USE OF HIERARCHICAL OCCUPANCY MODELS TO ESTIMATE THE SEASONAL DISTRIBUTION AND HABITAT USE OF STOCKED ROBUST REDHORSE *MOXOSTOMA ROBUSTUM* IN THE UPPER REACHES OF THE OCMULGEE RIVER, GEORGIA

by

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(Under the Direction of Cecil Jennings)

ABSTRACT

The robust redhorse *Moxostoma robustum* is an imperiled fish that inhabits large Atlantic slope rivers in Georgia and the Carolinas. To establish a refugial population, GA Power Company stocked robust redhorse in the upper Ocmulgee River, Georgia. I used occupancy modeling to estimate seasonal habitat use of the current population of stocked fish within the project site. Modeling results revealed robust redhorse have a conditional detection probability of $0.183(\pm 0.128)$ and an occupancy rate of $0.033 (\pm 0.046)$ throughout the project site. Further, the Upper Ocmulgee River population was found most frequently in areas with coarse substrates and high velocity year round. Although this habitat use pattern is different than that of the nearby Oconee River population, habitat characteristics differ between the two rivers. I conclude that robust redhorse were residing in shoals inaccessible to researchers or have left the headwaters entirely and reside in the Coastal Plain portion of the Ocmulgee.

INDEX WORDS: Catostomidae, suckers, Piedmont, site occupancy, presence, conditional detection, rare species, sonar imagery

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CHAPTER 1

INTRODUCTION

Discovery of Robust Redhorse

The robust redhorse (Moxostoma robustum) is a large fish that historically occupied medium to large rivers in the Piedmont and upper Atlantic Coastal Plains of Georgia, North Carolina, and South Carolina (Cope 1869, Bryant et al. 1996). In response to the robust redhorse's limited distribution and population decline attributable to extensive habitat loss and the introduction of invasive species, the fish became state listed as endangered in Georgia (Bryant et al. 1996, Grabowski and Jennings 2009). The robust redhorse was first described from the Yadkin River, North Carolina in 1869 (Cope 1869); however, additional specimens remained unnoticed by ichthyologists for over a century (Bryant et al. 1996) as a result of the species not being collected or being misidentified. In 1991, a catostomid matching Cope's original description was found in the Oconee River, GA, and subsequent taxonomic observations of collected specimens confirmed that the fish in question was similar to that described by Cope (1869). Eventually, the Oconee River catostomid was confirmed as a robust redhorse, which had remained unrecorded for over 120 years (Bryant et al. 1996, Ruetz and Jennings 2000). Soon after robust redhorse was found in the Oconee River, other Atlantic slope rivers such as the Savannah, Yadkin, and Pee Dee were surveyed for the mystery fish.

The "rediscovery" in the Oconee River led to the formation of the Robust Redhorse Conservation Committee (RRCC), which is a multi-stakeholder partnership formed by state and

federal agencies, non-governmental organizations, and private industries in Georgia, North Carolina, and South Carolina under a Memorandum of Understanding. Concerned with the potential extinction of robust redhorse, the RRCC set goals to determine the current status of the species, identify conservation and habitat needs, and coordinate efforts to address those needs. As a result, extensive captive propagation and stocking programs were implemented to reintroduce or augment populations throughout their presumed historic range in Coastal Plain ecoregions of Georgia and the Carolinas (robustredhorse.com, accessed November 2012). The persistence of wild and stocked populations in the Coastal Plain portions of the Oconee, Savannah, and Yadkin/Pee Dee rivers have been extensively monitored during the last decade (robustredhorse.com, accessed November 2012). However, the fate of stocked populations in the upper reaches of the Ocmulgee River, Georgia has not been documented.

Decline of Robust Redhorse

Historic robust redhorse abundance remains unknown; however, hypothesized contributors to the range-wide decline of aquatic fauna in the southeastern United States includes increased sedimentation, habitat degradation, and fragmentation related to the construction and operation of dams (Kinsolving and Bain 1993). Dams and impoundments affect riverine fishes, including large river catostomids, by creating physical boundaries, large fluctuations in discharge, temperature change, and the alteration of natural flow conditions (Kinsolving and Bain 1993). The introduction of large non-native predators, such as flathead catfish (*Pylodictis olivaris*) also may have contributed to the decline of robust redhorse populations during the latter portion of the twentieth century. Flathead catfish are voracious, generalist predators, known to consume many species that may not occur in the fish's diet within its native range when

introduced into a new body of water (Pine *et al.* 2005). Within the Ocmulgee River, introduced flathead catfish potentially prey upon juvenile and adult suckers such as notchlip redhorse (*Moxostoma collapsum*) and robust redhorse, as well as native catfishes such as snail bullheads (*Ameiurus brunneus*) and flat bullheads (*Ameiurus platycephalus*) (Bart *et al.* 1994).

Restoration of extirpated robust redhorse populations is part of a larger effort to preserve native and historic ichthyofauna in the Carolinas and Georgia. Although restoration efforts may aid in the re-establishment of extirpated robust redhorse populations, the ability of stocked individuals to survive and reproduce remains unclear. Catostomids, like other non-game species, have the potential to become threatened, endangered or extinct without notice because they usually received inadequate attention compared to economically or recreationally valuable fish species (Ricciardi and Rasmussen 1999; Cooke *et al.* 2005). To develop an effective conservation strategy, an understanding of catostomid biology is crucial, especially in cases where a population status is unknown (Cooke *et al.* 2005). In situations where traditional methods cannot be used or have little utility (e.g., low population size or capture probability), the application of new techniques (e.g., occupancy models) may augment the current knowledge of the ecology and life history of robust redhorse and allow managers to make more informed decisions regarding the conservations actions needed to preserve and ensure the persistence of the species.

Objectives

The primary goal of this study was to evaluate the relative influence of various environmental characteristics on robust redhorse habitat use and spatial distribution in an experimental population established in the Ocmulgee River, GA. Why this population was

established in this river is explained in the "Problem Statement" section that comes later in this thesis. My primary goal was achieved by assessing the occurrence of robust redhorse within the upper reaches of the Ocmulgee River, Georgia to address the following objectives.

- Determine if robust redhorse are naturally reproducing and recruiting.
- Identify the relative importance of in-stream habitat, mesohabitat, water quality, and seasonality on robust redhorse occupancy at the river reach and sampling unit levels.
- Quantify the degree of influence of the most important habitat characteristics, water quality variables, and various biotic interactions on robust redhorse detection and site occupancy.
- Use detection and occupancy rates to determine where sampling effort, monitoring programs, and management actions should be directed for the Ocmulgee population of robust redhorse.

Ultimately, I employ the results of these efforts to assess the utility of hierarchical occupancy modeling for determining detection probabilities and site occupancy of robust redhorse. This modeling framework can be applied to future robust redhorse research should these methods yield more realistic results of robust redhorse population status than traditional estimates. With better population estimates, scientists can more accurately interpret the true outcome of reestablishment efforts for robust redhorse than previous estimations. Managers will also be able to better determine if self-sustaining populations are a realistic goal for the species. In addition, this study will provide seasonal spatial distribution data of other catostomids throughout the project site.

CHAPTER 2

LITERATURE REVIEW

Species Description

The robust redhorse is a large riverine sucker that is distinguishable from other large redhorses (Genus Moxostoma) by its overall size (adults average 500-760 mm TL and 8+ kg) and stout body shape. Further, the presence of large, molariform, pharyngeal teeth, distinctive plicate lips, and bright red pigmentation on the caudal fin distinguish robust redhorse from other redhorse species (Jenkins and Burkhead 1993; Evans 1994; Bryant et al. 1996). Robust redhorse are characterized by a light, copper-to-bronze color on its dorsal and lateral surfaces and white on the ventral surfaces (Bryant et al. 1996). Similar to other catostomids, sexual differentiation is most easily accomplished during spring spawning activities when males develop secondary sexual characteristics such as nuptial tubercles, which are often located on the rostrum, anal fin, and ventral portion of the caudal fin (Jenkins 1970). Females typically are more rotund than males, particularly while gravid. Further, the manual expulsion of gametes during spawning season can be used to differentiate males from gravid females (Jenkins 1970). Similar to other catostomids, robust redhorse are a benthic species that feed primarily on a variety of aquatic invertebrates, but adults may use their large, molariform, pharyngeal teeth to crush shells of mollusks (Jenkins and Burkhead 1994).

Spawning Characteristics of Robust Redhorse

Spawning aggregations are often the focus of sampling efforts when attempting to capture robust redhorse. Spawning activities begin in spring and continue for approximately two weeks when water temperature averages 20-24 °C (Ruetz and Jennings 2000). Robust redhorse are broadcast spawners and spawn over loose gravel substrates, where embryos are left to develop and hatch in the interstitial spaces (Ruetz and Jennings 2000). In the Savannah River, robust redhorse are the last catostomid to spawn on mid-channel gravel bars below the New Savannah Bluff Lock and Dam (Grabowski and Isely 2007). The arrival of robust redhorse to spawning grounds occurs after spotted suckers (*Minytrema melanops*), northern hogsuckers (*Hypentelium nigricans*), carpsuckers (*Carpiodes spp.*), the undescribed brassy jumprock (*Scartomyzon sp. cf. lachneri*), and notch-lip redhorse have ceased spawning activities (Grabowski and Isely 2007). This behavior prevents the destruction of nest sites and is thought to result in robust redhorse having the lowest risk of interspecific, nest-site superimposition (Grabowski and Isely 2007).

Robust redhorse spawn in what is known as the redhorse triad (also called the "tremoring trio"); a termed used by Martin (1986) and Jenkins and Burkhead (1994) when examining the spawning behaviors of other members of the genus *Moxostoma*. The triad consists of a single female that is flanked by two males (Jenkins and Burkhead 1994). As a result of the vigorous quivering of the triad during spawning in combination with swift currents on the spawning grounds, the gravel within a nest site is swept free of debris and silt. Eggs are fertilized and deposited in the gravel, where they are buried by subsequent spawning acts and later abandoned (Jenkins and Burkhead 1994). Males typically spend more time than females within the spawning aggregation; they defend a new territory each day (depending on prevailing conditions,

such as water level and fluctuations in discharge; Grabowski and Isely 2008). Males are able to expend sperm over relatively long periods of time, which enables them to partake in multiple spawning bouts with multiple females (Grabowski and Isley 2008). Females, however, spend less time in the spawning aggregation and exhaust their egg supplies within 1-2 days of initial spawning activity (Grabowski and Isley 2008). In the Savannah River, robust redhorse reached maturity at a later age and had larger adult size, longer life span, and presumably higher fecundity than other catostomids (Grabowski *et al.* 2008).

Early Life Stages of Robust Redhorse

The formation of the RRCC initiated research on all life stages of robust redhorse to better understand overall life history, conservation needs, and to determine if a "critical period" existed for the imperiled catostomid. The capture of adult brood stock, captive propagation, and the rearing and stocking of captive fish have provided useful information on the physiology and biology of robust redhorse at various life stages. Numerous captive propagation studies used the early life stages of robust redhorse to test effects of fine sediments on larval survival to emergence (Jennings *et al.* 2010), effects of water flow on larval fish (Weyers *et al.* 2003), larval fish swimming performance (Ruetz and Jennings 2000), juvenile growth and survival when fed a variety of feeds (Higginbotham and Jennings 1999), physiological tolerance (Walsh *et al.* 1998) and flow preferences of juvenile fish (Mosley and Jennings 2007). As a result, the larval and juvenile stages of robust redhorse have been hypothesized to be critical stages for the species' survival and ultimate persistence.

One critical stage for robust redhorse is the time when developing embryos and larval fish are left in the gravel until exodus (also called swim-up or emergence). Larval survival to

emergence (STE) is largely dependent on the amount of fine sediments present in the substrate (Jennings *et al.* 2010). Although the spawning site may be swept clean of sediment by the spawning triad during the deposition of gametes, the interstitial spaces in the gravel are left vulnerable to sedimentation for several days after eggs have been deposited and fertilized. Survival to emergence is predicted to be 63.5% when fine sediments are absent, and STE is $\leq 8\%$ when treatments contained >25% fine sediment. Increased sedimentation through the historic loss of riparian buffers may have contributed to declines in robust redhorse populations, and reduction of fine sediments in spawning grounds would significantly increase survival to emergence (Jennings *et al.* 2010).

Juvenile robust redhorse are tolerant of short-term variations of temperature, heightened salinity, variations in pH, and low dissolved oxygen (DO) in isolation (Walsh *et al.* 1998). However, a combination of these environmental factors (e.g., increasing temperatures in addition to reduced DO levels during egg development and emergence to free-swimming larva) during early life stages may contribute to the overall species decline through the loss of entire age classes. Increased sedimentation, the overall increase of water temperature, and the increased occurrence of hypoxic conditions attributed to the construction and operation of hydropower facilities since the 1950s have also contributed to the overall species decline (Walsh *et al.* 1998).

The pulsed, high-velocity flows that occur downstream of hydropower dams have also been hypothesized to reduce robust redhorse survival at early life stages through physical displacement of eggs or larvae and reducing growth of those larvae. In general, the swimming performance of larvae increases with total body length when exposed to relevant velocities to those observed on the Oconee River (Ruetz and Jennings 2000). However, the habitat on the Oconee River is diverse, and the effects of discharge are dynamic. Consequently, the ability of

larval robust redhorse to maintain position in the water column or access low-velocity areas during dam release is unknown (Ruetz and Jennings 2000).

Similarly, through the use of modified aquaria, egg hatching success and larval growth and survival was evaluated when exposed to pulsed, high-velocity flows and steady, low-velocity flows for several weeks (Weyers *et al.* 2003). Hatch success and body length after emergence remained similar between treatments, but larvae exposed to pulsed high-velocity flows exhibited slower growth and had lower survival than larvae that were not exposed to pulsed flows. Altered flow regimes associated with hydropower generation have negative effects on the growth and survival of larval robust redhorse (Weyers *et al.* 2003).

Determining the fate of young robust redhorse proved challenging, primarily because of very low detection rates of both stocked and wild-born juveniles. Imperfect detection of the younger age classes of robust redhorse may be attributed to sampling gear bias, targeting incorrect juvenile habitat, limited reproduction occurring within the system, or any combination thereof (Jennings *et al.* 1998; Grabowski *et al.* 2009). Most juvenile robust redhorse sampling has concentrated on river meanders, where sandbars and lateral scours are present (Jennings *et al.* 1998). Flow preferences of juveniles held in a series of mesocosm experiments were modeled, and results revealed that juvenile robust redhorse showed a variation in flow preferences associated with seasonal changes, as well as a high affinity structure regardless of season (Mosley and Jennings 2007). In winter and early spring, juveniles avoided sections of the mesocosms with moderate flow. The preferred habitats during these seasons were a combination of backwaters and eddy. Fish were more active in springtime when fish traveling through sections of moderate flow to reach eddies for refuge. Fish also exhibited a high affinity for structure (e.g., walls, crevasses, stand pipes). The use of backwaters and structure during the

study suggests that naturalized, juvenile robust redhorse in the wild may use natural structure (i.e. large woody debris, rocks) as refuge from predators or fast flows, as well as food availability in foraging areas (Mosely and Jennings 2007).

Adult Robust Redhorse

To test the viability of stocking hatchery-reared fish into historic rivers as a tool to augment existing populations, additional investigations used radio telemetry to examine postrelease behavior and seasonal movements of captive-reared robust redhorse (Grabowski and Isely 2006; Grabowski and Jennings 2009). Although most stocked robust redhorse participated in spawning behaviors with their wild counterparts, some stocked redhorse were unable to locate suitable spawning habitat, presumably because of the lack of habitat, drought or behavioral differences (Grabowski and Jennings 2009). Mature fish from a known spawning site in the Savannah River were sexed, tagged with radio transmitters, and monitored through radio telemetry and underwater cameras to determine monthly, biweekly, and daily movements throughout the year (Grabowski and Isely 2006). Robust redhorse traveled downstream to deep pools and slow flow areas in the late fall and winter months.

Adult fish also were highly associated with complex structure and large woody debris, similar to the findings for juveniles later supported by Mosley and Jennings (2007). During spring observations, adult fish undertook long migrations (>100 river kilometers) upriver to gravel bars for spawning (Grabowski and Isely 2006). However, soon after spawning, the fish retreated downstream to the same over-wintering areas from which they began their spring migration. During the course of the study, robust redhorse displayed fidelity to both wintering and spawning sites. Such behavior affects efforts to detect fish seasonally and to locate

previously overlooked suitable spawning and potential wintering areas (Grabowski and Isely 2006).

Rare Species, Presence-Absence, and Occupancy Modeling

Site occupancy modeling approaches have become a widely used and effective method for estimating species occurrence (MacKenzie *et al.* 2002; MacKenzie *et al.* 2006). Occupancy modeling has been used in a variety of management settings for many different species including birds (e.g., Kroll *et al.* 2007; Nichols *et al.* 2007; Royle *et al.* 2007), amphibians (e.g., Bailey *et al.* 2007; Farmer *et al.* 2009; Weir *et al.* 2005), mammals (e.g., Rodhouse *et al.* 2010; Urban and Swihart 2009) and fish (Albanese *et al.* 2007; 2011; Wenger and Freeman 2008).

Site occupancy is the proportion of units that a species of interest is occupying and is often used as a metric of the current status of a population (MacKenzie *et al.* 2003). Site occupancy can also be interpreted as the probability that a sample unit is occupied. A sample unit is a patch of potential habitat for the species of interest based on either spatial location or various habitat characteristics that define that unit (MacKenzie *et al.* 2002). These units are surveyed multiple times to determine if a site is occupied or not occupied through visual detections, auditory surveys, or by actual capture through active or passive techniques (MacKenzie *et al.* 2002). Hence, for each sampling occasion, a binary code is used to classify site occupancy in one of two ways: a) the site is occupied by a species and the species is detected (1), or b) the site is either unoccupied or the species is present, but not detected (0). The capture history at a given site is described by a series of 1s and 0s (e.g., a capture history of 110 refers to a site in which the species was detected during the first two sampling occasions, but not detected on the third sampling occasion; MacKenzie *et al.* 2002). Generally, habitat characteristics at

each site are recorded to facilitate the formation of inferences about the effects of environmental variables' on species occupancy of a site. In aquatic systems, these characteristics may include variables such as temperature, soil or substrate type, distance to nearest cover or refuge, location, the size of the patch, and many others.

Sampling Design for Occupancy Models

There are many possible sampling designs for occupancy estimations, but design is dependent on the species of interest, the goal of the project, and available time and funding. Single-season sample designs may be useful, but provide only a snapshot of species occupancy over time. To take this into account, multi-season sampling designs (e.g., robust design, see Figure 1) are used most often when resource/habitat use may change through time for the species of interest (MacKenzie 2005). These models require data collection at numerous resource units over several sampling seasons, where sample season length and time between seasons depends on life history characteristics of the focal species (MacKenzie 2005).

Generally, once a rare species is detected, similar sites become highly prioritized for sampling while other areas are sampled less intensely or ignored. This practice produces inaccurate estimates in species abundance and distribution (MacKenzie *et al.* 2002). If prime or heavily used resource units are the only targeted sites, the accuracy of calculated occupancy across a landscape may be negatively affected (MacKenzie 2006). This is the case with most previous robust redhorse research, where many studies have concentrated on spring spawning aggregations, with less focus on other habitat types during other seasons. As a general strategy for rare species investigations, a greater number and diversity of units should be sampled less intensively, rather than fewer units sampled more intensively (MacKenzie and Royle 2005).

Imperfect Detection

In rare species studies, researchers must deal with species that are difficult to detect. Imperfect detection refers to the presence of a species or individual within a study site that remains undetected by researchers (MacKenzie 2005). The issue of imperfect detection is often a result of the rarity, cryptic nature (e.g., cryptic coloration or secretive behavior) of the species or the tendency of the focal species inhabiting hard to sample areas. Imperfect detection of a species must be considered when studying rare species and was incorporated into a zero-inflated binomial occupancy model by MacKenzie et al. (2002). Although imperfect detection was considered, the model does not account for abundance at occupied units. Occupancy modeling can be used to compare and contrast abundance estimates for rare versus common species (e.g., Royle and Dorazio 2006, Wenger and Freeman 2008). Incorporating imperfect detection and abundance, modeling occupancy for rare species can be achieved with current computer software such as Program MARK (available: http://warnercnr.colostate.edu/~gwhite/mark/ mark.htm) and the Program Presence (available: http://www.mbr-pwrc.usgs.gov/software/ presence.html).

Although logistic regression methods can be used to model the relation between habitat characteristics and a species' occupancy, regression methods can introduce bias because they only include habitat effects on occupancy when a species is present or not present, but do not account for non-detection, or imperfect detection (when a site is occupied by a species yet remains undetected; MacKenzie *et al.* 2002; Mackenzie and Bailey 2004). Large amounts of non-detections within the data are common in rare species studies, and the bias introduced by Type 2 error is often overlooked. Modeling site occupancy (versus logistic regression) incorporates non-detections and its associated bias to provide a single modeling framework that may provide useful information in rare species distributions (MacKenzie *et al.* 2002; Mackenzie

and Bailey 2004). Thus, such an approach may be useful and efficient method for assessing the range-wide status, distribution, and dynamics of robust redhorse populations.

CHAPTER 3

PROBLEM OVERVIEW

The Ocmulgee River Population

The RRCC and the implementation of a Candidate Conservation Agreement with Assurances (CCAA) program have prioritized captive propagation and the subsequent reintroduction of hatchery-reared robust redhorse to reestablish self-sustaining populations (Grabowski and Jennings 2009) in the Ocmulgee River, GA. As part of the Ocmulgee River CCAA, Georgia Power Company, Georgia Department of Natural Resources (GADNR) and the United States Fish and Wildlife Service (USFWS) collaborated to advance robust redhorse reestablishment and accomplish two objectives: 1) establish a refugial population of robust redhorse in the project site between Lloyd Shoals Dam and a low-head dam in Juliette, GA, and 2) increase understanding of habitat requirements and life history of robust redhorse (Department of Interior 2001). As outlined in the "Conservation Actions" of the CCAA in 2001, the project site was stocked, and studies to examine the movement, abundance, distribution, survival, and recruitment of the stocked fish are to continue until scientific evidence supports the conclusion that the Ocmulgee population is not in need of augmentation or monitoring (Department of Interior 2001). Stocking in the Ocmulgee River began in 2002; since then, more than 13,000 robust redhorse ranging from fingerlings to 5-year old adults have been stocked into the project site as of 2005 (J. Evans, Georgia Department of Natural Resources, personal communication; Grabowski and Jennings 2009). Stocking ceased as a result of anecdotal evidence of

reproduction by stocked robust redhorse within the project site (Joe E. Slaughter, Georgia Power Company, personal communication). Radio telemetry has been used to make substantial progress in the project site by investigating post-stocking habitat use and dispersal (Jennings and Shepard 2003) and spawning migration and seasonal habitat use of stocked fish (Grabowski and Jennings 2009).

Difficulties with Traditional Sampling for Robust Redhorse

Mark-recapture techniques to estimate population size were first used by G.J. Petersen in 1896 and F.C. Lincoln in 1930 (Southwood and Henderson 2000); the techniques are commonly used to estimate population size of fishes (e.g., Williams *et al.* 2002). However, mark-recapture methods can produce biased abundance estimates when capture probabilities are very low (e.g., cryptic species; MacKenzie 2006) or high heterogeneity in capture probabilities is not taken into account. To date, most robust redhorse sampling has been concentrated around spawning aggregations in spring; this sampling protocol violates the assumptions needed to estimate abundance via closed mark-recapture methods, and resultant estimates may be biased (Grabowski *et al.* 2009).

Given low abundance, benthic habits, cryptic behavior, and imperfect detection of robust redhorse, there are potential problems with accurately determining current distributions or population sizes. Robust redhorse often reside in waters deeper than 2 meters (Grabowski and Isely 2006; Grabowski and Jennings 2009), thus standard boat electrofishing techniques have been relatively unproductive and have yielded few fish. Targeted fish may evade the electrical field in deep waters or become trapped in submerged, woody debris after immobilization (Grabowski *et al.* 2009). Grabowski *et al.* (2009) applied a combination of tracking radio-tagged

fish and boat-mounted electrofishing sampling techniques to establish capture rates for robust redhorse and concluded that tagged robust redhorse exhibited little response to boat electrofishing. The results of their study on the Ocmulgee River suggest that robust redhorse had a capture probability of 0.031 with a 95% Bayesian credibility interval of 0.002–0.111 when using boat electrofishing techniques. Note that detection probability is the probability of detecting at least one individual of the focal species given the species is present in a given sampling unit (i.e., abundance and ease of capture influences detection probability), whereas capture probability is the probability of capturing one individual in a population of a given size (i.e., abundance or population density does not influence capture probability; Williams et al. 2002). The best predicting models used in the Grabowski et al. (2009) study resulted in population estimates with large confidence intervals, which proves that obtaining a precise robust redhorse abundance estimate is challenging. Because capture probabilities are low and variable, abundance is low, and robust redhorse are patchily distributed, obtaining a reasonable population estimate would require substantial effort. Grabowski et al. (2009) determined that the use of radio-tagged fish was effective as a guide for estimating capture rates and suggested that underestimation in abundance and the large variances associated with capture-mark-recapture studies of rare species can be avoided by the use of other approaches such as occupancy modeling that accounts for imperfect detection.

Implementation of Occupancy Models

Given the low capture probabilities after considerable sampling efforts on the Ocmulgee River (Grabowski *et al.* 2009), the occupancy methods suggested by MacKenzie *et al.* (2002, 2006) were a potentially useful approach to estimate site occupancy for this robust redhorse

population. When detection probability is imperfect, the model described by MacKenzie *et al.* (2002) can be used as the basis for estimating site occupancy during a single season. The probability that a site is occupied throughout the study can be calculated using probabilities of occupancy and detection. For example, if a site is visited twice in a season, there are four possible capture histories for that site, and probability of each capture history is estimated as: a probability of total sites occupied (ψ) can be seen as

Capture history	Probability of capture history
11	$\Psi_i * p_{i1} * p_{i2}$
01	$\psi_i * [1 - p_{il}] * p_{i2}$
10	$\psi_i * p_{i1} * [1 - p_{i2}]$
00	$\psi_i * [1 - p_{il}] * [1 - p_{i2}] + (1 - \psi_i)$

where Ψ_i is the probability that a species is present at site *i*; p_{it} is probability that a species will be detected at site *i* at time *t*, given the species is present. Note a capture history of 00 does not imply that the site is unoccupied; instead, the species may be present but was undetected during the time of sampling estimated as $\psi_i * [1 - p_{il}] * [1 - p_{i2}]$ above. Here, detection probabilities and the presence of the species are site specific and may be a function of covariates such as habitat characteristics, season, and site size.

Four assumptions and limitations exist for the occupancy estimator and include:

 A species' occupancy status at each site does not change over the course of the survey (i.e., the population is closed during the survey, also called the "closure assumption");
Occupancy is either constant across sites, or occupancy is modeled as covariates;
Detection probability constant across sites, or is a function of site survey covariates and there is no unmodeled heterogeneity in detection probability;

4) Detection of a species and detection histories at each location are independent.

CHAPTER 4

METHODS

Site Description

The study was conducted in a 29-km stretch of the Ocmulgee River bounded upstream by Lloyd Shoals Dam and downstream by East Juliette Dam in the Piedmont physiographic region of Georgia (Figure 2). Lloyd Shoals Dam (LSD) is a Georgia Power Company-regulated hydropower facility that marks the headwater of the Ocmulgee River. Lloyd Shoals Dam was completed in 1911 and impounds the Yellow, Alcovy, and South rivers to form Jackson Lake. Jackson Lake is approximately 1922 hectares (19.2 km²) that exhibited extreme signs of eutrophication through symptoms of fish kills, algal blooms, and anoxia in the 1960s (Kamps 1989). By the next decade, projects to improve wastewater treatment in the South and Yellow rivers were implemented to greatly reduce phosphorus loading (Kamps 1989). Since the 1970s, water quality within Lake Jackson has improved greatly.

The downstream terminus of the project site was Juliette Mill Dam (JMD), a low-head mill dam between Juliette and East Juliette, GA. Downstream from JMD, the Ocmulgee River is unimpounded and flows unimpeded to the Altamaha River and Atlantic Ocean. Immediately below LSD, the Ocmulgee River is characterized by large shoal complexes and long, sandy runs with copious amounts of woody debris. Below JMD, the Ocmulgee River crosses the Fall Line and enters the upper Atlantic Coastal Plain near Macon, GA. Here, the gradient decreases and

the river channel transforms into a series of tight meanders until its eventual confluence with the Oconee River, which forms the Altamaha River.

Sample design

The study area was divided into seven reaches based on accessibility and changes in habitat type. Each reach was stratified into 25 sample units based on habitat characteristics (shoal, meander, run), local water velocity, and substrate composition (Figure 2). Each sample unit was designated as a distinct sample site during fish surveys and for subsequent data analysis (see occupancy modeling below). Site boundaries were geo-referenced so field researchers could determine the length of the sample site and revisit each site every sampling period. The study area was visited in four seasons: spring 2010, summer 2010, fall 2010, and spring 2011. Using this multi-season sampling design, each of the 25 sample sites were visited twice per season (i.e., each unit was sampled eight times during the study). The spring 2010 season occurred from May 10th to May 30th (21 days); summer 2010 occurred from June 28th to August 3rd (37 days) fall 2010 occurred from September 23rd to November 11th (50 days); and spring 2011 occurred from March 25th to May 24th (61 days). Ideally, sample seasons should be relative short time periods provide an estimate of what is happening in a system during a particular season (e.g., spring 2010).

Logistical limitations restricted days spent sampling as time progressed from the spring 2010 and spring 2011 seasons. Because of these problems beyond my control, a seasonal effect was not included in the occupancy and detection models for this study, thus violating the closure assumption. When the closure assumption is violated, occupancy estimates may appropriately reflect the average across all sites, but there may be a large variance (MacKenzie et al. 2006).

Fish Sampling

Boat-mounted electrofishing techniques were used to sample robust redhorse and all other catostomids in accordance with survey sampling protocol outlined for this species by the RRCC (2002). Specifically, the boat-electrofishing protocol mandates a minimum of 20 minutes (1200 seconds) of pedal time per kilometer of river (RRCC 2002). Sample sites were sampled via electrofishing during daylight hours, usually between 09:00 and 17:00 hours. During each sampling occasion, pedal time was recorded at the end of each site, and sampling intensity was calculated by dividing the pedal time (seconds) by the length (km) of the sampled site. Electrofishing for catostomids was conducted with one of two available aluminum electrofishing boats of different size and shape, depending on availability and water conditions. Because each boat had a unique size and shape, each was rigged with different booms and cables and was equipped with different-sized gasoline generators, a standard current of 4-6 amps was used while electrofishing. Amperage was adjusted during sampling if fish were evading capture or if the electric current was causing severe damage or mortality of sampled fish. On each sampling occasion, the sampling crew was comprised of one driver and one netter. The netter worked the electrofishing pedal and gathered immobilized fish with a long (~ 2.5 m) dipnet.

As suggested by Graboswki and Isley (2006), Grabowski and Jennings (2009) and Grabowski *et al.* (2009), areas containing large amounts of cover (woody debris or boulders) and deep flowing waters (such as lateral scours or deep chutes near boulders) were targeted in lieu of shallow, sandy areas without submerged structure or cover. Lateral scours refers to the outside bends of meanders where water usually is flowing most swiftly and causes significant erosion. Lateral scours often produce large amounts of woody structure, where trees along the bank have fallen into the stream channel as a result of stream bank erosion (Bain and Stevenson 1999). If

available and accessible, lateral scours and shoal complexes were the preferred areas to sample each season. A shoal refers to a portion of the river that is shallower than the surrounding portions. In the Piedmont, shoals are often formed by bedrock outcrops and boulder extending into the river channel. Because of their shallow depths, shoals are often areas of swift current that can create chutes, plunge pools, and turbulent waters that often free of fine substrates like silt and sand. During each sampling occasion, samplers traveled with the flow of the river, adjacent to the banks where water was deep and woody debris was most abundant and where shoals were present. During much of the sampling seasons, shoals were either dewatered or largely exposed, which made these areas difficult to sample. However, in the higher water levels that occurred during spring, shoals and gravel bars with their adjacent areas were sampled intensely. These areas were of particular interest in spring because robust redhorse and other catostomids use these types of habitats for spawning (Grabowski and Isely 2007; Grabowski *et al.* 2008). Because lateral scours and shoals were targeted heavily, all inferences on robust redhorse habitat use are restricted to these habitats.

Data on all catostomids were collected to compare, contrast, and better understand the seasonal habitat use and distribution of all suckers in the upper reaches of the Ocmulgee River. Fish sampling and handling for this project were carried out as outlined in the University of Georgia's Animal Use Permit #A2010 11-607-YI-A0. Each robust redhorse captured was checked for coded wire tags (field sampling detector FSD-I, Northwest Marine Technologies, Inc®) and Passive Integrated Transponder (PIT) tags (Mini-Portable Reader 2 and PIT tags, Destron-Fearing Corporation®). All tag-related information (e.g., location of coded wire tags and the tag identification number for PIT tags) was recorded. If a tag was not detected, a uniquely-numbered PIT tag was implanted immediately caudo-laterally to the dorsal fin, on the

fish's right side. The total length (TL-mm) and weight (g) were determined for each fish and recorded. A Valor 3000 Xtreme scale (Ohause Corporation®) rated up to 6 kilograms was used to determine mass. Additional information such as sex, breeding condition or anomalies was also noted. All fish were released in the vicinity of their capture. For the duration of the study, any recaptures were noted as well as length, weight, tag number, and location of the tag.

Water Quality Data

Water quality measurements included water temperature, dissolved oxygen concentration, water clarity, current velocity, and discharge. With the exception of discharge, all water quality measurements were averaged between two measurements; one at the upstream boundary of the sampling unit prior to electrofishing, and one at the downstream terminus of the sampling unit after electrofishing. A YSI® model 55 temperature and dissolved oxygen meter was used to measure water temperature (°C) and dissolved oxygen (mg//L). A Hach® Model 2000 Flow-Mate water velocity meter was used to measure water velocity (m/s) in an area that best represented where the majority of sample effort took place. A weighted 15.2 cm Secchi disk was used to determine clarity by averaging the depth in meters (to the nearest 1/10th of a meter) at which the disk was no longer visible and the depth at which the disk reappeared after being retrieved. Additional data recorded included discharge (m³/s) from the United State Geological Survey (USGS) gauge #02210500 located between LSD and GA HWY 16.

Habitat Data

To estimate the size of each sample site, a 2009 NAIP aerial photograph for Jasper County, GA (Georgia GIS Clearinghouse, available: data.georgiaspatial.org) was imported into Environmental Systems Research Institute's (ESRI®) ArcGIS software. The measuring function of the software then was used to calculate length (m) and width (m) of each site. Three widths were recorded at approximately ¹/₄, ¹/₂ and ³/₄ of the sample unit length, and averaged to obtain a mean width for each site.

Preliminary reconnaissance visits to the project area between LSD and JMD revealed that obtaining accurate estimates of substrate types and quantifying woody debris were very difficult and time consuming in the Ocmulgee River, where nearly 30 kilometers of wide, shallow, and rocky areas must be surveyed. To overcome limitations of directly separating and quantifying in-stream habitat, I used a remote sensing technique developed by Kaeser and Litts (2010). This method employs an inexpensive and time-efficient Hummingbird® Side Imaging system with a boat-mounted transducer to obtain a geographic information system (GIS) layer of highresolution images of the stream channel. These images of the channel provided information such as substrate types, course structure within the water column, and relative depth. In the fall of 2010, an on-the-ground survey was conducted where known gravel bars could be seen and waded during a low-flow period. The gravel bars were outlined by walking the boundaries of each bar and tracing the path with a Garmin® eTrex hand-held GPS unit. The areas of these gravel bars were calculated in ArcGIS by creating a polygon from the path traced in the handheld GPS unit. The average size of the gravel was noted and compared to subsequent sonar surveys as a ground-truth. Substrates were classified into the following categories based on diameter: silt, sand (<10 mm), gravel (10-64 mm), cobble (64-256 mm), boulder (>256 mm), and bedrock (an adaptation of Gordon et al. 1992).

All accessible portions of the study area between a large series of shoals near 40-Acre Island and JMD were surveyed with side-scan sonar by a Georgia Department of Natural

Resources (GA DNR) field crew in the winter of 2011 during high water levels. Sampling during high or peak flows allows for the mapping of the entire streambed and banks. The upper Ocmulgee River from below 40-Acre Island downstream to Bridges Island (a small, privately owned island 1.1 km upstream of JMD) was surveyed with a Hummingbird 1197c Side Imaging system during a flood event on February 6, 2011. A small aluminum john boat was rigged with a custom wooden mount on the front of the boat, fixed with the sonar transducer on the bottom and a GPS antenna on the top. The front mounted transducer reduced the chance that the prop-wash from the boat motor interfered with the sonar imagery. The sonar survey used dual frequencies of 455 and 800 kHz. Generally, a frequency of 455 kHz employs a wider beam and allows for the image capture of distant stream banks and its associated woody debris and substrates. Conversely, a frequency of 800 kHz results in a narrower beam where distant banks and substrates may not be in the field of view, but areas in close proximity to the boat are displayed in higher resolution (Thom Litts, GA DNR, personal communication). During the survey, the boat traveled downstream at approximately 8 km/hour. This speed was slow enough to allow for greater image quality, but fast enough to cover the area without any distortions (e.g., objects in the stream bed appear to be distorted and elongated when traveling too slowly).

Most of the sonar data obtained in February 2011 by the GA DNR sonar team was collected during the largest flood event on the Ocmulgee since 2010. Despite the high water levels, the 9-km reach of river between HWY 16 and 40-Acre Island was still too shallow, rocky, and dangerous to map with side scan sonar. Although surveying during a high-water event is preferable, the flood resulted in the water column becoming saturated with suspended particles and sediments. The particles interfered with the sonar beam; and as a result, distinguishing the difference between coarse sand, fine gravel, and coarse gravel was extremely difficult. For the

purpose of this study, all rocky substrates with a diameter of 10mm or greater were combined into one "coarse substrates" category, which included gravel, cobble, boulder, bedrock, and unknown rock. In contrast, felled trees and other woody debris were distinct enough to allow for confident assessment of the quantity of woody structure within the project site. Woody structure was defined as any piece of submerge wood with a minimum diameter of 15 cm (6 in) and a length of 91 cm (3 ft).

The raw sonar data were imported into ArcGIS to create image mosaics (raw images were combined with recorded latitude and longitude; this procedure created one solid image of the location and shape of the Ocmulgee River). The sonar images obtained with the side-scanning imaging units allowed me to first calculate the area of the streambed, then identify and quantify woody debris and various substrate types within each sample site. ArcGIS was used to digitize (i.e., outline) woody structure, as well as classify (bedrock, large gravel, fine gravel, cobble, boulder, unknown rocky), and quantify (m²) substrates that were distinguishable. These habitat models were used in the occupancy analysis as predictor variables.

On September 9, 2011, the side scanning sonar survey was conducted on the ~ 2 km portion of river between LSD and HWY 16 that was not surveyed previously. This area was of particular interest because the majority of robust redhorse detections to date took place in this reach of river. A Hummingbird[®] unit identical to the one used in the GA DNR February survey was not available. However, the similar Lowrance[®] LSS-1 Structure Scan unit was available. A custom mount on the front of an aluminum boat was constructed in a comparable fashion to the GA DNR rig. Ideally, the survey would have taken place during a high-water event for ease of imaging both stream banks and all woody debris normally associated with each bank. However, the survey took place when discharge was less than 300 ft³/second (8.5 m³/second), which made

image capture from both banks very difficult with a single pass. If the entire stream bank and its associated woody structure was not captured, an under estimation of woody structure could occur. To account for this, a frequency of 455 kHz was used to map as much of the substrate and stream banks as possible in the shallow water, and multiple passes were used to capture images of the river banks. The same techniques described above were used to quantify woody debris and determine substrate types in ArcGIS.

Statistical Analysis

All fish, habitat, and water quality data of interest (e.g., season, substrate composition, water temperature, turbidity, discharge, dissolved oxygen) were included as predictor variables in the detection and occupancy models. Prior to model construction, Pearson correlation coefficients were calculated for all pairs of potential predictor variables to estimate the strength of correlations among variables. Strong correlations between predictor variables in the same model may result in multicollinearity and potentially unreliable or biased parameter estimates for the detection and occupancy models. Therefore, only uncorrelated variables ($|\mathbf{r}|<0.6$) were included within the same candidate model.

My primary goal was to evaluate site occupancy of robust redhorse. However, to obtain an accurate estimation of occupancy, I had to account for imperfect detection first. Habitat characteristics such as current velocity, substrate type, and available cover can often influence the detection of a stream fish species (Bailey and Peterson 2001). Occupancy models account for variation in detection and occupancy by incorporating various environmental covariates. I hypothesized that detection would vary with current velocity, woody debris, secchi depth, and

sampling intensity (Table 1) and that occupancy would vary by current velocity, the proportion of coarse substrates within the streambed, and water temperature (Table 2).

A global model (i.e., all predictor variables for detection and occupancy were used in a single model) was constructed in Program MARK (White and Burnham 1999). Prior to model fitting, all continuous predictor variables were standardized with a mean of zero and standard deviation of one to facilitate model fitting in MARK. Next, a large set of models (n=128) that consisted of all possible combinations of the predictor variables used in the global model was created. The parameter estimates and standard errors for each individual model were examined as a screening procedure to evaluate goodness-of-fit. Models with estimates or standard errors that were unrealistically high or low (e.g., 0.000000, 999999.9) indicated a lack-of-fit and were removed and excluded from further analysis. All remaining models were considered the candidate set of models.

I used an information-theoretic approach to evaluate the relative fit of each candidate occupancy model. I used Akaike's Information Criterion (AIC) as adjusted for a small sample size (AICc; Burnham and Anderson 2002) to determine the relative fit of each model. I determined the best fitting candidate models for site occupancy by calculating Akaike weights (w_i; Burnham and Anderson 2002) based on each model's AICc value. Akaike weights range from zero to one, where the model with the largest weight indicates the best fitting model (Burnham and Anderson 2002). To assess the relative support one candidate model had over another, I used the ratios of Akaike weights (Burnham and Anderson 2002), where each model's weight was divided by the weight of the best-predicting model (also referred to as percent maximum in MARK). I constructed a confidence set of models that included all models with Akaike weights that were within 10% of the best-approximating candidate model's Akaike
weight (similar to the 1/8th rule proposed by Royall 1997). I based all inferences on the confidence set of occupancy models.

Although each model in the confidence set is considered plausible, parameter estimates for the same predictors generally differ among models. Therefore, AIC model averaging was used to incorporate this uncertainty by weighting the parameter estimates and standard errors from each model in the confidence set to create composite model averaged estimates and standard errors (following Burnham and Anderson 2002). Model-averaged estimates calculated from the confident set of models were used to estimate the average conditional detection probability and robust redhorse occupancy across all sampled units. I also used model averaged estimates to evaluate the magnitude of the effect all predictor variables in the composite model on: (1) conditional detection probability, and (2) occupancy.

To facilitate interpretation, odds ratios and their 95% confidence intervals for each model averaged parameter estimate were calculated (Hosmer and Lemeshow 2000; Congdon 2001). Because the data were standardized, parameter estimates for continuous predictor variables corresponded to a one standard deviation change for each predictor variable. For clearer interpretation, scaled odds ratios (SOR) estimators were calculated. An odds ratio (OR) ranges from zero to infinity; an OR < 1 indicates an event (e.g., occupancy) is less likely to occur, an OR >1 indicates that an event is more likely to occur, and an OR = 1 indicating that there is no change in the likelihood of an event when the value of the predictor variable changes. The OR 95% confidence intervals were calculated, and intervals encompassing one were considered imprecise (Congdon 2001).

CHAPTER 5

RESULTS

Predictors Variables and Descriptors of Sampling Units

Water temperature, secchi depth, dissolved oxygen content, and water velocity were variable throughout the sampling seasons. Seasonal water temperature ranged from 14.9 °C in late fall to 31.2 °C in the summer (Table 3). Secchi depth (i.e., water clarity) was greatest in the fall sample season (4.5 m) and lowest in the rainy spring seasons (0.3 m; Table 3). Water velocity ranged from 0.0 to 1.1 m/second and discharge from LSD during sampling days ranged from 8.5 to 118.9 m³/second (Table 3). Mean sampling intensity for the entire study was 1697 seconds/rkm as compared to the 1200 seconds/rkm minimum requirement in the robust redhorse sampling protocol (RRCC 2002).

In general, substrate composition was relatively uniform in the majority of sampling units below Nelson Island; primarily consisting of sand with a few areas containing gravel, boulders, and bedrock. In most sampling units, the proportion of coarse substrates (the area of coarse substrates in a given unit divided by the streambed area of that sampling unit) was less than 20% (Figure 3). Only four units had more than 20% coarse substrates, and two of them were located in the upstream portion of the project site. The unit immediately below LSD had the largest proportion of coarse substrates at over 77% (Figure 3). On average, the downstream sampling units contained less coarse substrates; however, the exceptions were one lateral scour containing a large amount of bedrock and a small shoal complex farther downstream (Figure 3). The

quantity of woody debris (m^2/rkm) varied throughout the river and had a general inverse relationship with the presence of coarse substrates (Figure 3). Woody debris tended to be more abundant in the long, sandy runs present in the downstream portion of the project site than in the portion of river between LSD and HWY 16. The Pearson correlation procedure revealed sampling unit width and the proportion of coarse substrates, and sampling unit length and the amount of woody structure the only highly correlated (|r|>0.6)potential predictor variables.

Fish Captures

A total of 4,415 catostomids from four genera and at least six species were captured during the study (Table 4). In addition to robust redhorse, suckers encountered in the upper Ocmulgee River included notchlip redhorse, spotted sucker, as well as the brassy jumprock, striped jumprock, and two undescribed carpsuckers. Catch was relatively similar across all seasons: 26.2% (n=1155) of the suckers were netted in Spring 2010, 23.9% (n=1054) were netted in Summer 2010, 28.1% (n=1242) were netted in Fall 2010, and 21.8% (n=964) were netted in Spring 2011 (Table 5).

Only 0.2% (n=7) of the suckers captured in the study were robust redhorse. Of the seven robust redhorse netted, 2 were netted in the spring of 2010, and 5 were netted in the spring 2011 season. Although there were not physical captures of robust redhorse in the summer 2010 season, two fish were visually detected (one detection on each of the two sampling occasions). These observations were included as detections in the occupancy modeling. However, because the fish were not netted, they were not added to the total number of robust redhorse captured. Of all collected catostomids, notchlip redhorse represented 60.0% (n=2649) of the catch, spotted suckers made up 31.3% (n=1384), brassy jumprocks were 7.5% (n=331) of the catch, and striped

jumprocks were 0.9% (n=331). Carpsucker spp. consisted of 0.1% (n=3) of the Catostomid catch and was the only sucker species found in fewer numbers than robust redhorse (Table 5).

Throughout the course of this study, robust redhorse were detected in two of 25 sampling units in the upper Ocmulgee River. Robust redhorse were detected in Unit 1 (immediately below LSD) on both sampling occasions in Spring 2010 and Summer 2010. The Fall 2010 season yielded no detections of robust redhorse in any of the 25 sampling units. In Spring 2011, robust redhorse was detected in Unit 2 (103 m away from the downstream terminus of Unit 1) during the first sampling occasion and detected in Unit 1 during the second sampling occasion.

Confidence Set of Models

The confidence set of 41 models had Akaike weights that ranged from 0.067 to 0.007 (Table 6a, b, c). The best approximating model had an Akaike weight of 0.067, and included secchi depth in the detection component and velocity and water temperature in the occupancy component. The second best approximating model had a model weight of 0.065 (Δ AICc = 0.056), and included secchi depth in the detection component and only velocity in the occupancy component. All other models had a Δ AICc score of 0.275 or higher.

The model-averaged estimates revealed that robust redhorse had a conditional detection probability (the probability of detecting the species given it was present in the sampling unit at the time of sampling) of $0.183 (\pm 0.128)$ with the average sampling effort during this study (1697 seconds/rkm) (Table 7). Model-averaged estimates and odds ratios revealed sampling intensity (amount of time spent electrofishing per river kilometer) and current velocity were positively related to conditional detection of robust redhorse, where for every one standard deviation increase in sampling intensity and velocity, detection probability decreases. Conversely, woody structure and secchi depth were negatively related to conditional detection, where for every one standard deviation increase in woody structure and secchi depth increase, detection decreases (Table 8). None of the odds ratio 95% confidence limits for parameters influencing detection encompassed zero, and were not considered imprecise. Although odds ratio confidence limits for all parameters were positive, the lower 95% confidence limit for secchi depth was very close to zero (0.0004).

Based on the model average estimates for conditional occupancy, robust redhorse had a site occupancy of $0.033 (\pm 0.045)$ across all sampling units (Table 7). As revealed by model-averaged parameter estimates and odds ratios, current velocity and the proportion of coarse substrates within the streambed were positively related with occupancy, where for every one standard deviation increase in velocity and coarse substrates, occupancy increases. Conversely, water temperature was negatively related, where for every one standard deviation increase in water temperature, occupancy decreases (Table 9). None of the odds ratio 95% confidence limits for parameters influencing detection encompassed zero, and were not considered imprecise. Although odds ratio confidence limits for all parameters were positive, the lower 95% confidence limits for velocity (0.00002) and temperature (0.002) were very close to zero. In addition, the upper confidence limit for velocity

CHAPTER 6

DISCUSSION

This study marks the first attempt to use occupancy models as a means to determine seasonal distribution and habitat use of robust redhorse. Although tracking of radio-tagged fish has provided invaluable information regarding robust redhorse movements and individual habitat use, other studies have not incorporated imperfect detection to determine the likelihood of robust redhorse occupancy and detection probability. In the case of robust redhorse, occupancy models provide a means to estimate the probability that the species will be present in any given habitat unit based on the characteristics of that habitat unit. Once habitat characteristics are determined for a given reach of river, researchers can use this information for the stratification or allocation of potential sampling units.

Distribution of Robust Redhorse

Compared to the other catostomids occupying the project site, robust redhorse appeared to have a very restricted distribution. Robust redhorse was confirmed present in 8% of the sampling units (8%); whereas, other large-bodied catostomids (excluding carpsuckers) occurrence ranged from 92 – 100% of sampling units in a wide range of habitat types. Robust redhorse, on the other hand, were only detected within the two uppermost units of the project site, immediately below Lloyd Shoals Dam. Robust redhorse, although not the rarest fish within the project site, had the most limited distribution. Regardless of season, all detections of robust

redhorse were within 500 meters of one another; suggesting the Ocmulgee population has a very restricted home range.

Detection of Robust Redhorse

As expected, sampling intensity was the most precise predictor variable and had the largest positive influence on detection probability of robust redhorse. Sampling during this study followed the protocol outlined for robust redhorse (RRCC 2002). Mean electrofishing time exceeded the minimum time (20 minutes of pedal time per river kilometer) recommended in the RRCC (2002) by 8.3 minutes. This amount of time is ample for sampling catostomids in this portion of the Ocmulgee River. In general, pedal time was highest in areas containing shoals. Units not containing shoals had a relatively linear electrofishing path, where field personnel sampled one bank (usually the outside bends of the river where the water was deepest and wood was most abundant) rather than spending time in the middle of the river (areas of consisting of shallow sand without cover). In addition to the same technique mentioned above, all areas in and adjacent to shoals were also sampled. Also noteworthy is the fact that sampling intensity was highest on sampling occasions when robust redhorse were detected. This was a site-specific effect, where sampling intensity was greater in shoal units because targeted habitat (e.g., bedrock shoals) usually spanned the entire width of the sampling unit, which resulted in higher effort per river kilometer (Figure 6). Conversely, sampling intensity was less in lateral scour units, where the targeted habitat (i.e., woody debris) was usually confined to the stream banks (Figure 6). Because of the sampling methods and imprecise confidence intervals, sampling intensity is not a reliable predictor of robust redhorse occupancy.

Current velocity had a relatively strong positive relationship with detection, where for every 0.25m/s increase in current velocity, detection is 1.18 times more likely. Although there is a positive relationship with detection, velocity may not be a good predictor for detection as a result of site conditions when robust redhorse were captured. The presence of shallow, rocky shoals below Lloyd Shoals Dam only allowed sampling when water was being released from Lake Jackson. As a result, all sampling occasions in units where robust redhorse were detected were on days where water velocities were highest. So, robust redhorse may not actually be more likely to be detected in fast water, rather they were detected in units that only allowed sampling when waters velocities were at higher the average velocities.

Secchi depth also had a negative relationship with detection, where for every 0.20 m increase in secchi depth (visibility) detection was 2.05 times less likely. Although there was a general negative relationship observed, secchi depth was deemed to be an imprecise predictor of conditional detection probability as a result of the wide confidence intervals for the parameter estimate and odds ratio, and sampling conditions that included zero. Secchi depth was generally lower on sampling occasions when robust redhorse were detected below LSD because samplers were only able to access the sampling unit during days of relatively high discharge. The higher discharge from the dam resulted in higher turbidity, which reduced the ability to see and net fish. However, these days were also the only time field crews detected robust redhorse. Therefore, secchi depth may not be a good predictor for robust redhorse detection.

Woody structure provides refuge for numerous fish species, but stunned redhorse may avoid detection or capture when swept underneath or entangled in woody debris (Grabowski *et al.* 2009). In general, woody debris had a negative relationship with conditional detection probability of robust redhorse. Scaled odds ratios revealed for every 2 m² of woody structure per

rkm, robust redhorse are 1.24 times less likely to be detected. Although the lack of robust redhorse captures could be a result of entanglement in woody structure, field observations and abundant captures of other catostomids in and around woody structure during the course of the project makes this unlikely.

Detection probability for any given fish species is a function of capture probability (i.e., the probability of collecting an individual of that species) and fish abundance (Bayley and Peterson 2001). Rare species (e.g., robust redhorse) may have much lower detection probabilities than more common species (e.g., notchlip redhorse and spotted sucker) because of their low numbers, cryptic behavior, difficult habitat to sample, gear inefficiency, or other such reasons. For example, Grabowski *et al.*, 2009 report very low capture probability for robust redhorse (0.031), even when the electrofishing crew knew how many tagged fish were present in a 2 km reach of river. Using model-averaged estimates, my results showed that conditional detection probability (i.e., the probability of detecting a species given that it is present within the sampling unit) for robust redhorse is extremely low. Using a model-averaged estimate from the confidence set of models, robust redhorse conditional detection probability was 0.183 (±0.128), assuming average observed sampling conditions. The detection estimate shows that samplers have an 18.27% chance of detecting at least one individual any given unit during a sampling event if robust redhorse are present in that unit at the time of sampling.

All detections of robust redhorse were only in Units 1 and 2, where the habitat was virtually devoid of woody structure. If robust redhorse have a high affinity for woody debris (Jennings *et al.* 1996; Evans1998; Grabowski and Isely 2006; Mosely and Jennings 2007; Grabowski and Jennings 2009) and detection is higher than previously estimated, then why were more robust redhorse not captured during the study? Other factors such as low site occupancy

may help explain why robust redhorse have not been detected in the downstream portion of the study area where large amounts of woody debris are present throughout (Figure 7).

Occupancy of Robust Redhorse

This study's detection estimates revealed that robust redhorse in the upper reaches of the Ocmulgee River are not nearly as difficult to detect as previously assumed. However, the limiting factor associated with the low encounter rates and low total catch for robust redhorse for the duration of this study can be linked to site occupancy of the upper Ocmulgee population. Using the model-averaged estimates, the predicted presence (occupancy) of robust redhorse within all accessible units in the upper reaches of the Ocmulgee River was 0.033 (± 0.045).

As revealed by the occupancy estimates, robust redhorse presence is 3.3 % within the all accessible units regardless of habitat type. However, a distinction must be made between shoal and non-shoal habitats. Of the 25 sampling units, only two contained some sort of large shoal complex, and one of these was Unit 1, the unit where most robust redhorse were detected. Although only two sampling units contained a substantial amount of shoals, the purpose of making the distinction between units with shoals and units without shoals was so that inferences could be made about the probability of robust redhorse potentially occupying the shoal habitats that were inaccessible to researchers.

In addition, the low occupancy estimate (0.033) and its relatively high standard error (± 0.045) may be a result of a violation of the closure assumption. Robust redhorse were able to colonize or leave sampling units during the course of the study (i.e., occupancy could change from season to season). Each of the 25 sampling units may have a different rate of occupancy, but if detection of robust redhorse is constant across all units, the occupancy estimate may

appropriately reflect the average occupancy for the pooled units, but with a large variance. The occupancy estimate of 0.033 represents the average occupancy across all units, but occupancy rates within shoal units may be considerably larger.

Robust redhorse were captured in the shoal unit (Unit 1) below LSD on five out of eight (5/8) sampling occasions. Although robust redhorse occupancy is extremely low for the project area as a whole, occupancy in shoal units is likely much higher. In Unit 1, detecting robust redhorse on 5 out of 8 sampling occasions can be translated to a 62.5% detection probability for that unit. This higher detection estimate is not likely the result of a higher capture probably, but may be the result of local abundance within Unit 1. For instance, robust redhorse may not be extremely difficult to detect, but may only occupy very specific habitat types within the upper Ocmulgee River where they are locally abundant. Occupancy information for robust redhorse within Unit 1 can be used to assume that occupancy in other shoals within the project area may be similar. The majority of shoal habitat in the upper Ocmulgee River between LSD and JMD is located in a non-navigable, 9-km reach of river (between HWY 16 and Nelson Island) that was not sampled during this study. This reach of river is of relatively high gradient and is known for its large complexes of bedrock shoal habitat with fast, turbulent water, and coarse substrates interspersed throughout the shoals. Robust redhorse may occupy these shoal habitats at a similar rate as seen below LSD, yet remain inaccessible by researchers.

Similar to the effect of shoals, the results of these occupancy models also suggest a strong positive effect of the proportion of coarse substrates in the streambed on robust redhorse presence. Although the presence of shoals in Piedmont river systems is often associated with the presence of shallow cobble, boulders, bedrock, gravel and other coarse substrates, not all areas containing coarse substrates are considered to be shoals. For instance, gravel bars and bedrock

may be present, but this does not suggest that a shallow, turbulent shoal complex is also present. Scaled odds ratio for the influence of coarse substrates suggests that for every 10% increase in coarse substrates in the streambed, robust redhorse presence is 1.21 times more likely. Unit 1 had the most robust redhorse detections and also was the sampling unit that contained the highest proportion (~78 %) of coarse substrates at (Figure 3). In general, the remainder of accessible portions contained sand as the dominant substrate with the majority of units containing < 15% coarse substrates; Unit 9 had ~56 % coarse substrate and was the exception. Additionally middle sampling units (11-15) were in a reach of the river where the stream morphology changes from long runs to a series of meanders, and Unit 13 contained 46% coarse substrates. This meander section had relatively swift water and lateral scours where bedrock, boulders, and gravel were more abundant. Despite having tight meanders typical of Coastal Plain rivers, this reach contained relatively little wood (Figure 3) and the fewest number of captured catostomids captured downstream of Nelson Island (Figure 4).

Many shoals were available to fish within the project site, but most of the substrate in the accessible portions of the upper Ocmulgee consisted of long, sandy runs with large amounts of woody debris present along the deep, flowing scours near the bank. Robust redhorse have a high affinity for woody structure and pool habitats in non-spawning seasons in lower Oconee River (Jennings *et al.* 1996), lower Savannah River (Grabowski and Isley 2006), and Ocmulgee River (Grabowski and Jennings 2009). However, the results of this study showed something quite different. Robust redhorse were not captured in close proximity to woody structure during this study, and the sampling unit where robust redhorse were detected the most (Unit 1) had the lowest amount of woody debris per river kilometer (Figure 3). The occupancy estimates revealed the likelihood of robust redhorse presence in the upper reaches of the Ocmulgee River

decreased as woody debris increased. This 2010-2011 study is one of the first to document robust redhorse habitat use in the Piedmont physiographic regions, and these observations are indicative of differential habitat use between robust redhorse populations in the Piedmont and habitat use observed in Coastal Plain drainages. For instance, sampling units containing shoals and abundant course substrates were virtually devoid of woody habitat, but such sites were where all of the robust redhorse in the Piedmont were captured. Robust redhorse were first described from the Piedmont section of the Pee Dee River (Cope 1869), and the species is known to make long spawning migrations between the Coastal Plain and the Piedmont (or as far upstream as possible; Cook *et al.* 2005; Grabowski *et al.* 2007; Grabowski and Jennings 2009). Most extant natural populations occur in the Coastal Plain sections of the rivers, and information about habitat use in Piedmont sections of rivers is scarce. The apparent affinity for coarse substrates in Piedmont sections may be new information that was otherwise unavailable because so few populations exist in Piedmont sections.

The upper Ocmulgee River population of robust redhorse is unique because after sampling > 22 kilometers of river twice per season for four seasons, robust redhorse were only found in or adjacent to the shoals in the first 0.65 km of the Ocmulgee River below LSD. However, robust redhorse in other Georgia drainages (e.g., Oconee and Ogeechee) may demonstrate different habitat use because the morphologies of these rivers also are different. The Ogeechee River's narrow, tightly meandering channel flows at an elevation of only around 61 m above sea level below Louisville, GA. The Ocmulgee River is comparable to the Oconee River, but the Oconee River population of robust redhorse is only present below Lake Sinclair, where the elevation is around 76.2 m above sea level near the Fall Line in Milledgeville. The Oconee population is unable to enter the Piedmont portion of the stream that was accessible prior

to dam construction. The Ocmulgee project site for this study begins at an elevation of around 143 m immediately downstream of LSD and drops to about 110 m just upstream of JMD. Elevation on the Ocmulgee River does not match that of the Ogeechee and Oconee rivers until after Macon, GA where the Ocmulgee crosses the Fall Line, exits the Piedmont, and takes on the morphology that is typical of other Atlantic Coastal Plain rivers. The Ocmulgee River is unique because unlike the Oconee, a population of robust redhorse exists in the Piedmont and Coastal Plain portions of the river. If a wild population of robust redhorse historically occurred in the Ocmulgee, they could undertake long migrations between the Piedmont and Coastal Plain freely prior to dam construction. The current population of fish can traverse over JMD (Grabowski *et al.* 2009) and be in Coastal Plain habitats used during non-spawning seasons. However, these "outmigrants" are unable to return to the high-gradient Piedmont habitats above JMD; the result is that the project site is no longer accessible. There is evidence from other GA rivers that "outmigrants" would return to the Piedmont portion of the river to spawn if such habitats were accessible.

The Broad River is the only other Georgia river system that has a population of robust redhorse that is at a comparable elevation (about 110m) and relative position to the Fall Line as the project site on the Ocmulgee. The Broad River is located in northeast Georgia within the Piedmont physiographic region of the state. Although the Broad is above the Fall Line, the river is narrower and contains less wood and shoal habitat than the project site on the upper Ocmulgee. The Broad is also different from the Ocmulgee because it eventually drains into Clarks Hill Reservoir on the Savannah River. The Broad River is formed by the confluence of the Hudson River and the Middle Fork Broad between Royston and Ila, GA. In the Broad and Hudson rivers, robust redhorse have access to upstream shoals and numerous mid-channel gravel

bars for spawning purposes, in addition to having the reservoir available during non-spawning periods (RRCC 2010; 2011). In 2010, tagged robust redhorse spawned on gravel bars in the Hudson and Broad rivers 81-88 km upstream of Anthony Shoals (a large shoal complex located at the mouth of where the Broad River of Clarks Hill Reservoir) (RRCC 2010), and then 83% of the tagged fish migrated downstream 10-12 km into Clarks Hill Reservoir in the summer (RRCC 2011). The Broad River population attempts to migrate downstream (as they would have historically), but encounters a reservoir first and therefore cannot access the Coastal Plain habitats used by robust redhorse in the lower Oconee and Savannah rivers. However, these fish can leave the reservoir and return to the Piedmont habitats during spawning season and do so annually.

So, if thousands of robust redhorse have been stocked into the upper Ocmulgee River, why were only eight fish captured during the course of this study? One explanation was mentioned above. The results of this study suggests that the upper Ocmulgee population may be encountered most frequently in habitats containing large amounts of coarse substrates year-round rather than large amounts of woody debris in the sandy runs. All shoal portions of the project site are likely available to robust redhorse, but are not accessible by researchers. Over 96% of the shoals between LSD and JMD are located in the 9-km portion of river that was unable to be sampled in 2010 and 2011. Therefore, robust redhorse may be residing in and adjacent to the numerous shoals that occupy a 9-km, inaccessible reach of river. However, until robust redhorse can actually be located within this portion of the Ocmulgee that contains the overwhelming majority of shoal habitats, whether great numbers of robust redhorse inhabit shallow, rocky areas of the river year-round is uncertain.

There is a possibility that the Ocmulgee population contains two subgroups, which exhibit distinct behavioral patterns as observed in a population of robust redhorse within the Pee Dee River in North Carolina (Fisk 2010). Using radio-tagged robust redhorse in the Piedmont and Coastal Plain portions of the Pee Dee, Fisk (2010) observed a "resident" and a "migratory" subgroup. Resident fish (n=20) remained within the Piedmont section and made localized movements for spawning purposes, and migratory fish (n=7) took part in long seasonal migrations and spent most of their time in Coastal Plain habitats; they only returned to the Piedmont to spawn (Fisk 2010). The Ocmulgee population may contain similar subgroups as the Pee Dee population. The robust redhorse captured during the course of this study may be considered a residential subgroup that rarely ventures far from spawning grounds regardless of season. Although the Ocmulgee population may exhibit similar behaviors as the Pee Dee Population, the two rivers systems differ in the fact that the study area on the Pee Dee has connectivity between Coastal Plain and Piedmont habitats, whereas the Ocmulgee River project site is not accessible to fish within the Coastal Plain. The migratory subgroup of stocked robust redhorse may have traversed over JMD in search of Coastal Plain habitats during non-spawning seasons; however, once outside of the project area, fish cannot traverse the dam in the upstream direction.

Out migration to areas below JMD is a probable explanation for the low number of detections is robust redhorse stocked into the project site. In two other studies on the Ocmulgee, around one third of tagged juvenile (Jennings and Shepard 2003) and adult (Grabowski and Jennings 2009) robust redhorse in the project outmigrated over JMD. Recall that once below the dam, robust redhorse cannot get back upstream above the dam to recolonize the study site. Below JMD, the effects of the hydro-peaking and large discharge fluctuations from LSD are less

intense, and other migration barriers (e.g., dams) do not exist in the river. Also important to note is that the Ocmulgee River below JMD remains within the Piedmont, contains numerous shoals, and generally the same morphology seen in the project site between LSD and JMD. The river remains in the Piedmont region for an additional 40 km from JMD downstream until it reached the Fall Line in Macon, GA. So, although fish may find suitable Piedmont habitat once they travel over JMD, they cannot access the high-gradient portions of the river above JMD that they may have had access to during historic migrations.

Thousands of robust redhorse of mixed ages were stocked into the upper reaches of the Ocmulgee River, but their fate remains unknown. There is the possibility that the one-third of the stocked fish exiting the project site, as reported in previous years (Jennings and Shepard 2003; Grabowski and Jennings 2009), has increased with time, and the majority of stocked fish have traversed over JMD since those studies were completed. Many of these fish may have encountered habitat similar to their Coastal Plain Oconee counterparts by swimming downstream out of the project site. In the river below JMD, robust redhorse still have access to the Coastal Plain meanders and woody debris during non-spawning seasons, but can still participate in long spawning migrations into the Piedmont shoal habitats between JMD and Macon that contain coarse substrates. Although robust redhorse appear to be using (and potentially spawning) in the Piedmont portion of the river between JMD and Macon after they travel over JMD, the use of shoals below JMD may be because the fish are incapable of upstream movement pass JMD. As a result, whether fish would inhabit the high-gradient shoals that exist between LSD and JMD and would stay in the study reach is unknown.

Upper Ocmulgee River Spawning Aggregation

On the first sampling occasion (May 10th) in Spring 2010, 5-6 individual robust redhorse were visually detected (2 were captured) in the first set of shallow shoals immediately downstream of LSD (Unit 1). Water temperature was 22.9 °C. Although several fish were shocked on the spawning shoals, only one large male and one female were captured. Evidence of spawning included the presence of nuptial tubercles on the male's rostrum and anal fin. Two weeks later (May 24th), the spawning aggregation had dispersed, and one individual was detected visually (fish was surfaced during electrofishing, but was not captured) in turbulent waters immediately downstream of the spawning shoals. Individual single robust redhorse were detected in the deep, swift waters of the dam tailrace along the western riverbank during both Summer 2010 sampling occasions. In the Fall 2010 season, robust redhorse were not detected in any sampling unit on any sampling occasion.

The Spring 2011 sampling season was when most robust redhorse were captured. Individuals were not found in Unit 1 during the first sampling occasion of spring 2011, but a single male robust redhorse was captured along the eastern shoreline without canopy and without submerged structure or cover at the very beginning of Unit 2 on April 7th. Water temperature was 15.8 °C, and the male robust redhorse appeared to be coming into spawning condition, as several small nuptial tubercles were starting to develop on the rostrum. Two weeks later, (April 28th), a spawning aggregation of about six individuals was encountered in the same set of shoals where fish were found the previous year. Water temperature on this sampling date was 20.7 °C. Although about six fish were spotted, only four individuals were landed, all of which were males in spawning condition. All fish lacked protective slime coats, and their anal fins and ventral portions of the caudal fin were eroded away, which revealed that spawning activity or some sort of territorial defense had taken place. In addition, the two smallest males were missing scales from their flanks and had the posterior portion of their dorsal fin missing (Figure 5). Although sample size was low, the high male:female sex ratio followed that observed by Grabowski *et al.* (2007). The lack of slime-coat, missing scales, and tattered fins of the two smaller males has also been observed in other spawning catostomids (Jenkins and Burkhead 1993; Grabowski and Isley 2007) and may be a result of spawning attempts in the upper reaches of the Ocmulgee River.

Although robust redhorse were captured in the first set of shoals below LSD as part of a "spawning aggregation" in both spring sampling seasons, the question of whether successful reproduction occurred there still remains. This particular set of shoals was only submerged during large discharge events from LSD. When water levels returned to normal flow, this set of shoals was either dewatered or covered with very shallow, slow water where the substrate was covered by a layer of silt and sediment (Figure 8). If gametes were actually released in this area, the eggs and larval robust redhorse could be exposed, smothered or heated by warm water, which would cause mortality as described in Jennings et al. (2009). Also, visits to this set of shoals during normal flows revealed that typical spawning habitat that consists of loose gravel substrates (Jennings et al. 1996; Grabowski et al. 2007; Grabowsk and Isely 2007) was not present in this particular area. Instead of midstream gravel bars seen in the Oconee (Jennings, et al. 1996) and Savannah (Grabowski et al. 2007; Grabowski and Isely 2007) rivers, the area where most robust redhorse captures took place in the upper Ocmulgee consisted of mostly bedrock with some loose cobble scattered on or around the bedrock shoals. So, although territorial defense is occurring at this "spawning aggregation," whether active reproduction is

taking place is unknown, and robust redhorse may be taking part in "futile spawning runs" until they reach LSD and settle for substandard spawning substrates.

Capture of Other Catostomids of the Upper Ocmulgee

At least six species of the family Catostomidae occur in the ~30 rkm headwater portion of the Ocmulgee River, including robust redhorse, notchlip redhorse, spotted sucker, brassy jumprock, striped jumprock, and two species of carpsucker. The number of captures in each sampling unit (Table 10, Figure 4) varied with species.

The notchlip redhorse was the most abundant sucker species and was found at least once in every sampling unit within the project site (Table 10). However, notchlip redhorse were generally scarce in the upstream portion of the project site and were more abundant in the downstream portion of the project site (Figure 4). The species was captured most frequently in long sandy runs, where the river was shallow midstream and deeper closest to the bank. These areas were generally characterized by moderate flows and abundant woody debris. In general, notchlip redhorse were not captured in shallow, swift, and rocky habitats inhabited by jumprocks.

Spotted suckers were also detected in all sampling units at least once (Table 10), but exhibited different habitat use and spatial distribution than the notchlip redhorse (Figure 4). Spotted suckers were distributed relatively evenly throughout the project site, but their numbers were greatest in the three most downstream units, where the river widens and slows just before the low-head mill dam in Juliette. Spotted suckers also had a high affinity to woody structure and occurred most frequently in deep areas with low flows. Sexual differentiation during non-

spawning seasons was easiest for the spotted sucker; sexually mature males had visible "scars' remaining on their rostrums into the fall season.

In general, the jumprocks (Scartomyzon spp.) were found most frequently in areas with swift water and were often found associated with rocky substrates. Brassy jumprocks were found in greater numbers than striped jumprocks and were detected in 92% of the sampling units at least once during the study (Table 10). Brassy jumprock abundance was the highest immediately downstream of LSD in sampling Unit 1 (Figure 4), where water velocity was consistently greater than 0.75 m/second and the proportion of streambed occupied by coarse substrates was greater than 0.77. This sampling unit was also where the majority of robust redhorse were captured or detected. In the spring seasons, Unit 1 was sampled intensely, and groups of 10-20 brassy jumprocks were observed frequently in one small area of turbulence just below shoals. Brassy jumprocks were present throughout the project site, with the exception of the two most downstream sampling units. However, they were found in the greatest number just below LSD. Although brassy jumprocks were located in sites containing long sandy runs, they seemed to be confined to specific microhabitats within those runs. Specifically, they tended to occur in small areas of comparatively high water velocity, particularly in lateral scours where shoals, boulders or cobble were nearby.

Striped jumprocks were present in 44% of the sampling units (Table 10) and were found primarily in shoals, rocky outcrops, and other areas characterized by coarse substrates and high water velocities. Like brassy jumprock, most striped jumprock captures occurred in sampling Unit 1 just below LSD. However, rather than finding this species in deep, turbulent waters in the middle of the stream, striped jumprocks occurred in swift, shallow waters (<0.5m) over loose cobble, bedrock or rocky substrates. Striped jumprocks were detected most often in the fall

when water clarity was highest and water levels were lowest. The small overall size and specific habitat use of striped jumprocks may have influenced the relatively low numbers of detections of this species when sampling with boat electrofishing techniques.

Only the undescribed carpsuckers *Carpiodes spp*. were found in fewer numbers than robust redhorse (Table 10). On a sampling occasion later that spring, one individual (assumed to be a quillback *Carpoides sp. cf. cyprinus*) was found in the accessible unit just below Nelson Island in a deep flowing run, and two more individuals (believed to have been highfin carpsuckers *Carpiodes sp. cf. velifer*) were found about 7 km downstream in a shallow sandy run under woody debris. These two fish were in spawning condition (nuptial tubercles present on the rostrum, head, paired fins, and rear margins of scales on the dorsum and sides of the fish). These two individuals were presumably migrating upstream to spawn in or near the inaccessible shoals near 40-Acre Island. Other carpsuckers were not encountered until the next spring (2011), when a single quillback was captured in the silted, no-flow waters underneath the Juliette Road. Bridge approximately 200 meters upstream of JMD.

CHAPTER 7

CONCLUSIONS

Considering imperfect detection and the overall lack of captures for robust redhorse, occupancy modeling was somewhat useful in determining detection probabilities and probable habitat use for this rare species. However, parameter estimates were generally imprecise and unreliable. Some of the most useful information regarding the Ocmulgee population was gathered from field observations (e.g., captures, sampling conditions) and habitat types as observed through side-scanning sonar imagery. The extremely low occupancy estimate for robust redhorse (0.033 ± 0.128) is believable because robust redhorse were only observed in two of 25 units, both immediately downstream of LSD in the immediate vicinity of shoals. This occupancy rate of 3.3% can be used to make inferences regarding robust redhorse occupancy within the non-navigable portion of the river. However, the occupancy rates in the inaccessible habitats in the area between HWY 16 and Nelson Island shoals should not be considered to be identical to the occupancy estimates gathered from the accessible units as a whole. For instance, the current estimates include large areas that are primarily sandy runs with abundant woody debris. However, the majority of habitats within the non-navigable portion consist of shoals. Considering robust redhorse were found almost exclusively in shoal habitats during the course of the study, one may assume that robust redhorse are more likely to inhabit the inaccessible shoals as well. Although shoals in the inaccessible portion of river appear to be similar to those where robust redhorse were captured, Units 1 and 2 are unique. These units are located immediately below a hydropower dam, where conditions are dynamic and hydropeaking occurs during high

water levels in the winter and early spring months. This dam is also a migration barrier, where fish taking part in spawning runs may swim past shoal complexes downstream only to have further migration blocked by the dam, and fish may "settle" into the first set of shoals below the dam. Therefore, although the upper reaches of the Ocmulgee River contain numerous shoal habitats that could be used for reproduction by many catostomids, including the robust redhorse, true occupancy estimates for the entire study area cannot be determined until the inaccessible portion of the river can be sampled.

Abundant shoal habitat is available in the project site, but only a few of those areas were accessible for electrofishing and are located at the most upstream shoals within the project site. This situation confirms previous research (e.g., Graboswki and Isley 2006, Fisk 2010) that implied robust redhorse have high site fidelity to spawning areas used in the past or they may continue upstream until some barrier (e.g., dams) prevents further migration. The shoals directly below JMD (outside of the project site) could also serve as a potential spawning ground for robust redhorse. Local residents have reported "large fish with bright red fins hanging out in groups" in the area just below JMD during April and May. These reports suggest that robust redhorse may have moved out of the project site into a reach of river that is still within the Piedmont ecoregion, but fish still have access and connectivity to the downstream Coastal Plain habitats. From there, fish make long migrations upstream until a barrier (i.e., JMD) prevents further upstream movement or until suitable spawning habitat is found. The robust redhorse population observed between LSD and JMD in the current study was not found in association with woody debris and was found most frequently in shoals and areas containing abundant coarse substrates year round. However, this inference was made on less than 10 fish, and the species as a whole may use habitat types seasonally in a fashion similar to those seen in other

robust redhorse studies (e.g., Grabowski and Isely 2006; Mosely and Jennings 2007; Grabowski and Jennings 2010). In those studies, fish used gravel bars and shoals in spring, but retreated to deep areas containing large amounts of woody debris during non-spawning months. Along the Ocmulgee, suitable spawning habitat may be present between LSD and JMD, but much of the meandering habitat used in non-spawning seasons in the Coastal Plain is not present in the upper reaches of the Ocmulgee. To better understand the Ocmulgee River population of robust redhorse, a similar study from JMD downstream to Macon would be useful. This reach of river is located in the Piedmont region where robust redhorse have access to numerous shoals, as well as un-impounded waters flowing into the Coastal Plain region where fish may have similar habitats to their Oconee River conspecifics. In addition, if fish have traversed over JMD, the Coastal Plain habitats may be used by robust redhorse, but fish cannot return to the project site to use high-gradient shoals between LSD and JMD.

Another focus of this project was to determine if any natural reproduction and recruitment were occurring in the Ocmulgee River. Although robust redhorse were captured in probable spawning aggregations, the success of that activity remains unknown. The observed spawning aggregation took place just below Lloyd Shoals Dam, where springtime flows were often higher than in other seasons. However, the daily and weekly fluctuations in discharge from the dam can leave the shoals susceptible to sedimentation, changes in water quality or dewatering, potentially rendering spawning attempts unsuccessful (Ruetz and Jennings 2000; Weyers *et al.* 2003; Jennings *et al.* 2010).

The status of the Ocmulgee population remains unclear because abundance could not be estimated with the low capture rates experienced during this study. However, this study did demonstrate that even with limited date, useful information about the apparent occupancy,

detection, and habitat use of a rare species can inform management, and may be used to study other populations of robust redhorse or other rare suckers (e.g., sicklefin redhorse, Carolina redhorse; *Moxostoma spp*).

LITERATURE CITED

- Albanese, B., Peterson, J.T., Freeman, B.J., Weiler, D.A. 2007. Accounting for incomplete detection when estimating site occupancy of bluenose shiner (*Pteronotropis welaka*) in southwest Georgia. Southeastern Naturalist 6(4): 657-668.
- Albanese, B., Owers, K., Weiler, D., Pruitt, W., 2011. Estimating occupancy of rare fishes using visual surveys, with a comparison to backpack electrofishing. Southeastern Naturalist 10(3):423–442.
- Akaike, H. 1973. Information theory and an extension of the maximum likelihood principle. Second international Symposium on Information Theory. Eds.B.N. Petrov and F. Csaki. Akademiai Kiado, Budapest, Hungary. Pgs: 267-281.
- Bailey, L.L., Hines, J.E., Nichols, J.D., MacKenzie, D.I., 2007. Sampling design trade-offs in occupancy studies with imperfect detection: Examples and software. Ecological Applications 17, 281-290.
- Bain, M.B and Stevenson, N.J., editors. 1999. Aquatic habitat assessment; common methods. American Fisheries Society. Bethesda, Maryland.
- Bayley, P. B. and J. T. Peterson. 2001. An approach to estimate probability of presence and richness of fish species. Transactions of the American Fisheries Society 130: 620-633.
- Bart, H. L., M. S. Taylor, J. T. Harbaugh, J. W. Evans, S. C. Schleiger, and W. Clark.
 1994. New distribution records of Gulf slope drainage fishes in the Ocmulgee
 River system, Georgia. Southeastern Fishes Council Proceedings 30:4–9.

Betts, A.M., Clark, T.H., Yang, J.X., Treadway, J.L., Li, M., Giovanelli, M.A., Abdiche, Y.,

Stone, D.M., Paralkar, V.M., 2010. The application of target information and preclinical pharmacokinetic/pharmacodynamic modeling in predicting clinical doses of a Dickkopf-1 antibody for Osteoporosis. Journal of Pharmacology and Experimental Therapeutics 333(1), 2-13.

- Bryant RT, Evans J.W., Jenkins R.E., Freeman B.J., 1996. The mystery fish. Southern Wildlife 1: 26–35.
- Burnham, K.P. and Anderson, D.R. 2002 Model selection and inference: an information theoretic approach. Springer-Verlag, New York.
- Congdon, P. 2001. Bayesian statistical analysis. John Wiley & Sons Inc., New York.
- Cooke, S.J., Bunt, C.M., Hamilton, S.J., Jennings, C.A., Pearson, M.P., Cooperman, M.S.,
 Markle, D.F., 2005. Threats, conservation strategies, and prognosis for suckers
 (Catostomidae) in North America: insights from regional case studies of a diverse family
 of non-game fishes. Biological Conservation 121, 317-331.
- Cope, E. D. 1869. Partial synopsis of the fishes of the fresh waters of North Carolina. Proceedings of the American Philosophical Society 11:448–495.
- de Greef, R., Maloney, A., Olsson-Gisleskog, P., *et al.*, 2011. Dopamine D(2) occupancy as a biomarker for antiphychotics: quantifying the relationship with efficacy and extrapyramidal symtpoms. AAPS Journal 13(1), 121-130.
- Evans, J.W. 1994. A fisheries survey of the Oconee River between Sinclair Dam and Dublin, Georgia. Georgia Department of Natural Resources, Wildlife Resources Division.
- Farmer, A.L., Smith, L.L., Castleberry, S.B., Gibbons, J.W., 2009. A comparison of techniques for sampling amphibians in isolated wetlands in Georgia, USA. Applied Herpetology 6, 327-341.

- Fisher, W. L., and Rahel, F.J. 2004. Geographic information systems applications in stream and river fisheries. Pages 49-84 in W. L. Fisher and F. J. Rahel, editors. Geographic information systems in fisheries. American Fisheries Society. Bethesda, Maryland.
- Freeman, M.C., Bowen, Z.H., Bovee, K.D. and Irwin, E.R., 2001. Flow and habitat effects on juvenile fish abundance in natural and altered flow regimes. *Ecological Applications* 11, pp. 179–190.
- Grabowski, T.B., Ferguson, T.D., Peterson, J.T., Jennings, C.A., 2009. Capture Probability and Behavioral Response of the Robust Redhorse, a Cryptic Riverine Fish, to Electrofishing. North American Journal of Fisheries Management 29, 721-729.
- Grabowski, T. B., and Isely, J.J. 2005. Use of prepositioned grid electrofishers for the collection of robust redhorse broodstock. North American Journal of Aquaculture 67:89-92.
- Grabowski, T.B., Isely, J.J., 2006. Seasonal and diel movements and habitat use of robust redhorses in the lower Savannah River, Georgia and South Carolina. Transactions of the American Fisheries Society 135, 1145-1155.
- Grabowski, T.B., Isely, J.J., 2007. Spatial and temporal segregation of spawning habitat by catostomids in the Savannah River, Georgia and South Carolina, USA. Journal of Fish Biology 70, 782-798.
- Grabowski, T.B., Isely, J.J., 2008. Size of spawning population, residence time, and territory shifts of individuals in the spawning aggregation of a riverine catostomid. Southeastern Naturalist 7, 475-482.
- Grabowski, T.B., Jennings, C.A., 2009. Post-release movements and habitat use of robust redhorse transplanted to the Ocmulgee River, Georgia. Aquatic Conservation-Marine and Freshwater Ecosystems 19, 170-177.

- Grabowski, T.B., Ratterman, N.L., Isely, J.J., 2008. Demographics of the spawning aggregations of four catostomid species in the Savannah River, South Carolina and Georgia, USA. Ecology of Freshwater Fish 17, 318-327.
- Gordon, N.D., McMahon, T.A., and Finlayson, B.L., 1992. Stream Hydrology: An introduction for ecologists. John Wiley and Sons, Chichester, UK. 526 pp.
- Higginbotham, D.L., and Jennings, C.A., 1999. Growth and survival of juvenile robust redhorse Moxostoma robustum fed three different commercial feeds. North American Journal of Aquaculture 61, 167-171.
- Hosmer, D. W. Jr., and Lemeshow, S. 2000. Applied logistic regression. John Wiley & Son Inc., New York.
- Hurvich, C.M. and Tsai, C. 1989. Regression and time series model selection in small samples. Biometrika 76:297-307.
- Jenkins, R.E. 1970. Systematic studies of the catostomid fish tribe Moxostomatini. Ph.D Dissertation, Cornell University., 799 p.
- Jenkins, R.E., and Burkhead, N.M. 1994. The Freshwater Fishes of Virginia. The American Fisheries Society, Bethesda, MD. 1079 pp.
- Jennings, C. A. and Shepard D.C. 2003. Movement and habitat use of hatchery-reared juvenile robust redhorse Moxostoma robustum released in the Ocmulgee River, GA. Final Report prepared for Georgia Power Company. 36 p.
- Jennings, C.A., Dilts, E.W., Shelton, J.L., Peterson, R.C., 2010. Fine sediment affects on survival to emergence of robust redhorse. Environmental Biology of Fishes 87, 43-53.

Jennings, C.A., Shelton, J.L., Freeman, B.J., Looney, G.L., 1996. Culture techniques and

ecological studies of the robust redhorse Moxostoma robustum. Annual Report (1995) prepared for Georgia Power Company, Environmental Affairs Division, Atlanta, Georgia Project Number 25-21-RC295-387 University of Georgia, Athens, Georgia.

- Kamps, D.M., 1989. Jackson Lake: Response to Nutrient Reduction. Proceedings of the 1989Georgia Water resources Conference. May 16-17, 1989, Athens, Georgia.
- Kaeser, A.J., and Litts, T.L. 2010. A Novel Technique for Mapping Habitat in Navigable Streams Using Low-cost Side Scan Sonar. Fisheries 35, 4 &163-174.
- Kinsolving, A.D., Bain, M.B., 1993. Fish assemblage recovery along a riverine disturbance gradient. Ecological Applications 3, 531-544.
- Kroll, A.J., Duke, S.D., Runde, D.E., Arnett, E.B., Austin, K.A., 2007. Modeling habitat occupancy of orange-crowned warblers in managed forests of Oregon and Washinton, USA. Journal of Wildlife Management 71, 1089-1097.
- Lincoln, F. C. (1930). Calculating Waterfowl Abundance on the Basis of Banding Returns. United States Department of Agriculture Circular 118, 1–4.
- MacKenzie, D. T., Nichols, J. D., Lachman, G. B. *et al.* 2002. Estimating site occupancy rates when detection probabilities are less than one. Ecology 83, 2248-2255.
- MacKenzie, D.I., Nichols, J.D., Hines, J.E., Knutson, M.G., Franklin, A.B., 2003. Estimating Site Occupancy, Colonization and Local Extinction When a Species is Detected Imperfectly. Ecology 84, 2200-2207.
- MacKenzie, D.I. and Bailey, L.L. 2004. Assessing the fit and site-occupancy models. American Statistical Association and the International Biometric Society Journal of Agriculture, Biological, and Environmental Statistics 9, 300-318.

MacKenzie, D.I., 2005. What are the issues with presence-absence data for wildlife managers?

Journal of Wildlife Management 69, 849-860.

- MacKenzie, D.I. and Royle, J.A. 2005. Designing efficient occupancy studies: general advice and tips on allocation of study effort. Journal of Applied Ecology 42, 1105-1114.
- MacKenzie, D.I., 2006. Modeling the probability of resource use: The effect of, and dealing with, detecting a species imperfectly. Journal of Wildlife Management 70, 367-374.
- Martin, R.F., 1986. Spawning behavior of the gray redhorse, Moxostoma congestum (Piscues, Satostomidae) in central Texas. The Southwestern Naturalist 31, 399-401.
- Mosley, D.L., Jennings, C.A., 2007. Flow preferences for juvenile robust redhorses in an experimental mesocosm: Implications for developing sampling protocols. North American Journal of Fisheries Management 27, 1383-1392.
- Nichols, J.D., Hines, J.E., MacKenzie, D.I., Seamans, M.E., Gutierrez, R.J., 2007. Occupancy estimation and modeling with multiple states and uncertainty. Ecology, 88, 1395-1400.
- Petersen, C.G. J. 1896. The Yearly Immigration of Young Plaice Into the Limfjord From the German Sea. Report of the Danish Biological Station (1895) 6, 5–84.
- Peterson, J.T., Wisniewski, J.M., Shea, C.P., Jackson, C.R., 2011. Estimation of mussel population response to hydrologic alteration in a southeastern U.S. stream. Environmental Management, 48(1): 109-122.
- Pine, W.E., Kwak, T.J., Waters, D.S., Rice, J.A., 2005. Diet selectivity of introduced flathead catfish in coastal rivers. Transactions of the American Fisheries Society 134, 901-909.
- Pollock, K.H., 1982. Capture-recapture models for age-dependent survival and capture rate. Biometrics 44, 397-404.
- Ricciardi, A., Rasmussen, J.B., 1999. Extinction rates of North American freshwater fauna. Conservation Biology 13, 1220–1222.

Robust Redhorse Conservation Committee. 2002. Robust Redhorse Conservation Committee policies Available: www.robustredhorse.com/f/policies.pdf. (May 2010).

Robust Redhorse Conservation Committee. 2011. Report of the Robust Redhorse Conservation Committee Annual Meeting. Compiled by J. Zelko. Morrow Mountain State Park, Albemarle, North Carolina. October 3-5, 2011. Available:

www.robustredhorse.com/h/reportpubs.html

Robust Redhorse Conservation Committee. 2010. Report of the Robust Redhorse Conservation Committee Annual Meeting. Compiled by J. Zelko and A. Lawrence. Web Wildlife Management Area, Garnett, SC. September 7 – 9, 2010. Available:

www.robustredhorse.com/h/reportpubs.html

Rodhouse, T.J., Hirnyck, R.P., Wright, R.G., 2010. Habitat selection of rodents along a phion juniper woodland savannah gradient. Journal of Mammalogy 91, 447-457.

Royall, R.M. 1997. Statistical evidence: a likelihood paradigm. Chapman and Hall, New York.

- Royle, J.A. and R.M. Dorazio. 2006. Hierarchical models of animal abundance and occurrence. Journal of Agricultural, Biological, and Environmental Statistics 11: 249-263
- Royle, J.A., Kery, M., Gautier, R., Schmid, H., 2007. Hierarchical spatial models of abundance and occurrence from imperfect survey data. Ecological Monographs 77, 465-481.
- Ruetz, C.R. and Jennings, C.A., 2000. Swimming performance of larval robust redhorse
 Moxostoma robustum and low-velocity habitat modeling in the Oconee River, Georgia.
 Transactions of the American Fisheries Society 129, 398-407.

Scott, J.M., Heglund, P.J., Morrison, M.L., Haufler, J.B., Raphael, M.G., Wall, W.A., Samson,F.B., eds. 2002. Predicting Species Occurrences. Inland Press. Washington, D.C.

Southwood, T.R.E., and Henderson, P.A. 2000. Ecological Methods. Third edition. Blackwell

Science, Oxford.

- Spiegelhalter, D., Thomas, A., Best, M. 2006. WinBUGS, version 1.4. Available: www.mrc-bsu.cam.ac.uk. (June 2010).
- Travnichek, V.H. and Maceina, M.J., 1994. Comparison of flow regulation effects on fish assemblages in shallow and deep water habitats in the Tallapoosa River, Alabama. Journal of Freshwater Ecology 9, 207–216.
- Urban, N.A., Swihart, R.K., 2009. Multiscale perspectives on occupancy of meadow jumping mice in landscapes dominated by agriculture. Journal of Mammalogy, 90, 1431-1429
- Walsh, S.J., Haney, D.C., Timmerman, C.M., Dorazio, R.M., 1998. Physiological tolerances of juvenile robust redhorse, Moxostoma robustum: conservation implications for an imperiled species. Environmental Biology of Fishes 51, 429-444.
- Weir, L.A., Royle, J.A., Nanjappa, P., Jung, R.E., 2005. Modeling anuran detection and site occupancy on North American Monitoring Program (NAAMP) routes in Maryland. Journal of Herpetology 39, 627-639.
- Wenger, S.J., and Freeman, M.C. (2008) Estimating Species Occurrence, abundance, and Detection Probability Using Zero-Inflated Distributions. Ecology: Vol. 89, No. 10, pp. 2953-2959
- Weyers, R.S., Jennings, C.A., Freeman, M.C., 2003. Effects of pulsed, high-velocity water flow on larval robust redhorse and V-lip redhorse. Transactions of the American Fisheries Society 132, 84-91.
- Williams, B.K., Nichols, J.D., Conroy, M.J., 2002. Analysis and Management of Animal Populations. Academic Press, Oxford.

TABLES

Table 1. Interpretation of predictor variables used to estimate the conditional detection probability of robust redhorse in the upper Ocmulgee River, 2010-2011.

Predictor	Interpretation
Sampling Intensity	The amount of time spent electrofishing per kilometer of river may influence the probability of detecting a species.
Woody Structure	Fish may seek refuge in woody debris or may become entangled in woody structure after being immobilized, therefore influencing the conditional detection of robust redhorse in the upper Ocmulgee River.
Secchi Depth	The turbidity /water clarity on any given day may influence detection by affecting the netter's ability to see and captured immobilized fish, and/or allow fish to avoid the sampling equipment, thus leaving the sampling area.
Current Velocity	Immobilized fish may be swept away in areas of high water velocity, therefore affecting the detectability of that fish species.

Table 2. Interpretation of predictor variables used to estimate the probability of occupancy of robust redhorse in the upper Ocmulgee River, 2010-2011.

Predictor	Interpretation				
Temperature	Robust redhorse may occupy different spatial locations in the river based on water temperature or seasonal temperature differences; therefore, water temperature may influence the conditional occupancy of robust redhorse.				
Coarse Substrates	In spring months, robust redhorse may move into areas containing large amounts gravel or pebble substrates; therefore, the proportion of coarse substrates in the streambed of a sampling unit may influence robust redhorse occupancy.				
Current Velocity	In relation to other catostomids, robust redhorse may reside in faster flowing portions of the stream. Also, in spring months, robust redhorse may move into the faster flowing waters in search of spawning habitat; therefore, water velocity may influence conditional occupancy.				
Sason	Temperature	Dissolved	Velocity	Discharge	Secchi Depth
-------------	--------------	---------------	-------------	---------------	--------------
Season	(°C)	Oxygen (mg/L)	(m/s)	(m^3/s)	(m)
All	23.85 (4.40)	6.94 (1.02)	0.33 (0.24)	28.30 (28.99)	1.18 (0.92)
Spring 2010	23.64 (1.07)	7.37 (0.96)	0.39 (0.17)	41.46 (38.44)	1.15 (0.49)
Summer 2010	29.89 (0.83)	6.33 (0.66)	0.29 (0.26)	14.30 (7.63)	1.98 (1.03)
Fall 2010	20.92 (3.82)	7.55 (1.07)	0.25 (0.23)	21.13 (25.19)	2.24 (1.01)
Spring 2011	20.90 (2.75)	6.51 (0.78)	0.40 (0.28)	36.30 (27.31)	1.84 (0.69)

Table 3. Mean (standard errors) of water quality data recorded on each sampling occasion during all sampling seasons in the upper Ocmulgee River, 2010-2011.

Species	n	sub- sample n	Mean TL	Range
Moxostoma robustum Robust Redhorse	7	7	491.71	477-509
Moxostoma collapsum Notchlip Redhorse	2649	472	395.36	61-520
Minytrema melanops Spotted Sucker	1384	403	370.44	133-772
Scartomyzon rupricartes Striped Jumprock	39	18	174.78	83-253
<i>Scartomyzon sp. cf. lachneri</i> Brassy Jumprock	331	189	383.13	161-474
<i>Carpioides spp.</i> Carpsucker spp.	3	1	438.00	NA

Table 4. Total number of various catostomid species captured (n) in the upper reaches of the Ocmulgee River in 2010 and 2011, the number of each species weighed (sub-sample n), and their mean and range of total length in mm.

	<i>Mo. robustum</i> Robust Redhorse	<i>Mo. collapsum</i> Notchlip Redhorse	<i>Mi. melanops</i> Spotted Sucker	<i>Sc. rupricartes</i> Striped Jumprock	<i>Sc. sp. cf. lachneri</i> Brassy Jumprock	<i>Carpioides spp</i> . Carpsucker spp.
Spring 2010	2	617	434	1	98	3
Summer 2010	0	726	233	2	93	0
Fall 2010	0	781	381	24	56	0
Spring 2011	5	525	336	12	84	2

Table 5. Number of captured catostomids in the upper Ocmulgee River during each sampling season in 2010 and 2011, the total number captured, and each species' percentage of the total catch.

Table 6a. Confident set of models (n=41) used to predict robust redhorse occupancy in the upper Ocmulgee River in 2010 and 2011. Confident set of models is comprised of the top models with models weights within 10% of the best-approximating model. Table of models includes the detection predictor variables (P), the occupancy predictor variables (Psi), the number of parameters (K), AICc, Δ AICc, model weight (w_i), and the percentage of maximum weight for each model (% max w_i).

	Model								
Р	Psi	K	AICc	ΔAICc	W _i	\mathbf{W}_i			
Intercept + Secchi	5	30.143	0.000	0.067	100.0				
Intercept + Secchi	Intercept + Velocity	4	30.200	0.056	0.065	97.2			
Intercept + Secchi + Intensity	Intercept + Velocity	5	30.419	0.275	0.058	87.1			
Intercept + Secchi + Intensity	Intercept + Coarse Substrates	5	30.501	0.357	0.056	83.6			
Intercept + Secchi	Intercept + Coarse Substrates	4	30.625	0.482	0.052	78.6			
Intercept + Secchi + Intensity	Intercept + Velocity + Temperature	6	30.659	0.515	0.051	77.3			
Intercept + Secchi	Intercept + Velocity + Coarse Substrates	5	31.012	0.868	0.043	64.8			
Intercept + Wood + Secchi	Intercept + Velocity + Temperature	6	31.208	1.064	0.039	58.7			
Intercept only	Intercept + Coarse Substrates	3	31.217	1.073	0.039	58.5			
Intercept + Secchi + Intensity	Intensity + Velocity + Coarse Substrates	6	31.490	1.347	0.034	51.0			
Intercept + Wood + Secchi + Intensity	Intercept + Coarse Substrates	6	32.088	1.944	0.025	37.8			
Intercept + Velocity + Secchi	Intercept + Velocity	5	32.092	1.949	0.025	37.7			
Intercept + Velocity + Secchi	Intercept + Velocity + Temperature	6	32.270	2.127	0.023	34.5			
Intercept + Velocity	Intercept + Velocity + Coarse Substrates	5	32.362	2.219	0.022	33.0			
Intercept + Wood + Secchi + Intensity	Intercept + Velocity	6	32.485	2.342	0.021	31.0			
Intercept + Intensity	Intercept + Coarse Substrates	4	32.553	2.410	0.020	30.0			

Table 6b. Confident set of models (n=41) used to predict robust redhorse occupancy in the upper Ocmulgee River in 2010 and 2011. Confident set of models is comprised of the top models with models weights within 10% of the best-approximating model. Table of models includes the detection predictor variables (P), the occupancy predictor variables (Psi), the number of parameters (K), AICc, Δ AICc, model weight (w_i), and the percentage of maximum weight for each model (% max w_i).

	Model			`	.,	%
		-				max
P	Κ	AICc	ΔAICc	W _i	Wi	
Intercept + Wood + Secchi	5	32.560	2.417	0.020	29.9	
Intercept + Wood	Intercept + Coarse Substrates	4	32.703	2.560	0.019	27.8
Intercept only	Intercept + Velocity	3	32.746	2.602	0.018	27.2
Intercept + Velocity	Intercept + Velocity + Coarse Substrates + Temperature	6	32.795	2.652	0.018	26.6
Intercept + Velocity + Secchi	Intercept + Coarse Substrates	5	32.842	2.699	0.017	25.9
Intercept + Wood + Secchi + Intensity	Intercept + Velocity + Temperature	7	32.882	2.738	0.017	25.4
Intercept + Velocity	Intercept + Coarse Substrates	4	32.914	2.771	0.017	25.0
Intercept only	Intercept + Coarse Substrates + Temperature	4	32.920	2.777	0.017	24.9
Intercept only	Intercept + Velocity + Coarse Substrates	4	32.950	2.807	0.016	24.6
Intercept + Wood + Secchi	Intercept + Velocity + Coarse Substrates	6	32.974	2.830	0.016	24.3
Intercept + Wood + Secchi + Intensity	Intercept + Velocity + Coarse Substrates	7	33.198	3.055	0.014	21.7
Intercept + Wood	Intercept + Velocity	4	34.071	3.928	0.009	14.0
Intercept only	Intercept + Velocity + Coarse Substrates + Temperature	5	34.261	4.117	0.008	12.8
Intercept + Intensity	Intercept + Coarse Substrates + Temperature	5	34.339	4.195	0.008	12.3
Intercept + Velocity + Wood	Intercept + Velocity + Coarse Substrates	6	34.343	4.199	0.008	12.2
Intercept + Intensity	Intercept + Velocity	4	34.369	4.226	0.008	12.1

Table 6c. Confident set of models (n=41) used to predict robust redhorse occupancy in the upper Ocmulgee River in 2010 and 2011. Confident set of models is comprised of the top models with models weights within 10% of the best-approximating model. Table of models includes the detection predictor variables (P), the occupancy predictor variables (Psi), the number of parameters (K), AICc, Δ AICc, model weight (w_i), and the percentage of maximum weight for each model (% max w_i).

				· ·	.,	
	Model					%
		_				max
 Р	Psi	Κ	AICc	∆AICc	Wi	Wi
Intercept + Velocity + Wood	Intercept + Velocity	5	34.487	4.344	0.008	11.4
Intercept + Wood	Intercept + Coarse Substrates + Temperature	5	34.491	4.347	0.008	11.4
Intercept + Velocity	Intercept + Coarse Substrates + Temperature	5	34.558	4.415	0.007	11.0
Intercept + Intensity	Intercept + Velocity + Coarse Substrates	5	34.614	4.471	0.007	10.7
Intercept + Velocity + Intensity	Intercept + Velocity + Coarse Substrates	6	34.624	4.480	0.007	10.6
Intercept + Velocity + Wood	Intercept + Coarse Substrates	5	34.630	4.487	0.007	10.6
Intercept + Wood + Intensity	Intercept + Coarse Substrates	5	34.692	4.549	0.007	10.3
Intercept + Velocity	Intercept + Velocity	4	34.702	4.558	0.007	10.2
 Intercept + Wood	Intercept + Velocity + Coarse Substrates	5	34.721	4.577	0.007	10.1

Table 7. Predicted estimates of average conditional detection probability, and occupancy for robust redhorse across all sampling units in the upper Ocmulgee River in 2010 and 2011, their standard errors, and upper and lower 95% confidence intervals calculated using model average estimates from the confident set of 41 models.

			95 % Confidence						
			Inter	rvals					
Parameter	Estimate	SE	Lower	Upper					
Detection Probability (p)	0.1827	0.1282	0.0054	0.9014					
Occupancy (Psi)	0.0328	0.0455	0.0000	0.9975					

Table 8. Model average estimates for various parameters influencing detection of robust redhorse on the upper Ocmulgee River in 2010 and 2011, with standard errors (SE), 95% confidence intervals for each estimate, odds ratios (OR), 95% confidence intervals for OR. For ease of interpretation, unit changes, scaled estimators, scaled odds ratios, and 95% confidence intervals of the scaled odds ratios are also provided.

			95 %	CI of						
		Standard	Estir	mate	<u>.</u>	95 % C	I of OR	unit	scaled	scaled
Parameter	Estimate	Error	Lower	Upper	OR	Lower	Upper	change	estimator	OR
Intercept	-2.408	2.486	-7.280	2.464	—	—	—	—	—	_
Velocity	0.655	1.329	-1.950	3.261	1.925	0.142	26.067	0.250	0.164	1.178
Woody Structure	-0.218	1.434	-3.029	2.594	0.804	0.048	13.379	2.000	-0.436	0.647
Secchi Depth	-3.591	2.226	-7.954	0.772	0.028	0.000	2.165	0.200	-0.718	0.488
Sampling Intensity	1.492	1.429	-1.309	4.294	4.447	0.270	73.261	2.000	2.985	19.780

Table 9. Model average estimates for various parameters influencing detection of robust redhorse in the upper Ocmulgee River in 2010and 2011, with standard errors (SE), 95% confidence intervals for each estimate, odds ratios (OR), 95% confidence intervals for OR. For ease of interpretation, unit changes, scaled estimators, scaled odds ratios, and 95% confidence intervals of the scaled odds ratios are also provided.

		Standard	95 % Esti	CI of mate		95 %	CI of OR	unit	scaled	scaled
Parameter	Estimate	Error	LCL	UCL	OR	LCL	UCL	change	estimator	OR
Intercept	-4.492	2.316	-9.033	0.048	—	—	—	—	—	—
Velocity	2.309	6.774	-10.967	15.586	10.068	0.000	5.9x10 ⁶	0.100	0.231	1.260
Coarse Substrates	1.865	1.391	-0.862	4.591	6.454	0.422	98.584	0.100	0.186	1.205
Temperature	-2.033	2.063	-6.077	2.010	0.131	0.002	7.463	2.000	-4.067	0.017

	< Upstream								Unit Number						Downstream >											
Species	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	% Units
Moxostoma robustum Robust Redhorse	9	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	8
Moxostoma collapsum Notchlip Redhorse	11	2	1	242	225	143	120	148	68	126	74	50	58	28	86	146	148	127	146	111	64	114	71	41	48	100
Minytrema melanops Spotted Sucker	64	57	26	63	57	39	48	32	16	47	12	23	17	13	36	83	76	57	53	39	38	53	142	120	132	100
Scartomyzon rupricartes Striped Jumprock	18	2	0	1	0	0	0	3	4	1	0	0	1	0	2	0	4	0	1	0	0	1	0	0	0	44
Scartomyzon. sp. cf. lachneri Brassy Jumprock	95	2	3	13	21	32	15	13	26	15	8	5	12	6	12	5	7	6	6	8	4	8	1	0	0	92
<i>Carpioides spp.</i> Carpsucker spp.	0	0	0	2	0	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	12

Table 10. Total number of captures for each species, and the percentage of sites where each species was captured during all four sampling seasons in 2010 and 2011 withing the upper Ocmulgee River project site. Note: the verticle line represents the 9 km portion of river unable to be accessed by electrofishing boats.

FIGURES



Figure 1. Schematic of the robust design, where a sampling unit is either occupied (Ψ) or unoccupied (1- Ψ). Between seasons the species can either persist (1- ϵ), remain absent (1- γ), or the species can colonize (γ) the unit or become locally extinct (ϵ) from a sampling unit from one season to the next.



Figure 2. Reaches stratified into 25 sampling units (sites) bases on local habitat characteristics such as water velocity, substrate composition, and available habitat. Each mark represents the upstream or downstream boundary of a sampling unit in 2010 and 2011.



Figure 3. The proportion of coarse substrates occupying the streambed (solid line) and the quantity of woody structure (dotted line) throughout each sampling unit on the upper Ocmulgee River in 2010 and 2011, starting upstream at Unit 1 and ending downstream at Unit 25. Note the dashed line through the x-axis represents the 9 km portion of river inaccessible to sonar and electrofishing boats.



Figure 4. Total number of captures for robust redhorse *Moxostoma robustum* (solid black), notchlip redhorse *Mo. collapsum* (white with dots), spotted sucker *Minytrema melanops* (thin dark lines), striped jumprock *Scartomyzon rupriscartes* (black with white dots), and brassy jumprock *Sc. sp. cf. lachneri* (thick black bands) in each sampling unit in the upper Ocmulgee River study site in 2010 and 2011. Note: the dashed vertical line on the x axis represents the 9 km portion of river inaccessible to electrofishing boats.



Figure 5. Robust redhorse male captured on an aggregation in shoals immediately below Lloyd Shoals Dam on the Ocmulgee River in April 2011; note damaged anal and dorsal fins, and missing scales and absence of slime coat.



Figure 6. Graphic displaying how sampling intensity (electrofishing effort per river kilometer) was much higher in shoal units (left) than in lateral scour units (right) in the Upper Ocmulgee River, 2010-2011. Yellow lines and arrows indicate a potential electrofishing path.



Figure 7. Typical habitat containing large amounts of woody debris seen on the majority of the Ocmulgee River between Nelson Island and the confluence of the Towaliga River, 2010-2011.



Figure 8. Upstream and Downstream views of the same location of the where most robust redhorse captures took place on the Ocmulgee River in 2010 and 2011. Shoals remained exposed or stagnant during the majority of the year (as pictured), and were only under water during large discharge events from Lloyd Shoals Dam.