CONSERVATION OF THE SPOTTED TURTLE (*CLEMMYS GUTTATA*): IDENTIFYING CRITICAL DEMOGRAPHIC AND ENVIRONMENTAL CONSTRAINTS AFFECTING VIABILITY

Hillary M. Harms

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Committee:

Karen V. Root, Advisor

Candace C. Archer
Graduate Faculty Representative

Juan L. Bouzat

Enrique Gomezdelcampo

Helen J. Michaels

ABSTRACT

Karen V. Root, Advisor

The Spotted Turtle, *Clemmys guttata*, is a freshwater turtle species currently protected throughout most of its range. Urgent conservation action is warranted to assess population viability and to focus management for this species. This body of work is premised on four overarching questions which addressed the population viability, current population status, critical environmental variables, and management strategies. We performed sensitivity analyses utilizing demographic data from the literature incorporated into an age-based population model. We conducted a mark-recapture study at two study sites in the Oak Openings Region of northwest Ohio to assess the habitat and population characteristics of Spotted Turtles. We used presence and absence locations to identify critical environmental variables at the local and landscape scales, resulting in a habitat suitability model. Our sensitivity analyses identified the variables most influential to Spotted Turtle viability (i.e., survival rates of older age classes, population size, and age at reproduction). We found that Spotted Turtle density was higher than those reported in recent literature and that age structure was not as adult biased as many other populations. In general, turtles were using areas within sites that had higher water and taller, denser ground vegetation. At the local scale, turtle presence could be explained by low slope, higher levels of June moisture, and intermediate levels of March brightness. At the landscape scale annual solar radiation, June brightness, land cover, June NDVI, and slope were significant in explaining turtle presence. A habitat suitability map was created to locate other potentially suitable areas within the Oak Openings Region. Based on these results, the variables found to influence Spotted Turtle population persistence over time should be the focus of future field

work and monitoring throughout the range. Local management should focus on managing current sites since Spotted Turtles show high site fidelity, but also to acquire additional lands since potential habitat makes up less than 1% of the region. We have shown that Spotted Turtles have complex habitat requirements, making it important to have a multiscale view which considers the context of different environmental variables that accommodate the year round requirements for turtle viability.

Dedicated to my parents, Kevin and Gloria, for their

encouragement and support while I followed my dreams.

Also, to my husband, Rob, for his love and

understanding during this process.

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The field research took place at Kitty Todd Nature Preserve (The Nature Conservancy), Bumpus Pond (Metroparks of the Toledo Area), and Irwin Prairie Nature Preserve (Ohio Department of Natural Resources). I want to thank these agencies for permitting me to work in these sites and for taking the time to meet with me and answer my questions. The field work was also approved by the Bowling Green State University Institutional Animal Care and Use Committee (protocols 05-003 and 08-002).

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CHAPTER I

GENERAL INTRODUCTION

There is evidence that many freshwater turtle populations have been experiencing significant declines in population size and distribution over the past several decades, as several species have been protected under the Endangered Species Act. As of 1996, 62 of the 160 turtle species considered to be aquatic or semiaquatic were classified as requiring conservation efforts (Burke et al., 2000). Reasons for these declines include increased habitat loss, collection for the pet trade, and increased predation on adults and juveniles by subsidized predators (Ernst et al., 1994; Mitchell and Klemens, 2000; Burke et al., 2000). Many freshwater turtle species are more vulnerable to population decline because of life history characteristics such as delayed age of maturity and small clutch sizes (Ernst and Zug, 1994). It has been suggested that given the current trends of freshwater turtle population decline, all turtle species in North America and Canada are likely to be threatened within the next century (Ernst et al., 1994).

The current trends of population decline are alarming because freshwater turtles play an important role in the ecosystem. Freshwater turtles have the potential to contribute significant biomass to ecosystems because they aggregate near food and basking sources (Cagle, 1950; Ernst, 1971; Bury, 1979). These turtles are an important link in ecosystems, providing dispersal mechanisms for plants (Rowe and Parsons, 2000) and contributing to environmental diversity. Also, turtles increase the complexity of the food web by interacting with a diverse array of organisms from the variety of food that they eat (Rowe and Parsons, 2000) to the range of organisms that eat them (Ernst et al., 1994; Sloan and Lovich, 1995; Hamilton et al., 2002; Marchand and Litvaitis, 2004).

Besides playing an important role in ecosystems, turtles can act as an indicator of ecosystem health (Wilson and McCranie, 2003; Thompson and Thompson, 2005). There are many reasons for this including that turtles are sensitive to fragmentation effects, which cause road mortality (Mitchell and Klemens, 2000; Gibbs and Shriver 2002) and increased predation (Kolbe and Janzen, 2002; Hamilton et al., 2002). Turtles also have specific requirements making them more susceptible to human related disturbances (Dodd, 1990; Ernst et al. 1994; Lindsay and Dorcas, 2001). It has also been shown that at risk species are good indicators for conservation planning (Lawler et al., 2003).

Our research focused on the Spotted Turtle, *Clemmys guttata*, which is a species of freshwater turtle that occurs in disjunct populations from southern Ontario and Maine, south to Florida, and from Pennsylvania west to Illinois (Figure 1). They are protected in the majority of their range, being listed as critically imperiled, imperiled, or vulnerable (NatureServe, 2007). This shy species rarely exceeds five inches and can be identified by its black carapace that is marked with small yellow to orange spots. They are found in multiple wetland habitats such as bogs, marshes, and small streams that have a soft substrate and aquatic vegetation and have a short annual cycle with peak activity periods from March to May (Ernst et al., 1994). This species can live at least 30 years with individuals reaching sexual maturity between 7-15 years of age (Ernst et al., 1994; Litzgus and Brooks, 1998). Spotted Turtles are omnivores known to eat items such as aquatic grasses, algae, berries, insects, snails, and tadpoles. Large birds, skunks, and raccoons are known to eat Spotted Turtle eggs and it is common for a proportion of the adult population to show injuries such as damaged shells and amputated legs and tails. The main reason for Spotted Turtle population declines is habitat loss (Ernst et. al., 1994).

Published literature provides us with basic demographic data (i.e., clutch size, frequency, approximate survival rates of eggs and adults; Ernst et al., 1994; Litzgus and Mousseau, 2003; Litzgus, 2006), population parameters (i.e., population size and density; Graham, 1995; Milam and Melvin, 2001; Seburn, 2003; Litzgus and Mousseau, 2004a), and habitat information (i.e., habitat types and seasonal movements; Litzgus and Brooks, 2000; Milam and Melvin, 2001; Litzgus and Mousseau, 2004b), which describe various populations throughout the range. Most recent work has been conducted in the northern and southern portion of the range leaving a gap in knowledge for the central portion of the range.

These studies have hinted at what limits population viability, but a formal sensitivity analysis has not yet been conducted. A comparison of the literature has demonstrated that demographic and habitat parameters change by latitude due to climate and availability differences, and over time with land use changes influencing habitat (e.g., Litzgus and Brooks, 2000 versus Haxton and Berrill, 2001; Ernst, 1976 versus Milam and Melvin, 2001). The population declines seen and protected status of this species warrants urgent conservation action that will contribute to our basic ecological knowledge of this species and wetland habitats, as well as to make and assess management recommendations for this species.

Few studies have been performed in Ohio, the central portion of the range. Previous studies suggest that Spotted Turtle habitats are suboptimal and that populations are experiencing low recruitment rates (Lewis and Ritzenthaler, 1997; Lewis and Faulhaber, 1999; Lewis et al., 2004). Locations of known populations can be obtained, but there is not much known about current population status. Our research focused on determining the intrinsic and extrinsic factors that influence Spotted Turtle population viability, and to evaluate the status of and critical habitat variables for Spotted Turtles in Northwest Ohio so that successful conservation can occur.

This dissertation is organized in a series of three main chapters which address these goals:

1. Sensitivity Analysis for the Spotted Turtle, *Clemmys guttata*
2. An Assessment of the Habitat and Population Characteristics of Spotted Turtles (*Clemmys guttata*) in Northwest Ohio
3. The Identification of Critical Environmental Characteristics for Spotted Turtles (*Clemmys guttata*) at the Local and Landscape Scale in the Oak Openings Region: A Predictive Habitat Suitability Model

In the second chapter we describe how demographic variables such as fecundity, age at reproduction, and survival rates affect population persistence over time, and how changes in population size, poaching, and catastrophes affect population persistence over time. Research results identify variables that have a large influence on risk of population decline and can be used to focus future research and management strategies.

In the third chapter, we (1) explore the current status of Spotted Turtles in Northwest Ohio by measuring population size, density, and age structure; (2) determine how turtles use the landscape; and (3) identify critical environmental characteristics at the local scale. The results from the two study sites are compared to each other and to previous studies to increase the knowledge of local populations and populations within the center of the range. General management recommendations are made for populations throughout the range and more specific recommendations are made to guide local management.

In the fourth chapter, we identify the critical environmental characteristics for the Spotted Turtle at the local and landscape scales by comparing presence and absence points within study sites and between study sites and the Oak Openings Region. The landscape scale results are used to generate predictive habitat models for the Oak Openings Region which can be used to locate additional Spotted Turtle populations and potentially suitable habitat. Again, management recommendations are made to guide local management.

All chapters are formatted as required by the journals I plan on submitting manuscripts to (e.g., Copeia, Journal of Herpetology) resulting in the use “We” instead of “I”.

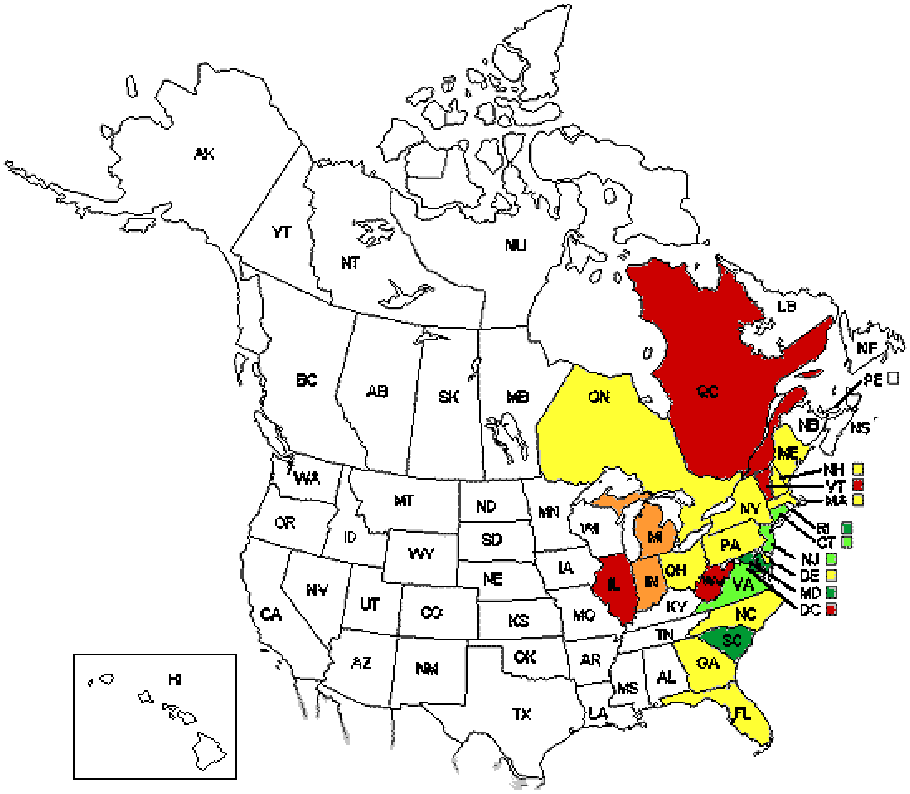

Figure 1. Range map for the Spotted Turtle, *Clemmys guttata* (NatureServe, 2007) color coded where red=critically imperiled, orange=imperiled, yellow=vulnerable, light green=apparently secure, green=secure.

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CHAPTER II

SENSITIVITY ANALYSIS FOR THE SPOTTED TURTLE, *CLEMMYS GUTTATA*

INTRODUCTION

Population viability analysis (PVA) is a powerful technique that is used to make predictions about a population typically for planning purposes. PVAs have been effectively used to predict the probability of persistence over time and to evaluate the threats faced by a population based on species specific data (Akcakaya and Sjogren-Gulve, 2000). This technique has numerous applications such as being used to determine additional data needed and to evaluate changes in management options (Brook et al., 2000). PVA plays an important role in conservation planning by providing the ability to determine the outcomes of proposed management and identifying parameters that highly influence population growth rate.

Sensitivity analyses are performed on PVA models to determine the parameters most influential on growth rate and, thus, population persistence over time. This process identifies parameters that have a large influence on model results by varying the value of a particular parameter in the model and comparing how much impact it has on model results. When small changes in a parameter make a large impact on model outcome, the parameter is considered to be influential. Many previous studies have demonstrated the importance of performing sensitivity and elasticity analyses on common and rare species (Wisdom and Mills, 1997; Benton and Grant, 1999; Servello, 2000; Cuthbert et al., 2001).

Sensitivity analyses have been performed on the life tables of various species of turtles (Frazer et al., 1991; Iverson, 1991; Mitrus 2005). Studies examining turtle populations have used sensitivity analyses to examine relationships between adult and juvenile survivorship (Congdon et al., 1993), management strategies (Heppell et al., 1996), and to compare similarities and differences between species (Heppell, 1998). Studies have found that sea turtle populations will benefit from enhanced survival of subadults or juveniles and that freshwater turtles will benefit from enhanced survival of adults (Heppell, 1996).

Various turtle species have been the focus for many sensitivity analyses because it has been recognized that many turtle species are suffering from population declines, with turtles such as the Bog Turtle, *Glyptemys muhlenbergii*, and the Ringed Map Turtle, *Graptemys oculifera*, being federally listed. These declines are of interest not only from the standpoint of maintaining biodiversity but also because freshwater turtles can act as indicators of ecosystem health since they are sensitive to fragmentation and human disturbances (Wilson and McCranie, 2003; Thompson and Thompson, 2005). Turtles share many life history traits, but there are reproductive and survival rate differences between species and sometimes within species (Heppell, 1996) suggesting that a sensitivity analyses is required for each species.

A sensitivity analysis has not been conducted with the Spotted Turtle, *Clemmys guttata*. The Spotted Turtle is a species of freshwater turtle that is protected in the majority of its range, being listed as critically imperiled, imperiled, or vulnerable (NatureServe, 2007), and can be found in shallow water with aquatic vegetation. Spotted Turtle populations are declining for a number of reasons including habitat loss, collection for the pet trade, and predation by subsidized predators (Ernst et al., 1994; Burke et al., 2000). They are vulnerable to population decline because of life history characteristics such as delayed age of maturity and small clutch sizes (Ernst and Zug, 1994) which elicit a slow response to environmental change. Given the current range-wide population declines, a viability assessment is critical to focus future research and management strategies.

Our objective was to perform a sensitivity analysis on the Spotted Turtle utilizing demographic data from the literature to represent populations throughout the range incorporated into an age-based population model. Specifically we were interested in (1) how demographic variables such as fecundity, age at reproduction, and survival rates affect population persistence over time, and (2) how changes in population size, poaching, and catastrophes affect population persistence over time. We hypothesized that adults and older juveniles would be the most influential variables on population persistence over time due to the long life span exhibited by turtles.

METHODS

Data Description.---We found demographic data in the literature for the Spotted Turtle throughout its range suitable for a sensitivity analysis. Range wide information describes the Spotted Turtle reaching sexual maturity when the individual has a carapace length between 80-105 mm usually between 7-15 years of age, with individuals in the northern portion of the range reaching maturity at a larger size and later age (Ernst et al., 1994; Litzgus and Brooks, 1998).

The average annual output of eggs is similar throughout the range when taking into account clutching frequency: 3.5-3.9 eggs per female (Litzgus and Mousseau, 2003). Survival rates of the eggs vary by site but were reported as 68% for eggs at one site in Pennsylvania (Ernst, 1970). Adult survival is thought to be very high (Seburn, 2003) and was estimated around 96% (Litzgus, 2006).

There is still debate on how long the Spotted Turtle live. One captive individual lived for 42 years (Ernst. et al., 1994) and models indicate that individuals can live 65-110 years based on survival rates (Litzgus, 2006). We chose to use a conservative estimate of 30 years longevity.

Models.---We used RAMAS GIS software (Applied Biomathematics, Setauket, New York, version 4.0) to create age based population viability models. We constructed a Baseline model representing a single population using demographic data found in the literature as a guide (Table 1). This model had a stable age distribution and was used as a basis for our comparisons of the potential impacts of changes in demographic or extrinsic parameters. We also constructed an alternative to the stable age distribution model, an adult biased model where 80% of the population was adults, to evaluate the effects of population structure on final average abundance and the probability of a 50% population decline.

Both models had an initial population size of 50 females, based on our population estimates of a population in NW Ohio (unpublished data). Simulations were run over 50 years with 10,000 replications and exponential growth (i.e., no density dependence). A female only model was chosen since females limit population growth and survival rates were assumed to be the same among sexes. We excluded density dependence because doing so required the fewest number of assumptions to be made about the population.

Baseline Model.---The annual fecundity value per female (1.19) was based on hatching success (68%) and the proportion of females that breed each year multiplied by the number of eggs per clutch (together totaling 3.5 eggs per female). Fecundity was kept constant among all adults since it has been reported that there was no decline in the reproductive output or nest success between females of different ages for the turtle species which have been studied (Congdon et al., 2001; Miller, 2001; Congdon et al., 2003). We used a coefficient of variation (CV) of 0.15 for fecundity to simulate stochasticity. In the Baseline model, females started breeding at 8 years of age. We used annual survival rates of 50% (age 1), 70% (ages 2-5), 80% (ages 6-7), and 93% (ages 8+) and a CV of 0.10 for all survival rates to simulate stochasticity.

Annual survival rates were based on data found in peer-reviewed literature and were modified to result in a growth rate near 1.0 since most turtle populations are not increasing in size.

Adult Bias Model.---Several published studies (Litzgus and Mousseau, 2004; Milam and Melvin, 2001; Seburn, 2003) as well as our own field work (unpublished data) indicate that some populations have more adults than juveniles. To evaluate the effect this may have on the population, we changed the initial stable age distribution to a starting population with 80% adults, 10% subadults, 6% juveniles, and 4% hatchlings. After the model was run, we compared the abundance of females over time and the probability of persistence over time with the Baseline model.

Demographic Variables.---We performed sensitivity analyses of the Baseline model by independently altering annual survival rates, annual fecundity rates, and age at reproduction to compare potential impacts of changes in the model. All sensitivity analyses were run over 50 years with 10,000 replications. We compared the resulting models to the Baseline model by using the final average abundance and the probability of a 50% population decline as the response variables. We chose the probability of a 50% population decline instead of the probability of extinction because when population abundance has been reduced by half management would need to occur.

Survival.---Survival rates vary by location based on extrinsic factors such as habitat quality and predation so we performed a sensitivity analysis on survival values by decreasing the survival rates of hatchlings (ages 0-1), young juveniles (age 2-3), older juveniles (ages 4-5), subadults (ages 6-7), young adults (ages 8-9), and adults (ages 10-11) independently by 10-30% allowing us to compare the impact of each age group’s annual survival on the model outcome.

We choose to use groupings of two years of age so that there were a similar number of individuals in each group.

Fecundity.---Our fecundity values included the proportion of females breeding, the number of eggs laid per female, and the survival rate of hatchlings. These values also vary by location due to extrinsic factors such as environmental conditions and levels of predation. We investigated the model's sensitivity to fecundity values by decreasing fecundity by 10-30% and compared these results to the Baseline model.

We also modeled the effects of a small proportion of subadults reaching breeding size before 8 years of age. In these models the adult fecundity remained at Baseline values, but 10% of Age 7 females also bred in one of the simulations (fecundity value of 0.119) and 20% of Age 7 females also bred in a second simulation (fecundity value of 0.238).

Age at Reproduction.---Since the Spotted Turtle reaches sexual maturity at different ages based on environmental variables such as temperature and habitat quality that affect growth and body size, we modeled the effect of age at reproduction on Spotted Turtle persistence over time. We increased the first age at reproduction from 8 to 9-12 years of age.

Scenarios.---We generated additional models and sensitivity analyses to evaluate the effects of population size, catastrophe, and poaching since these are all factors that may affect Spotted Turtle population abundance and persistence over time. Again, simulations were run over 50 years with 10,000 replications. We used the final average abundance and the probability of a 50% population decline as the response variables for comparison to the Baseline model.

Population Size.---We adjusted the initial population size of 50 females by ±40% resulting in two models: one with a population of 30 females (i.e., Small population) and another with a population of 70 females (i.e., Large population). In each of these population models we decreased the survival rates of hatchlings, young juveniles, older juveniles, subadults, young adults, and adults independently by 10% to determine the influence each age group on model outcome in populations of different sizes.

Catastrophe.---Environmental fluctuations such as extremely wet or dry years could result in no hatching survival for that year. We used the Baseline, Small, and Large population models and varied no hatchling survival by once every 5, 10, and 15 years.

We were interested in how no hatchling survival impacts the final average abundance and the probability of population persistence over time. We examined the data two ways by analyzing (1) how different frequencies of no hatchling survival events affects the final abundance and probability of population decline and (2) how no hatchling survival events affect the final abundance and the probability of population decline on populations of different sizes.

Poaching.---We assumed that a poacher would travel to a site and take as many individuals as possible within a day and then poach from other locations during the rest of the year to increase the maximum yield. Given that the maximum number of turtles we have captured at our study site, which is of similar size to the Baseline population consisting of 50 females, in one day is 8 and the majority of turtles we captured were adults (unpublished data) we assumed that a poacher may find a maximum of 10 turtles (or 5 females in our female based model) at a site in one day, with all turtles removed being adults. We varied the poaching interval in years from once every 5, 10, or 15 years to model the impact on the final average abundance and the probability of 50% population decline.

Statistical Analysis.---We examined the differences in the initial and final abundance of each model and compared it to the Baseline results. To compare the potential impacts of changes in the models, we used the Kolmogorov-Smirnov test statistic D to compare the maximum difference between the interval percent decline distributions of the different models and the Baseline model. This was reported by indicating the one point on the curve that had the maximum distance from the Baseline curve and the distance it was from the Baseline curve.

RESULTS

Baseline Model.---The Baseline demographic model was generated using the survival and fecundity values shown in Table 1 and resulted in a finite rate of increase (λ) of 1.0038. The population size averaged 50-61 females, with the number of females increasing gradually over time (Figure 1). There was a 0.2730 probability of a 50% population decline (Figure 2) and the extinction risk in 50 years was 0.0016.

Adult Bias Model.---The adult biased population had the same population growth rate as the Baseline model but a significantly different average stage abundances of females ($p<0.001$) and a significant difference ($p<0.001$, at $x=2$, $D=0.818$, where x is the value on the x-axis describing percent decline and D is the distance between the interval percent decline curves on the y-axis describing probability on a scale of 0-1) between the interval percent decline curves even though all other model parameters were the same. In this model the population size ranged from 50 - 119 females with the number of females increasing quickly for the first four years and then increasing gradually over time (Figure 1). There was a 0.0168 probability of a 50% population decline (Figure 2) and the extinction risk was 0.0000.

Survival.---By decreasing the survival rates of hatchlings, young juveniles, older juveniles, subadults, young adults, and adults independently by 10-30% (Table 2), we found that there was the smallest decline in final abundance when hatchling survival was reduced (e.g., 10% reduction produced a decline of 6.15 females, 30% reduction produced a decline of 29.09

females). When young juvenile, older juvenile, subadult, or young adult survival was decreased there was a greater decline in final abundance (10% reduction produced declines of 16.05 - 17.58 females, 30% reduction produced declines of 40.92 - 42.20 females).

We found that the difference in the interval percent decline of each of the model risk curves was significantly different (10% reduction, $p<0.001$; at x=36, D=0.198 for hatchlings, x=44, D=0.364 for young juveniles, x=46, D=0.366 for older juveniles, x=44, D=0.372 for subadults, X=46, D=0.342 for young adults, X=42, D=0.298 for adults) than the Baseline risks. Decreased hatchling survival had the least impact on the probability of a decline with a 10% decreased hatchling survival resulting in a 0.4451 probability of a 50% population decline. A decrease in young juvenile, older juvenile, subadult, or young adult survival had the most impact on the probability of a 50% population decline. A 10% decrease in the survival of these age classes resulted in a 0.6140 – 0.6391 probability of a 50% population decline.

Fecundity Values.-- When adult fecundity was decreased by 10% the average final abundance decreased by 7.41 females and when adult fecundity was decreased by 30% average final abundance decreased by 26.96 females (Table 3). We also modeled the effects of a small proportion of subadults breeding, with 10% of Age 7 females breeding in one model and 20% Age 7 females breeding in another model. When subadult fecundity was increased by 10% there was an increase in the average final abundance of 12.9 females and when fecundity was increased by 20% there was an increase in the average final abundance of 15.41 females.

Decreasing adult fecundity had more impact on the probability of a 50% population decline than increasing Age 7 fecundity. The differences in risks for all fecundity models were significantly different ($p>0.001$; at x=40, D=0.214 for 10% adult reduction, x=48, D=0.432 for 20% adult reduction, x=48, D=0.539 for 30% adult reduction, x=24, D=0.026 for 10% Age 7 breeding, x=22, D=0.041 for 20% Age 7 breeding) than the Baseline model. The probability of a 50% population decline increased with decreased adult fecundity. Adult fecundity was decreased by 10, 20, and 30% which resulted in a 0.4617, 0.7015, and 0.8122, respectively, probability of a 50% population decline. The probability of a 50% population decline decreased with increased Age 7 reproduction. Age 7 fecundity was increased by 10 and 20% which resulted in a 0.2517 and 0.2392, respectively, probability of a 50% population decline.

Age at Reproduction.---We modeled the effect of delayed maturity by increasing the first age at reproduction from 8 to 9-12 years of age (Table 4). We found that the deterministic growth rate decreased as the age of maturity increased from 9-12 years of age (0.9982, 0.9931, 0.9884, 0.9839 respectively). The final average number of females decreased as the age at reproduction increased (Table 4).

The differences in risk for all delayed maturity models were significantly different from the Baseline model (i.e., p>0.001, at x=36, D=0.189 for Age 9, x=40, D=0.364 for Age 10, x=46, D=0.495 for Age 11, x=52, D=0.614 for Age 12); each additional year of delay in reproduction had more of a negative impact on population persistence over time (Figure 3). The probability of a 50% population decline increased as age at reproduction increased from 9-12 years (Table 4).

Population Size.---We adjusted the initial population size of 50 females by ±40% (Table 5). All populations increased in size over the simulation duration, with the Large population having the largest increase in population size (+14.23 females) and the Small population having the smallest increase in population size (+0.63 females). We found that the Large population had the lowest probability of a 50% population decline (0.1975) and the Small population had the highest probability of a 50% population decline (0.6165).

We performed a sensitivity analysis on the Small and Large population models by decreasing the survival rate of each age grouping (i.e., Hatchlings, Young Juveniles, Older Juveniles, Subadults, Young Adults, and Adults) by 10% independently (Figure 4). We found that in the Small population the reductions in the survival of older individuals (Older Juveniles to Adults) have the largest impact on risk, as indicated when comparing the interval percent decline curves. While in the Large population reductions in the survival of younger individuals (Young Juveniles to Subadults) have the largest impact on risk, decreasing the survival of these age groups had higher probabilities of 50% population decline than decreases of survival in other age classes. The results of the Baseline model were similar to the results of the Large Population model with reductions in survival of older age classes (Young Juvenile to Young Adults) have the greatest influence on population persistence over time.

Catastrophe.---When we compared the time interval of catastrophes within the same population size we found that models with no hatchling survival once every 5 years had the largest decrease in abundance and models with catastrophes once every 15 years had the smallest percent change in abundance (Table 6). Similarly, models with catastrophes once every 5 years had the highest probability of a 50% population decline (0.7639-0.9025) and models with no hatchling survival once every 15 years had the lowest probability of a 50% population decline (0.3787-0.7111).

When comparing the different initial population sizes (Figure 5), the Small population with catastrophes had the greatest change in final average abundance (no hatchling survival once every 10 years; decrease of 44.33%). The Baseline model and the Large population model with catastrophes had similar percent changes in final abundance (no hatchling survival once every 10 years; decrease of 35.28 and 34.49% females, respectively).

Similarly, when we compared the probability of a decline, the Small population with catastrophes had the highest probability of 50% population decline (no hatchling survival once every 10 years; 0.7703 probability). The Baseline model and Large population with catastrophes had similar probabilities of 50% population decline (no hatchling survival once every 10 years; 0.5390 and 0.5028, respectively). The differences between the interval percent decline curves of both models from the Baseline model were significantly different (Once every 10 years; $p<0.001$, at $x=63.7$, $D=0.262$ for Small population with catastrophes and $x=60.0$, $D=0.079$ for Large population with catastrophes).

Poaching.---We simulated poaching by removing 5 female adults, or 10% of the adult population, from the model at intervals of once every 5, 10, or 15 years to examine the impact on the final average abundance and the probability of population persistence over time (Table 7). We found that the average final abundance of all poaching models was lower than the Baseline final abundance (Figure 6). Poaching once every 15 years had the least impact on the final average change in abundance (decrease of 25.62 females). Poaching once every 5 years had the most impact on final average change in abundance (decrease of 49.81 females).

The probability of a decline increased with increased frequency of poaching. Poaching once every 5 years had the highest probability of a 50% population decline (0.9995) and poaching once every 15 years having the lowest probability of a 50% population decline (0.7716). The maximum difference between the risks of all poaching models were significantly different than those of the Baseline model ($p<0.001$, at $x=64$, $D=0.458$ for Every 15 Years, $x=64$, $D=0.676$ for Every 10 Years, $x=94$, $D=0.986$ for Every 5 Years) which had a 0.2730 probability of a 50% population decline.

DISCUSSION

We found that changes in demographic variables, population size, catastrophes, and poaching affect population persistence of the Spotted Turtle over time, but that some variables had more impact on the probability of decline than others. The results supported our hypothesis that older age classes contribute more to population persistence over time in our Baseline model. We also found that changes in two other variables had a large impact on population persistence over time: age of reproduction and population size. Extending the age of sexual maturity decreases the annual growth rate and increases the probability of population decline. Population size influenced the probability of population decline, but it also influenced which age groups were most influential on population persistence over time.

Relationship between age structure and population persistence over time.--- Investigating the age distribution of the populations gives insight into whether or not field sampling methods are effective. If researchers are finding an adult biased population that is not rapidly increasing in abundance, the younger individuals are likely suffering from very low survival rates. While if researchers are finding an adult biased population that is increasing in abundance, their sampling techniques may have an adult bias.

It is becoming more common to find populations with an adult bias, as more species become threatened with extinction. For example, Rubin et al. (2004) found low juvenile survival rates for Blanding's turtles in urban areas, Reese and Welsh (1998) concluded that juveniles might be impacted by a dam in a population of Western Pond Turtles, and multiple Hellbender populations are declining for unknown reasons (Wheeler et al., 2003). In these instances it is clear that there is a lack of juvenile recruitment and that PVA models should be created to investigate the potential impacts of the observed population distribution and low juvenile survival rates using a skewed population structure.

On the other hand, there are some field techniques that can have an adult bias, such as hoop net traps with Painted Turtles (Gamble, 2004) and road surveys with turtles (Steen and Smith, 2006). It may not be clear if field techniques are selecting/excluding a particular age group, but examining the growth rate of the population will give an indication. Our sensitivity analysis of age structure utilizing an age-based population model highlights the usefulness of population models for testing these types of hypotheses based on field data. This technique can increase the effectiveness and efficiency of research efforts by verifying the field results and directing future research.

Relationship between demographic variables and population persistence over time.--- Our results suggest that changes in the fecundity of two ages of adults had a larger impact on population persistence than changes in fecundity for a single age of subadults. This may be the result of the larger number of individuals in the combined age class than in the individual age class. Spencer and Thompson (2005) investigated two species of turtles with similar adult survival and growth rates using a stage based population matrix. They found that, based on elasticity values, *Emydura macquarii* were more reliant on adult survival and *Chelodina expansa* were less reliant on adult survival for population stability, indicating different life-history strategies. We would like to note that *Emydura macquarii* had an adult to juvenile ratio of 9:1 and *Chelodina expansa* had a ratio of 2:1, which supports our conclusion that more individuals in an age group will have a larger influence on population persistence.

Populations of the Spotted Turtle in which individuals reproduce just one year later in life than our Baseline model had a lower finite growth rate and a higher probability of population decline. This suggests that in populations where individuals take longer to reach sexual maturity there must also be higher survival rates to achieve the same population growth rate. A similar trend was found by Heppell (1998). The Common Mud Turtle (*Kinosternon subrubrum*), Slider (*Trachemys scripta*), and Painted Turtle (*Chrysemys picta*) all reach sexual maturity between 4 - 7 years of age and have adult annual survival rates between 0.814 – 0.876. While Yellow Mud turtles (*Kinosternon flavescens*), Blanding's Turtles (*Emydoidea blandingii*), and Snapping Turtles (*Chelydra serpentina*) reach sexual maturity between 11-19 years of age and have adult annual survival rates between 0.930 – 0.966.

Delaying sexual maturity did, at times, have more effect on population persistence over time than decreased survival rates. Models with sexual maturity delayed to Age 11 and 12 had a higher probability of a 50% population decline than decreasing any age class survival rates by 10%. Overall, in the Baseline model, the survival rates of juveniles, subadults, and young adults were the most influential variables in the model unless sexual maturity was delayed by 3 or more years than the Baseline model. These results indicate that research should focus on obtaining accurate values for these sensitive variables. Also, management can aid populations like the one in our Baseline model by providing high quality habitat which will encourage robust individual growth rates and decrease the chances of an unusual delay of sexual maturity.

Relationship between population size and population persistence over time.---The size of the population made a difference in the probability of decline and which age groups had more impact on population persistence over time. There was a large difference in the probability of population decline when comparing the Small population to the Baseline or Large population, but not as much difference between the Baseline population and the Large population. This suggests that there are critical population sizes where a population is less likely to be able to respond to stochasticity and indicates that this parameter should be measured by researchers. A number of other studies have suggested the existence of population size thresholds for long-term persistence (e.g., Brito and Da Fonseca, 2006;.Wielgus, 2002; Horino and Miura, 2000; Wiegand et al., 1998).

The sensitivity of the model to survival rates of particular age groups was also dependent on the population size. We found that older individuals were more important to population persistence in small populations and younger individuals were more important to population persistence in large populations. This could be indicating that small populations need reproductive individuals to maintain and increase the population size while large populations need younger individuals to replace adults as they age. The concept of juveniles acting as a reservoir to replace lost adults has been demonstrated by Root (1998) who found that extra juveniles in a Scrub Jay population increased the probability of population persistence.

Relationship between catastrophes and poaching on population persistence over time.--- The results from the two scenarios, Catastrophe and Poaching, indicate that with the given survival rates and growth rate repeated periods of no hatchling survival or poaching will be detrimental to population persistence over time. The catastrophe simulation had less effect on population persistence over time than did the poaching simulation, indicating that adults are more important than hatchlings to population persistence over time. Others have modeled the effects of catastrophes or poaching on population persistence in other species (e.g., Guo et al., 2002; Takekawa et al, 2006; Wiegand et al., 1998; Linkie et al., 2006). Poaching and catastrophic events in these studies negatively affected adult age classes and the probability of population persistence varied depending upon growth rate and population size.

CONCLUSION

Population viability models and sensitivity analyses can be used for a multitude of purposes depending upon amount of data and research goals. Our research highlights a few ways in which sensitivity analyses can be used for the Spotted Turtle and species in which there is limited population data. Sensitivity analyses can also be used to direct future research and the management for rare species by focusing on variables found to be influential on population viability over time. Given that there is usually limited data on rare or cryptic species it is important to incorporate sensitivity analyses into the management process.

Our results indicate that there are many intrinsic and extrinsic factors that can influence model outcome which means that there are no general turtle models (Heppell, 1998) that can accommodate any species. Instead models need to be somewhat tailored to the specific demographic and population characteristics of the species and questions of interest. Our research took this a step farther by not only exploring the influence of age classes but also a variety of other scenarios.

In the case of the Spotted Turtle, our research highlights that it is critical for research to focus on age at reproduction, population size, and growth rate. One of the most interesting results was that population size had a large impact on which age classes were most influential on population viability over time. Incorporating the data collection of these variables into field studies will provide much more information than presence or absence surveys and will create a more complete picture of the threats this species faces in areas throughout the range.

Table 1. Shown are the mean annual survival (Sx) and fecundity (Fx) values and the Coefficient of Variation (CV) for females used in the Baseline model by age. Females began breeding at Age 8.

Age	Sx	CV ±	Fx	CV ±
1	0.50	0.10	0	0.15
2	0.70	0.10	0	0.15
3	0.70	0.10	0	0.15
4	0.70	0.10	0	0.15
5	0.70	0.10	0	0.15
6	0.80	0.10	0	0.15
7	0.80	0.10	0	0.15
8	0.93	0.10	1.19	0.15
9	0.93	0.10	1.19	0.15
10	0.93	0.10	1.19	0.15
11	0.93	0.10	1.19	0.15
12	0.93	0.10	1.19	0.15
13	0.93	0.10	1.19	0.15
14	0.93	0.10	1.19	0.15
15	0.93	0.10	1.19	0.15
16	0.93	0.10	1.19	0.15
17	0.93	0.10	1.19	0.15
18	0.93	0.10	1.19	0.15
19	0.93	0.10	1.19	0.15
20	0.93	0.10	1.19	0.15
21	0.93	0.10	1.19	0.15
22	0.93	0.10	1.19	0.15
23	0.93	0.10	1.19	0.15
24	0.93	0.10	1.19	0.15
25	0.93	0.10	1.19	0.15
26	0.93	0.10	1.19	0.15
27	0.93	0.10	1.19	0.15
28	0.93	0.10	1.19	0.15
29	0.93	0.10	1.19	0.15
30	0.10	0.10	1.19	0.15

Table 2. Shown are the results from reductions in the average annual survival rates of specific age groups compared to the Baseline model as the risk of a 50% reduction any time within the 50-year simulation and the change in final abundance. Survival rates were decreased independently by 10-30% for hatchlings (age 1), young juveniles (ages 2-3), older juveniles (ages 4-5), subadults (ages 6-7), young adults (ages 8-9), and adults (ages 10-11).

Model: % Decline in Survival	Probability of a 50% Population Decline	Change in abundance (Final – Initial)
Baseline	0.2370	+11.09
Hatchling: 10%	0.4451	-6.15
Hatchling: 30%	0.8457	-29.09
Young juvenile: 10%	0.6337	-17.15
Young juvenile: 30%	0.9919	-41.73
Older juvenile: 10%	0.6329	-17.31
Older juvenile: 30%	0.9914	-41.69
Subadult: 10%	0.6391	-17.58
Subadult: 30%	0.9927	-42.20
Young adult: 10%	0.6140	-16.05
Young adult: 30%	0.9837	-40.92
Older adult: 10%	0.5639	-12.62
Older adult: 30%	0.9617	-37.46

Table 3. Shown are results of reductions in the average annual adult fecundity and increase in Age 7 annual fecundity as the probability of a 50% population decline within the 50-year simulation and as the change in abundance over time.

Model: Change in Fecundity	Probability of a 50% population decline	Change in abundance (Final – Initial)
Baseline	0.2730	+11.09
Adult: -10%	0.4617	-7.41
Adult: -20%	0.7015	-21.04
Adult: -30%	0.8122	-26.96
Age 7: +10%	0.2517	+12.90
Age 7: +20%	0.2392	+15.41

Table 4. This table shows the results of delaying reproduction as the risk of a 50% reduction any time within the 50-year simulation and the change in final abundance.

Model: Age at Reproduction	Probability of a 50% Population Decline	Change in abundance (Final – Initial)
Baseline (8 years)	0.2730	+11.09
9 years	0.4309	-4.85
10 years	0.6155	-16.14
11 years	0.7672	-23.70
12 years	0.8852	-29.84

Table 5. Shown are the results from 10% reductions in the average annual survival rates of specific age groups of the Baseline, Small, and Large population models as the risk of a 50% reduction in abundance any time within the 50-year simulation. Bolded values are considered highly influential in population persistence over time.

	Small	Baseline	Large
Model	Prob. Of Decline	Prob. Of Decline	Prob. Of Decline
Hatchling	0.675	0.445	0.382
Young Juvenile	0.790	**0.634**	**0.601**
Older Juvenile	**0.846**	**0.632**	**0.590**
Subadult	**0.855**	**0.639**	**0.603**
Young Adult	**0.839**	**0.614**	0.549
Older Adult	**0.831**	0.563	0.488

Table 6. Shown are the results from varying no hatchling survival once every 5, 10, or 15 years within the Baseline, Large, and Small populations as the risk of a 50% reduction any time within the 50-year simulation and the change in final abundance.

No hatchling survival Scenarios	Probability of a 50% population decline	Change in abundance (Final – Initial)
Baseline Population	0.2730	+11.09
Once every 15 years	0.4520	+1.41
Once every 10 years	0.5390	-17.64
Once every 5 years	0.7690	-26.22
Large Population	0.1975	+14.23
Once every 15 years	0.3787	+2.19
Once every 10 years	0.5028	-24.14
Once every 5 years	0.7639	-37.43
Small Population	0.6165	+0.63
Once every 15 years	0.7111	-4.04
Once every 10 years	0.7703	-13.3
Once every 5 years	0.9025	-18.03

Table 7. Shown are the results from varying a poaching event once every 5, 10, or 15 years within the Baseline model as the risk of a 50% reduction any time within the 50-year simulation and the change in final abundance.

Poaching Scenarios	Probability of a 50% Population decline	Change in abundance (Final – Initial)	Percent change in abundance
Baseline Population	0.2730	+11.09	+22.18
Once every 15 years	0.7716	-25.62	-51.24
Once every 10 years	0.8764	-36.98	-73.96
Once every 5 years	0.9995	-49.81	-99.62

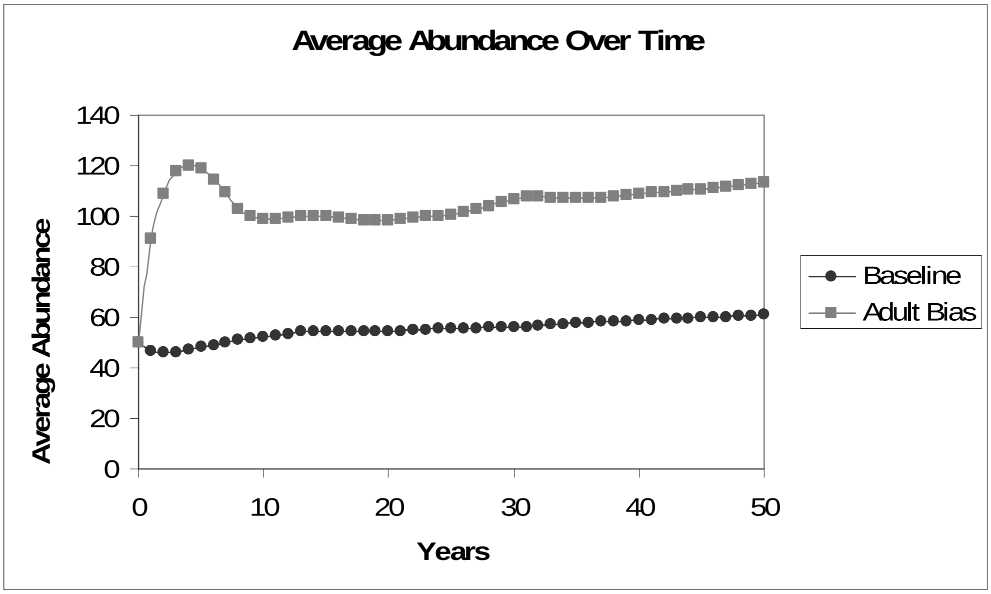

Figure 1. Shown are the results of the Baseline model with a stable age distribution and the Adult biased model that had a population of 80% adults as the average total female abundance over time as years.

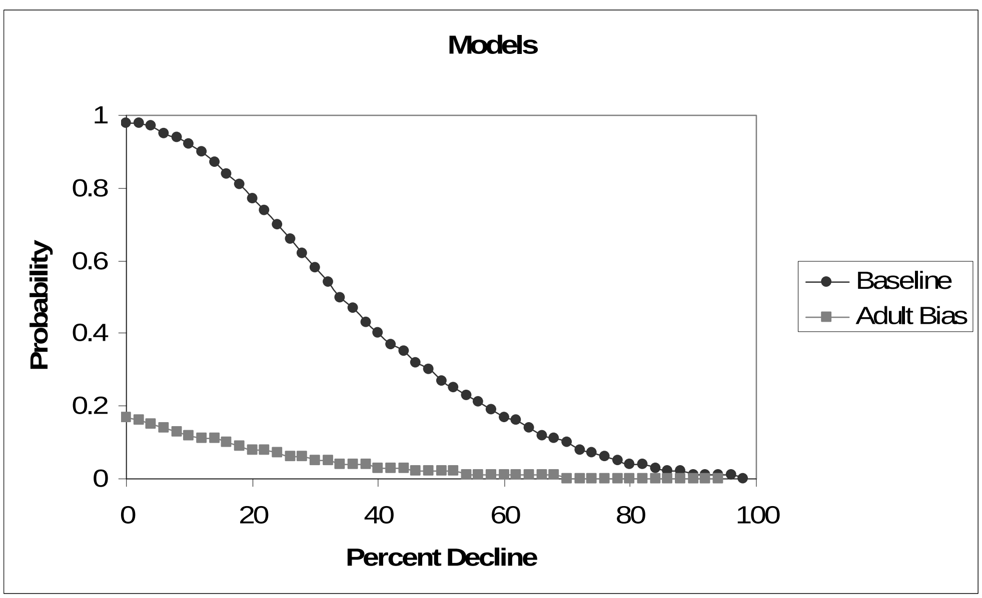

Figure 2. Shown are the probabilities of population percent decline of the Baseline model which has a stable age distribution and the Adult biased model which has a population of 80% adults.

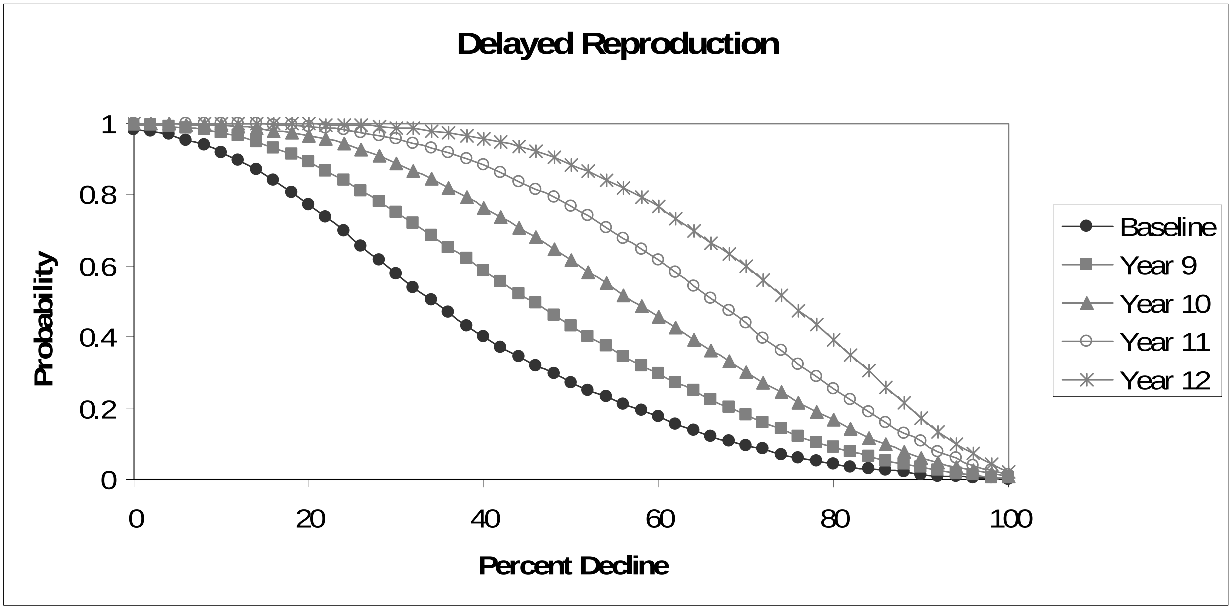

Figure 3. Shown are the results from delaying the age of maturity from 8 to 9-12 years of age. The interval percent decline curves had the maximum difference from the Baseline model at X=36 for Year 9, X=40 for Year 10, X=46 for Year 11, X=52 for Year 12.

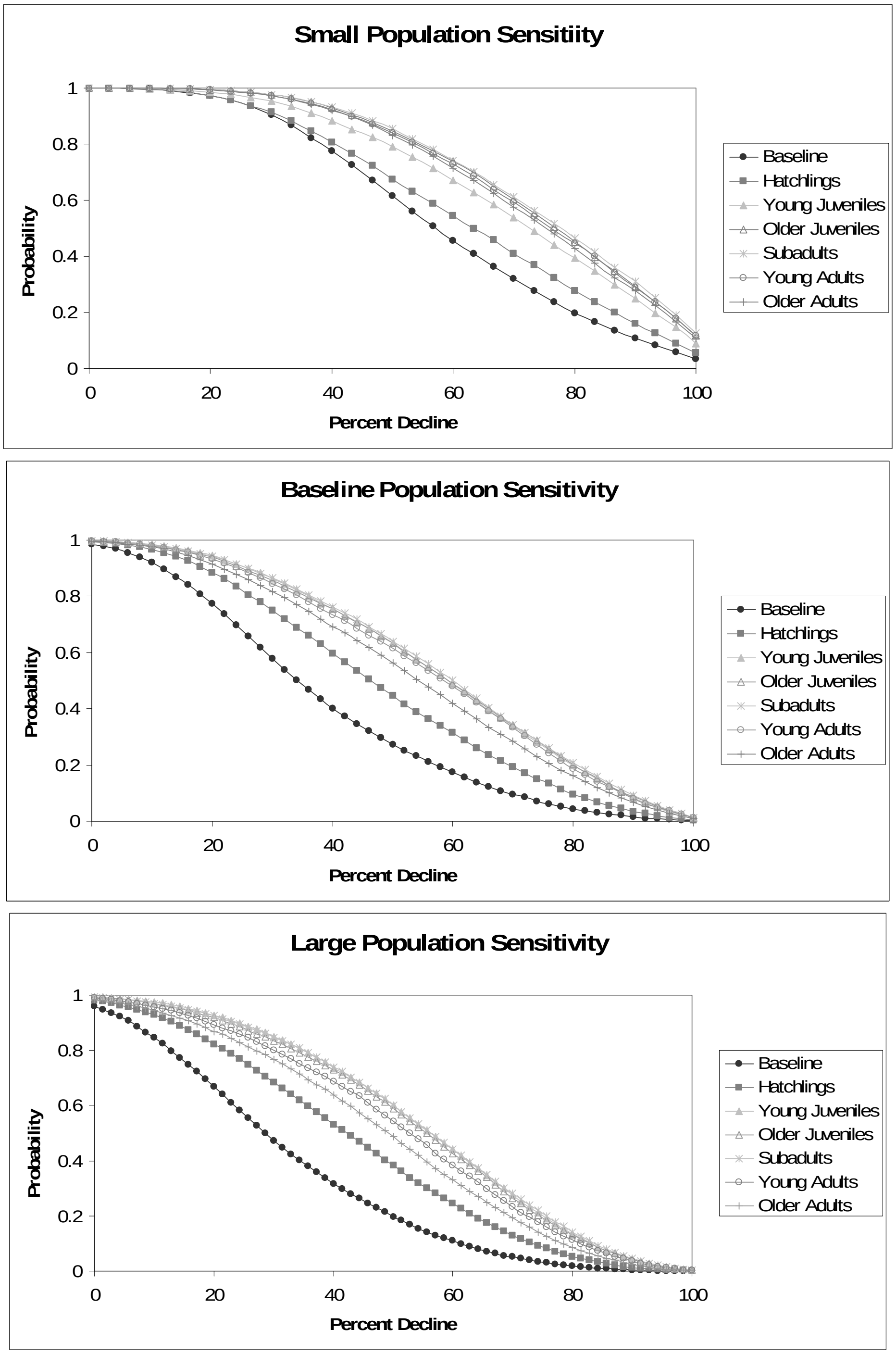

Figure 4. Shown are the results from reductions in the average annual survival rates of specific age groups of the Baseline, Small, and Large population models as the risk of a 50% reduction any time within the 50-year simulation.

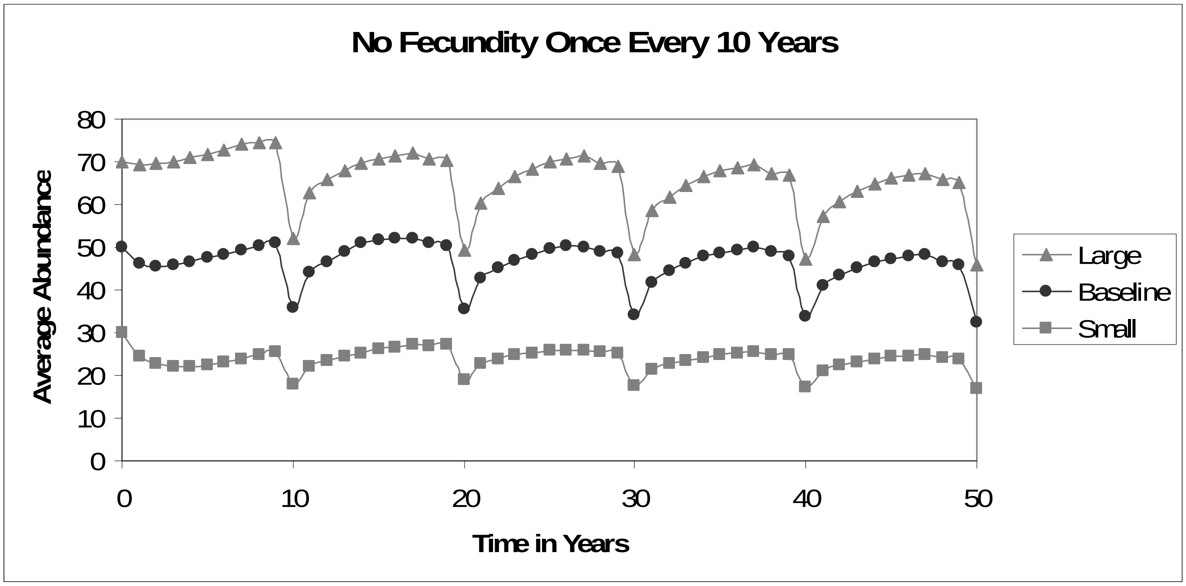

Figure 5. Shown are the results from the catastrophe models, indicating no fecundity events once every 10 years, for the Baseline, Large, and Small populations as changes in final average abundances.

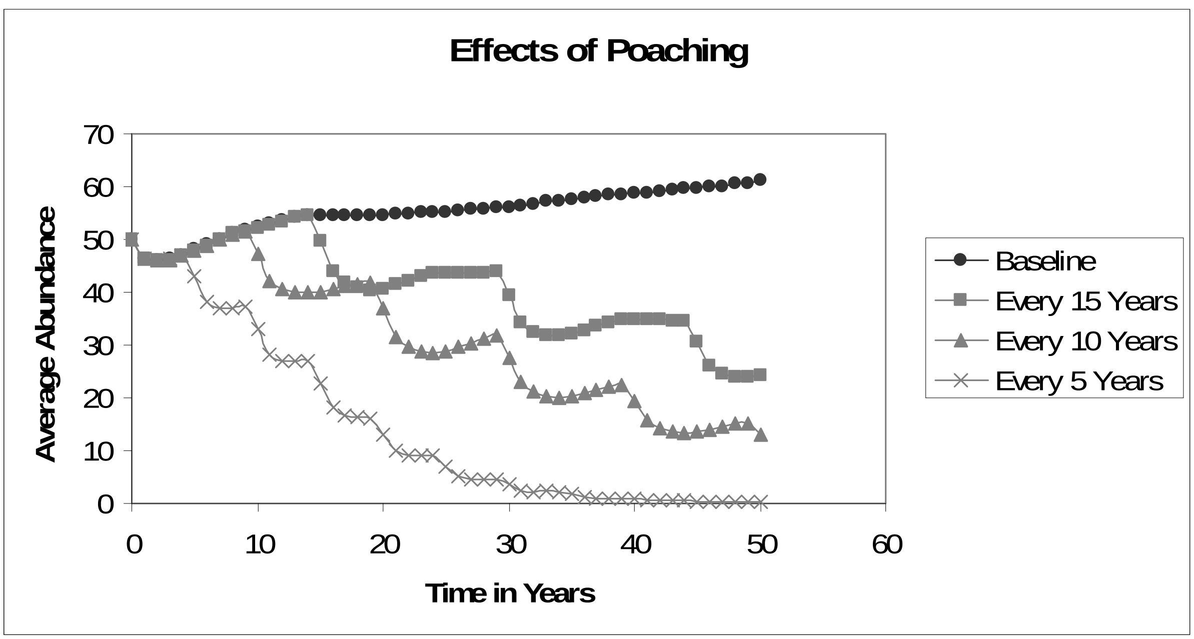

Figure 6. Shown are the results of a poaching event once every 5, 10, or15 years as the change in average final abundance.

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CHAPTER III

AN ASSESSMENT OF THE HABITAT AND POPULATION CHARACTERISTICS OF SPOTTED TURTLES (*CLEMMYS GUTTATA*) IN NORTHWEST OHIO

INTRODUCTION

The Spotted Turtle, *Clemmys guttata*, is a species of freshwater turtle that occurs in disjunct populations from southern Ontario and Maine, south to Florida, and from Pennsylvania west to Illinois. It is protected in the majority of its range, being listed as critically imperiled, imperiled, or vulnerable (NatureServe, 2007) and is threatened in Ohio (ODNR, 2006). This small species can be identified by its black carapace that is marked with small yellow to orange spots. Adults rarely exceed 5 inches in length and can be found in wetland habitats that have a soft substrate and aquatic vegetation (Ernst et al., 1994).

Spotted Turtle populations are declining for a variety of reasons, including habitat loss, collection for the pet trade, and increased predation by subsidized predators such as raccoons (Ernst et al., 1994; Mitchell and Klemens, 2000; Burke et al., 2000). Many freshwater turtle species are more vulnerable to population decline because of life history characteristics such as delayed age of maturity and small clutch sizes (Ernst and Zug, 1994). For these reasons studies should examine the critical habitat and demographic constraints of Spotted Turtles to improve our ability to protect them and the habitats they occupy.

Previous studies have investigated population parameters and habitat use of Spotted Turtles throughout the range since this information is useful in making management plans. Age structure, population size, and density of population vary by site (Graham, 1995; Milam and Melvin, 2001; Seburn, 2003; Litzgus and Mousseau, 2004a; etc) and can give insight into population viability. Specific environmental descriptions such as the characteristics of habitat structures used for summer dormancy and wintering have been described (Litzgus et al., 1999; Litzgus and Mousseau, 2004b) to obtain a sense of the heterogeneity required by this species.

One of the most reported aspects of Spotted Turtle ecology is landscape use during different seasons. It has been well documented that Spotted Turtles aestivate in the summer when water temperatures reach 32°C and are known to over-winter in communal hibernacula structures (Ernst et al., 1994). Specific seasonal movements can vary by location but generally consist of winter hibernation, emergence in or to aquatic locations, female nesting, summer aestivation, and fall migrations to hibernacula (Graham, 1995; Haxton and Berrill, 2001).

Details regarding these activities vary throughout the range based on biotic and abiotic conditions. The majority of recent work with Spotted Turtles has taken place in the northern and southern portion of the range making it desirable to have data from the center portion of the range, such as Ohio. Ohio studies have focused on threats to habitat (Lewis et al., 2004), home ranges (Lewis and Faulhaber, 1999), and characteristics of hibernacula (Lewis and Ritzenthaler, 1997). These studies have indicated that most Ohio Spotted Turtle habitats are suboptimal due to isolation and habitat alteration by invasive plant species, suggesting that Ohio Spotted Turtle populations may be declining.

Currently there are records of known locations of Spotted Turtles in Ohio which can be obtained through the Natural Heritage Database, but little is known about the status of these populations. There is an urgent need to identify the current status of Spotted Turtles in Ohio and to understand what habitat characteristics are critical throughout the year for long-term persistence. The goal of our study is (1) to further explore the current status of Spotted Turtles in Northwest Ohio by measuring population size, density, and age structure, (2) determining how turtles use the landscape, and (3) identifying critical environmental characteristics at the local scale.

Study Sites.---We conducted our study in the Oak Openings Region of Northwest Ohio which is an approximately 200 square kilometer area (Moseley, 1928) in Northwest Ohio consisting of black oak savanna, oak woodland and wet prairie communities fragmented by human development. Wet prairies are dominated by twigrush (*Cladium mariscoides*) and wiregrass (*Carex lasiocarpa*), seasonally inundated with water during late winter and spring, and have a fine sand soil (EPA, 2006).

Two of the major threats to wet prairies include reduction in groundwater and shrub invasion requiring that sites be managed with fire or mowing to reverse succession. Many of the wet prairies have been eliminated and those that still exist occur in small pockets surrounded by shrub thickets or pin oak stands where management practices don't occur (EPA, 2006).

We selected two sites, Kitty Todd Nature Preserve (Kitty Todd) and Bumpus Pond (Figure 1), based on the presence of Spotted Turtles, the accessibility of the site, close proximity to each other, and intensity of management (Figure 2). Kitty Todd is owned by The Nature Conservancy and has one of the highest concentrations of rare species of any Ohio preserve (The Nature Conservancy, 2008). This site is actively managed with recent management consisting of mowing shrubby vegetation.

Bumpus Pond consists of a series of land tracts that were purchased by Metroparks of the Toledo Area from 12/03 – 3/05. Recent management has consisted of some removal of the invasive species glossy buckthorn, *Rhamnus cathartica*. There are plans to engage in intensive management which will consist of cutting and removing large amounts of shrubby vegetation (personal communication, Tim Schetter, Land Planning and Acquisition Manager).

METHODS

We conducted the study at Bumpus Pond from 2005-2007 and Kitty Todd from 2006-2007, with the greatest intensity of sampling from March to May. All sampling in March to May was conducted on sunny to partly cloudy days between 0830 and 1800 h. During this period, in all years, Bumpus Pond was sampled at least once a week and Kitty Todd was sampled at least twice a week by systematically walking through the entire study site while visually surveying for turtles. More time was spent searching in wet areas than dry areas because we felt that it was harder to find turtles in the wet prairie areas than the forested areas due to the lack of dense ground cover in the forested areas.

We collected individuals by hand and each turtle greater than 30 grams and 57 mm carapace length was marked with a PIT tag (AVID Identification Systems, Norco, CA). For each turtle we recorded: weight, carapace and plastron length, activity during capture, whether it was previously captured, and general observations including the presence of injuries or apparent illness (e.g., damaged shell, swollen eyes). Weight was measured with a Pensola 300g spring scale (±0.3%) and shell length was measured with Cen-Tech 6” digital calipers (±0.001”).

We recorded the exact location of each capture point using a Garmin Etrex Vista GPS unit when accuracy was no less than 5-7m. Photographs were taken of each individual as a back up means of identification. A written description of each location, date, and time of capture was recorded. We recorded the air and water temperature, when applicable, with a Taylor Switchable Digital Pocket Thermometer at most capture points.

In addition to field surveys, we attached transmitters to two turtles at each site in 2006 and monitoring continued until September. In 2007 we had attached transmitters to three turtles at each site and monitored until November. Radio tracked individuals were chosen based upon three criteria: size, health, and location. We searched for adults over 170 grams to reduce the transmitter weight-to-body weight ratio. Only healthy individuals showing no signs of injury or illness were chosen for radio tracking. The transmitters obtained from Holohil Systems Ltd. (SI-2F; Carp, Ontario, Canada) were attached on posterior carapacial scutes via a non-toxic epoxy (PC·7; PC-Products, Allentown, PA).

Turtles were tracked, using a TRX-1000S receiver and three element Yagi antenna, anywhere from several times a week to once a month depending on turtle movement rates. More frequent tracking took place when turtles were frequently moving. We chose individuals found in different parts of the site to increase our chance of finding additional unmarked turtles throughout the site while locating animals carrying transmitters and to reveal the specific locations used during different times of the year.

***Analysis.*---**Population size was calculated using the Schumacher-Eschmeyer (Krebs, 1989) formula because these are geographically closed populations and we had multiple recapture dates. When examining mark recapture data we did not include the recaptures of radio tracked individuals since the majority of the time we did not find radio tracked turtles using our visual survey.

We assigned individuals to four age classes based on the plastron length at most recent capture: hatchlings under 30 mm, juveniles 30-79 mm, subadults 80-90 mm, and adults 90+ mm. The cut off points of each age class were based on published values (Ernst et al., 1994).

We used ArcGIS 9.2 to overlay the GPS points on a high-resolution (6”) aerial photograph which was taken in 2003 (Kaczala, 2005) to visualize areas used during different seasons and individual-specific movements. We determined site size by creating a minimum convex polygon around all point occurrences from PIT tagged and radio tracked turtles in each study site. We identified core areas within each site using a fixed kernel density analysis with 95, 90, and 50 percent volume contour lines (Hawth’s Tools, 2008; Figure 3).

Environmental Characteristics.---We used ArcGIS 9.2 to calculate the percentage of wet prairie, shrub/scrub, and forest in each study site. To do this we digitized polygons on the aerial photograph representing each land cover type using the photograph and our knowledge of the site as a guide.

In May 2008 we measured vegetation height and density and water height at 10-11 locations within the 50% (i.e., inner core) and 90% (i.e., outer core) volume contour lines and in 9 locations outside of the 90% contour line (i.e., buffer) at each site. We chose to take the measurements at points within the core and buffer areas that proportionally represented the heterogeneity of the sites (e.g., if the area consisted of half shrub and half wet prairie, half of the measurements were taken in shrub areas and half were taken in wet prairie areas).

We measured vegetation height, density, and water height using a Robel pole (Robel et al., 1970). Vegetation height represented the tallest vegetation within a 6” radius of the Robel pole. Vegetation density represented an average of the readings taken while standing at three meters to the north and south of the Robel pole. Water height represented the height of the water touching the Robel pole.

We determined if there were statistically significant differences in vegetation height, density, and water height between the three areas of the site (e.g., inner core, outer core, and buffer) using a Kruskal-Wallis test in SAS 9.1.

RESULTS

Population Characteristics.---We captured a total of 59 Spotted Turtles in our two study sites combined. At Bumpus Pond, we captured a total of 15 unique individuals, with 4-6 new individuals and 1-6 recaptures each year (Table 1). At Kitty Todd, we captured a total of 44 unique individuals, with 20-23 new individuals and 7-20 recaptures each year (Table 1). Overall, at Bumpus Pond we recaptured 7 individuals at least once, for a total recapture rate of 47%. At Kitty Todd we recaptured 12 individuals at least once, making the total recapture rate at this site 27%. Most of the turtles, i.e., 80%, were captured between mid-March and late-April when air temperatures averaged 12.3°C but ranged between 3.5 – 25.6°C. This correlates with spring thaw leading to lower water levels and/or drying up in the wet prairies.

Of the total number of turtles captured, at Bumpus Pond we found 6 adults, 4 subadults, 5 juveniles, and no hatchlings. At Kitty Todd we found 10 adults, 14 subadults, 20 juveniles, and no hatchlings. We found 20 turtles with signs of injury or abnormalities: 7 turtles at Bumpus Pond and 13 turtles at Kitty Todd. Of these 20 turtles 17 were subadults or adults. Based on our captures over the entire study period, the estimated population size of turtles at Kitty Todd was 73 with a confidence interval of 56 to 102 individuals. The population size at Bumpus Pond was 22 turtles with a confidence interval of 14 to 56 individuals.

We radio tracked a total of 10 individuals. The turtles chosen were over 170 grams, except one individual that was 123 grams, which we chose because it was in an area of the site where no other turtles had been captured.

During our visual surveys 97% of the turtles we found were either basking or swimming near the surface of the water. Turtles were found basking on sedges, grasses, and logs. Turtles that were under vegetation or deeper water could not be seen; 42% of the recaptures of radio tracked individuals were in locations where our visual survey would have missed them, such as hidden under vegetation, fallen wood, or buried in mud.

Distribution and Behavior.---Some turtles that were equipped with transmitters could be found during summer aestivation and winter hibernation, the times of year where there is the least amount of movement. Turtles were found aestivating in similar geographic areas as found in spring but at ground level where the soil was moist or under mud, in tall dense vegetation. On two occasions we measured the ground temperature versus the air temperature and found that the ground temperature was cooler than air temperature at waist height (difference of 5.2 and 7.0°C).

During late fall and winter we tracked three turtles to three different hibernacula locations: under upturned tree root ball, under a trash pile, and underground near the base of a tree. All locations were at the edge of the study sites and two were in forested areas. We observed that the upturned tree roots provided easy access to underground. The trash pile consisted of decaying wood, a mattress, and scrap metal potentially providing insulation from the cold. The location near the base of a tree consisted of leaf litter and loose soil, which presumably made burrowing easy. There was no water in these areas during late-summer and fall, but these locations were occasionally underwater in winter and were underwater in spring.

The size of the Kitty Todd site was 10.6 ha, and Bumpus Pond was 2.6 ha based on a minimum convex polygon surrounding our capture locations. The size of Kitty Todd was an overestimate since we have not found turtles in more than half of that area. To address this we created a polygon by connecting the point occurrences that allowed angles greater than 180° and found the area to be 4.0 ha. The density of turtles at Kitty Todd based on the estimated population size and site size actively being used by turtles was 18.25/ha. The density of turtles at Bumpus Pond was 8.46/ha.

We found that individuals could be found in similar locations in different years. For example, we found the same individuals basking in the same areas each spring and at Kitty Todd we found that turtles only used portions of the site and were never found in other areas of the site. There were only two turtles in which we had year round location data. The total area being used by the individual at Kitty Todd was 0.258 ha, and the turtle at Bumpus Pond used an area of 0.209 ha.

Environmental Characteristics.---While both the study sites contained wet prairie habitats with the tallest vegetation in the inner core and higher water levels in the inner and outer core versus the buffers, there were some differences such as the percentage of wet prairie, shrub/scrub, and forest. We found that Kitty Todd consisted of 87% wet prairie, 5% shrub/scrub, and 8% forest. Bumpus Pond consisted of 9% wet prairie, 36% shrub/scrub, and 55% forest.

We examined the vegetation height, density, and water height (Table 2, Figure 4) at Kitty Todd and found that the inner core, the area within the 50% volume contour line, had significantly higher water than the outer core (x^2 (1)=6.2741, p=0.0123) and the buffer (x^2 (1)=4.8790, p=0.0272). The vegetation height was significantly higher in the inner core versus the buffer area (x^2 (1)=6.6336, p=0.0100). There was no difference in vegetation density between any of the measured areas.

At Bumpus Pond the vegetation was the tallest and densest in the inner core area versus the outer core (x^2 (1)=5.5775, p=0.0182 and x^2 (1)=4.9229, p=0.0265, respectively) and buffer (x^2 (1)=12.8377, p=0.0003 and x^2 (1)=7.6708, p=0.0056, respectively). The water height was similar throughout the study site, but was lower in the buffer compared to the outer core (x^2 (1)=11.1364, p=0.0008).

DISCUSSION

We explored the current status of Spotted Turtles in Northwest Ohio by measuring age structure, population size, and density at two study sites. We found the age structure at Kitty Todd to be roughly a 1:1 ratio of sub-adults/adults to juveniles and the age structure at Bumpus Pond to be a 2:1 ratio. It is unusual to find as many juveniles as we did at Kitty Todd, since the age structure of most reported populations have an adult biased population with roughly 84-86% of the captures being sub-adults and adults (Seburn, 2003; Graham, 1995; Litzgus and Mousseau, 2004a). This suggests that the population at Kitty Todd was growing and that the current management regime was working well.

We found the population sizes of our two study sites varied with Kitty Todd having more than three times the number of turtles than Bumpus Pond. The population size of Spotted Turtle populations throughout the range tends to vary greatly with population size estimates ranging from 18-258 turtles (Ernst, 1976; Graham, 1995; Milam and Melvin, 2001; Seburn, 2003). Population size can be dependent upon the size and quality of the study site, with larger higher quality sites being more likely to support a larger quantity of turtles which has also been demonstrated with other species (Lin and Batzli, 2001; Reid et al., 2007).

Knowing the density of turtles also gives insight into the quality of the site. We found that the density is higher at Kitty Todd than Bumpus Pond indicating that wet prairie habitat may be able to support a larger population of turtles than the shrub/scrub of Bumpus Pond. The population densities at both of our sites were much higher than the densities reported in recent literature, such as Milam and Melvin (2001) reporting densities of 0.2-1.4 adult turtles/ha in Massachusetts and 0.36 turtles/ha by Litzgus and Mousseau (2004a) in South Carolina. One exception was that the density at Bumpus Pond was similar to the density of 6.7 turtles/ha found by Graham (1995) for a population of Spotted Turtles in Massachusetts. In contrast, Ernst (1976) reported densities ranging from 39.5-79.1 turtles/ha in Pennsylvania. This could indicate that range wide habitat has been degraded over the past 30 years.

We captured a larger proportion of turtles with injuries or abnormalities at Bumpus Pond (47%) than Kitty Todd (27%). We are unsure as to the reason for the difference between sites, though it is not uncommon for Spotted Turtles to show signs of predation. Others have reported populations with 13.5-31% of individuals showing signs of injuries (Ernst et al. 1994 cited: Ernst, 1976 and Lovich, 1989). Though our study did not investigate the surrounding landscape, it may play a role in the proportion of injuries. Both sites are surrounded by some forested areas and low density residential properties. Also we do not know the exact age of the adult turtles, but this may have influenced our results since we found that older individuals had more signs of injuries than younger turtles.

We also obtained information on how the turtles were using the landscape across space and over time. We found that turtles were demonstrating site fidelity with individual turtles being found in similar locations during the same seasons in different years. Though we only had complete year round movement data for two turtles, we found that recaptured turtles were staying in small areas of the study sites, indicating that all of the turtles' requirements (e.g., mating, nesting, hibernating, etc.) could be met within a portion of the study site. Litzgus and Mousseau (2004b) have also noted home range fidelity in Spotted Turtle populations.

The home range sizes of 0.258 ha and 0.209 ha for the two turtles for which we had year round data is smaller than what others have indicated in the literature. Average home ranges for Spotted Turtles vary by site and typically range from 0.53 ha (Litzgus and Mousseau, 2004b) to 3.5 ha (Milam and Melvin, 2001) with the exception of one study that found gravid females were using an average home range of 16 ha (Litzgus and Mousseau, 2004b). Home range size could be due to the quality of the sites or the habitat availability (i.e, finding adequate areas for nesting). It is possible that with additional point occurrences the home range sizes would increase.

Locating hibernacula in our area was of interest because most structures have been described in bogs that have year round water. Hibernacula in bogs consisted of areas under tree roots, rock caverns, or deep holes in organic muck (Lewis and Ritzenthaler, 1997; Litzgus et al, 1999; Seburn 2003). In all of these instances turtles were in water below ice or in water areas that didn't freeze. Litzgus and Mousseau (2004b) did observe turtles hibernating terrestrially under leaf litter during a drought year. In our sites, which typically had water only in late winter to early summer, we found turtles hibernating under upturned root balls, under decaying wood in a trash pile, and under soil and leaf litter.

We met our third goal of identifying critical environmental characteristics at the local scale and found that turtles at Kitty Todd were using areas with higher water and taller ground vegetation. Turtles at Bumpus Pond were using areas with higher water, taller and more dense vegetation. We believe that vegetation density was not significant at Kitty Todd because management had occurred the previous fall causing vegetation to be relatively short and we could see near the bottom of the Robel pole on all occasions. We did not find it surprising that vegetation and water characteristics were found to be significant since it is known that Spotted Turtles can be found in shallow wet areas with aquatic vegetation and a soft substrate (Ernst et al. 1994).

We were also interested in vegetation and water characteristics since habitat use is dependent upon what is available. Few studies have examined the environmental characteristics being used by Spotted Turtles. In general habitat descriptions pertain to areas being used during different seasons described as ponds, swamps, seasonal pools, upland forest, etc. (Litzgus and Brooks, 2000; Milam and Melvin, 2001). Lewis et al. (2004) did discuss the effect of invasive plants in Spotted Turtle habitat but did not measure differences between areas of high and low densities of turtles within a site.

Our study highlights the amount of information that can be obtained with a few years of data when multiple techniques such as mark-recapture, radio telemetry, and environmental surveys are incorporated. We found that the density of turtles in the study sites was greater than what other researchers have noted in recent literature and that turtles were showing high site fidelity. Not only did we gain insight on population status, but we obtained a better understanding of the complex seasonal habitat requirements of this species. In particular, turtles required heterogeneous sites to complete year round activities, but used core areas that consisted of deeper water, taller and denser understory vegetation. These techniques are applicable to a variety of other species and can be used to guide management.

Management Recommendations.---We encourage the management of sites occupied by Spotted Turtles since turtles showed high site fidelity. It is important to maintain or create site heterogeneity so that turtles can complete all yearly activities within the site. This should aid in lowering mortality since turtles will not be crossing roads and will spend less time exposed to predators. In addition to the heterogeneity, we found that Spotted Turtles spent much of the activity season in areas with high water and tall, dense grasses and sedges.

Though turtles were able to tolerate a range of vegetation densities, wet prairie habitat was found to support a greater density of turtles. This indicates that sites with similar environmental characteristics as ours should be managed every 2-5 years, depending upon the rate of succession, by removing some shrub/scrub to raise water levels and encourage the growth of native sedges and grasses. Some logs and tree limbs should remain at the site as they are used for basking and wood piles may provide protection from predators. Sites should be managed to avoid open water by assuring that native vegetation, such as twigrush and wiregrass in our sites, exist. Forested edges can remain as turtles utilize them during hibernation. Fire is not always an option to remove woody vegetation and Kitty Todd managers have shown that mowing is quite effective. The mowing height should be based on the size of slow moving wildlife that inhabits the area. In our case a mowing height of 6 inches would leave clearance for all reptile species.

Table 1. Number of New Captures and Recaptures at Bumpus Pond and Kitty Todd.

Study Site	Unmarked	Recaptured
Bumpus Pond		
2005	4	1
2006	5	5
2007	6	6
Total	15	
Kitty Todd		
2006	23	7
2007	21	20
Total	44	

Table 2. Average Environmental Characteristics at Bumpus Pond and Kitty Todd.

Study Site	Average Vegetation Density (dm)	Average Water Height (dm)	Average Vegetation Height (dm)
Bumpus Pond			
Inner Core	5	1.9	3.7
Outer Core	2.4	1.6	2.5
Buffer	1.8	0.4	1.8
Kitty Todd			
Inner Core	3.2	1.5	1.6
Outer Core	2.4	0.6	1.3
Buffer	1.2	0.9	1.6

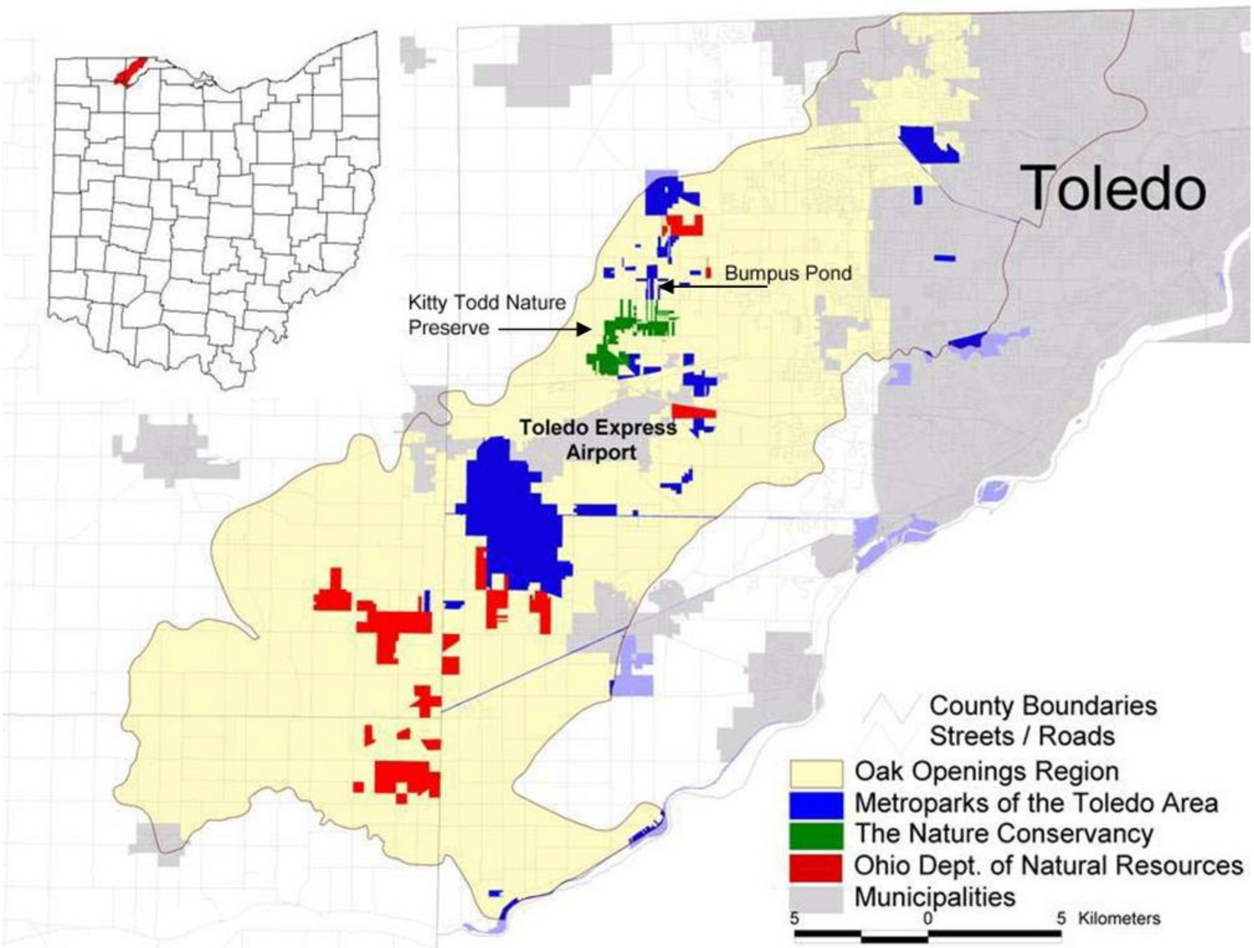
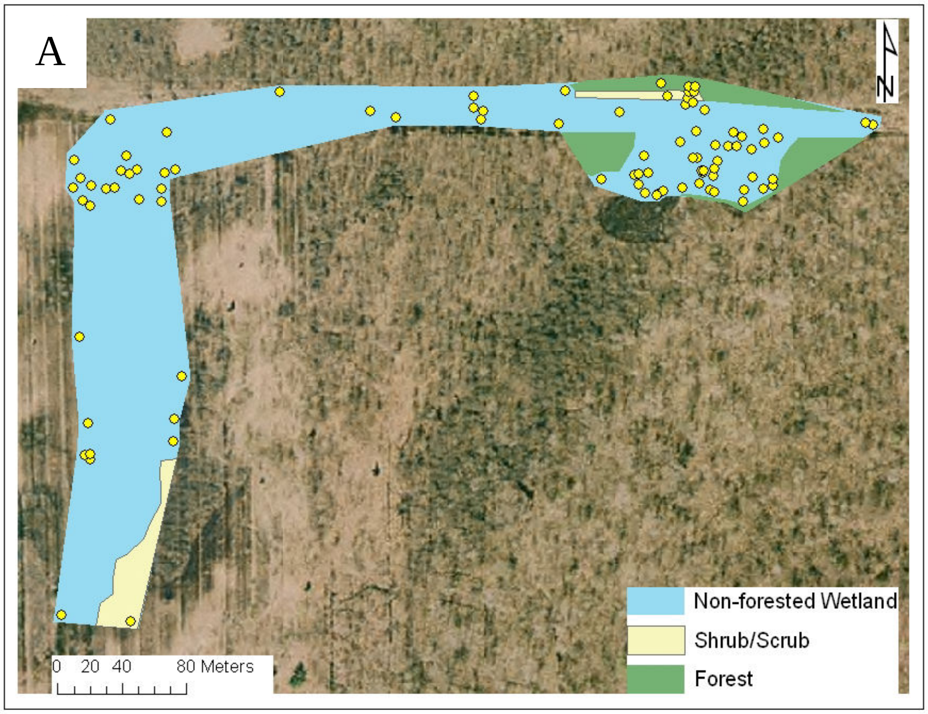


Figure 1. Location of Kitty Todd Nature Preserve and Bumpus Pond within the Oak Openings Region, Lucas County, Northwest Ohio. Map modified from Schetter and Root, in prep.



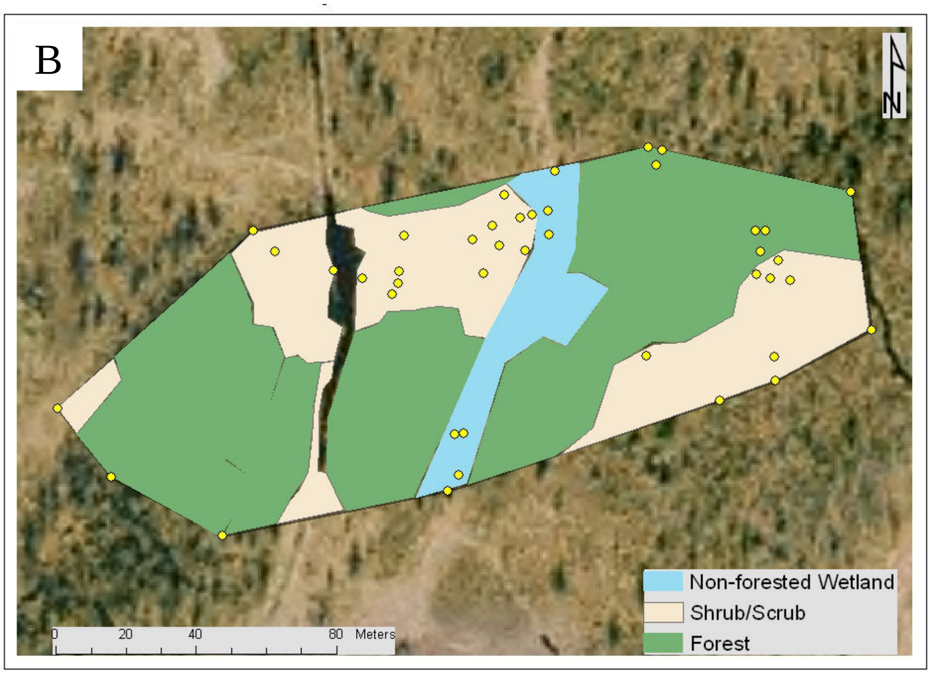
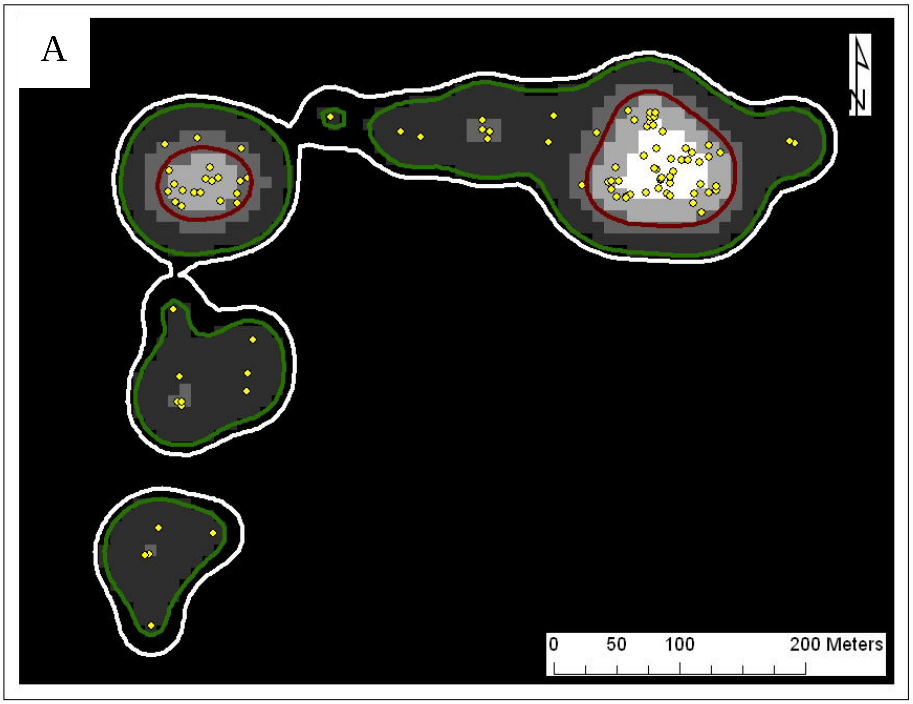


Figure 2. Shown are the land cover types at the two study sites. Top: Kitty Todd Nature Preserve. B: Bumpus Pond.



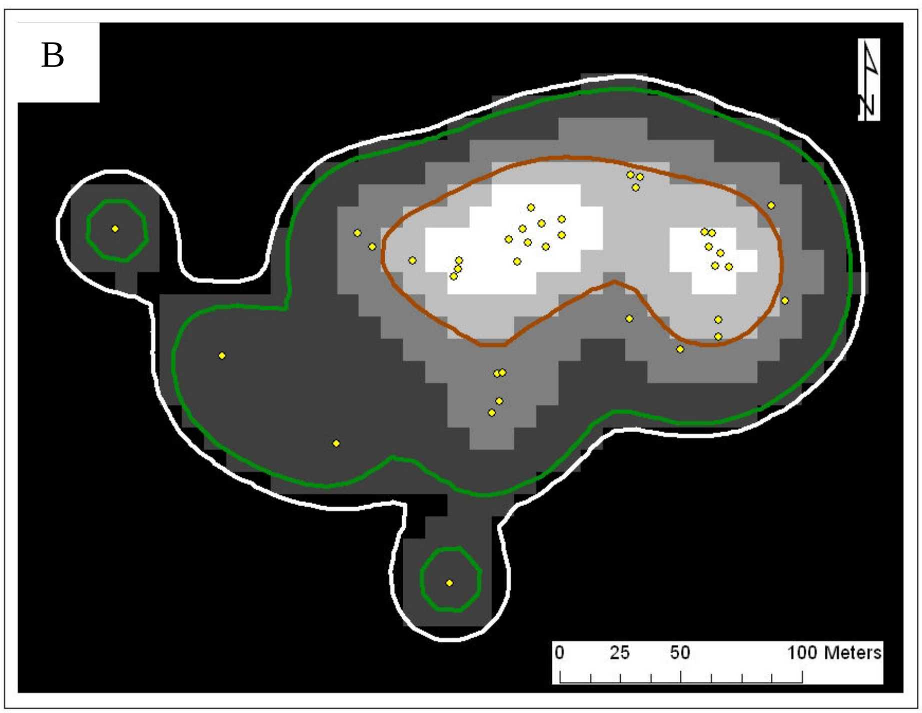


Figure 3. White areas indicate the highest density of turtles within each site, scaling down to black areas in which no turtles were found. The red lines represent the 50% density interval curve, green lines represent the 90% density interval curve, and the white lines represent the 95% density interval curve. A: Kitty Todd Nature Preserve, B: Bumpus Pond.

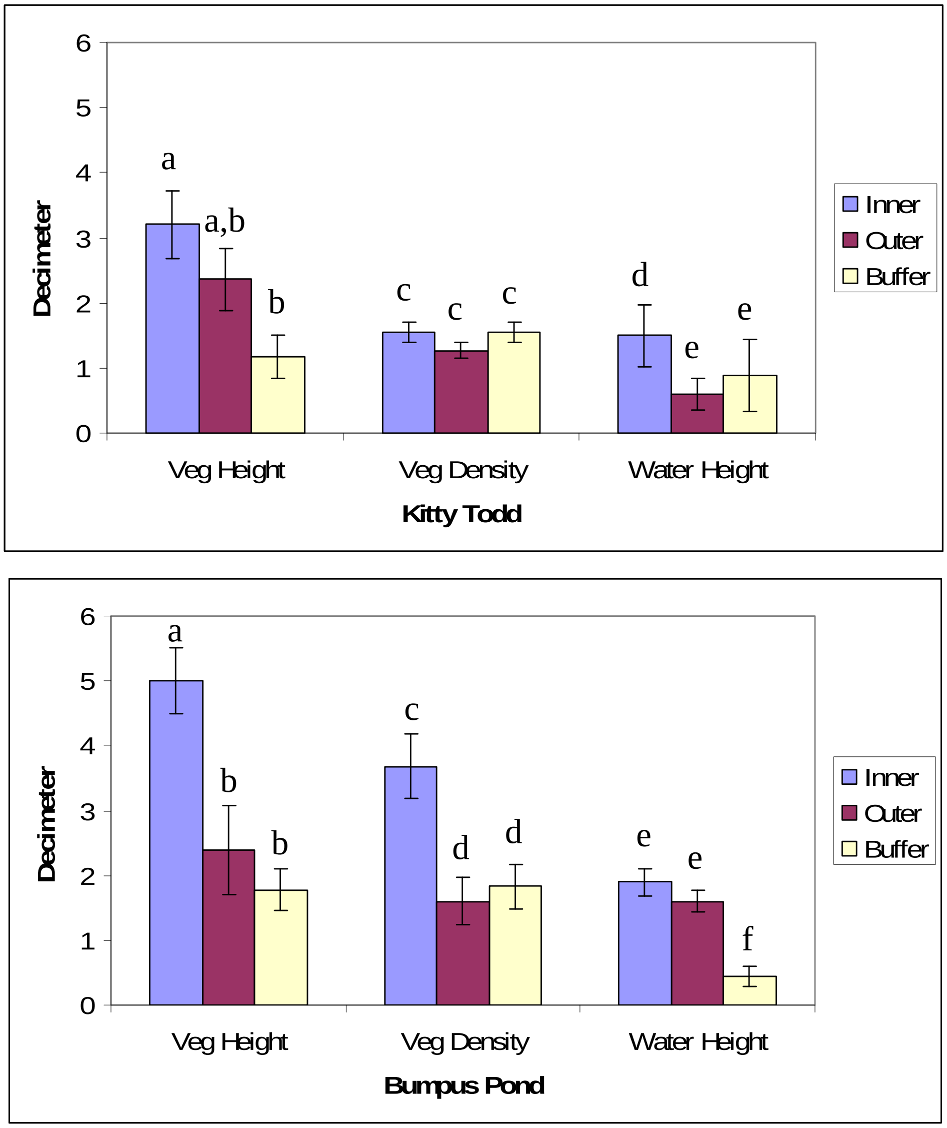


Figure 4. The average vegetation height, density, and water height taken in the inner core, outer core, and buffer areas of Kitty Todd and Bumpus Pond.

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CHAPTER IV

IDENTIFICATION OF CRITICAL ENVIRONMENTAL CHARACTERISTICS FOR SPOTTED TURTLES (*CLEMMYS GUTTATA*) AT THE LOCAL AND LANDSCAPE SCALE IN THE OAK OPENINGS REGION: A PREDICTIVE HABITAT MODEL

INTRODUCTION

Habitat models can be used for evaluating critical environmental requirements (e.g, Hashimoto et al., 2005; Zabala et al., 2006; Gavashelishvilli and Lukarevskiy, 2008; Turner et al., 2004), locating new populations (e.g., Guisan et al., 2005; Engler et al., 2004), and finding suitable habitat on the landscape (e.g., Cabeza et al., 2004). These studies have found that the critical environmental requirements varied by species, with surrounding land use, and the scale which was evaluated. Habitat models are especially important when knowledge about a species is limited (Klar et al., 2008) or the species is difficult to locate (Rhodes et al., 2006) and can maximize field surveys and prioritize management (Newbold and Eadie, 2004; Rachlow and Svancara, 2006). In this study, I utilized habitat models to examine the critical environmental factors influencing Spotted Turtle (*Clemmys guttata*) populations in their freshwater habitat in Northwest Ohio.

Studies have found that different environmental variables may be selected for based on the scale being evaluated and that for the majority of species data is only collected at one scale (Ritchie et al, 2008). For example, research with two bird species has shown that although the forest stand scale has been underestimated in predicting occupancy in the past, recent research has demonstrated that habitat models at a larger scale best described site occupancy in a heterogeneous forest (Smith et al., 2008). Also patterns of habitat use may differ based on the spatial scale explored. Kroll and Haufler (2006) found that large scale habitat preferences for the Dusky Flycatcher were associated with habitat occupancy and small scale preferences were associated with reproductive success.

Habitat suitability studies with turtles are of interest because population sizes are declining (Burke et al., 2000) and turtles are often secretive (Ernst el al., 1994) making it time intensive to locate and collect data on them. Few large scale studies have been conducted with turtle species (Rizkalla and Swihart, 2006; Suazo-Ortuno et al., 2008), as most focus on microhabitat such as nesting locations and land use changes with seasonal movements (Kolbe and Janzen, 2002; Najbar and Szuszkiewicz, 2007; Tuttle and Carroll, 2003; Meshaka and Blind, 2001). Large scale studies found that turtles were sensitive to changes in environmental characteristics associated with disturbances and that land cover and vegetation characteristics at multiple scales most likely affected turtle distributions.

The Spotted Turtle, in particular, is a rare species of freshwater turtle and can be difficult to study due to its secretive nature. It is known that the Spotted Turtle can be found in a multitude of habitat types including swamps, bogs, fens, wet prairies, marshes, and at the edges of bays and ponds, and streams. There are many studies that describe the small scale habitat use of Spotted Turtles (Graham, 1995; Litzgus and Brooks, 2000; Haxton and Berrill, 2001; Milam and Melvin, 2001). The characteristics known to be similar among these sites are a soft substrate and aquatic vegetation (Ernst et al. 1994, Haxton and Berrill 1999).

There is a limited amount of detailed information on large scale environmental characteristics of the habitat. Since the Spotted Turtle has a large range extending from southern

Ontario and Maine, south to Florida, and from Pennsylvania west to Illinois, habitat use is dependent upon what is available. Spotted Turtles are known to occur in the Oak Openings Region of Northwest Ohio, an area that is approximately 200 square kilometers (Moseley, 1928). The Oak Openings region sits on a portion of a sand belt that was deposited approximately 12,700 years ago due to glacial activity. Historically this region consisted of black oak savanna, oak woodland, and wet prairie communities which were surrounded by forests known as the Great Black Swamp. Six primary stresses have been identified for the Oak Opening Region: loss of habitat and fragmentation of habitat, woody plant succession, groundwater lowering, exotic plant species, and elimination of native species (US EPA 2006).

To our knowledge Spotted Turtles are only known to occupy four sites in the Oak Openings Region. We conducted mark recapture surveys utilizing radio telemetry at two of these sites: Kitty Todd Nature Preserve (Kitty Todd) and Bumpus Pond. Spotted Turtles use approximately 4.0 ha of wet prairie at Kitty Todd which is owned by The Nature Conservancy and consists of mainly wet prairie grasses and sedges. Approximately 2.6 ha of Bumpus Pond are utilized by Spotted Turtles. This site is owned by Metroparks of the Toledo Area and consists of mainly shrub/scrub and forested areas. Our goal was to investigate the critical habitat variables at the local and landscape scale in Northwest Ohio to gain additional information about Spotted Turtle environmental requirements, and create a predictive habitat model which can be used to limit the searching area to find additional populations and to focus management.

METHODS

We used ArcGIS 9.2 to analyze the differences between presence and absence locations at two scales: within study sites and within the Oak Openings Region (defined by Brewer and

Vankat, 2004). Our data consisted of presence points collected from field surveys at Kitty Todd from 2006-2007 and Bumpus Pond during 2005-2007, and 13 GIS layers with a resolution of 30 m^2: March NDVI, June NDVI, March greenness, June greenness, March brightness, June brightness, March moisture, June moisture, slope, aspect, annual solar radiation, soil type, and land cover. The presence points were obtained by recording the exact location of each capture point using a Garmin Etrex Vista GPS unit when accuracy was no less than 5-7m. We collected a total of 96 points at Kitty Todd and 38 points at Bumpus Pond.

Normalized Difference Vegetation Index (NDVI), greenness, brightness, and moisture layers were generated in IDRISI (Clark Labs, Clark University, Worcester, MA, USA) using the tasseled cap module by processing remotely sensed data (i.e., LANDSAT TM satellite images) from March and June 2006. The resulting layers consist of continuous data. NDVI is a vegetation index which creates values based on the reflectance of near-infrared and red wave lengths and describes the relative amount of green biomass. Values range from -1 to +1 with zero indicating no vegetation, +1 indicating dense vegetation and -1 indicating bare soil or rock. Greenness also refers to green vegetation cover and is an alternative analysis to NDVI, as it uses a different formula to calculate green biomass. Brightness refers to soil brightness with bare ground indicated as a high value and forest indicated with a low value. Moisture refers to soil moisture, where high values indicate areas with high soil moisture and low values indicate areas with low soil moisture.

Slope, aspect, and annual solar radiation were generated in ArcGIS 9.2 using Spatial Analyst Tools and the June 2006 satellite image. These layers consisted of continuous data. Slope is the rate of change from one cell to the next, on a scale of 0-90° where 0° represents flat areas. Aspect is the cardinal direction of maximum change and can be thought of as the slope direction. Annual solar radiation represents the amount of insolation based on topography and surface features. Greater values indicate areas that receive more insolation.

The soil layer is a categorical layer representing 62 different soil types in Lucas County based on soil surveys conducted between 1973 and 1976 (Stone et al., 1980) obtained from the Lucas County Auditor in its 2005 Auditor's Real Estate Information System (AREIS) update (Kaczala, 2005). Of the 62 soil types, 56 soil types are in the Oak Openings Region, but only 6 soil types make up over 63% of the Oak Openings Region. Only 2 soil types are found within the study sites: Granby loamy fine sand and Tedrow fine sand with 0-3% slope.

The land cover layer was generated using a supervised classification of multi-temporal LANDSAT TM satellite images from November 2005 to June 2006 (Schetter and Root, in prep). The classification resulted in 15 categories: turf, residential, urban, ponds, savanna, shrub/scrub wetland, wet prairie, pin oak swamp, conifers, xeric oak woodlands, mesic oak woodlands, floodplains and wet prairie, bare sand, cool season grasses, and prairie. A 16th category, croplands, was generated from the GIS database of Common Land Units (CLU) maintained by the U.S. Department of Agriculture (USDA, 2006). Overall accuracy of the wet prairie class is estimated at 60% due to the small coverage of this class on the landscape and limitations of grain size in the satellite images (30 m^2 pixel). We chose to use this layer because it is the most current and accurate layer available.

Within sites.---We converted the point occurrences into raster cells, which categorized the entire cell as present. The cells had the same resolution as the GIS layers (30 m^2 pixels), resulting in 32 presence cells at Kitty Todd and 19 presence cells at Bumpus Pond as a result of some raster cells containing multiple point occurrences. We generated the same number of random raster absence cells as there were presence cells within each study site. We used ArcGIS to generate a table which provided a value from each GIS layer for each presence and absence cell in each study site. We used a logistic regression to determine which variables were statistically significant in predicting Spotted Turtle presence within each site.

Within Oak Openings Region.---We used the combined set of 51 presence raster cells and generated the same number of random absence raster cells throughout the Oak Openings Region (Brewer and Vankat, 2004). We chose to create two models: restrictive and inclusive. Since it is known that spotted turtles are found in aquatic areas (Ernst et al., 1994), we modified the March and June soil moisture layers and land cover layer to focus on wet characteristics. The restrictive model was based on restrictive constraints to represent areas similar to the 50% core density areas of the two study sites. The cut off points for moisture layers were based on our previous knowledge of and represented the 50% and 90% core density areas used by spotted turtles in the study sites (Harms and Root, in prep, Chapter 3). Since this model does not represent the characteristics of less used areas in the study sites, we also created an inclusive model that incorporated the characteristics of all of the areas the spotted turtles used (i.e., 90% core density).

The restrictive model included a March moisture layer which represented the top 20% wettest areas while June moisture represented the top 14% of the wettest presence raster cells within both sites based on the 50% core density area at both study sites. This process resulted in the formation of categorical data layers with areas being categorized as suitable or unsuitable. The land cover layer only included wet prairie and shrub/scrub wetland as these are more similar to areas where Spotted Turtles are typically found based on vegetation composition (Ernst et al., 1994).

The inclusive model included a March moisture layer with values representing the top 45% wettest areas and a June moisture layer which represented the top 47% wettest presence raster cells within both sites based on the 90% core density area at both study sites. This process also resulted in categorical data layers with ranges of values being either suitable or unsuitable. The land cover layer included all categories which represent wet areas: wet prairies, shrub/scrub wetland, pin oak swamp, and floodplains.

We generated a table containing values from each GIS layer for each presence and absence cell using ArcGIS. We performed a Pearson product-moment correlation to determine if there were positive or negative correlations between our variables. Variables found to have a coefficient greater than ±73% were determined to be correlated; the threshold was chosen based on natural breaks in the data. To determine which correlated variables we would keep or reject we ran a Wald test, for both the conservative and restrictive models, which identified the significance of a single predictor variable. For each set of correlated variables we chose to keep the variable with the lowest Wald value.

We ran a forward logistic regression for the inclusive and restrictive models to determine which variables were statistically significant in determining Spotted Turtle presence in the Oak Openings Region.

We performed an Akaike's Information Criterion (AIC) analysis (Burnham and Anderson, 2002) on the statistically significant variables from the logistic regression models to select the most parsimonious model and determine which variables had more influence on the model. Models with the lowest AIC value were determined to be the best model. We chose the variables for the final restrictive and inclusive predictive habitat models based on AIC results. The final version of the inclusive and restrictive predictive habitat models were the sum of all significant GIS layers, determined by AIC analysis. We converted significant data layers with continuous data into categorical data sets in order to perform the Boolean additive analysis by using the range of variables found in all presence cells within the study sites to represent suitable areas, with the exception of the modified moisture and land cover layers. The final maps show areas of potential Spotted Turtle habitat within the Oak Openings Region, based on values of 1 indicating suitable areas and values of 0 indicating unsuitable areas.

We calculated the percentage of suitable area within the Oak Openings Region and the amount of that habitat that is currently protected by The Nature Conservancy, Metroparks of the Toledo Area, and Ohio Department of Natural Resources for the conservative and restrictive models. We also compared the results of the two models by adding the layers together to determine the amount of agreement between suitable and unsuitable potential habitat. We plan on ground truthing the model by measuring environmental variables and comparing our results to model predictions.

RESULTS

Within sites.---At Kitty Todd, we found that June moisture and slope were statistically significant (x^2=16.7116, p=<0.0001 and x^2=6.1099, p=0.0134, respectively) environmental variables, indicating that Spotted Turtles are more likely to be found in low slope areas (Figure 1) that have higher levels of June moisture (Figure 2). June NDVI, March brightness, March NDVI, Aspect, June brightness, March moisture, soil type, annual solar radiation, March greenness, land cover, and June greenness were not selected by the logistic regression model (Table 1).

At Bumpus Pond, March brightness was the statistically significant (x^2=4.6085, p=0.0318) environmental variable, indicating that turtles are more likely to be found in areas that have intermediate levels of March brightness (Figure 3). March NDVI, June moisture, March moisture, soil type, June NDVI, March greenness, Land cover, June brightness, slope, aspect, annual solar radiation, and June greenness were not selected by the logistic regression model (Table 1).

Within the Oak Openings Region.---We found that four sets of variables were correlated: March greenness and March NDVI, and June greenness and June NDVI were positively correlated (n=100, r=0.7369, p=<0.0001 and n=100, r=0.9588, p=<0.0001, respectively). March brightness and March moisture, and June brightness and June greenness were negatively correlated (n=100, r=-0.8419, p=<0.0001 and n=100, r=-0.8336, p=<0.0001, respectively).

Inclusive model.---The Wald test indicated that March greenness (x^2=0.5277, p=0.4676), June greenness (x^2=0.4047, p=0.5247), March brightness (x^2=0.0544, p=0.8156), and June moisture (x^2=0.0030, p=0.9566) had more influence on the model based on Wald values (Table 2), so we excluded March NDVI (x^2=0.7178, p=0.3969), June NDVI (x^2=0.4778, p=0.4894), June brightness (x^2=0.0285, p=0.8659), and March moisture (x^2=0.2365, p=0.6268) from the model.

The remaining environmental variables were used in a logistic regression analysis: annual solar radiation, aspect, March brightness, March greenness, June greenness, land cover, June moisture, slope, and soil. We found that land cover (x^2=54.7819, p=<0.0001), June moisture (x^2=11.4083, p=0.0007), slope (x^2=9.5153, p=0.0020), and annual solar radiation (x^2=6.9358, p=0.0084) were the variables best described the probability of Spotted Turtle presence (Table 3).

The logistic regression equation was y = -399.1 + 3.5288*(land cover) + 2.3094*(June moisture) – 3.3133*(slope) + 0.000316*(annual solar radiation).

An AIC analysis also confirmed that this set of four variables was the most parsimonious model (AIC=53.251). By performing a series of AIC analyses, excluding one variable at a time, we found that the variables were ranked from most influential to least influential as: land cover (n=3, AIC=74.311), slope (n=3, 67.698) annual solar radiation (n=3, AIC=60.587), and June moisture (n=3, AIC=60.179; Table 3).

The final map indicated potentially suitable habitat in the Oak Openings Region in Lucas County (Figure 4). We found that 4.05% of the region was potential Spotted Turtle habitat in the inclusive model and 23.36% of this potential habitat was protected by The Nature Conservancy, Metroparks of the Toledo Area, and Ohio Department of Natural Resources.

Restrictive model.---For the restrictive model, after performing a Wald test we included March greenness (x^2=0.3946, p=0.5299), June brightness (x^2=0.0074, p=0.9316), March moisture (x^2=0.3866, p=0.5341), and June NDVI (x^2=0.3471, p=0.5558) based on more significant Wald values (Table 2). We excluded March brightness (x^2=0.5265, p=0.4681), June greenness (x^2=0.3603, p=0.5483), June moisture (x^2=0.0133, p=0.9080), and March NDVI (x^2=1.1062, p=0.2929) from the model.

We ran a logistic regression on the remaining variables: annual solar radiation, aspect, June brightness, March greenness, land cover, March moisture, June NDVI, slope, and soil. We found that land cover (x^2=27.0990, p=<0.0001), June NDVI (x^2=16.1103, p=<0.0001), June brightness (x^2=21.6454, p=<0.0001), annual solar radiation (x^2=7.2820, p=0.0070), and slope (x^2=5.6627, p=0.0173) were the variables that best described potential Spotted Turtle habitat (Table 4). The logistic regression equation was y = -854.5 + 16.2506*(land cover) +

21.6181*(June NDVI) – 49.3208*(June brightness) + 0.000689*(annual solar radiation) – 6.6404*(slope).

An AIC test also indicated that this set of five variables was the most parsimonious model (AIC=40.420). We found that the variables were ranked from most influential to least influential as: June NDVI (n=4, AIC=55.423), slope (n=4, AIC=55.071), June brightness (n=4, AIC=52.558), land cover (n=4, AIC=52.436), and annual solar radiation (n=4, AIC=50.086; Table 4).

The final map indicated potential suitable habitat in the Oak Openings Region in Lucas County (Figure 5). We found that 0.26% of the landscape was potential Spotted Turtle habitat in the restrictive model and 50.35% of potential habitat was protected (Figure 6).

Model Comparison.---We found that 96.03% of the landscape was not considered potentially suitable by either model, 3.79% was considered suitable by only one model, and 0.18% of the landscape was considered potentially suitable by both models (Figure 7). Of the suitable habitat, 4.58% was considered suitable by both models and 95.42% was suitable by just one of the models.

DISCUSSION

We determined the significant environmental variables that predict the presence of Spotted Turtles within our study sites and within the Oak Openings Region of Northwest Ohio. Within sites we found that presence was determined by low slope, moderate to high levels of June moisture, and intermediate levels of March brightness. These variables correspond to what is known about Spotted Turtle habitat requirements throughout the range and described where Spotted Turtles were located within our sites. Spotted Turtles are known to occupy wet areas, many times in bogs, fens, and marshes that stay wet year round (Ernst et al., 1994). In Northwest Ohio the standing water levels lower or completely disappear in June, so it wasn't surprising to find that turtles were located in areas with more soil moisture. Slope can be influential in determining where water pools, also indicating areas with more soil moisture. The levels of March brightness indicated areas with wet prairie grasses and sedges, and shrub/scrub vegetation in which turtles were captured.

Within the Oak Openings Region we found that presence was determined by annual solar radiation, June brightness*, June moisture**, land cover, June NDVI*, and slope (*only restrictive model, **only inclusive model). Again, this made biological sense as these variables described the moisture (June moisture, slope) and vegetation/surface components (annual solar radiation, June brightness, June NDVI, slope) of the sites compared to absence points within the Oak Openings Region. It became clear that the landscape aspects in June played a large role in determining potential habitat suitability. Turtles need to avoid desiccation, predation, and to conserve energy resources in the summer (Litzgus and Brooks, 2000; Haxton and Berrill, 2001), especially in an area such as Oak Openings Region in which the water dries up in the summer. June moisture describes this requirement, as well as June brightness and June NDVI because sites with more woody vegetation dry up more quickly (EPA, 2006).

One other aspect known about Spotted Turtle habitat is that they require a soft substrate (Ernst et al., 1994). We expected soil type to be a significant variable in modeling potential habitat but it was found to be insignificant. Since the majority of the Oak Openings Region is characterized by six soil types there may not be enough variation to be significant. If this model was applied outside of the Oak Openings Region (e.g., all of Lucas County), then it would be likely that soil type would play a larger role in determining Spotted Turtle presence.

The two main differences between the landscape scale models were the amount of suitable habitat and the location of that habitat. The inclusive model used June moisture and the restrictive model used June brightness which were correlated variables. The restrictive model included a fifth variable, June NDVI which appears to have further reduced the amount of suitable habitat. The AIC tests indicated that NDVI was the most influential variable in the restrictive model, while land cover was ranked four out of five. Yet in the inclusive model, land cover was the most influential variable. This indicates that NDVI may do a better job at locating areas similar to the occupied study sites than the land cover layer because the restrictive model indicated less of the Oak Openings Region as suitable and field studies have only found the Spotted Turtle at 4 locations within this region.

It is also possible that the different range of values used in the moisture and land cover layers for the inclusive and restrictive models influenced the logistic regression outcome. Both models indicated the same area of the map as having the highest density of Spotted Turtle habitat. In general, areas the inclusive model found to be suitable expanded around the suitable areas identified in the restrictive model, but did not necessarily overlap with only 4.58% of the same suitable habitat being identified by both models.

There were differences in which variables were found to be significant between the local and landscape scales with slope, June moisture, and March brightness being the only significant variables at the local scale. Slope and June moisture were found to be significant at the landscape scale as well, but March brightness was not. One explanation for this finding may be that Bumpus Pond, where March brightness was found to be significant, consists of mainly forested and shrub areas with more turtles located in shrub than forest. We believe that few variables were found significant at the local scale because the study sites were relatively small, limiting the amount of heterogeneity that could be found at this scale.

No other studies with Spotted Turtles have examined this level of detail at these spatial scales. Spotted Turtle studies have investigated habitat use and movement resulting in general habitat descriptions described as ponds, swamps, seasonal pools, upland forest, etc. (Perillo, 1997; Litzgus and Brooks, 2000; Milam and Melvin, 2001) by conducting studies within a site or within a study area containing a wetland complex. Studies also provide detailed descriptions at the microhabitat scale such as descriptions of hibernacula locations (Lewis and Ritzenthaler, 1997; Litzgus et al, 1999; Seburn 2003). These studies are missing an intermediate level of detail which can be provided by studies such as this one.

Most other studies with freshwater turtles also focus on the microhabitat scale by identifying seasonal movements or specific habitat structures (Tuma, 2006; Joyal et al., 2001; Piepgras and Lang, 2000; Hartwig and Kiviat, 2007; Rossell et al., 2006). These studies are valuable by providing information which can be used to guide management, but lack details that can be critical for identifying species requirements. Our study found that different environmental variables are important depending on the spatial scale being explored, suggesting that studies should not only focus on the microhabitat scale but use a multiscale approach.

Studies that have investigated the landscape scale, which include turtle species, have done so with a community emphasis. This spatial scale helps to provide information on why species are where they are on the landscape. These studies have found that responses to disturbance differ among and within taxa, but that all turtle species were sensitive to fragmentation (Suazo-Ortuno et al., 2008) and that the community approach did not work well for rare species as species specific models could not be generated due to low sample size (Rizkalla and Swihart, 2006).

Compton et al. (2002) found that critical habitat variables could be missed by only evaluating one scale. They investigated habitat selection by wood turtles (*Clemmys insculpta*) within activity area and within the watershed. They found that at the watershed scale partially forested areas were preferred, but within the activity area forested areas were selected against. This was thought to be a trade-off between requiring the ability to thermoregulate in open areas and preying upon items such as earthworms, mushrooms, and berries, which can be found in the forest.

Local and landscape scale models can be used to identify overarching habitat requirements (Turner et al., 2004), potential corridors (Gavashelishvilli and Lukarevskiy, 2008), other locations on the landscape in which additional populations of a rare species could be found (Klar et al., 2008), and to find areas in which little management could be conducted to encourage rare species colonization (Newbold and Eadie, 2004). There are other variables that may be required for species presence such as adequate places to nest and hibernate, vegetation density and composition. These variables would only be identified by investigating a smaller scale than this study did and emphasizes the need to study all spatial scales.

As our multiscale study indicates, factors that influence turtle presence at one scale (e.g., March brightness) may not be influential at other scales. Overall, our predictive modeling approach based on currently occupied sites, provided useful information for locating additional potential habitat and suggested the presence of the Spotted Turtle was determined by variables that accounted for water levels at the driest time of the year and vegetation structure. We have shown that models at the local and landscape scale are useful in providing an intermediate level of detail for rare species and indicate why a particular species exists where it does. This information appears to be lacking for most freshwater turtle species and should be implemented more frequently in future research.

Management Implications.---Our study resulted in the creation of a potential habitat suitability map for the Spotted Turtle in the Oak Openings Region. Since habitat use is based on availability and the habitat model is based on only two sites it is only applicable to the Oak Openings Region. We feel that the restrictive model is a better indicator of potential habitat suitability than the inclusive model because it is based on more restrictive values, resulted in the most narrow search area, and had a lower AIC value.

We found that habitat suitability is based on appropriate levels of annual solar radiation, June brightness, land cover, June NDVI, and slope. These values, resulting in the final restrictive map, provide information on what the critical environmental variables are and the range of values these variables should be in, as well as where to potentially locate additional Spotted Turtle populations and which land tracts are of interest to conservation efforts. This approach should be useful for the conservation and management of the Spotted Turtle across its range.

Table 1. Critical environmental variables at the local scale: results of the logistic regression model. Variables that best predict Spotted Turtle presence are highlighted in bold.

Kitty Todd			Bumpus Pond		
Environmental Variable	x^2	p value	Environmental Variable	x^2	p value
June moisture	**16.7116**	**<0.0001**	**March Brightness**	**4.6085**	**0.0318**
Slope	**6.1099**	**0.0134**	March NDVI	1.7648	0.1840
June NDVI	3.1449	0.0762	June Moisture	1.4064	0.2357
March Brightness	2.7084	0.0998	March Moisture	2.3398	0.1261
March NDVI	1.5037	0.2201	Soil	1.4072	0.2355
Aspect	1.4831	0.2233	June NDVI	1.0332	0.3094
June Brightness	0.9177	0.3381	March Greenness	0.9515	0.3293
March Moisture	2.6935	0.1008	Land Cover	0.7013	0.4024
Soil	0.1592	0.6899	June Brightness	0.9836	0.3213
Annual Solar Radiation	0.0450	0.8321	Slope	1.0205	0.3124
March Greenness	0.0525	0.8187	Aspect	0.6265	0.4287
Land cover	0.0316	0.8590	Annual Solar Radiation	0.4485	0.5030
June Greenness	0.0148	0.9031	June Greenness	0.0455	0.8311

Table 2. Correlated variables with Wald values. Variables with lower Wald values, shown in bold, were included in the habitat suitability models.

Conservative Model		Restrictive Model	
Set of variables	Wald value	Set of variables	Wald value
March Greenness	**0.5277**	March Greenness	**0.3946**
March NDVI	0.7178	March NDVI	1.1062
June Greenness	**0.4047**	June Greenness	0.3603
June NDVI	0.4778	June NDVI	**0.3471**
March Brightness	**0.0544**	March Brightness	0.5265
March Moisture	0.2365	March Moisture	**0.3866**
June Brightness	0.0285	June Brightness	**0.0074**
June Moisture	**0.0030**	June Moisture	0.0133

Table 3. Logistic regression results for the Inclusive model. Variables that best predict Spotted Turtle presence at the landscape scale are highlighted in bold. For the AIC analysis, model terms include: Asr=annual solar radiation, Lc=land cover, Jm=June moisture, and Sl=slope.

Logistic Regression			AIC		
Environmental Variable	x^2	p value	Environmental Variables	AIC	Value excluded
Land Cover	**54.7819**	**<0.0001**	Asr, Lc, Jm, Sl	53.251	---
June Moisture	**11.4083**	**0.0007**	Lc, sl, Asr	60.179	Jm
Slope	**9.5153**	**0.0020**	Lc, Jm, sl	60.587	Asr
Annual Solar Radiation	**6.9358**	**0.0084**	Lc, Jm, Asr	67.698	Sl
March Brightness	3.6850	0.0549	Jm, sl, Asr	74.311	Lc
March Greenness	0.6756	0.4111			
June Greenness	0.6285	0.4279			
Soil	0.1922	0.6611			
Aspect	0.0018	0.9659			

Table 4. Logistic regression results for the Restrictive model. Variables that best predict Spotted Turtle presence at the landscape scale are highlighted in bold. For the AIC analysis, model terms include: Asr=annual solar radiation, Jb= June Brightness, Lc=land cover, JN=June NDVI, and Sl=slope.

Logistic Regression			AIC		
Environmental Variable	x^2	p value	Environmental Variables	AIC	Value excluded
Land Cover	**27.0900**	**<0.0001**	Asr, Jb, Lc, JN, Sl	40.420	---
June NDVI	**16.1103**	**<0.0001**	Jb, Lc, JN, Sl	50.086	Asr
June Brightness	**21.6454**	**<0.0001**	Asr, Jb, JN, Sl	52.436	Lc
Annual Solar Radiation	**7.2820**	**0.0070**	Asr, Lc, JN, Sl	52.558	Jb
Slope	**5.6627**	**0.0173**	Asr, Jb, Lc, JN	55.071	Sl
Aspect	1.3615	0.2433	Asr, Jb, Lc, Sl	55.423	JN
March Greenness	0.4784	0.4892			
March Moisture	0.2085	0.6480			
Soil	0.0723	0.7879			

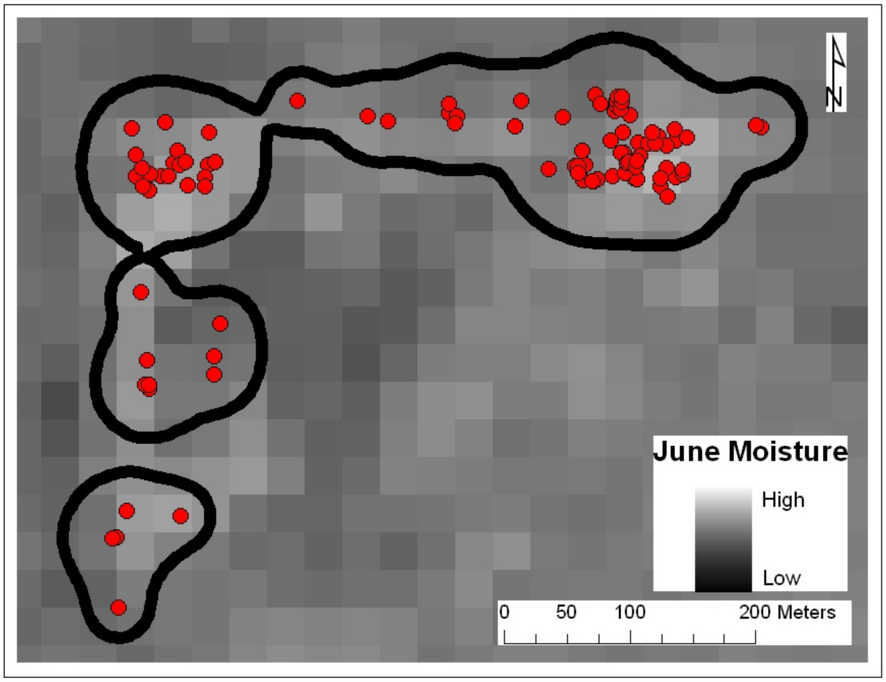

Figure 1. Point occurrences at Kitty Todd Nature Preserve shown inside 95% density interval curves, illustrating the June moisture values for point occurrences.

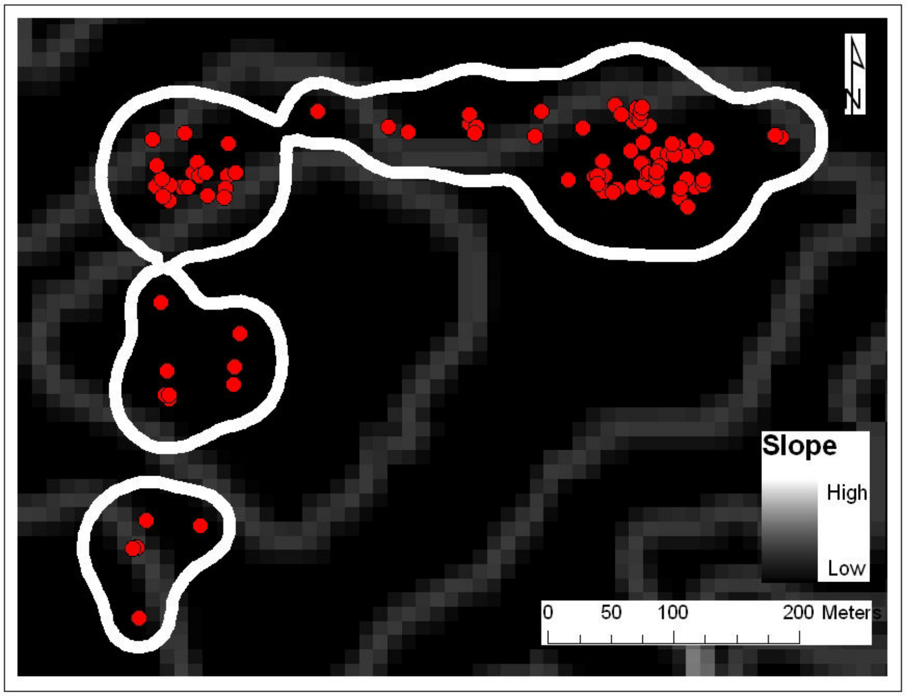

Figure 2. Point occurrences at Kitty Todd Nature Preserve shown inside 95% density interval curves, illustrating the slope values for point occurrences.

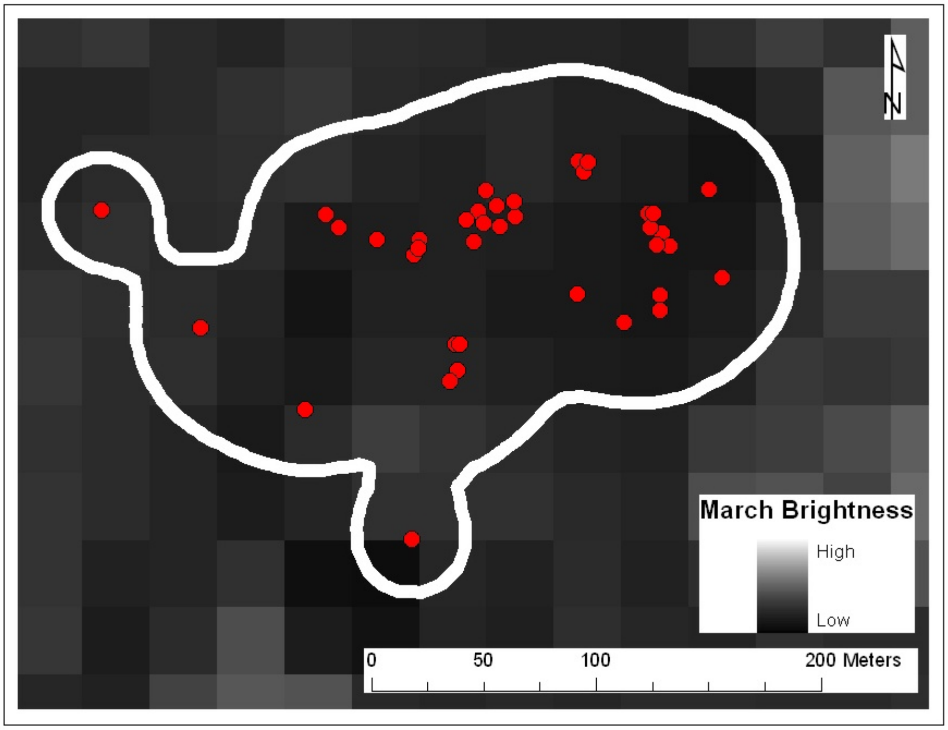

Figure 3. Point occurrences at Bumpus Pond shown inside 95% density interval curves, illustrating the March brightness values for point occurrences.

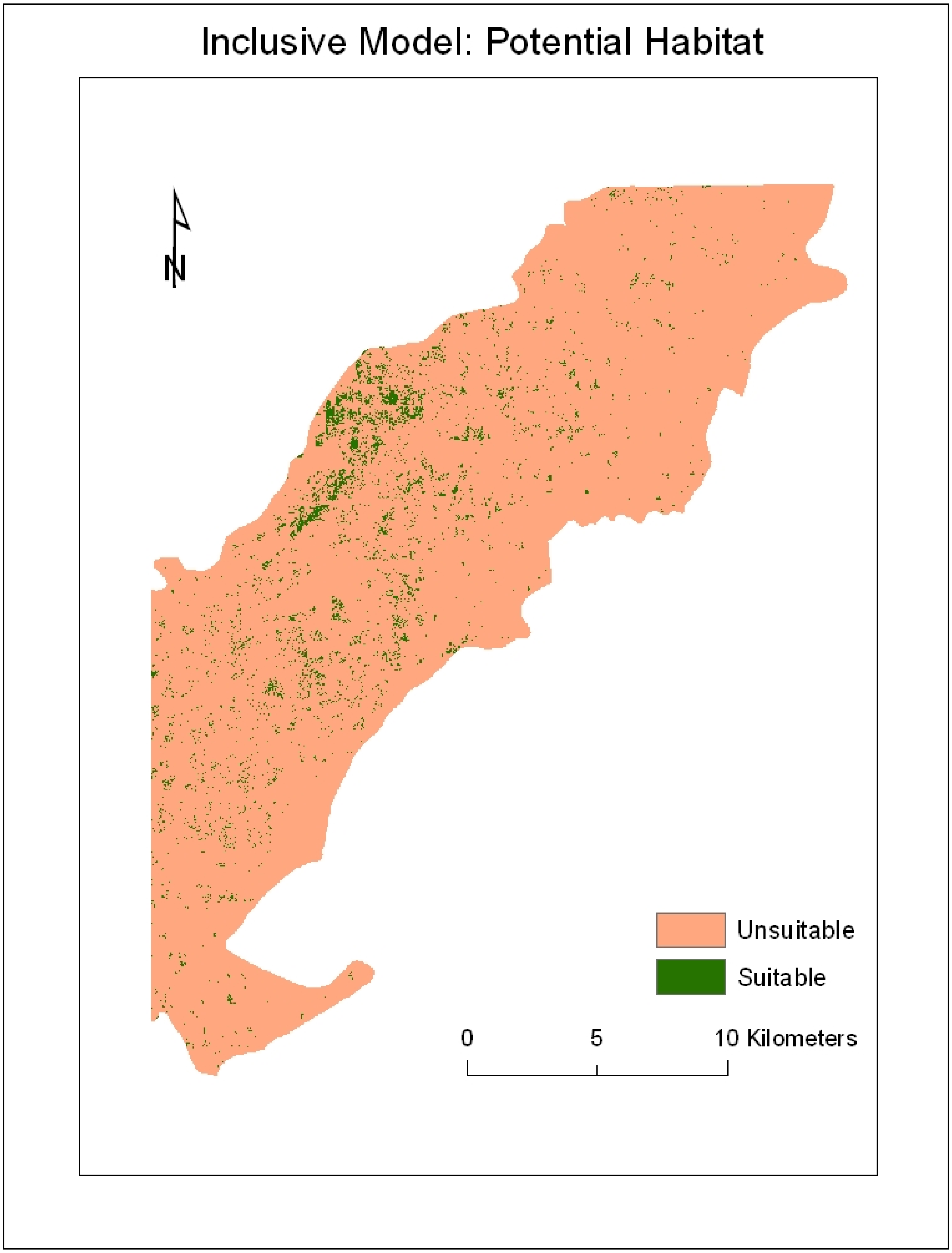

Figure 4. Inclusive model showing potential Spotted Turtle habitat within the Oak Openings Region of Northwest Ohio.

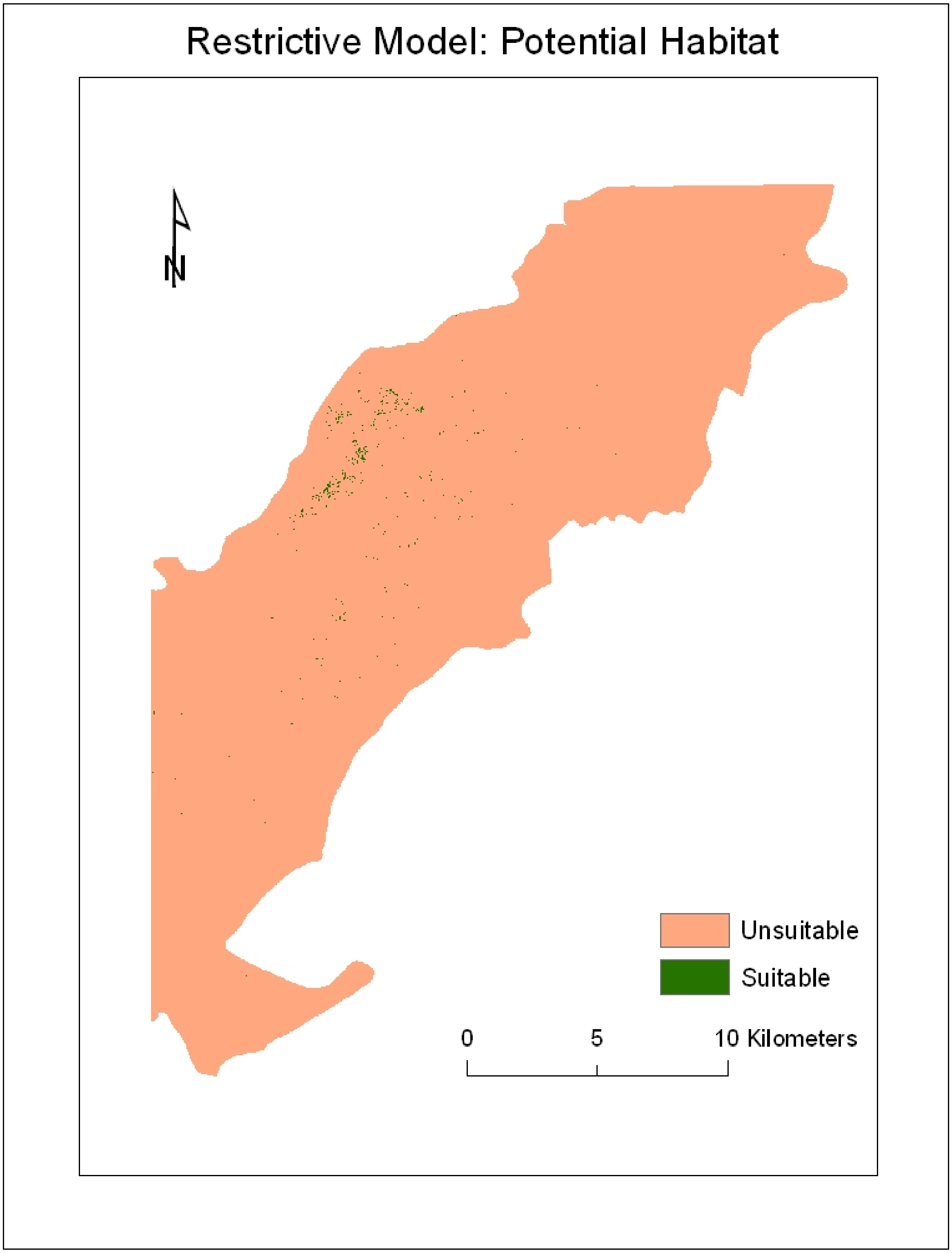

Figure 5. Restrictive model showing potential Spotted Turtle habitat within the Oak Openings Region of Northwest Ohio.

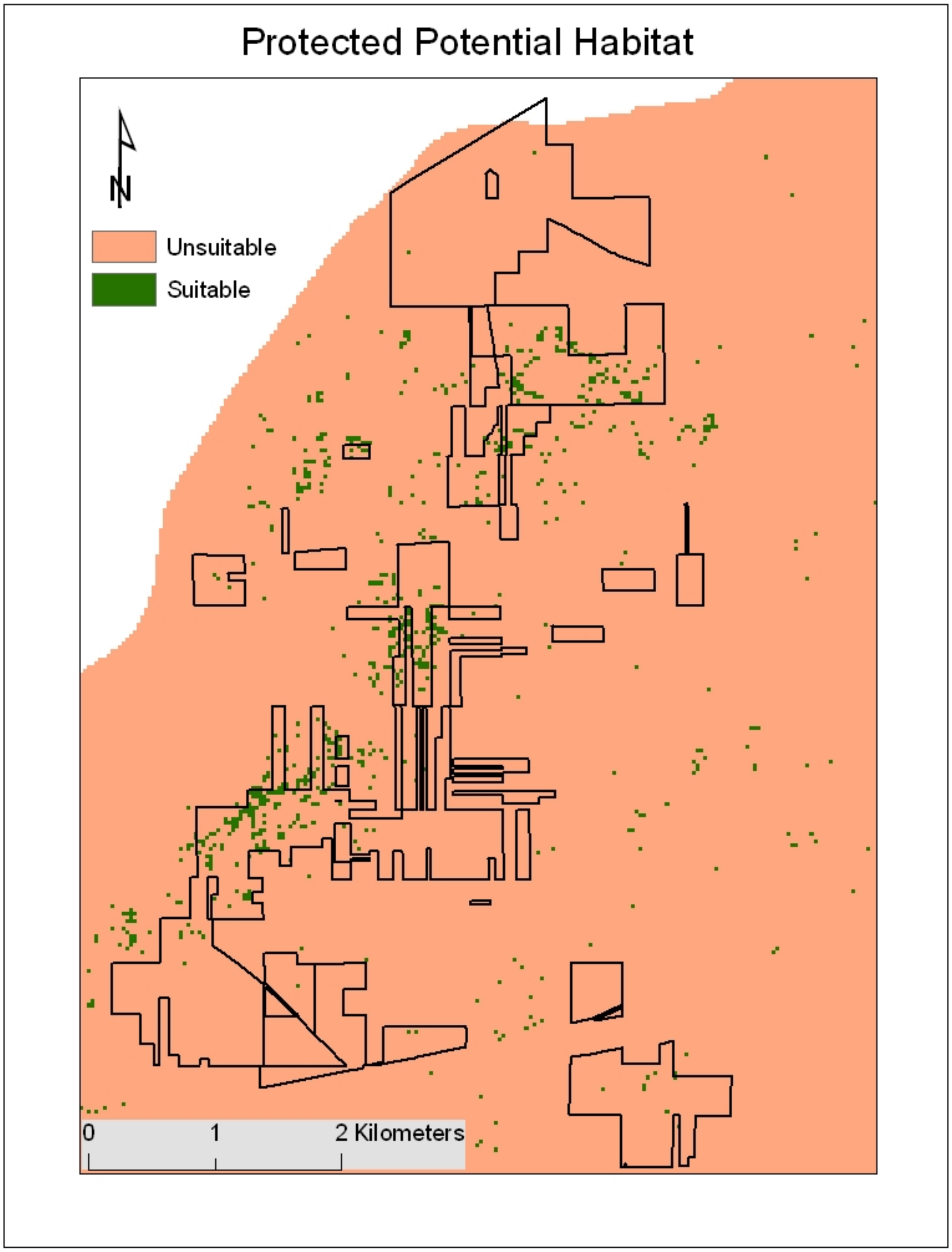

Figure 6. Subsection of Restrictive model showing majority of potential Spotted Turtle habitat. Black outlines indicate property boundaries of protected land.

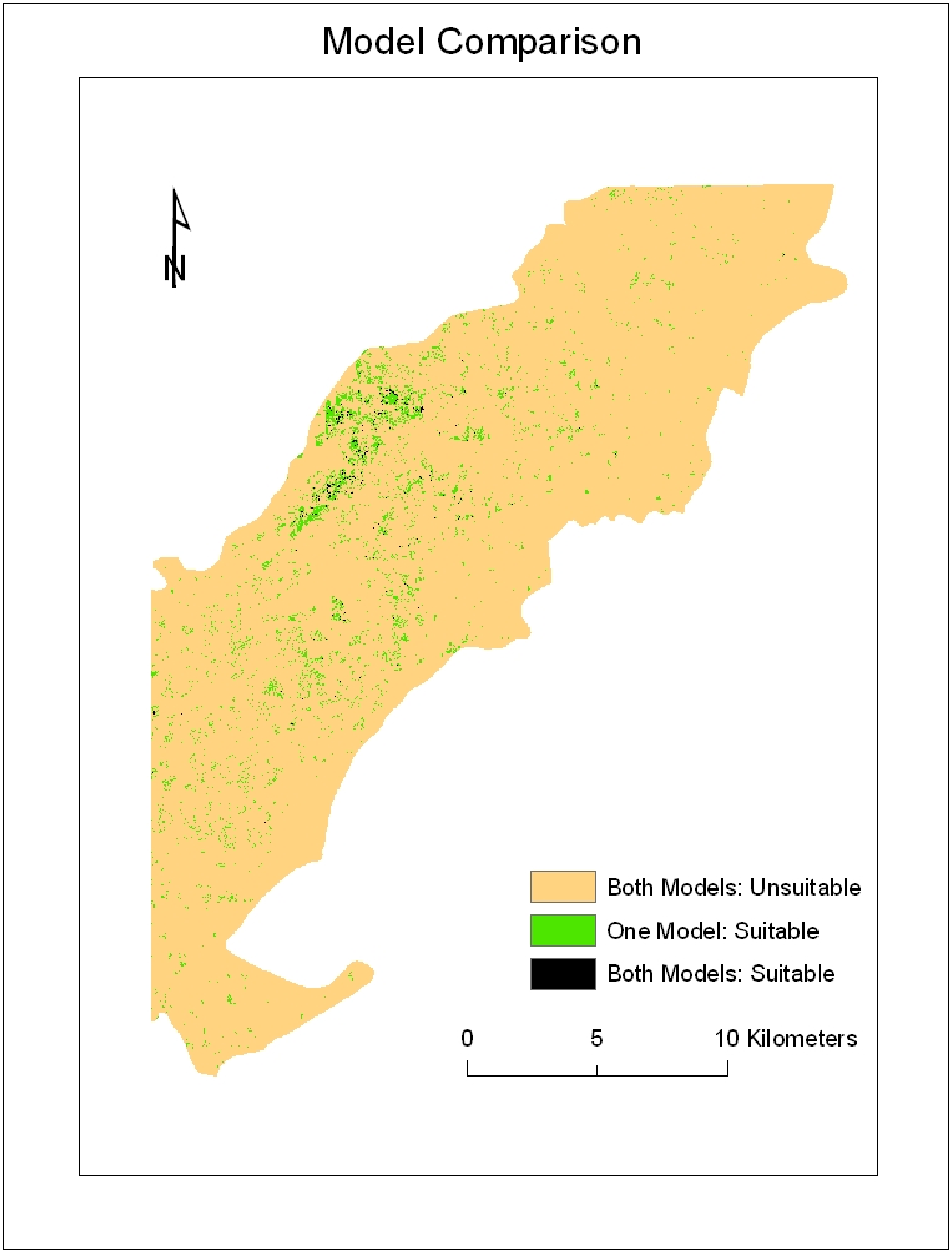

Figure 7. Inclusive and restrictive model comparison, illustrating the amount of the landscape found unsuitable or suitable in one or both models.

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CHAPTER V

GENERAL SUMMARY AND CONCLUSIONS

In this dissertation, we explored the biology of the Spotted Turtle in Northwest Ohio with results being applicable not only to this area but throughout the range. This body of work is premised on four overarching questions: (1) What limits Spotted Turtle population viability?, (2) What is the current status of populations in Northwest Ohio?, (3) What are the critical environmental variables associated with Spotted Turtle presence?, and (4) How do we manage this species?, which were addressed in the three main chapters of this document.

Previous sensitivity analyses have been performed on the life tables of various species of turtles (Frazer et al., 1991; Iverson, 1991; Mitrus 2005) and found that sea turtle populations will benefit from enhanced survival of subadults or juveniles and that freshwater turtles will benefit from enhanced survival of adults (Congdon et al., 1993; Heppell, 1996). Our research, described in Chapter II, took this a step farther. We found that population viability in Spotted Turtles is limited by changes in demographic variables, catastrophes, and poaching. Population size influenced the probability of population decline, but it also affected which age groups were most influential on population persistence over time. Extending the age of sexual maturity decreased the annual population growth rate and increased the probability of population decline, suggesting that populations which further delay sexual reproduction must have higher survival rates (Heppell, 1998).

In Chapter III, we explored the current status of Spotted Turtles in Northwest Ohio and the critical environmental variables at the study site scale. We found the age structure at Kitty Todd to be roughly a 1:1 ratio of sub-adults/adults to juveniles and the age structure at Bumpus

Pond to be a 2:1 ratio. The population densities at both sites were higher than the densities reported in recent literature (Milam and Melvin, 2001; Litzgus and Mousseau, 2004). It is unusual to find as many juveniles as we did at Kitty Todd, since the age structure of most reported populations have an adult bias (Seburn, 2003; Graham, 1995; Litzgus and Mousseau, 2004). We found that the density was higher at Kitty Todd than Bumpus Pond indicating that wet prairie habitat may be able to support a larger population of turtles than the shrub/scrub of Bumpus Pond.

We also identified critical environmental characteristics at the study site scale and found that turtles at Kitty Todd were using areas with higher water and taller ground vegetation. Turtles at Bumpus Pond were using areas with higher water, taller and more dense vegetation. No other studies with Spotted Turtles provide this level of detail regarding environmental characteristics. Other studies do discuss the types of habitats Spotted Turtles can be found in described as ponds, seasonal pools, upland forest, etc. (Litzgus and Brooks, 2000; Milam and Melvin, 2001).

In Chapter IV, we further explored the environmental variables critical to Spotted Turtle presence but at the local and landscape scales. At the local scale presence was determined by low slope, moderate to high levels of June moisture, and intermediate levels of March brightness. At the landscape scale, based on a restrictive model, we found that presence was determined by annual solar radiation, June brightness, land cover, June NDVI, and slope. Again, no other studies have explored this level of detail for the Spotted Turtle and few other studies using turtle species have conducted environmental studies at these scales (Compton et al., 2002; Rizkalla and Swihart, 2006; Suazo-Ortuno et al., 2008).

All chapters provided information that is useful for managing this rare species. The variables found to influence Spotted Turtle population persistence over time should be the focus of future field work and monitoring. We found that the survival rates of older age classes, population size, and age at sexual maturity were influential in assessing long term viability of populations. Managers can incorporate data collection of these variables into their monitoring program to gain more information than presence/absence data alone would provide. These data will enable population viability models to be created for specific populations. Population models suggested that low levels of catastrophes, such as no hatchling survival, and poaching can be detrimental to population persistence if population growth rate is near or below 1.0. Management should ensure that appropriate nesting locations exist and that poaching does not occur.

Management in the Oak Openings Region should focus on managing current sites since Spotted Turtles show high site fidelity, but also to acquire and protect additional lands since potential Spotted Turtle habitat makes up less than 1% of the region. We were able to make specific management suggestions, such as create heterogeneous sites, remove shrub/scrub to raise water levels, encourage the growth of native sedges and grasses, and avoid open water by assuring that native vegetation exist. We have shown that Spotted Turtles have complex habitat requirements, making it important to have a multiscale view which considers the context of different environmental variables (i.e., land cover, vegetation density, characteristics of hibernacula) that accommodate the year round requirements for turtle presence and viability.

The major strengths of this research were that it included multiple scales and techniques, and increased our understanding of Spotted Turtle biology by exploring several novel aspects. There is much value in evaluating multiple temporal and spatial scales as it provides a more complete picture of habitat requirements which can otherwise be missed. The field study took place over a three year period at Bumpus Pond and two years at Kitty Todd. The type and amount of information we collected could have only been obtained by multiple years of research at several scales, allowing us to assess the sites during different conditions such as wet and dry years and the environmental factors that affect presence at each scale.

We used multiple techniques, a mark-recapture field study utilizing radio telemetry, population modeling, and habitat modeling, which also provided a more complete picture of the requirements of and threats that Spotted Turtles face. Each technique provided a different type of information yet worked together to enhance the overall conclusions that could be drawn. These techniques can be used for a variety of species to make field studies more efficient by maximizing the value of sampling data, providing additional biological information, directing future research, and focusing management.

The strength and novelty of this research comes from an increased understanding of Spotted Turtle biology throughout the range and locally, as no published field studies have been conducted with Spotted Turtles in the Oak Openings Region and no field studies had been conducted at Bumpus Pond. Also, previous Spotted Turtle research has only consisted of field studies: a sensitivity analysis had not been performed, and GIS technology had only been used to explore seasonal movements. Our results contribute to the understanding of Spotted Turtle biology and highlight additional avenues research with this species can take.

There are several weaknesses of our research on which future studies should focus. During the field study we were not able to collect a large enough sample to determine a true home range size for Spotted Turtles within our sites, and we did not locate any nests within the sites. This information would strengthen our knowledge of the habitat use and population status of Spotted Turtles in the Oak Openings Region. Also, we did not collect enough data to confidently determine survival rates for Spotted Turtle age classes within the site, so we could not create a population viability model specific to Spotted Turtle populations in the region. Although we have not yet ground truthed the potential habitat suitability model, and feel that running additional statistical tests such as the Mahalanobis would greatly strengthen our research results.

In conclusion, this research utilized population viability modeling, several years of field research, and habitat modeling at multiple spatial scales which contributed to the data needed to manage rare freshwater turtles. We identified critical demographic variables future research should focus on, and the population and environmental variables critical to Spotted Turtle presence. By identifying the environmental requirements and the viability of Spotted Turtles in Northwest Ohio, we provided vital data that can be used for the management of this species throughout the range as well as for other freshwater turtle species.

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