THE ECOLOGY AND INFLUENCE OF LAND USE ON RIVER TURTLES IN SOUTHWEST GEORGIA

by

SEAN CHRISTOPHER STERRETT

(Under the Direction of John Maerz and Sara Schweitzer)

ABSTRACT

Human activities such as agriculture are a major factor influencing the current distribution and abundances of species. I used two survey methods, hoop trapping and snorkeling, to obtain estimates of detectability for riverine turtles, and to measure the relationship between percent forest cover within a 287-m buffer and turtle abundance, species richness, and evenness along two streams in southwest Georgia. Further, I used radio-telemetry to study habitat use by Barbour's map turtle (*Graptemys barbouri*), which is a species of conservation concern. Turtle evenness increased with increasing forest cover; however, turtle abundance declined with increasing forest cover as a result of an increased abundance of a generalist species, the yellow-bellied slider. Barbour's map turtle abundance increased with forest cover. Barbour's map turtle used deep pools with large woody debris, suggesting that removing riparian forest cover may reduce debris inputs important to the Barbour's map turtle and other aquatic species.

INDEX WORDS: Flint River Basin, land use, agriculture, spatial ecology, detection probability, Barbour's map turtle, yellow-bellied slider

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DEDICATION

This work is dedicated to my family, especially Mom, Mama K, and Aunt Lisa, the trio of women who raised me and have wholeheartedly supported my career path. It is also dedicated to the first natural area I have truly cared about, Ichawaynochaway Creek.

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CHAPTER 1

INTRODUCTION

Historical and Current Land Use Practices in Southwest Georgia

Many streams and riparian forests of the Southeastern Coastal Plain, including the Lower Flint River Basin (LFRB), have a long history of being degraded by human activities (Buhlmann and Gibbons 1997). Beginning in the 1700s with major human settlement, snagging operations throughout the early 1800s and continuing through the 1900s with river regulation and pollution, streams have been managed for human benefit with little thought to ecological consequences (Sedell et al. 1982).

In southwestern Georgia, the human population of many rural counties has been declining since 1920 and farming has consolidated into larger industrial row-crop farming operations and are now concentrated in the uplands (Ward et al. 2005). Riparian forests have regenerated and are approaching maturity (Michener et al. 1998). Currently, agricultural lands encompass approximately 25% of the Apalachicola-Chattahoochee-Flint (ACF: 50,688 km^2) River Basin (Ward et al. 2005) and approximately 50% of the Lower Flint River Basin (Golladay and Battle 2001). Cultivated land is mainly planted in corn, soybeans, peanuts, and cotton, and pasture lands are also abundant (Ward et al. 2005). Surface and ground water withdrawal permits for crop irrigation are plentiful in the area. Existing permits allow withdrawals of ≥368 mgal/day (238 ft^3/sec, Hicks and Golladay 2006). Both creeks in this study experience seasonal withdrawals for irrigation. Spring Creek is primarily impacted by groundwater withdrawal, whereas Ichawaynochaway Creek is more impacted by surface water withdrawal (Hicks and Golladay 2006).

The Georgia Erosion and Sedimentation Act of 1975 (GaDNR 2000 amendment) requires maintenance of an undisturbed, 15.24-m (50-ft) riparian buffer for secondary trout streams and a minimum 7.62-m (25-ft) buffer on all other state waters. However, several activities are exempt from maintaining riparian buffers, including surface mining, granite quarrying, common gardens, and agricultural operations (Georgia Erosion and Sedimentation Act, 1975). The Georgia Best Management Practices for Forestry suggest streamside management zones of 12.2 - 30.5 m, which take into account important parameters including slope and the erosive nature of the stream bank soils (Georgia Forestry Commission 1999). Three-zone buffer systems consisting of undisturbed area, managed forest area, and grassy areas around streams have been proposed primarily for agricultural land (Welsh 1991). However, these systems are only recommendations and compliance is voluntary in Georgia. In a review of buffer recommendation guidelines, the narrowest buffer width guidelines of any region in the United States occur in the Southeast where the greatest diversity of water body types occur (Lee 2004). Research on the persistence of riverine biota following regeneration of riparian forests may offer useful information for stream restoration efforts. A comparison of river reaches abutting intensive row-crop agriculture to reaches where streamside forests have regenerated and matured provides an opportunity to study the role of riparian forests in sustaining wildlife, and to evaluate the potential for riparian restoration to affect the conservation of declining river fauna.

Effects of Land Use on Aquatic Biota

Many effects of land use on freshwater systems have been recognized and targeted for regulation in the last few decades, including non-point source pollution (reviewed by Carpenter 1998), sedimentation (Lowrance et al. 1986), channelization (Williamson et al. 1992, Zaimes

2006), and altered instream woody debris (Gurnell and Sweet 1998, Angradi et al. 2004, Nakamura 2005). Most studies involving the effects of anthropogenic land use on aquatic biota have focused on macroinvertebrates, amphibians, and fishes. The effects of human land use on other taxa, such as reptiles, birds, and mammals, have been less well studied, despite the fact that many of these taxa are among the most threatened in the U.S. (Allan 1993). A survey of freshwater biologists identified agricultural activities as the top-rated threat to freshwater fauna in the U.S. (Richter et al. 1996).

Macroinvertebrates, fishes, and salamanders have been the focus of studies on land use pressures likely because they are often considered good indicators of stream health (Schiemer and Zalewski 1992, Wallace and Webster 1996, Welsh and Ollivier 1998). However, it is not known whether these species are affected more by local riparian conditions or by land use at the watershed scale (Allan et al. 1997, Moerke and Lamberti 2006). A study of fishes in north Georgia found that an assemblage, especially those species with specialized reproductive behavior, was negatively affected by upstream riparian deforestation (Jones 1999). In eastern Indiana, Sullivan (2004) used IBI metrics and found that fish community quality was negatively affected by channelization and changes in substrate in an area used primarily for row-crop agriculture. However, Meador and Goldstein (2003) studied stream sites across the U.S. and found that indirect factors such as sediment and nutrient loading may influence fish community composition, rather than land use per se. Nerbonne and Vondracek (2001) compared local land use of areas with farms using conventional agriculture and farms that have adopted best management practices in Minnesota, and concluded that land use is not as important as riparian management that impacts instream habitat directly.

Similar findings on effects of land use and buffers on aquatic salamanders have been reported. Wilson and Dorcas (2003) concluded that the amount of undisturbed habitat around streams in North Carolina may be a major factor in predicting stream salamander abundance. In southwest Georgia, there was a greater abundance of larval two-lined salamanders (*Eurycea cirrigera*) in stream reaches buffered from cattle access than in unbuffered reaches (Muenz et al. 2006). Numerous studies have demonstrated a connection between land use and the abundance and composition of aquatic macroinvertebrates (Richards 1993, Townsend et al. 1997, Wang et al. 1997, Lammert and Allan 1999, Sponseller et al. 2001, Hall and Killen 2005, Muenz et al. 2006), and have lead to recognition of the utility of these organisms as biological indicators of stream health (see Norris and Thoms 1999).

Historical land use is also an important factor to consider when assessing the structure and condition of present-day stream ecosystems. Several studies have found that land use history, particularly agriculture and urbanization, may have long term effects on instream habitat and aquatic communities, regardless of whether riparian zones have subsequently reforested (Harding et al. 1998, Iwata et al. 2003). Maloney et al. (2008) found that some streams had not fully recovered from agricultural impacts in the mid-1940s. Long term impacts primarily included streambed instability, which may reduce available habitat for macroinvertebrates and fishes. Therefore, land use history creates another layer of complexity when evaluating current land use effects on aquatic ecosystems. Perhaps more importantly, these studies elucidate the need to manage watersheds and protect riparian zones because of their inability to quickly recover following disturbance.

Since the early 1980s, riparian buffers, sometimes referred to as conservation buffers, have been studied as tools for functional mitigation of anthropogenic effects on aquatic systems.

Functionally, riparian buffers have served several purposes in mitigating anthropogenic effects on streams. Filtration of nutrients is one of the most studied functions of riparian buffers (Lowrance et al. 1984). Other functional roles of conservation buffers include mitigating erosion (Zaimes 2004), sedimentation (Lowrance et al. 2001), and providing habitat for riparian species (Semlitsch and Bodie 2003). However, riparian buffers do not protect core terrestrial habitat, which is required by many semi-aquatic species (Gibbons 1970a, Buhlmann 1995, Burke and Gibbons 1995, Bodie 2001, Semlitsch and Bodie 2003, Steen et al. 2007).

Effects of Stream Modification and Anthropogenic Land Use on Aquatic Turtles

Direct effects of human activities on riverine turtles, like exploitation for food (Klemens and Thorbjarnarsen 1994), recreational nesting pressures (Moore and Siegel 2006), and road mortality (Gibbs and Steen 2004), are harmful to turtle populations, while indirect pressures from land use activities may be damaging to turtles but they are often inconspicuous and difficult to detect (Moll and Moll 2000). Indirect effects of stream modification may include changes to the prey base or instream habitats. Abundance and distribution of aquatic turtles can be affected by changes in substrate, geomorphology, and channel morphology in riverine habitat (DonnerWright et al. 1999). Vandewalle and Christenson (1996) found that dredging, clearing and snagging, damming for reservoirs, and channel straightening, decreased species richness of riverine turtles in the Mississippi River Basin of Iowa. Species that were completely eliminated from disturbed sites included the common map turtle (*Graptemys geographica)* and smooth softshell (*Apalone mutica)*. Bodie (2001) suggested that, reduction of snags and log jams, pollution and siltation, flow regulation, and agriculture and urban land use, all common practices within the U.S, may have detrimental indirect effects on aquatic turtles. Large scale land use changes such as row-crop agriculture, deforestation, and mining are of concern for river turtles because of the potential for runoff and siltation of streams (Moll and Moll 2000). A textbook example of the detrimental effects of human land use on river turtles is the flattened musk turtle (*Sternotherus depressus*), which was nearly extirpated from the Warrior River Basin of Alabama due to mining operations (Dodd 1990). Land clearing and impoundments associated with the mine fragmented the already imperiled musk turtle populations and mining operations caused instream sedimentation and pollution. Urbanization is also suspected to affect freshwater turtle species richness and abundance. In a study that evaluated urbanization and turtle abundance, painted turtles (*Chrysemys picta)* were positively associated with forested land cover around wetlands (Marchand and Litvaitis 2004a). Some species are more resilient to land use change than others. For example, spiny softshell (*A. spinifera*) populations persisted despite heavy stream modification in an urban landscape (Plummer et al. 2008a). Turtles have also been affected by changes in nesting habitat in human modified sites (Kolbe and Janzen 2002). Marchand and Litvaitis (2004b) simulated turtle nesting to evaluate effects of human development and found clumped nests were depredated at a higher rate than nests that were spread across a landscape. Semlitsch and Bodie (2003) reviewed literature on aquatic turtle (both lentic and lotic species) use of terrestrial habitat and found mean minimum and maximum use of terrestrial habitat to be 123 and 287 m, respectively. Further, they found that riparian zones are core habitat for turtles that use riparian habitat to nest, thermoregulate and move through the landscape.

Specifically, agricultural land is thought to be detrimental to turtle populations but relatively few studies on this subject have been pursued. Agriculture alters the demography, mutilation rates, and growth of the wood turtle (*Glyptemys insculpta*; Saumure and Bider 1998).

Rizkalla and Swihart (2006) assessed the abundance and distribution of freshwater turtles in Indiana and found that abundance of red-eared sliders (*Trachemys scripta elegans*) was negatively affected by agricultural fragmentation. In a study of farm ponds in Oklahoma, temporal changes in abundance of several lentic species of turtle were found, including a decrease in a formerly common species, *Kinosternon subrubrum* (Stone et al. 1993). In contrast, populations of sliders (*T. s. elegans*) and painted turtles (*C. picta*) remained constant over time in these ponds. The temporal changes observed were attributed to a combination of factors related to land use including cattle grazing and fertilization. No studies have specifically examined the effects of agricultural land use on turtle assemblages in rivers. The impacts of agricultural irrigation on the hydrology of the LFRB are an issue that has been neglected. Since the 1970s, center pivot agriculture has expanded and has recently become a point of concern, especially during times of drought (Hicks and Golladay 2006). Golladay et al. (2004) found negative effects of record droughts on freshwater mussels in the LFRB with mussels using remaining pools of water under pieces of LWD. Although, no direct evidence exists, the compounded effects of drought and high agricultural irrigation may contribute to several negative effects on aquatic turtles including a decrease in available prey and forced movement due to lack of preferred habitat.

Freshwater turtle communities include both generalists and specialists, based on life history requirements such as diet and habitat preferences (Moll and Moll 2004). Specialists often have a limited geographic range and/or depend on particular habitat or diet, unlike generalists, that are often found in many aquatic environments (Moll and Moll 2000, 2004). While some species are able to thrive in altered habitats (Knight and Gibbons 1968, Gibbons 1970, Galaith and Sidis 1984, Sidis and Galaith 1985), those with specialized habitat or dietary requirements are often negatively impacted (Dodd 1990, Luiselli 2006). Some species, often those typically associated with lentic habitats, may occasionally fill river turtle niches, thereby shifting community composition (Moll and Moll 2004). These community shifts were found in the Illinois River where clearing and draining land for human use drastically reduced populations of some specialists like the Blanding's turtle (*Emydoidea blandingii)*, yellow mud turtle (*Kinosternon flavescens*), and smooth softshell (*A. mutica*, Moll 1980). Generalists, like the slider (*T. s. elegans*), false map turtle (*G. pseudogeographica*), and common snapping turtle (*Chelydra serpentina*), thrived in this altered environment, indicating that individual species characteristics may be a critical element when considering best management practices for river turtles as a group.

While it is generally held that stream and riparian zone modifications are likely harmful to most river turtles, there are examples of how these practices can be beneficial to turtles as well. Habitats that have been thermally influenced or nutrient enriched, enhance growth rates of individuals and population reproductive rates in some generalist species (*C. picta*, Knight and Gibbons 1968; *T. scripta*, Gibbons 1970b). High abundance and biomass of Geoffrey's side-necked turtle (*Phrynops geoffroanus*) were attributed to the pollution and degradation within an urban area in Brazil (Souza and Abe 2000). The lack of predators and ability to exploit human organic waste as a food source likely supported the proliferation of this species (Souza and Abe 2000). However, while human alteration of habitat may appear to benefit some species, this is likely a reflection of the ability of these species to exploit available resources and their tolerance of a wide range of conditions. Conservation action should focus on stream modifications that threaten biodiversity as a whole.

Spatial Ecology of River Turtles

Turtles move for several reasons: foraging, seeking appropriate refugia, basking, breeding, and nesting (Gibbons 1990). Nesting movements may require significant expenditures of energy for river turtles, depending on the distance to suitable nesting habitat (Moll and Moll 2004). Several studies have attempted to estimate the extent of freshwater turtle movements using mark-recapture or observational data (Sanderson 1974, Pluto and Bellis 1988, Buhlmann and Vaughn 1991). More recently, radio telemetry provides more accurate accounts of river turtle movements (Jones 1996, Bodie and Semlitsch 2000, Ryan et al. 2008).

The range of habitats used by many river turtles is not clear, although this knowledge is inherently imperative to the conservation of these animals. Home range, originally defined for mammals, is “that area traversed by the individual in its normal activities of food gathering, mating and caring for young” (Burt 1943). Modifications of this definition, including thermoregulation and nesting, make this definition applicable to reptiles. Estimates of daily movement for river turtles can help identify the extent and types of habitat necessary to conserve individual species. Map turtles (*Graptemys* spp.), for example, include several state and federally protected species and are often drainage-specific river specialists in the southern U.S., yet more are widespread in their habitat use in the northern part of their range. Three studies in natural settings (Vogt 1980, Pluto and Bellis 1988, Jones 1996) and one in an urban setting (Ryan et al. 2008), suggest map turtles have relatively large, linear home ranges. Jones (1996) found no significant differences in behavior between radio-marked male and female yellow-blotched map turtle (*G. flavimaculata*), which had home ranges of 0.5 to14 ha, and long distance movements commonly occurring in spring and fall. Common map turtles make large, short-term movements, as much as 1457.5 m in one day (Pluto and Bellis 1988). Ryan et al. (2008) found that *G. geographica* living in Indianapolis, used expansive parts of a canal, with a mean total range distance of 3 km. Buhlmann and Vaughan (1991) tracked a female and male river cooter (*Pseudemys concinna*) and found that they used 1.2 and 1.6 ha, respectively, with maximum movements of 358 and 321 m, respectively. Sterrett et al. (2008) used mark-recapture data and detected one river cooter that moved 1470 m in 5 hours, and another that moved 6350 m in less than 3 days. The reason for these long movements was unclear. The red-bellied turtle (*P. nelsoni),* a close relative to *P. concinna*, with closer ties to lentic habitats, used 120 m of spring run habitat in Rock Spring Run, Florida (Kramer 1995). Another semi-aquatic emydid turtle, the wood turtle (*G. insculpta*), used a large home range of 40.6 ha during the summer (Remsberg et al. 2006). While wood turtles are known to use river habitat, they also have great affinity for terrestrial areas during certain parts of the year unlike other river turtles that are strictly aquatic. One river turtle that rarely leaves the water is the Alligator snapping turtle (*Macrochelys temminckii*). In Oklahoma, *M. temminckii* had mean linear home ranges of 777.8 m, with female home ranges significantly larger than males (Riedle et al. 2006). In this study, they also noted distances moved between highly used sites to be 431.2 m for juveniles and 219.3 m for adults. Harrel et al. (1996) studied the movements of sub-adult alligator snapping turtles in Louisiana and found movements between fixed locations to vary between males and females but were comparable to movements for juveniles and adults found by Riedle et al. (2006). Although not covered fully in this review, sexual differences in movements may be attributed to many ecological functions like sexual dimorphism, often a proxy for diet, and reproductive voyages made by males for courtship and females for nesting.

Habitat use of River Turtles and Importance of Large Woody Debris

Knowledge of habitat requirements of aquatic turtles is essential information for management (Moll 1996). Turtles use various riverine habitats, from backwater sloughs to sandy runs or deep pools to rocky limestone shoals (Ernst et al. 1994). Fuselier and Edds (1994) studied habitat partitioning of three sympatric *Graptemys* species and determined that basking sites and substrate type were key factors in separating species. Lindeman (2003) found that habitat use of *G. versa* differed between males and females due to dietary differences. Various age/size classes within a species may also use habitat differently. Pluto and Bellis (1986) suggest that swimming speed, thermoregulation, and predator avoidance are important factors in habitat choice among size classes of map turtle.

Map turtles habitat use may differ from other groups because of their specific life history requirements, especially in the southeastern U.S. *Graptemys* spp. are sexually dimorphic and among most species, males and females have different diets; males eat mostly insects and small mollusks, while females rely heavily on mollusks. Because of differences in diet, male and female *Graptemys* may also use different habitats (Lindeman 1999). Alligator snapping turtles and river cooters are highly riverine and are often found in deep areas under rocky or woody shelter (Jenson 2008, Fahey and Buhlmann 2008). Basking sites may be a limiting factor for the persistence of the river cooter (Buhlmann and Vaughan 1991). The spiny softshell (*A. spinifera*), although referred to as an ecological generalist (Plummer et al. 2008), often selects clear, sandy-bottomed stream habitats in the Coastal Plain (Buhlmann 2008). Several recent studies have examined how substrate may be a determinate in growth and morphology of *Apalone* sp. (Plummer et al. 2008b, McGaugh 2008). Bodie and Semlitsch (2000) found frequent use of floodplain by *G. pseudogeographica* during flooding events in the Missouri River. Further, these turtles used all types of flood-scoured habitat, from forests to agricultural land. As with turtle movements, habitat use is likely a complex characteristic composed of sex, size, season and specific to particular turtles that live in rivers.

Snagging, or removal of large dead wood, from rivers has been a common practice throughout the southeastern U.S. (Sedell et al. 1982, Sedell and Froggatt 1984). However, the importance of large woody debris (LWD) to aquatic biota, its function in streams, and as habitat to aquatic turtles such as *Graptemys*, has been recognized (Lindeman 1999). Several authors have mentioned roles that LWD play in streams for aquatic turtles, such as resting, grazing substrate, thermoregulation, and protection from aquatic predators (Chaney and Smith 1950, Shively and Jackson 1985, Lindeman 1999, Jones 1996).

Goals and Implications of the Current Study

In this study, I addressed several questions related to aquatic turtles in the LFRB and the Southeastern U.S. In Chapter 2, I examine the efficacy of different sampling methods for turtles in the LFRB. While several different methods for capturing turtles are recognized, a comparison of effectiveness, biases associated with each and estimates of detection probability are lacking. In Chapter 3, I examine the relationship between land use and aquatic turtle assemblages. The objective of this study was to assess species richness and abundance of aquatic turtles on two major tributaries of the lower Flint River (Ichawaynochaway Creek and Spring Creek) and determine how variations in these measures may be related to surrounding land cover. Chapter 4 focuses on the spatial ecology of Barbour's map turtle (*G. barbouri*), a relatively understudied species despite its protected status. The goal of these studies was to provide insight into the ecological needs and anthropogenic effects, including land use and changes in instream habitats, of riverine turtles to aid aquatic conservation efforts to manage these species.

Description of Study Area

This study was conducted on Ichawaynochaway Creek (Baker County) and Spring Creek (Decatur and Miller Counties), both of which are tributaries to the Flint River Basin in southwest Georgia. The lower Flint River basin is part of the Dougherty Plain district, characterized by karst topography with Ocala limestone (Ward et al. 2005). Both creeks have ground water inputs fed primarily by the Upper Floridian Aquifer, the shallowest aquifer in the region (Hicks and Golladay 2006). In the Lower Flint River, rocky limestone shoals and deep, wide, sandy pools are common. The Apalachicola-Chattahoochee-Flint River Basin contains the highest reptile species diversity in the U.S., largely due to diversity of the physical landscape (Livingston 1992). Ichawaynochaway Creek on the Ichauway reserve has been private since 1993, and offers a large stretch of minimally disturbed stream habitat.

Both creeks in this study contained large amounts of coarse woody debris as well as “deadhead” logs (Kaeser and Litts 2008). In the late 1800s and early 1900s forest harvest was extensive in the southeast were prominent and large, old growth cypress (*Taxodium* spp.) and pine (*Pinus* spp.) trees were removed. Logs were bundled together to form rafts that were floated down creeks and rivers to lumber mills (described in Sedell et al. 1982). Rafts occasionally foundered, depositing what are now called “deadhead” logs in the stream channels. Deadhead logging has become a conservation concern because these logs contribute greatly to the total LWD in Coastal Plain streams and the integrity of instream habitat (Kaeser and Litts 2008).

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CHAPTER 2

SURVEY METHODS FOR MAXIMIZING DETECTION AND NUMBERS OF RIVER TURTLES IN THE SOUTHEASTERN COASTAL PLAIN

Introduction

There is increasing recognition of the importance of incorporating detection probabilities in herpetological surveys (MacKenzie et al. 2002, Mazzerolle et al. 2007). This information is particularly important when a suite of capture techniques is required to detect all species present (Liner 2006). When using a suite of capture techniques (Ream and Ream 1966), the practicality of chosen methods must be considered (Plummer 1979). To justify inferences made from population studies, like relative abundances or treatment effects on populations, the incorporation of detection probabilities is necessary (Mazzerolle et al. 2007).

Most aquatic turtles are readily captured in baited hoop traps (Legler 1960) or fyke nets (Vogt 1980). However, other trapping methods such as basking traps (Ream and Ream 1966, MacCulloch and Gordon 1978) are used to capture herbivorous and molluscivorous turtles, like *Pseudemys* spp. and *Graptemys* spp., respectively, that do not readily come to bait (Plummer 1979). Many studies rely on multiple methods to capture the wide array of turtle species, although the detection probabilities of the individual and combinations of techniques remain unknown (Dreslik et al. 2005, Smith et al. 2006, Browne and Hecnar 2007).

Many studies mention snorkeling (earlier known as “goggling”) as a technique to supplement other methods of aquatic turtle capture (Marchand 1945, Chaney and Smith 1950, Allen and Neil 1950). Hand capture via snorkeling is effective for some species of aquatic turtles particularly in clear, shallow lakes and rivers. For example, Cagle (1952) collected 393

Barbour's map turtles (*Graptemys barbouri*) from the Chipola River in Florida in 12 days of snorkeling. Marchand (1945) was also successful in capturing 163 *Pseudemys* spp. via snorkeling in Rainbow Run, a spring-fed river in west-central Florida. Polisar (1995) found that snorkeling for *Dermatemys mawii* resulted in more captures than any other method used in tributaries of the Belize River. Further, the snorkel method captured all size classes of *D. mawii*. However, the associated physical constraints and challenges of standardizing a snorkeling method are numerous. Some species like *Apalone* spp. are fast swimmers, making their capture more difficult than most species (S. Sterrett, per. obs.). Polisar (1995) described some challenges with free diving for turtles such as seasonal restrictions due to turbidity and stream depth and the observer's ability to reach all depths and search for turtles. Controlling for observer bias and effort with this technique allows for comparisons of captures between sites.

The objectives of this study were to 1) compare the detection probabilities of two survey methods (baited hoop traps and effort-managed snorkel surveys) in capturing aquatic turtles within streams in southwest Georgia, and 2) compare individual methods with the combination to estimate species richness and to gather information on abundance of aquatic turtles in southwest Georgia. The associated caveats and limits of methods used in this study also will be discussed.

Methods

Study Area

The study took place on Ichawaynochaway (Baker County) and Spring Creek (Decatur and Miller Counties) in the Lower Flint River Basin (LFRB) of southwest Georgia (Fig. 2.1). Study sites were located in the Dougherty Plain physiographic district, characterized by karst topography (Ward et al. 2005). Most streams have regenerated riparian forests composed of bald cypress (*Taxodium distichum*) and red cedar (*Juniperus virginiana*; Golladay and Battle 2002). Southwest Georgia has a high variability of annual rainfall with an average of 1270 mm per year (Golden and Hess 1991). In drainages of the LFRB, rocky limestone shoals and deep, wide, sandy pools are common. Both creeks have ground water inputs fed primarily by the Upper Floridan Aquifer, which is the shallowest aquifer in the region (Hicks and Golladay 2006). During low flows in late spring and summer, both creeks are clear enough to see the bottom in most areas unless there have been recent rain events which reduce visibility. Both tributaries support a diverse aquatic fauna, including at least seven river turtle species (Jensen et al. 2008).

Turtle Surveys

Seven randomly selected 1.5-km study reaches were identified on each creek (Fig. 2.1) and a 0.5-km section in the center of each 1.5-km reach was the focus of survey effort. Surveys took place from June-August 2007 on Ichawaynochaway Creek and June-September 2008 on Spring Creek. At both creeks, surveys were conducted twice over the sampling period using both baited hoop traps and effort-managed snorkel surveys.

During each survey, five large (1.2-m dia, 4 hoops, 3.8-cm mesh size) and five small (0.9-m dia, 3 hoops, 3.8-cm mesh) fish-baited hoop traps (Memphis Net and Twine, Memphis, TN) were placed in the 0.5-km stretch within the center of each 1.5-km study reach. Traps were set approximately 50 m apart on alternating banks where traps were mostly inundated by water. Traps were set for five nights on each stretch and were checked daily and re-baited as necessary. Total trapping effort for the study was 100 trap-nights at each creek (50 trap-nights x 2 surveys per sampling period).

During snorkel surveys, we controlled for search effort (3-4 surveyors for 2-3 hrs [exact time was recorded]), time of day (1300 h start time, when possible), and surveyor experience. During each survey, the study reach was searched twice (upstream and downstream), although high capture rates did not allow for this on one site. To the extent possible, surveyors thoroughly searched all potential turtle habitat within the stream. However, due to safety concerns, they were unable to free dive into deep holes (>4 m) that may have contained turtles and manually search mud bank habitat.

We recorded straight-line carapace length, plastron length, and body mass for each captured turtle. Each turtle was given a unique identification code by marking the marginal scutes (Cagle 1939), except for *Apalone* spp., which were marked with zip-ties in 2007 and notches in 2008 following Plummer (2008).

Data Analyses

We used program PRESENCE (MacKenzie et al. 2002) to estimate the detection probability (p) for turtle species captured with each method, each year. In the analysis, trap-nights (N = 10) and each snorkeling visit (N = 2) were used as sampling occasions. To calculate detection probability for both methods combined, we used the equation

$$p_{\text{both methods}}=1-(1-(p_{\text{method 1}}))(1-(p_{\text{method 2}}))$$

(pers. comm. Darryl MacKenzie). Standard error for both methods was calculated using the delta method of approximating standard error (Williams et al. 2001). In this study, we estimated detection probability for four species with sample sizes ≥60; Barbour's map turtle (*G. barbouri*), yellow-bellied slider (*Trachemys scripta*), river cooter (*Pseudemys concinna*), and loggerhead musk turtle (*Sternotherus minor*). I used a means separation test with means to compare the detection probabilities of both methods used to capture our most highly captured species. Means were considered significantly different at α=0.10.

Results

From our two study creeks, each sampled during one year, we made 823 captures of 674 individuals representing nine species. Four species (*T. scripta, G. barbouri, P.concinna, S. minor*) comprised 95% of all captures. Most (88%, n = 107) *G. barbouri* were captured by snorkeling. Conversely, most (87%, n = 392) *T. scripta* were captured in traps. Frequency of capture by traps and snorkel surveys, respectively, were similar for *P. concinna* (40%, 60%, n = 134) and *S. minor* (55%, 45%, n = 74). Seventy-two percent of *M. temminckii* (n = 18) were captured by trapping. *Apalone* spp. (n = 18) and *C. serpentina* (n = 3) were only captured in traps. All *P. floridana* (n = 7) were captured by snorkeling.

The detection probabilities were greatest for the four most frequently captured species, all captured by effort-managed snorkeling (Fig. 2.2). *G. barbouri, P. concinna*, and *S. minor* all had comparable detection probability for trapping (Fig. 2.2). Snorkeling yielded a higher detection probability for every species when compared to trapping (Fig. 2.2). *T. scripta* was detected at a high rate using both methods. The combination of methods did not yield a higher detection probability than snorkeling in any of the four highest captured species (Fig. 2.2).

Trapping yielded more captures of male and female *T. scripta*, while snorkeling captured higher male, female and juvenile *G. barbouri* (Fig. 2.3). More *P. concinna* males and females were also captured with snorkeling. However, both methods yielded similar sizes of turtles of both sexes (Fig. 2.4). No juvenile *S. minor* were trapped during the study.

Discussion

Both baited hoop trapping and effort-managed snorkel surveys were needed to capture the nine species of turtles observed in this study. However, some species were detected better with one method than the other. The use of baited hoop traps is a standardized and reliable method for detecting most aquatic turtles. In our study, most turtles were detected by baited hoop traps, but detection probabilities were not as high for baited traps as they were for effort-managed snorkeling. We captured most (n = 392, 87%) *T. scripta* with traps and mean detectability over 14 sample sites was 0.69, but with effort-managed snorkeling, detection probability was 0.86. Conversely, most (n = 107, 88%) *G. barbouri* were captured with effort-managed snorkeling, and mean detectability over 14 sample sites was 0.93, whereas mean detectability with traps was 0.23. It is also important to take into account the number of visits and effort. Trapping took place for 10 days (10 trap nights) whereas effort-managed snorkeling required two 3-hour visits (9-12 person hours) per site.

Hoop trapping is one of the most common methods of capturing aquatic turtles, although, to our knowledge, this is the first time that the detection probability for hoop trap surveys has been reported. Rizkalla and Swihart (2006) used hoop trapping and incorporated detection probability into occupancy modeling to examine wetland characteristics and their effects on a turtle community at multiple scales in an agricultural landscape. Koper and Brooks (1998) used population estimates generated from hoop traps, basking observation and hand capture to compare to a known population size. They found that none of the methods were adequate at estimating population sizes but a combination of methods improved the accuracy of the estimates. The current study elucidates the need to implement methods that insure detection of species and adequate representation of the population.

It was evident that our methods yielded different species and sex/age classes of turtles, and in some cases one method yielded greater numbers of captures than the other. However, a combination of both methods insured that a range of sizes, sex\age classes and species was captured from each site. These results agree with the findings of Ream and Ream (1966), which noted that no single method was appropriate to detect all turtle species, or for estimating population size for all species. We found that both methods resulted in comparable sizes of turtles (Fig. 2.3). Smaller turtles are often considered more cryptic (Carr 1952) and hence, may be easily missed underwater as they can stay concealed under substrate unlike larger turtles. However, we captured many juvenile *S. minor* by snorkeling but not by trapping. The lack of juvenile *S. minor* in traps is likely due to their small size (hatchlings 22-27mm) and their ability to slip through the mesh size of standard hoop traps. These small turtles were easily seen at the base of logs and twigs when snorkeling. Both methods were not comparable at capturing similar numbers of turtles. Baited hoop traps captured many more *T. scripta* of both sexes and snorkeling captured more *G. barbouri* of all sexes. Male and juvenile *G. barbouri* were visible and easily captured in shoals when snorkeling. Clearly, *G. barbouri* populations are represented more accurately with effort managed snorkeling than with baited hoop traps. The majority of *T. scripta* were captured in traps and it is probable that *T. scripta* used the muddy and vegetated undercut banks to hide and were not easily observed during snorkel surveys (personal observation). In contrast, as omnivores, *T. scripta* readily entered baited hoop traps. During snorkeling surveys in this study, two *Apalone* spp. were observed but not captured. The high swimming speed of softshell turtles may make effort managed snorkeling an unreliable method for capturing *Apalone* spp., however, we were at least able to confirm their presence. Use of fresh fish bait may have yielded more captures of *Apalone* spp. in hoop traps (pers. comm. Jim

Godwin). I did not attempt to use basking traps or direct observation of basking turtles in this study. Koper and Brooks (1998) suggested that basking observations are an efficient and unbiased way to estimate populations for *Chrysemys picta*. Basking traps are also effective for turtles not attracted to bait but knowledge of a species ecological preferences are needed to optimize this technique (Plummer 1979). I sampled 500 m study reaches and I feel that the effort involved with using basking traps or making observations at several points along these stretches would not have provided more information than the snorkel method. Further, I was interested in choosing methods that would maximize turtle capture and have minimal biases.

Both capture methods we examined have associated biases, so to decide which method to use in a study, clear goals must be established and the appropriate method selected to meet those goals with the greatest certainty and efficiency. Ream and Ream (1966) concluded that three reasons turtles are attracted to traps include bait offered, presence of conspecifics, and thermoregulatory needs. These attractions also bias turtle samples by sex, species, or size (Ream and Ream 1966, Frazer et al. 1990). Frazer et al. (1990) found that turtles escaped from traps much more often than previously known and that the initial capture in traps may determine the rest of the daily catch (Cagle and Chaney 1950, Frazer et al. 1990). Our use of a combination of methods attempted to correct for these associated biases. First, both large and small hoop traps were used to not limit larger sized turtles (*Macrochelys*) from entering. Second, traps were checked daily to limit time that turtles had to escape and to remove turtles that might bias further capture. Third, the direct capture method, effort-managed snorkeling, was used to capture turtles not easily attracted to traps (e.g., *Graptemys, Pseudemys*).

The methods used in previous studies of aquatic turtles may under-represent some species in turtle communities. Donnerwright et al. (1999) only used baited hoop traps to capture a turtle assemblage in the St. Croix River in the upper Midwest, which included two *Graptemys* spp., to compare longitudinal gradients to changes in turtle communities, which included sex ratios and size structure. While northern map turtles (*G. geographica*) are known to enter traps (Plummer 1979), Browne and Hecnar (2005) found that basking traps are more efficient at capturing this species. Therefore, sex, size and abundance may be skewed by relying entirely on one method for this turtle. Conversely, Browne and Hecnar (2007) found that age structure and abundance changed over time in Point Pelee National Park in Canada by using multiple techniques to survey aquatic turtles, including *G. geographica*. Dreslik et al. (2005) required 3000 fyke net trap hours to capture 10 species of aquatic turtles in an Illinois lake. In this six year study, *Graptemys* spp. had a very low overall capture percentage (0.1-3.2%). It is possible that supplementing fyke traps with other methods better known for capture of map turtles might increase capture and decrease the effort needed to detect these species.

The limiting factors of both methods should be considered when deciding upon a survey regime for aquatic turtles. Trapping is much more reliable in fluctuating environmental conditions like sunlight, floods or extreme water depths. Baited traps are often only limited by extreme high flow, which can trap turtles beneath water. Snorkeling conditions are limited by temporal and physical considerations such as water temperature, clarity, observer experience, and stream depth. In this study, snorkel surveys were conducted with experienced observers and were only performed when water clarity was relatively high. However, observer experience is hard to measure and likely to vary. Furthermore, heavy rains and low visibility caused us to postpone surveys for 1-2 weeks. Such events are not infrequent during late spring and summer in the Southeastern Coastal Plain and could easily disrupt surveys. Also, the few areas with deep water (>4 m) were not searched in this study, and it is recommend that deep areas be supplemented by including a pair of SCUBA divers in the survey crew.

It is necessary to assess the study assemblage before choosing methods used for sampling. In streams of the LFRB, both trapping and effort managed snorkeling surveys, were efficient at detecting species, capturing a range of sizes, sexes, and obtaining information on relative abundance. Snorkeling yielded 88% of total captures for Barbour's map turtle, a threatened species in Georgia and Alabama. Further surveys should keep the study goals in mind when assessing this species or the entire river turtle assemblage in Coastal Plain streams. I recommend using both methods to detect the maximum number of turtle species in Coastal Plain streams, and despite difficulties in standardizing snorkeling effort, this method is the better of the two to capture large numbers of *G. barbouri* and *P. concinna*, in these streams.

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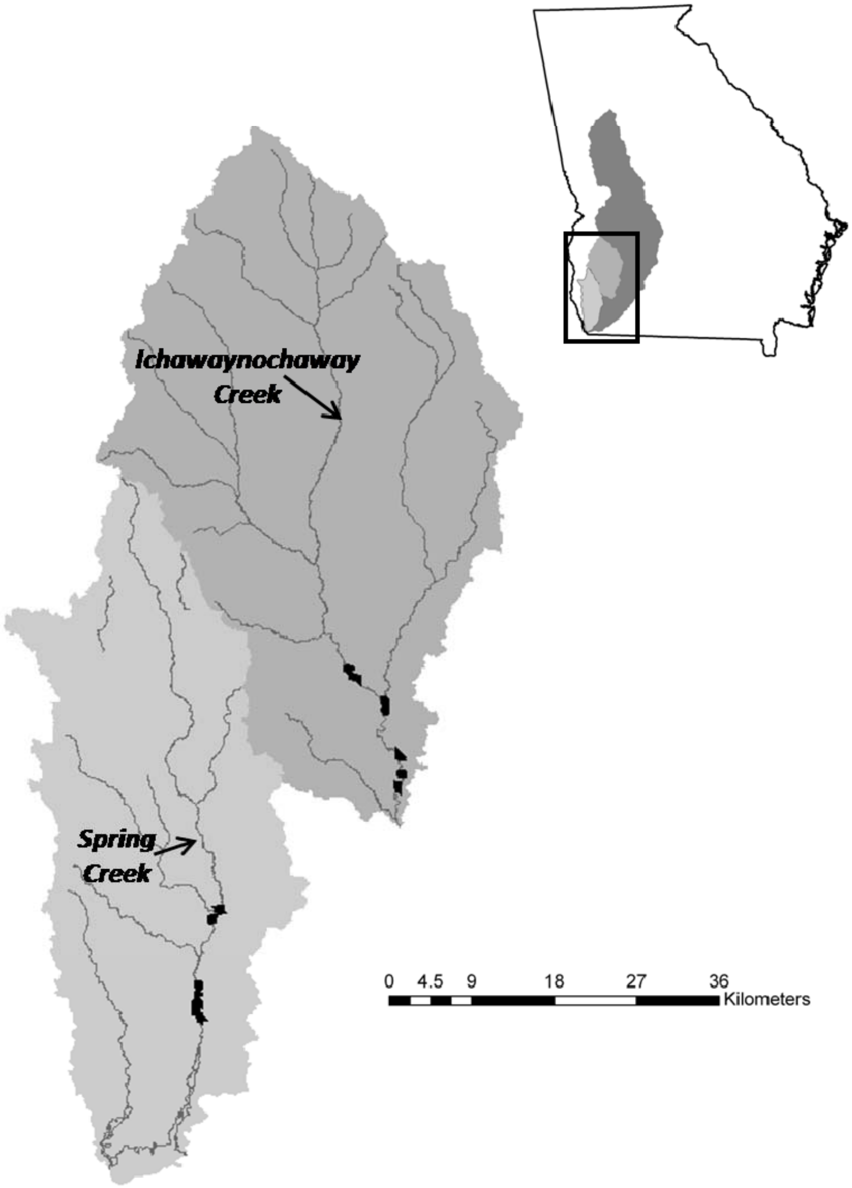

Figure 2.1. Locations of 14 turtle sampling sites, each 0.5 km, on Ichawaynochaway Creek (Baker County, Ga) and Spring Creek (Miller County, Ga).

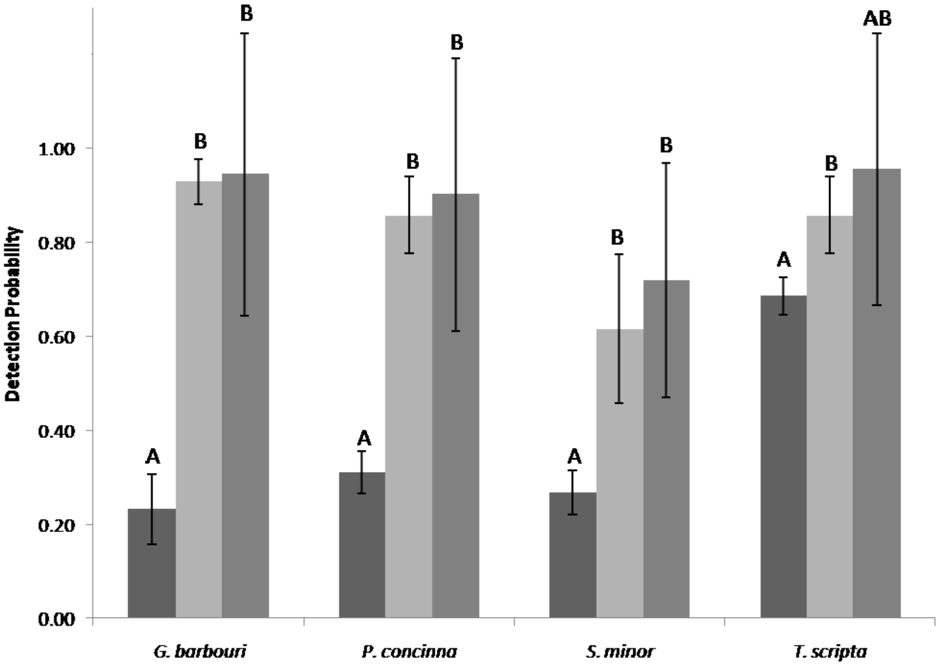

Figure 2.2. Detection probabilities of the four most frequently captured turtle species by sampling method and for both methods combined on Ichawaynochaway Creek and Spring Creek, 2007-2008. Error bars represent standard error. Letters represent differences in means separation test with α=0.10.

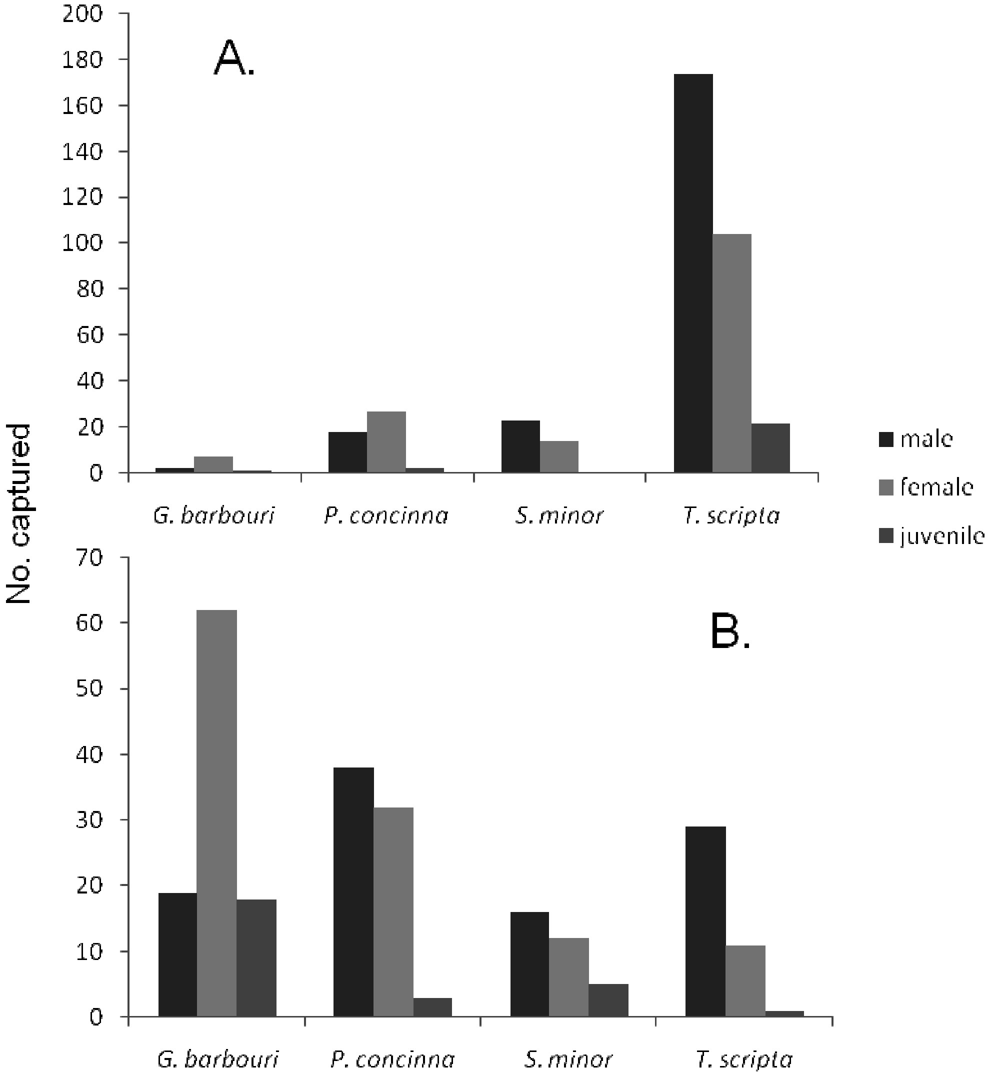

Figure 2.3. Number of turtles captured by sex and age class for the four most frequently captured species on Ichawaynochaway Creek and Spring Creek, 2007-2008. Sampling methods included A.) large and small hoop traps and B.) effort-managed snorkeling.

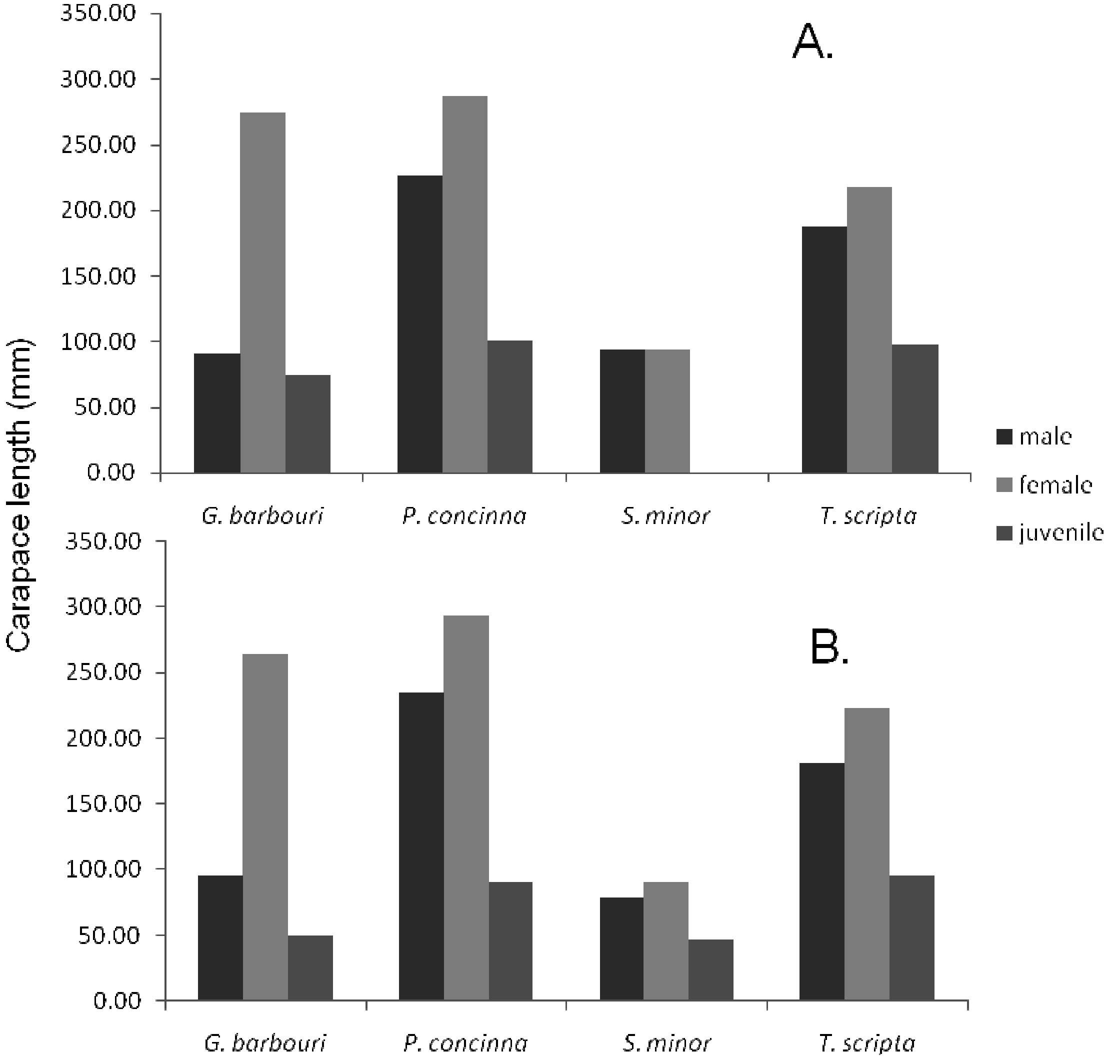

Figure 2.4. Sizes of the four most captured turtles by hoop trapping (A) and effort managed snorkeling (B) on Ichawaynochaway Creek and Spring Creek, 2007-2008.

CHAPTER 3

THE INFLUENCE OF LAND USE ON AQUATIC TURTLES IN STREAMS IN THE LOWER FLINT RIVER BASIN, GEORGIA

Introduction

Many aquatic fauna associated with stream and river ecosystems are vulnerable to anthropogenic activities in the surrounding watershed (Allan 2004). Urbanization, industrial practices, and certain agricultural activities are all linked to declines in some aquatic fauna, and activities associated with agriculture may be the largest threat to some species (Richter et al. 1996). The effects of agricultural activities on freshwater habitats are diverse (e.g., Richards et al. 1996, Wang et al. 1997, Carpenter 1998). Poor information on basic ecology of some river biota makes studying land use effects a priority for better conservation (Moll 1996).

Freshwater turtles are important components of aquatic ecosystems because of their roles in food webs (Moll and Moll 2004). However, they are particularly vulnerable to human activity (Klemens 2000). Direct effects of humans on turtles include exploitation for food (Klemens and Thorbjarnarsen 1994), disturbance of reproductive activity (Moore and Siegel 2006), and turtle-vehicle collisions (Gibbs and Steen 2004). However, indirect pressures may be more damaging to turtles because they are inconspicuous and often difficult to detect (Moll and Moll 2000). Indirect land use pressures, such as non-point source pollution, channelization, and sedimentation, all may degrade habitat for river turtles (Moll 1996, Moll and Moll 2004). Furthermore, concerns about these effects on rivers are compounded by the need for protection of core terrestrial habitat for semi-aquatic turtles (Semlitsch and Bodie 2003).

The southeastern United States harbors the greatest diversity of freshwater turtles in North America and is a global hotspot of freshwater turtle diversity (Buhlmann and Gibbons

1997). The Lower Flint River Basin (LFRB) of Georgia, part of the Apalachicola-Chattahoochee-Flint (ACF) River Basin, supports a diverse freshwater turtle fauna (Ward et al. 2005), including two state protected species, the alligator snapping turtle (*Macrochelys temminckii*) and Barbour's map turtle (*Graptemys barbouri*).

Historically, alligator snapping turtle populations were depleted by commercial exploitation for food (Sloan and Lovich 1995), but populations in some streams appear to be recovering (Jensen and Birkhead 2003). Threats to map turtles (*Graptemys* spp.) include over collection for the pet trade, malicious killing, sedimentation of streams where they occur (Moll 1996), and loss of basking (Lindeman 1999a) and nesting sites (Moore and Siegel 2006). *Graptemys barbouri* has a specialized diet, with females consuming predominantly mollusks (Sanderson 1974). Hence, the species is likely affected by intensive disturbance to riparian and instream habitats (Jensen 1999). In some ACF drainages, Barbour's map turtles are still locally abundant, while in others their status appears limited or unknown. Another more cosmopolitan species, the yellow-bellied slider (*Trachemys scripta*), is a common denizen of streams in the southeast and disperses throughout the landscape (Gibbons 1990). This species is known to withstand and even thrive in altered habitats (Gibbons 1970, Moll 1980). Although sliders have the ability to exploit a variety of resources, it is unclear whether this species replaces other turtles where conditions are suitable (Luiselli 2006).

The objectives of this study were to 1) assess turtle species richness and abundance on two major tributaries of the lower Flint River (Ichawaynochaway Creek and Spring Creek) and 2) determine how variation in surrounding land cover influences these measures. Specifically, we tested the hypotheses that *G. barbouri* abundance, and overall turtle species richness and abundance are negatively correlated with the amount of agricultural land adjacent to streams.

Methods and Materials

Study Area

The study took place on Ichawaynochaway (Baker County) and Spring Creek (Decatur and Miller Counties) in southwest Georgia (Fig. 3.1). The study sites are located in the Dougherty Plain, which is characterized by karst topography (Ward et al. 2005). In drainages of the Lower Flint River Basin, rocky limestone shoals and deep, wide, sandy pools are common. Both creeks have ground water inputs fed primarily by the Upper Floridan Aquifer, which is the shallowest aquifer in the region (Hicks and Golladay 2006). These tributaries were selected because they represent a contrast in human impacts. Ichawaynochaway Creek flows through extensive areas of minimal impact including Ichauway, the Joseph W. Jones Ecological Research Center (JWERC) property, comprising roughly 24 km of relatively undisturbed habitat. Although largely undisturbed, some northern portions of Ichawaynochaway Creek are located within agriculturally impacted areas. Spring Creek, in contrast, has greater amounts of adjacent agricultural areas and sections with minimal riparian buffers. Both streams are subjected to water withdrawals for irrigation during the growing season (April-September) which causes significant flow declines (Hicks and Golladay 2006). However, ground water and surface water withdrawals associated with agriculture are greater in the Spring Creek basin with greater impacts on low flows, whereas surface withdrawals are greater in Ichawaynochaway Creek (Hicks and Golladay 2006). Both tributaries support a diverse aquatic fauna, including at least seven turtle species (Jensen et al. 2008).

Site Selection and Land Cover Analysis

Using 2007 National Agriculture Imagery Program (USDA 2007) aerial photography (1 m) and ArcGIS, each creek was delineated into consecutive 1 km sections starting at an arbitrarily chosen point where the creek became channelized. Each section was then categorized as either undisturbed (mostly forested), marginally disturbed (partially forested), or severely disturbed (impacted by unforested areas, Fig. 3.2). Three undisturbed, two marginally disturbed, and two severely disturbed sections from each creek were randomly selected for turtle sampling (a total of seven sections per creek). Two sections (sites 2 and 30) on Spring Creek were sampled because the randomly selected sections were inaccessible. The sampling described below was conducted within an approximately 0.5 km reach located at the center of each study section.

Surrounding land cover (forested versus unforested) was quantified using ArcMap (ESRI, v 9.2) at three buffer widths for each of the 14- 1 km creek sections that contained study reaches. The first buffer width (15.24 m) was the standard for Georgia streams (Wenger 1999). The other buffer widths (123 and 287 m) represent the mean terrestrial migration distances for freshwater turtles, including river turtles (Semlitsch and Bodie 2003). We used 2001 National Land Cover Data (Homer et al. 2004, U.S. Geological Survey 2003, 30 m pixel size) to quantify forested versus unforested land cover. "Unforested" land cover included areas designated by NLCD as pasture, row crop and cultivated crops. All other land covers were included in the "forested" category. These land cover maps were then layered with 2007 National Agriculture Imagery Program (USDA 2007) aerial photography (1 m). All land cover changes between 2001 and 2007 were then edited to create a final 2007 land use map. Fluvial aquatic habitat, based on the average width of the stream in each section, was removed from the total land cover; hence, total land cover varied based on the width of the stream.

Turtle Sampling

Turtle sampling took place from June-August 2007 at Ichawaynochaway Creek and June-September 2008 at Spring Creek. At both creeks, sampling was conducted twice at each study reach over the sampling period using both hoop traps and effort-managed snorkel surveys. We chose these two sampling methods because they are appropriate for detecting the suite of turtle species that occurs in the region.

During each sampling period, five large (1.2 m dia, 4 hoops, 3.8 cm mesh size) and five small (0.9-m dia, 3 hoops, 3.8-cm mesh) fish-baited hoop traps (Memphis Net and Twine, Memphis, TN) were placed in each 0.5 km reach, approximately 50 m apart on alternating banks when water levels were suitable. Traps were set for five nights on each reach and were checked daily and re-baited as necessary. Each turtle was given a unique identification code by marking the marginal scutes (Cagle 1939), except for *Apalone* spp., which were marked with zip-ties in 2007 and notches in 2008 (following Plummer 2008a).

Each 0.5 km reach was surveyed twice by snorkeling. We controlled for search effort (3-4 surveyors for 2-3hrs), time of day (1300 h start time, when possible), and surveyor experience. During each survey, the study reach was searched twice (upstream and downstream), although high capture rates did not allow for this on one site. To the extent possible, surveyors thoroughly searched all potential turtle habitat within the stream. However, we were unable to free dive into deep holes (>4 m) that may have contained turtles. All turtles captured during snorkel surveys were measured and marked as described above.

Data Analyses

ANOVA was used to compare total number of individuals captured (all species, both methods combined), species richness and captures by species between creeks. Linear regression was used to determine whether turtle abundance and species richness varied with % forested land cover and to examine evenness of turtle species composition and forested land cover.

To test the hypothesis that % forested land cover adjacent to streams may affect turtle abundance and composition, we conducted a two factor MANCOVA with creek as a categorical predictor variable and % forested land cover within a 287 m buffer width as a continuous predictor variable, and compared these to our four most frequently captured species (*T. scripta, P. concinna, G. barbouri, and S. minor*). All statistical analyses were conducted using Statistica 8.0 (©1984-2008, StatSoft Inc., Tulsa, OK, USA).

Results

Sampling Effort

In 2007 and 2008, we logged 1400 trap nights and 242.75 person-hours of snorkeling on 14 study reaches on Ichawaynochaway and Spring Creek. Both methods were necessary to detect the nine species recorded. Barbour's map turtle was captured most frequently by snorkeling (88% of individuals) and yellow-bellied slider by trapping (87% of individuals, Fig. 2.2). River cooter and loggerhead musk turtle were captured in similar numbers with both methods. Three species (*A. ferox, A. spinifera, P. floridana*) were captured only in traps.

Turtle Capture

We had 823 captures of 674 individuals representing nine turtle species (Table 3.2; 349 at Ichawaynochaway Creek and 474 at Spring Creek). The mean number of captures for all study reaches combined was 59 ± 10.7 (range 21-172). Ninety five percent of captures were comprised of four species; yellow-bellied sliders (55%, 451), river cooter (16%, 134), Barbour's map turtle (15%, 121) and loggerhead musk turtle (9%, 60; Fig. 3.2). Alligator snapping turtles were captured in all but one of the study reaches on Ichawaynochaway Creek (N=8); however, the species was detected in only three reaches on Spring Creek (N=10). A single Florida softshell, Gulf Coast spiny softshell, and common snapping turtle were captured on Ichawaynochaway Creek during 2007, and 13 spiny softshell turtles were captured on Spring Creek in 2008. Florida cooter was only captured on Spring Creek, although this species occurs in Ichawaynochaway Creek (pers. obs. Sean Sterrett). We recaptured 149 turtles (1-5 times) on all study reaches. Most recaptures were sliders (73%, 109), followed by map turtles (13%, 19) and river cooters (8%, 12). Eleven individuals (*G. barbouri* (2)*, P. concinna* (5)*, P. floridana* (1) and *T. scripta* (3)) were recaptured in a reach different from their initial capture.

Land Cover

Percent forested land cover varied by reach, but generally decreased with increasing buffer width (Table 3.2). Most unforested land cover was in large continuous patches associated with agriculture. Sites within Ichauway were largely forested at all buffer widths, however, sites north of Ichauway property represented some of the most disturbed sites on Ichawaynochaway Creek. Forested land cover at all the buffers examined ranged from 42-100% (Table 3.2). Some residential areas were lumped into unforested category. There was no measurable difference in land cover at any of the buffer widths between creeks (15.24m: MS=144.3, $F_{1,12}$=1.768, p=.20833, 123m: MS= 13.1, $F_{1,12}$=.06470, p=.80353, 287m: MS=58.62, $F_{1,12}$=.2161, p=.65037). Therefore, further analyses in this paper refer only to land cover within the 287 m buffer.

Effects of Creek and Land Cover on the Turtle Assemblage

There was no measurable difference in the number of captures of Barbour's map turtle and yellow-bellied slider between creeks (MS=14, $F_{1,12}$=.39357, p=0.54, MS=240.29, $F_{1,12}$=.38823, p=0.54, respectively). River cooter were captured more frequently on Spring

Creek than Ichawaynochaway Creek (MS=224, $F_{1,12}$=4.8797, p=.05). Loggerhead musk turtle were captured more often on Ichawaynochaway Creek, although the difference was not statistically significant at α=0.05 (MS=, $F_{1, 12}$=4.2148, p=.06). There was no significant difference in species richness or total number of captures between creeks (MS=0.6429, $F_{1,12}$=.90000, p=.36150, MS=370.29, $F_{1,12}$=.44578, p=.52, respectively).

Counter to expectation, there was a negative relationship between the total number of turtles captured and % forested land cover at the 287 m buffer (range 19-121, $r^2 = 0.5442$; p = 0.0026, Fig. 3.3); however, consistent with expectation, evenness (J') was positively related to % forested land cover ($r^2 = 0.5860$; p = 0.0014, Fig. 3.4). This shift was driven mostly by increasing *T. scripta* captures and decreasing *G. barbouri* captures with decreasing forest cover (Fig. 3.4). MANCOVA results showed that within each creek, there was a measurable effects of forested land cover on the four most frequently captured species (*T. scripta, G. barbouri, P. concinna and S. minor*, Table 3.3, Fig. 3.5). Relationships between forest cover and captures were not consistent for *S. minor* and *P. concinna* between creeks (Fig. 3.5, Table 3.3), but were consistent for *G. barbouri* and *T. scripta* (Fig. 3.5).

Discussion

Agricultural land use is known to affect aquatic biodiversity although these relationships have not been described for most vertebrates other than fishes (Allan 2004). Land use changes such as agriculture and mining are of particular concern for river turtles because deforestation associated with these activities increases potential for runoff and siltation of streams (Dodd 1990, Moll and Moll 2000), which may affect prey availability and instream habitat. Our results suggest that turtle abundance and species composition in streams of the LFRB varied with %

forest cover, a factor that is directly related to land use. Somewhat surprisingly, our data did not support the hypothesis that turtle species richness and abundance is greater in forested (undisturbed) sites. We found a strong negative relationship between overall turtle captures and forested land cover (Fig. 3.3). This relationship was obviously driven by high numbers of captures of yellow-bellied sliders in disturbed sites (Fig. 3.4). Species richness ranged from 4-7 species and there was no relationship between richness and % forested land cover. Yellow-bellied sliders were represented across all sites but were more abundant at disturbed reaches (Fig. 3.4). Yellow-bellied sliders are habitat generalists, and their relatively broad omnivorous diet probably contributes to the ability of this species to thrive in disturbed conditions (Knight and Gibbons 1968, Gibbons 1970). In contrast to species richness, compositional evenness, which is a different measure of diversity, had a strong positive relationship with increasing forested land cover (Fig. 3.4). This shows a more even representation of all turtle species in sections of river with higher forest cover. This pattern reflects a decline in the dominance of sliders and an increased abundance of the more specialized Barbour's map turtle with increasing forest cover. Turtle composition is known to shift in degraded habitat, with generalized species populations increasing and specialists declining (Moll 1980). Further, similar shifts in composition were found with fishes responding to land use in the Appalachian regions of Georgia and North Carolina (Burcher 2008, Jones et al. 1999). In those studies, generalized species thrived in disturbed areas while nesting or feeding specialist declined. In order to sample both creeks in this study, units of replication needed to be chosen from each creek and due to the dependence of these sites, may be considered "pseudoreplicates." Independence of sites on each creek was attempted by separating sampling areas by at least 1.5 km. We tried to account for this by using random sampling to choose sites from each creek. Ideally, more sites from each creek would be sampled but the effort and limited crew did not allow for more surveys during this study.

We found a strong positive relationship between Barbour's map turtle captures and % forested land cover on both creeks. Juvenile musk turtles eat mostly insects and small snails and adults specialize on snails and small clams (Zappalorti and Iverson 2006), so, we expected to see the same relationship in the loggerhead musk turtles, another molluscivorous species in the streams. Our results contradict patterns seen for the flattened musk turtle (*Sternotherus depressus*), which was nearly extirpated from the Warrior River Basin of Alabama due to mining operations in adjacent land that caused instream sedimentation and pollution (Dodd 1990). It is reasonable to conclude that the low numbers of captures of loggerhead musk turtle (9% of total capture) may have limited our ability to measure the relationship between the species abundance and forest cover in our study sites, especially on Spring Creek, which showed no relationship. However, the strong negative relationship on Ichawaynochaway Creek is counterintuitive to what we expected to see (Fig. 3.5). These results may reveal a bit about the breadth of diet in *S. minor* and their attraction to baited traps. Our capture techniques might also be inadequate for this species. Loggerhead musk turtles are small and cryptic and may be less visible during snorkeling surveys. Further, loggerhead musk turtles were not captured in traps, likely because of their small size. It is also possible that agriculture in the LFRB does have the same effects on in stream conditions as mining had within the Warrior River Basin. The effects of agriculture and deforestation on instream habitat or biota in our study streams have not yet been evaluated. Runoff from agricultural land is known to increase nitrogen loading, which can increase abundance of macrophytes and algae (Allan 1995). Agricultural land use can also decrease availability of turtle prey including fish (Burcher et al 2008, Jones et al 1999), mollusks (Sharpe and Nichols 2007, Poole and Downing 2004) and other macroinvertebrates (Wang et al. 1997, Lammert and Allan 1999). While historically, map turtles preyed on native mussels, their diets have shifted to prey extensively on Asiatic clams (Shively and Vidrine 1984, Lindeman 2006a, 2006b). The integrity of prey in agricultural watersheds may be a driver for aquatic turtle persistence. If these processes are occurring, then we would expect to see increases in omnivores, like slider and cooter, and decreases in specialists like map and musk turtles. Intraspecific competition for these prey items, especially those limiting like mollusks, might limit the persistence or abundance of certain species, like map turtles, in areas of high agricultural land use. The impacts of agricultural irrigation on the hydrology of the LFRB are an issue that has been neglected. Since the 1970s, center pivot agriculture has expanded and has recently become a point of concern, especially during times of drought (Hicks and Golladay 2006). Golladay et al. (2004) found negative effects of record droughts on freshwater mussels in the LFRB with mussels using remaining pools of water under pieces of LWD. Although, no direct evidence exists, the compounded effects of drought and high agricultural irrigation may contribute to several negative effects on aquatic turtles including a decrease in available prey.

There may be physical alterations of instream habitat associated with unforested areas which may also affect distribution and abundance of turtles. Some river turtles are strongly associated with particular substrates, e.g. spiny softshell inhabit rivers with sandy substrate where they can burrow (McGauch 2008, Plummer et al 2008b, 2008c), whereas some map turtles rely on shoals to feed (Buhlmann et al. 2008, Sanderson 1974). Barbour’s map turtle are often associated with limestone substrate (Sanderson 1974, Enge and Wallace 2008), which is abundant in streams of the LFRB. In the current study, we found many Barbour’s map turtles sheltering under instream large woody debris (LWD). LWD (both instream and emergent) is likely important to map turtles in three distinct ways; substrate for available prey (mollusks, algae, macroinvertebrates), basking substrate for thermoregulation, and resting or sleeping substrate (Lindeman 1999a). It is also likely that map turtles use woody debris as a refuge from predators like American alligator (*Alligator mississippiensis*) or river otters (*Lontra canadensis*) during inactive periods. These habitat characteristics are also important to other emydid turtle species in this system; however, Auth (1975) found that sliders readily bask at the water surface unlike map turtles, which commonly bask aerially on emergent substrate (Sanderson 1974). Clearing land for agriculture could reduce the accumulation of LWD in streams. Angradi et al. (2004) related LWD density to unstabilized banks and forested riparian land use. Furthermore, a recent study found correlative relationships between riparian forest width and LWD in agricultural land classes (McIlroy et al. 2008). Interspecific competition for space including basking surfaces may also be a factor in structuring assemblages. Lindeman (1999b) studied aggressive basking behaviors between emydid species and found an effect of body size but not species on those individuals who "won" basking locations. Small turtles like *S. minor* and male *G. barbouri* may be at a disadvantage in competing for optimal basking sites. Other social aspects of competition among turtles for instream resources have been studied (Flaherty and Bider 1984, Lindeman 2000). Flaherty and Bider (1984) hypothesized that unknown intra- and interspecific factors may be important in structuring basking congregations of turtles in Canadian lakes; however, they found no differences in potential food during the active season, basking structure quality or the use of nesting sites by females. Lindeman (2000) studied resource partitioning of five sympatric species, including *Graptemys* spp. and *T. scripta*, and determined that phylogenetic relationships were more responsible for resource partitioning, like basking sites or prey, than interspecific competition. In the LFRB, G. *barbouri* and *T. scripta* are nearly opposite in breadth of known habitat and prey. It is unlikely that interspecific competition of these two species is occurring in this area and it may be difficult to separate this from the effects of land use.

Finally, the removal of surrounding forest could affect nesting patterns for some turtles. Unlike yellow-bellied sliders, which move easily throughout the terrestrial landscape and nest up to 500 m from water (Gibbons 1990), the river turtles in this study (*A. spinifera, G. barbouri, M. temminckii, P. concinna,* and *S. minor*) rarely leave the water except for the purpose of laying eggs; these species generally nest no further than 250 m from the water (Meylan 2006). Deforestation would alter the thermal environment and potential vulnerability of nests and nesting females to predators (Janzen and Morjan 2001, Spencer and Thompson 2003). While reducing or altering nesting habitat may be an intuitive mechanism, we must recognize that river turtles will make long distance aquatic movements to nesting sites (Moll and Moll 2004). For example, Daigle (2002) observed a spiny softshell which moved 7 km in a creek to find a suitable nesting site. While it is possible that alterations to adjacent land may reduce turtle nesting habitat, it less likely that there is a proximate relationship between turtle abundance and adjacent forest cover, especially in these streams where riparian disturbances are patchy.

This study suggests a significant effect of loss of forest cover associated with agricultural land use on the local composition and abundance of a turtle assemblage. It has been suggested that *Graptemys* spp. are among the most vulnerable of freshwater turtles to changes in river quality and associated prey resources (Dodd 1977, Lydeard and Mayden 1995). Future work will need to establish mechanistic relationships between forest cover, land use, and in stream conditions including prey abundance and the availability of LWD. Future work should also focus on the mechanistic interaction between agricultural land use and turtles. Indirect pressures from land use are inconspicuous, difficult to detect and have the potential to be more damaging to turtles (Moll and Moll 2000).

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Table 3.1. Turtles captured on Ichawaynochaway Creek and Spring Creek in southwest Georgia in summer 2007 and 2008. Turtles were captured using baited hoop traps and effort-constrained snorkeling.

Turtle Species	Ichawaynochaway Creek	Spring Creek	Total
Florida softshell turtle *Apalone ferox*	1	0	1
Spiny softshell turtle *Apalone spinifera*	1	13	14
Common snapping turtle *Chelydra serpentina*	1	2	3
Barbour's map turtle *Graptemys barbouri*	66	55	121
Alligator snapping turtle *Macrochelys temminckii*	8	10	18
River cooter *Pseudemys concinna*	35	99	134
Florida cooter *Pseudemys floridana*	0	7	7
Loggerhead musk turtle *Sternotherus minor*	60	14	74
Yellow-bellied slider *Trachemys scripta*	177	274	451
Total	349	474	823

Table 3.2. Percent forested cover within 0.5 km study reaches on Ichawaynochaway Creek and Spring Creek in southwest Georgia. Seven reaches were sampled on each creek; buffer widths were chosen based on Wenger 1999 and Semlitsch and Bodie 2003.

	15.24 m buffer	123 m buffer	287 m buffer
Ichawaynochaway Creek	90.76 ± 4.28	85.29 ± 5.54	80.93 ± 6.18
Spring Creek	97.18 ± 2.24	87.23 ± 5.21	76.84 ± 6.27

Table 3.3. MANCOVA analysis of the effects of forested land cover and creek (Ichawaynochaway Creek and Spring Creek) on the most captured species (*Graptemys barbouri, Trachemys scripta, Pseudemys concinna,* and *Sternotherus minor*).

Source of Variation	Wilk's *Λ*	F-value	Degrees of Freedom	P-value
Creek	0.207028	6.70295	4,7	0.015
% Forested Land Cover	0.115503	13.40110	4,7	0.002
Creek*Forested Land Cover	0.225687	6.00411	4,7	0.020

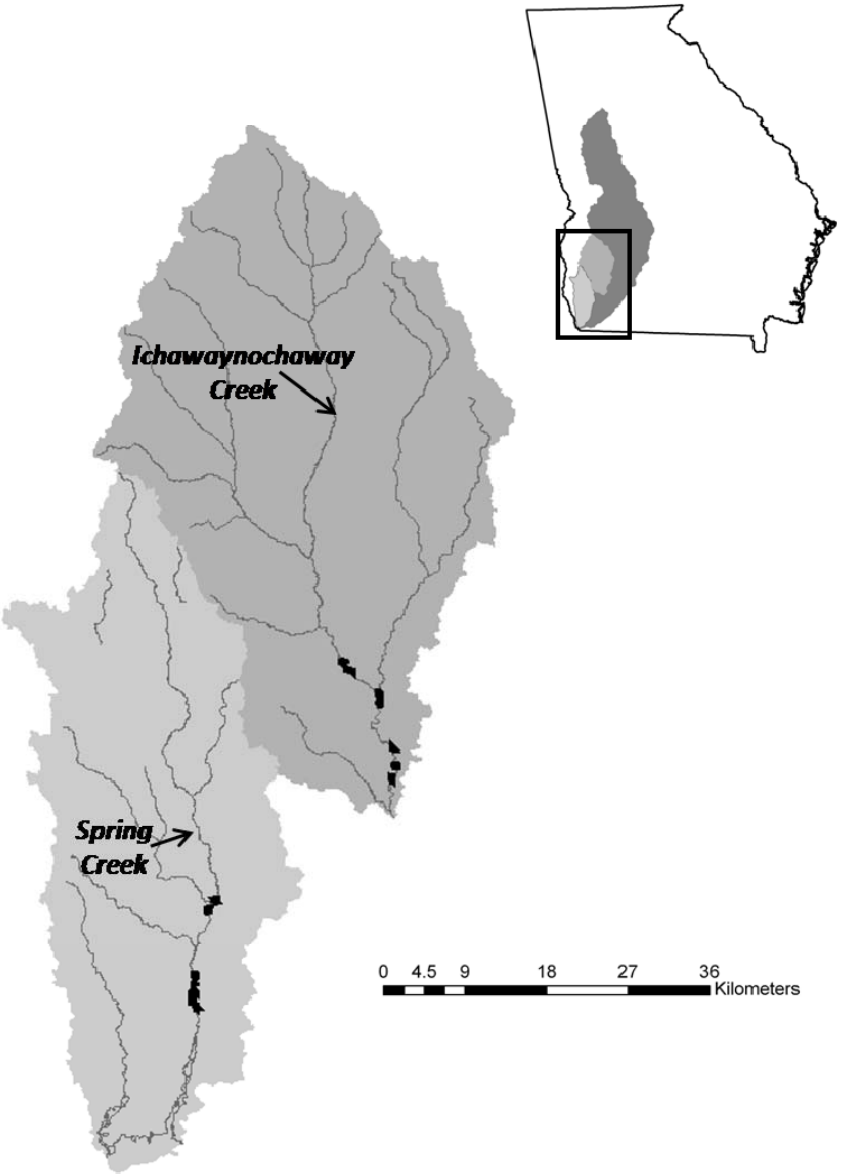

Figure 3.1. Location of 14 turtle study sites on Ichawaynochaway Creek (Baker County, Ga) and Spring Creek (Miller County, Ga).

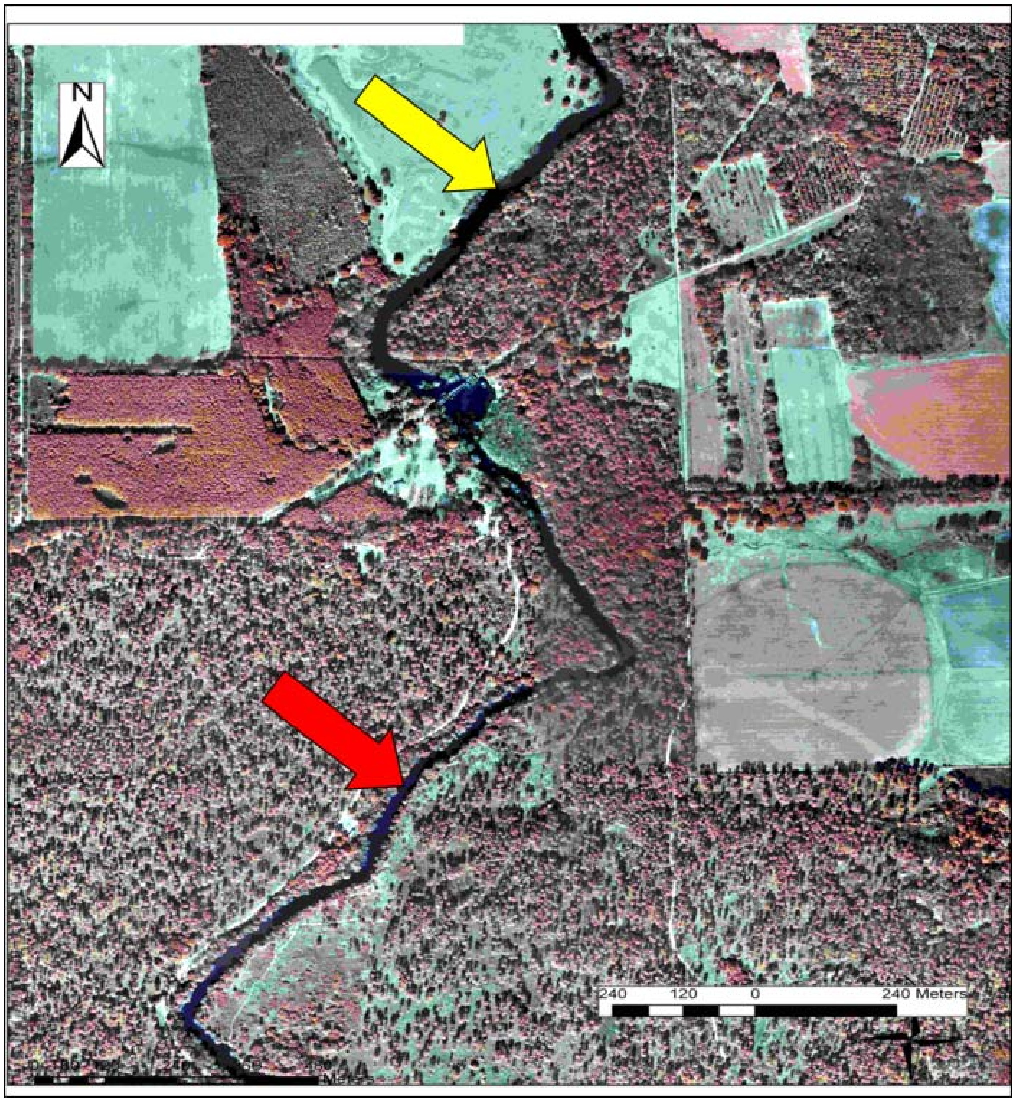

Figure 3.2. Aerial photograph depicting different land use categories on Ichawaynochaway Creek, in southwest Georgia. The yellow arrow indicates an impacted section and the red arrow indicates an unimpacted section.

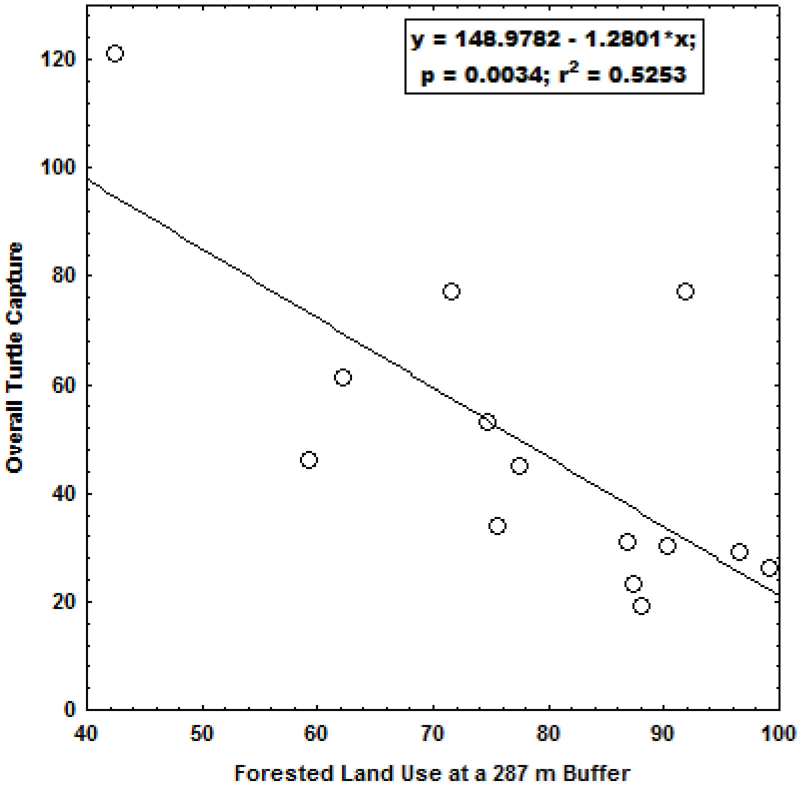

Figure 3.3. Relationship between total numbers of turtle captures versus % forested land cover at 14 study reaches on Ichawaynochaway Creek and Spring Creek in the Lower Flint River Basin in southwest Georgia.

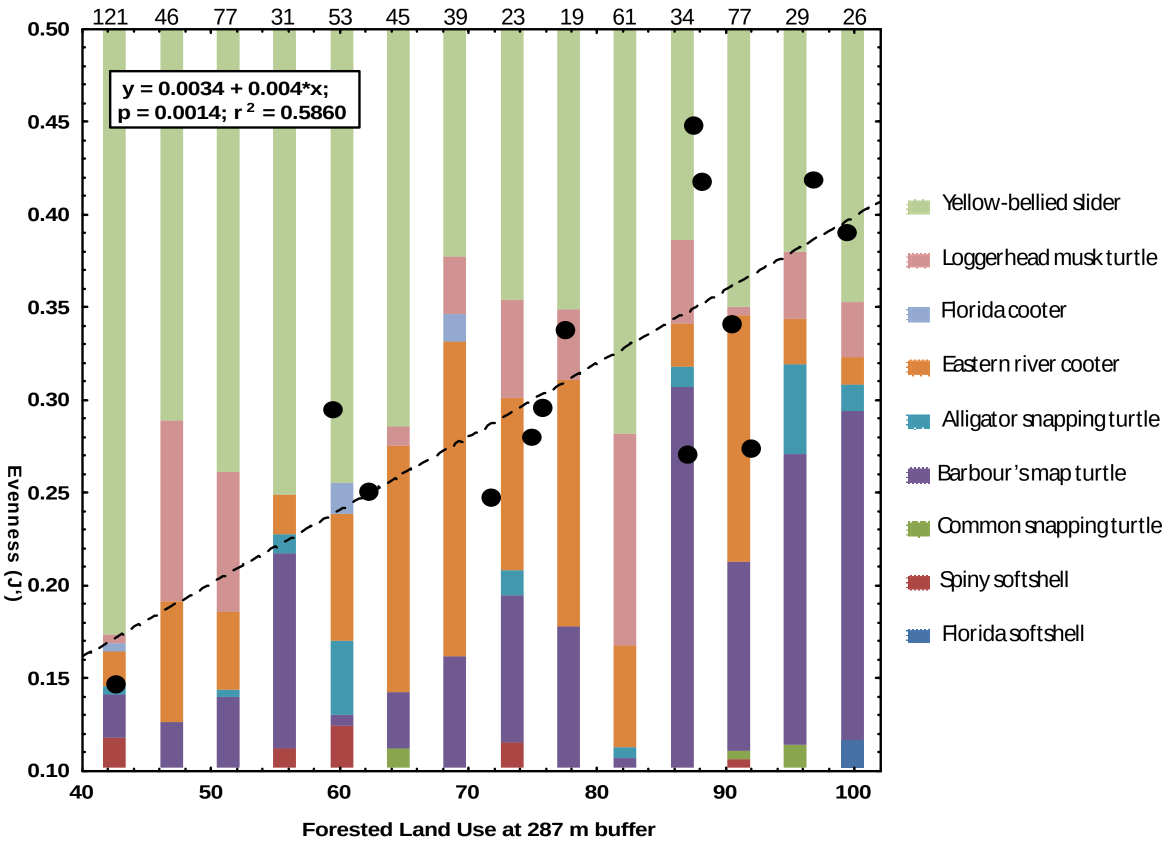

Figure 3.4. Relationship between evenness (J') of turtle species and % forested land cover at 14 study reaches on Ichawaynochaway Creek and Spring Creek in the Lower Flint River Basin in southwest Georgia. Points represent actual evenness values whereas bars represent relative percentage of species capture in individual sites along a gradient from most to least disturbed. Total capture values appear above each bar.

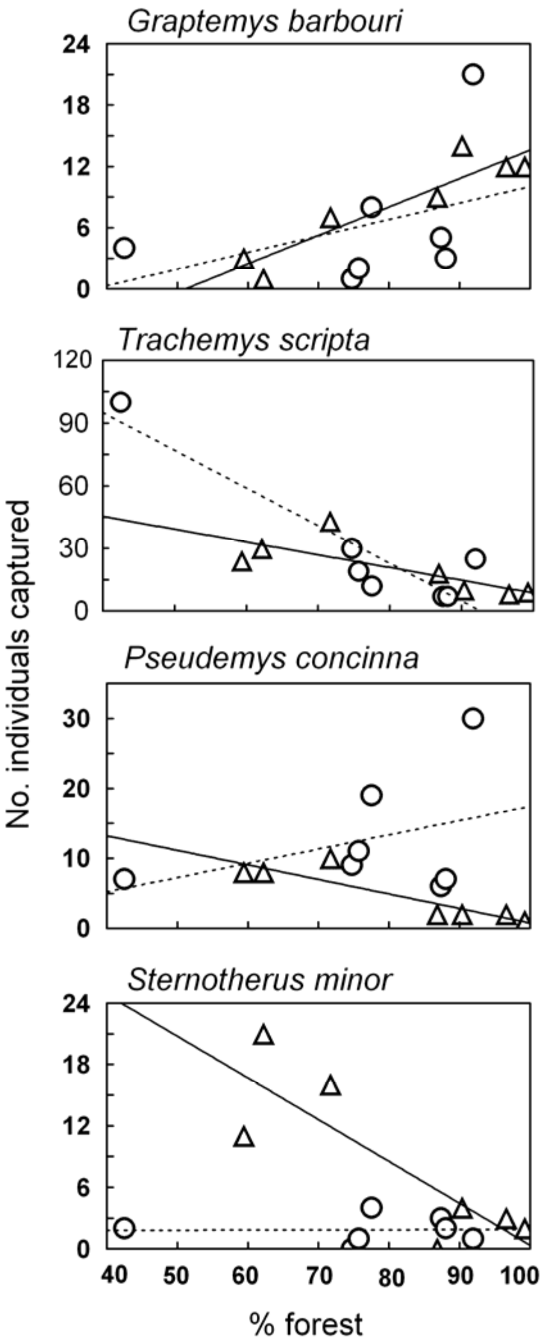

Figure 3.5. Linear regression of the four most frequently captured species versus % forested land cover on each creek, 2007-2008 (Ichawaynochaway Creek-triangles, solid line; Spring Creek-circles, dotted line).

CHAPTER 4

SPATIAL ECOLOGY AND INSTREAM HABITAT SELECTION OF FEMALE BARBOUR'S MAP TURTLE (*GRAPTEMYS BARBOURI*) IN ICHAWAYNOCHAWAY CREEK

Introduction

Map turtles (*Graptemys* spp.), the most diverse group of freshwater turtles in the United States, are generally drainage-specific river specialists in the southern part of their range, yet are more widespread habitat generalists in the northern part of their range (Ernst et al. 1994). These turtles exhibit extreme sexual dimorphism and males and females have distinct diets; males eat mostly insects and small mollusks and females feed primarily on large mollusks (Lindeman 1999). Map turtles are of conservation interest with all 13 recognized species listed in CITES Appendix III, with the most southern species protected throughout their range (U.S. Fish and Wildlife Service 2006). Due to their diversity, like other imperiled river taxa such as darters (Etheostomidae and Percidae) and mussels (Unionidae), map turtles are particularly vulnerable to human alterations of rivers and streams such as damming, channelization, and pollution (Buhlmann and Gibbons 1997, Bodie 2001). It is imperative to know more about basic ecological needs of river turtles to better serve species in need of conservation (Moll 1996).

Knowledge of the habitat requirements of river turtles is particularly important for their conservation. Several published studies have suggested relatively large home range estimates for *Graptemys* spp. in both natural (Vogt 1980, Pluto and Bellis 1988, Jones 1996, Bodie and Semlitsch 2000) and urban (Ryan et al. 2008) settings. Jones (1996) found no significant differences in linear home range of male (1861 ± 879 m) and female (1550 ± 320 m) yellow-blotched map turtle (*G. flavimaculata*), both of which frequently made long distance movements in spring and fall. Some map turtles make large short-term movements, as far as 1457.5 m in one day (*G. geographica*, Pluto and Bellis 1988) *Graptemys pseudogeographica* and *G. ouachitensis* are capable of moving 4 km over the course of a year (Vogt 1980). Ryan et al. (2008) found *G. geographica* in an urban area of Indiana using an expansive portion of a canal, with a linear home range of 3 km and daily movements of 300 m.

Across the range of the genus, *Graptemys* uses habitats as diverse as rivers and streams to lakes (Ernst et al. 1994). Fuselier and Edds (1994) studied habitat partitioning of 3 sympatric *Graptemys* species in Kansas and determined that basking sites and substrate were key factors that spatially separated these species. Lindeman (2003) found that habitat use differed between male and female Texas map turtles (*G. versa),* and attributed it to dietary differences. Adult female common map turtles generally use deep river habitat with high flows. Some studies have found partitioning of habitat by size class due to variation in swimming speed, thermoregulation behavior, predator avoidance, and interspecific social factors (Flaherty and Bider 1984, Pluto and Bellis 1986). Map turtle habitat use may differ from other turtle groups because of their specialized diet, especially in the southern U.S. Studies of map turtles have described several habitat characteristics such as, distance to shore, surface current velocity, and water temperature (Jones 1996, Lindeman 2000). Despite recognition of the importance of in-stream habitat features such as substrate type and water depth to map turtles (Fuselier and Edds 1994, Legler and Cann 1980, Moll 1980), few studies have quantified use of these habitats. With the advent of low-cost sonar imagery, in-stream habitat mapping is now feasible (Kaeser and Litts 2008), and in-stream habitat predictions for aquatic turtles can be examined.

In-stream large woody debris (LWD) provides grazing substrate for turtles, basking sites for thermoregulation, and protection from aquatic predators (Chaney and Smith 1950, Shively and Jackson 1985, Jones 1996, Lindeman 1999). Vandewalle and Christenson (1996) found that turtle species richness declined as habitat diversity decreased and cited snagging, or removal of large dead wood, as a potential factor. Snagging has been a common practice in rivers and streams throughout the southeastern U.S. (Sedell et al. 1982, Sedell and Froggatt 1984). However, effects of removal of LWD on aquatic biota and stream function, and as habitat to aquatic turtles such as *Graptemys*, has not been adequately quantified (Lindeman 1999, Gregory et al. 2006).

Barbour's map turtle (*G. barbouri*) is endemic to the Apalachicola-Chattahoochee-Flint River Basin, which extends through southwestern Georgia, southeastern Alabama and the panhandle of Florida, although other populations have been discovered outside of this basin (Godwin 2002, Enge and Wallace 2008). Males and small females are often associated with limestone rocky substrate and shoals, whereas large adult females are found more often in deep pools (Moulis 2008, Sanderson 1974). This may be a result of differences in diet between the sexes, although a complete study has never been undertaken (Sanderson 1974, Lindeman and Sharkey 2001). Only one study has quantified home range in Barbour's map turtles; Sanderson (1974) used mark-recapture data to estimate home range length in males and females (364.5 m and 273.0 m, respectively). Current technological advances, such as radio-telemetry, may provide data that estimate turtle movements more accurately, and Geographic Information Systems (GIS) allow detailed analysis of spatial patterns and habitat use.

The main objective of this study was to examine the spatial ecology of female Barbour's map turtle in a relatively undisturbed stream in southwest Georgia. In this evaluation, I used radio-telemetry and mapped in-stream habitat (Kaeser and Litts 2008) to predict habitat requisites of female map turtles by using logistic regression models. I expected adult female *G.*

barbouri home ranges and depth of habitat use to be larger than subadults and that female map turtles would select deep pools more frequently than other available in-stream habitats. I also hypothesized that female Barbour's map turtles would overall select deep, sandy pools associated with limestone and large woody debris.

Methods

Study Area

This study was conducted on a private portion (~24 km) of Ichawaynochaway Creek (Baker County, Georgia) on Ichauway, the site of the Joseph W. Jones Ecological Research Center (Fig. 4.1). Ichauway, a 12,000-ha ecological reserve, is managed for maintenance of the longleaf pine (*Pinus palustris*) ecosystem. The site was historically managed as a private quail (northern bobwhite, *Colinus virginianus*) hunting plantation. Ichawaynochaway Creek, which bisects this property, is a tributary of the Flint River, largely fed by the upper Floridian Aquifer, and is characterized by Ocala limestone outcrops along its margins, rocky boulder shoals and deep, sandy pools. The portion of creek on Ichauway has intact, forested riparian zones. The northern end of the property is bounded by a former Georgia Power dam. The dam was constructed in the early 1920s, but structurally failed shortly thereafter, allowing water to flow freely. However, it could still be an upstream barrier to turtle movement. The creek flows into the Flint River at the southern edge of the property.

Turtle Monitoring

Female Barbour's map turtles were hand captured by snorkeling in summer 2007 (7 individuals) and 2008 (14 individuals). Turtles were transported to a laboratory where they were measured (straight-line carapace and plastron length to nearest 1 mm) and weighed (to nearest g). Unmarked turtles were given unique identification marks by drilling the marginal scutes (Cagle 1939). Transmitters were attached with screws and nuts and reinforced with epoxy following Jones (1996). Each transmitter package weighed about 35 g (Models SI-2F and AI-2F, Holohil Systems, Inc) and was from 1 to 9% of the turtle's body mass. All turtles were returned to their capture location within 48 hours. All turtle handling and radiotransmitter attachment was conducted under the University of Georgia Animal Care and Use Committee (AUP # A2007-10102-0)

Home Range and Habitat Selection

Turtles were located by homing in on them approximately once a week in summer (1 June – 31 August) 2007 and 2008, and at least once a month in fall, winter, and spring (1 September – 31 May) 2007-2009. Turtle locations were determined from a kayak using a Yagi 3-element antenna and wildlife specialist receiver, then the location was recorded with a Trimble Geo3 Explorer™ (Trimble Navigations, LTD., Sunnyvale, CA) handheld GPS with differential correction post-processing (accuracy 1-5 m). In the event of high flow, turtle locations were biangulated from the bank. At each turtle's location, the following habitat characteristics were taken: depth at location (using a Hawkeye Handheld Digital Sonar System model DF2200PX), distance to bank and emergent debris (0-5, 5-10, 10-15, >15m) and presence/absence of limestone. When water clarity was high, activity and visual observations were also noted. All locations were incorporated into a GIS using ArcMap (ESRI v. 9.1).

Instream Habitat Mapping

During April 2008, Georgia DNR staff used boat-mounted sidescan sonar to capture images of the entire bankfull channel of Ichawaynochaway Creek (Kaeser and Litts *unpublished data*). Sonar imagery was spatially geo-referenced, rectified, and interpreted to create habitat cover maps (Kaeser and Litts 2008, Kaeser and Litts *In review*). Habitat maps included substrate classifications, continuous mid-channel depth, stream bank boundaries, and locations of LWD (defined as any piece of wood ≥10 cm diameter and ≥1.5 m in length; Fig 4.2). Map accuracy was assessed through a comprehensive assessment study that included the collection of reference data on actual substrates and LWD present throughout the study area (Kaeser and Litts 2008, Kaeser and Litts *In review*).

Analysis

ArcGIS (ESRI, v.9.2) was used to calculate the total length of creek used by each turtle (farthest distance travelled). Locations obtained by biangulation were placed in the center of the stream channel for home range analysis. Home range size (ha) of each radio-tagged turtle was estimated from sonar habitat maps described above. Kernel density estimates were analyzed with Home Range Tools Extension (HRT, version 1.1, Rodgers et al. 2007) to get 50 (core habitat), 90, and 95% adaptive kernel estimates (ha) using least squares cross validation bandwidth (h) selection.

To extract data from sonar habitat maps, I used ArcGIS to calculate distances from turtle (n = 462) and random (n = 462) locations to different substrate categories (island, rocky boulder, rocky fine, sand, unsure rocky, unsure sand; descriptions of each substrate class are provided in Kaeser and Litts (*In review*)) and LWD (Kaeser and Litts 2008). Nearest mid-channel depth measurements from all actual and random turtle locations were also included. I used a logistic regression (Hosmer and Lemeshow 2000) and information theoretic modeling approach (Burnham and Anderson 2002) to identify in-stream habitat features in supported models that best predicted turtle locations. I constructed a set of 14 *a priori* candidate models including a single variable and all combinations of substrate, depth, and LWD. Values for LWD and each substrate category represented distances from actual and random locations, and depth represented the nearest actual mid-channel value. The best candidate model had the lowest second order Akaike's Information Criteria (AIC_c) value and the best set of models included all models with ΔAIC_c values ≤ 2 (Burnham and Anderson 2002). To test whether the global model fit the data, I used a Hosmer and Lemeshow goodness of fit test. A significant *P*-value in this test suggested a model did not fit the data (Hosmer and Lemeshow 2000). All biangulated points ($n = 29$) were removed for habitat prediction analysis because they did not represent accurate instream locations. All random and actual turtle locations immediately south of the dam were excluded from the analysis because we were not able to map this portion of the creek.

I used model averaging to calculate parameter estimates (Burnham and Anderson 2002). Parameters that did not deviate from zero within 90% confidence intervals were not considered good model predictors. The importance of each variable in predicting turtle habitat was based on the size of its weight.

I used a one-way ANOVA to test if adult and subadult females had different home range sizes (creek length used or 50% kernel area) or were found at different depths. I considered turtles <210 mm CL as subadult ($N = 4$) and those ≥210 mm CL as adult ($N = 10$; Cagle 1952). Chi square analysis was used to determine if proportions of turtle observations at distances to bank and emergent debris categories differed between subadults and adults. All statistical analyses were considered significant at $\alpha = 0.05$. Means are reported ± one standard error. All analyses were performed using SAS (SAS Institute, Inc., Cary, NC) and Statistica 8.0 (©1984-2008, StatSoft Inc., Tulsa, OK, USA).

Results

Twenty-one female Barbour's map turtles were affixed with radio-transmitters. I relocated 14 of the 21 turtles 32.3 ± 3.1 times (range = 22-57) over 303 ± 42 days (range = 165-590 days; Table 4.1). Seven radio-tagged turtles did not have sufficient locations (≤ 20) to use in the home range analysis (see below). Turtles varied in size (mean = 254.5 mm CL, range = 125-308 mm; Table 4.2) but were all considered to be adults (Cagle 1952). Turtles were observed visually at 9% of radio-tracking events.

Home range size among females varied (mean creek length used: 839 ± 199 m, range = 235 - 3112 m, and mean area: 3.13 ± 0.73 ha, range = 0.93 – 11.58 ha; Table 4.1). Mean 50% kernel area was 0.23 ± 0.05 ha, (range = 0.03 – 0.60 ha; Table 4.1, Appen. A). Mean 95% kernel area was 1.68 ± 0.39 ha, (range = 0.28 – 5.15 ha; Table 4.1, Appen. A). The kernel estimates of two turtles (ID 691 and 1900) were not appropriate due to the gross overestimation by the analysis and were not reported. There was no difference between adults and subadults in creek length used or 50% kernel home range estimates (MS = 6.697, $F_{1,12} = 0.11$, $P = 0.74$; MS = 1 822.85, $F_{1,12} = 1.50$, $P = 0.24$, respectively).

Long distance movements were observed for female *G. barbouri*, primarily from June through August. One individual (ID 791) made two long movements (3000 m and 1723 m) between 16 June and 4 July 2008. Between 5 July 2007 and 3 August 2007, turtle ID 366 moved 5.44 km with the longest movement observed being 3.68 km in 11 days. Despite further attempts to track these two turtles, I was unable to detect a signal after these long movements. The longest movement recorded during this study was a 6.4 km movement made between 22 July and 12 August (ID 790). This turtle was removed from the study due to transmitter failure. An individual that was tracked over 573 days had three large movements that occurred between

30 June and 4 August 2007 and 2008. Two of these movements (1.08 and 1.81 m) occurred within the same time period between 22 July and 4 August 2007 and 2008.

Adults used deeper water (mean 3.4 ± 0.1 m) than subadults (mean 2.1 ± 0.1 m) (MS = 115.221, $F_{1, 360} = 59.349$, $P = 0.000$). Emergent or in-stream limestone was present at 76% of total turtle locations (N = 264) when it was able to be assessed. Distance to bank varied between subadults and adults ($\chi^2 = 8.36$, df = 3, $P = 0.039$), but there was no difference between turtles and emergent wood debris ($\chi^2 = 7.015$, df = 3, $P = 0.0714$).

The global model was the most supported competing model with substantially greater support than the next best model (Table 4.3). Further, the results of the Hosmer and Lemeshow goodness of fit test suggested that the global model fit the data when predicting Barbour's map turtle habitat ($\chi^2 = 7.7680$, df = 8, $P = 0.4565$). The next best model, containing the variables depth and substrate, had a $\Delta AIC_c < 2$ and was strongly supported ($w_i = 0.30435$). Individual variable models of substrate categories and LWD received lower ranking than the combination and depth models and also were not supported (Table 4.3). The rocky boulder average parameter estimate did not deviate from zero (Table 4.4). Model average parameter estimates for three variables (depth, LWD, and unsure sand) suggested a positive relationship between the variable and the probability of use by Barbour's map turtle (Table 4.4). Parameter estimates of the remaining four substrate variables (islands, rocky fine, sand, unsure rocky) suggested a negative relationship between the variable and the probability of use by Barbour's map turtle over the course of the study (Table 4.4).

Three of 21 radio-tagged turtles were found dead during the study. On 16 June 2008, ID 394 was found dead on a sandy beach near a shoal after 312 days of tracking. There were fresh egg shell fragments on a sandy beach in the vicinity and the predation was determined to be mammalian and likely raccoon (*Procyon lotor*). Ewert (2006) has also documented the raccoon as a predator of nesting female *G. barbouri* and raccoons are well known predators of adult aquatic turtles (Ernst et al. 1994). In December, another individual (ID 1094) was found in a small cypress island in a large bend of the creek and was likely preyed on by a river otter (*Lontra canadensis*). The turtle was found on its back, head removed with inguinal and axillary entry points into the body cavity. This depredation resembled those described by Brook et al. (1991), which documented depredation of hibernating common snapping turtles (*Chelydra serpentina*) by river otters. Smith et al. (2006) documented the presence of river otters on the Ichauway reserve. Another individual (ID 801) was found dead 160 m from the creek after Tropical Storm Fay raised the water level 3.66 m in three days.

Discussion

This is the first study of Barbour's map turtle home range using radio telemetry. Home range size varied among individuals, but in general, data from my study were comparable to that reported for other *Graptemys* spp. (Craig 1992, Jones 1996, Bodie and Semlitsch 2000, Carriere 2007, Table 4.1). Sanderson (1974) estimated female *G. barbouri* home range length from turtles (N = 18) recaptured >3 times during a 2-year study on the Chipola River. The mean linear home range was 273 ± 48 m, much lower than the mean estimates of my study. However, several radio-marked turtles had smaller home range sizes, similar to those reported from Sanderson (1974).

Several studies have found differences in home range size or habitat use by different sized turtles (Pluto and Bellis 1986, 1988; Jones 1996). In this study, however, I found no difference in home range size between the two size classes, perhaps due to the small sample size of subadult females. I found that water depth at locations and distance from location and bank varied between adults and subadults, with adult turtles found in deeper water and farther from the bank overall.

Sanderson (1974) had similar results with larger females frequently found in holes 2-4 m deep and towards the center channel where the current is strongest. Jones (1996) determined that male yellow-blotched map turtles (*G. flavimaculata*) did not venture into faster moving water, compared to the larger females. Pluto and Bellis (1986) also found a relationship between turtle size and water depth and distances from banks in *G. geographica.* They attributed this difference to decreased swimming speed in smaller individuals, likely excluding them from areas with high water currents. The differences in adult and subadult habitat predictability using remotely sensed data was not tested in this study. The minimum size at maturity for *G. barbouri* is questionable. Cagle (1952) found the smallest sexually mature female to be 176 mm (plastron length). Although the smaller turtles in this study were considered subadults and were approximately smaller than those reported by Cagle (1952), more research is needed to confirm these smaller turtles as subadults.

Seasonal long distance movements by Barbour's map turtle are likely attributed to nesting. Other studies have linked seasonal movements to nesting patterns for *Graptemys* spp. (Jones 1996, Bodie and Semlitsch 2000). Despite long stretches of creek with steep banks (Golladay et al. 2006), at base flow, Ichawaynochaway Creek has numerous sandy beaches accessible to nesting turtles. River turtles can make extensive movements to find optimal nesting habitat (Moll and Moll 2004). Due to the patchy nature of optimal riparian nesting beaches on Ichawaynochaway Creek and variation in home range size found in this study, I hypothesize that some female turtles nest away from their shelter and foraging areas. On 27 July 2005 (at 1000 hr), a Barbour's map turtle was found nesting on a road at the north end of Ichauway property where few nesting beaches occur. The turtle had moved through ~50 m of thick understory vegetation to nest on a sandy road. It is possible that turtles will move through unsuitable riparian habitat to find open nesting areas. Few Barbour's map turtle nests have been found more than 100 m from streams (Ewert et al. 2006). Although no nesting events were observed during this radiotelemetry study, one turtle found dead may have been nesting within its home range when it was depredated by a raccoon, a well known predator of aquatic turtles (Ernst et al. 1994, Ewert et al. 2006). Although it is possible that the five missing turtles in this study made unusually long movements leaving the study area, I suspect that transmitters failed or a signal could not be heard from the creek. Locations taken before and just after Tropical Storm Fay, which raised Ichawaynochaway Creek 3.66 m, revealed that no turtles were displaced as a result of this increase in flow. Sanderson (1974) found no movements in Barbour's map turtles on the Chipola River before and after a hurricane. He observed turtles in the floodplain where currents were the weakest. Barbour's map turtles exhibited high site fidelity within their home range. Some turtles were found repeatedly at the same few locations throughout the year or returned to a particular location after a large movement. This strong site fidelity was evident by small 50% kernel estimates (Appen. A). This suggests that turtles were selecting particular sites to meet specific habitat requirements (shelter, foraging; Arvisais et al. 2002). Many of the locations used repeatedly by turtles were deep (>3 m) sandy pools with limestone ledges and large wood debris (logs). Site fidelity has been reported for the wood turtle (*Clemmys insculpta*), another stream dwelling freshwater turtle, at the northern extent of their range (Arvisais 2002). In 2006, during river turtle snorkeling surveys, 18 *G. barbouri* were captured within a 400-m stretch of Ichawaynochaway Creek. Of these, all 11 females captured were taken from beneath two large logs found in a deep (~3 m) sandy pool. A year later on 26 May 2007, one of these turtles was recaptured under the same log. Three more of these turtles first captured in 2006, including one affixed with a transmitter for the current study, were recaptured in the same location on 18 August 2007.

The combination of substrate, depth, and LWD were critical habitat features for predicting radio-tagged female Barbour's map turtle locations on Ichawaynochaway Creek. The strongly supported global model suggested that all three habitat features had an additive effect on turtle locations. No substrate variables that deviated from zero were positively associated with the probability of turtle use (Table 4.4). However, the presence of limestone at 76% of locations is further evidence of turtles' affinity for this specific substrate (Sanderson 1974, Enge and Wallace 2008). Barbour's map turtles were positively associated with LWD (Table 4.4). Several studies have quantified or noted the importance of LWD as essential basking structure (Moll 1980, Pluto and Bellis 1986, Jones 1996, Lindeman 1999), but only a few have considered LWD as essential in-stream habitat for freshwater turtles (Chaney and Smith 1950). Aquatic turtles are rarely found in open water or on sandy bottoms that lack substrate (Legler and Winokur), with the exception of *Apalone* spp. (Ernst et al. 1994). Besides providing refuge, in-stream LWD may also be important as substrate for benthic macroinvertebrates that map turtles, especially males and juveniles, feed on (Moll 1980). Although males were not included in this study, the importance of limestone shoal areas and macroinvertebrates has been observed for *G. barbouri* in the Chipola River (Sanderson 1974, Lee et al. 1975). Female Barbour's map turtles were not often found in shoals but preferred deep areas (e.g., large model averaged parameter estimates, Table 4.4) which are found in large bends in Ichawaynochaway Creek. The diet shift from native mussels to *Corbicula* spp. has been well documented in map turtles (Moll 1980, Shively and Vidrine 1984, Lindeman 2006) and appears to be similar in female *G. barbouri* (Sterrett, unpublished data). This food preference may facilitate high site fidelity if *C. fluminea* is distributed in areas around these frequently used sites. However, turtles were only tracked weekly, which made the possibility of finding them foraging outside their core areas unlikely. *C. fluminea* is commonly found in various stream habitats (Howells et al. 1996) and commonly inhabits depths up to 8 m (Abbott 1979, Dudgeon 1983), which is similar to the deepest areas of Ichawaynochaway Creek.

The spatial ecology of male and juvenile Barbour's map turtles needs further study. I originally intended to use lighter weight transmitters (12 g) to track adult male map turtles; however, the transmitter package was too large and heavy and I felt it would affect natural movements, which is unacceptable for radio-telemetry studies of wildlife (Withey et al. 2001). Therefore, I chose to track females in a smaller size class than the large adults, which I felt could safely carry the transmitters. The dispersal and movements of juvenile map turtles also needs further study. There are several small radio transmitters available for tracking juveniles; however, detection range and battery life would be limited. Barbour's map turtle juveniles are often found in shallow, rocky and sandy shoals, possibly due to predator avoidance (Shoener 1977, Sterrett, pers. obs.). Distances that juveniles move to get to this habitat and their activities within the habitat are unknown.

This study illustrates the spatial extent and habitat features used by female Barbour's map turtles in Ichawaynochaway Creek. It also provides detailed information about habitat features important to female map turtles. Such features may also be important to male Barbour's map turtles, as well as other river turtles in southwest Georgia. Barbour's map turtle has specific habitat requirements, which can be altered by anthropogenic activities (see Ch. 3). These turtles prefer deep, sandy bends in streams and have high affinity for LWD and limestone substrate (Enge and Wallace 2008, current study). Agricultural practices often encroach upon the LFRB (see Ch. 3) and can alter natural water flow and riparian and channel habitat (Allan 2004). These changes may alter essential habitat and prey of Barbour's map turtle. Terrestrial buffers around critical in-stream habitat are also imperative for *G. barbouri* (Bodie 2001). Open sandy beaches found within riparian zones are often used for nesting (Ewert et al. 2006). Although natural alterations occur with these sandy beaches, these areas are particularly susceptible to drastic changes by human recreation and land use and changes in stream flow, a result of agricultural pumping in southwest Georgia (Hicks and Golladay 2004). Snagging is a management practice that can potentially fragment populations, reduce local abundance and change prey availability for freshwater turtles (Bodie 2001, Ewert et al. 2006). LWD is essential to Barbour's map turtle, not only as basking structure (Sanderson 1974, Lindeman 1999), but also as essential cover refuge and should be managed as principle habitat within streams.

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Table 4.1. Home range size of 14 Barbour's map turtles radio-tracked on Ichawaynochaway Creek, Baker County, Georgia from 2007-2009. Two turtles were removed from kernel density estimates (KDE) because low numbers of observations led to over estimation of KDE.

ID	Fixed locations	Creek length (m)	Creek area (ha)	50% KDE (ha)	95% KDE (ha)
371	49	782	2.78	0.06	1.12
690	53	521	1.77	0.07	0.66
691	57	3112	11.58	-	-
801	23	331	1.76	0.07	0.57
351	32	567	2.08	0.10	0.61
1090	29	611	2.16	0.26	1.74
1094	22	235	0.93	0.03	0.28
990	27	577	2.17	0.40	2.30
991	28	938	3.65	0.32	2.34
1500	28	336	1.39	0.22	1.68
1502	28	1492	5.80	0.60	5.15
1900	25	1121	3.47	-	-
1520	25	855	3.24	0.47	2.81
2500	26	266	0.98	0.13	0.88
Mean ± SE	32.29 ± 3.1	839 ± 199	3.13 ± 0.73	0.23 ± 0.05	1.68 ± 0.39

Table 4.2. Morphology of Barbour's map turtles affixed with radio transmitters on Ichawaynochaway Creek, Baker County, Georgia, 2007-2009.

ID	Carapace length (mm)	Mass (g)	Dates tracked (days)
371	258	2295	7/5/07-2/23/09 (590)
366*	280	2890	7/5/07-8/4/07 (28)
690	282	2804	7/13/07-2/23/09 (573)
691	283	2790	7/13/07-2/23/09 (573)
394†	294	2988	8/3/07-6/10/08 (312)
336*	125	282	9/7/07-10/20/07 (43)
801†	194	946	9/7/07-8/29/08 (357)
790¥	266	2405	6/2/08-8/12/08 (71)
351	289	3021	6/3/08-2/23/09 (241)
791*	308	3817	6/3/08-7/17/08 (44)
1090	209	1261	6/19/08-2/23/09 (252)
1094†	291	2689	6/19/08-12/1/08 (165)
990	291	2938	7/3/08-2/23/09 (235)
991	290	3131	7/3/08-2/23/09 (235)
1500	266	1960	7/31/08-2/23/09 (208)
1502	279	2581	7/31/08-2/23/09 (208)
1900	177	670	8/1/08-2/23/09 (207)
1570*	256	1844	-
1520	193	827	8/6/08-2/23/09 (201)
1573*	220	1210*	-
2500	294	2692	8/6/08-2/23/09 (202)
Mean ± SE	255 ± 11	2242 ± 11	

*Missing during the study.

†Found dead.

¥Transmitter removed.

Table 4.3. Candidate models with number of parameters in each model (K), Akaike's Information Criterion value adjusted for small sample sizes (AIC_c), difference between the best model and each subsequent model (ΔAIC_c), and Akaike's weights (w_i) for habitat selection of female Barbour's map turtle in Ichawaynochaway Creek, 2007-2009.

Model Name	K	AIC_c	ΔAIC_c	w_i
Substrate Depth LWD	9	1153.22	0.000	0.69565
Depth Substrate	8	1154.87	1.653.	0.30435
Depth	2	1185.93	32.708	0.00000
Depth LWD	3	1187.47	34.425	0.00000
Substrate LWD	8	1188.25	35.028	0.00000
Substrate	2	1196.75	43.527	0.00000
Sand	2	1233.63	80.410	0.00000
Island	2	1255.27	102.049	0.00000
Unsure Sand	2	1276.46	123.244	0.00000
LWD	2	1279.70	126.478	0.00000
Unsure Rocky	2	1282.62	129.401	0.00000
Null	1	1282.94	129.719	0.00000
Rocky Boulder	2	1283.33	130.112	0.00000
Rocky Fine	2	1283.35	130.128	0.00000

Table 4.4. Model averaged parameter estimates for 8 variables included in logistic regression analysis used to predict Barbour's map turtle habitat in Ichawaynochaway Creek, 2007-2009. Estimates in bold indicate significant variables that deviate from 0 within 90% confidence intervals.

Parameter	Estimate	SE	Odds Ratio	Upper 90% CI	Lower 90% CI
Depth	**0.41483**	0.07102	1.51411	0.53131	0.29835
LWD	**0.01718**	0.00904	1.01733	0.03200	0.00235
Islands	**-0.00011**	0.00003	0.99989	-0.00007	-0.00015
Rocky Boulder	-0.00028	0.01397	1.00028	0.02319	-0.02263
Rocky Fine	**-0.01285**	0.00763	0.98723	-0.00033	-0.02536
Sand	**-0.01852**	0.00499	0.98165	-0.01034	-0.02671
Unsure Rocky	**-0.00098**	0.00041	0.99902	-0.00031	-0.00166
Unsure Sand	**0.00209**	0.00113	1.00210	0.00395	0.00024

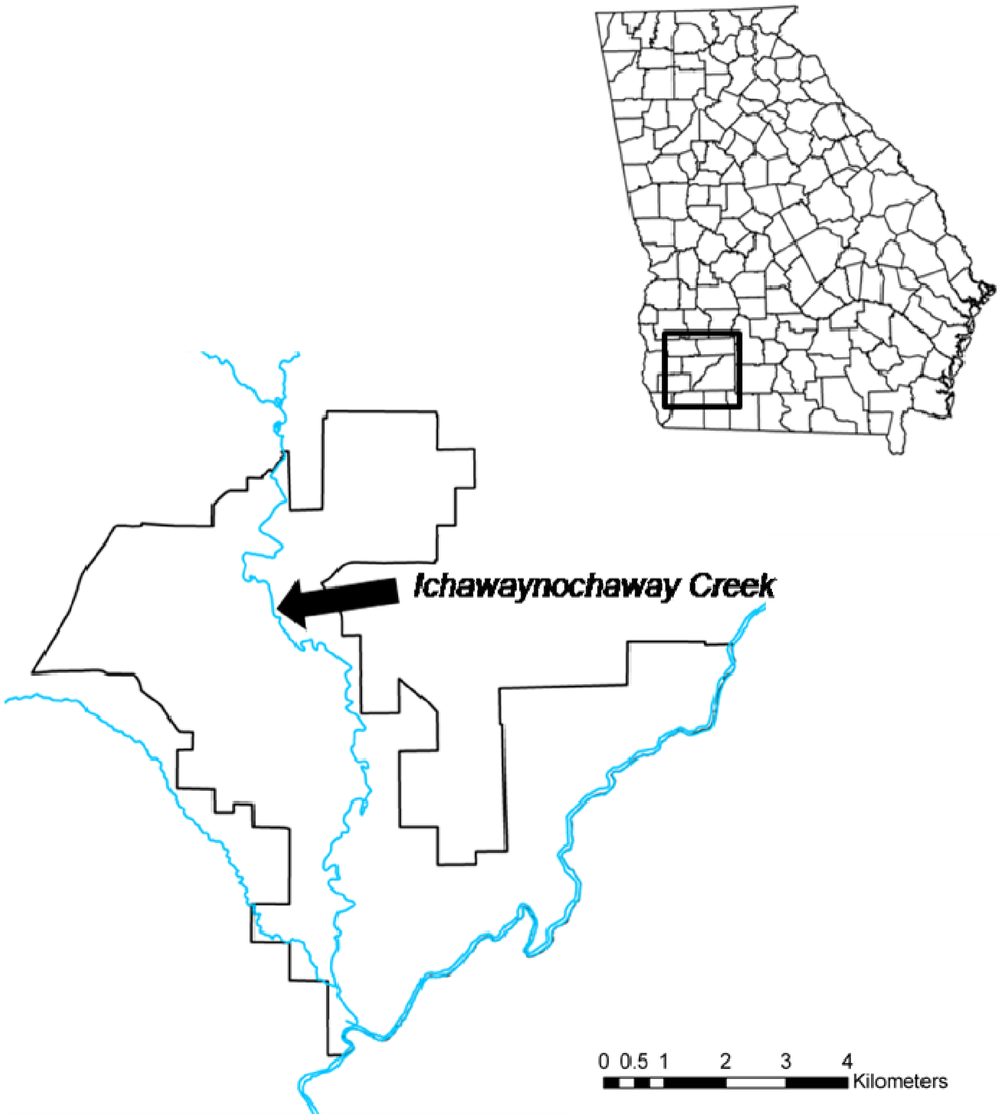

Figure 4.1. Ichauway reserve, located in Baker County, Georgia. Ichawaynochaway Creek flows through the center of Ichauway and the Flint River along the eastern border.

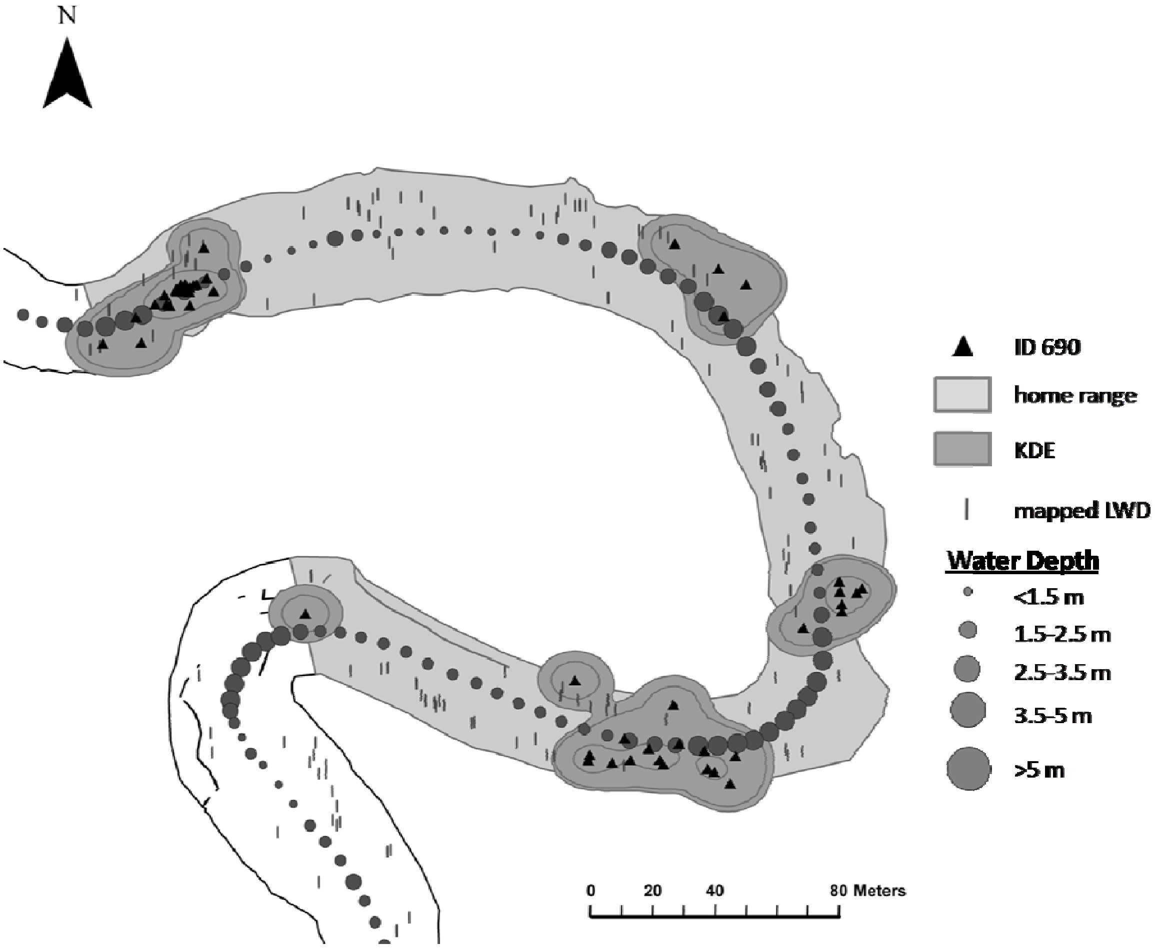

Figure 4.2. Example of an individual (ID 690) female Barbour's map turtle home range, kernel density estimated home range, and habitat features (depth categories and mapped LWD) used in analysis from Ichawaynochaway Creek, 2007-2009. Isopleths represent 50, 90, and 95% kernel density estimates (KDE).

CHAPTER 5

CONCLUSIONS

Stream dwelling turtles are among the most imperiled reptiles in the Southeastern U.S. and the most poorly understood (Buhlmann and Gibbons 1997). This study explores and expands upon our knowledge of river turtle ecology in the Lower Flint River Basin (LFRB) of southwest Georgia. Habitat modification, pollution, harvesting for food and the pet trade, malicious killing, and disease are all potential causes of turtle declines (Buhlmann and Gibbons 1997). Indirect land use pressures have the potential to be particularly damaging to aquatic turtles because they are inconspicuous and difficult to detect (Moll and Moll 2000). The objectives of this thesis were to (1) determine detection probability of two techniques used to capture river turtles, (2) examine the influence of land use on a river turtle assemblage in the LFRB, and (3) study the spatial ecology and habitat use of female Barbour's map turtles (*Graptemys barbouri*) in a relatively unimpacted section of Ichawaynochaway Creek.

Detection probability has rarely been reported for reptiles although its incorporation into inferences about populations is becoming more widespread (Mazzerolle et al. 2007). In this study, I determined the detection probability of river turtles for two techniques; baited hoop traps and effort managed snorkel surveys. This combination of methods yielded detection of nine species, which included all species expected in a LFRB drainage (Jensen et al. 2008). Hoop trapping was the most effective capture method (88% of individuals) for yellow-bellied slider (*Trachemys scripta*), while snorkel surveys yielded higher captures (87% of individuals) of Barbour's map turtle. River cooter (*Pseudemys concinna*) and loggerhead musk turtle (*Sternotherus minor*) were captured well by both methods. Similarly sized turtles were captured with both methods but species abundance by technique was highly skewed with more sliders captured by trapping and Barbour's map turtle by snorkeling. Despite the use of hoop trapping in many aquatic turtle studies (Plummer 1979), detection probability was higher in snorkel surveys for the four most commonly captured species in my study. Effort managed snorkeling was an effective survey method in this study because Coastal Plain rivers and creeks typically have exceptionally good water clarity during seasonal low flows. However, the efficiency of this method can be affected by water clarity, stream depth and flow, surveyor experience, and water temperature. Trapping alone is an effective way to detect yellow-bellied slider in the LFRB. I recommended that further surveys adjust survey techniques appropriately according to the study objectives when assessing river turtle assemblages in Coastal Plain streams.

It is well known that adjacent land use affects stream habitat and associated aquatic fauna (Allan 2004). Agriculture is the predominant land use in the LFRB of southwest Georgia and it frequently encroaches upon stream ecosystems. I found a significant effect of riparian forest cover on the local composition and abundance of turtles in two streams of the LFRB. Specifically, I found that there was a significant negative relationship with Barbour's map turtle abundance and the amount of forested land cover in riparian buffers; while in contrast, there was a significant positive relationship between abundance of yellow-bellied sliders and forest cover. In areas with intact forested riparian zones, such as the Ichauway reserve, fewer turtles were found with greater compositional species evenness. It has been suggested that *Graptemys* spp. are among the most vulnerable of freshwater turtles to changes in river quality and associated prey resources (Dodd 1977, Lydeard and Mayden 1995). Further studies are needed to establish mechanistic relationships between land use and instream processes and their potential influence on aquatic turtles.

Finally, I used radiotelemetry to study the spatial ecology of female Barbour's map turtle. Barbour's map turtle is endemic to drainages within the Apalachicola-Chattahoochee-Flint River basin and is a protected species in Georgia. Few studies have addressed the spatial ecology and habitat requirements of the species. I used logistic regression and an information theoretic approach to predict important habitat features of female map turtles from sonar imagery habitat maps. Barbour's map turtles made extensive movements coinciding with nesting season for the species (Ewert et al. 2006). Home range size varied among individuals, but most turtles used relatively small home ranges and had high site fidelity. Substrate type, water depth and the presence of large woody debris (LWD) were all important habitat features in predicting turtle occurrence. These findings elucidate the need for conservation of aquatic habitat, particularly LWD and deep pool areas, to maintain populations of Barbour's map turtle, as well as other river turtles in southwest Georgia. Large woody debris is often removed from streams and riparian zones to improve access and navigation (Wallace and Benke 1984). This practice continues in southwest Georgia (Kaeser and Litts 2008) and directly affects stream fauna (Benke 2001). Agricultural practices often encroach upon the Lower Flint River Basin altering natural water flow and riparian and channel habitat (Allan 2004). Collectively, these changes can alter essential habitat and prey sources of Barbour's map turtle. Sandy beaches in the riparian zone should also be recognized as critical habitat features for Barbour's map turtle.

The dominant theme of this study was the ecology of aquatic turtles and their connection with the integrity of stream ecosystems. Maintenance of remaining natural habitat is important for the persistence of turtles. Some turtles are generalized in diet and habitat and resilient to habitat alterations, while others are specialized and potentially vulnerable to changes in structural habitat features and prey. Future river turtle studies should focus specifically on nesting habitat, the use of LWD and other instream substrates by river turtles and the effects of land use on these essential structures.

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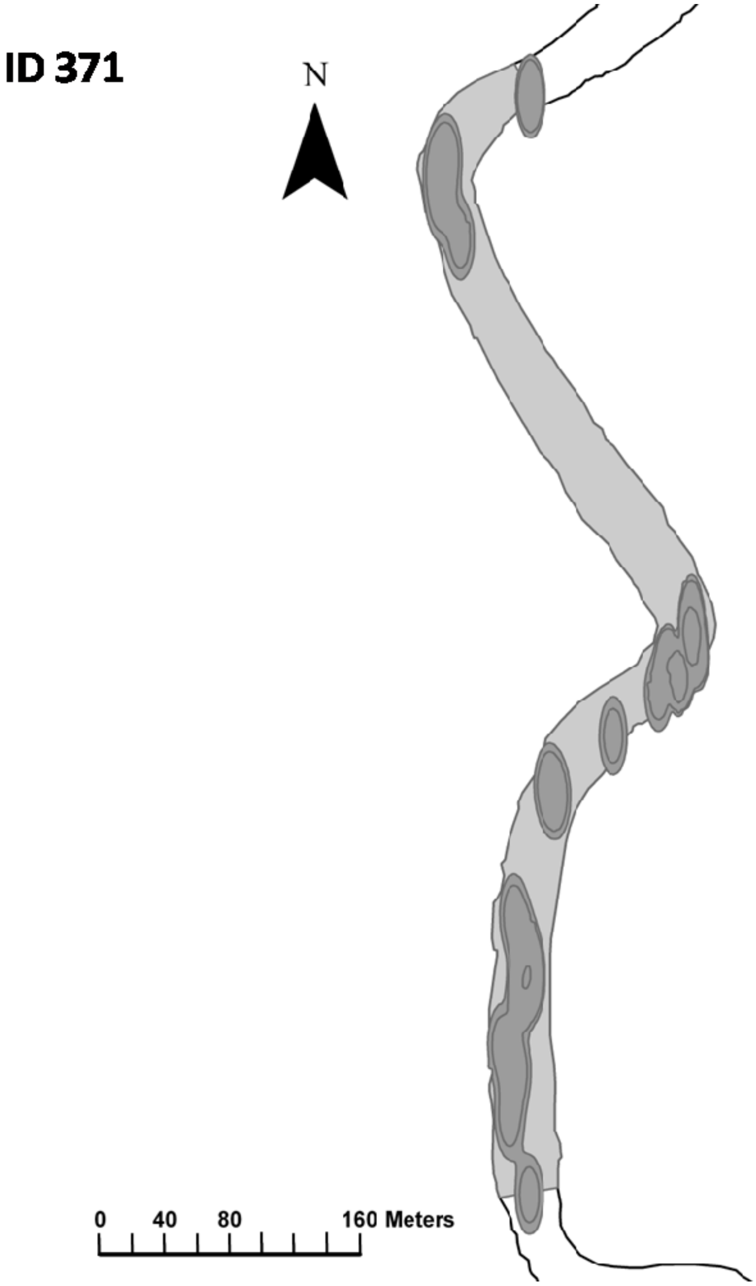
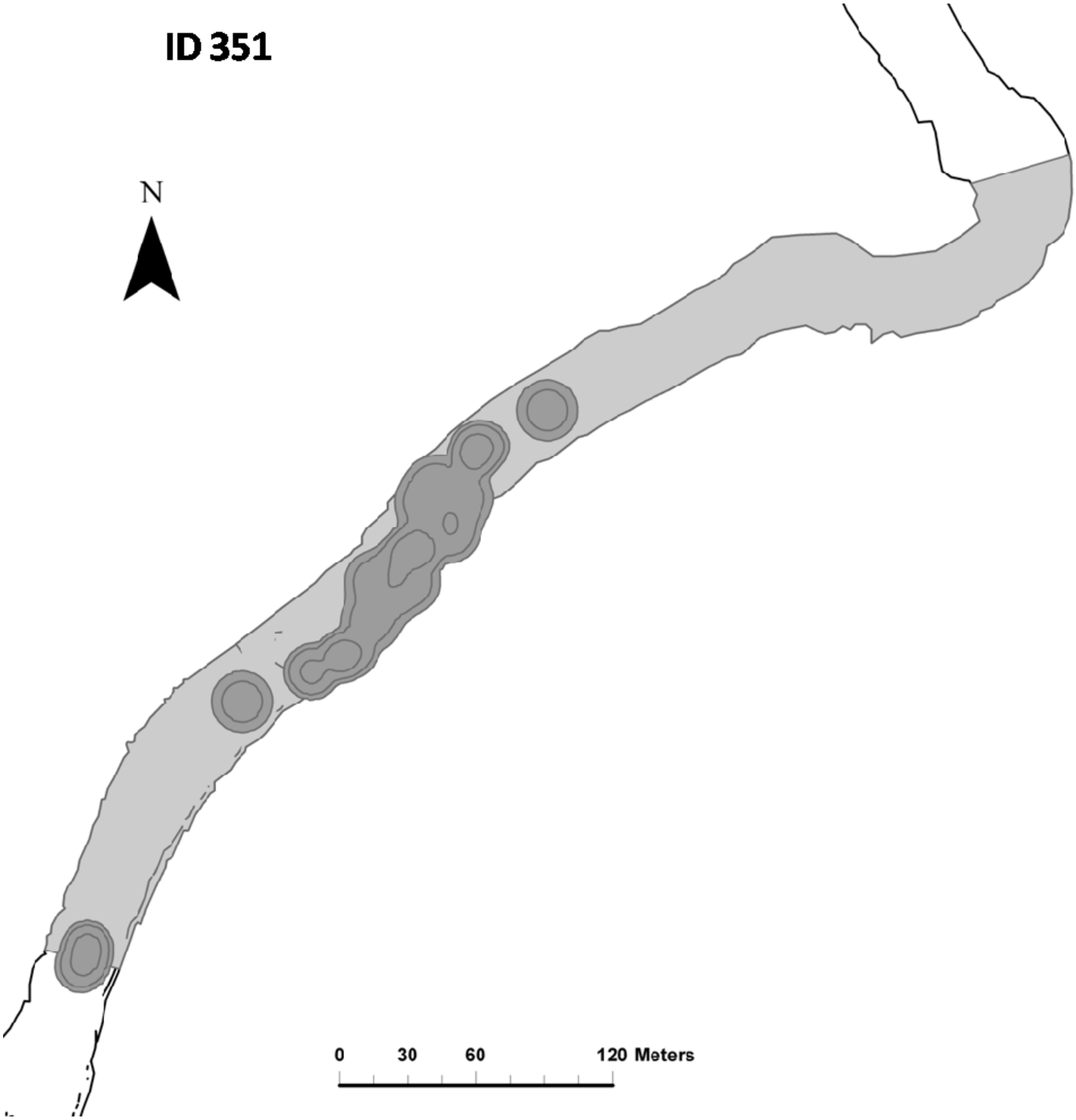
APPENDIX

APPENDIX A. Maps illustrating kernel density estimates of Barbour's map turtle (*Graptemys barbouri,* ID 690, Fig. 2). Light gray represents creek area home range. Dark gray isopleths represent 50, 90 and 95% kernels.

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60
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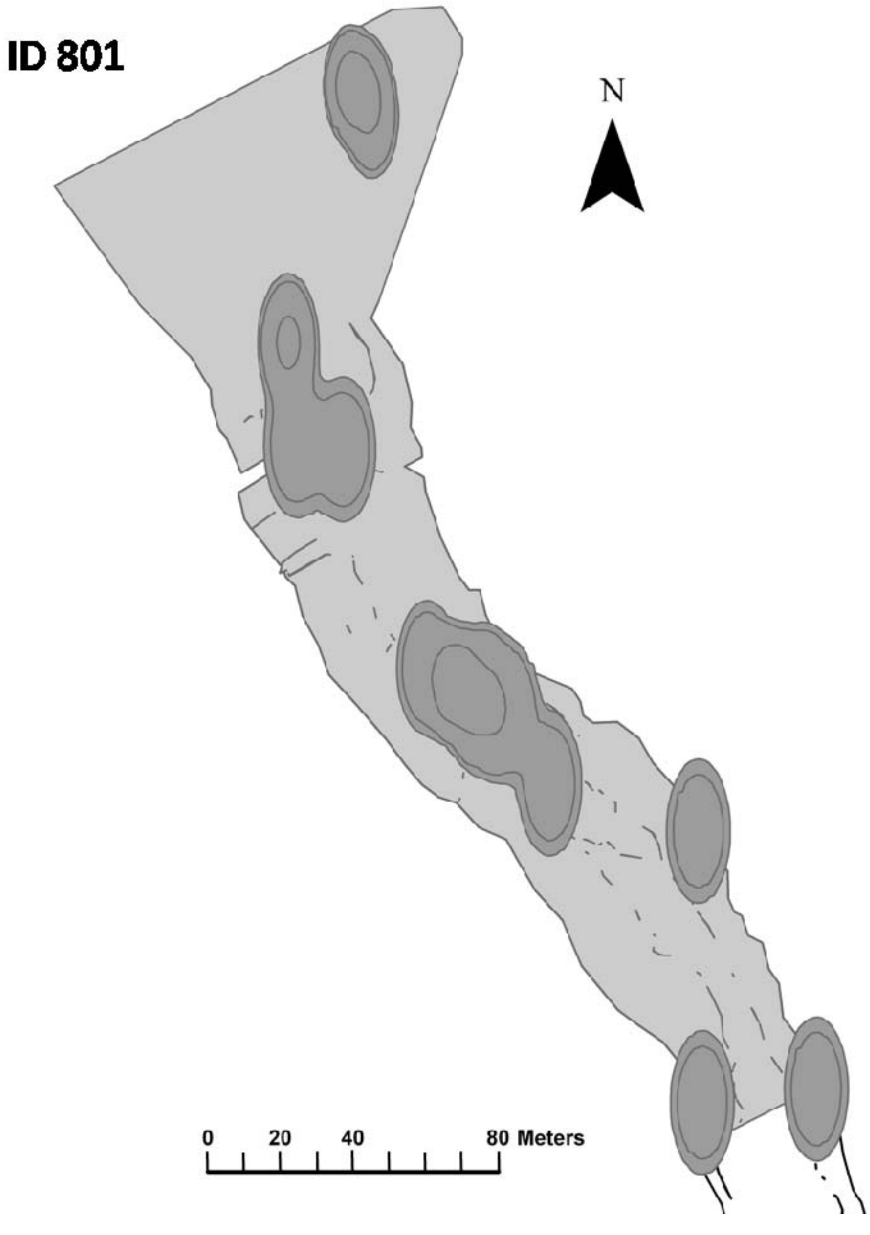
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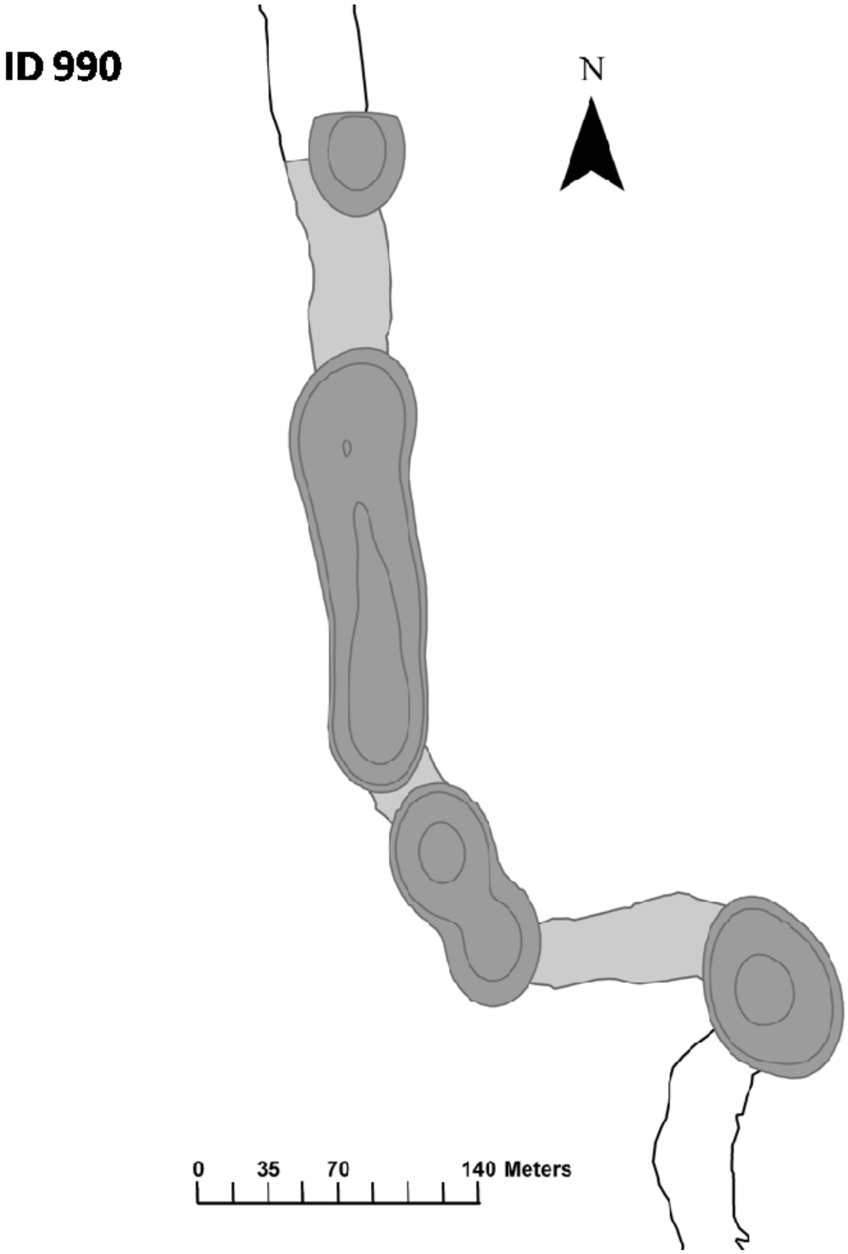
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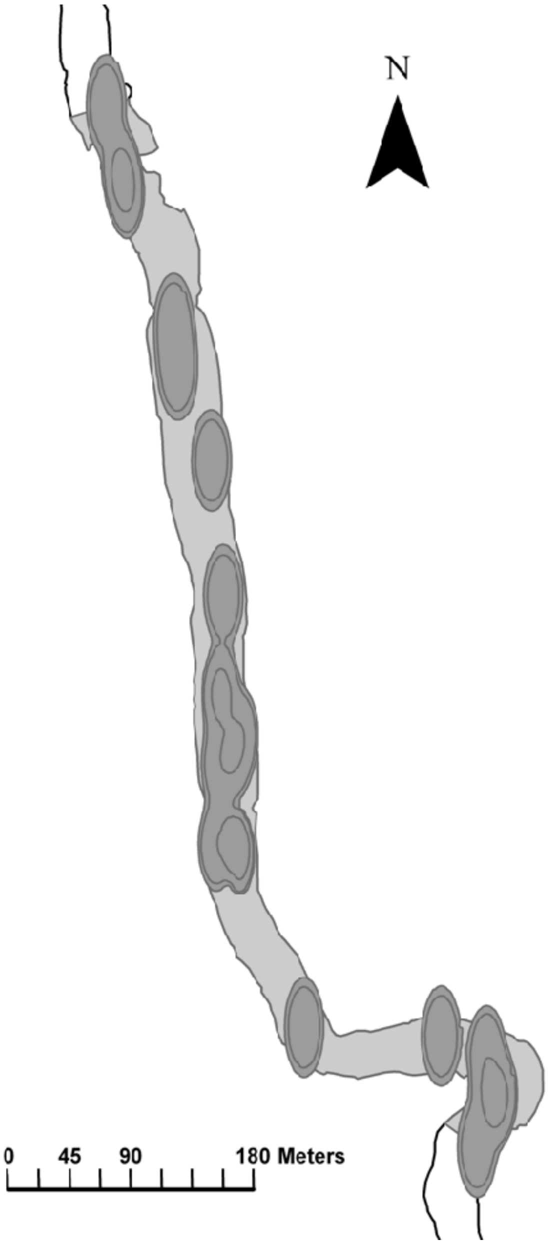
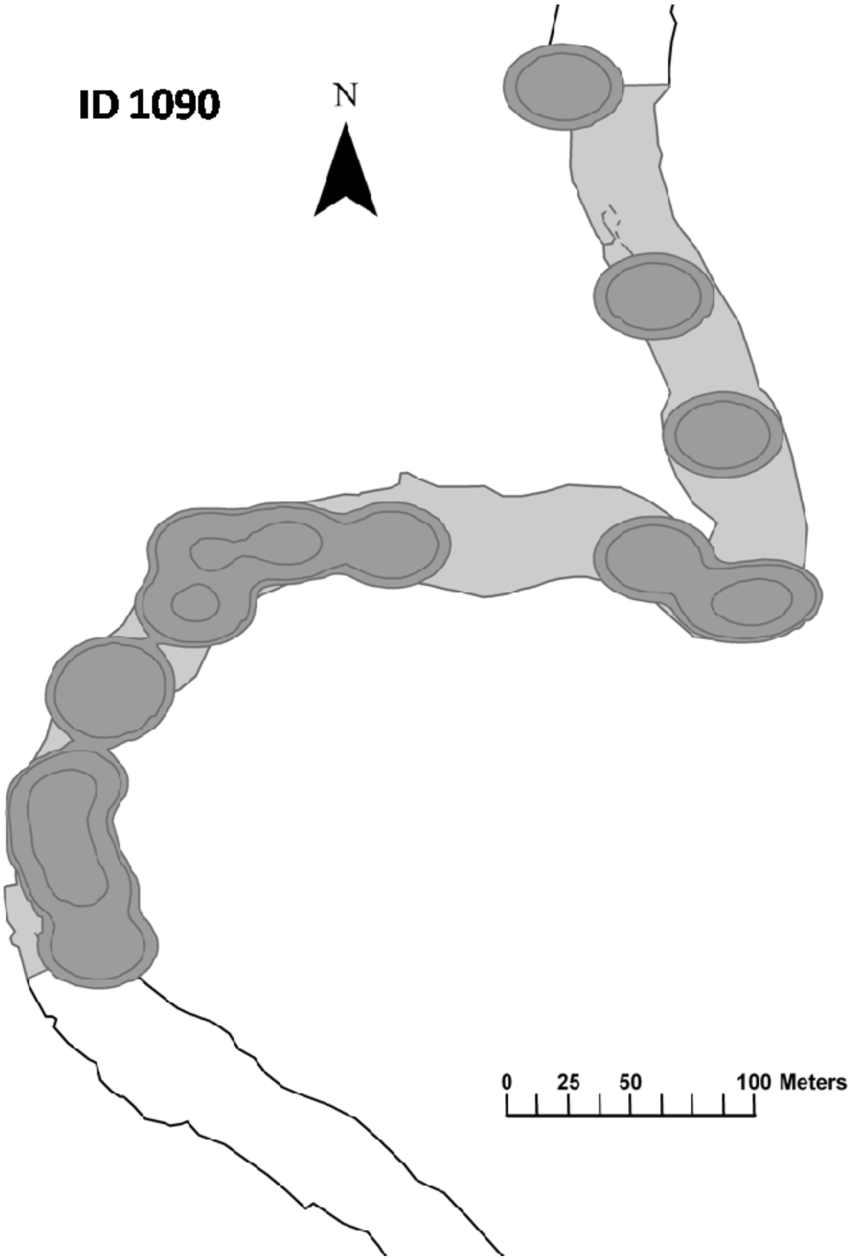
35
70
140 Meters

ID 991

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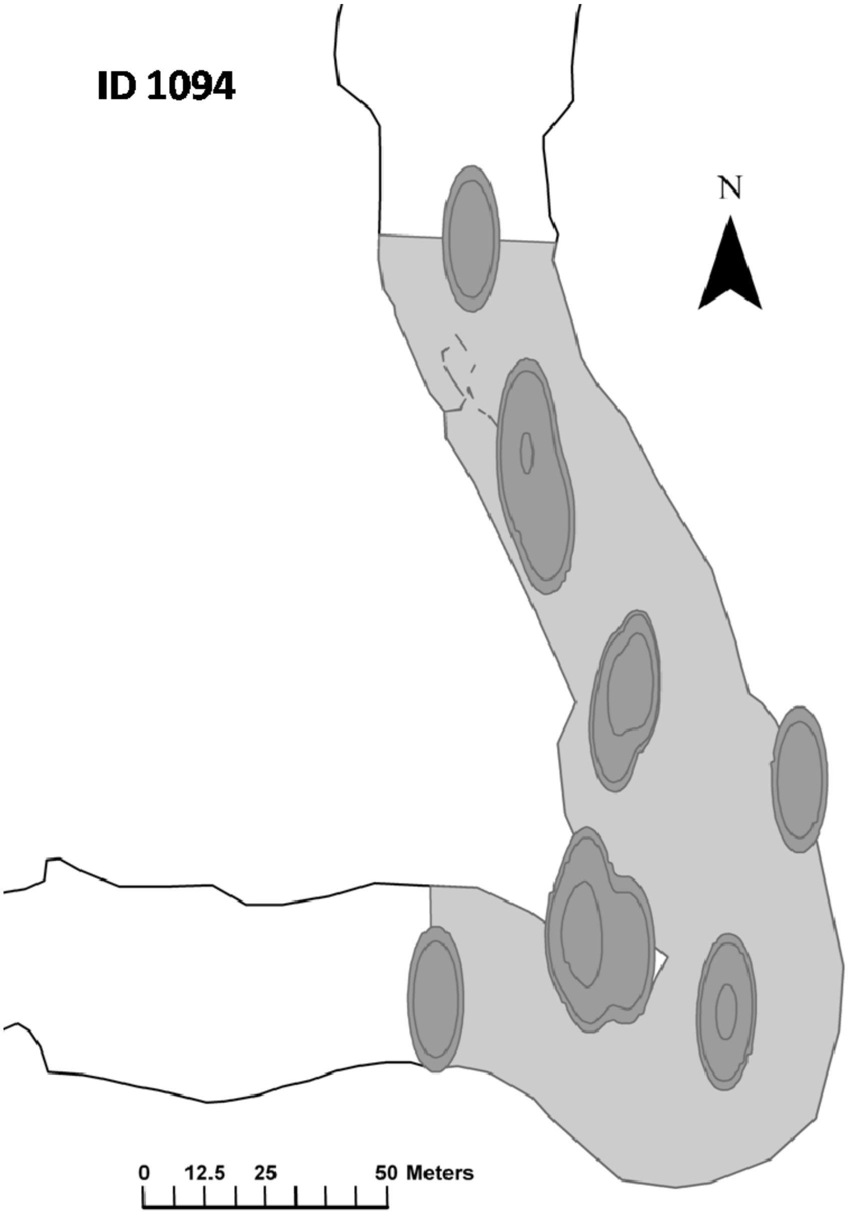
25
50
100 Meters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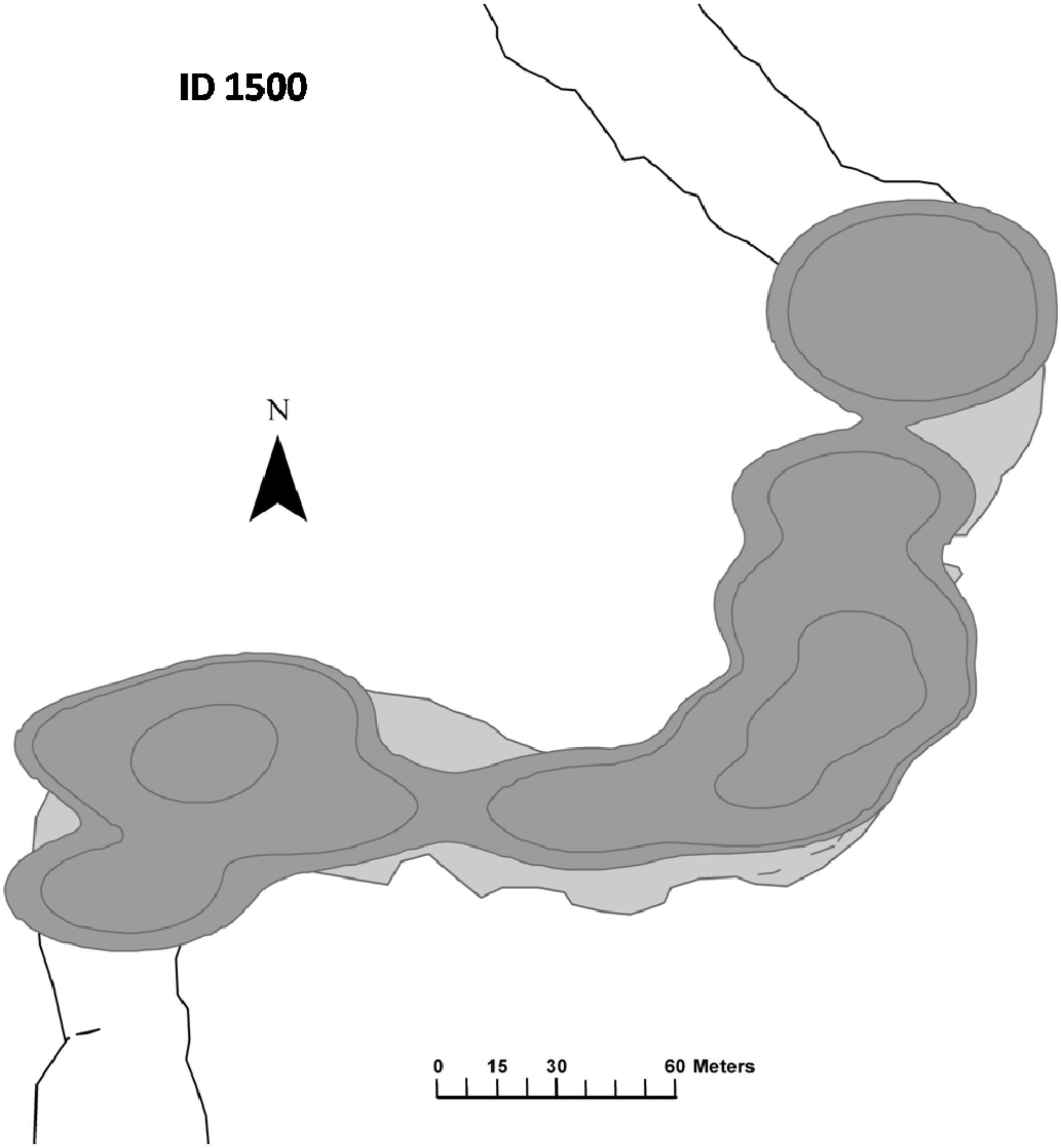
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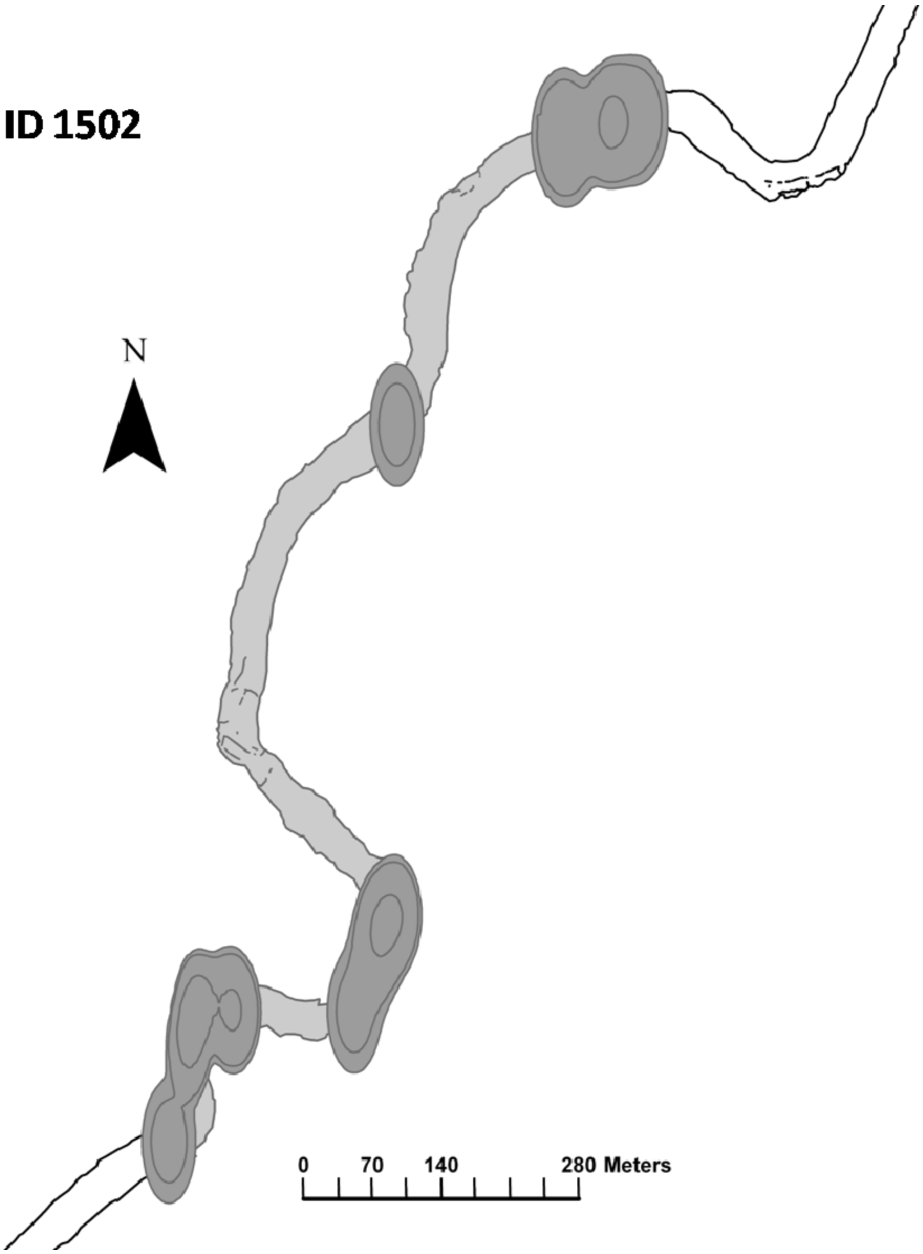
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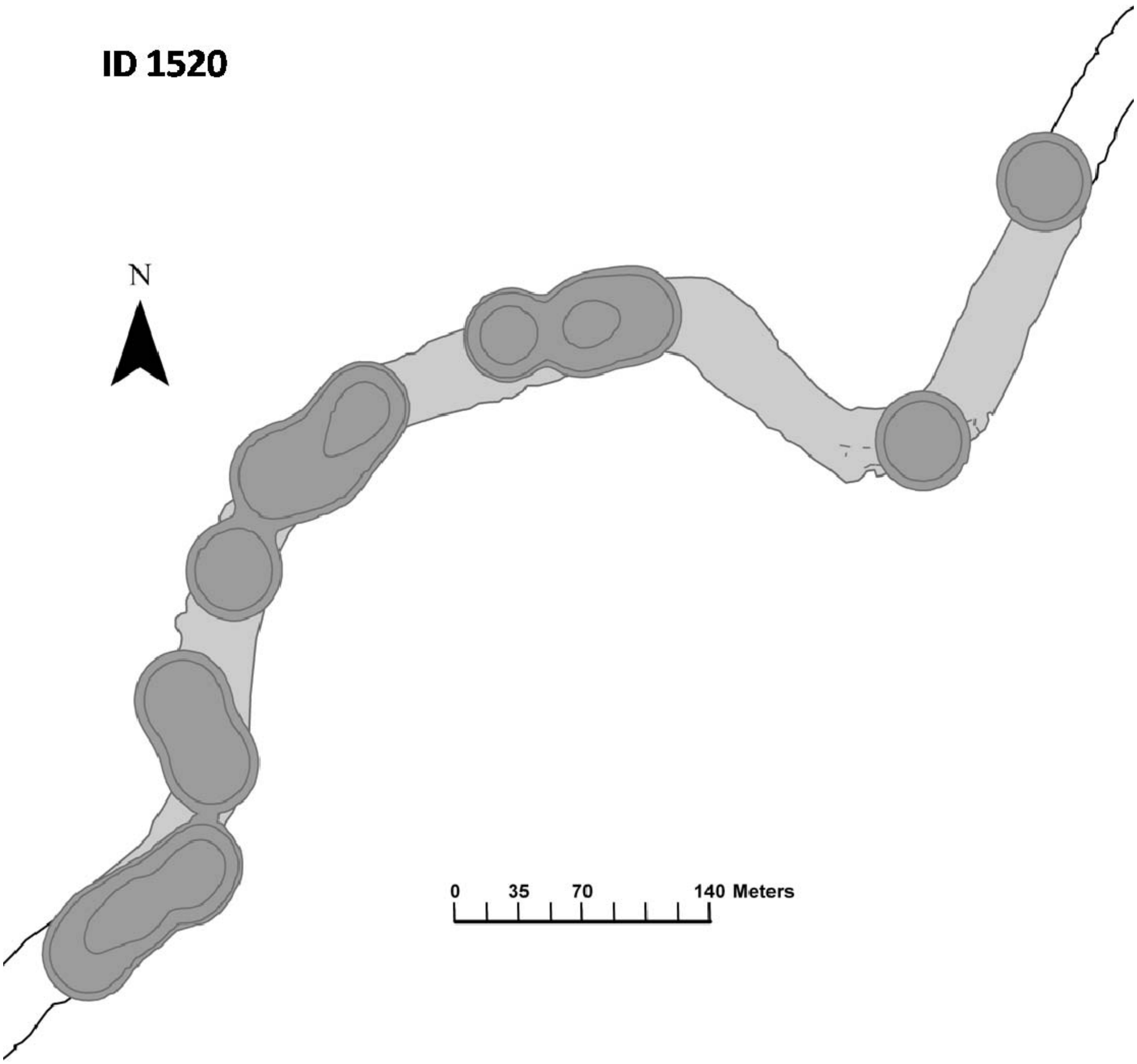
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