SPATIAL ECOLOGY AND WETLAND USE OF AQUATIC TURTLES IN THE COASTAL PLAIN OF GEORGIA

by

RACHEL LAUREN KING

(Under the Direction of Lora Smith and Alan Covich)

ABSTRACT

The Southeastern Coastal Plain of the United States is a global hotspot of aquatic turtle diversity yet little is known about the basic spatial ecology and habitat selection for many species. I described the differences in aquatic turtle assemblages in streams and geographically isolated wetlands in the Dougherty Plain physiographic district of southwestern Georgia, and used occupancy modeling and radio-telemetry to identify wetland characteristics important for turtles. I also examined spatial patterns of overland movement and terrestrial habitat associations of turtles, and used the results to generate potential corridors of terrestrial movement between aquatic systems using Linkage Mapper and Circuitscape. My results suggest that both isolated wetlands and stream systems are needed to support turtle diversity in the region and that aquatic turtles may demonstrate a functional linkage between these systems. Moreover, turtles moving overland were most often found in natural forests rather than agricultural fields or pine plantations. Turtles also and used geographically isolated wetlands as stepping stones across the landscape, which highlights the collective importance of these landscape features for turtles.

INDEX WORDS: aquatic turtles, geographically isolated wetlands, streams, detection probability, overland movements, radio-telemetry, *Chelydra serpentina*, *Trachemys scripta*

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RACHEL LAUREN KING

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RACHEL LAUREN KING

Major Professor: Lora Smith, Alan Covich

Committee: Steve Golladay, John Maerz

Electronic Version Approved:

Maureen Grasso
Dean of the Graduate School
The University of Georgia
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DEDICATION

I would like to dedicate my thesis to my grandfather, Daniel “Papa” Moncol, who sparked my love of the outdoors and all things creepy crawly and encouraged me all my life to follow my dreams. I remember him letting me go down to his lab in the basement and look through his microscope, and many of my favorite childhood memories include exploring and making mischief on his land in the mountains. He has been my biggest supporter throughout graduate school and I honestly could not have done this without him.

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CHAPTER 1

Introduction and Literature Review

Introduction

The Southeastern Coastal Plain of the United States is a global hotspot of aquatic turtle diversity due, in part, to the variety of available aquatic habitats (Smith et al., 2006; Buhlmann et al., 2009a; Georgia Department of Natural Resources, 2009). The Dougherty Plain physiographic district in southwestern Georgia has 12 species of freshwater turtles, which represents approximately 4% of the world's turtle diversity, and includes two state threatened species, Barbour's map turtle (*Graptemys barbouri*) and alligator snapping turtle (*Macrochelys temminckii*; Georgia Department of Natural Resources, 2009). Despite the high diversity of turtles, little is known about the basic spatial ecology and habitat selection by many species, particularly in the streams and geographically isolated wetlands of the Dougherty Plain.

Reptiles around the world are experiencing population declines and approximately 42% of all turtle species are threatened, primarily from habitat loss and degradation (Semlitsch and Bodie, 1998; Gibbons et al., 2000; Buhlmann et al., 2009a). Aquatic turtle species are particularly vulnerable to habitat degradation as many require both suitable aquatic and terrestrial habitats. Many species are also at risk due to the increased mortality associated with overland movements in developed areas (Gibbons, 1986; Buhlmann and Gibbons, 2001; Gibbs and Shriver, 2002; Steen et al., 2006).

I trapped aquatic turtles in geographically isolated wetland and stream habitats and collected turtles moving overland across a study site in the Dougherty Plain of Georgia during 2012 and 2013 in an effort to describe aquatic habitat use and overland movements by aquatic turtles. The primary objectives of this thesis were to: 1) describe differences in aquatic turtle assemblages in streams and wetlands in the Dougherty Plain of Georgia (Chapter 2); 2) use detection probabilities and telemetry to identify important wetland variables predicting turtle occupancy (Chapters 2 and 3); 3) examine patterns of overland movement and terrestrial habitat associations of aquatic turtles (Chapter 3); and 4) generate theoretical corridors of terrestrial movement among aquatic systems by turtles (Chapter 4).

Literature Review

Dougherty Plain and Aquatic Turtle Communities

The Dougherty Plain physiographic district is located within the Southeastern Coastal Plain in southwestern Georgia. The region is characterized by karst topography with an abundance of geographically isolated wetlands (Hendricks and Goodwin, 1952; Kirkman et al., 2000; Kirkman et al., 2012). These wetlands are formed by the gradual dissolution of calcium carbonate in the limestone bedrock, which causes depressions to develop; subsequent accumulation of impermeable sand and clay layers ultimately allows the wetlands to pond water (Hendricks and Goodwin, 1952). Geographically isolated wetlands are surrounded by uplands and not directly connected to rivers and/or other more permanent bodies of water (Tiner, 2003). These wetlands rely on rainfall to fill, and typically dry down in late spring and summer due to evapotranspiration, which often excludes fish from the wetlands (Battle and Golladay, 2001). Based on the dominant vegetation and soils, three types of isolated wetlands have been described in the Dougherty Plain: cypress-gum swamps, cypress savannas, and grassy marshes (Kirkman et al., 2000, Kirkman et al., 2012). Cypress-gum swamps typically have a longer hydroperiod than grassy marshes and cypress savannas (Battle and Golladay, 2001). However, depending on rainfall patterns wetlands may hold water or remain dry throughout the year.

In 2001, the U.S. Supreme Court heard the case of Solid Waste Agency of Northern Cook County (SWANCC) versus the U.S. Army Corp of Engineers, and reinterpreted the Clean Water Act to exclude jurisdiction over isolated wetlands, which are "not navigable" or are not connected to navigable waters (Nadeau and Leibowitz, 2003). This court decision impacted isolated wetlands by removing federal protection, despite the importance of these wetlands as wildlife habitat (Gibbons, 2003; Kusler, 2001; Semlitsch and Bodie, 1998). In 2006, the Supreme Court heard the case of Rapanos versus the United States and Carabell versus the U.S. Army Corp of Engineers, and decided to restore federal jurisdiction over wetlands with a "significant nexus" to navigable waters. However, this ruling lacked clarity, and the U.S. Environmental Protection Agency and U.S. Army Corp of Engineers interpreted this to assert jurisdiction over wetlands adjacent to navigable waters or those that have a significant nexus to navigable waters (e. g., chemical, physical, biological; United States Fish and Wildlife Service, 2013). Previous studies have provided evidence for wildlife linkages among geographically isolated wetlands (Gibbons, 2003; Roe et al., 2004; Subalusky, et al., 2009), but studies of aquatic turtles are less common despite the diversity of turtles in geographically isolated wetlands and navigable waters and their potential as examples of wildlife connectivity between systems.

In addition to geographically isolated wetlands, the Dougherty Plain also is characterized by deeply incised streams. Ichawaynochaway Creek is the stream ecosystem used in this study, and is a tributary of the Flint River. Ichawaynochaway Creek receives groundwater inputs from the upper Floridan aquifer in addition to precipitation and is characterized by numerous limestone shoals and deep pools with sandy bottoms (Livingston, 1992). The creek originates in a large swamp system and runs south for ~100 km through agricultural and forested lands before emptying into the Flint River (Golladay et al., 2000).

The Dougherty Plain supports diverse assemblages of aquatic turtles that include two state threatened species (i.e., *Graptemys barbouri* and *Macrochelys temminckii*; Georgia Department of Natural Resources, 2009). Habitat specialists (e. g., *Deirochelys reticularia* and *G. barbouri*; Gibbons and Greene, 1978; Jensen, 2008) and generalists (e.g., *Trachemys scripta* and *Chelydra serpentina*; Ernst et al., 1984; Gibbons, 1990) are both represented in the turtle assemblage in the Dougherty Plain.

Land Use Trends

The southeastern Coastal Plain historically was dominated by longleaf pine (*Pinus palustris*) forests noted for their plant and animal diversity (Guyer and Bailey, 1993). Today less than 3% of the original longleaf pine remains due to historical harvest, followed by conversion to agriculture and commercial pine stands or urbanization (Frost, 1993; Noss et al., 1995). Agriculture is now the dominant land use in southwestern Georgia, with extensive farming of cotton, peanuts, soybeans, and corn (Ward et al., 2005). These practices have impacted aquatic systems in the region. In the past 6 decades geographically isolated wetlands have been converted to cropland or farm ponds, with additional fragmentation of forested corridors both between wetlands, and between wetlands and streams (Martin, 2010; Martin et al., 2013; Stuber, 2013). Sterrett et al. (2011) found loss of riparian forest cover from agricultural practices to be detrimental to turtle species abundance and species composition. Specifically, generalist species including yellow-bellied slider (*Trachemys scripta*) were more abundant in stream reaches with less adjacent forest, whereas, dietary specialists including Barbour's map turtle (*G. barbouri*) were less abundant in these reaches than in more forested reaches (Sterrett et al., 2011) . In addition, since the 1970's there have been increasing surface and groundwater withdrawals for crop irrigation in the Dougherty Plain (Rugel et al., 2009). These withdrawals have been shown to significantly decrease stream flows in Ichawaynochaway Creek, especially during late spring and summer when crop irrigation is most prevalent (Golladay et al., 2004; Rugel et al., 2012). Runoff from agricultural irrigation can create temporary wetlands that potentially attract aquatic turtles during dry periods when water levels in river and wetlands habitats are decreased. These agricultural wetlands and surrounding agricultural landscape can be detrimental to turtle movements among natural and man-made aquatic habitats. These landscapes are often fragmented with little to no protective vegetative cover and offer poor quality aquatic habitats (Moll and Moll, 2004). Additionally, the slow moving nature of turtles renders them vulnerable to injury or death from agricultural machinery (Bowne et al., 2006; Erb and Jones, 2011; Saumure et al., 2007).

Aquatic Turtle Ecology

Aquatic turtles make up a large proportion of all extant turtle species and are present on every continent except Antarctica (Moll and Moll, 2004; Van Dijk et al., 2012). Aquatic turtles occupy diverse ecosystems and vary widely in life history. Specialists typically have narrow habitat preferences and/or diets, while generalists tend to occupy a wide variety of aquatic habitats, and through their movements have the potential to link otherwise isolated systems (Lundberg and Moberg, 2003; Moll and Moll, 2004). All aquatic turtles, regardless of life history strategies, move overland at least once in their lifetimes. Female turtles nest on land, and hatchling turtles disperse from nests to aquatic habitats. Some species use terrestrial habitats for overwintering, and many turtles move overland between freshwater ecosystems, including rivers, ponds, and wetlands in search of food, mates, or other resources (Gibbons, 1990, Gibbons, 2003; Tuberville et al., 1996). Thus, landscape connectivity and movement corridors may be important to conserve turtle populations, as certain land-use types and roadways are causes of mortality in aquatic turtles (Erb and Jones, 2011; Gibbs and Shriver, 2002; Gibbs and Steen, 2004).

Habitat specialists in the Dougherty Plain include chicken turtles (*Deirochelys reticularia*) and eastern mud turtles (*Kinosternon subrubrum*). Classified as isolated wetland specialists, they use terrestrial systems extensively by overwintering in upland nests as hatchlings, while males and females of all ages aestivate in upland habitat during drought (Skorepa and Ozment, 1968; Bennett, 1972; Gibbons, 1983; Buhlmann et al., 2009b). In contrast, river specialists (i. e., *M. temminckii*, *Sternotherus minor*, *Apalone spinifera*, and *G. barbouri*), typically move aquatically and generally only females travel overland to nest (Steen et al., 2012). Generalist species (e. g., *T. scripta*, *Chelydra serpentina*) use both lotic and lentic systems and often travel long distances. Understanding the extent to which turtles use different aquatic habitats is important to manage and develop conservation strategies for turtle diversity in the Southeast. Furthermore, understanding the degree to which certain species move among isolated depressional wetland and stream systems is important as these species may show important biological connections between systems, as has been recently demonstrated with the American alligator (*Alligator mississippiensis*; Subalusky et al., 2009).

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CHAPTER 2

Aquatic Turtle Occupancy in Streams and Isolated Wetlands in the Coastal Plain of Georgia

Introduction

The Southeastern Coastal Plain of the United States is a global hotspot of freshwater turtle diversity due, in part, to diversity of available aquatic habitats (Buhlmann et al., 2009a). A large proportion of turtle species are lotic, occurring in rivers, streams, and riparian swamps, whereas geographically isolated wetlands (Tiner 2003) are primary habitat for other turtle species. Several species occur in both streams and wetlands moving among them in response to changing hydrologic conditions and life history requirements. An understanding of how turtle species use different aquatic habitats is important in managing and developing conservation strategies for turtle diversity. Further, an understanding of how species move is important as these species may provide a wildlife link between different aquatic ecosystems, as has been demonstrated with the American alligator (Subalusky et al., 2009).

Within the southeastern U.S., the Dougherty Plain physiographic district in Southwest Georgia is characterized by karst topography dominated by Ocala limestone that has resulted in an abundance of geographically isolated wetlands. These wetlands are formed by the dissolution of calcium carbonate in the limestone bedrock, which causes depressions to develop over time; the accumulation of impermeable sand and clay layers over time ultimately allows the wetlands to pond water (Hendricks and Goodwin, 1952; Kirkman et al., 2012a). By definition, geographically isolated wetlands are surrounded by uplands and not directly connected to rivers and/or other more permanent bodies of water (Tiner, 2003). These wetlands rely on rainfall to fill, and generally dry down in late spring and summer due to evapotranspiration (Battle and Golladay, 2001). Based on the dominant vegetation, three types of geographically isolated wetlands have been described in the Dougherty Plain: cypress-gum swamps, cypress savannas, and grassy marshes (Kirkman et al., 2000). Of the 12 freshwater turtle species in the region, four species, the Florida softshell (*Apalone ferox*), chicken turtle (*Deirochelys reticularia*), eastern mud turtle (*Kinosternon subrubrum*), and common musk turtle (*Sternotherus odoratus*) are considered wetland specialists (Gibbons, 1983; Buhlmann and Gibbons, 2001; Buhlmann et al., 2009b). Chicken turtles and eastern mud turtles aestivate in upland habitats surrounding geographically isolated wetlands during drought and winter (Skorepa and Ozment, 1968; Gibbons, 1983; Gibbons and Greene, 1978; Buhlmann and Gibbons, 2001; Buhlmann et al., 2009b). Other wetland species include the common snapping turtle (*Chelydra serpentina*), Florida cooter (*Pseudemys floridana*), and yellow-bellied slider (*Trachemys scripta*); however, these turtles also use other aquatic systems, such as streams, in addition to geographically isolated wetlands (Smith et al., 2006; Jensen et al., 2008) and often move overland between aquatic ecosystems (Steen et al., 2010).

Agricultural land use has significantly impacted streams and wetland ecosystems in the Dougherty Plain. Many geographically isolated wetlands have been lost or degraded in the past six decades by conversion of wetlands to cropland or farm ponds and fragmentation of forested corridors between wetlands and between wetlands and streams (Martin, 2010; Martin et al., 2013, Stuber, 2013). Since the 1970's, there have been increasing surface and groundwater withdrawals in the Dougherty Plain for agricultural irrigation (Rugel et al., 2009). These withdrawals significantly decrease stream flows in Ichawaynochaway Creek, especially during droughts and in late spring and summer when crop irrigation is most prevalent (Golladay et al., 2004; Rugel et al., 2012).

Given habitat diversity in the Dougherty Plain and recent land use changes affecting wetlands and streams, my objective was to determine which ecosystems were used most often by different turtle species. Sterrett et al. (2011) described differences in the aquatic turtle assemblages of streams in the region related to differences in surrounding land use. However, little is known about the effects of land use and landscape characteristics of geographically isolated wetlands on turtles. Therefore, I used an occupancy modeling approach to identify important variables in predicting turtle occurrence and to assist in identifying high priority wetland habitat for conservation (MacKenzie et al., 2002). The study was initiated during a significant regional drought, followed by a period of above average rainfall (Georgia Automated Environmental Monitoring Network, www.Georgiaweather.net). Thus, I expected captures of generalist species to initially be greater in the creek than in wetlands because it provided more a more stable aquatic habitat. Likewise, I expected turtle occupancy of wetlands to be negatively related to distance to the creek.

Methods

Study Area

The study took place at Ichauway, the 11,300 ha research site of the Joseph W. Jones Ecological Research Center, which is located in the Dougherty Plain physiographic district in southwestern Georgia. Ichauway is managed for the longleaf pine (*Pinus palustris*) forest with native groundcover. There are more than 90 geographically isolated wetlands on Ichauway, including both cypress-gum swamps and grassy marshes (Kirkman et al., 2000, Kirkman et al., 2012a). Cypress-gum swamps have organic soils and a dense canopy of pond cypress (*Taxodium ascendens*) and swamp tupelo (*Nyssa biflora*) with little to no understory. Grassy marshes have sandy soils and an open canopy and understory of panic grasses (*Panicum* spp.) and cutgrass (*Leersia hexandra*; Kirkman et al., 2000). These wetlands typically draw down during late spring to fall, and fill during winter and early spring; cypress-gum swamps typically have a longer hydroperiod than grassy marshes (Battle and Golladay, 2001). However, depending on rainfall patterns geographically isolated wetlands may hold water or remain dry throughout the year. Ichauway is bordered on the east by a 21 km stretch of the Flint River and a 24 km stretch of Ichawaynochaway Creek runs through the center of the property.

Field Sampling

Field sampling took place from July-October 2012 and February-June 2013 at nine sites along Ichawaynochaway Creek. I attempted to distribute sampling sites at even intervals along the creek, but sites were ultimately placed from 1 to 6 km apart based on accessibility (Figure 2-1). I sampled 12 geographically isolated wetlands that were selected with varying distance from Ichawaynochaway Creek, vegetation type, and size (Figure 2-1). I sampled six cypress-gum swamps and six grassy marshes, with three of each within 2 km of the creek (short distance) and three >2.5 km from the creek (long distance). I sampled three large wetlands (cypress gum swamps >5 ha, grassy marshes >3 ha) and three small wetlands (cypress gum swamps <5 ha, grassy marshes <3 ha).

Creek and wetland sites were sampled during a drought from July through October 2012, and during a drought recovery period above normal rainfall from February through June 2013 (Georgia Automated Environmental Monitoring Network, www.Georgiaweather.net). Sites were sampled twice a month using two hoop traps (0.9 m diameter, four hoops, 3.8 cm mesh;

Memphis Net and Twine, Memphis, TN, USA) baited with pig liver for five consecutive days (four trap nights per session; eight trap nights per site). Traps were checked once a day. I also hand captured several turtles observed at the sites during trapping sessions. These “incidentally” captured turtles were included in the data set as captures.

All turtles captured were identified to species and were marked either by drilling (turtles caught in creek) or notching (turtles caught in wetlands) a unique combination of marginal scutes (Cagle, 1939). Softshell turtles (*Apalone* spp.) were notched (Plummer, 2008) and hatchlings and small juveniles of all species were marked with alpha-numeric tags (1.2 mm x 2.7 mm, Northwest Marine Technologies, Shaw Island, WA, USA), which were attached to the plastron using super glue (Loctite, Henkel Corporation, Rocky Hill, CT, USA). For each capture I recorded the site, capture date, capture session, ID number, recapture status, sex, reproductive status (females were hand-palpated to see if they carried shelled eggs; Cagle, 1944), age class (adult, juvenile), mass (g), plastron length (mm), carapace length (CL; mm), and any injuries or abnormalities. Age class was determined based on descriptions in Jensen et al. (2008). In addition, wetland and creek water levels during trapping sessions were obtained via wetland staff gauges (Jones Center Monitoring Data, unpublished) and U.S. Geological Survey stream gauge data (www.nwis.waterdata.usgs.gov).

<u>Data Analysis</u>

Turtle Trapping

Total and mean catch per unit effort (CPUE) were calculated for the 12 study wetlands and the nine sampling sites on Ichawaynochaway Creek. I calculated estimated species richness in wetlands and the creek based on hoop trap and incidental captures. Species richness estimates

(Chao 1 and 2; Chao et al., 2005) and Bray-Curtis abundance-based similarity indices were calculated using Estimate S software (Ver. 9.1.0; Colwell, 2013).

Wetland Turtle Occupancy

The 12 study wetlands were categorized by vegetation type (V): cypress gum swamps and grassy marshes (Kirkman et al., 2000). ArcGIS (Ver. 9.2, ESRI, Redlands, CA, USA) was used to calculate the size of each study wetland in hectares (S), as well as the distance in meters (D) from the wetland to Ichawaynochaway Creek using the near function tool. Water depth was measured twice monthly as part of a long term monitoring (unpublished data). I used these data to calculate the percent of time each wetland was inundated (IN) from June 2012-June 2013. I included isolation indices (S_i) for each wetland in occupancy models (Kirkman et al., 2012b). The equation for the isolation index was as follows, where higher absolute values of S_i signified less isolated wetlands (Hanski and Thomas, 1994):

$$Si = -\sum_{j}^{n}(exp\ (-\propto d_{ij}))$$

where α = 1 (constant for strength of distance and area affects); d_{ij} = distance (km) between focal wetland i to j through n = 11. I created two buffers around wetlands, one with a 200 m radius and one with a 1000 m radius using ArcGIS. The 200 m buffer was used to describe local scale characteristics surrounding the wetlands. The 1000 m buffer represented the landscape scale. Buffers were clipped to existing landcover and I categorized land cover within each buffer zone as forested or non-forested. Forested landcover types included pine (e.g., *Pinus palustris*, *P. elliottii*, *P. taeda*), and hardwoods, which were primarily oaks (e.g., *Quercus alba*, *Q. geminata*, *Q. falcata*, *Q. laevis*). Wildlife food plots, roads, oak scrub, open water, non forested wetlands, and agriculture were all considered non-forested. These variables (Table 2-1) were used to develop 18 *a priori* models: a global model, null model, a model for each of the six variables, and 2 post *priori* models, which were tested for an interaction between the top two candidate models (Tables 2-2, 2-3). These models were used to identify landscape and local scale variables that best predicted turtle occurrence and species richness. I hypothesized that wetland inundation and isolation would be the two most important variables for explaining turtle occupancy in wetlands, with wetlands having longer annual inundation periods and less isolating having the highest turtle occupancy. I used two sets of capture data to test the models, one using presence/absence data for all species except *T. scripta* (N=13 captures of 7 species), and one for only *T. scripta*, the most frequently captured species (N=35). I was unable to use presence/absence data for other species due to low capture numbers. Drought conditions during in the first year of field sampling left the majority of the wetlands dry; therefore, I used only data from February-June 2013, when 11 of the 12 wetlands were inundated. I excluded one wetland from analysis because the water was too shallow to place traps in. Models were developed using Program Presence (Ver. 6.1) with the Single Season Model (MacKenzie et al., 2002) to estimate detection and site occupancy. Due to small sample size, I used a second-order Akaike's Information Criteria (AIC_C) to evaluate the models.. I considered the model with the lowest AIC_C to be the best model from each set, and included the top three models as the best set of candidate models (Burnham and Anderson, 2002).

Results

Turtle Trapping

Total trapping effort for the creek was 1080 trap-nights (8 trap-nights x 15 sampling sessions x 9 sites; Table 2-4). I captured 89 individuals for a total of 103 captures (recapture rate: 12.62%), with a mean of 11.4 ± 7.9 captures per site (range 2-22). The mean CPUE across all trap sites on the creek was 0.095 turtles. Trapping effort for individual wetlands varied due to fluctuating water levels throughout the study; effort ranged from 8-112 trap-nights with a total CPUE of 0.077 turtles (Table 2-5). A total of 67 turtles, representing 50 individuals, were captured (recapture rate: 23.88%, with a mean across all wetland sites of 5.5 ± 5.46 captures per site (range 0-17). Catch per unit effort was highest in July 2012 and in May and June 2013 (Figure 2-2).

I captured seven species of turtles in Ichawaynochaway Creek (Table 2-6) and seven species in isolated wetlands (Table 2-7). The Chao2 estimate of species richness for the creek was 7 (95%CI: 7.14-8.09), while the Chao2 estimate of species richness for isolated wetlands was 7.93 (95%CI: 7.07-19.77). Two species, *T. scripta* and *C. serpentina* occurred in both the creek and wetlands (Table 2-8). The Bray-Curtis abundance-based similarity index for turtle species between the creek and wetlands was 0.564. The sex ratio (males: females) of turtles captured on the creek and wetlands were 1.33:1 and 1:1, respectively (Figure 2-3). Juvenile turtles represented 7.4% of creek captures and 5.8% of wetland captures. The smallest turtles captured in the creek and wetlands were two juvenile *T. scripta* (creek, CL = 33 mm, 7 g; wetland, CL=47 mm; 20 g).

Wetland Turtle Occupancy

The best fitting model (w_i= 0.5570) for predicting wetland-specific detection and occupancy across all sampled wetlands for all species except *T. scripta* was percent forest cover within a 1000 m buffer (Table 2-9). This model estimated overall occupancy as 0.9796 (Table 2-10), and predicted that detection probability decreased with an increase in surrounding forest cover within a 1000 m buffer. For *T. scripta*, the species with the highest captures, the best model (w_i= 0.3967) included the variable wetland size (S; Table 2-11). This model estimated an overall occupancy of 0.8353 (Table 2-12), and predicted that detection probability increased with decrease in wetland size. Other competing models included interactions between wetland size, distance to creek, isolation, and percent forest cover within a 1000 m buffer. There was a weak negative relationship between surrounding % forest cover and all species turtle captures (R= -0.67, R^2= 0.45), but no relationship between *T. scripta c*aptures and wetland size (R= -0.50, R^2= 0.25).

Discussion

My results suggested that both isolated wetlands and lotic systems supported somewhat different turtle species, and collectively, the two habitats supported high regional turtle species richness. I found *A. ferox, D. reticularia, K. subrubrum, P. floridana,* and *S. odoratus* only in isolated wetlands and *A. spinifera*, *G. barbouri*, *M. temminckii, P. concinna,* and *S. minor* only within the creek. The only species of turtle that were caught in both ecosystems were *T. scripta* and *C. serpentina*. The majority of the geographically isolated wetlands in the study area were dry for some portion of the study period. However, some species of turtles were able to persist in wetlands during these dry periods. For example, I had a reasonably high recapture rate of *T. scripta* within wetlands (24%). In addition, several *C. serpentina w*ere discovered aestivating in mud in deep areas of several dry cypress gum swamps, and one radio-tagged individual used the burrow of an American alligator (*Alligator mississippiensis*) in a cypress gum swamp (e.g., Chapter 3). Catch per unit effort was high in July 2012 when several wetlands retained water but decreased throughout the remainder of the year. Once wetlands began to fill during spring 2013, turtle detection and catch per unit effort rapidly increased (Figure 2-2).

Occupancy models for all species showed that percent forest cover in the 1000 m buffer was the most important variable explaining the occurrence of all species except *T. scripta*. This relationship was negative, which did not support my hypothesis that wetlands with greater surrounding forest cover would have higher detections of turtles than those with lower forest cover. This relationship likely resulted because the study wetlands with the highest captures were close to the boundary of Ichauway, and thus the 1000m buffer included non-forested agricultural lands. Wetland size was an important predictor of occupancy by *T. scripta*; however, I feel that this finding may have been an artifact of increased capture success (CPUE) in smaller wetlands than large wetlands. I was surprised that wetland isolation did not appear to influence turtle presence; however, *T. scripta*, the most commonly detected species in this study, is capable of long distance overland movements (Chapter 3; Morreale et al., 1984).

It is important to note that the wetland occupancy models developed for this study were limited by low numbers of captures, which were likely related to the long term regional drought (United States Drought Monitor, 2012). The occupancy models were also skewed by the large proportion of *T. scripta* captures (>70% of all captures). *T. scripta* is a widespread generalist species that can persist in many different aquatic habitats of varying quality and does not likely represent the regional turtle species assemblage in terms of wetland habitat selection and adaptations to drought (Ernst et al. 1994).

Overall, both isolated wetlands and streams are important for supporting a diverse turtle assemblage in the Southeastern Coastal Plain. Geographically isolated wetlands supported a different turtle assemblage than Ichawaynochaway Creek, despite drought conditions during a large portion of this study (United States Drought Monitor, 2012). Identification of local and landscape variables most important to supporting isolated wetland turtle assemblages will require additional study.

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Table 2-1. Land use and landcover variables used in occupancy models to explain occurrence of aquatic turtles in isolated wetlands at Ichauway, at Ichauway, Baker County, Georgia. V= wetland vegetation type, D= distance (m) to creek, S= Size (ha), S_i= isolation index, IN= % annual inundation, %F200= percentage of 200 m buffer around wetland in forested landcover, %F1000= percentage of 1000 m buffer around wetland in forested landcover.

Wetland ID	V	D	S	Si	IN	%F200	%F1000
W01	Cypress gum swamp	3930	5.3	-8.9	100	64.14	45.38
W02	Cypress gum swamp	2532	2.7	-7.4	62.96	93.83	73.84
W04	Cypress gum swamp	1387	12.1	-7.2	77.77	86.28	73.12
W12	Cypress gum swamp	1040	4.7	-8.4	37.04	80.15	74.48
W15	Grassy marsh	1816	19.6	-6.4	25.93	83.95	62.19
W16	Grassy marsh	1992	14.4	-6.5	100	93.77	87.29
W36	Grassy marsh	3946	1.9	-14.2	29.63	68.72	70.69
W37	Grassy marsh	3981	0.9	-14.4	40.74	82.20	65.80
W42	Grassy marsh	3716	2.3	-12.5	62.96	79.33	59.94
W53	Grassy marsh	803	3.2	-4.9	59.26	33.04	61.06
W68	Cypress gum swamp	1233	6.7	-6.9	40.74	81.83	63.28

Table 2-2. Models used to evaluate turtle occupancy (all species except *Trachemys scripta*) in geographically isolated wetlands at Ichauway, Baker County, Georgia. *Denotes –*post priori* model. Variables are vegetation type (V), distance to creek (D), size(S), isolation (Si), annual inundation (IN), and % forested in 200 m buffer (%F). A hypothesis for each a-priori model is provided.

Model	Hypotheses
V_D_S_Si_IN_%F (Global)	▪ All wetland variables are equally important for all species occupancy.
%F1000_Si*	▪ -*post priori* model
V	▪ Cypress gum swamps will have higher occupancy than grassy marshes.
D	▪ Wetlands closer to the creek will have higher occupancy.
S	▪ Larger wetlands will have higher occupancy.
Si	▪ Less isolated wetlands will have higher occupancy.
IN	▪ More inundated wetlands will have higher occupancy.
%F200	▪ Wetlands with more surrounding forest cover on a local scale will have higher occupancy.
%F1000	▪ Wetlands with more surrounding forest cover on a landscape scale will have higher occupancy.
Constant P (Null)	▪ Wetland variables will not influence turtle wetland occupancy.

Table 2-3. Models used to evaluate *Trachemys scripta*) occupancy in isolated wetlands at Ichauway, Baker County, Georgia.. * Denotes –*post priori* model. Variables are vegetation type (V), distance to creek (D), size(S), isolation (Si), annual inundation (IN), and % forested in 200 m buffer (%F). A hypothesis for each a-priori model is provided.

Model	Hypotheses
V_D_S_Si_IN_%F (Global)	▪ All wetland variables will have equal estimates for *T. scripta* occupancy
V	▪ Cypress gum swamps will have higher occupancy than grassy marshes.
D	▪ Wetlands closer to the creek will have higher occupancy.
S	▪ Larger wetlands will have higher occupancy.
Si	▪ Less isolated wetlands will have higher occupancy.
IN	▪ More inundated wetlands will have higher occupancy.
%F200	▪ Wetlands with more surrounding forest cover at a local scale will have higher occupancy.
%F1000	▪ Wetlands with more surrounding forest cover on a landscape scale will have higher occupancy.
Constant P (Null)	▪ Wetland variables will not influence turtle wetland occupancy.

Table 2-4. Hoop trapping effort for aquatic turtles along a 24 km stretch of Ichawaynochaway Creek, Baker County Georgia, 2012 and 2013. CPUE= catch per unit effort (#captures/trap night).

Creek Site	Trap Nights	# Captures	CPUE
1	120	22	0.18
2	120	16	0.13
3	120	2	0.02
4	120	15	0.13
5	120	12	0.1
6	120	9	0.08
7	120	4	0.03
8	120	2	0.02
9	120	22	0.18
Total:	1080	103	0.1

Table 2-5. Hoop trapping effort for aquatic turtles in 12 geographically isolated wetlands at Ichauway, Baker County, Georgia, 2012 and 2013. CPUE= catch per unit effort (# captures/trap night).

Wetland ID	Trap Nights	# Captures	CPUE
1	96	11	0.12
2	56	4	0.07
4	112	17	0.15
12	56	0	0
15	32	2	0.06
16	112	4	0.04
32	8	0	0
36	32	0	0
37	56	8	0.14
42	56	12	0.21
53	56	3	0.05
68	72	6	0.08
Total:	744	67	0.08

Table 2-6. Aquatic turtle captures by both hoop trapping and incidental observations along a 24 km stretch of Ichawaynochaway Creek, at Ichauway, Baker County, Georgia, 2012 and 2013. *Denotes total captures which accounts for aquatic turtles found incidentally in study wetlands.

Site ID	A. ferox	A. spinifera	C. serpentina	D. reticularia	K. subrubrum	G. barbouri	M. temminckii	P. concinna	P. floridana	S. minor	S. odoratus	T. scripta	Total Captures *	Total Species Richness*
1	0	0	0	0	0	1	1	1	0	4	0	17	22	5
2	0	2	0	0	0	1	1	5	0	1	0	7	17	6
3	0	0	0	0	0	8	0	1	0	2	0	1	12	4
4	0	0	0	0	0	0	0	1	0	1	0	14	16	3
5	0	2	0	0	0	0	0	1	0	0	0	10	13	3
6	0	0	0	0	0	2	2	2	0	1	0	1	8	5
7	0	0	0	0	0	0	0	1	0	0	0	3	4	2
8	0	0	0	0	0	2	0	0	0	0	0	3	5	2
9	0	0	1	0	0	0	0	4	0	2	0	15	22	4
Total:	0	4	1	0	0	14	4	16	0	11	0	71	121	7

Table 2-7. Aquatic turtle captures by hoop trapping and incidental observations in geographically isolated wetlands at Ichauway, Baker County, Georgia, 2012 and 2013. *Denotes total captures which accounts for aquatic turtles found incidentally in study wetlands.

Wetland ID	T. scripta	C. serpentina	K. subrubrum	S. odoratus	D. reticularia	A. ferox	A. spinifera	G. barbouri	M. temminckii	P. concinna	P. floridana	S. minor	Total Captures*	Total Species Richness*
W01	7	4	0	0	1	0	0	0	0	0	0	0	12	3
W02	4	0	0	0	0	0	0	0	0	0	0	0	4	1
W04	15	2	0	2	0	0	0	0	0	0	0	0	19	3
W12	2	0	0	0	0	0	0	0	0	0	0	0	2	1
W15	0	1	0	0	1	0	0	0	0	0	0	0	2	2
W16	1	0	0	1	1	1	0	0	0	0	1	0	5	5
W32	0	0	0	0	0	0	0	0	0	0	0	0	0	0
W36	0	0	1	0	0	0	0	0	0	0	0	0	1	1
W37	5	0	1	0	2	0	0	0	0	0	0	0	8	3
W42	12	0	0	0	0	0	0	0	0	0	0	0	12	1

W53	2	0	1	0	1	0	0	0	0	0	0	0	4	3
W68	6	0	0	1	0	0	0	0	0	0	0	0	7	2
Total	54	7	3	4	6	1	0	0	0	0	1	0	76	7

Table 2-8. Freshwater turtles captured in hoop net traps in twelve isolated wetlands and nine creek sites at Ichauway, Baker County, Georgia in 2012 and 2013.

Scientific Name	Common Name	Isolated Wetlands	Creek
Apalone spinifera	Gulf coast spiny softshell		X
Apalone ferox	Florida softshell	X	
Chelydra serpentina	Common snapping turtle	X	X
Deirochelys reticularia	Chicken turtle	X	
Kinosternon subrubrum	Mud turtle	X	
Graptemys barbouri	Barbour’s map turtle		X
Macrochelys temminckii	Alligator snapping turtle		X
Pseudemys concinna	Eastern river cooter		X
Pseudemys floridana	Florida cooter	X	
Sternotherus minor	Loggerhead musk turtle		X
Sternotherus odoratus	Eastern musk turtle	X	
Trachemys scripta	Yellow-bellied slider	X	X

Table 2-9. Models explaining the effects of wetland variables on turtle presence for all species excluding *T. scripta* in geographically isolated wetlands at Ichauway, Baker County, Georgia.. The number of predictor variables (*K*) in each model includes the intercept term. Models with lower second order Akaike's information criterion (AIC_C) and difference (ΔAIC_c) and greater Akaike weights (w_i) were more strongly supported by the data.

Model	K	AIC_C	ΔAIC_C	w_i	Model likelihood
%F1000	2	106.28	0.0	0.56	1.00
%F1000_Si	3	108.38	2.10	0.19	0.35
%F1000_%F200	3	109.72	3.44	0.18	0.18
Null	1	110.39	4.11	0.13	0.13
%F200	2	112.30	6.02	0.03	0.05
S_i	2	112.53	6.25	0.02	0.04
V	2	115.72	9.44	0.00	0.04
IN	2	130.56	24.28	0.00	0.00
D	2	136.80	30.52	0.00	0.00
Global	8	145.60	39.32	0.00	0.00
S	2	156.86	50.58	0.00	0.00

Table 2-10. Individual site detection probability, naïve occupancy, and estimated overall occupancy based on leading candidate model for all species except *T. scripta* presence/ absence (percent forest within 1000 m buffer) in geographically isolated wetlands at Ichauway, Baker County, Georgia.

Site	Detection Probability (SE)	95% CI
W01	0.1062 (0.0797)	0.0224-0.3810
W02	0.0303 (0.0401)	0.0021-0.3122
W04	0.0313 (0.0410)	0.0023-0.3139
W12	0.0294 (0.0393)	0.0020-0.3108
W15	0.0512 (0.0559)	0.0056-0.3396
W16	0.0163 (0.0259)	0.0007-0.2822
W36	0.0349 (0.0441)	0.0028-0.3195
W37	0.0436 (0.0507)	0.0042-0.3310
W42	0.0566 (0.0592)	0.0068-0.3450
W53	0.0538 (0.0575)	0.0062-0.3423
W68	0.0488 (0.0543)	0.0051-0.3370
Overall Occupancy		
Naïve	0.8182	
Estimated	0.9796 (0.7944)	0.0000-1.0000

Table 2-11. Models explaining the effects of wetland variables on presence of *T. scripta* in geographically isolated wetlands at Ichauway Baker County, Georgia. The number of predictor variables (*K*) in each model includes the intercept term. Models with lower second order Akaike's information criterion (AIC_C) and difference (Δ AIC*c*) and greater Akaike weights (w_i) were more strongly supported by the data.

Model	*K*	AIC_C	$\Delta\ AIC_C$	w_i	Model likelihood
S	2	172.17	0.00	0.24	1.00
S_D_%F1000	4	172.86	0.69	0.17	0.71
S_Si_%F1000	4	173.19	1.02	0.15	0.16
D	2	173.77	1.60	0.11	0.12
%F1000	2	174.35	2.18	0.09	0.09
Si	2	174.45	2.28	0.07	0.04
Null	1	176.18	4.01	0.04	0.04
IN	2	178.14	5.97	0.01	0.04
V	2	178.39	6.22	0.01	0.01
%F200	2	178.44	6.27	0.01	0.01
Global	8	182.97	10.80	0.00	0.00

Table 2-12. Individual site detection probability, naïve occupancy, and estimated overall occupancy based on leading candidate model for *T. scripta* presence/absence (wetland size) in geographically isolated wetlands at Ichauway, Baker County, Georgia.

Site	Detection Probability (SE)	95% CI
W01	0.1062 (0.5777)	0.0000-0.9999
W02	0.1422 (0.3774)	0.0004-0.9862
W04	0.0477 (0.6294)	0.0000-1.0000
W12	0.1143 (0.5408)	0.0000-0.9998
W15	0.0193 (0.4214)	0.0000-1.0000
W16	0.0365 (0.5761)	0.0000-1.0000
W36	0.1549 (0.2867)	0.0025-0.9306
W37	0.1726 (0.1484)	0.0265-0.6152
W42	0.1489 (0.3308)	0.0010-0.9669
W53	0.1355 (0.4216)	0.0001-0.9945
W68	0.1062 (0.5777)	0.0000-0.9999
Overall Occupancy		
Naïve	0.7273	
Estimated	0.8353 (0.1383)	0.4143-0.9732

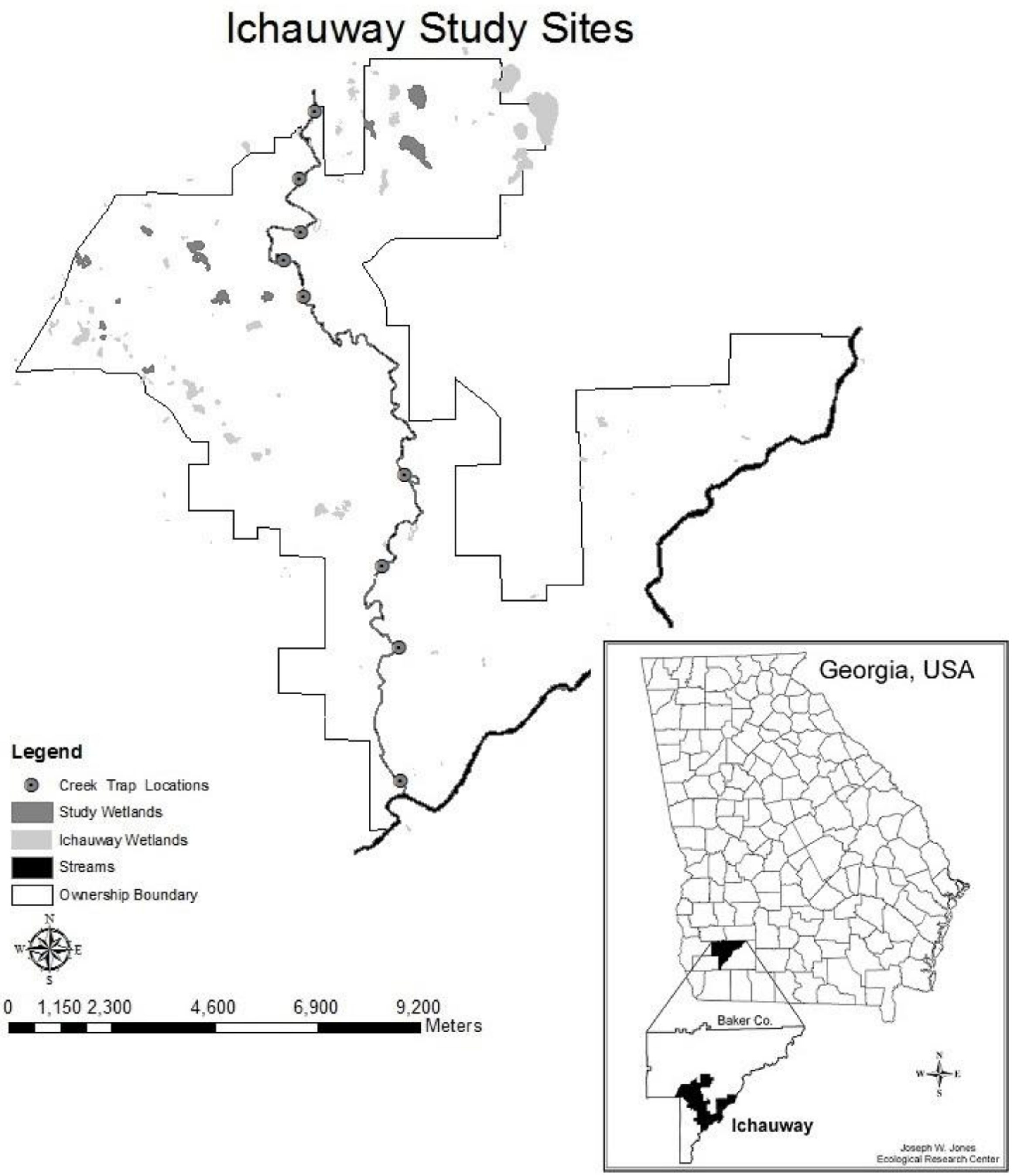

Figure 2-1. Locations of the nine creek trap sites along a 24 km stretch of Ichawaynochaway Creek and locations of 12 selected isolated wetlands at Ichauway, Baker County, Georgia, 2012 and 2013.

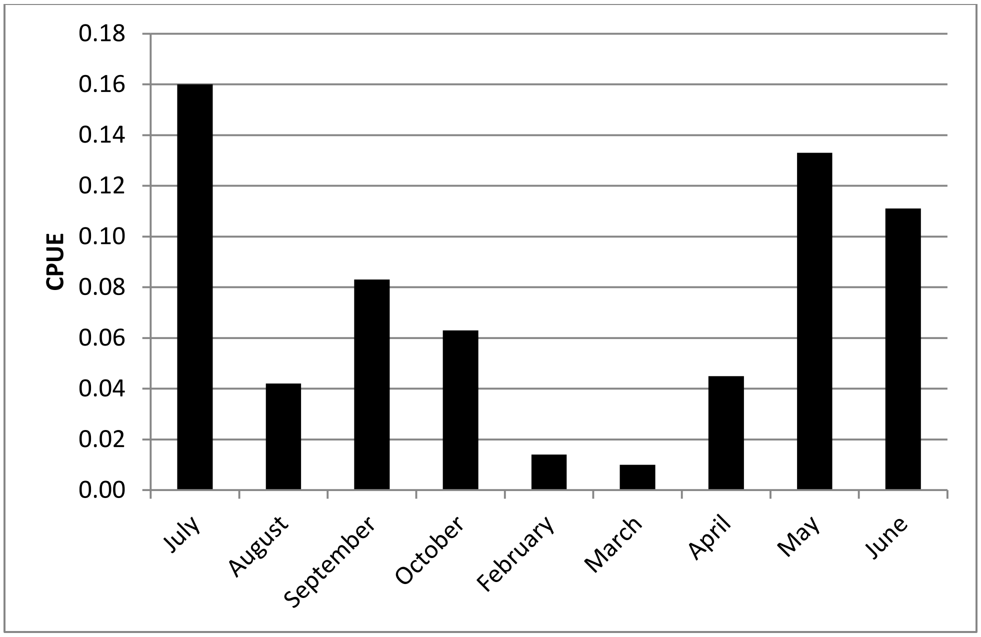

Figure 2-2. Monthly catch per unit effort (CPUE) for aquatic turtles across 12 wetland study sites at Ichauway, Baker County, Georgia from July-October 2012 and February-June 2013.

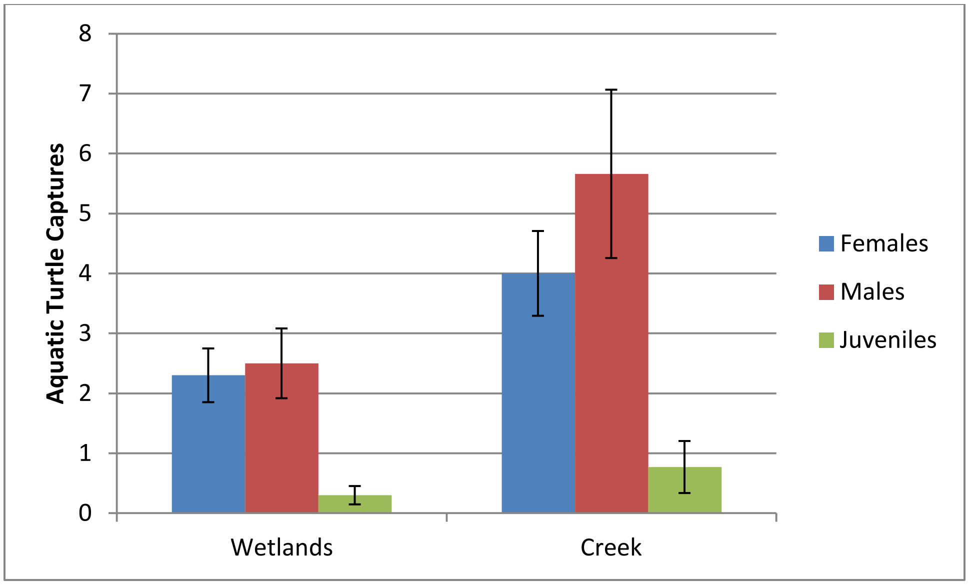

Figure 2-3. Mean number of turtle captures with standard error for creek and wetland study sites at Ichauway, Baker County, Georgia, by sex and age class (age classes were adults and juveniles, with juveniles being turtles that were too small to accurately determine sex; Jensen et al. 2008).

CHAPTER 3

Overland Movement by Aquatic Turtles in the Dougherty Plain of Georgia

Introduction

Reptiles are experiencing population declines globally and approximately 42% of all turtle species are threatened, primarily from habitat loss and degradation (Semlitsch and Bodie, 1998; Buhlmann et al., 2009a; Gibbons et al., 2000). Aquatic turtle species are particularly vulnerable to habitat degradation as some require both aquatic and terrestrial habitats. Many aquatic turtles use terrestrial habitats for nesting and overwintering. The importance of an intact terrestrial core around wetlands and streams to accommodate these activities has been well-documented (Semlitsch and Bodie, 2003; Buhlmann et al., 2009b). In addition to nesting and overwintering, many aquatic turtles migrate between freshwater ecosystems, including rivers, ponds, and wetlands in search of food, mates, or other resources (Gibbons et al., 1990, Tuberville et al., 1996; Gibbons, 2003). Very little is known about the extent of turtle movements and the permeability of different terrestrial habitats for migrating aquatic turtles.

The extent of terrestrial habitat use varies among turtle species and among sexes and different life stages. Male turtles are thought more likely to move overland to find new aquatic habitats and thus more potential mates (Parker, 1984; Gibbons, 1986). Among turtles in the southeastern U. S., chicken turtles (*Deirochelys reticularia*) and eastern mud turtles (*Kinosternon subrubrum*) often occur in geographically isolated wetlands. Both species use uplands by overwintering in nests as hatchlings, while males and females of all ages aestivate in upland habitat during drought (Skorepa and Ozment, 1968; Bennett, 1972; Gibbons and Greene, 1978; Gibbons, 1983; Buhlmann and Gibbons, 2001; Steen et al., 2007; Buhlmann et al., 2009b). In contrast, highly aquatic species typically found in streams including alligator snapping turtles (*Macrochelys temminckii*), loggerhead musk turtles (*Sternotherus minor*), Gulf Coast spiny softshells (*Apalone spinifera*), and Barbour's map turtles (*Graptemys barbouri*) rarely leave the water and typically only females travel overland to nest (Steen et al., 2012). The yellow-bellied slider (*Trachemys scripta*) and common snapping turtle (*Chelydra serpentina*) inhabit both wetlands and streams and make extensive overland movements. For example, Steen et al. (2010) documented a male *C. serpentina* moving over 1.7 km overland and *T. scripta* have been reported to move more than 3 km overland (Morreale et al., 1984).

Overland movements by aquatic turtles are greatly influenced by weather and climate patterns. Turtles often leave drying water bodies to find refugia during drought (Cagle, 1944a; Sexton, 1959; Gibbons, 1983), and migrate back when these habitats refill. Gibbons (1970) suggested that rainfall influences whether a turtle moves overland during drought, but does not influence terrestrial movements during periods of normal rainfall or overwintering. Turtles that inhabit geographically isolated wetlands in the southeastern U.S., which experience cycles of dry down and refilling, are adapted to aestivate or migrate when wetlands are dry. Isolated wetlands rely on rainfall to fill, and generally dry down in late spring and summer due to evapotranspiration (Battle and Golladay, 2001). To maintain aquatic turtle populations that use a suite of upland and aquatic habitats, it is imperative to maintain connectivity between wetland and riparian systems through conservation of migration corridors.

Overland movement is costly for aquatic turtles due to high energetic demands as well as high risk of mortality via desiccation, overheating, and predation. Risk is exacerbated by landscape development as turtles moving overland are more vulnerable to harvest by humans, predation (e.g., from domestic dogs), and roadway mortality, which particularly affects nesting females (Gibbons, 1986; Buhlmann and Gibbons, 2001; Gibbs and Shriver, 2002; Steen et al., 2006). Agricultural land, in particular, may be detrimental to turtle movement due to fragmentation with little to no protective cover and poor quality aquatic habitat (i.e., ecological traps; Moll and Moll, 2004). Additionally, the slow moving nature of turtles renders them vulnerable to injury or death by agricultural machinery (Bowne et al., 2006; Saumure et al., 2007; Erb and Jones, 2011).

Of the aquatic turtles species in southwestern Georgia, the yellow-bellied slider (*Trachemys scripta*), common snapping turtle (*Chelydra serpentina*), river cooter (*Pseudemys concinna*), and Florida cooter (*Pseudemys floridana*), use multiple habitats (i.e., streams, isolated wetlands) while moving through longleaf pine (*Pinus palustris*) uplands (Smith et al., 2006). The Florida softshell (*Apalone ferox*), chicken turtle (*Deirochelys reticularia*), eastern mud turtle (*Kinosternon subrubrum*), and common musk turtle (*Sternotherus odoratus*) use isolated wetlands in the region, and so are expected to move among theses wetlands as well (Smith et al., 2006).

The primary objective of this study was to examine overland movements of aquatic turtles among geographically isolated wetlands and streams within a longleaf pine landscape. More specifically, I 1) quantified temporal patterns of overland movements and looked for differences in movement patterns among species and sexes of aquatic turtles, and 2) identified terrestrial habitats used by migrating turtles to determine habitat permeability with the goal of informing selection of priority landscapes for conservation. I hypothesized that semi-aquatic species, (i.e., *A. ferox*, *C. serpentina*, *D. reticularia*, *K. subrubrum*, *P. concinna*, *P. floridana*, *S.*

odoratus, and *T. scripta*), would exhibit greater overall frequencies of overland movements than fully aquatic stream specialists, (i.e, *A. spinifera*, *G. barbouri*, *M. temminckii*, and *S. minor*; Smith et al. 2006), and that male turtles would move overland more frequently than females and juveniles to search for mates. I also hypothesized that during overland movements, turtles would be more often associated with forested habitats including pine uplands and bottomland hardwoods close to bodies of water than non-forested habitats and disturbed areas including scrub, agriculture, and developed habitats.

Methods

<u>Study Site</u>

The study took place on Ichauway, the 11,300 ha research site of the Joseph W. Jones Ecological Research Center, which is located in the Dougherty Plain Physiographic District in southwestern Georgia. Ichauway is a private reserve managed for longleaf pine and Northern bobwhite quail (*Colinus virginianus*) and consists of second growth longleaf pine forest characterized by an open canopy and a wiregrass (*Aristida stricta*) dominated understory. Other pine species including slash pine (*P. elliottii*) and loblolly pine (*P. taeda*) are also present in addition to hardwoods (e.g., *Quercus* spp.). Ichauway also contains scrub and deciduous riparian habitat as well as pine plantations, small agricultural fields and wildlife food plots for Northern bobwhite and white-tailed deer (*Odocoileus virginianus*), and areas classified as developed which consist of buildings and houses. There are more than 90 geographically isolated wetlands on Ichauway, including both cypress-gum swamps, cypress savannas and grassy marshes (Kirkman et al., 2000). Cypress-gum swamps are characterized as having a dense canopy of pond cypress (*Taxodium ascendens*) and swamp tupelo (*Nyssa biflora*) with little to no understory, and have organic soils. Cypress savannas have a sparse overstory of pond cypress and an herbaceous understory. Grassy marshes are characterized as having open canopies and understories of panic grasses (*Panicum* spp.), cutgrass (*Leersia hexandra*), and sandy soils (Kirkman et al., 2000). Ichauway is bordered on the east by a 21 km reach of the Flint River and a 24 km reach of Ichawaynochaway creek runs through the center of the property. The property is surrounded by extensive, privately owned agricultural lands.

Field Data Collection

In 2012 and 2013, I collected aquatic turtles encountered on roads at Ichauway. I also used existing unpublished data for aquatic turtles on roads that were collected on roads from 2003-1011 (unpublished data). Most turtle captures were associated with a predator exclusion fence around a 16 ha study plot (see Conner et al., 2010 for a detailed description of the plot) containing a 7 ha geographically isolated wetland (Wetland 0). The predator exclusion fence prevented turtles from moving freely to and from the wetland from 2003-2013. The fence line was monitored regularly over that time and collected, marked, and measured all migrating aquatic turtles and recorded whether they were entering or exiting the fence. All turtles were released across the fence after they were marked.

All turtles captured were identified to species and marked by notching a unique combination of marginal scutes (Cagle, 1939). Softshell turtles (*Apalone* spp.) were notched (Plummer, 2008) and hatchlings and small juveniles of all species were marked with alpha-numeric mussel tags (1.2 mm x 2.7 mm, Northwest Marine Technologies, Shaw Island, WA, USA) which were glued on the plastron using Super Glue (Loctite, Henkel Corporation, Rocky Hill, CT, USA). For each capture the date, ID number, recapture status, sex, reproductive status (females were hand-palpated in the spring and summer to see if they carried shelled eggs, Cagle, 1944b), age class (adult, sub-adult; Jensen et al., 2008), mass (g), plastron length (mm), carapace length (mm), and any injuries or abnormalities were recorded. The locations of captured turtles were mapped by hand using ArcGIS (version 9.3; Earth Systems Research Institute, Redlands, CA).

Data Analysis

Overland Movement Patterns

I calculated the total number and sex ratio of all turtles captured on land. Captures from 2003-2013 were pooled by month and year to describe seasonal patterns in overland movement. I calculated incidences of aquatic turtle movements during and after rainfall events from May 2012- June 2013 to determine whether rainfall affected turtle movements. I obtained rainfall data from the Georgia Automated Environmental Monitoring Network's weather station located at Ichauway (www.Georgiaweather.net)

I used ArcGIS and existing landcover data layers for Ichauway to calculate the distance (m) from each turtle location to the nearest geographically isolated wetland and nearest body of "permanent" water (i.e. Ichawaynochaway creek, Flint River, agricultural ponds). I compared mean distance of locations to nearest depressional wetland and permanent water body by species using t-tests (SAS 9.3). Only species with >10 captures were used in this analysis.

The number of turtles entering and exiting the fence surrounding Wetland 0 from 2003-June 2013 was recorded by species and sex. I examined relationships between turtle captures and season, water levels, as well as directionality of turtle movements using correlation analyses.

Habitat Associations

Locations of the most frequently captured species, *T. scripta* (n=179), were overlaid onto an existing land cover layer of Ichauway using ArcGIS. Most turtle captures (<90%) occurred in the central and northern portion of the property; therefore, I spatially defined the study area for this portion of the analysis as the 8736 ha portion of the property (Figure 3-1). I generated 179 random points within the study area using Hawth's Analysis Tools for ArcGIS to spatially represent the available surrounding habitat at a landscape scale. I created a 125-m buffer around these points and the *T. scripta* locations (Beyer, 2004.) I calculated the mean percentages of landuse variables within buffers around turtle locations and random points. Land cover types included: agriculture and wildlife food plots (AG), hardwood forest (HW), hardwood pine mixed forest (MX), open water (OP), pine plantation (PP), scrub (SC), upland pine (UP), developed (DV), and wetland (WT). Other variables were: road density (total length of paved and dirt roads within buffer; RD), habitat edge density (total perimeter of borders between different habitats within buffer; EG), and distance to nearest body of water (DW). Agricultural land consisted of small wildlife food plots and offsite center-pivot agricultural fields. Hardwood forests were typically associated riparian bottomlands and contained several species including live oak (*Quercus virginiana*), water oak (*Q. nigra*), laurel oak (*Q. laurifolia*), and red oak (*Q. falcata*), while mixed hardwood pine contained both oaks and pines. Open water included Ichawaynochaway Creek and the Flint River as well as any other permanent bodies of water. Pine plantations were typically young planted pine (<10 years old), though some were mature pine stands and all had generally less groundcover than upland pine habitat. Scrub habitat contained both oak thickets and abandoned pastures. Upland pine habitat was dominated by mature longleaf pine, but also contained slash pine and loblolly pine and diverse herbaceous groundcover. Developed areas included homes, barns and other buildings, and roads that included two county highways. Wetland habitat consisted of cypress gum swamps, cypress savannas, and grassy marshes.

Data were log-transformed and 27 a-priori logistic regression models (including global and null models; Table 3-1) were developed to investigate associations between *T. scripta* presence and specific habitat variables. Logistic regression models were run in SAS 9.3 (SAS Institute Inc., Cary, NC), and Akaike's Information Criterion (AIC) was used to rank models (Burnham and Anderson, 2002).

Results

Overland Movement Patterns

A total of 705 aquatic turtles were captured on land from 2003-2013. Twenty three percent of the total were recaptures. *T. scripta* accounted for 468 captures (66% of total captures) and riverine species *Apalone spinifera* and *Graptemys barbouri* accounted for <2% of total captures (Table 3-2). The majority of turtle captures (>90%) occurred from March-September, with highest capture numbers in May and June (Figure 3-2). Only in 2006 and 2013 were more than 80 turtles captured (Figures 3-3, 3-4). Sex ratios (males: females) among individual species varied from 0:1-2:1 (Table 3-2).

In 2012, during a period of extreme drought (United States Drought Monitor, 2012), 19 turtles were captured on land from May-September, with three peaks (>1/day for 2012) in captures. In 2013, 150 turtles were captured from February-June, with a total of 11 peaks (>4/day for 2013)in captures (Figure 3-5). Rainfall ranged from 0.03- 7.45 cm during these peaks and daily average temperature ranged 13.3-28 °C, and only four peaks in turtle captures in 2012 and 2013 were not preceded with rain events either on the date of or the date before capture.

Of the 705 captures from 2003-2013, 380 captures (6 species) resulted from turtles entering and exiting Wetland 0. *T. scripta* were captured the most frequently (n=235) followed by *D. reticularia* (n=43), *A. ferox* (n=39), *P. floridana* (n=38), *C. serpentina* (n=14), and *P. concinna* (n=11; Table 3-3). Recapture percentages were high for *C. serpentina* (35.7%), *P. floridana* (31.6%), and *T. scripta* (28.9%), and the recapture rate was 26.3% across all species. Of the captures around Wetland 0, 188 captures were of turtles moving to the wetland and 149 turtles were captured while migrating away from the wetland (Table 3-3). Of the turtles migrating to Wetland 0, 9.5% came from a northerly direction, 3.6% a southerly direction, 38% an easterly direction, and 48.9% a westerly direction. The majority of turtles migrating from the wetland appeared to be heading east with 44.4% of captures and west with 41.9%. 10.25 % of turtles exited from the south side of the wetland and 3.4% exited on the north (Table 3-4). The greatest number of turtles captured on land took place in 2006's active season (March-September), with 114 captures and 41.2% of the wetland filled, while only 6 turtles were captured in 2011 and 2012s' active seasons, when Wetland 0 was, on average 7.6% and 0.2% full, respectively, due to severe drought conditions (unpublished data). Overall movement increased with increasing wetland water depth (Figure 3-6), and immigration into the wetland typically increased with water levels, while emigration typically increased with decreasing water levels.

Of 708 turtle captures in 2003-2013; 308 had locations mapped in ArcGIS (version 9.3; Earth Systems Research Institute, Redlands, CA) on a landcover layer of Ichauway. Of the 6 species with more than 10 GPS locations, *T. scripta* (n=192), *D. reticularia* (n=25), *A. ferox* (n=22), *P. floridana* (n=22), and *C. serpentina* (n=14) were found closer to wetlands than permanent water (Table 3-5). *P. concinna* (n=19) were not significantly closer to either aquatic system.

Habitat Associations

Maximum likelihood estimates indicated that the percentage of upland pine (1.0718, P <0.0001), open water (0.8406, P = 0.0276), and wetland (1.4471, P <0.0001) habitats within buffers around *T. scripta* were significantly greater than expected by chance, while the percentage of scrub (-0.4417, P=0.0451), pine plantation (-0.9669, P <0.0001), and agriculture (-1.2361, P <0.0001) habitats were significantly lower than expected. *T. scripta* captures were significantly closer to water (-1.3308, P<0.0001) than random points. The percentages of hardwood forest (0.1656, P=0.3546), hardwood/pine mix (0.1536, P=0.3309), road density (-0.4812, P=0.4941) and edge density (1311, P=0.4380) did not differ between turtle captures and random points (Table 3-6).

The best model for predicting terrestrial locations of *T. scripta* during overland movements was the global model (AIC=406.06; Table 3-7). The upland pine and wetland habitat model (upland pine, wetlands, and distance to nearest water; AIC= 413.90) and the undisturbed habitat model (upland pine, hardwood forest, hardwood/pine mix, open water, and wetlands; AIC= 425.86 fell outside of 2 AIC units and thus, were not well supported.

Discussion

Of the 12 aquatic turtle species that occur in the Dougherty Plain, nine were captured on land during this study. This included two riverine species, *A. spinifera* and *G. barbouri*, indicating the importance of upland habitats for aquatic turtles. *Trachemys scripta* exhibited the most overland activity, which was expected of a habitat generalist (Ernst et al. 1994) using many types of aquatic habitats throughout the region. Other species that were frequently captured during overland forays were *Apalone ferox*, *Deirochelys reticularia*, and *Pseudemys floridana* (all wetland specialists), in addition to *Chelydra serpentina* and *Pseudemys concinna*. *Pseudemys floridana* was the only species where more males than females were captured overland, while all other species had either equal overland movements by sex or had females move more than males. This was unexpected as it does not agree with previous studies that found males to move more than females (Parker, 1984; Gibbons, 1986).However; this may be due to the relatively short hydroperiods of wetlands in the region, which forces both sexes to move to obtain resources and aquatic refuges necessary for survival and growth. Females of several species (i.e. *A. ferox*, *A. spinifera*, *C. serpentina*, *G. barbouri*, and *P. concinna*) moved overland more than males, though this is most likely due to nesting forays as evidenced by sudden influxes of gravid females during April and May, which are common nesting periods (Ernst et al., 1994).

The large numbers of captures and recaptures of six turtle species moving in and out of Holt Pond indicates high activity entering and leaving isolated depressional wetlands. Many individuals were captured entering and leaving during the same year. This could indicate that turtles are not permanent residents of a single wetland, but use multiple wetlands and, in the case of generalist species, other aquatics habitats. Movement between multiple water bodies suggests that aquatic turtles may be spending large amounts of time in the uplands. Many turtles were caught moving toward or coming from the east side of Wetland 0, where another depressional wetland (grassy marsh) is situated 200 m away. Turtles also exhibited high movement activity from the west, where an offsite agricultural pond was less than 1 km away. Both wetlands typically hold water throughout the year (RLK pers. obs.), and may be important habitat for turtles. Overall movements typically increased when water levels increased in Holt Pond, though there were some exceptions. Wetland water levels dropped throughout 2006, yet turtle movement to and from Holt Pond remained high. This may be explained by turtles moving through the wetland or using it as a “stepping stone” as they search for more permanent aquatic habitat. When water levels remained low throughout the year (i.e., 2007, 2011, and 2012), movement rapidly decreased. Overall movements to and from Holt Pond indicate high connectivity between isolated wetlands and extensive movement through upland habitat at Ichauway.

Despite the importance of dispersal corridors among wetlands for wildlife connectivity, policies are typically only designed to buffer aquatic resources and not terrestrial and wildlife resources (Crawford and Semlitsch, 2007). Along with other published studies (Semlitsch and Bodie, 2003; Steen et al., 2012) my data suggest that these buffers are not adequate to provide for terrestrial migration of aquatic turtles. For example, in this study, many turtles were captured further away from aquatic habitat than anticipated. Of the six species for which I calculated Euclidian distances from permanent water, primarily stream habitat, only *P. concinna*, a species that often inhabits rivers, had an average distance of <300 m. *P. concinna* also had the largest average distance to isolated depressional wetlands. *C. serpentina* and *T. scripta* had the largest average distances to permanent water, with individuals of both species found >3 km from streams. *C. serpentina* and *T. scripta* also had the greatest average distances to wetlands aside from *P. concinna*. Average distances for all other species fell between 94.8-141.1 m from wetlands. The majority of these distances are much larger than typical wetland (30-120 m) and river (12-20 m) buffer zones. My results suggest that a 287 m maximum core terrestrial zone around wetlands and a 150 m riparian buffer are more appropriate to protect turtle populations

(Semlitsch and Bodie, 2003; Steen et al., 2012); however, corridors between and among habitats may be a more appropriate approach to accommodating inter-wetland movements (see Chapter 4).

The most interesting finding of this study is the evidence supporting turtle preference for certain habitats when traveling over land. *T. scripta* were found more often in natural upland pine, wetland, and open water habitats than expected by chance and less often in scrub, pine plantations, and agriculture. Turtles also were found closer to aquatic habitats than expected by chance. Along with the results of the logistic regression models, this indicated that *T. scripta* preferred to move through upland pine forests near bodies of water and other undisturbed habitats, and avoided moving through more disturbed habitats including open scrub and agriculture and pine plantations.

Overall, this information may be beneficial for assigning priority landscapes for conservation of turtle populations in the Dougherty Plain and the Southeastern Coastal Plain, which was historically dominated by the longleaf pine ecosystem, of which <3% remains due to urbanization and conversion to agriculture and commercial pine stands (Frost, 1993; Noss et al., 1995). Many isolated depressional wetlands that also occurred in the region have been lost or degraded by agricultural land use practices over the past 6 decades by both conversion on wetlands to cropland or farm ponds and fragmentation of forested corridors between wetlands (Martin, 2010; Martin et al., 2013).

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Table 3-1. 27 a priori models and variables used in logistic regression for *Trachemys scripta* to describe habitat associations of aquatic turtles during overland movements at Ichauway, Baker County, Georgia from 2003-2013. Variables are scrub (SC), urban (UR), upland pine (UP), hardwood forest (HW), hardwood pine mix (MX), pine plantation (PP), open water (OW), wetland (WT), agriculture (AG), road density (RD), habitat edge density (EG), and distance to nearest water (DW).

Model	Description
Global	SC+DV+UP+HW+MX+PP+OW+WT+AG+RD+EG+DW
Undisturbed	UP+HW+MX+OW+WT
All Disturbed	DV+PP+AG+RD
Upland Pine and Wetland	UP+WT+DW
Natural Forested	UP+HW+MX
All Pine	UP+MX+PP
Riparian and Hardwood	OW+DW+HW
All Aquatic	OW+WT+DW
Heavily Disturbed	DV+AG+RD
All Wetland	WT+DW
Agriculture and Pine Plantation	PP+AG
Scrub and Pine Plantation	SC+PP
Natural Pine	UP+MX
Riparian	OW+DW
Scrub	SC
Developed	DV

Upland Pine	UP
Hardwood Forest	HW
Hardwood Pine Mixed	MX
Pine Plantation	PP
Open Water	OW
Wetland	WT
Agriculture	AG
Road Density	RD
Habitat Edge Density	EG
Distance to Water	DW
Null	None

Table 3-2. Number of captures, recaptures, percent of individuals recaptured, and sex ratios for aquatic turtle species captured on land at Ichauway, Baker County Georgia, 2003-2013.

Species	Captures	Recaptures	% Recaptures	Sex Ratio (M: F)
A. ferox	46	3	6.5	1:2
A. spinifera	2	0	0	0:1
C. serpentina	34	8	23.5	1:2
D. reticularia	58	11	19	1:1
K. subrubrum	4	0	0	1:0
G. barbouri	7	0	0	0:2
M. temminckii	0	0	0	N/A
P. concinna	39	7	17.9	1:3
P. floridana	47	13	27.7	2:1
S. minor	0	0	0	N/A
S. odoratus	0	0	0	N/A
T. scripta	468	121	25.9	1:1
Total	705	163	23.1	1:1

Table 3-3. Number of captures, recaptures, and sex ratios of aquatic turtles entering and exiting wetland Holt Pond at Ichauway, Baker County Georgia, 2003-2013.

Species	N	Recaptures	% Recaptures	Entering	Exiting	Sex Ratio
A. ferox	39	3	7.7	22	16	1:2
C. serpentina	14	5	35.7	8	4	1:3
D. reticularia	43	10	23.3	24	12	1:1
P. concinna	11	2	18.2	2	5	3:1
P. floridana	38	12	31.6	18	19	3:1
T. scripta	235	68	28.9	106	94	1:1
Total	380	100	26.3	180	150	1:1

Table 3-4. Cardinal directions of 308 aquatic turtles entering and exiting Holt Pond at Ichauway, Baker County Georgia, 2003-2013.

Direction	% Exiting	% Entering
North	3.4	9.5
South	10.2	3.6
East	44.4	38
West	41.9	48.9

Table 3-5. Mean distances to nearest permanent body of water and depressional wetland for aquatic turtle species captured on land at Ichauway, Baker County Georgia, 2003-2013. Only data from species with >10 captures are displayed. Differences were considered significant at α=0.05.

Species	N	Mean Distance to Permanent water (SE)	Distance to Wetland (SE)	P-value
A. ferox	22	484.3 (82.75)	113.4 (30.26)	<0.0001
C. serpentina	14	866.3 (268.4)	160.6 (50.37)	0.0157
D. reticularia	25	394.7 (90.16)	141.1 (38.39)	0.0106
P. concinna	19	224.6 (51.53)	358.3 (73.13)	0.0691
P. floridana	22	377.5 (63.53)	94.79 (27.24)	0.0002
T. scripta	192	612.0 (44.53)	294.8 (21.27)	<0.0001

Table 3-6. Analysis of maximum likelihood estimates of landcover types and road and edge densities within 125-m buffers around *T. scripta* locations and random road points within a 8736 ha study area at Ichauway, Baker County Georgia, 2003-2013. Differences were considered significant at α=0.05.

Analysis of Maximum Likelihood Estimates			
Variable	Estimate	Standard error	P > ChiSq
Scrub	-0.4417	0.2204	0.0451
Developed	0.4087	0.2531	0.1064
Upland	1.0718	0.2423	<0.0001
Hardwood	0.1656	0.1789	0.3546
Mix	0.1536	0.1580	0.3309
Plantation	-0.9669	0.2035	<0.0001
Open Water	0.8406	0.3816	0.0276
Wetland	1.4471	0.2201	<0.0001
Agriculture	-1.2361	0.1868	<0.0001
Road Density	-0.4812	0.7038	0.4941
Edge	0.1311	0.1690	0.4380
Distance to Water	-1.3308	0.2292	<0.0001

Table 3-7. Logistic regression models used to investigate effects of overland habitat variables on *T. scripta* overland movements on a 8736 ha study area at Ichauway, in Baker County, Georgia. Models were evaluated with Akaike's Information Criterion (Burnham and Anderson, 2002), where k equals the number of parameters, AIC= 2k- 2 ln(L), ΔAIC is the difference between each model and the best model, and w_i is the Akaike weight of each model.

Variables[1]	*K*	AIC	ΔAIC	w_i
SC+DV+UP+HW+MX+PP+OW+WT+AG+RD+EG+DW	13	406.06	0.00	0.98
UP+WT+DW	4	413.89	7.84	0.02
UP+HW+MX+OW+WT	6	425.86	19.79	0
DV+PP+AG+RD	7	432.2	21.79	0
PP+AG	5	434.91	26.14	0
WT+DW	3	437.29	28.85	0
OW+WT+DW	3	438.66	31.23	0
DV+AG+RD	4	448.98	32.60	0
WT	4	449.06	42.92	0
AG	2	449.11	43.00	0
DW	2	461.14	43.05	0
OW+DW	2	462.48	55.08	0
OW+DW+HW	3	464.42	56.42	0
UP+HW+MX	4	464.43	58.36	0
UP+MX+PP	4	466.94	58.37	0
UP+MX	4	473.11	60.88	0

SC+PP	3	473.75	67.05	0
PP	3	474.84	67.69	0
UP	2	476.48	68.78	0
OW	2	494.98	70.42	0
SC	2	496.22	88.92	0
DV	2	497.61	90.16	0
None	2	498.29	91.55	0
MX	1	499.34	92.23	0
HW	2	499.43	93.28	0
EG	2	499.68	93.37	0
RD	2	499.82	93.62	0

[1]Variables are scrub (SC), developed (DV), upland pine (UP), hardwood forest (HW), hardwood pine mix (MX), pine plantation (PP), open water (OW), wetland (WT), agriculture (AG), road density (RD), habitat edge density (EG), and distance to nearest water (DW).

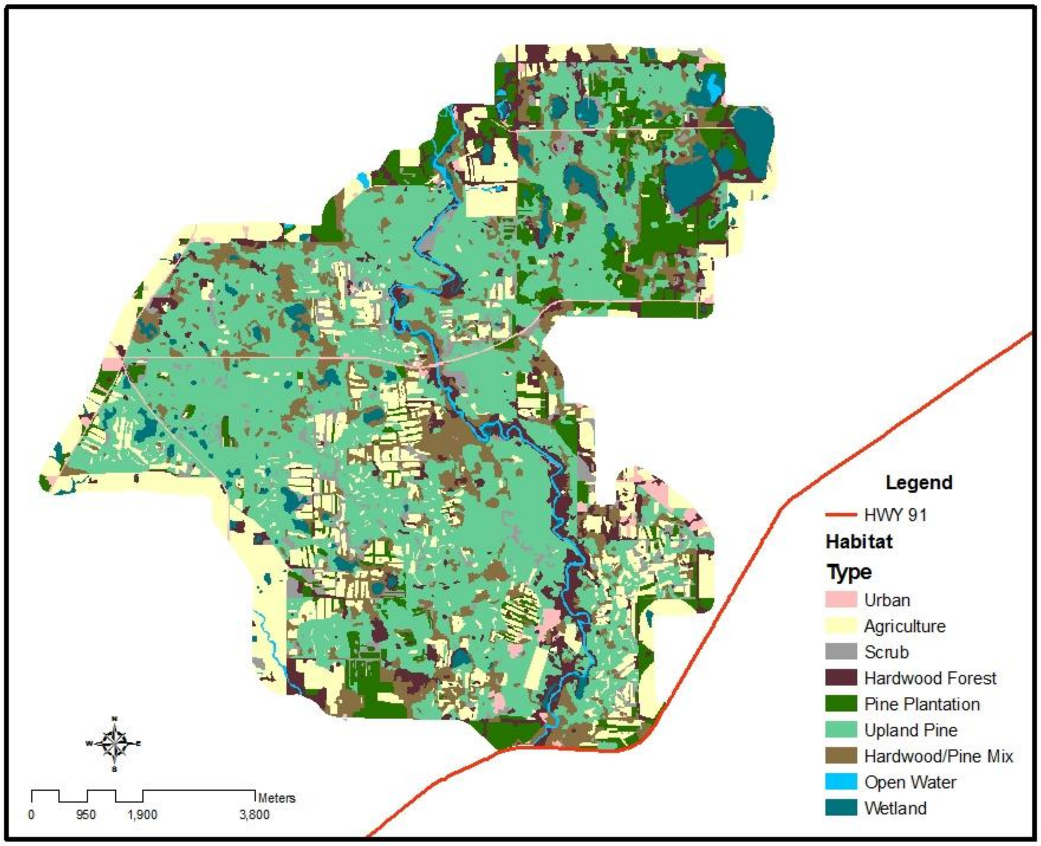

Figure 3-1. Map of the study area of Ichauway used to model habitat associations of *Trachemys scripta* during overland movements at Ichauway, Baker County, Georgia from 2003-2013.

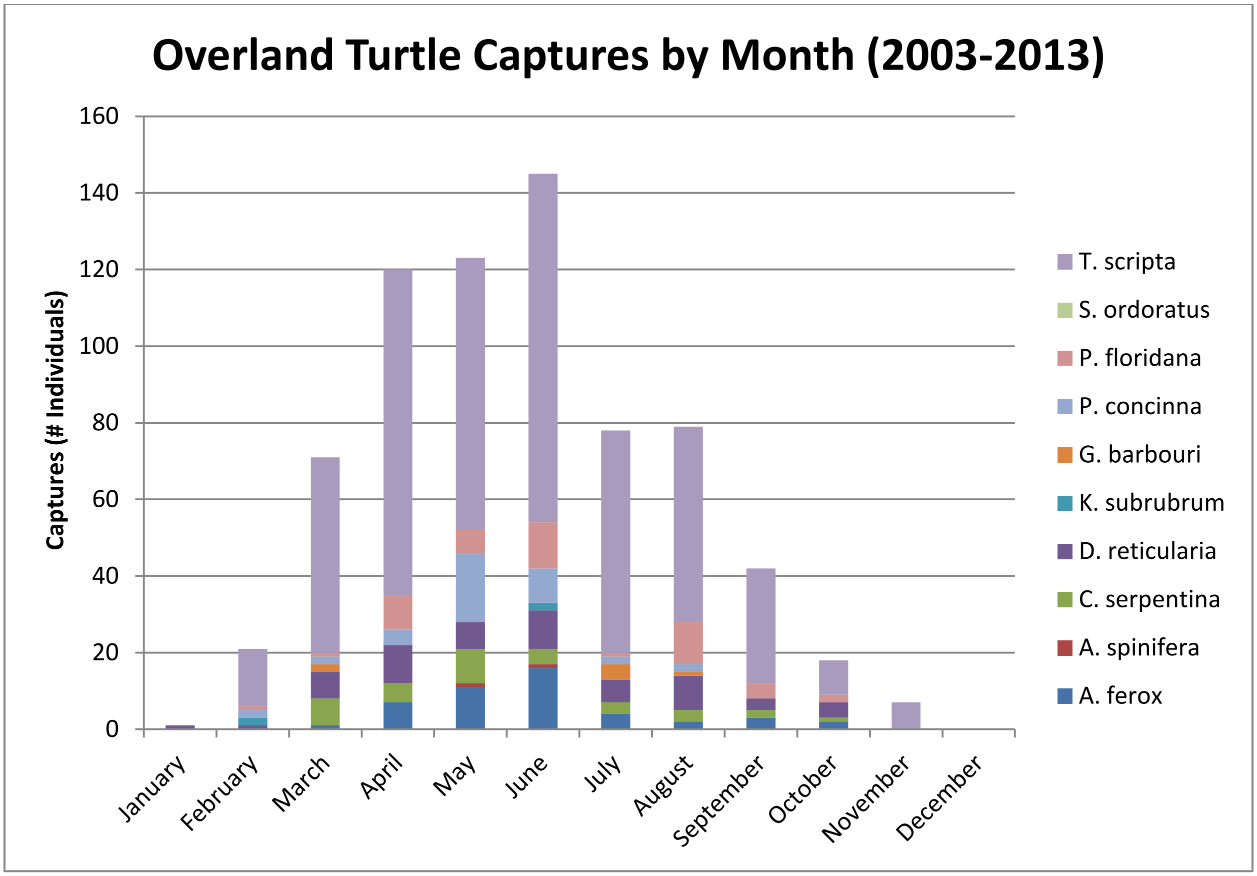

Figure 3-2. Aquatic turtle overland captures pooled by species and month at Ichauway, Baker County Georgia, 2003-2013.

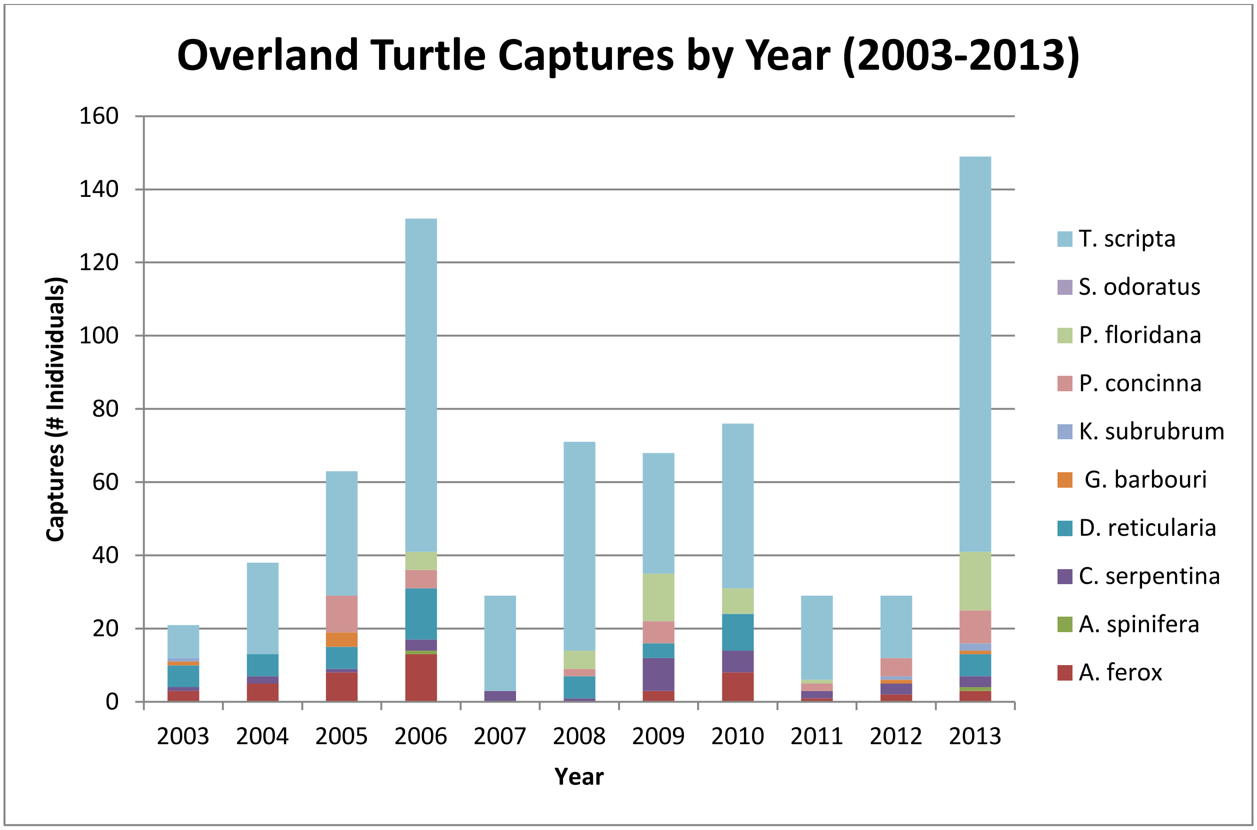

Figure 3-3. Aquatic turtle overland captures pooled by species and year at Ichauway, Baker County Georgia, 2003-2013.

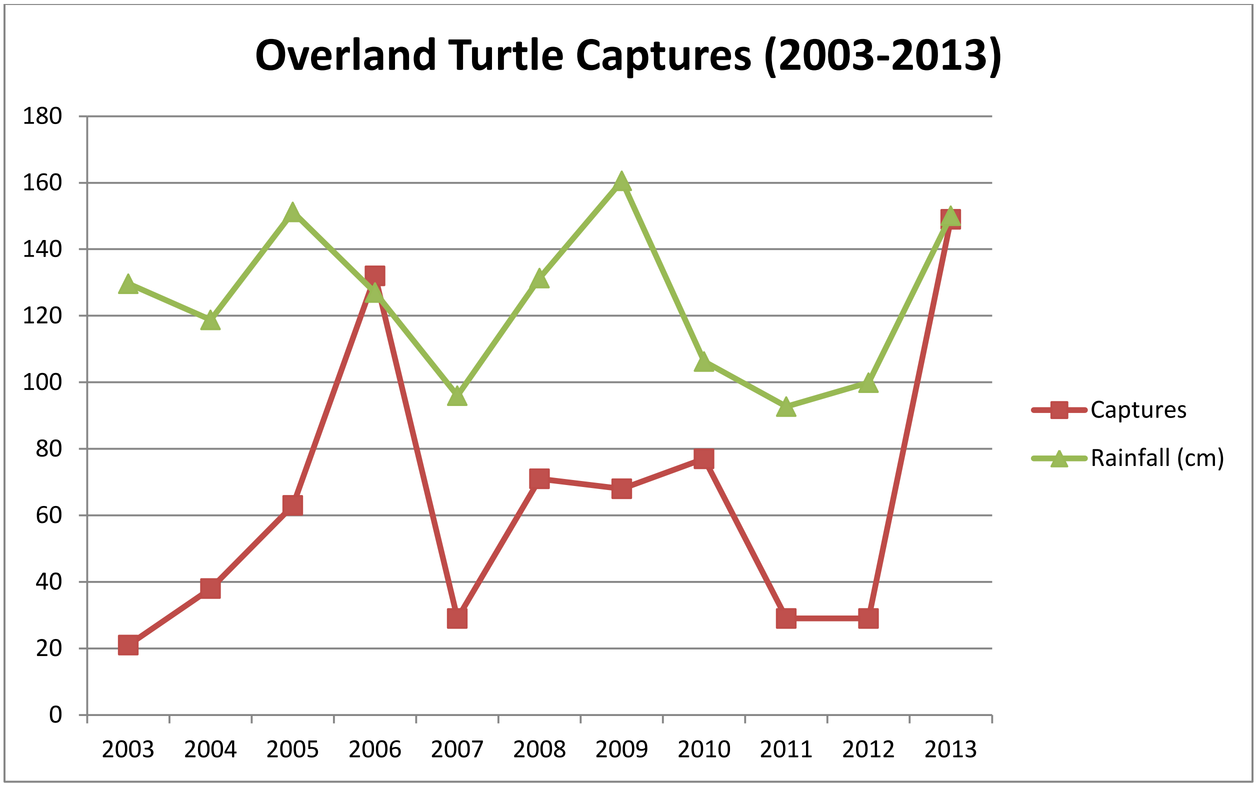

Figure 3-4. Aquatic turtle overland captures and cumulative rainfall (cm) at Ichauway, Baker County Georgia, 2003-2013.

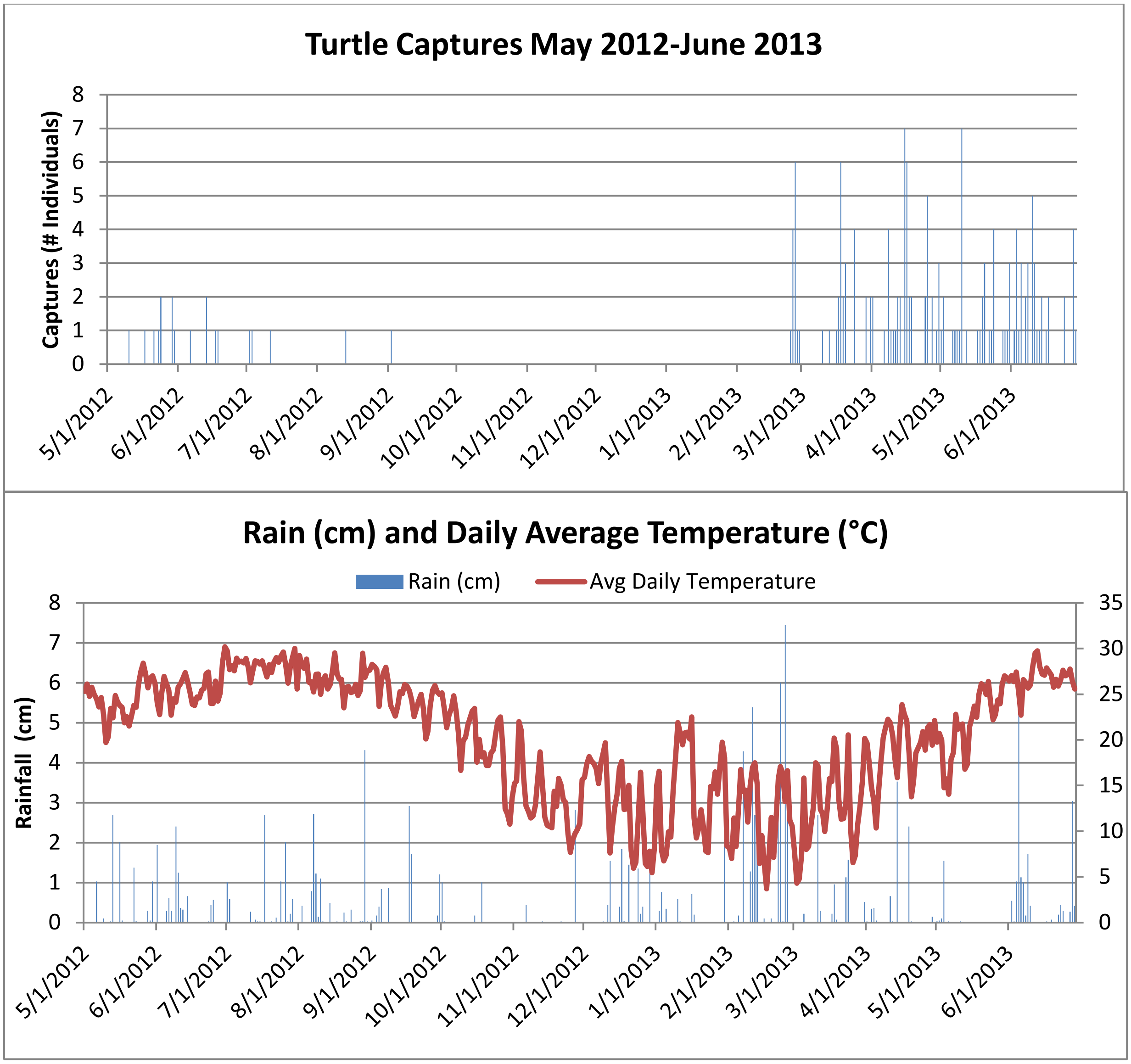

Figure 3-5. Daily aquatic turtle overland captures, rainfall (cm), and daily average temperature (°C), at Ichauway, Baker County, Georgia from May 2012- June 2013.

CHAPTER 4

Spatial Ecology and Wetland Habitat Use of Common Snapping Turtles (*Chelydra serpentina*) and Yellow-bellied sliders (*Trachemys scripta*) in a Longleaf Pine Ecosystem

Introduction

Geographically isolated wetlands within the Coastal Plain of the southeastern United States support high herpetofaunal diversity (Guyer and Bailey, 1993; Semlitsch et al., 1996). Isolated wetlands vary in size, depth, vegetation, and surrounding landscape characteristics, and although the influence of these wetland characteristics on amphibians has been described (Pechmann et al., 1989; Rothermel and Semlitsch, 2002; Liner et al., 2008), their influence on reptiles, and aquatic turtles in particular, is less well known. As many of these wetlands dry down seasonally, aquatic fauna often migrate through uplands, which were historically longleaf pine forests (*Pinus palustris*) to more permanent aquatic habitats (Subalusky et al., 2009). Thus, the upland habitat surrounding geographically isolated wetlands is critical to providing connectivity for migrating aquatic species. Research examining the permeability of upland habitats for aquatic fauna has primarily focused on amphibians (Semlitsch, 1998; Doyle et al., 2004). Much less is known about the importance of upland permeability for turtles despite the importance of geographically isolated wetlands for this group (Gibbons, 1983; Buhlmann and Gibbons, 2001; Chapter 2).

The Southeastern Coastal Plain of the United States has a variety of freshwater systems including tens of thousands of geographically isolated wetlands, i.e., wetlands that are typically not hydrologically connected to permanent bodies of water (Tiner, 2003; Martin et al., 2012). Several types of geographically isolated wetlands occur in the region, including cypress-gum swamps, grassy marshes, and cypress savannas (Kirkman et al., 2000). Cypress-gum swamps are characterized by a dense canopy of pond cypress (*Taxodium ascendens*) and swamp tupelo (*Nyssa biflora*) with little to no understory, and have organic soils. Grassy marshes have an open canopy structure with an understory of panic grasses (*Panicum* spp.) and cutgrass (*Leersia hexandra*), and sandy soils (Kirkman et al., 2000). Cypress savannas have a sparse canopy of pond cypress with an understory similar to that of grassy marshes. Geographically isolated wetlands rely on rainfall to fill, and generally dry down in late spring and summer due to decreased rainfall and increased evapotranspiration (Battle and Golladay, 2001). Determining the degree to which turtles use these wetlands and their surrounding habitat will provide information on wildlife linkages in these geographically isolated habitats and help identify priority conservation areas.

The common snapping turtle (*Chelydra serpentina*), and the yellow-bellied slider (*Trachemys scripta*) are widespread species that inhabit a variety of freshwater systems and exhibit long range terrestrial movements (Morreale et al., 1984; Steen et al., 2010). *C. serpentina* is one of the largest turtle species in North America and ranges east of the Rocky Mountains from Southern Canada to South Florida (Ernst et al., 1994). Habitat selection of *C. serpentina* has primarily been studied in the northern extent of its range; few studies exist on habitat selection in the southern part of its range or in geographically isolated wetlands. A study at a central Florida lake suggested that *C. serpentina* preferred habitats with slow moving water, abundant aquatic vegetation and a soft muddy bottom (Bancroft et al., 1983). A separate study in north Florida found that *C. serpentina* occurred in greatest abundance in small suburban ponds (Aresco and Gunzburger, 2007).

Trachemys scripta is a medium-sized turtle with three subspecies within the United States (*T. scripta elegans*, T. *scripta scripta,* and *T. scripta troostii*). *T. scripta scripta*, the yellow-bellied slider, ranges from southern Virginia to northern Florida and is the target subspecies for this study (Ernst et al., 1994). The majority of ecological studies on the yellow-bellied slider have been performed at the Savanna River Ecology Laboratory in Aiken County, South Carolina (Gibbons, 1990). *T. scripta* are found in aquatic habitats similar to the common snapping turtle; however, they also prefer habitats with quality basking sites (Ernst et al., 1994).

In this study, I used radio-telemetry to monitor movements of *C. serpentina* and *T. scripta* to describe their use of geographically isolated wetlands versus streams. Thus, the first objective of this study was to examine aquatic habitat use of each species. The study took place during a period of drought recovery from late winter-summer 2013 (Georgia Environmental Monitoring Network, http://georgiaweather.net). Based on previous studies of these species I hypothesized that individuals of both species would use multiple geographically isolated wetland types and, to a lesser extent, other aquatic habitats (i.e., streams and agricultural ponds) in proximity to isolated wetlands. I expected *T. scripta* to move greater distances within and among wetlands because they are smaller and more mobile than *C. serpentina* and the species has been described as a habitat generalist (Ernst et al., 1994). I also hypothesized that within geographically isolated wetlands, both species would select deeper habitats, which typically are the last areas to dry and often contain abundant vegetation and quality basking sites. The second objective of this study was to use telemetry locations of turtles and terrestrial habitat selection data (Chapter 3) to generate theoretical paths of overland movement of turtles using ArcGIS and two software packages: Linkage Mapper, which identifies measurable least-cost paths throughout a landscape (McRae and Kavanagh, 2011), and Circuitscape, a tool that uses circuit theory to map probable flow as a function of landcover resistance by running "currents" between core habitats in a landscape (McRae and Shah, 2009).

Methods

Study Site

The study took place on Ichauway, the 11,300 ha research site of the Joseph W. Jones Ecological Research Center, which is located in the Dougherty Plain physiographic district in Baker County, Georgia. Ichauway is a private reserve managed for longleaf pine (*Pinus palustris*) and Northern bobwhite quail (*Colinus virginianus*) and primarily consists of mature long leaf pine upland habitat with an open canopy and a wiregrass (*Aristida stricta*) dominated understory. Other pine species including slash pine (*P. elliottii*) and loblolly pine (*P. taeda*) are also present in addition to hardwoods (*Quercus* spp.). Ichauway also contains scrub habitat, deciduous riparian forest, pine plantations, small agricultural fields and wildlife food plots, and areas classified as developed consisting of buildings and houses. There are more than 90 geographically isolated wetlands on Ichauway, including cypress-gum swamps, cypress savannas, and grassy marshes (Kirkman et al., 2000). Other aquatic habitats include hardwood depressions and streams. Hardwood depressions are dominated by oaks (*Quercus* spp.) and are only occasionally inundated. Ichawaynochaway Creek is a tributary of the Flint River with numerous limestone shoals and deep sandy areas that runs south for >100 km through agricultural and forested land before joining the Flint River, and was the primary stream habitat used in this study. Ichauway is also bordered on the east by a 21 km section of the Flint River. A number of altered ponds are located in the surrounding agricultural lands bordering on Ichauway, and thus had the potential to be inhabited by turtles.

Turtle Captures and Radio Telemetry

From January 2013-May 2013, 12 male *T. scripta* and 14 *C. serpentina* (4 males, 10 females; Table 4-1) were captured either incidentally on land or in baited hoop traps in wetlands (0.9 m diameter, four hoops, 3.8 cm mesh; Memphis Net and Twine, Memphis, TN, USA; Chapter 2). All turtles captured were assigned unique identification numbers by notching the marginal scutes (Cagle, 1939). For each turtle, mass (g), plastron length (mm), and carapace length (mm) were recorded (Table 4-1). Transmitters (Model SI-2E, 9 g, Holohil Systems Ltd., Ontario, Canada; Model R1860, 15.3 g, ATS Advanced Telemetry Systems, Isanti, MN) were then attached to the carapace of each turtle using PC-plumbing putty epoxy (Protective Coating Co., Allentown, PA). Turtles were radio tracked by homing approximately once per week through 31 August 2013 using a three-element folding Yagi antenna (Wildlife Materials, Inc., Murphysboro, IL) and R1000 radio-telemetry receiver (Communication Specialists Inc., Orange, CA). The following data were collected each time a turtle was tracked: location taken with a Trimble Juno Global Positioning System (GPS; Trimble Navigation, Ltd, Sunnyvale, CA), general habitat type, and several behavioral traits. Habitat types consisted of the following: cypress gum swamps, grassy marshes, cypress savannas, hardwood depressions, streams, agricultural ponds, and terrestrial habitat. Behavior consisted of basking, feeding, mating, nesting (females), moving (either swimming or travelling overland), and stationary. GPS locations were mapped using ArcGIS (version 9.3; Earth Systems Research Institute, Redlands, CA). Locations separated by >5m were considered new locations.

Data Analysis

Movements and Aquatic Habitat Use

I calculated average daily movements of telemetered turtles using Euclidean distances (ArcGIS) between consecutive locations for each turtle. I used a Student's t-test to determine whether mean daily movement differed significantly between *C. serpentina* and *T. scripta*. Contour data (0.25 m resolution) were available for 8 of the geographically isolated wetlands used by turtles. I used these data in ArcGIS to show where turtles were encountered in these wetlands (Beyer, 2004. Hawth's Analysis Tools for ArcGIS).

I examined habitat use of both species by categorizing the habitats at each location (*C. serpentina* ,n= 223; *T. scripta*, n= 162) as one of the following using an existing landcover data layer for Ichauway: cypress gum swamps, grassy marshes, cypress savannas, hardwood depressions, streams, agricultural ponds, and terrestrial habitat. I used a Wilcoxon rank sum test (PROC npar1way; SAS 9.3) to test for differences in habitat use between *C. serpentina* and *T. scripta*.

Connectivity Modeling

I created a raster layer (1-m cells) of existing landcover vector data for Ichauway and used the results of the habitat association analysis in Chapter 3 to appoint resistance values to each landcover type described above. Lower raster values signified lower resistance (greater ease) of movement by turtles, while higher values represented greater resistance (Figure 4-1). Agricultural land consisted of small wildlife food plots and offsite center-pivot agricultural fields, and was shown to be avoided by *T. scripta* (Chapter 3). Hardwood forests were typically riparian bottomlands and contained live oak (*Quercus virginiana*), water oak (*Q. nigra*), laurel oak (*Q. laurifolia*), and red oak (*Q. falcata*), while hardwood pine mixed contained both oaks and pines. Open water included Ichawaynochaway Creek and the Flint River. Pine plantations were typically <10 years old, though some were mature pine stands and all had generally less groundcover than upland pine habitat. Scrub habitat contained both oak thickets and abandoned pastures. Pine plantations and scrub were avoided by *T. scripta* in the habitat association analysis (Chapter 3). Upland pine habitat was dominated by mature longleaf pine, but also contained slash pine and loblolly pine and diverse herbaceous groundcover. Developed areas included homes, barns and other buildings, and roads and were appointed a high resistance value due to increased risk to turtles from vehicles. Wetland habitat consisted of cypress gum swamps, cypress savannas, and grassy marshes. Only turtles that exhibited overland movement were used in this analysis. Locations of each telemetered turtle that used >1 habitat (4 *C. serpentina*, 8 *T. scripta*) were overlaid onto a landcover layer using ArcGIS, and Linkage Mapper (ArcGIS; McRae and Kavanagh, 2011; McRae et al., 2012) was run for each individual using the GPS locations as core areas, while Circuitscape (Version 3.5.8; McRae and Shah, 2009; Zeigler et al., 2011) was run using wetlands occupied by each turtle as core regions.

Least cost paths (LCP; in meters) for overland movement were generated using Linkage Mapper and compared to overland Euclidean distance data (m) for each turtle, to determine of turtles would have to move significantly greater distances between wetlands to pass through less resistant habitats. In addition, I compared average cost-to-distance ratios for LCP's and Euclidean distances using a Student's t test. I then used the outputs from Circuitscape, which uses electronic circuit theory to generate maps, with core habitats represented as electrical nodes while corridors represented flows of current (McRae and Shah, 2009; Zeigler et al., 2011). These "current" maps identified theoretical paths of overland movement between aquatic habitats by turtles.

Results

Movement and Aquatic Habitat Use

I tracked 14 *C. serpentina* from 78 to 201 days and 11 *T. scripta* from 35 to 164 days and acquired an average of 11 radio-locations per *C. serpentina* and 12 radio-locations per *T. scripta* (Table 4-1). All but two *T. scripta* moved overland, and two individuals travelled from isolated wetlands to Ichawaynochaway Creek. Only 4 of the 14 telemetered *Chelydra serpentina* moved overland during the study; 3 of the 4 travelled >1 km and one individual travelled > 3 km and visited 5 separate aquatic habitats. Of the four telemetered *C. serpentina* who moved overland, one was a gravid female that was initially captured on land during a potential nesting foray, and another female was captured directly after nesting in an open developed area under a live oak tree (*Q. virginiana*). *C. serpentina* (N=14) moved an average daily distance of 10.3 ± 9.84 m (range = 2-33.3 m), while *T. scripta* (N=11) moved an average 14.8 ± 7.3 m/day (range = 3.3-23.6). Average daily movement did not differ significantly between the two species (t_{23} = -1.31, P = 0.2047). Both species selected deep areas within wetlands (Figures 4-2 to 4-9), and telemetered *T. scripta* were often observed basking on fallen trees in these areas (RLK pers. obs.).

Both *C. serpentina* and *T. scripta* primarily inhabited cypress gum swamps, though *C. serpentina* selected for these wetlands significantly more often than *T. scripta* (Z = 4.3798, P < 0.0001; Table 4-2). *T. scripta* were located in streams (Z = -3.5228, P = 0.0004), agricultural ponds (Z = -1.9646, *P* = 0.0495), and hardwood depressions (Z = -3.9581, *P* < 0.0001) significantly more than *C. serpentina*. I found no difference in use of grassy marshes (Z = 1.4515, *P* = 0.1466), cypress savannas (Z = 0.9938, *P* = 0.3203), and terrestrial habitat (Z = -1.6432, *P* = 0.1003) between the two species.

Connectivity Modeling

Overland Euclidean distance and least cost paths (LCP) varied greatly among individuals (Euclidean: 311-3189 m; LCP: 240-4024.7 m), and LCP distances were greater than Euclidean distances for 9 of the 12 turtles, although there was no significant difference between the mean LCP and Euclidean distance for all turtles (t_{14} = 0.91, *P*= 0.3775). Mean cost-to-distance ratios (Euclidean and LCP) also varied among individuals, although cost-to-LCP ratios were consistently, but not significantly (t_{24} =0.44, *P* = 0.6667), lower than cost-to-Euclidean distance ratios for all individuals (Table 4-3).

Current maps for 4 *C. serpentina* and 8 *T. scripta* are presented in Figures 4-10 to 4-21. Flow paths created by currents varied depending on the distance among core habitats in addition to the surrounding landscape type. Many of the maps provided more than one flow path of current between cores. For example, one female *C. serpentina*, ID # 470, used two agricultural ponds that were 1.5 km apart during the study (Figure 4-10). The current map for this individual provided several flow paths from the pond of origin through forested landscape before narrowing down to a single path through an agricultural field to the other agricultural pond. Another turtle, a male *T. scripta*, was originally captured moving away from Ichawaynochaway Creek and visited two flooded hardwood depressions before moving to a cypress gum swamp (Figure 4-11).

The current map for this individual did not provide specific flow paths, but instead depicted a broad path between the visited wetland systems.

Discussion

Daily movement varied greatly among individual turtles in this study, and there was no difference in movement distances between *C. serpentina* and *T. scripta* despite the difference in body size and mobility between the two species. Additionally, total overland movement distances were highly variable and only 4 of the 14 telemetered *C. serpentina* moved overland during the study; however, 3 of these 4 turtles travelled >1 km overland during the study and one individual travelled > 3km demonstrating the ability of this large aquatic turtle to move long distances overland. Other studies have found that movement between aquatic habitats varies by sex in turtles, and that adult males move overland more often during mating season and adult females move farther during nesting season (Morreale et al., 1984). Male turtles typically move overland to increase mating opportunities and thus, reproductive fitness (Berry and Shine, 1980; Morreale et al, 1984; Gibbons, 1986, Tuberville et al., 1996). These assumptions were only partially confirmed by my results, as males did exhibit overland movements during mating season (April-November for *C. serpentina*, spring and fall months for *T. scripta*; Ernst et al, 1994); however, two of the four *C. serpentina* that moved overland were females and one of those females made several overland movements outside of nesting season (May-June; Ernst et al. 1994). Other studies have used turtle size as a predictor of movement, with larger turtles making more frequent overland movements than smaller turtles (House et al., 2010). However, in my study I tracked adult turtles of relatively similar sizes and it did not appear that body size within species influenced distance moved. Thus, my results were not consistent with these previous studies regarding the importance of size relative to distances travelled.

One possible explanation for the observed difference in propensity to move overland may relate to landscape and aquatic habitat availability in the region as well as rainfall patterns during the course of the study. The Dougherty Plain is composed of many small geographically isolated wetlands that dry up and fill depending on a multitude of variables (i.e., soil, elevation, climate, surrounding landscape), with fewer permanent aquatic habitats available (e.g. streams, reservoirs). The scarcity of permanent aquatic habitat may force turtles to use these dynamic aquatic ecosystems as “stepping-stones” over their lifetimes as they search for resources and mates.

My habitat use results indicated that *C. serpentina* primarily were most often found in cypress gum swamps (83.95% of locations), rarely used grassy marshes, cypress savannas, agricultural ponds, and did not use hardwood depressions or streams. However, it was surprising that *C. serpentina* primarily inhabited cypress gum swamps as this species also typically inhabits a large variety of aquatic habitats throughout its range; thus, this species may be more selective of aquatic habitat than previously thought (Ernst et al., 1994; Aresco and Gunzberger, 2007). A previous study at Ichauway noted the use of hardwood depressions and streams by adult *C. serpentina* (Steen et al., 2010), but these habitats were not used by individuals in the current study. I think the difference in habitat selection may be explained by differences in aquatic habitat availability, as the region was experiencing low precipitation and nearly all of the isolated depressional wetlands were dry during the previous study. In contrast, during the telemetry portion of my study, which followed a significant regional drought, rainfall was frequent and the majority of the wetlands were inundated in the current study (Georgia Environmental Monitoring Network, http://georgiaweather.net; Steen et al., 2010).

Trachemys scripta also primarily used cypress gum swamps (62.35%), but also showed greater breadth in habitats selected including grassy marshes, streams, agricultural ponds, and hardwood depressions. *Trachemys scripta*'s generalist habitat selection has been previously noted (Gibbons, 1990; Ernst et al., 1994). The use of both isolated wetlands and a stream suggests that this species can provide a link between aquatic ecosystems much like the American alligator (Subalusky et al., 2009). Additional study is needed to explore functional contributions that this species may provide to both aquatic systems (Deegan, 1993, Gibbons et al., 2006; Register et al., 2006).

Within geographically isolated wetlands, both *C. serpentina* and *T. scripta* appeared to prefer the deepest habitats. The deepest portions of the wetlands hold water longest (RLK pers. obs.); however, turtles continued to use these habitats even when the wetlands were fully inundated. There may be other aspects of deep areas that attracted turtles. Many of the deepest areas in geographically isolated wetlands (primarily cypress gum swamps) in this study received direct sunlight due to openings in the canopy, abundant vegetation including buttonbush (*Cephalanthus occidentalis*), and large woody debris (RLK pers. obs.). The combination of sunlight and woody debris may attract *T. scripta*, who often bask for thermoregulatory purposes (Ernst et al., 1994). *Chelydra serpentina* typically do not bask but may also prefer these areas for thermoregulatory purposes as well as the abundance of aquatic vegetation (Brown et al., 1990; Ernst et al., 1994). The deepest portion of the wetlands may also contain a stable prey base for turtles (Moll and Moll, 2004; Edwards et al., 2013).

Linkage Mapper and Circuitscape appeared to be useful tools for mapping potential movement corridors for turtles across landscapes, though both had limitations. Circuitscape generated multiple broad areas for potential movement and was able to illustrate the affects of distance and landscape on resistance of movements, but only provided visual outputs and little measurable data. Linkage Mapper was useful for calculating specific least cost path distances and cost-to-distance ratios based on likely permeability of different habitats and distance between core habitats. This method was useful for obtaining quantifiable data that could be tested statistically, but may not be realistic, as the LCPs were only one pixel (1 m x 1 m) wide. A caveat to using these programs is the need to have specific data on the ecology and habitat permeability for the organism of interest. For this study I was able to use the habitat selection results from a previous study on *T. scripta* (see Chapter 3); however; my sampling did not capture the annual home range of the turtles and may have under-represented their use of certain habitats. Moreover, these data may not be applicable for other turtle species in the same landscape, including *C. serpentina*, which may select different overland habitats to travel through than *T. scripta*. Therefore, I believe it is important for future research to obtain more data on species-specific overland habitat selection to more accurately model movement corridors, and to utilize multiple connectivity programs to best model potential corridors.

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Table 4-1. Mean body size (CL =carapace length), mass (g), and tracking data for 11 telemetered male yellow-bellied sliders, *T. scripta*, and 14 (4 male, 10 female) common snapping turtles, *C. serpentina*, at Ichauway, Baker County, Georgia, 2013.

Means (std)	Mass (g)	CL (mm)	No. Loc.	No. day tracked
Female *C. serpentina*	7190.0 (1770.4)	325.6 (25.7)	1.2 (.4)	113.3 (26.9)
Male *C. serpentina*	7375.0 (2509.2)	341.5 (43.1)	2.5 (1.9)	181.0 (32.6)
Overall *C. serpentina*	7242.9 (1905.3)	330.1 (30.7)	1.6 (1.2)	132.6 (41.9)
T. scripta	1065.7 (191.2)	193.6 (23.1)	1.9 (1.0)	138.5 (41.4)

Table 4-2. Average percentage of locations and Wilcoxon rank sum Z test statistics in different habitat types used by *C. serpentina* (n=162 locations) and *T. scripta* (n=162 locations) at Ichauway, Baker County Georgia, 2013. Differences were considered significant at α=0.05.

	Cypress gum swamp	Grassy marsh	Cypress savanna	Stream	Agricultural wetland	Hardwood depression	Terrestrial
C. serpentina (n=162)	83.95	7.41	0.62	0.00	7.41	0.00	0.62
T. scripta (n=162)	62.35	3.70	0.00	7.41	14.20	9.26	3.09
	Z = 4.3798	Z = 1.4515	Z = 0.9938	Z = -3.5228	Z = -1.9646	Z = -3.9581	Z = -1.6432
	$P < 0.0001$	$P = 0.1466$	$P = 0.3211$	$P = 0.0004$	$P = 0.0495$	$P < 0.0001$	$P = 0.1003$

Table 4-3. Euclidean distance (ED) and least cost paths (LCP) distances (in m) and cost: distance ratios for overland movements for 4 *C. serpentina* and 8 *T. scripta* at Ichauway, Baker County Georgia, 2013.

ID	Species	ED (m)	Cost : ED.	LCP (m)	Cost : LCP
260	*C. serpentina*	311	4.9: 1	240	4.1: 1
470	*C. serpentina*	2161	59.9 : 1	2726	55.1 : 1
490	*C. serpentina*	1860	5.8 : 1	2058.5	4.9 : 1
540	*C. serpentina*	3189	22.8 : 1	4024.7	18.7 : 1
1813	*T. scripta*	1024	5.9 : 1	1667	4.8 : 1
1814	*T. scripta*	312.5	7.5 : 1	292.5	6.2 : 1
1815	*T. scripta*	1442	25.0 : 1	3379	16.7 : 1
1817	*T. scripta*	1125.9	7.3 : 1	1774.5	5.3 : 1
1821	*T. scripta*	1564	19.5 : 1	1257	17.2 : 1
1824	*T. scripta*	2578.2	7.7 : 1	2128.5	6.4 : 1
1825	*T. scripta*	2298.5	6.5 : 1	2832	5.9 : 1
1851	*T. scripta*	1585	9.4 : 1	1653	8.7 : 1

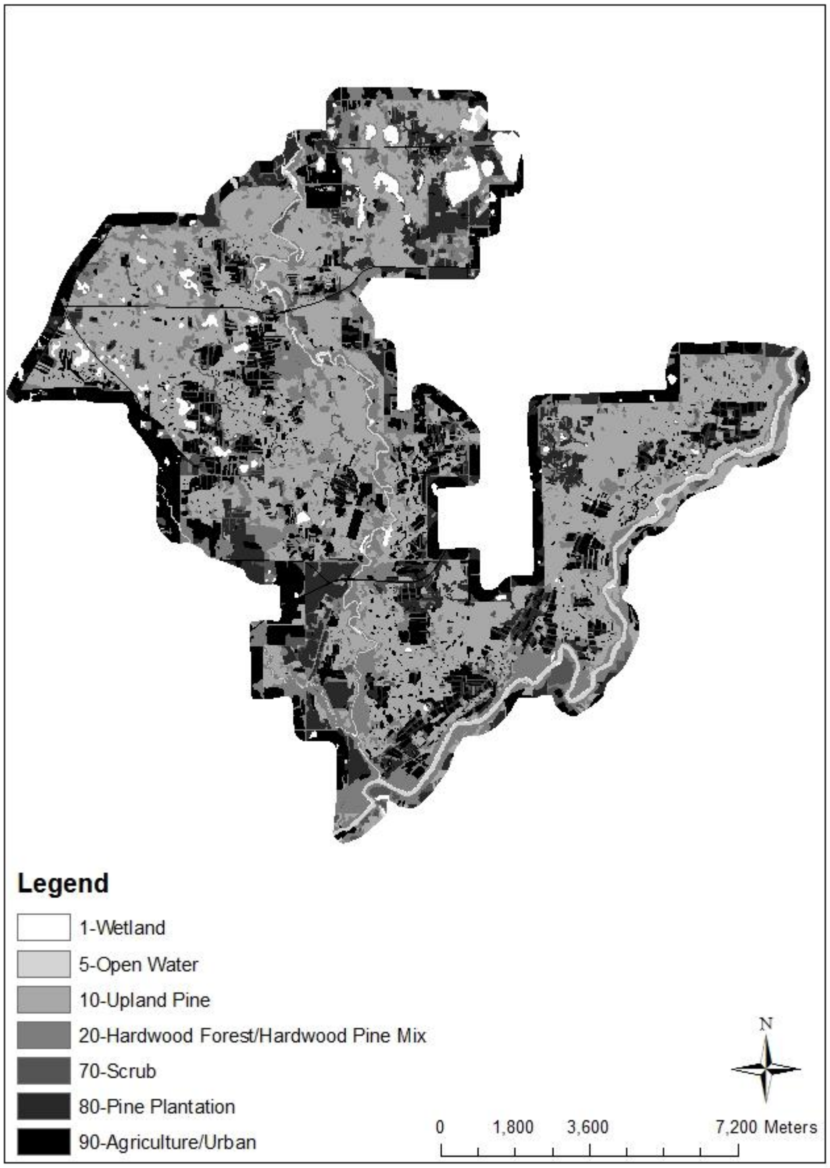

Figure 4-1. Map of Ichauway, Baker County, Georgia, showing landcover types and corresponding resistance values (1-90) for aquatic turtles moving overland used in Linkage Mapper and CircuitScape modeling. Lower resistance values signify greater ease of movement.

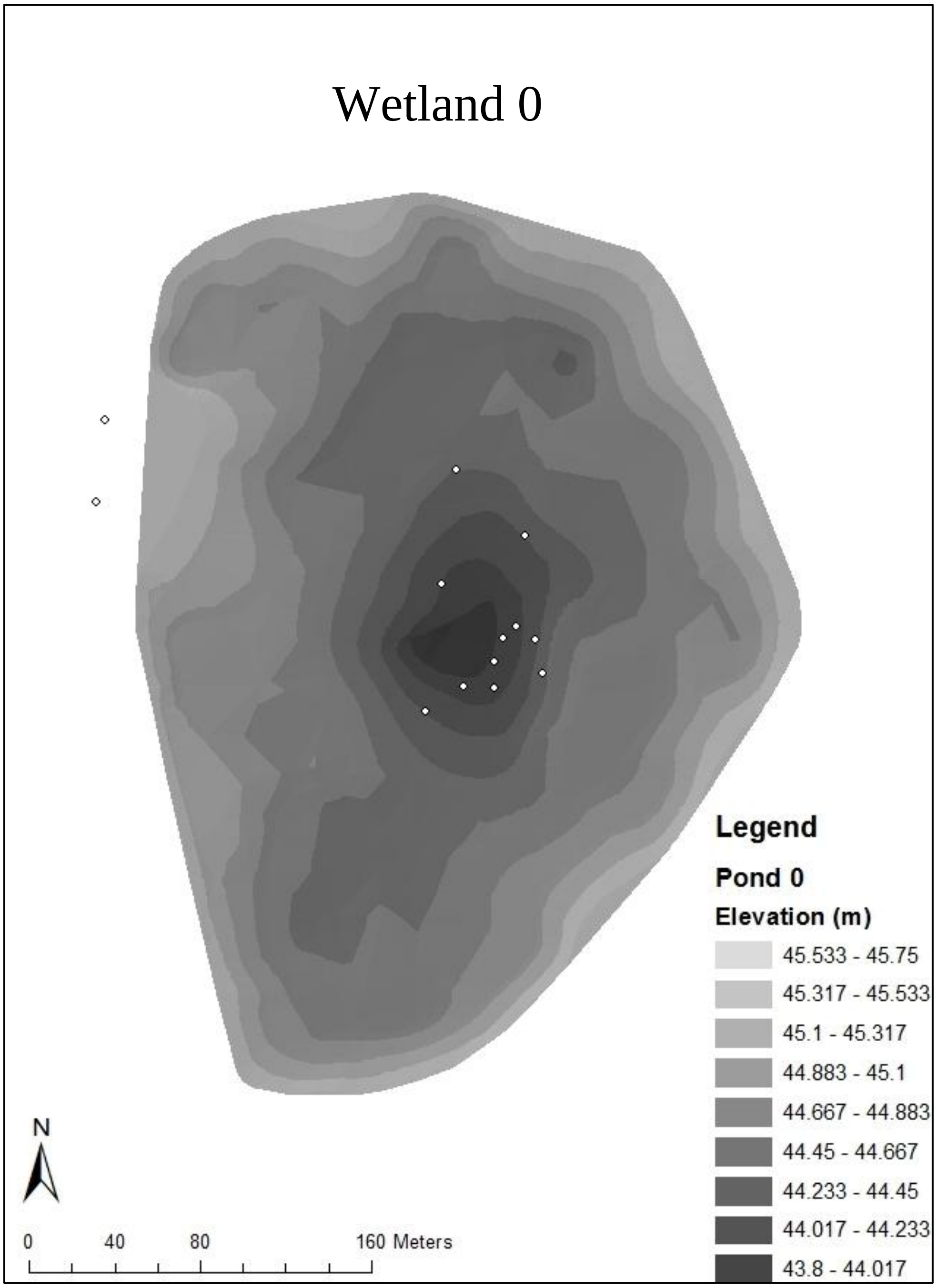

Figure 4-2. Contour map of Wetland 0 at Ichauway, Baker County, Georgia, showing locations of telemetered *Chelydra serpentina* and *Trachemys scripta* (white dots). Darker colors represent lower elevation.

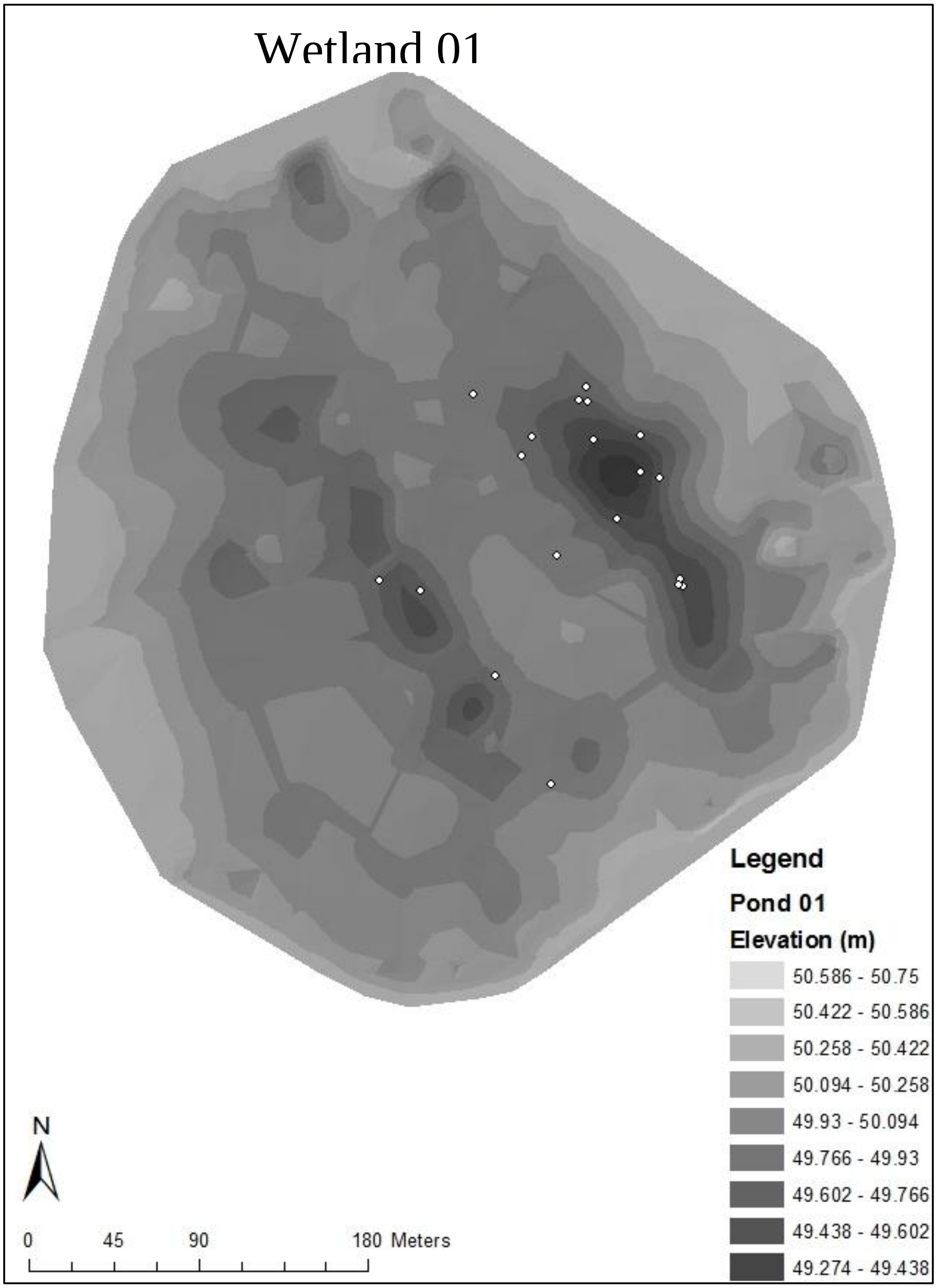

Figure 4-3. Contour map of Wetland 01 at Ichauway, Baker County, Georgia, showing locations of telemetered *Chelydra serpentina* and *Trachemys scripta* (white dots). Darker colors represent lower elevation.

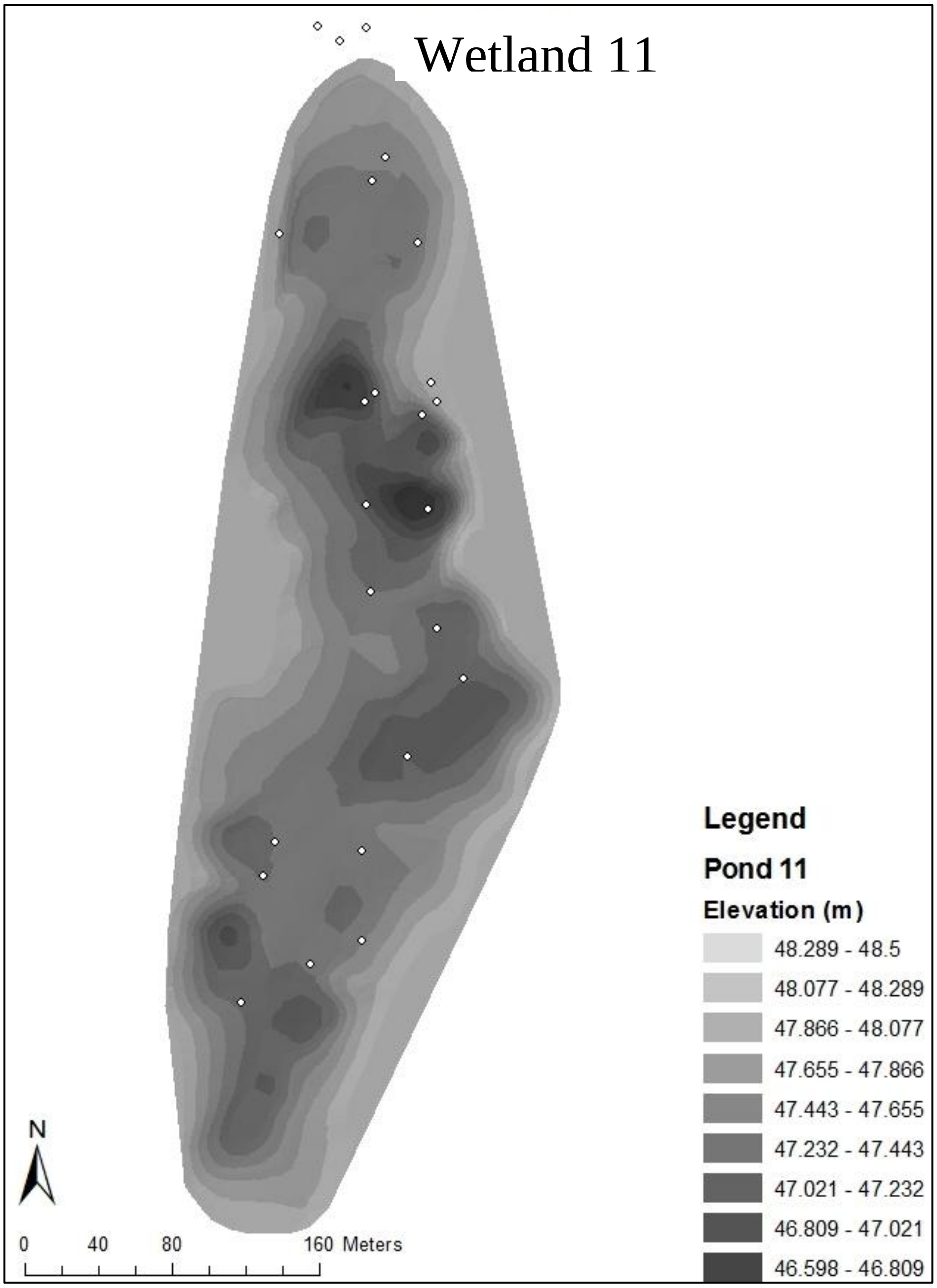

Figure 4-4. Contour map of Wetland 11 at Ichauway, Baker County, Georgia, showing locations of telemetered *Chelydra serpentina* and *Trachemys scripta* (white dots). Darker colors represent lower elevation.

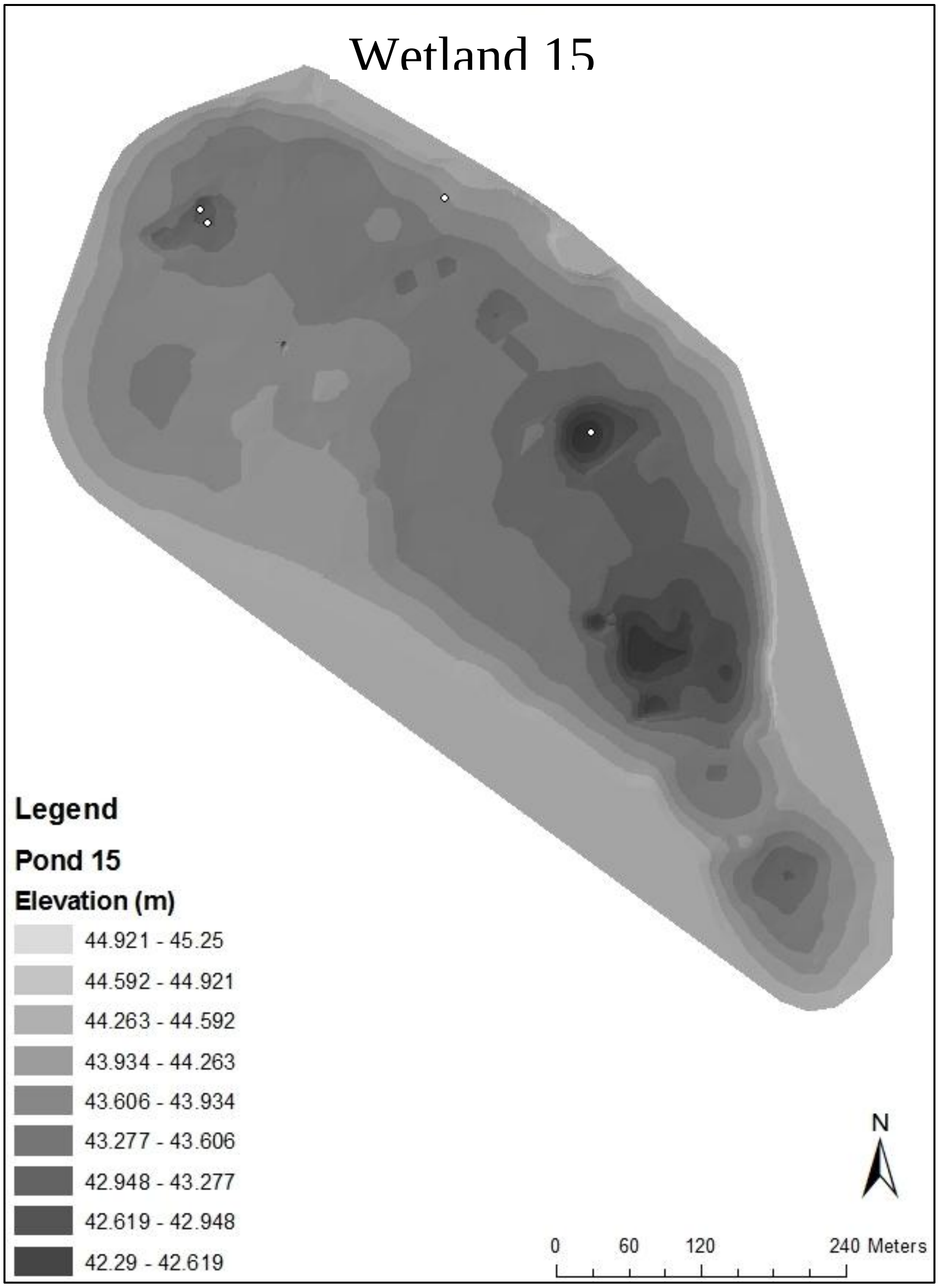

Figure 4-5. Contour map of Wetland 15 at Ichauway, Baker County, Georgia, showing locations of telemetered *Chelydra serpentina* and *Trachemys scripta* (white dots). Darker colors represent lower elevation.

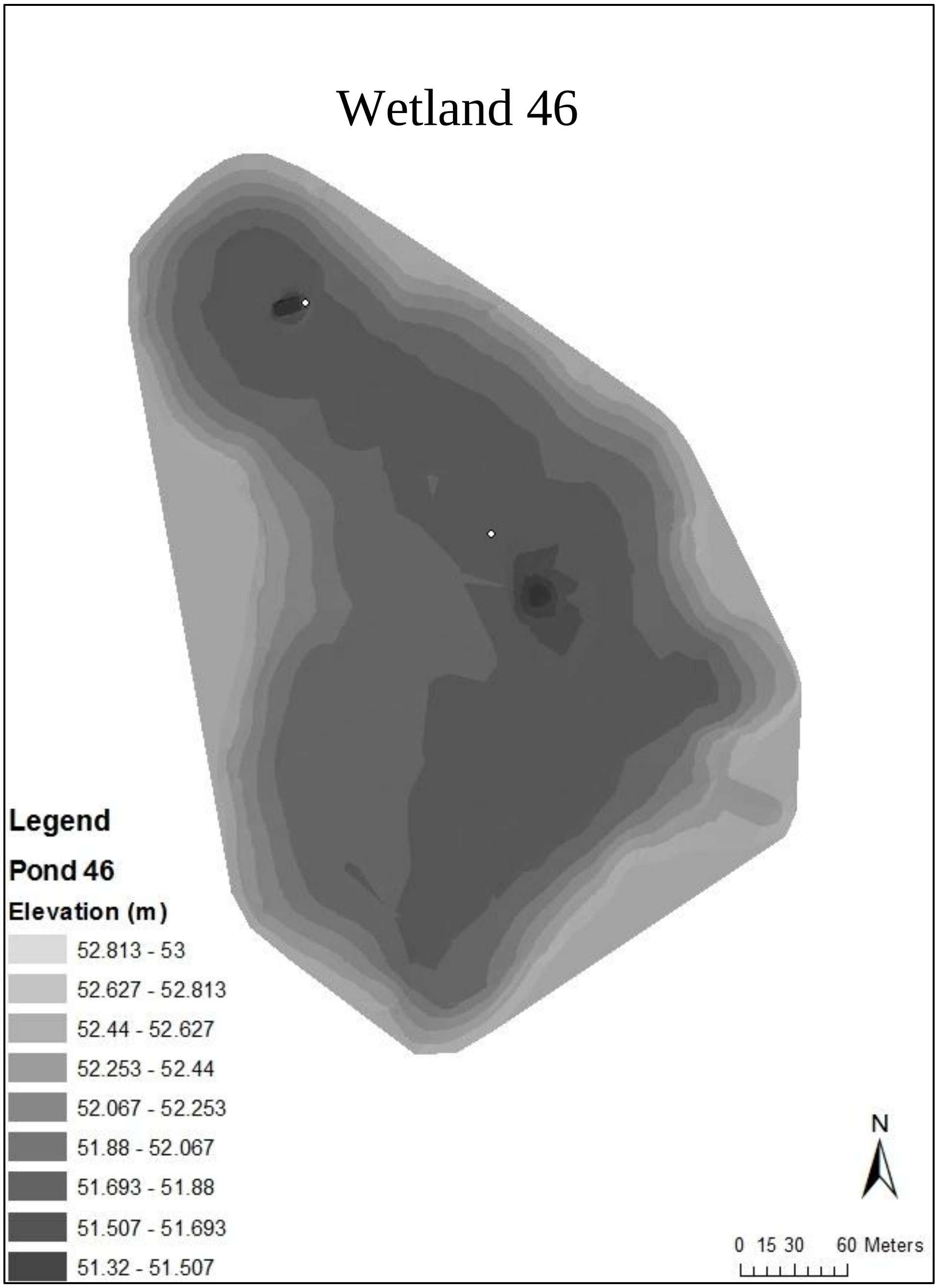

Figure 4-6. Contour map of Wetland 46 at Ichauway, Baker County, Georgia, showing locations of telemetered *Chelydra serpentina* and *Trachemys scripta* (white dots). Darker colors represent lower elevation.

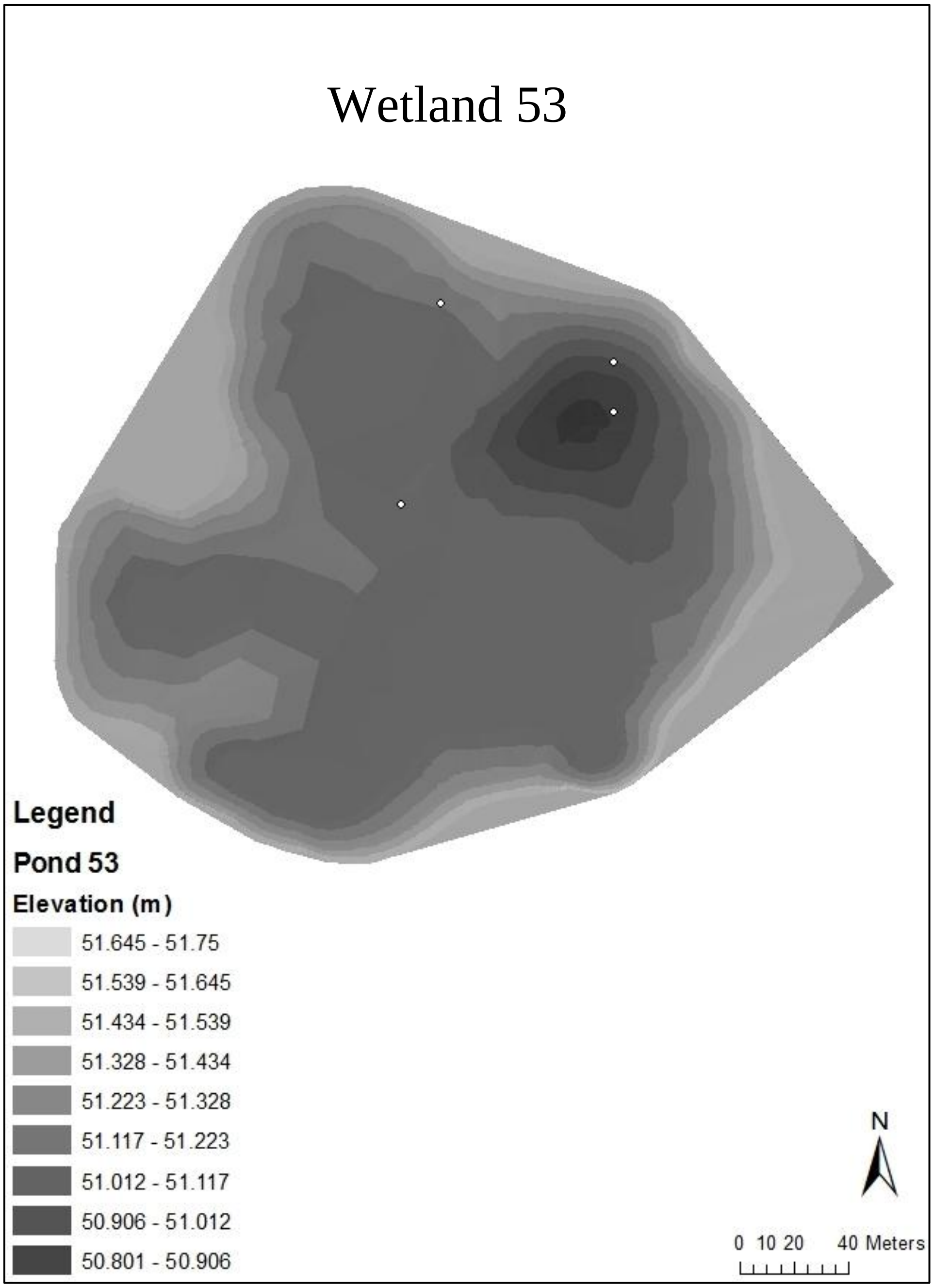

Figure 4-7. Contour map of Wetland 53 at Ichauway, Baker County, Georgia, showing locations of telemetered *Chelydra serpentina* and *Trachemys scripta* (white dots). Darker colors represent lower elevation.

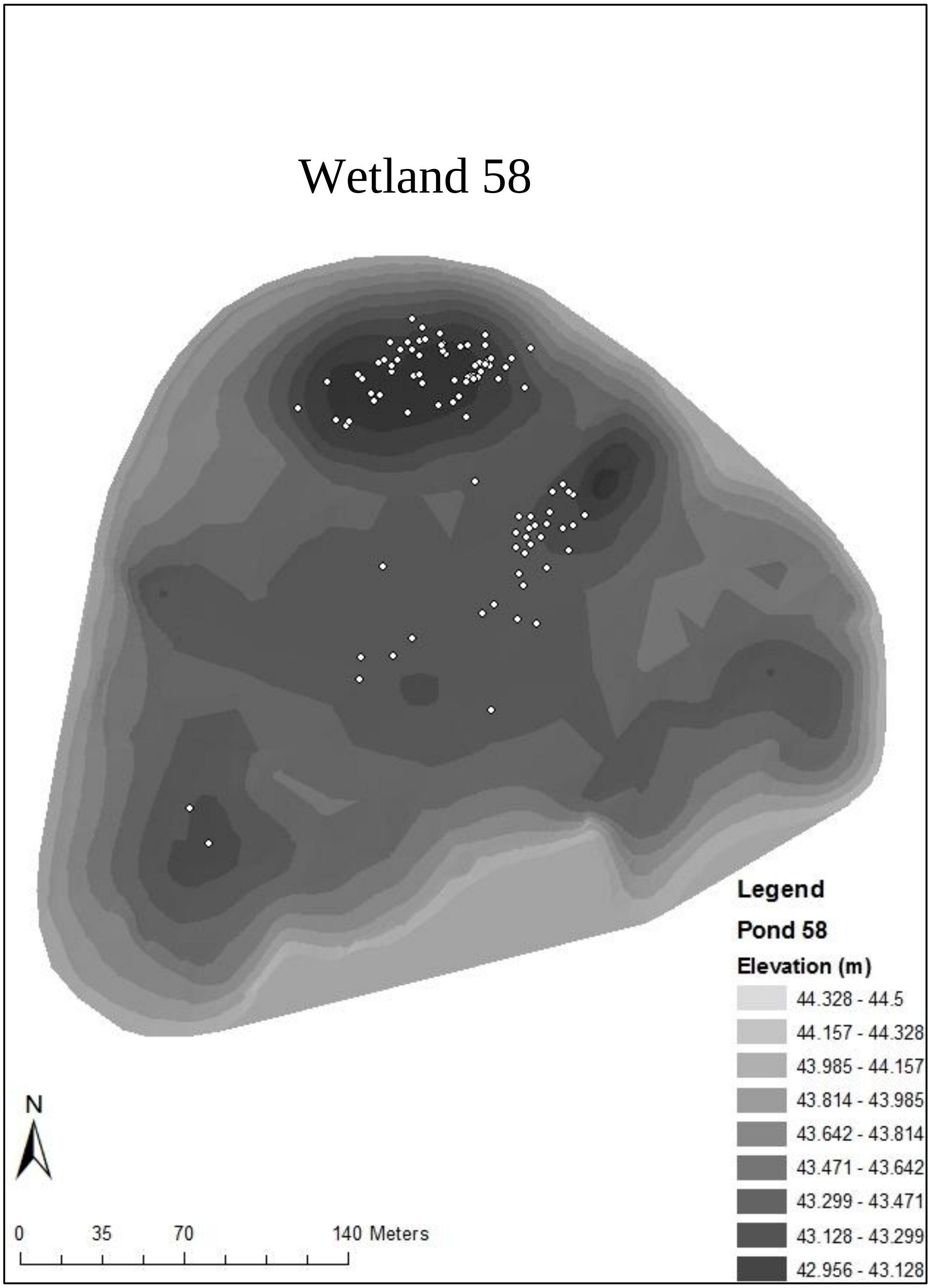

Figure 4-8. Contour map of Wetland 58 at Ichauway, Baker County, Georgia, showing locations of telemetered *Chelydra serpentina* and *Trachemys scripta* (white dots). Darker colors represent lower elevation.

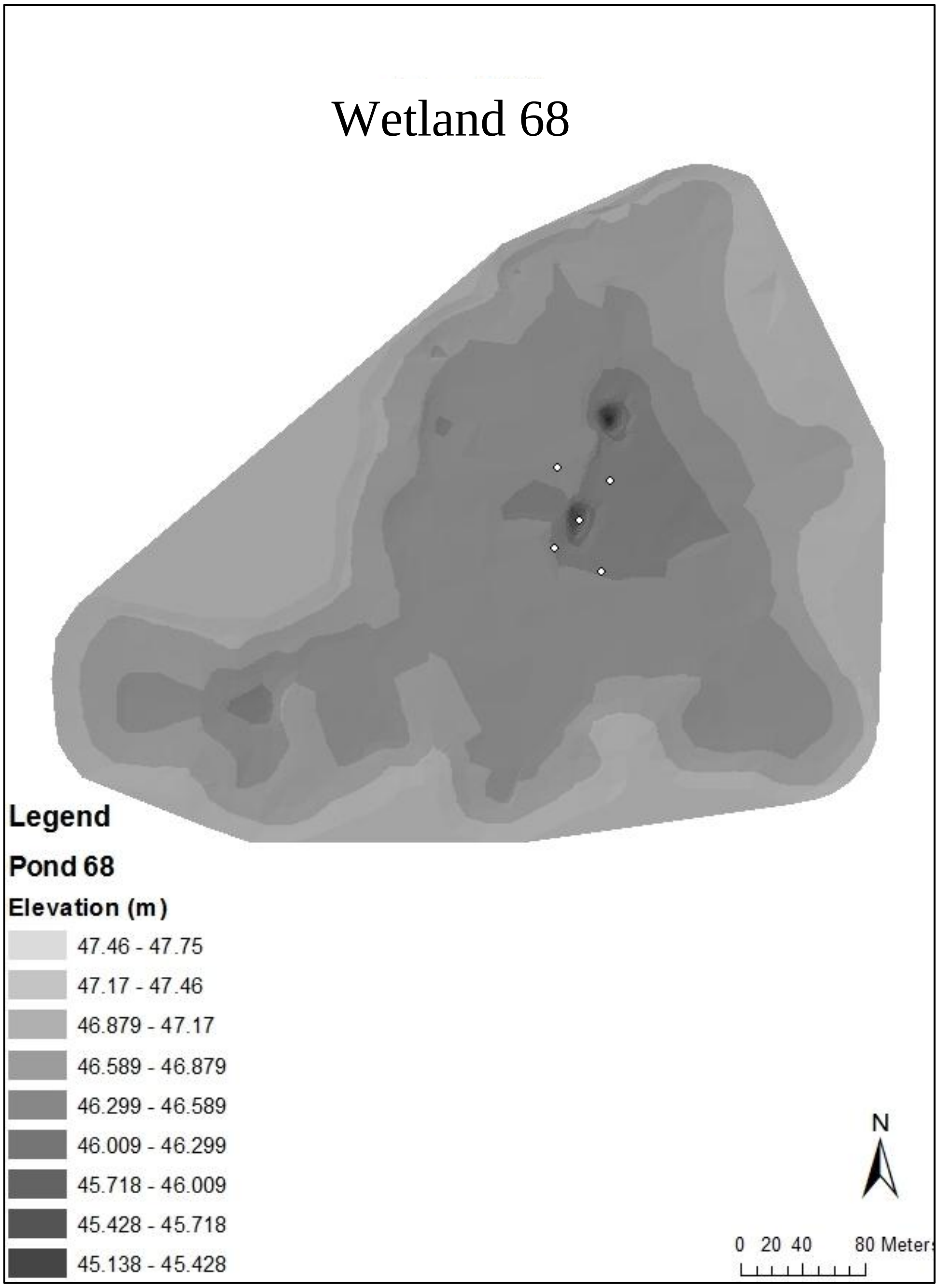

Figure 4-9. Contour map of Wetland 68 at Ichauway, Baker County, Georgia, showing locations of telemetered *Chelydra serpentina* and *Trachemys scripta* (white dots). Darker colors represent lower elevation.

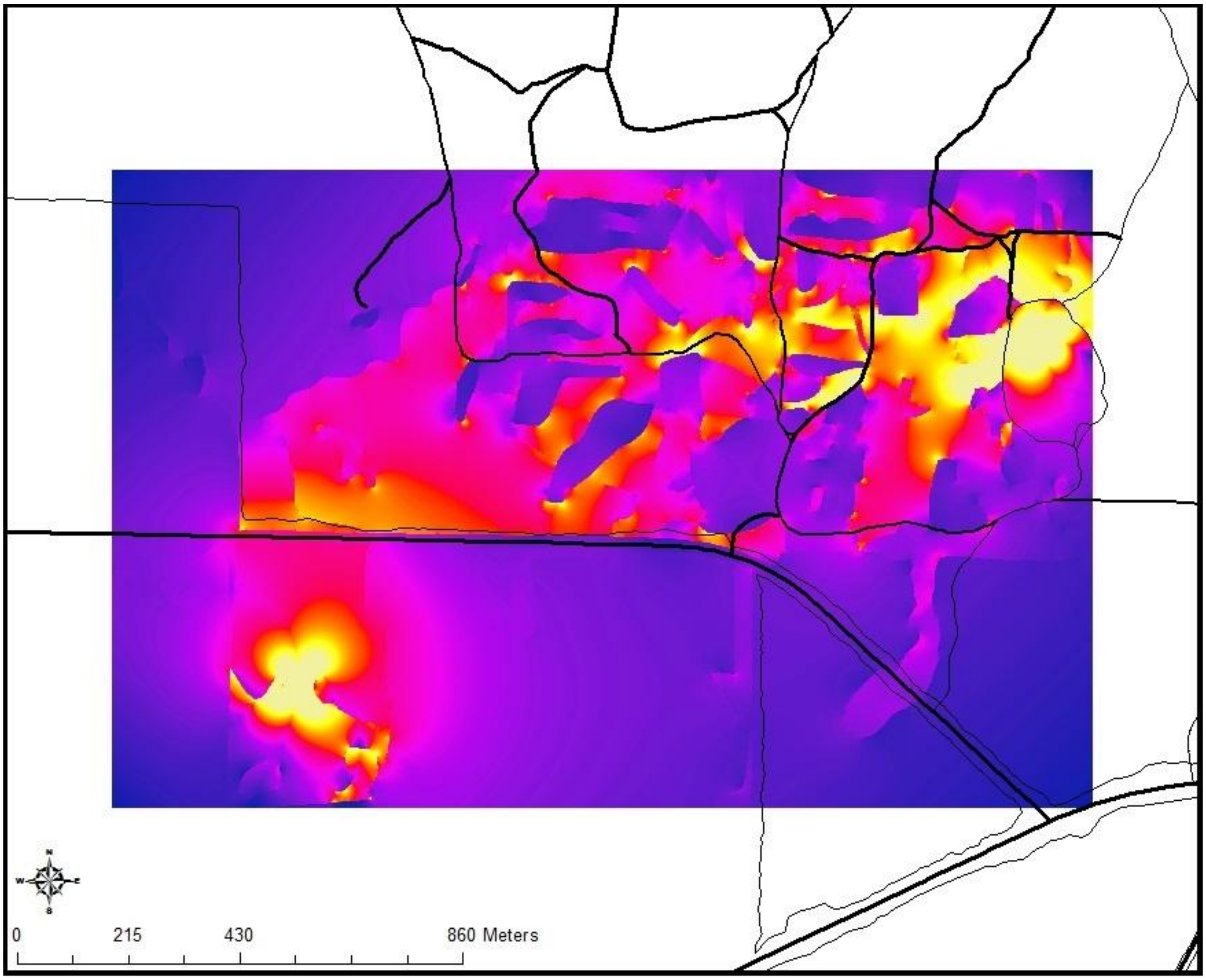

Figure 4-10. Current maps used to model probable movement between core habitat areas (blue polygons) for adult *Chelydra serpentina* ID # 470 at Ichauway, Baker County, Georgia. Warmer colors indicate areas with higher current density and greater ease of movement. Black lines indicate roads.

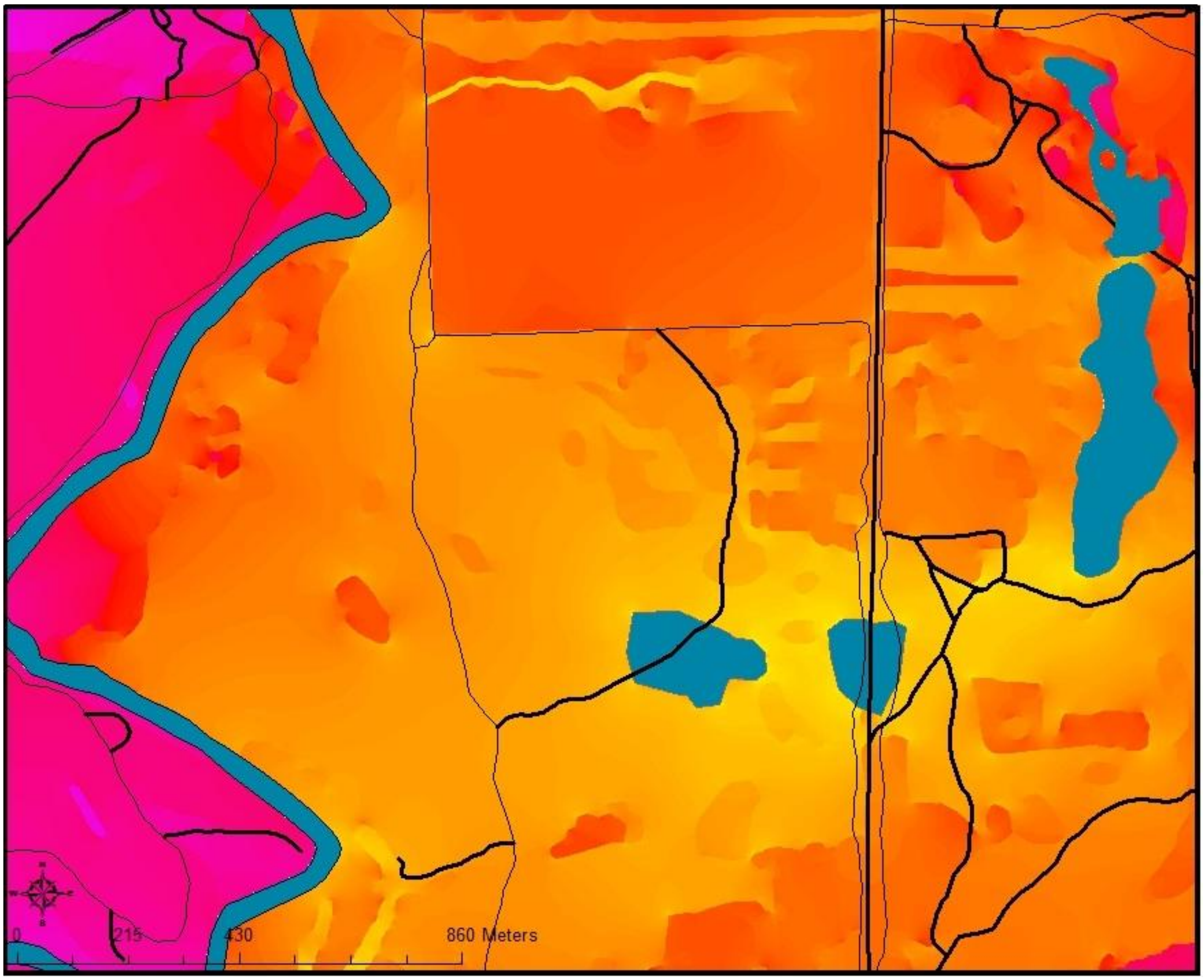

Figure 4-11. Current maps used to map probable movement between core habitat areas (blue polygons) for adult *Trachemys scripta* ID # 1821 at Ichauway, Baker County, Georgia. Warmer colors indicate areas with higher current density and greater ease of movement. Black lines indicate roads.

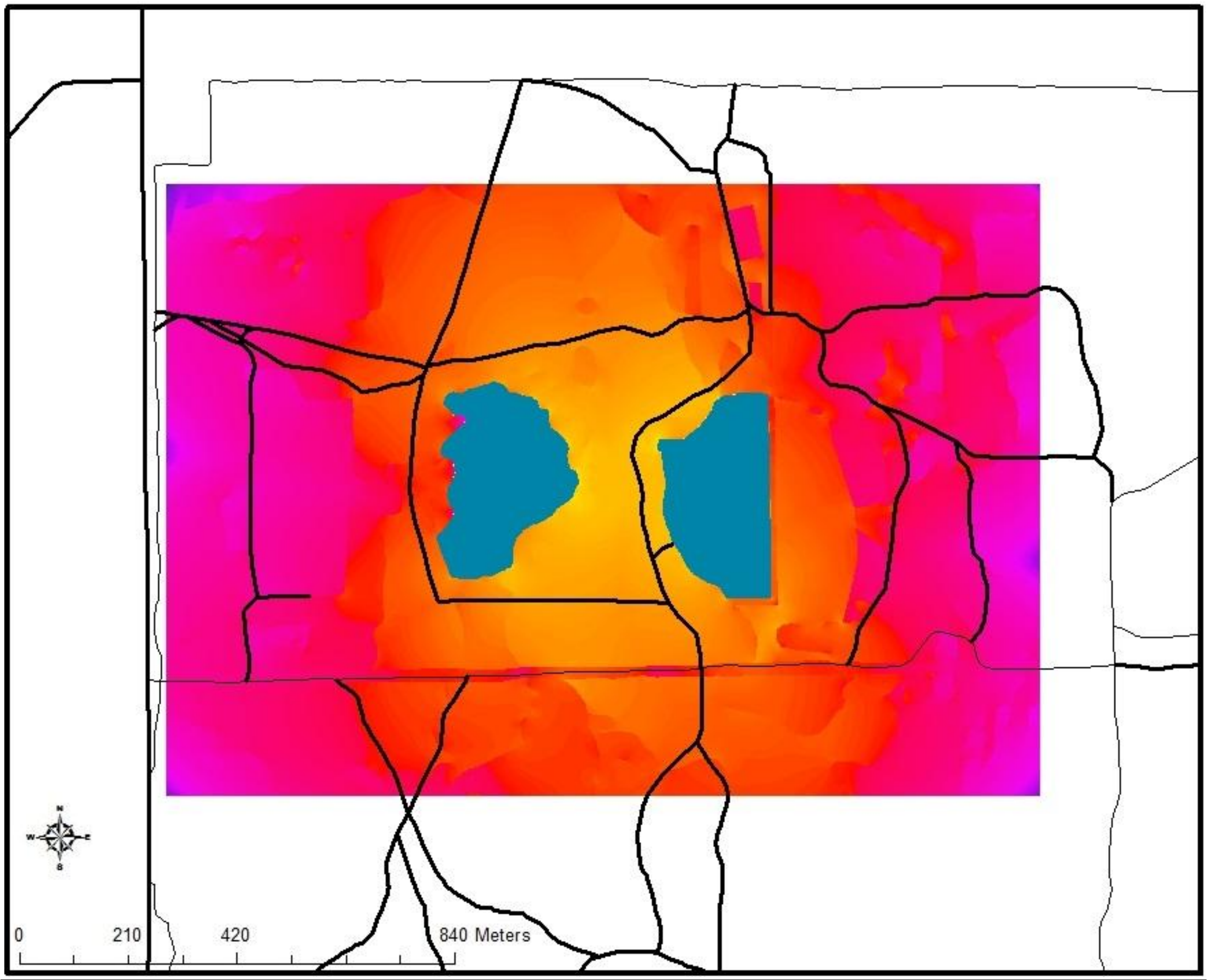

Figure 4-12. Current maps used to map probable movement between core habitat areas (blue polygons) for adult *Chelydra serpentina* ID # 260 at Ichauway, Baker County, Georgia. Warmer colors indicate areas with higher current density and greater ease of movement. Black lines indicate roads.

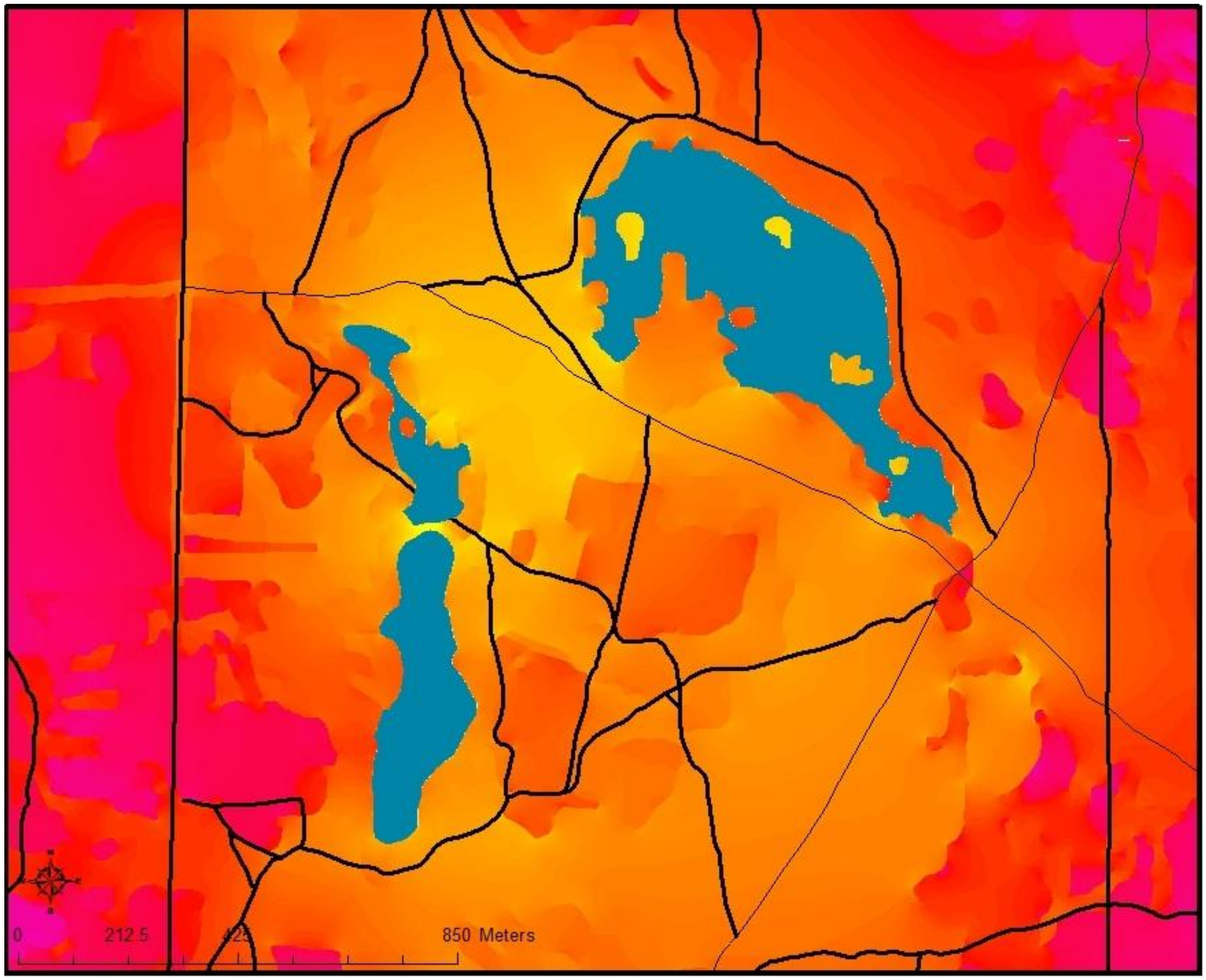

Figure 4-13. Current maps used to map probable movement between core habitat areas (blue polygons) for adult *Chelydra serpentina* ID # 490 at Ichauway, Baker County, Georgia. Warmer colors indicate areas with higher current density and greater ease of movement. Black lines indicate roads.

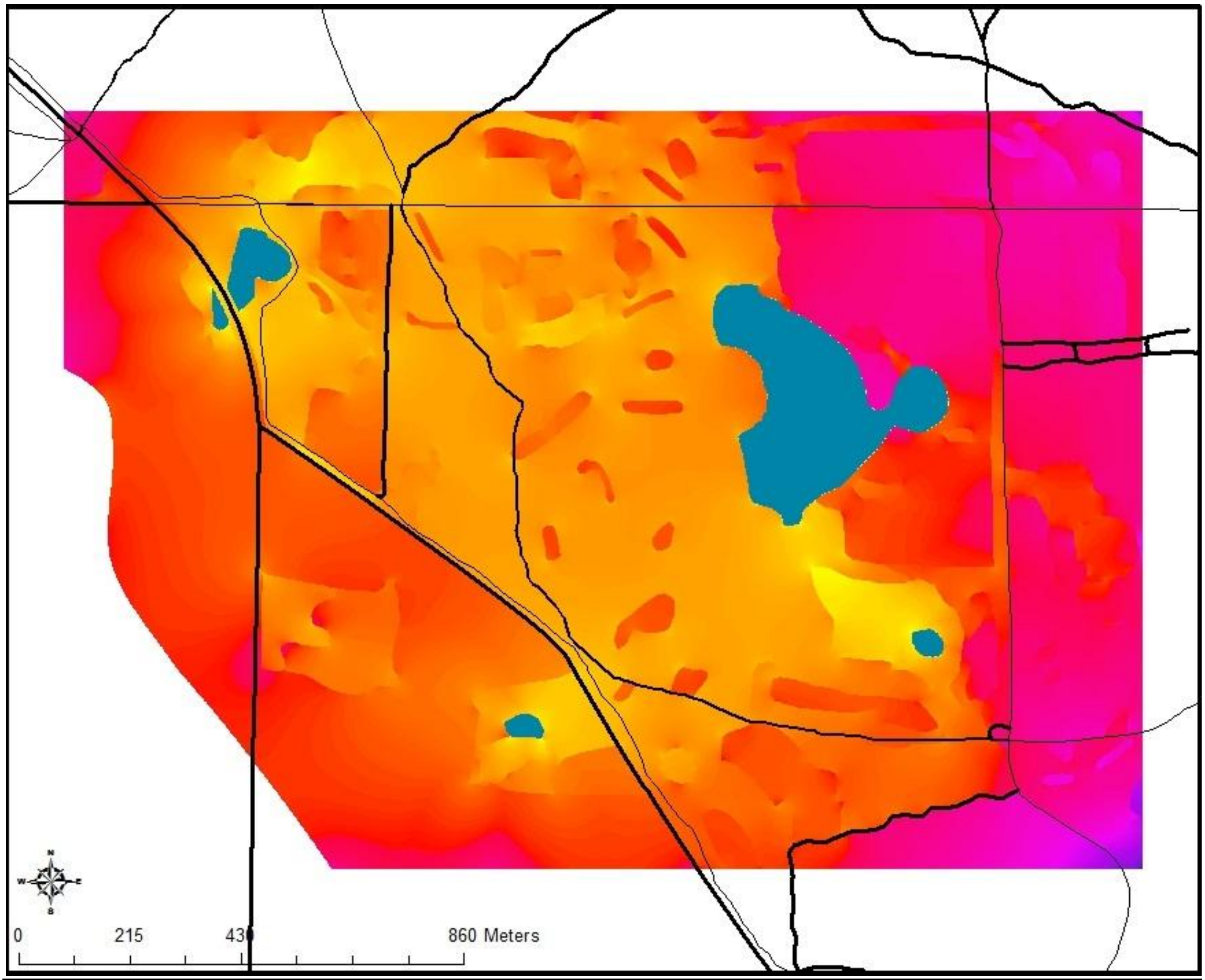

Figure 4-14. Current maps used to map probable movement between core habitat areas (blue polygons) for adult *Chelydra serpentina* ID # 540 at Ichauway, Baker County, Georgia. Warmer colors indicate areas with higher current density and greater ease of movement. Black lines indicate roads.

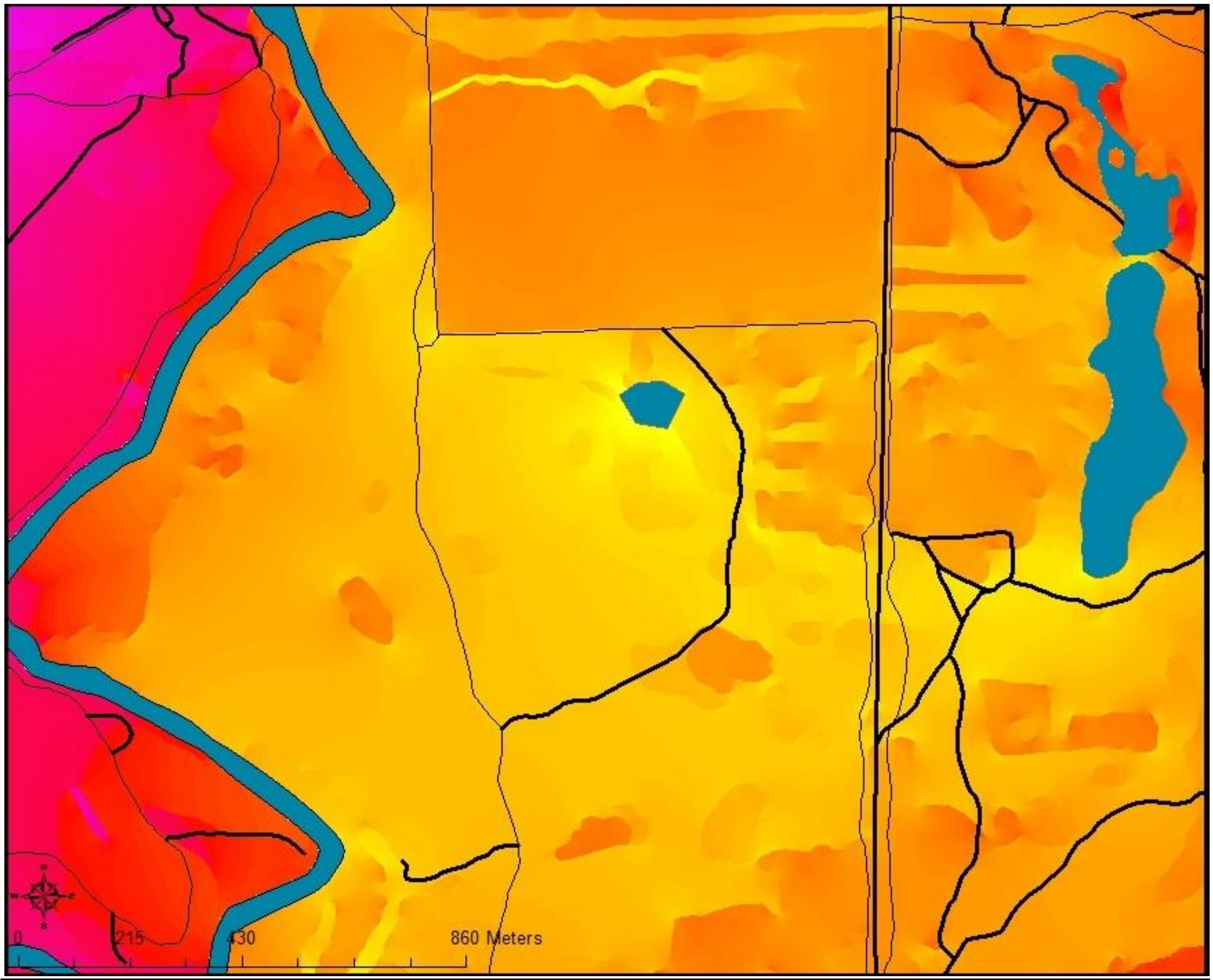

Figure 4-15. Current maps used to map probable movement between core habitat areas (blue polygons) for adult *Trachemys scripta* ID # 1813 at Ichauway, Baker County, Georgia. Warmer colors indicate areas with higher current density and greater ease of movement. Black lines indicate roads.

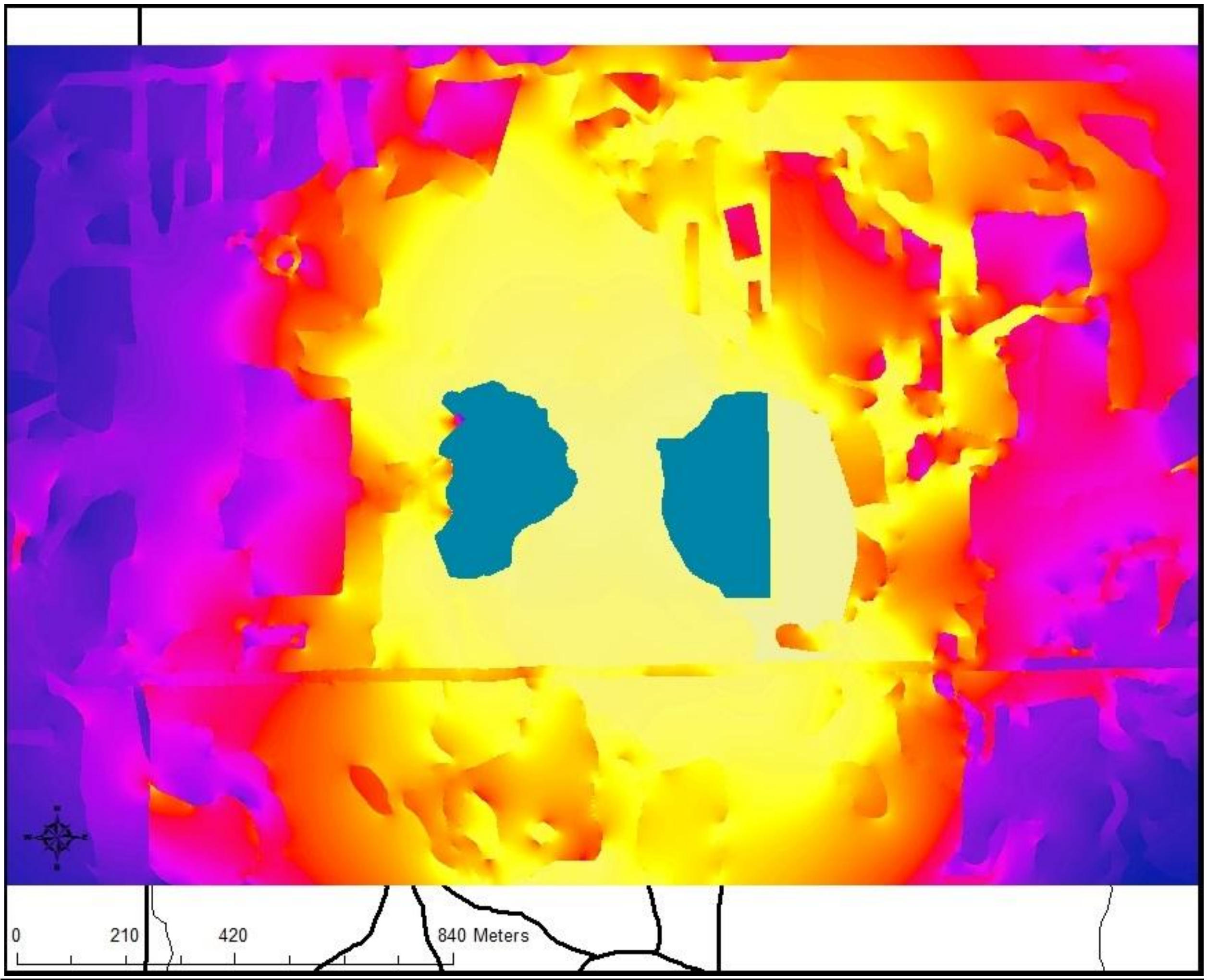

Figure 4-16. Current maps used to map probable movement between core habitat areas (blue polygons) for adult *Trachemys scripta* ID # 1814 at Ichauway, Baker County, Georgia. Warmer colors indicate areas with higher current density and greater ease of movement. Black lines indicate roads.

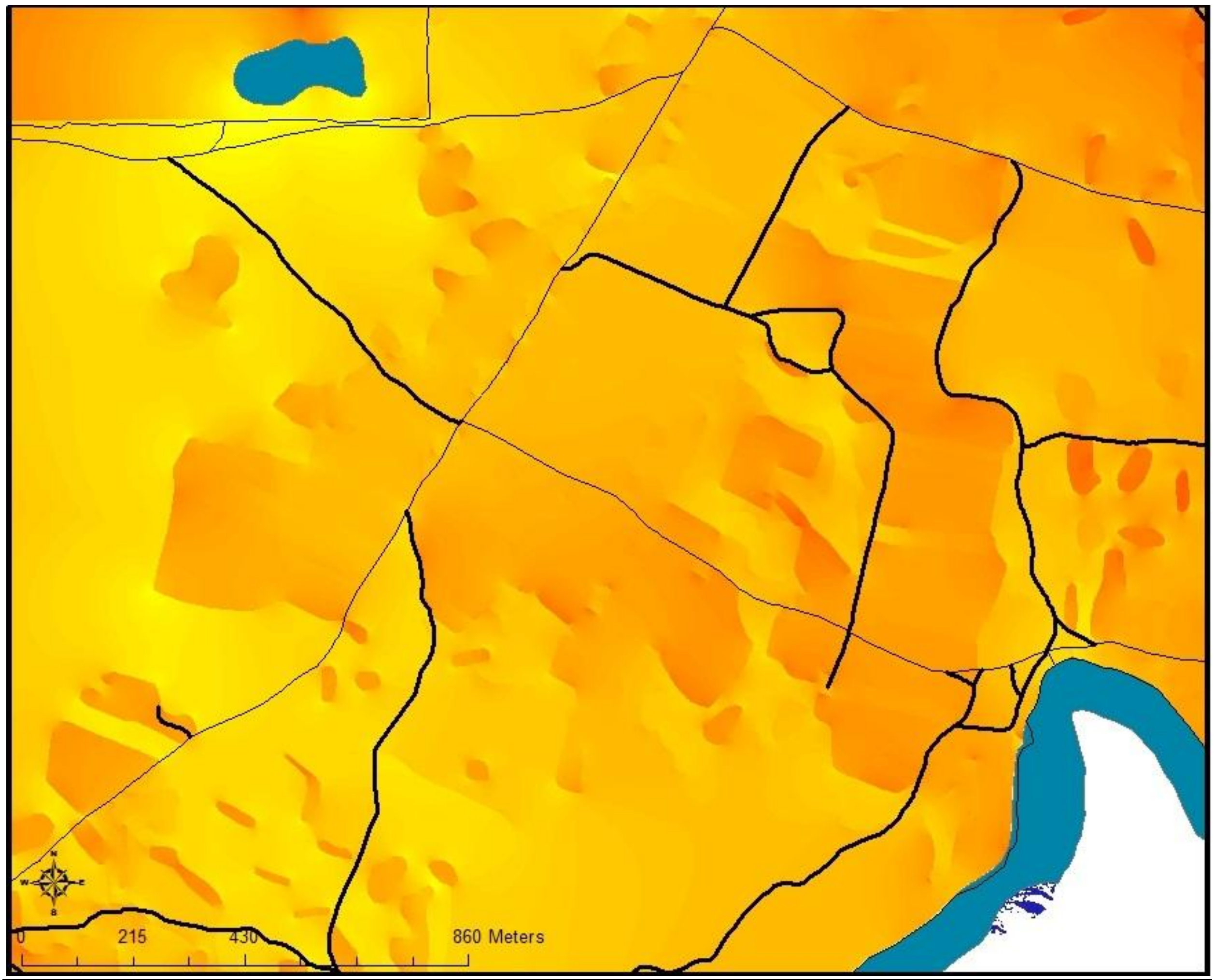

Figure 4-17. Current maps used to map probable movement between core habitat areas (blue polygons) for adult *Trachemys scripta* ID # 1815 at Ichauway, Baker County, Georgia. Warmer colors indicate areas with higher current density and greater ease of movement. Black lines indicate roads.

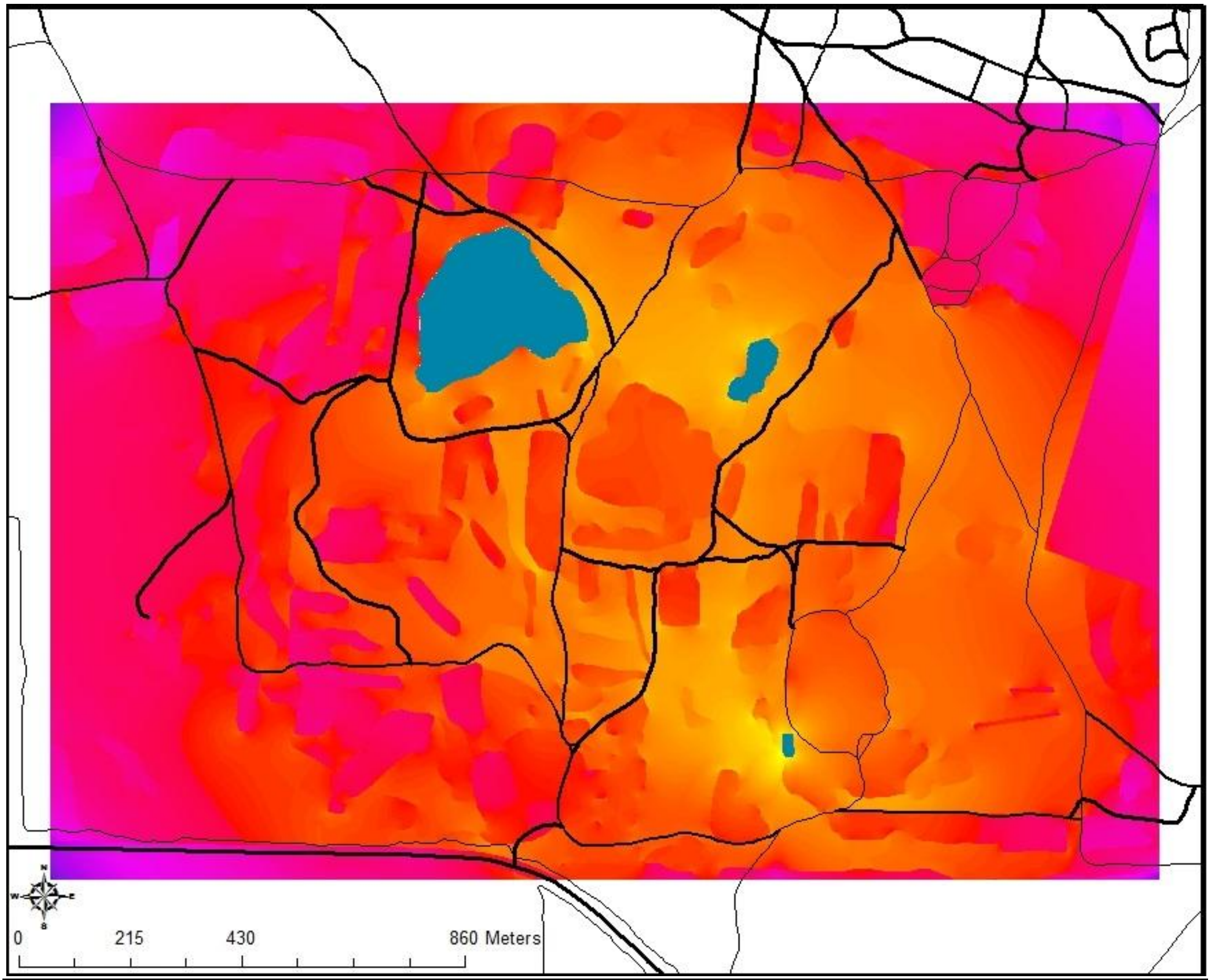

Figure 4-18. Current maps used to map probable movement between core habitat areas (blue polygons) for adult *Trachemys scripta* ID # 1817 at Ichauway, Baker County, Georgia. Warmer colors indicate areas with higher current density and greater ease of movement. Black lines indicate roads.

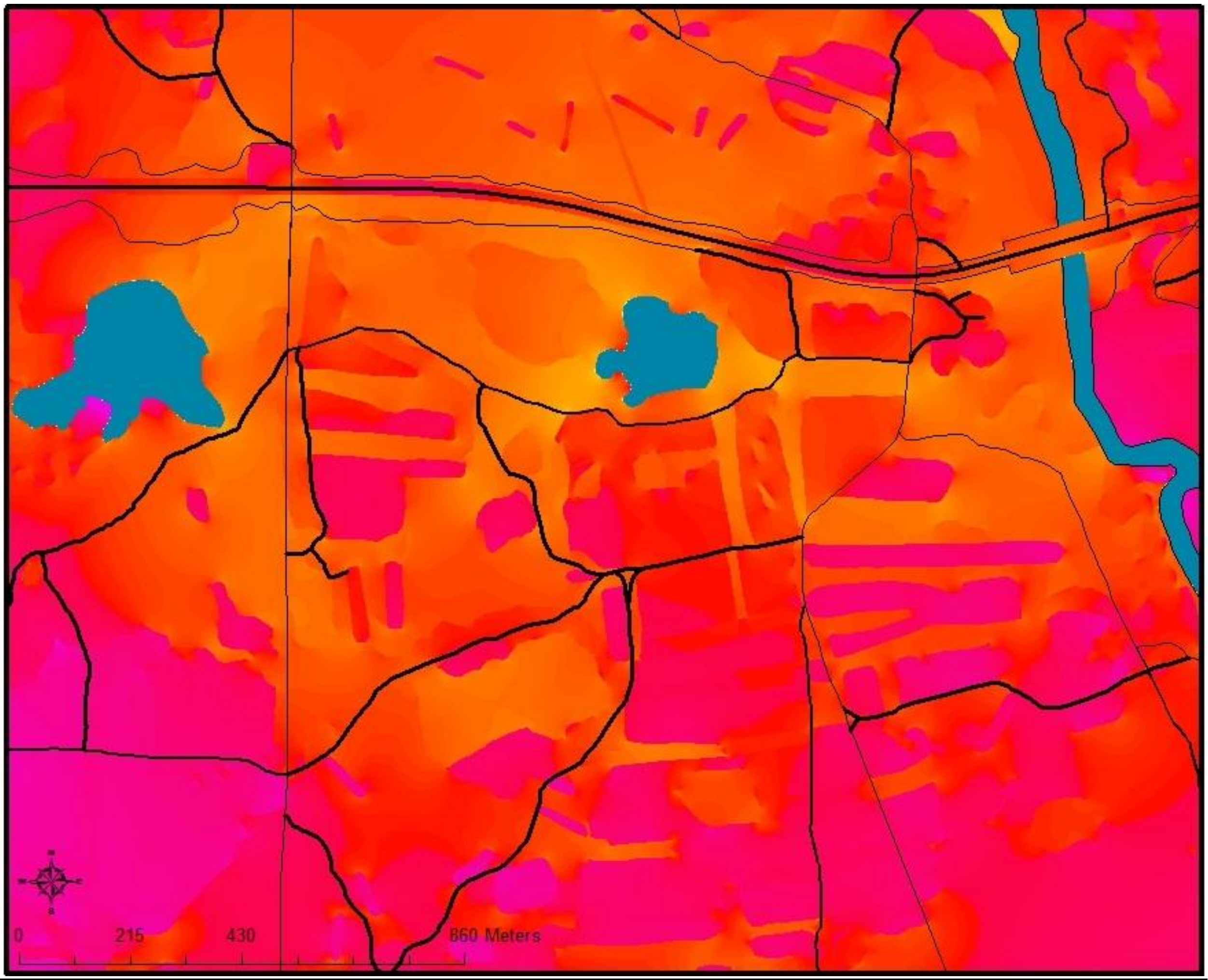

Figure 4-19. Current maps used to map probable movement between core habitat areas (blue polygons) for adult *Trachemys scripta* ID # 1824 at Ichauway, Baker County, Georgia. Warmer colors indicate areas with higher current density and greater ease of movement. Black lines indicate roads.

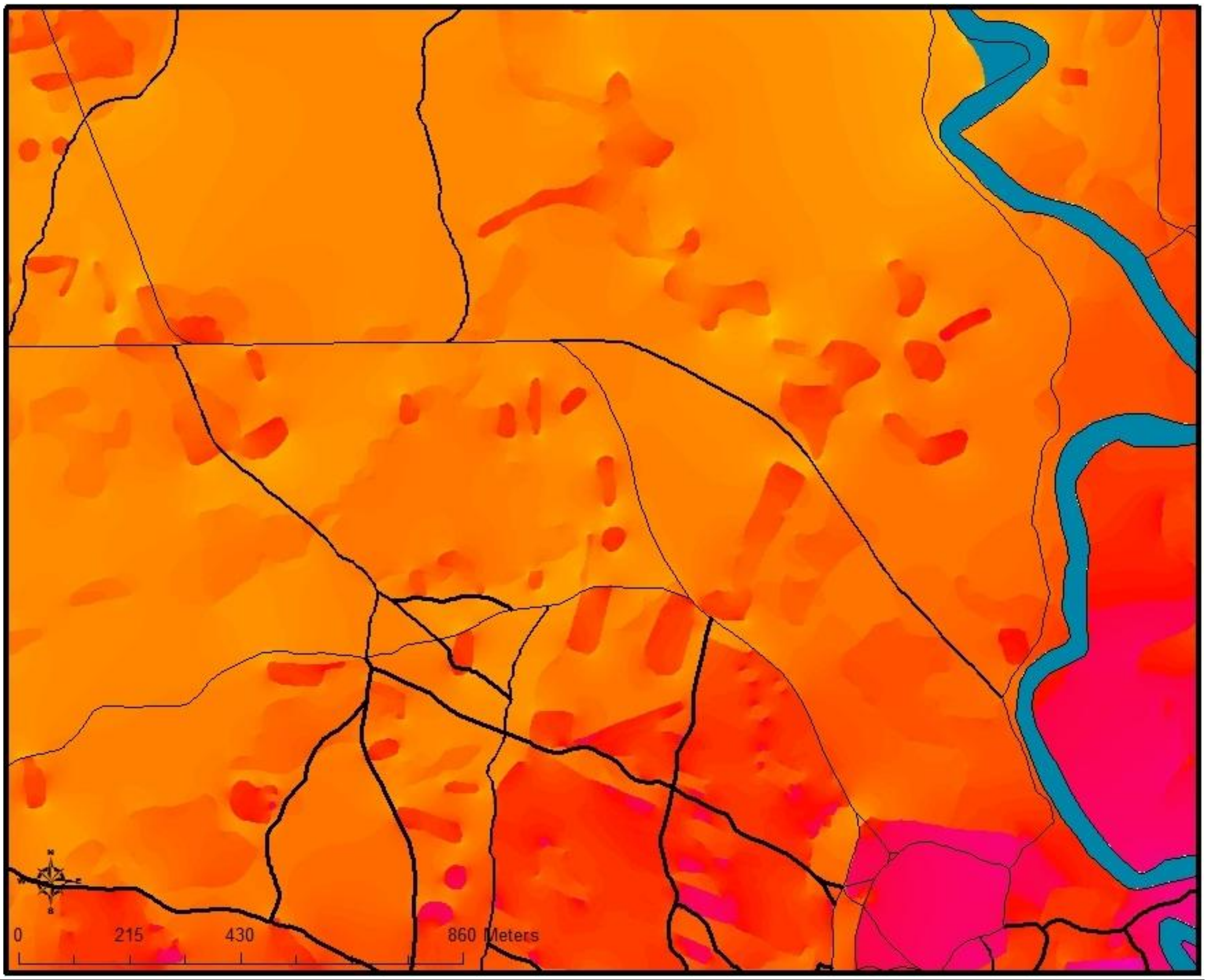

Figure 4-20. Current maps used to map probable movement between core habitat areas (blue polygons) for adult *Trachemys scripta* ID # 1825 at Ichauway, Baker County, Georgia. Warmer colors indicate areas with higher current density and greater ease of movement. Black lines indicate roads.

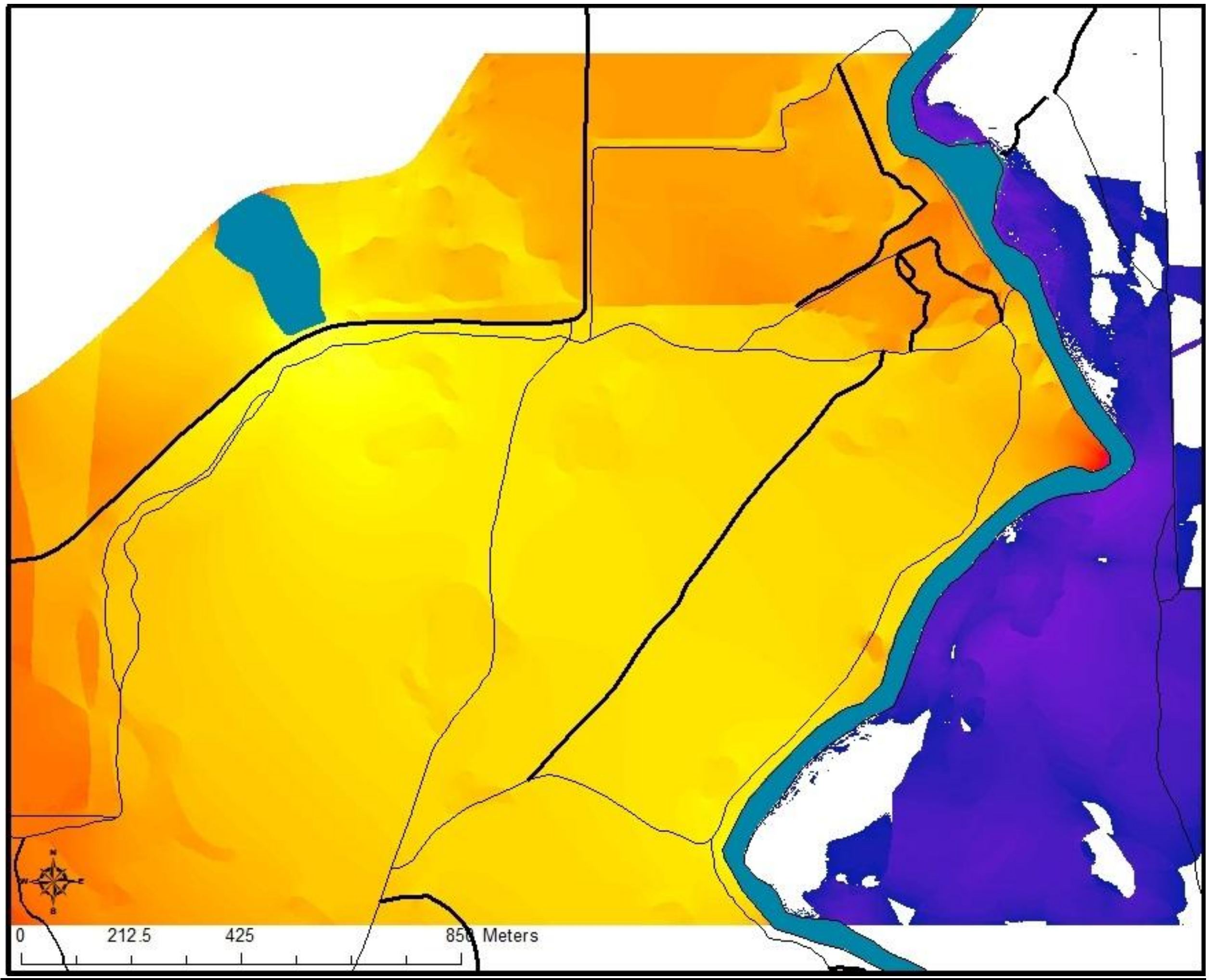

Figure 4-21. Current maps used to map probable movement between core habitat areas (blue polygons) for adult *Trachemys scripta* ID # 1851 at Ichauway, Baker County, Georgia. Warmer colors indicate areas with higher current density and greater ease of movement. Black lines indicate roads.

CHAPTER 5

Conclusions and Management Recommendations

Many studies have been conducted on aquatic turtles in the Southeastern U. S., yet little is known about habitat selection and movements of turtles among geographically isolated wetland systems, streams, and through the surrounding uplands landscapes. Both aquatic turtles and isolated wetlands have been adversely affected by human land use and other activities in the coastal plain of Georgia (Buhlmann and Gibbons, 1997; Kusler, 2001), and this study aimed to expand knowledge on turtle use of isolated wetlands and show evidence of wildlife connectivity within and among isolated wetlands and other aquatic habitats. Specifically, the objectives of this study were to 1) describe differences in aquatic turtle assemblages in streams and geographically isolated wetlands in the Dougherty Plain of Georgia; 2) use detection probabilities and radio telemetry of turtles to identify important wetland variables predicting turtle occupancy of isolated wetlands; 3) examine patterns of overland movement and terrestrial habitat associations of aquatic turtles; and 4) generate theoretical corridors of terrestrial movement between aquatic systems by turtles.

I trapped aquatic turtles in geographically isolated wetlands and Ichawaynochaway Creek on Ichauway a private reserve managed for longleaf pine forest, to determine species assemblages in these ecosystems. I found distinct difference in turtle presence, with only two species, *Trachemys scripta* and *Chelydra serpentina*, present in the stream and wetlands. Although both systems had similar estimates of species richness, the turtle assemblages were dissimilar, signifying that both geographically isolated wetlands and stream systems are needed to support regional turtle diversity. Captures of turtles were low compared to other studies (Frazer et al., 1990; Thomas et al., 2008; Sterrett, 2009). However, this may have been due to prolonged drought conditions that affected the hydrology of both the creek and the isolated wetlands (United States Drought Monitor, 2012).

I determined the detection probabilities of turtles in geographically isolated wetlands using occupancy modeling (MacKenzie et al. 2004). Specifically, I attempted to determine whether vegetation type, wetland size, proximity to the creek and other wetlands, hydroperiod, and surrounding forest cover influenced occupancy of wetlands by turtles. Of seven species were detected, captures were dominated by, *T. scripta*. I found that for most species, detection probability decreased with an increase in surrounding forest cover, while the detection probability of *T. scripta* was highest in smaller wetlands. These results were unexpected, as I hypothesized that large wetlands with a high percentage of surrounding forest cover would have the highest turtle detection probabilities. I suggest these results may be due to an overall low capture rate following a long term drought in which most isolated wetlands were dry (unpublished data). My results may have also been biased by the high catch per unit effort in a single wetland near the border of the study site, and by the increased capture probability in smaller wetlands. My telemetry study on *T. scripta* and *C. serpentina* also provided insight into isolated wetland characteristics important to aquatic turtles. Both species primarily used cypress gum swamps, but also used grassy marshes and off-site agricultural ponds, and preferred the deepest areas within these wetlands. Overall, *T. scripta* selected a wider variety of aquatic habitats than *C. serpentina* including hardwood depressions and the creek. Both species' use of agricultural ponds was interesting and I suspect that these altered wetlands, which often have an extended hydroperiods (RLK pers. obs.) provide suitable habitat for these and perhaps other turtle species, particularly when isolated wetlands are not inundated.

My study showed that aquatic turtles in the Dougherty Plain use a wide array of isolated wetland types and make frequent and extensive overland movements within the landscape. Among the species in my study, *T. scripta* exhibited the most overland activity, *Apalone ferox, C. serpentina*, *Deirochelys reticularia*, *Pseudemys concinna*, and *Pseudemys floridana* also showed a propensity to move overland. Many individuals moved or were located > 1 km from aquatic habitats, and one radio-tagged turtle (*C. serpentina*) travelled overland > 3 km during the study. The extensive movements of turtles in the Dougherty Plain may be due to the dynamic hydroperiods of isolated wetlands that may force both sexes to move frequently and use isolated wetlands as "stepping stones" to obtain resources and aquatic refuges necessary for survival and growth.

I used a long term data set of observations of *T. scripta* on land to determine if turtles were moving through particular landcover types. Logistic regression models indicated that *T. scripta* preferred moving through upland pine forests and other undisturbed habitats (i.e., hardwood pine mix, hardwood forests) near bodies of water, and avoided moving through open scrub, agricultural fields and pine plantations. I was able to use these results to model potential movement corridors for turtles between aquatic habitats at Ichauway using ArcGIS, Linkage Mapper, and Circuitscape software (ArcGIS version 9.3; Earth Systems Research Institute, Redlands, CA; McRae and Shah, 2009; McRae and Kavanagh, 2011; Zeigler et al., 2011; McRae et al., 2012). Linkage Mapper and Circuitscape have the potential to be useful management tools for identifying movement corridors for aquatic turtles, and both succeeded in generating theoretical pathways using Euclidean distance and landscape permeability between core habitats.

Circuitscape also demonstrated how both distance and landcover permeability affect resistance to movement of turtles. Landcover permeability became less of a factor to resistance as distance between core habitats decreased, and more of a factor as distance increased. This concept is important since many wetlands in the Southeast Coastal Plain have become altered or lost and much of the historic landcover has become converted to less permeable habitat for turtles.

The use of geographically isolated wetlands, agricultural ponds, and streams within the Dougherty Plain suggests that aquatic turtles, like the American alligator (*Alligator mississippiensis*), demonstrate a faunal connection among aquatic systems in this region (Subalusky et al., 2009). However, the extent to which turtles may represent a functional connection among these systems is unknown and warrants additional study. My results suggest the extensive movements of turtle among multiple wetlands and other aquatic ecosystems signifies the need to manage turtles in the Southeastern Coastal Plain at a larger scale than previously considered (Semlitsch and Bodie, 2007), with conservation of multiple aquatic ecosystems upwards of several kilometers from one another and their surround permeable landscape instead of single bodies of water.

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