ABSTRACT

Effects of Suburban Development on Lizard and Snake Assemblies in Central Texas

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A common threat to biological communities is habitat degradation, particularly in urban areas. Snakes and lizards (squamates) play significant roles in many ecosystems and may be limited by a variety of thermal conditions, habitat structures, and predator/prey abundance, which can all be altered by increased urbanization. The goal of this study is to compare variation in abundance, morphology, and habitat-use among various squamate species and locations with varying degrees of urbanization. I will use a multivariate regression and quantile regression to analyze morphology data, canonical correspondence analysis to establish relationships between species abundance and environmental variables, and a dissimilarity matrix and cluster analysis to compare study sites. I will demonstrate that morphology is significantly affected by degree of urbanization, show relationships between species abundance, ground cover, soil composition, and several vegetation measures, and establish several meaningful relationships between study sites.

Effects of Suburban Development on Lizard and Snake Assemblies in Central Texas

by

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A Thesis

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PREFACE

Squamates have a widespread occurrence (geographically and environmentally) which denotes their broad ecological, physiological and behavioral adaptations, making them an ideal clade to help study effects of urbanization.

The goal of this research is threefold:

1. To expand the knowledge of squamates and their response to urbanization gradients, this will help conservationists preserve their ecological communities in the wake of urban expansion.

2. To improve knowledge of how such development may affect the environment by demonstrating significant variation in biotic and abiotic variables along an urbanization gradient; this will help better understand how squamates are affected.

3. To provide the ground work for potential genetic studies for squamate species in response to urbanization; therefore, observational data were collected from an urbanized area with a long history of human disturbances.

As conservation biologists and population ecologists face the challenges caused by human expansion and activities, ways must be found to preserve and restore the environment sustainably with the needs of our ever growing population. I hope that this research will benefit reptiles, their natural environments, and human society.

The organization of this thesis follows the structure and form set forth by the Council of Science Editors Style Manual Committee in the *Scientific Style and Format: The CSE Manual for Authors, Editors, and Publishers*, 7th ed. Published in 2006, as well as the guidelines set forth by the Baylor University Graduate Department.

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DEDICATION

To God Almighty, creator of all things, and to my wife Jessica who is a blessing in my life

CHAPTER ONE

Introduction

Since the earliest times humans have utilized wild plants and animals altering their surrounding landscape (Groom, et. al 2006). This trend has drastically increased in recent history as urban and suburban developments have increased worldwide which can have a wide variety of environmental impacts. As human populations continue to grow and urbanization continues to spread, natural habitats are replaced with urban infrastructure (i.e. Buildings, roads, canals, etc.). This change in habitat structure causes a loss of species diversity, habitat fragmentation and degradation, decreasing patch size and connectivity, as well as having many other wide-ranging effects (Blewett and Marzluff 2005; Hammer and McDonnell 2010; Nazdrowicz et. al.2005; Pianka and Vitt 2003).

As urbanization continues, the amount, composition and abundance of vegetation is changed, which alters microhabitats, local temperatures, food supplies, predation, and parasitism (Blewett and Marzluff 2005; Hammer and McDonnell 2010; Pontes, et. al.2009). Species abundances are frequently highly variable among sites in the species distribution, with high abundance in only a few sites and relatively low abundance in others (VanDerWal, et al.2009). In addition, species abundance and assemblages are greatly affected by habitat fragmentation and degradation, and many studies have shown demographic changes in wildlife communities resulting from urbanization (French et al.2008). Organisms are often extirpated from these areas or forced to adapt to the new habitat conditions. As human activities continue to alter the landscape and encroach on natural habitats, the ability of species and populations to adapt to these new environment will become an increasingly important factor for long-term persistence and survival (French et al.2008).

Biological Communities

Biological communities have a variety of characteristics (species richness and diversity, intra-specific interactions, predation, etc.) and typically have trophic structures that persist as changes in species assemblages and abundance occur (Zug et. al 2001). The distinctiveness of biological communities defined by the diversity of species within them and those species interactions, change over time and may be influenced in the short term by changes in the habitat structure and in the long term by slower processes such as climate change and evolution (Futuyma 2005; Groom et. al 2006). Complex ecosystems with high species diversity and significant species interactions tend to be more stable over time, while simple ecosystems with low species diversity and few species interactions are easily perturbed and susceptible to collapse (Pianka and Vitt 2003). Typically, a stressed ecological community experiences a loss of species and a change in abundance of a several species (Groom et. al 2006). Since evolutionary changes take place in the context of biological communities, it is essential to understand these communities (Groom et. al 2006).

A common threat to biodiversity is habitat fragmentation and degradation due to the destruction and/or alteration of natural habitats by any number of human activities (Groom et. al 2006; Zug et. al 2001). In general, habitat fragmentation entails a reduction in the area covered by natural habitat types in the landscape and a change in the habitat configuration, with the remaining habitat split into smaller isolated patches (Groom, et al.2006). Specifically, habitat fragmentation may occur through a variety of human activities, the consequences of which may extend beyond the edge of the lost/altered habitat (Groom et. al 2006; Zug et. al 2001). This is of particular interest in urban and suburban areas as suitable habitats for species and community survival become increasingly reconfigured and isolated.

Similar to the theory of island biogeography, these isolated communities, or ecological islands (i.e. habitat patches surrounded by dispersal barriers), often change as different species may immigrate into these habitats (Futuyma 2005; Schilthuizen and Scott 2004). As some native species (initially excluded from the patch) recolonize a patch from other isolated patches or nearby less disturbed natural areas, or as non-native/invasive species may initially colonize the patch, the community structure changes (Futuyma 2005; Schilthuizen and Scott 2004). In addition, some species may emigrate away from these habitats in search of a more favorable environment; some species may become extinct (Futuyma 2005; Schilthuizen and Scott 2004).

Many species exhibit seasonal variation in habitat requirements (winter and summer habitats may differ considerably, especially species that hibernate in the colder months); habitat fragmentation may isolate these distinct habitats, further restricting species, contributing to additional local extinction; see Figure 1 (Futuyma 2005; Seigel and Collins 1993). Thus, biological communities may differ markedly between suitable habitats within a given region; this depends on the size of the suitable habitat surrounded by urban/suburban developments and its proximity to other habitats.

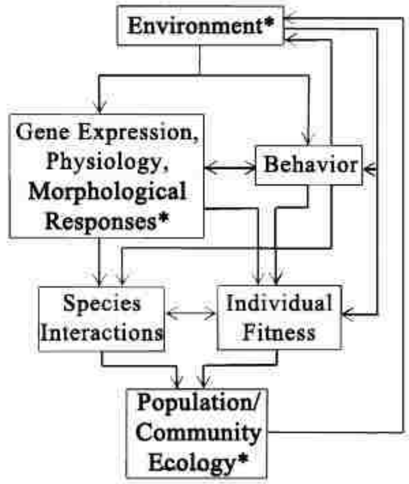

Figure 1 - An integrative view of organismal biology, ecology, and evolution with emphasis on feedback loops between the various traits. "*" denotes that the particular trait is within the scope of this study. This diagram derives in part from Sih and collaborators (2010, Fig. 1). Figure has been redrawn for uniformity.

Isolated patches of habitat within a suburban/urban landscape are subject to repeated and highly variable anthropogenic disturbances (i.e. vehicle traffic, removal of native flora and fauna, non-native predators, exposure to pollutants and warmer ambient temperatures). This is a common result of urbanization, presenting new selective forces which can act upon populations (French et. al. 2008). Various organisms are dependent on the presence of one or more plant species or a specific habitat type/quality (Steffens and Anderson 2006). Therefore, altered vegetation cover can greatly affect species abundance. The loss or reduction of particular plants (a common effect of urbanization) reduces needed foraging sites or refuges causing increased foraging and predation (Audsley et. al.2006). In urbanized areas there may also be an indirect effect on ecological communities; wildlife will alter behavior (Figure 1) in response to urban and suburban areas avoiding man-made structures (buildings, roads, etc.) or moving through degraded habitats faster or more directly than they would in a natural habitat (Patrick and Gibbs 2009; Rinehart, et. al 2009). However, these new environments may also provide some advantages (i.e. abundant and exotic anthropogenic food sources, refuge from the elements, and year round water sources, etc.) from which some species in the community may be able benefit and persist despite other disturbances (French et al.2008).

Water sources may be an especially important factor in arid regions or during serious droughts (French et al.2008). Such changes in the habitat configuration create unique selective forces, allowing some species/individuals to cope with and take advantage of their altered surroundings better than others. It is often assumed that variation in the geographic distribution and habitat types of a given species results in local adaptation to the existing or novel habitat conditions through natural selection (Seigel and Collins 1993). In addition, according to French et. al (2008), urban-associated variation in abundance and body condition is species-specific and possibly sex specific. This all could lead to new species assemblages and novel adaptations within a given species. There is evidence suggesting that selection can build up reproductive isolation; therefore, given enough time, urbanization could lead to speciation (Dobzhansky 1970).

Again applying the theory of island biogeography, where habitat fragmentation creates small ecological islands, the less mobile species (species that cannot easily move between isolated patches and therefore are functionally isolated) become cut off from the other populations; this drastically reduces the population size, essentially creating a bottleneck and increased inbreeding, which decreases genetic variability (Futuyma 2005; Groom, et. al 2006; Lowontin 1974; Zug, et. al 2001). These *small* ecological islands are subject to decreased gene flow between populations and increased random genetic drift compared to larger populations in large connected patches (Denno and Peterson 2004; Futuyma 2005; Groom, et. al 2006; Schilthuizen and Scott 2004).

Depending on the size of the patch and its distance from other habitats, a few individuals of a more mobile species may recolonize the patch where they become isolated (often referred to as the founder effect), this also leads to increase random genetic drift and inbreeding (Groom et. al 2006; Zug et. al 2001). Increased random genetic drift, inbreeding, and a decrease in gene flow may lead to loss of genetic diversity resulting in the rapid fixation or loss of specific traits that may be in equilibrium in the larger populations (Wright 2004). In addition, more mobile species may also emigrate from the patch in favor of larger or less disturbed habitats, thereby decreasing the species diversity of the smaller patches.

While these ecological islands may be subject to decreased gene flow and increases in random genetic drift and inbreeding, experiments have shown that these alone are seldom powerful enough to genetically isolate the small populations on ecological islands from the larger, more connected patches (Schilthuizen and Scott 2004). However, there is evidence that the resulting differentiation between isolated and less isolated populations is increased by any local variation in selective forces (Schilthuizen and Scott 2004; Wright 2004). If the ecological islands created by habitat fragmentation due to urbanization are sufficiently different from more natural habitats (different selective pressures) we could expect to see variations between species found in both habitats.

Soils Composition and Squamates

Many egg laying squamates dig nests that have physical contact with the soil and exchange gases and water with the surrounding environment (Marco, et al.2005). These soils usually consist of a number of horizons (layers), with rock weathering, water movement, and organic decomposition as the traditional factors affecting the development of a soil profile under varying climatic conditions (Schlesinger 1997). However, anthropogenic disturbances also play a dramatic role on soil development and alteration (Schlesinger 1997). Altered soil composition, including acidity and nutrient levels, has been shown in some species to have significant effects on embryo development (Marco, et al.2005).

There are several distinct horizons that comprise a soil profile. The uppermost layer, or O-horizon, consists of fresh, undecomposed plant debris (litter fall), below which is the A-horizon, comprised of partially decomposed organic matter (Schlesinger 1997). Under these layers, the E-, B-, and C-horizons are found. The E-horizon is typically light in color, consisting of mainly quartz grains, and typically contains very little nutrients due to a high degree of leaching (Schlesinger 1997). Materials leached from the A-, and E-horizons are deposited in the B-horizon, where clay minerals halt the downward movement of dissolved organic compounds, making this the zone of maximum nutrient accumulation (Schlesinger 1997). The C-horizon, found just above the parent bedrock rock material, consists of coarsely fragmented soil material and most closely resembles the underlying parent material; this layer is often sufficiently deep to resist weather in undisturbed soil profiles (Schlesinger 1997).

As a result of human developments, soils may be drastically altered. In agricultural areas, the soil organic matter declines typically by 20% to 30% within the first few decades (Schlesinger 1997). In addition, nitrogen, phosphorus and potassium levels can be greatly affected. When soils in agricultural areas are heavily fertilized there is a dramatic increase in these nutrients; alternatively, if agricultural soils receive little or no fertilization the soils quickly become depleted of these nutrients (Turner, et al.2001).

While there have been few studies on the response of terrestrial ecosystems to nutrient loading, the response may be similar to that of aquatic ecosystems where increased nutrients result in shifts in algal, zooplankton, insect and fish communities (Haddad, et al.2000). Studies have shown that the deposition of anthropogenically fixed nitrogen from the atmosphere onto soils is one of the most important factors causing global scale changes in terrestrial environments and may have significant consequences on every level of biodiversity (Groom, et al 2006). One such experimental study demonstrated that an increase in nitrogen concentrations resulted in an increase in total insect abundance and plant biomass, but a decrease in plant and insect richness; they also found a decrease in herbivore and predator species richness (Haddad, et al 2000). Similar responses may be evident in squamate communities.

Soil pollution and pH alteration, due to urbanization, may also influence embryonic developments and hatching success of some species. A study of the effects of pH on the eggs of *Lacerta monticola cyrenni,* a species with flexible and permeable shelled eggs, demonstrated that low pH had a significant effect on egg water exchange, hatchling size and running speed (Marco, et al.2005). This study also showed that a basic pH only slightly affected egg mass variation during incubation; however, pH had no effect on incubation duration and embryo survival (Marco, et al.2005). While increased soil acidity may not directly affect embryo survival, other studies have suggested that a decrease in burst speed restricts an individual's ability to evade predators and capture prey which could affect the individual's life expectancy (Lopez and Martin 2002).

In suburban and urban areas, the natural soil profile may be drastically changed. Depending on the topography of the land and the nature of the anthropogenic activity (i.e. agriculture, deforestation, urbanization), soils may be lost or become nutrient depleted; Natural soils may also be covered with layers of imported dirt, or covered entirely with relatively impervious materials (Nagaraju, et al.2011; Podmanicky, et al.2011). For example, roads often result in greater soil compaction, solar radiation and surface temperatures, than surrounding unaltered habitats, particularly in heavily wooded areas (Crow 2005).

The biophysical environment of the nest site influences virtually all aspects of the developing embryos phenotype, including its survivorship, duration of incubation, rate of development, hatching success, behavior, physiology and morphology (Angilletta, et al.2009; Zug, et al.2001). As most squamate eggs require some amount of water for development, nesting sites of oviparous squamates typically occur in soils with at least some moisture, such as inside rotting logs, piles of vegetation, under rocks, or in crevices where there is more moisture (Zug, et al.2001). However, while some moisture is required, studies of *Sceloporus undulatus* nesting sites and embryo development have shown that at a constant temperature of 28°C water potentials ranging from -530 to -150 kPa had no significant effect on the development, thermoregulation, locomotion, growth, or survival of hatchlings (Angilletta, et al.2009). Mortality is highest in the egg stage for squamates; therefore, egg placement greatly influences the survival rates as well as the growth rates of the developing embryos (Zug, et al.2001).

Climate Change, Weather, and Squamates

Squamates are ectothermic, relying on environmental sources for heat gain; therefore, global temperature is the main limiting factor for squamate distribution and diversity. On smaller landscape scales (i.e. single habitats), temperature is a major factor in the spatial occurrence and temporal activity of squamates in regards to the use and selection of microhabitats (Zug, et al.2001). It is therefore, predicted that global climate change will cause distributional shifts in the coming decades (Sinervo, et al.2010). Squamates will regulate their body temperature using their external environment and a mixture of heat exchange processes (i.e. radiation, convection, and conduction) in attempt to maintain a relatively stable temperature (Zug, et al.2001). Field studies confirm that temperature influences physical performance in natural situations and that physiological and behavioral performance are maximized across a narrow range of body temperatures (Zug, et al.2001).

In recent decades, there have been increases in global temperatures as well as local temperatures, especially for areas near urbanized centers (i.e. heat island effect). These increased temperatures can adversely affect squamates, resulting in altered time and duration of activities to maintain an optimal body temperature. When squamates spend extended periods of time restricted to thermal refuges, time spent foraging is limited and squamate will have constrained growth and development (Huey, et al.2010; Sinervo, et al.2010). When net energy gain through nutrient intake becomes insufficient, it prevents sexual reproduction (Huey, et al.2010; Sinervo, et al.2010). In addition, significantly altered body temperatures can effect predator evasion, limit feeding success and may have other negative consequences, including death (Sinervo, et al.2010; Zug, et al.2001). Sinervo, et al. (2010) predicted that nearly 40% of all global lizard populations will go extinct by 2080 due to increased temperatures and that rapid genetic adaptation is not likely. Although predictions are rarely validated by actual extinctions (Huey, et al.2010) it is clear that human induced climate change and altered local temperatures due to urbanization may have a drastic effect on squamate populations.

Research Goals

Squamates are wide spread in terrestrial environments but may be limited by a variety of thermal conditions, habitat structure, and predator/prey abundance (Pitt 2001). However, during the last several decades squamates, along with many other reptiles and amphibians, have seen a dramatic decline in abundance and distribution, which may have resulted from the habitat destruction, fragmentation, and degradation associated with urbanization (Hammer and McDonnell 2010). The complexities of vertical and horizontal habitat structures including, tree canopies, plant cover, litter fall and larger debris have been shown to effect squamate populations (Steffen and Anderson 2006; Bateman et. al 2009; Pitt 2001; Hammer and McDonnell 2010). Urbanization affects these habitat structures and may decrease the availability of basking, foraging, refuge, nesting, and overwintering sites for squamates (Hammer and McDonnell 2010).

The squamates of the central Texas historically encompass 62 species (See Appendices A, B, and C for information regarding squamate evolution, families and specific species commonly found in central Texas), several of which may be found in relative abundance in habitats affected by a varying degree of urbanization (Beher and King 1998; Conant and Collins 1998). The loss or change in species composition could have profound effects on other organisms (Hamer and McDonnell 2010; Pianka and Vitt 2003). Therefore, squamate species provide an excellent model in which to study variation in morphology and habitat in response to a variety of habitat conditions including degree of urbanization.

Suburban developments affect both biotic and abiotic conditions of the environment and may have affected squamate assemblages in a variety of ways. Squamates, and other organisms, often are forced to adapt in response to variation in their environments. Areas more heavily affected by human activity may have varying food and water supplies, refuges, predation, and temperatures presenting new selective forces (Blewett and Marzluff 2005; Hammer and McDonnell 2010; Patrick and Gibbs 2009; Pontes, et. al.2009; Rinehart, et. al.2009).

Roads are particularly disruptive to species assemblages and have been shown in squamates to cause direct mortality as well as altered behavior and movement patterns (Patrick and Gibbs 2009). Roads create barriers that isolate various squamates, depending on their mobility, which could prevent immigration and emigration between ecological islands. If there is insufficient food, water or shelter, a squamate may be forced to travel further (possibly over roads) to attain these different resources than under more natural conditions (Attum and Eason 2006). In addition, organisms may have to supplement their diet with foods that are less nutritious and therefore may be found foraging in different areas than otherwise expected.

Many squamates have been found in the study region (Waco, TX and surrounding areas) but little research has been done on their relative abundance in reference to degree of urbanization. Some squamates have been found in higher abundance in habitats with intermediate levels of disturbance but these studies did not include urban/suburban areas (Pontes et. al 2009).

At present, much of the contiguous United States of America's natural habitats have been anthropogenically altered (with the exception of few remote locations), and as such, we consider few areas to be truly natural, with even the least populated regions showing signs of human activity . Therefore, the goal of this study is to compare variation in abundance, morphology and habitat among various squamate species between locations with a varying degree of urbanization. To our knowledge, there have been no studies, either in Texas or The United States of America, to determine how terrestrial reptiles are affected by the degree of urbanization and how they relate to the remaining vegetation cover, ground cover and soil composition. Squamates have proven ideal for ecological studies because of their basic morphology, remarkable diversity, and relative abundance in a wide range of habitats (Pianka and Vitt 2003). The variation in habitat could potentially have a significant impact on each species, influencing body condition, reproduction, and feeding.

Questions to be Answered by this Research

It is expected that this study will help to answer several broad questions. First, is squamate composition and diversity affected by the degree of urbanization? I hypothesize that varying degrees of urbanization will affect squamate composition such that larger (i.e. greater mass) squamate species (*Sceloporus olivaceus, Cnemedophorus gularis, Nerodia eurythrogastor, Agkistrodon contortrix, Crotalis atrox*, etc.) will be more abundant at study sites that are less urbanized, while smaller (i.e. lesser mass) squamate species (*Anolis carolinenesis, Scincella lateralis, Hemidactylus turcicus, Virginia striatula*, etc.) will be more abundant at study sites that are more urbanized.

Second, what measurements of environmental conditions are important predictors of squamate assemblages? I hypothesize that the degree of urbanization, vegetation species, vegetation density, mean plant diameter at breast height, ground cover, and soil nutrient concentrations will all be useful predictors for squamate assemblages.

Third, how might habitat conditions affect variation in squamate assemblages and/or body condition? I hypothesize that the degree of urbanization will be a predictor of species abundance and diversity, with larger species being more abundant in habitats with a lower degree of urbanization and that these habitats will have a greater diversity. The patch size and vegetation type will also help determine species assemblages, in that some species will prefer areas with more edge habitats (often a result of urbanization) and some species will prefer areas will less edge habitat. Vegetation density and mean plant stem diameter will also likely be important predictors. Ground cover will likely be an important predictor as some species (*S. lateralis, V. striatula*, etc.) depend on dense ground cover such as leaf litter to hide from predators and forage for food while others prefer grassy or very little ground cover (*E. laticeps, E. fasciatus, C. gularis*, etc.). Soil nutrient concentrations may also be useful predictors for some squamate species as some of the species burrow (*S. lateralis, V. stiratula*, etc.) and would therefore likely be found in loamier soils, while others species (*C. gularis, C. sexlineatus*, etc.) are often associated with sandy or rocky soils (Behler and King, Conant and Collins 1998).

Fourth, do squamate body conditions correlate to the degree of urbanization? I hypothesize that the body condition will have a significant negative correlation for most species based on the degree of urbanization.

Finally, does squamate body condition correspond to species abundance? I hypothesize that the body condition will have a significant difference for most species based on degree of urbanization. The body condition for these species will have a direct correlation with that species' abundance, such that a species will have a higher body condition at study sites where they have a greater abundance and that a species will have a lower body condition at study sites where they have a lower abundance (e.g. If a species such as *A. carolinensis* is more abundant in habitats with a higher degree of urbanization then it will have a greater body condition than *A. carolinensis* populations in habitats with a lower degree of urbanization).

I predict greater variation in vegetation cover, ground cover, and soil composition at more urbanized locations is herein predicted; similarly, less abundance and worse body condition for most of the species in this study at more heavily urbanized sites is predicted. Herein, I compare a variety of morphological and landscape differences among abundance, morphological characteristics and habitat quality between locations with a varying degree of urbanization.

CHAPTER TWO

Materials and Methods

Study Area

The study region is comprised of 10 study sites in Waco, McLennan County, TX and the surrounding area (See Figure 2).

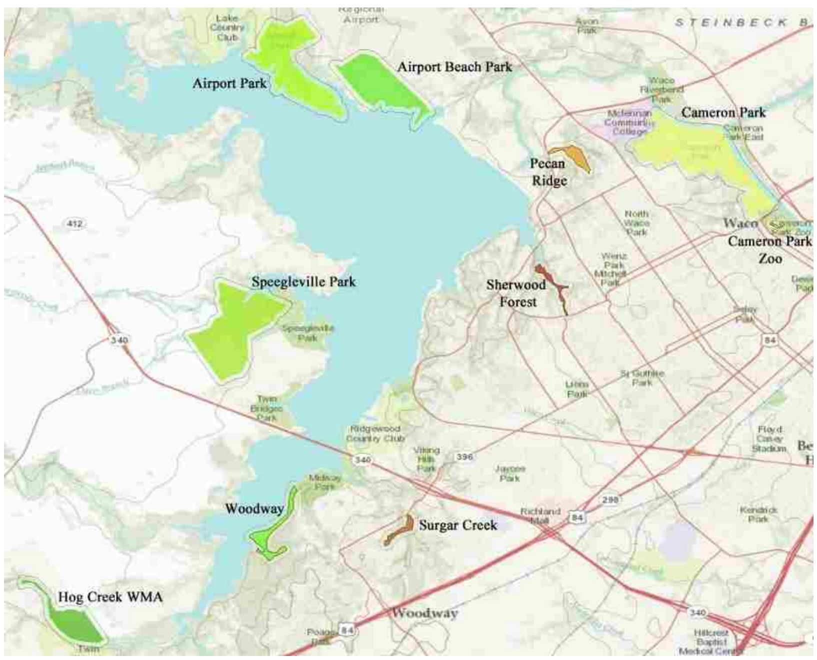

Figure 2 - GIS map of all study sites. Each site is highlighted to the extent of its boundaries. A 100-meter buffer around each site is included and indicates the extent to which road lengths were measured within and around the site.

Collection sites include: Airport Park (near Waco Regional Airport, N 31°36.136' W 097°14.345'), Airport Beach Park (near Waco Regional Airport, N 31°36.117' W 097°13.492'), Cameron Park (Waco N 31°35.260' W 097°09.759'), one site along the nature trail in Cameron Park Zoo (near downtown Waco; N 31°34.259' W 097°08.793'), Hog Creek Wildlife Management Area (Waco-area, N 31°29.609' W 097°16.828'), one site near Lake Shore Drive in an undeveloped area between subdivisions accessed through The Pecan Ridge Apartments (dubbed Pecan Ridge, N 31°35.082' W 097°11.169'), another study site near Lake Shore Drive in a ravine between subdivisions, accessed through a resident's personal property (dubbed Sherwood Forest for the name of the closest street, N 31°33.734' W 097°11.482'), Speegleville Park (Waco-area, N 31°33.209' W 097°15.092'), one sites along the Sugar Creek nature trail in Woodway, TX (suburb of Waco) near the Sugar Creek subdivision (dubbed Sugar Creek, N 31°30.739' W 097°13.119'), and another site in Woodway, TX between a subdivision and Lake Waco (dubbed Woodway, N 31°30.711' W 097°14.646').

Data Collection

I collected data at 10 sites in the Waco-area, McLennan County, Texas. Collections were made both day and night along and around ~30m transects; cover boards and pitfall traps were used to collect individuals as well as capturing them by hand (Ribeiro-Junior, et. al.2008). Pitfall traps are made of 5-gallon buckets, spray painted brown on the inside to give a more natural appearance and placed at the center of each of the 10 transects. Each pitfall trap has a lid suspended approximately two inches above the opening of the buckets and camouflaged with the surrounding leaf litter. Four (4) cover boards are placed along each transect, two (2) on either side of the pit fall trap; the centermost cover boards are approximately 5 meters from the pitfall trap and the outermost cover boards are each an additional 10 meters out (total of approximately 30 meters).

Study sites were visited during an extended period from May 2011 through June 2012. Upon each visit to a study location, a count of each species encountered (both those captured and those visibly encountered). In addition, time spent at each study site was recorded for each visit and then multiplied by the number of observers present to obtain the observer hours for that visit; total observer hours per study site are subsequently calculated as the sum of all observer hours at each study site. Abundance of species for at a study site was determined by dividing the total number of individuals of that species encountered by the total observer hours for that study site.

Upon capture, the date, time of day, capture location (i.e. cover board, pit fall trap, ground and vegetation type), general weather condition (i.e. clear sky, cloudy, windy, storming, etc.), and air temperature (°C) was recorded. I also recorded each individual's species, sex, body mass (g), snout-to-vent (SVL; tip of the snout to the cloaca; mm), and total length (TL; mm). A body condition index (BCI) was calculated as the ratio of body mass and SVL (Body Mass/SVL). After measurements were taken, I temporarily marked individuals by toe-claw clipping (Lizards) or scale clipping by trimming the free edges of scales (Snakes). Individuals were marked to prevent accidental data duplication as locations were sampled on more than one occasion.

Data for each study site were recorded to measure habitat conditions. Study site vegetation data was measured along two (2) strip-transects (10-meter by 30-meter) and includes the following: vegetation density (VD), tree height (CH), and tree diameter at breast height (dbh) Visual estimates of ground cover were assessed along three (3) 30-meter transects using a 1-square-meter pvc pipe frame. Percent total ground cover, percent grass cover, percent shrub cover, percent forb cover, percent litter fall cover, percent light woody debris (lwd) cover, percent heavy woody debris (hwd) cover, and percent tree/sapling cover for each location was estimated. I collected soil data for five (5) samples at each study site and assessed the soil map unit names, taxonomic class and texture using the United States Department of Agriculture (USDA) Natural Resources Conservation Service (NRCS) Web Soil Survey from the study sites GPS coordinates. The soil pH, nitrogen, phosphorus, and potassium concentrations for each sample were measured using the LaMotte Soil Test Kit. Nitrogen, phosphorus, and potassium concentrations are initially given in qualitative terms (i.e. "Very High," "High," "Medium High," etc.) which correspond to more specific ranges of concentrations, given in lbs/acre. In order to statistically analyze this data I used the concentrations at the low end of the given range.

Degree of urbanization is often measured using broad zoning categories (Urban, suburban, and rural, etc.) or more precise measures such as linear distances to the city center (Ramalho and Hobbs 2012). This data is frequently obtained from maps and other cartography data; however, while these measures are practical they have many limitations. These measures assume a linear urban-to-rural gradient, which oversimplifies urban areas, in that contemporary cities grow in rapid, complex, dispersed and expansive ways; therefore the use of categorical or quantitative measures of geographical distances in urban ecology is misleading and ambiguous (Ramalho and Hobbs 2012). Other measures often include other landscape metrics (population densities, socio-economic variables, land cover, land use, cartography, and remote-sensing data, etc.) which can be used individually or aggregated as proxies to characterize the degree of urbanization (Ramalho and Hobbs 2012). These landscape metrics only partially capture some of the non-linear complexity of cities; both linear urban-to-rural gradients and landscape metrics fail to address interactions affecting remnant biodiversity and lack any temporal variables (Ramalho and Hobbs 2012).

While temporal variables are useful in establishing long-term anthropogenic affects in the landscape, such information may not be readably available. Additionally, I believe that simple, linear, urban-to-rural gradients or using landscape metrics individually would not be useful for our study. As urbanization often entails a reduction in the area covered by the natural habitat and a change in the habitat configuration resulting in smaller patches with more complex shapes, I will use the study site's perimeter-to-area ratio with a combination of landscape metrics to calculate a simple measure for degree of urbanization. It is important to take into account each site's perimeter-to-area ratio when determining the degree of urbanization as each study site's shape complexity will help to determine the extent to which the site may be affected by the surrounding urban area (i.e. larger sites with simple shapes will be less affected by the surrounding area than smaller sites with complex shapes). In addition to site shape, I chose the use of human population density as a significant landscape metric due to its direct relationship with several disturbances to the habitat, such as (building densities removal of native flora and fauna, non-native predators, exposure to pollutants and warmer ambient temperatures). I also chose road lengths as a significant metric due to its direct effect on squamates (road kills, altered species movement, etc.) and their effect on the shape and configuration of the landscape. Therefore, I suggest the following measure for degree of urbanization (°U):

$$°U = \frac{P(PD + RL)}{A}$$

Where P is the study site's perimeter, A is the study site's area, PD is the human population density of the surrounding area and RL is the road lengths within the study site itself and surrounding regions. This gradient may range from 0 (relatively pristine environments) to several hundred or potentially several thousand for in area near large urban centers.

While this measure will adequately allow me to compare each study site along a standard gradient, this measure is limited. Like several other urbanization measures, our measure of degree of urbanization lacks a temporal measurement. Some studies have suggested that a temporal perspective is essential to more accurately determine the degree of urbanization; as urbanization ages, time-lagged social factors, the development history of the urban centers, and the surrounding agrarian legacies have all been shown to be important factors in determining current urban/suburban biodiversity and ecosystem patterns (Ramalho and Hobbs 2012). Unfortunately, accurate and complete temporal data, especially in areas that are not recently urbanized and have a long and varied land use history, such as our study sites, can be exceedingly difficult to come by, if not impossible. Considering the age of Waco and its varied land use patterns, an explicit means of directly incorporating a temporal variable into our measure was not feasible; therefore, I do include past human activities into our calculations, rather I consider their implications for each site in the discussion. Each study site's area (km^2), perimeter (km) and road lengths will be determined using ArcGIS 10.1. The population density of the surrounding area was derived from the United States Census Bureau's 2010 Census; population density from the census are given in persons per square mile, which I converted to persons per square kilometer to maintain the uniformity of the units.

Data Analysis

I used a multivariate regression to analyze the morphological data in relation to multiple environmental variables. Multivariate regression improves upon separate simple regressions because it can test for treatment effects (degree of urbanization) while simultaneously taking into account correlations among multiple environmental (i.e. vegetation density, mean plant stem diameter, soil type, etc.) and morphological variables (i.e. SVL and mass) (Berry and Feldman 1985; Izenman 2008; Olivieri 2008). This analysis assumes the variables are normally distributed, the mean of the error term equals zero, the variance of the error terms are consistent for all independent variables (homoscedasticity), and there is no autocorrelation present. Variables were transformed as necessary to ensure that datasets conform to assumptions of normality and homogeneity of variance. The assumption of the normality of the residuals was checked using a normal probability plot and Shapiro-Francia tests (Shapiro and Francia 1972). When the assumption of normality could not be achieved, a quantile regression was used to examine the variables.

Much like simple or multivariate regression, quantile regression can be used to compare a dependent variable against one or more independent variables (Cade and Noon 2003). However, where simple and multivariate regressions compare the mean of each variable in order to determine if the dependent variable is significantly correlated to any of the independent variables (assumption of normal distributed and homogeneity of variance must be met), quantile regression is a nonparametric technique (does not assume a normal distribution or homogeneity of variance), comparing the quantiles (typically the median, but others may be specified) of the of each variable in order to determine if the response variable is significantly correlated to any of the independent variables (Cade 2011; Cade and Noon 2003; Pritt and Frimpong 2010). Quantile regression provides a comprehensive method for comparing data distributions in a linear model without assuming a normal distribution and has the option of simultaneously analyzing specific portions of the distribution of the response variable (Cade 2011; Chamaillé-Jammes, et al.2007). There are many factors that affect ecological relationships; traditional statistical methods may show weak or no relationships between the mean of the response variable and the measure predictive variables, whereas there may be stronger and more useful predictive relationships when comparing other aspects of the variables distributions, such as the median (Cade and Noon 2003).

I used Canonical Correspondence Analysis (CCA) to extract the major gradients in the species abundance that can be accounted for by the measured species abundance and other environmental variables. CCA is a hybrid of ordination and multiple regressions and helps measure the species-environment relationship from community composition data and habitat measures (McGarigal, et al.2000; Ter Braak 1986). Most species-environment processes are complex and involve multiple interactions that make the use of a variety of statistical techniques problematic. CCA can be used to analyze these relationships in a way that best preserves the natural interactions (Sherry and Henson 2005). CCA is most appropriately used to examine the relationships between two variable sets (e.g. species abundance and environmental variables) that have a theoretical relationship and will help to visualize patterns of community variation and the main features of species abundance along environmental gradients (Sherry and Henson 2005; Ter Braak 1987). An assumption of CCA is that all variables and all linear combination of variables are normally distributed; this assumption, however, is often difficult to evaluate (Sherry and Henson 2005). Fortunately, CCA appears to be extremely resilient to deviations from this assumption (Ter Braak and Verdonschot 1995)

I also use Agglomerative Hierarchical Cluster Analysis (AHCA) with average linkages to determine the species composition at each study site and their relationships among each other based on the species compositions and other the environmental characteristics of the site. First, I created a dissimilarity matrix with squared Euclidean distance, then the AHCA assigned each species or study site (entities) into individual clusters and subsequently agglomerates each cluster into larger and larger clusters based on the shortest distance between entities (McGarigal, et al.2000). I then used dendrograms to illustrate the structure of the relationships and the degree of each relationship.

All analyses, except CCA, were carried out using Stata, Version 12.0 (StataCorp LP 2010). I performed CCA using XLSTAT 2012 software, trial version (http://www.xlstat.com; Accessed: August, 2012).

CHAPTER THREE

Results

Airport Park

Airport Park is predominately a woodland area owned and managed by the U.S. Army Corp of Engineers. The park is located along Lake Waco off of Skeet Eason Road on the southwest side of the Waco Regional Airport (See Figure 3; N 31°36.136' W 097°14.345').

Figure 3 - GIS map of Airport Park, highlighting the study site and its boundaries. A 100-meter buffer around the site is included and indicates the extent to which road lengths were measured within and around the site.

Habitat and Vegetation

Nineteen (19) trees were measured in the two strip-transects (See Figures 4a and b) including four (4) species (*Carya illinoinensis, Juniperus virginiana, Quercus* *virginiana,* and *Ulmus crassifolia*). The mean vegetation density is 68(8) percent, mean canopy cover is 88(3) percent, mean canopy height is 10.219(3.889) meters and the mean dbh is 0.219(0.080) meters. The total basal area of all trees measured is 2.003 square meters: The total basal area of *C. illinoinensis* is 0.003 square meters, the total basal area of *J. virginiana* is 0.472 square meters, the total basal area of *Q. virginiana* is 0.477 square meters and *U. crassifolia* is 0.048 square meters. Therefore, *J. virginiana* and *Q. virginiana* are the dominant tree species in Airport Park.


Figure 4a and b - Photographs of the Airport Park study site. Left (4a): First strip transect near a northern section of the site. Right (4b): Second strip transect near center of the site.

Fifteen (15) saplings/shrubs were measured in the two strip-transects including five (5) species (*Carya illinoinensis, Ilex decidua, Juglans nigra, Juniperus ashei,* and *Juniperus virginiana*). The mean sapling/shrub height is 4.792(2.326) meters and the mean dbh is 0.032(0.020) meters. The stem count of *C. illinoinensis* is 4; the stem count of *I. decidua* is 1; the stem count of *J. nigra* is 8; the stem count of *J. ashei* is 1; and the stem count of *J. virginiana* is 1. Therefore, *J. nigra* and *C. illinoinensis* are the dominant sapling/shrub species in Airport Park.

The soils at Airport Park are a Sunev Clay Loam with 1 to 3 percent slopes and a Fine-Loamy, Carbonatic, Thermic Udic Calciustolls. The mean pH is 7.4(0.5), the mean nitrogen concentrations is 12.0(16.4) pounds per acre, the mean phosphorus concentrations is 30.0(27.4) pounds per acre, and the mean potassium concentrations is 192.0(43.8) pounds per acre.

Squamates

Twenty-one (21) squamates were captured or observed along the transect and throughout Airport Park including six (6) species (*Anolis carolinensis, Cnemidophorus gularis gularis, Nerodia rhombifer, Sceloporus olivaceus, Scincella lateralis,* and *Virginia striatula*). A total of 17.756 hours were spent at Airport Park. The Simpson's Diversity Index for this study site is 0.814.

Two (2) *A. carolinensis* were captured with a mean snout-to-vent length (SVL) of 57.5(2.3) millimeters, a mean total length (TL) of 158.0(1.6) millimeters, a mean mass of 2.15(0.49) grams, and a mean body condition index (BCI) of 0.089(0.005). No additional individuals were observed, and the relative abundance is 0.113 per observer hour.

No *C. gularis gularis* were captured; therefore, no morphological data are recorded for this species. A total of eight (8) *C. gularis gularis* were observed, and the relative abundance is 0.451 per observer hour.

Three (3) *N. rhombifer* were captured with a mean SVL of 330.1(35.0) millimeters, a mean TL of 414.0(36.4) millimeters, a mean mass of 33.0(5.7) grams and a mean BCI of 0.101(0.019). No additional individuals were observed, and the relative abundance is 0.169 per observer hour.

No *S. olivaceus* were captured, therefore there is no morphological data recorded for this species. A total of three (3) *S. olivaceus* were observed, and their relative abundance is 0.169 per observer hour.

Two (2) *S. lateralis* were captured with a mean SVL of 46.3(3.4) millimeters, a mean TL of 99.7(10.5) millimeters, a mean mass of 2.5(0.6) grams and a mean BCI of 0.053(0.010). No additional individuals were observed, and the relative abundance is 0.113 per observer hour.

Three (3) *V. striatula* were captured with a mean SVL of 157.0(34.9) millimeters, a mean TL of 187.7(39.1) millimeters, a mean mass of 3.8(3.6) grams and a mean BCI of 0.022(0.016). No additional individuals were observed, and the relative abundance is 0.169 per observer hour.

Airport Beach Park

Airport Beach Park is predominately an open woodland area owned and managed by the U.S. Army Corp. of Engineers. The park is located along Lake Waco off of Skeet Eason Road on the south side of the Waco Regional Airport (See Figure 5; N 31°36.117' W 097°13.492').

Figure 5 - GIS map of Airport Beach Park, highlighting the study site and its boundaries. A 100-meter buffer around the site is included and indicates the extent to which road lengths were measured within and around the site.

Habitat and Vegetation

Sixteen (16) trees were measured in the two strip-transects (See Figures 6a and b) including four (4) species (*Celtis laevigata, Juniperus ashei, Juniperus virginiana,* and *Prosopis gladulosa*). The mean vegetation density is 40(0) percent, mean canopy cover is 40(21) percent, mean canopy height is 15.001(7.534) meters and the mean dbh is 0.317(0.163) meters. The total basal area of all trees measured is 1.392 square meters; the total basal area of *C. laevigata* is 1.257 square meters, the total basal area of *J. ashei* is 0.018 square meters, the total basal area of *J. virginiana* is 0.107 square meters and the total basal area of *P. gladulosa* is 0.009 square meters. Therefore, *C. laevigata* is the dominant tree species in Airport Beach Park.

Figure 6a and b - Photographs of the Airport Beach Park study site. Left (6a): First strip transect near a northern section of the site. Right (6b): Second strip transect near a south eastern section of the site.

Eight (8) saplings/shrubs were measured in the two strip-transects including five (5) species (*Celtis laevigata, Juniperus ashei, Juniperus virginiana, Prunus mexicanus* and *Triadica sebifera*). The mean sapling/shrub height is 3.078(0.486) meters, and the mean dbh is 0.034(0.021) meters.

The stem count of *C. laevigata* is 3; the stem count of *J. ashei* is 1; the stem count of *J. virginiana* is 1; the stem count of *P. mexicanus* is 2 and the stem count of *T. sebifera* is 1. Therefore, *C. laevigata* and *P. mexicanus* are the dominant sapling/shrub species in Airport Beach Park.

The soils at Airport Beach Park are both a Wilson Clay Loam with 0 to 2 percent slopes and a fine, smectitic, thermic oxyaquic vertic haplustalfs and a Payne Clay Loam with 1 to 3 percent slopes and, a fine, smectitic, thermic udic paleustalfs. The mean pH is 7.2(0.4), the mean nitrogen concentrations is 12.0(16.4) pounds per acre, the mean phosphorus concentrations is 20.0(27.4) pounds per acre, and the mean potassium concentrations is 120.0(0) pounds per acre.

Squamates

One-hundred and twelve (112) squamates were captured or observed along the transect and throughout the Airport Beach Park including six (6) species (*Crotalus atrox, Hemidactylus turcicus, Nerodia erythrogaster, Scincella lateralis, Thamnophis proximus,* and *Virginia striatula*). A total of 19.337 hours were spent at Airport Beach Park. The Simpson's Diversity Index for this study site is 0.248.

Two (2) *C. atrox* were captured with a mean SVL of 971.1(96.0) millimeters, a mean TL of 1117.1(46.4) millimeters, the mean mass of 1003.2(187.7) grams and the mean BCI of 1.048(0.297). No additional individuals were observed, and the relative abundance is 0.094 per observer hour.

Forty-two (42) *H. turcicus* were captured with a mean SVL of 47.5(4.5) millimeters, a mean TL of 93.8(7.5) millimeters, a mean mass of 5.0(1.2) grams, and a mean BCI of 0.106(0.022). A total of ninety seven (97) were observed or captured, and the relative abundance is 4.546 per observer hour.

No *N. erythrogaster* were captured; therefore, there is no morphological data recorded for this species. A total of 1 was observed and the relative abundance is 0.047 per observer hours.

One (1) *S. lateralis* was captured with a SVL of 51.7 millimeters, a TL of 136.1 millimeters, a mass of 3.5 grams, and a BCI of 0.068. A total of five (5) were observed or captured, and the relative abundance is 0.234 per observer hour.

Two (2) *T. proximus* were captured with a mean SVL of 173.5(7.6) millimeters, a mean TL of 242.6(10.7) millimeters, a mean mass of 1.75(0.4) grams, and a mean BCI of

0.010(0.002). A total of four (4) were observed or captured, with a relative abundance is 0.187 per observer hour.

Three (3) *V. striatula* were captured with a mean SVL of 185.3(6.4) millimeters, a mean TL of 201.6(5.5) millimeters, a mean mass of 4.6(3.1) grams, and a mean BCI of 0.025(0.017). No additional individuals were observed, and the relative abundance is 0.141 per observer hour.

Cameron Park

Cameron Park is predominately a woodland area managed by The City of Waco. The park is located along The Bosque and Brazos Rivers extending from McLennan Community College near Lake Shore Drive to Herring Avenue north of downtown Waco (See Figure 7; N 31°35.260' W 097°09.759').

Figure 7 - GIS map of Cameron Park, highlighting the study site and its boundaries. A100-meter buffer around the site is included and indicates the extent to which road lengths were measured within and around the site.

Habitat and Vegetation

Twenty-two (22) trees were measured in the two strip-transects (See Figures 8a and b), including six (6) species (*Carya illinoinensis, Celtis laevigata, Ligustrum lucidum, Morus rubra, Quercus buckleyi,* and *Ulmus crassifolia*). The mean vegetation density is 61.316(23.085) percent, mean canopy cover is 62(3) percent, mean canopy height is 18(12) meters, and the mean dbh is 0.317(0.117) meters. The total basal area of all trees measured is 1.713 square meters, the total basal area of *C. illinoinensis* is 0.470 square meters, the total basal area of *C. laevigata* is 0.466 square meter, the total basal area of *L. lucidum* is 0.060 square meters, the total basal area of *M. rubra* is 0.007 square meters, the total basal area of *Q.buckleyi* is 0.005 square meters, and the total basal area of *U. crassifolia* is 0.706 square meters. Therefore, *U. crassifolia, C. illinoinensis*, and *C. laevigata* are the dominant tree species in Cameron Park.

Figures 8a and b - Photographs of the Cameron Park study site. Left (8a): First strip- transect near a northern section of the site. Right (8b): Second strip-transect near the south eastern most section of the site.

Figure 8a and b - Photographs of the Cameron Park study site. Left (8a): First strip transect near a northern section of the site. Right (8b): Second strip transect near the south eastern most section of the site.

Forty-two (42) saplings/shrubs were measured in the two strip-transects including eight (8) species (*Aesculus glabra, Celtis laevigata, Ilex vomitoria, Ligustrum lucidum, Melia azedarach, Morus rubra, Juniperus virginiana* and *Ulmus crassifolia*). The mean sapling/shrub height is 5.491(3.224) meters and the mean dbh is 0.041(0.018) meters.

The stem counts of *A. glabra* is 3, the stem count of *C. laevigata* is 1, the stem count of *I. vomitoria* is 1, the stem count of *L. lucidum* is 28, the stem count of *M. azedarach* is 4, the stem count of *M. rubra* is 3, the stem count of *J. virginiana* is 1, and the stem count of *U. crassifolia* is 1. Therefore, *L. lucidum* is the dominant sapling/shrub species in Cameron Park.

The soils at Cameron Park are an Eddy gravelly clay loam with 3 to 15 percent slope, and a loamy-skeletal, carbonatic, thermic, shallow Typic Ustorthents. The mean pH is 8.0(0.0), the mean nitrogen concentrations is 0.0(0.0) pounds per acre, the mean phosphorus concentrations is 80.0(27.4) pounds per acre, and the mean potassium concentrations is 168.0(43.8) pounds per acre.

Squamates

One-hundred and three (103) squamates were captured or observed along the transect and throughout the Cameron Park, including ten (10) species (*Agkistrodon contortrix, Anolis carolinensis, Cnemidophorus gularis gularis, Elaphe obsoleta, Eumeces fasciatus, Eumeces laticeps, Sceloporus olivaceus, Scincella lateralis, Tantilla gracilis,* and *Virginia striatula*). A total of 25.072 hours were spent at Cameron Park. The Simpson's Diversity Index for this study site is 0.801.

Twelve (12) *Agkistrodon contortrix* were captured with a mean SVL of 431.5(88.2) millimeters, a mean TL of 498.0(101.1) millimeters, a mean mass of 94.8(54.7) grams, and a mean BCI of 0.207(0.090). A total of thirteen (13) were observed or captured, and the relative abundance is 0.519 per observer hour.

Seven (7) *A. carolinensis* were captured with a mean SVL of 58.2(7.7) millimeters, a mean TL of 149.1(20.5) millimeters, a mean mass of 5.7(3.6) grams, and a mean BCI of 0.096(0.062). A total of fourteen (14) were observed or captured, and the relative abundance is 0.558 per observer hour.

Three (3) *C. gularis gularis* were captured with a mean SVL of 60.3(7.8) millimeters, a mean TL of 176.8(38.8) millimeters, a mean mass of 11.1(6.0) grams, and a mean BCI of 0.178(0.072). A total of thirty one (31) were observed or captured, and the relative abundance is 0.1.276 per observer hour.

No *E. obsoleta* were captured; therefore, there is no morphological data for this species. One (1) *E. obsoleta* was observed with a relative abundance of 0.040 per observer hour.

One (1) *E. fasciatus* was captured with a SVL of 68.1 millimeters, a TL of 181.5 millimeters, a mass of 10.1 grams, and a BCI of 0.148. A total of five (5) were observed or captured with a relative abundance is 0.199 per observer hour.

Two (2) *E. laticeps* were captured with a mean SVL of 89.7(10.7) millimeters, a mean TL of 181.2(93.1*) millimeters (*Note: one individual was missing part of its tail), a mean mass of 22.5(5.7) grams, and a mean BCI of 0.249(0.033). A total of four (4) were observed or captured and the relative abundance is 0.160 per observer hour.

Eight (8) *S. olivaceus* were captured with a mean SVL of 64.6(15.5) millimeters, a mean TL of 167.3(31.7) millimeters, a mean mass of 13.4(8.3) grams, and a mean BCI of 0.190(0.090). A total of twenty nine (29) were observed or captured, with a relative abundance of 1.157 per observer hour.

No *S. lateralis* were captured; therefore, there is no morphological data for this species. A total of five (5) were observed, and the relative abundance is 0.199 per observer hours.

One (1) *T. gracilis* was captured with a SVL of 125.8 millimeters, a TL of 161.2 millimeters, a mass of 1.2 grams, and a BCI of 0.010. No additional *T. gracilis* were observed. The relative abundance is 0.040 per observer hour.

One (1) *V. striatula* was captured with a SVL of 114.9 millimeters, a TL of 141.9 millimeters, a mass of 2.2 grams, and a BCI of 0.019. No additional *V. striatula* were observed. The relative abundance is 0.040 per observer hour.

Cameron Park Zoo

The nature trail in Cameron Park Zoo is predominately a woodland area owned, managed and surrounded by the Cameron Park Zoo. The zoo and corresponding trail is located along the Brazos River, between Cameron Park Drive/N. University Park Drive and N. 4th Street north of downtown Waco (See Figure 9; N 31°34.259' W 097°08.793').

Figure 9 - GIS map of Cameron Park Zoo, highlighting the study site and its boundaries. A 100-meter buffer around the site is included and indicates the extent to which road lengths were measured within and around the site.

Habitat and Vegetation

Thirty-two (32) trees were measured in the two strip-transects (See Figures 10a and b) including nine (9) species (*Acer negundo, Carya illinoinensis, Celtis laevigata, Ilex coriacea, Populus deltoides, Quercus texena, Quercus velutina, Ulmus americana*

and *Ulmus crassifolia*). The mean vegetation density is 70(0) percent, mean canopy cover is 85(0) percent, mean canopy height is 8(3) meters, and the mean dbh is 0.087(0.005) meters. The total basal area of all trees measured is 3.793 square meters, the total basal area of *A. negundo* is 0.011 square meters, the total basal area of *C. illinoinensis* is 0.675 square meters, the total basal area of *C. laevigata* is 0.147 square meters, the total basal area of *Ilex coriacea* is 0.015 square meters, the total basal area of *P. deltoides* is 1.264 square meters, the total basal area of *Q. texenus* is 0.502 square meters, the total basal area of *Q. velutina* is 0.061 square meters, the total basal area of

U. americana is 1.051 square meters, and the total basal area of *U. crassifolia* is 0.076 square meters.

Therefore, *P. deltoides* and *U. americana* are the dominant tree species in Cameron Park Zoo.

Figure 10a and b - Photographs of the Cameron Park Zoo study site. Left (10a): First strip transect near an western section of the site. Right (10b): Second strip transect near a southern section of the site.

Sixty-two (62) saplings/shrubs were measured in the two strip-transects including twelve (12) species (*Acer negundo, Carya illinoinensis, Celtis laevigata, Cornus drummondii, Ilex coriacea, Ilex vomitoria, Ligustrum lucidum, Morus rubra, Quercus texena, Ulmus Americana*, *Ulmus crassifolia, and Viburnum rufidulum*). The mean sapling/shrub height is 3.600(1.331) meters and the mean dbh is 0.035(0.016) meters. The stem count of *A. negundo* is four (4), the stem count of *C. illinoinensis* is one (1), the stem count of *C. laevigata* is twenty one (21), the stem count of *C. drummondii* is eight (8), the stem count of *Ilex coriacea* is three (3), the stem count of *Ilex vomitoria* is five (5), the stem count of *L. lucidum* is ten (10), the stem count of *M. rubra* is one (1), the stem count of *Q. texenus* is one (1), the stem count of *U. americana* is one (1), the stem count of *U. crassifolia* is three (3), and the stem count of *V. rufidulum* is two (2). Therefore, *C. laevigata* and *L. lucidum* are the dominant sapling/shrub species in Cameron Park Zoo.

The soils at Cameron Park Zoo are an Eddy, gravelly clay loam with 3 to 15 percent slope and a loamy-skeletal, carbonatic, thermic, shallow Typic Ustorthents. The mean pH is 7.9(0.2), the mean nitrogen concentrations is 30.0(0.0) pounds per acre, the mean phosphorus concentrations is 0(0) pounds per acre, and the mean potassium concentrations is 144.0(21.9) pounds per acre.

Squamates

Forty-six (46) squamates were captured or observed along the transect and throughout the Cameron Park Zoo including five (5) species (*Agkistrodon contortrix, Anolis carolinensis, Hemidactylus turcicus, Sceloporus olivaceus,* and *Scincella lateralis*). A total of 10.727 hours were spent at Cameron Park Zoo. The Simpson's Diversity Index for this study site is 0.517.

One (1) *A. contortrix* was captured with a mean SVL of 516.5 millimeters, a mean TL of 572.0 millimeters, a mean mass of 198.0 grams, and a mean BCI of 0.383 No additional *A. contortrix* were observed. The relative abundance is 0.093 per observer hour.

Three (3) *A. carolinensis* were captured with a mean SVL of 57.6(4.1) millimeters, a mean TL of 144.3(19.2) millimeters, a mean mass of 9.3(3.0) grams, and a mean BCI of 0.160(0.045). A total of four (4) were observed or captured, and the relative abundance is 0.373 per observer hour.

Eight (8) *H. turcicus* were captured with a mean SVL of 36.7(8.8) millimeters, a mean TL of 72.2(24.2) millimeters, a mean mass of 2.9(1.2) grams, and a mean BCI of 0.077(0.030). No additional *H. turcicus* were observed. The relative abundance is 0.746 per observer hour.

No *S. olivaceus* were captured; therefore, there is no morphological data for this species. A total of two (2) were observed, and the relative abundance is 0.186.

Five (5) *S. lateralis* were captured with a mean SVL of 46.9(4.5) millimeters, a mean TL of 106.9(4.7) millimeters, a mean mass of 2.1(0.8) grams, and a mean BCI of 0.044(0.015). A total of thirty one (31) were observed or captured. The relative abundance is 2.890 per observer hour.

Hog Creek Wildlife Management Area

Hog Creek Wildlife Management Area (WMA) is a combination of grassland, marsh and riparian woodland owned and managed by the Texas Parks and Wildlife Department. Hog Creek WMA is located along Lake Waco the South Bosque River off of Barrett Road southwest side of Lake Waco (See Figure 11; N 31°29.609' W 097°16.828').

Figure 11- GIS map of Hog Creek WMA, highlighting the study site, its boundaries and a portion of the adjacent creek. A 100-meter buffer around the site is included and indicates the extent to which road lengths were measured within and around the site.

Habitat and Vegetation

Fifteen (15) trees were measured in the two strip-transects (See Figures 12a and b, including four (3) species (*Fraxinus pennsylvanica, Maclura pomifera* and *Ulmus crassifolia*). The mean vegetation density is 38(39) percent, mean canopy cover is 45(57) percent, mean canopy height is 4.890(0.085) meters, and the mean dbh is 0.093(0.0.001) meters. The total basal area of all trees measured is 0.593 square meters. The total basal area of *F. pennsylvanica* is 0.160 square meters, the total basal area of *M. pomifera* is 0.025 square meters, and the total basal area of *U. crassifolia* is 0.408 square meters; therefore, *F. pennsylvanica* and *U. crassifolia* are the dominant tree species in Hog Creek WMA.

Figure 12 a and b - Photographs of the Hog Creek WMA study site. Left (12a): First strip transect near an eastern section of the site. Right (12b): Second strip transect near a western section of the site.

Nine (9) saplings/shrubs were measured in the two strip-transects including two (2) species (*Celtis laevigata* and *Melia azedarach*). The mean height is 3.454(0.952) meters and the mean dbh is 0.031(0.023) meters. The stem count of *C. laevigata* is 6, and the stem count of *M. azedarach* is 3. Therefore, *C. laevigata* and *M. azedarach* are the dominant sapling/shrub species in Hog Creek WMA.

The soils at Hog Creek WMA are a combination of Aledo gravelly clay loam with 2 to 5 percent slopes and a loamy-skeletal, carbonatic, thermic Lithic Calciustolls and Bosque clay loam, occasionally flooded, a fine-loamy, mixed, superactive, thermic Cumulic Haplustolls. The mean pH is 7.7(0.4), the mean nitrogen concentrations is 36.0(32.9) pounds per acre, the mean phosphorus concentrations is 90.0(22.4) pounds per acre, and the mean potassium concentrations is 184.0(21.9) pounds per acre.

Squamates

Nineteen (19) squamates were captured or observed along the transect and throughout the Hog Creek WMA, including eight (8) species (*Anolis carolinensis, Elaphe obsoleta, Nerodia erythrogaster, Nerodia rhombifer, Opheodrys aestivus, Scincella lateralis, Thamnophis proximus,* and *Virginia striatula*). A total of 19.947 hours were spent at Hog Creek WMA. The Simpson's Diversity Index for this study site is 0.836.

Two (2) *A. carolinensis* were captured with a mean SVL of 54.7(13.4) millimeters, a mean TL of 167.4(53.5) millimeters, a mean mass of 9.2(1.5) grams, and a mean BCI of 0.169(0.014). No additional *A. carolinensis* were observed. The relative abundance is 0.050 per observer hour.

One (1) *E. obsoleta* was captured with a SVL of 1170.0 millimeters, a TL of 1394.9 millimeters, a mass of 550.0 grams, and a mean BCI of 0.470. No additional *E. obsoleta* were observed. The relative abundance is 0.050 per observer hour.

Two (2) *N. erythrogaster* were captured with a mean SVL of 708.9(34.2) millimeters, a mean TL of 934.6(26.4) millimeters, a mean mass of 271.0(18.5) grams, and a mean BCI of 0.383(0.045). A total of seven (7) were observed or captured; the relative abundance is 0.351 per observer hour.

No *N. rhombifer* were captured, therefore there is no morphological data for this species. A total of one (1) was observed; the relative abundance is 0.050 per observer hour.

Two (2) *O. aestivus* were captured with a SVL of 348.5(32.2) millimeters, and a mean TL of 561.6(54.4) millimeters. Mass was not recorded, however, due to equipment problems; therefore mean BCI could not be determined. No additional *O. aestivus* were observed. The relative abundance is 0.100 per observer hour.

Two (2) *S. lateralis* were captured with a mean SVL of 47.5(10.7) millimeters, a mean TL of 98.1(23.8) millimeters, a mean mass of 1.9(0.2) grams, and a mean BCI of 0.039(0.004). A total of three (3) were observed or captured and the relative abundance is 0.150 per observer hour.

No *T. proximus* were captured; therefore, there is no morphological data for this species. A total of three (3) were observed; the relative abundance is 0.150 per observer hour.

No *V. striatula* were captured; therefore, there is no morphological data for this species. A total of one (1) was observed, and the, relative abundance is 0.050 per observer hour.

Pecan Ridge

Pecan Ridge is predominately a woodland area located south of Lake Shore Drive and 19th Street paralleling Pecan Ridge Apartments (See Figure 13; N 31°35.082' W 097°11.169').

Figure 13 - GIS map of Pecan Ridge, highlighting the study site and its boundaries. A 100-meter buffer around the site is included and indicates the extent to which road lengths were measured within and around the site.

Habitat and Vegetation

Thirty-seven (37) trees were measured in the two strip-transects (Figures 14a and b) including seven (7) species (*Carya illinoinensis, Celtis laevigata, Melia azedarach, Juniperus virginiana, Ptelea trifoliate, Quercus macrocarpa,* and *Ulmus crassifolia*). The mean vegetation density is 80.541(6.951) percent, mean canopy cover is 88.514(2.317) percent, mean canopy height is 18(11) meters, and the mean dbh is 0.258(0.106) meters. The total basal area of all trees measured is 2.275 square meters; the total basal area of *C. illinoinensis* is 0.042 square meters, the total basal area of *C. laevigata* is 1.699 square meters, the total basal area of *M. azedarach* is 0.159 square meters, the total basal area of *J. virginiana* is 0.007 square meters, the total basal area of *P. trifoliata* is 0.064 square meters, the total basal area of *Q. macrocarpa* is 0.097 square meter, and the total basal area of *U. crassifolia* is 0.206 square meters. Therefore, *C. laevigata* is the dominant tree species in Pecan Ridge.

Figure 14a and b - Photographs of the Pecan Ridge study site. Left (14a): First strip transect near a western section of the site. Right (14b): Second strip transect near central section of the site.

Forty-five (45) saplings/shrubs were measured in the two strip-transects including eight (8) species (*Acer negundo, Celtis laevigata, Juniperus ashei, Ligustrum lucidum, Melia azedarach, Juniperus virginiana, Quercus macrocarpa, and Ulmus crassifolia*). The mean height is 3.097(1.501) meters, and the mean dbh is 0.029(0.016) meters. The stem count of *A. negundo* is three (3), the stem count of *C. laevigata* is eight (8), the stem count of *J. ashei* is one (1), the stem count of *L. lucidum* is seventeen (17), the stem count of *M. azedarach* is ten (10), the stem count of *J. virginiana* is one (1), the stem count of *Q. macrocarpa* is one (1), and the stem count of *U. crassifolia* is four (4). Therefore, *L. lucidum* and *M. azedarach* are the dominant sapling/shrub species in Pecan Ridge.

The soils at Pecan Ridge are a combination of both a Frio silty clay, occasionally flooded, a fine, smectitic, thermic Cumulic Haplustolls and Stephen-Eddy complex with 2 to 5 percent slopes and a combination of clayey, mixed, active, thermic, shallow Udorthentic Haplustolls and loamy-skeletal, carbonatic, thermic, shallow Typic

Ustorthents. The mean pH is 7.8(0.4), the mean nitrogen concentrations is 24.0(32.9) pounds per acre, the mean phosphorus concentrations is 100.0(0.0) pounds per acre, and the mean potassium concentrations is 184.0(21.9) pounds per acre.

Squamates

Forty-seven (47) squamates were captured or observed along the transect and throughout the Pecan Ridge including five (5) speecies (*Anolis carolinensis, Hemidactylus turcicus, Sceloporus olivaceus, Scincella lateralis,* and *Virginia striatula*). A total of 15.048 hours were spent at Pecan Ridge. The Simpson's Diversity Index for this study site is 0.654.

Four (4) *A. carolinensis* were captured with a mean SVL of 58.0(9.4) millimeters, a mean TL of 168.3(25.0) millimeters, a mean mass of 6.2(1.8) grams, and a mean BCI of 0.107(0.028). A total of five (5) were observed or captured and their relative abundance is 0.332 per observer hour.

Three (3) *H. turcicus* were captured with a mean SVL of 25.1(3.7) millimeters, a mean TL of 47.7(7.1) millimeters, a mean mass of 1.7(0.6) grams, and a mean BCI of 0.067(0.019). A total of seven (7) were observed or captured and their relative abundance is 0.465 per observer hour.

One (1) *S. olivaceus* was captured with a SVL of 41.9 millimeters, a TL of 114.0 millimeters, a mass of 3.0 grams, and a BCI of 0.072. A total of six (6) were observed or captured and their relative abundance is 0.266 per observer hour.

Ten (10) *S. lateralis* were captured with a mean SVL of 39.2(9.3) millimeters, a mean TL of 95.9(33.6) millimeters, a mean mass of 2.1(0.9) grams, and a mean BCI of

0.046(0.016). A total of twenty six (26) were observed or captured and their relative abundance is 0.563 per observer hour.

Three (3) *V. striatula* were captured with a mean SVL of 147.7(9.4) millimeters, a mean TL of 168.0(1.3) millimeters, a mean mass of 3.2(1.0) grams, and a mean BCI of 0.021(0.007). A total of three (3) were observed or captured and their relative abundance is 0.182 per observer hour.

Sherwood Forest

Sherwood Forest is predominately a woodland area in a ravine between subdivisions, located near Lake Shore Drive and Lake Waco south of the Lake Waco Dam, extending from a small section of the lake to Hillcrest Drive (See Figure 15; N 31°33.734' W 097°11.482')

Figure 15 - GIS map of Sherwood Forest, highlighting the study site and its boundaries. A 100-meter buffer around the site is included and indicates the extent to which road lengths were measured within and around the site.

Habitat and Vegetation

Thirty-six (36) trees were measured in the two strip-transects (See Figures 16a and b) including four (4) species (*Carya illinoinensis, Celtis laevigata, Juniperus virginiana,* and *Ulmus crassifolia*). The mean vegetation density is 80(0) percent, mean canopy cover is 86(8) percent, mean canopy height is 12.502(14.079) meters, and the mean dbh is 0.219(0.080) meters. The total basal area of all trees measured is 1.566 square meters; the total basal area of *C. illinoinensis* is 0.088 square meters, the total basal area of *C. laevigata* is 0.274 square meters, the total basal area of *J. virginiana* is 1.093 square meters, and the total basal area of *U. crassifolia* is 0.111 square meters. Therefore, *J. virginiana* is the dominant tree species in Sherwood Forest.

Figure 16a and b - Photographs of the Sherwood Forest study site. Left (16a): First strip transect near a northern section of the site. Right (16b): Second strip transect near the center of the site.

One-hundred and forty-nine (149) saplings/trees were measured in the two strip-transects, including fifteen (15) species (*Acer negundo, Carya illinoinensis, Castanea mollisima, Celtis laevigata, Cercis canadensis, Fraxinus texensis, Ilex vomitoria, Ligustrum lucidum, Morus rubra, Juniperus virginiana, Quercus buckleyi, Quercus* *laceyi, Rhamnus caroliniana, Rhus lanceolata,* and *Ulmus crassifolia*). The mean canopy height is 4.183(2.683) meters, and the mean dbh is 0.024(0.012) meters. The stem count of *A. negundo* is six (6), the stem count of *C. illinoinensis* is three (3), the stem count of *C. mollisima* is thirteen (13), the stem count of *C. laevigata* is twenty eight (28), the stem count of *C. canidensis* is two (2), the stem count of *F. texensis* is one (1), the stem count of *I. vomitoria* is thirty three (33), the stem count of *L. lucidum* is forty nine (49), the stem count of *M. rubra* is two (2), the stem count of *J. virginiana* is one (1), the stem count of *Q. buckleyi* is three (3), the stem count *Q. laceyi* is one (1), the stem count of *R. caroliniana* is five (5), the stem count of *R. lanceolata* is one (1), and the stem count of *U. crassifolia* is one (1). Therefore, *I. vomitoria* and *L. lucidum* are the dominant sapling/shrub species in Sherwood Forest.

The soils at Sherwood Forest are an Eddy-Urban land complex with 3 to 15 percent slope and a combination of loamy-skeletal, carbonatic, thermic, shallow Typic Ustorthents and man-made surfaces. The mean pH is 8.0(0.0), the mean nitrogen concentrations is 24.0(32.9) pounds per acre, the mean phosphorus concentrations is 60.0(54.8) pounds per acre, and the mean potassium concentrations is 184.0(21.9) pounds per acre.

Squamates

Twenty-five (25) squamates were captured or observed along the transect and throughout the Sherwood Forest including eight (8) species (*Anolis carolinensis, Hemidactylus turcicus, Leptotyphlops dulcis, Nerodia rhombifer, Sceloporus olivaceus,* *Scincella lateralis, Tantilla gracilis,* and *Virginia striatula*). A total of 16.466 hours were spent at Sherwood Forest. The Simpson's Diversity Index for this study site is 0.780.

No *A. carolinensis* were captured; therefore, there is no morphological data for this species. A total of one (1) was observed and their relative abundance is 0.061.

Four (4) *H. turcicus* were captured with a SVL of 27.2(4.1) millimeters, a mean TL of 52.5(13.5) millimeters, a mean mass of 1.3(0.4) grams, and a mean BCI of 0.047(0.009). No additional *H. turcicus* were observed. The relative abundance is 0.243 per observer hour.

One (1) *L. dulcis* was captured with a SVL of 164.0 millimeters, a TL of 171.1 millimeters, a mass of 2.1 grams, and a BCI of 0.013; No additional *L. dulcis* were observed. The relative abundance is 0.061 per observer hour.

Two (2) *N. rhombifer* were captured with a mean SVL of 354.4(133.6) millimeters, a mean TL of 450.2(170.7) millimeters, a mean mass of 29.1(10.0) grams, and a mean BCI of 0.083(0.003). No additional *N. rhombifer* were observed. The relative abundance is 0.121 per observer hour.

No *S. olivaceus* were captured; therefore there is no morphological data for this species. A total of one (1) was observed and the relative abundance is 0.061 per observer hour.

Five (5) *S. lateralis* were captured with a mean SVL of 37.7(14.0) millimeters, a mean TL of 80.2(39.1) millimeters, a mean mass of 2.6(1.4) grams, and a mean BCI of 0.057(0.019). A total of eleven (11) were observed or captured and their relative abundance is 0.688 per observer hour.

Two (2) *T. gracilis* were captured with a mean SVL of 119.5(11.8) millimeters, a mean TL of 159.5(15.0) millimeters, a mean mass of 2.2(0.5) grams, and a mean BCI of 0.018(0.002). No additional *T. gracilis* were observed. The relative abundance is 0.121 per observer hour.

Three (3) *V. striatula* were captured with a mean SVL of 201.9(46.5) millimeters, a mean TL of 239.7(48.8) millimeters, a mean mass of 7.2(3.3) grams, and a mean BCI of 0.034(0.012). No additional *V. striatula* were observed. The relative abundance is 0.182 per observer hour.

Speegleville Park

Speegleville Park is predominately a woodland area owned and managed by the U.S. Army Corp. of Engineers. The park is located along the west side of Lake Waco between Over Flow, Mclaughlin, and San Ann Roads (See Figure 17; N 31°33.209' W 097°15.092').

Figure 17 - GIS map of Speegleville Park, highlighting the study site and its boundaries. A 100-meter buffer around the site is included and indicates the extent to which road lengths were measured within and around the site.

Habitat and Vegetation

Twenty-four (24) trees were measured in the two strip-transects (See Figures 20a and b) including four (4) species (*Celtis laevigata, Gleditsia triacanthos, Prosopis glandulosa,* and *Ulmus crassifolia*). The mean vegetation density is 58(10) percent, mean canopy cover is 43(10) percent, mean canopy height is 10.348(4.724) meters, and the mean dbh is 0.165(0.045) meters. The total basal area of all trees measured is 0.605 square meters; the total basal area of *C. laevigata* is 0.444 square meters, the total basal area of *G. triacanthos* is 0.006 square meter, the total basal area of *P. glandulosa* is 0.037 square meters, and the total basal area of *U. crassifolia* is 0.118 square meters. Therefore, *C. laevigata* and *U. crassifolia* are the dominant tree species in Speegleville Park.

Figure 18a and b - Photographs of the Speegleville Park study site. Left (18a): First strip transect near a northern section of the site. Right (18b): Second strip transect near a central section of the site.

Twenty-three (23) saplings/shrubs were measured in the two strip-transects including five (5) species (*Carya illinoinensis, Celtis laevigata, Gleditsia triacanthos, Prosopis glandulosa,* and *Ulmus crassifolia*). The mean height is 4.199(1.420) meters, and the mean dbh is 0.048(0.021) meters. The stem count of *C. illinoinensis* is five (5), the stem count of *C. laevigata* is thirteen (13), the stem count of *G. triacanthos* is one (1), the stem count of *P. glandulosa* is two (2), and the stem count of *U. crassifolia* is two (2). Therefore, *C. laevigata* and *C. illinoinensis* are the dominant sapling/shrub species in Speegleville Park.

The soils at Speegleville Park are a Frio silty clay, occasionally flooded, a fine, smectitic, thermic Cumulic Haplustolls. The mean pH is 7.2(0.4), the mean nitrogen concentrations is 0.0(0.0) pounds per acre, the mean phosphorus concentrations is 70.0(27.4) pounds per acre, and the mean potassium concentrations is 152.0(43.8) pounds per acre.

Squamates

Twenty (20) squamates were captured or observed along the transect and throughout the Speegleville Park including eleven (11) species (*Anolis carolinensis, Elaphe guttata emoryi*, *Eumeces fasciatus, Eumeces laticeps*, *Nerodia erythrogaster, Nerodia rhombifer, Sceloporus olivaceus, Scincella lateralis, Storeria dekayi, Thamnophis proximus,* and *Virginia striatula*). A total of 20.093 hours were spent at Speegleville Park. The Simpson's Diversity Index for this study site is 0.924.

No *A. carolinensis* were captured; therefore, there is no morphological data for this species. A total of one (1) was observed, and their relative abundance is 0.050 per observer hour.

One (1) *E. guttata emoryi* was captured with a SVL of 367.9 millimeters, a TL of 446.2 millimeters, a mass of 18.1 grams, and a BCI of 0.049. No additional *E. guttata emoryi* were observed. The relative abundance is 0.050 per observer hour.

One (1) *E. fasciatus* was captured with a SVL of 65.1 millimeters, a TL of 133.9 millimeters, a mass of 7.6 grams, and a BCI of 0.117. A total of three (3) were observed or captured and the relative abundance is 0.149 per observer hour.

No *E. laticeps* were captured; therefore, there is no morphological data for this species. A total of one (1) was observed and the relative abundance is 0.050 per observer hour.

One (1) *N. erythrogaster* was captured with a SVL of 479.8 millimeters, a TL of 636.2 millimeters, a mass of 76.7 grams, and a BCI of 0.160. No additional *N. erythrogaster* were observed. The relative abundance is 0.050 per observer hour.

One (1) *N. rhombifer* was captured with a SVL of 245.9 millimeters, a TL of 303.2 millimeters, a mass of 12.9 grams, and a mean BCI of 0.052. No additional *N. rhombifer* were observed. The relative abundance is 0.050 per observer hour.

No *S. olivaceus* were captured; therefore, there is no morphological data for this species. A total of two (2) were observed, and the relative abundance is 0.100 per observer hour.

No *S. lateralis* were captured; therefore, there is no morphological data for this species. A total of one (1) was observed, and the relative abundance is 0.050 per observer hour.

Two (2) *S. dekayi* were captured with a mean SVL of 156.6(46.0) millimeters, a mean TL of 196.0(67.7) millimeters, a mean mass of 8.1(1.3) grams, and a mean BCI of

0.055(0.025). A total of three (3) were observed or captured and the relative abundance is 0.149 per observer hour.

Two (2) *T. proximus* were captured with a mean SVL of 328.8(44.8) millimeters, a mean TL of 459.2(48.2) millimeters, a mean mass of 11.6(5.2) grams, and a mean BCI of 0.034(0.011). A total of three (3) were observed or captured; the relative abundance is 0.149 per observer hour.

Four (4) *V. striatula* were captured with a mean SVL of 155.8(40.4) millimeters, a mean TL of 185.0(40.4) millimeters, a mean mass of 2.0(0.1) grams, and a mean BCI of 0.013(0.003). No additional *V. striatula* were observed. The relative abundance is 0.199 per observer hour.

Sugar Creek

Sugar Creek is predominately a woodland area in a ravine between two sections of a subdivision (Sugar Creek) in Woodway, TX (See Figure 19; N 31°36.136' W 097°14.345').

Figure 19 - GIS map of Sugar Creek, highlighting the study site and its boundaries. A100-meter buffer around the site is included and indicates the extent to which road lengths were measured within and around the site.

Habitat and Vegetation

Nine (9) trees were measured in the two strip-transects (See Figure 20a and b) including eight (8) species (*Celtis laevigata, Ilex vomitoria, Juglans nigra, Melia azedarach, Morus rubra, Populus deltoides, Quercus laceyi,* and *Ulmus crassifolia*). The mean vegetation density is 60(15) percent, mean canopy cover is 90(0) percent, mean canopy height is 15(7) meters, the mean dbh is 0.290(0.152) meters. The total basal area of all trees measured is 0.762 square meters; the total basal area of *C. laevigata* is 0.075 square meters, the total basal area of *I. vomitoria* is 0.025 square meter, the total basal area of *J. nigra* is 0.276 square meters, the total basal area of *M. azedarach* is 0.123 square meters, the otal basal area of *M. rubra* is 0.006 square meters, the total basal area of *P. deltoides* is 0.019 square meter, the total basal area of *Q. laceyi* is 0.067 square meters, and the total basal area of *U. crassifolia* is 0.172 square meters. *J. nigra* and *U. crassifolia* are the dominant tree species in Sugar Creek.

Figure 20a and b - Photographs of the Sugar Creek study site. Left (20a): First strip transect near an eastern section of the site. Right (20b): Second strip transect near a western section of the site.

One-hundred and eighteen (118) saplings/shrubs were measured in the two strip-transects including twenty-two (22) species (*Celtis laevigata, Ilex vomitoria, Juniperus virginiana, Morus rubra, Juglans nigra, Rhus glabra, Frangula caroliniana, Acer negundo, Cornus drummondii, Quercus macrocarpa, Quercus texena, Ulmus Americana, Ulmus crassifolia, Aesculus glabra, Carya illinoinensis, Fraxinus texensis, Melia azedarach, Populus deltoids, Prunus mexicanus, Rhus copallinum, Sideroxylon lanuginosum, and Styrax grandifolius*). The mean height is 3.996(1.940) meters, and the mean dbh is 0.031(00.015) meters. The stem count of *C. laevigata* is twenty nine (29), the stem count of *I. vomitoria* is twenty nine (29), the stem count of *J. virginiana* is fourteen (14), the stem count of *M. rubra* is eleven (11), the stem count of *J. nigra* is five (5), the stem count of *R. glabra* is five (5),, the stem count of *F. caroliniana* is four (4), the stem count of *A. negundo* is two (2), the stem count of *C. drummondii* is two (2), the stem count of *Q. macrocarpa* is two (2), the stem count of *Q. texena* is two (2), the stem count of *U. Americana* is two (2), the stem count of *U. crassifolia* is two (2), the stem count of *A. glabra* is one (1), the stem count of *C. illinoinensis* is one (1), the stem count of *F. texensis* is one (1), the stem count of *M. azedarach* is one (1), the stem count of *P. deltoids* is one (1), the stem count of *P. mexicanus* is one (1), the stem count of *R. copallinum* is one (1), the stem count of *S. lanuginosum* is one (1), the stem count of *S. grandifolius* is one (1). Therefore, *C. laevigata, I. vomitoria,* and *J. virginiana* are the dominant sapling/shrub species in Sugar Creek.

The soils at Sugar Creek are a Eddy-Urban land complex, with 3 to 15 percent slope, and a loamy-skeletal, carbonatic, thermic, shallow Typic Ustorthents; man-made surfaces. The mean pH is 8.0(0.0), the mean nitrogen concentrations is 0.0(0.0) pounds per acre, the mean phosphorus concentrations is 20.0(27.4) pounds per acre, and the mean potassium concentrations is 160.0(0.0) pounds per acre.

Squamates

Forty-eight (48) squamates were captured or observed along the transect and throughout the Sugar Creek, including five (5) species (*Anolis carolinensis, Hemidactylus turcicus, Sceloporus olivaceus, Scincella lateralis,* and *Virginia striatula*). A total of 12.428 hours were spent at Sugar Creek. The Simpson's Diversity Index for this study site is 0.789 per observer hour.

Five (5) *A. carolinensis* were captured with a mean SVL of 31.7(6.5) millimeters, a mean TL of 172.8(17.6) millimeters, a mean mass of 6.5(1.4) grams, and a mean BCI of 0.104(0.014). A total of nine (9) were observed or captured, and the relative abundance is 0.724 per observer hour.

Four (4) *H. turcicus* were captured with a mean SVL of 41.5(10.8) millimeters, a mean TL of 83.8(22.1) millimeters, a mean mass of 4.1(1.6) grams, and a mean BCI of 0.100(0.036). A total of fifteen (15) were observed or captured; the relative abundance is 1.207 per observer hour.

Four (4) *S. olivaceus* were captured with a mean SVL of 78.3(10.9) millimeters, a mean TL of 205.2(29.8) millimeters, a mean mass of 24.7(13.0) grams, and a mean BCI of 0.303(0.132). A total of twelve (12) were observed or captured and the relative abundance is 0.966 per observer hour.

Five (5) *S. lateralis* were captured with a mean SVL of 43.9(3.6) millimeters, a mean TL of 105.5(25.4) millimeters, a mean mass of 1.8(0.6) grams, and a mean BCI of 0.041(0.012). A total of seven (7) were observed or captured; the relative abundance is 0.563 per observer hour.

Five (5) *V. striatula* were captured with a mean SVL of 164.7(26.8) millimeters, a mean TL of 204.6(33.6) millimeters, a mean mass of 4.1(1.3) grams, and a mean BCI of 0.025(0.005). No additional *V. striatula* were observed. The relative abundance is 0.402 per observer hour.

Woodway

Woodway is predominately a woodland area owned by the U.S. Army Corp. of Engineers as part of the flowage easement. The park is located along the southeast side of Lake Waco off of Estates Drive in Woodway, TX (See Figure 21; N 31°30.711' W 097°14.646').

Figure 21 - GIS map of Woodway, highlighting the study site and its boundaries. A 100-meter buffer around the site is included and indicates the extent to which road lengths were measured within and around the site.

Habitat and Vegetation

Twenty-seven (27) trees were measured in the two strip-transects (See Figures 22a and b), including nine (9) species (*Acer negundo, Celtis laevigata, Fraxinus texensis, Gleditsia triacanthos, Maclura pomifera, Juniperus virginiana, Quercus virginiana, Salix nigra* and *Ulmus crassifolia*). The mean vegetation density is 61(10) percent, mean canopy cover is 78(15) percent, mean canopy height is 11.452(5.683) meters, and the mean dbh is 0.200(0.087) meters. The total basal area of all trees measured is 1.004 square meters; the total basal area of *A. negundo* is 0.014 square meters, the total basal area of *C. laevigata* is 0.346 square meters, the total basal area of *F. texensis* is 0.119 square meters, the total basal area of *G. triacanthos* is 0.065 square meters, the total basal area of *M. pomifera* is 0.055 square meters, the total basal area of *J. virginiana* is 0.179 square meters, the total basal area of *Q. virginiana* is 0.016 square meters, the total basal area of *S. nigra* is 0.042 square meter, and the total basal area of *U. crassifolia* is 0.168 square meters. Therefore, *C. laevigata* and *J. virginiana* are the dominant tree species in Woodway.

Figure 22a and b – Photographs of the Woodway study site. Left (22a): First strip transect near the westernmost section of the site. Right (22b): Second strip transect near the northeastern most section of the site.

Thirty-two (32) saplings/shrubs were measured in the two strip-transects, including six (6) species (*Celtis laevigata, Fraxinus texensis, Gleditsia triacanthos, Melia azedarach, Quercus sinuate,* and *Ulmus crassifolia*). The mean height is 4.299(3.386) meters, and the mean dbh is 0.030(0.020) meters. The stem count of *C. laevigata* is two (2), the stem count of *F. texensis* is one (1), the stem count of *G. triacanthos* is five (5), the stem count of *M. azedarach* is nineteen (19), the stem count of *Q. sinuata* is one (1), and the stem count of *U. crassifolia* is four (4). Therefore, *M. azedarach* is the dominant sapling/shrub species in Woodway.

The soils at Woodway are a McLennan clay loam, with 8 to 15 percent slopes, and a fine-silty, carbonatic, thermic Udic Haplustepts. The mean pH is 8.0(0.0), the mean nitrogen concentrations is 0.0(0.0) pounds per acre, the mean phosphorus concentrations is 20.0(27.4) pounds per acre, and the mean potassium concentrations is 136.0(21.9) pounds per acre.

Squamates

Thirty-one (31) squamates were captured or observed along the transect and throughout the Woodway including three (3) species (*Anolis carolinensis, Sceloporus olivaceus,* and *Scincella lateralis*). A total of 8.308 hours were spent at Woodway. The Simpson's Diversity Index for this study site is 0684.

Five (5) *A. carolinensis* were captured with a mean SVL of 60.7(6.9) millimeters, a mean TL of 177.2(20.4) millimeters, a mean mass of 6.3(1.6) grams, and a mean BCI of 0.103(0.018). A total of twelve (12) were observed or captured; the relative abundance is 1.444 per observer hour.

Four (4) *S. olivaceus* were captured with a mean SVL of 55.9(10.2) millimeters, a mean TL of 151.8(30.6) millimeters, a mean mass of 9.6(4.3) grams, and a mean BCI of 0.164(0.048). A total of ten (10) were observed or captured and the relative abundance is 1.204 per observer hour.

Two (2) *S. lateralis* were captured with a mean SVL of 46.1(1.13) millimeters, a mean TL of 127.6(10.5) millimeters, a mean mass of 2.7(0.4) grams, and a mean BCI of 0.059(0.011). A total of nine (9) were observed or captured; the relative abundance is 1.083 per observer hour.

Body Condition Index

I used a multivariate regression to analyze the mean body condition index (BCI) in relation to degree of urbanization and multiple environmental variables for species where a sufficient number of individuals were captured. The BCI for species where only a few individuals were captured was not analyzed. Variables were transformed as necessary to ensure datasets conformed to the assumptions of normality and homogeneity of variance. The assumption of the normality of the residuals was tested using a normal probability plot and Shapiro-Francia tests (Shapiro and Francia 1972). When the assumption of normality was not achieved, a quantile regression was used to examine the relationships among the variables.

The multivariate regression analysis for *Scincella lateralis* (29 individuals captured) found that the degree of urbanization (p-value = 0.048), mean vegetation density (p-value = 0.001), percent grass cover (p-value = 0.001), percent forb cover (p-value = 0.013), and percent litter fall cover (p-value = 0.062) had a significant effect on the mean BCI for *S. lateralis*. However, based on the Shapiro-Francia test for normality (p-value = 0.00001) the assumption of normality was not met. I was unable to transform the data to achieve normality; therefore, quantile regression analysis was used.

The quantile regression analysis did not reveal any significant relationships between *S. lateralis* median BCI and any of the other abundance or environmental variables.

The multivariate regression analysis for *Hemidactylus turcicus* (61 individuals captured), found that degree of urbanization (p-value = 0.000), mean vegetation density (p-value = 0.000), and mean tree height (p-value = 0.000) had a significant effect on the mean BCI for *H. turcicus*. However, based on the Shapiro-Francia test for normality (p-value = 0.00001) the assumption of normality was not met. I was unable to transform the data to achieve normality. Therefore, quantile regression analysis was used.

The quantile regression analysis reveals that there is a significant but slight negative relationship between *H. turcicus* median BCI and the degree of urbanization (p-value = 0.000) as well a significant but slight negative relationship between the median BCI and canopy height (p-value = 0.020).

The multivariate regression analysis for *Anolis carolinensis* (28 individuals captured), found that only degree of urbanization (p-value = 0.000) had a significant effect on the mean BCI for *A. carolinenesis*. However, based on the Shapiro-Francia test for normality (p-value = 0.00001) the assumption of normality was not met. I was unable to transform the data to achieve normality. Therefore, quantile regression analysis was used.

The quantile regression analysis did not reveal any significant relationships between *A. carolinensis* median BCI and any of the other abundance or environmental variables.

The multivariate regression analysis for *Virginia striatula* (22 individuals captured) found that only the mean total length of the species (p-value = 0.000) and no environmental variables had a significant effect on the mean BCI for *V. striatula*. However, based on the Shapiro-Francia test for normality (p-value = 0.00001) the assumption of normality was not met. I was unable to transform the data to achieve normality; therefore, quantile regression analysis was used.

The quantile regression analysis reveals that there is a significant but slight positive relationship between *V. striatula* median BCI and the degree of urbanization (p-value = 0.002).

The multivariate regression analysis for *Sceloporus olivaceus* (17 individuals captured) found that squamate species diversity (p-value = 0.000) and mean total length of the species (p-value = 0.000) had a significant effect on the mean BCI for *S. olivaceus*. However, based on the Shapiro-Francia test for normality (p-value = 0.00001) the assumption of normality was not met. I was unable to transform the data to achieve normality; therefore, quantile regression analysis was used.

The quantile regression analysis reveals that there is a significant but slight negative relationship between *S. olivaceus* median BCI and the phosphorus concentrations in the soil (p-value = 0.015) as well a significant but slight negative relationship between the median BCI and grass cover (p-value = 0.035).

Abundance and Composition

Canonical Correspondence Analysis

I used Canonical Correspondence Analysis (CCA) to extract the major gradients in the species abundances that are accounted for by other measured species abundance and other environmental variables. I then created triplots to help analyze and visualize these relationships in a way that best preserves the natural interactions. I first compared species abundance with vegetation density, canopy height, canopy cover, and diameter and breast height (Figure 23):

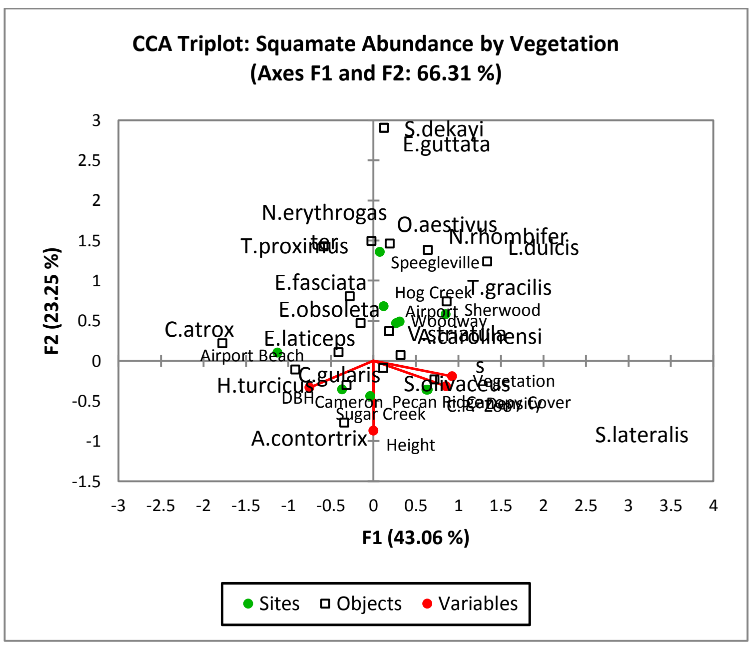

Figure 23 - CCA Triplot depicting relationships among squamate species abundance and vegetation measurements. Proximity of study sites, species, soil measurements indicate close relationships. The length and direction of each line designates variable's magnitude and direction of change along the gradients.

The CCA for species abundance compared with vegetation density, canopy height, canopy cover and diameter and breast height (dbh) shows that *Agkistrodon contortrix* (found only at the Cameron Park and Cameron Park Zoo study sites) was generally associated with greater canopy heights. *Anolis carolinensis* (found throughout many of the study sites) was generally associated with low vegetation density and canopy cover. *Cnemidophorus gularis* (found only at the Cameron Park and Airport Park study sites) was generally associated with medium dbh and low canopy heights. *Crotalus atrox* (found only at the Airport Beach Park Study Site) was not closely associated with any of the vegetation measures.

Elaphe guttata (found only at the Speegleville Park study site) was not closely associated with any of the vegetation measures. *Elaphe obsoleta* (found only at the Hog Creek WMA, Pecan Ridge, and Cameron Park study sites) was not closely associated with any of the vegetation measures. *Eumeces fasciatus* (found only at the Speegleville Park and Cameron Park study sites) was not closely associated with any of the vegetation measures. *Eumeces laticeps* (found at the Speegleville Park and Cameron Park study sites) was generally associated with a small dbh. *Hemidactylus turcicus* (generally found at the more urbanized study sites) was closely associated with a large dbh.

Leptotyphlops dulcis (found only at the Sherwood Forest study site) was not closely associated with any of the vegetation measures. *Nerodia erythrogaster* (found at the Hog Creek WMA, Speegleville Park and Airport Beach Park study sites) was not closely associated with any of the vegetation measures. *Nerodia rhombifer* (found at the Hog Creek WMA, Sherwood Forest and Airport Park study sites) was not closely associated with any of the vegetation measures. *Opheodrys aestivus* (found only at the Hog Creek WMA study site) was not closely associated with any of the vegetation measures. *Sceloporus olivaceus* (found at all study sites except Hog Creek WMA and Airport Beach Park) was closely associated with both increased canopy cover and vegetation density.

Scincella lateralis (found at all of the study sites) was closely associated with both increased canopy cover and vegetation density. *Storeria dekayi* (found only at the Speegleville Park study site) was not closely associated with any of the vegetation measures. *Tantilla gracilis* (found at the Cameron Park and Sherwood Forest study sites) was not closely associated with any of the vegetation measures. *Thamnophis proximus* (found at the Hog Creek WMA and Airport Beach Park study sites) was not closely associated with any of the vegetation measures. *Virginia striatula* (found at all study sites except Cameron Park Zoo and Woodway) was not closely associated with any of the vegetation measures.

I then compared species abundance with the percent ground cover data (Figure 24):

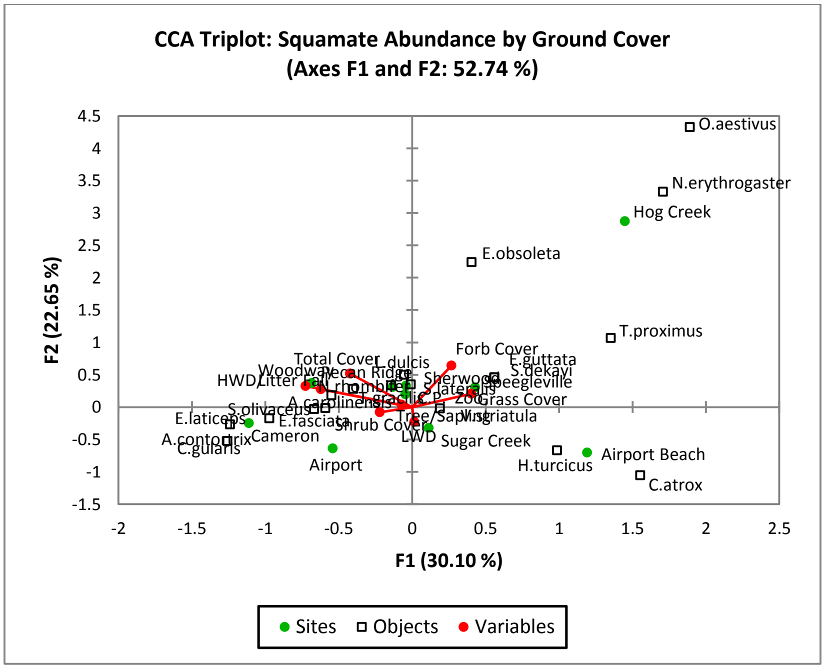

Figure 24 - CCA Triplot depicting relationships among squamate species abundance and percent ground cover data. Proximity of study sites, species, soil measurements indicate close relationships. The length and direction of each line designates the variable's magnitude and direction of change along the gradients.

The CCA for species abundance compared with the percent ground cover data shows that *Agkistrodon contortrix* (found only at the Cameron Park and Cameron Park Zoo study sites) was not closely associated with any of the ground cover types. *Anolis carolinensis* (found throughout many of the study sites) was generally associated with both increased percent of total cover and tree/sapling cover. *Cnemidophorus gularis* (found only at the Cameron Park and Airport Park study sites) was not closely associat with any of the ground cover types. *Crotalus atrox* (found only at the Airport Beach Park Study Site) was not closely associated with any of the ground cover types.

Elaphe guttata (found only at the Speegleville Park study site) was loosely associated with both increased percent forb cover and grass cover. *Elaphe obsoleta* (found only at the Hog Creek WMA, Pecan Ridge, and Cameron Park study sites) was not closely associated with any of the ground cover types. *Eumeces fasciatus* (found only at the Speegleville Park and Cameron Park study sites) was not closely associated with any of the ground cover types. *Eumeces laticeps* (found at the Speegleville Park and Cameron Park study sites) was not closely associated with any of the ground cover types. *Hemidactylus turcicus* (generally found at the more urbanized study sites) was not closely associated with any of the ground cover types.

Leptotyphlops dulcis (found only at the Sherwood Forest study site) was loosely associated with low percent litter fall and heavy woody debris (hwd), but increased with tree/sapling cover; *L. dulcis* was closely associated with both increased percent total cover and forb cover. *Nerodia erythrogaster* (found at the Hog Creek WMA, Speegleville Park and Airport Beach Park study sites) was not closely associated with any of the ground cover types. *Nerodia rhombifer* (found at the Hog Creek WMA, Sherwood Forest and Airport Park study sites) was loosely associated with a low percent of litter fall and hwd, but increased with tree/sapling cover; *N. rhombifer* was closely associated with both increased percent total cover and forb cover. *Opheodrys aestivus* (found only at the Hog Creek WMA study site) was not closely associated with any of the ground cover types. *Sceloporus olivaceus* (found at many of the study sites) was generally associated with both increased litter fall and hwd

Scincella lateralis (found at all of the study sites) was loosely associated with low percent litter fall and hwd, but increased with tree/sapling cover; *S. lateralis* was closely associated with medium amounts of total cover and forb cover. *Storeria dekayi* (found only at the Speegleville Park study site) was loosely associated with both increased percent forb cover and grass cover. *Tantilla gracilis* (found at the Cameron Park and Sherwood Forest study sites) was closely associated with medium amounts of litter fall and hwd, but increased with total cover; *T. gracilis* was loosely associated with increased tree/sapling cover. *Thamnophis proximus* (found at the Hog Creek WMA and Airport Beach Park study sites) was not closely associated with any of the ground cover types. *Virginia striatula* (found at all study sites except Cameron Park Zoo and Woodway) was closely associated with medium amounts of grass cover and a low percentage of light woody debris (lwd).

I then compared species abundance with the soil composition data (Figure 25):

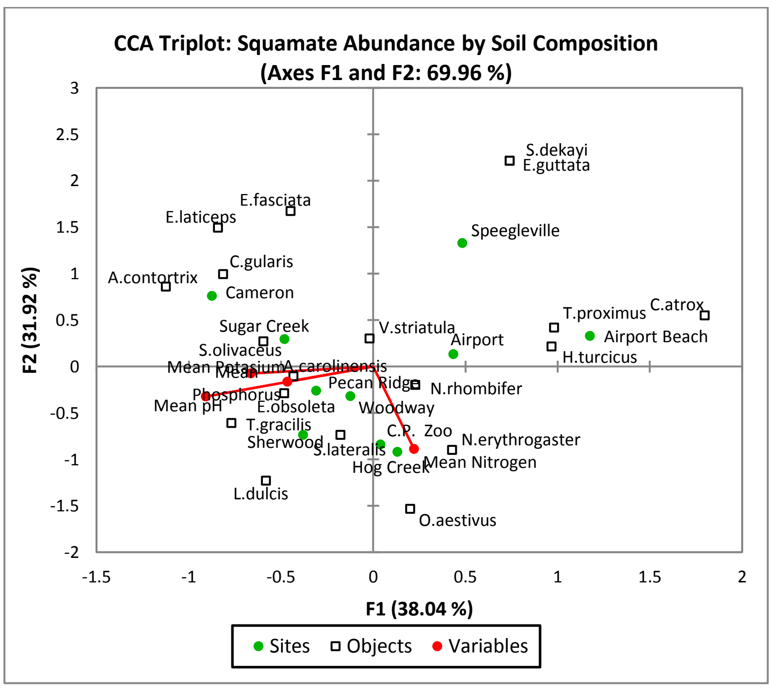

Figure 25 – CCA Triplot depicting relationships among squamate species abundance and soil composition. Proximity of study sites, species, soil measurements indicate close relationships. The length and direction of each line designates variable’s magnitude and direction of change along the gradients.

The CCA for species abundance compared with the percent ground cover data shows that *Agkistrodon contortrix* (found only at the Cameron Park and Cameron Park Zoo study sites) was not closely associated with soil acidity or any soil nutrient concentrations.

Anolis carolinensis (found at many of the study sites) was closely associated with medium levels of both potassium and acidity; *A. carolinensis* was also closely associated with high levels of phosphorus.

Cnemidophorus gularis (found only at the Cameron Park and Airport Park study sites) was not closely associated with soil acidity or any soil nutrient concentrations.

Crotalus atrox (found only at the Airport Beach Park Study Site) was not closely associated with soil acidity or any soil nutrient concentrations.

Elaphe guttata (found only at the Speegleville Park study site) was not closely associated with soil acidity or any soil nutrient concentrations.

Elaphe obsoleta (found only at the Hog Creek WMA, Pecan Ridge, and Cameron Park study sites) was closely associated with high levels of phosphorus and medium levels of acidity; *E. obsoleta* was generally associated with medium levels of potassium.

Eumeces fasciatus (found only at the Speegleville Park and Cameron Park study sites) was not closely associated with soil acidity or any soil nutrient concentrations.

Eumeces laticeps (found at the Speegleville Park and Cameron Park study sites) was not closely associated with soil acidity or any soil nutrient concentrations.

Hemidactylus turcicus (generally found at the more urbanized study sites, including: Airport Beach Park, Cameron Park Zoo, Pecan Ridge, Sherwood Forest, and

Sugar Creek) was not closely associated with soil acidity or any soil nutrient concentrations.

Leptotyphlops dulcis (found only at the Sherwood Forest study site) was not closely associated with soil acidity or any soil nutrient concentrations.

Nerodia erythrogaster (found at the Hog Creek WMA, Speegleville Park and Airport Beach Park study sites) was generally associated with high levels of nitrogen.

Nerodia rhombifer (found at the Hog Creek WMA, Sherwood Forest and Airport Park study sites) was loosely associated with low to medium levels of nitrogen.

Opheodrys aestivus (found only at the Hog Creek WMA study site) was not closely associated with soil acidity or any soil nutrient concentrations.

Sceloporus olivaceus (found at many of the study sites) was loosely associated with high levels of potassium.

Scincella lateralis (found at all of the study sites) was loosely associated with high levels of nitrogen.

Storeria dekayi (found only at the Speegleville Park study site) was not closely associated with soil acidity or any soil nutrient concentrations.

Tantilla gracilis (found at the Cameron Park and Sherwood Forest study sites) was loosely associated with a high soil pH.

Thamnophis proximus (found at the Hog Creek WMA and Airport Beach Park study sites) was not closely associated with soil acidity or any soil nutrient concentrations.

Virginia striatula (found at most of the study sites) was loosely associated with low soil acidity and low levels of all soil nutrients.

Dissimilarity Matrices and Cluster Analysis

I used Agglomerative Hierarchical Cluster Analysis (AHCA) with average linkage to help determine the species composition at each study site, as well as their relationships among each site. I performed each AHCA based a dissimilarity matrix produced from the site's squamate species abundances, tree species basal areas, sapling/shrub stem counts, ground cover data, soil nutrient condition, and any combination thereof, using squared Euclidean distances

An AHCA was then performed for each, assigning each study site into individual clusters and subsequently agglomerating each cluster into larger and larger clusters based on the shortest distance between entities.

The dissimilarity matrix for the study sites based only on squamate species' abundance is shown below in Table 1. Figure 26 is a dendrogram of the cluster analysis that was produced to show site groupings based on squamate abundance.

Table 1 - Dissimilarity Matrix for Squamate Species Abundance. Obs1 = Hog Creek WMA, Obs2 = Speegleville Park, Obs3 = Airport Beach Park, Obs4 = Woodway, Obs5 = Airport Park, Obs6 = Cameron Park, Obs7 = Cameron Park Zoo, Obs8 = Pecan Ridge, Obs9 = Sugar Creek, Obs10 = Sherwood Forest.

	Obs1	Obs2	Obs3	Obs4	Obs5	Obs6	Obs7	Obs8	Obs9	Obs10
Obs1	0.00									
Obs2	0.45	0.00								
Obs3	4.60	4.61	0.00							
Obs4	2.11	2.10	5.02	0.00						
Obs5	0.65	0.56	4.62	2.02	0.00					
Obs6	1.93	1.85	4.96	1.88	1.50	0.00				
Obs7	2.91	3.00	4.67	2.46	2.95	3.28	0.00			
Obs8	1.75	1.81	4.39	1.67	1.77	2.33	1.23	0.00		
Obs9	1.82	1.75	3.62	1.57	1.72	1.94	2.57	1.62	0.00	
Obs10	0.73	0.75	4.37	1.88	0.78	1.93	2.33	1.16	1.51	0.00

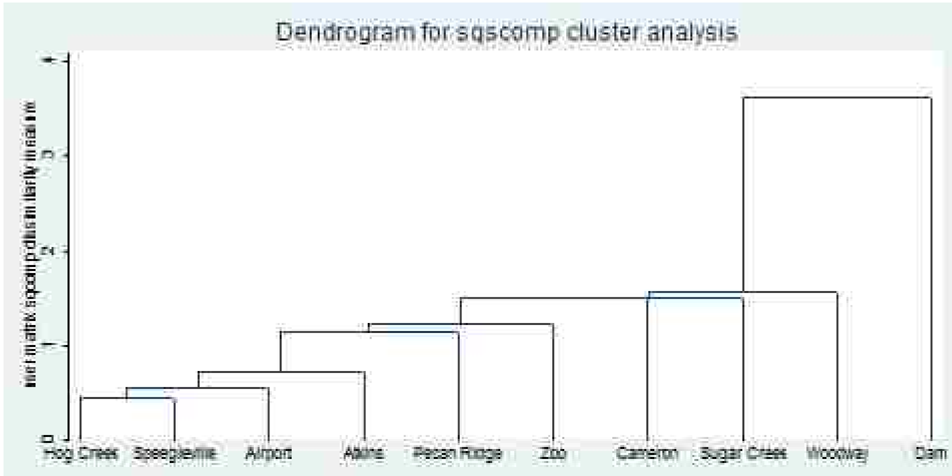

Figure 26 – Dendrogrom showing clusters of most similar sites based in the dissimilarity matrix derived solely from squamate species abundance at each site.

The dissimilarity matrix for the study sites based on only tree species' basal area is shown in Table 2. The accompanying dendrogram of the cluster analysis showing site groupings based on tree species' basal area is presented below in Figure 27.

Table 2 - Dissimilarity Matrix derived solely from tree species basal areas. Obs1 = Hog Creek WMA, Obs2 = Speegleville Park, Obs3 = Airport Beach Park, Obs4 = Woodway, Obs5 = Airport Park, Obs6 = Cameron Park, Obs7 = Cameron Park Zoo, Obs8 = Pecan Ridge, Obs9 = Sugar Creek, Obs10 = Sherwood Forest

	Obs1	Obs2	Obs3	Obs4	Obs5	Obs6	Obs7	Obs8	Obs9	Obs10
Obs1	0.00									
Obs2	0.62	0.00								
Obs3	5.09	4.74	0.00							
Obs4	1.46	1.18	3.68	0.00						
Obs5	1.38	1.42	5.10	1.77	0.00					
Obs6	8.31	8.05	3.56	6.96	8.30	0.00				
Obs7	8.36	8.11	3.89	7.04	8.33	1.88	0.00			
Obs8	8.43	8.09	3.38	7.02	8.40	1.40	2.41	0.00		
Obs9	5.01	4.76	1.25	3.65	5.05	3.41	3.67	3.66	0.00	
Obs10	2.68	2.44	2.87	1.40	2.50	6.01	6.11	6.11	2.81	0.00

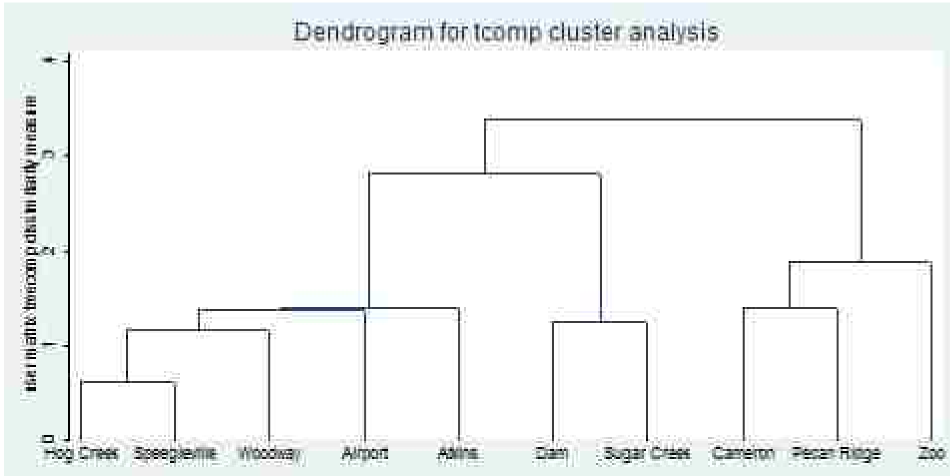

Figure 27- Dendrogrom showing clusters of most similar sites based in the dissimilarity matrix derived solely from tree species basal areas at each site.

The dissimilarity matrix for the study sites based on only sapling/shrub stem counts is shown below in Table 3. Figure 28 is a dendrogram of the cluster analysis that was produced to show site groupings based on only sapling/shrub stem counts.

Table 3- Dissimilarity Matrix derived solely from sapling/shrub stem counts. Obs1 = Hog Creek WMA, Obs2 = Speegleville Park, Obs3 = Airport Beach Park, Obs4 = Woodway, Obs5 = Airport Park, Obs6 = Cameron Park, Obs7 = Cameron Park Zoo, Obs8 = Pecan Ridge, Obs9 = Sugar Creek, Obs10 = Sherwood Forest.

	Obs1	Obs2	Obs3	Obs4	Obs5	Obs6	Obs7	Obs8	Obs9	Obs10
Obs1	0.00									
Obs2	9.59	0.00								
Obs3	5.00	11.87	0.00							
Obs4	17.75	23.09	20.30	0.00						
Obs5	11.31	15.68	9.75	22.16	0.00					
Obs6	28.83	31.54	28.81	32.65	30.05	0.00				
Obs7	21.56	17.52	23.71	31.18	27.33	29.50	0.00			
Obs8	19.24	21.45	21.10	21.10	23.66	15.65	20.71	0.00		
Obs9	42.30	39.10	43.68	48.31	45.44	51.88	34.21	45.11	0.00	
Obs10	65.15	63.06	66.19	69.43	67.76	49.75	51.55	53.44	54.65	0.00

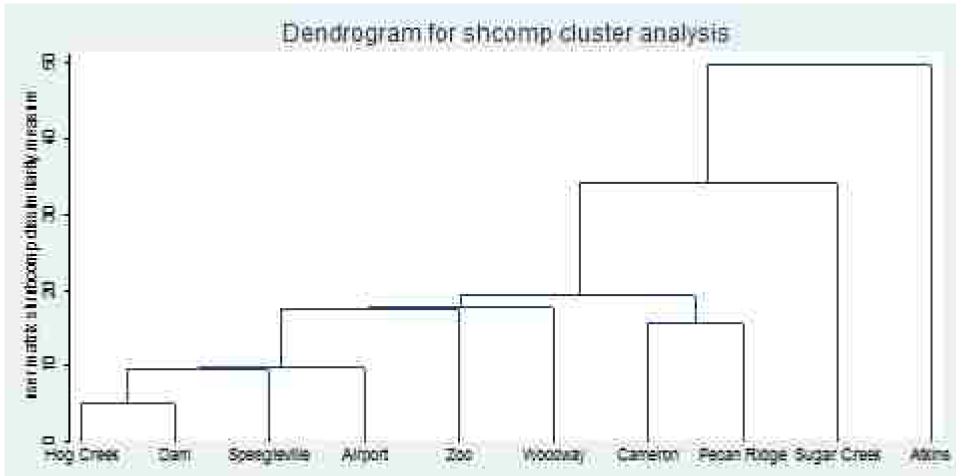

Figure 28- Dendrogrom showing clusters of most similar sites based in the dissimilarity matrix derived solely from sapling/shrub stem counts at each site.

The dissimilarity matrix for the study sites based on only ground cover data is shown in Table 4. A dendrogram of the cluster analysis was produced to show site groupings based on ground cover percentages is seen in Figure 29.

Table 4- Dissimilarity Matrix derived solely from ground cover data. Obs1 = Hog Creek WMA, Obs2 = Speegleville Park, Obs3 = Airport Beach Park, Obs4 = Woodway, Obs5 = Airport Park, Obs6 = Cameron Park, Obs7 = Cameron Park Zoo, Obs8 = Pecan Ridge, Obs9 = Sugar Creek, Obs10 = Sherwood Forest.

	Obs1	Obs2	Obs3	Obs4	Obs5	Obs6	Obs7	Obs8	Obs9	Obs10
Obs1	0.00									
Obs2	30.47	0.00								
Obs3	60.39	44.66	0.00							
Obs4	57.43	46.38	81.60	0.00						
Obs5	62.03	48.86	59.69	40.58	0.00					
Obs6	70.94	60.92	70.38	46.18	14.54	0.00				
Obs7	82.87	70.62	82.04	47.64	25.54	16.28	0.00			
Obs8	72.27	64.81	77.28	45.30	23.61	13.81	21.61	0.00		
Obs9	94.30	82.37	95.25	53.27	42.36	33.41	25.71	27.08	0.00	
Obs10	74.50	68.39	85.85	41.25	28.63	19.32	20.27	14.40	27.76	0.00

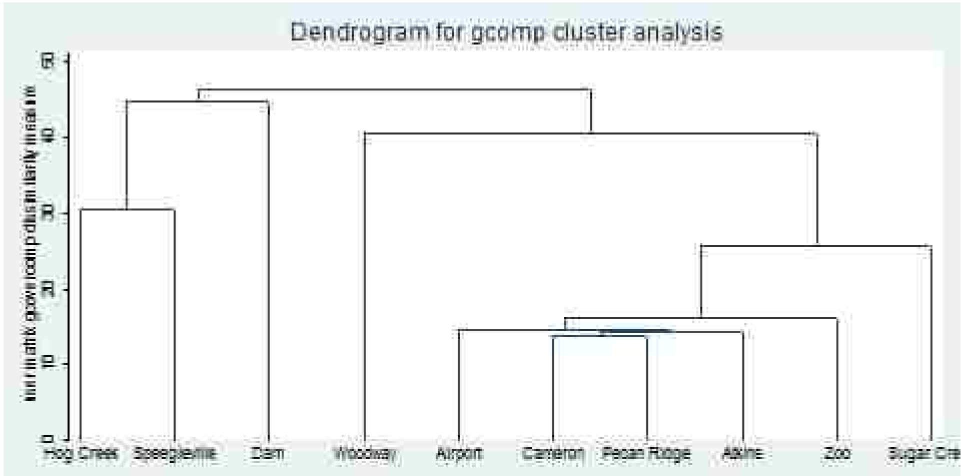

Figure 29- Dendrogrom showing clusters of most similar sites based in the dissimilarity matrix derived solely from ground cover data at each site.

The dissimilarity matrix for the study sites based on only soil nutrient data is shown in Table 5. A dendrogram of the cluster analysis produced to show site groupings based on soil nutrient conditions can be seen in Figure 30.

Table 5- Dissimilarity Matrix derived solely from soil nutrient data. Obs1 = Hog Creek WMA, Obs2 = Speegleville Park, Obs3 = Airport Beach Park, Obs4 = Woodway, Obs5 = Airport Park, Obs6 = Cameron Park, Obs7 = Cameron Park Zoo, Obs8 = Pecan Ridge, Obs9 = Sugar Creek, Obs10 = Sherwood Forest.

	Obs1	Obs2	Obs3	Obs4	Obs5	Obs6	Obs7	Obs8	Obs9	Obs10
Obs1	0.00									
Obs2	52.16	0.00								
Obs3	97.84	60.56	0.00							
Obs4	88.20	53.86	16.02	0.00						
Obs5	65.12	57.83	72.69	56.89	0.00					
Obs6	40.65	18.88	77.77	69.05	56.75	0.00				
Obs7	45.12	31.06	58.31	53.74	65.02	39.70	0.00			
Obs8	15.62	50.00	103.2	94.06	71.47	35.10	50.36	0.00		
Obs9	82.29	50.64	41.77	26.83	35.61	60.53	60.46	86.90	0.00	
Obs10	32.31	41.24	76.42	63.62	33.29	35.10	41.67	40.00	52.46	0.00

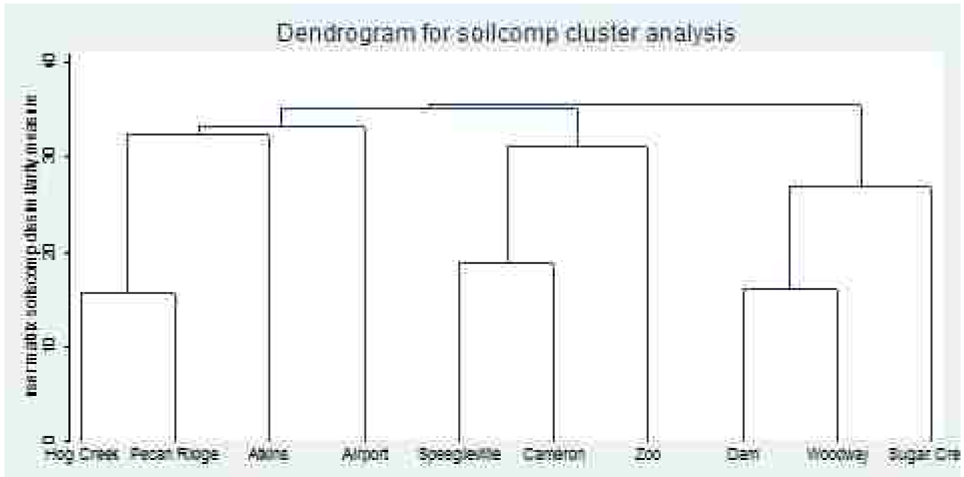

Figure 30- Dendrogrom showing clusters of most similar sites based in the dissimilarity matrix derived solely from soil nutrient data at each site.

The dissimilarity matrix for the study sites based on tree species basal areas, sapling/shrub stem counts, ground cover, and soil nutrient data can be seen in Table 6. A dendrogram of the cluster analysis produced to show site groupings based on tree species basal areas, sapling/shrub stem counts, ground cover, and soil nutrient data can be seen on Figure 31.

Table 6 - Dissimilarity Matrix derived from all environmental data. Obs1 = Hog Creek WMA, Obs2 = Speegleville Park, Obs3 = Airport Beach Park, Obs4 = Woodway, Obs5 = Airport Park, Obs6 = Cameron Park, Obs7 = Cameron Park Zoo, Obs8 = Pecan Ridge, Obs9 = Sugar Creek, Obs10 = Sherwood Forest.

	Obs1	Obs2	Obs3	Obs4	Obs5	Obs6	Obs7	Obs8	Obs9	Obs10
Obs1	0.00									
Obs2	61.2	0.00								
Obs3	115.2	76.33	0.00							
Obs4	106.8	74.74	85.68	0.00						
Obs5	90.7	77.33	94.70	73.33	0.00					
Obs6	87.09	71.61	108.9	89.53	66.36	0.00				
Obs7	97.15	79.53	103.5	78.61	75.48	52.10	0.00			
Obs8	76.87	85.01	130.7	106.8	79.35	40.86	58.63	0.00		
Obs9	132.2	104.4	112.8	76.84	71.79	86.51	74.17	101.7	0.00	
Obs10	104.1	101.8	132.7	102.8	80.79	64.16	69.58	68.56	80.73	0.00

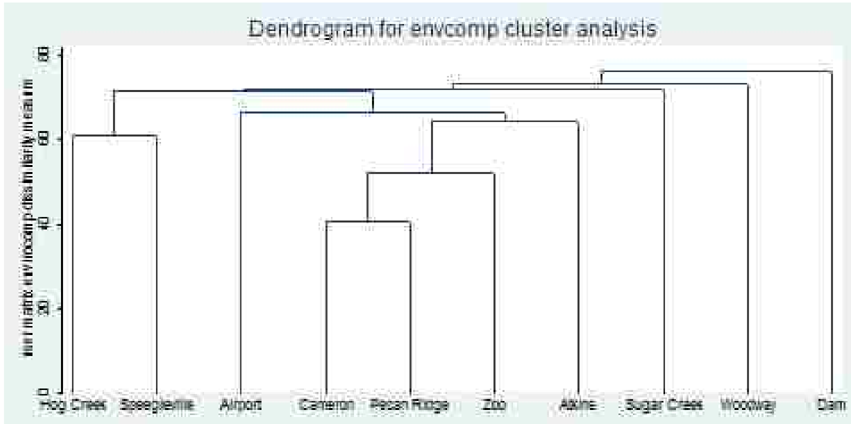

Figure 31- Dendrogrom showing clusters of most similar sites based in the dissimilarity matrix derived from all environmental data at each site.

Table 7 is the dissimilarity matrix for the study sites based on squamate species abundance and all other environmental data. Figure 31 displays the dendrogram of the cluster analysis which was produced to show site groupings based on all environmental variables can be seen on Figure 32.

Table 7 - Dissimilarity Matrix derived from squamate species abundance and all other environmental data. Obs1 = Hog Creek WMA, Obs2 = Speegleville Park, Obs3 = Airport Beach Park, Obs4 = Woodway, Obs5 = Airport Park, Obs6 = Cameron Park, Obs7 = Cameron Park Zoo, Obs8 = Pecan Ridge, Obs9 = Sugar Creek, Obs10 = Sherwood Forest.

	Obs1	Obs2	Obs3	Obs4	Obs5	Obs6	Obs7	Obs8	Obs9	Obs10
Obs1	0.00									
Obs2	3741	0.00								
Obs3	13291	5847	0.00							
Obs4	11400	5590	7365	0.00						
Obs5	8218	5980	8988	5382	0.00					
Obs6	7588	5131	11868	8019	4406	0.00				
Obs7	9446	6334	10729	6185	5705	2725	0.00			
Obs8	5911	7229	17089	11397	6299	1675	3439	0.00		
Obs9	17482	10905	12740	5907	5156	7487	5507	10336	0.00	
Obs10	10846	10360	17619	10576	6527	4120	4846	4702	6520	0.00

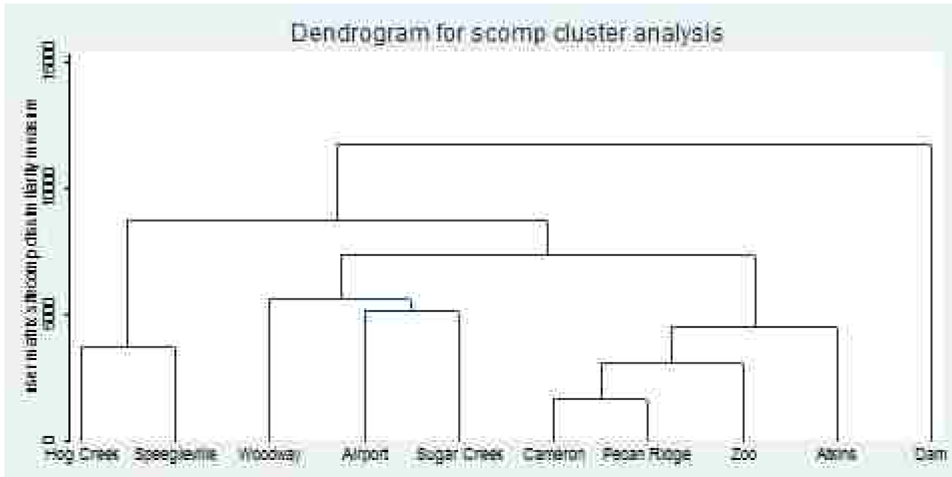

Figure 32 - Dendrogrom showing clusters of most similar sites based in the dissimilarity matrix derived from squamate species abundance and all other environmental data at each site.

Urbanization

Each study site varied in their degree of urbanization based on the population density of the surrounding area, road lengths (contained with the boundaries of the site and a 100-meter buffer zone), site area and perimeter. The degree of urbanization ranges from approximately 15 to 450. Study site landscape metrics and their corresponding degree of urbanization are as follows (from smallest degree of urbanization to greatest).

The Hog Creek WMA study site has an area of 0.643 square kilometers (km^2) and a perimeter of 5.388 km. The population density of the surrounding area is approximately 0.386 persons per km^2, and a total of 0.975 km of road within the site and/or its buffer area; the degree of urbanization (°U) is 3.154. I am unaware of any previous land use history for this site; however, surrounding areas are used for a local golf course and agriculture, and it is likely that this has been the dominant land use recently. Some of the land near this site would have been previously uninundated, until the dam and lake level were increased in the mid 1950's. The dam and lake levels were increased again in the late 1990's, and more land around this site became inundated.

The Speegleville Park study site has an area of 2.251 km^2 and a perimeter of 7.927 km. The population density of the surrounding area is approximately 0.386 persons per km^2 with a total of 8.026 km of road within the site and/or its buffer area. The °U is 10.913. According to public records, the land in and around this study site was quarried for gravel and used for agricultural purposes in the mid 1950's; some of the land around this site was also above the level of the lake. By 1970, parts of previously uninundated land was submerged when the level of the dam and subsequently the lake was increased; several of the gravel quarries still remained and the land adjacent to this site was still used for agriculture. The dam and lake levels were increased again in the late 1990's, and more land around this site became inundated. The land around this study sites is predominately used for agricultural purposes.

The Airport Beach Park study site has an area of 1.361 km^2 with a perimeter of 6.418 km; the population density of the surrounding area is approximately 0.386 persons per km^2. It has a total of 7.521 km of road within the site and/or its buffer area; the °U is13.694. According to public records, in the mid 1950's the land directly adjacent to this area was used for the Municipal Airport and the land in and around this study site was used in part as a golf course and racetrack; some of the land was quarried for gravel. By 1970 parts of previously uninundated land was submerged when the level of the dam, and subsequently the lake, was increased; Much of the former golf course and gravel pit were submerged, and the race track had been removed. The dam and lake levels were increased again in the late 1990's, and more land around this site became inundated. The Airport has remained and is still in use today.

The Woodway study site has an area of 0.309 km^2 and a perimeter of 5.775 km; the population density of the surrounding area is approximately 0.386 persons per km^2, and a total of 1.953 km of road in the site and/or its buffer area. The °U is 14.093. I am unaware of any previous land uses for this study site; however, prior to the construction of the dam much of the land around this site would have been above the level of the lake. By 1970, parts of previously uninundated land was submerged when the level of the dam, and subsequently the lake, was increased; the dam and lake levels were increased again in the late 1990's, and more land around this site became inundated. The land around this study sites is predominately used for suburban growth and development.

The Airport Park study site has an area of 1.757 km^2 and a perimeter of 9.369 km. The population density of the surrounding area is 0.386 persons per km^2 with a total of 6.952 km of road in the site and/or its buffer area; the °U is 14.313. According to public records, in the mid 1950's the land directly adjacent to this area was used for the Municipal Airport and the land in and around this study site was quarried for gravel. This site shares the same dam and lake-rise history as Airport Beach Park.

The Cameron Park study site has an area of 2.457 km^2 with a perimeter of 10.957 km. The population density of the surrounding area is 0.386 persons per km^2, and a total of 16.024 km of road in the site and/or its buffer area; the °U is 27.590. The land in and around this study site has been used for suburban growth and development over the past century; however, suburban growth has been limited to the edges of this site as it is owned and managed by the city of Waco as a natural park.

The Cameron Park Zoo study site has an area of 0.017 km^2 and a perimeter of 0.933 km; the population density of the surrounding area is approximately 3.86 persons per km^2. There is a total of 0.394 km of road in the site and/or its buffer area and the °U is 83.489. The land in and around this study site has been used for suburban growth and development over the past century; however, to our knowledge suburban growth has been limited to the edges of this site as it was initially owned and managed by the city of Waco as part of Cameron Park. It is currently owned and managed by the Cameron Park Zoo, which was constructed in the early 1990s.

The Pecan Ridge study site has an area of 0.182 km^2 and a perimeter of 2.603 km; the population density of the surrounding area is approximately 3.861 persons per km^2. There is a total of 2.584 km of road in the site and/or its buffer area; the °U is 142.691. The land in and around this study site has been used for suburban growth and development over the past century. In addition, there is some agricultural activity along the northern edge of this study site.

The Sugar Creek study site has an area of 0.099 km^2 and a perimeter of 2.280 km; the population density of the surrounding area is approximately 3.861 persons per km^2. There is a total of 2.561 km of road in the site and/or its buffer area, and the °U is 227.725. Over the past century the land in and around this study site has been used for suburban growth and development. I am unaware of any other previous land use history for this site. However, based on public records, while this area did experience some urban growth in the early 1900s, it was not as heavily affected by urbanization until several decades later.

The Sherwood Forest Park study site has an area of 0.114 km^2 and a perimeter of 3.469 km; the population density of the surrounding area is approximately 3.861 persons per km^2 with a total of 3.794 km of road in the site and/or its buffer area. The °U is 445.758. The land in and around this study site has been subject to urban growth since the early 1900s; however, prior to the expansion of the dam, much of the land around this site would have been uninundated. In the 1970s, parts of previously uninundated land were submerged when the new dam was constructed and subsequently the lake boundaries were increased; the dam and lake levels were increased again in the late 1990's and more land around this site became inundated. The land around this study sites is predominately used for suburban growth and development.

CHAPTER FOUR

Discussion and Conclusions

Body Condition Index

A total of nineteen (19) species were captured; however, only five (5) species (*Anolis carolinensis, Hemidactylus turcicus, Sceloporus olivaceus, Scincella lateralis,* and *Virginia striatula*) were captured in sufficient quantities to compare their body conditions index (BCI) along urbanization and habitat gradients. I first ran a backward stepwise multivariate regression for all five (5); however, all failed to meet the assumption of normality. I was unable to transform the variable in order to normalize its distribution. Therefore, I performed a quantile regression, a nonparametric analyses to compare species' BCI to species' abundance and other environmental variables. I do discuss some of the results of the multivariate regression as a comparison; however, any conclusion drawn from the results of these analyses may be erroneous.

Scincella lateralis

A quantile regression analysis between *S. lateralis* median BCI and other variables did not reveal any significant correlations. This suggests that *S. lateralis* BCI remains unaffected by degree of urbanization or any other variable measured in this study. Such a conclusion is not surprising in that this species was found at most study sites in relative abundance. It is likely that their small size, adaptability and general food preferences have allowed *S. lateralis* to live in close proximity to human development without negative or positive effects on their fitness (Behler and King 1998; Conant and Collins 1998).

As the quantile regression yielded no significant results, I will discuss the results of the multivariate regression; however, as the assumption of normality was not met, these conclusions may be erroneous. The multivariate regression for *S. lateralis* revealed that degree of urbanization (P = 0.048), mean vegetation density (P = 0.001), percent grass cover (P = 0.001), percent forb cover (P = 0.013), and percent litter fall cover (P = 0.062) had a significant effect on the mean BCI. Degree of urbanization was found to have a very slight positive correlation (Coef. = 0.0000545) to BCI, which indicates that *S. lateralis* becomes healthier with increased fitness as the degree of urbanization increases. As *S. lateralis* is often found in suburbia (particularly in gardens and compost piles), it is possible that they are able to utilize man-made refuges, more permanent water sources, and find sufficient food to maintain a net gain in energy consumption. Mean vegetation density and percent grass cover also have a slight positive correlation (Coef. = 0.0011355 and Coef. = 0.0012474, respectively) to BCI. If these results are accurate, it may help explain the discrepancy in results for effect of urbanization between the multivariate and quantile regressions.

As urbanization increases, there tends to be a general decrease in vegetation density due to anthropogenic habitat disturbances (Lagarde et al.2012). Therefore, if mean vegetation is decreasing I would expect a slight decrease in BCI. However, as degree of urbanization increases, there tends to be increase grass cover, particularly in suburban areas (Schneider et al.2012); this would lead to a slight increase in *S. lateralis* mean BCI. It is likely that the BCI would not exhibit a significant change (as reported by the quantile regression) or would experience only a slight change in the direction of the variable with the highest coefficient. Consequently, as percent grass cover has a slightly greater effect on *S. lateralis* BCI than mean vegetation density, I would expect to see a very slight increase in BCI (as reported by the multivariate regression).

Hemidactylus turcicus

A Quantile regression analysis between *H. turcicus* median BCI and other variables revealed that degree of urbanization (P=0.000) and canopy height (P=0.020) had a significant effect on BCI. There is a slight negative correlation between BCI and both degree of urbanization and canopy height (Coef. = -0.0001929 and Coef. = -0.0070919, respectively). This suggests that despite *H. turcicus* association with urbanized areas in the United States since its introduction in the early 1900s that this species general health and fitness decrease with increased urbanization and increased canopy height.

Upon further examination, the negative correlation between BCI and degree of urbanization may stem from other less obvious effects of urbanization. There is typically an increased use of pesticides in more heavily urbanized areas, while the various chemical used may or may not have a direct effect on *H. turcicus* it would undoubtedly effect their prey. A reduction of prey abundance and/or quality would certainly account for a decrease in *H. turcicus* BCI.

The negative correlation between BCI and canopy height may be a result of their natural history. *Hemidacylus turcicus* naturally occurs in southwest Asia and regions surrounding the Mediterranean where their non-anthropogenic habitats include rocky cliffs and wooded areas, living in crevices in the rock or under bark (Locey and Stone 2006; Gomex-Zlatar et. al.2006). These surfaces receive heat from the sun which *H. turcicus* is able to utilize to increase its body temperature and maintain its activity levels throughout the night. However, an increase in canopy height would also entail an increase in shading and a reduction in heat absorbed by any such surface. This decrease in ambient surface temperature and likely reduction in activity levels would result in increased difficulty in both prey capture and predator avoidance which could account for the negative relationship between canopy height and BCI for *H. turcicus*.

Anolis carolinensis

A Quantile regression analysis between *A. carolinenesis* median BCI and other variables did not reveal any significant correlations. This suggests that *A. carolinenesis* BCI remains unaffected by degree of urbanization or any other variable measured in this study. Such a conclusion is not surprising in that this species was found at most study sites in relative abundance. It is likely that their small size, adaptability and general food preferences have allowed *A. carolinenesis* to live in close proximity to human development without negative or positive effects on their fitness (Behler and King 1998; Conant and Collins 1998).

Since the quantile regression yielded no significant results, I will discuss the results of the multivariate regression; however, as the assumption of normality was not met, these conclusions may be erroneous. The multivariate regression for *A. carolinenesis* revealed that only degree of urbanization (P = 0.000) had a significant effect on the mean BCI. Degree of urbanization was found to have a very slight positive correlation (Coef. = 0.0006747) to BCI; this indicates that *A. carolinenesis* are healthier with increased fitness as the degree of urbanization increases. *Anolis carolinenesis* are often found in suburban areas climbing on walls, fences, trees, shrubs and vines and seek refuge in crevices in and around buildings in suburbia; it is possible that these man-made habitats and refuges, and more permanent water sources benefit *A. carolinenesis* by allowing them to use less metabolic energy in search of refuges and adequate territories (Behler and King 1998; Brown 1950; Conant and Collins 1998).

Virginia striatula

A Quantile regression analysis between *V. striatula* median BCI and other variables revealed that only degree of urbanization (P=0.002) had a significant effect on BCI. There is a slight positive correlation between BCI and degree of urbanization (Coef. = 0.0000504), suggesting that *V. striatula* are healthier with increased fitness as the degree of urbanization increases. This is likely due primarily to their natural history.

Virginia striatula are relatively common in urban areas, particularly suburban gardens, where it is seldom seen on the surface, preferring to hide under leaves, decaying logs, and gardener's compost piles (Behler and King, Conant and Collins 1998; Dixon and Werler 2005). In addition, this snake feeds mainly on earthworms, but will also eat slugs, snails and small frogs, all common prey items found in and around suburban areas and particularly gardens (Behler and King, Conant and Collins 1998). The combination of necessary habitat requirements and presence of abundance food sources should make more urbanized areas ideal for *V. stiratula*. However, it is likely that increasing the degree of urbanization above and beyond that found in suburban areas might have a negative impact if suitable habits and food sources become diminished.

Sceloporus olivaceus

A Quantile regression analysis between *S. olivaceus* median BCI and other variables revealed that phosphorus concentrations in the soil (P=0.015) and percent grass cover (P=0.035) had a significant effect on BCI. There is a negative correlation between BCI and both phosphorus concentrations and percent grass cover (Coef. = - 0.0030938 and Coef. = -0.0046084, respectively) suggesting that *S. olivaceus* are less healthy with decreased fitness as either phosphorus concentrations or percent grass cover increases.

According to Taiz and Zeiger (2010), phosphorus concentrations in the soil affect plant growth and development. Altered plant development could result in changes in plant coloring and growth making *S. olivaceus* a more visible target to predators. Therefore, the lizard would be forced to expend more energy in predator avoidance; this could account for the decrease in BCI. As shown by Haddad, et al.(2000), altered nutrient concentrations affect insect abundance. If, unlike nitrogen concentration, phosphorus concentration decreases insect abundance, then this would account for a decrease in *S. olivaceus* BCI since there would be less prey to sustain healthy metabolic levels. Another possibility is that, like pH, increases in phosphorus concentrations could affect embryonic development and could result in a decrease in hatchling size or running speed which would limit an individual's ability to evade predators and capture prey (Marco, et al.2005; Lopez and Martin 2002).

Sceloporus olivaceus are relatively arboreal, often found in trees and on fallen logs, or any other place that offers refuge in the form of cracks, cavities and crevices (Behler and King 1998; Brown 1950; Conant and Collins 1998). This would explain the negative correlation between percent grass cover and BCI. As percent grass cover increases, there would be less suitable refuges for *S. olivaceus*; this would, in turn, force the lizards to expend more energy on predator avoidance and thereby decrease BCI. In addition, grass typically grows in more open habitats; fewer trees would decrease suitable habitat for finding prey, causing *S. olivaceus* to expend more energy in search of food, also resulting in a decrease of BCI.

Abundance and Composition

Using the canonical correspondence analyses (CCA), I found several associations between squamate species abundance and a variety of environmental variables. I was also able to classify study sites based on their similarity (dissimilarity) to one another using squamate species abundance and the environmental variables; I did this by creating a dissimilarity matrix and subsequent cluster analysis. Using CCA I found that *Agkistrodon contortrix* was generally associated greater canopy heights, but not with other environmental variables. This suggests that *A. contortrix* are more abundant in wooded areas, likely with some old growth. Our data supports this reasoning as almost all *A. contortrix* were found in Cameron Park, a large wooded area that has been mostly protected from urban growth since the early 1900s.

I found that *Anolis carolinensis* was generally associated with low vegetation density and canopy cover, increased percent of total cover and tree/sapling cover, with a close correlation with medium levels of both potassium and acidity; *A. carolinensis* was also closely associated with high levels of phosphorus. The vegetation and ground cover relationships suggest that *A. carolinensis* are more abundant at the edge of wooded habitats or in suburban areas where there is low vegetation and canopy cover, with an increased total ground cover and tree/sapling cover. This suggests that the results of the multivariate regression might have some validity (despite their nonconformance to the assumption of normality) in that *A. carolinensis* is benefited by increased urbanization.

Cnemidophorus gularis was generally associated with medium dbh and low canopy heights. This is not surprising as *C. gularis* are typically found in clearings or along woodland edges where the canopy was either nonexistent or significantly lower and generally corresponded to a smaller dbh. This suggests that *C. gularis* are more abundant in areas where the trees have not reached full maturity. It is likely that such areas would be ideal for *C. gularis* because these locations likely receive more sunlight, which allows the lizards to maintain a high metabolic rate, while also offering cover from potential predators.

Eumeces laticeps was generally associated with a small dbh. This makes sense because I generally encountered these lizards when they were on the ground. This suggests that *E. laticepts,* which is a relatively bulky lizard compared to its smaller cousins, is predominately terrestrial in nature and would rarely climb trees.

I found that *Elaphe guttata* was loosely associated with both increased percent forb cover and grass cover. This intuitively makes sense as this species is more commonly found in open woodlands and grasslands (as its names, “Great Plains Rat Snake” suggests). This species was only found at the Speegleville Park study site, but it is also likely that it might also be found and the Hog Creek WMA and Airport Beach Park study sites as both locations have similar ground cover (Figure 29) and both are open woodland areas.

Elaphe obsoleta was closely associated with high levels of phosphorus and medium pH levels and was generally associated with medium levels of potassium. As *E. obsoleta* is a generalist and able to adapt well to a variety of habitats, it is interesting that there is a relationship between its abundance and the soil composition. It suggests that *E. obsoleta* may have some specific requirements for embryonic development and hatchling success or that this snake has other environmental need that is met by these soil components.

Soil pH has been linked to significant effects on egg water exchange, hatchling size and running speed, which could relate to survival later in life (Marco, et al.2005). The association with phosphorus and potassium levels could indicate that either, or both, might affect embryonic development or alter the surrounding environment in a way that is beneficial to *E. obsoleta*; Further experimental studies would be needed to determine the validity of this. Using soil composition as a predictor of *E. obsoleta* abundance, it is likely that this snake could also be found at the Speegleville Park and Sherwood Forest study sites (Figure 30).

I found that *Hemidactylus turcicus* was closely associated with a large dbh. At first glance this would seem to make sense as *H. turcicus* is an arboreal lizard and larger trees would seem to offer a more beneficial habitat (i.e. more refuges and greater food sources); however, the results of the quantile regression demonstrated a significant *decrease* in BCI in response to an increase in canopy height. If both results are accurate, then as tree dbh increases so will *H. turcicus* abundance, but as tree dbh increases there will also be a general increase in canopy height, thereby reducing BCI. This may suggest that as the tree dbh increases, there is an increase in surface area and presumably refuges allowing for significantly more lizards to inhabit the tree; however, with an increase in overall abundance, there is increased competition forcing *H. turcicus* to expend more energy to compete for food, thereby decreasing BCI.

Sceloporus olivaceus was generally associated with both increased litter fall and hwd, closely associated with both increased canopy cover and vegetation density, and was loosely associated with high levels of potassium. *Sceloporus olivaceus* is a medium sized lizard that relies heavily on camouflage to avoid predators; this is the likely reason for their association with the ground cover and vegetation variables. I typically found these lizards on fallen logs (i.e. hwd) or on tall trees, both of which offer ideal camouflage to hide from predators. An increased vegetation density would further benefit *S. olivaceus* by preventing predators (i.e. birds of prey) from seeing far through habitat, allowing them to avoid detection. Increased litter fall also offers these lizards camouflage when moving from tree to tree or fallen log.

Scincella lateralis was loosely associated with low percent litter fall and hwd, but also with increased tree/sapling cover; *S. lateralis* was closely associated with both increased canopy cover and vegetation density and with medium amounts of total cover and forb cover. The close association with increased canopy cover, vegetation density, total cover and forb cover all suggest that *S. lateralis* is most abundant in areas where it can best avoid detection by predators. The loose association with a low percent of litter fall and hwd, however, is slightly confounding, as both offer excellent refuge. However, this may simply suggest that while and increase in cover is necessary, other ground cover types are more beneficial.One explanation for why litter fall is not beneficial is because it creates more noise when the lizard moves on or through it; this would increase the risk of predators noticing them. Likewise, hwd may not be beneficial because if *S. lateralis* is moving across the surface of the hwd and is detected by a predator, it cannot simple disappear through the wood but must run to an edge before taking suitable refuge wasting time and risking capture.

I also found that *Scincella lateralis* abundance was loosely associated with high nitrogen levels. Again, this could suggest some benefit for embryonic development or benefit in the surrounding environment such as an increase in insect abundance.

Urbanization

I established a new measure of degree of urbanization by combining the population density of the surrounding area, road lengths, site area, and perimeter. While our measure does not quantitatively incorporate a temporal variable, I did include the past land use for our study sites qualitatively. Our measure of urbanization allowed us to effectively compare study sites for changes in squamate morphology and composition across several environmental characteristics.

This measure of degree of urbanization was found to have a significant effect on the BCI of 4 out of the 5 species examined using either multivariate regression or the nonparametric quantile regression: (*Scincella lateralis*, Multivariate Regression, P=0.048; *Hemidactylus turcicus*, Quantile Regression, P=0.000; *Anolis carolinensis*, Quantile Regression, P=0.000; *Virginia striatula*, Quantile Regression, P=0.048). This degree of urbanization also fits well with two of the AHCA performed most notably for the clustering of sites based on the shrub/sapling stem counts (Figure 28) and on the percent ground cover data (Figure 29). As we continue to study the effects of urbanization on the environment it is important to have a simple and quantifiable measure of urbanization that allows researchers to track changes in particular habitats over time and allows for the comparison of differing sites. I propose our measure of degrees of urbanization (°*U*) as a potential standard for future use in conservation biology.

Climate

While the only direct measure of climate included in this study was the temperature of the microhabitat where each squamate was captured, I should also note that all off our study sites experienced abnormal weather prior to and during the study period. Prior to our research period, the Waco-area experienced a relatively harsh and bitter winter. Immediately following the winter season and during the study period much of the United States, all of Texas, and therefore, all off our study sites were under drought conditions and experienced record high temperatures. According to data collected and analyzed by the National Oceanic and Atmospheric Administration (NOAA) beginning March of 2011, 42.97 percent of the contiguous United States was under drought conditions (including all of Texas), conditions have continued to worsen and currently (as of July 24 2012) 80.08 percent of the contiguous United States is under drought conditions (National Weather Service Climate Prediction Center). While squamates are resilient, such a severe drought and extended periods of record high temperatures likely altered local squamate communities, as well as their body conditions. In addition, squamates may have altered their behavior (foraging times and duration of foraging) to compensate for the abnormal temperatures and could potentially further alter our findings. I should also note that I altered the time of day I sampled squamates as I noted a decrease in squamate activity approximately between the hours of 1000 and 2000 (as I did not measure squamate activity rates this is purely anecdotal). While our results do show a significant but slight decrease in species diversity as the degree of urbanization increased, it is likely that these results do not represent the true trend as the more heavily urbanized areas have more permanent sources of water and man-made refuges (French et al.2008). These water sources and refuges would provide resources and shelter not only for squamates but also their prey. This means that squamates in areas with a higher degree of urbanization are more likely to find sufficient resources and refuge to survive and potentially thrive. Our results demonstrated a significant, albeit slight, correlation in the body condition index (BCI) among 4 of the species tested as degree of urbanization increased; however, considering the abnormal weather during our study, it is entirely possible that these results may not represent normal conditions of each squamate population, and that stronger correlations may be present.

Conclusions

As the human population continues to grow and we continue to exploit the natural environment altering our surrounding landscape, it becomes increasingly imperative that we attempt to expand our knowledge and understanding of ecological communities to better preserve and restore them. Many researchers have studied how ecosystems and organisms respond to urbanization, demonstrating the far-reaching effects of urbanization on the composition and abundance of a wide variety of organisms, on landscape composition on both global and local scales, as well as extensive effects on global and local climate (Blewett and Marzluff 2005; French, et al.2008; Groom, et al.2006; Hammer and McDonnell 2010; National Weather Service Climate Prediction Center 2012; Pontes, et. al.2009; Turner, et al.2001). Our study compared the variation in abundance, morphology and habitat among various squamate species between locations with a varying degree of urbanization.

I demonstrated that squamate composition and diversity were affected to some extent by degree of urbanization. The locations with a higher degree of urbanization generally had a greater abundance of smaller squamate species (particularly in regards to snakes snakes), while larger squamate species (particularly snakes) were generally more abundant at sites with a lower degree of urbanization. The likely cause of this trend is that larger squamate species cannot find sufficient refuge or food in more highly urbanized areas and, in the case of snakes, may be actively removed from these areas. There was a general decrease in species diversity as the degree of urbanization increased (with Airport Beach Park as the exception); this trend is likely due to a decrease in specialists, which would have trouble adapting to altered anthropogenic environments (Doxa et al.2012).

I also demonstrated that the vegetation measure, groundcover, and soil composition were useful predictors for squamate assemblages, and that squamate body conditions correlate to the degree of urbanization for several of the species tested. However, I hypothesized that a negative correlation would exist between squamate species BCI and degree of urbanization, but this was not always the case. For *Scincella* *lateralis* there was a significant and slight positive correlation between BCI and degree of urbanization. I also determined that a few of the environmental variables also had a significant relationship with squamate species BCI.

Furthermore, I was also able to answer several of our specific questions. I demonstrated that some squamates are more abundant in sites with a lower degree of urbanization while others are more abundant in sites with a higher degree of urbanization. I found that the degree of urbanization affected squamate abundance such that several of the larger (i.e. greater mass) squamate species were more abundant at study sites that were less urbanized. For example, *Cnemedophorus gularis* and *Agkistrodon contortrix*, were found at study sites with a degree of urbanization less than 85, and the largest squamate species encountered in this study, *Crotalis atrox,* was found at a study site with a degree of urbanization less than 15 (See Figures 25-28 for associations of species abundance with specific study sites). I hypothesized that smaller (i.e. lesser mass) squamate species (i.e. *Anolis carolinenesis, Scincella lateralis, Hemidactylus turcicus, Virginia striatula*, etc.) would be more abundant at study sites that are more urbanized. Based on the results of the CCA and their corresponding triplots (Figures 25-28), smaller squamate species abundance had a greater association to sites with a higher degree of urbanization. For the squamate species tested, I found no evidence to suggest that squamate BCI correspond to species abundance, contradicting my hypothesis. Although as previously discuss, further studies should be conducted to adequately determine if these results are accurate or a result of possible altered conditions due to extreme drought and temperature conditions.

Finally, I determined that degree of urbanization was a predictor of squamate species diversity, in that as degree of urbanization increases there was generally a decrease in the habitat's squamate species diversity. I found ground cover to be an important predictor as some species (e.g. *S. lateralis, V. striatula*, *L. dulcis, A. carolinensis,* etc.) depend on differing ground cover types including, increased leaf litter to hide from predators or forage for food, increased percent grass cover or low total ground cover (*S. olivaceus, V. stiratula, C. gularis*, etc.). Soil composition was also a useful predictor for some squamate species possibly due to the need of developing embryos in nest sites.

Further studies should be conducted to better examine the independent effects of each of the environmental variables on squamate morphology and abundance. In addition, experimental studies should be conducted to definitively prove the effect of specific variables.

> "No matter how intently one studies the hundred little dramas of the woods and meadows, one can never learn all the salient facts about any one of them."
>
> — Aldo Leopold, *A Sand County Almanac: With Other Essays on Conservation from Round River*

APPENDICES

APPENDIX A

Squamates - Evolution and Diversity

Snakes and Lizards (Squamates) play significant roles in many ecosystems because of their diversity, serving as both predators and as prey of other vertebrates and invertebrates (Bateman, et. al 2009; Ford and Lancaster 2007). In addition, their basic morphology, remarkable diversity, and relative abundance have made them ideal for ecological studies (Pianka and Vitt 2003). Squamates are the most speciose and diverse living clade of reptiles comprised of nearly 7200 species (Zug, et. al 2001). Squamates possess over 50 shared derived traits that attest to their monophyly, including well-developed, paired, copulatory organs (known as hemipenes), saccular ovaries, a vomeronasal (Jacobson's) organ, femoral and preanal glands, and the presence of an egg tooth at birth (Zug et. al 2001). Lizards and their snake descendants are the only living squamates and have a widespread occurrence (all continents except Antarctica and most tropical and subtropical oceanic islands) which denotes their broad ecological, physiological and behavioral adaptations to a wide range of habitat conditions (Zug et. al 2001). The extant squamate families begin in the late Jurassic (ca. 150 mya), and squamate diversity is evident in the late Cretaceous (ca. 70-65mya), although many argue for a mid-Mesozoic radiation (Zug et. al 2001). While the assignment of these extinct squamates to modern taxa is debated, the transition from Cretaceous squamate fauna to modern fauna began in the early Tertiary, including a combination of both extinct and extant families and genera (Zug et. al 2001). While each family is well established, a resolution of phylogenetic relationships among these groups is not firmly resolved; origins of both amphisbaenians and snakes are currently hypothesized to be subgroups of lizards, as seen in Figure 33 (Zug et. al 2001). The two major competeing hypotheses are that snakes (Serpentes) are a sister group of varanids/varanoids or to a dibamid- amphisbaenid clade (Zug, et. al 2001).

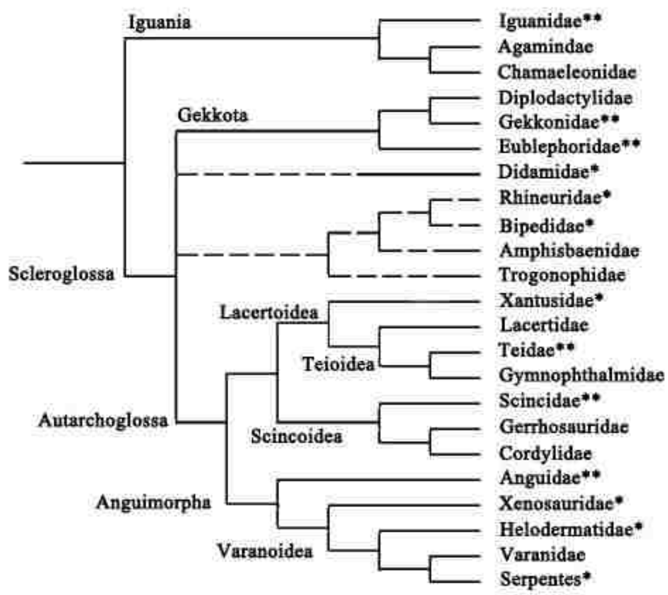

Figure 33- A cladogram depicting relationships among extant taxa of squamates with emphasis on the phylogeny of Lizards. "*" denotes that at least one representative of the family may be found in North America. "**" denotes that at least one representative of the family/taxa may be found in Texas. The cladogram is derived from Zug, et. al (2001, Fig 21.1) and Pianka and Vitt (2003, Fig 1.4). Figure redrawn from originals for uniformity.

Snakes are all limbless or nearly so; the pectoral girdle and forelimbs are completely absent and the pelvic girdle and/or hind limbs (when present) are rudimentary and visible externally as small "spurs" on either side of the cloaca (Zug, et. al 2001).

Snake species vary in length, and the elongation of their bodies is accomplished through increased vertebrate which, on average, range between 120 and 240, but may exceed 500 in some cases (Zug et. al 2001). Without limbs, snakes must capture, manipulate and consume their prey using only their body and mouth; this has led to major modifications of the cranial anatomy, including the exclusion of the supraoccipital from the margin of the foramen magnum by exoccipitals and a flexible ligamentous symphysis between the dentaries (Zug et. al 2001). Snakes also have transparent scales (spectacle) covering each eye, and have a complete absence of the tympanum and the Eustachian tubes (Zug et. al 2001). As with the other squamates, snake phylogeny (Figure 34) is also highly debated, and any relationships among families are putative and may change with increased knowledge (Zug, et. al 2001).

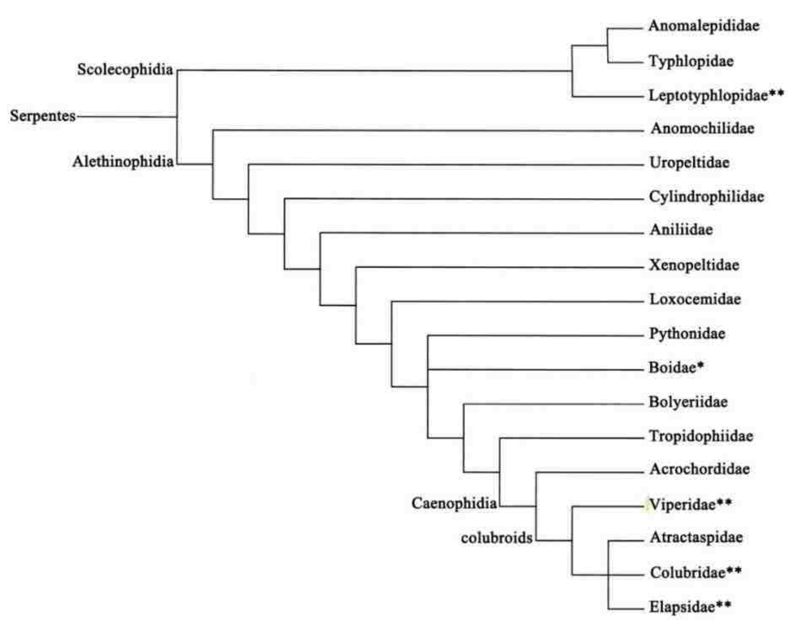

Figure 34- A cladogram depicting relationships among extant snakes. “*” denotes that at least one representative of the family may be found in North America. “**” denotes that at least one representative of the family may be found in Texas. The cladogram is derived from Zug, et. al (2001, Fig 21.1). Figure redrawn from original for uniformity.

APPENDIX B

Variability and Adaptability of Squamates

Some of the more common families/clades of squamates to range across North America include Iguanidae, Gekkotans (Gekkonidae, Eublepharidae), Teidae, Scincidae, Anguidae, Leptotyphlopidae, Viperidae, Colubridae, and Elaphidae. These families are of particular interest as representatives from each have at least one historical distribution through central Texas (Behler and King 1998; Brown 1950; Conant and Collins 1998; Pianka and Vitt 2003; Zug, et. al 2001).

Iguanids range in size from small [30 mm adult snout-vent length (SVL), *Anolis sp.*] to large (750mm adult SVL, *Cyclura nubilia*) with a long to moderately long tail which may have caudal anatomy with fracture planes along the caudal vertebrae (Zug et. al 2001). Some researchers have contested that iguanids are actually a composite of several different families, arguing that each subfamily should be elevated to family status; however, the details of evolutionary relationships remain unresolved. Therefore, I will adopt a more conservative view retaining Iguanidae as a family with its respective subfamilies (Pianka and Vitt 2003; Zug, et. al 2001).

Four subfamilies of Iguanids (ten genera) are found in Texas including, Crotaphytinae, Iguaninae, Phrynosomatinae, and Polycrotinae (Behler and King 1998; Zug, et. al 2001). Crotaphytines (two genera and three species found in Texas) are a small clade of lizards; commonly known as collard and leopard lizards, they are moderately large lizards, averaging 100-140 mm adult SVL, and are generally found in dry open and rocky habitats (Pianka and Vitt 2003; Zug, et. al 2001). These lizards are mainly diurnal, usually preying voraciously on arthropods (sometimes other lizards); Crotaphytines are fast and elusive (capable of bipedal running) and will actively chase their prey (Conant and Collins 1998; Pianka and Vitt 2003; Zug, et. al 2001).

Iguanines (*Ctenosaura pectinata* - the only Genus and species found in Texas; non-native) are large lizards with most species exceeding 200-mm adult SVL (Conant and Collins 1998; Zug, et. al 2001). These lizards are strongly arboreal and predominately herbivorous feeding on a wide range of plant parts (Pianka and Vitt 2003; Zug, et. al 2001).

Phrynosomatines (six genera and eighteen species found in Texas), horned lizards and their relatives, are the dominant iguanid lizard found in North America; they are predominately adapted to arid and semiarid habitats (Pianka and Vitt 2003; Zug, et. Al 2001). These lizards range in size from 50-200 mm adult SVL, feed mostly on insects and other arthropods, and have territorial display patterns featuring head-bobby, nodding and push-ups (Conant and Collins 1998; Zug, et. al 2001).

Polycrotines (*Anolis carolinensis* and *A. sagrei* are the only two Genus and species found in Texas) are the most speciose iguanid lizards; they include anoles and their relatives, are predominately arboreal, and have specialized foot morphology called toe lamellae (Conant and Collins 1998; Pianka and Vitt 2003; Zug, et. al 2001). These diurnal lizards display using a throat fan (dewlap) which they use for social communication and are generally sexually dimorphic with larger males; males also have larger dewlaps (Conant and Collins 1998; Pianka and Vitt 2003; Zug, et. al 2001). The

Genus *Anolis* has a unique reproduction system in they have continual egg production, laying one egg at a time (Zug, et. al 2001).

Gekkotans (two families and three genera found in Texas including two non-native genera) are small (16-18 mm adult SVL) to large (370 mm adult SVL) lizards, typically covered by small, granular scales that are occasionally interspersed with tubercles and are one of the few lizards that will vocalize (Conant and Collins 1998; Pianka and Vitt 2003; Zug, et. al 2001). All geckos have fracture planes posterior to the transverse process of each caudal vertebrae and some have unique foot anatomy (lamellar toe pads cover in up to several billion microscopic hooked hair-like setae) that allows them to cling to shear surfaces, even to climb along ceilings (Conant and Collins 1998; Pianka and Vitt 2003; Zug, et. al 2001). Two Families of geckos may be found in Texas including, Eublepharidae and Gekkonidae (Behler and King 1998; Conant and Collins 1998; Zug, et. al 2001).

Eublepharids (*Coleonyx brevis* and *C. reticulatus* are the only two genus and species found in Texas) are moderate to large terrestrial geckos (45 to 155 mm adult SVL) which hunt insects nocturnally (Zug, et. al 2001). Gekkonids [*Cyrtodactylus scaber* and *Hemidactylus turcicus* (both non-native) are the only two genus and species found in Texas] are the most speciose lizard group and vary significantly in their morphology (especially in foot morphology); most, however, retain the nocturnal activity pattern (Conant and Collins 1998; Zug, et. al 2001). Often found in arid lands and forests, gekkonids commonly occur on rocky outcrops and cliffs; some may be terrestrial and are found living among leaf litter (Zug, et. al 2001). *Cyrtodactylus scaber* and *Hemidactylus turcicus* are introduced species to Texas from the Middle East and South

East Asia and were accidently transported to the United States, *H. turcicus* early in the 1900's and *C. scaber* in the early 1980's (Bloom, et. al 1986; Locey and Stone 2006; Selcer and Bloom 1984).

Teids (one subfamily and one genus found in Texas) are a New World Family, commonly known as racerunners, whiptails, amevias, and tegus (Pianka and Vitt 2003; Zug, et. al 2001). These lizards range in size from small (55mm adult SVL) to large (400mm adult SVL) with small, granular scales along the dorsal and lateral sides (Pianka and Vitt 2003; Zug, et. al 2001). Large ventral scales arranged in transverse rows, and an unusually long, autotomic tail with fracture planes occurring anterior to the transverse process of the caudal vertebra (Behler and King 1998; Conant and Collins 1998; Pianka and Vitt 2003; Zug, et. al 2001).

Teiinae is the only subfamily found in Texas; Teiines (11 species found in Texas), comprised entirely of one genus in Texas (*Cnemidophorus*), are often found with high population densities and are active at high temperatures (Behler and King 1998; Zug, et. al 2001). Many *Cnemidophorus* species are parthenogenic, making them hard to identify and determine their phylogenetic relationships (Pianka and Vitt 2003; Zug, et. al 2001). These lizards forage mainly on the ground for arthropods; however, two species are known to be herbivorous (Zug, et. al 2001). All teiines are oviparous and their clutch sizes are associated with their body size; five of the species found in Texas are unisexual, reproducing through parthenogenesis (Behler and King 1998; Conant and Collins 1998; Pianka and Vitt 2003; Zug, et. al 2001).

Scincids (two subfamilies and two genera found in Texas) are the largest lizard family with more than 120 genera; they range in size from small to large (27-350 mm adult SNL) and are almost entirely covered in overlapping scales underlain with body plates (osteoderms) along the trunk (Behler and King 1998; Pianka and Vitt 2003, Zug, et. al 2001). The body form of scincids are generally cylindrical, ranging from entirely legless to strong limbed and may have long to moderately long autotomic tails, often with fracture planes (some exceptions) anterior to the transverse process of each caudal vertebra (Behler and King 1998; Conant and Collins 1998; Zug, et. al 2001).

Two subfamilies, Lygosominae and Scincinae, are found in Texas (Zug, et. al 2001). Lygosomines (*Scincella lateralis* is the only species found in Texas) generally have limbs; however, limbs of some species may be highly reduced (Zug, et. al 2001). These lizards vary in their behavior and ecology ranging from being highly arboreal to semi-fossorial, from diurnal to nocturnal, from sedentary to migratory and from territorial to nonteritorial (Conant and Collins; 1998; Zug, et. al 2001). Scincines [one genus (*Eumeces*) and seven species found in Texas] are probably paraphyletic; these primitive skinks also generally have limbs; however, the limbs of some species may be highly reduced. Scincines are significantly less speciose than lygosomines (Pianka and Vitt 2003; Zug, et. al 2001). These lizards are generally terrestrial or semi-fossorial but may climb tress to forage and find refuge (Zug, et. al 2001). Scincines are generally insectivores, but larger species may also prey on small vertebrates (Zug, et. al 2001).

Anguids (two subfamilies and two genera found in Texas) range in size from small (55-77 mm adult SVL) to very large (500-520mm adult SVL) and have heavily armored, non-overlapping scales underlain with osteoderms dorsally and ventrally, resulting in stiff bodies; some taxa have a longitudinal ventral-lateral groove or fold separating the dorsal and ventral scale armor (Behler and King 1998; Conant and Collins

1998; Pianka and Vitt 2003; Zug, et. al 2001). The body forms of these lizards range from no external limbs to strong limbs with most species possessing an autotomic tail with a fracture plane anterior to each transverse process (Behler and King 1998; Conant and Collins 1998; Zug, et. al 2001). Two subfamilies, Anguinae and Gerrhonotinae, are found in Texas (Zug, et. al 2001). Anguines (*Ophysuarus attenuates* is the only species found in Texas) are elongate and robust lizards, lack external limbs and have tails usually two-thirds the length of the lizard's total length (Pianka and Vitt 2003; Zug, et. al 2001). These lizards have a preference for open habitat with heavy ground cover, and have slow, methodical, prey-search behavior (Zug, et. al 2001).

Gerrhonotines (*Gerrhonotus liocephalus* is the only species found in Texas) are New World Lizards, collectively known as alligator lizards, which resemble small crocodilians because of their large plate-like scales; these lizards have short, well developed limbs and a stout body with a tail less than the body length (Conant and Collins 1998; Pianka and Vitt 2003; Zug, et. al 2001). Feeding mainly on arthropods and small vertebrates, these heavily armored lizards are mostly moderately sized lizards (less than 110 mm adult SVL) and are found in moist habitats, such as upland forest and coastal to montane forest (Behler and King 1998; Zug, et. al 2001).

Leptotyphlopids (*Leptotyphlops dulcis* and *L. humilis* are the only genus and species found in Texas), also known as thread snakes and worm snakes, are extremely thin snakes reaching a maximum SVL of approximately 400mm with an average length between 150 and 250 mm (Behler and King 1998; Zug, et. al 2001). This family has no external limb vestiges, but remnants of the pelvic girdle are present in the trunk musculature; each dentary has only four or five teeth, and these snakes have a small vestigial eye, appearing as black dots (Behler and King 1998; Conant and Collins 1998; Zug, et. al 2001).

Leptotyphlopids are fossorial snakes, occurring in a variety of habitats ranging from semiarid regions to rain forests, and feed predominately on termites and ants (Behler and King 1998; Conant and Collins 1998; Zug, et. al 2001). Often found near their food, leptotyphlopids will routinely inhabit termite and ant nests permanently, secreting a compound that deters attacks; occasionally leptotyphlopids may be found above ground, particularly at night (Behler and King 1998; Zug, et. al 2001). Theses snakes are oviparous, laying long slender eggs, and some species exhibit parental care (Behler and king 1998; Zug, et. al 2001).

Viperids (one subfamily and two genera found in Texas), comprised of both vipers and pitvipers, are found worldwide; although only the subfamily Crotalinae are found in the Americas (Behler and King 1998; Zug, et. al 2001). These venomous snakes have a rotating fang apparatus, which has allowed for long fang development in this family, with fangs standing erect while biting or striking and folded against the palate when the mouth is closed (Behler and King 1998; Zug, et. al 2001).

The subfamily Crotalinae (commonly known as pitvipers) have well-developed loreal pits for infared receptions which helps these nocturnal snakes hunt, feeding predominately on vertebrates (Conant and Collins 1998; Zug, et. al 2001). Most Crotalines are viviparous (all species found in Texas are viviparous) with only a few exceptions that are oviporous; however, these species commonly display egg-attendance behavior (Behler and king 1998; Zug, et. al 2001).

Colubrids (three subfamilies and thirty one genera found in Texas) represent the most structurally, ecologically, and behaviorally diverse snake group and contain approximately 78% of all the snake species (Behler and King 1998; Conant and Collins 1998; Zug, et. al 2001). Colubrids may have either solid or grooved teeth; at least one North American genus (Heterodon) produce mild venom (Behler and King 1998; Conant and Collins 1998; Zug, et. al 2001). Three subfamilies are found in Texas, including Colubrinae, Natricinae, and Xenodontinae (Zug, et. al 2001).

Colubrines (nineteen species found in Texas) range in size and body form, providing a variety of ecological roles (Zug, et. al 2001). They range in habitat from aquatic (both brackish and fresh water) habitats to arid regions to high mountain forests; others may be fossorial, terrestrial or semiarboreal (Zug, et. al 2001).Most Colubrines are oviparous with a few exceptions; some of the smaller species may be viviparous (Zug, et. al 2001).

Natricines (six species found in Texas) range in size from 160-250 mm SVL in adults (*Virginia stiratula*) to 1.4-2.0 m total length (*Nerodia sp.)* with most species considered terrestrial or semifossorial,; a few are well known to be aquatic (Zug, et. Al 2001). Terrestrial species typically feed on slugs, snails, earthworms and other soft body arthropods while the aquatic species tend to favor amphibians and fish (Zug, et. al 2001).

Xenodontines (six species found in Texas) are small to moderate sized snakes but have a wide range of body form, ecology and behavior (Zug, et. al 2001). Xenodontines occur in all habitats except marine environments, and most appear to be generalists/dietary opportunists, feeding on small vertebrates with a few species considered as dietary specialists (Zug, et. al 2001).

Elaphids (one subfamily and genera found in Texas) are dangerously venomous snakes with an erect grooved fang anteriorly on each maxilla bone (Behler and King1998; Conant and Collins 1998; Zug, et. al 2001). Best known for cobras and kraits, the only Elapids naturally occurring in the North America, belonging to the subfamily Elapinae, are the Texas coral snake (*Micrurus fulvius*) and the Arizona coral snake (*Micruroides euryxanthus*) (Behler and King 1998; Zug et. al 2001). Most Elapines are semifossorial (only two African arboreal taxa) and typically display aposematic coloration warning potential predators of their venomous bite (Behler and King 1998; Zug, et. al 2001). Both species found in North America are oviparous and eat predominately snakes and lizards (Zug, et. al 2001).

APPENDIX C

Common Squamate Species

While I am interested in all squamates in the study region, several of the local squamates are relatively abundant in some of the sites, including ground skinks (*Scincella lateralis*), Mediterranean geckos (*Hemidactylus turcicus*), green anoles (*Anolis carolinensis*), Texas spiny lizards (*Sceloporus olivaceus*), rough earth snakes (*Virginia striatula*), and copperheads (*Agkistrodon contortrix*).

Ground skinks (*Scincella lateralis*) are small ground-dwelling lizards which are common throughout much the southeastern United States of America ranging through to central Texas (Conant and Collins 1998). They are often found in a variety of forests (including forested grasslands) depending on leaf litter, decaying wood and detritus for refuge; but, they are also commonly found in suburbia, particularly in gardens (Behler and King 1998; Conant and Collins 1998). *Scincella lateralis* also depends on the leaf litter to find food, mainly eating small insects and spiders (Behler and King 1998). These lizards, while often considered mainly diurnal, may also be found frequently searching for food at dusk and well into the evening (Behler and King 1998; Brown 1950; Conant and Collins 1998).

The Mediterranean Gecko (*Hemidactylus turcicus*) is introduced and well-established in southeastern North America and Mexico (Davis, 1974; Gomez-Zlatar' et. al, 2006; Locey and Stone, 2006; Williams and McBrayer, 2007). Native to Southwest Asia and the Mediterranean, *H. turcicus* was first documented in 1910 in Key West, Florida and its range has since expanded (Locey and Stone, 2006). An abundant species in Southeastern United States, *H. turcicus* is a nocturnal, small-bodied lizard commonly found in urban areas, living in high densities and reaching adult sizes ranging from 102 to 127 mm total length (Behler and King, 1998; Conant and Collins, 1998).

Green anoles (*Anolis carolinensis*) are generally slender tree dwelling lizards, easily recognized by their grassy green color (brown when basking; some with indications of dark streaks or spots) and their extending throat fan or dewlap. *A. carolinensis* are common in the deep south of the United States of America through to central Texas and as far south as the Rio Grande Valley, with the escarpment of the Edwards plateau as western region of its range (Behler and King 1998; Brown 1950; Conant and Collins 1998). These lizards are often found in suburban areas but are also common in less urbanized regions, climbing on walls, fences, trees, shrubs and vines (Behler and King 1998; Brown 1950; Conant and Collins 1998). These lizards are solely diurnal and are easily captured at night when they can be found sleeping on leaves or vines (typically in less urbanized areas) but, they may also seek refuge in crevices in and around buildings in suburbia (Behler and King 1998; Conant and Collins 1998). Male and female *A. carolinensis* exhibit sexual dimorphism in both body and head size; males growing larger and having bigger heads, showing distinct differences in skull shape; males also have significantly larger throat fans than females (Herrel, et. al 2007; Jenssen, et. al 2000).

Texas spiny lizards (*Sceloporus olivaceus*) are inconspicuous, gray to rusty-brown lizards that camouflage well against the bark of trees, often going unnoticed until they move or make noise by climbing (Conant and Collins 1998). These lizards are common through much of central Texas, extending north into extreme south central

Oklahoma and south well into northeast Mexico (Behler and King 1998; Brown 1950; Conant and Collins 1998). *Sceloporus olivaceus* are skilled climbers, often found in trees, but may also be found basking on fallen logs, patches of prickly pear, on fences and around houses, or any other place that offers refuge in the form of cracks, cavities and crevices (Behler and King 1998; Brown 1950; Conant and Collins 1998). Male and female *S. olivaceus* exhibit sexual dimorphism, with males exhibiting a light blue patch at either side of the belly, sometimes with a significantly smaller, light blue patch on either side of the throat; females tend to have a uniform pale coloration of their bellies (Behler and King, Conant and Collins 1998).

Rough earth snakes (*Virginia striatula*) are common but secretive ground-dwelling snakes, found throughout the southeastern United States, and ranging well through central Texas, but are distinctly absent from much of the Mississippi River flood plain (Behler and King, Conant and Collins 1998). This cone-headed snake has a distinctly pointed snout, is gray or brown to reddish-brown in coloration (dorsally), and has keeled scales from where the "rough" in its name is derived (Behler and King 1998; Conant and Collins 1998; Dixon and Werler 2005). While feeding mainly on earthworms, this snake has also been seen eating slugs, snails and small frogs (Behler and King, Conant and Collins 1998). *Virginia striatula* may be found in dry coastal plains, woodlands, rocky wooded hillsides, heavily timbered uplands and valleys; they are relatively common in urban areas, particularly suburban gardens, where it is seldom seen on the surface, preferring to hide under leaves, decaying logs, and gardener's compost piles (Behler and King, Conant and Collins 1998; Dixon and Werler 2005).

Copperheads (*Agkistrodon contortrix*) are venomous snakes, comprised of five subspecies, common throughout much of the south and eastern portions of the United States of America, ranging from west Texas and Mexico (*A. c. pictigaster*) northeast through to New York and New Hampshire (*A. c. mokasen*) (Behler and King, Conant and Collins 1998). However, two subspecies, the southern copperhead (*A. c. contortrix*) and broadband copperhead (*A. c. laticinctus*) are most prevalent throughout much of Texas and integrate over a wide area, making it hard to distinguish between the two (Behler and King, Conant and Collins 1998). These nocturnal snakes are often considered almost lethargic, lying motionless or quietly retreating when approached, depending on their natural camouflage to hide them (Behler and King, Conant and Collins 1998). However, once aroused they will strike vigorously, commonly vibrating their tail tails in warning (Behler and King, Conant and Collins 1998). *Agkistrodon contortrix* are commonly found in lowland habitat waterways, such as swamps and cypress bordered streams and rivers, but may also be found in wooded hillsides and rocky canyons near ponds, springs or other waterways (Behler and King, Conant and Collins 1998; Dixon and Werler 2005). These snakes are gregarious, wintering together in a den known as hibernaculum, and feed on a wide range of prey including, rodents, frogs, lizards, caterpillars and cicadas (Behler and King, Conant and Collins 1998).

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