Ecological studies of larval and juvenile robust redhorse *Moxostoma robustum*: abundance and distribution in the Oconee River, Georgia.

Annual Report for Project Year 2006

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Task 1. Artifical Propagation of Robust Redhorse (*Moxostoma robustum*)

Broodfish Collection

Artificial propagation of robust redhorse for population conservation and research purposes continued in 2006, but with experimental protocols that represent significant modification from those used in previous years. The rationale for making these changes, and the details of the modifications were presented at the 2005 Robust Redhorse Conservation Committee (RRCC) Annual Meeting. These changes were intended to significantly reduce the effort needed to collect broodfish through a combination of modified electrofishing techniques, different sampling areas, and altered sampling flows. The objectives of this spawning effort were to provide sufficient numbers of male and female robust redhorse in spawning condition to produce healthy fertilized embryos for: 1) hatchery rearing of robust redhorse to meet stocking goals established by the Robust Redhorse Conservation Committee, 2) experimental studies approved by the Robust Redhorse Conservation Committee, and 3) improving the efficacy of current propagation techniques.

The Oconee River was sampled for adult robust redhorse during the weeks of May 1, May 8, and May 15, 2006. For the first time, pre-positioned electric grids were used for broodfish collection (Grabowski and Isely 2005) at a known spawning aggregation located near the Avant Kaolin Mine. Boat electrofishing was also conducted by Georgia DNR personnel in the area between the Central of Georgia Railroad trestle and Dublin where all broodfish have been collected for spawning in previous years. The boat sampling was primarily conducted as part of the Georgia DNR standardized monitoring program for the Oconee River robust redhorse population, but any suitable broodfish collected were to be utilized in the spawning effort.

Modified flows from Sinclair Dam were provided by Georgia Power Company. A total of 12 specimens were collected in 2006 (10 males, 2 females). Fin clips were collected and preserved in ethanol for subsequent genetic evaluation. Passive Integrated Transponder (PIT) tags were inserted in all fish that did not already have them. Lengths (mm TL) and weights (Kg) were recorded, and ovulation stage of females was evaluated by physical examination. Fish in suitable spawning condition were transported to a temporary spawning facility constructed on the river bank next to the Avant Kaolin Mine boat ramp.

At the beginning of each week of sampling, flows were reduced to 600 cfs at Sinclair Dam in order to provide suitable conditions for deployment of five pre-positioned electric grids over a gravel deposit near the Avant Mine (Figure 1-1), and to provide lower flows for efficient boat electrofishing in other areas. Flows were reduced at Sinclair Dam on Sunday, April 30 for sampling during the week of May 1, and on Monday for sampling during the weeks of May 8 and May 15. Inflows into the Sinclair Project dictated that low flows be maintained for no more than five consecutive days in each week.

Robust redhorse were not observed near the gravel spawning bar prior to flow reduction, and did not appear at the site until low flows had been maintained for 2 - 3 days. A total of 9 – 10 adult robust redhorse, including 1 – 2 females, were observed at the spawning bar each week during the weeks of May 1 and May 8, but fish did not appear during the week of May 15. Spawning was observed at water temperatures between 21 and 24 ^{o}C. Broodfish collection efforts were terminated on Friday, May 19.

All spawning activity during the week of May 1 occurred over a small gravel deposit located under a snag at depths of 2 - 3 ft. where grids could not be deployed. Seven males and one female were collected at this and an adjacent location on May 4 using an electrofishing boat.

Figure 1-1. Prepositioned electric grids used for broodfish collection at Avant Kaolin Mine boat ramp, May, 2006.

By contrast, all spawning activity during the week of May 8 occurred at two locations on the gravel bar at depths of 0.5 – 2.0 ft. where the grids could effectively be deployed. On May 12 a spawning triad that included the only available female was easily collected using the electric grids. In summary, a total of eight broodfish were collected by boat electrofishing and three with the electric grids (nine males and two females) at the Avant site during the two-week period.

Additional boat sampling was conducted on May 9, 10, and 11 between the Central of Georgia Railroad trestle and Dublin and one male robust redhorse was collected. Although sampling conditions on these days were similar to those in previous years when electrofishing was highly effective in this area, 2006 catch rates were low, and further broodfish collection efforts were confined to the Avant site.

Spawning

Of the 12 total specimens collected during spring of 2006, one of 2 females and 2 of 10 males were used for pairings. Fish were anesthetized using tricaine methanesulfonate (MS-222) prior to handling. All spawned fish were returned to the river immediately. Fertilized eggs were water hardened, placed in polyethylene bags with pure oxygen, and transported in insulated fish-shipping boxes to incubation facilities at Warm Springs National Fish Hatchery (NFH) and McDuffie State Fish Hatchery (SFH). Table 1-1 provides basic information on fish received at the spawning facility. Table 1-2 provides information on matings and embryo production. As in previous years, batches of eggs collected from each female were split into multiple lots and each lot was fertilized with milt from various males. This protocol is designed to ensure optimal genetic heterogeneity among progeny.

Table 1-1. Information on adult robust redhorse used for spawning at the Avant Mine site during spring 2006.

Floy Tag	Floy Tag	PIT Tag	TL	WT	Captured	Sex
01160	01161	403407145A	625	4423	5/12/2006	F
01566	01356	40335D5746	692	4196	5/12/2006	M
01596	01597	442E16187E	591	3969	5/12/2006	M

Table 1-2. Spawning matrix for 2006 indicating tag numbers for males and females, dates of mating, number of eggs produced.

Date	Female	Male	# Eggs
5/12/2006	403407145A	40335D5746	8207
5/12/2006	403407145A	442E16187E	5498
Total		**13705**	

Incubation

Total embryo production for 2006 was 13,705, with 6,853 being shipped to Warm Springs NFH, and 6,852 being shipped to McDuffie SFH. Embryos were transferred to hatching jars for incubation. Once hatching began, yolk-sac fry were transferred to aquaria. When the incubating fry reached swim-up, they were provided with freshly hatched *Artemia* nauplii. At Warm Springs NFH, when fry reached 0.6 to 0.8 inches in length (19 days old) they were distributed to one pond at Walton SFH. At McDuffie SFH, when fry reached an average weight of 22 mg (19 days) they were distributed to two ponds at Richmond Hill SFH. A total of 13,200 fry were produced in 2006, with 13,087 being stocked into ponds at Georgia Department of Natural Resources state fish hatcheries for grow-out to fingerling stage. Table 1-3 summarizes Oconee River hatchery production for year-class 2006. Table 1-4 summarizes the 2006 spawning effort and compares results to previous years, including the number of fingerlings ultimately produced from spawned robust redhorse.

Conclusions

Artificial propagation of robust redhorse from the Oconee River population in 2006 involved broodfish collection efforts during the weeks of May 1, May 8 and May 15. The broodfish collection protocol for 2006 represents a major departure from methods used in previous years. These changes were implemented in an effort to significantly reduce the increasing amount of effort needed to collect sufficient numbers of broodfish required to meet the fingerling production goals of the RRCC. Reduced flows from Sinclair Dam at the beginning of each week of broodfish collection resulted in Oconee River flow conditions similar to those in most previous years (Table 1.4). Prior to 2006 all broodfish have been collected using boat

Table 1-3. Summary of hatchery production of robust redhorse year class 2006 at Warm Springs NFH and McDuffie SFH including location of ponds receiving all fry produced from Oconee River broodfish.

Hatchery	Embryos received	Yolk-sac fry (% survival from embryos to swim-up stage)	Swim-up fry (% survival from embryo to pond stocking)	Pond Stocking for grow-out to Phase I fingerling stage
Warm Springs NFH	6,853	6,600 (96%)	6,600 (96%)	6,600 (Walton 6)
McDuffie SFH	6,852	6,600 (96%)	6,487 (95%)	2,870 (Richmond Hill C13) 3,617 (Richmond Hill C14)
TOTAL	13,705	13,200 (96%)	13,087 (95%)	13,087

Table 1-4. Number of robust redhorse brood fish spawned, eggs, fry and fingerlings produced from spawning at the temporary hatchery facility adjacent to the boat ramp at the Beaver Dam Wildlife Management Area, Oconee River, Georgia during spring 1995 - 2006. Table includes mean Oconee River flows (cfs) measured at Dublin, GA for days when brood fish were collected.

Year	Males	Females	Annual CPUE (#/hr)[1]	# Eggs (% survival-egg to fingerling)	# Fry (% survival-fry to fingerling)	# Fingerlings	Flows at Dublin, GA
1995	20	20	16.5	652,750 (6.2)	71,769 (56.4)	40,468	1,375
1996	21	11	7.8	477,119 (0)	98,089 (0)	1	2,420
1997	21	12	6.1	360,219 (10.1)	189,167 (19.2)	36,285	1,434
1998	10	4	3.7	142,662 (9.1)	55,683 (23.4)	13,030	2,687
1999	13	16	5.4	560,227 (4.3)	62,350 (38.4)	23,964	1,862.5
2000	31	13	5.1	308,774 (9.3)	82,939 (34.5)	28,600	1,073.5
2001	10	2	2.8	28,484 (34.5)	11,864 (82.9)	9,841	1,345
2002	11	5	2.1	124,687 (14.7)	37,313 (49.0)	18,280	1,542.5
2003	0	0	0.2	0	0	0	NONE
2004	10	3	1.0	97,048 (8.8)	31,462 (27.2)	8,548	1,287.5
2005	7[2]	4	0.4	34,996 (17.7)	9,666 (64.1)	6,195[3]	1,376
2006	2	1	0.1	13,705 (0.7)	12,100 (0.8)	91	1,480

[1] Annual electrofishing catch per unit effort (CPUE) is calculated based on all fish collected, primarily during the spring spawning season. The total number of fish collected in many years was significantly higher than the number of broodfish spawned.

[2] Only 2 of 7 males used for spawning in 2005 were actually captured from the Oconee River during broodstock collection; 3 were captive fish reared at WSNFH, and two were cryopreserved milt samples from 2004.

[3] This value does not include an additional 969 fingerlings produced from feeding studies conducted in tanks at WSNFH.

electrofishing in the area between the Central of Georgia Railroad trestle and the city of Dublin. However, significant boat electrofishing effort resulted in relatively few broodfish being collected in this area during 2005 or 2006 (Table 1-4). Sampling in 2006 which employed a combination of boat electrofishing and pre-positioned electric grids in the area of the Avant Mine site resulted in the collection of a total of 11 broodfish (8 broodfish were collected by boat electrofishing and 3 with the electric grids during the period). Electric grid sampling was demonstrated to be an effective broodfish collection technique at this site.

A total of 13,705 eggs were collected, fertilized and transferred to McDuffie SFH and Warm Springs NFH for incubation in 2006, as compared to 34,996 in 2005 and 97,048 in 2004. This decline in egg production is coincident with a decline in the availability of broodfish in spawning condition from the Oconee River. Overall survival to fry stage from fertilized embryos produced in 2006 was the highest ever reported (approximately 90%) compared to 28% in 2005, and 30% in 2004. Survival of fry stocked in ponds and reared to fingerling stage in 2006 was among the lowest ever reported (less than one percent of total eggs produced). Hatchery personnel at Walton SFH attributed poor survival to water quality problems observed in fingerling ponds; while hatchery personnel at Richmond Hill SFH attributed poor survival to predation by otters and cormorants. Survival to fingerling stage for all years of artificial propagation (1995-2006) has been relatively low but highly variable, ranging from zero to 34%. The reasons for this high degree of variability remain unknown.

Task 2. Reproductive and Recruitment Success of

Robust Redhorse, *Moxostoma robustum*, in the Oconee River, Georgia.

Introduction

Reproductive success of robust redhorse has been investigated in a limited reach of the lower Oconee River since 1995 (Jennings et al. 1996, 1998, 2003, 2004a, 2004b, 2005, 2006, 2007 and Peterson et al. 2007a, 2007b, 2008). This work was undertaken to help assess the status of the Oconee River population, which apparently was comprised of older individuals (Jennings et al. 1996). Though successful, documentation of reproductive success of robust redhorse during the past 11 years has been variable and probably was influenced by floods (Jennings et al. 2004a, Peterson et al. 2007a, 2008) and droughts (Jennings et al. 2004b, 2005, 2006, 2007) that occurred during the study period. Further, the ability to document robust redhorse reproductive success was complicated because of an overlap in spawning seasons of robust redhorse and notchlip redhorse, which was first noted during 1999 (Jennings et al. 2004b, 2005, 2006, 2007, Peterson et al. 2007b). The overlap of the spawning season resulted in the co-occurrence of the larvae of both species, and the available taxonomic keys could not reliably distinguish between the two species. As a result, project objectives were expanded to include documenting reproductive success of both redhorse species and developing mathematical models to explain possible relationships between the abundance larval and age-0 redhorses and river discharge variables. The assumption for this change in methodology was that both species respond similarly to river discharge conditions during similar life stages (i.e., spawning, egg stage, larval, age-0); therefore, inferences based on the abundance of both species would be useful for making inferences about either species.

The initial evaluation of the relationship between the abundance of larval and age-0 redhorse and selected river discharge data in 2000 led to the hypothesis that low-stable flows (LSF) during the spawning season (i.e., maximum May flows < 4,000 cfs,) may promote strong year-classes of redhorses (Jennings et al. 2005). However, in 2004 and 2005, this model did fit the data as well in previous years (Peterson et al. 2007b, Peterson et al. 2008). The poor fit of the existing model led to questions about whether other flow-related metrics might be better predictors of larval and age-0 redhorse abundance. Accordingly, a suite of other flow-related variables used by Richter et al. (1996) to assess a river's Index of Hydraulic Alteration were evaluated for possible relationships with the abundance of larval redhorses.

Wild-spawned juvenile (age-1+) robust redhorse have never been collected in the Oconee River. This absence is remarkable because recruitment of this age class has been investigated by using a variety of gear to sample different areas from 1998 to 2006. Hoop nets were set in 1998 and 1999 in bends of the Oconee River in the same study area where larval and age-0 samples were collected (Jennings et al. 2004a, b). Backpack electrofishers were used in 2001 to sample tributaries of the Oconee River (Jennings et al. 2006). Gill nets were set in 2002, 2003, and 2005 in the Oconee, lower Ocmulgee, and Altamaha rivers (Jennings et al. 2007, Peterson et al. 2007, Peterson et al. 2008). Although, wild robust redhorse juveniles were not collected in the Oconee, Ocmulgee, or Altamaha rivers; a stocked juvenile robust redhorse was collected in a gill net in the Altamaha River during sampling in 2002 (Jennings et al. 2007). Many competing hypotheses have been advanced to explain the absence of juveniles from samples; these hypotheses include sampling in habitats where this life stage doesn't occur, gear inefficiency, or a true decline of the robust redhorse population in the Oconee River, Georgia (Mosley and Jennings 2007). There is limited evidence to support the “sampling in the wrong habitat” hypothesis (Mosley and Jennings 2007).

The background and justification for the investigating robust redhorse reproductive and recruitment success in the Oconee River are given in Jennings et al. (1996; 1998; and 2003); the overall goal of the 2006 effort was expanded to include developing and evaluating mathematical models that incorporate a variety of flow-related metrics to help assess the reproductive and recruitment success of the robust redhorse in the Oconee River, Georgia. The specific goals were to: 1) determine the abundance and distribution of larval and age-0 robust redhorse in the study reach; 2) determine if 2006 data improves the fit of the original model that uses maximum May flows to explain the abundance of larval and age-0 redhorses; 3) develop and evaluate competing mathematical models that contain other-flow related metrics and determine if there was a strong relationship between redhorse abundance and other river discharges, and 4) determine if juvenile (age-1+) robust redhorse are present in the Altamaha River system (lower Oconee, confluence of Ocmulgee and the Altamaha rivers) during non-spawning periods.

Materials and Methods

Larval and age-0 sampling and processing

Larval and Age-0 fishes were sampled from the study of the Oconee River, which is near Toomsboro, Georgia (between Milledgeville and Dublin) and encompasses river kilometers 145-165 (Figure 2-1). Sampling methodology was the same as in previous years; the various fish sampling gear, general areas as well as a full description of the sample area are given in Jennings et al. (2006). Generally, push nets, light traps, and seine samples were collected twice a week during May and June. Light traps were set in slack water areas at dusk on Monday and Thursday

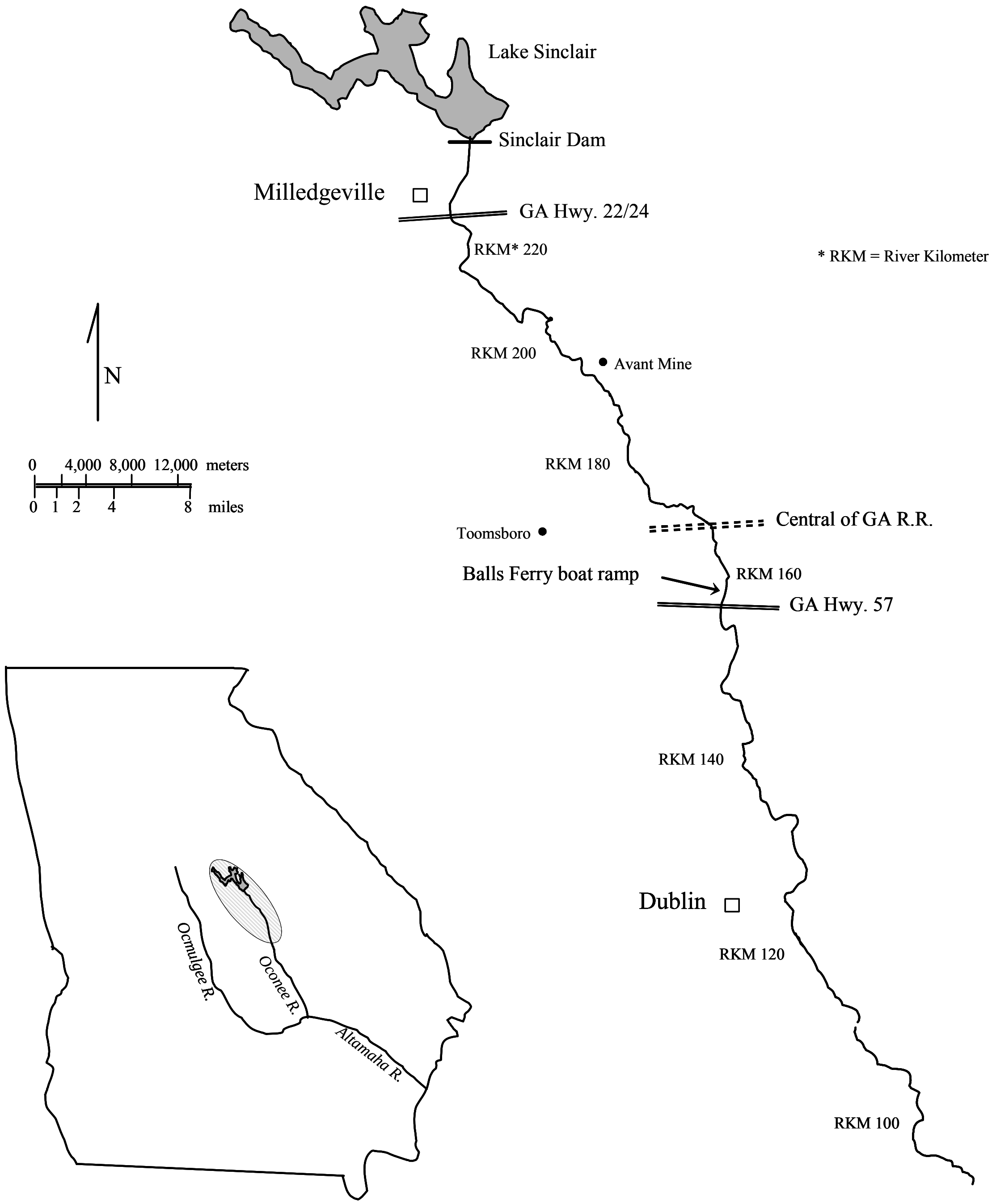

Figure 2-1. Oconee, Ocmulgee and Altamaha rivers below the fall line in Georgia. Larval and age-0 sampling occurs in the Oconee River between river kilometers 145 – 165 (in shaded circle).

evenings, after which push net samples were collected in the main channel. Light traps were fished overnight and retrieved Tuesday and Friday mornings. After light traps were collected, seine hauls were conducted. The seine (6.1 x 1.8 m, 4.76-mm mesh) was used to sample fishes from the littoral zones along sandbars. Seining consisted of stretching the net perpendicular to shore and pulling it downstream and parallel to shore. There were numerous sandbars throughout the study area, and three sandbars were chosen at random during each sampling event. Each sandbar was sampled in three different areas (3 samples per sandbar for a total of nine samples). Sandbars were sampled at random without replacement until all sandbars were sampled. This process was continued through the sample season. Only seine hauls were conducted during July because robust redhorse were able to avoid the other gear. Seine sampling during July was conducted three times a week in the same manner as during May and June.

Samples from push nets, light traps, and seines were preserved immediately in 90% ethanol. Preserving specimens in ethanol allowed fishes identified taxonomically as redhorse to be genetically identified as either robust redhorse or notchlip redhorse. Genetic identification is needed because redhorse species are virtually indistinguishable at small sizes; and in the past, spawning periods of the two species have overlapped (Jennings et al. 2004, 2005, 2006, 2007, Peterson et al. 2007b, 2008).

Samples from all gears were transferred to the fisheries laboratory at University of Georgia's Whitehall Forest where they were drained and rinsed to remove ethanol; all fishes and eggs were extracted from debris and enumerated. Twenty percent of the samples were resorted to assess the efficiency of the extraction of fishes and eggs; the resorting was conducted by someone other than the original sorter. Taxonomic keys (Hogue et al. 1976; Kay et al. 1994) and a dissecting scope (10x eye pieces, option for polarized light) were used to identify fishes to lowest possible taxa by identifying morphometric (e.g., body depth, melanophores) and meristic (e.g., myomeres, fin rays) characteristics. Redhorses were enumerated, measured (total length; TL) to the nearest 0.1 millimeter (mm) with jaw-type dial calipers, and grouped into size classes by 1-mm increments (e.g., 15.0 - 15.9 = 15 mm, TL). The specimens were then sent to Dr. C. J. Narin (University of Georgia, School of Forestry and Natural Resources) for genetic identification per the assay described in Wirgin et al. (2004).

Model development and evaluation

Modeling the relationship between the observed abundance of larval and age-0 redhorses and river flows began in 2001 when samples size was sufficiently large to produce meaningful results. This early effort resulted in an exponential decay model that indicated May maximum river discharge had a strong relationship with the abundance of larval and age-0 redhorses. However, by 2004, the exponential decay model (*alpha* =0.05) did not fit all the available data as well as in several previous years. This result suggested that May maximum flow may not be the best variable to explain the relationship between river discharge and the abundance larval and age-0 redhorses. As a result, other models based on a different suite of flow-related variables were designed and tested.

Magnitude, timing, duration, variability, and frequency of river discharge events influence the riverine habitat in regulated and unregulated rivers (see Richter et al. 1996). Therefore, selected aspects of the Oconee River flows were used to develop new models for explaining the observed variability of larval redhorses in the system. Specifically, the new "predictor" variables included selected river measurements to represent each category (e.g., magnitude) for the period April through June, which is when both redhorse species spawn and their larvae hatch, emerge, and recruit to nursery areas. The general hypothesis was:

$$\text{Larval and age-0 redhorse abundance} = F_{\text{Magnitude}} + F_{\text{Variability}} + F_{\text{Duration}} + F_{\text{Timing}} + F_{\text{Frequency}}$$

Where magnitude was the mean of the maximum monthly river discharge for April, May, and June; variability was the standard deviation of the mean monthly river discharge for April, May, and June; duration was the number of consecutive days river discharge was < 25%ile (3-6 days, short-; 7-14 days, intermediate; and 15+ days, long-term) during April through June; and frequency and timing were the number of high pulses (> 75th %ile) during April, May, and June (Table 2-1).

Magnitude and variability for 1995 - 2006 were calculated with river discharge data from the Oconee River, Georgia (Avant Mine, USGS gauge number 02223056; USGS 2008a). The USGS gage at Avant Mine was used because this is near a known location of robust redhorse spawning. The 25th and 75th %iles were based on historical, pre-dam daily mean river discharges from the Oconee River at Milledgeville, GA (USGS gauge number 02223000, USGS 2008b) for April, May, and June from 1904 to 1952. We expected that high magnitude, high river discharge variability, and high frequency of flood-pulses would negatively affect abundance, while stability of river discharge would positively affect abundance.

Akaike's information criterion (AIC; Akaike 1973, Burnham and Anderson 2002) corrected for small-sample bias (AIC_c; Hurvich and Tsai 1989, Burnham and Anderson 2002) was used to determine the best-fitting models between river discharge variables and larval and age-0 redhorse abundance. SAS statistical software (SAS Institute Inc. 2001) was used for this portion of the analysis. The SAS code that executed AIC analysis and model-averaging was

Table 2-1. Selected river variables, abbreviations, and their meanings.

Index	Variable	Meaning
Magnitude	Mag1	Maximum monthly river discharge for April
	Mag2	Maximum monthly river discharge for May
	Mag3	Maximum monthly river discharge for June
Variability	Var1	Standard deviation of the mean monthly river discharge for April
	Var2	Standard deviation of the mean monthly river discharge for May
	Var3	Standard deviation of the mean monthly river discharge for June
Duration	Dur1	The number of 3-6 consecutive days of river discharge < 25%ile April-June
	Dur2	The number of 7-14 consecutive days of river discharge < 25%ile April-June
	Dur3	The number of 15+ consecutive days of river discharge < 25%ile April-June
Timing and Frequency	Freq1	The number of high pulses (> 75^{th} %ile) during April
	Freq2	The number of high pulses (> 75^{th} %ile) during May
	Freq3	The number of high pulses (> 75^{th} %ile) during June

written by J. T. Peterson (2008). Pearson correlation analysis was used to evaluate autocorrelation among candidate metrics, and metrics with high r (> 0.7) were eliminated from candidate models to reduce redundancy in models. Linear regression was used to examine relationships between abundance of larval redhorses and the candidate indices; however, squareroot transformation was used to "normalize" the larval abundance data. According to the correlation analysis, May magnitude, June magnitude, April variability, short- , intermediate, and long-term duration, and the frequency of high pulses in June were not auto-correlated. Therefore, the global model for the AIC analysis included these indices, and another nine candidate models were constructed based on subsets of the variables in the global model (Table 2-2). A confidence set of models, which contains the most plausible model given the data tested, was determined by selecting all candidate models whose AIC value was 10% of the best-fitting model weight (Royall 1997). To determine how much more likely the best-fitting confidence model was to the next best-fitting model, the w_i of the top model was divided by the w_i of the second model, and uncertainty of the models was assessed by model-averaging (Burnham and Anderson, 2002).

Water quality and river measurements

Water temperature and dissolved oxygen were measured with a YSI® dissolved oxygen meter, turbidity was measured with a Hach® portable turbidimeter (Model 2100P), current was measured with General Oceanics® flow meter, and depth was measured with Lowrance® boat-mounted depth finder or a graduated depth pole. These measurements were made immediately after sampling was conducted. Daily river discharge (cfs) for the Oconee River,

Table 2-2. Global and candidate models and corresponding hypotheses of factors potentially effecting larval and age-0 redhorse abundance in the Oconee River, GA, near Toomsboro.

Model	Variables	Hypothesis
Global model	Mag2 Mag3 Var1 Dur1 Dur2 Dur3 Freq3	– May and June magnitude flow – variability April flow + short-term duration + intermediate duration + long-term duration of low-flow – frequency of high pulses in June
Candidate model 1	Mag2 Dur2 Freq3	– May magnitude flow + intermediate duration of low-flow – frequency of high pulses in June
Candidate model 2	Mag2 Dur3 Freq3	– May magnitude flow + long-term duration of low-flow – frequency of high pulses in June
Candidate model 3	Mag3 Dur2 Freq3	– June magnitude flow + intermediate duration of low-flow – frequency of high pulses in June
Candidate model 4	Mag3 Dur3 Freq3	– June magnitude flow + long-term duration of low-flow – frequency of high pulses in June
Candidate model 5	Mag2 Var1 Dur2 Freq3	– May magnitude flow – variability April flow + intermediate duration– frequency of high pulses in June
Candidate model 6	Mag2 Var1 Dur3 Freq3	– May magnitude flow – variability April flow + long-term duration – frequency of high pulses in June
Candidate model 7	Mag3 Var1 Dur2 Freq3	– June magnitude flow – variability April flow + intermediate duration – frequency of high pulses in June
Candidate model 8	Mag3 Var1 Dur3 Freq3	– June magnitude flow – variability April flow + long-term duration – frequency of high pulses in June
Candidate model 9	Mag2 Mag3 Dur2 Dur3	– May and June magnitude flow + intermediate duration + long-term duration of low-flow

Georgia was downloaded from US Geological Survey website (Avant Mine, USGS gauge number 02223056; USGS 2007a) at a later date.

Juvenile (age-1+) sampling and river measurements

Boat electrofishing was conducted in the lower Oconee River (from below the fall line to the confluence), lower Ocmulgee River (just above the confluence), and the Altamaha River (from the confluence to below Doctortown, GA) in an attempt to capture juvenile robust redhorse. Sampling was conducted from September through November, and different habitats were sampled (e.g., river banks, woody debris, eddies, mid-channel). Only suckers (Catostomidae) were netted and placed in an on-boat holding tank. Suckers were identified to the lowest possible taxonomic level in the field and released. Boat electrofishing also was used to sample the Savannah River between Augusta, SC and Milhaven GA two days to determine if juvenile robust redhorse could be collected in another system with an extant population of adult robust redhorse.

Water quality measurements were collected before electrofishing occurred as well as when robust redhorse were collected; water quality sampling methods were the same methods as described for larval and age-0 sampling. Daily river discharge (cfs) was downloaded from US Geological Survey website for: the Oconee River, Georgia (near Oconee USGS gauge number 02223248; USGS 2007b), for the Ocmulgee River (Lumber City, USGS gauge number 02215500; USGS 2007c), for Altamaha River, Georgia (Doctortown, USGS gauge number 02226000; USGS 2007d), and for Savannah River, GA (near Millhaven, USGS gauge number 02197500 USGS 2008c) at a later date.

Results and Discussion

Larval and age-0 sampling and processing

Sampling was conducted from May 8th to July 31st, 2006. Frequency and duration of sampling, as well as habitat sampled, varied with each gear in response to expected ontogenetic shifts in habitats by larval and age-0 robust redhorse (Table 2-3). During 2006, there were 373 samples, which contained 46,255 fishes from 11 families. Estimated efficiency of fish and egg extraction from samples was > 99%. The 2006 catch was similar to previous years and was dominated again by minnows (90.6%), which is in the same range as previous years (78-93% Table 2-4). Throughout the study years, the next most abundant families (not always in this order) have been: shad (Clupeidae), suckers (Catostomidae), sunfish/black bass (Centrarchidae), and mosquitofish (Poeciliidae). The next most abundant families collected in 2006 were: suckers (3.7%), mosquitofish (3.0%), and shad (1.4%). Catch composition of larval and age-0 suckers collected throughout the study years include: spotted sucker (*Minytrema melanops*), carpsuckers (*Carpiodes* spp.), creek chubsucker (*Erimyzon oblongus*), northern hogsucker (*Hypentelium nigricans*) and redhorses (*M. collapsum* and *M. robustum*; Table 2-5).

One hundred seventy five larval and age-0 redhorses were collected during 2006; however, only one was genetically identified as robust redhorse (Narin 2007). The remaining 174 were identified as notchlip redhorse (Nairn 2007). This pattern of notchlip redhorses dominating the catch of redhorses has been evident since 2002, when all redhorse have been identified genetically. For example, in 2002 robust redhorse comprised 7.0% of the redhorses collected (11/158, Jennings et al. 2007). Neither robust nor notchlip redhorses were collected during 2003, possibly because of flood conditions throughout the sampling period (Peterson et al. 2007a). During 2004 robust redhorse comprised only 0.2% of the redhorses collected

Table 2-3. Gear types used for sampling and deployment information for collecting larval and age-0 robust redhorse in the Oconee River, Georgia between May - July 2006.

Gear (mesh µm)	Dates	Effort/ sampling event	Frequency	No. of samples	No. of fishes	Habitat sampled
Push-nets[4] (505)	05/8/06 to 06/29/06	6 tows 2 stations 3 replicates	2 x's /week May - June	42	628	Mid-channel (occasionally deep pools)
Light traps[5] (N/A)	05/8/06 to 06/29/06	1-3 traps ~ 2 stations	2 x's /week May - June	88	1,629	Slack water habitats off main channel (occasionally mouths of creeks)
Seine nets[6] (800)	05/9/06 to 07/31/06	9 hauls 3 stations 3 replicates	2 x's /week June 3x's/week July	243	43,998	Sandbars (occasionally mud-flats)

[4]Mean water volume sampled was 100 m^3
[5]Light traps were fished for an average of 12 to 13 hours.
[6]Seine hauls were on average 55 m^2

Table 2-4. Number of fishes collected, by family and percent catch composition, from the study reach of the Oconee River, Georgia 1995-2006.

	Number of fishes per family (% catch composition)							
Year	Lepisosteids	Clupeids	Cyprinids	Catostomids	Ictalurids	Esocids	Aphredoderids	Antherinids
2006	5 (<1.0)	635 (1.4)	41,900 (90.6)	1,699 (3.7)	47 (<1.0)	0 (0.0)	0 (0.0)	199 (<1.0)
2005	6 (<1.0)	238 (3.3)	6,350 (87.1)	79 (1.1)	10 (<1.0)	1 (<1.0)	38 (<1.0)	0 (0.0)
2004	1 (<1.0)	255 (1.0)	23,043 (77.5)	4,416 (14.9)	16 (<1.0)	2 (<1.0)	0 (0.0)	122 (<1.0)
2003	0 (0.0)	119 (1.6)	6,581 (85.9)	13 (<1.0)	7 (<1.0)	0 (0.0)	2 (<1.0)	139(1.8)
2002	2 (<1.0)	91 (<1.0)	64,385 (92.9)	2,150 (3.1)	31 (<1.0)	0 (0.0)	5 (<1.0)	196 (<1.0)
2001	0 (0.0)	455 (3.8)	10,496 (87.5)	179 (1.5)	109 (<1.0)	4 (<1.0)	55 (<1.0)	39 (<1.0)
2000	0 (0.0)	8 (<1.0)	59,416 (90.3)	1,894 (2.9)	58 (<1.0)	3 (<1.0)	0 (0.0)	445 (<1.0)
1999	4 (<1.0)	82 (<1.0)	74,275 (91.5)	3,685 (4.5)	329 (<1.0)	0 (0.0)	1 (<1.0)	388 (<1.0)
1998	3 (<1.0)	323 (1.4)	21,421 (91.0)	999 (4.2)	211 (<1.0)	0 (0.0)	3 (<1.0)	45 (<1.0)
1997	2 (<1.0)	938 (4.3)	19,128 (88.6)	261 (1.2)	38 (<1.0)	1 (<1.0)	0 (0.0)	187 (<1.0)
1996	3 (<1.0)	393 (1.0)	35,373 (91.4)	705 (1.8)	92 (<1.0)	0 (0.0)	0 (0.0)	311 (<1.0)
1995	4 (<1.0)	1,041 (2.3)	35,658 (78.0)	3,468 (7.6)	243 (<1.0)	0 (0.0)	0 (0.0)	739 (1.6)

Table 2-4 Con't. Number of fishes collected, by family and percent catch composition, from the study reach of the Oconee River, Georgia 1995 - 2006.

	Number of fishes per family (% catch composition)							
Year	Belonids	Fundulids	Poeciliids	Moronids	Centrarchids	Percids	Soleids	Unknown
2006	4 (<1.0)	0 (0.0)	1,381(3.0)	0 (0.0)	234 (<1.0)	149 (<1.0)	1 (<1.0)	0 (0.0)
2005	9 (<1.0)	2 (<1.0)	297 (4.1)	1 (<1.0)	85 (1.2)	176 (2.4)	0 (0.0)	0 (0.0)
2004	16 (<1.0)	0 (0.0)	1,041 (3.5)	0 (0.0)	209 (1.0)	270 (1.0)	1 (<1.0)	326[7] (1.1)
2003	0 (0.0)	0 (0.0)	638 (8.3)	1 (<1.0)	83 (1.1)	78 (1.0)	0 0.0)	0 (0.0)
2002	11 (<1.0)	0 (0.0)	1,880 (2.7)	0 (0.0)	456 (<1.0)	65 (<1.0)	0 (0.0)	36 (<1.0)
2001	2 (<1.0)	0 (0.0)	344 (2.9)	0 (0.0)	186 (1.6)	131 (1.1)	0 (0.0)	0 (0.0)
2000	1 (<1.0)	0 (0.0)	2,608 (4.0)	0 (0.0)	1,217 (1.8)	109 (<1.0)	1 (<1.0)	60 (<1.0)
1999	7 (<1.0)	0 (0.0)	604 (<1.0)	0 (0.0)	1,518 (1.9)	177 (<1.0)	0 (0.0)	60 (<1.0)
1998	4 (<1.0)	0 (0.0)	186 (<1.0)	8 (<1.0)	109 (<1.0)	107 (<1.0)	0 (0.0)	236 (<1.0)
1997	1 (<1.0)	0 (0.0)	680 (3.1)	0 (0.0)	169 (<1.0)	143 (<1.0)	1 (<1.0)	46 (<1.0)
1996	6 (<1.0)	0 (0.0)	688 (1.8)	0 (0.0)	459 (1.2)	151 (<1.0)	2 (<1.0)	532 (1.4)
1995	16 (<1.0)	0 (0.0)	956 (2.1)	0 (0.0)	2,675 (5.8)	94 (<1.0)	1 (<1.0)	282 (<1.0)

[7] One sample was filled with small fishes that were all too soft and decomposed to be identified.

Table 2-5. Number of catostomids collected by gear from the lower Oconee River near Toomsboro, GA during 2003-2006[8].

Year & Gear	Species						
	robust redhorse	notchlip redhorse	spotted sucker	carpsucker [9]	creek chubsucker	northern hogsucker	unknown
2006							
light trap	0	2	86	0	1	0	0
push - net	1	0	4	19	0	0	0
seine	0	172	2	1,412	0	0	0
2005							
light trap	0	0	15	0	3	0	0
push - net	0	0	2	4	0	0	0
seine	0	51	0	1	0	0	3 [10]
2004							
benthic light	0	0	0	1	0	0	0
light trap	0	25	798	8	48	0	4
push - net	0	3	34	28	0	0	7
seine	4	1,948	294	922	1	0	97
2003							
benthic light	0	0	0	0	0	0	0
light trap	0	0	0	0	0	0	0
push - net	0	0	0	1	0	0	0
seine	0	0	2	9	0	1	0

[8] For 1995 - 2002 information see Jennings et al. 2007.

[9] There are two undescribed carpsucker species *Carpiodes* in the Oconee River. They are related to the quillback *C. cyprinus* and highfin *C. velifer* carpsuckers.

[10] These were physically identified as redhorse spp., but were not genetically confirmed as such.

(4/1,980, Peterson et al. 2007b). Robust redhorse were not collected among the 51 redhorses tested in 2005 (Peterson et al. 2008), but they comprised 0.5% of the catch (1/175) of the redhorses collected in 2006. This result is surprising because both species seem to have similar spawning requirements, with the notable exception that notchlip redhorse spawn at slightly cooler temperatures than robust redhorse (Grabowski and Isely 2007).

Redhorses were collected in all three gears (Table 2-5) and throughout the sample season (Figure 2-2). The length-frequency histogram of the redhorses was mostly unimodal and ranged from 13 - 71 mm TL (Figure 2-3). The robust redhorse was 13.1 mm TL and was collected in a stretch of river between State route 57 (i.e., Ball Ferry boat ramp) and Commissioner Creek in a push net on May 22nd.

Early evaluation of the relationship between observed abundance of larval and age-0 redhorses and flow-related metrics resulted in an exponential decay model in which maximum May flows <4,000 cfs) explained the most of the variability (e.g., R^2's ~ 0.74) in larval abundance (Jennings et al. 2004b, 2006, 2007; and Peterson et al. 2007a). However, when larval abundance data for 2004 and 2005 were added to entire data set, the model fit was reduced to R^2 of ~0.50 (Peterson et al. 2007b and 2008). To rectify the reduced model fit, the abundance data for both 1995-2004 and 1995-2005 were log10 transformed and reanalyzed. The now-linear model (with transformed data) improved the fit of the model based on maximum May flow back to R^2 of ~0.75 (Peterson et al. 2007b and 2008). This pattern continued in 2006 for both the exponential decay and log10 transformed models (Figure 2-4 and Figure 2-5 respectively). These results indicate that maximum May Oconee River discharge is not the best environmental indicator to estimate redhorse abundance.

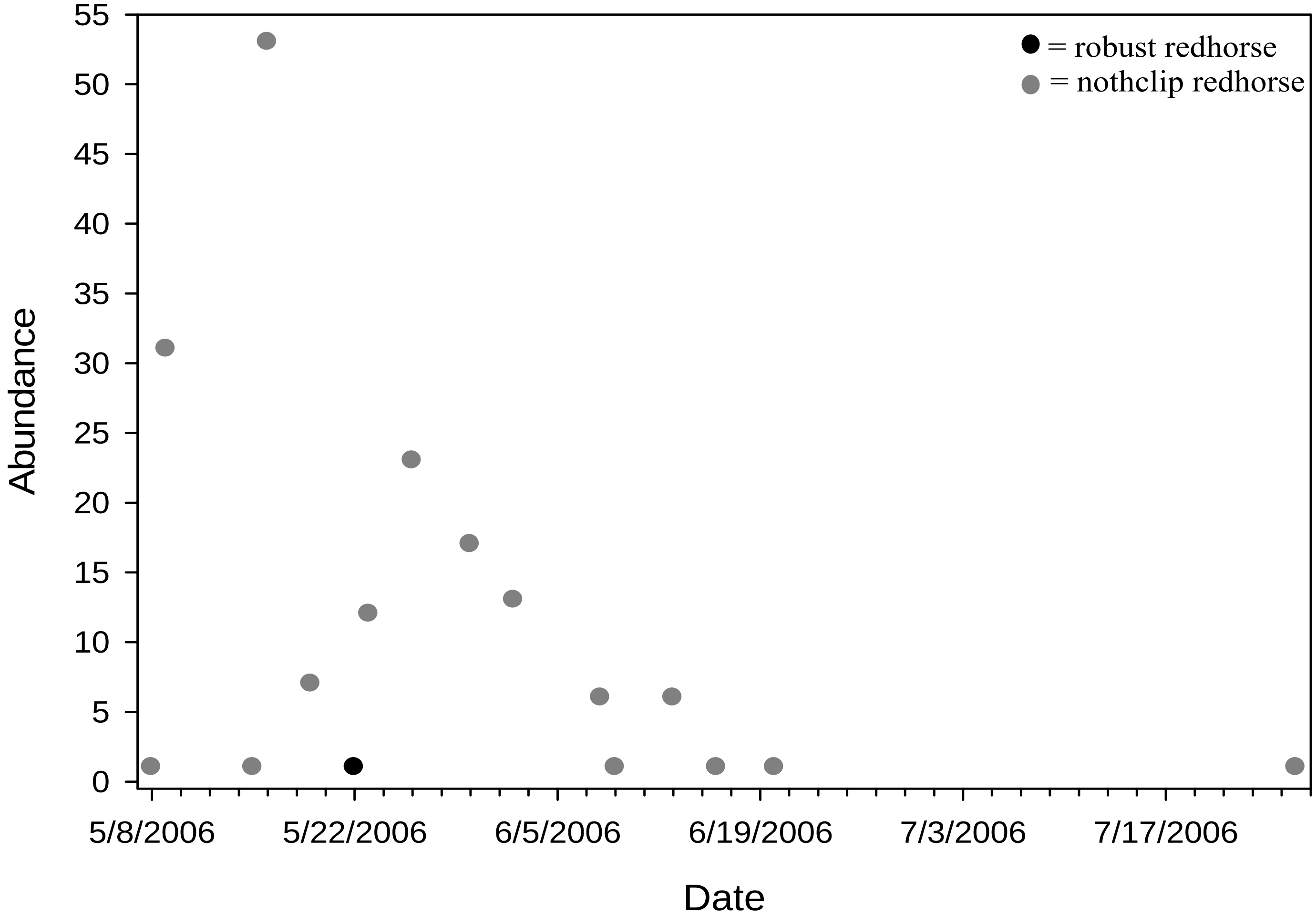

Figure 2-2. Abundance of larval and age-0 redhorses captured by date. Samples were collected in the Oconee River, near Toomsboro, GA, May- July 2006.

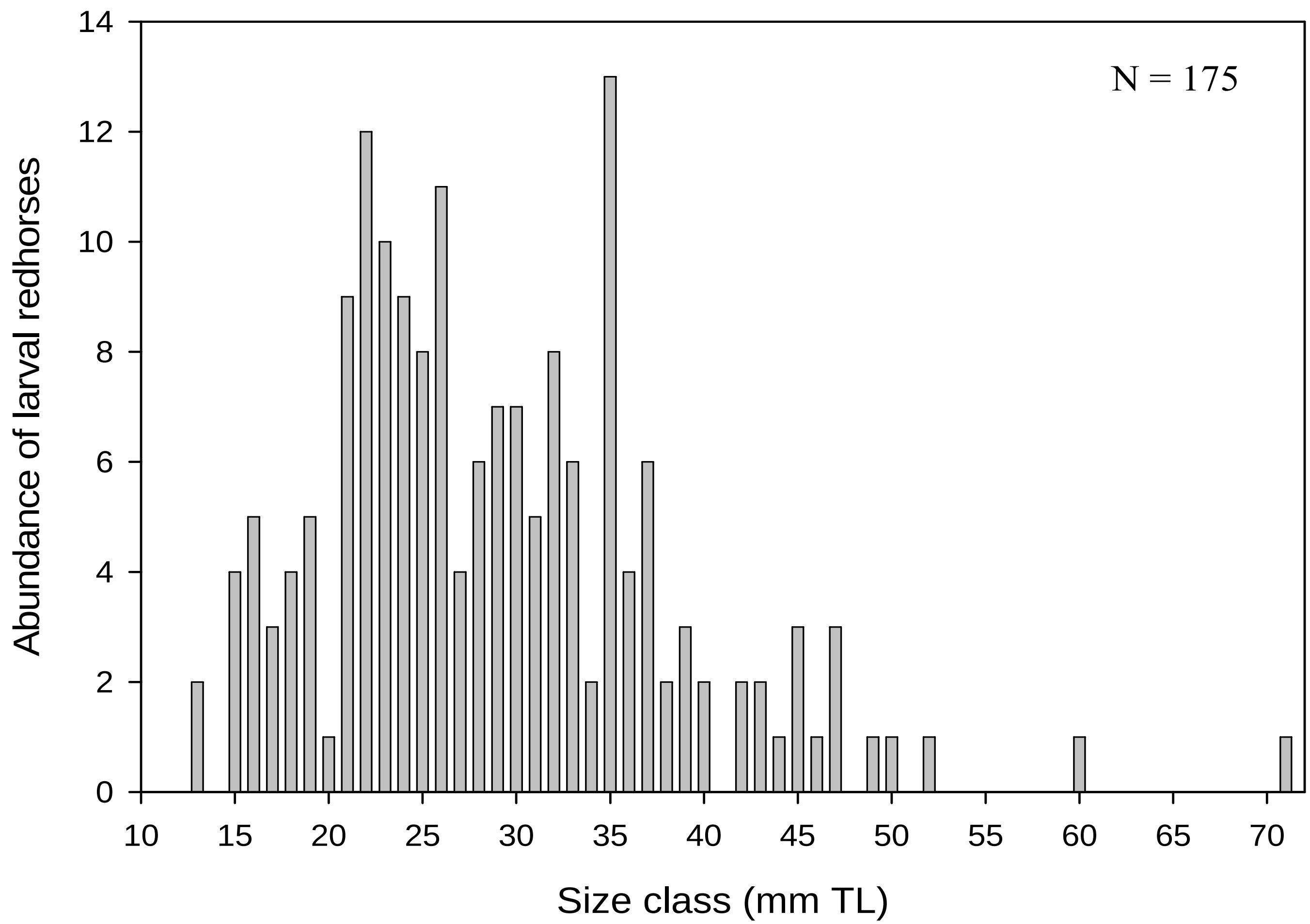

Figure 2.3. Length-frequency histogram of larval and age-0 redhorses (robust and notchlip redhorse) collected in the Oconee River, GA during 2006. Only one robust redhorse was collected (13 mm TL).

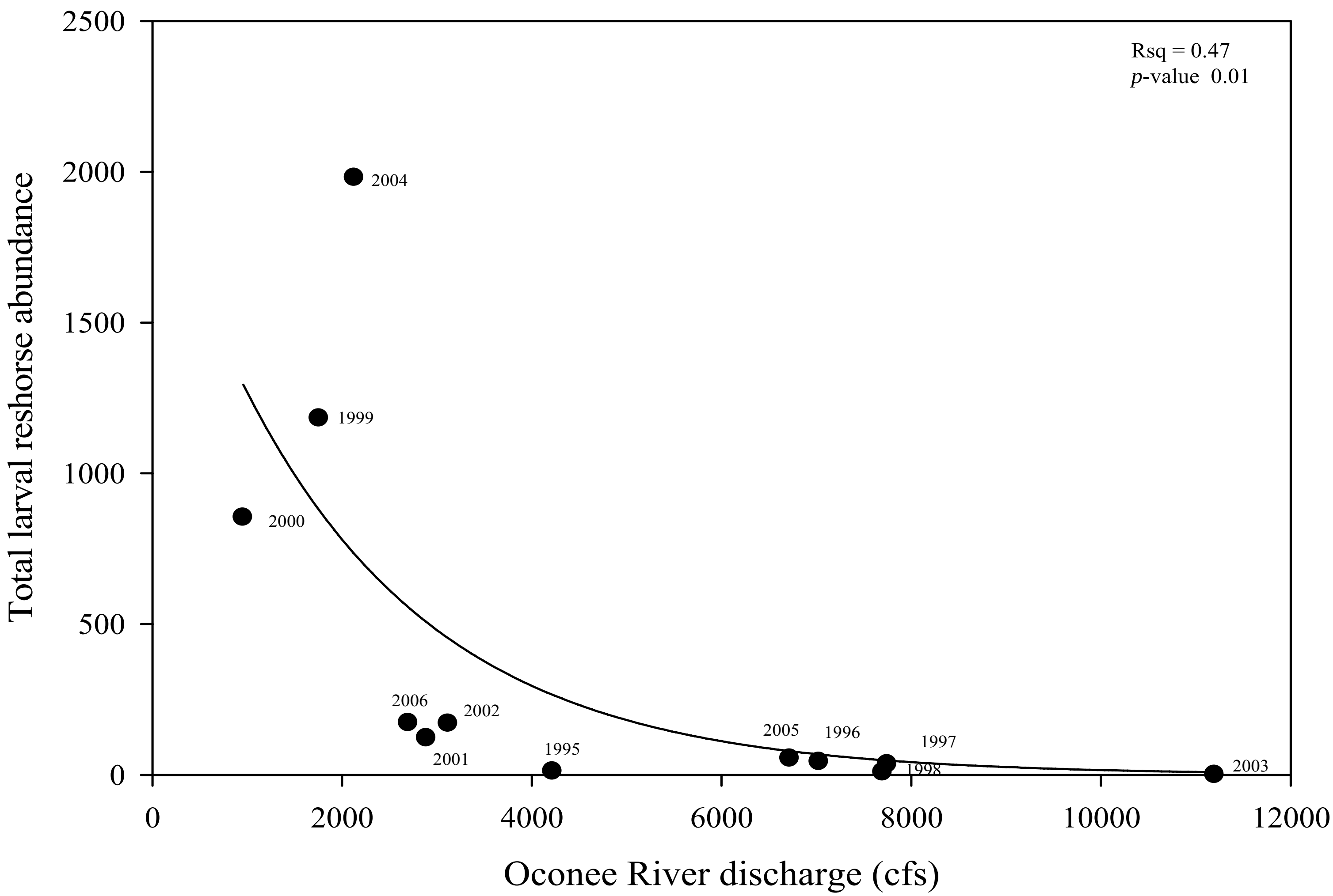

Figure 2-4. Maximum May Oconee River discharge (cfs) recorded at Avant Mine (USGS gauge No. 02223056), and total abundance of larval and age-0 redhorses during 1995-2006.

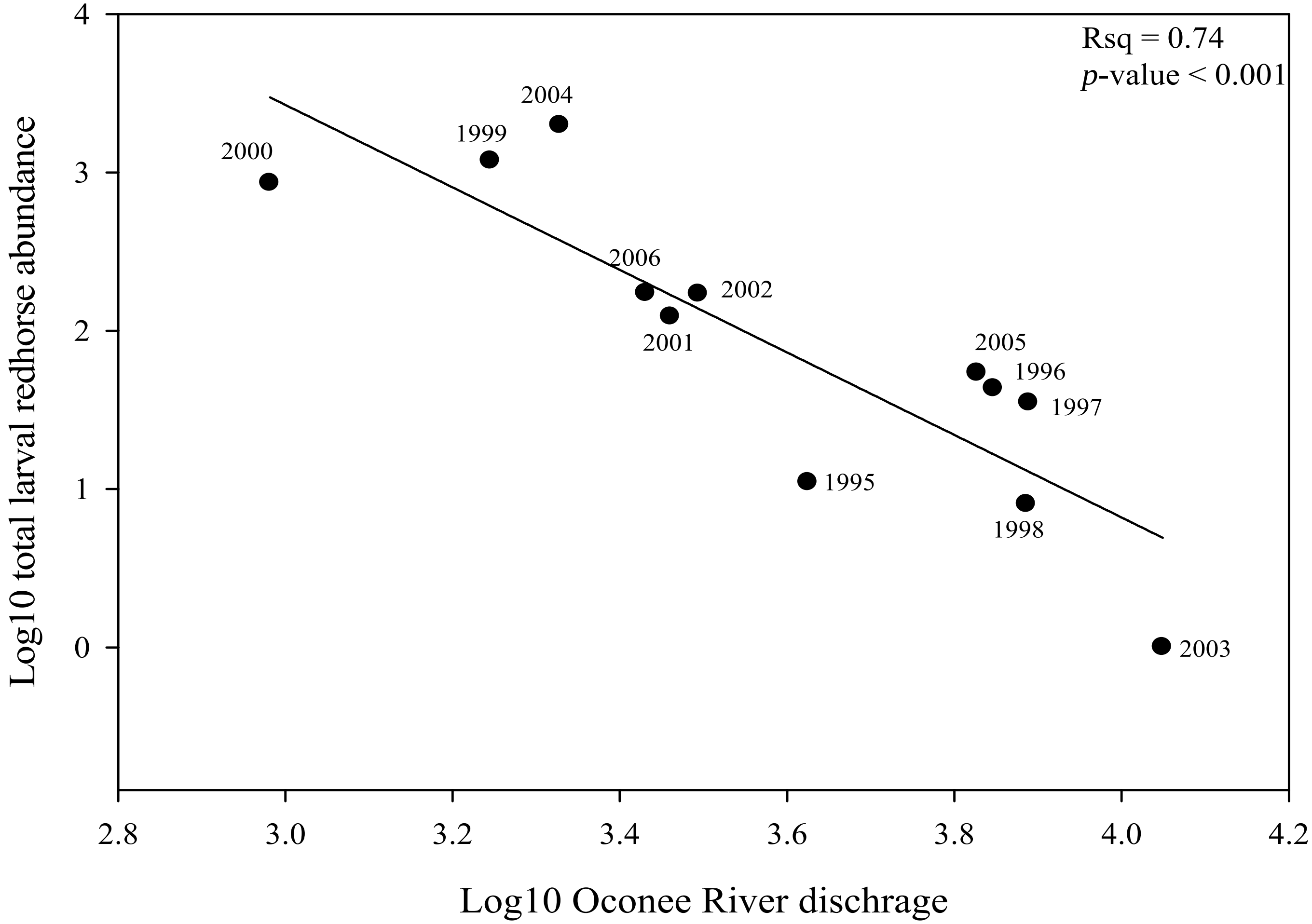

Figure 2-5. Log 10 maximum May Oconee River discharge (cfs) recorded at Avant Mine (USGS gauge No. 02223056), and total abundance of larval and age-0 redhorses during 1995-2006.

AIC_c analysis revealed two useful models that explained a significant portion of the variability observed in the abundance of larval redhorses during the 12 study years. The weight of the best-fitting candidate model was 0.798; therefore, models whose Akaike weight (w_i) was ≥ 0.08 (10% of the best-fitting model) were considered confidence models (Table 2-6). The best-fitting confidence model was candidate model 3, which contains June mean maximum river discharge, intermediate duration of low flows, and the number of high pulses during June (Table 2-6). The next best-fitting model was candidate model 1, which contains May mean maximum river discharge, intermediate duration of low flows, and the number of high pulses during June (Table 2-6). Candidate model 3 is 9.6 times more likely to be the "true" model than candidate model 1 (w_i = 0.805 and 0.084. 0.805/0.084= 9.58). The model-averaged results for the candidate models suggest that there is a negative relationship between larval and age-0 abundance and June mean maximum river discharge and a positive relationship between larval and age-0 abundance and intermediate duration of low-flow during spawning and rearing period (Table 2-7). There is a possibly negative relationship between larval and age-0 abundance and May mean maximum river discharge and a possible positive relationship between larval and age-0 abundance and long-term duration of low-flow during the spawning and rearing period (Table 2-7). In addition, there is a possible negative relationship for short-term duration of low flows, which may be attributed to the need for more consecutive days of low flow during spawning and rearing periods. These results indicate that low-stable flows during May and June are important for strong year-classes of redhorses.

Table 2-6. Predictor variables, Akaike's information criterion with small-sample bias (AIC_C), AIC_C differences (ΔAIC_C), and Akaike weights (w_i), for models describing larval and age-0 redhorse abundance in response to river discharge variables on the Oconee River near Toomsboro, GA, 1995 - 2006. Confidence models are in bold.

Model name	Model[11]	AIC_C	ΔAIC_C	w_i
Candidate model 3	**Mag3 Dur2 Freq3**	**103.129**	**0.000**	**0.805**
Candidate model 1	**Mag2 Dur2 Freq3**	**107.656**	**4.527**	**0.084**
Candidate model 2	Mag2 Dur3 Freq3	108.7887	5.659	0.048
Candidate model 4	Mag3 Dur3 Freq3	109.5012	6.372	0.033
Candidate model 9	Mag2 Mag3 Dur2 Dur3	110.9505	7.821	0.016
Candidate model 7	Mag3 Var1 Dur2 Freq3	111.9248	8.795	0.010
Candidate model 5	Mag2 Var1 Dur2 Freq3	114.6199	11.490	0.003
Candidate model 6	Mag2 Var1 Dur3 Freq3	116.2734	13.144	0.001
Candidate model 8	Mag3 Var1 Dur3 Freq3	118.2516	15.122	0.000
Global model	Mag2 Mag3 Var1 Dur1 Dur2 Dur3 Freq3	188.4922	85.363	0.000

[11] See Table 2-1 for definitions of the variables and Table 2-2 for definitions of the models

Table 2-7. The model-average with 90% confidence intervals (90% CI) and relationships for composite logistic regression models describing larval and age-0 redhorse abundance in response to river discharge variables on the Oconee River near Toomsboro, GA, 1995 - 2006.

Parameter	Parameter estimate	Standard error	Scaled Upper 90 % CI	Scaled Low 90 % CI	Relationship to abundance
Intercept	21.349	5.393	30.193	12.505	
Mag2	-0.002	0.002	0.001	-0.006	Possible negatively related
Mag3	-0.005	0.002	-0.002	-0.008	Negatively related
Var1	-0.002	0.004	0.006	-0.009	Inconclusive
Dur1	-1.114	1.435	1.241	-3.468	Possible negatively related
Dur2	16.997	5.799	26.508	7.487	Positively related
Dur3	6.135	6.050	16.056	-3.787	Possible positively related
Freq3	0.116	0.560	1.035	-0.803	Inconclusive

Although adverse river discharge is one hypothesis for the reduced number of larval and age-0 robust redhorse collected over the years, other hypotheses may explain the current catch of larval robust redhorse. Alternative hypotheses for the observed low abundance of larval robust redhorse include reduced numbers of adults and shifts in population center (or spawning areas). Fewer spawning adults may result in the reduction larval and age-0 redhorse abundance (J. Evans, personal communication). Alternatively, documented changes in channel morphology and resultant shifts in areas frequented by robust redhorse (e.g., after 1998 flood) may explain the decline in the number of adults captured during broodstock sampling. Changing channel morphology also may affect spawning areas and result in the use of undocumented spawning areas other than where sampling has occurred traditionally. If either explanation is accurate, then reduced numbers (including the complete absence) of larval and age-0 robust redhorse observed would be expected. If neither is accurate, then there is cause for concern about the observed low abundance of robust redhorse in the Oconee River.

Water quality and river measurements

Monthly mean water temperature for May – July 2006 ranged from 24.4 to 29.1 EC, and increased as the season progressed. During 1995 through 2006 May mean water temperatures ranged from 21.5 to 25.2 EC, June ranged from 23.9 to 28.2 EC, and July ranged from 27.9 to 31.5 EC (Table 2-8). Monthly mean dissolved oxygen for 2006 varied among sites and days throughout the sample season and ranged from 5.1 to 7.9 mg/l; this result is similar to previous study years (Table 2-8). In 2006, mean turbidity ranged from 19.6 to 24.0 ntu's (Table 2-9). Turbidity levels were lowest during drought years with stable flows (i.e., 2000), but increased when water released from the dam for power-generation or when river flows increased naturally

Table 2-8. Monthly mean (standard deviation) water temperature and dissolved oxygen. Measurements were taken during fish sampling May through July of 1995 - 2006 in the Oconee River near Toomsboro, GA.

Year	Month					
	May		June		July	
	Water Temperature (EC)	Dissolved Oxygen (mg/l)	Water Temperature (EC)	Dissolved Oxygen (mg/l)	Water Temperature (EC)	Dissolved Oxygen (mg/l)
2006	24.4 (2.4)	7.9 (0.1)	27.9 (1.0)	6.4 (1.2)	29.1 (1.4)	5.1 (0.5)
2005	23.6 (0.9)	7.5 (0.4)	27.1 (1.0)	8.4 (1.3)	28.8 (1.0)	6.1 (0.4)
2004	24.9 (2.2)	7.1 (0.4)	28.0 (1.1)	6.2 (0.3)	29.6 (0.7)	5.8 (0.5)
2003	NM	NM	25.8 (1.1)	5.7 (1.4)	25.9 (2.3)	8.5 (2.4)
2002	23.3 (2.2)	8.6 (1.6)	28.2 (1.8)	6.8 (0.4)	29.6 (1.6)	7.2 (0.9)
2001	24.3 (1.0)	7.7 (0.3)	26.2 (0.9)	6.6 (0.7)	27.9 (1.3)	6.5 (0.6)
2000	25.2 (2.2)	7.7 (0.5)	28.2 (1.6)	7.3 (0.8)	29.0 (1.4)	6.9 (0.4)
1999	23.8 (1.8)	8.3 (1.5)	27.5 (1.1)	7.4 (0.4)	27.9 (1.4)	6.8 (0.5)
1998	23.6 (2.3)	7.5 (0.3)	28.1 (0.9)	7.4 (0.4)	31.5 (0.8)	7.0 (0.3)
1997	21.5 (1.6)	7.9 (0.6)	23.9 (1.5)	7.5 (1.2)	28.1 (0.7)	7.0 (0.3)
1996	22.2 (1.6)	NM	26.6 (1.2)	7.0 (0.3)	29.2 (0.8)	7.2 (0.6)
1995	24.9 (1.9)	7.8 (1.5)	26.9 (1.5)	6.7 (0.5)	30.1 (1.5)	7.0 (0.8)

NM= No measurement

Table 2-9. Monthly mean (standard deviation) turbidity and current velocity. Measurements were taken during fish sampling in May through July of 1995 - 2006 in the Oconee River near Toomsboro, GA.

Year	Month					
	May		June		July	
	Turbidity (ntu)	Current (m/s)	Turbidity (ntu)	Current (m/s)	Turbidity (ntu)	Current (m/s)
2006	23.4 (4.7)	0.46 (0.29)	24.0 (16.4)	0.27 (0.20)	19.6 (5.3)	0.25 (0.12)
2005	30.0 (8.9)	0.40 (0.38)	39.4 (17.3)	0.58 (0.46)	52.0 (16.3)	0.32 (0.12)
2004	12.5 (4.4)	0.41 (0.27)	22.4 (12.2)	0.35 (0.26)	17.6 (10.6)	0.23 (0.14)
2003	NM	NM	37.6 (5.4)	0.77 (0.40)	39.4 (11.2)	0.47 (0.12)
2002	16.6 (8.1)	0.43 (0.34)	10.8 (3.8)	0.32 (0.17)	4.1(1.4)	0.30 (0.13)
2001	32.7 (9.6)	0.49 (0.36)	48.3 (13.2)	0.56 (0.37)	22.7 (9.2)	0.30 (0.13)
2000	12.1 (1.9)	0.24 (0.27)	6.9 (1.5)	0.27 (0.10)	8.0 (3.1)	0.27 (0.11)
1999	12.8 (3.3)	0.56 (0.55)	13.7 (10.0)	0.20 (0.18)	43.4 (23.6)	0.35 (0.23)
1998	46.3 (6.8)	1.18 (0.52)	32.1 (6.2)	0.78 (0.51)	11.1 (3.5)	0.38 (0.41)
1997	42.7 (11.7)	0.62 (0.46)	28.5 (5.8)	0.39 (0.44)	21.7 (9.3)	0.39 (0.39)
1996	27.9 (0.8)	0.00 (0.00)	27.2 (10.3)	0.41 (0.58)	12.5 (5.4)	0.40 (0.38)
1995	NM	0.24 (0.15)	NM	0.19 (0.18)	NM	0.15 (0.15)

NM= No measurement

(i.e., from rainfall). Monthly mean current velocity for 2006 ranged from 0.25 to 0.46 m/s (Table 2-9). The measurements of water quality taken during sampling appear to be within an appropriate range for larval and age-0 redhorses to survive (Walsh et al 1998). River discharge fluctuated among years (Figure 2-6), but apparently, low flow areas generally were available each year to provide nursery habitat (Ruetz and Jennings 2000).

Juvenile (age 1+) sampling

Boat electrofishing began September 25th and was conducted for a total of 21 days, ending November 16th, 2006. Pedal time varied between ½ hr and 3 hrs, with and average of 2 hours at a site. Spotted suckers (N=173) and notchlip redhorse (N=92) were the two most abundant suckers in the electrofishing catch (Table 2-10). Anecdotal evidence suggests that robust redhorse approach maturity at about 400 mm TL, while notchlip redhorse become adults around 350 mm TL (Sessions et al. 2008). Notchlip redhorse collected ranged between 134 and 472 mm TL. Two adult robust redhorse were collected in the Oconee River near Ball's Ferry (Figure 2-7) in the afternoon of September 27th; one was 656 mm TL, 3.7 kg (Figure 2-8) and other was 660 mm TL, 4.2 kg. The fish were captured in a bend in the river across from a sandbar, near woody debris; this type of habitat is similar to areas sampled for broodfish by GA DNR in the spring (a bend in the river across from a sandbar, near woody debris). Water temperature was 23.4 EC, dissolved oxygen was 8.1 mg/l, turbidity was 11.6 ntu's, depth at collection site was 1.3 m, current velocity was between 0.4 - 0.5 m/s, and the river discharge was about 477 cfs (USGS 2007b).

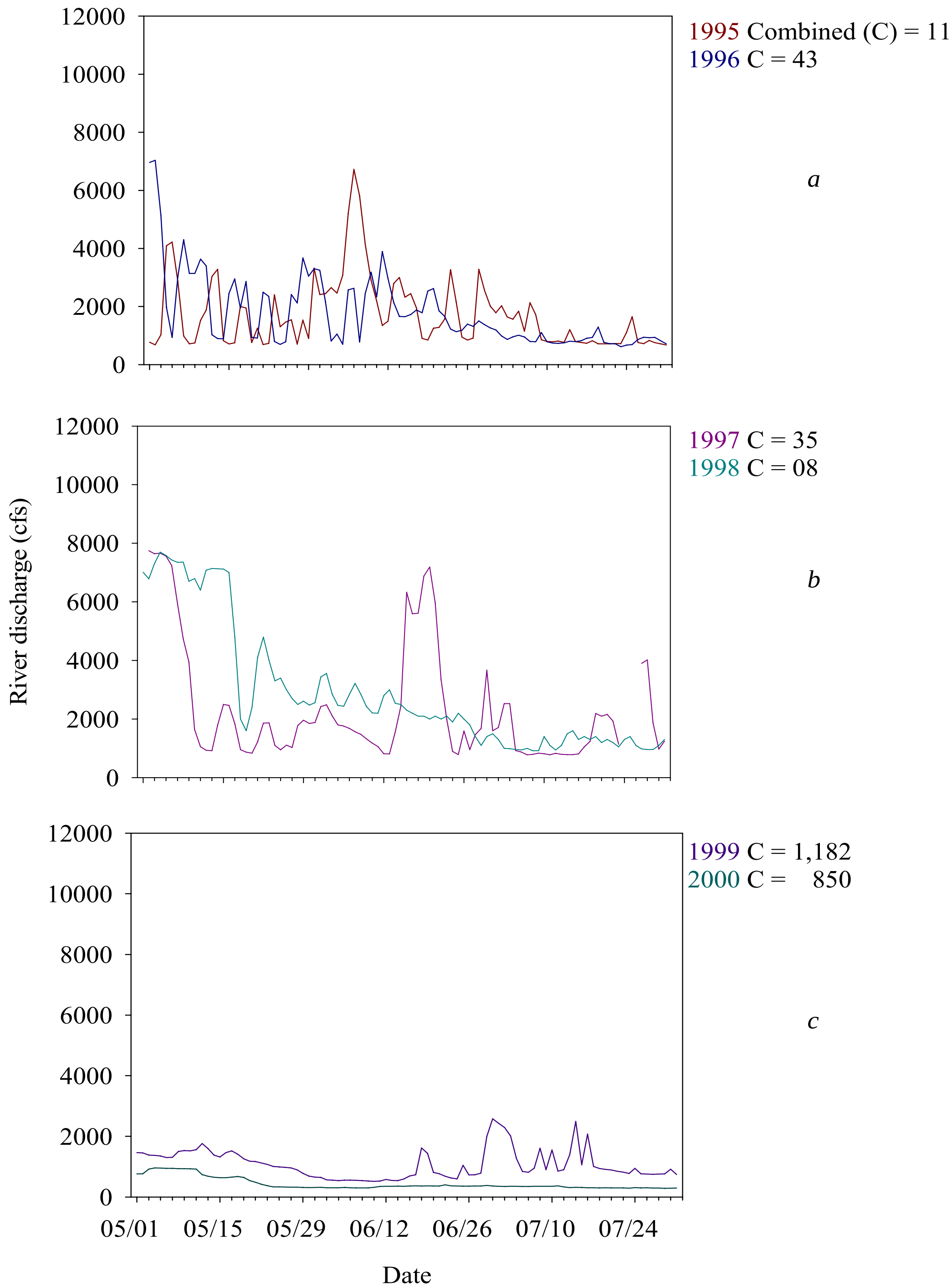

Figure 2- 6. Mean daily river discharge (cfs) from Avant Mine (USGS gauge No. 02223056) in the Oconee River, Georgia from May through July 1995-2000; panel *a* = 1995-1996, panel *b* = 1997-1998, panel *c* = 1999-2000.

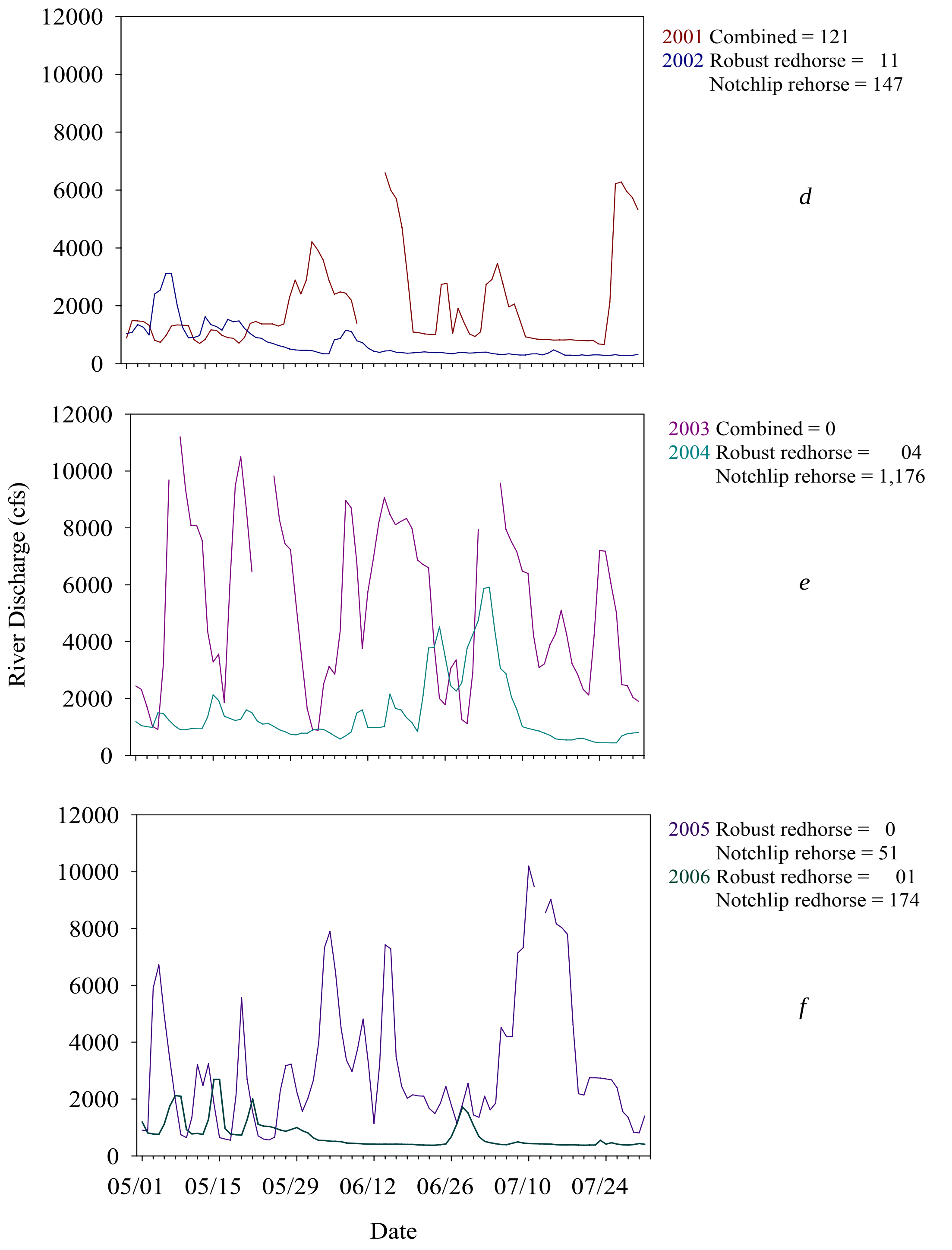

Figure 2- 6 con't. Mean daily river discharge (cfs) from Avant Mine (USGS gauge No. 02223056) in the Oconee River, Georgia from May through July 2001-2006; panel *d* = 2001-2002, panel *e* = 2003-2004, panel *f* = 2005-2006.

Table 2-10. Number and size range of catostomids collected during fall 2006. Suckers were collected in the Oconee, Ocmulgee, Altamaha and Savannah[12] rivers.

	Oconee River		Savannah River	
Sucker	Number	Size range (mm TL)	Number	Size range (mm TL)
Carpsucker spp.	71	69 - 501	1	370
Northern hogsucker	0	NA	2	254 and 267
Spotted sucker	173	134 - 481	9	390 - 440
Notchlip redhorse	92	134 - 472	3	390 - 465
Robust redhorse	2	656 and 660	2	600 and 617

NA = Not applicable

[12] The number of suckers collected in the Savannah River is under-represented, especially spotted suckers. Not all suckers were brought on board because the goal was to collect robust redhorse, not sample suckers in the Savannah River.

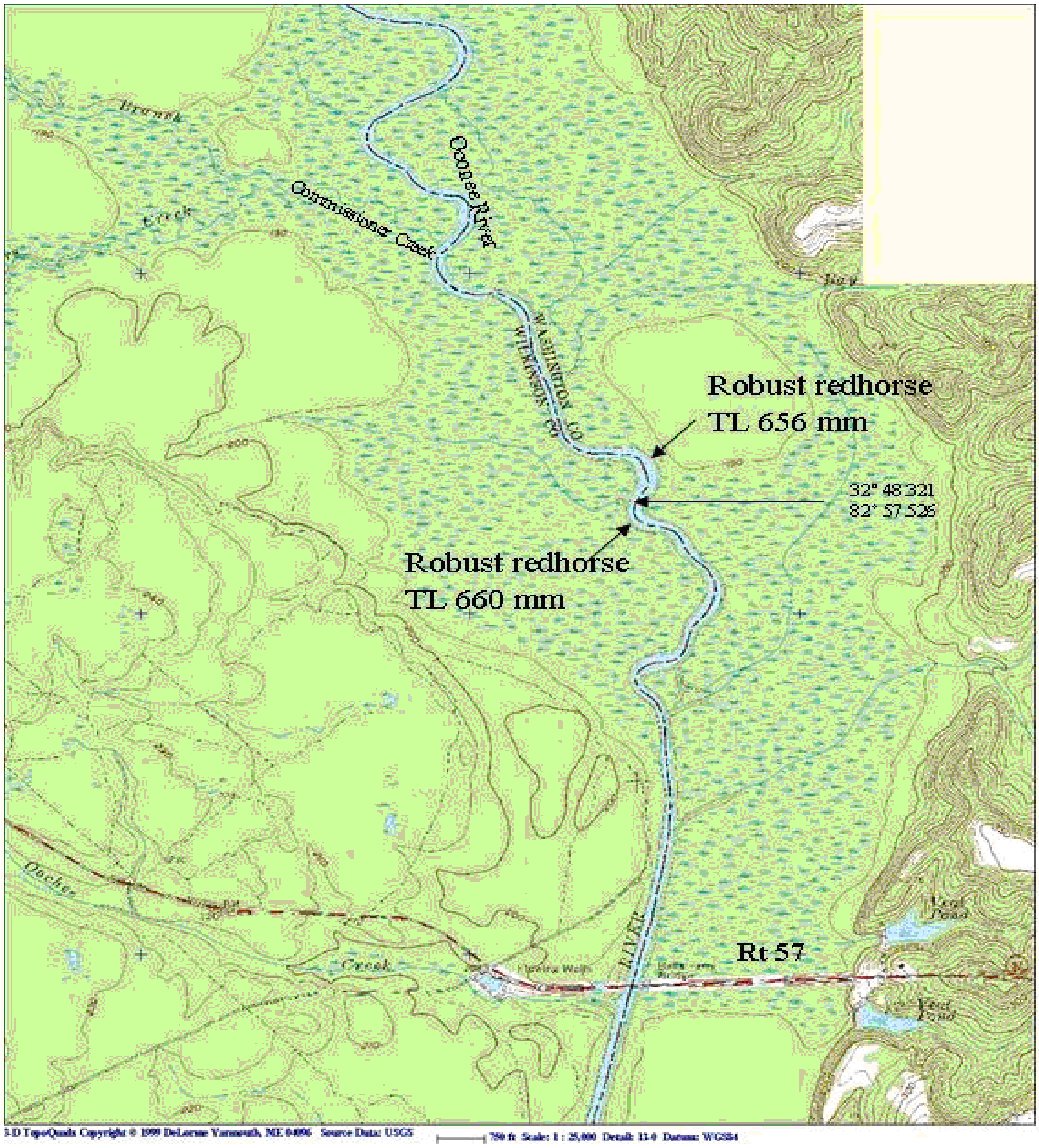

Figure 2-7. Location where two adult robust redhorse were collected in the Oconee River, GA on September 27th 2006.

a

b

Figure 2-8. Adult robust redhorse collected in the Oconee River, GA September 27th , 2006(*a*) and an adult robust redhorse collected in the Savannah River GA/SC October 19th ,2006 (*b*).

In comparison, the Savannah River was sampled for 2 days and yielded 2 adult robust redhorse; juveniles were not captured (Table 2-10). Both adults were collected October 19th, 2006 near US route 301 Bridge (Figure 2-9). The measurements were 600 mm TL, 3.5 kg (Figure 2-8) and 617 mm TL, 3.7 kg. Water temperature was 20.6 EC, dissolved oxygen was 7.1 mg/l, turbidity was 8.1 ntu's, and the river discharge was about 4,900 cfs (USGS 2008c).

Other studies have successfully used boat electrofishers to collect redhorse species (Hackney et al. 1967, Ruetz et al. 2007, Coughlin et al. 2007, Reid et al. 2008). Adult *Moxostoma* have been collected in deep runs or pools in rivers (Reid et al. 2008). However, robust redhorse may be more elusive or less abundant than other congeners as suggested by the collection of shorthead and notchlip redhorse but not robust redhorse in the Wateree River, South Carolina where all three species reside (Coughlin et al. 2007). Experimental evaluation of habitat preference for juvenile robust redhorse identified eddies and backwater with low flows (0.0 to 0.15 m/s) as preferred juvenile habitats (Mosley and Jennings 2007).

Personal observations of electrofishing for robust redhorse indicate that when a robust redhorse is shocked, it rises to the surface and then quickly sinks. There is also speculation that robust redhorse may not even surface because it is a benthic fish with a reduced air bladder and might simply roll-over along the bottom of the river when shocked. This difficulty to see stunned robust redhorse leads to the question of detectability for this species. A study conducted on the Ocmulgee River, GA, found that electrofishing was not a very effective method (detection probability = 0.031) for collecting adult robust redhorse; the low detection may result from their cryptic nature (i.e., behavior and habitat preferences; Grabowski et al. 2008). Electrofishing for robust redhorse in good conditions (low flows, reduced turbidity, and calm waters) can be difficult; sampling conducted in turbid and/or fast moving water may not be effective.

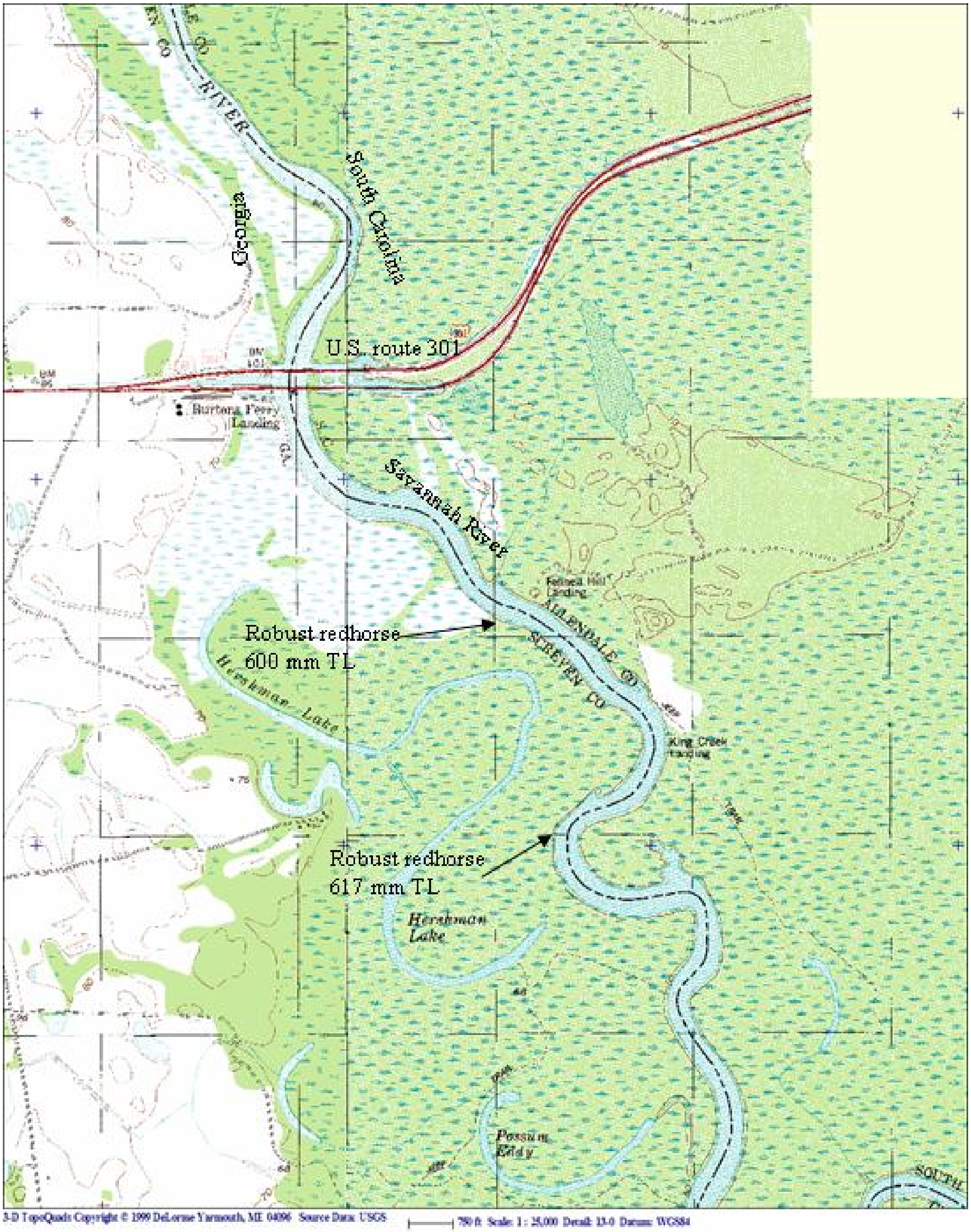

Figure 2-9. Location where two adult robust redhorse were collected in the Savannah River, GA/SC on October 19th 2006.

There has been an ongoing debate regarding the absence of juvenile robust redhorse in fish samples taken from the lower Oconee, lower Ocmulgee and Altamaha rivers. Reasons for this absence include: the actual abundance of juvenile robust redhorse, gear inefficiency, or sampling in areas not frequented by this life-stage. How the catch data from the Oconee River can be interpreted can be guided by other lines of evidence from the system and from lines of evidence for catostomids from other systems. For example, adult robust redhorse continue to recruit to the population, albeit at low levels. Therefore, juvenile robust must be in the system somewhere. Further, we previously reported (Jennings et al. 2005), that “missing juveniles” have been reported healthy populations of other sucker species. For example, the pattern of missing juveniles has been observed among healthy populations of adult blue sucker (*Cycleptus elongatus*), which are routinely captured in the Yazoo River, Mississippi; however a concurrent study on juvenile blue suckers did not collect any (Hand and Jackson 2003). Whether our results of “missing juveniles” are “typical” of other healthy populations of sucker or is indicative of a recruitment problem is unknown. The continued recruitment of new adults to the population is one cause for optimism.

Juvenile (age 1+) river measurements

Monthly mean water quality measurements during juvenile sampling varied temporally; water temperatures from September to November ranged from 14.0 to 27.5 EC; dissolved oxygen ranged from 6.6 to 9.3 mg/l; and turbidity ranged from 7.1 to 21.6 ntu (Table 2-11). River discharge for Oconee River ranged from 408 – 1,020 cfs with an average of 500 cfs; Altamaha River ranged from 1,730 – 3,000 cfs with an average of 2,100 cfs; and Ocmulgee River ranged from 987 – 2,060 cfs with an average of 1,261 cfs.

Table 2-11. Monthly mean (standard deviation) water quality measurements taken during gill net sampling on the Altamaha River system, Georgia from September - November 2006.

	Month		
Measurement	September	October	November
Water Temperature (EC)	25.5 (1.7)	20.7 (4.5)	16.5 (1.9)
Dissolved Oxygen (mg/l)	7.2 (0.6)	7.9 (0.7)	8.9 (0.3)
Turbidity (ntu)	13.3 (5.1)	11.4 (2.4)	15.8 (4.5)

Conclusion

During the past 12 years, attempts to collect larval, age-0, and juvenile robust redhorse have met with limited success. Successful spawning by robust redhorse, the successful hatching and emergence of larvae, and their subsequent transition to age-0 fish have been documented during some years. However, the overall question regarding the reproductive status of robust redhorse in the Oconee River remains uncertain

Wild-produced juveniles have never been collected in the Oconee River (or elsewhere); therefore, the eventual fate of the age-0 individuals in the Oconee remains unclear. There is evidence that a few age-0 individuals recruit to the adult population; however, whether there is sufficient recruitment to sustain the adult population is unknown. Further, the available evidence is insufficient to determine if the lack of robust redhorse juveniles in fish survey data is because of to poor recruitment, sampling ineffectiveness, low species detection, changes in adult spawning locations, or population decline. The low numbers of young, in addition to the declining numbers of adults collected during spawning, are troubling and may indicate that the size of the adult population has declined since the beginning of this study.

Multiple hypotheses testing via information theoretic approach has provided new insight into how various flow-related variables affect the abundance of larval and age-0 redhorses. Specifically, larval and age-0 redhorse abundance in the Oconee River seems to be dependant on low May and June mean maximum flows, at least moderate duration (i.e., 7 – 14 days) of flows below 25 %ile of the long-term average during April – June, and infrequent high (> 75%ile of long term average) during June. This pattern certainly is true for notchlip redhorse, but small sample size limits our ability to make inferences about the degree to which these factors affect the abundance of larval and age-0 robust redhorse. If this pattern holds true for robust as well as notchlip redhorse, then managing for low-stable flows of at least a two-week duration and limiting the number of high flow events during May and June would help produce a large successful year-class of robust redhorse. If this pattern does not satisfactorily explain the observed abundance of larval and age-0 robust redhorse in the Oconee River, then much work remain to uncover the as-yet undefined mechanism(s) determining year-class strength of robust redhorse in this system.

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