Conservation and Restoration of the Robust Redhorse *Moxostoma robustum* in the Oconee River, Georgia

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TABLE OF CONTENTS

1. Introduction

This report is the eighth report in a series of bi-annual reports required by the Federal Energy Regulatory Commission (FERC) license for Georgia Power Company's (GPC) Sinclair Hydroelectric Project (FERC No. 1951). Article 404 of the Sinclair Project license, issued by the FERC on 19 March 1996 (effective date 1 May 1996), requires the submission of a progress report every two years to the FERC, "*which summarizes the status of the robust redhorse and makes a determination on the adequacy of flow releases in meeting the needs of this species*."

This reporting period begins in March 2011 and continues through February 2013. The format of this report follows that of *Volume 7* with greater emphasis placed on recent activities over previously documented and reported work. More thorough discussions of activities towards robust redhorse conservation can be found in previous volumes and in information maintained at the RRCC website, www.robustredhorse.com.

The material for this report was gathered from many sources, including complete and incomplete project reports, RRCC updates, letters, personal communications, and oral presentations.

1.1 Sinclair Hydroelectric Project

Sinclair Dam, a 45 megawatt hydroelectric project owned and operated by GPC, was completed in 1952 on the Oconee River near Milledgeville, GA. The dam forms the 15,330 acre Lake Sinclair, a popular fishing and recreation destination in central Georgia (Figure 1). The Sinclair Project is primarily used to provide generation capacity during peak demand periods, and it serves as the lower reservoir for Georgia Power's Wallace Dam pumped storage project.

During the early stages of FERC relicensing in 1991, a rare fish was "rediscovered" in the Oconee River downstream of the Sinclair Project. The fish was eventually identified as the robust redhorse (*Moxostoma robustum*) by several ichthyologists.

Figure 1. State of Georgia showing the location of GPC's Sinclair Hydroelectric Project and major rivers within the Georgia portion of the historic range for the robust redhorse.

1.2 Robust Redhorse (*Moxostoma robustum*)

The robust redhorse was originally described in 1870 by Edward Cope from specimens collected in the Yadkin River, NC. Unfortunately, Cope's original specimens were lost, and labels from those specimens were mistakenly applied to another species. Over the next 100 years, the robust redhorse was known by only two specimens, collected from the Savannah River, Georgia/South Carolina in 1980 and from the Pee Dee River, North Carolina in 1985. Those two specimens were believed to belong to an undescribed species of redhorse. The discovery of the Oconee River population of robust redhorse helped to clarify the description of this species.

In August 1991, biologists from the Georgia Department of Natural Resources (GA-DNR) collected five large suckers from the Oconee River downstream of Sinclair Dam. Several well-known ichthyologists including Dr. Henry Bart (then curator of the Auburn University fish collection), Dr. Byron Freeman, curator of the University of Georgia (UGA) fish collection, and Dr. Robert Jenkins of Roanoke College, Virginia, worked to identify the specimens. They concluded the five specimens from the Oconee River were the same species as the two existing specimens collected in 1980 and 1985, and all these specimens belonged to the species originally described by Cope in 1870. The currently accepted historic range consists of southeastern Atlantic slope rivers, extending from the

Altamaha River system in Georgia to the Pee Dee River system in North and South Carolina.

Subsequent reviews of available information by many agencies and individuals suggested that conservation and restoration actions should begin immediately for this species. Part of the concern centered on the lack of other records for the species, which potentially indicated that a sole remnant population had been rediscovered in the Oconee River. Another concern was that fish collections from the Oconee River showed a population comprised primarily of larger individuals (all greater than 400 mm TL), prompting concerns about a senescing population or some other problems that might be affecting recruitment of robust redhorse. The concerns included artificial flows from power generation, erosion and siltation, and introduced predatory species such as flathead catfish.

In 2010, the Center for Biological Diversity (CBD) submitted a citizen's petition to the FWS for listing consideration of 404 Southeastern Aquatic Species (http://www.biologicaldiversity.org/programs/biodiversity/1000_species/the_southeast_freshwater_extinction_crisis/index.html). Among those species included in the petition was the robust redhorse. CBD's in-house assessment of the status of robust redhorse was largely informed by NatureServe online data, miscellaneous reports and meeting notes from the RRCC website, and earlier volumes of this report. CBD asserted in its petition that dams, dredging/straightening, and land use have and continue to destroy suitable habitat, that historical overfishing may have occurred, that predation potential is likely high due to the introduction of nonnative piscivores, and that state listing designations are inadequate to fully protect the species. The Center went on to say that while actions by the RRCC MOU signatories to recover the species are to be applauded, the MOU and RRCC lack the requisite regulatory protection to ensure conservation of the species. It is also noteworthy that the Center's petition does acknowledge the existence of the Ocmulgee CCAA, but discounts the ability of that agreement to provide adequate protections to the species given the continued degradation of habitat across the species range. Furthermore, the petition fails to acknowledge any FERC related compliance obligations of RRCC members (such as this report and flow augmentation for robust redhorse at Sinclair) and any ongoing FERC relicensing project activities with other facilities or entities designed to accommodate and enhance robust redhorse recovery activities.

In response to this and several other petitions, the FWS agreed to a settlement with CBD which sets a rough timetable for consideration and listing decision for the species contained in the petition. FWS has agreed to publish annual timelines updating activities toward listing review for these species and has agreed to prioritize their process such that those species who were already candidates would be considered first, followed by non-candidate species. Since robust redhorse was not considered a candidate species as of 2010, the FWS will defer listing determination until at least 2016, although their information gathering process is ongoing.

As a result of this petition and subsequent new listing review, the RRCC has embarked upon a major revision and update to our website which includes updating information, reports, meeting minutes and presentations. While very much a work in progress, we invite the Commission to engage that resource or any of the RRCC partners for additional information beyond that which is included in this report.

1.3 Robust Redhorse Conservation Committee

The RRCC was formed by the signing of a Memorandum of Understanding (MOU) in 1995. The RRCC was designed as a stakeholder partnership to restore the robust redhorse throughout its currently accepted former range. The primary goals of the RRCC are to implement research and conservation measures, enhance recruitment in existing populations, and re-establish robust redhorse populations in appropriate river systems within the species' former range.

The RRCC directs recovery efforts for the robust redhorse and sets priorities for necessary research and action building on previous results. Through collaborative information and resource sharing among members and other interested parties, the RRCC has identified potential threats to the species, conducted research related to those threats, and formulated solutions and implemented conservation actions. The RRCC has also been very effective in publicizing the recovery effort. As originally intended, the RRCC has been the driving force behind the conservation and restoration of the robust redhorse.

Mr. Ryan Heise of North Carolina Wildlife Resources Commission served as the 8th Chair of the RRCC from October 2010 through October 2012. Alice Lawrence of the US Fish and wildlife Service is the current Chair and will serve in that capacity through 2014. While some individual representatives have changed, member organizations comprising the Executive Committee (Excom) have remained the same since 2005. Those members include the Georgia Department of Natural Resources (GA DNR), South Carolina Department of Natural Resources (SC DNR), North Carolina Wildlife Resources Commission (NC WRC), US Fish and Wildlife Service (USFWS), United States Geological Survey (USGS), Georgia Power Company (GPC), Duke Energy, Progress Energy and representatives from Academia among others.

Memorandum of Understanding

The MOU's purpose is to establish and describe the RRCC. The first MOU was approved in 1995 and expired December 31, 2004. The MOU was revised, became effective Jan 1, 2005, and again expired December 31, 2009. The current operating version of the MOU became effective on January 1, 2010 and expires December 31, 2015. No changes to the MOU have been made since the 2005 revision.

Robust Redhorse Conservation Strategy

The Robust Redhorse Conservation Strategy (Strategy) describes the extent of knowledge of robust redhorse and its distribution, discusses problems facing the species, and lists specific goals and objectives for robust redhorse conservation throughout its historic range. The Strategy also outlines procedures and actions believed necessary to reach those conservation goals and objectives. The Strategy is intended to be a flexible document and the RRCC may revise the Strategy as new information becomes available. No changes to the Conservation Strategy have been made since its approval in 2003.

Robust Redhorse Conservation Committee: Policies

The RRCC has developed a policy document, adopted October 18, 2002, which unifies practices and activities of member organizations needed to implement the long- and short-term goals established in the Strategy. These policies also provide a framework for the development of individual management plans for specific robust redhorse populations. In general, the policies are organized such that consistency among goals, conservation activities, and administration of the RRCC are maintained at all levels.

1.4 Candidate Conservation Agreement with Assurances for the Robust Redhorse: Ocmulgee River, Georgia

One of the primary stated goals for the RRCC is to create additional populations of robust redhorse by introducing the species to rivers within its historic range. In many cases, reintroduction can be successfully accomplished without incident. However, the RRCC recognized that reintroducing a rare species with potential to require future listing under the Endangered Species Act (ESA) could be problematic. In this case, the RRCC needed a sound approach for effectively handling one of the most critical components of the conservation effort.

One approach, published by the USFWS in 1999 (64 Federal Register 32726-32736 and 50 C.F.R. §§ 13 and 17), was the use of Candidate Conservation Agreements with Assurances (CCAA). CCAAs promote conservation actions by encouraging partnerships between private entities and state and federal natural resources agencies to protest rare species with the goal of addressing potential threats to their survival. Voluntary participants in such agreements may receive assurances from the USFWS that limit risk, should the target species of that agreement become listed under the ESA.

The Ocmulgee River, a candidate site for reintroduction, provided an opportunity for applying the CCAA policy. The upper reaches of the Ocmulgee River are influenced by generation from GPC's Lloyd Shoals Hydroelectric facility, which has a 30-year FERC license expiring January 1, 2024. During relicensing, minimum flow was increased to enhance aquatic habitat, and a labyrinth weir was constructed to improve dissolved oxygen concentrations in the river. GA DNR, USFWS, and the RRCC determined that the 18 mile reach downstream of Lloyd Shoals Dam was suitable habitat for a proposed reintroduction. Since that time, the weir has been removed adding habitat and connectivity within the dam tailrace, and water quality has been greatly improved with the installation of passage aeration devices in penstock draft tubes.

GPC has invested considerable time and dollars on environmental enhancements to the upper Ocmulgee River and believed these enhancements would also benefit any potential robust redhorse population. However, GPC also believed that a reintroduction of robust redhorse potentially represented an undefined risk to the Lloyd Shoals facility, if the species was federally listed under the ESA. GPC expressed these concerns to GA DNR and the USFWS, and those discussions ultimately led to a CCAA for the robust redhorse (Candidate Conservation Agreement with Assurances for the Robust Redhorse (*Moxostoma robustum*), Ocmulgee River, Georgia, 2001).

Under the CCAA, GPC agreed to support specific conservation actions following introduction by the Georgia DNR, including funding for telemetry studies on the reintroduced fish, surveys, and population estimates. In return, GPC received assurances that if the robust redhorse is listed under the ESA, and the CCAA has been implemented in good faith by GPC, the USFWS will not require additional land, water, or resource restrictions beyond those that GPC voluntarily committed to under the terms of the original agreement. These assurances include the preservation of the flow regime described in the current FERC license for the Lloyd Shoals Project. The assurances are provided through an Enhancement of Survival Permit which will take effect if and when the robust redhorse is federally listed under the ESA.

This CCAA is important because it provides additional conservation actions for the robust redhorse while providing some regulatory certainty and operational flexibility to GPC. However, the CCAA might be more important to the overall conservation effort because it provides a working example of how potential reintroductions can be structured as a cooperative effort to benefit the species. It is believed that this CCAA for the robust redhorse was the second CCAA implemented in the United States. It was also the first CCAA to involve an aquatic species and a private company.

1.5 Flow Advisory Team for the Oconee River

The Flow Advisory Team for the Oconee River (Advisory Team) is implemented under Article 404 of the Sinclair license. The current members of the Advisory Team are the GA-DNR, GPC, Georgia Wildlife Federation (GWF), USFWS, and USGS. The primary responsibilities of the Advisory Team are to monitor the effectiveness of the negotiated flows for the Sinclair Project for the robust redhorse in the Oconee River. The agreement provides that the Advisory Team reviews flow data from the Oconee River, studies developed by the RRCC, and other pertinent information related to the robust redhorse to help determine if any changes to the negotiated flow agreement are necessary. If studies suggest that flow changes are needed for the Oconee River to improve habitat for the robust redhorse, the Advisory Team may petition the FERC, under consensus of members, with its recommendations. These recommendations would then be subject to appropriate FERC evaluation and approval.

Negotiated Flow Agreement
A negotiated flow agreement was finalized in 1995 (implemented June 1996) prior to the submittal of the license application for the Sinclair Project. The negotiated flow agreement, outlined in Table 1 below, was designed primarily to enhance reproductive success of the robust redhorse. Specifically, the flow agreement provides: 1) significant increases in minimum flows throughout the year, 2) a significant increase in flow stability throughout the year, and 3) run-of-river flows during spawning and early rearing periods for robust redhorse. Although primarily directed at robust redhorse, anadromous species

were also considered during the formation of the flow agreement. The effects of this flow regime are discussed further below.

Table 1 Negotiated flow agreement for the Sinclair Hydroelectric Project.

MONTH	FLOW	OPERATION
Dec - Feb	500 cfs minimum	normal peaking
Mar - Apr	1500 cfs minimum	modified peaking[a]
May	run-of-river	
Jun[b] - Nov	700 cfs minimum	normal peaking

[a] modified peaking refers to the number of units (1 or 2) utilized, depending on inflow into the reservoir
[b] from June 1-10, units are operated run-of-river unless electric system demands necessitate normal peaking operation. The agreement also provides for an increase in generation (from 5 to 7 days per week) to reduce extended low-flow periods that previously resulted from little weekend generation.

2. Current Rangewide Species Status

Currently, robust redhorse populations exist in the Oconee, Ocmulgee, Ogeechee, and Broad Rivers, Georgia; in the Savannah River, Georgia and South Carolina; in the Broad and Wateree Rivers, South Carolina; and in the Pee Dee River drainage, North and South Carolina (Figure 2). The Oconee, Savannah, and Pee Dee populations are native, while the remaining five are introduced.

Below, I generalize the current status of these robust redhorse populations based on the summary information compiled and published by the RRCC as its annual reports. The reports themselves are contained as Appendices 1 and 2 for project years 2011 and 2012 respectively. In 2012, the final report for a telemetry study described conducted on the Oconee River from 2008-10 (described in detail previously in Volume 7) was completed and is included as Appendix 3.

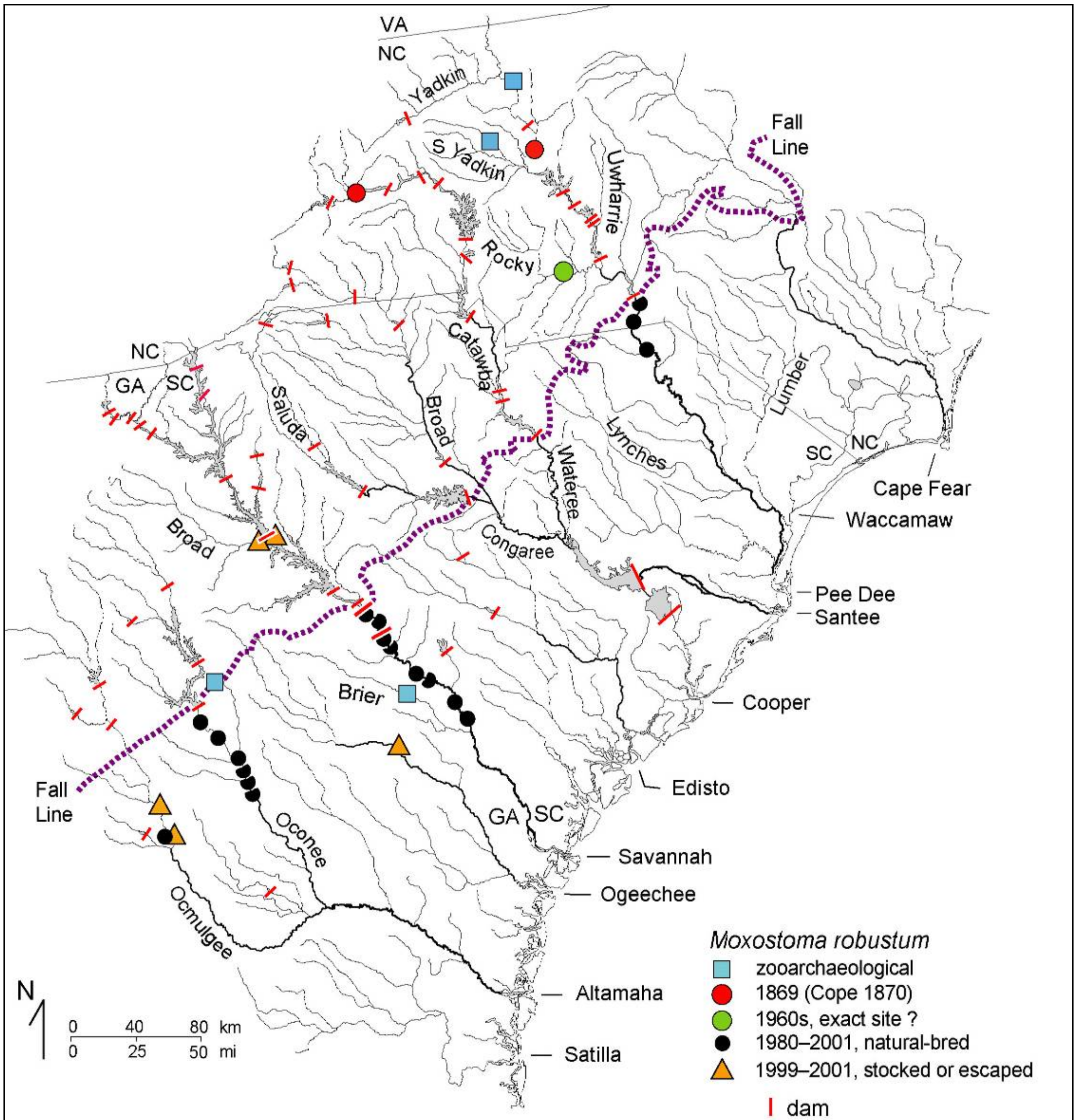

Fig. 00. Robust redhorse records of natural-bred fish (squares and circles); and of artifically-bred fish (triangles) captured after stocking or escape from rearing ponds. Dams shown mainly for larger streams (south of Cape Fear drainage). Savannah R. sites of the 4 record symbols crossed by dam symbols are below respective dams. Fall Line drawn from Anonymous (1963a–c) and Harris and Zullo (1991). Oconee R. detail in Fig. 00; hypothetical total range in Fig. 00.

Map by R. E. Jenkins, B. J. Freeman, and J. W. Evans (Dec 2001)

Figure 2. Map of the current range of robust redhorse in Georgia, South Carolina, and North Carolina.

2.1 Oconee River Population (GA)

Most information on the status of the Oconee River population is based on selective electro-fishing along a 30 river mile section during spring broodfish collection from 1994 to 2010. During broodfish collection and other studies on the Oconee River between 2002 and 2008, catch rates of adult fish decreased from previous years, and no juveniles or young-of-year were collected. Since 2008, sampling surveys have failed to collect any robust redhorse in the Oconee River below Sinclair Dam. While the Sinclair Dam licensed flow regime was designed for the benefit of robust redhorse and other aquatic species, the continued decline following flow implementation likely indicates that other factors have been affecting the population such as competition or predation by invasive species and possibly deterioration of certain habitats.

In 2012, the effort was expanded to include sampling areas above Sinclair Dam in order to determine if robust redhorse or suitable habitat might be present. During an electrofishing survey in the Little River just upstream of the Lake Sinclair impoundment, GADNR collected a single female robust redhorse in what has been described as near spawning condition. While the origin of that individual is unclear, this collection did expand the known and accessible range of the robust redhorse in the Oconee River to above Sinclair Dam. Future surveys are planned for other areas of the Lake Sinclair watershed as well as areas upstream of Wallace Dam into the headwaters of the Oconee River. A more in depth discussion of the Oconee River population status is included below in Section 3.

2.2 Ocmulgee River Population (GA)

As a component of the Ocmulgee CCAA between GPC and USFWS, the USGS Coop Unit at the University of Georgia was contracted in 2010 to conduct a study aimed at designing a technique to estimate population size of adult robust redhorse in the Ocmulgee River. From 2010 through early 2013, that study was ongoing, and while preliminary results are available, the final report written as a Master's student thesis is still undergoing final review at the time of this writing. Preliminary results from the study however indicate that robust redhorse in the Ocmulgee River tended to favor higher flow velocity areas with course substrates in contrast to the Oconee and Ogeechee populations who are typically associated with woody structure. The study has also hypothesized that capture probability may in fact be higher than suggested in previous research; however that higher capture probability is correlated with relatively low occupancy rates in areas accessible to sampling. Since the Ocmulgee contains several long stretches of higher velocity, course substrate habitats that are inaccessible to electrofishing, the model assumes occupancy in those areas at similar rates to those sites nearer Lloyd Shoals Dam with similar physical attributes and where sampling has been conducted and typically yields robust redhorse in small and often variable numbers. It is anticipated that while the application of this technique for future population estimation seems promising, the final report will likely fall short of being able to provide a useful population estimate due to the extremely low sample sizes in field collections coupled with the wide expanses of inaccessible water to sample.

Due to the intensive nature of sample collection activities conducted by USGS on the Ocmulgee River in 2011 and 2012, no additional surveys or studies were undertaken during that timeframe. While catch rates were not sufficient to yield a reliable population estimate, adult robust redhorse were collected in the stocked reach, indicating some unknown level of population has been established.

2.3 Broad, Wateree, and Savannah River Populations (SC)

South Carolina's efforts have involved stocking fingerlings from Savannah River-strain broodstock. South Carolina has stocked the Broad River, SC every year since 2004 (over 50,000 fingerlings stocked to date) and the Wateree River every year since 2005 (over 15,000 fingerling and advanced fingerlings stocked to date. All fish were either tagged with coded-wire tags or P.I.T. tags, and mature fish of hatchery origin have been collected in both rivers. The goal for these stockings was to introduce progeny from 100 reproducing pairs. Through 2009, offspring from 98 individual crossings had been produced. In 2010, an additional 17 individual crosses produced over 25,000 larvae, but harvest of hatchery rearing ponds was extremely low. In order to achieve the target 100 individual crosses, SCDNR will continue hatchery production into 2012. Once the 100 crosses target is met, all activities will shift to an "evaluation" period and future stocking will be either postponed or terminated.

SCDNR has also initiated sonic tagging of robust redhorse captured below Wateree Dam, and through 2011, eight individuals were fitted with sonic transmitters and have returned to the Wateree during spring each year. Also, six of the tagged fish moved great distances, ascending the Congaree River in late spring 2011. A migration distance of 124km in 2.6 days has been recorded with one individual, and 30km/day or more has been common among other tagged individuals.

Since first introduced into the Wateree River, SC, in 2005, collections of robust redhorse have steadily increased each spring. Electrofishing efforts for diadromous fish below the Wateree Dam each spring have noted increasing numbers and sizes of robust redhorse. The maximum size of robust redhorse, the number of fish, and the number of sexually mature fish have increased each spring. The collections indicate that the SCDNR’s relocation effort has been initially very successfully. While triads of mature adults have been collected during spring in the Wateree River, at this time, no wild juveniles have been collected (Dave Coughlan, Duke Energy, personal communication, March 2011). While low in annual number, robust redhorse have been collected at the base of Wateree Dam annually since stocking began, and Duke Energy data show that the annually increasing trend in total length and weight continues.

2.4 Yadkin/Pee Dee River Population (NC)

The North Carolina Wildlife Resources Commission and Duke Energy (formerly Progress Energy) have a flow agreement providing increased minimum flows below Blewett Falls Dam in the Pee Dee River, and implementation of the flow agreement began in 2012 ahead of the anticipated 2013 license issuance. As such, population level monitoring for robust redhorse has been suspended for four to five years allowing the robust redhorse population time to respond to the new flow regime.

NCWRC has also begun the pursuit of a long-term hatchery program to propagate robust redhorse at McKinney Lake Fish Hatchery to produce fish for stocking above Blewitt

Falls Dam as well as downstream of Tillery Dam or in the Pee Dee River.

2.5 Broad River Population (GA)

Four year classes (n = 32,189) were stocked in the Broad River, GA, between 1995 and 1998 from the Oconee River stock. Although populations are not expected to mix due to Clark Hill Reservoir, stocking halted after the incidental collection of a single robust redhorse from the native Savannah River population in October 1998. At present, the population in the Broad River (GA) is stable.
A telemetry study was conducted in the Broad by Dr. Bud Freeman at the University of Georgia beginning in 2010 through 2012. Preliminary results of that study show that individuals from the Broad River population largely spent their winter and non-spawning seasons in or near Clarks Hill Reservoir. In the spring however, fish moved into suspected spawning shoals higher upstream in the Broad River watershed, with some individuals moving as much as 55 km from the reservoir upstream to suspected spawning sites.

Over a slightly longer time period, 2007 through 2012, five spawning locations were identified and studied in the Broad River. Preliminary data from these sites indicates that spawning in the Broad occurs at an average temperature of approximately 22 C (range 19-26C), at a depth of approximately 0.4m, at a surface flow velocity of 0.27m/s, and over course substrate measuring from 12.5 to 50mm in diameter. While spawning had been documented among these sites annually since 2007, efforts to collect juvenile robust redhorse in the Broad River have only yielded other sucker species.

2.6 Ogeechee River Population (GA)

A total of 43,048 robust redhorse from 7 year classes were stocked into the Ogeechee River through 2010. In late-2010, a telemetry study began in the Ogeechee to determine habitat use and spawning site selection by the recently created population. Through 2011, 19 robust redhorse had been collected and tagged in the Ogeechee…11 short of the 30 fish goal set for the project.

3. Status of the Oconee River Population through 2012

The Oconee River robust redhorse population has been sampled extensively since 1991. In general, sampling strategies have been diverse in nature and technique, and have targeted various life stages and numerous habitat types within the system. Some of the most rigorous sampling efforts have targeted adult robust redhorse during their spawning aggregation and subsequent migrations to known spawning areas within the river. Other sampling surveys have been conducted in proposed spawning locations (i.e. in locations where suitable gravel substrate and flow velocities exist for spawning activity), in meander/bend sections of river where studies have suggested that robust redhorse preferred habitats exist (i.e., outside bends and pools associated with moderate flows and woody debris), and in various other habitats where surrogate species studies and laboratory experimentation has suggested that the species might reside. With these studies, numerous datasets have been developed, and results from those data have been highly variable.

The two most consistent long-term datasets for analysis of adult population status have resulted from broodfish collection for propagation activities and exploratory monitoring surveys designed to identify additional spawning aggregates or spawning locations. While targeted collections at known spawning sites were highly productive at the onset of species monitoring, collections of adult robust redhorse at those sites has steadily declined over time. Causes of this decline are unclear, but several hypotheses seem to fit. The first hypothesis is that the adult robust redhorse population originally sampled in abundance in the early 1990's was senescing, and recruitment of juveniles was slow or nonexistent. Another potential cause of the decline is a shift in spawning location driven by either repeated sampling/handling at known sites, change of the known sites to a point where they no longer supported large-scale spawning activities, or shifts in preferred locations due to changes in flow (including changes in flow regime related to drought). Instream flow conditions in the Oconee River might also have led to the apparent decline in spawning aggregate abundance at known sites, since the population was relatively stable prior to the flow change and has clearly declined since the implementation of the current flow regime in 1995 (Figure 3). Flathead catfish abundances within the Altamaha Basin have also steadily increased since their discovery in the system in 1970's, and with their increase comes increased predation potential above and beyond that of the existing predator community. Any or all of these factors, coupled with numerous years of excessive drought, may have ultimately led to the continued decline in adult robust redhorse collections at known spawning sites.

For long-term monitoring purposes, targeted broodfish/spawning adult collections and the resulting data may be somewhat biased in that only those fish actively spawning or moving onto the spawning bar are collected and included. Those targeted collections might also be misleading if flows change resulting in missed spawning cues or if the condition of the known spawning sites becomes degraded over time. Spawning site collections also may not incorporate suitable effort, gears, or location for collecting non-spawning or lesser dominant individuals. To best understand the status of the population in its entirety, the right combination of gear type(s), sampling location(s), and seasonality must be achieved. To that end, we have analyzed data from the Oconee River collected during monitoring and exploratory surveys, generally using consistent methods (i.e. electrofishing gears and techniques), and collected during Spring of each year to address the current status of the population, provide context for future management, provide insight on enhancing the monitoring program, and set up a long-term database from which causation of the population's apparent decline can be addressed.

Current Status

As reported in the previous volume of this report, the Oconee TWG proposed to place emphasis on the following objectives or tasks beginning in 2011:

1. GADNR standardized spring electrofishing sampling from the Avant Kaolin Mine to the mouth of Black Creek.
2. Monitor robust redhorse use of gravel augmentation sites
    a. Periodic visual observations for spawning activity
    b. Audible observations using hydrophones
    c. Collection, identification, and enumeration of larvae
3. Sample upper reaches of the Oconee River upstream of Wallace Dam/Lake Oconee

Unfortunately, no robust redhorse have been collected or observed in the Oconee River downstream of Sinclair Dam since 2008 despite continued efforts in both 2011 and 2012. While sampling effort has been curtailed in recent years compared to the amount of effort exerted in the late 1990's and early 2000's, sufficient effort under adequate flow regimes, and during the appropriate timeframe has been spent to produce robust redhorse if they still exist in the system in suitable numbers. Additionally, the collection effort added at artificial gravel augmentation sites has yielded no robust redhorse through either visual, audible, or electrofishing methodologies.

GADNR also conducted sampling in the upper reaches of tributaries to Lake Sinclair as well as upstream of Wallace Dam on the mainstem Oconee River during 2012 pursuant to item #3 above. Those surveys were conducted over the course of approximately 10 days, with four sampling segments per stream. In total, they sampled 2.1 miles of Little River, 1.3 miles of Murder Creek, and 10.7 miles of the mainstem Oconee River, and water temperatures during the survey varied from 14.1 to 24.5C. While no robust redhorse were collected in either Murder Creek of the upper Oconee River, a lone ripe female was collected just upstream of the Sinclair impoundment in Little River. Physiological evaluation by the collectors suggested that the individual was ripe and only a few days from spawning. Given the approximate location of collection and the proximity of that sampling location to a gravel/shoal area just upstream of the site, it was assumed that she was in a pre-spawn staging location, and that the gravel/shoal area is a viable potential spawning site. Further evaluation of that site is pending.

What is unclear from the collection of a ripe female robust redhorse in Little River in 2012 is the origin of that lone specimen. Little River is the ultimate receiving stream for escapees from Walton State Fish Hatchery, a facility charge with raising robust redhorse in the past. A scale taken from the captured individual was roughly aged to approximately 18 years of age, which may correspond to a 1995 dam failure and unintentional/uncontrolled stocking event into a nearby stream from Walton Hatchery. Unfortunately, there are no definitive marks or tags to identify the origin of that specimen, therefore the possibility remains that this individual is from an isolated, fragmented population that survived entirely bound within the Lake Sinclair watershed between Sinclair and Wallace Dams. Further, and more intensive collections are planned for subsequent years in hopes of better informing our knowledge of what population may exist in Lake Sinclair or its tributaries.

4. Flow Suitability for Oconee River Robust Redhorse

The Sinclair Flow Advisory Team has been discussing the adequacy of existing flows at Sinclair Dam relative to the robust redhorse population since its inception. In recent years however, no robust redhorse have been collected in the Oconee River, perhaps indicating that flow modification is the not the main cause of population level declines of the species. The reality of fewer robust redhorse collections, coupled with the documented ineffectiveness of sampling gears as described in previous studies (and outlined in greater detail in previous volumes), has led to the need to make management decision based on data from surrogate species.

For example, robust redhorse as well as other sucker species are known to reproduce in current over cobble/gravel substrates. As a result of surveys showing fewer gravel deposits of suitable type in the river, a gravel augmentation project was enacted by GADNR in an attempt to increase suitable spawning habitat. While only a few years removed from this augmentation project, preliminary results are positive that spawning habitat for robust redhorse has been increased due to colonization and use of these artificial gravel bars by other species. Monitoring of gravel sites is slated to continue for the foreseeable future in hopes of documenting use by surrogate sucker species and perhaps even robust redhorse.

From 2005-2009, a series of surveys were conducted on larval fishes within the Oconee River, and larval fish production was compared to various flow characteristics. Through a complex set of analyses and statistical modeling exercises, it was suggested that larval production of other species of Moxostoma was increased in years with at least 14-days of run-of-river flows during June. Under the existing license regime, only 10 days of run-of-river flows are prescribed (June 1-10), although instream conditions have resulted in several instances of de facto run-of-river flows extending beyond the June 10 date. Based on these data (as described in greater detail in the Peterson et al. 2009 report; Appendix XX), the Sinclair Flow Advisory Team is evaluating and preparing a request for May run-of-river flows to extend annually to June 14 (rather than June 10) unless electric system demands necessitate normal peaking operations during the June 1-14 time period. While the addition of only four days to the existing June flow scenario may seem some insignificant, the association between strong sucker year-classes and 14 days of low steady June flows was strong.

Unfortunately, what this does not account for is the reality that while a 14 day low steady flow period may benefit Moxostoma and presumably robust redhorse larvae, we have no indication in recent data that any adults still exist to produce those larvae. It is also unclear how increased predation pressures will affect recruitment, regardless of gains in larval fish abundance if the flow modifications actually do work.

Given that uncertainty, it is my suggestion that the operational and economic costs of such a continuation of flow modifications be identified and thoughtfully considered prior to adoption of any further robust redhorse related flow modification scenario. While there is no good way to make a quantitative economic or operational flexibility comparison versus ecological benefit to a rare species such as robust redhorse, I think it seems reasonable to weigh the economic cost of continued and more restrictive modifications through qualitative comparison to the expected value by our partner resource agencies.

6. Future Directions for Oconee River Robust Redhorse Conservation

Understanding the causes of the decline in the Oconee River robust redhorse numbers continues to represents the most important future direction for the species' recovery. The robust redhorse population in the Oconee River simply has not responded to the significant effort extended by the cooperators. While dams do modify flows and can change instream habitats, it remains unclear if the existence of Sinclair Dam on the Oconee River played a major role in robust redhorse decline, and the license effort to protect robust redhorse via flow design and augmentation has not produced the anticipated results for the species. In order to truly address causation, other likely impacts must be studied and rectified.

A number of other factors exist that have only been explored at a cursory level (if at all) including the introduction of exotic species, changes in land use, and development of other industries within the watershed. Flathead catfish for example are introduced to the Altamaha basin and have been shown to restructure fish communities through predation, especially catastomid assemblages (citation). Other invasive species like common carp or other introduced cyprinids can disrupt spawning of native species and prey upon fertilized eggs and/or larvae (citation). More recent studies of robust redhorse diet preferences indicate an affinity for the invasive Asiatic clam, but it is unclear if shifting to a diet comprised almost entirely of invasive species has any impact on individual fitness and subsequent reproductive success. There may also be complex interactions among native and non-native species and other environmental factor that have led to the decline. Future efforts within the Oconee River must include characterizing the impacts of invasive species, exploring possible mechanisms to prevent the further spread of invasives, and evaluation of possible control measures for those invasives that already exist.

Until it is fully understood what biotic or abiotic conditions are precluding successful recruitment of robust redhorse in the Oconee, habitat research and restoration activities must continue. Restoration activities will likely be sporadic in the foreseeable future, but study of current project success should guide those future efforts. Also, with the institution of the National Fish Habitat Initiative and resulting partnerships, like the Southeastern Aquatic Resource Partnership (SARP), new funding may be available for further habitat enhancement for the benefit of many species in addition to robust redhorse.

Finally, the partnership among members of the Robust Redhorse Conservation Committee will continue to guide robust redhorse conservation efforts throughout its range. Each year, the committee recaps lessons learned through management and research, and refocuses on steps for the following year or years. The Oconee River robust redhorse population is of the highest priority with the Committee, and restoring the population of robust redhorse within the river is among its highest goals.

Appendix 1

REPORT OF THE

ROBUST REDHORSE CONSERVATION COMMITTEE ANNUAL MEETING

Morrow Mountain State Park
Albemarle, North Carolina
October 3 – 5, 2011

Attendees of the 2011 annual meeting

Report compiled by
Jaclyn Zelko
U.S. Fish & Wildlife Service

T A B L E O F C O N T E N T S

A C R O N Y M S & A B B R E V I A T I O N S

CPLC	Carolina Power and Light Company
CVIOG	Carl Vinson Institute of Government
DPC	Duke Power Company
FERC	Federal Energy Regulatory Commission
GA Coop	University of Georgia Cooperative Fish & Wildlife Resource Unit
GA DNR	Georgia Department of Natural Resources
GPC	Georgia Power Company
GRN	Georgia River Network
GWF	Georgia Wildlife Federation
NC WRC	North Carolina Wildlife Resources Commission
NCS MNS	North Carolina State Museum of Natural Sciences
NYU	New York University
SC Coop	South Carolina Cooperative Fish & Wildlife Research Unit
SC DNR	South Carolina Department of Natural Resources
SCEG	South Carolina Electric and Gas
SCA	South Carolina Aquarium
UGA	University of Georgia
USACOE	U.S. Army Corps of Engineers
USFS	U.S. Forest Service
USFWS	U.S. Fish and Wildlife Service
USGS	U.S. Geological Survey (Biological Resources Division)

FTC	Fish Technology Center
NFH	National Fish Hatchery
SFH	State Fish Hatchery
WMA	Wildlife Management Area

CCAA	Consolidated Conservation Agreement with Assurances for the Ocmulgee River
Excom	Former Technical Advisory Group to the RRCC
GIS	Geographic Information System
IT TWG	Information Technology Technical Working Group
MOU	Memorandum of Understanding
PIT	Passive Integrated Transponder Tags
RRCC	Robust Redhorse Conservation Committee
TAG	Technical Advisory Group
TWG	Technical Working Group

AGR	Artificial genetic refuge
C	Celcius
cfs	Cubic feet per second
cm	Centimeter
g	Gram
kg	Kilogram
km	Kilometer
m	Meter
mg/l	Milligrams per liter
mm	Millimeter
MWe	Megawatts of electrical output
m3/s	Cubic meter per second
N*e*	Effective population size
ppt	Parts per thousand
rkm	River kilometer
RM	River mile
TL	Total length
YC	Year class
YOY	Young of year

E X E C U T I V E   S U M M A R Y

The robust redhorse recovery effort, in its 17th year, encompasses management activities and research and conservation efforts undertaken by members of the Robust Redhorse Conservation Committee (RRCC), university scientists, and other affiliates. The RRCC, established by a Memorandum of Understanding (MOU) signed in 1995, is responsible for developing and managing a recovery approach for the imperiled robust redhorse (*Moxostoma robustum*). The effort and expertise applied to the questions of recovery are brought together at the annual meeting of the RRCC.

The seventeenth annual meeting of the RRCC was held October 3 – 5, 2011 at Morrow Mountain State Park in Albemarle, North Carolina. Approximately 30 representatives of the signatory agencies to the MOU, university research affiliates and other interests attended the meeting. The 13 signatory agencies include: Georgia Department of Natural Resources, South Carolina Department of Natural Resources, North Carolina Wildlife Resources Commission, Georgia Power Company, Progress Energy (formerly Carolina Power and Light Company), Duke Energy, South Carolina Electric and Gas Company, U.S. Fish and Wildlife Service, U.S. Geological Survey, U.S. Forest Service, U.S. Army Corps of Engineers, Georgia Wildlife Federation, and South Carolina Aquarium. University research affiliates include: University of Georgia Warnell School of Forest Resources, University of Georgia Institute of Ecology, University of Georgia Cooperative Fish and Wildlife Research Unit, Roanoke College Department of Biology, University of Georgia Carl Vinson Institute of Government, University of Georgia Department of Genetics, Cornell University Department of Molecular Biology and Genetics, Clemson University Cooperative Fish and Wildlife Research Unit, New York University School of Medicine Institute of Environmental Medicine, and State University of West Georgia. In addition, representatives of other concerns with interest in recovery of the robust redhorse include: Santee Cooper Power Company, Georgia Aquarium, Georgia River Network, and the North Carolina State Museum of Natural Sciences. The success of the recovery effort, to a large extent, depends on the willingness of RRCC members and others to participate in the annual meeting and to continue to support recovery throughout the year.

This report summarizes updates on management activities, research findings, and conservation efforts and decisions made at the 2011 RRCC Annual Meeting. The RRCC Annual Meeting Reports have become important documents of research, science, management, and recovery that are often referred to and cited. The format of this year's report closely follows the format of previous reports and it provides a more accurate record of activities. The report notes discussion points, questions, main ideas, and/or notes recorded by the participants.

I N T R O D U C T I O N

Historically, the robust redhorse (*Moxostoma robustum*) inhabited Atlantic slope drainages from the Pee Dee River system in North Carolina to the Altamaha River system in Georgia. The first scientifically confirmed sighting of robust redhorse since naturalist Edward Cope described the species in 1869 occurred when the fish was re-discovered in the Oconee River in Georgia in 1991. In the Altamaha River drainage, the species is presently known to exist in a relatively short reach of the Oconee River between Sinclair Dam and Dublin, Georgia and in a short upper Coastal Plain section of the Ocmulgee River. Individuals also have been found in the Savannah River (the boundary river between Georgia and South Carolina) in the Augusta Shoals area as well as below the New Savannah River Bluff Lock and Dam. In addition, robust redhorse have been captured in the Pee Dee River below Blewett Falls Dam in North Carolina. Robust redhorse populations have also been reintroduced within their historic range into the Broad and Ocmulgee Rivers, Georgia, as well as the Broad and Wateree Rivers, South Carolina. The robust redhorse appears to inhabit specialized areas of large rivers, which are difficult to sample but regardless of the absence of sightings, small numbers are usually found when species-targeted surveys are conducted.

River impoundments, predation by introduced nonnative species, and significant deterioration of habitat due to sedimentation and water pollution are believed to have contributed to the decline of the species. The complex and diverse problems facing the robust redhorse require an interdisciplinary approach, using a broad spectrum of experience, expertise, and management authority to maintain and restore this imperiled species. In addition, it is essential that recovery efforts include a process that works closely with the private sector as well as government agencies potentially impacted by and interested in robust redhorse conservation.

The Robust Redhorse Conservation Committee (RRCC) was established by a Memorandum Of Understanding (MOU) signed in 1995 to develop and manage a recovery approach for the robust redhorse (*Moxostoma robustum*), previously a Category 2 candidate for Federal listing under the Endangered Species Act. The RRCC is actively committed to the recovery of the imperiled robust redhorse throughout its former range. It identifies priority conservation needs for the robust redhorse and its habitat and coordinates implementation of research and management programs for addressing those needs.

A D M I N I S T R A T I O N

Welcome – Ryan Heise
Ryan welcomed the participants to the 17th Annual robust redhorse meeting. He thanked the sponsors of this year's meeting (NC Wildlife Resources Commission – state wildlife grant program, Duke Energy, SC Aquarium, Progress Energy, and NC State Parks). Ryan introduced Shannon Deaton, NCWRC Habitat Conservation Program Manager, and she welcomed all to the meeting. A presentation was given by J. R. Murr on the history and function of Morrow Mountain State Park.

Memorandum of Understanding Renewal – Ryan Heise
The MOU establishes the RRCC and allows the RRCC to establish operating guidelines. The previous MOU expired at the end of December, 2009. The newest version is valid from January 1, 2010 to December 31, 2014. Revisions made after the 2009 meeting were incorporated and representatives were sent the updated copy. At this time, Ryan has received signatures from all but 2 signatories. Once he receives the final copies, he will send them out to the group.

M A N A G E M E N T   A C T I V I T I E S

Update on the 2011 robust redhorse recovery effort in Georgia – Jimmy Evans
In Georgia the robust redhorse recovery project is in what might be termed Phase III-IV. In general terms, the phases are as follows:
***Phase 1*.** After discovery of the Oconee population, a status assessment was initiated which strongly suggested that potential risks existed to the species in the Oconee.
***Phase II*.** An extensive hatchery program was begun that lasted from 1993 until 2008. Refugial ponds and three rivers, the Ocmulgee, Ogeechee, and Broad, were stocked with numerous year classes. Limited stockings were also made in the Oconee River.
Phase III. This is the monitoring phase that consists of an evaluation of the relative success of the stockings in the three rivers and a continuing effort to monitor the status of the Oconee population.
Phase IV consists of efforts to improve the status of the Oconee population and has occurred concurrently with other phases. It has had four general components to date:

> ***1.*** Implementation of altered flow regimes to improve recruitment success as a result of Sinclair Dam relicensing in 1996. Research has been conducted to evaluate changes in reproduction and recruitment in association with these flow changes.
>
> ***2.*** Limited stockings of fingerlings as well as larger juveniles and adults in the Oconee.
>
> ***3.*** Habitat improvements, primarily in the form of a large gravel augmentation project, to improve spawning habitat at five locations.
>
> ***4.*** Currently we are evaluating flathead catfish predation and attempting to determine the nature and magnitude of that threat, and what if anything can be done to reduce it.

The major challenge remaining in Georgia is to improve the status of the Oconee population. Although all the evidence is not in regarding sustainability, the riverine stockings have to date been largely successful. Although we have implemented significant management actions to improve the status of the Oconee population, we cannot document any resulting improvement, and this remains our most significant challenge.

At present, we have no plans to resume the hatchery program. There appears to be no present requirement for hatchery reared robust redhorse in Georgia, although this may change in the future. Any future stockings would likely involve use of adults collected from stocked rivers. If fingerlings were ever produced again in Georgia, fish from stocked rivers would probably serve as the brood source.

Spring 2011 standardized electrofishing survey on the Oconee River.

One of the major objectives of sampling this spring was to sample the area where most of the relocations of telemetered fish were observed. Since this area was above Black Creek and in the traditional sampling exclusion zone, broodfish sampling may have excluded a significant robust redhorse aggregation area resulting in an underestimation of population size. The other objective was to continue the

standardized robust redhorse monitoring program in the traditional broodfish collection area from the Central of Georgia railroad trestle to the end of the long meander section just above Dublin. These two areas combined represent almost the entire known range of the species in the Oconee River. Sampling was conducted on May 17, 2011 with three crews, one each from the Georgia Department of Natural Resources-Wildlife Resources Division (GADNR-WRD), Georgia Power, and the Georgia Coop Unit. Total distance sampled was about 30 RM and electrofishing effort totaled 10 hrs. Temperature was 22C and sampling conditions were good to excellent. No robust redhorse were observed.

Monitoring of gravel augmentation sites

The Oconee River gravel augmentation project was completed in March 2010 at five sites. Site 1 is located at a traditional spawning area adjacent to the Avant Mine. This site was augmented by placing gravel along the shore above the target site and allowing natural processes to erode the gravel into the channel and onto the target site. This method was marginally successful. Sites 2-5 are located below the Central of Georgia Railroad Trestle and were chosen because hard substrates were present that could anchor the gravel, and they contained the preferred depths and velocities. At sites 2 –5 gravel was loaded onto barges and transported to the sites, then washed off using water pumps. Post-project observations at low flows suggested that suitable sites had been created, varying in quality from fair to excellent, and that the gravel has persisted. Total area augmented was 2.7 acres.

The objective of monitoring was to determine if the augmented sites were being used by robust redhorse as spawning habitat. Bud Freeman and Carrie Straight monitored the traditional gravel spawning site at Avants (Site 1), recently augmented slightly, as well as augmentation sites 2, 3, and 5. The smallest and least accessible Site 4 was not monitored. Monitoring was conducted on May 9, 2011 and methods were visual observations and hydrophone recordings (hydroacoustics). Jimmy Evans also made visual observations at Avants and at 2 of the 4 sites located below the railroad trestle on May 10. Temperature was 23C and conditions for observations good to excellent, however, no robust redhorse were observed.

Implications of monitoring

There are several implications to the absence of any robust redhorse in either the electrofishing survey or in the monitoring of gravel augmentation sites. A thorough discussion of all the implications would require a separate presentation, however it now appears that the population is extremely low throughout the Oconee River from Sinclair Dam to Dublin, and that there are no significant aggregations that have been excluded or overlooked within this area. Within this area the population seems to have declined below the detection point with the resources we have available to sample it. Viable options are to focus sampling on other areas, such as below Dublin or above Lake Sinclair, or to increase sampling effort in the Sinclair Dam to Dublin area, or both. The spring 2012 robust redhorse sampling will focus on the area above Lake Sinclair and in the Oconee River between Lake Oconee and Barnett Shoals Dam.

Other topics

The research being conducted on the Broad, Ogeechee, and Ocmulgee rivers constitutes the majority of the robust redhorse recovery effort in Georgia and these projects have been thoroughly discussed in separate presentations at this meeting. However, several other areas of recovery activity in Georgia should be mentioned as well. First is obviously the recent petition to list the robust redhorse as well as many other species under the ESA. The petition, the U. S. Fish and Wildlife Service (FWS) response, and associated time lines have already been discussed. These developments have implications for all members of the Robust Redhorse Conservation Committee (RRCC). The Georgia Aquarium continues to highlight the recovery project with a display in the Georgia Gallery portion of the facility. We also have robust redhorse displays at the new Go-Fish-Georgia Center in Perry, GA. The juvenile fish that were on display in the jewel tanks died and will have to be replaced with juveniles from the Dennis Wildlife Center, SC. We also have live adult robust redhorse on display with associated species in the Piedmont exhibit, as well as mounted specimens inside the main building.

We are currently engaged in environmental reviews at four projects that have the potential to affect robust redhorse populations in the Ocmulgee, Broad, and Savannah rivers in Georgia. One of these projects is the expansion of a water intake structure at the Macon Water Authority (MWA) water treatment plant just above Macon and downstream of a known robust redhorse spawning site. The natural resource agencies are working with the MWA and the U. S. Army Corps of Engineers (ACOE) to assure that the structure will not cause entrainment/impingement of larval or young-of-the-year robust redhorse. We are also in the final stages of negotiations on the design of a Denil fish ladder at the Juliette Dam between Macon and Lake Jackson. Robust redhorse were stocked above the dam but apparently large numbers passed over and at least two spawning sites exist below the dam. The fish ladder would probably result in some passage of robust redhorse, but the magnitude or significance of passage is unclear and there is some skepticism that the facility will ever be completed. Also, the FWS and the GADNR-WRD are reviewing a wastewater treatment facility in the Broad River drainage and a Savannah River drought flow operations plan. The proposed Plant Washington water intake on the Oconee River at the Avant site remains an important issue as well. The proposed coal-fired power plant is to be located in Sandersville, GA. Water permits have been issued that include various mitigation measures to reduce entrainment/impingement of robust redhorse larvae as well as other species at the water intake structure. The air permits have still not been issued and the project is now far behind schedule, but all indications suggest that the plant will eventually be built.

In the conservation arena, a 90–100 acre ACOE trust fund preservation site has been created on the South Fork of the Broad River near Watson Mill State Park. This preservation site should help improve water quality in the area. Of particular significance is a 7,000 ac wetlands mitigation site that has been created on the Oconee River immediately across and generally downstream of the Avant site. A 500 ac future state park tract on the Oconee River at Balls Ferry has also been purchased, although funds are not now available to develop the area. These efforts combined with gravel augmentation projects on Oconee River demonstrate significant progress in the area of habitat protection and enhancement.

South Carolina 2011 Update – Scott Lamprecht

Carolina Santee Basin Robust Redhorse (RRH) restoration efforts experienced its first production failure in 2010. While fry production was ~25,000, only 200 individuals were harvested in November and all of these were retained for further grow-out. Entering 2011 we have stocked a total of 50,500 phase I fingerlings in our two Broad River restoration sites. The Wateree River site has received 12,601 phase I fingerlings, 2,400 phase II juveniles (age 1+), and 400 phase III juveniles (age 2+). At the beginning of 2011, our goal of using the progeny of 100 parental crossings to restore or re-establish RRH to the Santee Basin had yet to be achieved and remained at 95.

Our 8th annual RRH spawning trip to the Savannah River gravel bar located below Augusta at RK 173.3 (~14.5 Km below Augusta Shoals Lock and Dam), took place on May 12th. Twenty three adults were collected, but only one female. Her meager supply of eggs were divided into 3 parts and fertilized with three different males. Seven of the fish had been previously PIT tagged, with two males having been tagged way back in 2002 (1 floy tag still present, but unreadable). One of these two males has been collected a total of 5 times (02, 04, 05, 06, 11) and the other 3 times (02, 07, 11). Approximately 2,500 fry were stocked out in production ponds that will be harvested in November 2011. Provided survival to harvest is adequate, a total of 98 unique parental crosses have been used to stock fingerlings out in the Santee Drainage restoration sites, indicating a need to continue our spawning effort in 2012.

In addition to the two sonic transmittered RRH initially collected and release in the Wateree Dam Tailwater in 2009, 6 more individuals were similarly equipped in May of 2011. The seasonal movement pattern of the newer study animals corresponded to that of the older specimens. All the study fish occupied the Wateree Tailrace during spawning season, which is not surprising since all were initially collected there in the spring. The two 2009 tagged fish have returned to the Tailrace between 3/26 and 4/15 in both 2010 and 2011. During the three springs these two fish have been monitored, both departed the Tailrace area between 5/14 and 6/13. In 2011, six of the eight study fish ascended the Congaree River between 5/25 and 6/21. Long distance movement of these fish can occur relatively quickly; one fished moved downstream 124 km in 2.6 days and there are numerous instances of fish moving more than 30 km/day.

The number of RRH observed using the Columbia Diversion Dam Fishway (Broad River) continues to grow. The number observed by Jennifer Hand (Kleinschmidt) doubled this year to 26. Extrapolating this number produces a rough estimate of 207 individuals potentially using the ladder during the spring of 2011. Upstream passage was observed from March 22 thru May 17 with temperatures ranging from 16.5 to 24^{o} C. This corresponds to temperatures and timing of adult RRH use of the Wateree Dam Tailrace, which enforces the assumption of the availability of more than one spawning area in the system.

North Carolina 2011 Update – Ryan Heise

The objective of the 2011 field study by the Yadkin-Pee Dee technical working group (TWG) was to continue looking for any additional Robust Redhorse spawning shoals. TWG members tracked radio-tagged robust redhorse in April and May and individuals were only relocated in previously documented spawning areas (Jones Creek and Hitchcock Creek shoals). This highlights the importance of these sensitive areas and we are happy to report that these locations are receiving some protection by ownership of the adjacent riparian lands by RRCC members (NC Wildlife Resources Commission and Progress Energy). Much has been learned about the Pee Dee river population (e.g. habitat use/suitability, migration patterns) since the formation of the TWG (see pervious RRCC annual reports). Currently, robust redhorse are only found downstream from Blewett Falls dam and the TWG is studying the possible reintroduction of robust redhorse upstream of the dam. North Carolina Wildlife Resources Commission with help from Progress Energy has funded a study at North Carolina State University to model the suitable upstream habitats (located downstream of Tillery Dam). In addition, a separate project at NCSU will look at water quality in Pee Dee River. The results of these studies will help determine our reintroduction options for Robust Redhorse.

Wateree River Collections – Dave Coughlan

The Santee Cooper River Basin is 15, 900 m^2 and include the Santee, Cooper, Wateree, Catawba, Congaree, Saluda, and Broad rivers. Phase II fish were first PIT tagged and stocked into the Wateree River in 2005. Additional stockings have taken place in 2006 and 2008 – 2011. Robust redhorse have been collected since then at the base of the Wateree Hydro Tailrace in 2006, 2008 – 2011.

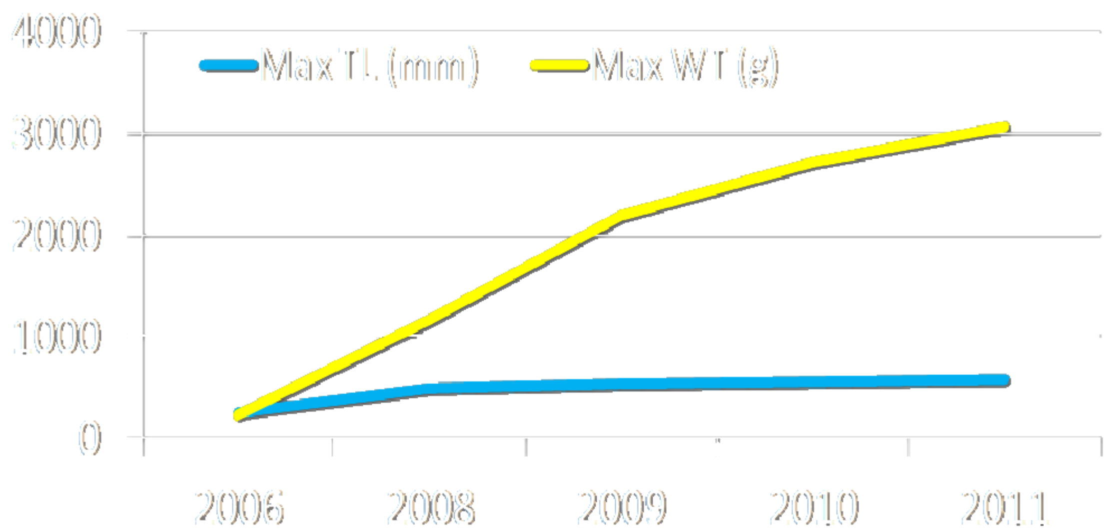

Figure 1. Maximum length and weight of robust redhorse captured in Wateree River from 2006 – 2011.

R E S E A R C H   U P D A T E S

Use of hierarchical occupancy models to estimate seasonal distribution of stocked robust redhorse in the upper reaches of the Ocmulgee River, GA – Will Pruitt
Previous studies on the Ocmulgee population revealed capture probability is very low (0.031) and other approaches (e.g., occupancy models) must be explored. To determine habitat use of robust redhorse, we assessed physical underwater habitat (e.g., woody debris and substrate composition) using side-scanning sonar imagery in combination with fish capture data. To account for the imperfect detection of robust redhorse, the current study employs hierarchical occupancy models to determine detection probability, estimate site occupancy and seasonal habitat use of the Ocmulgee River population. Using this new approach, our preliminary results indicated that water temperature and quantity of woody debris have a negative relationship on site occupancy. However, the most influential factors include water velocity and the proportion of the streambed occupied by coarse substrates (i.e., gravel, cobble, boulder, and bedrock), both of which have a positive relationship with site occupancy. Contrary to previous findings, our best-approximating model revealed robust redhorse had an average conditional detection probability of 0.315 (±0.19). While detection for the species is higher than expected, the low number of robust redhorse captures during this study may be contributed to the extremely low occupancy rates, where the average conditional occupancy was only 0.134 (±0.15). We conclude that robust redhorse may not be as difficult to detect as previously thought, and rather than having a high affinity towards woody structure like their Oconee and Ogeechee River counterparts, the Ocmulgee River robust redhorse may reside only in the inaccessible or difficult-to-sample shoal portions of the river year-round.

Abundance, size structure, and spawning locations of robust redhorse stocked in the Ogeechee River, Georgia. – Patrick Ely & Cecil Jennings
Between November 2010 and March 2011, we conducted 10 electrofishing trips to the Ogeechee River and have collected, tagged, and released 19 robust redhorse. One robust redhorse was captured on 01 December 2010, three were captured on 23 February 2011, seven were captured on 02 March 2011, and eight were caught on 09 March 2011. We will continue electrofishing for robust redhorse until we have a total of thirty radio tagged individuals. The radio-tagged fish will be tracked weekly during the spring spawning season. These data should help identify where in the system robust redhorse are spawning and allow for habitat characterization and protection of spawning site(s). After the spawning season, 10 sampling stations will be established and sampled during the summer and fall to ascertain the abundance of juvenile robust redhorse in the system.

Broad River, Georgia, 2011 Review – Carrie Straight and Bud Freeman
Our current research in the Broad River watershed includes movements of tagged fish spawning behavior, and juvenile sampling.

<u>Movements</u>. In early spring of 2010, we tagged six robust redhorse (2 female and 4 male) with sonic transmitters. We tracked these six fish from their tagging location at

Anthony Shoals upstream to two spawning shoals (approximately 81-88 river km from the tagging location). One individual visited, and presumably spawned, at two different gravel bars approximately 6.5 river km apart on the Hudson and Broad Rivers. Tagged individuals moved downstream after the spawning season was completed and five of the sixed tagged fish entered the Clark's Hill Reservoir by mid-August. One individual has not been detected since late-May 2010 during its downstream migration. The remaining five fish were recorded moving 10 – 13 km into the reservoir (downstream of the original tagging location).

In early spring of 2011, we captured and tagged an additional 14 fish (3 female, 11 males) with sonic transmitters. Tagged males had an average weight of 2775 g (range 1890-4330 g) and an average standard length of 471 mm (range 439-555 mm). Tagged females had an average weight of 3163 g (range 2800-3350 g) and an average standard length of 491 mm (range 467-510 mm). The first tagged fish was recorded moving upstream on the 2^{nd} of March and the first fish was recorded in the vicinity of the one of the documented spawning shoals on 26 April 2011. Five tagged fish were recorded at a known spawning location on the Hudson River, three fish were recorded at one spawning location on the Broad River, and two fish were recorded at both of those spawning locations during the 2011 spawning season.

<u>Spawning Behavior</u>. The 2011 spawning season for robust redhorse in the Broad River system was first documented on 3 May at two different locations, one on the Hudson River and the main site on the Broad River (see table below). On the Hudson River, spawning was documented from 3 May until 12 May 2011. At the main location documented on the Broad River, spawning was documented from 3 May until 23 May 2011. At the secondary site documented on the Broad River (upstream site), spawning was documented from 7 May until 21 May 2011. The site with the highest estimated number of fish was located on the Broad River and was the main documented site used in 2010. At the main site, robust redhorse used six distinct spawning areas within a 150 m reach of river and covered approximately 185 m^2 of habitat. Spawning depths in 2011 averaged 0.53 m (0.3 - 0.88 m). Spawning velocities averaged 0.81 m/s (0.42 - 1.4 m/s) at 60% depth and 0.36 m/s (-0.01 - 0.85 m/s) on the bottom. These water velocities are range and average higher than those recorded previously on the Savannah and Oconee River spawning locations.

Spawning information for the three spawning locations used during spring 2011

Location	Temperature °C	Maximum Number of Fish*
Hudson River	15-23	10 (no estimate of males/females; on 5/9)
Broad River (main)	16.5 – 21.5	73 (12 female; 61 male; on 5/12)
Broad River (upstream)	16.5-22	24 (2 female; 22 males; on 5/12)

*(estimated number of females and males and date of occurrence)

<u>Juvenile Sampling</u>. In fall of 2009, we conducted juvenile robust redhorse sampling. We chose 21 random localities from upstream of the spawning shoals downstream to the reservoir. We collected suckers at 16 of the 21 locations, including M*oxostoma collapsum*, *Moxostoma* sp. (brassy jumprock), and *Minytrema melanops*. No robust

redhorse were collected during these samples. Our 2011 juvenile sampling is not yet complete.

In the fall of 2011, we will continue to conduct juvenile sampling, focusing our efforts in upstream reaches closer to the spawning shoals. We also plan to continue tracking fish within the reservoir and any spring movements of fish tagged in spring 2011. During the spring of 2012, we will conduct a study of flow pulses in relation to spawning behavior in the Savannah River using a hydrophone to record spawning sounds in relation to discharges from Thurmond Dam.

Modeling Suitable Habitat for Robust Redhorse: An Assessment for Reintroduction – Michael Fisk

A remnant population of robust redhorse persists downstream of Blewett Falls Dam, the terminating hydroelectric dam in the Pee Dee River, North Carolina. Due to anthropogenic processes, including habitat fragmentation and alteration from dams, the species has been extirpated from upstream reaches. Tillery hydro-facility is the next dam upstream of Blewett Falls and contains a lotic reach 30 rkm long upstream of Blewett Falls Lake. The implementation of a new minimum flow regime at the Blewett Falls Hydro-facility will create more suitable available habitat for the Blewett Falls reach but has not been quantified for the lotic reach upstream of Blewett Lake where flows are controlled by the Tillery Hydro-facility. Habitat suitability indices (spawning site and non-spawning period) based on field microhabitat measurements from downstream of Blewett Falls Hydro-facility were applied to model weighted usable area (suitable available habitat) for the proposed minimum flows. The objectives of this study were to (1) quantify suitable available habitat in the Tillery reach based on these suitability indices and compare the current and proposed minimum flows between the Tillery and Blewett Falls reaches and (2) identify limiting microhabitat variables.

Modeled suitable available habitat was found for both spawning sites and non-spawning period with spawning sites being affected more by flows. There was little to no increase in suitable available habitat for both periods between the current and proposed minimum flows although proposed minimum flows will inundate gravel bars throughout the reach. Modeled suitable available habitat for spawning in the Tillery reach was higher than the Blewett Falls reach while modeled non-spawning suitable available habitats were similar between reaches throughout the flow range. Substrate and depth were the most limiting microhabitat variables for spawning sites and depth was the most limiting for the non-spawning period.

Our results will help managers make informed decisions about flow manipulations during critical time periods for species of concern and guide research for a potential reintroduction for the robust redhorse in the Tillery reach.

Population Genetic Characterization of Savannah and Pee Dee River Robust Redhorse – Tanya Darden and Carolyn Tarpey

Overall, our genetic evaluation indicates substantial levels of genetic structure between the Savannah and Pee Dee rivers as indicated by the high R_{ST} value and distinct allele

frequency distributions, with a high number of private alleles in each system. The detection of significant genetic differentiation between the Savannah and Pee Dee rivers is congruent with both Wirgin's estimation that genetic divergence between these systems occurred 1.5 million years ago (DeMeo 2001) based on mitochondrial control region sequence data and his unpublished preliminary microsatellite evaluation of these systems (Wirgin et al. 2001). Collectively, these results support the current management of rivers as distinct population segments and should be continued, as suggested by Wirgin et al. (2004), due to the importance of genetic composition for future evolutionary growth of the species.

Both the Pee Dee and Savannah populations show high within-population diversity (>0.79) as well as low levels of inbreeding as compared to the average genetic diversity measured for freshwater fishes (0.54, DeWoody and Avise 2000). Additionally, *M. robustum* population diversity estimates from both rivers are in the upper range of those reported for other *Moxostoma* species (0.63 in black redhorse, *M. duquesnei*, Reid et al. 2008a; 0.72 in river redhorse, *M. carinatum*, Reid et al. 2008b; 0.76 in shorthead redhorse, *M. macrolepidotum*, Reid et al. 2008b; 0.77 in copper redhorse, *M. hubbsi*, Lippe et al. 2006; 0.85 in sicklefin redhorse, *M. sp.*, Moyer et al. 2009).

All estimates of N_e differed between rivers with consistently lower estimates in the Pee Dee River, which is consistent with the suggestion of a smaller population size in the Pee Dee River (Wirgin et al. 2004). However, even the higher contemporary N_{eb} estimates for the Savannah River were lower than those estimated for the endangered *M. hubbsi* ($N_{eb(LD)}$=480, Lippe et al. 2006). Additionally, the estimates of contemporary N_{eb} are well below the goals identified in the conservation strategy for *M. robustum* (Nichols 2003). Similar evolutionary population trends were detected in the Pee Dee and Savannah Rivers. As no recent population bottlenecks were detected in either system, the substantial reduction from long-term to contemporary estimates likely indicates gradual population decreases over very long time periods for both *M. robustum* populations. Bottleneck detection capability is dependent on the severity of the event; however, the tests utilized here are highly robust with population reductions to N_e<10 (Luikart and Cornuet 1998); therefore, a recent bottleneck would have certainly been detected in Pee Dee River had one occurred recently. Although interpretation of genetic data suggested a similar long term trend for *M. hubbsi* (Lippe et al. 2006), it is interesting that the long term estimates of N_e were higher in both the Pee Dee and Savannah populations of *M. robustum* (*M. hubbsi* N_e: 4,476).

Similar to other *Moxostoma* species, *M. robustum*'s life history strategy is characterized by both a long life span and overlapping generations. The maximum age reported for *M. robustum* is 27 years with reproductive maturity occurring at 4-5 years in males and 5-6 years for females, leaving approximately a 22 year reproductive window for each individual (Robust Redhorse Conservation Committee 2002). Therefore, although the very low N_{eb} estimate in the Pee Dee River population is concerning from a genetic management standpoint, their long life span and overlapping generations appear to result in a high potential for across-year class spawning and is likely contributing to the maintenance of high genetic diversity in light of their low effective population sizes. Although the high genetic diversity and lack of inbreeding indicators observed within both the Pee Dee and Savannah river populations of *M. robustum* would normally be

indicative of populations in good genetic health with sufficient adaptive potential, it is unknown if *M. robustum*'s life history characteristics and current high genetic diversity will be capable of overcoming the negative effects of low effective population sizes in the long term. Long-term simulation modeling supports this concern with results indicating more rapid declines in allelic richness with higher maintenance of heterozygosity. Therefore, conservative management approaches and continued monitoring of the populations are recommended as Kuo and Janzen (2004) have suggested that long life and overlapping generations could potentially mask accelerated rates of drift in small populations. The lack of demographic population history for robust redhorse makes it challenging to ground truth interpretation of genetic results and monitoring and management recommendations would greatly benefit from current demographic population estimates (particularly in the case of simulating diversity retention). The contemporary LD-based estimates of N_e for two robust redhorse populations provide an important benchmark for future detection of bottlenecks as it has recently been shown that LD-based estimates have the sensitivity to comparatively detect population reductions within a single generation (Antao et al. 2011). A substantial level of knowledge and intensive effort is necessary for successful recovery of protected species, and the genetic data generated during this study provide information on an important aspect of *M. robustum* biology that will be valuable in the continued monitoring and management of this species.

The microsatellites used to evaluate *M. robustum* were initially developed for other Catostomids, but have proved to be an excellent genetic tool for *M. robustum* as well. In addition to genetic characterization and monitoring of these populations, the marker suite provides a statistically robust mechanism of parentage analysis and individual identification in both rivers. Evaluation of the success of any restoration effort is dependent on the ability to identify stocked individuals, which necessitates the use of a tag or mark to distinguish hatchery from wild produced fish (Blakenship and Leber 1995). The use of molecular markers as genetic tags avoids some of the constraints and pitfalls associated with conventional tags, in that molecular markers require no additional tagging, the mark is never lost, and tag recovery is non-lethal. The archiving of all South Carolina *M. robustum* production and genetic information will allow for offspring identification of future recaptures within the Santee River during re-establishment efforts. As genotyping of Santee River offspring progresses, genetic characterization of the new population can be assessed and compared to the Pee Dee and Savannah river populations.

Potential impacts of non-native flathead catfish on the Oconee River robust redhorse population – Jimmy Evans

Robust redhorse were collected from the Oconee River during 1993–2008 to supply broodfish for an artificial propagation program that eventually resulted in the stocking of several refugial ponds, as well as the Broad, Ocmulgee, Ogeechee, and Oconee rivers in Georgia. Broodfish sampling was generally conducted from below Sinclair Dam near the Central of Georgia railroad trestle downriver for about 20 RM to the end of a long meander section above Dublin. Electrofishing catch rates during broodfish sampling in this area began to decline in about 1996–1997 and have continued to decline from a high of 15–20 fish per hour in 1993-1995 to 0.5 fish per hour in 2008. Population monitoring

in the Sinclair Dam to Dublin area in 2009–2011 has failed to capture any robust redhorse.

The possibility of a future demographic decline was recognized in the early–mid 1990s through an evaluation of annual length distributions that indicated an aging population with limited recruitment, and this was one of the reasons for implementing the artificial propagation program. The flow regime at Sinclair Dam was altered in 1996 as a result of FERC relicensing, partially in response to limited robust redhorse recruitment, and in 2008 five gravel spawning sites were augmented to improve spawning habitat quality. However, these measures have not resulted in any documented improvement in recruitment success to date and no strong year classes have been produced.

Several causes have been proposed for the decline of the Oconee River robust redhorse population, but one of the first to be recognized was the introduction of flathead catfish into the Ocmulgee River in the mid-1970s, followed by their appearance in the Oconee River in about 1980. The flathead catfish is a large voracious, ambush-type piscivore with a particularly large gape. Indigenous fishes in rivers such as the Oconee have evolved no well-developed defenses against this non-native predator. Negative effects of non-native flathead catfish on indigenous fishes are well documented, including the alteration of entire native fish communities. Some species are more affected by flathead catfish predation than others and several lines of evidence suggest that robust redhorse may be especially vulnerable, but conclusive proof is lacking.

The first line of evidence is the correlation between the appearance of flathead catfish in the Oconee River in the early 1980s and the apparent decline in robust redhorse recruitment. Length distributions of robust redhorse from the early-mid 1990s are unusual because of the low numbers of juveniles but also because the length/age distribution is shifted to near the maximum known length/age for the species. These length distributions strongly predicted the demographic decline that occurred and has continued to the present. An age and growth study using opercles conducted by Dr. Robert Jenkins indicated that this large group of fish, composing most of the population, was 10–25 years of age and was therefore produced primarily in the 1970s before flathead catfish appeared in the Oconee. After the appearance of flathead catfish in the early 1980s, recruitment appears to have been much lower and the population has aged, eventually declining dramatically.

A second line of evidence that implicates flathead catfish predation in the decline of the Oconee River robust redhorse population comes from the Ocmulgee River in the late 1980s. A comprehensive fish population study of the Ocmulgee River (Evans 1991) found that flathead catfish did not at the time exist above the Juliette Dam, the first barrier to fish migration on the Ocmulgee. Although robust redhorse were not found in this section, notchlip redhorse were common and up to ten times more abundant above the Juliette Dam where flathead catfish were absent than below the dam where they were present. The implication from these data is that sucker species abundance may be reduced by flathead catfish predation. However, the results of this analysis is complicated

by natural habitat alterations associated with the fall line and other factors that may also have influenced observed longitudinal changes in notchlip redhorse abundance.

Finally, a third line of evidence implicating flathead catfish predation in the decline of the Oconee River population is the apparent significant overlap in habitat utilization of the two species observed from radio telemetry studies. In principal, greater exposure of prey species to predators through habitat overlap will increase opportunities for predation and therefore elevate predation pressures. Habitat overlap has been used to explain the virtual disappearance of bullheads from numerous rivers following the introduction of flathead catfish. In general, telemetry studies conducted in coastal plain areas such at the Oconee River between Sinclair Dam and Dublin indicate that non-spawning adult robust redhorse prefer deeper portions of meander sections with concentrations of woody debris. Preference of adult robust redhorse for this habitat type has been observed in the Oconee, Ocmulgee, and Savannah rivers. Telemetry studies of flathead catfish in several rivers also indicate a preference for these habitat types. Dr. Tom Kwak will review these studies and expand on habitat preferences for the two species in the following presentation. Following Dr. Kwak's presentation Joey Slaughter will further discuss the relationship of habitat overlap to predation as it applies to flathead catfish and razorback suckers in western rivers.

The questions we are exploring in these three presentations are: Can the two species coexist? Can they coexist in some areas and not others? What is the cumulative evidence in support of the suggestion that flathead catfish predation has played a major role in the decline of the Oconee River robust redhorse population. Is there other evidence indicating that flathead catfish predation might not have played a significant role in the decline? Do we have enough data to answer these questions?

Interaction of Nonnative Flathead Catfish with Imperiled Redhorses - Thomas J. Kwak, J. Michael Fisk, and Ryan J. Heise

The flathead catfish, *Pylodictis olivaris*, has been widely introduced in the United States beyond its native range. This domestic invasive species receives less scientific and media attention relative to exotic fish introductions, but its ecological impacts may be equally or more severe. It has been implicated for the decline of sport and imperiled fishes and can restructure fish communities. It is an aggressive obligate carnivore with great potential to alter native fish assemblages. Since the 1950s, it has been introduced into Atlantic Slope rivers from Florida to Pennsylvania, established by releases of few individuals, and its distribution overlaps that of the robust redhorse, *Moxostoma robustum*. The flathead catfish has been considered easily collected by electrofishing, of low densities, with sedentary behavior, restricted to freshwater, and feasible to manage in restricted river units, but recent research suggests that electrofishing is an inefficient gear, it occurs in dense populations, individuals migrate throughout a drainage, it tolerates brackish waters, and populations must be managed at the basin scale (see relate publications below). Microhabitat suitability analyses suggest substantial habitat overlap between flathead catfish and robust redhorse, and fluvial restricted redhorses, such as the robust redhorse are more vulnerable to flathead catfish predation than fluvial specialist fishes. Management of introduced catfish focuses on limiting dispersal among basins, public

education, and encouraging harvest. Additional research is needed to elucidate the effects on native fishes and develop and assess alternative population control measures.

A physiological evaluation of predation potential of flathead catfish on razorback suckers – Joey Slaughter

Flathead catfish are well established in the Colorado River below Parker Dam. This section of river is also within the native range of razorback suckers and is the site of ongoing recovery efforts. Previous studies have shown that flathead catfish actively feed on razorback suckers when they coexist within a given area, and recent work suggests that mortality of stocked razorbacks is very high. Razorback body size was compared to flathead gape size to determine at what size catfish were able to ingest a given size of razorback sucker. The size distribution of flathead catfish present below Parker Dam was then analyzed to determine the abundance of catfish by size within the river. Proportions of flathead catfish available to prey upon various sizes of razorback suckers were calculated and compared to mortality curves estimated for various stocking sizes of razorbacks. This information was used to determine at what size razorbacks could or should be stocked to minimize mortality induced by flathead predation. Ultimately, all razorbacks of any size are vulnerable to predation by the largest flathead catfish within the system, but increased stocking size could lead to higher survival by decreasing the proportion of flatheads large enough to feed upon stocked razorbacks.

TECHNICAL WORKING GROUP REPORTS

Oconee River Technical Working Group – Alice Lawrence

The tasks in the management plan that were addressed during the past year and tasks that the Oconee TWG is considering as our top priorities for the upcoming year were summarized:

Task: Continue to document spawning activity at known sites and identify any additional sites, and
Task: Continue evaluation of habitat augmentation and identify augmentation strategies to address habitat bottlenecks.

Georgia DNR visually monitored gravel augmentation sites over a two-day period this spring and the Oconee TWG conducted the annual standardized spring electrofishing event. No robust redhorse were detected. More recently, acoustic monitoring equipment was purchased by Georgia ES (FWS) for UGA to monitor robust redhorse spawning activity. This equipment will be used in the Broad and Savannah Rivers, GA, but because there are multiples of the equipment available, we are hoping to use some of the equipment in the Oconee to continuously monitor for spawning activity. The Oconee TWG deemed monitoring of the gravel augmentation sites as one of the top three priorities for 2012. The Oconee TWG feels that it is important to monitor these sites not only for robust redhorse use, but also for use by the other native fishes in the Oconee River because this is a habitat restoration method that is not commonly used, especially in the southeastern United States.

Task: Survey areas not specifically targeted in the past, sampled only sporadically, or outside the management unit, and
Task: Evaluate the need for establishing additional refugial populations.

Manpower was not available this spring to survey these extra areas, but the Oconee TWG has deemed exploring if a remnant population exists above Sinclair Dam as one of the top three priorities for 2012. This is a necessary step before the group considers introducing robust redhorse above Sinclair Dam. The group will be sampling areas above Sinclair Dam this spring instead of conducting the spring standardized sampling event in the Oconee River below Sinclair Dam. Reconnaissance surveys above Sinclair Dam are already underway, with more work planned for this winter. Springtime survey work will consist of electrofishing in riverine reaches and gill-netting in Lakes Oconee and Sinclair.

Task: Review existing data on habitat quality and quantity to develop a more accurate estimate of available habitat.

A sub-task in the management plan specifically mentions updating the flow regime at Sinclair Dam. Since the FERC license was issued for the project in the

mid-1990's, we now have more information including robust redhorse population estimates, catch-per-unit-effort data, and now Jennings et al. 2008 that correlates abundance of larval and age-0 redhorse with April-June flow parameters. Because the Jennings et al. 2008 results include parameters that are slightly different than the current flow regime, the Oconee TWG deemed providing Georgia Power with a formal flow tweak recommendation as one of the top three priorities for 2012. The mechanism for doing this will be a Flow Advisory Team meeting, which will translate the data results into a management recommendation for Georgia Power.

Task: Expand public outreach and outreach efforts.

In addition to the SC Aquarium and the GA Aquarium, now there is also the newly-opened Go Fish Education Center in Perry, Georgia operated by GDNR. The RRCC website has been updated with the Oconee TWG Management Plan and is being updated with the past RRCC Annual Meeting summaries.

Task: Actively participate in the environmental review process, as appropriate.

There were no projects on the mainstem Oconee in the robust redhorse range that the Service or GDNR is aware of this past year. However, there are some riparian lands in this area that are permanently protected, including a 6700+ acre wetland mitigation bank in Wilkinson County that encompasses one bank of the river at the only known robust redhorse spawning site. Other protected lands along the mainstem Oconee River in Baldwin, Wilkinson, Washington, Johnson, and Laurens counties, that the Service is aware of, include protected public lands such as the Berry Farm Conservation Area, a State Parks property, Beaverdam WMA, as well as mitigation properties such as the Wilkinson/Oconee Mitigation Bank, the Engelhard Corporation Mitigation Site, Imery's Clay Mitigation Site, and a proposed Commissioner Creek Mitigation Bank.

Yadkin-Pee Dee Technical Work Group Activities – Ryan Heise

The objective of the 2011 field study by the Yadkin-Pee Dee technical working group (TWG) was to continue looking for any additional Robust Redhorse spawning shoals. TWG members tracked radio-tagged robust redhorse in April and May and individuals were only relocated in previously documented spawning areas (Jones Creek and Hitchcock Creek shoals). This highlights the importance of these sensitive areas and we are happy to report that these locations are receiving some protection by ownership of the adjacent riparian lands by RRCC members (NC Wildlife Resources Commission and Progress Energy). Much has been learned about the Pee Dee river population (e.g. habitat use/suitability, migration patterns) since the formation of the TWG (see pervious RRCC annual reports). Currently, robust redhorse are only found downstream from Blewett Falls dam and the TWG is studying the possible reintroduction of robust redhorse upstream of the dam. North Carolina Wildlife Resources Commission with help from Progress Energy has funded a study at North Carolina State University to model the suitable upstream habitats (located downstream of Tillery Dam). In addition, a separate project at NCSU will look at water quality in Pee Dee River. The results of these studies will help determine our reintroduction options for Robust Redhorse.

Information Technology Technical Working Group – Jaci Zelko

The status of the annual reports, website, and database was relayed to the meeting participants. Jaci asked all participants to check on their latest dataset and send updated copies to be included in the master spreadsheet.

Jaci relayed that the new protocol of each presenter submitting an abstract has greatly streamlined the annual report process. As of this meeting she has completed the 2003, 2004, 2005, 2009 reports and is drafting the 2010 report. These documents need to be uploaded to the RRCC as well as many other pictures and documents. Jaci will work with Ryan to get this accomplished by the next annual meeting.

Habitat Technical Working Group – Alice Lawrence

Alice reported that the group is currently looking for funding options to monitor the gravel augmentation project on the Oconee River.

B U S I N E S S

Research Topics and Resource Needs
A general discussion was held concerning research needs. The following list includes these topics.

- A larval source may be needed in the future for the following projects (carried over from the 2010 Annual Meeting):
    - Determining bottlenecks in certain populations
    - Fish cage experiments concerning inter-sex fish (Produce fingerlings from Pee Dee fish for tag retention and toxicology studies)
    - Larval research concerning Plant Washington
    - Fingerlings to replenish Aquarium stocks
    - Preserved series for Georgia and North Carolina Museums.
    - .
- Genetic characterization of the Georgia population.
- Estimate demographic sizes from all populations.
- Evaluate Yadkin River for additional spawning habitats.
- Continue to monitor the gravel augmentation sites in Oconee River.
- Cryopreservation samples from Savannah and Pee Dee males for repository.
- How to monitor stocked populations to determine sustainability in Georgia when funding runs out?

Update on the 404 Species Petition – Alice Lawrence
The Service received a petition to list 404 southeastern aquatic, riparian, and wetland species from the Center for Biological Diversity in April 2010. Separate settlement agreements with WildEarth Guardians and the Center for Biological Diversity were filed in federal court in May 2011 and July 2011, respectively, requiring the Service to make listing decisions for 700+ species by 2018. The judge ruled on September 9, 2011, approving those settlement agreements. Subsequently, the Service filed a partial 90-day finding addressing the CBD petition on September 27, 2011.

Per the settlement agreements which include a scheduled work plan, the Service agreed to make listing decisions on 251 species that are currently candidates (per the Service's 2010 Candidate Notice of Review), along with other select species, within the next 6 years. Eighteen of the 404 species in the CBD petition are already candidates, so they will be addressed within the next six years. One of the 404 species will be handled by NMFS, because it is under NMFS' jurisdiction. Eleven of the 404 species have not been addressed yet. The Service's 90-day finding states that for the remaining 374 species, the petition presents substantial scientific or commercial information indicating that listing may be warranted. Therefore, the Service is initiating a status review of these species and is soliciting scientific and commercial information regarding these species. The 60-day comment period is now open and ends November 28, 2011. However, 12-month findings on these 374 species, including the robust redhorse, are not scheduled to be

completed within the next 6 years; they will likely follow completion of the court-approved work plan that schedules listing decisions over the next 6 years.

The Service will use information obtained during the public comment period, as well as information contained in the Service's files, for the status review. The RRCC website needs to be updated with a comprehensive list of journal articles, and any gray literature needs to be linked to the website. If someone decides to submit information as part of the public comment period, then it needs to be substantiated with accompanying data, gray literature (or citations to gray literature if it is linked to the RRCC website), and journal articles (or citations to journal articles).

A T T A C H M E N T S

Attendees of the 2010 Meeting:

Last Name	First Name	Organization
Wilkins	David	S.C. Aquarium
Heise	Ryan	NC WRC
Zelko	Jaclyn	U.S. FWS
Starnes	Wayne	NC Museum Nat. Sci
FISK	MICHAEL	NC STATE
Bowles	Tom	SCE+G
Hailey	Rebecca	NCWRC
Tarpey	CAROLYN	SCDNR
Darden	Tanya	SCDNR
Ewing	Todd	NCWRC
Swing	Mike	PROGRESS ENERGY
STRAIGHT	CARRIE	UGA
Brown	Jason	Progress Energy
Lawrence	Alice	USFWS
Sessions	Forrest	SCDNR
Rodgers	Angie	NC NHP
Quattlebaum	Milton	SCANA/SCE&G
JENNINGS	CECIL	USGS
Zimpfer	Steve	UGA
PRUITT	WILL	Georgia Coop. / UGA
JONES	BRENA	NCWRC
Ely	Patrick	UGA
Deaton	Shannon	WRC
Kwak	Tom	NCSU / USGS
Evans	Jimmy	GADNR/WRD
SLAUGHTER	JOEY	GA POWER
Abney	Michael	Duke Energy
Lamprecht	Scott	SCDNR

Appendix 2

REPORT OF THE

ROBUST REDHORSE CONSERVATION COMMITTEE ANNUAL MEETING

Morrow Mountain State Park
Albemarle, North Carolina
October 8 – 10, 2012

Attendees of the 2012 annual meeting

Report compiled by
Jaclyn Zelko
U.S. Fish & Wildlife Service

TABLE OF CONTENTS

A C R O N Y M S & A B B R E V I A T I O N S

CPLC	Carolina Power and Light Company
CVIOG	Carl Vinson Institute of Government
DPC	Duke Power Company
FERC	Federal Energy Regulatory Commission
GA Coop	University of Georgia Cooperative Fish & Wildlife Resource Unit
GA DNR	Georgia Department of Natural Resources
GPC	Georgia Power Company
GRN	Georgia River Network
GWF	Georgia Wildlife Federation
NC WRC	North Carolina Wildlife Resources Commission
NCS MNS	North Carolina State Museum of Natural Sciences
NYU	New York University
SC Coop	South Carolina Cooperative Fish & Wildlife Research Unit
SC DNR	South Carolina Department of Natural Resources
SCEG	South Carolina Electric and Gas
SCA	South Carolina Aquarium
UGA	University of Georgia
USACOE	U.S. Army Corps of Engineers
USFS	U.S. Forest Service
USFWS	U.S. Fish and Wildlife Service
USGS	U.S. Geological Survey (Biological Resources Division)

FTC	Fish Technology Center
NFH	National Fish Hatchery
SFH	State Fish Hatchery
WMA	Wildlife Management Area

CCAA	Consolidated Conservation Agreement with Assurances for the Ocmulgee River
Excom	Former Technical Advisory Group to the RRCC
GIS	Geographic Information System
IT TWG	Information Technology Technical Working Group
MOU	Memorandum of Understanding
PIT	Passive Integrated Transponder Tags
RRCC	Robust Redhorse Conservation Committee
TAG	Technical Advisory Group
TWG	Technical Working Group

AGR	Artificial genetic refuge
C	Celcius
cfs	Cubic feet per second
cm	Centimeter
g	Gram
kg	Kilogram
km	Kilometer
m	Meter
mg/l	Milligrams per liter
mm	Millimeter
MWe	Megawatts of electrical output
m3/s	Cubic meter per second
N*e*	Effective population size
ppt	Parts per thousand
rkm	River kilometer
RM	River mile
TL	Total length
YC	Year class
YOY	Young of year

E X E C U T I V E   S U M M A R Y

The robust redhorse recovery effort, in its 18th year, encompasses management activities and research and conservation efforts undertaken by members of the Robust Redhorse Conservation Committee (RRCC), university scientists, and other affiliates. The RRCC, established by a Memorandum of Understanding (MOU) signed in 1995, is responsible for developing and managing a recovery approach for the imperiled robust redhorse (*Moxostoma robustum*). The effort and expertise applied to the questions of recovery are brought together at the annual meeting of the RRCC.

The seventeenth annual meeting of the RRCC was held October 8 – 10, 2012 at Morrow Mountain State Park in Albemarle, North Carolina. Approximately 30 representatives of the signatory agencies to the MOU, university research affiliates and other interests attended the meeting. The 13 signatory agencies include: Georgia Department of Natural Resources, South Carolina Department of Natural Resources, North Carolina Wildlife Resources Commission, Georgia Power Company, Progress Energy (formerly Carolina Power and Light Company), Duke Energy, South Carolina Electric and Gas Company, U.S. Fish and Wildlife Service, U.S. Geological Survey, U.S. Forest Service, U.S. Army Corps of Engineers, Georgia Wildlife Federation, and South Carolina Aquarium. University research affiliates include: University of Georgia Warnell School of Forest Resources, University of Georgia Institute of Ecology, University of Georgia Cooperative Fish and Wildlife Research Unit, Roanoke College Department of Biology, University of Georgia Carl Vinson Institute of Government, University of Georgia Department of Genetics, Cornell University Department of Molecular Biology and Genetics, Clemson University Cooperative Fish and Wildlife Research Unit, New York University School of Medicine Institute of Environmental Medicine, and State University of West Georgia. In addition, representatives of other concerns with interest in recovery of the robust redhorse include: Santee Cooper Power Company, Georgia Aquarium, Georgia River Network, and the North Carolina State Museum of Natural Sciences. The success of the recovery effort, to a large extent, depends on the willingness of RRCC members and others to participate in the annual meeting and to continue to support recovery throughout the year.

This report summarizes updates on management activities, research findings, and conservation efforts and decisions made at the 2012 RRCC Annual Meeting. The RRCC Annual Meeting Reports have become important documents of research, science, management, and recovery that are often referred to and cited. The format of this year's report closely follows the format of previous reports and it provides a more accurate record of activities. The report notes discussion points, questions, main ideas, and/or notes recorded by the participants.

I N T R O D U C T I O N

Historically, the robust redhorse (*Moxostoma robustum*) inhabited Atlantic slope drainages from the Pee Dee River system in North Carolina to the Altamaha River system in Georgia. The first scientifically confirmed sighting of robust redhorse since naturalist Edward Cope described the species in 1869 occurred when the fish was re-discovered in the Oconee River in Georgia in 1991. In the Altamaha River drainage, the species is presently known to exist in a relatively short reach of the Oconee River between Sinclair Dam and Dublin, Georgia and in a short upper Coastal Plain section of the Ocmulgee River. Individuals also have been found in the Savannah River (the boundary river between Georgia and South Carolina) in the Augusta Shoals area as well as below the New Savannah River Bluff Lock and Dam. In addition, robust redhorse have been captured in the Pee Dee River below Blewett Falls Dam in North Carolina. Robust redhorse populations have also been reintroduced within their historic range into the Broad and Ocmulgee Rivers, Georgia, as well as the Broad and Wateree Rivers, South Carolina. The robust redhorse appears to inhabit specialized areas of large rivers, which are difficult to sample but regardless of the absence of sightings, small numbers are usually found when species-targeted surveys are conducted.

River impoundments, predation by introduced nonnative species, and significant deterioration of habitat due to sedimentation and water pollution are believed to have contributed to the decline of the species. The complex and diverse problems facing the robust redhorse require an interdisciplinary approach, using a broad spectrum of experience, expertise, and management authority to maintain and restore this imperiled species. In addition, it is essential that recovery efforts include a process that works closely with the private sector as well as government agencies potentially impacted by and interested in robust redhorse conservation.

The Robust Redhorse Conservation Committee (RRCC) was established by a Memorandum Of Understanding (MOU) signed in 1995 to develop and manage a recovery approach for the robust redhorse (*Moxostoma robustum*), previously a Category 2 candidate for Federal listing under the Endangered Species Act. The RRCC is actively committed to the recovery of the imperiled robust redhorse throughout its former range. It identifies priority conservation needs for the robust redhorse and its habitat and coordinates implementation of research and management programs for addressing those needs.

A D M I N I S T R A T I O N

Welcome – Ryan Heise and John Crutchfield

Ryan welcomed the participants to the 18th Annual robust redhorse meeting. He thanked the sponsors of this year's meeting (NC Wildlife Resources Commission – state wildlife grant program, Duke Energy, SC Aquarium, and NC State Parks). Ryan introduced John Crutchfield, and he welcomed all to the meeting on behalf of Duke Energy.

Memorandum of Understanding Renewal – Ryan Heise

The MOU establishes the RRCC and allows the RRCC to establish operating guidelines. The previous MOU expired at the end of December, 2009. The newest version is valid from January 1, 2010 to December 31, 2014. Revisions made after the 2009 meeting were incorporated and representatives were sent the updated copy. At this time, Ryan has received signatures from all but 1 signatory. The Excom will discuss the next step at the next meeting.

M A N A G E M E N T   A C T I V I T I E S

Georgia 2012 Update – Jimmy Evans

Recovery Phases

Phase I. After discovery, status assessment indicates risks due to low recruitment

Phase II. Hatchery program 1994 – 2008, multiple year classes stocked in:

- Refugial ponds
- Broad, Ocmulgee, Ogeechee rivers to establish refugial populations, and eventually reproducing populations
- Oconee – small augmentation stockings

Phase III. Monitoring

- Success of stockings
- Status of wild Oconee population

Phase IV. Efforts to improve status of Oconee population

- Flows modified during relicensing; additional modifications possible
- Research to evaluate responses to flow modifications
- Limited stocking of fingerlings and juveniles
- Habitat improvements, mainly gravel augmentation
- Evaluation of predation threats

Phase V. Search for other populations, potential reintroduction sites

- Upper Oconee above Sinclair and Wallace dams

Current Activities

Activities in 2012

Recently completed research

- Movement patterns, habitat use and home range of adult robust redhorse released into the Oconee River, GA. (Patrick Ely). Final report completed
- Abundance, size structure, movement patterns, and recruitment success of robust redhorse stocked into the Ogeechee River, GA. (Patrick Ely). Report in preparation
- Use of hierarchical occupancy models in the Ocmulgee River, GA. (Will Pruitt). Report in preparation

Ongoing research

- Population status and assessment of reproduction and recruitment of robust redhorse in the Broad River system. (Carrie Straight and Bud Freeman)
- Oconee River population status assessment (Oconee TWG)
- Search for wild and/or stocked populations above Sinclair Dam (Little River, Murder Creek) and above Wallace Dam (Apalachee and Oconee rivers). (Jimmy Evans)
- Monitoring of Oconee River gravel augmentation sites (Jimmy Evans)

Environmental reviews

- Expansion of water intake structure on Ocmulgee by Macon Water Authority
- Continued negotiations with Eastern Hydro on construction of Denil fish ladder at Juliette Dam on Ocmulgee
- Design of bridge and other mitigation measures for Fall Line Freeway crossing of Oconee River above Avant Mine

- Received $10,000 in mitigation funds for study to monitor Oconee River gravel augmentation sites in spring 2013
- Expansion of Franklin County wastewater treatment facility; reduced scope of impacts
- Negotiations with Savannah COE over Savannah River reservoir drought operations

<u>*Public relations*</u>

- Live fish displays at Georgia Aquarium and Go-Fish-Georgia Center
- Display at Macon Museum of Natural History
- FWS video featuring Ocmulgee River CCAA
- New state park being constructed at Balls Ferry on Oconee will increase awareness of recovery efforts

<u>*March 1- May 10, 2012 Status Survey Background and rationale*</u>***:*** Sinclair Dam was constructed on the Oconee River near Milledgeville in1950 creating Lake Sinclair. Wallace Dam was constructed above Lake Sinclair in 1980 creating Lake Oconee, the upper reservoir in a pump-storage operation (Figure 2). The robust redhorse was discovered in the Oconee River below Sinclair Dam in 1991 and the possibility therefore exists that a segment of this population could have been isolated above Lakes Sinclair and/or Oconee with the construction of Sinclair and Wallace Dams. However, no robust redhorse have been documented in over 20 years of standardized gillnet and electrofishing sampling on Lakes Sinclair and Oconee, suggesting that if a populations exists in this area, it is probably small. The first objective of the upper Oconee robust redhorse status survey was to sample the major tributaries of Lakes Sinclair and Oconee (Little River, Murder Creek, Apalachee River, and Oconee River) to determine if a remnant wild robust redhorse population presently exits in this area.

The robust redhorse hatchery program began in Georgia in 1994 and continued through 2008. In June 1995 a total of 219 robust redhorse fingerlings (average total length 192 mm) that had been stocked at Walton Hatchery escaped into a small tributary of Little River due to a dam failure. Since Little River enters the upper end of Lake Sinclair, the escaped fingerlings could have moved down Little River and into Lake Sinclair. This escapement could have resulted in the establishment of a stocked robust redhorse population in Little River, Lake Sinclair, or Murder Creek (the other major tributary to Lake Sinclair). However, since no robust redhorse have been documented in over 20 years of standardized gillnet and electrofishing sampling in Lake Sinclair, if an accidentally stocked population of robust redhorse exists in this area, it is probably small. The second objective of this status survey was to sample the major tributaries of Lake Sinclair (Little River and Murder Creek) during the peak of the robust redhorse spawning season to determine if a spawning population of stocked fish exists in the upper Lake Sinclair drainage.

<u>*Methods and results:*</u> The Little River, Murder Creek, and the Oconee River between Hwy 15 and Barnett Shoals Dam were sampled by electrofishing during March 1 - May 10, 2012 (Table 1). The intent of sampling the lower reaches of these tributaries was to intercept any robust redhorse that might exist in the area as they moved upstream to

spawn. Each stream segment was sampled four times and the distances sampled were 2.1 miles on Little River, 1.3 miles on Murder Creek, and 10.7 miles on the Oconee River. Electrofishing effort per sampling event ranged from 0.5 to 3.0 hours and water temperatures varied from 14.1 to 24.5 C. No robust redhorse were collected from Murder Creek or the Oconee River, however, one robust redhorse was captured on April 17 from Little River below Hwy 129 and immediately above the impoundment of Lake Sinclair (Figure 2). This individual was a large female in peak spawning condition (total length 673 mm and weight 5,335 g) (Figure 1). Condition of the mucous coating, coloration, appearance of vent area, and flaccid abdomen indicated that this female was only a few days from spawning. It is assumed that the fish was migrating up the Little River to spawn and preliminary observations at bridge crossings above Hwy 129 following the capture indicate that spawning habitat may exist from above Hwy 129 to at least Glades Road on Oconee National Forest. However, no detailed habitat surveys have been conducted in the area. Since this fish was captured from the Little River, the receiving stream for the escaped fish from Walton Hatchery, and observations of annular rings on scale samples correspond roughly to a calculated age of 18 years, it is assumed that this is a stocked rather than a wild individual. A fin clip was collected in the event that further verification of origin is needed.

<u>*Conclusions:*</u> The capture of a single large female robust redhorse from the Little River suggests that a small spawning population of robust redhorse presently exists in the Little River and upper end of Lake Sinclair. In addition, it is probable that this population originated from the accidental escapement of about 200 robust redhorse fingerlings from the Walton Hatchery in 1995. Despite very thorough sampling of the lower end of Murder Creek above Lake Sinclair, no robust redhorse were collected and these findings suggest that a spawning population probably does not exist in this stream. Based on sampling results and habitat observations, it is unlikely that a spawning population exits in the Oconee River between Hwy 15 and Barnett Shoals Dam. However, sampling in this section of the Oconee River was significantly hampered by problems with navigation at the extreme low flows that existed during the survey.

Additional sampling should be conducted in the Oconee River above Hwy 15 in 2013 to verify these preliminary conclusions. Low flows and manpower constrains prevented the planned sampling on the Apalachee River and this work should be conducted in 2013 as well. Finally, there is a need to conduct a habitat survey on the Little River above Lake Sinclair to locate possible robust redhorse spawning areas. Visual observations of spawning activity at gravel spawning sites may be the most efficient method of evaluating the status of the existing stocked robust redhorse population in the Little River.

Table 1. Results of robust redhorse status survey conducted on the upper Oconee River, Little River, and Murder Creek, March 1 – May 10, 2012.

Stream	Distance Sampled (mi)	Dates	Temp (C)	Effort (hrs)	No. RRH Collected	Length (mm)	Weight (g)
Little River	2.1	3/14	17.4	0.5	0	-	-
		4/17	17.5	1.2	1	673	5,335
		4/25	14.1	1.2	0	-	-
		5/3	21.5	1.2	0	-	-
Murder Creek	1.3	3/14	18.2	0.5	0	-	-
		4/17	20.0	1.1	0	-	-
		4/25	18.0	1.1	0	-	-
		5/3	24.5	1.1	0	-	-
Oconee River	10.7	3/1	-	1.0	0	-	-
		4/19	18.1	3.0	0	-	-
		4/17	19.1	0.2	0	-	-
		5/10	19.5	0.4	0	-	-

Figure 1. Photo of robust redhorse collected from the Little River on April 17 during status survey conducted on the upper Oconee River, Little River, and Murder Creek, March 1 – May 10, 2012.

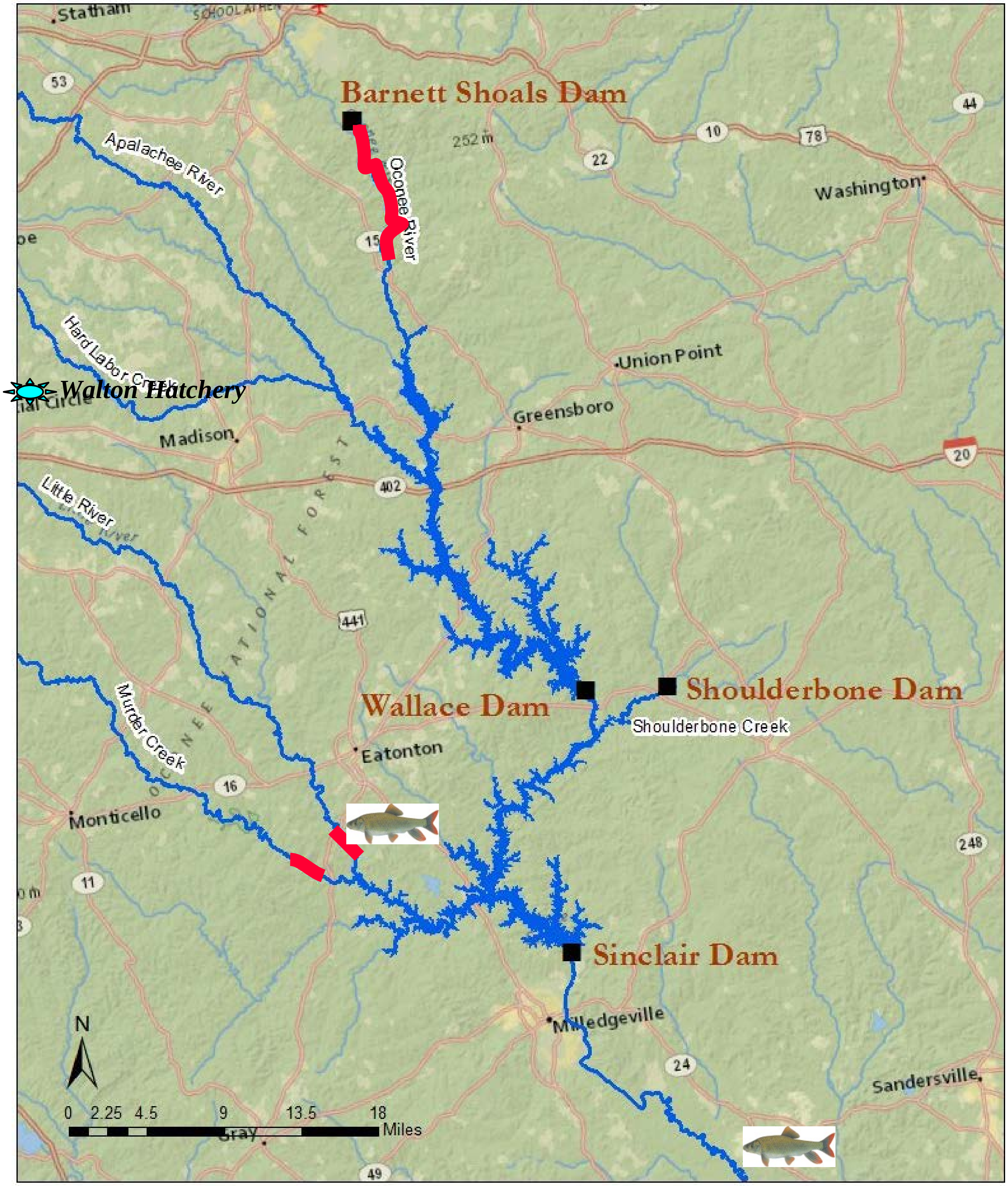

Figure 2. Sampling areas for robust redhorse status survey conducted on Little River, Murder Creek, and Oconee River, March 1 – May 10, 2012. Locations of existing wild robust redhorse population in the Oconee River below Sinclair Dam and the one robust redhorse collected from Little River during the survey are indicated. Location of Walton Hatchery in the Little River drainage is also noted.

South Carolina 2012 Update – Scott Lamprecht

North Carolina 2012 Update – Ryan Heise

The long term goal of Yadkin-Pee Dee technical working group (TWG) is to ensure a viable, self-sustaining population of robust redhorse in the Pee Dee River. Thus, the TWG has continued discussions about supplementing the small population downstream of Blewett Falls Dam and reintroduction downstream from the Tillery Dam. Duke Energy (previously Progress Energy) has already begun implementing parts of the proposed FERC (Federal Energy Regulatory Commission) license and the issuance the new license is expected in 2013. The Yadkin-Pee Dee TWG has conducted numerous studies in the Pee Dee River allowing us to make informed decisions about robust redhorse management (see previous annual reports and publications on our website). We are pursuing a long term hatchery program at the Wildlife Recourses Commission's McKinney Lake Fish Hatchery and a pilot project is scheduled begin in the spring of 2013. Discussions are ongoing between Duke Energy, U.S. Fish and Wildlife Service, NC Wildlife Resources Commission, SC Department of Natural Resources concerning a possible conservation agreement.

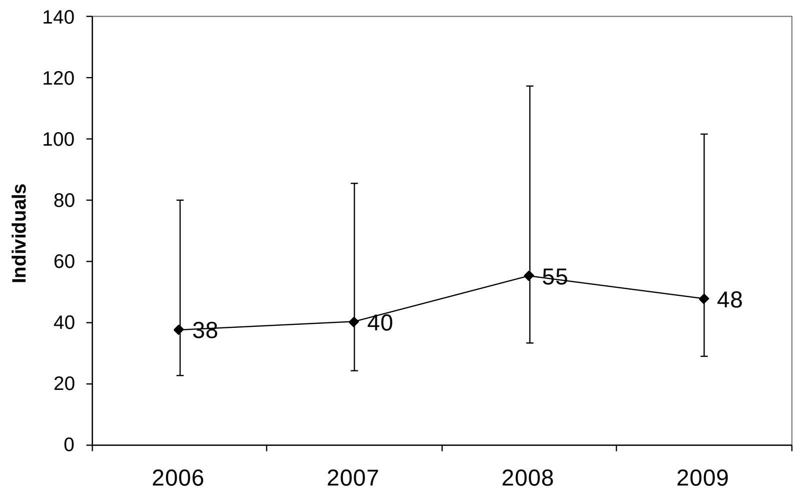

Figure 3. Adult population size of robust redhorse in the Pee Dee River.

Wateree River Collections 2012 Update – Dave Coughlan

Duke Energy continued its springtime sampling program for diadromous fish downstream of the Wateree Hydro in 2012. This program has been in place since 2004 though robust redhorse collections only began in 2006, after introductions of fingerlings by the SCDNR in December 2005. A steadily increasing trend in numbers caught, CPUE, and 'best day' CPUE were evident through 2011. The unusually warm winter and spring of 2012 may have impacted our ability to sample fish at an appropriate time. Poor catches from spring 2012 sampling were discouraging but mirror those from other rivers within the RRH range. Despite the collection of only two RRH in 2012, the trends of annually increasing maximum total length and weight continued. Collection efforts will continue in 2013.

Table 2. Number of fish collected from 2006 to 2012 downstream of Wateree Hydro Dam.

	#	Pedal Time (hr)	CPUE	Best Day CPUE	Max TL (mm)	Mac WT (g)
2006	1	6.52	0.15	1	243	217.5
2008	4	3.92	1.02	2	475	1164
2009	10	9.04	1.11	3	521	2176
2010	11	9.06	1.21	3	548	2716
2011	22	9.03	2.44	7	569	3066
2012	2	9.15	0.22	1	593	3576

Figure 4. PIT Tag is inserted into a Phase II fish prior to stocking in the Wateree River.

R E S E A R C H   U P D A T E S

Robust Redhorse Recovery and Habitat Restoration: Assessing Water Quality Stressors and Food Web Contaminant Dynamics – Tom Kwak, Greg Cope, and Ryan Heise

The robust redhorse (*Moxostoma robustum*) is a rare and imperiled, large catostomid fish found in only three regulated river drainages in the southeastern U.S. It has large pharyngeal teeth for crushing mollusks and other invertebrates known to sequester anthropogenic contaminants. The robust redhorse has been negatively affected by habitat modification and fragmentation from hydroelectric dams, introduced species, sedimentation, and water pollution and is protected by state endangered status in Georgia and North Carolina. Previous research by the authors and their students on physical instream habitat suitability has shown that habitat suitability will be enhanced by prescribed flow augmentations from hydroelectric dam releases; however, the impacts of water quality and contaminant loads remain unknown. In addition to the unknown effects of traditional organic and inorganic contaminants, recent research suggests that the impact of emerging contaminants, such as endocrine disrupting compounds, may be of significant detriment to fishes in the Pee Dee River.

To further elucidate the impact and potential threat of water quality and contaminant dynamics on the robust redhorse, we proposed six research objectives to pursue in the Pee Dee River of North Carolina and South Carolina. We will (1) conduct systematic field sampling of habitat and food web components, (2) conduct experimental field bioassay exposures with captively-propagated fish, (3) perform laboratory analyses of traditional and emerging contaminants (4) determine aquatic food web structure, (5) develop population and food web models to describe effects of habitat and water quality modifications, and (6) synthesize results for robust redhorse recovery from population and ecosystem perspectives. This research is unique in that it will yield results and inference that are descriptive (systematic sampling), explanatory (experimental bioassays, food web analyses), and predictive (population and food web modeling) at multiple scales and across disciplines to inform decision making and management. If the proposed research is funded and conducted, it will guide management objectives and goals for species recovery and habitat restoration.

Genetic guidelines for Robust Redhorse reintroduction and supplementation in the Pee Dee River – Greg Moyer and Tanya Darden

A draft genetic guideline for Robust Redhorse reintroduction and supplementation in the Pee Dee River has been developed by the USFWS. This stocking plan describes how to minimize genetic risks and provides recommendations for the mating design, number of individuals to release, and collection and release techniques.

Table 3. The number of robust redhorse progeny needed to obtain 15 year classes of approximately 20-100 adults/age class assuming age-specific survival.Note that the overall estimate of adults in this scenario is 791 (sum of # of individuals from age-5 to age-20).

Age	# individuals	*S*
0	15,542	0.1
1	1,554	0.5
2	777	0.5
3	388	0.5
4	194	0.5
5	97	0.9
6	87	0.9
7	78	0.9
8	70	0.9
9	63	0.9
10	57	0.9
11	51	0.9
12	46	0.9
13	41	0.9
14	37	0.9
15	33	0.9
16	30	0.9
17	27	0.9
18	24	0.9
19	22	0.9
20	20	0.9

Robust redhorse, *Moxostoma robustum*, in the Broad River, Georgia 2012 Update – Carrie A. Straight and Byron J. Freeman

Movements. In 2010 and 2011, we tagged 20 robust redhorse with sonic tags (see table). Fifteen of the 20 individuals had coded-wire tags detected in a location indicating they were from the 1997 YC. We did not detect coded-wire tags in the remaining five individuals. We tagged all individuals within the influence of Clark's Hill Reservoir (Anthony Shoals) suggesting that they spent the winter prior to their tagging year within the reservoir. We had over 93,500 detections of 18 individuals. One individual (a male) either lost its tag or died within two weeks of its tagging. We failed to detect one individual (a female) since its tagging day. At least two individuals appeared to remain within the river during the winter of 2011-2012. Of the ten individuals detected within the main portion of Clark's Hill Reservoir, seven individuals were relocated upstream of the Broad River arm and three individuals were detected moving within the area downstream of the Broad River arm. One individual moved16 km downstream of Anthony Shoals within Clark's Hill Reservoir. In the springs of 2010, 2011, and 2012, we documented 10 of 18 tracked fish at or within 250 m of known spawning sites within the upper portion of the Broad River system. Five additional fish travelled at least 55 river km from Anthony Shoals upstream in the vicinity of known spawning locations, but were not located at any specific spawning location.

Sex, weight, and length of 20 robust redhorse, tagged and tracked within the Broad River system, Georgia.

	Weight (g)	**SL (mm)**	**TL (mm)**
Male (15)	2801 (1890-4330)	475.9 (439-555)	585.5 (535-690)
Female (5)	2974 (2490-3350)	482.2 (465-510)	589.4 (563-620)

<u>Locale-scale Spawning Site Characteristics</u>. There are five known spawning sites used by robust redhorse between 2007 and 2012. We have observed robust redhorse at two of these sites every year (except 2009 when water levels were too high to observe spawning fish). Two other sites have been used either intermittently and one site was first discovered in 2012.

In the spring of 2012, robust redhorse spawning occurred from April 26 to May 7. At peak spawning, the maximum number of fish at three sites totaled 103 individuals. We observed evidence of spawning at one additional site (freshly manipulated gravel similar to those at sites where fish were observed), but we observed no fish at this site. Using long-term temperature monitors, water temperatures in the Broad River ranged from 19.1-25.6 C with an average of 22.3 C. Spawning water temperatures in the Hudson River water temperatures ranged from 22.1-26.8 C and averaged 24.4 C. Water depth at 66 spawning locations averaged 0.4 m (SE = 0.01). Water velocity at the 66 sites averaged 0.57 m/s at 60% and 0.27 m/s on the bottom. At each spawning group in 2011 and 2012, we collected substrate samples that we sieved according to size fractions and weighed. The dominant size fraction for spawning sediment from 2011 was between 12.5 and 50 mm in diameter. We are in the process of completing 2012 samples.

<u>Juvenile Sampling</u>. In 2009, we randomly chose 21 sites between the influence of Clark's Hill reservoir upstream to above the known spawning locations. At 16 of 21 sites, we captured young-of-year suckers and included 13 *Moxostoma* sp. (jumprocks), 37 *Moxostoma collapsum*, and 34 *Minytrema melanops*. All of the young-of-year suckers occurred in sites within the upstream half of the area sampled. In 2011, we focused our efforts in the upstream section and sampled 14 sites. We sampled some of these locations both during the day and at night. Thirteen of fourteen sites had young-of-year suckers and included 12 *Moxostoma* sp. (jumprocks), 10 *Moxostoma collapsum*, and 12 *Minytrema melanops*.

<u>Landscape-scale Spawning Site Characteristics</u>. We are currently conducting a landscape scale analysis of stream characteristics of known spawning sites in the Broad River. We have divided the mainstem of Broad River and its major tributary into fine scale segments (100m) and coarse scale segments (16 segments based on contributing watershed area). Within these segments, we have calculated standardized slope, bank width, valley width, valley confinement (ratio of bankfull width to valley width), and elevation. Using these

variables, we hope to define characteristics of spawning sites relative to areas not used for spawning.

Acoustic Surveys of Spawning Suckers. One topic concerning reproductive behavior of robust redhorse is the influence of water releases from dams on interrupting spawning. If water levels permit, we will be looking at the influence of water releases on spawning behavior of river redhorse (*Moxostoma carinatum*) in the Coosawattee River and robust redhorse in the Savannah River in the spring of 2013. Spawning suckers create a distinctive acoustic signature relative to ambient river noises. Using long-term acoustic recordings, we can look at spawning frequency relative to time in the spawning season, time of day, and changes in water velocity. We plan to compare these measurements in regulated river reaches to those in the Broad River system that are not influenced by water releases from dams. In the spring of 2012, we collected 395 hours of acoustic data from the Broad River system and 120 hours from the Coosawattee River. We did not collect any data within the Savannah River because of low water levels and the odd timing of spawning robust redhorse in the Savannah River.

Occupancy and Habitat Use of Stocked Robust Redhorse in the Upper Reaches of the Ocmulgee River, GA – William A. Pruitt, James T. Peterson, Cecil A. Jennings
As part of Candidate Conservation Agreement with Assurances (CCAA) between Georgia Power, Georgia Department of Natural Resources, and the U.S. Fish and Wildlife Service, robust redhorse of mixed age classes of Oconee River broodstock were stocked into the upper reaches of the Ocmulgee River in attempt to establish a refugial population. Prior studies on the Ocmulgee examined the movement of introduced fish, and determined that robust redhorse capture probability was extremely low, and other methods (e.g., occupancy models) should be explored to determine the status of the Ocmulgee River population.

To determine habitat use of robust redhorse, we assessed physical in stream habitat (woody structure and substrate composition) using side-scanning sonar imagery, which was used in combination with other habitat data (current velocity, secchi depth, temperature, etc.) and fish capture data (via boat electrofishing), to be incorporated into zero-inflated occupancy models. We used an information theoretic approach to evaluate the scale of influence of various habitat characteristics on robust redhorse distribution in the upper reaches of the Ocmulgee River.

Our confidence set of occupancy models revealed that robust redhorse had an average conditional detection probability of 0.518 (±0.046); meaning samplers had about a 51.8% chance of detecting robust redhorse if the species was present in that unit at the time of sampling. Although detection was much higher than expected, occupancy was low in units containing shoals (0.281 ±0.049) and even lower in non-shoal habitats (0.038 ±0.011); meaning robust redhorse are 28.1% likely to be present in units containing shoals and 4.8% likely in units without a shoal present. In 2010-2012 sampling seasons, only seven robust redhorse were captured – all of which were captured within 1 km of Lloyd Shoals Dam. Robust redhorse occupancy was highest in units where coarse substrates (bedrock, boulders, gravel, etc) dominated the streambed, and fish generally avoided units containing abundant woody debris. Our results suggest that fish are either (1) residing in the inaccessible portions of the project site that contain relatively large amounts of coarse substrates, or (2) robust redhorse have left the project site entirely in search of the coastal plain habitats similar to those used by their Oconee River counterparts.

Abundance, size structure, spawning in Ogeechee River, Georgia – Patrick Ely………

TECHNICAL WORKING GROUP REPORTS

Oconee River Technical Working Group – Alice Lawrence
This presentation summarizes the tasks in the management plan that we addressed during the past year and presents the tasks that we are considering as our top priorities for the upcoming year:

Task: Continue to document spawning activity at known sites and identify any additional sites, and
Task: Continue evaluation of habitat augmentation and identify augmentation strategies to address habitat bottlenecks.
The Oconee TWG deemed monitoring of the gravel augmentation sites as one of the top three priorities for 2012. GDNR visually monitored gravel augmentation sites over a two-day period this spring; no robust redhorse were detected. An intern has been hired by GDNR, via mitigation funding from GDOT, to monitor the five gravel augmentation sites in the Oconee River more intensively in 2013. Monitoring will include visual observations for robust redhorse, collecting and analyzing subsequent seine samples for larval robust redhorse, and developing a summary report.

Task: Survey areas not specifically targeted in the past, sampled only sporadically, or outside the management unit, and
Task: Evaluate the need for establishing additional refugial populations.
The Oconee TWG deemed exploring if a remnant population exists above Sinclair Dam as one of the top three priorities for 2012. This is a necessary step before the group would consider introducing robust redhorse above Sinclair Dam. Reconnaissance surveys above Sinclair Dam took place in Fall-Winter 2012 in the Oconee River to Barnett Shoals Dam, Little River, Murder Creek, Apalachee River, Shoulderbone Creek, and Hard Labor Creek to assess available habitat and accessibility. Based on the results of those reconnaissance surveys, electrofishing surveys took place in spring 2012 in the Oconee River to Barnett Shoals Dam, Little River, and Murder Creek. One robust redhorse was collected in Little River. In Spring 2013, electrofishing and/or gillnet surveys are planned for the Oconee River to Barnett Shoals Dam, Wallace Dam tailrace, Little River, Apalachee River, and Shoulderbone Creek.

Task: Review existing data on habitat quality and quantity to develop a more accurate estimate of available habitat.
The Oconee TWG deemed providing Georgia Power with a formal flow tweak recommendation as one of the top three priorities for 2012. A sub-task in the management plan specifically mentions updating the flow regime at Sinclair Dam. Since the FERC license was issued for the project in the mid-1990's, we now have more information including robust redhorse population estimates, catch-per-unit-effort data, and now Jennings et al. 2008 that correlates abundance of larval and age-0 redhorse with April-June flow parameters. The Jennings et al. 2008 results include parameters that are slightly different than the current flow regime. A Flow Advisory Team meeting is to be

scheduled for fall 2012, in which the data results will be translated into a management recommendation for Georgia Power.

Task: Expand public outreach and outreach efforts.
The Service, with participation from Georgia Power, USGS, and GDNR, produced a short video highlighting the story of the robust redhorse and the benefits of CCAA's. The video has been featured on the Service's national homepage, the Service's regional Candidate Conservation webpage, GDNR's webpage, and the RRCC webpage. YouTube has recorded approximately 1,400 views in a six-week timeframe.

Task: Actively participate in the environmental review process, as appropriate.
Both the Service and GDNR are involved in the ongoing review process for an auxillary Macon Water Authority proposed water intake on the Ocmulgee River. The resource agencies have provided environmental recommendations including construction and operational timeframes, alternate designs, and monitoring recommendations to reduce impacts to anadromous fishes and robust redhorse.

Yadkin-Pee Dee Technical Work Group Activities – Ryan Heise
The long term goal of Yadkin-Pee Dee technical working group (TWG) is to ensure a viable, self-sustaining population of robust redhorse in the Pee Dee River. Thus, the TWG has continued discussions about supplementing the small population downstream of Blewett Falls Dam and reintroduction downstream from the Tillery Dam. Duke Energy has already begun implementing parts of the proposed FERC (Federal Energy Regulatory Commission) license and the issuance the new license is expected in 2013. The Yadkin-Pee Dee TWG has conducted numerous studies in the Pee Dee River allowing us to make informed decisions about robust redhorse management (see previous annual reports and publications on our website). We are pursuing a long term hatchery program at the Wildlife Recourses Commission's McKinney Lake Fish Hatchery and a pilot project is scheduled begin in the spring of 2013. Discussions are ongoing between Duke Energy, U.S. Fish and Wildlife Service, NC Wildlife Resources Commission, SC Department of Natural Resources concerning a possible conservation agreement.

Information Technology Technical Working Group – Jaci Zelko
Jaci asked all participants to check on their latest dataset and send updated copies to be included in the master spreadsheet.

Jaci relayed that the new protocol of each presenter submitting an abstract has greatly streamlined the annual report process. As of this meeting she has completed the 2003 – 2007 and 2009 – 2011 reports. These documents have been uploaded to the RRCC website. The missing reports from 2002 and 2008 are currently being written. The website has also been reorganized on some of the pages and a new YouTube video has been added as well as many other pictures and documents.

B U S I N E S S

Update on the 404 Species Petition – Sandy Tucker
The Service was taken to task for having a long list of candidate species. We agreed to review and address the needs of 251 candidate species over 6 years, to determine if they should be added to the ESA list. Sixty-one of these are in the Southeast Region.

The Service's 90-day finding, issued in September 2011, was prompted by an April 2010 petition to list 404 aquatic, riparian and wetland fish, plants and animals. The status reviews for 374 species will likely follow work on the court-approved, multi-year listing for the 251 species sometime after 2016. The robust redhorse is included in this group. With such a long list of species, and the fact that most of the species occur on private land, the FWS is engaging many partners in efforts to find out about and conserve these species.

Listings decisions are made solely on the basis of the best available scientific and commercial information. Listing determinations consider these five factors:

- The present or threatened destruction, modification, or curtailment of its habitat or range
- Overutilization for commercial, recreational, scientific or educational purposes
- Disease or predation
- The inadequacy of existing regulatory mechanisms
- Other natural or man-made factors affecting survival

The Policy for Evaluating Conservation Efforts addresses each of those five factors, and is guidance for how the FWS can evaluate the conservation efforts of the RRCC. The RRCC can give the 5 factors serious scrutiny and prepare a status assessment for the FWS that explains, with justification, why the RRH is stable or improving. Additional CCA/As would be useful – use the PECE to make them rock solid.

Candidate conservation agreements are formal partnerships involving any agency, specific conservation measures and no permit or regulatory assurances. A candidate conservation agreement with assurances involves non-Federal landowners and covers species whose threats are adequately understood. The conservation activities embodied in the agreement are expected to typify those needed to preclude listing. A permit is included that provides for incidental take of the species if it becomes listed. By signing onto the CCAA, the signatories receive assurance that no additional conservation actions will be required of them for that species within the covered area.

Installation of Incoming RRCC Chairperson – Ryan Heise
Alice Lawrence was installed as the new RRCC Chairperson by outgoing Chair Ryan Heise. She is very excited to be the new chair and was thankful for all of our dedication over the years to the robust redhorse recovery effort.

A T T A C H M E N T S

Attendees of the 2012 Meeting:

Name	Organization
Ryan Heise	NCWRC
David Wilkins	SC Aquarium
Brena Jones	NCWRC
Jaci Zelko	USFWS
Will Pruitt	UGA
Tom Kwak	NC State / USGS
Tom Thompson	Duke Energy
Tomas Ivasauskas	NCSU
Laura Belica	NCSU
Carrie Straight	UGA Ecology
John Fridell	USFWS
Dave Coughlan	Duke Energy
Cecil Jennings	USGS / UGA
Patrick Ely	UGA
Steve Zimpfer	UGA
Tanya Darden	SCDNR
Jimmy Evans	GADNR
Milton Ettelbaum	SCAASA / SCE&G
Tom Bowles	SCE&G
Andrea Leslie	NC NHP
Alice Lawrence	USFWS - Georgia Ecological Services
Nathan Farnau	Georgia Aquarium
Cory Brosius	Georgia Aquarium
Wayne Starnes	NC Museum Nat. Sciences
Greg Moyer	USFWS Warm Springs FTC
Laura Fogo	USFWS RFO
Cindy Carr	WRC
Sandy Tucker	USFWS
Scott Lamprecht	SCDNR
Rick Bradford	NCWRC

Appendix 3

Movement patterns, habitat use, and home range of adult robust redhorse *Moxostoma robustum* released into the Oconee River, Georgia

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Final Report

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EXECUTIVE SUMMARY

The robust redhorse *Moxostoma robustum* is a large, long-lived riverine catastomid native to Atlantic slope drainages in the southeastern United States. Currently, natural populations inhabit the Upper Coastal Plain ecoregion of the Oconee River, Georgia, the Piedmont and Upper Coastal Plain ecoregions of the Savannah River, Georgia/South Carolina, and the Pee Dee River, North Carolina/South Carolina. In 1995, the Robust Redhorse Conservation Committee (RRCC) was established under a memorandum of understanding between state and federal resource agencies, private industry, and academic institutions with the goal of developing and managing a recovery approach for the robust redhorse. Because of concerns over low recruitment rates and population declines in the Oconee River, the RRCC initiated a plan to create refugial populations by stocking hatchery-reared individuals, propagated from Oconee River broodstock, into the Ogeechee, Broad, and Ocmulgee rivers in Georgia. Our goal for this study was to use radio telemetry to assess the movement patterns and habitat use of adult robust redhorse in the section of the Oconee River referred to as the lower Oconee, which extends from Sinclair Dam down to its confluence with the Ocmulgee River. Because of diminishing catch rates of adults and a decline in the number of fish spawning annually at the historic Avant Mine gravel bar, we used naturalized hatchery-reared robust redhorse transplanted from the Ogeechee River as surrogates for wild Oconee River fish. Our specific objectives were to: 1) document movement patterns and habitat use, and estimate home range of robust redhorse in the lower Oconee River, 2) compare movement patterns, habitat use, and home range size of stocked fish during specified periods, and 3) use radio-tagged fish as guide fish to locate previously unknown spawning aggregations or population centers. From April 2008 through June 2010, radio-

tagged robust redhorse released into the Oconee River exhibited behavior patterns that were like wild fish, including making spawning migrations, forming spawning aggregates over habitat associated with gravel substrates and fast current, and returning to preferred non-spawning habitat (woody debris over sandy substrates, deep water with current) the remainder of the year. Tagged fish were located in previously unknown spawning locations in 2009 and 2010. Morphological changes to the main channel of the lower Oconee River seem to influence the recruitment and location of gravel substrate and consequently the location of spawning robust redhorse. Since 1994, declining catch rates indicate a severe reduction in the abundance of adult robust redhorse in areas of the Oconee River typically sampled during the spring (i.e., Central Georgia Railroad Trestle (CGRT) to Dublin, GA). However, during April 2004, May 2010, and May 2011, electrofishing surveys from the top of the study reach (i.e., Sinclair Dam) down to Dublin, GA were conducted. This effort was a multi-agency collaboration to address whether historic catch rates reflected overall population decline or if the population distribution shifted into areas above the CGRT that previously received limited sampling effort. Results of the April 2004 electrofishing survey documented a continued decline in catch rate from previous years but also indicated that most of the population was located in the previously restricted sampling area above the CGRT. The absence of robust redhorse from the 2010 and 2011 electrofishing surveys suggest that the abundance of wild-spawned adult robust redhorse in the lower Oconee River has continued to decline even though telemetry results indicate that robust redhorse, if present, would be located in the reach between the Avant Mine site and the CGRT. However, sampling data for the previously restricted area above the CGRT is still limited and additional electrofishing surveys in the area would help to verify the actual abundance and fate of adult robust redhorse in the lower Oconee River, Georgia.

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TABLE OF CONTENTS

INTRODUCTION

The robust redhorse *Moxostoma robustum* is a large, long-lived riverine catastomid, native to Atlantic slope drainages in the southeastern United States. The historic range included the Yadkin-Pee Dee River drainage in North Carolina/South Carolina southward to the Altamaha River basin in Georgia. The species was extirpated from much of its range and lost to science for over a century until its rediscovery in the Oconee River, Georgia, in 1991 (Evans 1994, Bryant et al. 1996; Ruetz and Jennings 2000). Currently, natural populations inhabit the Upper Coastal Plain ecoregion of the Oconee River, Georgia, the Piedmont and Upper Coastal Plain ecoregions of the Savannah River, Georgia/South Carolina, and the Pee Dee River, North Carolina/South Carolina. The imperiled robust redhorse is currently classified as Endangered by the Georgia Department of Natural Resources and is considered a Species of Special Concern by the U.S. Fish and Wildlife Service (RRCC 2010). Declines of robust redhorse have been attributed to increased sedimentation caused by deforestation and poor farming practices, which can degrade spawning sites, and to the construction of dams, which can block seasonal migrations, alter riverine flows, reduce water quality, and modify habitat (Evans 1994; Hendricks 1998; Cooke et al. 2005). Introduced species such as flathead catfish *Pylodictis olivaris*, which some believe may prey on robust redhorse (Bart et al. 1994; Hendricks 1998, 2002), are another potential cause for reduction in robust redhorse abundance.

Robust redhorse are potamodromous and make seasonal migrations sometimes over long distances, to spawning grounds and then return to preferred habitat the remainder of the year (Grabowski and Isely 2006; RRCC 2010). Adults form spawning aggregates over loose gravel substrate in moderate to swift current from late April to early June when water temperatures are between 18–24°C (Hendricks 1998; Freeman and Freeman 2001). Non-spawning adults in the Coastal Plain ecoregion are generally found in the bends of meandering rivers, usually with woody debris and deep water with moderate to swift current (Grabowski and Isely 2006; Grabowski and Jennings 2009; RRCC 2010). Spawning activity has only been documented in two locations along the Oconee River; these sites are located between Milledgeville and Dublin, Georgia and consist of 1) a near-shore to mid-channel gravel bar located in a section of meander bends below Ball's Ferry Landing at river kilometer (rkm) ~ 151 (RRCC 2010). This site was apparently abandoned several years prior to initiation of the current study (Jimmy Evans, Georgia Department of Natural Resources, personal communication); and 2) a larger mid-channel gravel bar adjacent to the Avant Kaolin Mine (rkm ~ 191; Freeman and Freeman 2001). Over the past decade, there has been a dramatic decrease in the number of individuals observed spawning at the Avant Mine gravel bar site as well as a continued decline in annual catch rates during electrofishing surveys and broodstock collection between the Central Georgia Railroad Trestle (CGRT; rkm ~166) and Dublin, Georgia (rkm ~ 120; RRCC 2010). These decreases have raised questions as to whether the overall Oconee River population is in decline or if unknown spawning aggregations or population centers exist elsewhere.

In 1995, the Robust Redhorse Conservation Committee (RRCC) was established under a memorandum of understanding between state and federal resource agencies, private industry, and academic institutions with the goal of developing and managing a recovery approach for the robust redhorse. Because of concerns over low recruitment rates and population declines of robust redhorse in the Oconee River, the RRCC initiated a plan to create refugial populations by stocking hatchery-reared individuals, propagated from Oconee River broodstock, into the Ogeechee, Broad, and Ocmulgee rivers in Georgia.

Radio telemetry has been used successfully to document dispersal rates, movement patterns, and habitat use of hatchery-reared juvenile robust redhorse released in the Oconee (Hess et al. 2001) and Ocmulgee (Jennings and Shepard 2003) rivers. Radio telemetry has also been used to determine movement patterns and habitat use of wild adult robust redhorse in the Savannah (Grabowski and Isely 2006) and Pee Dee (Fisk 2010) rivers, as well as hatchery-reared adult robust redhorse in the Broad (Freeman and Straight, in preparation) and Ocmulgee (Grabowski and Jennings 2009) rivers. Accordingly, radio telemetry was determined to be a suitable tool for addressing the questions about adult robust redhorse movement patterns, habitat use, and alternate spawning locations in the Oconee River. However, recent low catch rates in the Oconee River suggest that capturing sufficient numbers of individuals to effectively conduct a telemetry study might be problematic.

Hatchery-reared robust redhorse in refugial populations exist and have been successfully used as surrogates for wild robust redhorse in recent studies (Grabowski and Jennings 2009; Freeman and Straight, in preparation). Although some studies suggest that hatchery fish may have lower fitness levels than wild fish in a natural system (Bettinger and Bettoli 2002; Araki 2008), other studies indicate that the discrepancy in fitness levels between hatchery and wild fish becomes less obvious when the hatchery fish have been exposed and acclimated to a natural environment (Brown and Day 2002; Huntingford 2004). Grabowski and Jennings (2009) transplanted hatchery-reared adult robust redhorse from naturalized refuge populations in the Ogeechee and Broad rivers into the Ocmulgee River and used radio telemetry to document that hatchery-reared individuals adopted behavioral patterns that were analogous with those previously observed for radio-tagged wild fish in the Savannah River (Grabowski and Isely 2006). The recent successes by researchers (Jennings and Shepard 2003; Grabowski and Isely 2006; Graboswki and Jennings 2009; Fisk 2010) conducting telemetry studies on both hatchery-reared and wild individuals, coupled with the perceived decline in robust redhorse abundance, has renewed interests in the use of radio telemetry to address questions about the location and movements of adult robust redhorse in the Oconee River.

Our goal for this study was to use radio telemetry to assess the movement patterns and habitat use of adult robust redhorse stocked in the Oconee River, Georgia. Our specific objectives were to: 1) document movement patterns and habitat use, and estimate home range of robust redhorse in the Oconee River, 2) compare movement patterns, habitat use, and home range size of stocked fish during specified periods, and 3) use radio-tagged fish as guide fish to locate previously unknown spawning aggregations or population centers.

METHODS

Study Area

The Oconee River Basin drains approximately 13,800 km^2 and is located in the Piedmont and Coastal Plain of central Georgia (GAEPD 1998). The Oconee River is about 360 km long and converges with the Ocmulgee River to form the Altamaha River (Figure 1). Our study focused on the section of river referred to as the lower Oconee, which originates below Sinclair Dam and extends approximately 230 river kilometers (rkm) to the confluence with the Ocmulgee River. Sinclair Dam is a main-stem, Georgia Power Company hydroelectric facility that creates an impassable upstream barrier to fish.

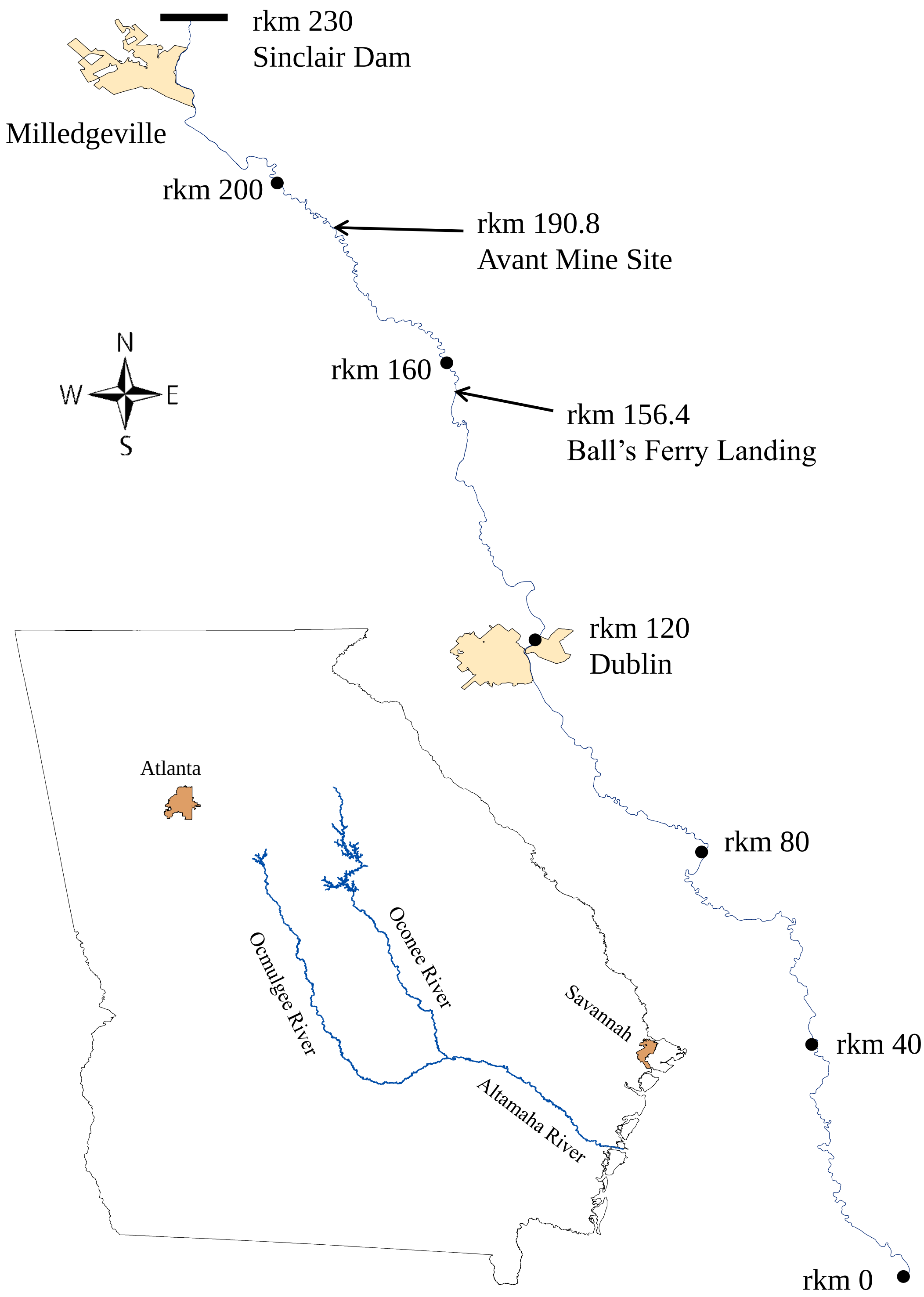


Figure 1. Map of the study area on the lower Oconee River, from its confluence with the Ocmulgee River at river kilometer (rkm) 0 to Sinclair Dam at rkm 230. The inset shows the location of the Altamaha River system in the state of Georgia.

Mean daily discharge from Sinclair Dam ranged from 6 m^3/s to 1280 m^3/s; mean daily water temperatures that occurred at robust redhorse relocations in the lower Oconee River during this study ranged from 7°C to 32°C (Figure 2).

Located directly below Sinclair Dam (rkm 230) is a small Piedmont reach that extends approximately 6 to 7 kilometers to Highway 22/24 (rkm ~ 223) in Milledgeville, Georgia. This section of river is primarily straight and cover generally consists of rocky shoals and boulders with occasional woody debris (i.e., fallen logs, branches, and stumps) and sediment types mostly consist of rocky substrates (i.e., bedrock, gravel, and cobble). The remaining portion of the Oconee River to the confluence primarily falls within the Upper Coastal Plain ecoregion and consists of meander sections with cover that generally includes woody debris, separated by long, straight reaches, and a few rocky shoals and boulders. Sediment types include sand, mud, and rocky substrates.

A mid-channel gravel bar located adjacent to the Avant Kaolin Mine is the last known spawning site of robust redhorse in the Oconee River, Georgia (Figure 3). In past observations, spawning aggregations at the Avant Mine site generally consisted of 30–50 adults, but recently the number of individuals has decreased substantially (RRCC 2010). The cause(s) for the decline in individuals at the spawning site is unclear, although morphological changes to the river channel may have negatively affected the suitability of the gravel bar as a spawning site. Over a decade ago, the creation of a new oxbow changed the course of the main river channel and moved it away from a gravel-embedded bluff located just upstream of the Avant Mine spawning site. Because the hydraulics of the river have changed (Figure 3), flows that previously eroded the bluff and transported new gravel downstream to the spawning site occur much less often than before the oxbow was created. As a result, the lack of new gravel input could have negatively affected the suitability of the Avant Mine gravel bar as a spawning site and caused the fish to seek

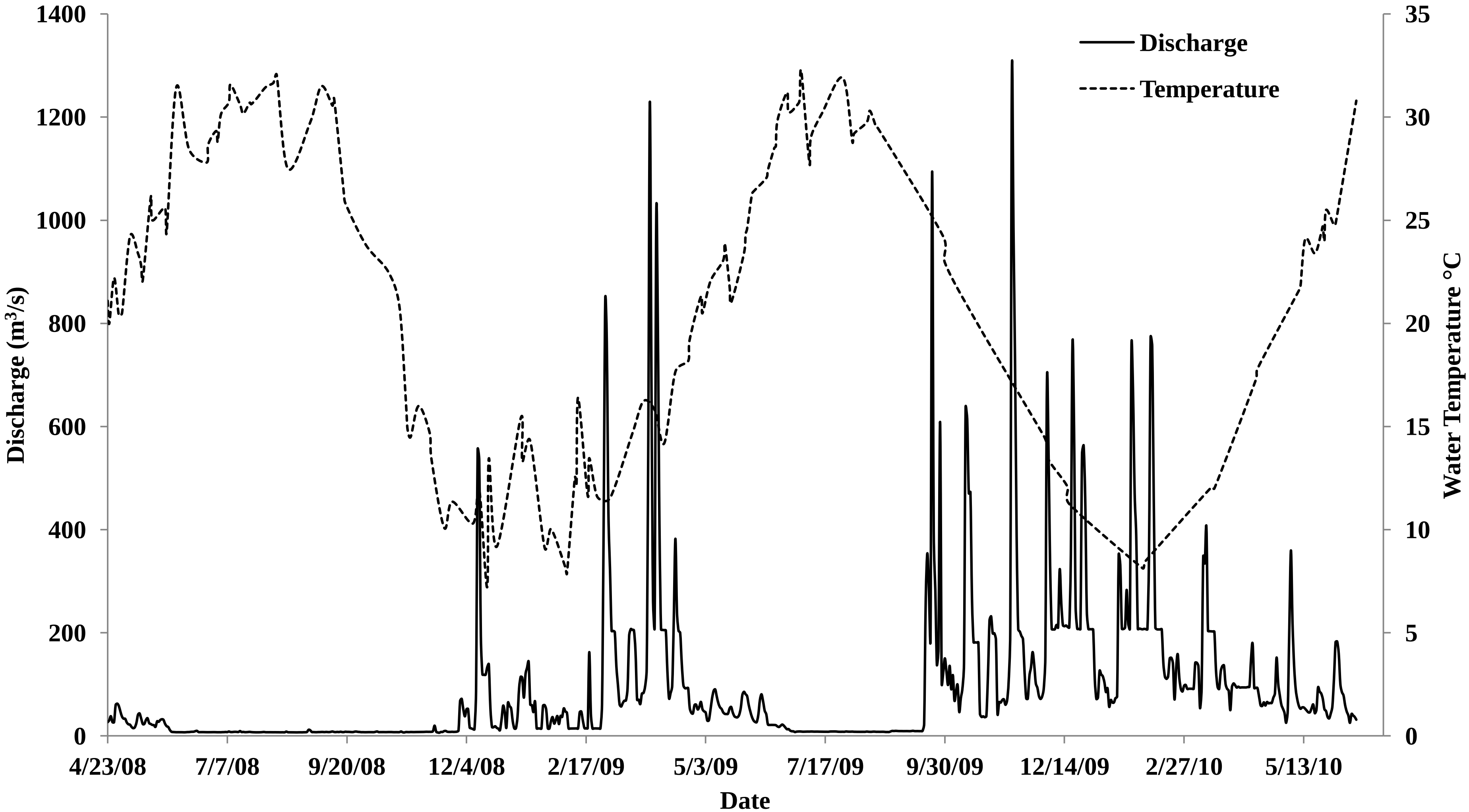


Figure 2. Mean daily water temperatures (dashed line) taken from radio-tagged robust redhorse relocations throughout the lower Oconee River and mean daily discharge (solid line) below Sinclair Dam (U.S. Geological Survey gauging station 0223000 on the Oconee River at Milledgeville, Georgia) between April 2008 and June 2010.

Figure 3. Satellite image from 2009 of the lower Oconee River, Georgia, at the Avant Mine site. The historic gravel bar (rkm 190.8), old river channel, and flow direction are marked and labeled with white arrows. The old river channel was confirmed from satellite imagery taken in 1993.

alternate spawning locations. Gravel substrates similar to those at the Avant Mine site have been documented in other locations in the Oconee River (Jimmy Evans, Georgia Department of Natural Resources, personal communication; EA 1994), and undiscovered spawning sites may exist elsewhere in the system.

Fish Sampling

Boat-mounted electrofishing was used to collect 33 adult robust redhorse (448−576 mm TL, 1270−2980 g) from a naturalized population of robust redhorse in the Ogeechee River, Georgia. These fish were hatchery-produced progeny of Oconee River broodstock that had been stocked into the Ogeechee River as fingerlings over multiple years from 1997 to 2004. Following collection on 23 April (n=17) and 24 April (n=10) 2008, a total of 27 study fish were placed in oxygenated hauling tanks and transported to Ball's Ferry Landing on the Oconee River for surgery and release the day of capture. To assess capture-related handling mortality, six other individuals were collected and transported to the University of Georgia's Whitehall Fisheries Laboratory on 18 April (n=4) and 24 April (n=2) 2008 and held in an aerated 500-L fiberglass tank for 4 to 10 days prior to transmitter implantation. Following surgery on 28 April 2008, tagged fish were held for an additional four days to monitor recovery before being transported to Ball's Ferry Landing where they were released into the river on 02 May 2008.

Transmitter Implantation

An internal radio transmitter (Model F1850) with a trailing whip antenna (Advanced Telemetry Systems [ATS] Inc., Isanti, Minnesota) was surgically implanted into each study fish. Each transmitter was uniquely coded by frequency, possessed a minimum battery life of 708 days, and weighed approximately 23 g in air. In an effort to decrease mortality and avoid alteration of fish behavior following implantation, all transmitters were less than 2% of the body weight of the smallest study fish, per the recommendations of Winter (1996). Prior to surgery, each fish was anesthetized in a solution of 140 mg/l sodium bicarbonate buffered tricaine methanesulfonate (MS-222). Once a fish was anesthetized, an electronic, handheld wand detector (Northwest Marine Technology Inc., Shaw Island, Washington) was used to magnetically check for the presence of a coded wire tag (CWT), and a passive integrated transponder (PIT) tag (Biomark Inc., Boise, Idaho) was implanted just below the distal end of the dorsal fin. The location (e.g., cheek, pelvic fin, pectoral fin, anal fin) of the CWT, which was used to code for year class during initial stocking in the Ogeechee River, and number of the PIT tag were recorded. The fish was then placed ventral side up into a surgery cradle fitted to the top of a 48-quart cooler containing an aerated, sedative solution (70 mg/L) of buffered MS-222, which was pumped through the fish's gills during surgery (see Jennings and Shepard 2003). A surgical scalpel (No. 11 blade) was used to make a small (≤ 3 cm) midline incision just below the pectoral fins and a radio transmitter was implanted into the peritoneal cavity of the fish. The whip antenna was allowed to exit the fish's body through a small opening created by a hollow surgical needle about 4 cm below the incision. Ethicon® 2-0 PDS II suture material with a FS-1 reverse cutting needle was used to close the incision with 3–4 interrupted sutures. The surgical procedure for each robust redhorse took about 6 minutes to complete. After surgery, tagged individuals were monitored in a separate recovery tank for 15–30 minutes prior to release.

Fish Relocation and Environmental Data Collection

Radio-tagged robust redhorse were monitored by boat weekly to bi-weekly for 16 months and then monthly for the remaining 10 months of the study except during spawning season (May), when tagged fish were relocated multiple days a week. If any of the tagged fish could not be relocated in the lower Oconee River, then tracking was extended upstream into the Ocmulgee River and along the entire length of the Altamaha River. Two separate 24-hr tracking events (15–16 April 2009, 21–22 October 2009) also were conducted; during each event, three to four individuals were relocated every 2 hours over a continuous 24-hr period. Night tracking during the October event was temporarily interrupted because of dense fog, which rendered navigation hazardous.

An ATS R2100 scanning radio receiver with a tunable loop antenna was used to relocate study fish. Once a fish had been detected, tracking continued in the direction of the strongest signal. When the signal reached its peak, the loop antenna was replaced with a less-sensitive, lower-gain, 18-cm straight antenna, then with a weaker 5-cm straight antenna until the strongest signal was observed. At this point, the antenna was removed. The specific location of a fish was determined when the boat was positioned directly over a tagged fish; this positioning allowed for the strongest, omnidirectional signal to be observed without the use of an antenna. Once a transmitter's position had been confirmed within about ± 1.5 m, a Garmin® high-sensitivity, handheld, WAAS (Wide Area Augmentation System)-enabled GPS receiver (Garmin International Inc., Olathe, Kansas) was used to record the location (latitude, longitude; accuracy ± 3 m) of the fish. Prior to data analysis, ArcGIS® 9.3.1 mapping software (Environmental Systems Research Institute, Redlands, California) was used to convert GPS positions (latitude, longitude) into river kilometers (rkm). Depth, current velocity, water temperature, dissolved oxygen (DO), turbidity, dominant cover type, and substrate composition were recorded at fish relocations[1]. Dominant cover was classified as woody debris, rocks (> 256 mm), or none (i.e., no cover). Substrate composition was classified as muddy (< 0.06 mm), sandy (0.06–2.00 mm), or rocky (2.00–256 mm).

Data Analysis

<u>Time period movement patterns</u>

Methods similar to those of Grabowski and Isely (2006) and Grabowski and Jennings (2009) were used to determine movement patterns of radio-tagged robust redhorse. Movement patterns were grouped into time periods (n=5) based on calendar month and the migratory behavior of tagged robust redhorse. They were: 1) Summer (July – August); 2) Fall (September – November); 3) Winter (December – February); 4) Pre-spawn (March – April); and 5) Spawning/ Post-spawn (May – June). For every individual, absolute distance moved, displacement, and linear home range were calculated for each time period. Absolute distance moved was defined as the sum of the distance moved between relocations without regard to direction and was calculated as $|P_{t+1} - P_t|$, where P_t is an individual's position in rkm at time t and P_{t+1} is the same individual's position at time $t+1$. Displacement, defined as the net distance moved, was calculated as $P_{t+1} - P_t$, where upstream movements were designated as positive integers and downstream movements were designated as negative integers (Grabowski and Jennings 2009). Time period absolute movement and displacement were calculated by summing each individual's movements for each time period. Linear home range was defined as the distance between the most upstream and most downstream location in rkm for an individual within a time period (Grabowski and Isely 2006).

[1] Water quality and habitat data were not taken during the 24-hr tracking events to avoid influencing an individual's movement or behavior.

Shapiro–Wilk and Levene's tests were used, respectively, to determine whether data needed to calculate absolute distance moved, linear home range, and displacement were normally distributed and homoscedastic (Zar 1996). PROC RANK (SAS institute Inc. 2008) was used to rank transform movement data for absolute movement and linear home range, so parametric tests could be used for statistical analysis (Conover and Inman 1981; Hobbs 2009).

A mixed-model analysis of variance (ANOVA) was used to determine if absolute movement and linear home range differed among time periods (fixed effects) while controlling for individuals and year (random effects; Zar 1996). A Tukey–Kramer pair-wise comparison was used to determine differences among time-periods for both absolute movement and linear home range (SAS institute Inc. 2008). A non-parametric Kruskal–Wallis test was used to determine if mean displacement differed among time periods (Sokal and Rohlf 1995). Additionally, for each movement test, median values were calculated by time period and used to determine if the reported mean values were being skewed by variability among individual study fish.

Finally, absolute distance moved, displacement, and linear home range were used to describe 24-hr tracking events by month (October, April) and diel period (Day, Night). Median movement was not reported for 24-hr tracking data because of the limited number of individuals. A significance level (α) of 0.05 was used for all movement tests, and mean movements are reported with 95% confidence intervals (95% CI) unless otherwise noted.

Time period and directional habitat use/water quality

Methods similar to those of Grabowski and Jennings (2009) were used to determine habitat and water quality associations of radio-tagged robust redhorse.

Shapiro–Wilk and Levene's tests, respectively, were used to determine whether data needed to calculate mean depth, current velocity, temperature, dissolved oxygen (DO), and turbidity were normally distributed and homoscedastic (Zar 1996). PROC RANK (SAS institute Inc. 2008) was used to rank transform movement data for depth and current velocity so parametric tests could be used for statistical analysis (Conover and Inman 1981; Hobbs 2009). A mixed-model analysis of variance (ANOVA) was used to determine if mean depth and current velocity differed among time periods (fixed effects) while controlling for individuals and year (random effects; Zar 1996). Time period was used as a random effect when determining if depth and current velocity differed by direction (upstream or downstream) relative to the release location (Ball's Ferry Landing). A Tukey–Kramer pair-wise comparison was used to determine differences among time periods for both depth and current velocity (SAS institute Inc. 2008). A Kruskal–Wallis (non-parametric) test was used to determine if mean temperature, dissolved oxygen, and turbidity differed among time periods, and a Wilcoxon–Mann–Whitney (non-parametric) test was used to determine if those means differed by direction (upstream or downstream) relative to Ball's Ferry Landing (Sokal and Rohlf 1995). The amount of habitat (i.e., cover, substrate, depth, velocity) available to radio-tagged robust redhorse in the lower Oconee River was not assessed during this study. Therefore, all comparisons of habitat use are based only on instantaneous observations of tagged fish.

Directionality

Although rocky cover and substrate were present upstream of Ball's Ferry Landing and are the dominate cover and substrate type from Sinclair Dam to Hwy 22/24 in Milledgeville, there also appeared to be a considerable amount of rocky cover and substrate downstream of the release point (Ball's Ferry Landing), particularly near the city of Dublin, Georgia. Additionally, during time periods of limited movement, study fish generally were separated into two distinct groups; one group (i.e., ~75% of the study population) was located about 25 rkm upstream of Ball's Ferry Landing and the other group (i.e., the remaining ~25% of the study population) was located about 30 rkm downstream of Ball's Ferry Landing. Because of the distance and potential differences in available habitat we divided observations of radio-tagged robust redhorse into two groups based on their directional relationship to Ball's Ferry Landing (upstream or downstream) to see if there were any differences in habitat associations between the two.

A Pearson's chi-squared test was used to evaluate differences in substrate among time periods and by directionality (upstream or downstream) in relation to Ball's Ferry Landing. A Fisher's exact test and a Monte Carlo simulated Fisher's exact test were used to detect differences in cover type by directionality and time period, respectively (Sokal and Rohlf 1995; SAS institute Inc. 2008). A significance level (α) of 0.05 was used for habitat tests and means are reported with 95% confidence intervals (95% CI) unless otherwise noted.

<u>Spawning versus non-spawning</u>

Habitat associations were additionally separated into two spawning classification periods ("spawning" and "non-spawning"). The "spawning" period was delineated as May 1 – May 31 and was determined by the following criteria: 1) water temperatures were between 17–26.7°C (Freeman and Freeman 2001); 2) a majority of tagged fish had migrated toward areas with gravel substrate; and 3) some fish were found in close proximity to each other near gravel substrates in water velocities ≥ 0.2 m/s (EA 1994; Freeman and Freeman 2001). Robust redhorse were considered in the "non-spawning" period if all three of the criteria were not met (i.e., all other months besides May). For substrate comparisons between the spawning and non-spawning periods, rocky sediment (2–256 mm) was further separated into two size classes; gravel (2–64 mm) and cobble (64–256 mm). A mixed-model analysis of variance (ANOVA) was used to determine if depth and current velocity differed between spawning and non-spawning periods (fixed effects) while controlling for individuals and year (random effects; Zar 1996). A Pearson's chi-squared test and a Fisher's exact test were used to determine differences in substrate and cover, respectively, between the spawning and non-spawning periods (Sokal and Rohlf 1995). A significance level (α) of 0.05 was used for habitat tests and means are reported with 95% confidence intervals (95% CI) unless otherwise noted.

Annual home range

Kernel density estimates for tagged robust redhorse were calculated for the first year of the study (July 2008 – June 2009) by using a similar procedure described by Vokoun (2003). In an effort to maintain a reasonable sample size while decreasing autocorrelation caused by the variability of the tracking schedule; we only used fish that had $\geq$ 25 relocations with a minimum sampling interval of 5 days in the analysis (Otis and White 1999; Malindzak 2006). The location coordinates taken for each fish were imported into ArcMap 9.3.1 software. ArcMap 9.3.1 and digital aerial photographs from 2007–2009 were used to create a line that traced the middle of the river channel from Sinclair Dam down to the confluence. Reference points were distributed every 10 m along the entire river line and each fish location was rounded to the nearest 10-m reference point. The referenced fish locations were then exported into SAS 9.1 where kernel density estimates of home range were calculated with the Kernel Density Estimation procedure (i.e., PROC KDE). Bandwidth was selected using the Sheather–Jones plug-in method (Jones et al. 1996; Vokoun 2003), and grid points were set at 10-

unit intervals corresponding to the 10-m reference points. The utilization distribution (i.e., UD), which is a delineated distance that has a defined probability of an individual's occurrence (i.e., percentage of time spent) during a particular time period (White and Garrott 1990; Vokoun 2003), was specified to output the 99%, 95%, 90%, and 50% level home range estimates. The 50% level UD estimate has been referred to as an animal's core area and is the area in which an animal has been estimated to spend 50% of its time during the period of interest (Blundell et al. 2001). The annual linear home range was also calculated for each fish and was defined as the distance between the most upstream and downstream locations along the river line (Logan 1963; Vokoun 2003).

RESULTS

Between 23 April 2008 and 02 July 2010, there were 999 relocations of radio-tagged robust redhorse released into the lower Oconee River, Georgia. All transmitters were relocated at least three times during the study, and live individuals were relocated from 3 to 72 times. Each fish was relocated an average of 31 (95% CI = 23–40) times.

Time Period Movement Patterns

Absolute movement

Mean absolute movement during the fall, pre-spawn and spawning/post-spawn time periods were similar to each other (mean range = 41.7–58.6 rkm) but significantly higher than during the summer (8.8 ± 6.7 rkm; mean ± 95% CI) and winter (9.0 ± 5.0 rkm; mean ± 95% CI) periods ($t_{88} \leq 8.41$; $P < 0.0001$; Figure 3). Median absolute movement (median range = 2.0–40.8 rkm) was 23–72% smaller than mean absolute movement (mean range = 8.8–58.6 rkm) throughout the study.

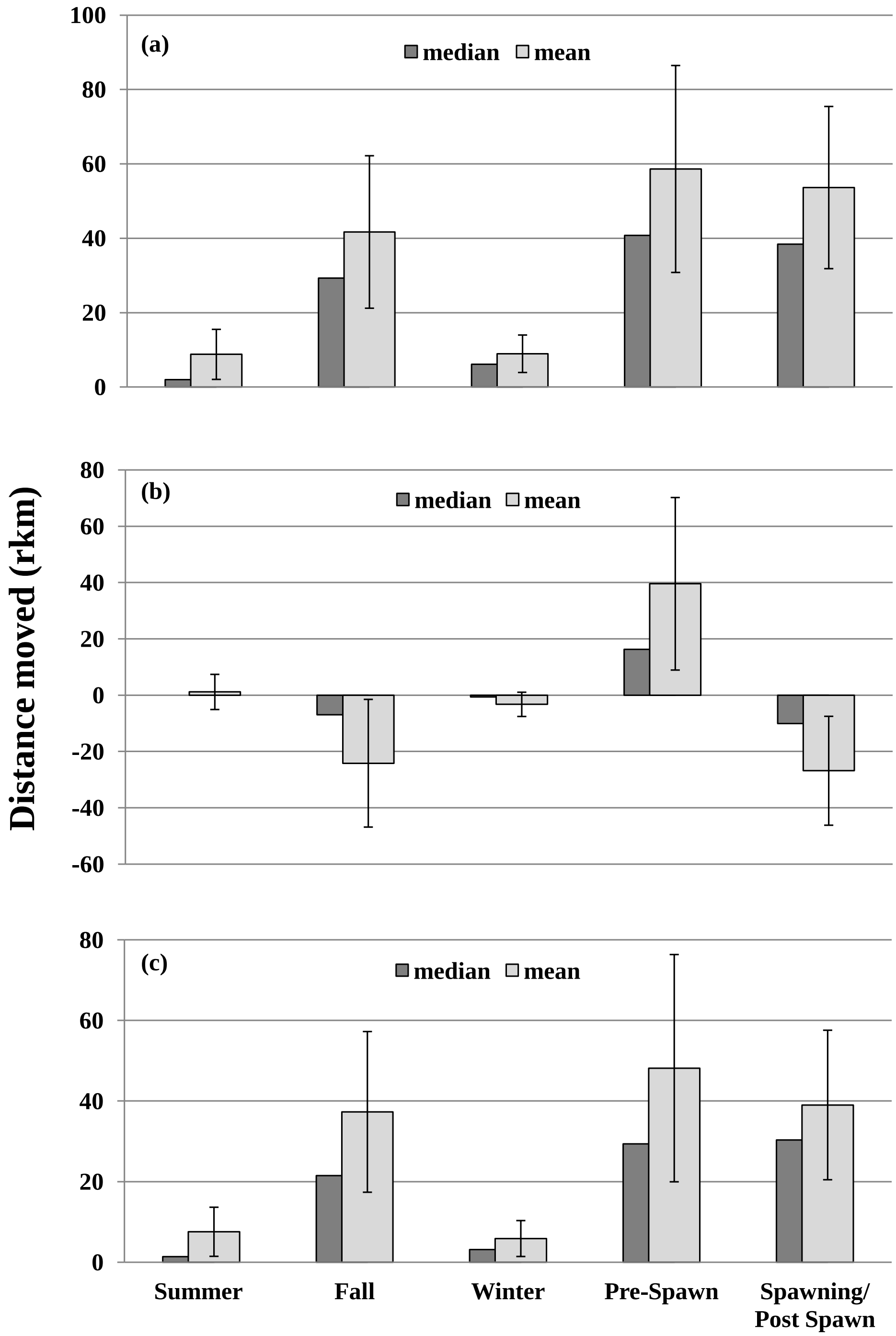


Figure 3. Mean (± 95% CI) and median time period; (a) absolute movement, (b) displacement, and (c) linear home range of radio-tagged robust redhorse in the lower Oconee River, Georgia, from July 2008 to June 2010.

Linear home range

Similar to absolute movement, mean linear home range during the fall, pre-spawn and spawning/post-spawn time periods were similar to each other (mean range = 37.3–48.2 rkm) but significantly higher than during the summer (7.5 ± 6.1 rkm; mean ± 95% CI) and winter (5.9 ± 4.5 rkm; mean ± 95% CI) periods ($t_{88} \leq 8.04$; $P < 0.0001$; Figure 3). Median linear home range (median range = 1.4–30.3 rkm) was 18–78% smaller than mean linear home range (mean range = 5.9–48.2 rkm) throughout the study.

Displacement

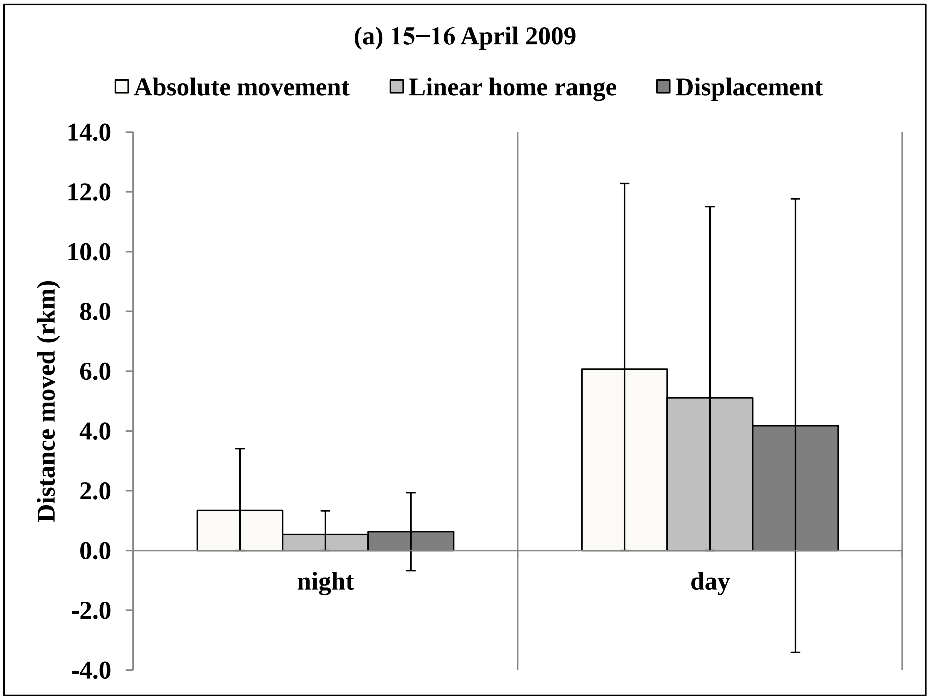
Displacement varied among time periods ($H = 33.1$; d.f. = 4; $P < 0.0001$) with the largest upstream movements having occurred during the pre-spawning period (39.6 ± 30.6 rkm; mean ± 95% CI); whereas, the largest downstream movements were observed during the spawning/post spawn (-26.8 ± 19.3 rkm; mean ± 95% CI) and fall (-24.2 ± 22.7 rkm; mean ± 95% CI) time periods (Figure 3). Mean displacement observed during the summer (1.2 ± 6.2 rkm; mean ± 95% CI) and winter (-3.2 ± 4.3 rkm; mean ± 95% CI) periods were limited. Median displacement (median range = -10.1–16.3 rkm) was 0–41% smaller than mean displacement (mean range = -26.8–39.6 rkm) throughout the study.

24-hr tracking

From 15 to 16 April 2009, four live radio-tagged robust redhorse were relocated about once every 2 hrs for 24 continuous hours; there was a total of 51 relocations with three individuals relocated 13 times and the other individual relocated 12 times. From 21 to 22 October 2009, three live individuals were relocated about once every 2.6 hrs for 24 continuous hours; there was a total of 29 relocations with two individuals relocated 10 times and the other individual relocated 9 times.

In April, absolute movement averaged 1.3 rkm (95% CI = 0.0–3.4 rkm) at night and 6.1 rkm (95% CI = 0.0–12.3 rkm) during the day (Figure 4). Similarly, linear home range averaged 0.5 rkm (95% CI = 0.0–1.3 rkm) at night and 5.1 rkm (95% CI = 0.0–11.5 rkm) during the day; displacement averaged 0.6 rkm (95% CI = -0.7–1.9 rkm) at night and 4.2 rkm (95% CI = -3.4–11.8 rkm) during the day (Figure 4). Two of the four fish moved upstream about 9.5–10.0 rkm during daylight hours (Figure 5). Of the remaining two fish, one sedentary robust redhorse demonstrated limited absolute movement throughout the 24-hr study period and the other fish exhibited limited displacement by going upstream and then returning back to its original spot (Figure 5).

In October, absolute movement averaged 0.2 rkm (95% CI = 0.0–0.5 rkm) at night and 0.4 rkm (95% CI = 0.0–1.2 rkm) during the day (Figure 4). Similarly, linear home range averaged 0.1 rkm (95% CI = 0.0–0.3 rkm) at night and 0.3 rkm (95% CI = 0.0–0.8 rkm) during the day; displacement averaged 0.0 rkm (95% CI = -0.1–0.1 rkm) at night and 0.1 rkm (95% CI = -0.5–0.7 rkm) during the day (Figure 4). Two fish made small localized moments during the day, but without obvious directional displacement and the remaining fish was mostly sedentary throughout the 24-hr study period (Figure 5).



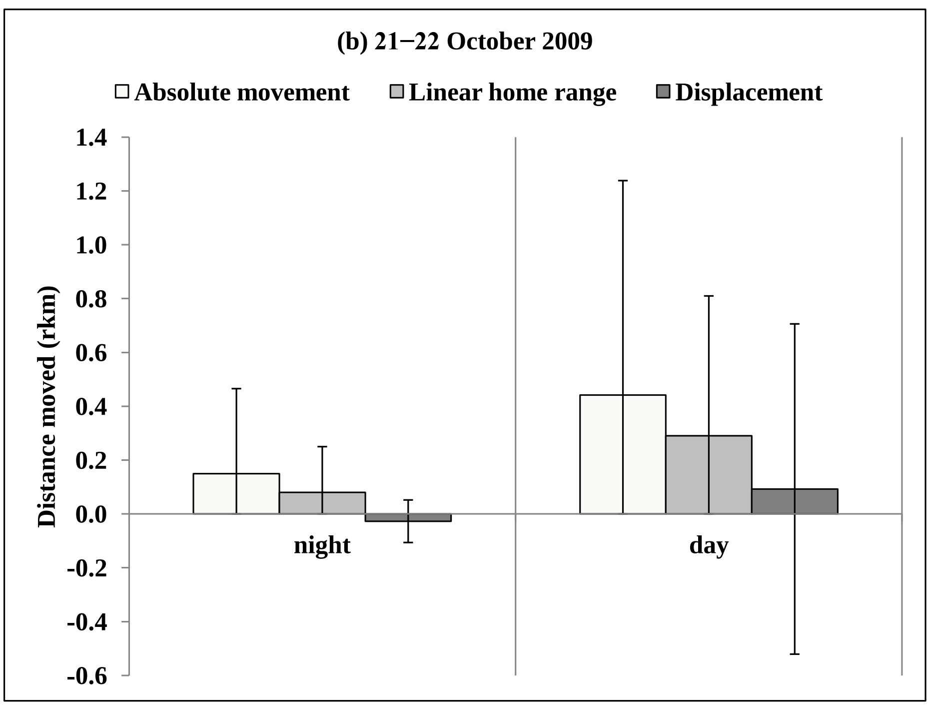
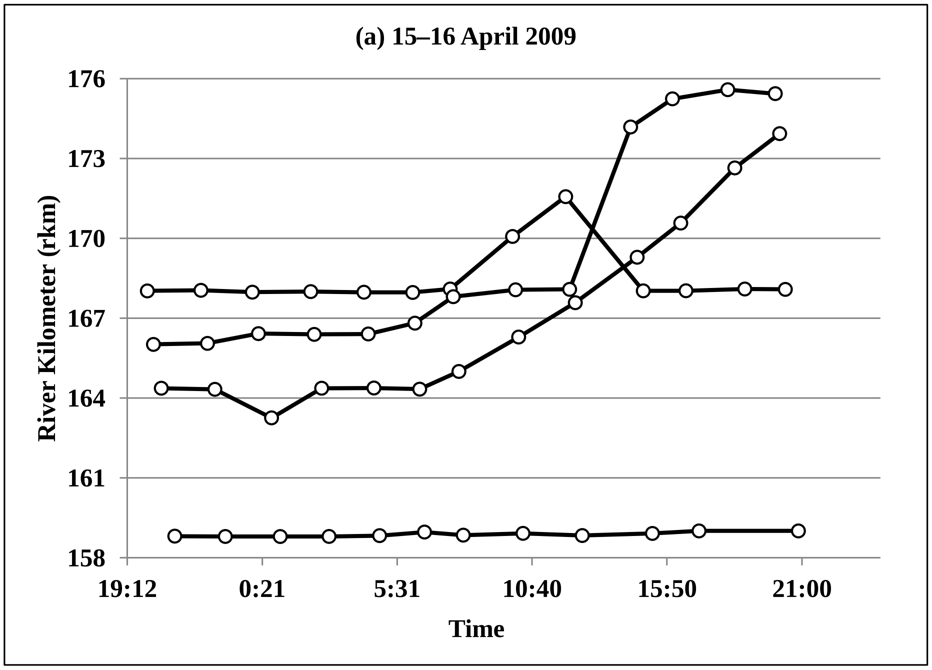


Figure 4. Mean (± 95% CI) 24-hour absolute movement, linear home range, and displacement for radio-tagged robust redhorse in the lower Oconee River, Georgia, on (a) 15–16 April 2009 and (b) 21–22 October 2009.



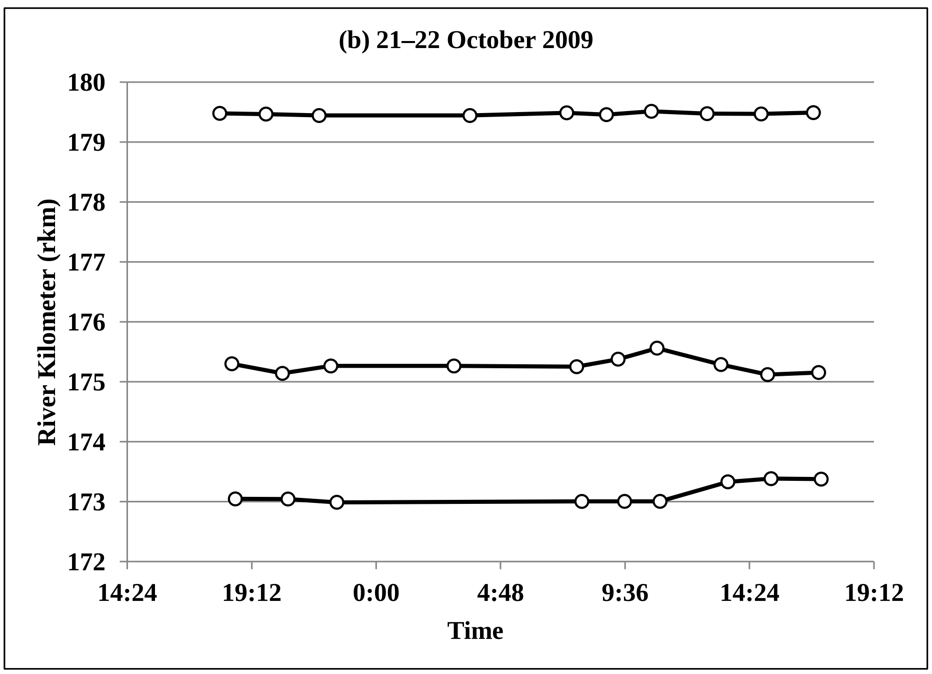


Figure 5. Relocations (rkm) of individual radio-tagged robust redhorse in the lower Oconee River, Georgia, tracked over a 24-hour period during (a) 15–16 April 2009 and (b) 21–22 October 2009.

Time Period and Directional Habitat Use/Water Quality

Depth

Radio-tagged robust redhorse were relocated in similar shallow depths during the summer (1.8 ± 0.1 m; mean ± 95% CI) and fall (2.0 ± 0.2 m; mean ± 95% CI) periods but were located in significantly deeper water (3.4 ± 0.4 m; mean ± 95% CI) during the pre-spawning period compared to all other time periods ($t_{85} \leq 8.40$; $P \leq 0.0051$; Table 1). Mean water depth was not related to directionality upstream or downstream of Ball's Ferry Landing ($F_{1,32} = 0.08$; $P = 0.7788$; Table 1). In general, robust redhorse appeared to favor deep water regardless of time period.

Current velocity and water quality

Current velocities occupied by radio-tagged robust redhorse during the summer (0.22 ± 0.03 m/s; mean ± 95% CI) and fall (0.22 ± 0.07 m/s; mean ± 95% CI) periods were similar to each other but significantly lower than all other time periods (mean range = 0.54–0.68 m/s) ($t_{84} \leq 11.53$; $P < 0.0001$; Table 1). Mean current velocity was not related to directionality upstream or downstream of Ball's Ferry Landing ($F_{1,31} = 0.86$; $P = 0.3611$). Mean temperature (mean range = 10.9–30.2^{o}C), dissolved oxygen (mean range = 7.4–9.5 mg/l), and turbidity (mean range = 12.6–51.6 ntu) varied among different time periods ($H \leq 342.0$, d.f.= 4; $P < 0.0001$; Table 1), but did not differ by directionality upstream or downstream of Ball's Ferry Landing ($z \leq 0.14$; $P \geq 0.0672$).

Table 1. Mean (± 95% CI) and range (minimum, maximum) of environmental measurements for robust redhorse relocations and the directionality of individuals located upstream or downstream of Ball's Ferry Landing according to time period from July 2008 to June 2010.

Time Period	Depth (m)	Current Velocity (m/s)	Temperature (°C)	DO (mg/l)	Turbidity (ntu)	Directionality	
						Upstream	Downstream
Summer (July – Aug)	1.8 (± 0.1) 0.5 3.5	0.22 (± 0.03) -0.08 0.75	30.2 (± 0.3) 24.1 34.0	7.4 (± 0.3) 5.6 9.8	13.0 (± 1.3) 3.0 33.5	84% (n=21)	16% (n=4)
Fall (Sept – Nov)	2.0 (± 0.2) 0.5 4.0	0.22 (± 0.07) -0.04 0.88	20.9 (± 1.8) 10.0 34.5	8.5 (± 0.5) 5.0 10.2	12.6 (± 2.8) 3.0 41.1	64% (n=14)	36% (n=8)
Winter (Dec – Feb)	2.5 (± 0.2) 0.8 5.0	0.54 (± 0.07) 0.00 1.20	10.9 (± 0.5) 7.0 16.4	9.5 (± 0.2) 8.1 11.3	22.2 (± 1.9) 10.2 50.5	61% (n=11)	39% (n=7)
Pre-Spawn (March – April)	3.4 (± 0.4) 0.8 5.3	0.68 (± 0.09) 0.10 1.21	15.9 (± 0.6) 11.0 21.3	8.7 (± 0.3) 7.4 12.5	51.6 (± 5.8) 14.1 85.0	94% (n=16)	6% (n=1)
Spawning/Post Spawn (May – June)	2.6 (± 0.2) 1.0 4.6	0.65 (± 0.05) 0.00 1.45	24.7 (± 0.5) 19.2 32.6	7.4 (± 0.1) 5.8 9.5	34.6 (± 1.9) 9.1 58.1	71% (n=10)	29% (n=4)

Cover

During all time periods, regardless of directionality (upstream or downstream) to Ball's Ferry Landing, robust redhorse were primarily associated with woody debris (78.2%; Figure 6). Lack of cover (18.7%) and rocks (3.0%) were the second and third most observed cover types, respectively (Figure 6). The type of cover robust redhorse were associated with varied among time periods ($\chi^2 = 39.0$; d.f. = 8; $P < 0.0001$) and tagged fish were more often located in areas without cover during the pre-spawn (25.3%) and spawning/post-spawn (33.1%) periods, compared to all other time periods (range = 10.3–12.6%; Figure 7). Fish located downstream of Ball's Ferry Landing were more likely to be associated with rocky cover (13.5%) than upstream fish (0.6%) ($\chi^2 = 57.9$; d.f. = 2; $P < 0.0001$; Figure 6).

Substrate

For all time periods, regardless of directionality to Ball's Ferry Landing, robust redhorse were detected primarily over sandy substrates (59.9%; Figure 6). The type of substrate robust redhorse were associated with varied among time periods ($\chi^2 = 28.7$; d.f. = 8; $P = 0.0004$) and tagged fish were less likely to be detected over muddy substrate during the pre-spawn (16.7%) and spawning/post-spawn (14.9%) periods, compared to all other time periods (range = 25.6–30.4%; Figure 7). Robust redhorse were more likely to be associated with rocky substrate during the fall, pre-spawning, and spawning/post spawn time periods (range = 21.6–29.2%) as compared to the summer (11.6%) and winter (13.8%) periods (Figure 7). Study fish located downstream of Ball's Ferry Landing were more likely to be found over rocky substrate (35.6%) than upstream fish (13.6%) ($\chi^2 = 42.3$; d.f. = 2; $P < 0.0001$; Figure 6).

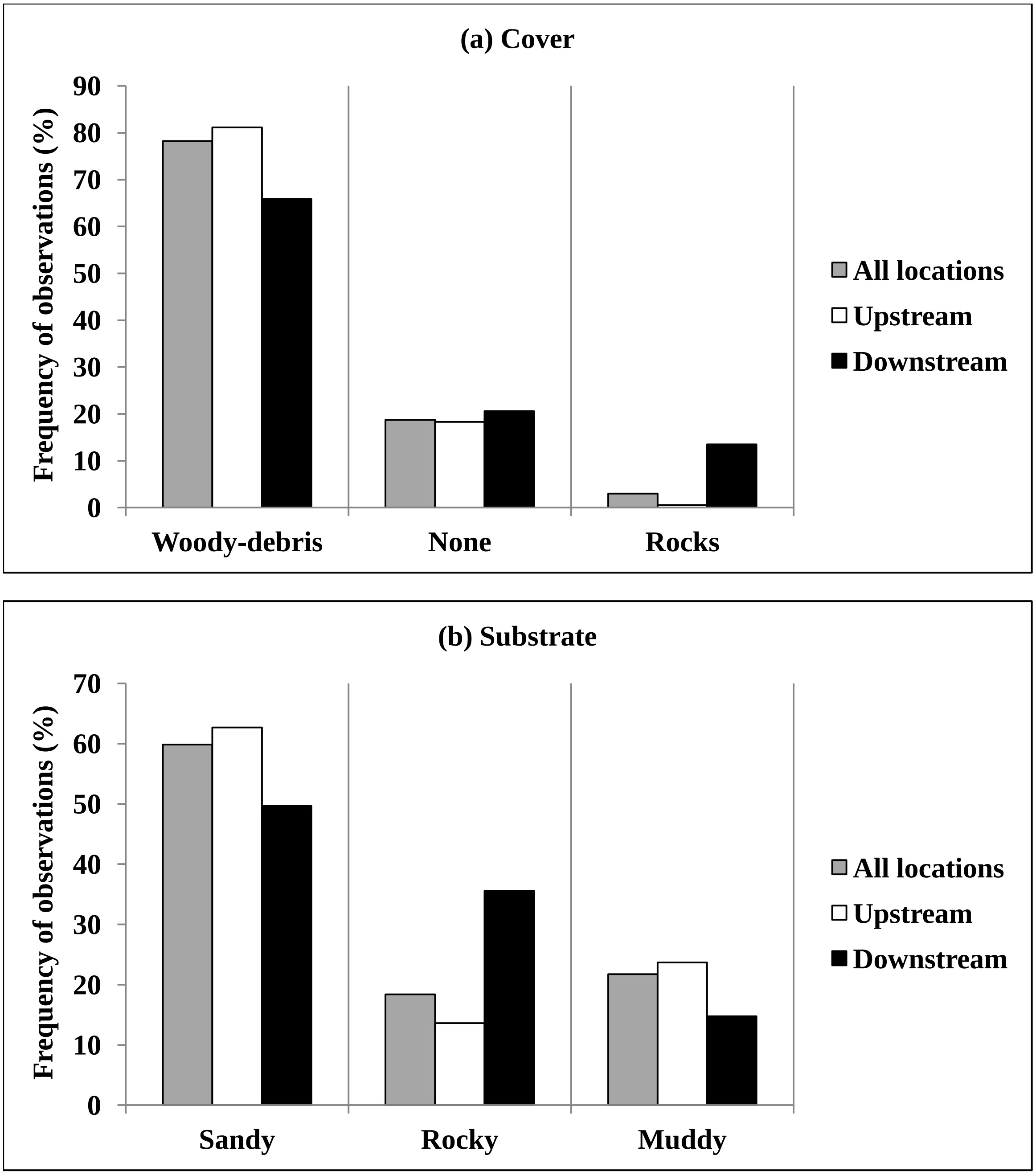


Figure 6. Frequency of radio-tagged robust redhorse locations from July 2008 to June 2010 associated with (a) cover (woody-debris, none, rocks) and (b) substrate (sandy, rocky, muddy) in the lower Oconee River, Georgia, as well as locations that are either upstream or downstream relative to Ball's Ferry Landing.

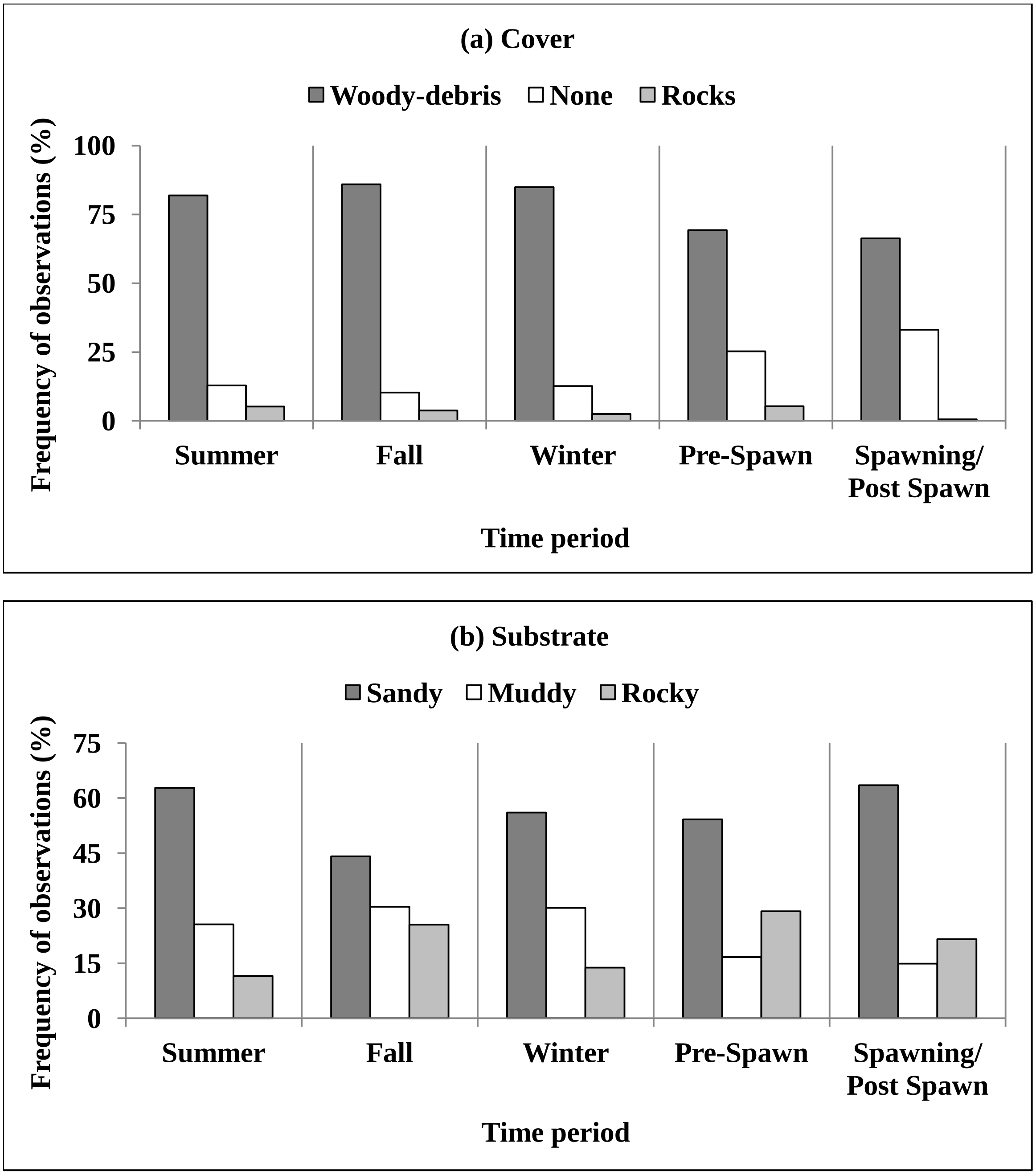


Figure 7. Time period frequency of radio-tagged robust redhorse locations associated with (a) cover type (woody-debris, none, rocks) and (b) substrate (sandy, muddy, rocky) in the lower Oconee River, Georgia, from July 2008 to June 2010.

Spawning versus non-spawning

During the spawning season (May) of 2009, radio-tagged robust redhorse migrated toward the Avant Mine site and occupied the area between Black Creek (rkm ~ 175) and rkm ~ 195 (Figure 8). None of the tagged fish were located at the historic Avant Mine gravel bar; however, an aggregate of tagged fish was located about 1.4 rkm upstream in an oxbow cut through (Figure 9). Within 0.2 km of the cut through, 50% of live individuals (7 of 14) were located at least once during the spawning season, and three of those fish were relocated multiple times (range = 2–5). Eighty-six percent of those individuals (6 of 7) located within 0.2 km of the cut through, were located over gravel substrate at least once, and four of those fish were relocated over gravel multiple times (range = 2–4; Figure 9). Additionally in May 2009, seven radio-tagged robust redhorse were located at least once, and four of those were relocated multiple times (range = 2–3) in a 1-km stretch of river about 2 rkm downstream of the Avant Mine gravel bar (Figure 10). Fifty-seven percent (4 of 7) of those individuals were located over gravel substrate once during the spawning period (Figure 10).

During the 2010 spawning season (May), none of the remaining fish (n=3) were relocated in the cut through area, and sandy substrate was detected at locations that contained gravel substrate the previous spawning season. However in May 2010, two of the three remaining tagged fish were detected in that same 1-km stretch of river located about 2 rkm downstream of the Avant Mine gravel bar and one of those individuals was relocated over gravel substrate (Figure 10).

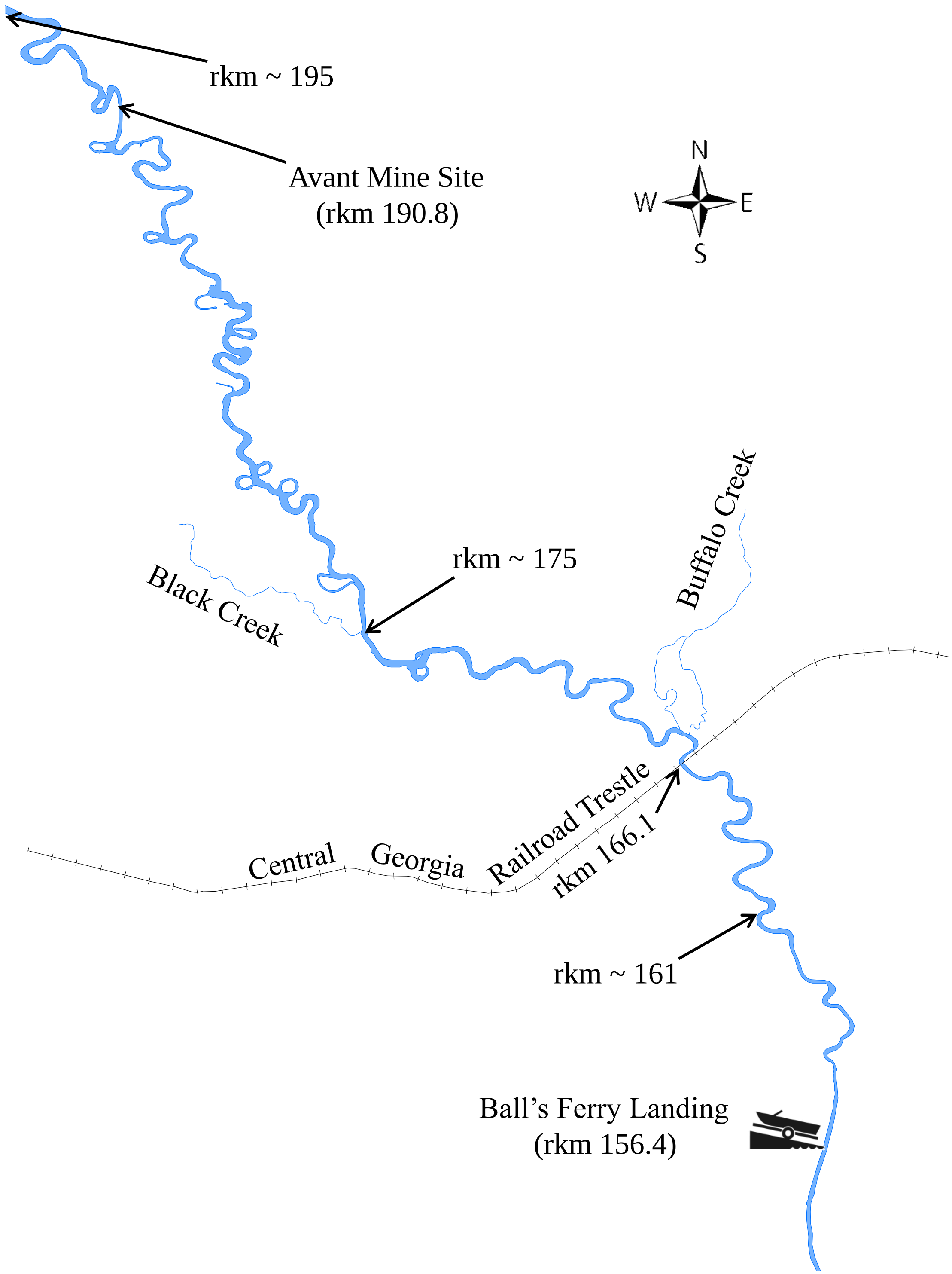


Figure 8. Map of the study area on the lower Oconee River, Georgia, from Ball's Ferry Landing at rkm 156.4 to rkm ~ 195.

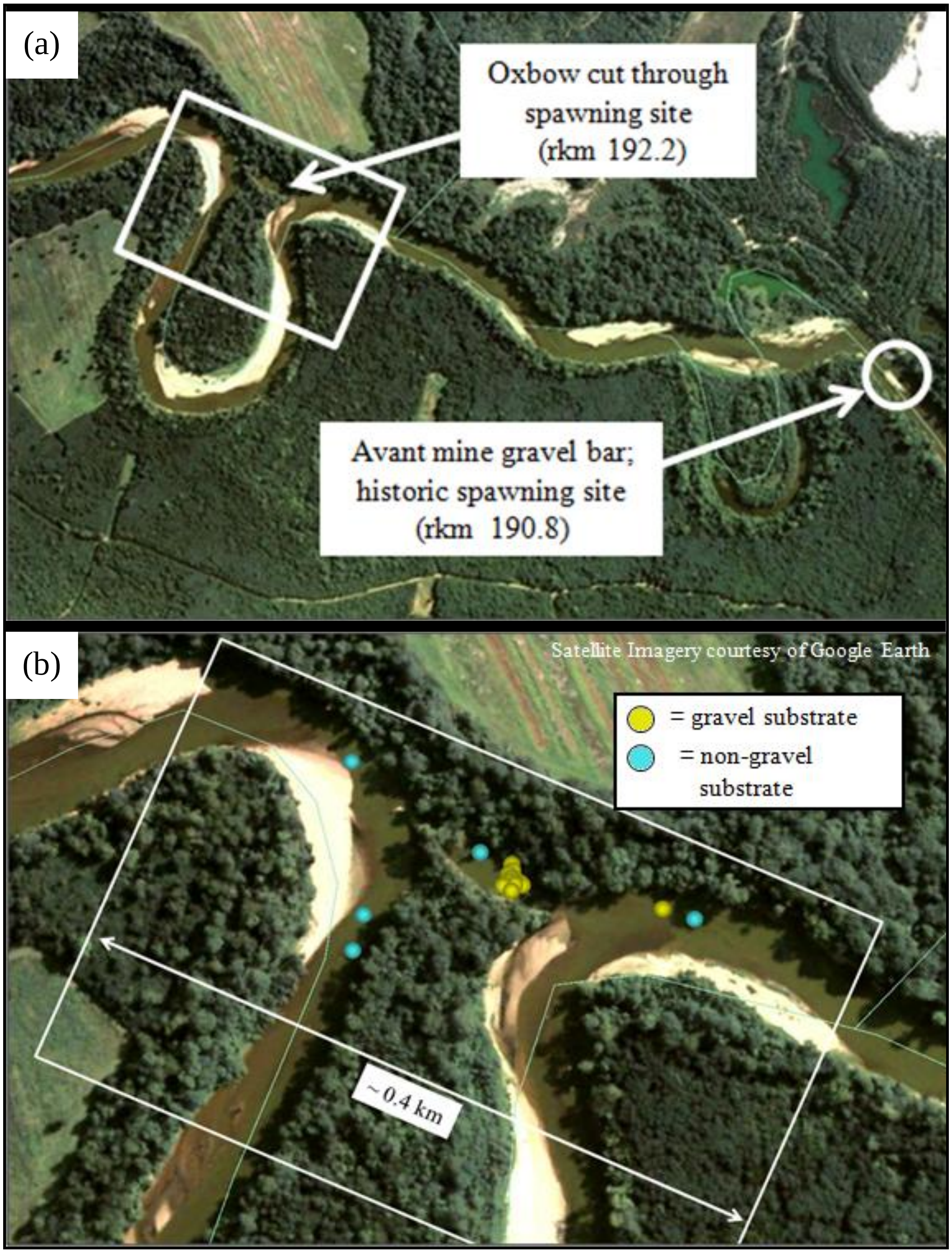


Figure 9. Satellite image of; (a) the oxbow cut through spawning location in relation to the historic Avant Mine gravel bar and (b) the oxbow cut through during the spawning period of 2009, where the yellow dots indicate relocations of radio-tagged robust redhorse over gravel substrate and blue dots indicate relocations over non-gravel substrate.

Figure 10. Satellite image of the downstream spawning locations of radio-tagged robust redhorse in relation to the historic Avant Mine gravel bar. Yellow dots indicate relocations of tagged individuals over gravel substrate and blue dots indicate relocations over non-gravel substrate during the 2009 and 2010 spawning periods (combined).

Cover

The type of cover radio-tagged robust redhorse were associated with was significantly different between the spawning and non-spawning time periods ($\chi^2 = 37.7$; d.f. = 2; $P < 0.0001$), as encounters were more frequent near woody debris during the non-spawning period (82.3%) than during the spawning period (63.5%; Figure 11). Additionally, tagged fish were more likely to be located in an area without cover during the spawning period (35.8%) than during the non-spawning period (14.0%; Figure 11).

Substrate

The type of substrate radio-tagged fish were associated with was significantly different between the spawning and non-spawning time periods ($\chi^2 = 32.7$; d.f. = 3; $P < 0.0001$); robust redhorse were more likely to be located over muddy substrate during the non-spawning period (26.2%) than during the spawning period (7.9%; Figure 11). Also, during the spawning period, study fish were more likely to be located over gravel substrate (19.5%) than during the non-spawning period (9.8%; Figure 11).

Depth and Velocity

Radio-tagged robust redhorse were located in similar water depths during the spawning (2.4 ± 0.2 m; mean ± 95% CI) and non-spawning (2.2 ± 0.1 m; mean ± 95% CI) periods ($F_{1,45} = 2.39$; $P = 0.1294$). In general, robust redhorse were located in water depths between 1–3 m throughout the study (Figure 12). The mean current velocity in which radio-tagged robust redhorse were located was significantly higher during the spawning period (0.69 m/s ± 0.04 m/s; mean ± 95% CI) than during non-spawning (0.38 m/s ± 0.03 m/s; mean ± 95% CI) ($F_{1,44} = 114.48$; $P < 0.0001$; Figure 13). During the

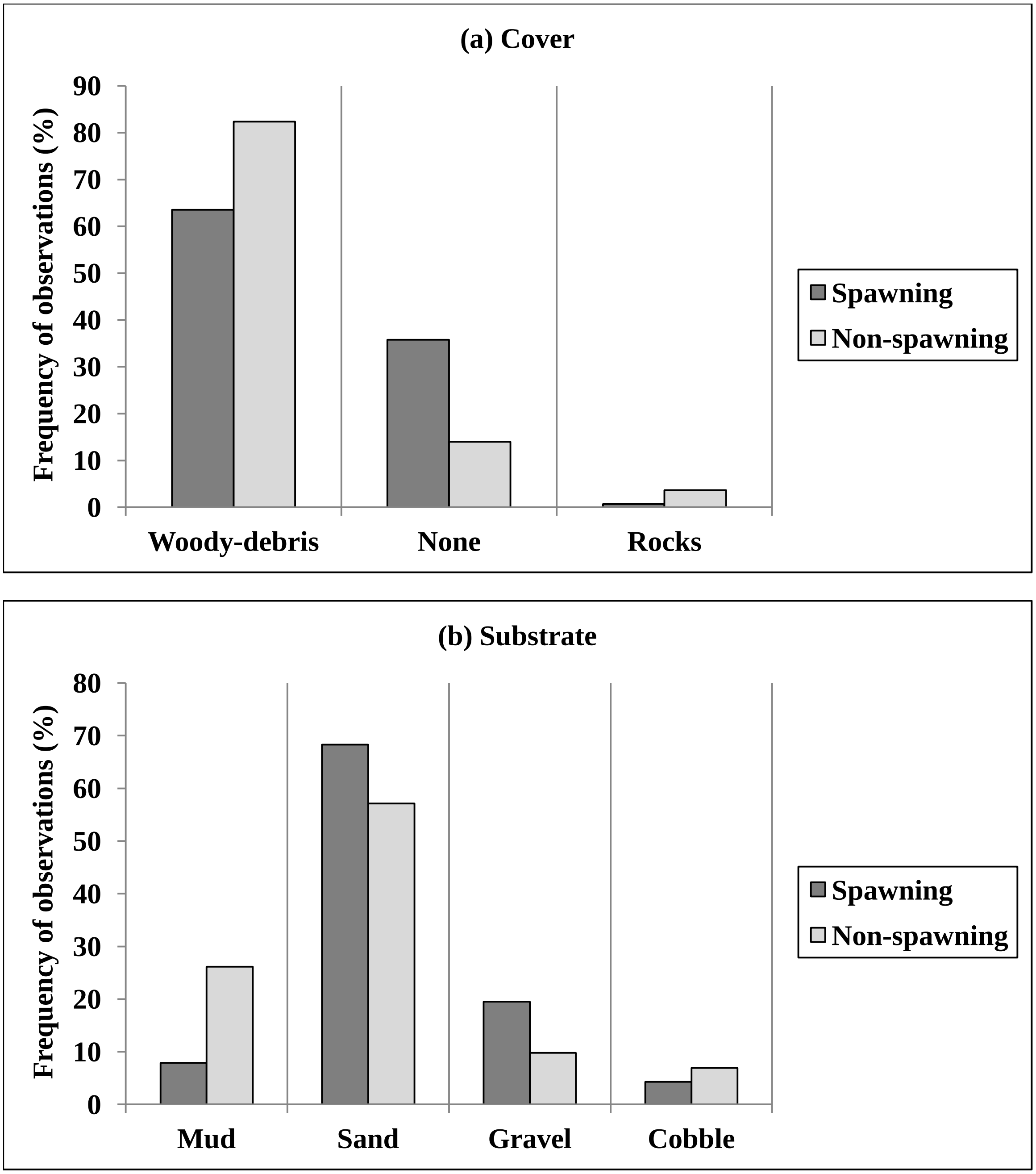


Figure 11. Frequency of radio-tagged robust redhorse locations associated with (a) cover type (woody-debris, none, rocks) and (b) substrate (mud, sand, gravel, and cobble) in the lower Oconee River, Georgia, during the spawning and non-spawning periods.

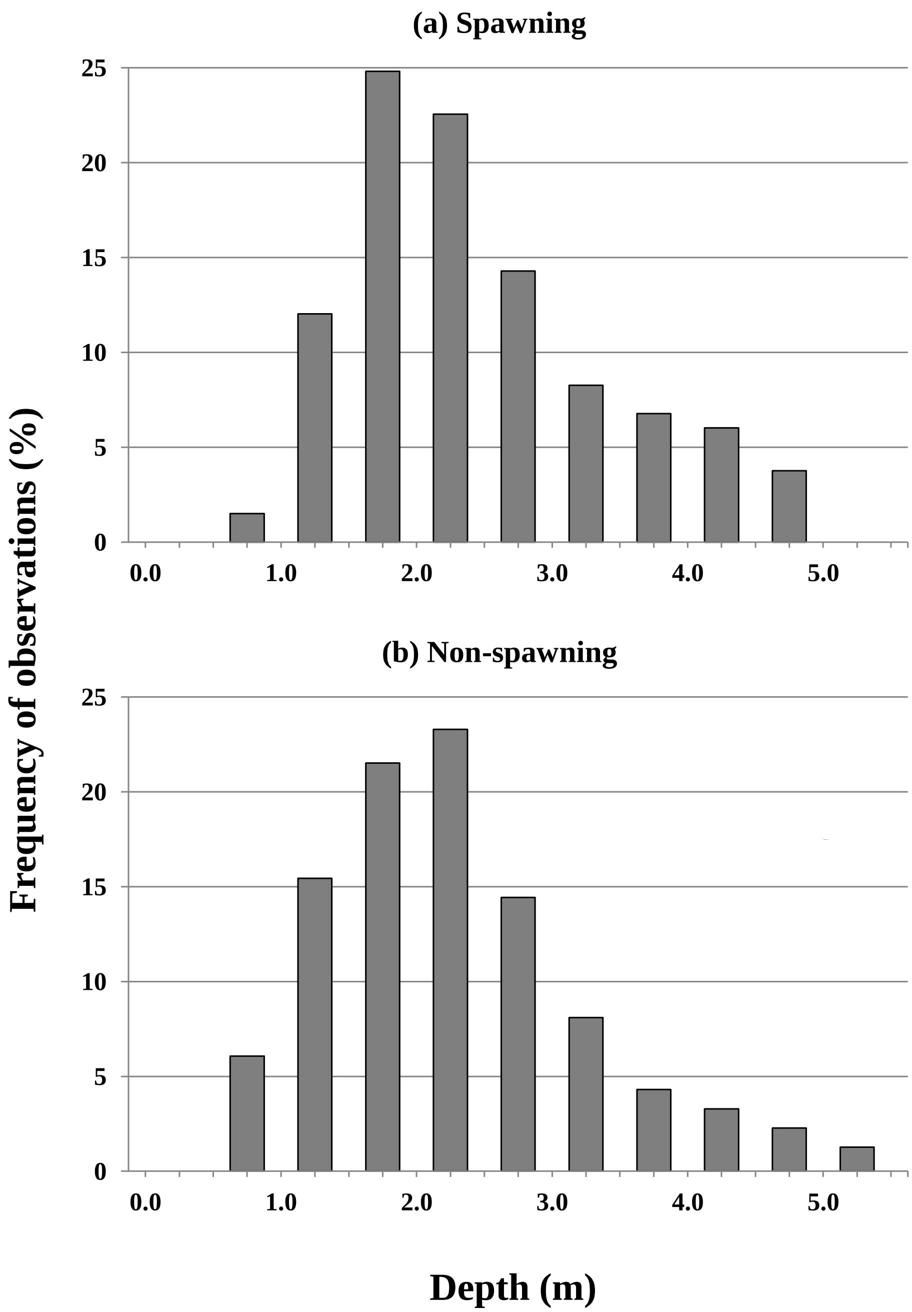


Figure 12. Frequency distribution of observed depths (m) at locations of radio-tagged robust redhorse in the lower Oconee River, Georgia, during the (a) spawning period and (b) non-spawning period.

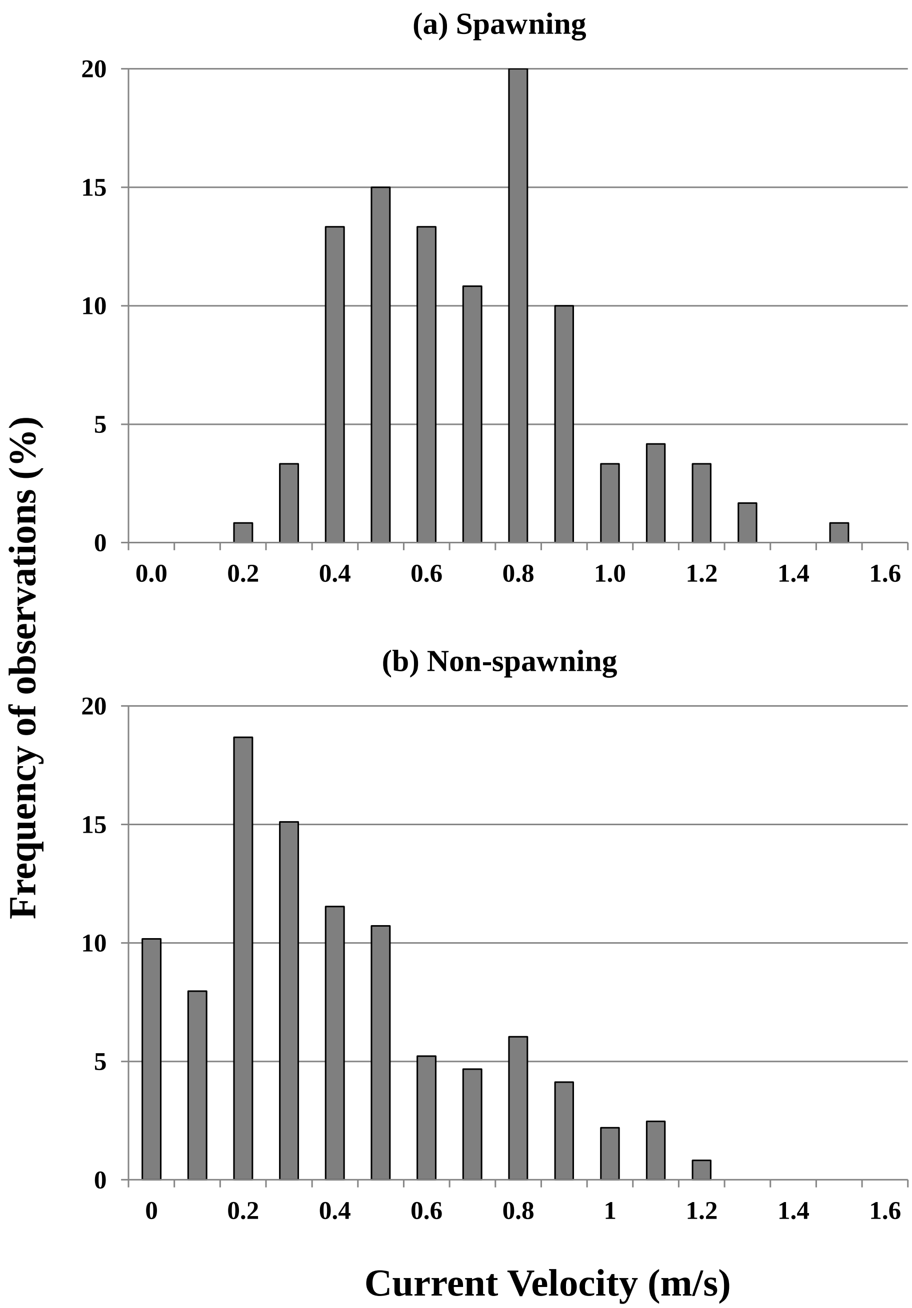


Figure 13. Frequency distribution of observed current velocities (m/s) at locations of radio-tagged robust redhorse in the lower Oconee River, Georgia, during the (a) spawning period and (b) non-spawning period.

spawning period, robust redhorse were mostly found in water velocities between 0.4–0.9 m/s and during the non-spawning period, fish were mostly located in water velocities between 0–0.5 m/s (Figure 13). Radio-tagged robust redhorse tended to occupy areas with flowing water regardless of time period but periodically targeted swifter currents during the spawning season.

Annual Home Range

Annual linear home range estimates for robust redhorse (n=12) averaged 57.3 rkm in size and ranged from 25.6 to 138.3 rkm; the 99% kernel estimate of home range was slightly larger (~ 4.9 rkm) than the linear home range for all fish (Table 2). Overall, mean kernel density estimates were similar for each individual at the 95% and 90% levels. The 50% level core estimates averaged 12.7 rkm but ranged widely from 2.3 to 43.4 rkm; the size of the 50% level core estimates did not appear to be related to the size of the linear ranges (Table 2). The mean upper (rkm 202) and lower (rkm 140) limits of the 99% level estimates were slightly larger than the mean linear range estimates (upper = rkm 199, lower = rkm 142; Table 3). The mean limits of the 95% (upper = rkm 199, lower = rkm 155) and 90% (upper = rkm 199, lower = rkm 156) level estimates were similar to each other but larger than the mean limits of the 50% (upper = rkm 184, lower = rkm 171) level core estimates (Table 3). Seven fish (n=12) had 100% and one fish had approximately 75% of their respective core areas (50% kernel density estimates) fall between the Avant Mine site (rkm ~191) and the Central Georgia Railroad Trestle (CGRT; rkm ~166) (examples; figure 14 and 15).

Table 2. Annual home range size estimates for radio-tagged robust redhorse with at least 25 relocations (n=12) in the lower Oconee River, Georgia, from July 2008 to June 2009. Linear range is the distance in river kilometers (rkm) between the most upstream and downstream relocations for each individual fish. Kernel density estimates for the 99%, 95%, 90%, and 50% levels represent utilization distributions at that specified percentage.

		Home range (rkm)				
Transmitter frequency	Number of relocations	Linear	99% kernel	95% kernel	90% kernel	50% kernel
40.011	25	138.3	145.3	36.4	33.8	10.1
40.091	26	56.2	72.7	70.3	70.0	14.3
40.141	33	44.7	49.8	49.7	49.1	2.8
40.630	26	73.3	83.8	81.3	81.0	8.0
40.641	34	43.3	44.9	41.6	41.4	11.3
40.661	36	52.5	53.9	20.2	19.3	5.6
40.671	34	26.2	29.2	28.2	27.7	3.4
40.681	34	25.6	27.5	25.0	24.6	18.1
40.771	33	77.0	78.3	36.8	34.6	28.6
40.791	33	43.1	45.4	28.3	27.8	4.0
40.821	28	74.1	78.5	75.5	74.4	43.4
41.233	34	33.0	37.4	37.4	36.4	2.3
Mean	31	57.3	62.2	44.2	43.3	12.7

Table 3. Annual home range boundary estimates (~ rounded) for radio-tagged robust redhorse (n=12) in the lower Oconee River, Georgia, from July 2008 to June 2009. Linear range is the river kilometer (~ rkm) associated with the most upstream (Upper) and downstream (Lower) relocations for each individual fish. Kernel density range estimates for the 99%, 95%, 90%, and 50% levels represent the estimated upstream (Upper) and downstream (Lower) utilization distribution locations (rkm) at that specified percentage.

	Kernel density estimate (~ rkm)									
Transmitter frequency	~ Linear		~ 99%		~ 95%		~ 90%		~ 50%	
	Upper	Lower	Upper	Lower	Upper	Lower	Upper	Lower	Upper	Lower
40.011	222	84	229	84	227	190	226	192	219	209
40.091	217	161	226	153	224	154	224	154	219	205
40.141	184	139	186	137	186	137	186	137	184	181
40.630	193	120	198	114	197	115	196	115	135	127
40.641	210	166	211	166	210	168	210	168	182	171
40.661	192	140	194	140	194	173	193	174	182	176
40.671	192	166	194	165	193	165	193	165	170	166
40.681	192	167	194	167	194	169	193	169	189	171
40.771	193	116	195	116	193	156	192	158	190	162
40.791	209	166	209	164	193	164	192	164	179	175
40.821	194	120	194	115	192	116	191	116	164	121
41.233	190	157	193	155	193	155	192	156	190	188
Mean	199	142	202	140	199	155	199	156	184	171

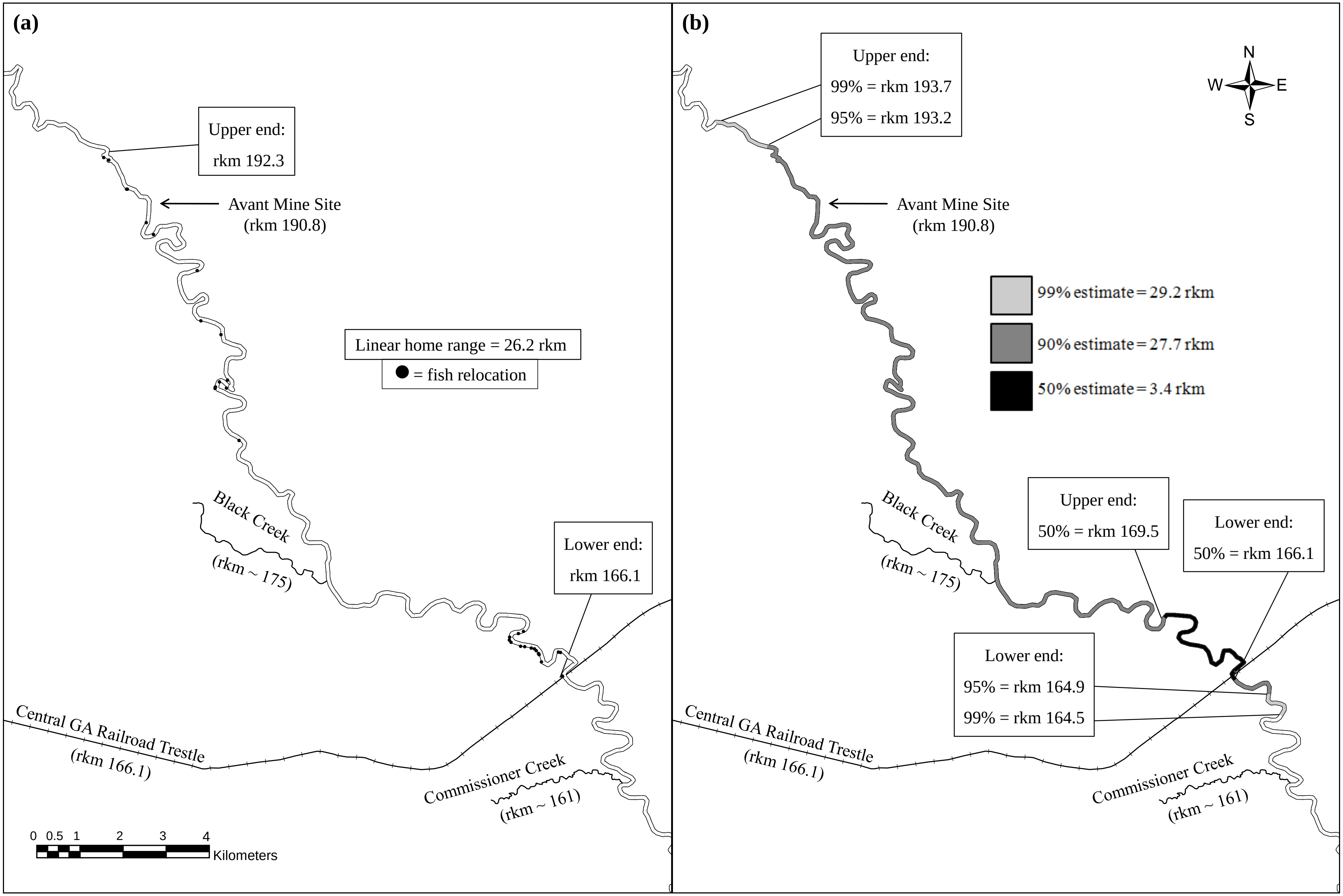


Figure 14. (a) Distribution of relocation points and corresponding linear home range; and (b) corresponding 99%, 90%, and 50% kernel density estimates for robust redhorse transmitter frequency 40.671 in the lower Oconee River, Georgia, from July 2008 to June 2009.

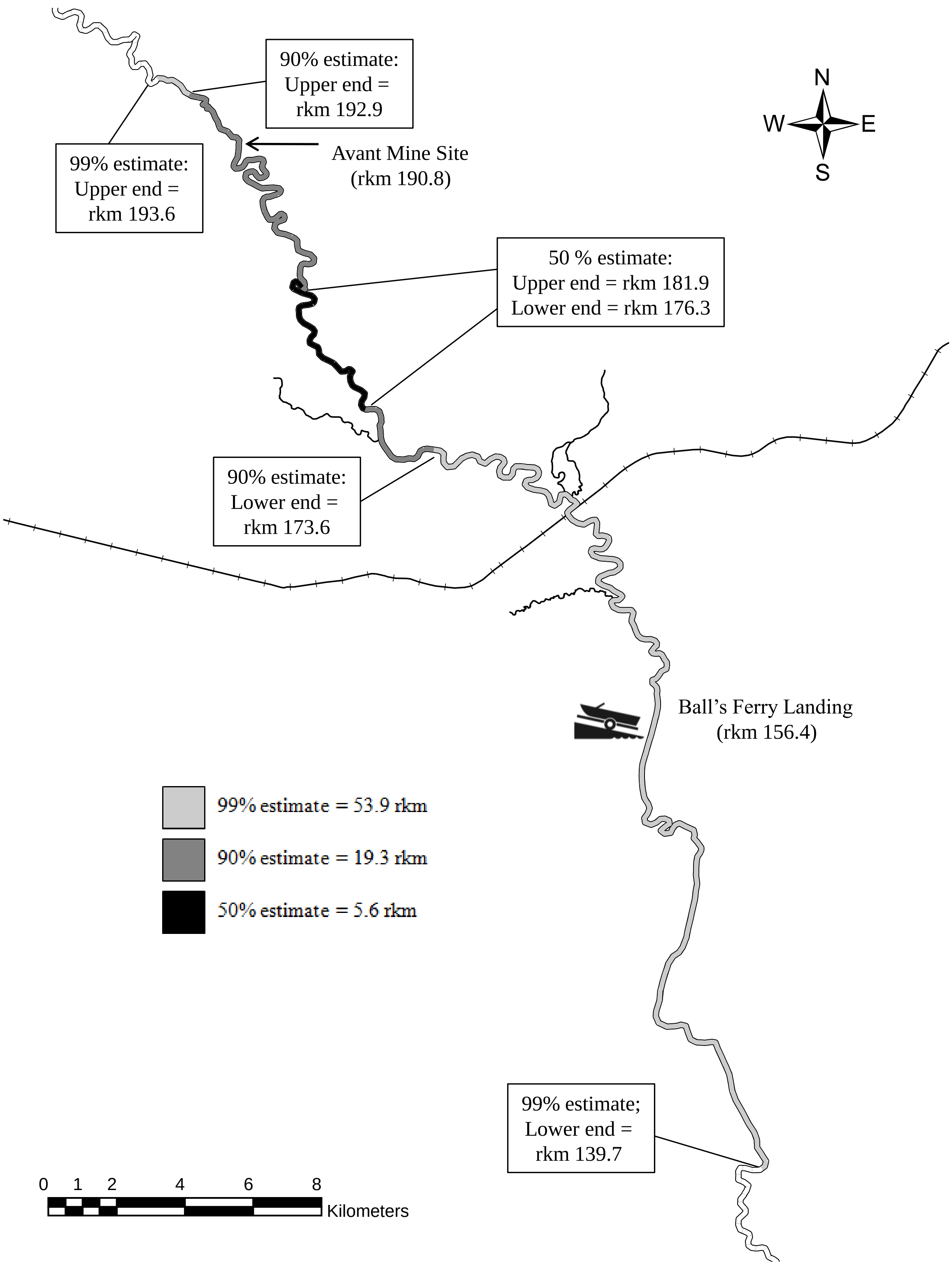


Figure 15. Mapped example of the 99%, 90%, and 50% kernel density estimates for robust redhorse transmitter frequency 40.661 in the lower Oconee River, Georgia, from July 2008 to June 2009.

Additional Observations

Within two weeks of transporting and releasing the study fish into the lower Oconee River, about 79% (n=19) of live relocated robust redhorse (n=24) were detected 8.0 rkm (95% CI = 2.6–13.4 rkm) upstream of the release point at Ball's Ferry Landing. Within four weeks of release, about 29% (n=7) of live relocated fish had traveled an average of 33.7 rkm (95% CI = 32.7–34.8 rkm) upstream and were detected near the historic Avant Mine site between rkm 185 and 195 (Figure 16). The following two springs (2009 and 2010), all of the remaining tagged fish migrated toward and were detected in the vicinity of the historic Avant Mine site during spawning season (Figure 17). Following spawning, fish generally returned downstream close to their previous pre-spawning migration location (Figure 17).

During the first winter time period (December 08 – February 09), following a high water event, an individual (transmitter frequency = 40.101) who had been previously located during fall was determined to be missing from the lower Oconee River. Tracking for this individual was extended downstream the entire length of the Altamaha River without success. During the pre-spawning period of 2009, tracking continued into the Ocmulgee River where the fish was relocated on 05 March 2009, approximately 65 rkm upstream of the confluence. That individual later re-entered the lower Oconee River and was detected on 25 March 2009 just south of Dublin, Georgia, an approximate absolute distance of 143 rkm from its previous location (Figure 17). Over the course of April 2009, fish # 40.101 continued traveling upstream another 123 rkm until it was relocated multiple times near the Avant Mine site during spawning season.

Robust redhorse were typically located within the main channel of the Oconee River throughout the study except during a few pre-spawning (March – April) high-water events in which some fish moved into floodplains and tributaries. On 04 March 2009, a fish was located on a flood plain near Commissioner Creek (rkm ~ 161); and on 01 April 2009, five different individuals entered flooded timber areas around Black Creek (rkm ~ 175; Figure 8). During mid-April 2009, one fish that had been previously detected near Black Creek was relocated about a kilometer into Buffalo Creek just upstream of the Central Georgia Railroad Trestle (CGRT; rkm ~ 166) near Oconee, Georgia (Figure 8).

A total of 22 robust redhorse (67%) either expelled their tags or died over the course of the study (four within one month; 10 between 2–6 months; eight between 11–26 months). An individual was considered to be dead or have an expelled transmitter if the transmitter did not change location over the course of 30 days. After a fish was deemed to have died or shed its transmitter, additional data were not recorded for this fish. Transmitters that were not moving were still relocated periodically throughout the study to ensure that receiver units were operating properly. Two of the non-moving transmitters were found along the shoreline during periods of low water. Transmitters that were previously thought to be in live fish but could not be relocated were considered missing[2]. By fall 2009, the number of missing fish had increased to seven individuals. As a result, tracking was extended into both the Altamaha and Ogeechee rivers in search of missing fish to no avail. A proportion of previously known non-moving transmitters (used for testing receivers) were discovered to have stopped producing a signal. By comparing the proportion of failed, non-moving transmitters to the number of missing fish, eight missing transmitters were deemed to have failed prematurely.

[2] We have evidence that some of the batteries in the transmitters did not last as long as was advertised (i.e., failed prematurely) and believe that this phenomenon contributed to the high incidence of “missing” fish.

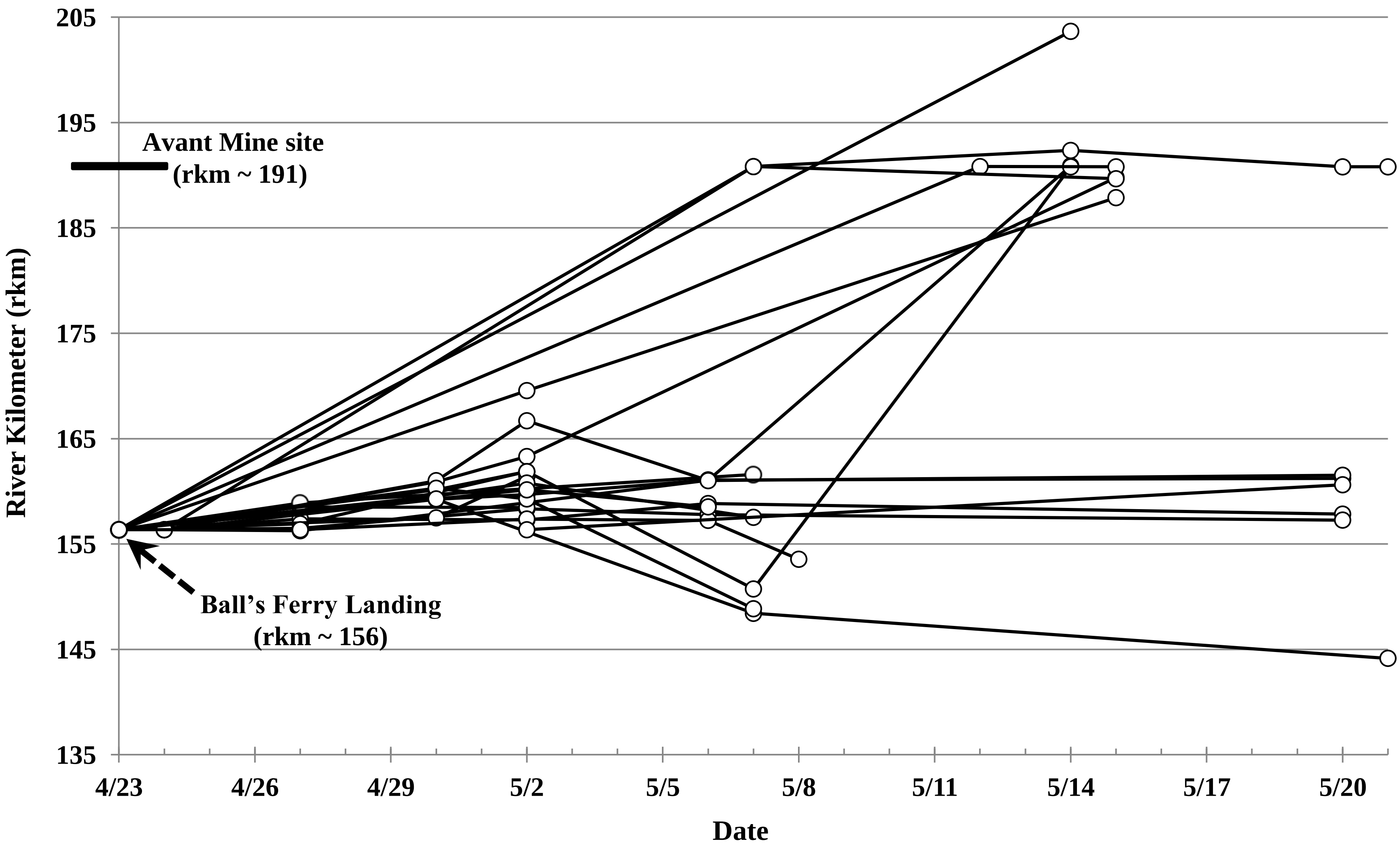


Figure 16. Initial locations (rkm) of radio-tagged robust redhorse released into the lower Oconee River, Georgia, from 23 April 2008 to 21 May 2008. The points represent individual locations and the lines represent the time between relocations. The general location of the Avant Mine site (rkm ~191) and Balls Ferry Landing (rkm ~ 156) are shown by a short black line and a dashed arrow, respectively.

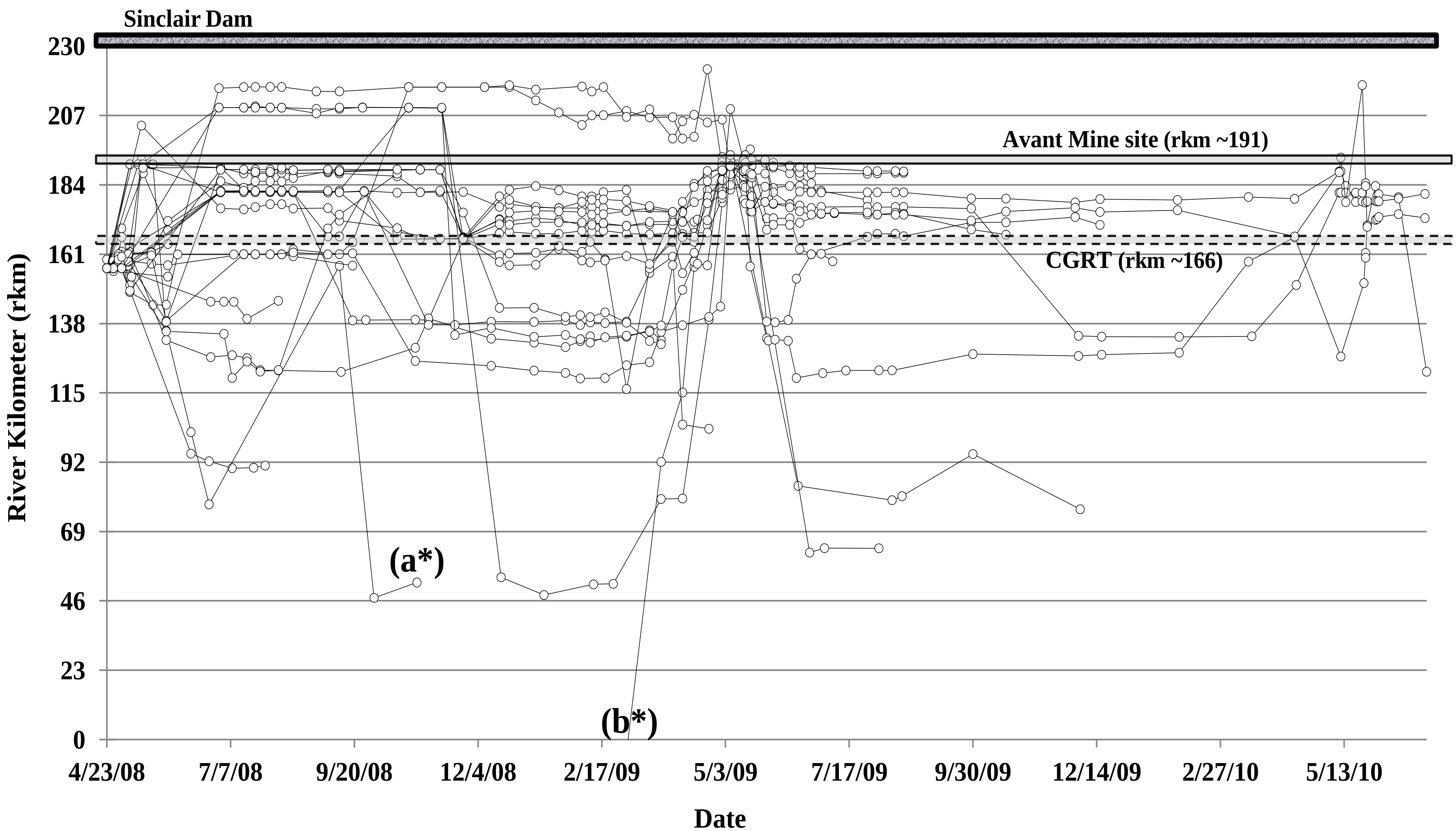


Figure 17. Locations (rkm) of radio-tagged robust redhorse in the lower Oconee River, Georgia, from 23 April 2008 to 02 July 2010. The points represent individual relocations and the lines represent the time between relocations. (a*) represents the last known location of fish 40.101 prior to being relocated in the Ocmulgee River. (b*) represents the relocation of fish 40.101 ~65 rkm into the Ocmulgee River. The general location of the Avant Mine site (rkm ~191) and the Central Georgia Railroad Trestle (CGRT; rkm ~ 166) are shown by solid and dashed lines, respectively.

DISCUSSION

Habitat use and movement patterns exhibited by fish in the present study were consistent with the findings of previous telemetry-based investigations of both wild and hatchery-produced, radio-tagged robust redhorse in other southeastern rivers (Grabowski and Isely 2006; Grabowski and Jennings 2009; Fisk 2010). For example, during the spawning season, radio-tagged robust redhorse transplanted into the Oconee River seemed to form spawning aggregates and were more likely to be located in habitat associated with gravel substrates, fast current, and without cover. Some fish migrated long distances to spawning grounds and then returned to preferred, non-spawning habitat (woody debris over sandy substrates, deep water with current) for the remainder of the year. Tagged individuals in the present study also exhibited potamodromous behavior similar to other sucker species such as the greater redhorse *Moxostoma valenciennesi* (Bunt and Cooke 2001), razorback sucker *Xyrauchen texanus* (Tyus and Karp 1990), and blue sucker *Cycleptus elongates* (Neely et al. 2009). Seasonal movements of robust redhorse in the Oconee River were smaller than those of the blue sucker (Neely et al. 2009) but larger than those of river redhorse *Moxostoma carinatum* (Hackney et al. 1968) and greater redhorse (Bunt and Cooke 2001). Seasonal movements of fish in the current study were similar to those observed for wild adult robust redhorse in the Savannah River, Georgia/South Carolina (Grabowski and Isely 2006) but larger than those of robust redhorse found in the Pee-Dee River, North Carolina/South Carolina (Fisk 2010).

Previous telemetry studies have shown that hatchery-reared robust redhorse transplanted into the Ocmulgee River, Georgia, exhibited a downstream movement for up to 120 days post release before adopting behaviors like wild fish (Jennings and Shepard

2003; Grabowski and Jennings 2009). In contrast, most of the transplanted hatchery-reared fish in the present study moved upstream immediately following release, with a portion being relocated about 35 rkm upstream near the historic Avant Mine spawning site. This upstream movement mimics spawning migration patterns similar to those of wild spawning robust redhorse in other river systems (Grabowski and Isely 2006; Fisk 2010). There were similarities between my methods and those of Grabowski and Jennings (2009). In both studies, robust redhorse were collected from the Ogeechee River, surgically implanted with radio transmitters, and transplanted to a major tributary of the Altamaha River during the beginning of spawning season. Consequently, differences in initial direction and distances moved between the studies may not be related to the time of year and the presence of spawning cues when the fish were released. In the present study, tagged fish were released at a location that was about 75 rkm downstream of Sinclair Dam, which is the nearest migration barrier. Conversely, Grabowski and Jennings (2009) released their fish at a location that was about 0.5 rkm below Lloyd Shoals Dam, which would block upstream migration. Further, hydropower generation from Lloyd Shoals Dam could have increased turbulent flows and induced the tagged fish in the Grabowski and Jennings (2009) study to move downstream with increased discharge.

During the fall of 2008, most tagged robust redhorse traveled in a downstream direction with some intermittent upstream movements. This behavior is similar to the post-release exploratory patterns (i.e., movements outside areas of normal activity; Kramer and Chapman 1999) exhibited by hatchery-reared juvenile and adult robust redhorse released into the Ocmulgee River (Jennings and Shepard 2003; Grabowski and Jennings 2009) as well as other stocked migratory species such as steelhead trout

Oncorhynchus mykiss (Wampler 1984) and razorback sucker (Mueller et al. 2003). The delayed exploratory movements probably were related to an increase in water level following drought conditions, coupled with a seasonal decrease in water temperatures. This behavior may not be typical of fall movement patterns for wild or naturalized fish because the tagged fish in the present study did not display this type of behavior during the second year of the study. Further, exploratory movements have not been observed in the fall for robust redhorse in other rivers (Grabowski and Isely 2006; Grabowski and Jennings 2009).

For the 24-hour tracking events, mean movements (absolute, displacement, and linear range) were larger in April 2009 than they were in October 2009 regardless of diel period, and fish appeared to move less at night than during the day regardless of month. Similarly, wild adult robust redhorse in the Savannah River, Georgia/South Carolina moved significantly more during the day than at night regardless of season (Grabowski and Isely 2006).

Median movement was consistently less than mean movement throughout most of the present study, which indicated that a small portion of fish sometimes moved considerably more than the majority of study fish. For example, three fish in the present study had linear home ranges of over 100 rkm during at least one time period. Similar phenomenon has also been observed for radio tagged wild robust redhorse in both the Savannah (Grabowski and Isely 2006) and Pee Dee (Fisk 2010) rivers. This behavior could be the result of historically patchy distribution of suitable habitat, such that some individuals had to range far to find suitable feeding, overwintering/oversummering habitat, or spawning grounds.

Home range estimates of fishes in lotic systems are typically reported as linear ranges (Logan 1963; Clapp et al. 1990; Daughtry and Sutton 2005), which is the distance between the most upstream and downstream locations for an individual during a specified period of time. Although linear home ranges are easy to calculate and useful in determining and comparing distance boundaries, they do not describe the internal structure of a home range (Vokoun 2003; Hodder et al. 2007). Kernel home range estimates are non-parametric density estimators calculated from relocations that take into account the amount of time an animal spent in any given area of the home range and can be sectioned into levels of use categories called utilization distributions (Worton 1989). Kernel density estimates of home range have mostly been used for studying terrestrial animals but have recently been applied to fish species such as flathead catfish (Vokoun 2005; Malindzak 2006) and robust redhorse (Fisk 2010).

In the present study, the 99% kernel estimates were larger than the corresponding linear home ranges for all robust redhorse. Volkoun (2005) also found that 99% kernel estimates for flathead catfish were greater than their corresponding linear home ranges. This is a common result for kernel estimates at the 99% level because the method estimates the probability that a fish may have traveled beyond the observed points needed to calculate linear range (Vokoun 2003). The 50% level core estimates of robust redhorse ranged from 2.3 to 28.6 rkm and did not appear to be related to the size of their corresponding linear ranges. Smaller core ranges may indicate that some robust redhorse spent most of the year within a small section of the river except during migratory and/or exploratory movements. Larger core ranges may indicate that some robust redhorse moved throughout their home range during the year, including seasonal migrations and/or exploratory movements. Overall, annual core ranges and seasonal linear ranges in the present study were larger than those reported by Fisk (2010) for robust redhorse in the Pee Dee River, North Carolina/South Carolina. Conversely, seasonal linear home range estimates and other movement patterns were similar to those reported by Grabowski and Isely (2006) for radio tagged robust redhorse in the Savannah River, Georgia/South Carolina. Home ranges of robust redhorse have been suggested to be larger in the Savannah and Altamaha drainages than in the Pee Dee River because of dams that limit access to suitable habitat found in Piedmont reaches (Grabowski and Isely 2006; Fisk 2010). Findings from the Graboswki and Isely (2006) study support this hypothesis as a small portion of their tagged fish were able to pass above the dam and occupy Piedmont reaches throughout the year without displaying any seasonal movements. However, in the present study, none of the tagged fish were ever located in the 6 to 7 km reach of Piedmont habitat that was available directly below Sinclair Dam. Although access to this section of river may be limited during periods of low water, study fish did not appear to attempt to enter this reach at all during the study as fish were rarely relocated in the vicinity of the area even during periods of high water with increased accessibility. Why tagged robust redhorse did not attempt to access this Piedmont reach is unclear; however, additional research to assess the amount and suitability of habitat in this section of river may help to address this question.

Increased discharge and subsequent high water levels during the spring may play an important role in initiating spawning behavior and movements of robust redhorse. During the pre-spawning period (March – April 2008 – 2010), river discharge increased and a majority of tagged fish made upstream migrations towards historic spawning grounds. Spawning migrations in response to rising flows have also been documented for other potamodromous species such as the paddlefish *Polyodon spathula* (Miller and

Scarnecchia 2008), sacramento sucker *Catostomus occidentalis* (Jeffres et al. 2006), and humpback chub *Gila cypha* (Muth et al. 2000). Tagged robust redhorse usually stayed within the main channel of the Oconee River except during spring high-water events when some occupied nearby floodplains and tributaries. This behavior has been documented for both hatchery-reared and wild-spawned robust redhorse in the Ocmulgee and Savannah rivers (Grabowski and Isely 2006; Grabowski and Jennings 2009). Grabowski and Isely (2006) suggested that robust redhorse could be using the floodplain for foraging to improve condition and fecundity in preparation for spawning. Our findings support this hypothesis as tagged individuals were only detected in the floodplains and tributaries prior to the spawning period, despite periodic high-water events providing access to these areas throughout the year.

Habitat use of robust redhorse sometimes varied between times periods and directionality (upstream or downstream of Ball's Ferry Landing) and is probably related to the amount of suitable habitat that is available as well as fish behavior (e.g, spawning, overwintering). For example, fish were located in shallower and lower flowing water during the summer and fall, which also had the lowest recorded discharge and water levels. The substrate type with which robust redhorse was associated was less variable in the summer and winter periods when fish movement was the most limited. Tagged robust redhorse located downstream of Ball's Ferry Landing were more likely to be associated with rocky cover and substrate than upstream fish. This distribution is probably a function of increased available rocky habitat near Dublin, Georgia. Woody debris did not seem to be a limiting factor, as it was consistently abundant throughout the entire river. Although robust redhorse require gravel substrates to spawn, the rocky substrate downstream may have been unsuitable for spawning. For example, during spawning season, tagged fish located near and below Dublin migrated upstream to areas in the vicinity of the Avant Mine site that contained gravel substrates. As previously mentioned, tagged fish did not attempt to enter the Piedmont reach directly below Sinclair Dam, which is dominated by rocky substrates (including gravel). Future research should focus on determining the amount and suitability of spawning and non-spawning habitat available to robust redhorse in the lower Oconee River.

The lower Oconee River is a dynamic system where morphological changes such as the creation of oxbows, and the recruitment and location of gravel substrates can ultimately influence the location of spawning robust redhorse. Over the past three spawning seasons (2008, 2009, and 2010), spawning activity of robust redhorse has not been visually observed nor have any tagged fish been relocated at the historic Avant Mine gravel bar. Lack of new gravel input, attributed to a shift of the main river channel, is considered to be a primary reason for the decline in robust redhorse use of the historic Avant Mine spawning site. The importance of morphological changes on the location of spawning radio-tagged robust redhorse was demonstrated during the 2009 and 2010 spawning seasons. In May 2009, an aggregate of tagged fish was believed to have spawned about 1.4 rkm upstream of the historic Avant Mine site in an oxbow “cut through” associated with swift current and loose gravel substrates. A recent shift in the main channel eroded away the remaining land that separated two bends in the channel. The result was the “cut through”, which formed an oxbow lake and seems to have exposed and/or collected gravel and created the new spawning location. However, during the following spawning season in 2010, study fish were not relocated at the “cut through”, and sandy substrate was detected at locations around the cut through that previously contained gravel substrate. High flows seemed to have widened the “cut through" and subsequently washed away or buried the gravel substrate, which made the site unsuitable for spawning. However, during the 2009 and 2010 spawning periods, study fish were located in the area about 2 rkm downstream of the historic gravel bar; this new site contained gravel substrate. Whether fish were successfully spawning in this area is unknown, but gravel substrates were still present as of May 2010.

Since 1994, declining annual electrofishing catch rates and population estimates indicate a severe reduction in the abundance of adult robust redhorse in areas of the lower Oconee River typically sampled during the spring. However, distribution data, historical catch rates, and related abundance estimates may be biased because sampling has generally been restricted to river sections between the Central Georgia Railroad Trestle (CGRT) and Dublin, GA. However, during April 2004, May 2010, and May 2011, electrofishing surveys from the top of the study reach (i.e., Sinclair Dam) down to Dublin, GA were conducted. This effort was a multi-agency collaboration to address whether historic catch rates reflected overall population decline or if the population distribution shifted into areas above the CGRT that previously received limited sampling effort (Jimmy Evans, Georgia Department of Natural Resources, personal communication). The specific objective of the May 2010 and May 2011 electrofishing surveys was to sample areas where tagged fish had been located during the previous spawning season (i.e., sections above the CGRT) to determine if wild individuals were occupying the same river sections[2]. In April 2004, eight adult robust redhorse were captured and 75% (6 of 8) of those fish were collected above the CGRT. Robust redhorse were not collected during the May 2010 and May 2011 surveys (Jimmy Evans, Georgia Department of Natural Resources, personal communication). Results of the

[3] In 2010, inclement weather limited sampling to only sections of river outside of the area where tagged fish were located during the previous spawning period (Jimmy Evans, GADNR, personal communication).

2004 survey documented a continued decline in catch rate from previous years (RRCC 2010) but also indicated that most of the population was located in the previously restricted sampling area above the CGRT. Telemetry results of the present study were similar to the general distribution of robust redhorse collected in April 2004. The 50% kernel density estimates from the present study indicate that most radio-tagged robust redhorse are located between the Avant Mine site (rkm ~ 191) and the CGRT (rkm ~ 166) throughout the year; and during spawning season, study fish were concentrated between rkm ~ 195 and Black Creek (rkm ~ 175). However, the absence of robust redhorse from the 2010 and 2011 electrofishing surveys suggest that the abundance of wild-spawned adult robust redhorse has continued to decline even though telemetry results suggest that robust redhorse, if present, would be located in the reach between the Avant Mine site and the CGRT. However, sampling data for the previously restricted area above the CGRT is still limited and additional electrofishing surveys in this area would help to verify the actual abundance and fate of adult robust redhorse in the lower Oconee River, Georgia.

Conclusions

This study provided long-term data on movement patterns, habitat use, and home range size (linear and kernel density) of hatchery-produced adult robust redhorse released into the lower Oconee River, Georgia. Hatchery-produced individuals used in the present study behaved similar to those of wild-born fish in other studies and led to the discovery of previously unknown potential spawning sites. The current research suggests that the dynamic morphology of the main channel of the lower Oconee River (i.e., creation of oxbows, and the recruitment and location of gravel substrate) can affect the location of spawning robust redhorse. Telemetry results of the present study suggest that fish distribution was similar to distribution noted during sampling of robust redhorse collected during April 2004. However, the absence of robust redhorse from the 2010 and 2011 electrofishing surveys suggest that the abundance of wild-spawned adult robust redhorse has continued to decline even though telemetry results indicate that robust redhorse, if present, would be located in the reach between the Avant Mine site and the CGRT. However, sampling data for the previously restricted area above the CGRT is still limited and additional electrofishing surveys in this area would help to verify the actual abundance and fate of adult robust redhorse in the lower Oconee River. Taken in total, the new information provided by this study could help in the establishment of a standardized sampling protocol for adult robust redhorse in the lower Oconee River and thus assist managers in making decisions for restoring or enhancing the species.

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