Spawning location, size structure, and year-class strength of robust redhorse *Moxostoma robustum* stocked in the Ogeechee River, Georgia

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EXECUTIVE SUMMARY

The robust redhorse *Moxostoma robustum* is a large, long-lived riverine catostomid, native to the Atlantic slope drainages of the southeastern United States from the Altamaha River, Georgia to the Pee Dee River, North Carolina/South Carolina. The Robust Redhorse Conservation Committee (RRCC) was established in 1995 under a Memorandum of Understanding between state and federal agencies, private industry, conservation groups, and academic institutions with the goal of developing and managing a recovery approach for the species. Because of the concerns over low recruitment rates and potential population declines, the RRCC initiated a plan to create refugial populations by stocking hatchery-reared robust redhorse, propagated from Oconee River broodstock, into the Ogeechee, Broad, and Ocmulgee rivers in Georgia. Later, hatchery produced offspring of Savannah River broodfish were stocked in the Broad and Wateree rivers in South Carolina to create additional refugial populations. The Ogeechee River was chosen as a robust redhorse stocking site for a variety of reasons, including: 1) the flathead catfish, a presumed predator, has not been introduced to the system; 2) the river is geographically isolated from all other populations of robust redhorse, thereby decreasing the probability of mixing genetically distinct populations; 3) the Ogeechee River is one of few North American rivers without major impoundments that impede the free flow of water or negatively affect fish habitat and water quality; and 4) a limited amount of gravel substrate, thought to be suitable for spawning, is known to exist in the upper portions of the basin. The overall goal of this project was to evaluate reproduction and recruitment success for the robust redhorse population stocked in the Ogeechee

River, Georgia. Specific objectives were to: 1) document spawning location(s) and spawning migration patterns; 2) determine if reproduction and recruitment are occurring; and 3) estimate the size structure and year-class strength of the population, if feasible. Stocked individuals used in the present study made spawning migrations similar to those of wild-born and hatchery-reared fish in other studies and led to the discovery of a previously unknown spawning site upstream of the Louisville boat ramp. Although other areas of gravel substrate were discovered in the Ogeechee River within the known range of robust redhorse, evidence of spawning activity only exists at the Louisville site. The current research suggests that drought conditions may limit the spawning activity of robust redhorse. Size structure data from 2008 and 2010/2011 shows that stocked individuals are growing and most are from the 2002 year class; however, evidence for successful reproduction and recruitment remains lacking because untagged robust redhorse <425 mm TL were not collected during the present study. Other researchers have also reported difficulty sampling for juvenile robust redhorse, and whether the observed population size structure in the Ogeechee River results from failed recruitment or an inability to detect juvenile robust redhorse remains uncertain. Current research suggests that inefficiencies in capturing juvenile robust redhorse may be more related to not concentrating sampling in the appropriate environments, not sampling during the appropriate season(s), low densities, or fish behavior (i.e., sensitivity to disturbance), rather than sampling gear. Continued monitoring of the spawning population may be the best way to determine if any wild born individuals are being recruited to the adult population in the Ogeechee River. Overall, the data provided by this study could help locate new robust redhorse spawning aggregations in the Ogeechee River and aid in designating the Louisville spawning site an important conservation area.

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INTRODUCTION

The robust redhorse *Moxostoma robustum* is a large, long-lived riverine catostomid, native to the Atlantic slope drainages of the southeastern United States from the Altamaha River Basin, Georgia to the Pee Dee Basin North Carolina/South Carolina. The species was originally described in 1870 by E.D. Cope (1870) but went unrecorded and unnoticed until 1991, when it was rediscovered in the Oconee River, Georgia (Evans 1994; Bryant et al. 1996; Ruetz and Jennings 2000). Currently, natural populations inhabit the Yadkin-Pee Dee River drainage in North Carolina/South Carolina, the Savannah River in Georgia/South Carolina, and the Altamaha River Basin in Georgia (Jennings et al. 2010). The robust redhorse is classified as Endangered by the Georgia Department of Natural Resources, a Species of Special Concern by the U.S. Fish and Wildlife Service, and has recently been petitioned for listing under the U.S. Endangered Species Act (RRCC 2010a). The species is threatened by a combination of environmental and biological pressures that include: 1) deforestation and poor farming practices that increase sedimentation, resulting in the subsequent degradation of spawning sites (Evans 1994; Jennings et al. 2010); 2) the presence of dams which block seasonal migrations, alter riverine flows and temperatures, reduce water quality, and modify spawning habitat (Weyers et al. 2003; Grabowski and Isely 2007); and 3) the introduction of the flathead catfish *Pylodictis olivaris*, a predator native to the Gulf Coast drainages of the Southeast, which some believe preys on robust redhorse (Bart et al. 1994; Hendricks 1998, 2002).

Robust redhorse are potamodromous and make seasonal migratory runs to spawning grounds and then return to preferred non-spawning habitat for the remainder of the year (Grabowski and Isely 2006; RRCC 2010a; Ely 2012). Adults spawn in triads over loose gravel substrate in moderate to swift currents from late April to early June, when water temperatures are between 18–24^{o}C (Jennings et al. 1996; Hendricks 1998; Freeman and Freeman 2001). Spawning triads consist of one female flanked by two males facing the direction of the current; the fish rise together in the water column and quiver vigorously using their caudal and anal fins to scour out pockets of gravel where gametes are released (Jennings et al 1996; Grabowski and Isely 2007). The scouring process causes a displacement of sediment, which creates brief visible streaks of mud (i.e., mud streaks) in the water column (RRCC 2005; Jennings et al. 2010). Non-spawning adults in the Coastal Plain ecoregion are generally found in the bends of meandering rivers and are typically associated with woody debris and current (Grabowski and Isely 2006; Grabowski and Jennings 2009; RRCC 2010a; Ely 2012).

The Robust Redhorse Conservation Committee (RRCC) was established in 1995 under a memorandum of understanding between state and federal agencies, private industry, conservation groups, and academic institutions with the goal of developing and managing a recovery approach for the species. Following its rediscovery, monitoring of robust redhorse in the Oconee River revealed that the population was comprised mainly of older individuals and that recruitment rates were very low (Bryant et al. 1996; RRCC 2010a). Because of the concerns over low recruitment rates and potential population declines, the RRCC initiated a plan to create refugial populations by stocking hatchery reared robust redhorse, propagated from Oconee River broodstock, into the Ogeechee, Broad, and Ocmulgee rivers in Georgia. Later, hatchery produced offspring from Savannah River broodstock were stocked into the Broad and Wateree rivers in South Carolina to create additional refugial populations (RRCC 2005).

The Ogeechee River was chosen as a robust redhorse stocking site for a variety of reasons, including: 1) the flathead catfish, a presumed predator, has not been introduced to the system; 2) the river is geographically isolated from all other populations of robust redhorse, thereby decreasing the probability of mixing genetically distinct populations; 3) the Ogeechee River is one of few North American rivers without major impoundments[1] that impede the free flow of water or negatively affect fish habitat and water quality; and 4) a limited gravel substrate, thought to be suitable for spawning, is known to exist in the transitional area between the Piedmont Province and the Upper Coastal Plain ecoregion known as the Fall Line (*see* Figure 1, page 12). However, the availability and accessibility of spawning habitat, which is critical to reproductive success and ultimately the self-sustainability of the stocked population, has not been verified for the Ogeechee River.

From 1997 to 2004, about 43,000 fingerling robust redhorse, representing seven year classes, were successfully released into the Ogeechee River at three different locations (RRCC 2005; Slaughter 2008; Table 1). Limited monitoring of the population has confirmed that individuals have dispersed throughout the river and that many individuals have reached sexual maturity (Tim Barrett, Georgia Department of Natural Resources, personal communication; Grabowski and Jennings 2009; Ely 2012).

[1] Currently, the Ogeechee River has only one minor impoundment that would block migrating fish; a mill dam near Mayfield, Georgia (~ River Kilometer [rkm] 402), located in the Piedmont Province, positioned between Jewell's Mill (~ rkm 395) and the Ogeechee River's headwaters (~ rkm 435).

Table 1. Robust redhorse fingerling stocking rates for the Ogeechee River, Georgia, and the location(s) of the stocked fish per year from 1997–2004.

	Stocking location(s) / Number stocked		
Year	Mayfield [+] (rkm 402) & Jewell's Mill (rkm 395) [‡]	Highway 88 boat ramp (rkm 343)	Cumulative total stocked per year
1997	1,762	0	1,762
1998	876	0	2,638
1999	10,382	0	13,020
2000	8,025	0	21,045
2001	7,541	0	28,586
2002	0	10,263	38,849
2003	0	0	38,849
2004	4,253	0	43,102
		Total	**43,102**

[+] Fish were stocked directly below the mill dam near Mayfield, Georgia.

[‡] The number of stocked fish was divided and distributed evenly between Mayfield and Jewell’s Mill.

Intermittent monitoring of this population has produced favorable catch rates of adults[2] and has documented apparent growth and survival of stocked individuals (RRCC 2009; RRCC 2010b). Although enough time has elapsed for some stocked robust redhorse to breed and for their progeny to grow to adult size and reproduce, the overall status of the population, including recruitment and size-structure, remains unknown. Further, spawning activity of stocked individuals in the Ogeechee River has not been documented.

Radio telemetry has been used successfully to document movement patterns and spawning locations of wild adult robust redhorse in the Savannah (Grabowski and Isely 2006) and Pee Dee (Fisk 2010) rivers, as well as hatchery-reared adults in the Broad (RRCC 2011), Ocmulgee (Grabowski and Jennings 2009), and Oconee (Ely 2012) rivers. Radio-tagged fish can be used as guide fish to locate previously unknown spawning sites within a river system (Grabowski and Jennings 2009). Once a new spawning aggregate is discovered, the spawning site can be protected, eggs and larvae can be collected, critical habitat can be characterized, and the number and size structure of spawners can be quantified. Therefore, radio telemetry was chosen as the preferred method for addressing questions about spawning activity of stocked robust redhorse in the Ogeechee River.

Collections of eggs and larvae are indicative of successful reproduction; however, they do not address recruitment status. For example, robust redhorse eggs have been collected from a spawning site within the Hudson River in the Broad River drainage

[2] Based on previous sampling efforts by the Georgia Department of Natural Resources, the known upper range of robust redhorse in the Ogeechee River is around the Hwy 88 boat ramp (rkm 343.3), and the highest catch rates have come from just above the Lousiville boat ramp near rkm 306.6 (Joel Fleming, Georgia Department of Natural Resources, personal communication).

(RRCC 2009), and seines, push nets, and light traps have been used to collect larvae in the Oconee River (RRCC 2005). However, confirmation of recruitment has been problematic across the entire range of the robust redhorse, because very few juveniles have been collected (Jennings et al. 2005; Mosley and Jennings 2007; RRCC 2009). Currently, the occurrence of untagged robust redhorse <425 mm TL in the Ogeechee River would demonstrate successful reproduction and recruitment because all hatchery reared individuals received a coded wire tag, and fish from the last stocked year class (2004) have grown beyond this size limit (Cecil Jennings, United States Geological Survey, personal communication).

The overall goal of this project was to evaluate reproduction and recruitment success for the robust redhorse population stocked in the Ogeechee River, Georgia. Specific objectives were to: 1) document spawning location(s) and migration patterns during the spawning season; 2) determine if reproduction and recruitment are occurring; and 3) estimate the size structure and year-class strength of the population, if feasible.

METHODS

Study Area

The Ogeechee River Basin drains approximately 14,300 km^2 and is located in mid to southeastern Georgia (GAEPD 2001). The Ogeechee River is about 435 km long and originates at the confluence of the North and South Fork Ogeechee rivers in the southeastern edge of the Piedmont Province and flows southeastward through the Coastal

Plain Province to the Atlantic Ocean (Figure 1). Its largest tributary is the Canoochee River, which drains approximately 3,600 km^2 into the Ogeechee River near Richmond Hill, Georgia (GAEPD 2001). The Ogeechee River is a blackwater system with limited watershed development and is one of few North American rivers without major impoundments because of its low gradient (Meyer et al. 1997). Currently, the Ogeechee River has only one minor impoundment, a mill dam near Mayfield, Georgia (~ rkm 402), located in the Piedmont Province, positioned between Jewell's Mill (~ rkm 395) and its headwaters (~ rkm 435).

The Piedmont Province extends downstream to the Fall Line and comprises about 5% of the basin. This section of river is a high-gradient area with rocky shoals and boulders that generally consists of pools and rapids. The remaining 95% of the river basin is located within the Coastal Plain Province, which can be further divided into Upper and Lower ecoregions (Griffith et al. 2003). The Upper Coastal Plain ecoregion comprises about 57% of the river basin, and the Lower Coastal Plain ecoregion comprises the remaining 38% of the basin. The Coastal Plain portion of river extends from the Fall Line to the coast and generally consists of meander sections separated by long, straight. reaches, and becomes wider and deeper with decreasing gradient as it transitions between ecoregions. Cover includes woody debris and a few rocky shoals; sediment types include sand, mud, and rocky substrates, including limited gravel deposits.

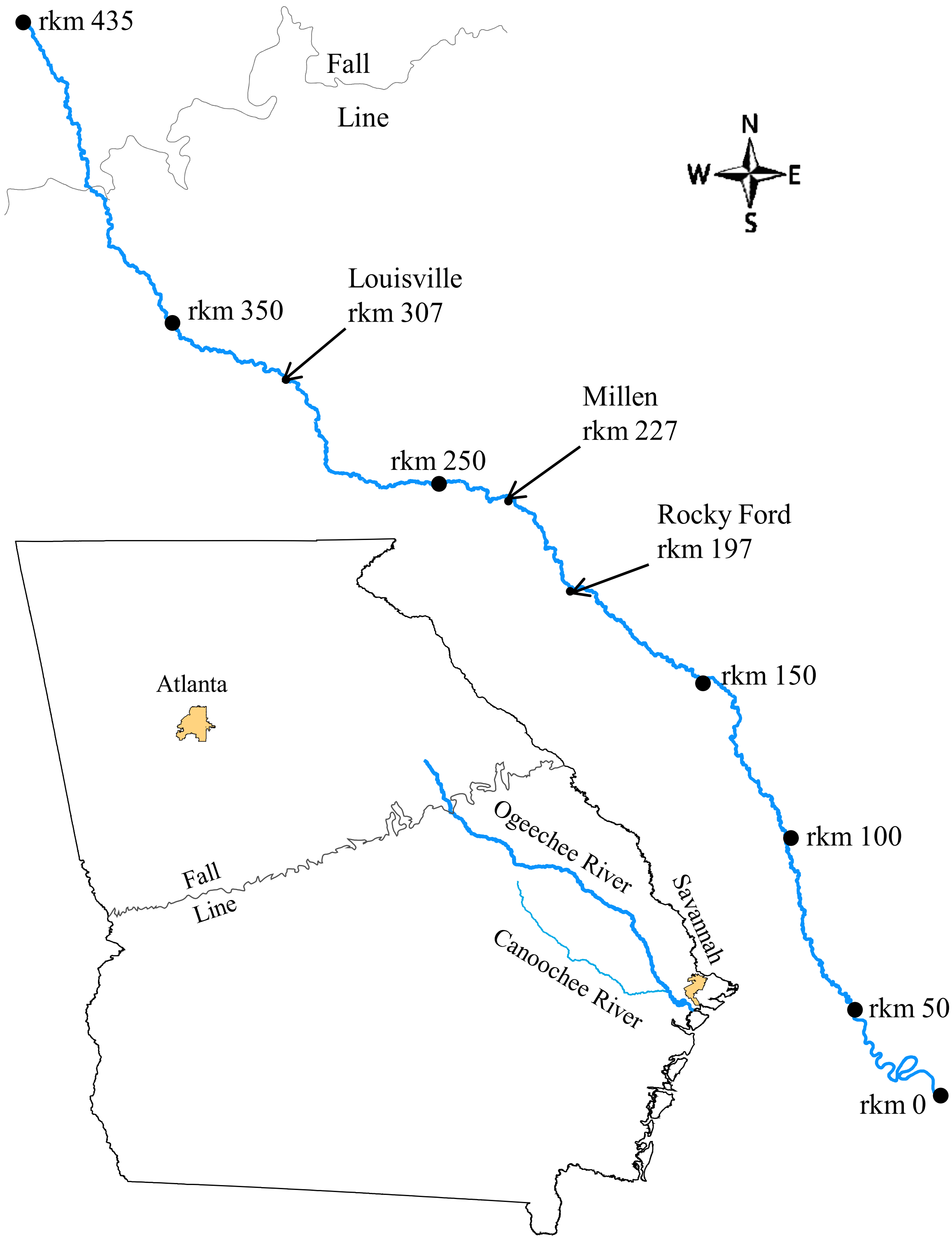

Figure 1. Map of the study area on the Ogeechee River, Georgia. The inset shows the location of the Ogeechee and Canoochee rivers in the state of Georgia.

Spawning activity of robust redhorse has never been documented in the Ogeechee River and whether naturally occurring gravel bars suitable for spawning exist within the system is unknown. Because of a perceived lack of suitable spawning sites, gravel substrate was introduced into the Ogeechee River in 2009 at the Rocky Ford boat ramp (~ rkm 197; Figure 1) in an effort to create an artificial spawning area (SARP 2009). The Rocky Ford site was chosen to receive gravel because it was easily accessible and possessed the depth and flow requirements needed for robust redhorse to spawn (SARP 2009). Additionally, the site contained hard substrates needed to stabilize and prevent erosion of introduced gravel (Jimmy Evans, Georgia Department of Natural Resources, personal communication).

Fish Collection

Boat-mounted electrofishing was used to collect adult robust redhorse from ~ 80 rkm reach of the Ogeechee River between Louisville (~ rkm 307) and Millen (~ rkm 227), Georgia (Figure 1). From November to December 2010, and in April 2011, one crew (i.e., one electrofishing boat) sampled the river on eight separate occasions. From February to March 2011, two separate crews[3] (i.e., two electrofishing boats) sampled simultaneously near different boat ramps on four different occasions. Effort during fish collection was recorded as the total number of hours spent electrofishing (i.e., pedal time) during each sampling occasion, regardless of the number of sampling crews. Catch per unit effort (CPUE) was used to determine the relative abundance of robust redhorse

[3] Sampling was conducted as a collaborative effort among the Georgia Department of Natural Resources, the U.S. Geological Survey, and the University of Georgia.

during the collection period (December 2010 – April 2011) and was calculated as the number of study fish caught divided by the total pedal time during each sampling occasion. Following collection, fish were held in aerated hauling tanks, implanted with radio transmitters, and released back into the Ogeechee River the day of capture.
On days when two electrofishing boats were used, the surgery site would be located at one crew's location, and the other crew would transport their fish to that boat ramp for transmitter implantation and release.

Transmitter Implantation

Methods used for implanting transmitters were similar to Ely (2012). An internal radio transmitter (Model F1835) 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 an advertised battery life of 654 days (warranty life = 327 days), and weighed approximately 14 g in air. In an effort to decrease mortality and avoid altering fish behavior after 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 solution of 140 mg/l sodium bicarbonate-buffered tricaine methanesulfonate (MS-222). Once a fish was anesthetized; total length (mm) and weight (kg) were recorded, and 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), then 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 exited 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 to 4 interrupted sutures. The surgical procedure for each robust redhorse took about 7 minutes to complete. After surgery, tagged individuals were monitored in a separate recovery tank for about 1 hour prior to release.

Tracking

In 2011, radio-tagged robust redhorse were tracked by boat on a weekly to bi-weekly basis during March and April. During spawning season (i.e., May), fish were monitored by boat and foot multiple days a week. Because of low water levels, which severely limited boat tracking, tagged fish were tracked by helicopter on 02 November 2011. A subsequent tracking trip (08–09 November 2011) was conducted by boat and foot into accessible areas where tagged-fish had previously been located by the helicopter to verify their locations and determine if any study fish had been missed by the helicopter.

In 2012, radio-tagged robust redhorse were tracked by boat on a weekly to bi-weekly basis from March to May. Additionally, because of low water conditions, previously unknown gravel bars were identified and subsequently monitored for spawning activity. Visual surveys of spawning activity were conducted at the gravel bars when water temperatures were between 18–24 °C. For each survey, two crew members, wearing polarized sunglasses, would stand on higher ground at different locations along the bank and monitor a gravel bar for 20–30 minutes.

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 strength 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 that 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. The locations of gravel bars were also recorded with the GPS unit. 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).

Summer/Autumn Sampling

A total of 14 sampling stations were established at various locations along the main stem of the Ogeechee River from Jewell's Mill (rkm 394.6) in the Piedmont Province down to Morgan Bridge (rkm 66.3) in the Coastal Plain Province (Figure 2). Stations 1 – 2 were located in the Piedmont Province to the edge of the Fall Line. Stations 3 – 11 were located in the Upper Coastal Plain ecoregion, and stations 12 – 14 were located in the Lower Coastal Plain ecoregion.

From July to October 2011, each sampling site (n=14) was sampled at least twice with one or more sampling methods that included boat electrofishing, backpack electrofishing, and seining. The chosen sampling method depended on river and habitat conditions within a given site. In deeper non-wadeable areas, boat electrofishing was used to sample all suckers; each boat electrofishing station was from 1 to 3 rkm in length. Boat electrofishing was used to sample all types of available habitat; however, low water conditions throughout the summer and autumn generally restricted sampling to areas close to boat ramps. In shallower wadeable areas, backpack electrofishing and seining were used to sample small, juvenile, and young-of-the-year suckers. Backpack electrofishing was used primarily in rocky habitats characterized by shallow-medium pools and riffles. Seining was also used to sample medium-large pools, outside and middle sections of meander bends (e.g., sand bars), backwaters, and eddies.

A portion of suckers collected by boat electrofishing were identified in the field; those fish, which generally consisted of larger individuals, were counted and released into the river. Additionally, all captured adult robust redhorse were weighed (kg), measured (mm TL), and examined for the presence of a coded wire tag (CWT) and a passive

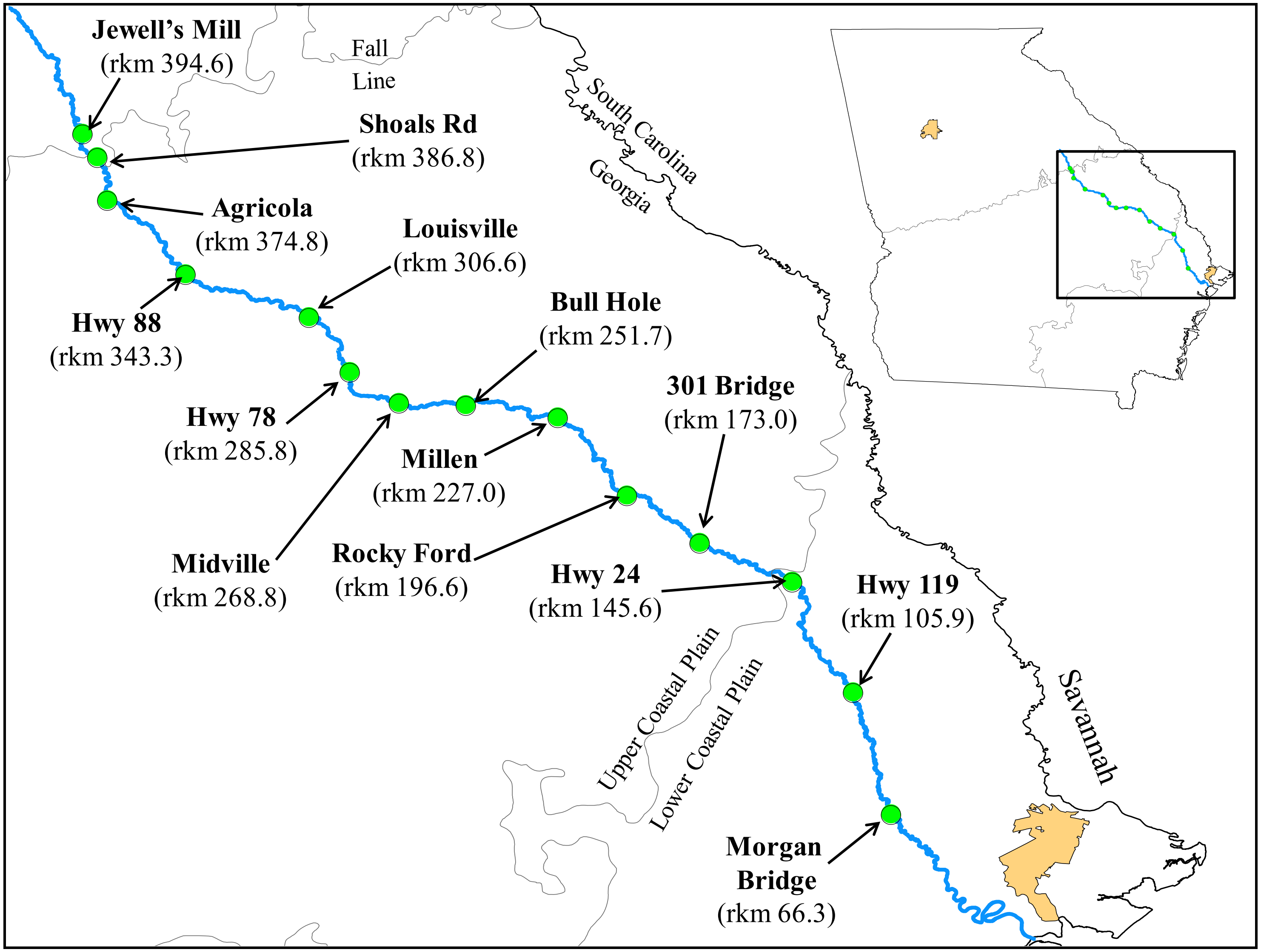

Figure 2. Distribution of the sampling stations (n=14) along the Ogeechee River, Georgia, that were sampled for suckers during the Summer/Autumn of 2012. Dots represent the sampling stations and the separation of ecoregions is also shown.

integrated transponder (PIT) tag. If a PIT tag was not detected, a new one was implanted just below the distal end of the dorsal fin, and the fish was released back into the river. Juvenile and other small suckers were humanely euthanized in the field with a buffered MS-222 solution, placed in 95% ethanol, and transported back to the laboratory for identification. Juvenile and other small suckers were sorted according to sampling station and gear type, identified to family or species, and measured to the nearest millimeter (TL).

Data Analysis

<u>Movement Patterns</u>

Methods similar to those of Grabowski and Isely (2006), Grabowski and Jennings (2009), and Ely (2012), were used to determine movement patterns of radio-tagged robust redhorse. Movement patterns were calculated for the pre-spawn/spawning time period (February – May) of 2011 and were based on the observed migratory and spawning behavior of tagged fish. Absolute distance moved, displacement, and linear home range were calculated for every individual collected between February and April that had at least three relocations from its release date through the end of May. Absolute distance moved was defined as the sum of the distance moved between relocations without regard to direction and was calculated as $\left| Pt+1 - Pt \right|$, where Pt is an individual's position in rkm at time t and $Pt+1$ is the same individual's position at time $t+1$. Displacement, defined as the net distance moved, was calculated as $Pt+1 - Pt$, 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. Linear home range was defined as the distance between the most upstream and most downstream location in rkm for an individual robust redhorse within a time period (Grabowski and Isely 2006; Ely 2012).

Relative Abundance

Catch per unit effort (CPUE) was used to determine the relative abundance of every sucker species collected from July through October 2011. CPUE was calculated as the number of individuals collected by species divided by total effort. Effort was defined by the type of sampling method used; electrofishing effort (boat and backpack) was recorded as the total number of hours of pedal time per sampling site, and seining effort was recorded as the total number of hauls per sampling site.

Size Structure and Year Class

To demonstrate increases in growth and determine if year-class strength fluctuates over time, length and year-class frequency distributions for individuals collected in the current study are presented with individuals collected from the same population sampled in 2008. During April 2008, robust redhorse (n=35) were collected from the Ogeechee River, weighed and measured (mm TL), and used for a different telemetry study (*see* Ely 2012). The estimated annual growth rate of robust redhorse stocked in the Ogeechee River was calculated by subtracting the mean length and weight of robust redhorse collected during the present study (March and April 2011) from the mean length and weight of study fish collected from the Ogeechee River in April 2008; those results were then divided by the average amount of time (years) elapsed between the two studies.

There were similarities between our methods and those used in the Ely (2012) study. In both studies, two separate crews (in two separate electrofishing boats) sampled simultaneously near different boat ramps (Louisville and Hwy 78). Each captured robust redhorse was measured to the nearest mm TL, weighed (kg), and checked for the presence of a coded wire tag (CWT); the location of the CWT was used to code for year class. Therefore, because similar methods were used in both studies, reliable comparisons can be made between the two studies.

RESULTS

Fish Collection and Transmitter Implantation

During the period December 2010 – April 2011, 30 adult robust redhorse (467−603 mm TL, 1.40−2.80 kg) were captured in the Ogeechee River, surgically implanted with radio transmitters, and released back into the river at four different boat ramps. The release sites were: 1) Louisville (rkm 306.6; n=4); 2) Hwy 78 (rkm 285.8; n=9); 3) Midville (rkm 268.8; n=9); and 4) Millen (rkm 227.0; n=8; Table 2). CPUE was lowest in November and December (range = 0.0−0.6 fish/h) but increased in March and April (range = 2.2−3.4 fish/h; Table 2).

Table 2. Electrofishing catch rate, sampling location(s), surgery date, and release sites for robust redhorse in the Ogeechee River from November 2010 to April 2011.

						Sampling location(s)			
Release date	# of robust redhorse	# of electrofishing boats	Total pedal time (h)	CPUE	Surgery / release site	Boat ramp 1	rkm	Boat ramp 2	rkm
11/17/10	0	1	1.03	0.0	--	Louisville	306.6	*	*
11/19/10	0	1	0.58	0.0	--	Louisville	306.6	*	*
12/02/10	1	1	1.66	0.6	Louisville	Hwy 78	285.8	*	*
12/03/10	0	1	0.60	0.0	--	Louisville	306.6	*	*
12/08/10	0	1	1.88	0.0	--	Hwy 88	343.3	*	*
12/13/10	0	1	1.82	0.0	--	Hwy 78	285.8	*	*
12/15/10	0	1	1.30	0.0	--	Morgan Bridge	66.3	*	*
02/23/11	3	2	3.39	0.9	Louisville	Louisville	306.6	Hwy 78	285.8
03/02/11	7	2	3.25	2.2	Hwy 78	Hwy 78	285.8	Midville	268.8
03/09/11	8	2	2.38	3.4	Millen	Millen	227.0	Midville	268.8
03/16/11	9	2	3.41	2.6	Midville	Midville	268.8	Millen	227.0
04/14/11	2	1	0.84	2.4	Hwy 78	Hwy 78	285.8	*	*

-- Indicates that fish were not implanted with radio transmitters and released on that date.

* Indicates that only one electrofishing crew (i.e., electrofishing boat) was used to sample that date

Movement and Spawning 2011

Radio-tagged robust redhorse were located 141 times in the Ogeechee River from February to May 2011; all transmitters (n=30) were located from two to eight times. Radio-tagged robust redhorse used in the analysis (n=24) were located 123 times; those individuals were located from three to eight times, and averaged five observations per fish.

During the pre-spawn/spawning period of 2011, absolute movement for robust redhorse averaged 41.7 rkm (95% CI = 28.8–54.7 rkm; Figure 3) and ranged from 3.5 to 111.5 rkm. Similarly, linear home range averaged 36.4 rkm (95% CI = 24.5–48.3 rkm; Figure 3) and ranged from 2.5 to 83.8 rkm. Mean displacement was positive (i.e., upstream), averaged 29.3 rkm (Figure 3), and ranged from -11.3 to 82.8 rkm.

Most (58%; n=14) live relocated robust redhorse (n=24) made large, upstream migrations (> 20 rkm) from their respective release sites; those individuals moved upstream an average of 51.0 rkm (range = 24.2–82.8 rkm) and the majority ended up near the Louisville boat ramp between rkm 315 and 305 (Figure 4). For robust redhorse used in the analysis (i.e., live individuals), the individual that was located farthest upstream was detected just above Hwy 88 (~ rkm 343) on 3 May 2011; the farthest downstream robust redhorse was detected on 21 April 2011 around rkm 222, which is located about 5 rkm upstream of the Millen boat ramp (~ rkm 227).

A previously unknown spawning site (rkm 307.4) with gravel substrates was discovered about 0.8 rkm upstream of the Louisville boat ramp (rkm 306.6) on 12 May 2011 (Figure 5). The spawning aggregation consisted of 10–15 robust redhorse and was discovered by using three radio-tagged individuals as guide fish. After locating the three tagged fish in close proximity to each other, a visual survey was conducted from the

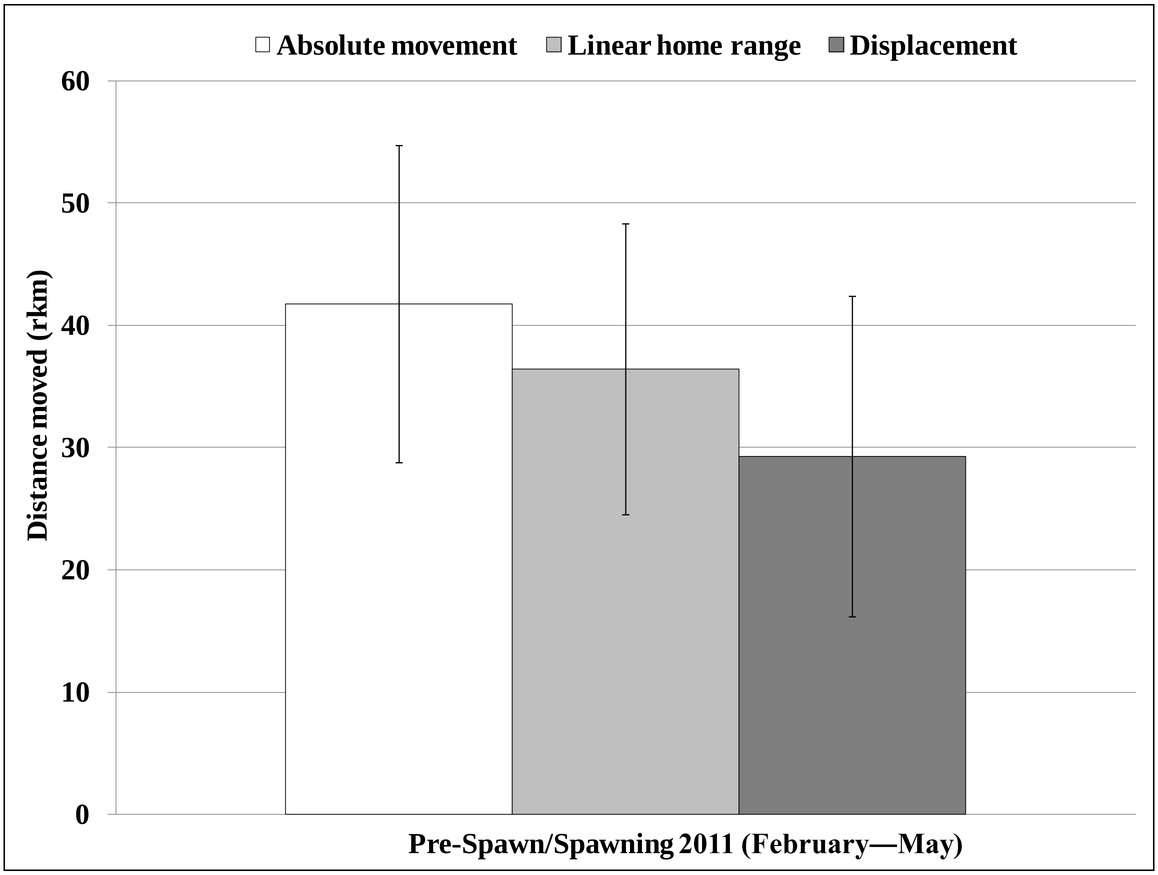

Figure 3. Mean (± 95% CI) pre-spawn/spawning absolute movement, linear home range, and displacement for radio-tagged robust redhorse in the Ogeechee River, Georgia, from February through May 2011.

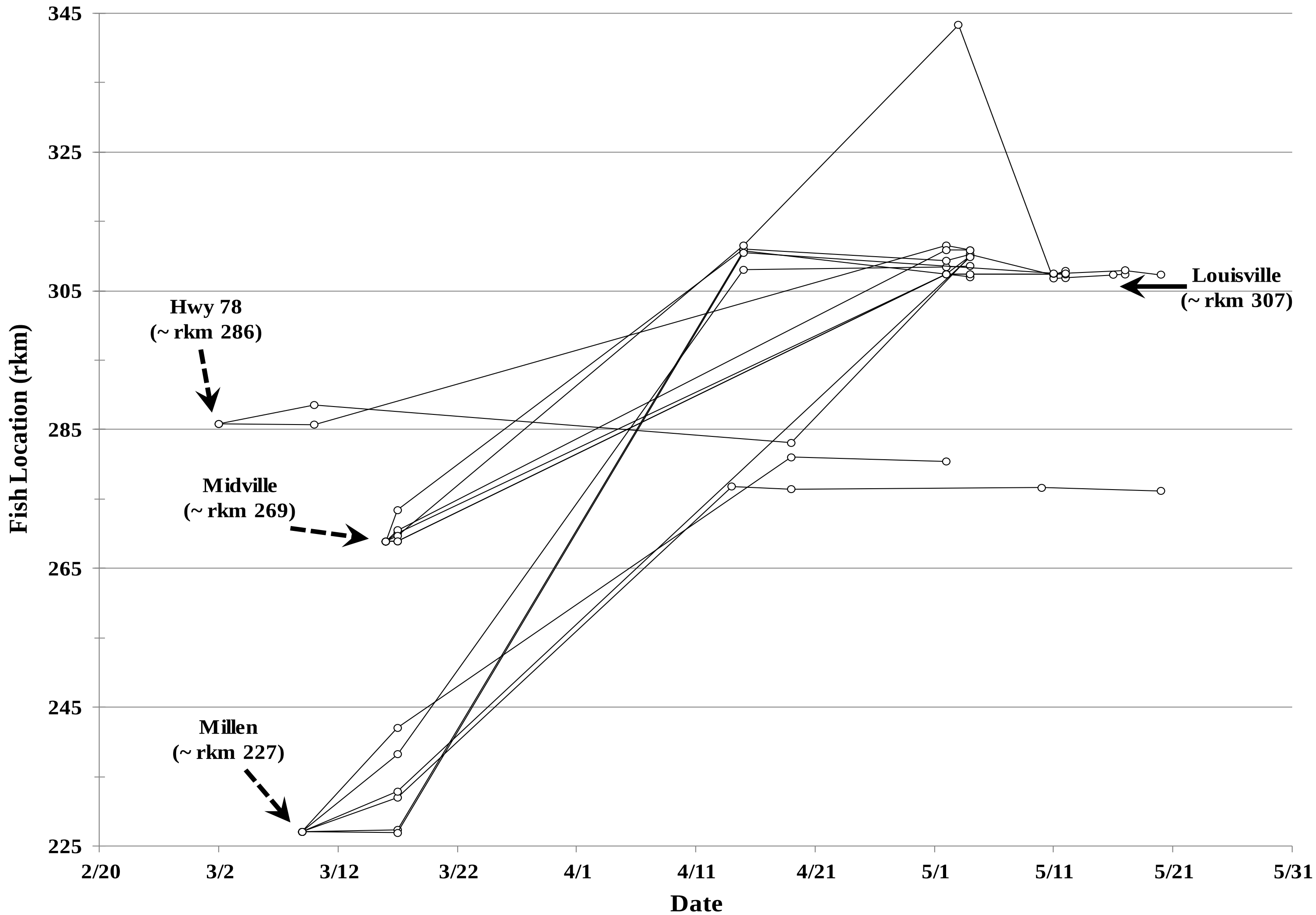

Figure 4. Initial locations (rkm) of radio-tagged robust redhorse in the Ogeechee River that migrated > 20 rkm upstream (n=14) following release, from 24 February 2011 to 20 May 2011. The points represent individual locations and the lines represent the time between relocations. The post-surgery release sites of those individuals are shown by dashed arrows and the location of the Louisville boat ramp is shown with a solid arrow.

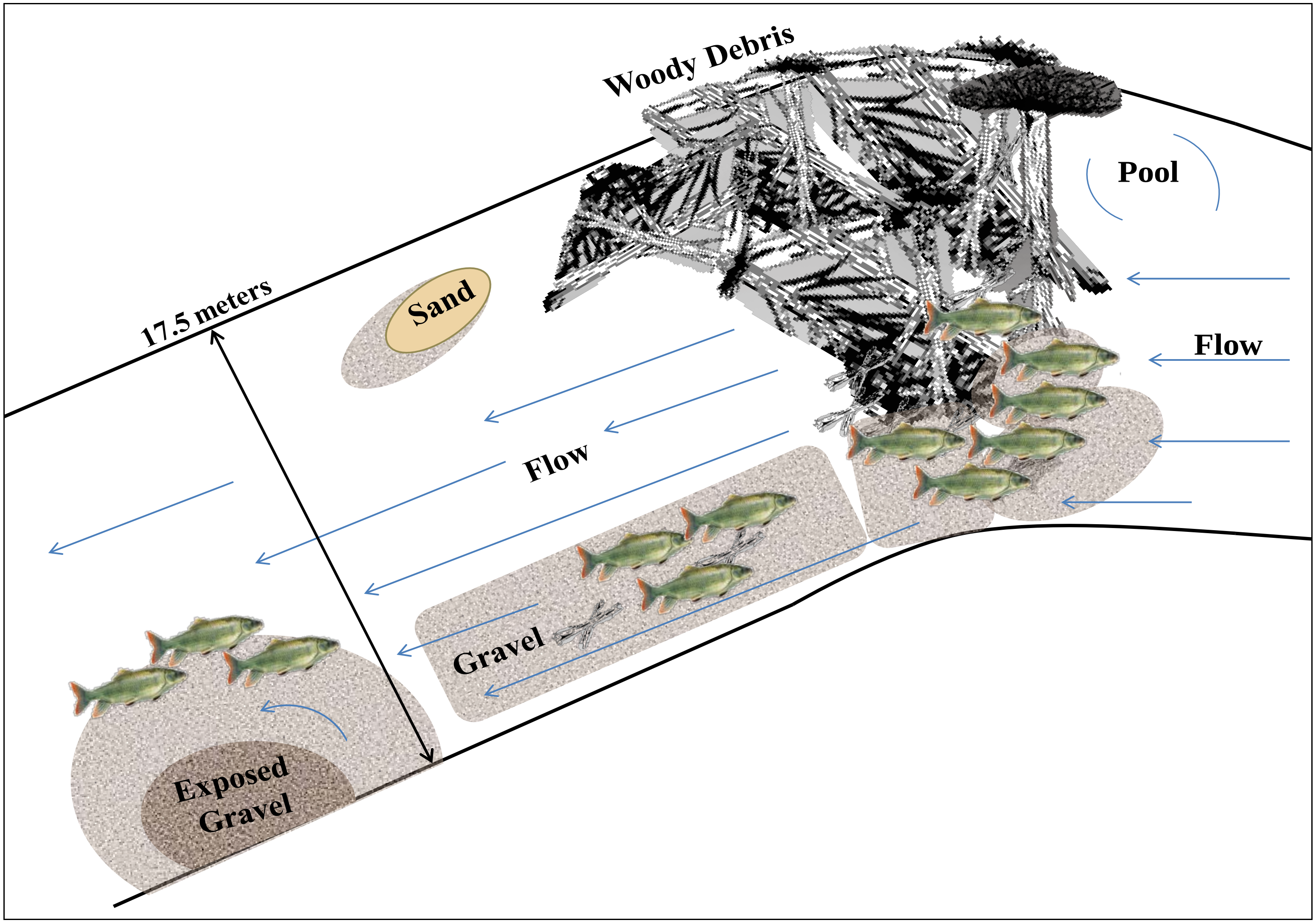

Figure 5. Schematic of the newly discovered robust redhorse spawning site (rkm 307.4) upstream of the Louisville boat ramp during May 2011. The locations of the fish represent the areas where spawning activity was observed.

bank, and spawning activity was observed (Figure 6). The spawning aggregation was observed on four different days from 12 May 2011 to 20 May 2011; recorded water temperatures during spawning activity at the site ranged from about 20 to 22 °C (n=4). From 12 May 2011 through 20 May 2011, 33% (n=8) of radio-tagged robust redhorse (n=24) were located at the spawning site at least once, and five of those individuals were relocated there multiple times (range = 2–4). Sixty-three percent of those individuals (5 of 8) at the spawning site were located over gravel substrates; four were located once, and the other was located twice over gravel. By 24 May 2011, robust redhorse appeared to have abandoned the spawning site; radio-tagged individuals were not located in the area and untagged fish were not visually observed despite water temperatures being about 21°C.

November Telemetry 2011

A helicopter telemetry trip was conducted along the entire length of the Ogeechee River from its headwaters to the coast on 02 November 2011. About 37% (n=11) of all radio-tagged robust redhorse (n=30) were relocated between Louisville (~ rkm 307) and Rocky Ford (~ rkm 197). Most (91%; n=10) of those fish occupied the section of river between Louisville (~ rkm 307) and Midville (~ rkm 269).

A radio monitoring trip (by boat and foot) was conducted the following week over the course of two days (8–9 November 2011) into accessible areas of the river, where study fish were previously located by way of the helicopter. During boat and foot tracking, two fish found during the helicopter flight were relocated, and two additional fish were found that were not previously located during helicopter tracking. Therefore, the helicopter telemetry trip appears to have missed a portion of radio-tagged fish that were between Louisville (~ rkm 307) and Midville (~ rkm 269) during November 2011.

Figure 6. Picture of spawning activity at the upper end of the newly discovered robust redhorse spawning site (rkm 307.4) upstream of the Louisville boat ramp during May 2011. Note the three individuals (circled in white); adults spawn in triads that consist of one female and two males. During the spawning process, males establish territories that are forcefully defended from rivals; males jockey for position and frequently breakup spawning triads.

Movement and Spawning 2012

Radio-tagged robust redhorse were located 104 times in the Ogeechee River from 26 March to 31 May 2012 and 80% (n=24) of all transmitters (n=30) were located from one to seven times. Two transmitters were located out of the water along the bank and buried in sediment. An additional 14 transmitters did not appear to have changed position since being located the previous year, indicating either mortality or transmitter expulsion. The remaining fish (n=8) were located a total of 40 times; individuals were located from four to seven times and averaged five observations per fish.

Movement of radio-tagged robust redhorse was severely limited and spawning migration patterns were not observed; fish were generally confined to deep, slow moving water in sections of river located between Louisville (~ rkm 307) and Midville (~ rkm 269; Figure 7). During April and May 2012, mean daily discharge (3 m^3/s; range = 1−7 m^3/s) was low compared to both 2011 (mean = 16 m^3/s; range = 3−58 m^3/s) and the 50th percentile (i.e., median) of mean daily flows from 2003−2010 (mean = 36 m^3/s; range = 16−61 m^3/s (Figure 8). Furthermore, the mean daily discharge during April and May 2012 (3 m^3/s; range = 1−7 m^3/s) was lower than the minimum of daily mean flows from 2003−2010 (mean = 9 m^3/s; range = 2−17 m^3/s; Figure 8).

A total of eight gravel bars were identified and subsequently monitored for spawning activity during the pre-spawn/spawning season (March−May) of 2012 (Figure 9). Two of the gravel bars had been previously identified: they were 1) the Louisville spawning site discovered in 2011; and 2) the artificial spawning site created at Rocky Ford in 2009. The other six gravel bars were previously unknown. From 17 April 2012 to 31 May 2012, each gravel bar was monitored from three to seven times, averaging five

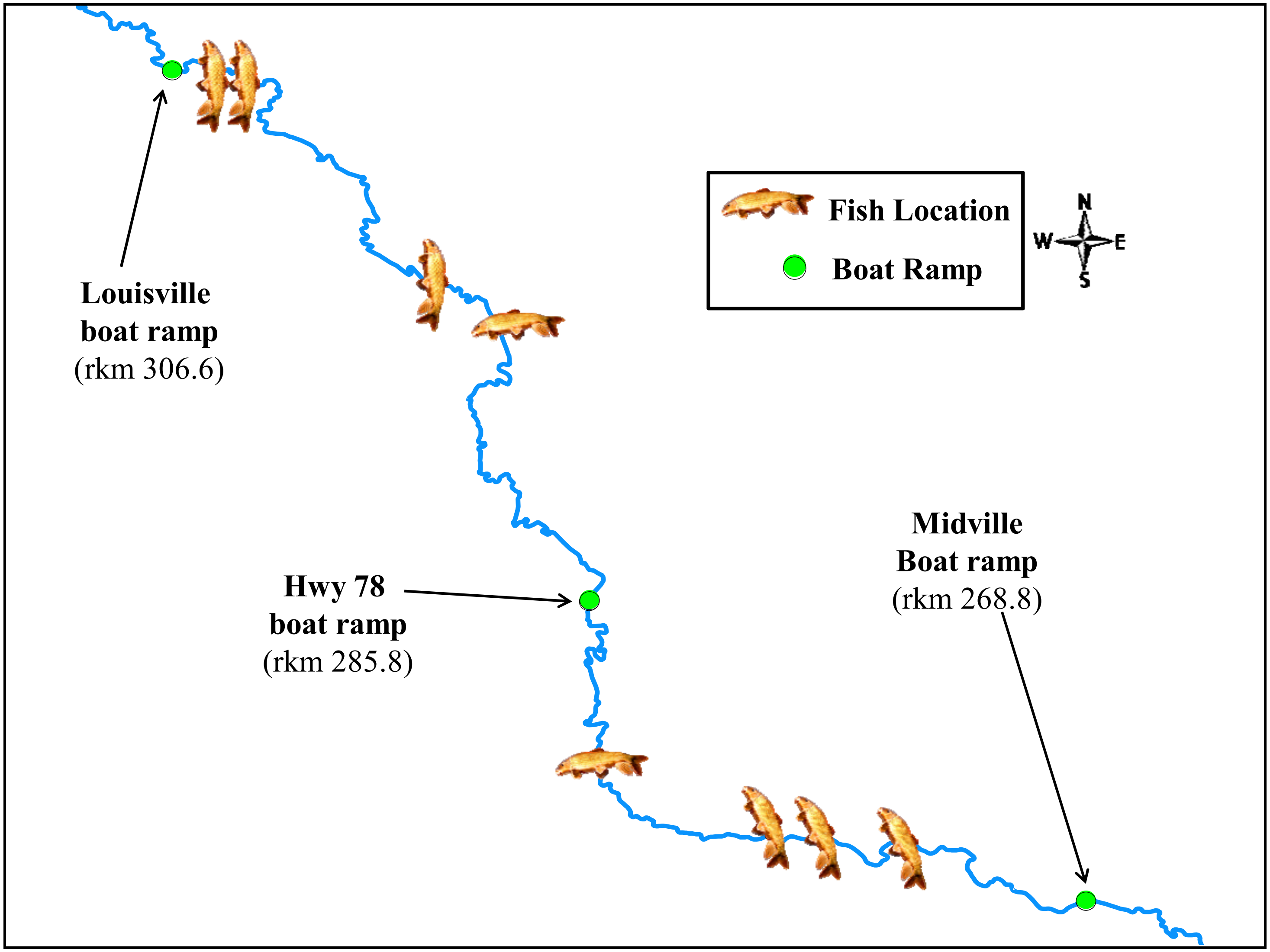

Figure 7. Distribution of the remaining radio-tagged robust redhorse (n=8) located between the Louisville (rkm 306.6) and Midville boat ramps (rkm 268.8) in the Ogeechee River, Georgia, during the pre-spawn/spawning season of 2012. The dots represent boat ramps and the fish represent individual positions.

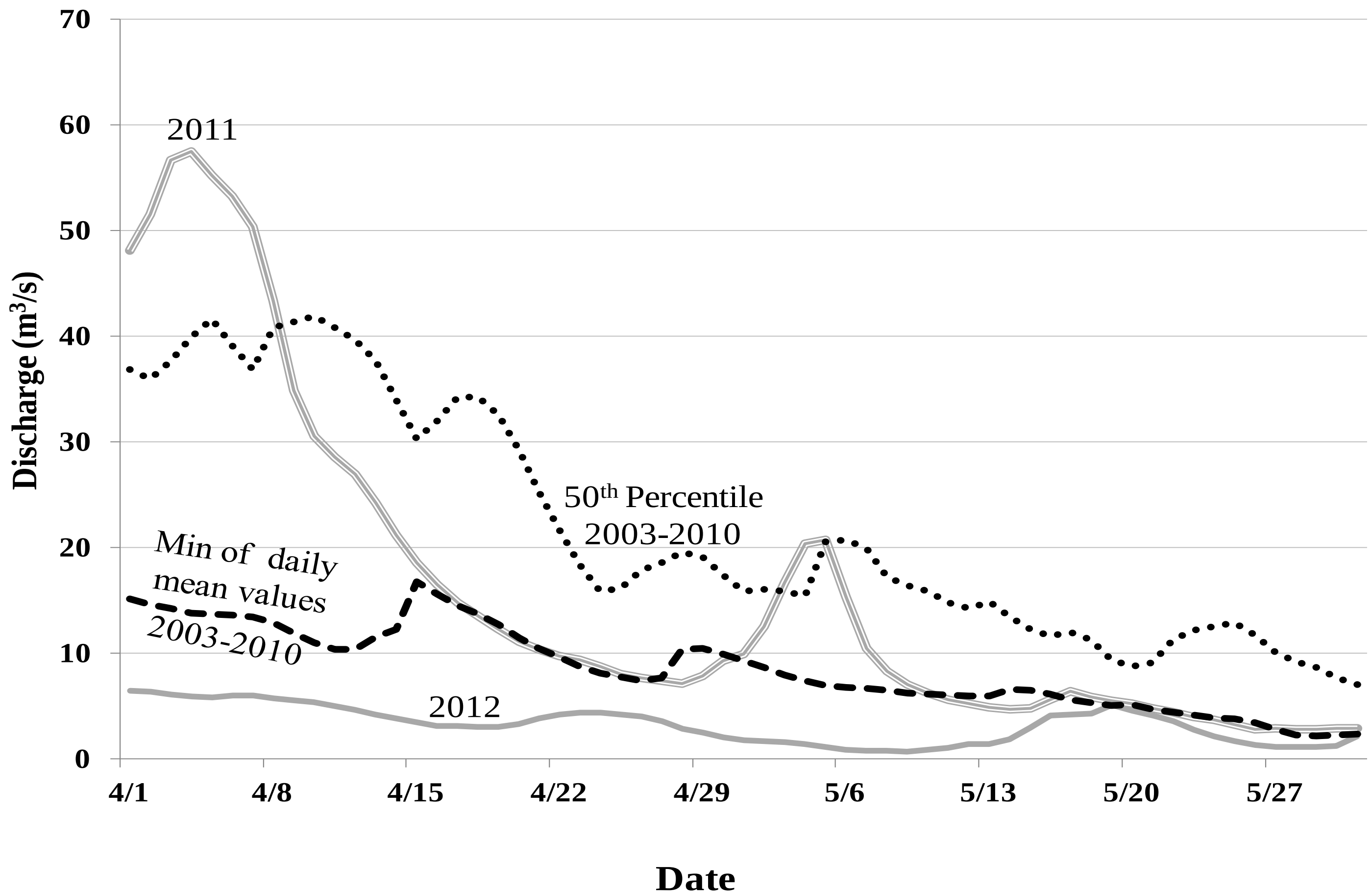

Figure 8. Mean daily discharge (m^3/s) of the Ogeechee River at Midville (U.S. Geological Survey gauging station 02201230) during April and May: 2011 (grey striped line) and 2012 (grey solid line); the daily 50th percentile (i.e., median) of mean daily flows from 2003–2010 (dotted black line), and the minimum of daily mean values from 2003–2010 (dashed black line).

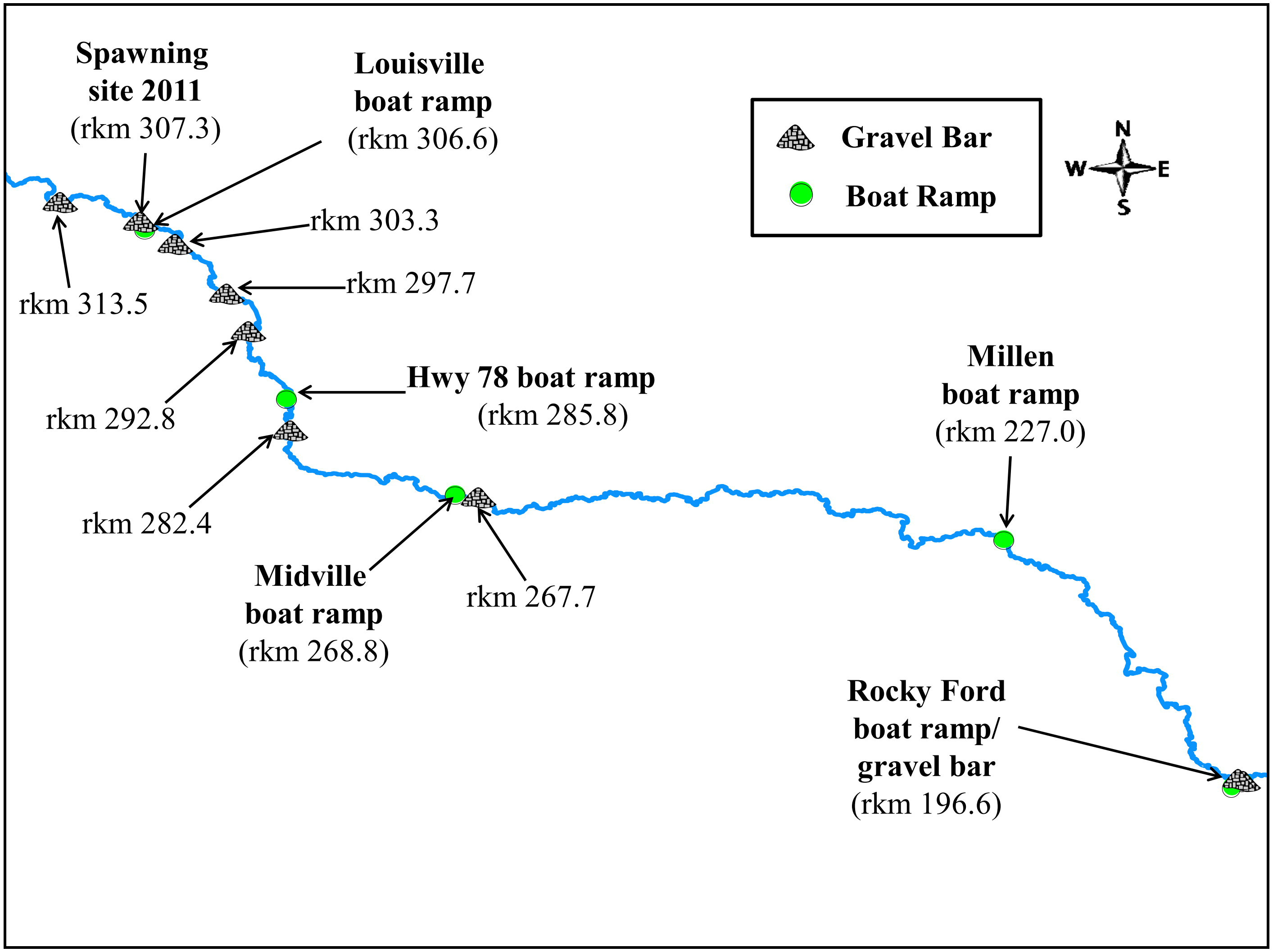

Figure 9. Distribution of the gravel bars (n=8) in the Ogeechee River, Georgia, that were monitored for robust redhorse spawning activity during the pre-spawn/spawning season of 2012. The dots represent boat ramps and the grey, textured piles represent gravel bars.

visual surveys per gravel bar. Spawning activity was not observed at any of the gravel bars during 2012; however, in May, scoured out pockets of gravel were documented at the Louisville site in areas where robust redhorse were observed spawning the previous year (i.e., May 2011).

Summer/Autumn Sampling

Backpack Electrofishing

From July to September 2011, backpack electrofishing was used to sample six different sites along the Ogeechee River. Sampling effort totaled 4.8 hours (h) and ranged from 0.1 to 2.0 h per site (Table 3). A total of 62 suckers were collected from four of the six sites sampled; the catch was comprised of chubsuckers *Erimyzon spp.* (92%; n=57) and brassy jumprock *Moxostoma sp. cf. M. lachneri* (8%; n=5); (Table 3). Chubsuckers (58–176 mm TL) were collected from four sampling sites; CPUE at those sites ranged from 3.0 to 24.5 fish/h and was largest at Rocky Ford (rkm 196.6; Table 3). Brassy jumprock (50–265 mm TL) were collected from two sampling sites; CPUE at those sites ranged from 1.5 to 2.0 fish/h and was largest at Shoals Rd (rkm 386.8; Table 3). Robust redhorse and notchlip redhorse were not captured by backpack electrofishing at any site throughout the study.

Seining

From August to October 2011, seining was used to sample 12 different sites along the Ogeechee River. Sampling effort totaled 123 hauls and ranged from 3 to 23 hauls per site (Table 4). A total of 104 suckers were collected from 7 of the 12 sites;

Table 3. Total backpack electrofishing effort (hours), number of suckers collected, and the catch per unit effort (CPUE) of each sucker species according to sampling site from July to September 2011.

		Species					
		Erimyzon spp.		*Moxostoma sp. cf. M. lachneri*		*Moxostoma robustum*	
Sampling station	Total effort (h)	Number collected	CPUE	Number collected	CPUE	Number collected	CPUE
Jewell's Mill	0.56	0	0.0	0	0.0	0	0.0
Shoals Rd	2.03	24	11.8	4	2.0	0	0.0
Agricola	0.66	2	3.0	1	1.5	0	0.0
Rocky Ford	1.02	25	24.5	0	0.0	0	0.0
Hwy 24	0.12	0	0.0	0	0.0	0	0.0
Hwy 119	0.34	6	16.9	0	0.0	0	0.0

Table 4. Number of seine hauls (effort), number of suckers collected, and the CPUE of each sucker species according to sampling site from August to October 2011.

		Species							
		Minytrema melanops		*Erimyzon spp.*		*Moxostoma sp. cf. M. lachneri*		*Moxostoma robustum*	
Sampling station	Total effort (hauls)	Number collected	CPUE	Number collected	CPUE	Number collected	CPUE	Number collected	CPUE
Jewell's Mill	6	0	0.0	0	0.0	0	0.0	0	0.0
Shoals Rd	8	0	0.0	0	0.0	2	0.3	0	0.0
Agricola	9	6	0.7	0	0.0	1	0.1	0	0.0
Louisville	3	0	0.0	0	0.0	0	0.0	0	0.0
Midville	9	0	0.0	0	0.0	0	0.0	0	0.0
Bull Hole	23	2	0.1	0	0.0	0	0.0	0	0.0
Millen	7	6	0.9	0	0.0	0	0.0	0	0.0
Rocky Ford	3	0	0.0	0	0.0	0	0.0	0	0.0
301 Bridge	12	1	0.1	0	0.0	0	0.0	0	0.0
Hwy 24	7	0	0.0	0	0.0	0	0.0	0	0.0
Hwy 119	14	14	1.0	0	0.0	0	0.0	0	0.0
Morgan Bridge	22	71	3.2	1	0.0	0	0.0	0	0.0

catch was comprised of spotted suckers *Minytrema melanops* (96%; n=100), brassy jumprock (3%; n=3), and chubsuckers (1%; n=1); (Table 4). Spotted suckers (57–128 mm TL) were collected from six sampling sites; CPUE at those sites ranged from 0.1 to 3.2 fish/haul and was largest at Morgan Bridge (rkm 66.3; Table 4). Brassy jumprock (50–177 mm TL) were collected from two sampling sites; CPUE at those sites ranged from 0.1 to 0.3 fish/haul and was largest at Shoals Rd (rkm 386.8; Table 4). One chubsucker (94 mm TL) was collected by seine (CPUE = 0.01 fish/haul) from the Morgan Bridge site (rkm 66.3; Table 4). Robust redhorse and notchlip redhorse were not collected by seine at any site throughout the study.

Boat Electrofishing

From August to October 2011, boat electrofishing was also used to sample suckers at nine different sites along the Ogeechee River. Sampling effort totaled 14.41 hours (h) and ranged from 0.14 to 2.60 h per site (Tables 5 and 6). The entire catch (n=446) was divided into juvenile (Table 5) and adult suckers (Table 6).

A total of 127 juvenile suckers were collected from seven of the nine sites and transported back to the laboratory for identification and measurement; the catch was comprised of spotted suckers (81%; n=104) and chubsuckers (18%; n=23); (Table 5). Spotted suckers (75–144 mm TL) were collected from seven sampling sites; CPUE at those sites ranged from 1.2 to 21.7 fish/h and was largest at Millen (rkm 227.0; Table 5). Chubsuckers (64–120 mm TL) were collected from five sampling sites; CPUE at those sites ranged from 0.4 to 4.5 fish/h and was largest at Hwy 78 (rkm 285.8; Table 5). Robust redhorse < 425 mm were not collected at any site throughout the study.

Table 5. Boat electrofishing effort (hours), number of juvenile suckers collected and identified in the lab, and the CPUE of each species according to sampling site from August to October 2011.

		Species					
		Minytrema melanops		*Erimyzon spp.*		*Moxostoma robustum*	
Sampling station	Total effort (hours)	Number collected	CPUE	Number collected	CPUE	Number collected	CPUE
Hwy 88	1.87	0	0.0	0	0.0	0	0.0
Louisville	1.54	7	4.5	6	3.9	0	0.0
Hwy 78	1.79	6	3.4	8	4.5	0	0.0
Midville	2.60	3	1.2	1	0.4	0	0.0
Bull Hole	2.30	16	7.0	5	2.2	0	0.0
Millen	0.88	19	21.7	0	0.0	0	0.0
Rocky Ford	0.14	0	0.0	0	0.0	0	0.0
Hwy 24	0.86	16	18.6	3	3.5	0	0.0
Morgan Bridge	2.43	37	15.2	0	0.0	0	0.0

Table 6. Boat electrofishing effort (hours), number of adult suckers collected and identified in the field, and the CPUE of each species according to sampling site from August to October 2011.

		Species									
		Minytrema melanops		*Erimyzon spp.*		*Moxostoma sp. cf. M. lachneri*		*Moxostoma collapsum*		*Moxostoma robustum*	
Sampling station	Total effort (hours)	Number collected	CPUE	Number collected	CPUE	Number collected	CPUE	Number collected	CPUE	Number collected	CPUE
Hwy 88	1.87	45	24.1	0	0.0	2	1.1	2	1.1	1	0.5
Louisville	1.54	22	14.2	0	0.0	5	3.2	2	1.3	0	0.0
Hwy 78	1.79	35	19.5	0	0.0	8	4.5	2	1.1	2	1.1
Midville	2.60	47	18.1	1	0.4	6	2.3	0	0.0	0	0.0
Bull Hole	2.30	36	15.6	0	0.0	1	0.4	2	0.9	0	0.0
Millen	0.88	69	78.7	0	0.0	2	2.3	1	1.1	0	0.0
Rocky Ford	0.14	5	35.2	0	0.0	0	0.0	0	0.0	0	0.0
Hwy 24	0.86	0	0.0	1	1.2	0	0.0	0	0.0	0	0.0
Morgan Bridge	2.43	22	9.1	0	0.0	0	0.0	0	0.0	0	0.0

A total of 319 adult suckers were collected from nine of the nine sampling sites, identified in the field, and released into the Ogeechee River. The catch was comprised of spotted suckers (88%; n=281), brassy jumprock (8%; n=24), notchlip redhorse *Moxostoma collapsum* (3%; n=9), robust redhorse (1%; n=3), and chubsuckers (<1%, n=2); (Table 6). Spotted suckers were collected from eight sampling sites; CPUE at those sites ranged from 9.1 to 78.7 fish/h and was largest at Millen (rkm 227.0; Table 6). Brassy jumprock were collected from six sites; CPUE at those sites ranged from 0.4 to 4.5 fish/h and was largest at Hwy 78 (rkm 285.8; Table 6). Notchlip redhorse were collected from five sites; CPUE at those sites ranged from 0.9 to 1.3 fish/h and was largest at Louisville (rkm 306.6; Table 6). Adult robust redhorse were collected at two of the nine sites; CPUE at those sites ranged from 0.5 to 1.1 fish/h and was largest at Hwy 78 (rkm 285.8; Table 6). Chubsuckers were collected at two sites; CPUE at those sites ranged from 0.4 to 1.2 fish/h and was largest at Hwy 24 (rkm 145.6; Table 6). Total lengths (mm TL) of the captured robust redhorse (n=3) ranged from 496 to 505 mm.

Size Structure and Year Class

Robust redhorse (n=33), collected from December 2010 through October 2011, were primarily in the 500−520 mm (30%; n=10) and 520−540 mm (27%; n=9) size range classes followed by the 480−500 mm (15%; n=5) and 540−560 mm (15%; n=5) size classes (Figure 10)[4]. The smallest robust redhorse collected was 467 mm TL. A coded wire was located on 22 of 33 (67%) robust redhorse; most coded wire tags were determined to be from the 2002 year class (64%; n=14) followed by the 2004 (18%; n=4) and 2000 (14%; n=3) year classes (Figure 11).

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[4] Size range classes in Figure 10 have been converted from mm to cm.

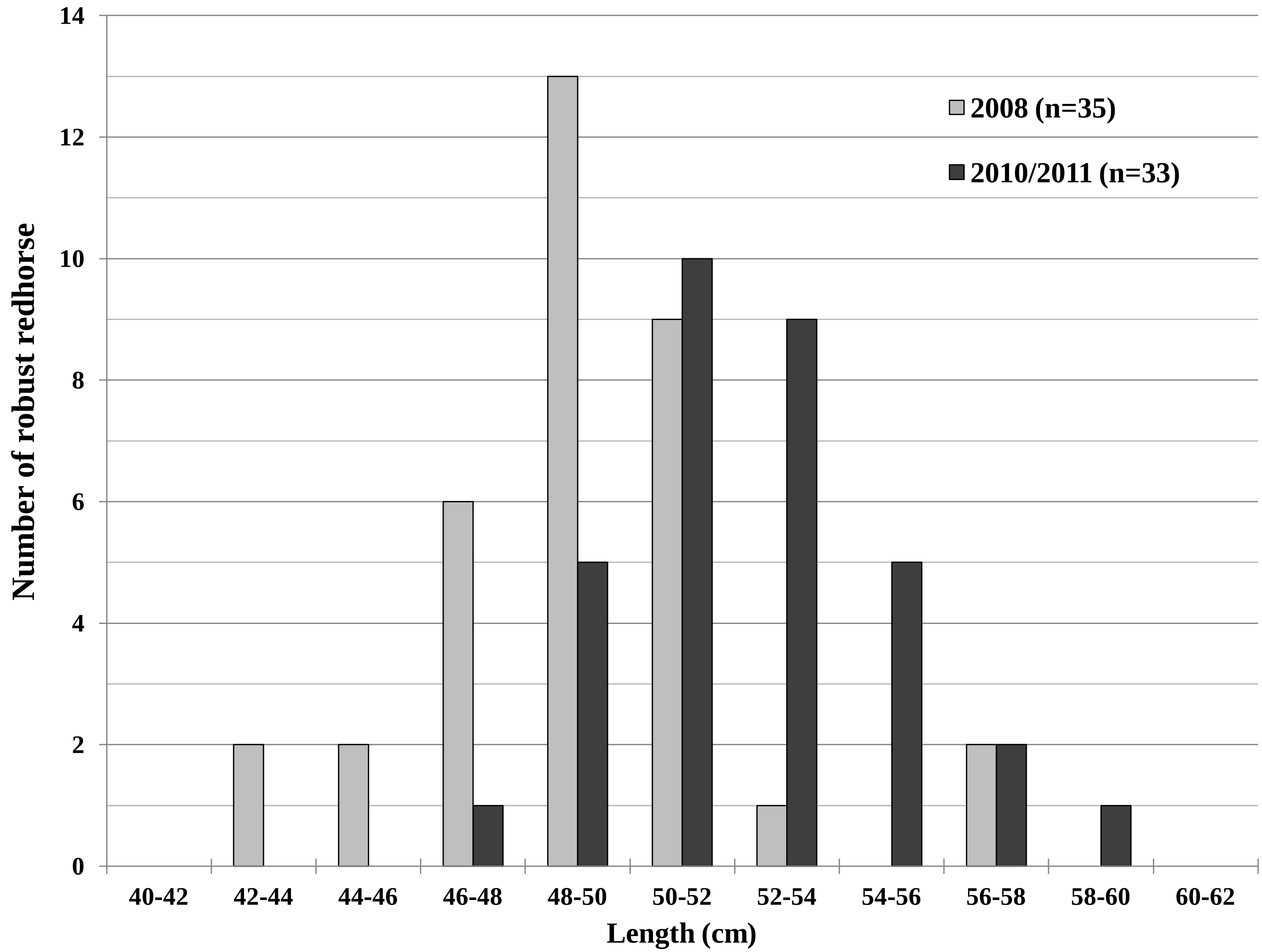
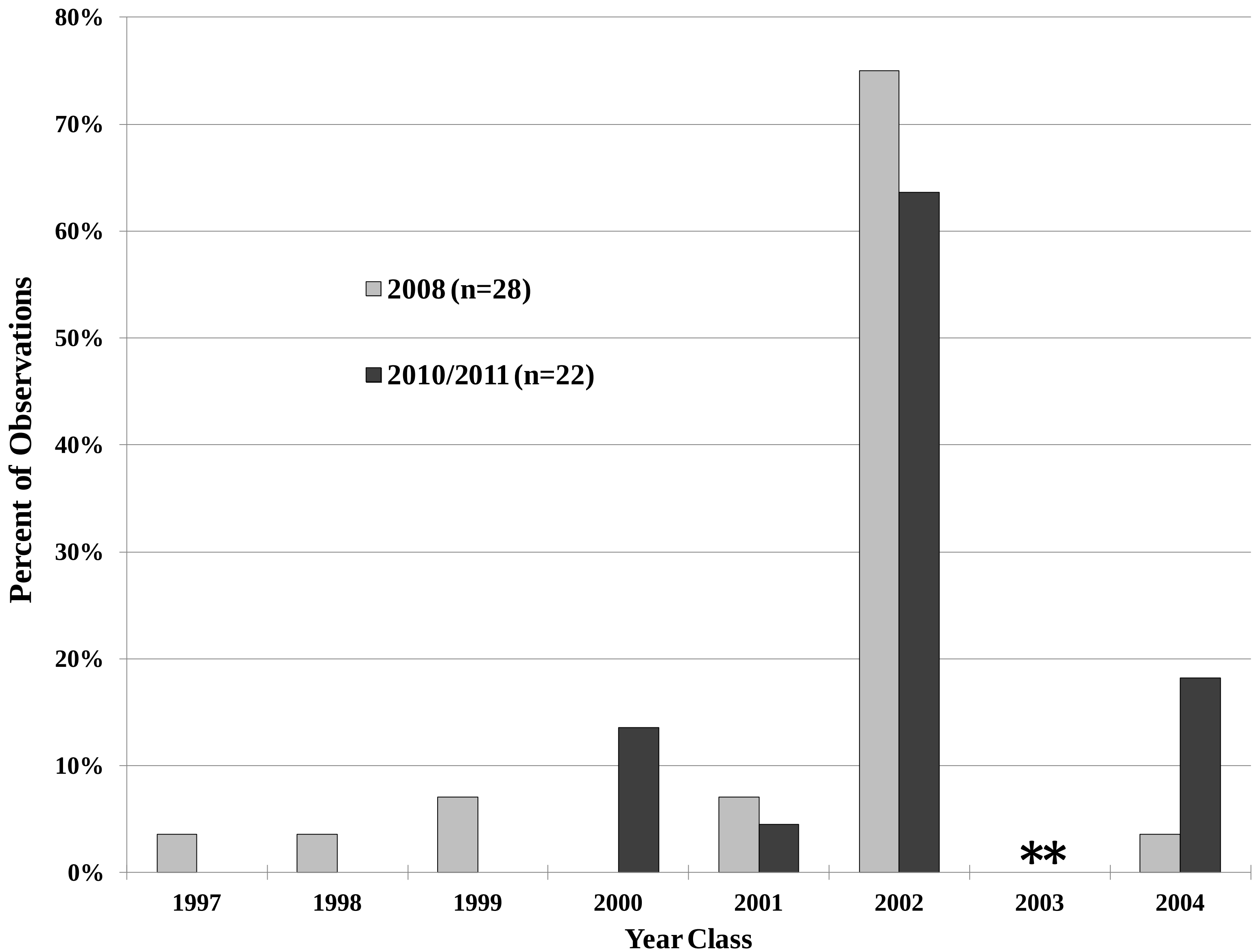


Figure 10. Length distribution (cm) of stocked robust redhorse collected in the Ogeechee River by boat electrofishing in 2008 and 2010/1011. (Note: 1 cm = 10 mm).



** Robust redhorse were not stocked into the Ogeechee River in 2003.

Figure 11. Year class distribution (%) for robust redhorse collected from the Ogeechee River in 2008 and 2010/2011.

Robust redhorse (n=35) collected in April 2008 during the Ely (2012) study were primarily in the 480−500 mm size class (37%; n=13), followed by the 500−520 mm (26%; n=9) and 460−480 mm (17%; n=6) size classes (Figure 10). About 6% (n=2) of robust redhorse were each found in the 420−440 mm, 440−460 mm, and 560−580 mm size classes. The smallest robust redhorse collected was 425 mm TL. A coded wire was located on 28 of 35 (80%) of robust redhorse; most coded wire tags were determined to be from the 2002 year class (75%; n=21) followed by both the 1999 (7%; n=2) and 2001 (7%; n=2) year classes (Figure 11).

Annual Growth Rate

The mean length and weight of robust redhorse captured in April 2008 (n=35) was 495 mm and 1,690 g, respectively; mean length and weight of robust redhorse captured in March and April 2011 (n=28) was 522 mm and 1,840 g, respectively. The mean length of time between the captures of the 2008 study fish and the 2011 study fish was 2.88 years. Therefore, the estimated annual growth rate of stocked robust redhorse in the Ogeechee River was 10 mm total length per year, and 54 g in weight per year.

DISCUSSION

Fish movement and habitat use

Spawning migrations by fish in the present study were similar to those of both wild- and hatchery-produced, radio-tagged robust redhorse in other southeastern river systems (Grabowski and Isely 2006; Grabowski and Jennings 2009; Fisk 2010; Ely 2012). However, migration distances of robust redhorse differed among river systems and appear to be larger for those populations that live within the Coastal Plain ecoregion instead of the Piedmont ecoregion. For example, migration distances for radio-tagged robust redhorse stocked in the Ogeechee River were similar to those for wild robust redhorse in the Savannah River, Georgia/South Carolina (Grabowski and Isely 2006) and stocked robust redhorse in the Oconee River, Georgia (Ely 2012), but larger than those of robust redhorse found in the Pee Dee River, North Carolina/South Carolina (Fisk 2010). This phenomenon has been hypothesized to occur because suitable habitat is patchier in rivers that primarily fall within the Coastal Plain compared to Piedmont rivers and because dams limit access to preferred habitat in Piedmont reaches (Grabowski and Isely 2006; Fisk 2010). Findings from two radio-telemetry studies, one using wild-spawned robust redhorse in the Savannah River (Grabowski and Isely 2006) and the other using hatchery-reared robust redhorse in the Ocmulgee River (Grabowski and Jennings 2009), each support this hypothesis. In both studies, a portion of tagged fish occupied Piedmont reaches above a dam throughout the year while displaying limited movement patterns; the remaining portion of tagged fish occupied the Coastal Plain ecoregion of river below a dam throughout the year and made spawning migrations, sometimes long distances, to spawning grounds. During the Savannah River study (Grabowski and Isely 2006), one tagged individual was able to pass through the dam (by way of the navigational lock) and migrate to Piedmont habitat where it was located for the remainder of the study. Once this fish was above the dam, it exhibited limited movement patterns.

Fisk (2010) noted that two different behavioral subgroups of radio tagged robust redhorse were observed in the Pee Dee River, North Carolina/South Carolina in a section where impoundments do not restrict access between the Piedmont and Coastal Plain ecoregions. During the Fisk (2010) study, one subgroup (n=21) stayed in the Piedmont reach throughout the year and made localized movements during the spawning season, while the other subgroup (n=7) made substantial downstream migrations into the Coastal Plain reach of river during the non-spawning period and migrated back upstream into the Piedmont reach during spawning. Currently, the Ogeechee River does not have dams to restrict access to Piedmont habitat; however, radio-tagged fish in the present study were never located in that section of river. Although robust redhorse fingerlings were stocked in the Piedmont section of river for five consecutive years from 1997–2001 (RRCC 2001; RRCC 2003), summer/autumn sampling during the present study did not result in the capture of any robust redhorse. Therefore, evidence of robust redhorse occupying Piedmont reaches of the Ogeechee River remains lacking. The reason why radio tagged robust redhorse were not found in Piedmont habitat could be related to the Ogeechee River's relatively low discharge, which could limit habitat availability and suitability, as compared to other southeastern rivers that have robust redhorse populations. Further, relatively low water levels observed throughout the present study could have restricted access to Piedmont reaches, especially through high gradient reaches near the fall line (e.g., Shoals). Additionally, suitable spawning habitat (gravel substrates, swift current) apparently is available to robust redhorse where they are currently located within the Coastal Plain. A similar occurrence was observed for stocked robust redhorse in the Oconee River (Ely 2012), where tagged fish migrated to gravel areas located within the Coastal Plain ecoregion. Further, the Oconee River study fish did not attempt to enter Piedmont reaches where gravel deposits and potential spawning habitat exist, despite higher flows that allowed accessibility between ecoregions during spawning season and various other times throughout the year.

Spawning sites

Although the number and location of robust redhorse spawning sites can fluctuate annually, some studies show that spawning aggregates can be limited to just one or two locations during a given spawning season (Grabowski and Isely 2006; Fisk 2010; Ely 2012). Also, a high incidence of spawning-site fidelity (i.e., returning annually to the same spawning ground) has been observed for wild, radio-tagged robust redhorse (Grabowski and Isely 2006; Fisk 2010). In the present study, an aggregate of spawning robust redhorse was located during May 2011 near the Louisville boat ramp; this location is currently the only known spawning site in the Ogeechee River. Indirect evidence suggests that this spawning site was also used during the previous and following spawning seasons; in June 2010, four mature robust redhorse that had typical post-spawning injuries were collected near the Louisville boat ramp (RRCC 2011). In May 2012, scoured pockets of gravel were documented at the site in areas where robust redhorse were visually observed spawning the previous year. Other areas of gravel substrate were discovered in the Ogeechee River within the known range of robust redhorse; however, evidence of spawning activity only existed at the Louisville site. Although substrate size was not quantified during this study, the gravel at the Louisville spawning site appears to be similar in size to other gravel bars in the Ogeechee River, but smaller than gravel substrates at robust redhorse spawning sites in other river systems. Woody-debris located at the Louisville site seems to collect and stabilize gravel needed for spawning, and similar occurrences have also been observed at spawning sites in the Oconee River (Ely 2012; Cecil Jennings, United States Geological Survey, unpublished data; Jimmy Evans, Georgia Department of Natural Resources, personal communication). However, changes in discharge and water levels can change the suitability of an existing spawning site, create new sites, and destroy old spawning sites. Consequently, water levels can influence an individual's behavior and movement patterns (Grabowski and Isely 2007; Ely 2012). For example, high flows in the Oconee River recently eroded a strip of land that separated two river bends; this erosion exposed or collected gravel and led to the discovery of a new spawning site in 2009 (Ely 2012). However, by the following spawning season, continued erosion had further widened the area and washed away or buried the gravel substrate, which made the site unsuitable for spawning in 2010 (Ely 2012). Also, robust redhorse have been documented moving back and forth between known spawning sites in search of suitable spawning habitat as a result of changing river conditions (Grabowski and Isely 2006; Fisk 2010). Whether the Louisville site is the only spawning site in the Ogeechee River and if stocked robust redhorse will continue to spawn there are currently unknown; however, additional research to assess the amount of available spawning habitat as it relates to fluctuations in flow may help address these questions.

Discharge and water levels during the spring and summer appear to play an important role in the spawning behavior and movements of robust redhorse. During a period of increased discharge in the spring of 2011, tagged fish made upstream migrations, some to a spawning ground. Migrations in response to rising flows have also been documented for both wild and hatchery-reared robust redhorse (Fisk 2010; Ely 2012) as well as other potamodromous species such as the paddlefish *Polyodon spathula* (Firehammer and Scarnecchia 2006; Miller and Scarnecchia 2008), sacramento sucker *Catostomus occidentalis* (Jeffres et al. 2006), and humpback chub *Gila cypha* (Muth et al. 2000). Conversely, low water levels and decreased discharge have the potential to create barriers to fish migration (Lake 2011). During the present study, low flows during the spring and summer of 2012 seem to have limited upstream migration patterns as spawning activity was not observed during that time. Similarly, low flows prevented the spawning migration of the federally Endangered Cui-ui *Chamistes cujus*, also a large, long-lived catastomid (Scoppettone et al. 2000). Other potamodromous species such as paddlefish, may skip or abandon spawning as a result of low or decreasing flows (Paukert and Fisher 2001; Firehammer and Scarnecchia 2007). Some long-lived species are adapted to compensate for non-spawning years by increasing fecundity the following spawning period (Scoppettone et al. 2000; Lake 2011); however, if spawning does occur prior to decreasing water levels, nest-sites can dewater or become exposed to zero-flow conditions, which may increase the mortality of embryos and larvae (Grabowski and Isely 2007).

Droughts and fish kills

Because of drought conditions throughout most of the study, tagged fish were generally confined to deeper pools during non-spawning periods, with some individuals being located in close proximity to each other. During low water conditions, deeper pools can act as refuges for fish (Magoulick and Kobza 2003; Lake 2011). Similarly, a group of radio-tagged robust redhorse in the Oconee River used a deep oxbow lake for refuge during severe drought conditions during the summer of 2008 (RRCC 2009). However, during drought conditions when there are high densities of fish confined together in pools, their susceptibility to stress can become increased, especially during summer when water temperatures are high and DO levels may be reduced. An increase in stress can decrease fish health and potentially lead to a disease outbreak; in worst case scenarios, these stressors can lead to fish kills. For example, some stream fishes concentrated in pools during an extreme drought in southwest Virginia survived through the drought in certain pools whereas fishes in other pools did not (Brett Albanese, Georgia Department of Natural Resources, personal communication). Furthermore, in May 2011, more than 35,000 fish were reported dead in the Ogeechee River in what has been called the largest fish kill in Georgia history. The fish kill spanned about 115 river kilometers and originated below a wastewater discharge that was in violation of the Georgia Water Quality Control Act (GAEPD 2011). Ultimately, the fish were determined to have died from Columnaris, a bacterial disease caused by environmental stressors including low river levels, high temperatures, and pollutants (GAEPD 2011). During May 2012, about 100 dead fish were found in various sections of the Ogeechee River; this second fish kill was smaller than the one the previous year (GAEPD 2012).

The exact cause of the 2012 fish kill is unknown; however, it has been attributed to drought-related conditions (i.e., low flows and high temperatures; GAEPD 2012). Although most tagged robust redhorse were located throughout the study in sections of river above those directly affected by the fish kills, drought-induced stress associated with low flows, crowding, lack of food, and poor water quality may explain why a portion of our fish died or expelled their transmitters over the course of the study. After transmitter implantation, high water temperatures and other environmental stressors negatively affect fish health as well as increase mortality and transmitter loss (Knights and Lasee 1996; Bunnell et al. 1998; Walsh et al. 2000). Additionally, if robust redhorse were confined to isolated pools during the drought, otter predation could have increased fish mortality (Jimmy Evans, Georgia Department of Natural Resources, personal communication).

Recruitment

Currently, evidence for juvenile robust redhorse recruitment in the Ogeechee River and other stocked populations is lacking, and evidence of recruitment in wild populations is limited. Spawning activity was observed for adult robust redhorse in the Ogeechee River during the present study; however, naturally recruited robust redhorse (< 425 mm) were not collected. Although other studies have shown evidence of successful reproduction, most have not documented evidence of juvenile recruitment (RRCC 2010). For example, naturally occurring robust redhorse larvae have been collected in the Oconee River, but juvenile robust redhorse (30–410 mm TL) have not been collected (Jennings et al. 2000; Mosley and Jennings 2007; RRCC 2010b). Similar to the present study, spawning activity has also been observed for genetically identical, hatchery-reared robust redhorse stocked in the Broad and Ocmulgee rivers, but evidence of natural recruitment for those stocked populations is lacking because juveniles have not been collected from either population (RRCC 2005; RRCC 2011). However, 11 immature robust redhorse, ranging in size from 413 mm to 468 mm TL, were collected from the Oconee River from 1994 to 2001 by boat electrofishing; these individuals were not stocked and are most likely the result of natural reproduction (RRCC unpublished data; Jimmy Evans, Georgia Department of Natural Resources, personal communication). In the Upper Coastal Plain portion of the Pee Dee River in South Carolina, three juvenile robust redhorse (375–430 mm TL) were collected with boat electrofishing during 2001–2002 (RRCC 2004). In the Savannah River, two immature (450 and 460 mm TL) and one possible juvenile (420 mm TL) wild-spawned robust redhorse were captured in the Upper Coastal Plain section during 2001–2002 by boat electrofishing (RRCC unpublished data; Jimmy Evans, Georgia Department of Natural Resources, personal communication). More recently, a 304-mm TL juvenile robust redhorse was caught with boat electrofishing in the Lower Coastal Plain ecoregion of the Savannah River near Hardeeville, South Carolina during September 2012 (Alice Lawrence, U.S. Fish and Wildlife Service, personal communication). Overall, recruitment seems to be extremely low but present in wild populations of robust redhorse; however, signs of recruitment in stocked populations remain lacking.

Difficulty sampling juveniles has been reported for robust redhorse as well as other suckers, including those populations where adults are easily collected. Hoop nets and boat electrofishing methods were successful at capturing adult blue suckers

Cycleptus elongates, but failed to catch juveniles (Hand and Jackson 2003; Morey and Berry 2003). In the present study, boat electrofishing was used to capture both wild-spawned, adult notchlip redhorse and adult, stocked robust redhorse; however, juveniles were not collected regardless of sampling gear type. Hatchery-reared robust redhorse (20–100 mm TL), genetically identical to those in the Ogeechee River, were stocked over multiple years in the Broad River, Georgia, from 1995 through 1998 (Freeman et al. 2002). As part of a post-stocking monitoring program in the Broad River, seining, gill-netting, and various electrofishing techniques (e.g., backpack, grid, boat) were used to sample annually for robust redhorse and other suckers from 1996 to 2001 (Freeman et al. 2002). In October 1997, 300 fingerlings were stocked into a tributary of the Broad River; the stocking location was sampled (with backpack electrofishing) within 24 hours of release, but only 29 robust redhorse were recovered (Freeman et al. 2002). Since then, only fish that are least 4 years old and ≥ 385 mm TL have been captured in the Broad River system (Freeman et al. 2002; Mosley and Jennings 2007). However, the abundance and size frequency of other suckers, including notchlip redhorse and jumprock, collected during the Freeman et al. (2002) study, would have overlapped with the size frequency of robust redhorse. Similarly, in the present study, different sampling methods were used throughout the study area to capture varying sizes of both spotted suckers and jumprocks that would overlap with juvenile robust redhorse.

Factors affecting recruitment

The cause(s) for the lack of juvenile robust redhorse in the present study remains unknown and may reflect a number of possible factors including behavior that facilitates increased gear avoidance, inefficiency of sampling gear, low densities, or a complete lack of juvenile robust redhorse in the habitats we sampled in the Ogeechee River. Another hypothesis advanced to explain the lack of juvenile robust redhorse suggests that early life stages may have migrated into areas that have not been sampled extensively or sampled at all. Juveniles from other abundant adult species such as gar *Lepisosteus* spp. and bowfin *Amia calva* in the Ogeechee River were not collected or seen during the present study, which suggests that they could be in areas where sampling has been limited or nonexistent. According to Jimmy Evans of the Georgia Department of Natural Resources (personal communication), the recent (2012) collection of a small juvenile robust redhorse from the lower Savannah River suggests that juvenile robust redhorse in the Ogeechee River, if present, may have migrated into the Lower Coastal Plain ecoregion in search of preferred rearing habitat. During the present study, three of the 14 sampling sites (~21%) were located in the Lower Coastal Plain ecoregion of the Ogeechee River. Across all sampling gears, the Lower Coastal Plain sites received around 29% of the total effort and produced about 51% of all small suckers collected, which suggests that juvenile suckers may have been concentrated in the lower reached of the Ogeechee River during the study. However, for all sampling methods, most of the total (juvenile) catch consisted of spotted suckers followed by chubsuckers; juvenile notchlip redhorse and robust redhorse were not captured in the Lower Coastal Plain or any other ecoregion throughout the study. Most (85%) of all small suckers collected with seine nets were caught in the Lower Coastal Plain ecoregion, which suggests that seining can be an effective tool for sampling juvenile suckers. Therefore, seining could be effective in capturing juvenile robust redhorse in the Ogeechee River, if present.

However, there is a possibility that drought conditions during the study may have limited access to some habitats that have never been sampled before or that have received limited sampling efforts in the past. Generally, low water levels throughout the present study limited sampling to areas near boat ramps; access to backwater areas and possibly other potential rearing habitats were limited. Future research should focus on sampling those areas that were not sampled during the present study.

Hatchery-reared juvenile robust redhorse prefer either low-velocity environments or areas without flow in an experimental riverine mesocosm, and Mosley and Jennings (2007) suggest that collecting juveniles in the wild may be improved by sampling eddies and backwaters during winter and spring months. In the present study, we used a variety of methods to sample all accessible habitats, including eddies and backwaters during summer and fall months and did not catch any juvenile robust redhorse. Therefore, our catch may also reflect seasonal biases in the current sampling schedule and not necessarily the type of sampling gear used. In the present study, we sampled during the summer and autumn when water levels are typically low. Although sampling is generally easier during summer and autumn months, juvenile suckers may concentrate in backwater areas during periods when increased flows create access to flood plain habitat (e.g., spring). Given that backwater habitat generally provides more food and protection for juvenile fishes, juvenile robust redhorse’s use of flood plain habitat when available (i.e., under increased suitable flow and water level conditions) is feasible. Studying the behaviors and habitat preferences of juvenile robust robust redhorse during all seasons under laboratory conditions would provide researchers insight into preferred juvenile habitat and could lead to increases in juvenile catch rates.

Conclusions

This study provided information on spawning migration patterns, spawning site location, year-class strength, and size structure of a refugial population of hatchery-produced robust redhorse stocked in the Ogeechee River, Georgia. Stocked individuals used in the present study made spawning migrations similar to those of wild-born and hatchery-reared fish in other studies and led to the discovery of a previously unknown spawning site upstream of the Louisville boat ramp. Although other areas of gravel substrate were discovered in the Ogeechee River within the known range of robust redhorse, evidence of spawning activity only exists at the Louisville site. The current research suggests that drought conditions may limit the spawning activity of robust redhorse as well as negatively affect fish health as a result of chronic stress. Size structure data from 2008 and 2010/2011 shows that stocked individuals are growing; however, evidence for successful reproduction and recruitment remains lacking because untagged robust redhorse <425 mm were not collected during the present study. Although drought conditions experienced during the study limited our sampling range and ability, other studies have also shown difficulty sampling for juvenile robust redhorse in other southeastern river systems. Whether the observed population size structure in the Ogeechee River results from failed recruitment or an inability to detect juvenile robust redhorse remains uncertain; however, current research suggests that inefficiencies in capturing juvenile robust redhorse may be more related to inaccessible habitats and the inability to sample appropriate environments (caused by drought conditions), low densities, or fish behavior (i.e., sensitive to disturbance), rather than sampling gear. Continued monitoring of the spawning population may be the best way to determine if any wild born individuals are being recruited to the adult population in the Ogeechee River; distinguishing new recruits from stocked fish should become more obvious over the years as fish size continues to increase. Overall, this study has located at least one new robust redhorse spawning aggregation in the Ogeechee River and may be useful in finding others. Further, information from this study may also aid in designating the Louisville spawning site an important conservation area, which when protected, will contribute to the maintenance of a self-sustaining population of this imperiled species.

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