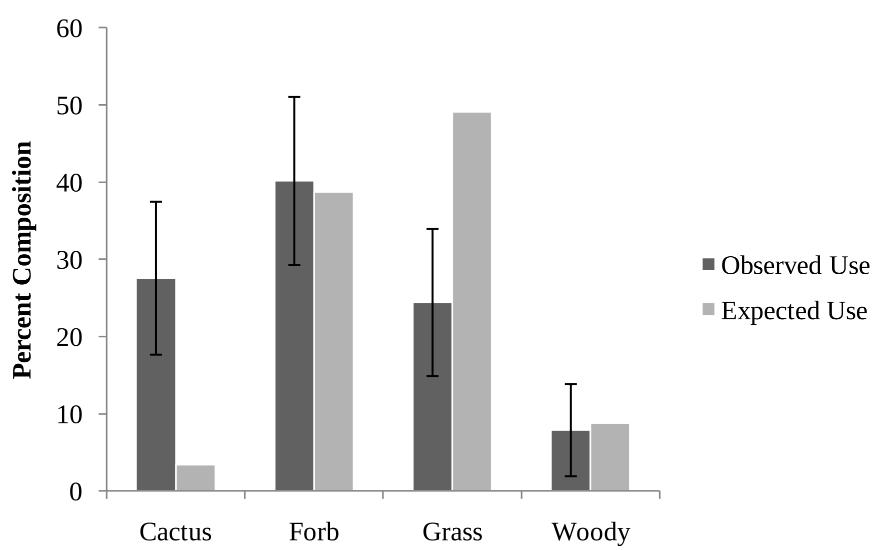


Figure 7. Percent composition of used and available forage classes at Chaney Lake Ranch shown with Bonferroni adjusted 95% family of confidence intervals.

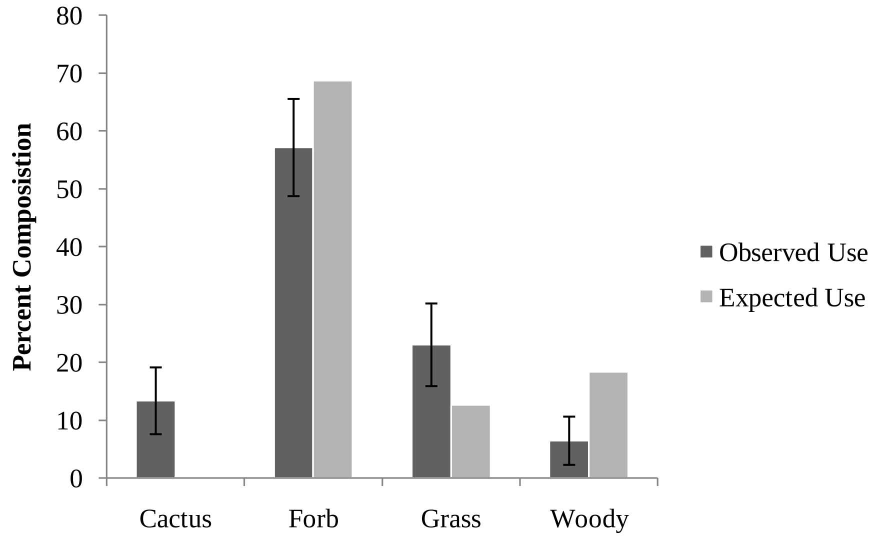


Figure 8. Percent composition of used and available forage classes at Dos Venados Ranch shown with Bonferroni adjusted 95% family of confidence intervals.

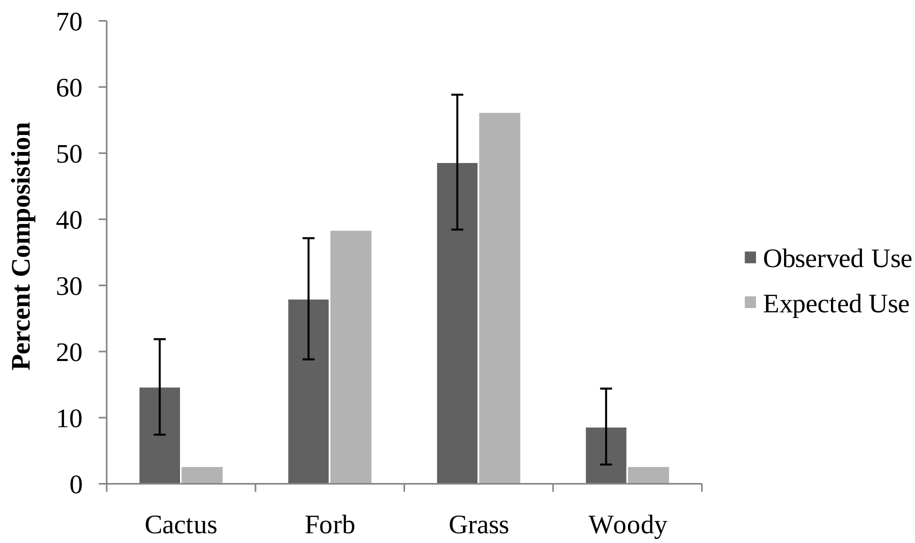


Figure 9. Percent composition of used and available forage classes at Las Palomas WMA shown with Bonferroni adjusted 95% family of confidence intervals.

Table 4. Manly's α and use of food items defined as preferred (P) if α > 0.25 or avoided (A) if α < 0.25.

| Forage Class | Chaparral WMA | | Jones Ranch | | Chaney Lake Ranch | | Dos Venados Ranch | | Las Palomas WMA | | All Sites | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | α | Use | α | Use | α | Use | α | Use | α | Use | α | Use |
| Cactus | 0.554 | P | 0.862 | P | 0.770 | P | 0.944 | P | 0.531 | P | 0.894 | P |
| Forb | 0.017 | A | 0.064 | A | 0.098 | A | 0.015 | A | 0.071 | A | 0.040 | A |
| Grass | 0.006 | A | 0.022 | A | 0.047 | A | 0.034 | A | 0.084 | A | 0.019 | A |
| Woody | 0.423 | P | 0.052 | A | 0.085 | A | 0.007 | A | 0.314 | P | 0.048 | A |

## Differences by Sex and Age Class

I identified 850 fragments from male tortoises, 1,200 from females, and 500 from juvenile tortoises. The diet of males differed significantly from females ($\chi^2_4 = 42.1$, $p < 0.001$). Male tortoise fecal samples had 2.12% animal fragments, 33.9% cactus, 36.2% forb, 19.7% grass and 8.1% woody (Fig. 10). Female fecal samples had 6.83% animal fragments, 24.8% cactus, 35.2% forb, 24.2% grass and 9% woody (Fig. 10). Dietary differences between adult and juvenile tortoises were also significant ($\chi^2_4 = 30.3$, $p < 0.001$). Juvenile tortoises had 9.4% animal fragments, 25.8% cactus, 41.2% forb, 14.6% grass and 9% woody (Fig. 10).

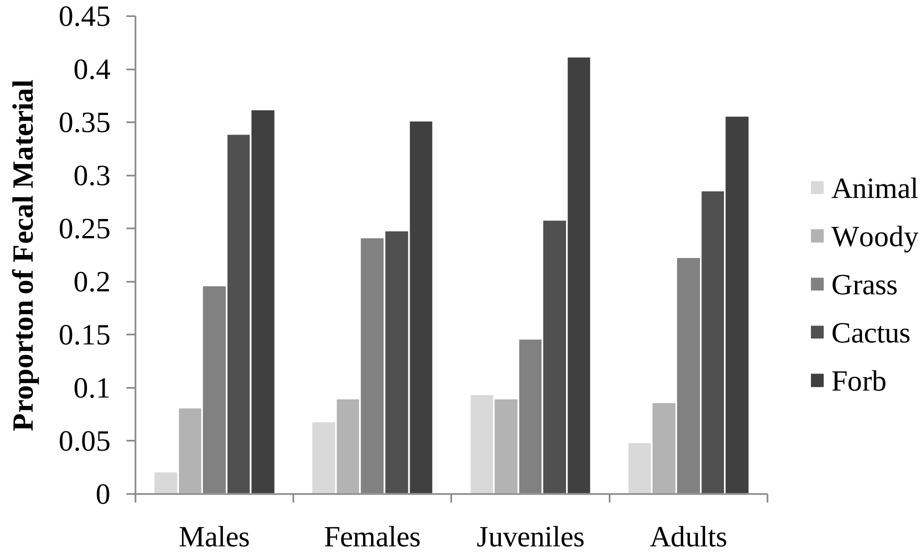


Figure 10. Proportions of forage classes found in Texas tortoise fecal material for males, females, juveniles and adults. Data for adults are the combination of male and female data and is compared to juveniles.

# CHAPTER IV

## DISCUSSION

Based on the results of the chi-square test, I rejected the null hypothesis that expected and observed frequencies of forage classes consumed by Texas tortoises do not differ. These results are consistent with what is known about congeners of the Texas tortoise. Desert tortoises are selective foragers (Nagy et al., 1998; Jennings, 2002) and gopher tortoises are considered local specialists (MacDonald and Mushinsky, 1988) similar to Texas tortoises being selectively foragers.

Overall, cactus was a selected forage item being consistently selected for out of proportion to availability at all study sites. Also, cactus made up a large portion of fecal materials (28%) and occurred in > 98% of the fecal samples suggesting cactus is an important food item for Texas tortoises. Auffenberg and Weaver (1969) described the importance of prickly pear (*Opuntia* spp.) pads and fruits for Texas tortoises. Manly's alpha preference index also suggests that cactus is a preferred forage class consistently at each site and all sites combined.

Forbs were eaten within proportion to availability at all sites combined (Fig. 4) and Manly's alpha preference index suggests forbs were avoided. However, forbs were the only forage class that occurred in 100% of fecal samples and made up the largest portion of fragments found in the fecal material (36.7%), highlighting the importance of forbs as a food item. Also, at Jones Ranch, Texas tortoises selectively foraged for forbs.

Potentially, small sample sizes at three study sites could have influenced the importance of forbs in Texas tortoise diets. Juvenile gopher tortoises were found to negatively select grasses when forbs were readily available (Mushinsky et al., 2003). My data suggest that Texas tortoises are avoiding grasses because they composed > 49% of the available forage but only 20.8% of the identified fecal materials. The Manly's alpha for grass from all sites combined was 0.019, which was smaller than all other forage classes and much smaller than 0.25 meaning it was greatly avoided. Results for woody vegetation were not consistent but were never highly avoided or preferred.

The Texas tortoise is anecdotally considered a strict vegetarian and yet there were several instances of animal fragments found in fecal material. Samples with only a few observations of animal fragments are likely due to accidental ingestion. Samples with many observations could be due to coprophagy by tortoises. Auffenberg and Weaver (1969) noted seeing Texas tortoises eating feces of Texas tortoises and other animals and found animal fragments in tortoise feces. Macdonald and Mushinsky (1988) found 75% of 63 gopher tortoise fecal samples contained insect parts which they believe suggested intentional ingestion for nutrients. Coprophagy by tortoises could affect the results of the selectivity analysis because if tortoises are consuming feces of other animals they could be eating both plant and animal parts previously selected by another animal, and it may be beneficial to remove samples with large incidences of animal fragments from the analysis entirely. Also, direct observation of tortoises could provide more information on the extent to which tortoises perform coprophagy.

The vegetative sampling method I used may be inadequately portraying the proportions of plants available to tortoises. For example, *Opuntia* species typically have patchy growth and may not occur within frames placed every 10 m on transects, or may be completely missing from the transect entirely. This could cause cactus to be under-represented in vegetative data in comparison to other forage types. It may be possible to increase confidence by using more transects. Alternative vegetative sampling methods could also be used to better estimate the presence and abundance of woody species such as the line intercept method or the quadrat method.

Another potential source of error that should be addressed is differential digestibility. Differential digestibility produces a problem in that easily digested items are underestimated and less easily digested items are over estimated when examining fecal contents (Neal et al., 1973). This is an often encountered problem and correction coefficients could more accurately estimate diet (Brand, 1978), but Gill et al. (1983) predicted correction coefficients will not consistently improve estimates when diets contain a diversity of species within forage classes. Other types of dietary studies could further the advancement of what we know about Texas tortoise diet. A cafeteria style study could emphasize tortoise selection between specific species of plants or forage types, but would be difficult to accurately portray the immense potential food choices available to free roaming tortoises. A direct observational study could provide information unattainable by other types of studies. Observational studies paired with fecal analysis could determine if certain species consumed are completely digested and therefore unrepresented in fecal matter and could determine the extent of coprophagy.

It is important to determine if differences in Texas tortoise food habits exist throughout their active season. Temporal variation in diet has been seen in giant Alcedo tortoises (*Geochelone elephantopus vandenburghi*) (Fowler De Neira and Johnson, 1985) and desert tortoises (Jennings, 2002). There is potential for seasonal differences in tortoise diet as precipitation rates change and affect the availability of forage plants. Similarly, there is potential for differences between drought years and non-drought years. More long-term data should be collected to assess these differences.

Despite potential problems associated with fecal analysis, this study provides a wealth of information on tortoise diets and opens doors to future studies. Judd and Rose (2000) drew attention to the need for more intensive studies from other sites as most of what we know about Texas tortoises comes from three sites in Cameron County, and one site in La Salle and Dimmit Counties (Chaparral WMA).

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## VITA

Jonathan (Jonny) Scalise was born in Houston, Texas to Jim and Jo Scalise. He graduated from Bellaire High School and enrolled at Texas State University-San Marcos in 2003. He received his Bachelor of Arts in Wildlife Ecology with a minor in Photography in May of 2007. Immediately upon graduating he began thesis field work as a graduate at Texas State University-San Marcos. While in graduate school he worked as a research assistant on several projects including surveying pecan tree recruitment on the Edwards Plateau and urban nest site selection by Western kingbirds. He worked as an instructional assistant and as lead IA for Functional Biology Lab. He was awarded the Texas State Celebrity Classic Scholarship in 2009. Jonny also served as an officer for the Student Chapter of the Wildlife Society at Texas State and the Biology Graduate Student Organization and was very active in other university organizations including Tri Beta Biological Honor Society and the Bobcat Botany Club.

Permanent Address: 517 Harvey Street

San Marcos, Texas 78666

This thesis was typed by Jonathan L. Scalise.