DISTRIBUTION OF POPULATIONS AND SUITABLE HABITAT FOR SPOTTED TURTLES (*CLEMMYS GUTTATA*) AND BLANDING'S TURTLES (*EMYDOIDEA BLANDINGII*) IN INDIANA

by

Jessica R. Hinson

A Thesis

Submitted to the Faculty of Purdue University

In Partial Fulfillment of the Requirements for the degree of

Master of Science

Department of Biology

Fort Wayne, Indiana

December 2018

THE PURDUE UNIVERSITY GRADUATE SCHOOL
STATEMENT OF COMMITTEE APPROVAL

Dr. Bruce A. Kingsbury, Chair
Department of Biology
Dr. Mark A. Jordan
Department of Biology
Dr. Jordan M. Marshall
Department of Biology

Approved by:
Dr. Jordan M. Marshall
Head of the Graduate Program

For my dad, Tim Hinson — a fellow scientist at heart and mind.

ACKNOWLEDGMENTS

I want to start by thanking Jill Josimovich, Monica Matthews, and Reine Sovey for being the best colleagues and friends I could ask for throughout this program. We had so many great times together—whether it be in the field or in the office. Thank you for constantly listening to my concerns and giving me encouragement every step of the way in this journey. I really do not know what I would have done without all of you.

Next, I would not have pursued this new step in my career if not for my parents, Tim Hinson and Candi Heiss. Thank you for being my backbone and encouraging me to continue in pursuing my dreams and embrace my passions. I know how proud you both are of me, and I plan to make you even more proud as I graduate and go into the next step of my life and career. I would also like to extend thanks to my dog, Beach, and two cats, Allie and Gonzo. While you all have since passed away while I was here, I still want to say thank you for being my best friends throughout much of my life, and I don't know what I would've done without your love, adoration, and excitement every time I went home.

I am eternally grateful to Dr. Kingsbury for accepting me under his wing as a graduate student and giving me the chance to work with such amazing animals through his lab and further my knowledge in applied conservation of wildlife. I have gained such valuable skills due to the freedom you gave me in this project. From writing reports, interacting with various conservation agencies, and even experiencing the inner-workings of the hiring process, my skill set has grown tremendously with your encouragement and assistance. Dr. Jordan, thank you for your support and introducing me to turtle trapping methodology. It was a pleasure to be able to assist you and your students in the genetics side of this statewide project. And Dr. Marshall, thank you for listening and assisting me with my questions about statistics and even species distribution modeling. Of course, your fascination and love for tarantulas was also appreciated as my little group of them grew!

I wouldn’t have been able to actually search for these turtles without the partnership and support from various agencies. I would like to thank the Department of Natural Resources and United States Fish and Wildlife Services for funding this project and giving me an opportunity to search for two endangered species in the state. I would also like to extend thanks to The Nature Conservancy, ACRES Land Trust, National Park Service, Shirley Heinz Land Trust, and Save the Dunes Council for giving me access and guiding me through their properties across the state. There are a few specific individuals from these agencies I would like to thank, due to their dedication and willingness to help me with the permit and reporting processes: Roger Hedge, Linnea Petercheff, Richard Dunbar, Nathan Engbrecht, and Gia Wagner. I would also like to extend thanks to some of the agency workers and property managers who assisted me and my team in the field in search for these two turtle species: Emily Stork, Nathan Simons, and Derek Luchik. I would also like to thank all of my technicians and volunteers that have helped me with field work over the past two years.

I would like to thank the various educational institutions and museums that were willing to share their element occurrences and collections with me: American Museum of Natural History, California Academy of Sciences, Carnegie Museum of Natural History, Chicago Academy of Sciences, Chicago Field Museum of Natural History, Florida Museum of Natural History, Louisiana State University Field Museum, Ohio State University, San Diego Museum of Natural History, Smithsonian Museum of Natural History, University of Colorado, University of Kansas, and University of Michigan.

I also would not have been able to be here without the endless support from my undergraduate mentor and professors: Dr. Allison Welch, Professor Kathleen Janech, and Dr. Melissa Hughes. A huge thanks to Jeff Holmes, Ab, and Chrissy of the Amphibian and Reptile Conservancy survey team in South Carolina, who helped me hone my survey skills and have constantly cheered me on as I have continued my career.

Finally, I would not have been able to do this work without the spotted turtles and Blanding's turtles of Indiana. You are both amazing species, and I am blessed to have been able to work with you! I hope that the future is bright for your species!

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

ABSTRACT

Author: Hinson, Jessica, R. MS
Institution: Purdue University
Degree Received: December 2018
Title: Distribution of Populations and Suitable Habitat for Spotted Turtles (*Clemmys guttata*) and Blanding's Turtles (*Emydoidea blandingii*) in Indiana
Committee Chair: Bruce Kingsbury

The spotted turtle (*Clemmys guttata*) and Blanding's turtle (*Emydoidea blandingii*) are two state-endangered species in Indiana whose populations are in decline. Historically, both species were found across the northern portion of Indiana in various wetland habitats. There are multiple causes of population decline for both species, including habitat fragmentation, habitat loss and degradation, urban development and encroachment, poaching, and road mortality. Despite efforts to record these species across the state, there has been no intensive population assessments. Based on this need, I conducted both visual encounter surveys across the state and used Maximum Entropy (MaxEnt) modeling to facilitate understanding the current distribution of both species in Indiana. Twenty-three locations were visited and surveyed in Indiana, with trapping being conducted at an additional four locations where populations were known to be larger. Surveys aided in delineation of six populations of Blanding's turtles and five populations of spotted turtles. A total of 69 Blanding's turtles and 70 spotted turtles were observed between surveying and trapping. Delineated populations were mainly found in the northern third of Indiana. This data and other occurrences were used to predict suitable habitat across Indiana. The Blanding's turtle models were sufficiently resolved to predict potential localities or potential sites for focused management or repatriation. Spotted turtle model performance reflected the need for more samples, but also the likelihood of fewer numbers due to declining habitat availability. Both Blanding's turtle and spotted turtle models argue for the need of more intense

survey efforts based on historical occurrences, as well as restoration efforts across the state. Most models for both species were observed to have a trend towards suitable habitat in the northern third of the state, correlating with the results of the survey efforts. The results of this project indicate that Blanding's turtle and spotted turtle populations are still in decline likely due to limited habitat availability.

POPULATION ASSESSMENTS AND DISTRIBUTIONS OF SPOTTED TURTLES AND BLANDING'S TURTLES IN INDIANA

Introduction

Background

Indiana was once dominated by various natural habitats, including a now-endangered resource within the state—wetland habitats. However, Indiana is now a state overcome by urban development, agricultural lands, and industry. Before the arrival of European settlers, there were many wetland habitat types across the state, such as marshes, swamps, fens, bogs, floodplains, and wet prairies, and other aquatic habitats like lakes and ponds. It is estimated that during the 1780s, approximately 24 to 26% of Indiana's surface was covered by various wetland and aquatic habitat types, and with them a variety of aquatic or semi-aquatic flora and fauna occurred across the state (Indiana Wetlands Conservation Plan, 1996; Myers, 1997; Whitaker & Amlaner Jr., 2012).

With arrival of settlers in the late 1780s, many of these wetlands were drained for their fertile soils in order to grow crops, or to be built over for settlements. At least 85% of the original wetlands in the state were lost, and contributed to a significant decline in wildlife and flora. Wetlands that still remain are not only reduced in size, but fragmented and isolated from each other. Wetland restoration has replaced many of the wetlands lost, but the percentage remaining compared to historical wetlands is still very low (Dahl, 1990; Indiana Wetlands Conservation Plan, 1996; Myers, 1997).

The spotted turtle (*Clemmys guttata*) and Blanding's turtle (*Emydoidea blandingii*) are two species of turtles in Indiana whose populations are in decline. Both species inhabit various wetlands in the state and are historically distributed across the northern portion of Indiana (Harding, 1997; Barlow, 1999; MacGowan et al., 2005; Ernst & Lovich, 2009). Their decline can be attributed to various factors, including habitat fragmentation, habitat loss and degradation, urban development and encroachment, poaching, and road mortality. Along with these threats, populations are unable to recover quickly enough due to the long generation time and low fecundity in both species (Harding, 1997; Minton, 2001; MacGowan et al., 2005; Beaudry et al., 2009; Ernst & Lovich, 2009). Both species are considered state-endangered in Indiana (Indiana State Wildlife Action Plan, 2015) and are on the International Union for the Conservation of Nature's (IUCN) Red List of Threatened Species as endangered. Along with being state-endangered in Indiana, both species have also received Convention on International Trade in Endangered Species of Wild Fauna and Flora (CITES) protection and were petitioned for being listed as federally threatened to the U.S. Fish and Wildlife Service (Adkins Giese, 2012; Racey, 2015). Due to their widespread declines and status as state-endangered turtles in Indiana, there is increasing concern over their conservation.

The Study Animals

Spotted Turtle

The spotted turtle (*Clemmys guttata*) is a semiaquatic turtle of the family Emydidae, or the pond and box turtles. This species is small with a smooth, black or brown carapace that has multiple yellow spots. The yellow spots may extend to be on the head as well. The plastron is unhinged and yellow or orange in base color, with black appearing on the edge of every scute (Harding, 1997; MacGowan et al., 2005; Ernst & Lovich, 2009). The carapace is usually between 9 to 13.5-centimeters for adults. Males and females can be distinguished through morphological features such as coloration, plastron concavity, and vent location. Males often have dark-colored eyes with a black or brown lower jaw, while females have bright orange eyes and a yellow or orange lower jaw (Harding, 1997; MacGowan et al., 2005). The plastron on adult males is concave compared to the females, which is more flat or convex. Finally, the male vent extends past the edge of the carapace when the tail is extended, while female vents are behind the carapace edge (Harding, 1997; MacGowan et al., 2005).

The range of the spotted turtle extends from the northeastern part of Illinois to the southern portion of Maine. From Maine, the range extends south along the Atlantic coast to the northern Florida (Harding, 1997; Litzgus & Mosseau, 2004a; MacGowan et al., 2005). Ernst (2009) describes the range to go even further south in Florida, but only in very isolated populations. In Indiana, spotted turtles are historically found in the northern half of the state. They are relatively uncommon to find, especially in the Great Lakes region, and are reported mainly in isolated populations (Harding, 1997).

Spotted turtle populations have greatly declined throughout their range due to habitat modification and fragmentation (Harding, 1997; Lewis et al., 2004; MacGowan et al., 2005; Beaudry et al., 2009). Another reason of decline is the collection of spotted turtles from the wild for the pet trade (Harding, 1997; MacGowan et al., 2005; Beaudry et al., 2009). Spotted turtles have been listed as state endangered in Indiana, as well as many others throughout its range, which is important for decreasing their collection by humans. Within still existing habitats and populations, spotted turtles are at risk of road mortality, encroaching development, increasing invasive plant species, increasing predator ratios, and illegal poaching (Ernst, 1976; Harding, 1997; Minton, 2001; Lewis et al., 2004; Beaudry et al., 2009).

Blanding's Turtle

The Blanding's turtle (*Emydoidea blandingii*) is also a semiaquatic turtle belonging to the family Emydidae. Blanding's turtles have a domed and elongated carapace that is smooth and has no keels. It is usually brown or black in color, with various patterns of tan or dull yellow spots/streaks. The hinged plastron of the Blanding's turtle is yellow in color with black on the edge of each scute and has a posterior notch. The lower jaw is bright yellow in coloration, with the top jaw being notched that gives the characteristic "smile" for the species. There is also dull-colored mottling on the head (Minton, 1997; Harding, 1997; MacGowan et al., 2005; Ernst & Lovich, 2009). As adults, these turtles have been measured to have a carapace length as small as 15.2 cm and as large as 27.4 cm. Males and females are not easily distinguishable by coloration, but are through vent location and plastron concavity (Harding, 1997; MacGowan et al., 2005). As observed for spotted turtles, vent location in males extends past the edge of the carapace when the tail is extended. Plastrons are also more concave in adult males than in females (Harding, 1997).

The range of the Blanding's turtle extends from Minnesota and Nebraska, east to the very northwest corner of Pennsylvania, and then extending north into Quebec and Ontario. There are isolated populations in New York, Maine, New Hampshire, and Nova Scotia (Harding, 1997; MacGowan et al., 2005; Ernst & Lovich, 2009). In Indiana, Blanding's turtles are historically found in the northern half and extend a little farther south on the west side of the state. While the Blanding's turtle is in decline throughout its range, it is relatively easy to find (Harding, 1997; MacGowan et al., 2005).

Blanding's turtle populations are in decline throughout their range due to habitat degradation, with the most abundant populations being reported in the southern portion of the

Great Lakes region. While habitat degradation has caused a major loss of habitat for the Blanding's turtle, road mortality is also a significant cause of population decline (Harding, 1997; MacGowan et al., 2005; Beaudry et al., 2009). The pet trade is considered a reason for population decline, and the turtles are also collected as food and by other supply companies. While large wetlands are usually a focus of conservation, attention is recommended for smaller wetlands as well, since these are more likely to be used for nesting and intermediate areas when the turtles move long distances. Populations are also at risk if predator populations are abnormally high, as the eggs of these turtles are targets of various predators like raccoons (Harding, 1997; Minton, 2001; MacGowan et al., 2005; Beaudry et al., 2009).

Spotted Turtle and Blanding's Turtle Habitat Use

Spotted turtles can be found in wetlands with still or slow-moving waters, such as ponds, bogs, fens, wet meadows, and swamps. They are often found in shallower water that has organic soils, resulting in areas with high amounts of emergent vegetation (Harding, 1997; Haxton & Berrill, 1999; Barlow, 1999; MacGowan et al., 2005; Ernst & Lovich, 2009; Stevenson et al., 2015). Barlow (1999) determined that these turtles greatly enjoy emergent wetlands that are marsh-like, but will use scrub-shrub habitats as well. They are considered to be inactive at night and emerge early in the spring (Ward et al., 1976; Ernst, 1976; Harding, 1997; MacGowan et al., 2005; Ernst & Lovich, 2009). Their average home ranges can be as small as half of a hectare to over three hectares, and often utilize wetland complexes that are made of riparian habitat and different wetland habitat types (Ernst, 1970; Ward et al., 1976; Harding, 1997; Barlow, 1999; Milam & Melvin, 2001; Rasmussen & Litzgus, 2010). Barlow (1999) found the home range of spotted turtles to be 3.1 (±2.20) hectares. However, Litzgus & Mosseau (2004b) found that gravid female home range size in a southern population was approximately 16-hectares due to their nesting behavior, which was much larger than the male home range. Most movement occurs by males likely looking for mates or females looking for nesting habitat (Harding, 1997). Mating occurs soon after emergence and occasionally before hibernation, with nesting starting in early summer (Harding, 1997; Ernst & Lovich, 2009). Hibernation occurs in areas of shallow water, but not shallow enough to completely freeze at the bottom and stay relatively stable in temperature (Ward et al., 1976; Harding, 1997; Litzgus et al., 1999; Barlow, 1999; MacGowan et al., 2005; Ernst & Lovich, 2009). Spotted turtle diets include multiple invertebrates such as worms or crustaceans, but they will also feed on carrion. Their vegetative diet includes algae, plant leaves, and seeds (Harding, 1997; MacGowan et al., 2005; Ernst & Lovich, 2009).

Blanding's turtles can be found in wetlands much like the spotted turtle, such as ponds, marshes, bogs, fens, wet meadows, and swamps, with nearby upland habitats for nesting. They have also been found in deeper waters such as lake inlets, rivers, and edges of lakes (Kofron & Schreiber, 1985; Harding, 1997; Barlow, 1999; Hartwig, 2004; MacGowan et al., 2005; Ernst & Lovich, 2009). Blanding's turtles are considered to be diurnal like the spotted turtle (Smith and Iverson, 2004), and emerge in early April from hibernation. Blanding's turtles are known to move far distances (Joyal et al., 2001; Congdon et al., 2011), with activity centers being around 2.3-hectares (Rowe and Moll, 1991). Their home ranges can be very large compared to spotted turtle home ranges, and vary greatly in size (Rowe, 1987; Barlow, 1999; Innes et al., 2008; Millar & Blouin-Demers, 2011; Hasler et al., 2015). Like spotted turtles, their home ranges encompass wetland complexes that have various wetland habitat types and riparian habitat that the turtles travel between (Kiviat, 1997). Hasler et al. (2015) reported an average of 19.06-hectares for a home range size. Barlow (1999) averaged that Blanding's turtle home ranges at 4.96 (±4.87) hectares, and Rowe (1987) found the average home ranges were 10.6 (±7.8) hectares for males and 8.0 (±6.7) hectares for females. Males move a longer distance in search for mates while females are more concerned with nesting sites near the core wetland complex (Harding, 1997; Markle and Chow-Fraser, 2014). In Illinois, they have been found as early as March 29 due to their tolerance of cooler water temperatures (Rowe and Moll, 1991). Mating occurs after emergence and the turtles hibernate in late October or early November (Harding, 1997; Ernst & Lovich, 2009). Blanding's turtle overwintering sites are similar to spotted turtles, and often require deep enough water for stable temperatures and not shallow enough to freeze at the bottom (Harding, 1997; Barlow, 1999; MacGowan et al., 2005; Ernst & Lovich, 2009). Their diet mainly consists of crustaceans, but may also include other invertebrates, frogs, and some plant material (Harding, 1997; MacGowan et al., 2005; Ernst & Lovich, 2009).

Objectives

Although efforts are made to record occurrences of both Blanding's turtles and spotted turtles across Indiana, there have been no intensive population assessment done in Indiana for either species. Due to the population decline of both species through habitat loss and poaching, population assessments can provide information on current population and habitat distribution. By conducting population assessments, pertinent information can be obtained that can be used to further the understanding and efforts in providing management and conservation strategies for both of these state endangered species of turtles. From this need, the objectives were to 1) determine the presence of Blanding's turtles (*Emydoidea blandingii*) and spotted turtles (*Clemmys guttata*) in the state of Indiana, 2) physically assess habitat suitability and connectivity that may not be obvious in aerial imagery, 3) delineate populations based on known and assumed habitat suitability and connectivity observed in surveys and aerial imagery, and 4) analyze the habitat composition and plant communities at locations where either species occur now or in the recent past.

Through these objectives, conservation efforts and appropriate management entities can be provided information that is pertinent to the survival and reproduction of spotted turtles and Blanding's turtles, such as remaining viable populations and habitat quality and suitability in Indiana.

Methods

Population assessments were conducted through population surveys across the state of Indiana, based on the historical distribution of both species, preliminary habitat modeling, and records of sightings. Surveys determine presence of the species, as well as provide more details on habitat quality and sustainability in Indiana throughout their distribution. Habitat assessments were done through visual identification and line-intercept transects across wetland habitats based on where surveys were conducted. The habitat assessments were conducted in an effort to determine broad plant community composition of the wetland habitats within areas that were surveyed for spotted turtles and Blanding's turtles. Despite differences in macro- and microhabitat use by both species (Barlow, 1999; Joyal et al., 2001; Beaudry et al., 2009; Anthonysamy et al., 2014), they have been found to co-exist in the same wetland complexes (Harding, 1997; Minton, 2001; MacGowan et al., 2005; Ernst & Lovich, 2009). Because of similar habitat usage, historical distribution, and population declines, both species were in joint consideration for population surveying, habitat assessment, and population delineation.

Survey Location Identification

In order to conduct population surveys, potential locations of interest needed to be identified that were based on the historical distribution of both species and previous sightings. Previous sightings included element occurrences (EOs) and visual observation reports provided to me. Multiple element occurrences and visual encounter records were retrieved in 2016 from a variety of sources including the Indiana Department of Natural Resources, HerpMapper (https://www.herpmapper.org/), museums, and educational institutions (American Museum of Natural History, California Academy of Sciences, Carnegie Museum of Natural History, Chicago Academy of Sciences, Chicago Field Museum of Natural History, Florida Museum of Natural History, Louisiana State University Field Museum, Ohio State University, San Diego Museum of Natural History, Smithsonian Museum of Natural History, University of Colorado, University of Kansas, and University of Michigan). Several occurrences were also collected through personal communication with property managers or owners, and field researchers. Museums and institutions were chosen and contacted based on the records stored in the VertNet database (http://www.vertnet.org). The oldest EO with a date was 1892 for spotted turtles and 1896 for Blanding's turtles, while the most recent was 2016 for both species. The EOs obtained were mapped as points using GIS (geographic information systems; ArcMap 10.5 and QGIS 2.18.12) to visualize distributions and compare it to the historical distribution of both species (Harding, 1997; Litzgus, J.D. Mosseau, 2004a; MacGowan et al., 2005; Ernst & Lovich, 2009).

Survey Location Priority

The list of potential locations based on EOs and visual observations was extensive, and while it would have been ideal to survey all the identified locations, it was not possible based on time restrictions and available resources. Because of this, occurrences and their associated locations were prioritized to guide my survey efforts and allow me to choose where to survey for the turtles. Prioritization was done by categorical code in two separate steps. The first step of prioritization used only two hierarchal rankings, low and high, and looked at the age of occurrences. The second step of prioritization used three hierarchal rankings, low, medium, and high, and looked at habitat quality and level of urban development. Locations that appeared to have remaining suitable wetland habitat and where it was uncertain if either species remains were of greatest interest and thus further prioritized.

Age of Occurrences

All records and corresponding locations were first prioritized as low or high based on age of occurrences to better understand the historic distribution of either species for future management and conservation purposes. The initial records obtained ranged from 1892 to 2016 between both species of turtles, and were used to create a list of potential locations. Due to the number of records that this created and the time consumption of priority ranking, records from 1892 to 1969 were ranked low and excluded from survey prioritization (Figure 1). It also further narrowed the list of locations to those where it was more likely that the turtles may still occur. Records from 1892 to 1969 were considered historic and of low priority, due to the increasing likelihood that these sightings were in areas no longer suitable for either species of turtle. The year 1969 was chosen as the threshold arbitrarily. Further, associated locations with the most recent occurrence dating 2012 to 2016 were given low priority (Figure 1). Locations with occurrences until 2011 were given high priority for surveying based on the need to know whether either species was there. Records from 2012 to 2016 were given low priority for surveying since the species were seen within the past five years and are more likely to still occur in these locations, especially if the amount of records in an area was high and habitat was suitable. Occurrences and associated locations with occurrences dated 1970 to 2011 were ranked high. By focusing on the time span of 1970 to 2011, an extensive number of sites was obtained for further prioritization (Figure 1).

Hydric Soils and Soil Quality

Hydric soil presence and soil quality were ranked individually before used in combination to rank habitat quality. Hydric soils were defined as soils that hold great amounts of water and are heavily saturated (Soil Survey Staff, USDA, 2016). These soils are often associated with areas of presence of water and fertile soils of wetlands. It was assumed that higher ranking of hydric soils at a location of interest indicated an area able to hold water and be saturated for seasonal use by the turtles.

Soil quality was defined as the level of organic matter in a soil (Soil Survey Staff, USDA, 2016). Spotted turtles and Blanding's turtles are often found in places with emergent vegetation (Harding, 1997; Barlow, 1999; Hartwig, 2004; MacGowan et al., 2005; Ernst & Lovich, 2009), and emergent vegetation is associated with soils that have a decent amount of organic matter (Myers, 1997). Based on the association of emergent vegetation and organic matter, sites were prioritized further based on whether the soils were going to be able to produce emergent vegetation.

Polygons were created in the Web Soil Survey (WSS, Soil Survey Staff, USDA, 2016) to represent an area of interest, and hydric soil presence and soil quality data were collected. An area of interest was an individual polygon that was drawn around the occurrence(s) and the associated location. Ratings were measured in percentages. On average, hydric soil ratings were observed to range from 0 to 100% while soil quality ratings ranged from 0 to 75% for suitable wetland habitats in Indiana. Based on this trend, only soils with a hydric soil rating of ≥ 90% and a soil quality rating of ≥ 70% were considered to represent areas of suitable wetland habitat. Thus, both hydric soil presence and soil quality was considered of high ranking when it made up ≥ 50% of the area, indicating a suitable wetland habitat. (Figure 2).

Vegetation Cover

Locations were also prioritized based on the canopy cover. While spotted turtles and Blanding's turtles are known to be in forested wetlands when traveling between open wetlands in Indiana (Barlow, 1999), areas of low canopy cover were focused upon due to indications for available basking sites. Surveying for turtles is most efficient when turtles are likely to be basking rather than moving between wetlands, and thus locations with low canopy cover were given a high ranking (Figure 2).

Based on the rankings of the soil quality, hydric soil presence, and vegetation, habitat quality was determined as high, medium, or low (Figure 1). In cases where the resulting habitat quality ranking was difficult to conclude incompatible the soil quality, hydric soil presence, and vegetation rankings with the rules in Figure 1, the habitat quality ranking was manually decided based on the available information and rankings. Urban development was considered a separate ranking factor rather than part of habitat quality. Due to heavy wetland fragmentation in Indiana, it was desired to assess level of urban development and habitat quality as separate factors.

Stage of Urban Development

Another consideration for survey location prioritization is the stage of urban development surrounding a location. Due to the extensive fragmented wetland habitat in the historical distribution of both turtle species, urban development was a significant factor to include in location prioritization. When considering a location, the area around the core wetland of interest was assessed for level of urban development (e.g. agricultural and industrial). The area around the core wetland of interest was chosen to be a 1-kilometer buffer zone, based on the suggestions and methodology in King (2013) and Hartwig et al. (2009). King (2013) is a conservation assessment strategy plan for the Blanding's turtle in Illinois that defined buffer zones based on Hartwig et al. (2009) that the turtles would use throughout the season. One of the buffer zones is called the Conservation Zone, which is considered the surrounding area of the core wetland habitat that Blanding's turtles were expected to use on a seasonal basis and be in regularly throughout the active season. Due to the survey period being during emergence season, the 1-kilometer Conservation Zone likely covered the extent that a turtle would travel from a core wetland while surveying occurred. While turtles are expected to move between wetlands as the season progresses, any major movement distances that would likely involve a turtle encountering developed areas (if present) would occur after the survey period. While King (2013) and Hartwig et al. (2009) focus on the movements and conservation of Blanding's turtles, spotted turtles are known to have similar seasonal behavior, although do not move as great of distances as Blanding's turtles. Due to this, the management guidelines were used for both species.

Urban development was assessed using aerial imagery, with a high ranking being assigned to a location if there was little development and contained more natural landscape that indicates suitable habitat for either species to utilize (Figure 2).

Prioritization

Once habitat quality and surrounding area rankings were determined, survey priority was ranked based on those two variables (Figure 1). Further priority was given to surveying at high priority locations that had occurrences for both species during the 2017 field season. This was decided in order to utilize time as efficiently as possible, and since the project centered on surveying for both species, it was assumed best to look in areas where it was likely to see at least one of them if they still inhabited the area. For the 2018 season, priority was given to survey at locations with spotted turtles, due to the low number of spotted turtles found in the 2017 field season. This was done in an attempt to identify more spotted turtle populations for modeling, but also for the population genetics project.

Population Delineation

In addition to survey location prioritization, Blanding's turtle and spotted turtle populations were also delineated. Although a threshold was applied to survey location prioritization, occurrences dating before 1970 were also included to delineate historical populations. Populations were delineated based on NatureServe (2004) and NatureServe (2005) recommendations (wetland connectivity, suitable habitat, presence of barriers like roads, and corridors). Historical populations were delineated on similar recommendations, but historical road and landcover maps were used as needed from the National Geologic Map Database (USGS, 2018). Population delineation was mainly done through aerial imagery, but surveying also assisted in providing more information on features like barriers and corridors.

Turtle Surveying

Visual encounter surveys (VES) were used to survey for Blanding's turtles and spotted turtles. VES are used when there is time constraint and to sample the species richness and abundance of a set area, compared to using other survey methods like transect surveys or trapping methodology (Crump & Scott, 1994; Graeter et al., 2013; Dodd, Jr., 2016). Crump and Scott (1994) suggest that VES are best used for species that are difficult to find and trap. While

Blanding's turtles are not as cryptic as spotted turtles and have been reported in traps, both species are considered uncommon and not as easily found as other species. Surveys allowed the presence of either species to be determined at a location, as well as an idea of the distribution of the target species in the area. Surveying also aided in characterization of the preferred habitat for the two target species in Indiana.

The sampling design for VES included non-random intensive surveying around the wetlands of the location. Surveying focused on the most suitable habitats at a location, often involving shallow water areas and shorelines of wetlands. Binoculars and spotting scopes were used opportunistically while surveying, mainly to identify basking turtles and inspecting the visible habitat for any turtles before moving forward to avoid disturbing individuals. Turtle species were often seen basking in open water on a log or other substrate, in which case binoculars or a spotting scope were the most useful tools to identify species and collect data. This sampling design allowed focus on the primary habitat that the turtles are likely to be found, and to delineate the wetlands in the location. It also utilized time to survey for the turtles efficiently, since it focused on the most suitable habitat.

Surveying was conducted during the emergence time of both species, which usually ranges from late-March/early-April to late-June. As the summer continues, turtles become more difficult to find due to a decrease in basking activity and the growth of vegetation (Rowe & Moll, 1991; Harding, 1997; Ernst & Lovich, 2009). The field seasons were during the spring and summers of 2017 and 2018. The 2017 survey season began in early April and concluded in mid-June, while the 2018 season began early April and ended early June. The goal was to visit each site at least three times and obtain a minimum of 30 survey hours per site, unless a target species was found earlier. The amount of survey hours per visit per location were affected mainly by weather, such as temperatures or severe storms.

Some wetlands were especially large and thus subdivided into individual “sites” for ease of surveying and data collection. For example, if Location 1 was particularly large or suitable habitat was fragmented, then each area surveyed was given a site number (e.g. Site 1, Site 2). If Location 2 was small enough to easily survey as an entire “site,” then it was only written as having one site rather than multiple.

Data collected for each site included the start and end times of the survey, and date of the survey. The name of the location, surveyor(s), and number of people surveying per site were recorded as well. Shaded air temperature at approximately 1-meter, water temperature, cloud cover, and the wetland community type (e.g. bog, fen, marsh, swamp, lake, pond, sedge meadow, other) were also recorded at the beginning of the survey period for each site.

If a turtle was observed, its coordinates were recorded with a global positioning system (GPS) unit. In addition, behavior (e.g. basking/resting, traveling, feeding, nesting, other), substrate (e.g. log, soil, grass, leaves, water, other), and approximate distance from the observer were recorded. The time, air temperature, water depth (if applicable), and exposure to sunlight were also recorded. Other notes of interest were recorded as well. Data that was classified as other was described in the notes section or photographed. If a turtle was seen in the open water and could not be reached for accurate coordinates, a projected coordinate was approximated either through the GPS unit or GIS based on the distance from the observer and approximate orientation. Every effort was made to obtain a photo of each individual target species observed for a photo voucher.

Other herpetofauna encountered were recorded as well. The recording of other herpetofauna during the surveys was a representation of the wildlife diversity of the location and the other species that can be found inhabiting the same location as Blanding's turtles and spotted turtles (Beaudry et al., 2009). Coordinates and photos were taken for state-endangered, federally listed, or threatened species; otherwise, common species had further data taken by choice of the observer.

Turtle Trapping

Once surveying concluded due to observing decreased basking behavior, trapping for the target species began. The decrease in basking behavior was often correlated with warmer temperatures and vegetation growth, indicating that turtles did not need to bask as often and mating and nesting seasons had likely started. Trapping was used to increase the sample size of turtles encountered for population genetic analysis for a concurrent study, but also provided further information on population viability. Traps were set in locations where populations were either identified by surveying or in locations where a suitable population was already assumed to occur. Trapping started soon after surveying season stopped and concluded in late July in 2017 and mid-July in 2018.

Traps utilized were either Promar® Collapsible Minnow traps (36" x 12"; dual 5-inch entrances; 0.25-inch polyethylene netting), hoop net traps (36-inch diameter; single entrance; 3-inch square mesh), or a combination of both. A maximum of 20 Promar® and 20 hoop net traps were used per location. Hoop net traps are ideal for capture of larger turtle species (e.g. Blanding's turtles), due to the high likelihood of small turtles or juveniles escaping through the large net holes. Promar® traps are ideal for smaller turtle species (e.g. spotted turtles) or juveniles, due to the smaller mesh openings. A combination of both hoop net and Promar® traps were utilized in locations where both species were known or assumed to occur or only Blanding's turtles occurred, while only Promar® traps were utilized in locations that only spotted turtles occurred. Known or assumed occurrence were based on both survey efforts and previous survey prioritization methods, and any information obtained from property managers regarding turtle populations at locations. All traps were baited with canned sardines in oil, and replaced as needed throughout the time the traps were set.

Traps were set based on the methodology described in Willey and Jones (2014). Methodology used involved choosing reference points to represent a single core wetland. Each reference point was then buffered by 400-meters. Within the buffer zone, five sets of traps were set in suitable habitat and water depth. Each set of traps contained one hoop net trap, one Promar® trap, or a combination of both. When used in combination, Promar® traps and hoop net traps were placed within a 10-meter radius of each other. When a location was especially small and only contained one wetland suitable for traps, the number of trap sets in the single reference point was disregarded to cover a greater expanse of the only available wetland in that location. The maximum time that traps were set out was four nights and five days, and checked every 24 hours. Air and water temperature were recorded for each trap check, and the number of target species was recorded in addition to any other reptiles (and amphibians, if requested by property managers) captured.

Intensive Habitat Assessment

Data Collection

Once surveying and trapping season concluded and vegetation had fully flushed, the plant community was assessed at each site for each location that surveys or trapping occurred.

Understanding the plant community at each site allowed the potential analysis of habitat composition preferences of both turtles, which is important to future conservation efforts. The plant community was assessed through identification of plant functional groups that can allow habitat preferences of the target species to be analyzed. Barlow (1999) found different habitat uses of spotted turtles and Blanding's turtles in the Pigeon River Fish and Wildlife Area. By looking at habitat in multiple locations throughout their historical distribution, a better understanding of habitat preferences could potentially be gained for conservation and management purposes.

The functional group classification included: obligate annuals, facultative annuals, reeds, clonals, tussocks, clonal stress-tolerators, and clonal dominants (Table A1). Two more categories were added to further accommodate wetland habitat: open water and other. Open water was described as any water that had no visible plant life below, at, or above the water surface, while other category incorporated scrub-shrub and dead plant material. Both of these additional categories were important to add due to the likelihood of encountering them in wetland habitats that were surveyed or trapped.

A 100-meter line intercept transect was established along the long axis of the core wetland per site per location where surveying and trapping was conducted. The long axis of the wetland was determined using the GIS ruler measurement tool and its endpoint coordinates were recorded. Transects began at or near one of the long axis endpoints, chosen mainly by accessibility on foot. If neither endpoint could be accessed, then efforts were made to begin the transect as close to one of the endpoints as possible.

Plant functional groups were recorded that touched the transect represented by a 100-meter measuring tape. Transect length for each functional group traveled was recorded and converted to a proportion of 100-meters. Caution was taken to not heavily trample vegetation during transect establishment. If habitat was inaccessible by factors such as thick shrubbery or deep water, the transect was stopped prematurely and data had to be estimated for that portion of the transect. The transect was continued after the inaccessible portion, if possible. Upland habitat was noted but not included in plant functional group identification due to the transect focus being on wetland vegetation.

In addition to the transect, each site where a transect was conducted was also categorized as an emergent wetland, scrub-shrub wetland, or forested wetland (Table A2). Broadly categorizing the wetlands allowed further habitat information to be gathered, such as certain plants or trees present and what kind of wetlands the turtles are often found in. The wetland classifications were based on the type of vegetation seen and the wetland community type classification from surveying, if applicable.

Data Analysis

Following habitat assessments, various statistical analyses were conducted in R v. 3.5. Functional group measurements for each transect were summed or remained in proportions of 100-meters, depending on the needs of the statistical tests and how data had to be prepared in R.

A Chi-square test was conducted to observe any independence or associations between functional groups across the three broad habitat coarse types. The chi-square residual values were analyzed for individual associations between functional groups and habitat types. Positive residual values indicated a positive association, while negative indicated a negative association. Percent contribution of each association to the test results were also analyzed. Proportions of each functional group were used due to transects being done in only areas surveyed or trapped, which were often biased to be in habitat that the turtles were most likely to occur. In other words, transects were not done across an entire location and all habitat types, since transects were only conducted at sites where surveying or trapping occurred. Because of the bias, proportions were chosen to standardize the results.

A two tailed t-test was also done test for differences between two of the broad habitat types through the functional groups. Equal variance was assumed and the raw numbers rather than the proportions were used, since all transects measured 100-meters. The t-test was only done between two of the three broad habitat types: emergent and scrub-shrub wetlands.

A multi-correlation was conducted in the Hmisc package (version 4.1-1) to explore relationships between functional groups based on wetland site occurrence. This was visualized as a correlation matrix. By conducting multiple comparisons, the risk of a Type I error increases and so the Benjamini-Hochberg (BH) method was applied for a p-value adjustment (Benjamini & Hochberg, 1995; Roback & Askins, 2005; Bluthgen et al., 2006; Waite & Campbell, 2006). The BH method controls the false discovery rate (FDR) and has been found to be a stronger option compared to other common adjustment methods, like Bonferroni or Holm methods (Benjamini & Hochberg, 1995; Waite & Campbell, 2006).

The sites were compared visually by Bray-Curtis dissimilarity using nonmetric multi-dimensional scaling (NMDS) ordination in the Vegan package (version 2.5-2) in R. Species occurrences were used as a basis for comparison in order to look at the dissimilarity between the wetland sites based on Blanding’s turtle, spotted turtle, both species, or neither species being found in the area through surveys or trapping. Property ellipses were also added to ordination plots to visualize sites managed by different organizations and entities (e.g. DNR, TNC, private, public).

STEP 1

Survey Priority	Age of Occurrence
H	≥ 1970
L	≤ 1969; ≥ 2012

STEP 2

Habitat Quality Ranking	Hydric Soil Presence Ranking	Vegetation Ranking	Soil Quality Ranking
H	H/M	H/M	H/M
M	M/L	M/L	M/L
L	L	L	L

Survey Priority Ranking	Habitat Quality Ranking	Urban Development Ranking
H	H/M	H/M
M	M	M/L
L	L	L/M

Figure 1. Survey location prioritization methodology. Step 1 of prioritization only considered the age of the occurrences, while Step 2 considered habitat quality and urban development for ultimate survey priority ranking. Habitat quality ranking was determined by hydric soils, soil quality, and vegetation, as seen in Step 2.

HYDRIC SOIL PRESENCE	
Ranking	**Classification rules**
H	≥ 50% of selected area
M	25 – 49.9% of selected area
L	≤ 24.9% of selected area

SOIL QUALITY	
Ranking	**Classification rules**
H	≥ 50% of selected area
M	25 – 49.9% of selected area
L	≤ 24.9% of selected area

VEGETATION	
Ranking	**Classification rules**
H	Little canopy cover over wetlands
M	Some canopy cover over wetlands
L	Great amount of canopy cover over wetlands

STAGE OF URBAN DEVELOPMENT	
Ranking	**Classification rules**
H	Little development
M	Some development
L	Major developed area, little to no natural landscape

Figure 2. Determination of high (H), medium (M), or low (L) ranking of the individual prioritization factors: hydric soils, soil quality, vegetation, and level of urban development.

Results

Location Prioritization and Population Delineation

A total of 126 locations were prioritized for surveying. During step one prioritization that only considered age of occurrences, 44 locations were found to be of low priority, while 82 were of high priority (Table A3). Following step one prioritization, the 82 high locations were further prioritized in step two for habitat quality and urban development. The prioritization methods for locations having occurrences from 1970 to 2011 yielded a list of 44 locations as high priority, with 14 of these having occurrences for both species, 18 having only Blanding's turtles recorded, and the remaining 12 having only spotted turtles recorded. Thirty-two locations were determined to be of medium priority (23 with only Blanding's turtles, 5 with only spotted turtles, and 4 with both species). Finally, 6 locations were determined to be of low priority (1 with only spotted turtles, and 5 with only Blanding's turtles) (Table A4).

Over the two field seasons, three high priority locations were removed from the original 44 high priority locations. One location for spotted turtles and one for Blanding's turtles were placed in low priority due to a recent sighting reported to me during the second field season. The other location was removed from the list altogether when the occurrence was determined to likely be associated with another nearby survey location and part of that population due to turtle movement and more suitable habitat. High priority locations were further finalized for surveying, with 2017 efforts focusing on surveying at locations with records of both spotted turtles and Blanding's turtles, while 2018 focused on spotted turtles due to the need for more records compared to Blanding's turtles.

While locations based on occurrences since 1970 were further prioritized for surveying purposes, all occurrences dating from 1892 to 2018 were used to delineate populations between both species. Any occurrences with no date or reliable locality data were ultimately removed from consideration. A total of 98 Blanding's turtle populations and 63 spotted turtle populations were delineated. Eighty-one of the Blanding's turtle and 38 of the spotted turtle delineated populations fall within the survey prioritization year range of after 1970, while the remaining are considered historic. It is important to note that delineated populations may have several records from various dates that are considered part of the same population. For example, a wetland complex may have several occurrences recorded, some historic and some recent. Delineated populations, especially historical ones, did not take into account population viability, and thus some delineated populations were only based on a single occurrence and the assumption of population boundaries through suitable habitat and connectivity. The age of the occurrences was not a criterion for population delineation, as all of those records occur in the same complex and thus are part of the same population that inhabits that wetland.

Location prioritization mainly relied on how managers delineate their property boundaries, but population delineation relied on wetland connectivity and how the turtles move between available wetlands. Because of this, the number of delineated populations does not equal the number of prioritized locations. Also, physically surveying locations aided in population delineation, and so some populations were not delineated until after surveying was conducted at the location.

Surveys and Trapping

A total of 23 locations were surveyed at least once, with an additional four locations being visited for trapping only (Table 1). Two locations surveyed were also revisited for trapping. Three of these locations were not visited more than once due to lack of suitable habitat or lack of time. Of the 23 locations surveyed, Blanding's turtle and spotted turtle presence was confirmed in nine locations, with three of these having both species, two having only spotted turtles, and four having only Blanding's turtles (Table 1; Figures 3 and 4). From these nine locations, six populations of Blanding's turtles and five populations of spotted turtles were delineated. Both species were encountered often in counties that are towards the northern portion of their historical distribution in Indiana, although I did confirm presence of one population of spotted turtles in Carroll County (Table 1; Figures 3 and 4).

Over the course of both field seasons, approximately 754.45 person hours were spent surveying. The number of people varied between each survey effort, but was often between two and four surveyors. A total of 1418 trap nights were conducted over both seasons, with 972 being at locations where both species are known to occur, 411 with Blanding's, and 35 with spotted turtles. Based on the number of turtles physically caught in traps, the capture rate for Blanding's turtles was approximately 0.040 and 0.024 for spotted turtles. Between surveying and trapping over both seasons, 69 Blanding's turtles and 70 spotted turtles were recorded (Table 1).

Ten of the Blanding's were observed during the survey season, with the remaining 58 captured while trapping was conducted. One of the ten Blanding's turtles could not be captured by hand, and only seen through a spotting scope. Fifty-six of those captured during trapping season were caught in traps, while the remaining two were caught by hand opportunistically. One Blanding's turtle was not able to be captured and only observed during trapping, but was recorded on a handheld GPS unit. Of the 69 Blanding's turtles encountered, three of these were assumed to be hatchlings or juveniles in age (Table 1).

Similarly, 12 spotted turtles were observed during survey season, with the remaining 51 being captured while traps were set. Twenty-four of those captured during trapping were caught in traps, while the remaining 31 were captured by hand opportunistically. Two of the 70 spotted turtles encountered were assumed to be a hatchling or juvenile in age (Table 1). All spotted turtles recorded were able to be captured by hand.

In addition to the target species, several other herpetofauna were recorded at locations visited. Of particular note, federally listed eastern massasauga (*Sistrurus catenatus*) and IUCN listed/state protected eastern box turtle (*Terrapene carolina carolina*) were encountered. Nine massasaugas were encountered across four locations and recorded. Blanding's turtles were also found in two of these locations. Eleven eastern box turtles were encountered across five locations. Northern cricket frogs (*Acris crepitans*) were also recorded in five locations, and although common through much of its range in Indiana, it is considered rare in the northwest portion of the state. Many common species in Indiana were also encountered (Table A5), with the midland painted turtle (*Chrysemys picta marginata*), common snapping turtle (*Chelydra serpentina*), green frog (*Lithobates clamitans*), and bullfrogs (*Lithobates catesbeianus)* being found in the most locations.

Habitat Assessments

A total of 78 transects were established across the 27 surveyed and trapping locations, and an additional location that was only ground validated and not surveyed. Sixty-one of these transects were conducted in classified emergent wetlands, 16 in scrub-shrub wetlands, and one in a forested wetland. Of the nine functional groups recorded, clonal dominants made up most of the measurements in emergent habitat, with the other functional group being the most measured in scrub-shrub and forested habitat.

Chi-Square

The chi-square association test revealed the proportions of all functional group variables and broad habitat types vary ($X^2 = 606.72$, df = 16, $p < 0.05$; Table 2). The residuals for the emergent habitat type indicate a positive association with the clonal and clonal dominant functional groups, a strong negative association with other, and a negative association with facultative annual (Table 3). The scrub-shrub habitat type residuals indicate a strong positive association with other and facultative annual, a positive association with obligate annual and tussocks, and a strong negative association with clonal and clonal dominant (Table 3). Finally, forested habitat type is indicated to be negatively associated with clonal, tussock, and clonal dominant, but strongly positively associated with the other functional group (Table 3). It should be noted that only one transect was classified under the forested habitat type, and thus the results should be analyzed with caution.

T-test

The obligate annual means between emergent and scrub-shrub habitat was different ($t = -3.018$, $p < 0.05$; Figure 5A). No other differences between categories were found by the t-test. The single forested habitat type transect was mainly composed of the other functional group (Figure 5B). The t-test was only between the emergent and scrub-shrub habitat types because there was only one transect at a site characterized as a forested wetland. Instead, descriptive statistics were used for the one forested wetland transect.

Multi-correlation

The correlation matrix revealed several positive and negative correlations between functional groups, but only two were found to be statistically significant ($p < 0.05$; Table 4). A positive correlation between tussock and facultative annual and between obligate annual and facultative annual were found to be statistically significant (Table 4).

Bray-Curtis Dissimilarity

A three axis NMDS ordination had a stress value of 0.131. Distance between points in the NMDS ordination plot (Figure 6A) represented dissimilarity (i.e. closer points were less dissimilar than farther points). Overall, the habitat composition of sites where Blanding's turtles, spotted turtles, or both species were found is relatively similar between each other. The habitat in sites where neither species was recorded is also similar to the habitats that turtles were found in, suggesting suitable habitat at these locations despite lack of turtle presence. No clustering of sites was found when property ellipses were overlaid on the NMDS plot, meaning that all sites were similar in habitat suitability across different management entities (Figure 6B).

Table 1. The list of locations that were surveyed or trapped, how many person hours were spent surveying, whether Blanding's turtles or spotted turtles were found or known to occur, how many were recorded, if juveniles were detected, the most recent occurrence year before visited, and what species historically occurred at the location. Single asterisks (*) denote locations that were solely trapped at due to known occurrence of one or both species, and thus do not have survey hours. BT = Blanding's Turtle, ST = Spotted Turtle.

		BLANDING'S TURTLE		**SPOTTED TURTLE**				
Location ID	**# Survey Hours**	**Found or Known?**	**# Recorded**	**Found or Known?**	**# Recorded**	**Juveniles?**	**Recent Occurrence Year**	**Historical Species Occurrence**
Carroll 1	16.0			x	13	Yes (teenager)	2007	Spotted Turtle
Elkhart 1	25.0	x	15	x	1	No	2000 (BT & ST)	Both
Elkhart 2	44.2	x	1			No	2014 (BT); 1998 (ST)	Both
Fulton 1	70.7						1997 (BT); 1986 (ST)	Both
Jasper 1	29.4						2011 (BT); 1936 (ST)	Both
Kosciusko 1	5.0						1989 (BT); 1954 (ST)	Both
LaGrange 2	41.1						2002 (BT); 1954 (ST)	Both
LaGrange 1	39.8	x	24	x	1	No	1998 (BT & ST)	Both
LaGrange 3	47.9	x	1			Yes (hatchling)	1987	Spotted Turtle
Lake 1	30.8						1991 (BT); 2005 (ST)	Both
Lake 9*		x	5	x	20	Yes (BT: teenager)	2016 (BT & ST)	Both
Lake 10*				x	27	Yes (hatchling)	2016	Spotted Turtle
Lake 11*		x	12			No	2016	Blanding's Turtle
LaPorte 1	46.0	x	2			No	2005 (BT); 1989 (ST)	Both
LaPorte 2	6.6			x	1	No	2005	Spotted Turtle
LaPorte 3	27.2						1985 (BT); 1989 (ST)	Both
LaPorte 4	19.0						1989	Spotted Turtle
Marshall 1	24.9						2008	Spotted Turtle
Newton 1	3.5						2013	Blanding's Turtle
Noble 1	26.9						1989	Spotted Turtle
Porter 1*		x	0	x	0	No	2016 (BT & ST)	Both
Starke 1	6.0						2001 (BT); 1988 (ST)	Both
Steuben 1	119.2						1994 (BT); 1985 (ST)	Both
Steuben 2	52.3	x	6			No	2000 (BT); 1989 (ST)	Both
Steuben 3	10.5	x	3	x	7	Yes (BT: hatchling)	1989	Spotted Turtle
Steuben 4	34.7						2001	Blanding's Turtle
Tippecanoe 1	27.9						2011	Blanding's Turtle

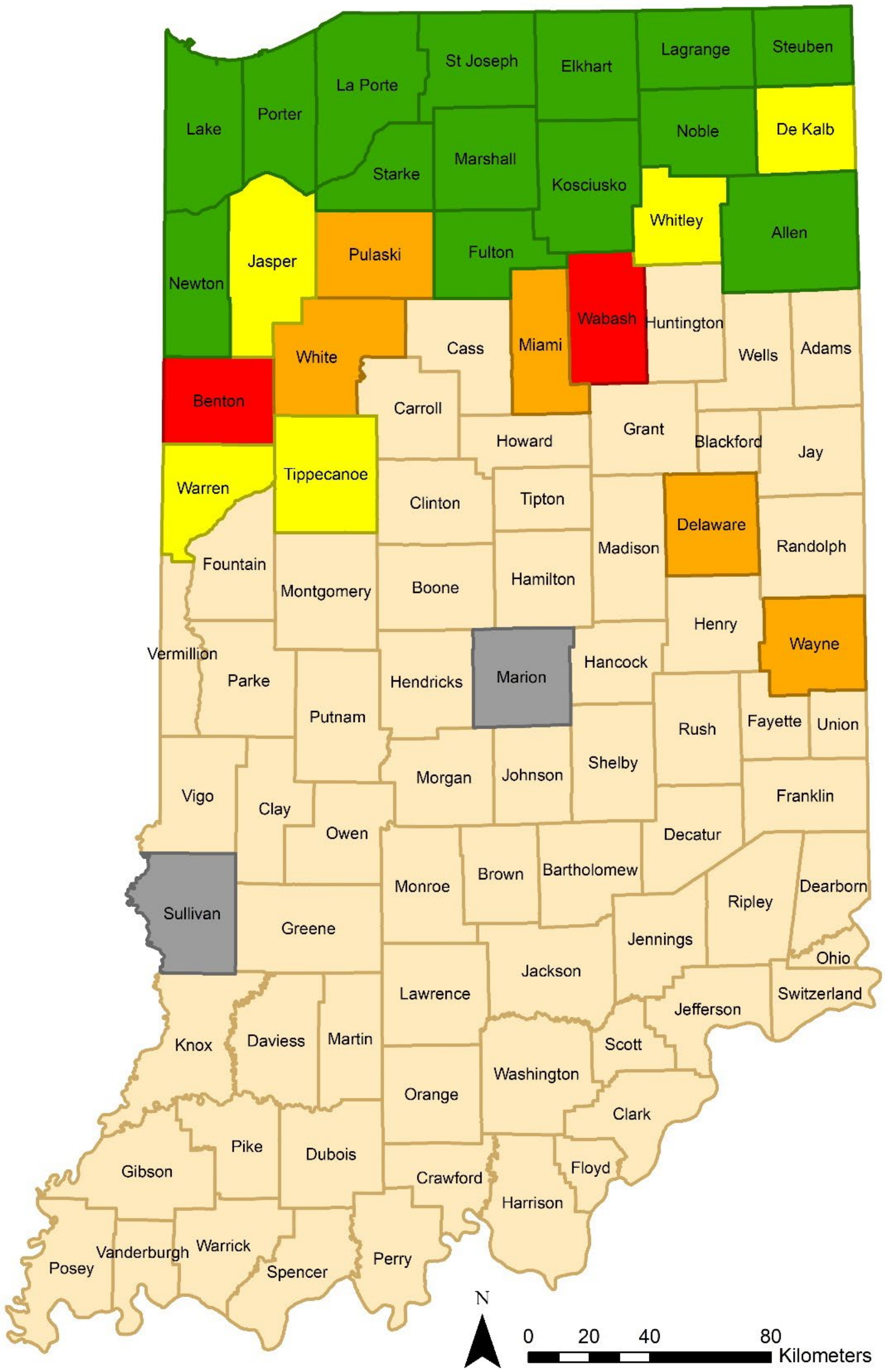

Figure 3. Blanding's turtle historical and current county presence. Green = 2012 to present, yellow = 2000 to present, orange = 1970 to present, red = pre-1970, gray = uncertain presence.

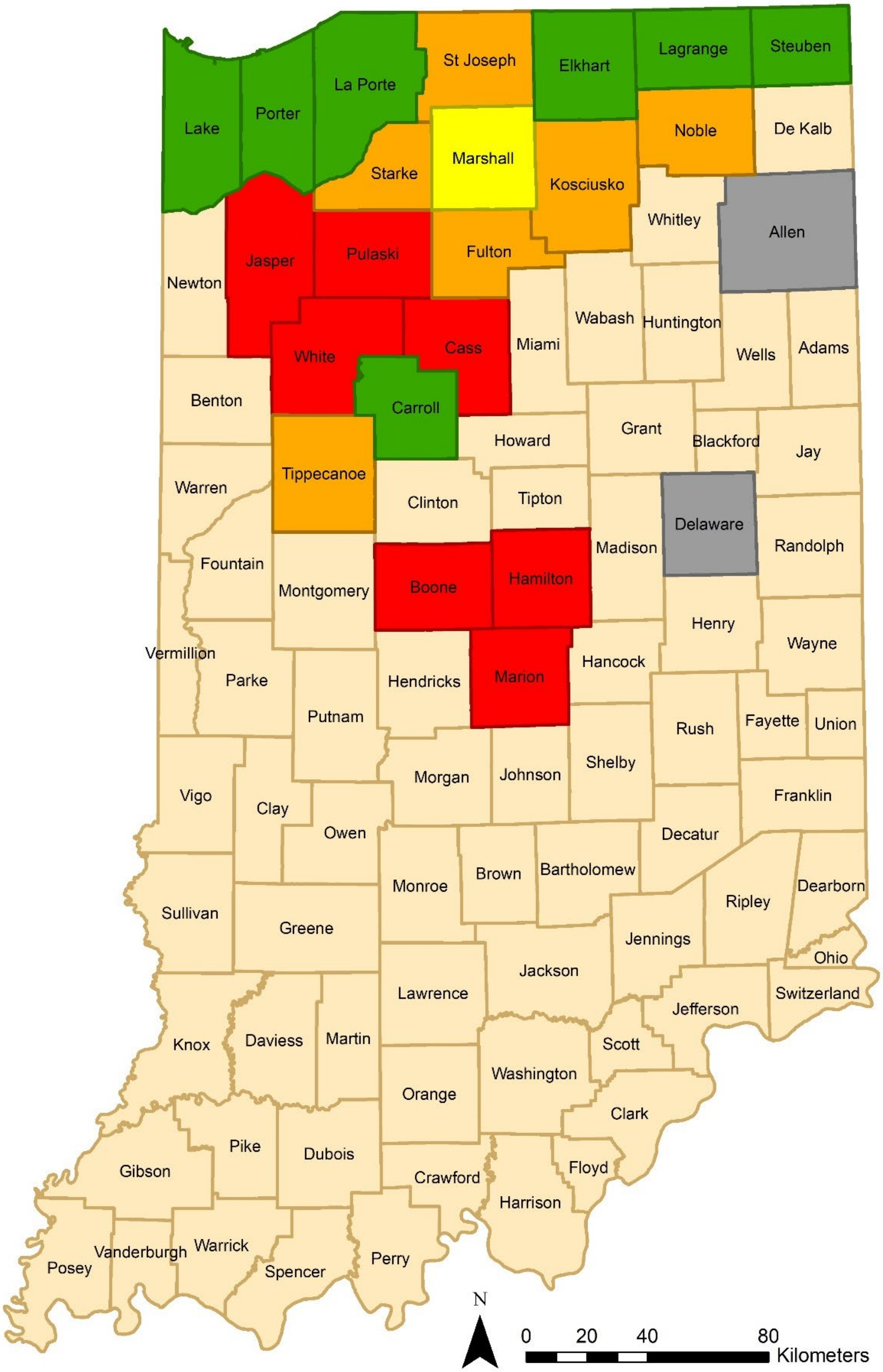

Figure 4. Spotted turtle historical and current county presence. Green = 2012 to present, yellow = 2000 to present, orange = 1970 to present, red = pre-1970, gray = uncertain presence.

Table 2. Chi square percent contribution. Asterisks (*) indicate cell values that contributed the most to the total chi square value (X^2). OA = obligate annual, FA = facultative annual, CST = clonal stress tolerator, CD = clonal dominant, OW = open water.

	Emergent	**Scrub-shrub**	**Forested**
OA	0.18	1.005	0.013
FA	0.742	4.648	0.343
Reed	0.035	0.141	0.022
Clonal	2.044	7.179*	2.852
Tussock	0.259	2.388	1.326
CST	0.001	0.001	0.011
CD	1.956	6.357*	3.799
OW	0.029	0.06	0.172
Other	8.309*	20.611*	35.518*

Table 3. Chi-square residual values that were used to analyze positive or negative associations between functional groups and habitat category. OA = obligate annual, FA = facultative annual, CST = clonal stress tolerator, CD = clonal dominant, OW = open water.

	Emergent	**Scrub-shrub**	**Forested**
OA	-1.045	2.469	-0.275
FA	-2.122	5.31	-1.442
Reed	0.461	-0.925	-0.363
Clonal	3.521	-6.6	-4.16
Tussock	-1.253	3.806	-2.836
CST	0.066	-0.063	-0.257
CD	3.445	-6.21	-4.801
OW	-0.417	0.602	1.023
Other	-7.1	11.182	14.68

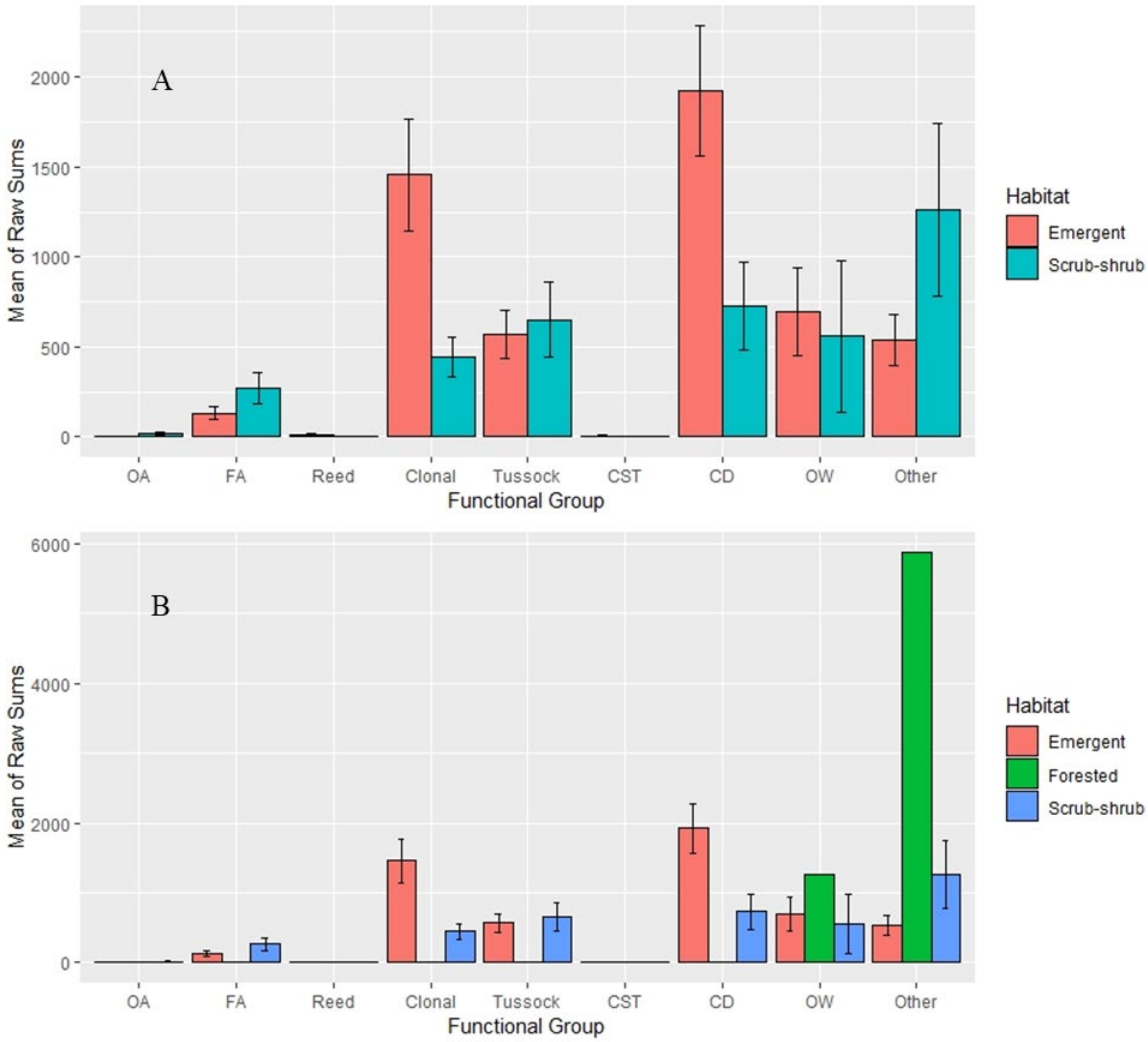

Figure 5. A) Comparison of raw sum means with standard error bars of each functional groups between emergent wetlands and scrub-shrub wetlands. B) The same graph but includes the forested wetland data for broad comparison. OA = obligate annual, FA = facultative annual, CST = clonal stress tolerator, CD = clonal dominant, OW = open water.

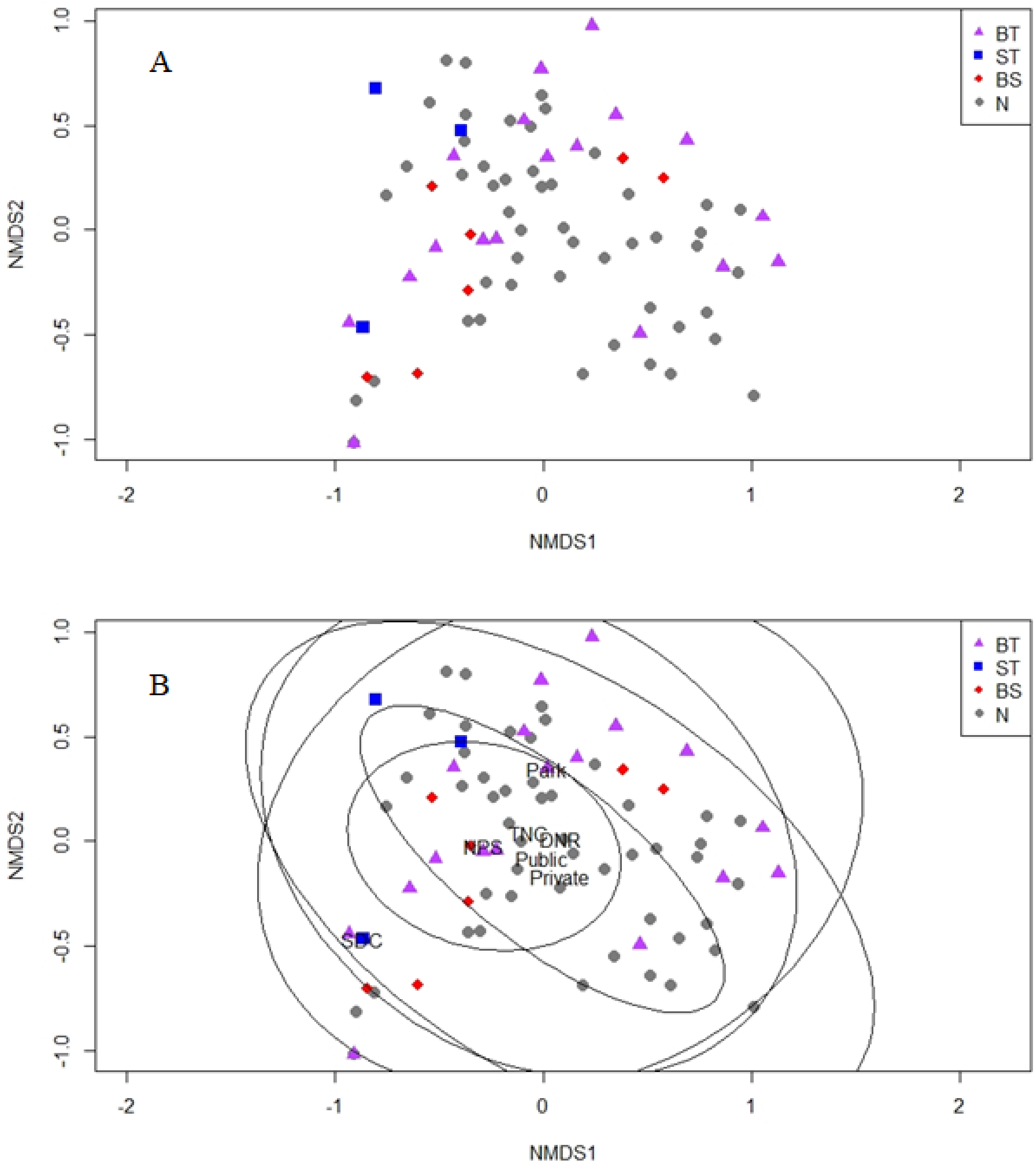

Figure 6. A) Nonmetric multidimensional scaling (NMDS) ordination plot of each transect. Distance calculated as Bray-Curtis dissimilarity of target species occurrence (1/0). BT = Blanding's turtles, ST = spotted turtle, BS = both species, N = neither. B) Confidence ellipses (95% confidence interval) based on the type of property each transect fell within. DNR = Department of Natural Resources, TNC = The Nature Conservancy, Park = County park, NPS = National Park Service, SDC = Sand Dunes Council.

Table 4. Correlation matrix of P-values, showing relationships between functional group presences, omitting redundant values. Asterisks (*) indicate a significant P-value and significant correlation ($p < 0.05$). OA = obligate annual, FA = facultative annual, CST = clonal stress tolerator, CD = clonal dominant, OW = open water.

	FA	**Reed**	**Clonal**	**Tussock**	**CST**	**CD**	**OW**	**Other**
OA	0.014*	0.9205	0.7182	0.2861	0.9249	0.8048	0.9476	0.9907
FA	-	0.9476	0.8048	0.0004*	0.8578	0.8578	0.8578	0.9249
Reed		-	0.9907	0.7878	0.9476	0.9907	0.8578	0.8578
Clonal			-	0.6035	0.9907	0.1061	0.9907	0.6035
Tussock				-	0.9907	0.6586	0.5163	0.8048
CST					-	0.8578	0.9205	0.9205
CD						-	0.6035	0.6586
OW							-	0.7878

Discussion

Current Distribution Based on Surveying and Trapping

My survey results suggest the current distribution of Blanding's turtles and spotted turtles in Indiana is becoming or is already limited to the northern third of the state. Blanding's turtles were detected by surveying in four counties: LaGrange, Steuben, Elkhart, and LaPorte. Spotted turtles were detected by surveying in five counties: LaGrange, Steuben, Elkhart, LaPorte, and Carroll. Further, juveniles were detected at three of these locations for Blanding's turtles and two locations for spotted turtles, suggesting recruitment and reproduction within the associated populations. With the exception of one population of spotted turtles in Carroll County, the nine locations surveyed where presence was confirmed and where juveniles were detected are towards the Indiana-Michigan state border.

Both species were once distributed across the northern half of the state, with some occurrences being recorded in the central portion of the state. Some of these historical presences could potentially be of released pets or misidentifications that cannot be confirmed due to lack of photographs or descriptions. Despite this, both species were known to have a greater distribution across Indiana in the past (Harding, 1997; MacGowan et al., 2005; Ernst & Lovich, 2009; Ernst, 2009). Although my results suggest limited distribution, true absence of either species was not confirmed at any locations. More surveys at locations where presence or absence is unknown can help gain a better understanding the current distribution of both species in Indiana.

Surveying as Method of Detection

Surveys identified seven locations with occurring Blanding's turtles and five locations with spotted turtles. Ten individual Blanding's turtles and 12 individual spotted turtles were detected using surveying, most being adults but five juveniles were also detected using surveying between both species. The finding of both species shows that using visual encounter surveying as a method of detection is suitable for both of these species.

While the surveys conducted did confirm presence of one or both species in several locations and allowed population delineation, many challenges arose when conducting these surveys. Neither species is difficult to detect with the correct equipment (e.g. binoculars, spotting scopes) or when looking through shallow wetlands, but the habitat that these turtles inhabit is not easy to traverse. Many locations that were visited during the past two years often had deep water and soft peat that hindered surveying efforts due to safety concerns. In addition, the limited number of surveyors proved to be a challenge. With the number of surveyors available, it was nearly impossible to adequately survey a particularly large suitable wetland. Since the objective was to visit as many locations as possible in such a short amount of time, extended survey time (e.g. more than three visits) was not feasible. To adequately survey using VES, a large group of surveyors is recommended, either for division among multiple areas or to cover all accessible suitable habitat in a large location.

Setting traps can also be a method of surveying (Graeter et al., 2013; Dodd, 2016). During the trapping efforts, I was able to detect numerous individuals. Fifty-fix Blanding's turtles, with one being a juvenile, and 24 adult spotted turtles were physically captured in traps. Based on these results, Blanding's turtles and spotted turtles can both be captured in traps, as long as populations are known to be viable or there are numerous individuals.

An issue with relying on trapping for surveying, though, is that it is time consuming and requires extensive resources. Traps cannot be expected to capture target species—especially endangered ones—within a 24-hour period if the population viability is unknown. In addition, spotted turtles and Blanding's turtles are considered difficult to trap and have low capture rates (King, 2013; Willey & Jones, 2014), as seen in my trapping efforts (0.040 for Blanding's turtles and 0.024 for spotted turtles), and trapping in a location where population viability is unknown only decreases the capture rate further. Due to these disadvantages, I suggest that traps are used for surveying if 1) there is a very limited amount of locations to visit that would allow substantial time for traps to be out, or 2) enough resources are available to trap at multiple locations at once. Due to this project's objectives being statewide surveys, trapping as a survey method was not ideal.

Habitat Assessments

The correlation tests revealed statistically significant correlations ($p < 0.05$) between tussocks and facultative annuals and between obligate annuals and facultative annuals, and suggests a relationship between these functional group pairs within transects. In addition, the chi-square test ($X^2 = 606.72$, df = 16, $p < 0.05$) showed several positive and negative associations between functional groups and their presence in the different habitat types. It suggests that the relationship between the other functional group and scrub-shrub and forested wetland types contributed the most to the chi-square test. This is not unexpected due to the definition of the other functional group as being woody plant matter, which is expected to be in scrub-shrub wetlands and forested wetlands. Because of this, it was not surprising to see the other functional group being the most prominent or having association with both habitat types in the chi-square test.

While intensive habitat assessments provided useful information on types of wetlands and broad plant or tree types in sites of turtle presence, the results reflect the difficulty of conducting habitat work in a statewide survey project. Given the time constraint and objectives of the project, the scale of the habitat assessments had to be quite broad to collect data for all locations and sites visited for surveying or trapping. First, using the line-intercept transect method failed to identify understory plants, as it was often laid across taller, mid-story plants that prohibited the measuring tape from reaching the ground. Efforts were not made to manually place the tape closer to the ground, because this would create substantial bias. An understory quadrat can accompany the line-intercept transects to counter this issue, but this could not be done due to time constraint and the broad scale of the project. Second, the transect conducted only measured 100-meters for an entire wetland, meaning that it could not capture the true diversity of functional groups in that wetland. Wetlands are often not made of a single wetland community type—many wetland community types can co-exist in a single, large wetland (Myers, 1997; Whitaker & Amlaner Jr., 2012). Unless the wetland is small, a 100-meter transect will not be able to record all plant functional groups in that wetland. A transect that encompasses the entire wetland length would be the only way to quantitatively record plant functional groups, but this is usually not possible.

The line-intercept transect method was useful in this project due to the scale, and did reveal potential relationships in two ways: between functional groups in broad habitat categories and between habitat categories and functional group presence. While useful information, more in-depth data should be collected to potentially identify habitat preference through the plant community for either turtle species. It is understood that spotted turtles and Blanding's turtles utilize mainly emergent and scrub-shrub wetland habitat types (Harding, 1997; Barlow, 1999; Hartwig, 2004; MacGowan et al., 2005; Ernst & Lovich, 2009) throughout their range, but understanding the relationships in the plant community can provide pertinent information for when considering repatriation or wetland restoration with these species in mind (Harding, 1997;

Barlow, 1999; Hartwig, 2004; MacGowan et al., 2005; Ernst & Lovich, 2009; Kingsbury & Gibson, 2012; Stevenson et al., 2015).

Conservation and Management Implications

Surveying and trapping efforts were conducted at various locations across the state, some with less wetland fragmentation than others. Wetlands were often fragmented by urban or agricultural development, but where more natural landscape still existed, wetlands were separated by riparian or upland habitat that turtles likely utilized for nesting and travel. During surveying and trapping efforts in larger location with several wetland sites, it was not uncommon or unexpected to see multiple individuals of Blanding's turtles or spotted turtles that are likely of the same population due to their known movements between wetlands (Harding, 1997; Barlow, 1999; Lewis et al., 2004; MacGowan et al., 2005).

Based on what was observed in the survey efforts and is known about the ecology of both species, several conservation and management strategies can be taken into consideration to prevent further population decline. First, management and conservation efforts can focus on the identification of functional population units, or management units (MUs). MUs are areas that may contain multiple wetland complexes, habitats, and populations that are suggested to be managed as one major area. If MUs are identified and created, focus can be put on the creation of corridors and establishing wetland connectivity. Blanding's turtles and spotted turtles are known to utilize multiple wetlands and will actively travel between them during the active season (Harding, 1997; Barlow, 1999; Hartwig, 2004; MacGowan et al., 2005; Ernst & Lovich, 2009; Kingsbury & Gibson, 2012; Stevenson et al., 2015), as observed in some of the larger locations that were surveyed or trapped. If connectivity between different wetland complexes in a single

MU is achieved, then the turtles are at less of a risk of encountering a barrier like roads that would prevent them from traveling between the wetlands.

Road mortality is considered a significant factor in population decline for many turtle populations (Minton, 2001; Gibbs & Shriver, 2002; Steen & Gibbs, 2004; Steen et al., 2006; Congdon, et al, 2008; Ernst, 2009), and by alleviating the risk when traveling between wetlands, population recovery and breeding is possible. During my surveys, we did not observe any direct road mortality of spotted turtles or Blanding's turtles, but saw many other species that had been hit by a car in locations where one or both species were detected, which suggests the likelihood that both target species may suffer the same fate at some of the survey locations. Road mortality is especially detrimental to the females in a population (Steen & Gibbs, 2004; Steen et al., 2006). It is suggested in multiple studies that female turtles of many species, as females are more likely to make large movements in order to nest, are at more risk. Females can even make repeated travels before they lay their eggs, thus increasing their chances of being killed by a car. Wetland connectivity and providing preferable nesting habitat close to core wetlands are highly suggested to alleviate road mortality risks.

Wetland connectivity can be achieved by installation of corridors or by simply providing undisturbed upland habitat (i.e. no barriers). Efforts can also be made to restore wetlands in between two or more fragmented core wetlands. Corridors like bridges or culverts could be effective in providing wetland connectivity. Bridges are effective by allowing both a road to exist, and thus satisfying urban travel, while also giving animals an alternate way to travel between habitats and connect already existing ones together. Culverts are another corridor that has not been heavily explored in turtle usage—especially spotted turtles and Blanding's turtles. Spotted turtles have been reported to use large culverts when traveling between wetlands (Kaye et al., 2005), but more research should be done on the effectiveness of their use as a main method of connectivity. Finally, providing undisturbed upland habitat or restoring wetlands between fragmented wetlands in the same management unit can be useful for wetland connectivity. Many of the survey locations where the species was found had wetlands and upland habitat suitable for nesting and traveling for many species of turtles, including spotted turtles and Blanding's turtles. Spotted turtles and Blanding's turtles are known to travel between wetlands through upland habitat (Harding, 1997; Barlow, 1999; Lewis et al., 2004; MacGowan et al., 2005), and if no roads are built and it is relatively undisturbed, it can serve as a way to keep wetlands connected by allowing the turtles to safely traverse.

Conclusions

My surveys suggest that the distribution of spotted turtles and Blanding's turtles in the state of Indiana has likely becoming limited to the northern third of the state compared to historical distribution. Their populations are likely still in decline due to numerous factors that should be considered in conservation and management strategies, like wetland fragmentation, habitat loss, and mortality through barriers like roads. Visual encounter surveying (VES) is an effective method of determining presence of spotted turtles and Blanding's turtles in a statewide survey, but has its disadvantages with the type of habitat that the turtles are known to occur due to difficulty traversing. Trapping is suggested as another method of surveying, only if very few locations are of survey interest or there is a significantly sized team that can cover multiple locations at once, but this is unlikely to happen in a statewide situation such as this project. In addition, habitat assessment can provide important information on habitat preference for both species, as well as provide information for wetland restoration and habitat management with spotted turtles and Blanding's turtles in mind. Broad relationships between plant communities and habitat type can be seen, but also habitat relations in terms of where species occur. Other habitat assessment methodologies at different scales can potentially reveal further relationships and habitat community information.

PREDICTING SUITABLE HABITAT THROUGH HABITAT MODELING

Introduction

Habitat Modeling

The Blanding's turtle (*Emydoidea blandingii*) and spotted turtle (*Clemmys guttata*) are two state-endangered species of turtles in Indiana. Historically, both species were found across the Great Lakes region within their geographic distribution, but with habitat loss and heavy poaching, the number of sustainable populations has significantly decreased (Dahl, 1990; Indiana Wetlands Conservation Plan, 1996; Myers, 1997; Harding, 1997; Lewis et al., 2004; MacGowan et al., 2005). In Indiana, the multiple wetland types that both species utilize have become heavily fragmented or destroyed for agricultural use or urban development (Harding, 1997; Lewis et al., 2004; MacGowan et al., 2005). While these species will traverse between wetlands by various upland habitat types, the success of these movements is often limited by barriers, such as roads and lack of wetland connectivity (Minton, 2001; Gibbs & Shriver, 2002; Steen & Gibbs, 2004; Steen et al., 2006; Congdon, et al, 2008; Ernst, 2009).

With the continuing decline of these two species in their historical distribution, the current distribution and identification of remaining sustainable populations must be understood for future conservation and management strategies. Visual encounter surveys (VES) were conducted to understand the current distribution of both species in Indiana in 2017 and 2018. Presence was confirmed in eight locations for one or both species. No population assessments have been conducted for Indiana as it has for other states and provinces in both species' ranges, and thus these surveys were necessary.

While presence was confirmed in eight locations visited of one or both species, surveying could not occur at all prioritized locations. Presence or suitable habitat could not be physically confirmed at all locations that were considered of surveying need. In addition, my preliminary survey location prioritization relied heavily on GIS (geographic information system) and aerial imagery (Google Maps; Google Earth; all seasons; 2016), which is not always accurate in depicting the habitat, and thus is not easy to interpret. For example, some locations that were ranked as high priority for surveying through use of aerial imagery, actually had a lack of suitable habitat which could only be determined through ground validation. While ground validation of all survey locations would be ideal, it is not possible to conduct in a statewide survey in a short amount of time. By predicting suitable habitat across the distribution of the spotted turtle and Blanding's turtle, suggestions can be made for survey need and the possibility of repatriation.

Species distribution modeling (SDM) (also known as habitat modeling and many other terms) is a useful tool for conservation and management strategies. SDM is often used to understand the spatial relationship between a species and its environment, as well as test hypotheses surrounding the known distributions and ranges of species, such as specific habitat use characteristics. In addition, and more recently since SDM was developed, it is now being applied to predicting factors, such as species occurrence estimates and habitat suitability across a known geographic range (Franklin, 2009; Royle et al., 2011; Fitzpatrick et al., 2013; Merow & Silander Jr., 2014). My objective was to predict suitable habitat, which is often called the synonymous term of "habitat suitability modeling" or simply "habitat modeling" (Franklin, 2009). In order to implement conservation and management strategies effectively, factors such as how species use their habitat or the amount of suitable habitat remaining in their range is critical, especially for endangered or threatened species that are in decline due to habitat loss. Through habitat modeling, attempts can be made to understand the relationship of a species and its environment, which is a critical component for conservation efforts, but also predicts suitable habitat outside of surveyed or studied areas.

Habitat suitability modeling is based off two types of data: presence-only data or presence-absence data (Phillips et al., 2006; Franklin, 2009; Elith et al., 2011; Royle et al., 2011). Presence data only includes where the species in question is known to occur or has been recorded. Absence data is based on confirming the absence of a species at a location, which can be difficult in endangered or cryptic species, mainly due to misidentification or a low likelihood of finding an individual. Presence-only models utilize the presence data when absence data is not available, which is often the case when a species has not been studied across its range (Phillips et al., 2006; Franklin, 2009; Elith et al., 2011; Royle et al., 2011). Much data of species, especially endangered species, exist through museum collections, personal records, and old studies, but often absence has not been confirmed or recorded (Phillips et al., 2006; Franklin, 2009; Elith et al., 2011; Royle et al., 2011). Statewide surveys conducted in 2017 and 2018 were ultimately used to confirm presence rather than absence, based on the inability to survey all suitable habitat and that species may still occur at a location but are functionally extirpated. While spotted turtles and Blanding's turtles are considered easy to find and identify, the difficulty of traversing an entire survey site and strong possibility that many populations are functionally extirpated made absence confirmation difficult. Due to the lack of absence data for this project and species in Indiana, presence-only models were sought to be used rather than presence-absence models as a first step in habitat prediction for both species.

To my knowledge, no other modeling efforts have been undertaken on either spotted turtles or Blanding's turtles for the state of Indiana. General SDM efforts have been conducted for Blanding's turtles in Ontario, Canada (Millar & Blouin-Demers, 2012; Markle & Chow-Fraser, 2016), Ohio (Ponyter, 2011), and New York (Stryszowska et al., 2016), but landscape ecology and habitat use has been assessed for both species across their range (Harding, 1997; Barlow, 1999; Joyal et al., 2001; MacGowan et al., 2005; Beaudry et al., 2009; Ernst & Lovich, 2009; Anthonysamy et al., 2014). Barlow (1999) is the only project to explore habitat use for both species solely in Indiana. By exploring habitat suitability modeling, not only can pertinent potential habitat distribution information be obtained for the state of Indiana, but can also serve as a baseline for future conservation and modeling to occur in the state.

Objectives

While actively surveying for spotted turtles and Blanding's turtles across Indiana to understand the current distribution and confirm presence, it was not possible to cover all locations in need of surveying. Since habitat loss and fragmentation are major factors in the decline of both species, it is important to understand remaining suitable habitat distribution across the state. Understanding these factors is important for planning conservation and management strategies for both species in the state of Indiana. Based on this need, the objectives were to 1) predict suitable habitat across the historical distribution of both species to focus future survey efforts and assess areas for repatriation possibilities, 2) visualize and interpret the habitat loss over time for both species, and 3) assess a presence-only modeling program's ability to adequately predict habitat suitability for use in conservation and management strategies.

Habitat suitability modeling was used to meet all three objectives for both spotted turtles and Blanding's turtles. Since both species are known to inhabit the same wetlands and are in decline due to habitat fragmentation, habitat suitability modeling was used for both species and compared.

Methods

Maximum Entropy Modeling

The Maximum Entropy (MaxEnt v. 3.4.1.; Phillips, et al., 2004; Phillips, et al., 2006; https://biodiversityinformatics.amnh.org/open_source/maxent/) statistical program is a species distribution modeling program that applies maximum entropy to presence data and environmental variables to create an output that serves as a predicted habitat suitability map (Phillips et al., 2006; Phillips & Dudik, 2008). The MaxEnt authors describe the output using the terminology "occurrence probability map," but this is often mistaken to mean that MaxEnt can make proper occurrence estimations. The terminology likely originated from the idea that there is a higher chance for the species of interest to still occur in areas of high habitat suitability rather than low suitability. Due to the possible terminology confusion, the output will be described as a habitat suitability prediction map (or alike) here.

For predicting habitat suitability for spotted turtles and Blanding's turtles, MaxEnt was utilized as the habitat modeling method due to its popular usage for SDM and its better predictive accuracy compared to other presence-only modeling techniques. MaxEnt was found to have higher predictive accuracy compared to Genetic Algorithm for Rule-set Production (GARP) and Ecological Niche Factor Analysis (ENFA), although the predicted suitability maps between the programs were found to be relatively accurate estimates of range and geographic distribution (Hernandez et al., 2006; Phillips et al., 2006; Sergio et al., 2007; Braunisch & Suchant, 2010; Wang et al., 2010; Tong et al., 2013). It also had higher predictive accuracy with small sample sizes ($n < 25$) compared to GARP, BIOCLIM, and Domain (Hernandez et al., 2006; Wisz et al., 2008; Elith et al., 2011), which is an important consideration when working with endangered species that may have limited presence data.

The habitat suitability maps from MaxEnt are built from presence data and a set of environmental variables in a pixel format, where each pixel is assigned a value from zero to one. The values of the pixels represent the habitat suitability probability or ranking, with one being high habitat suitability and zero being no habitat suitability (Phillips et al., 2006; Phillips & Dudik, 2008; Elith et al., 2011; Phillips et al., 2012; Merow et al., 2013; Phillips et al., 2017). MaxEnt creates these maps by contrasting the pixels with presence data to randomly chosen background pixels (or points) that has no value of presence or absence. Since MaxEnt does not require absence data, these background points are often referred to as pseudo-absence points (Merow et al., 2013; Phillips & Dudik, 2008).

The number of max background points was set to 20000 rather than the default 10000 to account for the larger datasets and ensure all occurrences were considered. It is important to note, though, that Phillips & Dudik (2008) suggest that models with the default background sample setting have the same model performance as when increasing the setting (i.e. using all occurrences in background sampling), and can significantly decrease running time. Since the running time was not significantly different using 20000 for these models, it was used instead of the default. Due to the number of models being run, auto features were left selected, but the use of threshold and product features in model outputs was avoided. Threshold and product features have been reported to be not be useful or harm model output (Yost et al., 2008; Elith et al., 2011; Phillips et al., 2017), and thus were chosen to be excluded from being used to create model outputs. All other options were left to their default settings.

Presence Data

To explore further conservation and management strategies for both species and test the capability of MaxEnt, presence data were chosen and subdivided based on year of occurrence and sampling method. Presence data was used from multiple element occurrences and visual encounter records that were retrieved from a variety of sources, including the Indiana Department of Natural Resources, HerpMapper (https://www.herpmapper.org/), museums (American Museum of Natural History, Carnegie Museum of Natural History, Chicago Field Museum of Natural History, Florida Museum of Natural History, Louisiana State University Field Museum, San Diego Museum of Natural History, Smithsonian Museum of Natural History), educational institutions (California Academy of Sciences, Chicago Academy of Sciences, Ohio State University, University of Colorado, University of Kansas, and University of Michigan), property managers and owners, field researchers, and the 2017 and 2018 surveying and trapping efforts. Occurrences dating back to 1970 were chosen as an arbitrary threshold, and were then further subdivided into three arbitrary year ranges: 1970 to present, 2000 to present, and 2012 to present. The year 1970 was chosen as the arbitrary threshold for the same reason as survey location prioritization (e.g. historical data and lack of suitable habitat). Any occurrences that did not have coordinates or coordinates that did not represent the general area of occurrence were removed in the final selection. The presence data was subdivided in order to compare and contrast the results across year ranges, which can prove to be useful information when considering conservation and management strategies. The year range subdivisions were arbitrarily chosen, but ultimately assumed to be able to represent a timeline of habitat loss. It is important to consider how habitat has changed in a location, especially if the species in question was known to occupy the location decades ago but is no longer found there.

Three sampling methods were also implemented to eliminate sampling bias and compare the results: all occurrences, systematic sampling, and duplicate sampling. By using all of the occurrences, MaxEnt has more data to use to make habitat suitability predictions, but it cannot take into account the sampling bias that may be involved (Phillips, 2009; Kramer-Schadt et al., 2013). When surveys are conducted for species, results often only represent the 1) accessible habitat and 2) survey effort at any one location (Phillips, 2009; Kramer-Schadt et al., 2013). The wetland habitat that spotted turtles and Blanding's turtles inhabit can be difficult terrain for a human to traverse, and thus affect the number of turtles found and recorded. Further, if a sizable population is known to occur at a location, surveyors may want to sample that population more than other locations, which causes more occurrences to be at one location. These factors cause an unequal representation of populations in a statewide study and can affect model outputs, since the model assumes that a location with more occurrences has more suitable habitat than the location with one occurrence.

To deal with potential sampling bias (Phillips et al., 2009; Kramer-Schadt et al., 2013; Merow et al., 2013), systematic sampling and duplicate sampling were applied to each year range of data. Systematic sampling involves randomly choosing a single occurrence from each population, eliminating the unequal distribution of occurrences across various locations (Phillips et al., 2009; Ruiz-Gutierrez & Zipkin, 2011; Royle et al., 2012; Kramer-Schadt, 2013). The consequences of systematic sampling are the reduction of sample size for the model to use to create an output and possible misrepresentation of a very large area that could have various habitat types that the species uses. Duplicate sampling was used in an attempt to counter data loss in systematic sampling by allowing a second occurrence in a population, but only if the second occurrence was at least 1-kilometer away from the systematically chosen occurrence.

Duplicate records were present in all datasets due to trapping sampling effort, often having more than one individual captured in the same trap. All duplicate records based on identical coordinates were removed before being used. If more than one occurrence was in a single grid cell on the map, and thus sharing the same environmental information, duplicate records were also removed using MaxEnt's default option to remove duplicate data.

Environmental Variables and Bias Files

Several environmental variables were used in the models that were based off the known ecology of both species (Table B1). Bedrock, Canopy Cover, Distance to nearest wetland (DNWI), Hydrogeology, National Land Cover, Presettlement Land Cover, Road Density, Soils, Wetland Complexes (CNWI), and National Wetland Inventory (NWI) were included in the models. All environmental layers used were tested for high multicollinearity using ENMTools (Warren et al., 2010). Pearson's correlation coefficient (r) was used test for correlation between any two environmental variables. Any r-values ≥ 0.7 were considered collinear (Warren et al., 2014). No layers were highly correlated with each other and so all respective species layers were included in the respective models. In addition, all environmental layers only encompassed the northern half of Indiana, due to the historical distribution of both species not extending into southern Indiana. The landscape and habitat of southern Indiana is considered quite different from the northern half of the state (Homoya et al., 1997; Whitaker & Amlaner Jr., 2012).

Two environmental variables were created to further incorporate movements and habitat usage of spotted turtles and Blanding's turtles. Due to both species being associated mainly with emergent wetlands and scrub-shrub wetlands (Kofron & Schreiber, 1985; Harding, 1997; Barlow, 1999; Haxton & Berrill, 1999; Hartwig, 2004; MacGowan et al., 2005; Ernst & Lovich, 2009; Stevenson et al., 2015), a Euclidean distance raster was created in ArcMap 10.5 for all emergent and scrub-shrub wetlands based on the maximum home range length of males. Although gravid females will move more than males and have been reported to have larger home range sizes compared to males and non-gravid females (Litzgus & Mosseau, 2004b), this is likely due to the seeking of nesting areas. Between males and non-gravid females, males often have larger home range sizes (Harding, 1997; Litzgus & Mosseau, 2004b; Markle and Chow-Fraser, 2014). Due to variation in home range calculation and methodology of several studies across the ranges of both species (Ernst, 1970; Ward et al., 1976; Rowe, 1987; Barlow, 1999; Milam & Melvin, 2001; Hartwig, 2004; Litzgus & Mosseau, 2004b; Innes et al., 2008; Rasmussen & Litzgus, 2010; Millar & Blouin-Demers, 2011; Hasler et al., 2015), the home range length was based on a single radio-telemetry study done in Indiana (Barlow, 1999). A distance raster was created for each species and used in their respective models.

The second variable created was a wetland complex layer. It was based on the idea that turtles do not remain in single wetland for the entirety of their life; they travel between wetlands quite often (Harding, 1997; Barlow, 1999; Lewis et al., 2004; MacGowan et al., 2005). By traveling between wetlands, the turtles do face barriers, such as roads or fragmented habitat, which may inhibit their ability to travel between wetlands (Minton, 2001; Gibbs & Shriver, 2002; Steen & Gibbs, 2004; Steen et al., 2006; Congdon, et al, 2008; Ernst, 2009). The wetlands that they can travel between without barriers are then considered a wetland complex. To achieve representation of this idea, all wetland types were buffered by 1-kilometer and dissolved before being divided with roads to create wetland complexes for the model to use.

The road density layer was only used in the models using systematic sampling and duplicate sampling methods for both species. Preliminary models showed high road density as having a positive relationship with species occurrence in the models using all occurrences, which does not follow with the known ecology of either species or their relationship to roads (Minton, 2001; Gibbs & Shriver, 2002; Steen & Gibbs, 2004; Steen et al., 2006; Congdon, et al, 2008; Ernst, 2009). It was found that it was being heavily associated when using all occurrences due to the sampling bias issue. Certain populations in dense urban areas were sampled heavily for the collaborating population genetics project, and therefore more occurrences existed for these populations. These populations are very isolated and separated by a dense urban environment, thus causing MaxEnt to predict high road density being a suitable environmental layer when in fact more roads are likely to be detrimental to populations. To create more realistic statewide outputs, road density was thus excluded when using all occurrences because of the issue of sampling bias, but remained in use in the other sampling methods since sampling bias was significantly less in these. Road density is still an important feature to consider when building models, especially for animals that are known to cross roads and suffer road mortality (Minton, 2001; Gibbs & Shriver, 2002; Steen & Gibbs, 2004; Steen et al., 2006; Congdon, et al, 2008; Ernst, 2009).

Due to the high range of values in the Soils layer (USDA Soil Survey), attempts were made to broadly categorize the multiple soil types (e.g. loams, muck, sands). This decreased over 2000 values to approximately 50 values based on broad categories, and thus allowed clearer interpretation of response curves in the models.

Finally, bias files were created to ensure MaxEnt chose background samples from within both species' distribution. Without a background sample bias file, there is a risk of MaxEnt choosing its background points from outside of the distribution of the species in question, which can skew the model outputs to include areas that they have not been known to historically inhabit. Bias files were created by creating a buffered minimum convex polygon (Brown, 2014;

Brown et al., 2017), with the buffer distance being based off the maximum home range length of male turtles of each species (Barlow, 1999). A bias file was created and used with each sampling method, totaling nine bias files for each species.

Model Evaluation

Before a final output could be created, models underwent evaluation to ensure that a potentially useful model was capable of being created given the data. Cross validation was chosen as the model evaluation technique due to its universal use and popularity (Kohavi, 1995; Fielding & Bell, 1997; Franklin, 2009; Borra & Di Ciaccio, 2010; Hijmans, 2012; Merow et al., 2013). During *k*-fold cross validation, the presence dataset is randomly separated into *k* mutually exclusive subsets and run *k* amount of times. All of the mutually exclusive subsets are used for training the data, except for one which is used as the test dataset (Kohavi, 1995; Fielding & Bell, 1997; Franklin, 2009; Borra & Di Ciaccio, 2010; Hijmans, 2012; Merow et al., 2013). Two-fold cross validation ($k = 2$) was used for all models for both species. Two-fold cross validation was used due to the number of model outputs that would be compared and the time required for *k*-fold cross validation to run based on the value of *k* (Kohavi, 1995).

In addition to cross validation, regularization values (reg.) 1 through 5 were used for each model set (Merow et al., 2013). Regularization is an option that can reduce over-fitting, and it is recommended to use a range of values rather than just one to evaluate model performance (Merow et al., 2013).

Models were evaluated based on their area under the receiver operating characteristic curve (AUC), which is a method to measure the performance of models in evaluation (Phillips et al., 2006; Lobo et al., 2008). AUC represents the probability that the model can rank a random occurrence point above a random background point in MaxEnt. A value of 0.5 is the default setting, and considered the random average ranking, while a value of 1.0 being a perfect ranking. Elith (2002) suggested that when evaluating models to use 0.75 as a threshold, with anything ranking above it as possibly being a valuable model. Since cross validation is used to evaluate models, the average training and test AUC values were analyzed for model performance evaluation.

Final Model Selection

Final model selection was based on the area under the curve (AUC) values and the difference of the corrected Akaike information criterion (ΔAICc). AUC has also been used as a model selection method in addition to evaluation due to the limited options when presence only modeling was becoming popular (Phillips et al., 2006; Lobo et al., 2008). It is also a given value in MaxEnt and does not require using an outside program to calculate. While models can be selected based on AUC values, they can over-inflated when independent test data is lacking (Merckx et al., 2011), as is the case here since training and test data was built from the same dataset. There is also much debate among presence only modeling users as to how valuable AUC interpretation is in model evaluation and selection (Lobo et al., 2008; Warren & Seifert, 2011; Merow et al., 2013). Due to this, another method of model selection was also chosen for comparison: the corrected Akaike information criterion (AICc). AICc is derived from AIC, but is useful with small sample sizes in addition to large sample sizes. Due to the sample size varying between models, AICc was chosen as the best alternative to rank and select models for a final output. ΔAICc values were obtained by taking the difference of the AICc values of each model set using the lowest AICc value in the model set. A value of 0 indicated the best fit model for ΔAICc, and the highest AUC value indicated the best fit model.

The raw output of the final model was used to obtain the AUC and AICc values. Fifty percent random test percentage was used to coincide with how the models were evaluated using cross validation. In the output files of a model run, MaxEnt calculated the training and test AUC automatically. The AICc was obtained using a free and compatible program called ENMTools (Warren et al., 2010), requiring the use of a raw output in order to calculate the necessary values. AICc values could not be exported from the cross-validation outputs, since it does not produce a lambda file, which is required for ENMTools to be able to calculate AICc values. This is why the final model's raw output was used rather than the cross-validation output. By using the final model's raw output for the AUC values, it was also ensured that the AUC and AICc values were derived from a model built on the same training and test data across various regularization values.

All final model outputs were visualized using the cloglog output format in MaxEnt. Cloglog is the newest format option provided by MaxEnt, and is suggested over the original logistic output (Phillips et al., 2017) since it outperforms the other formats. Although the cloglog format may only have a small impact on model performance, it was found to improve performance when especially using a target background file (i.e. bias file).

Complex and Parsimonious Model Outputs

Two groups of models were run. The "complex" model outputs utilized all environmental layers applicable to each species. The final complex models were ranked based on the ΔAICc and AUC values, but all cloglog outputs were assessed for which environmental layers contributed the most to the models. Any layers that contributed less than five percent to the complex model output were excluded before the models were run again to obtain the “parsimonious” model outputs. All settings remained the same except the choice of environmental variables.

By excluding the environmental variables that contribute less than five percent, attempts were made to avoid over-parameterization and over-fitting (Warren et al., 2014). Removal of the environmental variables also allows assessment of what environmental variables are considered most important in the models of spotted turtles and Blanding’s turtles out of those that were included. Parsimonious models were thus considered the ideal models for testing and visual comparison and interpretation that would ultimately be used in conservation and management suggestions.

Model Testing

The selected parsimonious models were tested by assessing their ability to map suitable habitat in historic distributions. This was done by mapping the delineated populations over the AUC and ΔAICc final models for all sampling methods for each species. This also allowed an assessment of each output and which most accurately resembles the historic distribution of both species. A threshold of 0.50 habitat suitability ranking was used to determine if there was a greater than random chance of suitable habitat (identified at least 50% of populations). It is assumed that historic populations will have lower suitability due to the greater chance of extirpation and fewer occurrences (Dahl, 1990; Whitaker & Amlaner Jr., 2012), and thus the threshold of 0.50 was chosen to be the most useful for testing the models for historical transferability.

Results

Blanding's Turtle

Complex Model Outputs

Overall, ΔAICc values tended to indicate higher regularization values than the test AUC values (Table 5). The exceptions included the sets of models that used all occurrences (1970 to present, 2000 to present, and 2012 to present), as well as the 1970 to present duplicate sampling model set where two regularization values were selected as best fit for ΔAICc and one of these was the same regularization value as the AUC selected model (Table 5).

Two models with the best ΔAICc values were the 1970 systematic sampling (reg. 4 and 5) and in the 2000 using all occurrences (reg. 1 and 2) due to the second model being within 2 units of the best model (ΔAICc value of 0). In addition, the 2012 AUC selected model shared the same test AUC value between two models (reg. 3 and 4). These models had different numbers of parameters and a difference in log likelihood, encouraging me to further test these models despite being visually the same and having the same environmental variables contribute more than five percent.

Environmental Variable Responses of Complex Models

All environmental layers that contributed five percent or more to each model, and thus included in the parsimonious models, are summarized in Table B2. Distance to nearest wetland (DNWI) and National Land Cover were the only environmental layers consistently found to contribute more than five percent across all AUC and ΔAICc candidate models within respective year ranges.

The 1970 year range models were most associated with a closer distance to the nearest wetland in all AUC and ΔAICc supported models. National Land Cover variables most positively associated with habitat suitability were Woody Wetlands and Emergent Herbaceous Wetlands. Other variables that had some association were Open Water and Scrub-shrub, but these were not as strong. The Presettlement Land Cover variable that was positively associated in the appropriate models was the Quercus-Carya forests (Figure 7). Multiple wetland complexes were also found to be positively associated with suitability. The soil categories associated with suitability in the all occurrences AUC model were drummer soils, Darroch soils, urban soils, Ockley soils, Russel soils, and other soils, while systematic sampling AUC and ΔAICc selected models associated Darroch soils, urban soils, Ockley soils, and Russel soils with suitability (Figure 8). Road Density variables suggested that more road density was associated with suitability in the systematic sampling method, likely due to certain populations being found in urban areas. All wetland types (emergent wetland, scrub-shrub wetland, pond, lake, riverine) of the Wetland layer were most associated with suitability.

The 2000 year range models were positively associated with shorter distances to the nearest wetland. The most associated National Land Cover variables included Woody Wetlands and Emergent Herbaceous Wetlands, with a weaker association for Scrub-shrub being found when using all occurrences and in the duplicate sampling AUC candidate model. Association was found with multiple wetland complexes. The Quercus-Carya forests of the Presettlement Land Cover were most associated with suitability (Figure 7). Hydrogeology values strongly associated with suitability were the Steuben-Huntertown-Wawasee Subbasin and Terrain-Fringing Outwash Plains and Sluiceways values. There was also a weaker association with the Southwestern Glaciated Region and South-Central Driftless Area values (Figure 9).

The 2012 year range were positively associated with shorter distance to nearest wetland. National Land Cover variables most associated were the Woody Wetlands and Emergent Herbaceous Wetlands, with a strong association but still positive association of Scrub-shrub also seen in the All Occurrences models. However, the Duplicate Sampling AUC candidate model did not associate Emergent Herbaceous Wetlands with suitability. The association of Scrub-shrub becomes weaker in the systematic sampling AUC candidate model and in the duplicate sampling models. The National Land Cover strong positive associations become less apparent in the systematic sampling ΔAICc candidate model. Multiple wetland complexes were found to be strongly associated in appropriate models. The Quercus-Carya forests were found to be the most associated in the Presettlement Land Cover layer (Figure 7). The Mississippian, Lake, and Silurian values of the bedrock layer were found to have a strong association with suitability. Emergent wetlands were associated with suitability in the systematic sampling AUC candidate model.

Parsimonious Model Outputs

A similar trend was seen in the candidate parsimonious models in AUC and ΔAICc selection (Table 6). ΔAICc selected models that had a higher regularization value than AUC in half of the systematic sampling and duplicate sampling model sets across all year ranges. The other half selected the same model as the AUC values. When all occurrences were used, the 2000 ΔAICc selected model had a higher regularization value, while 1970 and 2012 did not in comparison to AUC selected models. The parsimonious models did not suffer from over-parameterization like the complex models, showing a positive effect from only including the important environmental variables. In addition, the differences between the ΔAICc values were much smaller compared to the complex models, showing the advantage of tuning the parsimonious model variables to be included.

Like the complex models, ΔAICc selected two models within three model sets due to the second model being with two units of the best model. The model sets included the 1970 systematic sampling models (reg. 4 and 5), 1970 systematic sampling models (reg. 4 and 5), and 2012 duplicate sampling models (reg. 4 and 5) (Table 6).

Environmental Variable Responses of Parsimonious Models

As with the complex models, DNWI and National Land Cover consistently contributed the most to all parsimonious candidate models within the respective year ranges. AUC and ΔAICc candidate models within year ranges and sampling method model sets seemed to share similar contributing environmental variables more so than the complex candidate models. For example, the 1970 Duplicate Sampling AUC and ΔAICc candidate complex models differed by one contributing environmental variable. The 1970 Duplicate Sampling AUC and ΔAICc candidate parsimonious models, though, shared the same contributing environmental variables (Table B2).

The 1970 parsimonious candidate models had similar environmental variable contribution as the candidate complex models. The values of the environmental variables that characterized the candidate models of each sampling method coincided with those of the complex models.

The 2000 parsimonious candidate models also had similar environmental variable contribution as the complex models, although both of the Duplicate Sampling candidate models did include wetland complexes while only the AUC candidate model in the complex models had wetland complexes as a contributing variable. Like the 1970 model sets, most values of the environmental variables that characterized the candidate models of each sampling method coincided with those of the complex models. The Southwestern Glaciated Region and South-Central Driftless Area values of the Hydrogeology variable were less associated in the All Occurrences candidate models than in the complex models (Figure 9).

The 2012 parsimonious candidate models had similar environmental variable contribution as the complex models, although the wetland type variable was included in one more model. Overall, the variable values tended to overlap with those that characterized suitable habitat in the corresponding sampling methods of the complex models.

Current Distribution

The candidate parsimonious models that applied systematic sampling and duplicate sampling produced similar habitat suitability maps within their respective year ranges (Figure 10 - 12). The only exception is the AUC selected model for the 2000 duplicate sampling model, which shows a limited suitability map compared to the ΔAICc selected model. This is likely due to the low regularization value, which may be causing overfitting. The candidate parsimonious models that use all occurrences also produce similar habitat suitability maps between the AUC and ΔAICc selected models within their respective years, although the 2012 AUC selected model shows more variation but still similar “hotspots” of high suitability (Figure 12).

Overall, the ΔAICc selected models for systematic sampling and duplicate sampling in all year ranges tended to show more potential for suitable habitat compared to the AUC selected models (Figure 10 – 12). This is likely due to ΔAICc selecting models with higher regularization values, thus avoiding overfitting more so than the AUC selected models. In contrast, only the 2000 ΔAICc selected models that use all occurrences showed more potential habitat (Figure 11), with the 1970 and 2012 year ranges showing the AUC selected models having more potential suitable habitat (Figure 10; Figure 12). “Hotspots” tend to disappear and broaden in the candidate 1970 and 2012 duplicate sampling models (Figure 10; Figure 12), and in the candidate 2000 systematic sampling models (Figure 11).

The model sets that utilized all occurrences were more constrained overall compared to the model sets that used systematic sampling and duplicate sampling (Figure 10 – 12). Those that used all occurrences were limited and showed obvious “hotspot” areas, likely an effect of the heavy sampling bias since those habitats with more occurrences would be considered more suitable than those with only one occurrence. Although the models that used all occurrences still resemble the historic distribution of Blanding’s turtles, they are likely the least useful due to the heavy sampling bias for management and conservation efforts. They still do show distribution trends, though, that are useful in understanding how suitable habitat has been affected over time.

Based on the select models, the current distribution of Blanding’s turtles has likely decreased compared to 1970 based on available suitable habitat. When focusing on the high suitable habitat ranking only, it can be seen that this decreases across the same sampling method as the data becomes more limited when approaching 2012 (Figure 10 – 12). This is not unexpected, as the occurrences for Blanding’s turtles become fewer over time across the same sampling method due to their population decline over the years. As of 2012, the Blanding’s turtle distribution is suggested to be concentrated in the upper third of Indiana based on the highest suitability rankings of available habitat (Figure 12). The highest suitability is observed to fall in the following counties: Lake, Porter, LaPorte, St. Joseph, Elkhart, LaGrange, Steuben, Newton, Jasper, Pulaski, Fulton, Starke, Marshall, Kosciusko, Noble, and Allen. Although not having as high of suitable habitat, DeKalb County was predicted to have suitable habitat. Of these counties, Lake, Porter, LaPorte, St. Joseph, Elkhart, LaGrange, Steuben, Newton, Fulton, Starke, Marshall, Kosciusko, Noble, and Allen counties are known or assumed to have populations, although some of these need to be further confirmed or studied for viability (Figure 3).

Model Testing

All except for four of the AUC and ΔAICc select models across the year ranges were able to predict suitable habitat conditions within current or historical delineated populations (Table 7). There was a total of 98 delineated Blanding's turtle populations, and many of the select models were able to identify suitable habitat within these delineated buffer zones with less than five not being identified. The 2000 duplicate sampling AUC and ΔAICc select models were not able to predict suitable habitat better than random, with only 26 of 98 and 29 of 98 populations identified with suitable habitat, respectively (Table 7).

In addition, the select models using all occurrences performed the worst between the three sampling methods. While the 1970 AUC and ΔAICc select models and 2000 ΔAICc select model were able to predict better than random, the number was still much lower than the majority of models (Table 7). The other two select models that used all occurrences performed worse than random. The poor performance in model testing is likely due to the strong sampling bias in this sampling method, constricting the predicted suitable habitat due to heavy sampling at certain locations and skewing the outputs.

Spotted Turtle

Complex Model Outputs

ΔAICc selection tended to favor lower regularization values than the AUC selection, contrast to the Blanding's turtle models. However, the 2000 ΔAICc and AUC select models were the same, and the 2000 and 2012 systematic sampling and 2012 duplicate sampling ΔAICc select models were of higher regularization values (Table 8).

Environmental Variables Responses of Complex Models

All environmental layers that contributed five percent or more to each model, and thus included in the parsimonious models (Table B3). Distance to nearest wetland (DNWI) was the only environmental layer consistently found to contribute more than five percent across all AUC and ΔAICc selected models within respective year ranges. It also was the only layer to contribute more than five percent in a few of the AUC and ΔAICc selected models within the 2000 and 2012 year ranges of systematic sampling and duplicate sampling (Table B3).

In the 1970 year range, a shorter distance to the nearest wetland was strongly associated to suitability in all models. Multiple wetland complexes were strongly associated with suitability in the appropriate models. The Woody Wetlands and Emergent Herbaceous Wetlands variables of the National Land Cover layer were strongly associated with suitability in the appropriate models, and Scrub-shrub was also strongly associated in 1970 all occurrences model set. The soil categories associated with suitable habitat are Darroch soils, Ockley soils, Russel soils, and other soils (Figure 8). The Presettlement Land Cover revealed the Quercus-Carya value is most associated with suitability (Figure 7). All wetland types (emergent wetlands, scrub-shrub wetlands, lake, riverine) were positively associated with suitability in the duplicate sampling AUC candidate model.

In the 2000 year range, a shorter distance to the nearest wetland was strongly associated with suitability in all selected models. Multiple wetland complexes were strongly associated with the selected model using all occurrences, but fewer in the selected models of the systematic sampling model set and only one in the ΔAICc candidate model for duplicate sampling. In the

ΔAICc selected model of the duplicate sampling model set, there seemed to be more positive association with less canopy cover with suitability. In both the AUC and ΔAICc candidate models of the same sampling method, the Quercus-Carya forests of the Presettlement land cover were associated with suitability (Figure 7). Soil categories in the duplicate sampling ΔAICc candidate model revealed a strong association with Darroch soils and Russel soils (Figure 8).

In the 2012 year range, there was a strong association of a shorter distance to the nearest wetland with suitability in all models. Less than ten wetland complexes were strongly associated with suitability in the models sets using all occurrences and AUC selected models of the systematic sampling and duplicate sampling model sets. The National Land Cover values of Emergent Herbaceous Wetlands and Scrub-shrub was positively associated with suitability in the all occurrences ΔAICc candidate model. Bedrock values of Mississippian, Lake, and Silurian were also found to be associated with suitability (Figure 13).

Parsimonious Model Outputs

Similar to the complex models, the ΔAICc selection method seemed to choose lower regularization values than the test AUC. There was an exception in the 1970 systematic sampling model set when ΔAICc chose a higher regularization value. ΔAICc and AUC selection methods chose the same model in the 2012 model set using all occurrences (Table 9). In contrast to the Blanding's turtle models, the spotted turtle parsimonious models showed an increase in the ΔAICc values between models within a model set, except for the 1970 model set using all occurrences and 2012 duplicate sampling model set (Table 8; Table 9).

Environmental Variables Responses of Parsimonious Models

For the parsimonious models, the DNWI still remained the only consistent layer that contributed the most to all models within respective year ranges (Table B3). The candidate models tended to be ones that resembled the complex models in contributed variable composition. In addition, the AUC and ΔAICc candidate models within the respective year ranges and sampling methods seemed to share similar contributed environmental variable composition (Table B3). The all occurrences AUC and ΔAICc candidate model were the same model, while in the complex models they were separate and had different environmental variable composition (Table 8; Table 9; Table B3).

The 1970 candidate parsimonious models chose models with similar environmental variable contribution as the candidate complex models (Table B3). National Land Cover contributed more in the parsimonious models in the systematic sampling set, but soils contributed less in the duplicate sampling set. Overall, the environmental variable values that characterized suitable habitat in the candidate complex models were similar in the parsimonious models.

The 2000 candidate parsimonious models also chose mainly the same models, and thus the same contributed environmental variables in each sampling method as the complex models (Table 8; Table 9). Wetland complexes were not as important in the parsimonious models, since the systematic sampling AUC candidate model was one with only DNWI instead of both. The values of the contributed environmental variables associated with suitability were not different from the candidate complex models.

The 2012 candidate parsimonious models had similar environmental variable contribution as the complex models. The values of the contributed environmental variables that characterized the suitable habitat overlapped with those of the complex models.

Current Distribution

The candidate parsimonious models for systematic sampling and duplicate sampling within the 1970 and 2012 year ranges produced similar habitat suitability maps in the select models with higher regularization values. The systematic sampling and duplicate sampling select models within the 2000 year range did not produce as similar of habitat suitability maps between lower or higher regularization values (Figure 14 – 16). In addition, the 2012 ΔAICc selected models in systematic sampling and duplicate sampling were of lower regularization values and resembled each other (Figure 16). The 2000 candidate parsimonious models that use all occurrences produce similar habitat suitability maps between the AUC and ΔAICc select models. The 2012 AUC and ΔAICc selected models were the same regularization value, and thus the same suitability map represents both and has nothing to compare to. The 1970 selected models do differ by more than just variation, with the “hotspots” that are present in the ΔAICc selected model becoming fewer in the AUC selected model (Figure 14).

In contrast to Blanding’s turtles, the spotted turtle AUC selected models tended to show more potential suitable habitat versus the ΔAICc selected models in all sampling methods (Figure 14 – 16). This is likely due to the ΔAICc select models often being of a lower regularization value (Table 9). Exceptions included the selected 2012 systematic sampling models, 2000 using all occurrences, and 2012 using all occurrences (Figure 14 – 16). “Hotspots” were observed to disappear or broaden considerably between the ΔAICc and AUC select models, with hotspots being more focused in the select models with lower regularization values due to more overfitting.

Similar to the Blanding's turtle models, the candidate model sets that used all occurrences were more constrained overall and showed definitive "hotspot" habitat areas (Figure 14 – 16). This likely represents the overfitting of data in the model due to sampling bias and low regularization values. The 1970 AUC and ΔAICc selected models did show more potential suitable habitat and was not as constrained as the other year ranges, but still constrained compared to the duplicate sampling and systematic sampling models (Figure 14). The only model that used all occurrences that resembles the historical distribution of spotted turtles is the 1970 ΔAICc selected model (Figure 14), but still did not perform as well as the Blanding's turtle models. Due to sampling bias and the overall lack of resemblance to the known spotted turtle historical distribution, the selected models from using all occurrences and all year ranges will likely not be useful in management and conservation efforts, but still show distribution trends.

The spotted turtle models did not perform as well in predicting the current distribution of the species based on habitat suitability. When looking across the model sets as a whole (Figure 14 – 16), it can be seen that suitable habitat was predicted to have decreased compared to 1970. Unfortunately, this was not as clear when comparing the highly suitable habitat ranking across the same sampling method from 1970 to 2012, except in the models sets that use all occurrences. This was likely due to the 2000 and 2012 systematic sampling and 2012 duplicate sampling select models only had one environmental variable contributing (DNWI) (Figure 14 – 16; Table B3). Because MaxEnt only had one variable to use in these models and the fact that layer is a distance raster for wetlands, it highlighted essentially all of the emergent and scrub-shrub wetlands from the National Wetland Inventory in upper Indiana, which is not as helpful for conservation and management efforts.

It can be assumed from current knowledge and surveys of the species, as well as the trend seen in the model sets using all occurrences, that the current distribution of spotted turtles is mainly focused in the upper third of the state like Blanding's turtles. It is known from surveys that at least one population still occurs in Carroll County, which is more south, but this is the only known extant population (Table 1; Figure 4). The highest suitability is observed to fall in the following counties: Lake, Porter, LaPorte, Elkhart, LaGrange, Steuben, Carroll, Newton, and St. Joseph. The 2012 select models that only used the DNWI layer to build the model were not considered when observing county overlay, as it shows suitable habitat along all emergent and scrub-shrub wetlands and is not a good representation of predicted suitability compared to historical distribution of the species. Of these counties, Lake, Porter, LaPorte, Elkhart, LaGrange, Steuben, and Carroll counties are known or assumed to have population, although viability should be confirmed through further study in some of these (Figure 4).

Model Testing

All except eight of the AUC and ΔAICc select models across the year ranges performed better than average in predicting suitable habitat in the delineated 63 spotted turtle populations (Table 10). Many select models were able to identify suitable habitat within the delineated buffer zones, with less than ten not being identified in at least two models. The ΔAICc select model for 1970 duplicate sampling performed worse than the other models, not performing worse or better than average by identifying 31 of 63 populations. The select models unable to predict suitable habitat better than random were the selected ΔAICc models for 2012 duplicate sampling (18 of

63), and 2000 and 2012 and systematic sampling models (21 of 63 and 7 of 63, respectively) (Table 10).

In addition, all except one select model that used all occurrences could not predict suitable habitat better than random (Table 10). Although predicting better than random, the select ΔAICc model for 1970 could only identify 35 of 63 populations and thus tested worse than the majority of other models. The other ΔAICc and AUC select models using all occurrences were unable to predict better than random (Table 10). This was also observed in the testing of Blanding's turtle models that used all occurrences, and thus likely these results reflect the sampling bias apparent in these model sets.

Table 5. Summary of the results from the Blanding's turtle complex models. Each column in each year range represents an individual model, with an asterisk (*) indicating the model selected by the best fit methods (AUC and ΔAICc). Comparison numbers are a visual representation of which candidate models were compared to each other. No comparisons of performance were made between year ranges, only sampling methods in the same year range.

		All Occurrences			Systematic Sampling			Duplicate Sampling		
Year Range	Regularization	Training AUC	Test AUC	ΔAICc	Training AUC	Test AUC	ΔAICc	Training AUC	Test AUC	ΔAICc
1970	1	0.9966*	0.9420	4.96	0.9985*	0.8882	1437.34	0.9977	0.9146	506.61
	2	0.9949	0.9423*	0.00*	0.9979	0.8925	506.59	0.9955	0.922	272.05
	3	0.9909	0.9413	54.59	0.9959	0.8957	349.73	0.9883	0.9227*	210.42
	4	0.9729	0.9395	31.17	0.9511	0.8978*	1.11*	0.939	0.9219	10.19
	5	0.9716	0.9388	54.03	0.9469	0.8973	0.00*	0.9379	0.9183	0.00*
2000	1	0.9977	0.9570	0.639*	0.9993	0.9173	3207.13	0.9990	0.8763	2071.11
	2	0.9960	0.9605	0.00*	0.9992	0.9193	603.68	0.9979	0.8856*	500.44
	3	0.9929	0.9610*	32.55	0.9990	0.9199	435.62	0.9947	0.8809	337.34
	4	0.9640	0.9595	59.62	0.9003	0.9223	8.51	0.9533	0.8798	5.42
	5	0.9632	0.9583	88.45	0.8868	0.9239	0.00*	0.9530	0.8780	0.00*
2012	1	0.9987	0.9562	0.00*	0.9992*	0.8543	N/A	0.9989*	0.8681	N/A
	2	0.9980	0.9598	2.71	0.9976	0.8802*	118.05	0.9983	0.8895	453.89
	3	0.9960	0.9610*	30.11	0.9028	0.8793	2.63	0.9930	0.89800	319.59
	4	0.9669	0.9610*	58.87	0.8799	0.8799	0.00*	0.9110	0.9045*	4.50
	5	0.9665	0.9605	92.33	0.8689	0.8782	10.21	0.8965	0.9038	0.00*
	Comparisons	1			2			3		

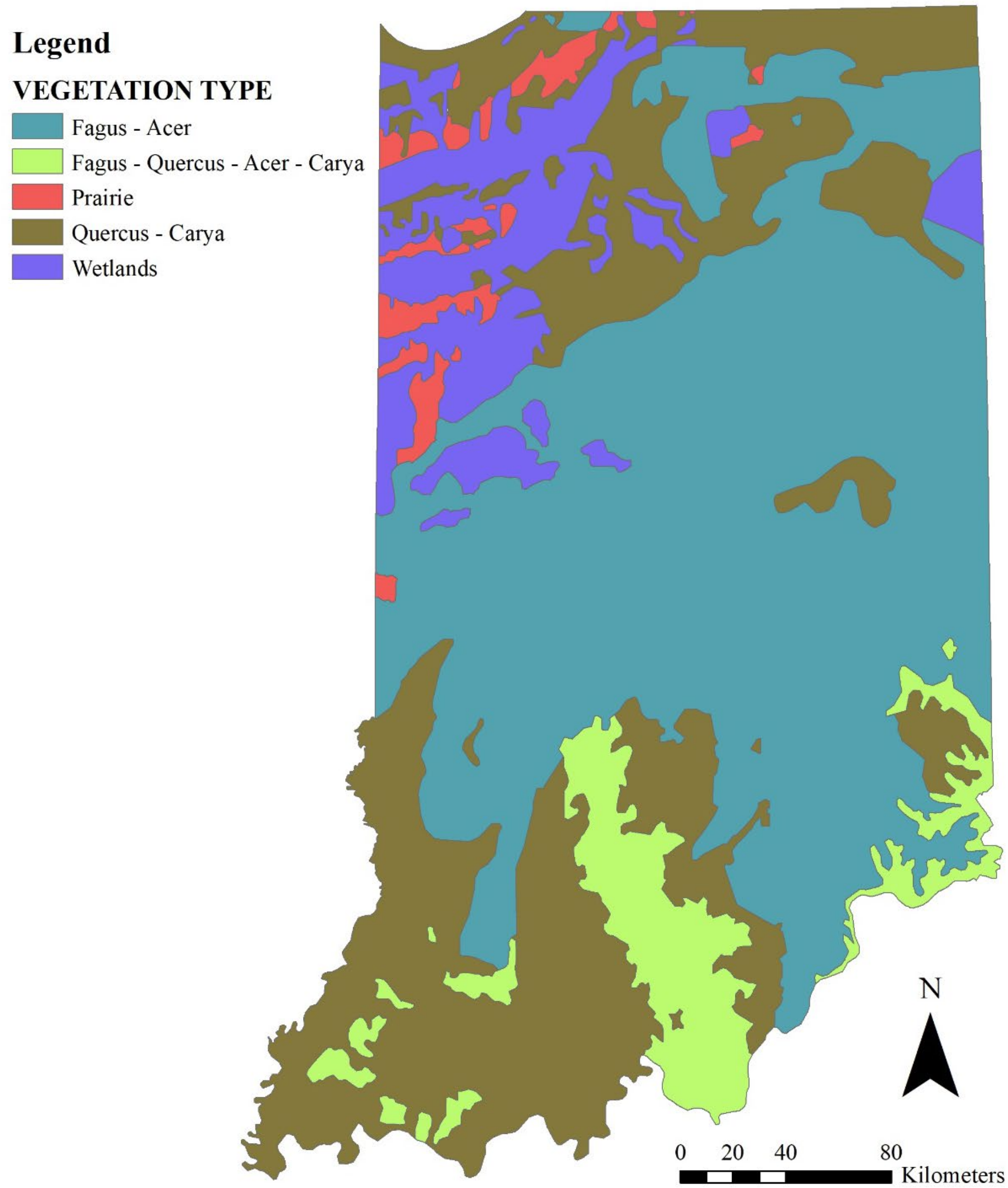

Figure 7. Indiana's presettlement land cover environmental layer. For both Blanding's turtle and spotted turtle candidate models, only the Quercus-Carya vegetation type was associated with suitability.

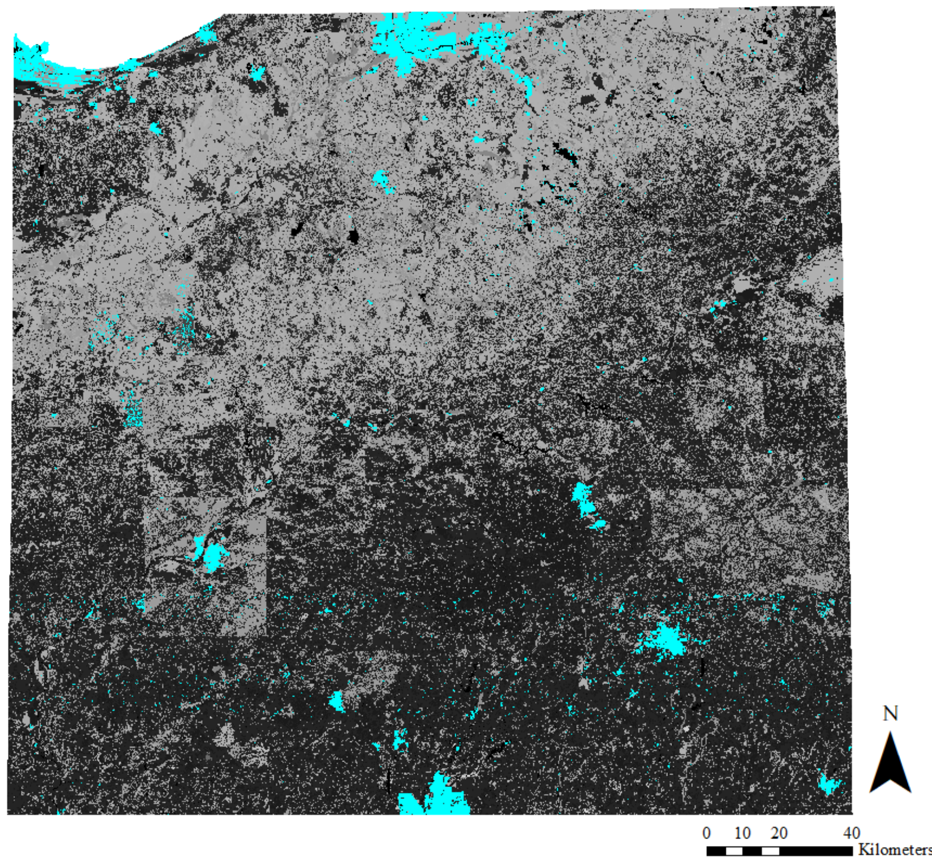

Figure 8: The soils layer of Indiana with soils broadly categorized. Highlighted in bright blue are the soil categories associated with habitat suitability between the Blanding's turtles and spotted turtles.

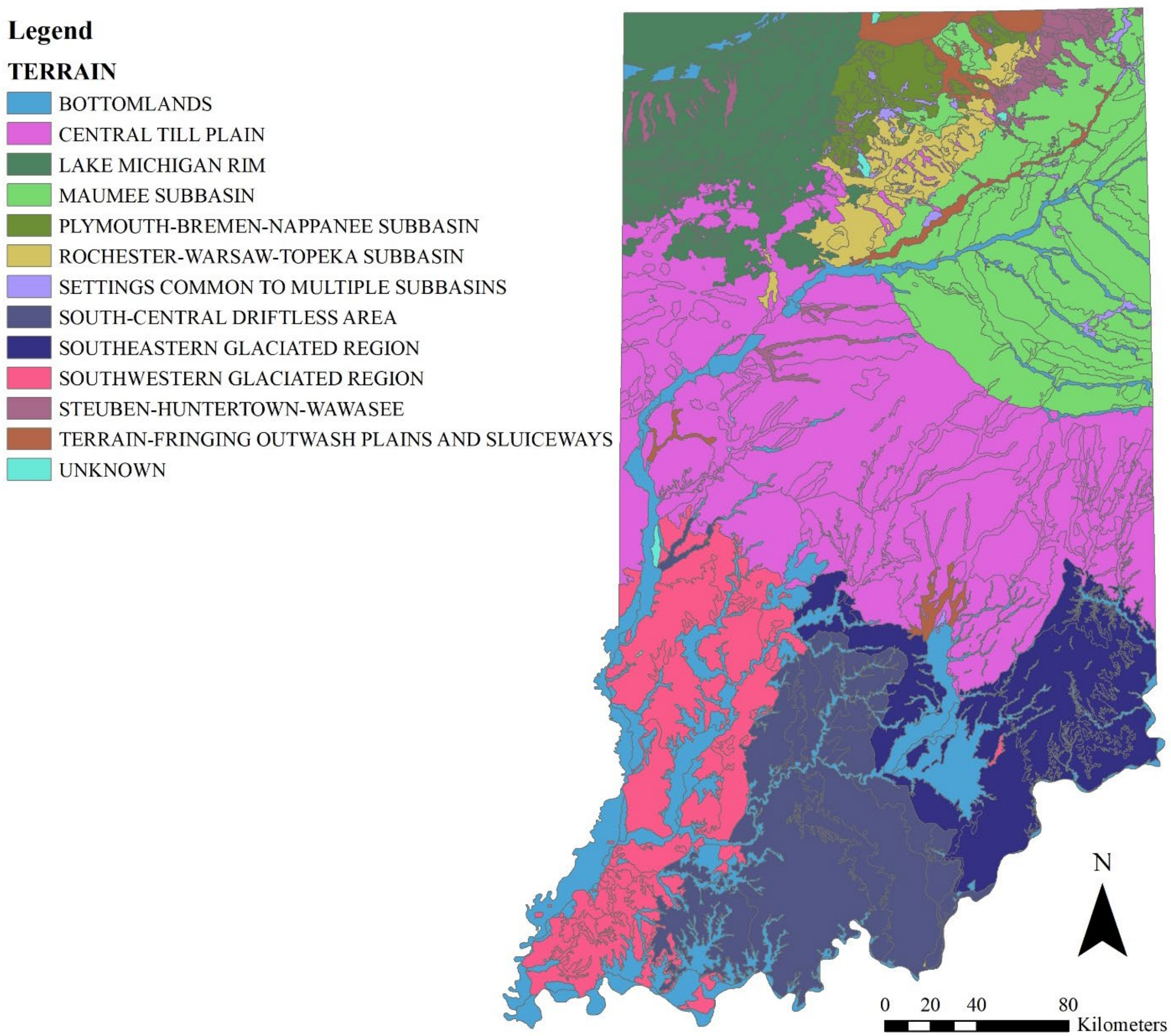

Figure 9: Indiana's hydrogeology environmental layer.

Table 6. Summary of the results from the Blanding's turtle parsimonious models. Each column in each year range represents an individual model, with an asterisk (*) indicating the model selected by the best fit methods (AUC and ΔAICc). Comparison numbers are a visual representation of which candidate models were compared to each other. No comparisons of performance were made between year ranges, only sampling methods in the same year range.

		All Occurrences		Systematic Sampling		Duplicate Sampling	
Year Range	Regularization	Test AUC	ΔAICc	Test AUC	ΔAICc	Test AUC	ΔAICc
1970	1	0.9392	0.00*	0.8876	246.25	0.8854	63.90
	2	0.9403*	13.23	0.8931	154.99	0.8918	9.62
	3	0.9364	120.41	0.8909	176.60	0.8924	63.06
	4	0.9318	262.32	0.8943	0.299*	0.8950*	0.671*
	5	0.9316	264.91	0.8947*	0.00*	0.8948	0.00*
2000	1	0.9604	305.47	0.8896	123.62	0.8747*	2.43
	2	0.9626	284.91	0.908	42.52	0.8703	0.00*
	3	0.9633*	270.72	0.9257	25.90	0.8586	20.50
	4	0.9598	0.00*	0.9302*	0.00*	0.8561	16.34
	5	0.9577	45.09	0.928	8.98	0.8562	17.32
2012	1	0.9404	0.00*	0.8704	119.98	0.9011	217.72
	2	0.9489	19.75	0.8938*	71.99	0.8944	163.53
	3	0.9546*	55.76	0.8888	0.00*	0.9005	63.67
	4	0.9538	117.05	0.8880	7.62	0.9070*	0.00*
	5	0.9544	141.20	0.8168	24.14	0.9067	1.95*
	Comparisons	1		2		3	

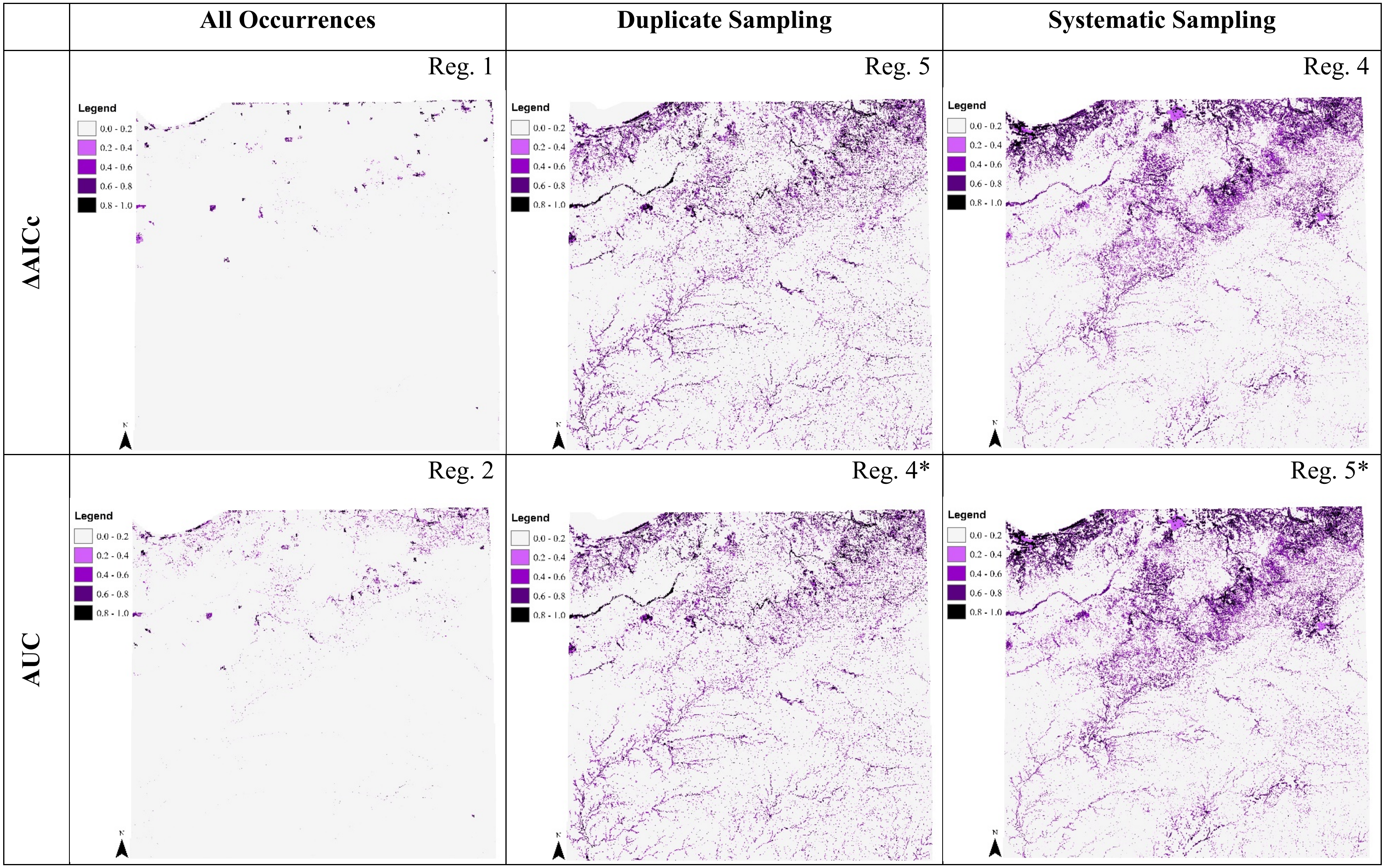

Figure 10. Blanding's turtle ΔAICc and AUC parsimonious candidate models using the 1970 to present data set. Asterisks (*) indicate that the model output was selected by both ΔAICc and AUC as a best model.

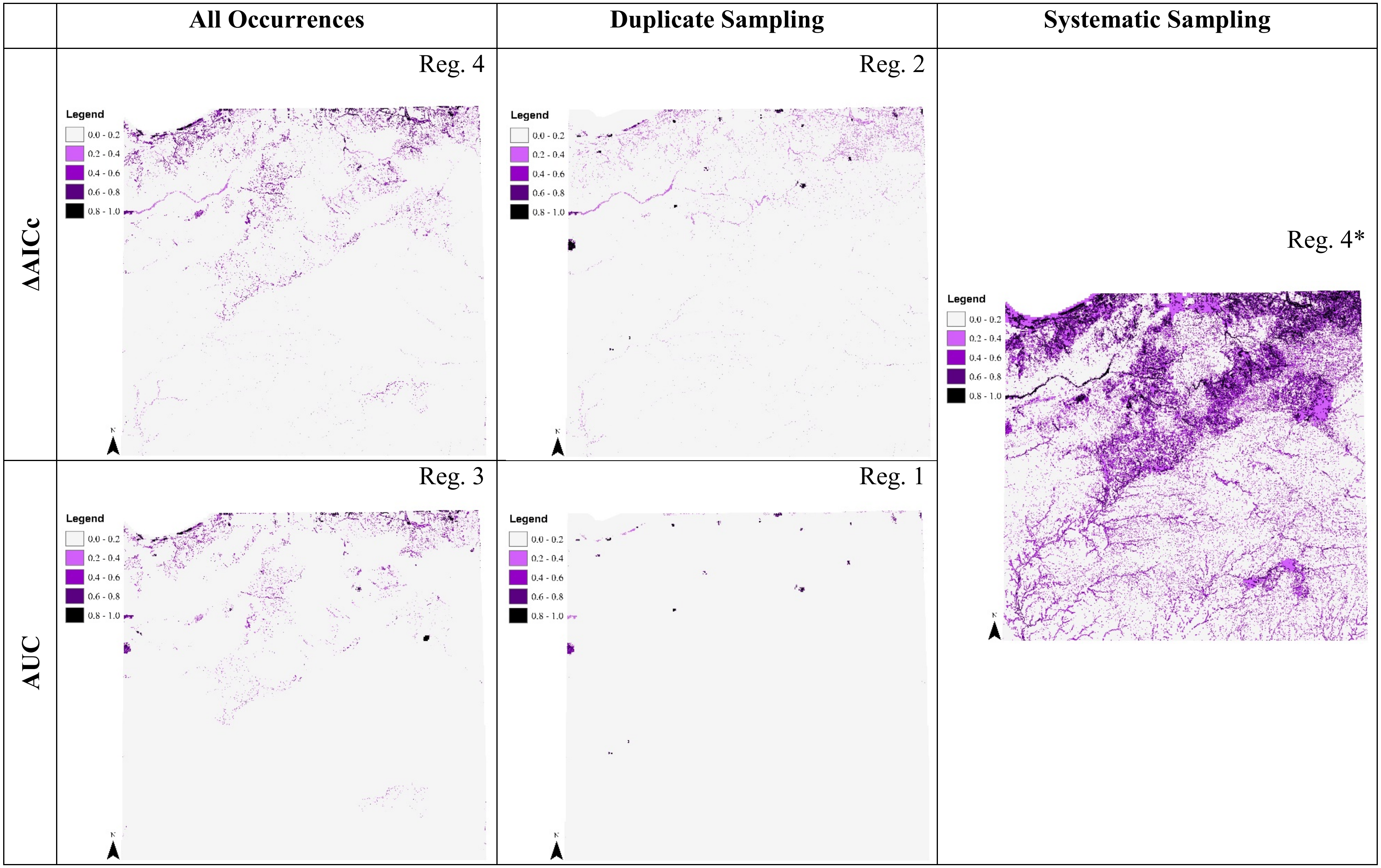

Figure 11. Blanding's turtle ΔAICc and AUC candidate model using the 2000 to present data set. Asterisks (*) indicate that the model output was selected by both ΔAICc and AUC as a best model.

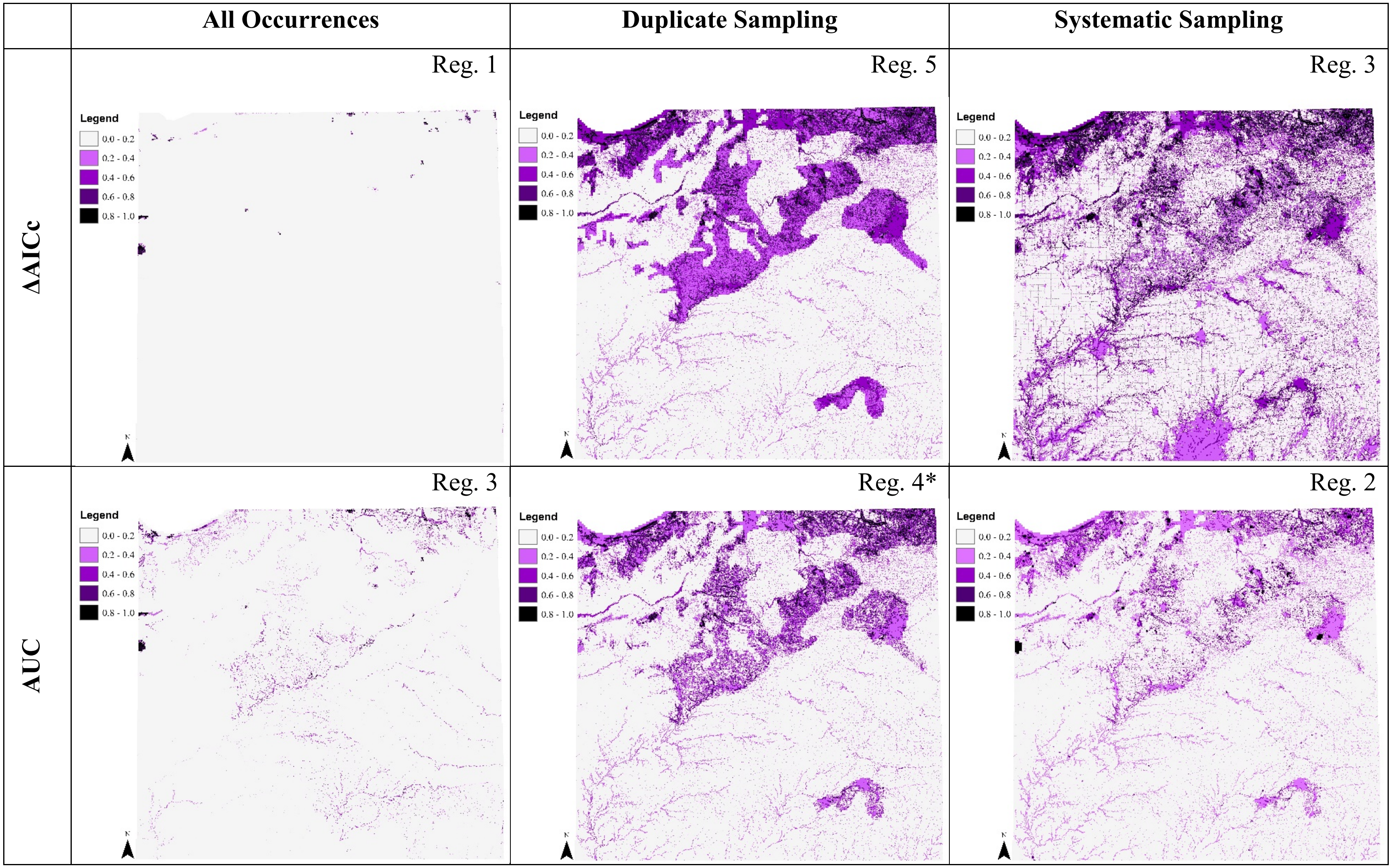

Figure 12. Blanding's turtle ΔAICc and AUC parsimonious candidate models using the 2012 to present data set. Asterisks (*) indicate that the model output was selected by both ΔAICc and AUC as a best model.

Table 7. Blanding's turtle model testing results for all parsimonious candidate models. "Reg" is short for regularization. Populations identified are out of a total of 98 delineated populations. Asterisks (*) indicate the models that predicted below average (0.50), and thus performed poorly in model testing.

Sampling Method	Year Range	Model Selection	Reg. Value	Populations Identified
Duplicate	1970	AUC and AICc	4	97
		AICc	5	97
	2000	AUC	1	26*
		AICc	2	29*
	2012	AUC and AICc	4	95
		AICc	5	94
Systematic	1970	AUC and AICc	5	97
		AICc	4	97
	2000	AUC and AICc	4	97
	2012	AUC	2	95
		AICc	3	98
All	1970	AUC	2	81
		AICc	1	63
	2000	AUC	3	41*
		AICc	4	80
	2012	AUC	3	40
		AICc	1	28*

Table 8. Summary of the results from the spotted turtle complex models. Each column in each year range represents an individual model, with an asterisk (*) indicating the model selected by the best fit methods (AUC and ΔAICc). Comparison numbers are a visual representation of which candidate models were compared to each other. No comparisons of performance were made between year ranges, only sampling methods in the same year range.

		All Occurrences			Systematic Sampling			Duplicate Sampling		
Year Range	Regularization	Training AUC	Test AUC	ΔAICc	Training AUC	Test AUC	ΔAICc	Training AUC	Test AUC	ΔAICc
1970	1	0.9973*	0.9810	23.24	0.9994*	0.8958	0.00*	0.9991*	0.9247	N/A
	2	0.9965	0.9824	0.00*	0.9994*	0.8977	2.43	0.9990	0.9376	0.00*
	3	0.9949	0.9830	29.99	0.9992	0.8982	32.64	0.9985	0.9445	36.82
	4	0.9771	0.9831*	9.00	0.9697	0.8987*	98.04	0.9499	0.9483*	94.31
	5	0.9745	0.9828	65.59	0.9626	0.8974	100.81	0.9464	0.9441	105.62
2000	1	0.9983*	0.9953*	0.00*	0.9998*	0.9610*	N/A	0.9998*	0.8768	N/A
	2	0.9983*	0.9949	89.89	0.9859	0.9567	0.00*	0.9889	0.9038	0.00*
	3	0.9982	0.9947	192.05	0.9736	0.9541	2.84	0.9883	0.9124	13.14
	4	0.9944	0.9843	351.54	0.9685	0.9550	14.42	0.9875	0.9184	18.65
	5	0.9940	0.9831	409.99	0.9615	0.9447	15.131	0.9835	0.9240*	18.16
2012	1	0.9988*	0.9955	0.00*	0.9998*	0.9719*	N/A	0.9998*	0.9479*	N/A
	2	0.9987	0.9961	91.88	0.9913	0.9650	0.00*	0.9859	0.9450	0.00*
	3	0.9986	0.9963*	155.60	0.9825	0.9650	5.62	0.9828	0.9434	5.86
	4	0.9977	0.9921	241.03	0.9700	0.9587	5.4	0.9830	0.9447	9.02
	5	0.9972	0.9914	290.23	0.9700	0.9567	7.01	0.9660	0.9369	9.06
	Comparisons	1			2			3		

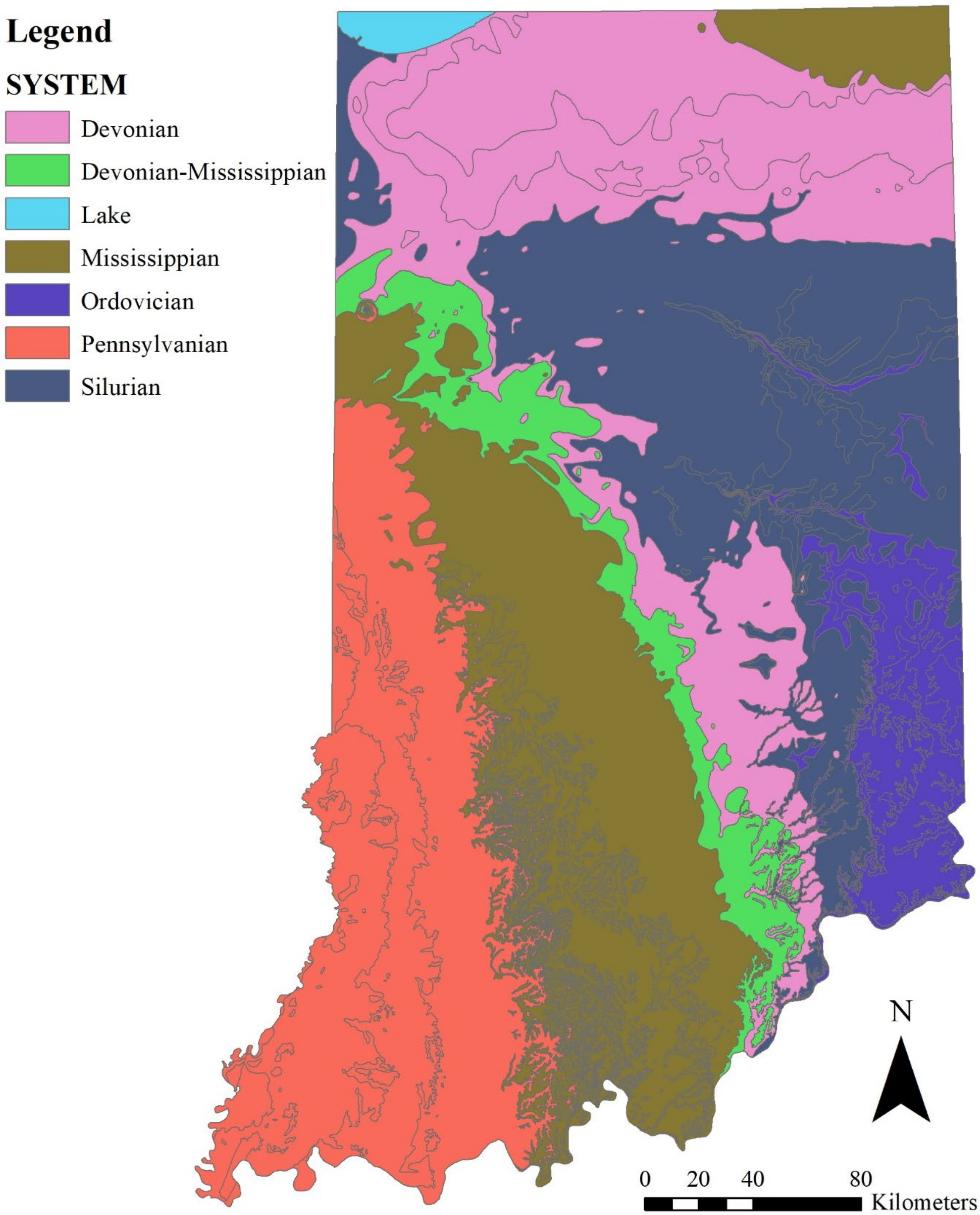

Figure 13: Indiana's bedrock layer.

Table 9. Summary of the results from the spotted turtle parsimonious models. Each column in each year range represents an individual model, with an asterisk (*) indicating the model selected by the best fit methods (AUC and ΔAICc). Comparison numbers are a visual representation of which candidate models were compared to each other. No comparisons of performance were made between year ranges, only sampling methods in the same year range.

		All Occurrences		Systematic Sampling		Duplicate Sampling	
Year Range	Regularization	Test AUC	ΔAICc	Test AUC	ΔAICc	Test AUC	ΔAICc
1970	1	0.9811	0.00*	0.8829	138.63	0.9134	0.00*
	2	0.9817	56.84	0.9025*	187.29	0.9288	174.92
	3	0.9818	139.33	0.8994	207.53	0.9405	395.96
	4	0.9822*	231.03	0.8978	0.00*	0.9447*	34.55
	5	0.9820	287.92	0.8947	7.09	0.9358	34.23
2000	1	0.9917	0.00*	0.9442	0.00*	0.8705	594.96
	2	0.9917	27.85	0.9446	23.67	0.9054	0.00*
	3	0.9918	76.47	0.9447	26.69	0.918	10.04
	4	0.9742	220.14	0.9456	35.83	0.9201	13.90
	5	0.9742	242.37	0.9456	38.28	0.9217	14.61
2012	1	0.9949*	0.00*	0.957	0.00*	0.9339	0.00*
	2	0.9919	95.80	0.9574*	12.19	0.9425*	11.12
	3	0.9919	128.79	0.9574*	13.77	0.93810	7.17
	4	0.9857	198.23	0.9574*	15.40	0.9381	8.21
	5	0.9857	223.58	0.9574*	17.00	0.9381	9.42
	Comparisons	1		2		3	

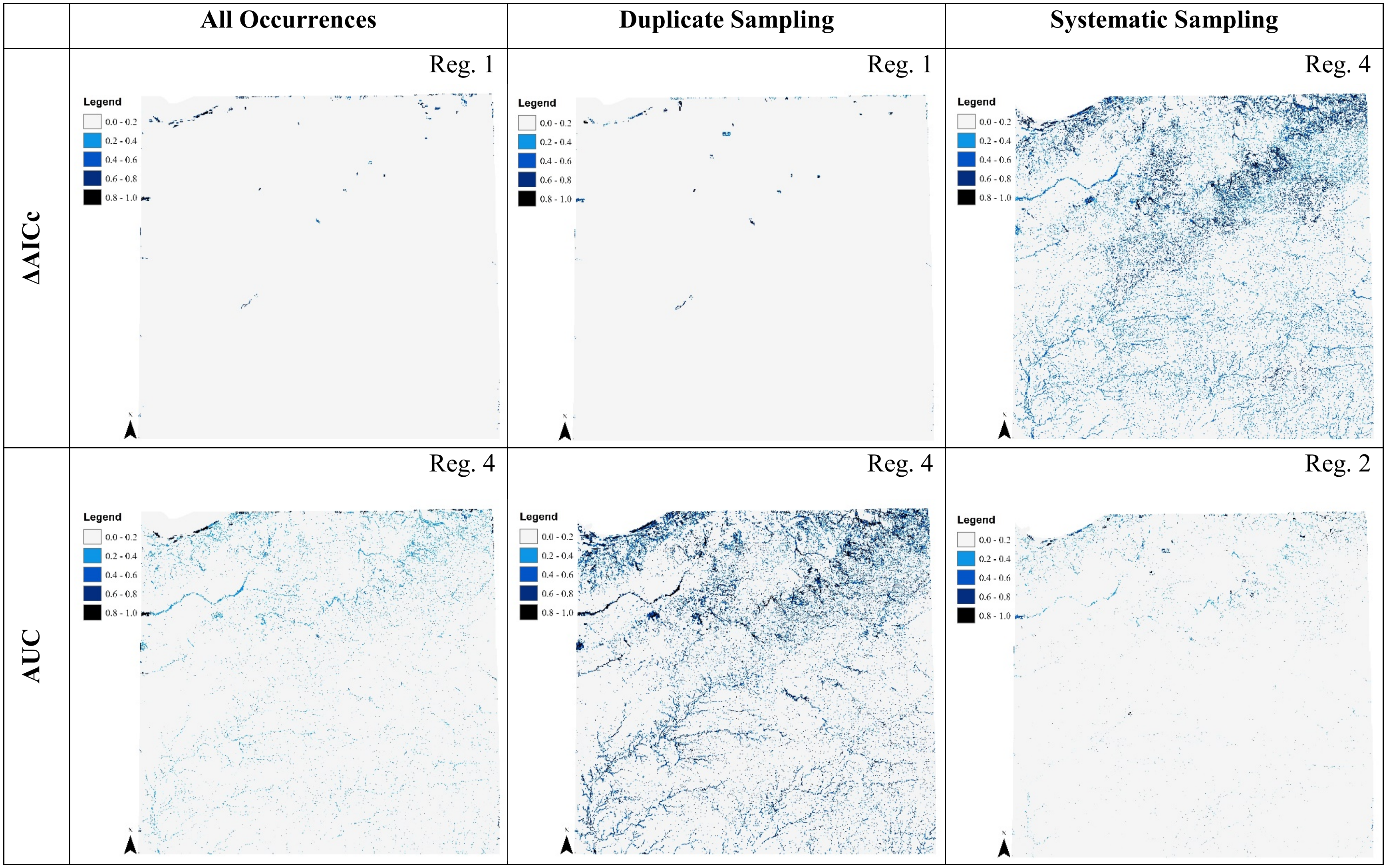

Figure 14. Spotted turtle ΔAICc and AUC parsimonious candidate models using the 1970 to present data set.

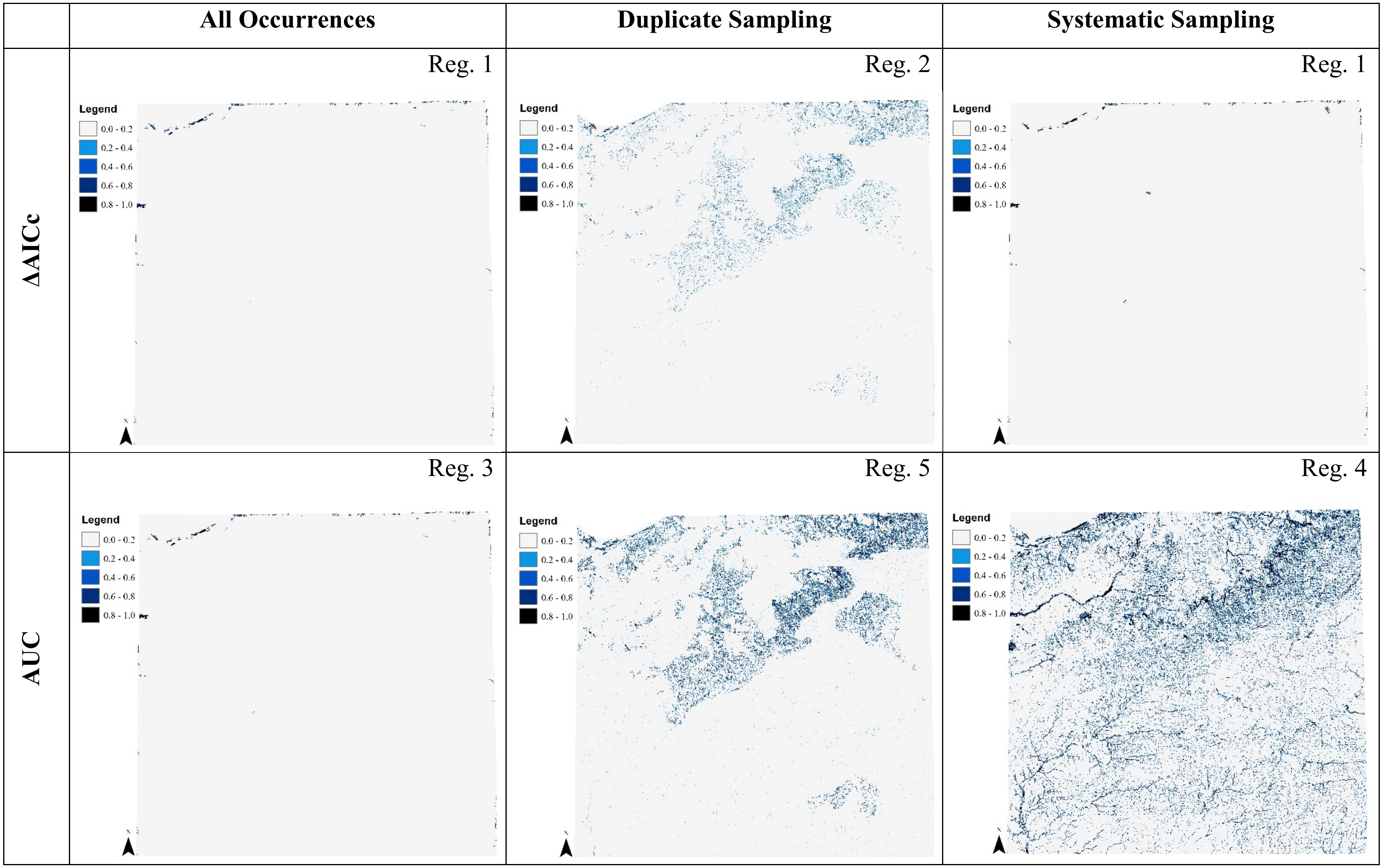

Figure 15. Spotted turtle ΔAICc and AUC parsimonious candidate models using the 2000 to present data set.

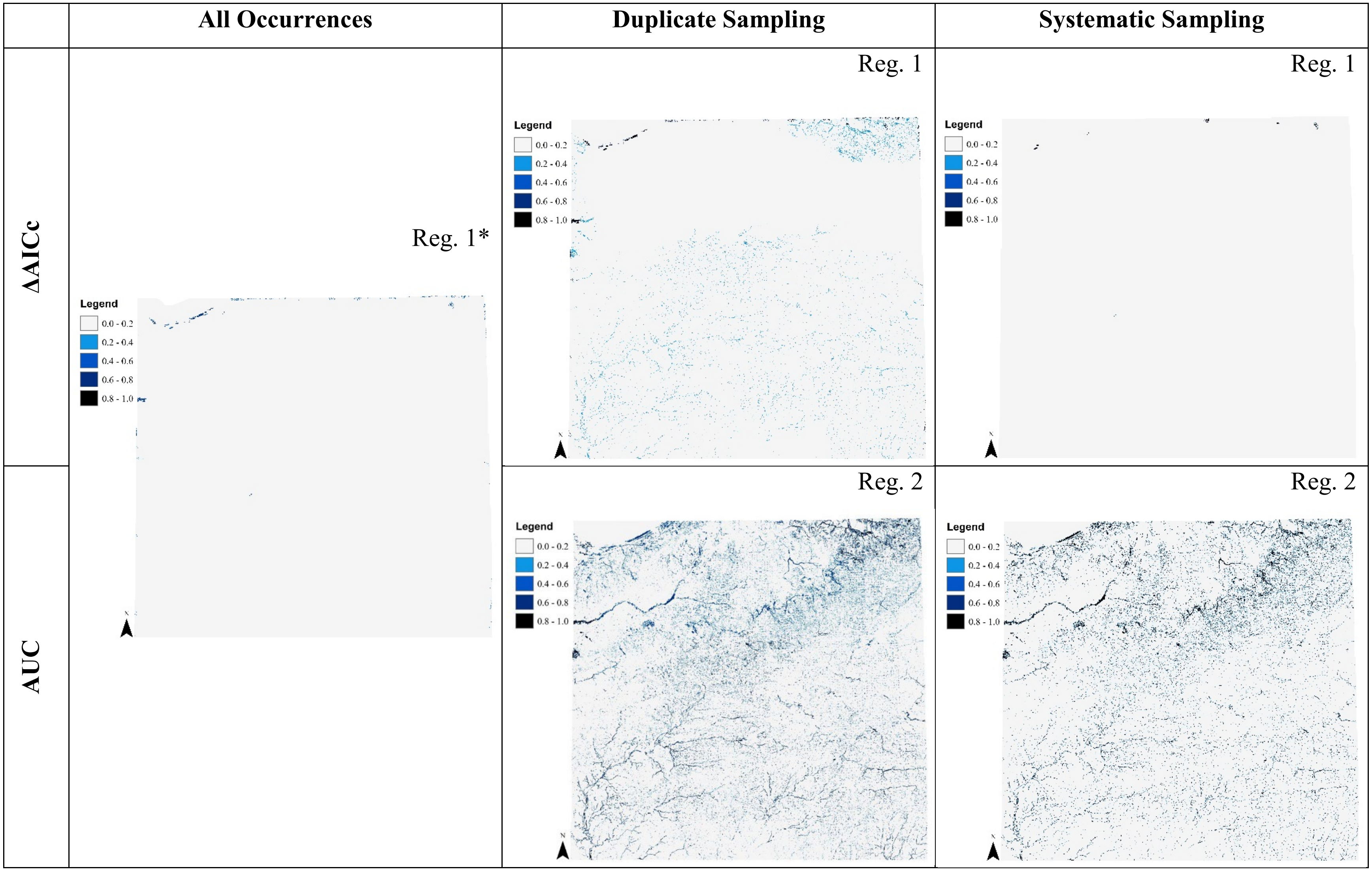

Figure 16. Spotted turtle ΔAICc and AUC parsimonious candidate models using the 2012 to present data set.

Table 10. Spotted turtle model testing results for all parsimonious candidate models. "Reg" is short for regularization. Populations identified are out of a total of 63 delineated populations. Asterisks (*) indicate the models that predicted below average (0.50), and thus performed poorly in model testing.

Sampling Method	Year Range	Model Selection	Reg. Value	Populations Identified
Duplicate	1970	AUC	4	63
		AICc	1	31
	2000	AUC	5	54
		AICc	2	54
	2012	AUC	2	63
		AICc	1	18*
Systematic	1970	AUC	2	61
		AICc	4	63
	2000	AUC	4	63
		AICc	1	21*
	2012	AUC	2	63
		AICc	1	7*
All	1970	AUC	4	19*
		AICc	1	35
	2000	AUC	3	20*
		AICc	1	20*
	2012	AUC and AICc	1	19*

Discussion

Ecological Implications of Variables

Based on the environmental variable responses in the Blanding's turtle and spotted turtle candidate models, the Distance to nearest wetland (DNWI), National Land Cover, and Wetland Complexes (CNWI) variables contribute the most to many of the models. Models indicated that both turtle species are positively associated with a close proximity to emergent, scrub-shrub, and even woody wetlands, as well as the presence of wetland complexes.

These results are not unexpected based on the known ecology of both species. Blanding's turtles and spotted turtles are known to utilize various types of wetlands, mainly emergent and scrub-shrub but also using forested or woody wetlands during breeding and nesting season when moving between wetlands (Kofron & Schreiber, 1985; Harding, 1997; Haxton & Berrill, 1999; Barlow, 1999; Hartwig, 2004; MacGowan et al., 2005; Ernst & Lovich, 2009; Stevenson et al., 2015). A positive association with wetland complex presence further suggests the use of several wetlands. This corresponds with the observation that neither species will utilize a single wetland within their home range, but multiple wetlands and travel through smaller wetlands and riparian habitat to traverse between wetlands (Ernst, 1970; Ward et al., 1976; Rowe, 1987; Harding, 1997; Kiviat, 1997; Barlow, 1999; Milam & Melvin, 2001; Innes et al., 2008; Rasmussen & Litzgus, 2010; Millar & Blouin-Demers, 2011; Hasler et al., 2015). Based on these results, it further suggests that management and conservation efforts should focus on both larger and smaller wetlands, as well as suitable riparian habitat, which is likely used as nesting and temporary areas during the breeding and nesting season (Harding, 1997; Minton, 2001; MacGowan et al., 2005; Beaudry et al., 2009).

Distribution Based on Suitable Habitat Availability

Candidate Blanding's turtle models predicted suitable habitat comparable to known historical and current distribution better than the candidate spotted turtle models. This was likely due to more populations being available in the systematic sampling and duplicate sampling for Blanding's turtles than in spotted turtles. The models that used all occurrences were limited in predicting suitable habitat due to sampling bias, with "hotspot" areas correlating with the more sampled populations for both species. Due to the sampling bias, models using all occurrences were deemed less useful than the systematic sampling and duplicate sampling candidate models and will likely not be used in future statewide conservation and management efforts of both species.

Overall, for Blanding's turtles, most of the ΔAICc supported models were able to identify suitable habitat in delineated historical and current populations better than the AUC supported models. This trend was seen especially in the systematic sampling and duplicate sampling methods across all year ranges, but not when all occurrences were used. The ΔAICc candidate models typically had higher regularization values than those of the AUC candidate models, unless it was the same candidate model as the AUC selected model. This is likely why the ΔAICc models overall performed better at identifying suitable habitat across historical and current distribution since higher regularization values have less overfitting and give more potential habitat values (Phillips et al., 2006; Phillips & Dudik, 2008). This suggests that the ΔAICc supported models performed better than the AUC supported models and that the ΔAICc is a better form of model selection (Warren & Seifert, 2011; Warren et al., 2014). Across all year ranges, the candidate models for the systematic sampling method also seemed to be the best at predicting suitable habitat that corresponds with the historical and current distribution of

Blanding's turtles based on its ability to identify delineated populations and visually being comparable. ΔAICc models are likely more transferable to historical distribution than current distribution of suitable habitat, due to allowing more generalization in model output. The AUC models identify more "hotspots" and limited habitat that could represent the current distribution in relation to suitable habitat of the respective year range.

The spotted turtle models were the opposite of the Blanding's turtle models in ΔAICc and AUC candidate model performance. AUC selected models were able to identify suitable habitat for historical and current populations than the ΔAICc selected models. Like the Blanding's turtle models, this trend was especially apparent in the systematic sampling and duplicate sampling methods, but not when using all occurrences. The AUC candidate models could likely identify more suitable habitat due to being of higher regularization values, while ΔAICc candidate models were of lower regularization values (Phillips et al., 2006; Phillips & Dudik, 2008). Similar to the Blanding's turtle models, the systematic sampling method seemed to perform best at predicting suitable habitat that corresponds with the historical and current suitable habitat that is comparable with respective distributions. In contrast to the Blanding's turtle models, the spotted turtle AUC candidate models are likely more transferable to historical suitable habitat. The AUC models identify more "hotspots" and limited habitat, which could be more representative of the current distribution of spotted turtles in relation to suitable habitat of the respective year range.

Based on the better performance of the candidate models using systematic sampling across all year ranges for both species, these will be the likely models used in developing conservation and management strategies. The systematic sampling models also are the least biased of the three sampling methods, making them ideal candidates to use further in assessments.

Model Selection Using AUC and ΔAICc

In the complex models for both Blanding's turtles and spotted turtles, training AUC values selected the lowest regularization value, suggesting training AUC selects models that would typically be the most constricting and have a high chance of overfitting. Warren and Seifert (2011) suggest strongly against using training AUC as a model selection method, since they found it to perform poorly compared to the test AUC and AIC selected models in their study. In addition, some models in the complex model sets for both species suffered from over-parameterization, preventing the use of training AUC as a comparison method against ΔAICc. Thus, it was favorable to compare the test AUC and ΔAICc selected models within the parsimonious model sets, and omit the training AUC selected models in future comparisons.

Using ΔAICc as a model selection variable allowed adequate comparison between the best fit models according to AUC and ΔAICc for both species. In some cases, though, ΔAICc actually chose more than one best fit model based on another model ΔAICc value being within 2 units of the model with a value of 0. Parameters and log likelihood were assessed between these models to determine if the second model was actually competitive with the best model, and it was found that while the differences in parameters and log likelihood were small, they were still different enough to warrant the second model as a candidate model (Burnham & Anderson, 2002). The differences in parameters and log likelihood values of the Blanding's turtle parsimonious models were small in the 1970 and 2012 duplicate sampling models, but larger in the 1970 systematic sampling models. Under these conditions, the second models were chosen to be more competitive than similar (Burnham & Anderson, 2002), and thus were further tested as candidate models.

In addition, there were cases where AUC chose several models as the best fit by sharing the same values. There were two models in the 2000 systematic sampling set and four models in the 2012 systematic sampling set that had the same high test AUC values, and were thus selected as AUC models. However, when these models were compared against each other, parameter numbers were not different, but log likelihood was slightly different. According to Burnham and Anderson (2002) when using these variables for comparing two chosen ΔAICc models, it is suggested that this would make these models similar to each other and not competitive. In addition, these models shared the same environmental variables (Table B3). Following the suggestions of these variables, only one of the AUC models for each year range was chosen for further testing.

ΔAICc values between individual models within a set were also compared to observe the level of overfitting. Burnham & Anderson (2002) suggest that smaller differences between the individual ΔAICc values for models indicates less overfitting. The Blanding's turtle complex models had larger differences between the ΔAICc values, while the parsimonious models had smaller. This suggests that the Blanding's turtle parsimonious models are suffering from less overfitting than the complex models, and are more reliable as model outputs. Between the spotted turtle complex and parsimonious models, though, the opposite was seen, and suggests that the parsimonious models are actually suffering from more overfitting than the complex models. Because of this, the spotted turtle parsimonious models may not be as reliable of a model output compared to the Blanding's turtle parsimonious models (Burnham & Anderson, 2002).

MaxEnt Use and Performance

MaxEnt as a modeling method of presence-only data performed well in regards to predicting suitable habitat for Blanding's turtles, but potentially not spotted turtles. This is likely due to the lower sample sizes and lesser geographic distribution of these samples compared to Blanding's turtles. MaxEnt is reported to be a useful modeling tool with smaller sample sizes, especially when using its regularization multiplier feature (Hernandez et al., 2006; Wisz et al., 2008; Elith et al., 2011; Merow et al., 2013), but the models performed worse as the sample sizes grew smaller due to sampling method application. As sample sizes grew smaller, fewer environmental variables were considered to contribute more than five percent to the models and thus the outputs were often predicted on only one or two environmental variables. When this occurred, the models resembled representations of the environmental variables more so than a possible distribution in relation to suitable habitat. By these observations, it is also possible that the program performed well given the data available, but this is hard to determine at this time without more occurrences and population identification.

Multiple settings had to be considered when using MaxEnt. First, MaxEnt cannot consider sampling bias without manual interference since it assumes an equally sampled landscape by default (Phillips et al., 2006; Phillips & Dudik, 2008; Elith et al., 2011; Merow et al., 2013). Sampling bias can be alleviated either through altering the presence data file or through a bias file. If sampling bias is not considered, the model outputs could potentially be skewed to the areas that are heavily sampled and limit the predicted suitable habitat, as seen with the Blanding's turtle and spotted turtle models that used all occurrences. Accounting for sampling bias can severely limit the amount of presence data, and so methods for dealing with sampling bias should be chosen carefully.

MaxEnt has a feature that allows for input of a bias file into its program for each run. This bias file is often used to account for sampling bias as mentioned before, but also targeted background selection. MaxEnt will randomly choose background points across the entire extent of the landscape if a bias file is not entered. Due to my modeling being a statewide effort and with two species that historically occur in only certain portions of the upper half of Indiana, a bias file that used targeted background selection was desirable. Targeted background selection should be considered in most cases since it has been found that models using targeted background selection performed better than those without it (Phillips et al., 2006; Barbet-Massin et al., 2012; Merow et al., 2013). The bias file I created was a minimum convex polygon based on the presence data files, telling MaxEnt to only sample background points within that polygon. This prevents the program from potentially choosing background points in a portion of northern Indiana that neither Blanding's turtles nor spotted turtles were ever recorded.

A range of regularization values should be considered when using the MaxEnt modeling program (Merow et al., 2013). As observed in my modeling efforts, a regularization value of 1 (the default setting) often suffers from severe overfitting of data. The overfitting of data becomes especially apparent when more environmental variables are entered into the program as well. By exploring a range of regularization values, models can be assessed in overfitting and performance under different conditions. Another method of reducing over fitting is the removal of environmental variables that do not contribute more than five percent to the models, as suggested by Warren et al. (2014). Minimizing overfitting is desirable due to increased model performance, and thus I suggest that exploring a range of regularization values should be done to assess overfitting. Removal of certain environmental variables should also be considered to reduce overfitting, since less environmental variables allows MaxEnt to utilize each variable to a greater extent and often gives a broader and potentially useful prediction map.

I highly recommend testing models using different settings other than the default. Multiple studies suggest that the default settings do not perform as well as those where features and settings are modified (Phillips et al., 2006; Barbet-Massin et al., 2012; Merow et al., 2013). Settings that I modified in my models were previously discussed, but other modifications can be made to the features available on the home screen of MaxEnt. There are five features that can be used in MaxEnt modeling: hinge, quadratic, linear, threshold, and product. The default settings of the newest version of MaxEnt excludes threshold features automatically due to a recent finding that it is not as useful to models and may actually be harmful (Phillips et al., 2017). All of these features are able to be included or excluded through check boxes, and I strongly recommend modifying these based on the ecological question and project. If left to default, the model uses the appropriate features based on sample size (Phillips et al., 2006; Phillips & Dudik, 2008). Phillips et al. (2017) recommends that threshold and product features are two to be considered omitting for use. Ideally, models should be tested using all combinations of these features to assess performance, but this is may not be possible due to time and resources.

Finally, MaxEnt outputs and unexpected environmental variable associations should be assessed, especially when working with species that are often seen outside of their suitable habitat during traveling movements. In my case, I found some question in the NWI and soils layers mainly due to the fact that the NWI layer does not always represent accurate wetland delineations or classifications compared to ground validation efforts, and MaxEnt may be associating soils with occurrences that would otherwise be outside of their suitable habitat due to turtle movements for breeding and nesting. A method that could be considered to fix these issues is the creation of separate layers that associate the layer data to the occurrence. Another option is to manually remove occurrences of traveling instances, such as road kill or the occurrence being outside of suitable habitat, but this can increase sampling bias and limits the number of presence data points.

Variable Evaluation

The 2014 National Wetland Inventory (NWI) was used to create the distance to nearest wetland (DNWI) layers for each species and wetland complex layer. It was also used on its own as a layer and categorized by wetland type in the modeling efforts. Although DNWI and wetland complexes were often associated with suitability in both Blanding's turtle and spotted turtle models, it is important to note the disadvantages that accompany the NWI layer for Indiana that should be considered when assessing and using the model outputs for further studies.

While evaluation of the NWI for Indiana was not an objective in this project, discrepancies were noted when mapping occurrences gathered over the two field seasons. First, the classifications of wetlands in the NWI do not seem to correlate with aerial imagery. Second, the delineated wetlands did not overlap with the aerial imagery correctly, even when using the same coordinate reference system for all layers. In addition, not all wetlands present in Indiana are delineated, despite the relatively recent year of publication for the Indiana NWI. This was apparent in a few locations that were surveyed or trapped, with the wetland delineations of the NWI not extending to areas that, by physical visitation and aerial imagery, were known to be wetland habitat.

The NWI layer was not the only layer that should be considered with caution. The Presettlement Land Cover layer for Indiana is very coarse compared to other states. A more detailed Presettlement Land Cover layer would be ideal to understand suitable habitat associations, but is not available. While it often contributed more than five percent to models, this was likely due to the coarse classification of the layer.

Finally, the soils variables that were associated with suitability should be assessed with caution. Many occurrences used, especially in earlier year ranges, were likely opportunistic sightings of spotted turtles and Blanding's turtles as they were crossing roads or traveling to nesting areas. The areas that turtles use to travel is not necessarily suitable habitat, as their objective is to reach what they considered suitable habitat for mating or nesting activities. Thus, soil categories associated with suitability, especially in early year ranges like 1970, should be considered with caution as these may only be suitable since MaxEnt could only understand that occurrence location was likely suitable habitat and produced predictions from this methodology.

Future Work

Based on the candidate model outputs, MaxEnt proved useful in initial efforts of predicting habitat suitability for two state endangered species of turtles. However, more tuning and variable manipulation is desired to further test and analyze habitat suitability maps that could prove useful to conservation and management strategies.

Two additional environmental variables I would like to try and include in the Blanding's turtle and spotted turtle models are wetland associations and elevation. Wetland associations may counter issues seen with the NWI and Soils layer by associating nearby wetland attributes to occurrences outside of what is known to be suitable habitat for these turtle species (Harding, 1997; Barlow, 1999; Hartwig, 2004; MacGowan et al., 2005; Ernst & Lovich, 2009; Stevenson et al., 2015). In addition, an elevation variable could help identify landscape depression that may be indicative of wetland habitat (Myers, 1997; Whitaker et al., 2012).

Due to MaxEnt not creating outputs representing try estimations of occurrence probability, it is desirable to look at other modeling programs to use alongside and compare to the predicted habitat suitability maps presented here. Modeling programs that estimate occurrence probability, such as the package Maxlike in R (Royle et al., 2011; Fitzpatrick et al., 2013; Merow & Silander, Jr., 2014), would be a useful component in addition to habitat suitability maps to predict the distribution of spotted turtles and Blanding's turtles. It could also provide more information to conservation and management strategies for these two endangered turtles.

Habitat suitability modeling for spotted turtles and Blanding's turtles ultimately will be used to identify and delineate management units (MUs), or functional population units, for each species. MUs are defined by potentially separate populations in which individuals are clustered by their likelihood of ability to interbreed (Palsbøll et al., 2007). MUs can guide management and conservation strategies by suggesting what areas could be managed as one large unit under a single management entity. Identification of MUs will be a combination of factors such as suitable habitat, species observations in the field, presence of barriers, presence of corridors, and genetic similarity. Once the units are delineated and ranked, conservation and management strategies can be further developed for both species based on the location of potential suitable habitat and populations across the state of Indiana.

Conclusions

MaxEnt was able to create predictive habitat suitability maps that correlated with known historical and current distributions of populations for Blanding's turtles. Spotted turtle models did not perform as well, but this was likely a result of there being far fewer delineated spotted turtle populations compared to Blanding's turtles. Overall, modeling efforts showed that suitable habitat for both species has decreased over time. Populations are likely still in decline due to lack of suitable habitat across a fragmented landscape, and will continue to decline unless efforts are made to restore and maintain suitable habitat.

REFERENCES

Adkins Giese, C.L., Greenwald, D.N., Curry, T. (2012) "Petition to List 53 Amphibians and Reptiles in the United States as Threatened or Endangered Species under the Endangered Species Act." *Center for Biological Diversity*. Center for Biological Diversity, 11 July 2012. 1-454.

Anthonysamy, W.J.B., Dreslik, M.J., Mauger, D., Phillips, C.A. (2014) A preliminary assessment of habitat partitioning in freshwater turtle community at an isolated preserve. *Copeia* 2: 269-278.

Banning, W.J. (2007) Nesting ecology of the Blanding's turtle, *Emydoidea blandingii*, at the Lockport Prairie Nature Preserve, Will County, Illinois. *Illinois Natural History Survey Technical Report* 40: 1-25.

Barlow, C. (1999) Habitat use and spatial ecology of Blanding's turtles (*Emydoidea blandingii*) and spotted turtles (*Clemmys guttata*) in Northeast Indiana. M.S. Thesis, Purdue University, Fort Wayne, IN.

Beaudry, F., de Maynadier, P.G., Hunter Jr., M.L. (2009) Seasonally dynamic habitat use of spotted (*Clemmys guttata*) and Blanding's turtles (*Emydoidea blandingii*) in Maine. *Journal of Herpetology* 43 (4): 636-645.

Benjamini, Y. and Hochberg, Y. (1995) Controlling the false discovery rate: a practice and powerful approach to multiple testing. *Journal of the Royal Statistical Society Series B* 57: 289-300.

Bluthgen, N., Metzner, A., Ruf, D. (2006) Food plant selection by stick insects (Phasmida) in a Bornean rain forest. *Journal of Tropical Ecology* 22(1): 35-40.

Boutin, C. and Keddy, P.A. (1993) A functional classification of wetland plants. *Journal of Vegetation Science* 4: 591-600.

Borra, S. and Di Ciaccio, A. (2010) Measuring the prediction error: a comparison of cross-validation, bootstrap and covariance penalty methods. *Computational Statistics and Data Analysis* 54: 2976-2989.

Braunisch, V. and Suchat, R. (2010) Predicting species distributions based on incomplete survey data: the trade-off between precision and scale. *Ecography* 33(5): 826-840.

Brown, J.L. (2014) SDMtoolbox: a python-based GIS toolkit for landscape genetic, biogeographic and species distribution model analyses. *Methods in Ecology and Evolution* 5(7): 694-700.

Brown, J.L., Bennett, J., French, C.M. (2017) SDMtoolbox 2.0: the next generation python-based GIS toolkit for landscape genetic, biogeographic and species distribution model analyses. *PeerJ* 5: e4095.

Congdon, J.D., Kinney, O.M., Nagle, R.D. (2011) Spatial ecology and core-area protection of Blanding's turtle (*Emydoidea blandingii*). *Canadian Journal of Zoology* 89: 1098-1106.

Crump, M.L. and Scott Jr., N.J. (1994) "Visual encounter surveys." *In* W.R. Heyers, M.A. Donnelly, R.W. McDiarmid, L.C. Hayek, and M.S. Foster (eds.) *Measuring and monitoring biological diversity: standard methods for amphibians*, pp. 84-92. Smithsonian Institution Press, Washington, DC. 364 pp.

Dahl, T.E. (1990) Wetland losses in the United States 1780's to 1980's. U.S. Department of Interior, Fish and Wildlife Service, Washington, D.C. 13 pp.

Dodd Jr., C.K. (ed.) (2016) *Reptile Ecology and Conservation: A Handbook of Techniques*. Oxford: Oxford University Press.

Elith, J. (2002) Quantitative methods for modeling species habitat: comparative performance and an application to Australian plants. *In:* Ferson, S. and Burgman, M (eds), *Quantitative methods for conservation biology*, pp. 39-58. Springer Science and Business Media. 321 pp.

Elith, J., Kearney, M., Phillips, S. (2010) The art of modelling range-shifting species. *Methods in Ecology and Evolution* 1: 330-342.

Elith, J., Phillips, S.J., Hastie, T., Dudik, M., Chee, Y., Yates, C.J. (2011) A statistical explanation of MaxEnt for ecologists. *Diversity and Distributions* 17: 43-57.

Ernst, C. H., and Lovich, J.E. (2009) *Turtles of the United States and Canada*. JHU Press,City.

Ernst, C.H. (1970) Home range of the spotted turtle, *Clemmys guttata* (Schneider). *Copeia* 2: 391-393.

Ernst, C.H. (1976) Ecology of the spotted turtle, *Clemmys guttata* (Reptilia, Testudines, Testudinidae), in southern Pennsylvania. *Journal of Herpetology* 10 (1): 25-33.

Fielding, A.H. and Bell, J.F. (1997) A review of methods for assessment of prediction errors in conservation presence/absence models. *Environmental Conservation* 24(1): 38-49.

Fitzpatrick, M.C., Gotelli, N.J., Ellison, A.M. (2013) MaxEnt versus MaxLike: empirical comparisons with ant species distributions. *Ecosphere* 4(5): 55, 1-15.

Franklin, J. *Mapping Species Distributions: Spatial Inference and Prediction*. Cambridge University Press, 2010. 319. Print.

Gibbs, J.P. and Shriver, G. (2002) Estimating the effects of road mortality on turtle populations. *Conservation Biology* 16 (6): 1647 – 1652.

Graeter, G.J., Buhlmann, K.A., Wilkinson, L.R., Gibbons, J.W. *Inventory and Monitoring: Recommended Techniques for Reptiles and Amphibians*. Partners in Amphibian and

Reptile Conservation Technical Publication IM-1, Birmingham, Alabama, 2013. 321 pp. Print.

Harding, J.H. *Amphibians and Reptiles of the Great Lakes Region*. University of Michigan, 1997. 378 pp. Print.

Hartwig, T. S., Stevens, G., Sullivan, J., Kiviat, E. (2009) Blanding's turtle habitats in southern Dutchess County. Report to the Marilyn Milton Simpson Charitable Trusts and New York State Department of Environmental Conservation Hudson River Estuary Program.

Hartwig, T.S. (2004) Habitat selection of Blanding's turtle (*Emydoidea blandingii*): a range-wide review and microhabitat study. M.S. Thesis, Bard College, Annandale-on-Hudson, NY.

Hasler, C.T., Robinson, K., Stow, N., Taylor, S.R. (2015) Population size and spatial ecology of Blanding's turtle (*Emydoidea blandingii*) in south March Highlands, Ottawa, Ontario, Canada. *Canadian Journal of Zoology* 93: 509-514.

Haxton, T. and Berrill, M. (1999) Habitat selectivity of *Clemmys guttata* in central Ontario. *Canadian Journal of Zoology* 77(4): 593-599.

Hernandez, P.A., Graham, C.H., Master, L.L., Albert, D.L. (2006) The effect of sample size and species characteristics on performance of different species distribution modeling methods. *Ecography* 29(5): 773-785.

Hijmans, R.J. (2012) Cross-validation of species distribution models: removing spatial sorting bias and calibration with a null model. *Ecology* 93(3): 679-688.

Homoya, M.A., Campbell, R.K., Huffman, H., Abrell, D.B., Hedge, R.L., Post, T.W., Dunbar, R., Casebere, L.A., Hedge, M.M. (1997) "Part 2: The Natural Regions of Indiana." *In* Jackson, M.T., ed. *The Natural Heritage of Indiana*, pp. 157-222. Indiana University Press, Bloomington. 489 pp. Print.

Indiana State Wildlife Action Plan. (2015) Indiana Department of Natural Resources, 1-315.

Indiana Wetland's Conservation Plan. (1996) Indiana Department of Natural Resources, 1-78.

Innes, R.J., Babbitt, K.J., Kanter, J.J. (2008) Home range and movement of Blanding's turtles (*Emydoidea blandingii*) in New Hampshire. *Northeastern Naturalist* 15(3): 431-444.

Joyal, L.A., McCollough, M., Hunter Jr., M. L. (2001) Landscape ecology approaches to wetland species conservation: a case study of two turtle species in southern Maine. *Conservation Biology* 15 (6): 1755-1762.

Kaye, D.R., Walsh, K.M., Ross, C.C. (2005) Spotted turtle use of a culvert under relocated Route 44 in Carver, Massachusetts. *In*: Proceedings of the International Conference of Ecology and Transportation, San Diego, CA, pp. 426–432.

King, R.B. (2013) Illinois Conservation Assessment for the Blanding's turtle (*Emydoidea blandingii*). Illinois Endangered Species Protection Board. 1-91.

Kingsbury, B.A. and Gibson, J. (eds.) (2012) *Habitat Management Guidelines for Amphibians and Reptiles of the Midwestern United States*. Partners in Amphibian and Reptile Conservation Technical Publication HMG-1, 2nd. Edition, 155 pp. Print.

Kiviat, E. (1997) Blanding's turtle habitat requirements and implications for conservation in Dutchess County, New York. *Proceedings: Conservation, Restoration and Management of Tortoises and Turtles—an International Conference*: 377-382.

Kramer-Schadt, S. Niedbella, J., Pilgrim, J.D., Schroder, B., Lindenborn, J., Reinfelder, V., Stillfriend, M., Heckmann, I., Scharf, A.K., Augeri, D.M., Cheyne, S.M., Heran, A.J., Ross, J., Macdonald, D.W., Mathai, Eaton, J., Marshall, A.J., Semiadi, G., Rustam, R., Bernad, H., Alfred, R., Smejima, H., Duckworth, J.W., Breitenmoser-Wuersten, C., Belant, J.L. Hofer, H., Wilting, A. (2013) The importance of correcting for sampling bias in MaxEnt species distribution models. *Diversity and Distributions* 19: 1366-1379.

Kuhn, Max and Kjell Johnson. *Applied predictive modeling*. Vol. 26. New York: Springer, 2013.

Kofron, C.P. and Schreiber, A.A. (1985) Ecology of two endangered aquatic turtles in Missouri: *Kinosternon flavescens* and *Emydoidea blandingii*. *Journal of Herpetology* 19(1): 27-40.

Kohavi, R. (1995) A study of cross-validation and bootstrap for accuracy estimation and model selection. *International Joint Conference on Artificial Intelligence*.

Lewis, T.L., Ullmer, J.M., Mazza, J.L. (2004) Threats to spotted turtle (*Clemmys guttata*) habitat in Ohio. *Ohio Journal of Science* 104 (3): 65-71.

Litzgus, J.D., Cotanzo, J.P., Brooks, R.J., Lee Jr., R.E. (1999) Phenology and ecology of hibernation in spotted turtles (*Clemmys guttata*) near the northern limit of their range. *Canadian Journal of Zoology* 77: 1348-1357.

Litzgus, J.D. and Mosseau, T.A. (2004a) Demography of a southern population of the spotted turtle (*Clemmys guttata*). *Southeastern Naturalist* 3(3): 391-400.

Litzgus, J.D. and Mosseau, T.A. (2004b) Home range and seasonal activity of southern spotted turtles (*Clemmys guttata*): implications for management. *Copeia* 4: 804-817.

MacGowan, B., Kingsbury, B., Williams, R. *Turtles of Indiana*. West Lafeyette, IN: Purdue University, 2005. 64 pp. Print.

Markle, C.E. and Chow-Fraser, P. (2014) Habitat selection by the Blanding's turtle (*Emydoidea blandingii*) on a protected island in Georgian Bay, Lake Huron. *Chelonian Conservation and Biology* 13 (2): 216-226.

Merckx, B, Steyart, M., Vanrausel, A., Vincx, M., Vanaverbeke, J. (2011) Null models reveal preferential sampling, spatial autocorrelation and overfitting in habitat suitability modelling. *Ecological Modelling* 222: 588-597.

Merow, C. Smith, M.J., Silander Jr., J.A. (2014) A comparison of Maxlike and Maxent for modelling species distributions. *Methods in Ecology and Evolution* 5: 215-225.

Merow, C. Smith, M.J., Silander Jr., J.A. (2013) A practical guide to MaxEnt for modeling species' distributions: what it does, and why inputs and settings matter. *Ecography* 36: 1058, 1069.

Milam, J.C. and Melvin, S.M. (2001) Density, habitat use, movements, and conservation of spotted turtles (*Clemmys guttata*) in Massachusetts. *Journal of Herpetology* 35(3): 418-427.

Millar, C.S. and Blouin-Demers, G. (2012) Habitat suitability modelling for species at risk is sensitive to algorithm scale: a case study of Blanding's turtle, *Emydoidea blandingii*, in Ontario, Canada. *Journal for Nature Conservation* 20: 18-29.

Millar, C.S. and Blouin-Demers, G. (2011) Spatial ecology and seasonal activity of Blanding's turtles (*Emydoidea blandingii*) in Ontario, Canada. *Journal of Herpetology* 45(3): 370-378.

Minton, S.A. (1997) "Creepers, Crawlers, and Hoppers: Amphibians and Reptiles." *In* Jackson, M.T., ed. *The Natural Heritage of Indiana*, pp. 319-327. Indiana University Press, Bloomington. 489 pp. Print.

Minton, S.A. (2001) *Amphibians and Reptiles of Indiana*. Indiana Academy of Science, Indianapolis, IN.

Myers, E. (1997) "An Endangered Natural Resource: Wetlands." *In* Jackson, M.T., ed. *The Natural Heritage of Indiana*, pp. 67-75. Indiana University Press, Bloomington. 489 pp. Print.

United States Geological Survey (USGS) (2018) The National Geologic Map Database. Available online at URL: https://ngmdb.usgs.gov/ngmdb/ngmdb_home.html

NatureServe (2004) "Comprehensive Report Species: *Emydoidea blandingii* – Population/Occurrence Delineation." *NatureServe*. Available at URL: http://explorer.natureserve.org/servlet/NatureServe?searchName=Emys+blandingii

NatureServe (2005) "Comprehensive Report Species: *Clemmys guttata* – Population/Occurrence Delineation." *NatureServe*. Available at URL: http://explorer.natureserve.org/servlet/NatureServe?searchName=Clemmys+guttata

Palsbøll, P.J., Berube, M., Allendorf, F.W. (2007) Identification of management units using population genetic data. *Trends in Ecology and Evolution* 22: 11-16.

Phillips, S.J, Dudík, M., Schapire, R.E. [Internet] Maxent software for modeling species niches and distributions (Version 3.4.1). Available from url: http://biodiversityinformatics.amnh.org/open_source/maxent/.

Phillips, S.J. (2017) A brief tutorial on MaxEnt. Available from url: http://biodiversityinformatics.amnh.org/open_source/maxent/.

Phillips, S.J., Dudik, M., Schapire, R.E. (2004) A maximum entropy approach to species distribution modelling. *In*: Proceedings of the 21st International Conference on Machine Learning, pp. 655-662, ACM Press, New York.

Phillips, S.J., Anderson, R.P., and Schapire, R.E. (2006) Maximum entropy modeling of species geographic distributions. *Ecological Modelling* 190: 231-259.

Phillips, S.J. and Dudik, M. (2008) Modeling of species distributions with MaxEnt: new extensions and a comprehensive evaluation. *Ecography* 31: 161-175.

Ponyter, B.M. (2011) An assessment of viable habitat for Blanding's turtle (*Emydoidea blandingii*) in the state of Ohio using GIS and remote sensing. M.S. Thesis, Cleveland State University, Cleveland, OH.

Racey, M. (2015) "Federal Wildlife Officials Respond to Petitions to List Dozens of Species under the Endangered Species Act." *U.S. Fish and Wildlife Service*. U.S. Fish and Wildlife Service, 30 June 2015. Web.

Rasmussen, M.L. and Litzgus, J.D. (2010) Habitat selection and movement patterns of spotted turtles (*Clemmys guttata*): effects of spatiral and temporal scales of analyses. *Copeia* 1: 86-96.

Roback, P.J. and Askins, R.A. (2005) Judicious use of multiple hypothesis tests. *Conservation Biology* 19(1): 261-267.

Rowe, J.W. (1987) Seasonal and daily activity in a population of Blanding's turtles (*Emydoidea blandingii*) in northern Illinois. M.S. Thesis. Eastern Illinois University, Charleston, IL.

Rowe, J.W. and Moll, E.O. (1991) A radiotelemetric tudy of activity and movements of the Blanding's turtle (*Emydoidea blandingii*) in northeastern Illinois. *Journal of Herpetology* 25(2): 178-195.

Royle, J.A., Chandler, R.B., Yackulic, C., Nichols, J.D. (2012) Likelihood analysis of species occurrence probability from presence-only data for modelling species distributions. *Methods in Ecology and Evolution* 3: 545-554.

Russell, K.R., Van Lear, D.H., Guynn, D.C. (1999) Prescribed fire effects on herpetofauna: review and management implications. *Wildlife Society Bulletin* 27(2): 374-382.

Sergio, C., Figueira, Draper, D., Menezes, R. Sousa, A.J. (2007) Modelling bryophyte distribution based on ecological information for extent of occurrence assessment. *Biological Conservation* 135: 341-351.

Smith, G.R. and Iverson, J.B. (2004) Diel activity patterns of the turtle assemblage of a northern Indiana lake. *The American Midland Naturalist* 152: 156-164.

Soil Survey Staff, Natural Resources Conservation Service, United States Department of Agriculture. (2016) Web Soil Survey. Available online at the URL: https://websoilsurvey.sc.egov.usda.gov/.

Steen, D.A and Gibbs, J.P. (2004) Effects of roads on structure of freshwater turtle populations. *Conservation Biology* 18(4): 1143-1148.

Steen, D. A., Aresco, M.J., Beike, S.G., Compton, B.W., Condon, E.P., Dodd Jr., C.K., Forrester, H., Gibbons, J.W., Greene, J.L., Johnson, G., Langen, T.A., Oldham, M.J., Oxier, D.N., Saumure, R.A., Schueler, F.W., Sleeman, J.M., Smith, L.L., Tucker, J.K., Gibbs, J.P. (2006) Relative vulnerability of female turtles to road mortality. *Animal Conservation* 9(3): 269-273.

Stevenson, D.J., Jensen, J.B., Schlimm, E.A., Moore, M. (2015) The distribution, habitat use, activity, and status of the spotted turtle (*Clemmys guttata*) in Georgia. *Chelonian Conservation and Biology* 14 (2): 136-142.

Sun, G., & Ranson, K. J. (2000) Modeling lidar returns from forest canopies. *IEEE Transactions on Geoscience and Remote Sensing* 38(6): 2617-2626.

Tong, R. Purser, A., Guinan, J., Unnithan, V. (2013) Modeling the habitat suitability for deep-water gorgoanian corals based on terrain variables. *Ecological Informatics* 13: 123-132.a

Waite, T.A. and Campbell, L.G. (2006) Controlling the false discovery rate and increasing statistical power in ecological studies. *Ecoscience* 13(4): 439-442.

Wang, X.Y., Huang, X.L., Jiang, L.Y., Qiao, G.X. (2010) Predicted potential distribution of chestnut phylloxerid (Hemiptera: Phylloxeridae) based on GARP and Maxent ecological niche models. *Journal of Applied Entomology* 134: 45-54.

Ward, F.P., Hohmann, C.J., Ulruch, J.F., Hill, S.E. (1976) Season microhabitat selections of spotted turtles (*Clemmys guttata*) in Maryland elucidated by radioisotope tracking. *Herpetologica* 32(1): 60-64.

Warren, D.L., Glor, R.E., Turelli, M. (2010) ENMTools: a toolbox for comparative studies of environmental niche models. *Ecography* 33: 607-611 (Version 1.4.4).

Whitaker Jr., J.O. and Amlaner Jr., C.J., eds. (2012) *Habitats and Ecological Communities of Indiana: Presettlement to Present*. Indiana University Press, Bloomington. Print.

Willey, L.L. and Jones, M.T. (2014) Conservation plan for the Blanding's turtle and associated species of conservation need in the Northeastern United States draft. Northeast Blanding's turtle Working Group.

Wisz, M.S., Hijmans, R.J., Li, J., Peterson, A.T., Graham, C.H., Guisan, A., NCEAS Predicting Species Distributions Working Group. (2008) Effects of sample size on the performance of species distribution models. *Diversity and Distributions* 14(5): 763-773.

Yost, A.C., Petersen, S.L., Gregg, M., Miller, R. (2008) Predictive modeling and mapping sage grouse (*Centrocercus urophasianus*) nesting habitat using Maximum Entropy and a long-term dataset from Southern Oregon. *Ecological Informatics* 3: 375-386.

APPENDIX A. SURVEYS

Table A1: Functional group and coinciding guild classification used in intensive habitat assessments (Boutin & Keddy, 1993).

Guild	Functional Group	Identification Features
Ruderal	Obligate annual	Multiple short stems, large crown area
	Facultative annual	Few tall stems, small crown area, second year have inflorescence
Interstitial	Reed	Multiple leafless aerial shoots
	Clonal	Neither reed nor tussock-like, not as clumped
	Tussock	Clumped/bunched, often includes sedges or grasses
Matrix	Clonal stress-tolerators	Short, great amount of lateral spread, often in infertile soil (i.e. sand)
	Clonal dominants	Tall, great amount of lateral spread, often in fertile soil

Table A2: The criteria on how the dominant coarse habitat type at each site was determined.

Dominant Coarse Habitat Type	**Characteristics**
Emergent wetland	Dominated by herbaceous emergent vegetation (excludes mosses and lichens); little woody vegetation; vegetation is present for most of growing season (i.e. not streams)
Scrub-shrub wetland	>30% covered by woody vegetation *less than 6-meters tall*
Forested wetland	>30% covered by woody vegetation *equal to or greater than 6-meters tall*

Table A3. Original prioritization of all locations in step one occurrence based on only age of the most recent occurrence. Asterisks (*) indicate locations that changed in survey priority as more information and occurrences were received over the two years after original prioritization was done. H = high, L = low. BT = Blanding's turtle, ST = spotted turtle.

Location ID	Recent Occurrence Year	Survey Priority	Historical Species Occurrence
Allen 1	1970	H	Blanding's Turtle
Carroll 1	2007	H	Spotted Turtle
De Kalb 1	2010	H	Blanding's Turtle
Deleware 1	1970	H	Blanding's Turtle
Elkhart 1	2000 (BT & ST)	H	Both
Elkhart 2	2014 (BT); 1998 (ST)	H	Both
Elkhart 3	1990	H	Blanding's Turtle
Elkhart 4	1994	H	Blanding's Turtle
Elkhart 5	1994	H	Spotted Turtle
Fulton 1	1997 (BT); 1986 (ST)	H	Both
Jasper 1	2011 (BT); 1936 (ST)	H	Both
Kosciusko 1	1989 (BT); 1954 (ST)	H	Both
Kosciusko 2	1998	H	Blanding's Turtle
Kosciusko 3	1986	H	Blanding's Turtle
Kosciusko 4	1995	H	Spotted Turtle
Kosciusko 5	1987	H	Spotted Turtle
Kosciusko 6	2015 (BT); 1992 (ST)	H	Both
Lagrange 1	1998 (BT & ST)	H	Both
Lagrange 2	2002 (BT); 1954 (ST)	H	Both
Lagrange 3	1987	H	Spotted Turtle
Lagrange 4	1988	H	Blanding's Turtle
Lagrange 5	1970	H	Blanding's Turtle
Lagrange 6	1978	H	Blanding's Turtle
Lagrange 7*	1985	H	Spotted Turtle
Lake 1	1991 (BT); 2005 (ST)	H	Both
Lake 2	1992	H	Blanding's Turtle
Lake 3	2003	H	Blanding's Turtle
Lake 4	1993	H	Blanding's Turtle
Lake 5	1998	H	Blanding's Turtle
Lake 6	2007	H	Blanding's Turtle
Lake 7	2007	H	Blanding's Turtle
Lake 8	1979	H	Blanding's Turtle
LaPorte 1	2005 (BT); 1989 (ST)	H	Both
LaPorte 2	2005	H	Spotted Turtle
LaPorte 3	1985 (BT); 1989 (ST)	H	Both
LaPorte 4	1989	H	Spotted Turtle
LaPorte 5	1983	H	Blanding's Turtle
LaPorte 6	1982	H	Blanding's Turtle
LaPorte 7	1989	H	Spotted Turtle

Table A3. Continued.

LaPorte 8	1977	H	Spotted Turtle
LaPorte 9	1995	H	Spotted Turtle
LaPorte 10	1987	H	Blanding's Turtle
LaPorte 11	1982	H	Blanding's Turtle
LaPorte 12	2004	H	Spotted Turtle
Marshall 1	2008	H	Spotted Turtle
Marshall 2	1998	H	Blanding's Turtle
Miami 1	1999	H	Blanding's Turtle
Newton 1*	1983	H	Blanding's Turtle
Newton 2	2009	H	Blanding's Turtle
Noble 1	1989	H	Spotted Turtle
Noble 2	2002	H	Blanding's Turtle
Noble 3	1986	H	Blanding's Turtle
Noble 4	1979	H	Blanding's Turtle
Noble 5	1990	H	Blanding's Turtle
Noble 6	2000	H	Blanding's Turtle
Noble 7	2008	H	Blanding's Turtle
Porter 1	1986	H	Blanding's Turtle
Porter 2	1989	H	Blanding's Turtle
Pulaski 1	1999 (BT); 1952 (ST)	H	Both
St. Joseph 1	1996 (BT); 1998 (ST)	H	Both
St. Joseph 2	1999	H	Blanding's Turtle
St. Joseph 3	1986	H	Blanding's Turtle
St. Joseph 4	1983	H	Blanding's Turtle
St. Joseph 5	1997 (BT); 1984 (ST)	H	Both
St. Joseph 6	1990 (BT); 1987 (ST)	H	Both
St. Joseph 7	1997	H	Blanding's Turtle
Starke 1	2001 (BT); 1988 (ST)	H	Both
Starke 2*	1990	H	Spotted Turtle
Steuben 1	1994 (BT); 1985 (ST)	H	Both
Steuben 2	2000 (BT); 1989 (ST)	H	Both
Steuben 3	1989	H	Spotted Turtle
Steuben 4	2001	H	Blanding's Turtle
Steuben 5	1980	H	Blanding's Turtle
Steuben 6	1994	H	Blanding's Turtle
Steuben 7	1993	H	Blanding's Turtle
Steuben 8	1981	H	Spotted Turtle
Steuben 9	2001	H	Blanding's Turtle
Tippecanoe 1	2011	H	Blanding's Turtle
Tippecanoe 2	1984	H	Spotted Turtle

Table A3. Continued.

Wayne 1	1996	H	Blanding's Turtle
White 1	1995	H	Blanding's Turtle
Whitley 1	1992	H	Blanding's Turtle
Allen 2	2014	L	Blanding's Turtle
Allen 3	1949	L	Blanding's Turtle
Benton 1	1951	L	Blanding's Turtle
Boone 1	1951	L	Spotted Turtle
Cass 1	1938	L	Spotted Turtle
Elkhart 6	2014	L	Blanding's Turtle
Elkhart 7	2016	L	Blanding's Turtle
Fulton 2	2013	L	Blanding's Turtle
Hamilton 1	1953	L	Spotted Turtle
Jasper 2	1953	L	Blanding's Turtle
Kosciusko 7	2013	L	Blanding's Turtle
Kosciusko 8	1956	L	Spotted Turtle
Kosciusko 9	1911 (BT); 1899 (ST)	L	Both
Lagrange 9	1954	L	Blanding's Turtle
Lake 10	2014	L	Spotted Turtle
Lake 11	1991	L	Blanding's Turtle
Lake 12	2012	L	Blanding's Turtle
Lake 9	2016	L	Both
LaPorte 13	1938	L	Spotted Turtle
Marion 1	1962	L	Spotted Turtle
Marshall 3	2013	L	Blanding's Turtle
Marshall 4	1954 (BT); 1924 (ST)	L	Both
Marshall 5	1934	L	Blanding's Turtle
Marshall 6	1906	L	Spotted Turtle
Newton 3	1946	L	Blanding's Turtle
Noble 8	1892	L	Spotted Turtle
Noble 9	1907	L	Blanding's Turtle
Porter 3	2018	L	Both
Porter 4	1939	L	Spotted Turtle
Porter 5	1939	L	Spotted Turtle
Porter 6	1934	L	Both
Porter 7	1939	L	Blanding's Turtle
Porter 8	1934	L	Both
Porter 9	1938	L	Spotted Turtle
Starke 3	2014	L	Blanding's Turtle
Starke 4	1907 (BT); 1892 (ST)	L	Spotted Turtle
Steuben 10	2016	L	Blanding's Turtle

Table A3. Continued.

Steuben 11	2016	L	Blanding's Turtle
Steuben 12	1960	L	Blanding's Turtle
Steuben 13	1950	L	Spotted Turtle
Steuben 14	1961	L	Blanding's Turtle
Wabash 1	1953	L	Blanding's Turtle
White 2	1952 (BT); 1954 (ST)	L	Both
Whitley 2	1903	L	Blanding's Turtle

Table A4. Original prioritization of all in the step two categorization. Asterisks (*) indicate locations that changed in survey priority as more information and occurrences were received over the two years after original prioritization was done. H = high, M = medium, L = low. BT = Blanding's turtle, ST = spotted turtle.

Location ID	Survey Priority	Habitat Quality	Urban	Hydric Soils	Soil Quality	Vegetation	Recent Year Occurrence	Historical Species Occurrence
Carroll 1	H	H	M	H	L	H	2007	Spotted Turtle
Elkhart 1	H	H	M	M	M	H	2000 (BT & ST)	Both
Elkhart 2	H	H	M	H	L	H	2014 (BT); 1998 (ST)	Both
Fulton 1	H	H	M	M	M	H	1997 (BT); 1986 (ST)	Both
Jasper 1	H	M	H	M	L	H	2011 (BT); 1936 (ST)	Both
Kosciusko 1	H	H	M	H	L	H	1989 (BT); 1954 (ST)	Both
Kosciusko 2	H	H	M	H	L	H	1998	Blanding's Turtle
Kosciusko 3	H	H	M	H	M	H	1986	Blanding's Turtle
Kosciusko 4	H	H	M	H	L	H	1995	Spotted Turtle
Lagrange 1	H	H	H	H	L	H	1998 (BT & ST)	Both
Lagrange 2	H	H	M	H	M	H	2002 (BT); 1954 (ST)	Both
Lagrange 3	H	H	M	H	H	H	1987	Spotted Turtle
Lagrange 4	H	H	M	M	M	H	1988	Blanding's Turtle
Lagrange 5	H	H	M	H	H	M	1970	Blanding's Turtle
Lagrange 7*	H	H	M	H	H	H	1985	Spotted Turtle
Lake 1	H	H	M	M	M	H	1991 (BT); 2005 (ST)	Both
Lake 2	H	H	M	H	L	H	1992	Blanding's Turtle
LaPorte 1	H	H	M	H	L	H	2005 (BT); 1989 (ST)	Both
LaPorte 2	H	H	M	H	L	H	2005	Spotted Turtle
LaPorte 3	H	H	M	H	L	H	1985 (BT); 1989 (ST)	Both
LaPorte 4	H	H	M	H	L	H	1989	Spotted Turtle
LaPorte 5	H	H	M	H	L	H	1983	Blanding's Turtle
LaPorte 6	H	H	M	H	H	H	1982	Blanding's Turtle
LaPorte 7	H	H	M	H	M	M	1989	Spotted Turtle
Marshall 1	H	H	M	H	H	H	2008	Spotted Turtle
Newton 1*	H	H	M	M	M	H	2013	Blanding's Turtle
Newton 2	H	H	M	H	L	H	2009	Blanding's Turtle
Noble 1	H	H	M	H	L	H	1989	Spotted Turtle
Noble 2	H	H	M	H	H	H	2002	Blanding's Turtle
Noble 3	H	M	H	L	L	M	1986	Blanding's Turtle
Noble 4	H	H	M	M	M	H	1979	Blanding's Turtle
Noble 5	H	H	M	H	M	H	1990	Blanding's Turtle
Porter 1	H	M	H	M	L	H	1986	Blanding's Turtle
Porter 2	H	H	H	H	L	H	1989	Blanding's Turtle

Table A4. Continued.

St. Joseph 1	H	H	M	H	M	M	1996 (BT); 1998 (ST)	Both
Starke 1	H	H	M	H	H	H	2001 (BT); 1988 (ST)	Both
Starke 2*	H	H	M	H	M	H	1990	Spotted Turtle
Steuben 1	H	H	M	H	M	H	1994 (BT); 1985 (ST)	Both
Steuben 2	H	M	H	L	L	H	2000 (BT); 1989 (ST)	Both
Steuben 3	H	H	M	H	M	H	1989	Spotted Turtle
Steuben 4	H	H	M	H	M	H	2001	Blanding's Turtle
Steuben 5	H	H	M	M	M	H	1980	Blanding's Turtle
Tippecanoe 1	H	H	M	H	M	H	2011	Blanding's Turtle
Tippecanoe 2	H	H	M	M	M	H	1984	Spotted Turtle
Allen 1	M	M	M	M	L	H	1970	Blanding's Turtle
De Kalb 1	M	L	M	L	L	M	2010	Blanding's Turtle
Deleware 1	M	M	M	L	L	H	1970	Blanding's Turtle
Elkhart 3	M	M	M	M	L	H	1990	Blanding's Turtle
Elkhart 4	M	M	M	H	L	M	1994	Blanding's Turtle
Elkhart 5	M	M	M	M	L	H	1994	Spotted Turtle
Kosciusko 5	M	M	M	M	L	H	1987	Spotted Turtle
Kosciusko 6	M	M	M	M	L	H	2015 (BT); 1992 (ST)	Both
Lagrange 6	M	M	M	L	L	H	1978	Blanding's Turtle
Lake 3	M	M	M	M	L	L	2003	Blanding's Turtle
Lake 4	M	M	M	M	L	H	1993	Blanding's Turtle
Lake 5	M	M	M	M	L	H	1998	Blanding's Turtle
Lake 6	M	M	M	L	L	H	2007	Blanding's Turtle
Lake 7	M	M	M	L	L	H	2007	Blanding's Turtle
Lake 8	M	M	M	L	L	H	1979	Blanding's Turtle
LaPorte 8	M	M	M	M	L	H	1977	Spotted Turtle
LaPorte 9	M	M	M	L	L	M	1995	Spotted Turtle
Marshall 2	M	M	M	H	L	H	1998	Blanding's Turtle
Noble 6	M	M	H	M	M	H	2000	Blanding's Turtle
Noble 7	M	M	M	M	L	H	2008	Blanding's Turtle
Pulaski 1	M	M	M	M	L	M	1999 (BT); 1952 (ST)	Both
St. Joseph 2	M	M	M	H	L	M	1999	Blanding's Turtle
St. Joseph 3	M	M	M	L	L	H	1986	Blanding's Turtle
St. Joseph 4	M	M	M	M	L	H	1983	Blanding's Turtle
St. Joseph 5	M	M	M	M	L	H	1997 (BT); 1984 (ST)	Both

Table A4. Continued.

St. Joseph 6	M	M	M	M	L	H	1990 (BT); 1987 (ST)	Both
Steuben 6	M	M	M	M	L	H	1994	Blanding's Turtle
Steuben 7	M	M	M	M	L	M	1993	Blanding's Turtle
Steuben 8	M	M	M	M	L	H	1981	Spotted Turtle
Wayne 1	M	M	M	L	L	M	1996	Blanding's Turtle
White 1	M	M	M	M	L	H	1995	Blanding's Turtle
Whitley 1	M	M	M	M	L	M	1992	Blanding's Turtle
LaPorte 10	L	H	L	H	M	H	1987	Blanding's Turtle
LaPorte 11	L	L	M	L	L	H	1982	Blanding's Turtle
LaPorte 12	L	L	M	L	L	L	2004	Spotted Turtle
Miami 1	L	L	L	M	L	L	1999	Blanding's Turtle
St. Joseph 7	L	L	M	L	L	L	1997	Blanding's Turtle
Steuben 9	L	L	M	L	L	L	2001	Blanding's Turtle

Table A5. Herpetofauna encountered in survey and trapping locations. Asterisks (*) indicate only trapping occurred. Numbers are the location ID numbers. ST – spotted turtle, BT – Blanding's turtle, M – massasauga, BXT – eastern box turtle, AT – eastern American toad, BF – bullfrog, CF – northern cricket frog, GF – green frog, GT – gray treefrog, L – *Lithobates* sp., LF – northern leopard frog, SP – spring peeper, UF – unknown frog, WCF – western chorus frog, WF – wood frog, GL – slender glass lizard, TS – tiger salamander, BR – blue racer, BS – brown snake, GS – common garter snake, RS – ribbon snake, T – *Thamnophis* sp., US – unknown snake, WS – northern water snake, CST – common snapping turtle, EMT – eastern musk turtle, MT – northern map turtle, PS – pond slider sp., PT – midland painted turtle, RST – red-eared slider turtle, SST – eastern spiny softshell turtle, UT – unknown turtle.

	SPECIES																																
	Species of Concern				**Frog**											**Lizard**	**Salamander**	**Snake**								**Turtle**							
Location	ST	BT	M	BXT	AT	BF	CF	GF	GT	L	LF	SP	UF	WCF	WF	GL	TS	BR	BS	GS	RS	T	US	WS	CST	EMT	MT	PS	PT	RST	SST	UT
Carroll 1	x			x			x					x	x	x											x				x			
Elkhart 1	x	x		x		x	x	x			x									x				x	x				x			x
Elkhart 2		x		x	x	x		x													x			x	x			x	x			
Fulton 1								x		x				x							x				x	x	x		x	x	x	x
Jasper/Pulaski 1					x	x		x						x							x				x				x			
Kosciusko 1																											x		x			x
LaGrange 1						x		x	x			x													x		x		x		x	x
LaGrange 2		x	x					x													x								x			
LaGrange/Steuben 1	x	x		x	x					x	x	x		x				x						x	x	x			x		x	x
Lake 1					x	x								x							x			x	x				x			x
Lake 2*	x	x				x	x									x									x				x			
Lake 3*		x																							x				x			
Lake 4*	x						x									x	x								x				x			
Lake/Porter/LaPorte 1*	x	x																							x				x			
LaPorte 1		x			x			x											x		x			x	x				x			x
LaPorte 2	x			x	x			x													x											
LaPorte 3						x		x							x														x			x
LaPorte 4								x				x									x								x			
Marshall 1								x				x																	x			
Marshall 2			x	x	x	x		x			x	x		x										x					x			x
Newton 1																													x			
Noble 1					x	x		x			x	x		x							x		x						x			
Steuben 1			x		x	x		x	x	x					x				x					x	x		x		x		x	x
Steuben 2		x	x			x		x	x			x	x	x				x			x	x		x	x	x			x			x
Steuben 3		x									x	x		x											x				x			
Steuben 4								x						x							x				x	x			x			
Tippecanoe 1						x	x	x	x			x		x											x				x			

APPENDIX B. MODELING

Table B1: The environmental layers used and how they were defined in the MaxEnt program. The asterisk (*) next to Road Density indicates that it was excluded from being used in the models based on using all occurrences, but was still used in systematic and duplicate sampling. The source labeled 'personal' indicates that original layers from outside sources were modified to create the final layer used in the models. NWI = National Wetland Inventory, IDOT = Indiana Department of Transportation, IGS = Indiana Geologic Survey, NLCD = National Land Cover Database, IDNR = Indiana Department of Natural Resources, USDA = United States Department of Agriculture.

Environmental Variable	**Variable Type**	**Source(s)**
Bedrock	Categorical	IGS
Canopy Cover	Continuous	NLCD
Distance to nearest wetland (DNWI)	Continuous	NWI, Personal
Hydrogeology	Categorical	IGS
National Land Cover	Categorical	NLCD
Presettlement Land Cover	Categorical	IDNR
Road Density*	Continuous	IDOT, Personal
Soils	Categorical	USDA Soil Survey
Wetland Complexes (CNWI)	Categorical	NWI, IDOT, Personal
Wetlands	Categorical	NWI

Table B2: The environmental variables that contributed at least five percent in the Blanding's turtle complex models, and were then used when running the parsimonious models. CNWI = wetland complexes, DNWI = distance to nearest wetland, SoilCat = Soil Categories, Wetland = wetland types, RoadDens = road density.

Year Range	Regularization	All Samples	Systematic	Duplicate
1970	1	CNWI, DNWI, National Land Cover, Presettlement	CNWI, DNWI, National Land Cover, SoilCat, Presettlement	CNWI, DNWI, National Land Cover, Wetland
	2	DNWI, National Land Cover, CNWI, Presettlement, SoilCat	CNWI, DNWI, National Land Cover, SoilCat, Presettlement	CNWI, DNWI, National Land Cover, Wetland
	3	DNWI, National Land Cover, CNWI, Presettlement	CNWI, DNWI, National Land Cover, SoilCat, Presettlement, RoadDens	CNWI, DNWI, National Land Cover, Wetland
	4	DNWI, National Land Cover, Presettlement	DNWI, National Land Cover, SoilCat, Presettlement, RoadDens	DNWI, National Land Cover, Wetland
	5	DNWI, National Land Cover, Presettlement	DNWI, National Land Cover, SoilCat, Presettlement, RoadDens	DNWI, National Land Cover, Wetland
2000	1	CNWI, DNWI, National Land Cover, Presettlement, Hydrogeology	CNWI, DNWI, National Land Cover	CNWI, DNWI, National Land Cover
	2	CNWI, DNWI, National Land Cover, Presettlement, Hydrogeology	CNWI, DNWI, National Land Cover	CNWI, DNWI, National Land Cover
	3	CNWI, DNWI, National Land Cover, Presettlement, Hydrogeology	CNWI, DNWI, National Land Cover, Presettlement	CNWI, DNWI, National Land Cover
	4	CNWI, DNWI, National Land Cover, Presettlement, Hydrogeology	DNWI, National Land Cover, Presettlement	DNWI, National Land Cover
	5	CNWI, DNWI, National Land Cover, Presettlement, Hydrogeology	DNWI, National Land Cover, Presettlement	DNWI, National Land Cover
2012	1	CNWI, DNWI, Landcover, Bedrock	CNWI, Landcover, Wetland, DNWI	CNWI, DNWI, Landcover, Presettlement
	2	CNWI, DNWI, Landcover, Bedrock, Hydrogeology	CNWI, Landcover, Wetland, DNWI, Presettlement	CNWI, DNWI, Landcover, Presettlement
	3	DNWI, CNWI, Landcover, Bedrock, Presettlement, Hydrogeology	Landcover, Wetland, DNWI, Presettlement	CNWI, DNWI, Landcover, Presettlement
	4	DNWI, CNWI, Landcover, Bedrock, Presettlement, Hydrogeology	Landcover, DNWI, Presettlement	DNWI, Landcover, Presettlement

Table B2. Continued

	5	DNWI, Landcover, Bedrock, CNWI, Presettlement, Hydrogeology	Landcover, Presettlement	DNWI, Landcover, Presettlement

Table B3: The environmental variables that contributed at least five percent in the spotted turtle complex models, and were then used when running the parsimonious models. CNWI = wetland complexes, DNWI = distance to nearest wetland, SoilCat = Soil Categories, Wetland = wetland types, RoadDens = road density.

Year Range	Regularization	All Samples	Systematic	Duplicate
1970	1	CNWI, DNWI, National Land Cover	CNWI, DNWI, SoilCat	CNWI, DNWI, National Land Cover
	2	CNWI, DNWI, National Land Cover	CNWI, DNWI, SoilCat, National Land Cover	CNWI, DNWI, National Land Cover, SoilCat
	3	CNWI, DNWI, National Land Cover	CNWI, DNWI, SoilCat, National Land Cover, Presettlement	CNWI, DNWI, National Land Cover, SoilCat, Wetland
	4	CNWI, DNWI, National Land Cover	DNWI, SoilCat, Presettlement	DNWI, National Land Cover, SoilCat, Wetland
	5	CNWI, DNWI, National Land Cover	DNWI, SoilCat, Presettlement	DNWI, National Land Cover, Wetland
2000	1	CNWI, DNWI	CNWI, DNWI	CNWI, DNWI, SoilCat, NLCD, National Land Cover
	2	CNWI, DNWI	CNWI, DNWI	DNWI, NCLD, Presettlement, SoilCat, CNWI
	3	CNWI, DNWI	CNWI, DNWI	DNWI, NCLD, Presettlement
	4	CNWI, DNWI	DNWI	DNWI, NCLD, Presettlement
	5	CNWI, DNWI	DNWI	DNWI, NCLD, Presettlement
2012	1	CNWI, DNWI, National Land Cover	CNWI, DNWI	CNWI, DNWI, Bedrock
	2	CNWI, DNWI	DNWI	DNWI, Bedrock
	3	CNWI, DNWI	DNWI	DNWI
	4	CNWI, DNWI	DNWI	DNWI
	5	CNWI, DNWI	DNWI	DNWI