ABSTRACT

The Influence of Urbanization on the Basking Behavior of a Central Texas Freshwater Turtle Community

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Urbanization induced landscape modifications can dramatically alter riparian corridor dynamics and the composition of wildlife communities. Urbanized riparian corridors may alter or eliminate suitable freshwater turtle basking habitat by fragmenting shoreline vegetation, reducing basking substrates, and increasing the frequency of human disturbance. For this research, basking behaviors of the freshwater turtle community in the Brazos River (McLennan County, Texas) were observed from October 2004 to November 2007. The basking freshwater turtle community included the Texas river cooter, *Pseudemys texana* (Baur); red ear slider, *Trachemys scripta elegans* (Schoepff); Mississippi map turtle, *Graptemys pseudogeographica kohni* (Baur); Mississippi mud turtle, *Kinosternon subrubrum hippocrepis* (Gray); smooth softshell, *Trionyx muticus muticus* (Le Sueur); and spiny softshell, *Trionyx spiniferus pallidus* (Webb). Turtle community composition, basking site attributes, and the intensity of shoreline urbanization were measured for each observation of a basking turtle. Results showed that the community of basking freshwater turtles was moderately diverse with an endemic, *P.*

texana, as the most abundant species. Abundances of basking *P. texana* were greater where potential basking sites were abundant. The number of potential basking sites and a basking site's distance from shoreline facilitated greater basking abundances of *T. scripta*. All species preferentially basked alone. In cases of multiple occupancy on a single site, *P. texana* and *T. scripta* basked indescriminantly relative to the species present on the basking site. Basking site size and orientation contributed to cases of multiple occupancy. Responses to basking site attributes and social dynamics varied widely across taxa. Four indices of shoreline urbanization at three spatial scales were used to assess the relationship between urbanization and basking turtle behavior. Indices included local-scale Shoreline Modification and Disturbance Frequency, broad-scale Building Density, and reach-scale Human Density. At the local scale, abundances of basking turtles were greatest in areas of high Shoreline Modification characterized by a substantial reduction in woody shoreline vegetation. Also at the local scale, Disturbance Frequency of human intrusion limited basking turtle abundance in areas of daily disturbance. Most basking turtle species tolerated, and may have actively selected basking sites in areas of relatively high levels of localized urbanization.

The Influence of Urbanization on the Basking Behavior of a Central Texas Freshwater Turtle Community

by

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DEDICATION

To Mom and Dad,
for always encouraging me to play outside

CHAPTER ONE

Introduction and Background

Turtle Tales

Reptiles were once maligned for their alien appearance, reclusive behavior, and potential for deadly encounters. Even Carolus Linnaeus referred to reptiles as “foul and loathsome creatures”. But as this ancient lineage battles with the consequences of modern technology, the public’s opinion has changed to one of support and interest in this unique taxa. Chelonians have become one of the most beloved orders, championing the plight of all reptiles.

Primitive turtle fossils appeared in the Triassic, approximately 200 million years ago. While some anatomical changes occurred, such as shifts in the position of the apses of the skull and the loss of teeth, the single most identifying characteristic of turtles, the shell, has remained intact.

The order Chelonia consists of the side-necked (Pleurodira) and hidden-necked (Cryptodira) turtles and includes 244 species in 13 families (Halliday and Adler 2000). With the exception of Antarctica, their distribution is world-wide. Turtles use a variety of habitats including marine, freshwater, terrestrial and even subterranean environments. Within Texas, there are seven representative Pleurodiran families (Table 1.1). Species from four of these families (Chelydridae, Kinosternidae, Emydidae, and Trionychidae) are found within Texas’s freshwater systems.

Table 1.1: Texas freshwater, marine and terrestrial turtle species. Species occurring in McLennan Co., Texas are denoted with an asterisk.

Family	Genus and Species	Common Name
Chelydridae	*Chelydra serpentina**	Snapping Turtle
	Macroclemys temminckii	Alligator Snapping Turtle
Kinosternidae	*Kinosternon flavescens**	Yellow Mud Turtle
	Kinosternon hirtipes	Mexican Mud Turtle
	*Kinosternon subrubrum**	Eastern Mud Turtle
	*Sternotherus carinatus**	Razorback Musk Turtle
	*Sternotherus odoratus**	Stinkpot
Emydidae	*Chrysemys picta*	Painted Turtle
	*Deirochelys reticularia**	Chicken Turtle
	Graptemys caglei	Cagle's Map Turtle
	*Graptemys pseudogeographica kohni**	Mississippi Map Turtle
	Graptemys ouachitensis	Ouachita Map Turtle
	Graptemys versa	Texas Map Turtle
	Malaclemys terrapin	Diamondback Terrapin
	Pseudemys concinna	River Cooter
	Pseudemys gorzugi	Rio Grande River Cooter
	Pseudemys nelson	Florida Red-bellied Turtle
	*Pseudemys texana**	Texas River Cooter
	*Terrapene carolina**	Eastern Box Turtle
	*Terrapene ornate**	Western Box Turtle
	Trachemys gaigeae	Big Bend Slider
	*Trachemys scripta**	Slider
Testudinidae	*Gopherus berlandieri**	Texas Tortoise
Trionychidae	*Trionyx muticus**	Smooth Soft-Shell
	*Trionyx spiniferus**	Spiny Soft-shell
Chelonidae	*Caretta caretta*	Loggerhead
	Chelonia mydas	Green Turtle
	Ertmochelys imbricate	Hawksbill
	Lepidochelys kempi	Atlantic Ridley
Dermochelyidae	*Dermochelys coriacae*	Leatherback

Freshwater Turtles

Freshwater turtles are particularly important both ecologically and economically. Freshwater turtles account for a large portion of biomass in lentic and lotic systems and play a key role in the food web (Moll and Moll 2004). As a food source, turtle eggs and hatchlings are eaten by many vertebrates. As consumers, diets for freshwater turtles include insects, algae, vegetation, mollusks, and fish. There are ontogenic shifts in food preference; young turtles are primarily insectivores while adult turtles are primarily herbivores (Ernst et al. 1994). And turtles play a role in seed dispersal and nutrient cycling.

In addition to their role in food web dynamics, turtles routinely affect their habitat. Soils are aerated by nesting, hibernation, and aestivation. Instances of freshwater turtles interacting with a variety of taxa have been reported (Vogt 1979). Many freshwater turtles exhibit exceptional dispersal abilities, ranging from a few meters to several kilometers (Jones 1996, Lovich et al. 1992, Parker 1984). Dispersal rates and distances fluctuate depending on season, sex, and age of the turtle (Ernst et al.1994). Dispersal can occur over terrestrial environments or along a river channel.

Notable physiological characteristics include ectothermy (Dreslik and Kuhns 2000), unique cardiovascular system, cutaneous respiration, freeze tolerance (Packard and Packard 2001) and exceptional longevity (Ernst et al.1994). Fertilization is internal, amniotic eggs are laid in moist soils, and most species undergo temperature dependent sex determination (Moll and Moll 2004). Freshwater turtles often have webbed feet, are sexually dimorphic, and can be avid baskers (Conant and Collins 1998).

Because of their sensitivity to environmental degradation, turtles have been dubbed indicator species for habitat integrity. Economically, freshwater turtles are valuable to the pet trade, food industry, and as traditional medicines. This sensitivity to ecological variables and high human demand has driven many turtle populations to the brink of catastrophic losses.

It's Not Easy Being Green

Of the 31 species of turtles federally listed as endangered or threatened and thereby entitled to the protection and management of the U.S. Fish and Wildlife Service, five are freshwater turtles and native to North America (Alabama red-belly turtle, *Pseudemys alabamensis*, bog turtle, *Clemmys muhlenbergii*, flattened musk turtle, *Sternotherus depressus*, ringed map turtle, *Graptemys oculifera*, and yellow-blotched map turtle, *Graptemys flavimaculata*). Two species of freshwater turtles are considered candidates for listing (Cagle's map turtle, *Graptemys caglei*, and Sonoyta mud turtle, *Kinosternon sonoriense longifemorale*). And it is probable that this list will continue to grow, as the literature is rife with concerns over the future of freshwater turtle populations (Gibbons et al. 2000, DonnerWright et al.1999, Garber and Berger 1995).

Threats to freshwater turtles include anthropogenic activities, such as increased exploitation, habitat loss and degradation, introduction of invasive species, and disease (Gibbons et al. 2000). Human exploitation of freshwater turtle populations comes in several forms. In the southern United States, freshwater turtle eggs are regularly consumed and adults are hunted for their meat. The consumption of turtles is more pronounced in Mexico and Asia, where turtles are considered a delicacy and also used as traditional medicines. Demand for turtles in Asia is so substantial that local freshwater turtle populations are devastated and consequently, suppliers in the United States are providing turtles to the Asian market. From 1996-2000, turtle exports from Texas exceeded 100,000 individuals per year, which only accounted for less than 1% of the total number of turtles exported from the United States (Ceballos and Fitzgerald 2004). Over-collection for the pet trade is also a significant contributor decreasing freshwater turtle populations (Gamble and Simons 2004, Lewis et al 2004).

Urbanization

Habitat loss and degradation provides substantial challenges in maintaining sustainable freshwater turtle populations as they use a multitude of habitats (Joyal et al. 2001, Jones 1996). Freshwater turtles swim, feed, and bask within the water column. They are often in contact with the substrate of the active river channel for resting, foraging, or burrowing. Shorelines are used for nesting and basking, and over-land dispersal is common. Many species also use associated sloughs and wetlands during various life stages or seasons. Patch isolation and corridor removal causes nesting females and dispersing males to transverse potentially hostile terrain, as illustrated by freshwater turtle's susceptibility to road mortality (Gibbs and Steen 2005, Steen and Gibbs 2004, Gibbs and Shriver 2002). Removal of shoreline vegetation may constrain suitable basking sites. River channelization removes potential nesting sites and increases water velocity. And damming may shift optimum depths and temperatures.

Habitats may also become unsuitable due to more direct human disturbances. River systems with heavy watercraft traffic caused the yellow-blotched map turtle (*Graptemys flavimaculata*) to delay or abandon nesting attempts, potentially aborting the clutch, and to abandon basking sites (Moore and Seigel 2006). Turtles are often inadvertently caught while pole or trot-line fishing. Gibbons et al. (2001) found increased mortality for diamondback terrapins (*Malaclemys terrapin*) as by-catch in crab traps.

The detrimental effect on native species due to the introduction of invasives has become a substantial problem. Turtles are often released outside their range when pet owners tire of caring for them. For example, the red-eared slider (*Trachemys scripta elegans*) has been introduced in Europe and is a competitor for basking sites locations with the endangered European pond turtle (*Emys orbicularis galloitalica*) (Cadi and Joyl 2003).

Disease and illness may also result from anthropomorphic stressors. Brites and Ratin (2004) found that 28% of urban *Phrynops geoffroanus* harbored ectoparasites, while no ectoparasites were found on turtles captured in rural settings. Hemogregarine endoparasites were more abundant in urban turtles (38%) than rural (15%). Freshwater turtles have also exhibited developmental and genetic abnormalities when exposed to polychlorinated biphenyls (Crews et al. 1995) and metals (Lamb et al. 1995). Undoubtedly, freshwater turtle populations are exposed to a combination of these threats, thereby underscoring the need for complete life history information and careful monitoring of species specific turtle abundances.

Riparian Corridor

A riparian corridor consists of a river, the surrounding shoreline vegetation and the floodplain (Forman 1995). Riparian zones provide an interface between land and water and are heavily used by wildlife and humans alike. Anthroprogenic uses of riparian corridors include recreation, habitation, transportation and as a water source.

Hydrologic and particulate flows are dynamic processes that greatly affect the ecological functionality of the corridor.

Modifications to riparian corridors are common. Alterations in hydrologic flows and recreational activity, such as watercraft use, fishing, and swimming, are but a few of the factors that change riparian corridor dynamics (Reese and Welsh 1998, Naiman and DeCamps 1997). Because riparian corridors play a critical role in ecosystems, active management of both the aquatic and terrestrial portions of the corridor has become widespread.

Management techniques of woody shoreline vegetation may reduce the quantity of vegetation or alter the composition of that vegetation (Tabacchi and Planty-Tabacchi 2003). Stream inputs from shoreline vegetation enrich the available nutrients and provide critical habitat for wildlife. Specifically, these inputs, in the form of tree falls, broken branches and emergent woody vegetation provide basking substrate for freshwater turtles. Abundance of deadwood basking sites may be affected by reductions in woody shoreline vegetation. Understanding the relationship between the quantity of shoreline vegetation and the subsequent quantity of deadwood within the river or stream will allow for the design of appropriate management techniques and aid in sound shoreline development. This research addresses that issue.

The ecological importance of riparian corridors is immense. They provide habitat and resources for both aquatic and terrestrial species as well as function as a corridor (Forman 1995). Water quality and river geomorphology can greatly influence aquatic wildlife. Turtle assemblages are sensitive to substrate type, the presence of basking sites, water velocity, water depth, uniformity in channel bottom, stream width, quantity of algae on logs, primary productivity, and presence of underwater refugia (DonnerWright et al. 1999, Reese and Welsh 1998, Galbraith et al. 1988, Shively and Jackson 1985). Pluto and Bellis (1986) found a significant positive relationship between turtle carapace length and the turtle's distance from shoreline, water depth, surface current, and swimming speed.

Basking Ecology

Turtles are among the most visible aquatic vertebrate fauna because they tend to bask. It is common to see turtles vying for position on emergent deadwood. The act of basking is particularly well developed in the turtles in the family Emydidae (Ernst et al. 1994). Many freshwater turtle species spend significant time basking (Dreslik and Kuhns 2000). It aids in thermoregulation (Boyer 1965), digestion (Moll and Legler 1971), vitamin D synthesis (Pritchard and Greenhood 1968), and algal and ectoparasite removal (Boyer 1965, Neill and Allen 1954, Cagle 1950). Further investigation is needed to better define the relationship between basking, the importance of deadwood abundance, and the attributes of potential basking sites.

Freshwater turtle basking behavior, ecology, and physiology are well-studied phenomena (Dreslik and Kuhns 2000, Lindeman 1999a, Lindeman 1999b, Manning and Grigg 1997, Boyer 1965). However, the abundance and characteristics of basking sites, especially relative to urbanization levels, are rarely studied explicitly. Lindeman (1999b), on observing basking behavior in *Graptemys*, quantified basking turtle densities with deadwood substrates used for basking. His results showed a positive correlation with deadwood abundance and turtle basking densities. DonnerWright et al. (1999) found that the abundances of *Chelydra serpentina, Graptemys pseudogeographica,* *Chrysemys picta bellii* were positively associated with the number of basking sites. Additionally *Clemmys marmorata* and *Graptemys ouachitensis sabinensis* preferentially selected areas with basking sites (Reese and Welsh 1998, Shively and Jackson 1985).

However deadwood basking sites have a variety of characteristics other than abundance that might influence basking behavior in freshwater turtles. Basking site length, circumference, distance from the shoreline, and angle to the water's surface may play a role in basking site suitability. Variation in basking sites may be of little consequence to turtles simply seeking warmth, a drying substrait, and some degree of protection. Conversely, turtles may be highly perceptive, scrutinizing the suitability of a basking site and actively selecting sites with particular attributes. Understanding the role of basking site characteristics may provide insights on the habitat requirements of freshwater turtles.

Study Location

Research was conducted along both shorelines of 14.5 km of the Brazos River in McLennan Co. Texas (Figure 1.1) and included basking surveys and trapping effort. This segment of the Brazos is typically slow moving (2004 – 2007 mean annual flow of 0 - 0.5 m sec^{-1}) and deep (2004 – 2007 mean gauge height of 1.5 m), with sediments ranging from gravel to sandy clay loam. The Brazos is the longest river in Texas (1690 km), extending from eastern New Mexico to the Gulf of Mexico. The major tributaries of the Brazos include the Clear Fork, Bosque, Lampasas, Leon, Little River, and Navasota. It has the largest discharge of any Texas river (Handbook of Texas Online 2008). The Brazos River runs through and near several major metropolitan areas, including Lubbock, Waco, and Freeport, Texas, and is dammed in three places, forming Possum Kingdom

Lake, Lake Granbury, and Lake Whitney. The majority of the shoreline is characterized by cottonwoods (*Populus* spp.), elms (*Ulmus* spp.), and sugarberries (*Celtis laevigata*). Emergent herbaceous growth is primarily absent from the active river channel.

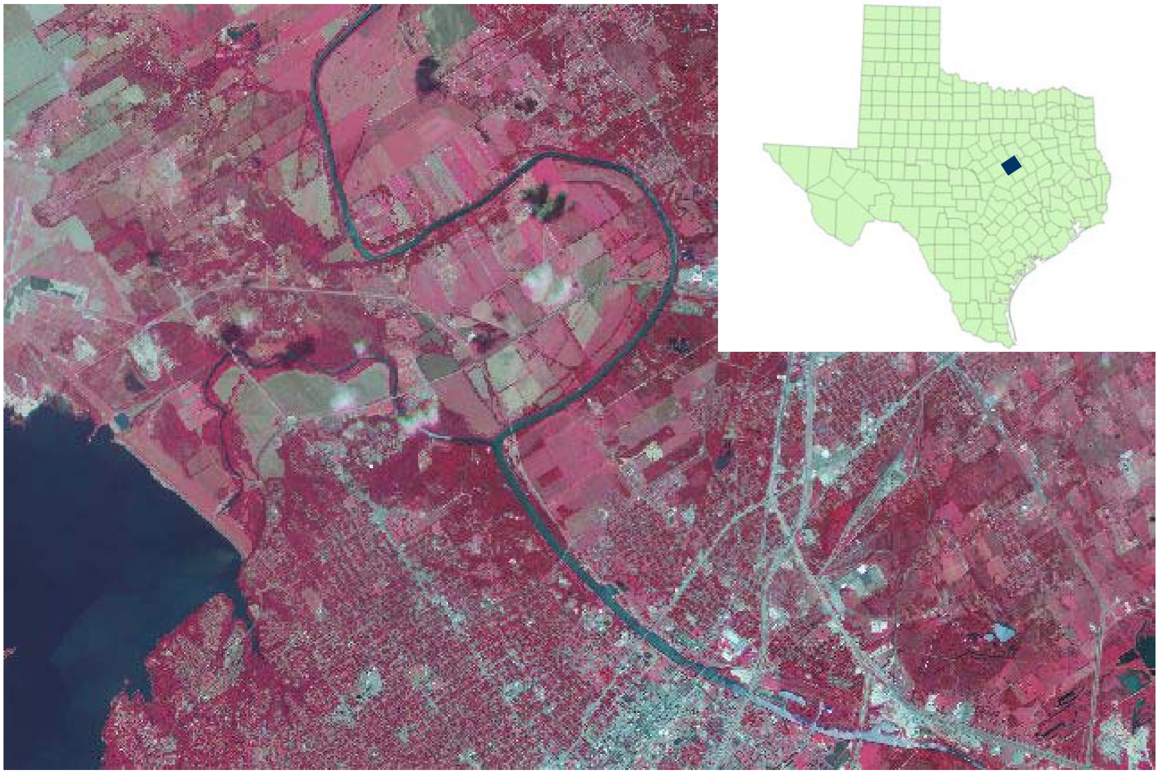

Figure 1.1: Brazos River study site in McLennan County, Texas . The Brazos is the longest river in Texas (1690 km), extending from eastern New Mexico to the Gulf of Mexico. The major tributaries of the Brazos include the Clear Fork, Bosque, Lampasas, Leon, Little River, and Navasota. The study site encompassed 14.5 km of the river, spanning a rural to urban gradient. The infrared image is provided by the The Texas Orthoimagery Program and National Agricultural Imagery Program to quantify vegetation which reflects near infrared energy, thus appearing as dark red on the image. The inset was provided VARGIS and ESRI.

Study Focus

The spatial distribution of basking freshwater turtles along the shoreline may be influenced by the attributes of the basking site, community composition basking on the site, and the level of urbanization around the site. Chapter Two focuses on the basking ecology of freshwater turtles in the Brazos River. Overall community composition within the river and on basking sites was quantified. Basking site attributes of length, circumference, distance from the shoreline and angle from the water's surface were measured. These attributes were assessed to determine which basking site characteristics facilitate turtle basking. Chapter Two addresses four primary questions: 1) Do freshwater turtles preferentially bask on sites of particular dimensions? 2) To what degree to basking site characteristics facilitate turtle basking? 3) Which attributes facilitate multiple occupants on a single site? and 4) Do freshwater turtles selectively bask with conspecifics?

Chapter Three focuses on the ecology of the endemic *Pseudemys texana*. The endemic status of *P. texana* evokes an impression of a limited, isolated population, sensitive to environmental stressors and vulnerable to extinction with a specialized, narrow niche. Endemic populations need to be characterized in terms of their adaptability, roles in the community, stability, competitiveness, resistance to disturbance, and potential for growth. Additionally, natural history information for this species is limited as much of the litereature confuses *P. texana* with other *Pseudemys* (Dixon 2000, Ernst et al. 1994, Etchberger and Iverson 1990). Size classes, age structure, sex ratios and spatial distributions of *P. texana* are discussed in the context of conservation. Chapter Three addresses two primary questions: 1) What is the population structure of *P. texana*? and 2) Does urbanization negatively influence the abundances of basking *P. texana*?

Chapter Four measures the influence of urbanization on freshwater turtle community structure and basking behavior. The shoreline was characterized with three indices of urbanization. Indices included 1) Shoreline Modification, 2) Disturbance Frequency, and 3) Building Density. These three urbanization indices encompass two spatial scales: local and broad. Species-specific responses to sources and scales of urbanization were analyzed and compared. Chapter Four address three primary questions: 1) How does shoreline urbanization relate to the spatial distribution of turtles basking along the shoreline? 2) At what scale are basking turtle abundances greatest? 3) Is the response of freshwater turtles to shoreline urbanization species-specific?

CHAPTER TWO

Community Structure and Basking Site Preferences of Freshwater Turtles in Central Texas

Abstract

Basking site attributes and social interactions may influence the spatial distribution of basking freshwater turtles and their choice of sites. Basking behaviors within the freshwater turtle community in the Brazos River (McLennan County, Texas) were observed from August 2006 to September 2007. The community of basking freshwater turtles includes the Texas river cooter, *Pseudemys texana* (Baur); red ear slider, *Trachemys scripta elegans* (Schoepff); Mississippi map turtle, *Graptemys pseudogeographica kohni* (Baur); Mississippi mud turtle, *Kinosternon subrubrum hippocrepis* (Gray); smooth softshell, *Trionyx muticus muticus* (Le Sueur); and the spiny softshell, *Trionyx spiniferus pallidus* (Webb). Community composition and basking site attributes were measured and associated with each observation of a basking turtle. In addition to basking surveys, turtles were trapped from 2004 to 2007 and identified, measured, marked, and released. Results showed that the community of basking turtles in the Brazos River is moderately diverse with an endemic, *P. texana*, as the most abundant species. Abundances of basking *P. texana* were greater where potential basking sites were more abundant. The density of potential basking sites and a basking site's distance from shoreline facilitated greater basking abundances of *T. scripta*. All species preferentially basked alone. In cases of multiple occupancy on a single site, *P. texana* and *T. scripta* basked indiscriminately relative to the species composition on a basking

site. Basking site size and orientation contributed to use of sites by multiple occupants. Responses to basking site attributes as well as social dynamics varied widely across taxa.

Introduction

Freshwater turtles that actively bask are a unique subset of the turtle community. Their spatial distribution along the shoreline depends at least to some degree on basking site attributes and social interactions with conspecifics. Turtle preferences for basking site attributes, such as size, orientation, and abundance, as well as the intensity of competition for basking sites may influence where freshwater turtles choose to bask. Basking behavior by freshwater turtles not only promotes thermoregulation (Boyer 1965), but also facilitates digestion (Moll and Legler 1971), vitamin D synthesis (Pritchard and Greenhood 1968), and algal and ectoparasite removal (Boyer 1965, Cagle 1950, Neill and Allen 1954).

Emergent deadwood is the predominant substrate for turtle basking (Lindeman 1999b). Preferences for basking site attributes have been demonstrated by freshwater turtles in previous studies (Dreslik and Kuhns 2000, Flaherty and Bider 1984, Lindeman 1999b, Lindeman 1996, Shively and Jackson 1985) and vary among species and across habitats. As part of their overall ecology, this variation warrants further investigation on freshwater turtle preferences for basking site attributes.

The number of turtles occupying a basking site varies from a single individual to abundances so great that turtles stack on top of each other. In cases of multiple occupancy, species composition on a basking site may range from a single species to a more complex structure, consisting of several species. Multiple occupancy on basking sites provides an opportunity for social interaction (Lindeman 1999a, Lovich 1990, Lovich 1988). While aggressive interactions between basking turtles have been documented (Lindeman 1999a, Lovich 1988), interference competition is at a minimum as most potential basking sites are unused and multiple occupancy is not uncommon. Understanding which basking site characteristics facilitate the presence of multiple baskers on a given site will help explain the distribution of turtles along the shoreline.

Freshwater turtles comprise a substantial portion of biomass in aquatic systems (Moll and Moll 2004), and they vary temporally (Stone et al. 1993) and spatially (Owen 1989) within and across systems. The turtle fauna in Texas includes 28 species, several of which are endemic, in seven different families (Dixon 2000). Turtles of family Emydidae are especially common. Ten species of freshwater turtles have been documented within McLennan County, the area of this study (Dixon 2000). With such a diverse turtle community, elucidating the processes underlying community structure will provide valuable insight for management practices for some of our most visible, aquatic vertebrate fauna. To this end, this study focuses on species specific basking site preferences, basking site attributes that facilitate multiple occupancy, preferences of the species for a given neighbor, and a description of the freshwater turtle community structure and addresses four primary questions: 1) Do freshwater turtles preferentially bask on sites of particular dimensions? 2) To what degree to basking site characteristics facilitate turtle basking? 3) Which attributes facilitate multiple occupants on a single site? and 4) Do freshwater turtles selectively bask with conspecifics?

Materials and Methods

Data Collection

Research was conducted along both shorelines of 14.5 km of the Brazos River in McLennan County, Texas. All stationary pieces of emergent deadwood with a circumference greater than 15 cm were considered potential basking sites and surveyed for basking turtles. Sixteen surveys of basking turtles were conducted from August 2006 to September 2007, and were restricted to warm (>20° C) sunny days with less than 30% cloud cover. For each observation of a basking turtle, its location, species and size class as small (<10 cm), medium (10-20 cm), or large (>20 cm), were recorded. For 524 of the 1600 observations of basking turtles, the air temperature, number of basking sites within 30 m, and basking site characteristics were recorded. Specifically, the length, circumference, angle to shoreline, angle to the water's surface and distance to the shoreline were measured for 364 basking sites. The western shoreline was videotaped to quantify the abundance and characteristics of all available basking sites from which turtles were selecting. A meter stick was positioned within the frame to increase the accuracy of basking site attribute estimates. The tape was reviewed using Microsoft Windows Media Player (version 11.0) and the array of attributes for all pieces of deadwood were quantified and recorded.

To measure community diversity, turtles were trapped from October to December in 2004 and 2005, and from December 2006 to June 2007. Species richness and their rank order was similar across trapping seasons. Basking traps were square PVC frames (167 x 167 x 30.5 cm) with a central mesh basket and wire basking platforms attached to the outer edges. Traps were deployed for one week at randomly selected locations along the study site. Trapped turtles were identified to species, sexed, marked individually by notching the marginal scutes (Cagle 1939), and measured for carapace and plastron length and width before releasing at the point of capture.

Statistical Analysis

An ordination of basking site characteristics was performed using Principal Components Analysis (PCA) in PC-ORD version 5. PCA is a data reducing ordination technique that measures the strength of co-variation among variables and creates synthetic principal components, or axes. PCA assumes normality and linearity. The PCA ordination of basking site attributes was created using a correlation cross-products matrix and distance-based biplot. The data matrix included basking site attributes of basking site length, circumference, distance from shoreline, angle to shoreline, and angle to the water's surface. A secondary matrix of turtle species abundances were overlaid on the original basking site attributes ordination. Overlays change the size of the ordination points so they are proportional to species abundance. To meet PCA assumptions, the scatter-plot matrix of basking site attributes was assessed for deviations in linearity. Normality was assessed by calculating skewness and kurtosis, which were high (skew > 1) for the distance from shoreline and the angle to the water's surface. The attribute variables were therefore log (x + 1) transformed so that skewness was approximately 1 and kurtosis was< 3. Outliers with an average distance from other observations of more than 2 standard deviations from the grand mean of distances between observations were removed. Eigenvalues are the roots of a polynomial in the correlation matrix which represent a portion of the original total variance for each principal component. A Monte Carlo randomization test indicated the number of interpretable principal components by determining the probability of obtaining an eigenvalue greater than or equal to those calculated in the original ordination (McCune and Grace 2002).

Classification and Regression Trees (CART) were created to explain variance in turtle species abundances relative to basking site characteristics (McCune and Grace 2002). CART builds on PCA results with a quantitative model that organizes regressors (e.g., basking site attributes) according to the magnitude of variance they explain in the response variable (e.g., basking turtle abundance). CART recursively partitions data into increasingly homogenous groups while maximizing between-group heterogeneity. This yields a tree (dendrogram) whose branch lengths are proportional to the variance explained by each variable defining the split. Stopping rules and cross validation dictate where the tree stops growing. No fewer than twenty observations were specified for a terminal node. To determine the appropriate number of splits in the tree, cross validation of the dendrogram of basking site attributes divided the data into ten groups. Fifty iterations of cross validation were performed using the one standard error rule. Regression trees were created in the statistical software R version 2.5.1.

Poisson regressions modeled basking site characteristics that facilitated basking for each species. Poisson regressions model the log of count data. Poisson regressions are appropriate when the distribution of the response variable, in this case basking turtle abundance, is positively skewed (Long 1997). To avoid pseudo-replication of basking site measurements among the 16 surveys, the single survey with the greatest abundance of a species was modeled in the Poisson regression. Poisson regressions build on CART analyses by calculating the magnitude of change in the response variable corresponding to a one unit difference in a regressor, such as basking site length.

Stepwise logistic regression modeled basking site characteristics that facilitate multiple occupancy, be it of the same or different species. Turtle abundances are dichotomously coded as present or absent. From this data, the natural log of the odds ratio determined the probability of multiple occupancy. Logistic regression assumes a binomial distribution of the residuals (Peng et al. 2002). As with the Poisson regressions, the single survey with the largest sample size was used in the stepwise logistic model. Poisson and stepwise logistic regressions were modeled in SAS, version 9.1.3.

For each species, a chi-square goodness of fit test detected deviations from a 50:50 sex ratio. Differences in the attributes of occupied and unoccupied basking sites were determined via chi-square as well.

Results

Basking Turtle Community

Observations of basking turtles (n = 1597) revealed a community comprised of the endemic Texas river cooter, *Pseudemys texana* (n = 650, 40.7%); the red ear slider, *Trachemys scripta elegans* (n = 336, 21.0%); Mississippi map turtle, *Graptemys pseudogeographica kohni* (n = 51, 3.2%); and the Mississippi mud turtle, *Kinosternon subrubrum hippocrepis* (n = 7, 0.4%). Since the two species of softshells (*Trionyx muticus muticus* and *Trionyx spiniferus pallidus*) were indistinguishable from a distance, observations were recorded collectively as softshells and represented 1.6% (n = 26) of the basking community. The remaining observations of the basking community (n = 527, 33.0%) consisted of turtles that retreated into the water before they could be identified to species. These unidentified turtles were included in analyses of all cumulative turtle taxa but were omitted from species-specific responses. The Shannon diversity index for the basking turtle community was 0.93. The mean number of basking turtles per kilometer of shoreline was 44.6 km^{-1} for *P. texana*, 23.1 km^{-1} for *T. scripta*, 3.6 km^{-1} for *G. kohni*, 1.8 km^{-1} for softshells, and 0.5 km^{-1} for *K. subrubrum*. The range of air temperatures where turtles were observed basking was between 25.3° C and 46.8° C with a mean of 34.4° C.

Basking site occupancy ranged from a solitary individual to substantially larger densities. Single occupancy on a basking site was common for all turtle species (61.8%). In cases of multiple occupancy on a single basking site, 53% of *P. texana* basked with other individuals of the same species. *P. texana* basked with *T. scripta* 38% of the time, *G. kohni* 7%, and the softshells 2%. *T. scripta* basked with *P. texana* (61%) more often than with itself (32%), rarely basked with *G. kohni* (6%) and *K. subrubrum* (1%), and was never observed basking with a softshell. As was true for *T. scripta*, *G. kohni* basked more frequently with *P. texana* (61%) than with itself (4%) or with *T. scripta* (35%). *G. kohni* was never observed basking with the softshells or *K. subrubrum*. Softshells exclusively basked with *P. texana* (83%) or with other softshells (17%). Only one observation was made of *K. subrubrum* basking with any other species, which was *T. scripta*.

To determine if species preferentially basked together, a chi-square goodness of fit test compared the proportions of species basking together to the overall proportions that they were found basking. *P. texana* (χ^2 = 7.44, df = 4, p = 0.11) and *T. scripta* (χ^2 = 2.67, df = 3, p = 0.45) basked with other species on the same basking site in the same proportions as each species is found within the community. The rarest observations for multiple occupancy in the *T. scripta* analysis (sliders basking with softshells or with mud turtles) were combined to meet the criterion of five observations per category. Limited sample size made chi-square analysis of multiple basking by *G. kohni*, the softshells, and *K. subrubrum* inappropriate. There is no evidence that *P. texana* or *T. scripta* preferentially bask with any species in this community. Rather, the proportion of species sharing a basking site is comparable to the proportions observed basking alone.

Selection of Basking Site Attributes

Attributes of basking site circumference, angle to the shoreline, angle to the water's surface, and distance from the shoreline were significantly different between the occupied and unoccupied basking sites when considering turtle taxa cumulatively (Table 2.1). Length was the only basking site attribute selected in a proportion similar to what was available. Among species specific trends in basking site preferences, *P. texana* and *T. scripta* were selective for basking site attributes with one exception; *T. scripta* selected lengths in proportion to those available.

The PCA ordination of basking site attributes calculated vectors whose length and direction indicate the magnitude and direction of each attribute (Figure 2.1). A Monte Carlo permutation test randomized the data to determine if stronger axes could be derived simply by chance. These randomizations indicated that the first principal component (axis one) was statistically significant ($p = 0.001$) and explained 25.6% of the variance in the dataset. Basking site circumference correlated strongest ($r = 0.75$) with axis one, followed closely by basking site length ($r = 0.72$). Thus, positive loading on axis one primarily corresponds with measures of basking site size. Negative loading on axis one moderately correlated with basking site angle to the water's surface ($r = -0.48$) and distance to the shoreline ($r = -0.47$).

Table 2.1: Contingency chi-square results comparing the attributes of basking sites used by all turtle taxa cumulatively and for the species specific responses of *P. texana*, and *T. scripta* to the attributes of all potential basking sites in the study site. The variable ASL is the basking site's angle to the shoreline, AWS is the angle to the water's surface, and DSL is the distance from the shoreline. Two asterisks indicate statistical significance at alpha of 0.01.

	All Turtles		*P. texana*		*T. scripta*	
Attribute	χ^2	df	χ^2	df	χ^2	df
Length	11.79	10	28.12**	5	9.17	5
Circumference	245.62**	8	91.46**	4	43.98**	4
ASL	146.32**	16	35.14**	8	268.33**	4
AWS	195.43**	7	53.59**	7	70.82**	4
DSL	598.65**	7	408.07**	6	250.30**	6

These measures of basking site orientation correspond with negative values of axis one. The number of basking sites within 30 m (r = -0.14) and the site's angle to the shoreline (r = -0.05) had little correlation with axis one. Sites near the origin of the vectors cluster relatively tightly indicating that most occupied sites were short, small in circumference, relatively close to shore, and flush with the water's surface. Scatter towards the positive loading of axis one suggests that larger basking sites were used but less frequently.

Overlays illustrate species responses to basking site attributes. The overlay of all turtles (Figure 2.2) demonstrates the response cumulatively to basking site attributes. Response of the total basking turtle community to basking site attributes spanned all measures of basking site size represented by axis one (Figure 2.2). *P. texana* (Figure 2.3) and *T. scripta* (Figure 2.4) typically selected moderately sized basking sites that were flush with the water's surface and moderately distant from the shoreline. However, preferences of *P. texana* and *T. scripta* for these attributes were weak. *G. kohni* preferred smaller basking sites with greater angles to the water's surface (Figure 2.5). Softshells tended to bask on larger sites with no preference for basking site orientation (Figure 2.6).

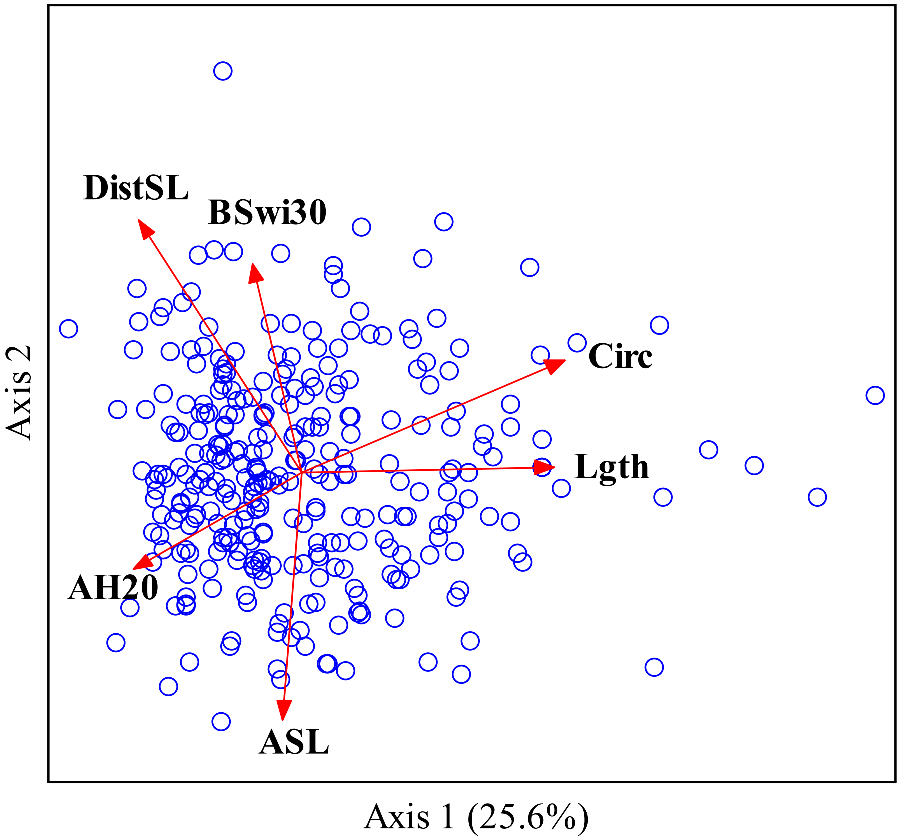

Figure 2.1: PCA ordination of basking site characteristics with vectors representing basking site distance to the shoreline (DistSL), number of basking sites within 30 m (BSwi30), angle to the water's surface (AH20), angle to the shoreline (ASL), circumference (circ) and length (lgth). Points represent basking sites where interpoint distances are proportional to the similarity of the basking site's attributes. Vector length and direction indicate greater magnitudes in the indicated direction. Axis 1 was statistically significant, explaining 25.6% of the variation in the basking site attributes. The basking site attributes of size (circumference and length) primarily explain the gradient represented by Axis 1.

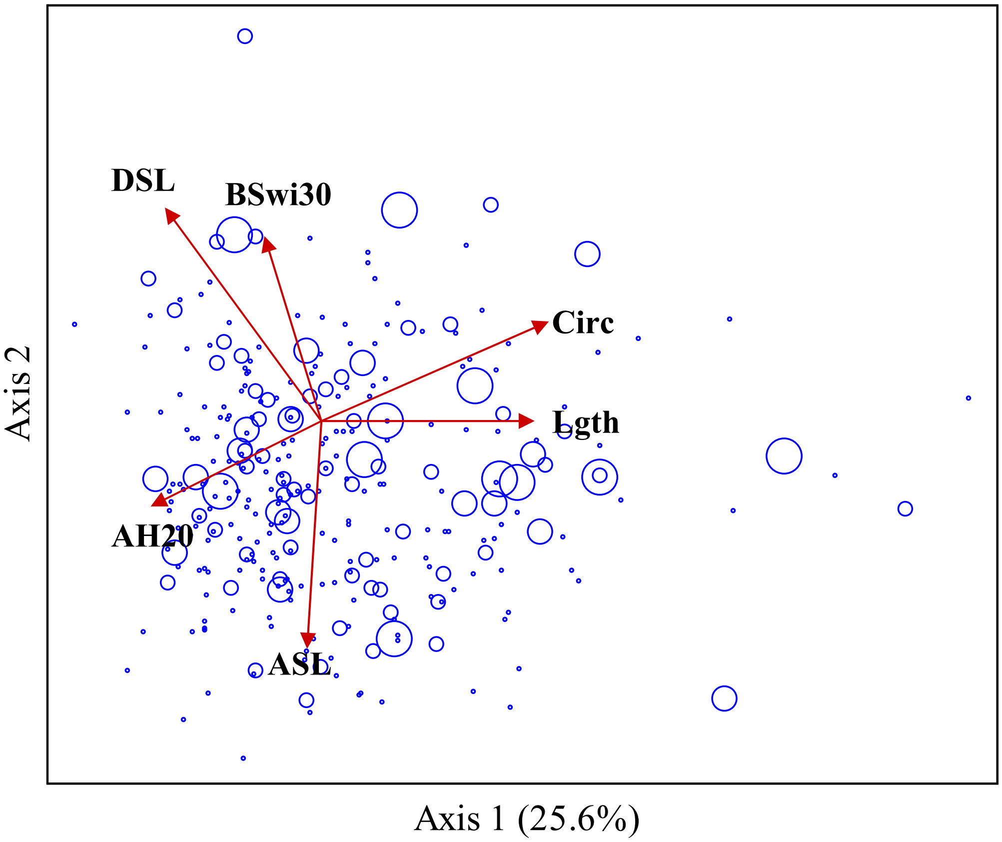

Figure 2.2: All species overlay on PCA ordination of basking site characteristicswith vectors representing basking site distance to the shoreline (DistSL), number of basking sites within 30 m (BSwi30), angle to the water's surface (AH20), angle to the shoreline (ASL), circumference (circ) and length (lgth). Points represent basking sites where interpoint distances are proportional to the similarity of the basking site's attributes. Greater point sizes indicate basking sites where basking turtles were more abundant. Vector length and direction indicate greater magnitudes in the indicated direction. Axis 1 was statistically significant, explaining 25.6% of the variation in the basking site attributes. The basking site attributes of size (circumference and length) primarily explain the gradient represented by Axis 1.

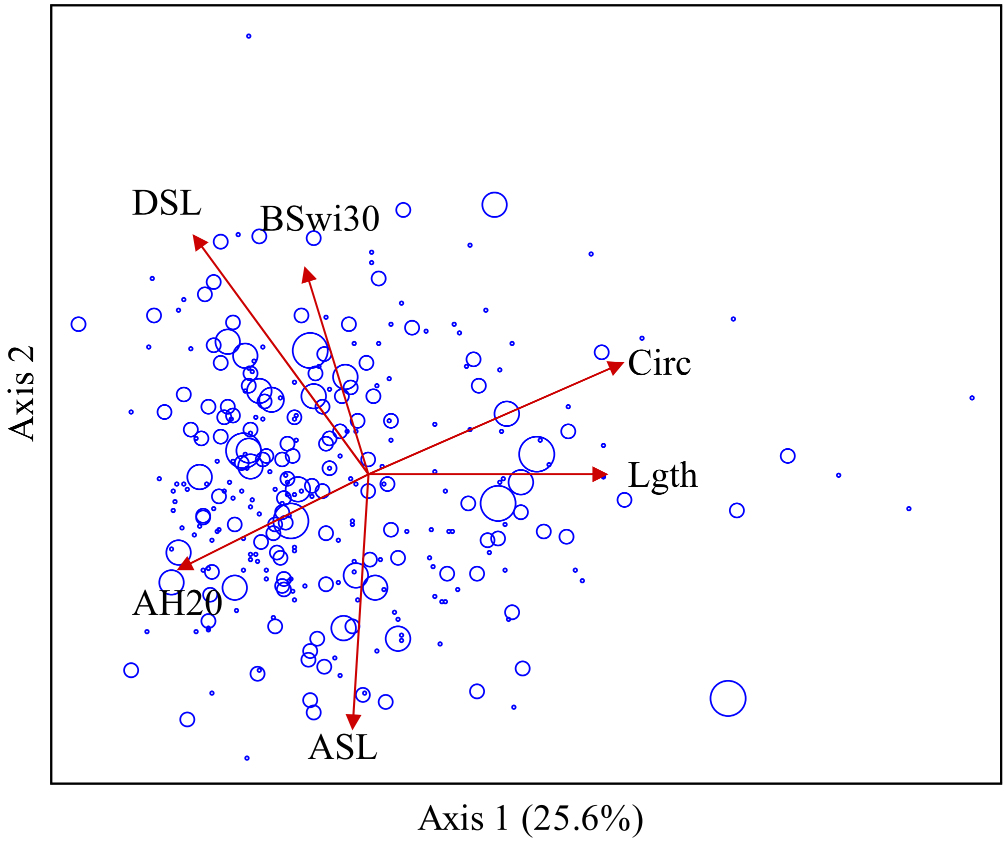

Figure 2.3: *P. texana* overlay on PCA ordination of basking site characteristicswith vectors representing basking site distance to the shoreline (DistSL), number of basking sites within 30 m (BSwi30), angle to the water's surface (AH20), angle to the shoreline (ASL), circumference (circ) and length (lgth). Points represent basking sites where interpoint distances are proportional to the similarity of the basking site's attributes. Greater point sizes indicate basking sites where basking turtles were more abundant. Vector length and direction indicate greater magnitudes in the indicated direction. Axis 1 was statistically significant, explaining 25.6% of the variation in the basking site attributes. The basking site attributes of size (circumference and length) primarily explain the gradient represented by Axis 1.

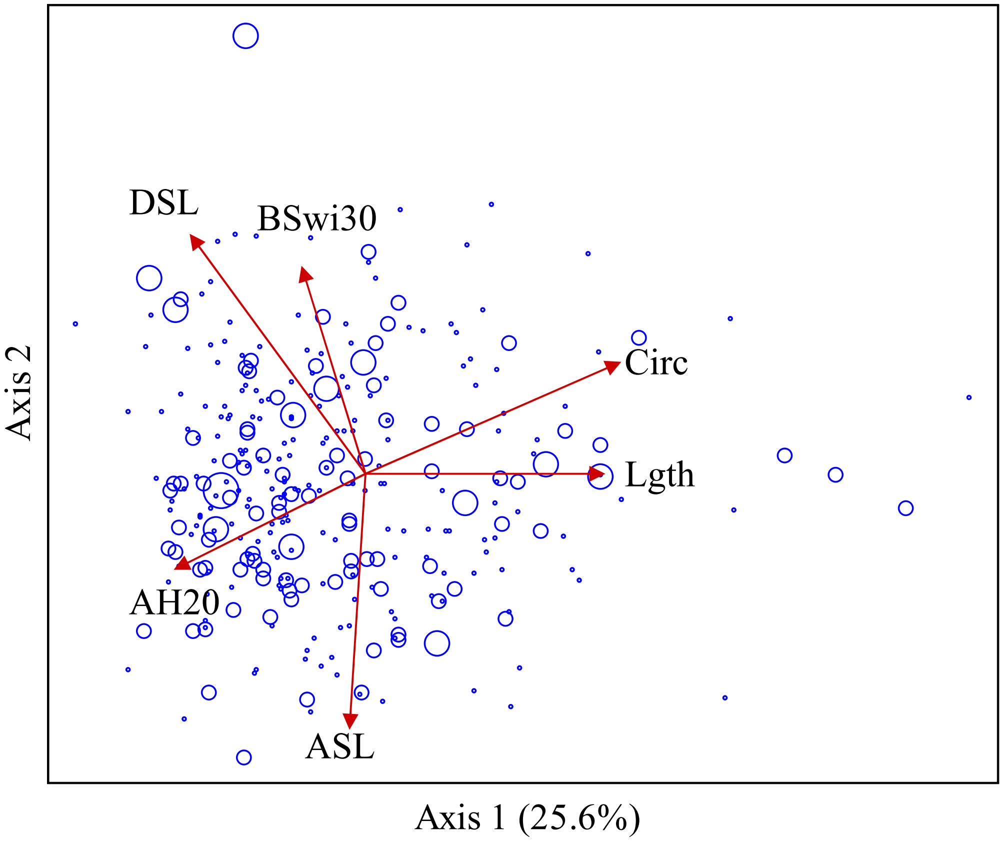

Figure 2.4: *T. scripta* overlay on PCA ordination of basking site characteristicswith vectors representing basking site distance to the shoreline (DistSL), number of basking sites within 30 m (BSwi30), angle to the water's surface (AH20), angle to the shoreline (ASL), circumference (circ) and length (lgth). Points represent basking sites where interpoint distances are proportional to the similarity of the basking site's attributes. Greater point sizes indicate basking sites where basking turtles were more abundant. Vector length and direction indicate greater magnitudes in the indicated direction. Axis 1 was statistically significant, explaining 25.6% of the variation in the basking site attributes. The basking site attributes of size (circumference and length) primarily explain the gradient represented by Axis 1.

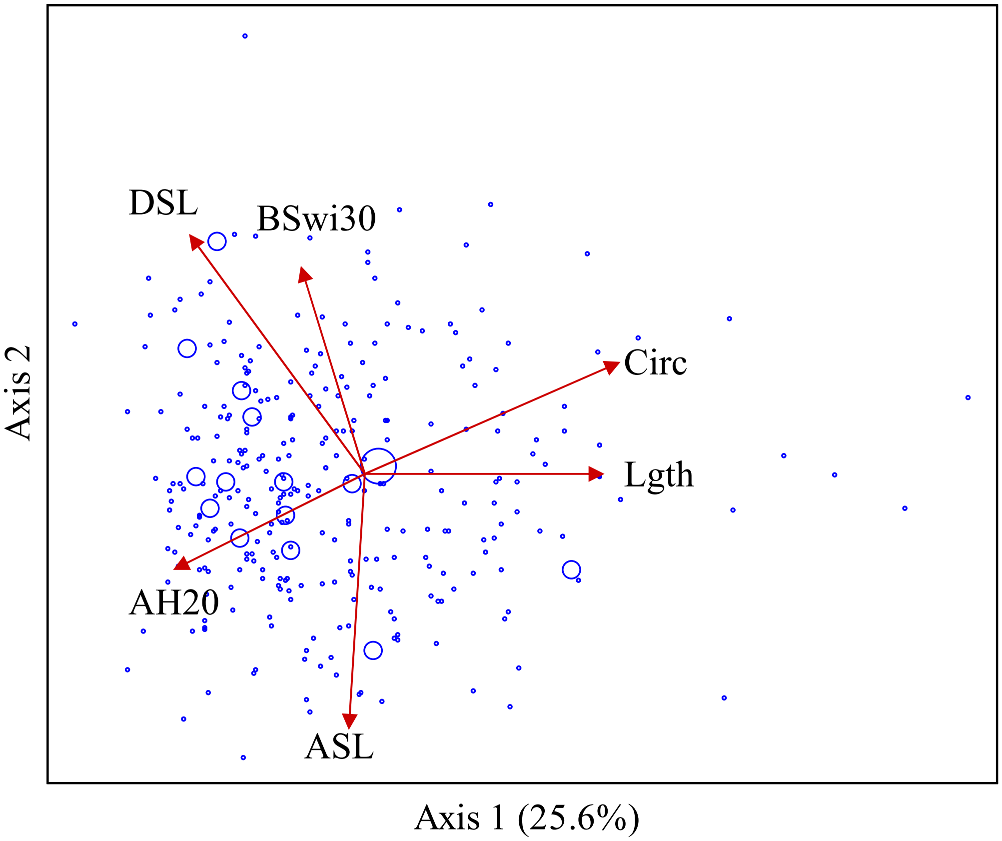

Figure 2.5: *G. kohni* overlay on PCA ordination of basking site characteristicswith vectors representing basking site distance to the shoreline (DistSL), number of basking sites within 30 m (BSwi30), angle to the water's surface (AH20), angle to the shoreline (ASL), circumference (circ) and length (lgth). Points represent basking sites where interpoint distances are proportional to the similarity of the basking site's attributes. Greater point sizes indicate basking sites where basking turtles were more abundant. Vector length and direction indicate greater magnitudes in the indicated direction. Axis 1 was statistically significant, explaining 25.6% of the variation in the basking site attributes. The basking site attributes of size (circumference and length) primarily explain the gradient represented by Axis 1.

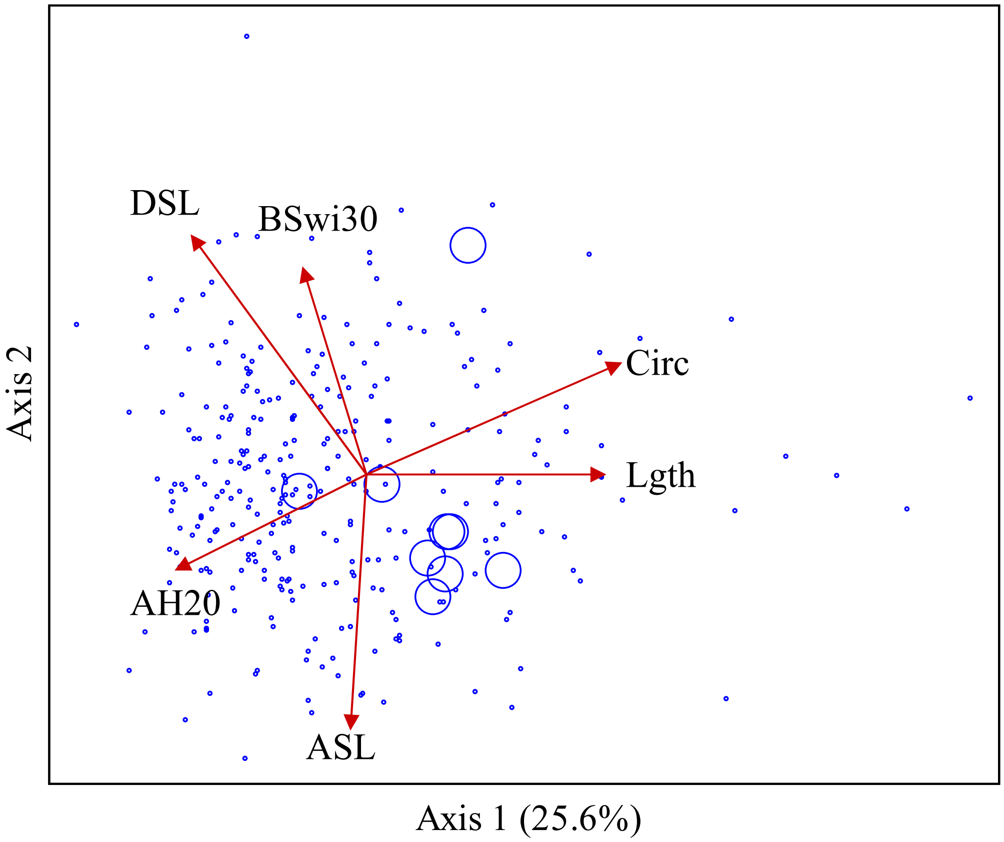

Figure 2.6: Softshells overlay on PCA ordination of basking site characteristicswith vectors representing basking site distance to the shoreline (DistSL), number of basking sites within 30 m (BSwi30), angle to the water's surface (AH20), angle to the shoreline (ASL), circumference (circ) and length (lgth). Points represent basking sites where interpoint distances are proportional to the similarity of the basking site's attributes. Greater point sizes indicate basking sites where basking turtles were more abundant. Vector length and direction indicate greater magnitudes in the indicated direction. Axis 1 was statistically significant, explaining 25.6% of the variation in the basking site attributes. The basking site attributes of size (circumference and length) primarily explain the gradient represented by Axis 1.

CART analysis of *P. texana* yielded a validated tree of basking site attributes (Figure 2.7). Basking site attributes included in the regression were the four variables explaining the most variance in the model: length, circumference, angle to the shoreline, and angle to the water's surface. Cross validation of this tree indicated that one split was appropriate for basking site length, and explained 4% (partial r^2) of the model variance.

CART partitioned basking site length into two groups separated at 107.5 cm, which explained the most within group homogeneity and between group heterogeneity. Nearly twice the number of *P. texana* basked on sites larger than 107.5 cm. Regression trees for subsequent species did not validate, even with a reduced number of predictors, and were therefore inappropriate for analysis.

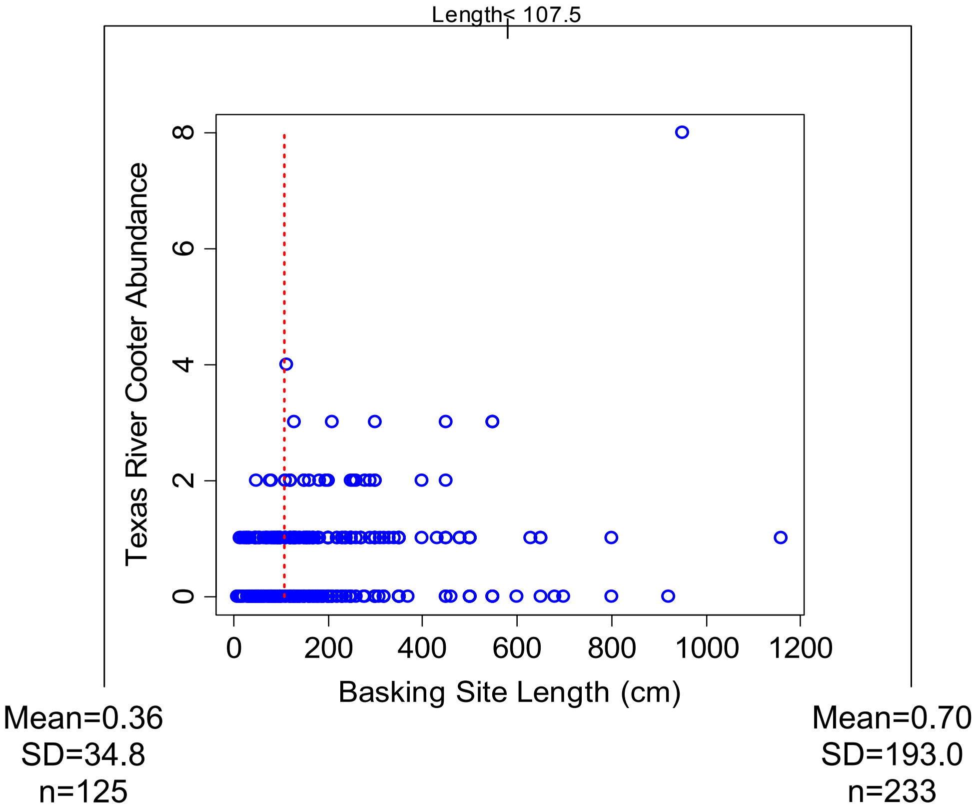

Figure 2.7: CART dendrogram of basking site length on abundances of basking *P. texana*. The basking site characteristic of length explained 4% of the variance in basking *P. texana* abundances and was the only basking site characteristic validated by the model. The length of 107.5 cm defines the split in the branch.

Poisson regressions modeled basking site characteristics that facilitated greater abundances of basking turtles. A Pearson chi-square value near 1 ($\chi^2 = 0.91$) indicated data were neither over nor under-dispersed for the *P. texana* model (n = 95). The basking site attribute of distance to shoreline was statistically significant (p = 0.01) with a modest estimate (0.0001). A Pearson chi-square of 1.03 indicated that a Poisson regression was appropriate to model abundances of basking *T. scripta* (n = 95). Distance to the shoreline (estimate = 0.001, p = 0.05) and the number of potential basking sites within 30 m (estimate = 0.049, p = 0.05) were statistically significant predictors of basking *T. scripta* abundance. Limited sample sizes and issues with dispersion made Poisson regressions inappropriate for the remainder of species in the community.

Stepwise logistic regression determined if basking site attributes facilitated multiple occupancy. The likelihood ratio test for overall model significance was statistically significant (Walds $\chi^2 = 22.1$, df = 2, $p < 0.0001$). The model was a good fit for the data, as indicated by the non-significant Hosmer and Lemeshow test (Walds $\chi^2 = 11.5$, df = 8, p = 0.18). Basking site length (Estimate = 0.0019, SE = 0.0007, Walds $\chi^2 = 6.92$, df = 1, p = 0.01, Odds Ratio = 1.002) and distance from shoreline (Estimate = 0.0011, SE = 0.0003, Walds $\chi^2 = 10.12$, df = 1, p = 0.01, Odds Ratio = 1.001) significantly predicted multiple occupancy of a single basking site.

Trapping and Community Structure

Turtles (n = 383) were trapped at 47 randomly selected locations. Trapped turtles included *P. texana* (66%), *T. scripta* (29%), *G. kohni* (3%), *T. muticus* (1%) and *T. spiniferus* (1%). The Shannon diversity index for the trapped turtles was 0.81. For all species, turtles in the medium size class were trapped most frequently, which was also the most common size class observed basking (Figure 2.8). Sex ratios were male-biased for trapped *P. texana* ($\chi^2 = 14.29$, df = 1, $p < 0.001$), and unbiased for *T. scripta* and *G. kohni*. Sex ratios were not calculated for the small samples of softshells.

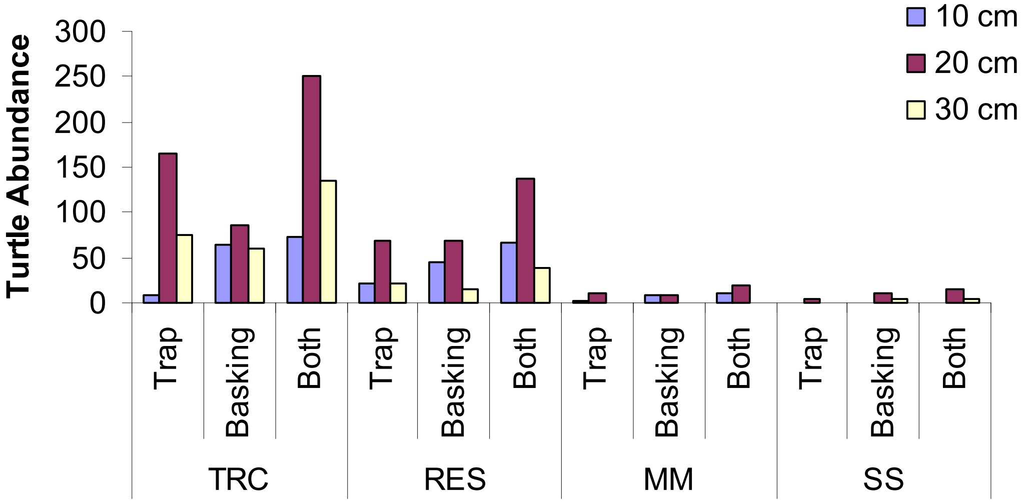

Figure 2.8: Abundances of turtle size classes for trapped turtles, basking surveys, and total trapped and basking turtles. Mid-line carapace length grouped as small (10 cm), medium (20 cm), and large (30 cm) turtles. The abbreviations of TRC, RES, MM, and SS represent the Texas river cooter, red ear slider, Mississippi map turtle, and the softshells.

Discussion

The community of basking turtles in the Brazos River in Central Texas includes six species whose abundances are dominated by *P. texana* and *T. scripta*. *G. kohni* was moderately abundant while *T. muticus*, *T. spiniferus*, and *K. subrubrum* were uncommon. Observations of basking species composition were in similar proportions to the trapped species. While the Shannon diversity values for both the basking observations (0.93) and trapping data (0.81) are modest, they included only turtles in the basking community and excluded bottom dwelling species. In the Mississippi River, Shannon diversity values for

19 freshwater turtle communities ranged from 1.08 to 2.45 (Moll and Moll 2004). The disparity between the Shannon diversity values between the Brazos River community and the Mississippi River communities may be attributable to differences in trapping techniques as this study used basking traps exclusively. As with this Central Texas community, freshwater turtle species richness is typically low and communities are dominated by one or two species (Moll and Moll 2004).

Equal sex ratios and elevated juvenile recruitment often indicate a stable population. *P. texana* was the only species with a skewed, male biased sex ratio. While small *P. texana* were regularly observed basking, they were trapped infrequently. Potentially, reduced trapping success of small *P. texana* indicates limited juvenile recruitment. However, frequent observations of basking small *P. texana* suggests trap avoidance rather than reduced juvenile recruitment. As the only endemic in this basking community, the status of *P. texana* is particularly important. Their skewed sex ratio may be cause for concern and warrants further monitoring of the population, especially for juvenile recruitment.

Freshwater turtles may preferentially select basking sites based on their size, orientation, and abundance. Lindeman (1996) found that the razorback musk turtle (*Kinosternon carinatum*) basked primarily on inclined surfaces with a diameter greater than their carapace width. Flaherty and Bider (1984) compared differences among sites occupied and unoccupied by *Graptemys geographica* in bays of the Lake of Two Mountains in Quebec, Canada. They found that turtles occupied basking sites that were longer, narrower, farther from land, farther from aquatic vegetation and in deeper waters.

Species in this Central Texas freshwater turtle community also exhibited preferences for basking site orientation and site.

Preferences for basking site attributes varied between species. *P. texana* preferred longer basking sites, as supported by the chi-square comparison of occupied and unoccupied basking sites, the PCA ordination of basking site characteristics with the subsequent species overlay, and CART analysis. However, the Poisson regression found distance to shoreline as the only significant predictor of *P. texana* basking abundance. For *T. scripta*, distance from shoreline and the number of basking sites within 30 m predicted basking abundance.

Variation in preferences for basking site attributes has been noted in the literature. Lindeman (1999b) found that deadwood abundance significantly correlated with basking densities for several species of *Graptemys*. This relationship was variable, as basking densities were not consistently correlated with deadwood densities throughout all studied river drainages. Alternatively, Shively and Jackson (1985) found no significant correlation between the density of the Sabine Map Turtle (*Graptemys ouachitensis sabinensis*) and an index value of basking site area. Reese and Welsh (1998) found that western pond turtles used areas that contained smaller basking objects, rather than large. Wide variation in basking preferences suggests that basking site attributes only partially explain the spatial distribution of basking freshwater turtles along the shoreline.

Multiple turtles basking on a single site provide an opportunity for social interaction. While observations of such multiple basking were not uncommon, crowded basking sites were the exception. Coupled with a high incidence of solitary basking, there was no evidence for social attraction as species basked together in frequencies comparable to overall abundances. However, some basking site attributes facilitate multiple occupancy. Longer basking sites further from the shoreline have a higher incidence of multiple occupancy, suggesting increased size may mitigate the effects of competition.

Conclusion

The basking turtle community of the Brazos River in McLennan County, Texas, is moderately diverse, and dominated by the endemic *P. texana*. Basking sites farther away from the shoreline facilitate greater basking abundances of *P. texana* and *T. scripta*. Additionally, abundances of *T. scripta* are greater where more potential basking sites are present. While incidences of solitary basking are considerable for all species, multiple occupancy is not uncommon. In cases of multiple occupancy, *P. texana* and *T. scripta* do not preferentially bask with any species in the community. Basking site attributes that facilitate multiple occupancy include length and distance from the shoreline. Basking site preferences are present for several species but varied among taxa and only partially explained the spatial distribution of basking freshwater turtles along the shoreline.

Acknowledgments

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CHAPTER THREE

Basking Ecology of the Endemic Texas River Cooter (*Pseudemys texana* Baur)

Abstract

Texas river cooters (*Pseudemys texana*) are endemic freshwater turtles whose range extends through five drainages across south-central Texas. Repeated spotting scope surveys revealed the spatial distribution, size classes, and basking habits of *P. texana* in the Brazos River, McLennan County, Texas. Basking traps were deployed, and captured individuals were measured, sexed, and assessed for injury and ectoparasites. Turtles basked more frequently in the lower reach of the study site characterized by a wider channel and less canopy cover than the upper, less urbanized reach of the river. While the number of trapped juveniles was limited, hatchlings were frequently observed basking. The maximum size of both sexes was larger than any size previously reported from other river drainages. The population was male-biased for all trapping years. However, a stable population of *P. texana* was indicated by large abundances with low ectoparasite loads and moderate shell injury or malformation.

Introduction

The Texas river cooter, *Pseudemys texana*, is a Texas endemic found in the Brazos, Colorado (Concho, Llano, San Saba), Guadalupe, Frio, and San Antonio river drainages (Ernst et al. 1994). It was formally described in 1893 by Baur, but since this original description much of the natural history information for this species has been confused with that of *Pseudemys concinna* and *Pseudemys floridana* (Dixon 2000, Ernst et al. 1994). Historically, the *Pseudemys* complex has been poorly defined in field observations, and identification of *P. texana* has been inconsistent. Research on the diet of *P. texana* (Strecker 1927) and dicephaly (Pilch 1981) did not use the current definition of the species. Research on the genetics (Killebrew 1977), carapace algae (Dixon 1960), size distributions (Killebrew and Porter 1989), and choanal morphometrics (Parsons 1960, Parsons 1968) have combined samples from both *P. texana* and *P. concinna*. Etchberger and Iverson (1990) reviewed this confusion.

Recent research on *P. texana* has focused on food habits (Lindeman 2007, Fields et al. 2003), reproduction (Lindeman 2007, Rose et al. 1996, Whiting 1994), morphology (Bever 2008, Lindeman 2007, Seidel 1994, McAllister and Lamar 1987), and endoparasite loads (McAllister and Upton 1992). While the body of literature on *P. texana* is growing (Lindeman 2001, Lindeman et al. 1999), limited information for this species and the previous confusion among congeners warrants continued ecological and behavioral research on this endemic (Ernst et al. 1994).

As with many members of Emydidae, *P. texana* is frequently seen basking along the shorelines of rivers and lakes (Ernst et al. 1994). Basking facilitates thermoregulation (Boyer 1965), digestion (Moll and Legler 1971), vitamin D synthesis (Pritchard and Greenhood 1968), and removal of alga and ectoparasites (Boyer 1965, Cagle 1950, Neill and Allen 1954).

The endemic status of *P. texana* evokes an impression of a limited, isolated population, sensitive to environmental stressors and vulnerable to extinction with a specialized, narrow niche. Endemic populations need to be characterized in terms of their adaptability, roles in the community, stability, competitiveness, resistance to disturbance, and potential for growth. To this end, this research characterizes basking behavior (and associated parameters) as a window into population dynamics and as a representative depended variable responding to the major challenges of urbanization. This study addresses two primary questions: 1) What is the population structure of *P. texana*? and 2) Does urbanization negatively influence the abundances of basking *P. texana*?

Materials and Methods

Data Collection

Observations and research were conducted along both shorelines of 14.5 km of the Brazos River in McLennan County, Texas (Figure 3.1) and included basking surveys and trapping. This segment of the Brazos is typically slow moving (2004 – 2007 mean annual flow of 0 - 0.5 m sec^{-1}) and deep (2004 – 2007 mean gauge height of 1.5 m), with substrates ranging from gravel to sandy clay loam. The Brazos is the longest river in Texas (1690 km), extending from eastern New Mexico to the Gulf of Mexico. The major tributaries of the Brazos include the Clear Fork, Bosque, Lampasas, Leon, Little River, and Navasota. It has the largest discharge of any Texas river, with an annual mean of approximately 5.5 million acre-feet of water released into the Gulf of Mexico. The Brazos River runs through or near several major metropolitan areas, including Lubbock, Waco, and Freeport, Texas, and is dammed in three places, forming Possum Kingdom Lake, Lake Granbury, and Lake Whitney. The shoreline is characterized by cottonwoods, elms, and sugarberries. Emergent herbaceous growth is noticeably absent from the active river channel.

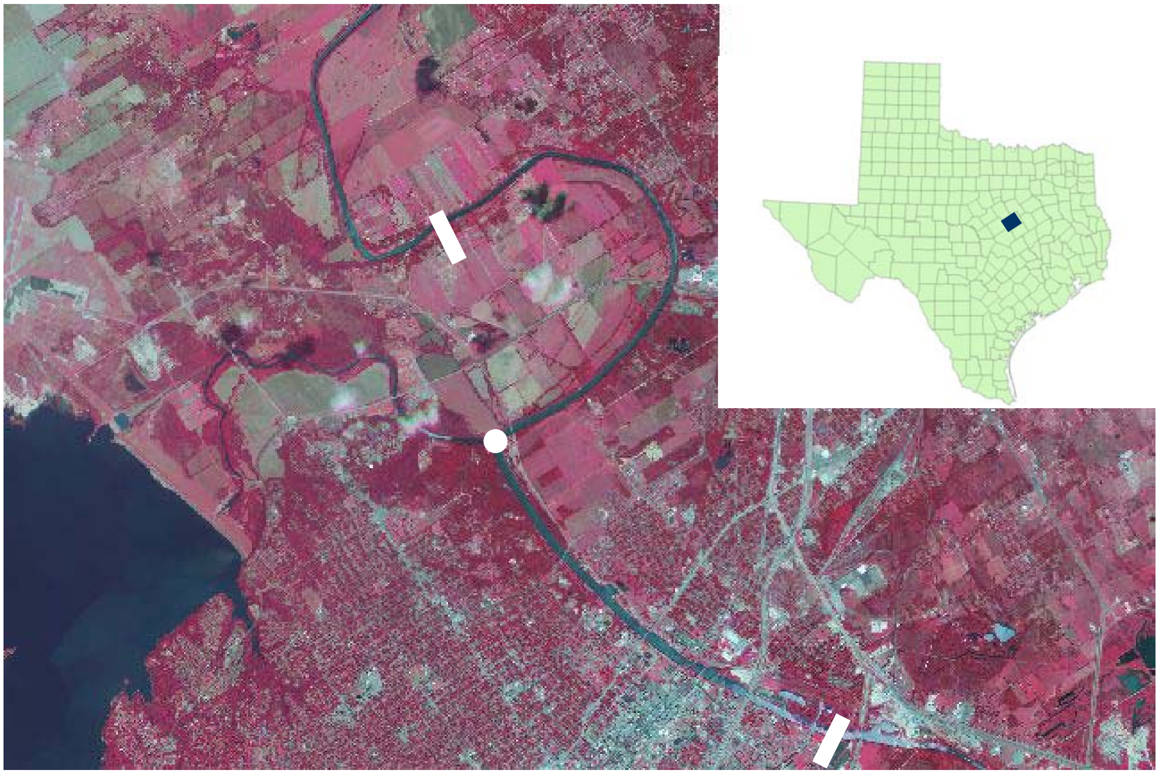

Figure 3.1: Brazos River study site in McLennan County, Texas. The Brazos is the longest river in Texas (1690 km), extending from eastern New Mexico to the Gulf of Mexico. The major tributaries of the Brazos include the Clear Fork, Bosque, Lampasas, Leon, Little River, and Navasota. The study site encompassed 14.5 km of the river, spanning a rural to urban gradient. Solid bars bisecting the river indicate the extent of the study site. The circle separates the Upper from the Lower Reach. Results from spotting scope surveys and trapping characterized the population of *P. texana* in this region of the Brazos. The infrared image is provided by the The Texas Orthoimagery Program and National Agricultural Imagery Program to quantify vegetation which reflects near infrared energy, thus appearing as dark red on the image. The inset was provided VARGIS and ESRI.

Sixteen spotting scope surveys censused basking *P. texana* from August 2006 to September 2007. These surveys were restricted to warm (>20 °C) sunny days with less than 30% cloud cover. For each observation of a basking turtle, the location, air temperature, and size class of the turtle was recorded. Size classes were categorized as small (< 10 cm), medium (10 - 20 cm), and large (> 20 cm). Location coordinates of basking turtles were projected on Digital Orthophoto Quarter Quads (DOQQ) from the National Agricultural Imagery Program of a 1-m resolution using the Universal Transverse Mercator (UTM) projection and 1983 North American Datum (NAD83). DOQQ's were analyzed to determine river width, percent canopy (20 x 20 m plot), land use class within the 20 x 20 m plot (forested, developed, agricultural, mixed developed, mixed agricultural), and river kilometer from the nearest upstream dam (Whitney Dam) for each incidence of basking *P. texana.* DOQQ images were taken in August 2004, and obtained from the Texas Natural Resource Information System.

Trapping and data collection occurred from October to December in 2004 and 2005, and from December 2006 to June 2007. Basking traps were PVC frames (167 x 167 x 30.5 cm) supporting a central catch basket surrounded by wire basking platforms. Traps were deployed at randomly selected locations within the study site. Trapped *P. texana* were sexed, individually marked (Cagle 1939), measured for midline carapace and plastron length and width, assessed for injury or leech infestation, and released at the point of capture. Males begin to exhibit secondary sex characteristics (elongated foreclaws, cloacal position and tail size; Ernst et al. 1994) at a carapace length of approximately 10 cm. Therefore sex was recorded for individuals that exceeded 10 cm carapace length. Individuals with a carapace length less that 10 cm are referred to as hatchlings and with their sex unspecified.

Data Analysis

Sex ratios were tested for deviation from 50:50 using a chi-square goodness of fit test. Nonmetric multidimensional scaling (NMS) ordinations were calculated for the environmental characteristics of river width, percent canopy cover, and river kilometer from the Whitney Dam (PC Ord version 5.10). The ordination was overlaid with a secondary matrix of abundances for *P. texana*. For independent variables, NMS has relaxed distribution assumptions that are often required by parametric techniques (Clarke 1993). Inter-point distances on the ordination have the same rank order as the corresponding dissimilarities between samples (Wong et al. 2003). Ranked elements in an NMS dissimilarity matrix are iteratively configured to minimize stress until the specified stability criterion is met. A Bray-Curtis distance measure, random starting configuration, three axes, and 100 runs were specified for the NMS. This is to say, NMS creates a scatter plot where distances between points indicate the similarity of the original data values. Points closer to each other are more similar than those further apart. Stress is defined as the deviation of the ordination from the original data matrix, which is minimal in strong ordinations. A scree plot in conjunction with a Monte Carlo randomization test assessed the appropriate number of dimensions for the ordination. The Monte Carlo permutation procedure determined if the axes being extracted were stronger than those expected by chance (McCune and Grace 2002).

Results

Basking Surveys

P. texana (n = 649) were observed basking on 459 sites. Basking air temperatures ranged from 25° to 46° C with most turtles basking at 36° C (Figure 3.2). The majority (75%) of observations were of single individuals on a basking site. In cases of multiple occupancy where *P. texana* was the only species present, 65% of the basking sites had two turtles, 20% had three, and 15% had four or more turtles. A maximum of ten *P. texana* were observed together on a single site.

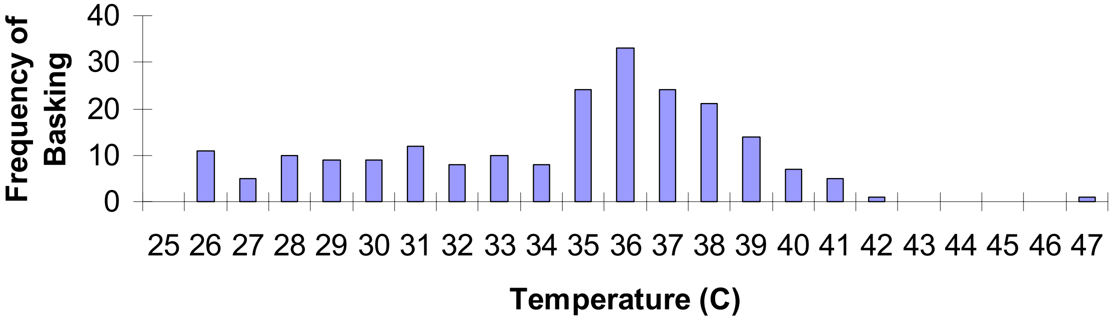

Figure 3.2: Frequency distribution of observed basking *P. texana* versus ambient air temperatures. Frequency data from 16 basking surveys in 2006-2007 are combined.

P. texana basked with three other species of freshwater turtle. When basking with another species, *P. texana* basked with the red ear slider (*Trachemys scripta elegans*) 85% of the time, 11% with the Mississippi map turtle (*Graptemys pseudogeographica kohni*), and 4% with a softshell (*Trionyx* spp.).

The mean number of basking turtles observed per kilometer of shoreline was 44.6. The Upper Reach of the Brazos River contained 43.9 basking *P. texana* km^{-1} (n = 369). The Upper Reach extends from N 31°36.948', W 97°9.884' to confluence with the Bosque River (N 31°35.386', W 97°9.329'). The Lower Reach was downstream from this confluence (i.e. from N 31°35.386', W 97°9.329' to N 31°33.245', W 97°6.632'). In the Lower Reach, 45.1 km^{-1} (n = 275) *P. texana* were observed basking (Figure 3.1).

Several environmental differences distinguished the Upper Reach from the Lower Reach of the Brazos River. River width within the Upper Reach ranged from 52 m to 112 m with a mean of 79 m. The Lower Reach was substantially wider, ranging from 92 m to 241 m with a mean of 125 m. In the Upper Reach, the most prevalent land use associated with basking *P. texana* was forest (83%) followed by mixed development (10%) and mixed agriculture (7%). In the Lower Reach, the most prevalent land use was developed (69%), forested (28%) and mixed developed (3%). Riparian vegetation was more abundant in the Upper Reach. Mean percent canopy cover was 95%, compared to 58% in the Lower Reach.

Upper and Lower Reach characteristics were included in a two-dimensional NMS (249 randomized runs, $p = 0.004$ for both axes, final stress of 8.7 for a two-dimensional solution). Distance from the Whitney dam (Figure 3.3), river width (Figure 3.4) and percent canopy cover (Figure 3.5) were the variables used to create the ordination. River width and river kilometer from the Whitney dam were correlated with ($r_{width} = -0.77$ and $r_{dam} = -0.76$) and negatively loaded on axis two. Percent canopy cover correlated ($r = 0.92$) with positive loading on axis two. Basking observations at the top of the ordination were those in the Upper Reach of the Brazos River, where the river is narrower, with greater canopy cover, and is nearer the Whitney Dam. Observations at the bottom of the ordination were from the Lower Reach. Basking *P. texana* were weakly correlated with axis one ($r = -0.07$) and two ($r = 0.02$) with a wide scatter of abundances across both reaches (Figure 3.6).

Trapping

A total of 253 *P. texana* were trapped and marked from 2004 to 2007. Recapture rates were low. Twelve individuals were recaptured once and two individuals were recaptured twice. A mean of 0.68 *P. texana* trapping-day^{-1} ($n = 117$) were captured in the Upper Reach while 0.57 trapping-day^{-1} ($n = 136$) were captured in the Lower Reach.

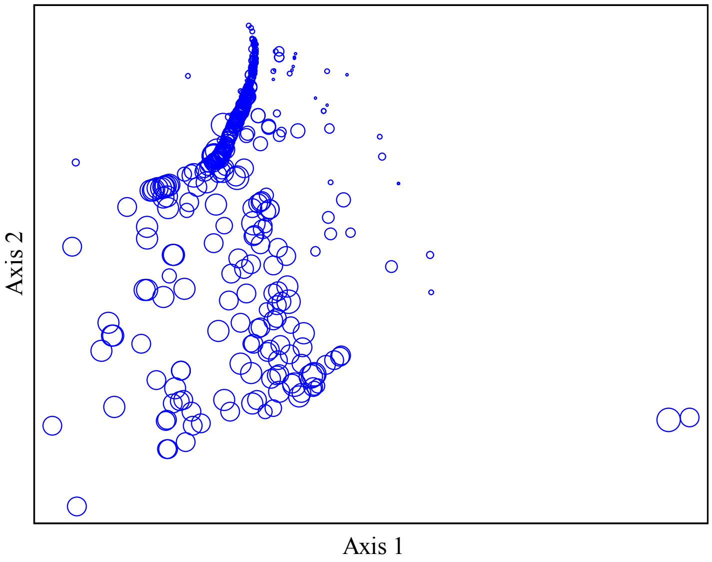

Figure 3.3: River kilometer from the Whitney Dam overlay on the NMS ordination of environmental parameters . Both axises were statistically significant ($p < 0.01$) with a low final stress (8.7). Sites in the lower portion of the ordination are further downstream from the dam and thus represent the urban portion of the study site.

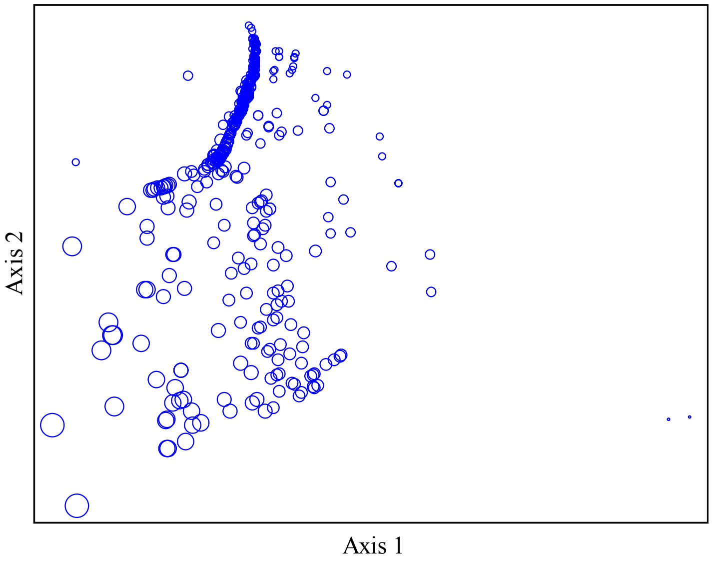

Figure 3.4: River width overlay on the NMS ordination of environmental parameters . Both axises were statistically significant ($p < 0.01$) with a low final stress (8.7). Sites in the lower portion of the ordination are further downstream from the dam and thus represent the urban portion of the study site.

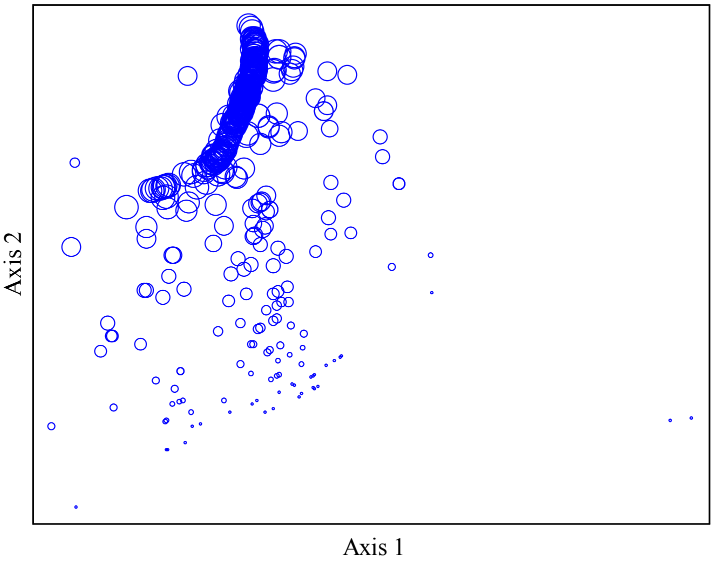

Figure 3.5: Percent canopy cover overlay on the NMS ordination of environmental parameters . Both axises were statistically significant (p < 0.01) with a low final stress (8.7). Sites in the upper, rural portion of the study site were characterized with greater percent canopy cover and are represented by point in the upper portion of the ordination.

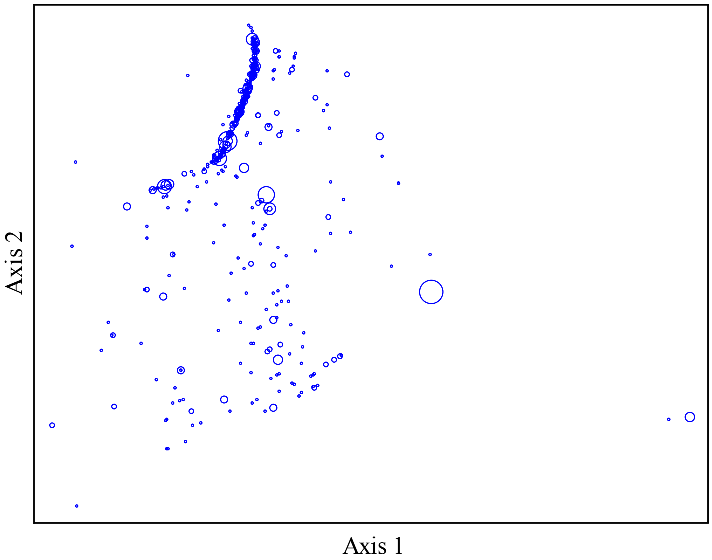

Figure 3.6: *P. texana* overlay on NMS ordination of environmental parameters . Both axises were statistically significant (p < 0.01) with a low final stress (8.7). Raw basking abundances were marginally greater in the upper portion of the ordination, which represents the rural portion of the study site.

Sex ratios of trapped turtles were consistently male biased for the entire study site and over all trapping years (Table 3.1). In the Upper Reach, 33% (n = 38) of trapped *P. texana* were female, while in the Lower Reach, 41% (n = 53) of trapped turtles were female. A total of 7 hatchlings were trapped, 1 in the Upper Reach and 6 in the Lower Reach. Sex was unspecified for these hatchlings due to lack of reliable secondary sex characteristics at this small size.

Table 3.1: Number of male and female captures Trapping success and sex ratios of *P. texana*for each trapping year and for Upper and Lower Reaches of the Brazos River. Chi - square tested for deviations from 50:50 sex ratio. One asterisk denotes statistical significance at an alpha of 0.05 while two asterisks denote statistical significance at an alpha of 0.01.

Year and Reach	Male	Female	Total	Chi – Square
2004	28	13	41	5.49 *
2005	10	3	13	3.77 *
2006	14	2	16	9.00 **
2007	103	73	176	5.11 *
Upper Reach	78	38	116	13.79 **
Lower Reach	77	53	130	4.43 *

Mean carapace and plastron length and width of females were larger than for males (Table 3.2). While maximum carapace sizes were largest in females, maximum plastron size was exhibited by males. In the Upper Reach, female median carapace length was 22.4 cm and ranged from 10.2–32.4 cm while male median carapace length was 17.2 cm and ranged from 12.3-30 cm. Carapace size was smaller in the Lower Reach with lengths ranging from 10-29.2 cm (median = 18.7 cm) for females and 12-25 cm (median = 15.7 cm) for males. Medium sized turtles were the most common size class both in basking observations and in trapped turtles (Figure 3.7).

Table 3.2: Carapace and plastron length (cm) and width (cm) of *P. texana* for trapped male, female and unsexed *P. texana*.

Sex	Statistic	Carapace Length	Carapace Width	Plastron Length	Plastron Width
Male	Max	30.0	25.6	29.9	26.8
	Min	12.0	10.7	10.0	4.8
	Mean	17.3	15.4	14.7	6.7
Female	Max	32.4	29.2	28.4	19.3
	Min	10.0	9.5	8.0	4.0
	Mean	20.3	18.8	18.0	8.0
Unspecified	Max	9.8	9.6	7.8	4
	Min	4.6	4.8	3.6	2.2
	Mean	7.6	7.5	6.2	3.3

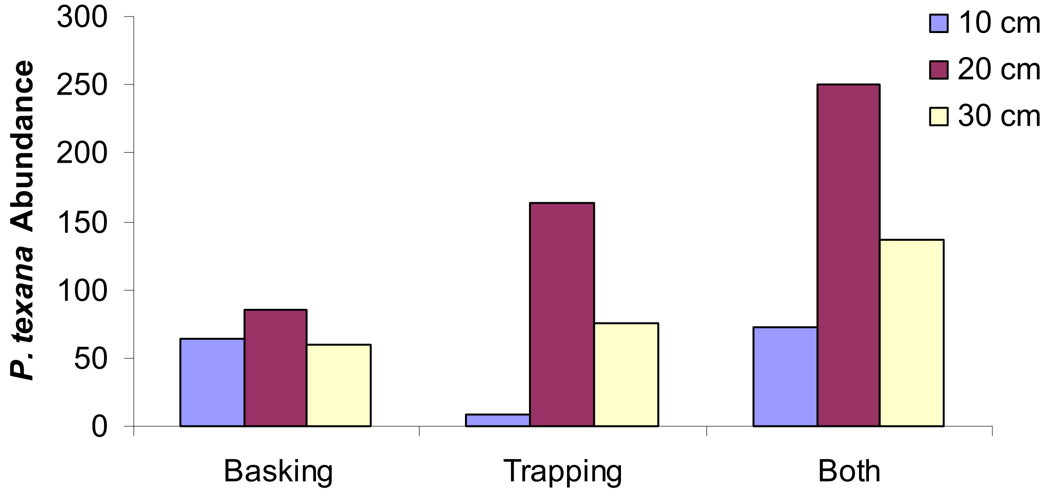

Figure 3.7: Abundance of each size class of *P. texana* observed basking, captured in traps, and the sum of basking and captured turtles. Abundances combine basking and trapping data from 2004 - 2007, on the Brazos River, Texas.

Of the 22 turtles with injury or shell malformations, 17 (64%) had affected carapaces, five (23%) had affected plastrons, and both were affected in three individuals (13%). Most carapace injuries or malformations were of the marginal scutes but occasionally extended into the costal scutes and rarely to the vertebral scutes. In addition to shell malformation, two individuals had injury to integument. One individual had a large fleshy tumor replacing the nuchal scute and the first scutes on both the left and right side. The other individual had extensive abrasions on the integument, in addition to shell damage and exposed bone. Leech loads were modest. Five turtles were parasitized. One leech was found on the plastron of four out of the five parasitized *P. texana*. The remaining turtle had seven leeches, four on the rear of the carapace, two on the hind left leg, and one just below the tail.

Discussion

Pseudemys texana is the most abundant species in the community of basking freshwater turtles within our study site on the Brazos River, Texas (Hill and Vodopich unpubl. data). *P. texana* basked throughout the study site, as supported by the ordination. Standardized abundances of basking *P. texana* were slightly greater in the Lower Reach of the study site, where the shoreline is urbanized and there is reduced riparian vegetation. Therefore *P. texana* basks slightly more frequently in the urban Lower Reach of the study site.

While *P. texana* typically basks alone, multiple occupancy on a single basking site was common. Even in cases of multiple occupancy, the number of turtles together on a single basking site remained low, with the majority of incidences of multiple basking consisting of only two turtles. Incidences of multiple occupancy were observed in the same proportions between the Upper (25%) and Lower (24%) Reaches of the river.

The most frequent baskers were medium-sized turtles. This was also the size class most frequently trapped. Sex size dimorphism is not uncommon in *Pseudemys* (Lindeman 2007), with females typically being larger. Maximum carapace length was greater for both males and females in the rural Upper Reach of the study site, suggesting that urban waterways may limit body size in *P. texana*.

While the proportions of small versus large turtles were relatively similar for baskers, the number of small turtles from trapping was low. The discrepancy between the number of small turtles observed basking and the number trapped may be due to trap avoidance by hatchling *P. texana*. Trapping success of small *P. texana* may also be suppressed by aggressive interactions during basking, where large turtles displace smaller ones (Lindeman 1999a). Aggressive interactions limiting trapping success of hatchlings is supported by the low (13%) occurrences of basking hatchlings found on the same site with a medium turtle. Hatchlings were never observed basking with large turtles. Low trapping success of hatchlings may indicate limited juvenile recruitment, but it is unlikely. Low trapping success is likely due to trap avoidance by small turtles. The basking observations of small turtles (30%) indicate a significant recruiting class.

Maximum carapace length was greater in this study site than that reported for other populations of *P. texana* for both sexes. In the Brazos River, the largest female carapace was 30.5 cm (McAllister and Lamar 1987). Lindeman reported a maximum size of 24.1 cm for females and 16.1 cm for males in the south Llano River (2007). The largest female in the Guadalupe River was 31.9 cm while 25.3 cm was the largest male (Killebrew and Porter 1989). In Hays County, Texas, *P. texana* carapace and plastron length ranged from 12.7–30.7 cm and 11.4-27.5 cm, respectively (Fields et al. 2003). Maximum sizes may be a measure of population health, and the extensive variation of maximum sizes from wide-ranging populations of *P. texana* warrants further investigation.

Sex ratios were consistently skewed toward males for each trapping year. Male biased sex ratios in freshwater turtles have commonly been attributed to high mortality in females, who spend substantial time on the shoreline. Upland activities, such as crossing roads in search of adequate nesting sites, make females especially vulnerable to car strikes (Gibbs and Shriver 2002). Male-biased sex ratios are a concern for any species as it may reduce juvenile recruitment and portend a population decline. This is especially pertinent as turtles are long lived and reach sexual maturity slowly, which may result in a significant time lag before any reduction in population size is noticeable.

Conclusion

The population of *Pseudemys texana* in the Central Texas portion of the Brazos River basks slightly more frequently in the lower, more urban, reach of the study site. This species most frequently basks alone but is occasionally found basking on the same site with conspecifics. The large number of individuals, large maximum size, low proportion of injured or parasitized turtles, and relatively equitable distribution of size classes among basking turtles indicates a relatively stable population in the Brazos River. However, low numbers of trapped hatchlings and skewed sex ratios should temper this conclusion. The freshwater turtle community in the Brazos River is unique – not only containing an endemic, *Pseudemys texana*, but because this endemic is the most abundant turtle in the community. Future monitoring of this population is warranted to maintain this valuable resource.

Acknowledgments

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CHAPTER FOUR

The Influence of Urbanization on the Basking Behavior of Freshwater Turtles

Abstract

Urbanization of riparian corridors may alter or eliminate suitable freshwater turtle basking habitat due to fragmentation of riparian vegetation, reduction of basking site substrates, or frequent human disturbance. In this study, four indices of shoreline urbanization at two spatial scales were used to assess the relationship between shoreline urbanization and basking turtle behavior on the Brazos River in Central Texas. Indices included local-scale Shoreline Modification and Disturbance Frequency and the broad-scale Building Density. The community of basking freshwater turtles included the Texas river cooter, *Pseudemys texana* (Baur); red ear slider, *Trachemys scripta elegans* (Schoepff); Mississippi map turtle, *Graptemys pseudogeographica kohni* (Baur); Mississippi mud turtle, *Kinosternon subrubrum hippocrepis* (Gray); smooth softshell, *Trionyx muticus muticus* (Le Sueur); and the spiny softshell, *Trionyx spiniferus pallidus* (Webb). At the local scale, abundances of basking turtles were greatest in areas of high Shoreline Modification characterized by a substantial reduction in woody shoreline vegetation. Also at the local scale, Disturbance Frequency of human intrusion limited basking turtle abundance in areas of daily disturbance. At the broad-scale, the majority of turtles basked adjacent to shorelines where buildings were present. All members of the freshwater turtle community basked in urban environments but the degree of urbanization tolerated varied between species.

Introduction

Urbanization of riparian corridors and associated anthropogenic activity can negatively affect freshwater turtle abundance, alter community structure, and modify key behaviors through habitat alteration, degradation, or loss (DonnerWright et al. 1999, Garber and Burger 1995, Gibbons 2000). Urban landscapes may amplify these effects (Marchland and Litvaitis 2004), and aquatic systems are especially vulnerable to habitat degradation (Naiman et al. 1993). Riparian woodlands are frequently fragmented in urban landscapes (Decamps et al 1988; Maisonneuve and Rioux 2001), which further degrades associated aquatic habitats.

Freshwater turtles inhabit a variety of microhabitats within the riparian corridor. Uplands, sloughs, and the main river channel facilitate critical behaviors such as basking, feeding, breeding, hibernation, nesting, and dispersal (Moll and Moll 2004). Since freshwater turtles use the riparian corridor in its entirety, shoreline stressors may be just as influential as aquatic ones. Highly urbanized landscapes can disrupt turtle behaviors on both terrestrial and aquatic fronts by removing shoreline vegetation, increasing human intrusion, increasing pollutants, and altering river geomorphology via damming and channelization (Moore and Seigel 2006, Tucker et al. 2001). These activities subdivide and fragment turtle populations in areas as large as a drainage basin or as small as an isolated tributary (Shively and Jackson 1985). Intolerant species may be reduced or eliminated entirely by urbanization.

Basking behavior critical to freshwater turtles may be altered by urbanization and the resulting loss of basking substrates (Moore and Seigel 2006; Spinks et al. 2003). Many freshwater turtle species spend significant time basking (Dreslik and Kuhns 2000).

It aids in thermoregulation (Boyer 1965), digestion (Moll and Legler 1971), vitamin D synthesis (Pritchard and Greenhood 1968), and algal and ectoparasite removal (Boyer 1965, Cagle 1950, Neill and Allen 1954). Emergent deadwood is the predominant substrate for turtle basking (Lindeman 1999b). Thus, riparian vegetation is important to freshwater turtles not only as upland habitat for nesting, but also as a source of basking substrates in the form of tree falls, broken branches, snags, and stumps. Deadwood also provides underwater refugia and a substrate for food such as algae and aquatic invertebrates. Urbanization may reduce deadwood inputs to the river by reducing the quantity of woody shoreline vegetation and thereby constrain turtle basking (Spinks et al. 2003)

Life history characteristics of freshwater turtles make them especially susceptible to the effects of urbanization (Baldwin et al. 2004). High juvenile mortality and delayed sexual maturity in freshwater turtles accentuate the effects of urbanization, such as habitat modification (Browne and Hecnar 2007), disturbance (Dodd and Dreslik 2008), and capture for commercial sales (Ceballos and Fitzgerald 2004) and contribute to reduced turtle abundances (Ernst et al. 1994). This impact dramatically underscores the importance of assessing and monitoring the influence of urbanization on freshwater turtle community structure.

Characterizing urbanization is particularly challenging, because anthropogenic stressors are varied and affect systems at multiple scales. To address these challenges, urbanization indicies were developed that were potentially relevant to the basking behavior of freshwater turtles. Local-scale shoreline urbanization was characterized by activity immediately adjacent to a basking turtle and broad-scale urbanization is characterized by tens of meters of the shoreline adjacent to a basking turtle. This study focuses on the effects of shoreline urbanization from multiple sources and at multiple scales on the structure of a freshwater turtle community, their basking behavior, and the availability of potential basking sites in a Central Texas river. Specifically, this research address three primary questions: 1) How does shoreline urbanization relate to the spatial distribution of turtles basking along the shoreline? 2) At what scale are basking turtle abundances greatest? 3) Is the response of freshwater turtles to shoreline urbanization species-specific?

Materials and Methods

Indexing Urbanization

Research was conducted on 14.5 km of the Brazos River (29 km of shoreline) in McLennan Co., Texas (Figure 4.1). Shoreline development within this study site ranges from an intact, active riparian corridor of native vegetation to the complete absence of vegetation and the addition of impenetrable surfaces such as cement. We characterized the shoreline with three distinct indices of urbanization, which included: 1) Shoreline Modification, the degree of modification of shoreline vegetation, 2) Disturbance Frequency, frequency of human intrusion and disturbance, and 3) Building Density, the number of buildings within 30 m of each incidence of basking.

These three urbanization indices encompass two spatial scales: local and broad. The local-scale urbanization indices are Shoreline Modification and Disturbance Frequency. They measure the shoreline immediately adjacent to each incident of a basking turtle. The broad-scale urbanization index, Building Density, involves a larger area of the shoreline, encompassing 15 m on each side of a basking turtle.

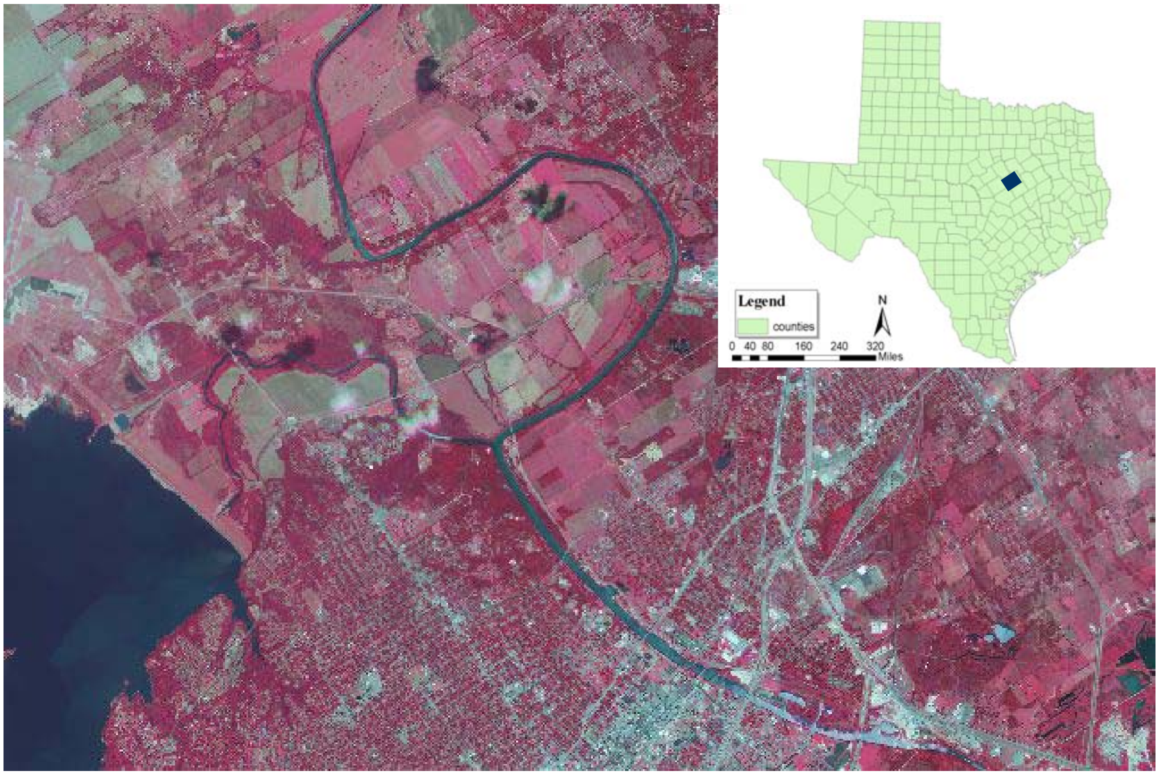

Figure 4.1: Brazos River study site in McLennan County, Texas. The Brazos is the longest river in Texas (1690 km), extending from eastern New Mexico to the Gulf of Mexico. The major tributaries of the Brazos include the Clear Fork, Bosque, Lampasas, Leon, Little River, and Navasota. Results from basking surveys and trapping characterized the community of basking freshwater turtles in this region of the Brazos. The infrared image is provided by the The Texas Orthoimagery Program and National Agricultural Imagery Program to quantify vegetation which reflects near infrared energy, thus appearing as dark red on the image. The inset was provided VARGIS and ESRI.

The variables Shoreline Modification and Disturbance Frequency were expressed in ranked categories (1-5). Shoreline Modification is measured as the degree of altered shoreline vegetation. Categories include extreme (rank 1), high (rank 2), moderate (rank 3), slight (rank 4), and unmodified (rank 5) shorelines. In extremely modified shorelines, the native woody vegetation has been removed with evidence of landscaping and the possible addition of ornamental trees, such as a residential yard (Figure 4.2). Highly modified shorelines exhibit a patchy distribution of native vegetation with evidence of shoreline management, such as a boat dock (Figure 4.3). In moderately modified shorelines the native vegetation is reduced but intact with some evidence of management, as might be observed in a park (Figure 4.4). In slightly modified shorelines native vegetation is reduced but contiguous with no evidence of shoreline management (Figure 4.5). Unmodified shorelines have extensive, native vegetation with no evidence of shoreline management (Figure 4.6).

Figure 4.2: An example of extreme Shoreline Modification where the native riparian vegetation is primarily absent, there is evidence of landscaping, and ornimenal plants are present.

Figure 4.3: An example of high Shoreline Modification characterized by a patchy distribution of riparian vegetation with evidence of landscaping.

Figure 4.4: An example of moderate Shoreline Modification characterized by contiguous riparian vegetation with some evidence of landscaping.

Figure 4.5: An example of slight Shoreline Modification characterized by contiguous, but reduced riparian vegetation with no evidence of landscaping.

Figure 4.6: An example of an unmodified shoreline where riparian vegetation is completely intact and there is no evidence of landscaping.

Disturbance Frequency refers to the frequency of human presence on the shoreline. Disturbance levels were categorized as daily (rank 1), weekly (rank 2), monthly (rank 3), semiannually (rank 4), and undisturbed (rank 5). Disturbance Frequency was assessed via evidence of recent human presence, such as structures, trails, litter, vandalism, or landscape maintenance. A city park exemplifies daily shoreline disturbance while a rural fishing trail typifies monthly disturbance.

The study site was delineated into overall distances representing each category of Shoreline Modification and Disturbance Frequency. For the local scale indices (Shoreline Modification and Disturbance Frequency) observations were standardized by this distance to yield observations per kilometer of each category.

Building Density was recorded as an index of urbanization. For each incidence of a basking turtle, the number of buildings within 15 m on each side of the basking turtle was recorded. In a separate survey of Building Density, Digital Orthophoto Quarter Quads (DOQQ) from the National Agricultural Imagery Program (Figure 4.1) of a 1-m resolution using the Universal Transverse Mercator (UTM) projection and 1983 North American Datum (NAD83) were used to calculate the number of buildings in 30 m segments of both shorelines of the study site. DOQQ images were taken in August 2004, and obtained from the Texas Natural Resource Information System. Basking turtle abundances were standardized by the remotely sensed Building Density data.

Survey of Potential Basking Sites

All potential basking sites in the study site were surveyed in August 2006, April 2007, and August 2007 to determine the effect of various levels of urbanization on the availability of sites. Emergent stationary woody vegetation with a circumference greater than 15 cm and an angle to the water's surface less than 90 degrees was considered a potential basking site. Potential basking site abundances were standardized by the distance of shoreline characterized for each urbanization index.

Basking Surveys

Sixteen surveys of basking turtles were conducted from August 2006 to September 2007, and were restricted to warm (> 20° C) sunny days with less than 30% cloud cover. Site location and species were recorded for turtles observed basking (n = 1593) and the shoreline at that site was characterized for the degree of Shoreline Modification, Disturbance Frequency, and Human Density. Basking turtle abundances were standardized by the distance of shoreline characterized for each urbanization index.

Trapping

Trapping occurred from October to December in 2004, October to December in 2005, and from December 2006 to June 2007. Basking traps were PVC frames (167 x 167 x 30.5 cm) with wire basking platforms attached to the outer edge of the frame and rising 20 cm above the water. A central mesh basket filled the interior of the frame and caught turtles leaving the basking platforms toward the interior of the frame. Traps were deployed at randomly selected locations. Abundances of trapped turtles were standardized to the number of days a trap was deployed at each location. Trapped turtles were identified to species, sexed, individually marked by notching the marginal scutes (Cagle 1939), and measured for carapace and plastron length and width before releasing at the point of capture.

Data Analysis

The relationship between the urbanization indices of Shoreline Modification, Disturbance Frequency, and Building Density with basking turtle abundance was illustrated by a Nonmetric Multidimensional Scaling (NMS) ordination, created in PC ORD (version 5.10). NMS ranks elements in a dissimilarity matrix that are iteratively configured to minimize stress until a specified criterion of stability is met (McCune and Grace 2002). This is to say, NMS creates a scatter plot where distances between points indicates the similarity among the original data values. Points close to each other are more similar than those far apart. Stress is defined as the deviation of the ordination from the original data matrix, which is minimal in strong ordinations. Sorensen (Bray-Curtis) distance measure, random starting configuration, three axes, and 100 runs were specified for the ordination. A scree plot assessed the appropriate number of dimensions for the NMS ordination. A Monte Carlo randomization test was run to determine if stronger axes are being extracted than those expected by chance.

Poisson regressions were used to model the three urbanization indices (Shoreline Modification, Disturbance Frequency, and Building Density) with basking turtle and potential basking site abundances. Poisson regressions model the log of count data. Poisson regressions are appropriate when the distribution of the response variable, in this case basking turtle abundance or potential basking site abundance, is skewed to the right (Long 1997).

Results

Indexing Urbanization

Values of the urbanization indices varied along the shoreline of the study site. Shoreline Modification for both banks was predominantly extremely modified (9.7 km), followed by unmodified (9.0 km), slightly modified (4.0 km), moderately modified (4.3 km) and highly modified (1.8 km). The majority of the shoreline was disturbed daily (12.8 km), followed by undisturbed (6.5 km), semiannually (4.5 km), monthly (2.1 km), and weekly disturbance (1.9 km). The shoreline was predominantly devoid of buildings (24.8 km) with 3.2 km of shoreline with one building, 0.8 km of shoreline with two buildings, and 0.2 km of shoreline with 3 or more buildings.

Survey of Potential Basking Sites

Potential basking sites (n = 7972) were most abundant on shorelines that were moderately (29%) or highly (28%) modified (Figure 4.7). Availability of potential basking sites was greatest in undisturbed (40%) regions or semiannually disturbed (24%) regions (Figure 4.8). Most potential basking sites (77%) were found in areas with no buildings on the shoreline. The Poisson model explained only 4% of the variance in potential basking site availability with Disturbance Frequency as the only statistically significant predictor (Table 4.1). Basking site availability is not strongly affected by urbanization.

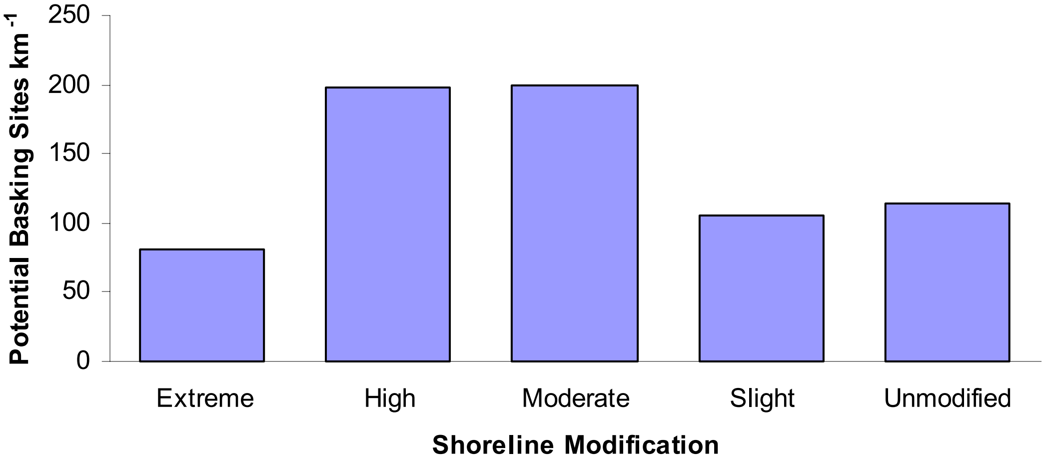

Figure 4.7: Abundance of potential basking sites and Shoreline Modification standardized for the quantity of shoreline categorized as one of the five levels of Shoreline Modification.

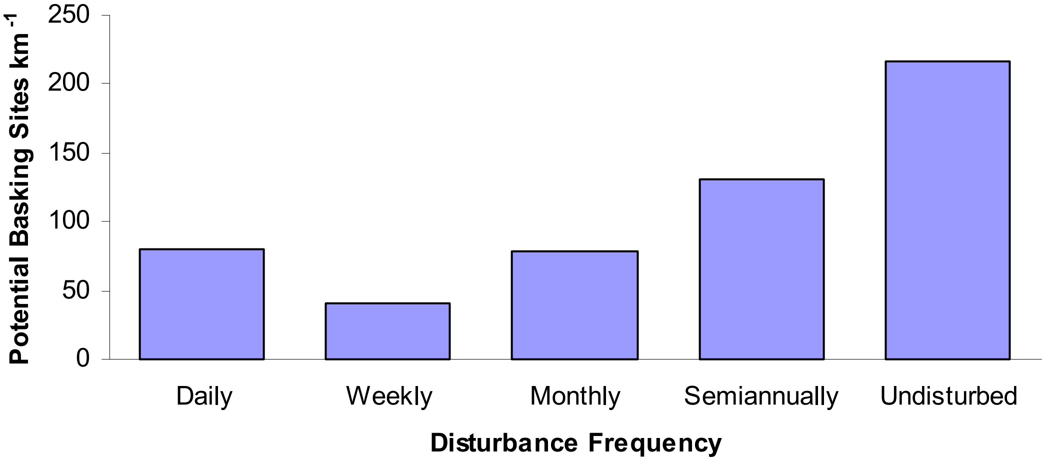

Figure 4.8: Abundance of potential basking sites and Disturbance Frequencystandardized for the quantity of shoreline categorized as one of the five levels of Disturbance Frequency.

Basking Surveys

Observations of basking turtles (n = 1597) revealed a community comprised of the endemic Texas river cooter, *Pseudemys texana* (n = 650, 40.7%); the red ear slider, *Trachemys scripta elegans* (n = 336, 21.0%); Mississippi map turtle, *Graptemys* *pseudogeographica kohni* (n = 51, 3.2%); and the Mississippi mud turtle, *Kinosternon subrubrum hippocrepis* (n = 7, 0.4%).

Table 4.1: Poisson regression coefficients modeling the log of species abundance to the regressors of the urbanization indices. Statistically significant ($p \leq 0.05$) parameter estimates are denoted with an asterisk. Abbreviations include: TRC which represent Texas river cooters, while RES are red-ear sliders, MM are Mississippi map turtles, SS are softshells, and EM are eastern mud turtles.

	Species					
Urbanization Indices	TRC	RES	MM	SS	EM	Potential Basking Sites
Shoreline Modification	-0.19*	-0.11*	0.39*	-0.14	-0.52	-0.015
Disturbance Frequency	0.09*	0.03	-0.26*	0.19	-0.33	0.082*
Building Density	0.06	0.07	-0.17	0.27	0.05	-0.014
Variance (r^2)	0.036	0.009	0.045	0.014	0.111	0.036
Pearson Chi-Square	1.28	1.18	0.95	1.06	0.81	1.41

Since the two species of softshells (*Trionyx muticus muticus* and *Trionyx spiniferus pallidus*) were indistinguishable from a distance, observations were recorded collectively as softshells and represented 1.6% (n = 26) of the basking community. The remaining observations of the basking community (n = 527, 33.0%) consisted of turtles that retreated into the water before they could be identified to species. These unidentified turtles were included in analyses of all combined turtle taxa but omitted from analysis of species specific responses.

All members of the Brazos River turtle community, except *G. kohni*, responded similarly to Shoreline Modification (Figure 4.9). They basked in a similar proportion for each category of modification. Cumulatively, freshwater turtles were observed basking most frequently in areas of high modification (38%), with relatively equal distributions in moderately (19%), extremely (17%), and slightly (17%) modified shorelines.

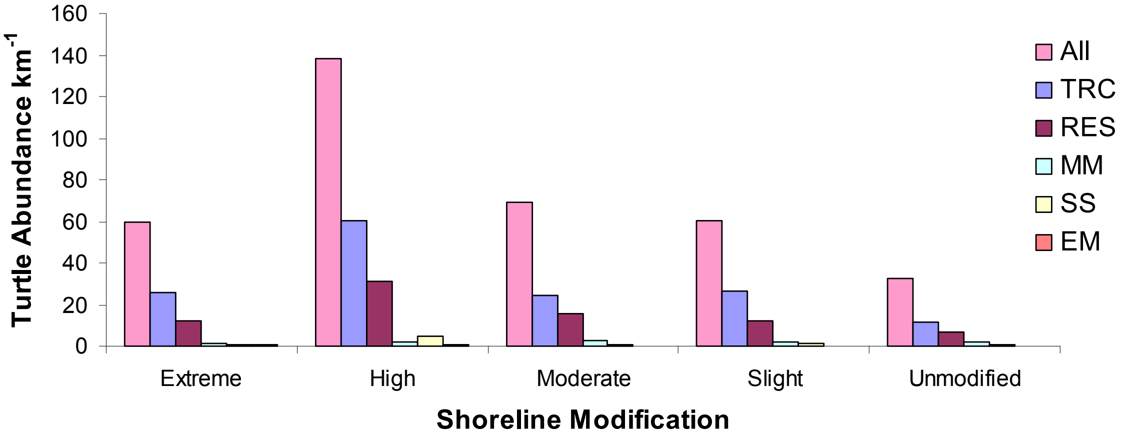

Figure 4.9: Abundance of basking freshwater turtle species standardized for the length of shoreline categorized as one of the five levels of Shoreline Modification. In the legend, All indicates the response of all turtle taxon cumulatively while TRC are Texas river cooters, RES are red-ear sliders, MM are Mississippi map turtles, SS are softshells, and EM are eastern mud turtles.

Interestingly, turtles were observed least frequently adjacent to unmodified shorelines (9%). While these proportions were similar in *P. texana* and *T. scripta*, basking *G. kohni* were most prevalent in areas with moderate modification (28%), less prevalent in slightly (22%) and highly (21%) modified shorelines, and least prevalent in extremely (11%) and unmodified (18%) shoreline. Like the cooter and slider, softshells basked most frequently next to highly modified shorelines, but at a substantially greater proportion than observed in other taxa (63%). Of the softshells, 16% were observed basking in areas of slight modification, and abundances were similarly low in extreme (8%), moderate (8%) and unmodified shorelines (6%). *K. subrubrum* basked almost exclusively in the most urbanized areas and was absent on the least urbanized shorelines.

The response of basking freshwater turtle abundances to the urbanization index of Disturbance Frequency was strikingly different than the response to Shoreline Modification (Figure 4.10). *P. texana* basked in areas of lower disturbance (semiannually = 28%, undisturbed = 22%) and were less abundant in areas of weekly (19%), monthly (17%), and daily (15%) disturbance.

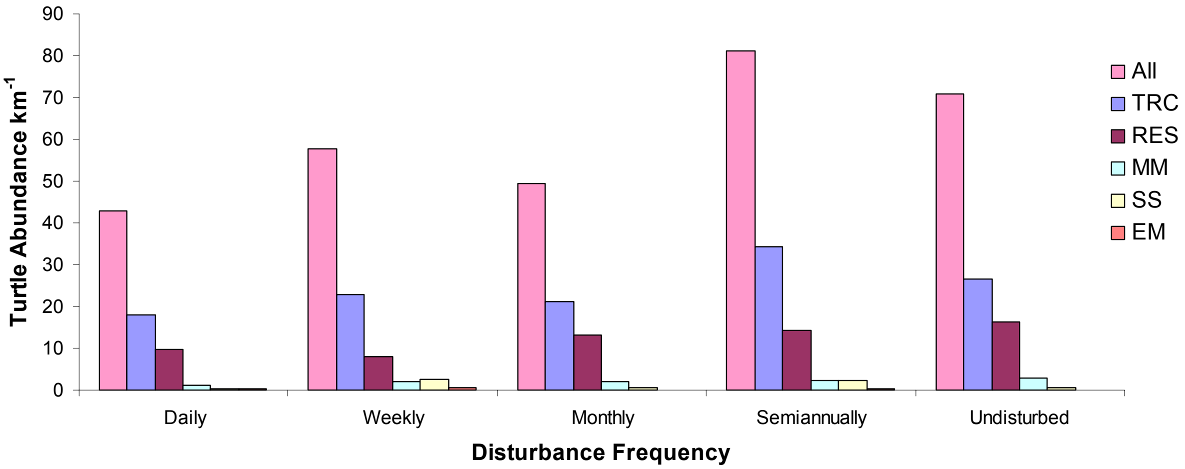

Figure 4.10: Abundance of basking freshwater turtle species standardized for the length of shoreline categorized as one of the five levels of Disturbance Frequency. In the legend, All indicates the response of all turtle taxon cumulatively while TRC are Texas river cooters, RES are red-ear sliders, MM are Mississippi map turtles, SS are softshells, and EM are eastern mud turtles.

T. scripta was more tolerant of moderate disturbance. *G. kohni* basked in similar proportions (18 - 27%) near shorelines of all categories of disturbance except extremely disturbed areas (12%). Choice of disturbance levels by softshells was bimodal. They most often chose areas with weekly (41%) and semiannual (37%) disturbance. As with the trend in modification, *K. subrubrum* was found most frequently in areas of greatest disturbance (weekly = 47% and daily = 34%).

Response to the broad-scale urbanization index of Building Density was consistent across most turtle taxa. Basking turtle abundance was greatest where buildings were present on the shoreline. Incidences of basking were greatest (48 - 60%) in areas with one building for all but the softshells. Softshells basked in relatively equal numbers with zero, (26%), one (32%), or two (28%) buildings on the shoreline but less frequently (14%) with three or more buildings. For all species, between 20 and 26% of basking occurred adjacent to shorelines with no buildings, except for *K. subrubrum*, that rarely basked near shorelines with no buildings (2%).

A two-dimensional NMS was created for the three scales of urbanization (Figure 4.11). The ordination was valid as indicated by the Monte Carlo randomization ($p = 0.004$) and scree plot. Final mean stress was 10.5. Shoreline Modification was correlated highly with axis two ($r = -0.88$) and to a lesser degree with axis one ($r = 0.33$). Disturbance Frequency also had a strong negative correlation with axis two ($r = -0.94$) and no correlation with axis one ($r = 0.09$). Building Density was moderately correlated with axis one ($r = 0.57$) and axis two ($r = 0.59$).

The large spread of greater abundances across both axes of the NMS ordination indicates an association of all turtle taxa to multiple urbanization indices (Figure 4.12).

Axis two primarily represents the local scale effect of modification and disturbance. Abundances of basking *P. texana* and *T. scripta* were distributed along axis two, indicating that these species are present in all categories of Shoreline Modification and Disturbance Frequency (Figures 4.13 and 4.14). Slightly greater abundances of *P. texana*, *T. scripta*, and the softshells on the negative loading of axis one indicates that basking was greatest where Building Density was low. *G. kohni* (Figure 4.15) and softshell (Figure 4.16) abundances were concentrated in the lower half of axis two, suggesting basking was highest in areas of low Shoreline Modification or Disturbance Frequency.

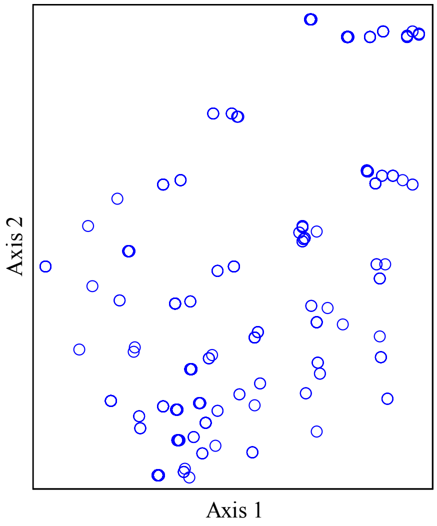

Figure 4.11: A two-dimensional NMS of the three scales of urbanization. Final mean stress was 10.5. Shoreline Modification and Disturbance Frequency were strongly correlated with with axis two (r = -0.88 and r = -0.94 respectively). Building Density was moderately correlated with axis one (r = 0.57) and axis two (r = 0.59).

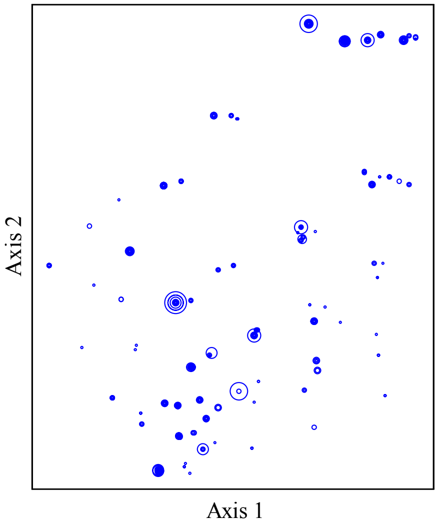

Figure 4.12: All turtle taxon overlay on NMS ordination of urbanization indicies. Wide variation in turtle abundances across both axes indicate that turtles bask across all levels of urbanization.

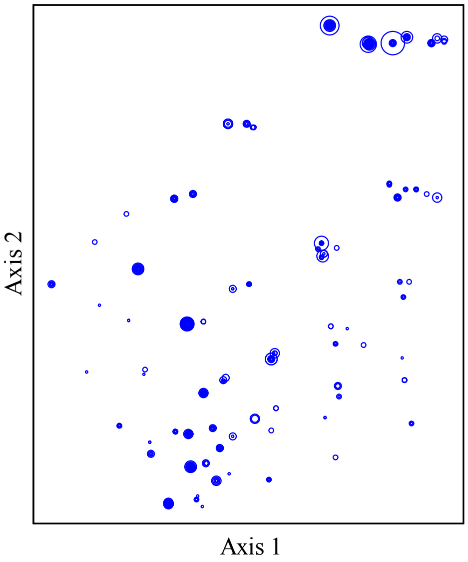

Figure 4.13: *P. texana* overlay on NMS ordination of urbanization indicies. Wide variation in turtle abundances across both axes indicate that *P. texana* basks across all levels of urbanization.

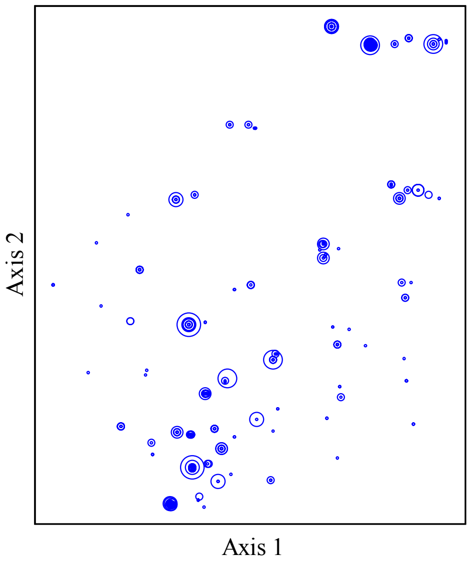

Figure 4.14: *T. scripta* overlay on NMS ordination of urbanization indicies. Similar to *P. texana*, wide variation in turtle abundances across both axes indicate that *T. scripta* basks across all levels of urbanization.

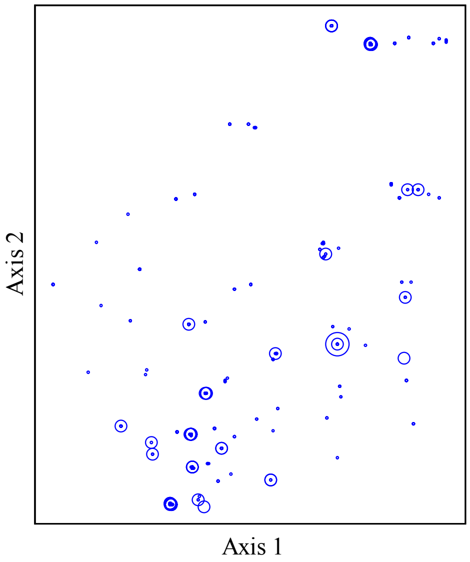

Figure 4.15: *G. kohni* overlay on NMS ordination of urbanization indicies. Concentration of greater *G. kohni* abundances in the lower portion of the ordination indicate that this species basks with greater frequency in areas of low urbanization.

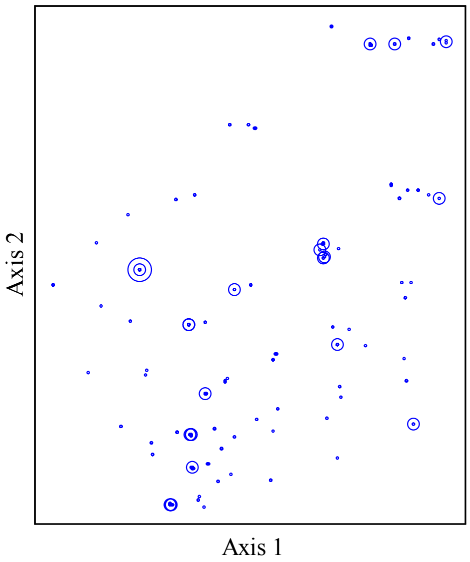

Figure 4.16: Softshell overlay on NMS ordination of urbanization indicies. Concentration of greater basking abundances in the lower portion of the ordination indicate that softshells basks with greater frequency in areas of low urbanization.

Responses to Shoreline Modification and Disturbance Frequency were species specific, as indicated by the Poisson regressions (Table 4.1). *P. texana* responded strongly to shoreline urbanization at the local scale. Abundances were highest in areas with more modification and less disturbance. *T. scripta* also had highest abundances in areas with more modification. In contrast to *P. texana*, *G. kohni* had highest abundances in less modified and more disturbed shorelines (Table 4.1).

A draw-down of the Brazos River occurred from September 30 to October 13, 2007. A basking turtle survey was conducted on November 7, 2007, when the river reached 30% of its mean annual flow. Post draw-down basking turtle abundances (n = 500) were comparable to abundances observed in May of the same year (n = 610) and greater than abundances observed in September (n = 281).

Trapping

Trapping at 47 randomly selected locations within the study site yielded 383 turtles. The community of turtles trapped was similar in proportions to the species observed basking. Trapped turtles included *P. texana* (66%), *T. scripta* (29%), *G. kohni* (3%), *T. muticus* (1%) and *T. spiniferus* (1%).

Trapping success for all species was greatest at high modification sites (Figure 4.17). *T. muticus* was trapped exclusively adjacent to highly modified shorelines similar to trapped *T. spiniferus* (94%). *G. kohni* was trapped most frequently adjacent to highly modified shorelines (48%) followed by moderately (24%) and slightly (19%) modified shorelines.

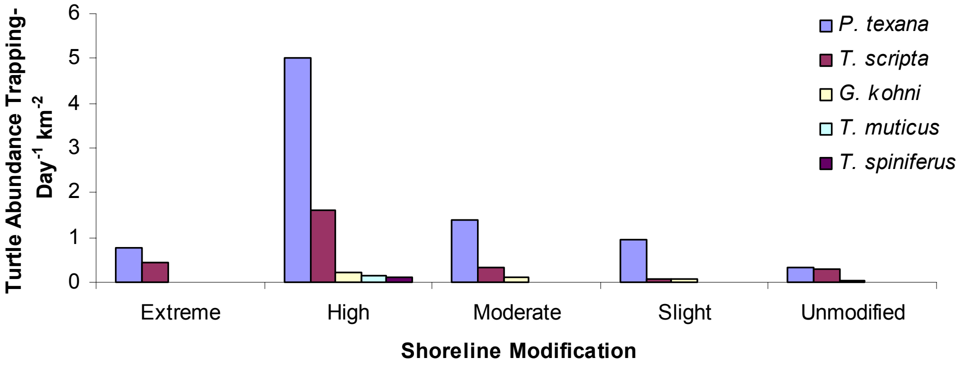

Figure 4.17: Trapping success of freshwater turtle species standardized for the number of trapping days and quantity of shoreline categorized as one of the five levels of Shoreline Modification.

Frequency of disturbance affected trapping success (Figure 4.18). *P. texana* was trapped most frequently in areas of weekly (33%) to monthly (29%) disturbance, which was similar to the proportions of trapped *G. kohni*. *T. scripta* was trapped most frequently in areas of monthly (43%) and daily (23%) disturbance. Most captures of smooth softshells (94%) were in areas of monthly disturbance while most spiny softshell captures (70%) were in areas of daily disturbance.

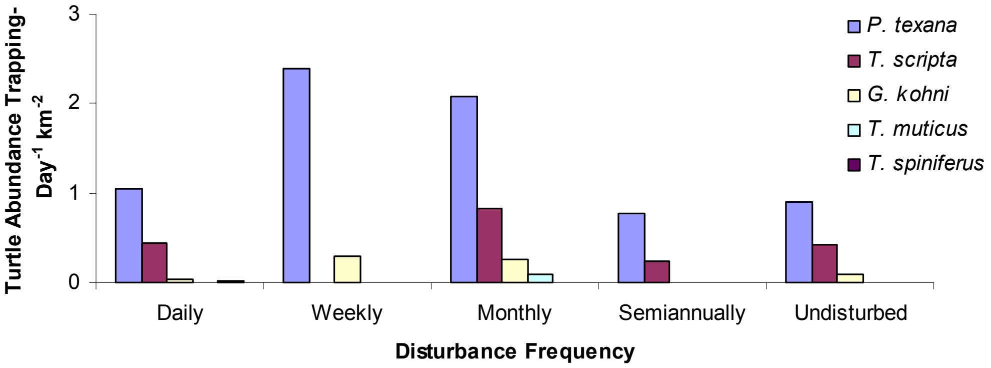

Figure 4.18: Trapping success of freshwater turtle species standardized for the number of trapping days and quantity of shoreline categorized as one of the five levels of Disturbance Frequency.

Analyses of the broad-scale urbanization index of Building Density revealed that 72% to 82% of all captures of *P. texana*, *T. scripta*, and *G. kohni* were in areas with one to two buildings on the shoreline. *T. muticus* was captured exclusively in areas with no buildings. *T. spiniferus* was never captured in areas with more than one building on the shoreline.

Discussion

Basking Surveys

Shoreline urbanization, at least to some degree, facilitates turtle basking behavior. Selection of basking location relative to Shoreline Modification was similar in all species in this freshwater turtle community. They preferentially bask in areas of high modification of shoreline vegetation. Considering the commonly held premise that turtles avoid basking in areas of greater urbanization, this result is counterintuitive. Preferentially basking adjacent to highly modified shorelines may be explained by the lack of solar radiation reaching basking sites near unmodified shorelines. The dense canopy of riparian vegetation typically extends over near-shore areas, filtering direct sunlight reaching potential basking sites. Increased Shoreline Modification, by definition, reduces the number of trees and shade and provides warmer, more productive basking sites. *G. kohni* was the exception to greater basking abundances adjacent to highly modified shorelines, as it basked most frequently in areas of moderate to low modification.

Cooters and sliders, the most abundant turtles in this community, were intolerant of frequent disturbance while *Trionyx* spp. and *K. subrubrum*, the rarest turtles in this community, basked almost exclusively in areas of moderate to high disturbance. Interestingly, while *G. kohni* is sensitive to shoreline modification, this species was observed basking at sites fairly evenly distributed across all levels of disturbance, with a slight preference for more disturbed areas. Moore and Seigel (2006) found that disturbance, in the form of watercrafts, caused *Graptemys flavimaculata* to dislodge from a basking site but reemergence onto that site was common (77%).

Turtles responded more strongly to the local-scale urbanization indices of Shoreline Modification and Disturbance Frequency than to the broad-scale measure of Building Density. Modification was a significant predictor of basking turtle presence for three of the five species, and disturbance for two of the five. Unilaterally, turtles failed to respond to the broad-scale urbanization index as the number of buildings on the shoreline was not a significant regressor related to basking in any species.

Recent research has shown great variation in freshwater turtle responses to urbanization. *Phrynops geoffroanus* had substantial leech loads in urbanized portions of the Uberabinha River (Brites and Rantin 2004). In the highly urbanized Ribeiraão Preto Stream however, abundances of *P. geoffranus* were remarkably high (Souza and Abe 2000). Even in protected areas freshwater turtle populations may be in decline. Browne and Hecnar (2007) documented the extirpation of *Clemmys guttata* and reduced abundances of Blanding's turtles with skewed sex ratios, and reduced juvenile recruitment, despite long term habitat protection.

Trapping

As with the basking data, abundances of freshwater turtles were greatest in areas of high modification. This was especially consistent for the softshells who showed high fidelity to areas with reduced vegetation. An exception was *G. kohni*, whose abundance was evenly distributed across all categories of modification. All turtle species basked in the greatest abundances near where disturbance was fairly infrequent. Spiny softshells were trapped most frequently in undisturbed and extremely disturbed areas. This is probably an artifact of limited trapping success for this species.

Survey of Potential Basking Sites

Potential basking sites were more available along shorelines where riparian vegetation was reduced. Areas adjacent to moderately and highly modified shorelines contained the most potential basking sites. This may be associated with increased erosion by the river. Reduced vegetation would result in fewer roots to stabilize the soil, allowing water to erode the shoreline, and consequently, trees fall into the river.

Alternatively, the sparse distribution of woody vegetation in a thinned forest may increase the weathering of the wood, causing greater tree falls and lost branches. Availability of potential basking sites may also be controlled by deposition and scouring within the active river channel, which may dilute the intuitive relationship between greater shoreline vegetation and deadwood inputs into the river. The remaining indices of Disturbance Frequency and Building Density indicated that basking sites are most abundant where urbanization is reduced.

Conclusion

The influence of urbanization on the basking ecology of freshwater turtles varies for each species across indices and scales. The basking ecology of *P. texana* and *T. scripta* was strikingly similar and often distinct from the remainder of the community.

Freshwater turtles respond most strongly to urbanization at a local scale. Cooters and sliders tolerated the removal of shoreline vegetation but preferred to bask in areas of low human disturbance. In contrast, *G. kohni* preferred shaded, unmodified shorelines but tolerated human disturbance. *K. subrubrum* basked near substantially modified and disturbed shorelines.

Potential basking site abundance was greatest in areas of high and moderate modification and low disturbance. Since *P. texana* and *T. scripta* bask at their greatest frequencies in these areas, plentiful basking sites may facilitate greater abundances of these species.

The influence of urbanization on basking abundances is not entirely negative, with the Brazos supporting large populations of basking freshwater turtles. All species in this basking turtle community tolerate some level of urbanization, and two species are found exclusively in highly urbanized areas. Even the rarest species in the community can be found basking in the most metropolitan portion of this study site. Anthropogenic activities immediately adjacent to a basking turtle, which is to say, at a local scale, were most affecting to the Emydidae.

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CHAPTER FIVE

Conclusion

The basking turtle community of the Brazos River in McLennan County, Texas, is moderately diverse, and dominated by the endemic *P. texana*. Basking site preferences are present for several species but varied among taxa and only partially explained the spatial distribution of basking freshwater turtles along the shoreline. Basking *P. texana* and *T. scripta* select sites based on orientation. Specifically, basking sites farther away from the shoreline facilitate greater basking abundances of *P. texana* and *T. scripta*. *T. scripta* basks more frequent where potential basking sites are abundant. For all species, solitary basking is more frequent than incidences of multiple occupancy. However, multiple occupancy is not uncommon. *P. texana* and *T. scripta* bask with several species in the community. They do not selectively bask with a given species, nor do they avoid them, indicating that in cases of multiple occupancy *P. texana* and *T. scripta* bask indiscriminately relative to the species composition on a basking site. Basking site attributes that facilitate multiple occupancy include length and distance from the shoreline.

The freshwater turtle community in the Brazos River is unique as it contains an endemic, *Pseudemys texana*, and because this endemic is the most abundant turtle in the community. The population of the endemic *Pseudemys texana* in the central Texas portion of the Brazos River basks slightly more frequently in lower, more urban, reach of the study site. The large number of individuals, large maximum size, low proportion of injured or parasitized turtles, and relatively equitable distribution of size classes among basking turtles indicates a relatively stable population in the Brazos River.

The influence of urbanization on the basking ecology of freshwater turtles varies for each species across sources and scales. Turtles respond most strongly to urbanization at a local scale. Cooters and sliders tolerated the removal of shoreline vegetation but preferred to bask in areas of low human disturbance. In contrast, *G. kohni* preferred shaded, unmodified shorelines but tolerated human disturbance. *K. subrubrum* is particularly tolerant of urbanization, basking frequently near substantially modified and disturbed shorelines.

Potential basking site abundance was greatest in areas of high and moderate modification and low disturbance. *P. texana* and *T. scripta* bask at their greatest frequencies in these areas, which is further conformation that plentiful basking sites facilitate greater basking abundances of these species

All species in this basking turtle community tolerate some level of urbanization, and two species are found exclusively in highly urbanized areas. Even the rarest species in the community can be found basking in the most metropolitan portion of this study site. Anthropogenic activities immediately adjacent to a basking turtle, which is to say, at a local scale, were most affecting to the Emydidae.

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