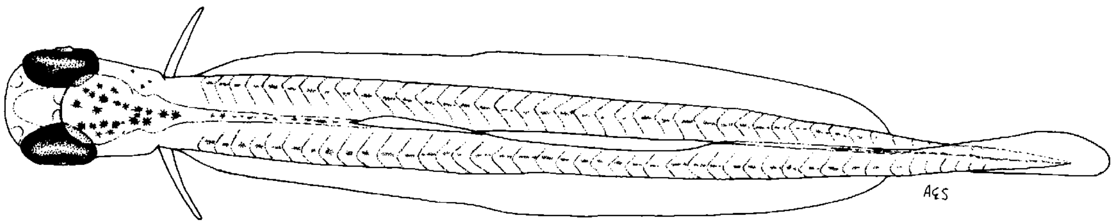
Culture techniques and ecological studies of the robust redhorse Moxostoma robustum: Distribution and abundance of wild-caught larval robust redhorse in the Oconee River, GA and evaluations of methods for radio-tagging juveniles and adults.



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December 2006

Task 1. Artificial Propagation of Robust Redhorse (*Moxostoma robustum*)
Broodfish Collection

Introduction

Artificial propagation of robust redhorse for research and husbandry purposes continued this year as in previous years. Adult robust redhorse were collected from the Oconee River by Georgia DNR biologists between April 23 and May 21, 2001. The objectives of this 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. Low flows from Sinclair Dam were provided by Georgia Power Company, and broodfish were captured by electrofishing. A total of 56 specimens were collected during this period (43 males, 10 females and 3 juveniles). Fin clips were collected and preserved in ethanol for subsequent genetic evaluation. PIT (Passive Integrated Transponder) tags were inserted in all fish that did not already have them. Lengths (mm TL) and weights (Kg) were recorded for all fish, and ovulation stage of females was determined. Fish in suitable spawning condition were transported to a temporary spawning facility constructed on the river bank next to the Beaverdam Wildlife Management Area boat ramp (refer to Robust Redhorse Conservation Committee Annual Report, 1997 for details of broodfish collection protocol).

Spawning

Of the 56 specimens collected during spring of 2001, 33 were transported to the temporary spawning facility at Beaverdam WMA. The rest were determined unsuitable for spawning when examined at the time of capture. Only two of 5 females and 10 of 28 males received at the spawning facility were used for a total of 10 mating pairs. Fish were anesthetized (10 ppm Metomidate) prior to handling. All spawned fish were released at the Beaverdam WMA boat landing. 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. Table 1.1 provides basic information on fish received at the spawning facility. Table 1.2 provides information on matings and embryo production.

Based on observations from previous years, the peak of robust redhorse spawning activity is expected to occur in the first or second weeks in May. Despite a protracted period of brood fish collection (five weeks) centered around this peak, most fish collected during spring 2001 were found to be in poor spawning condition (based on degree of mucus loss, tuberculation and condition of genital dome). Only ten females were collected this year (compared to 31 in year 2000), and only two of those spawned (one naturally and one via hormone induction). While a number of adult males were collected (43 this year compared to 52 in year 2000), most exhibited low sperm motility and a number exhibited low milt volume. Milt from viable males was cryopreserved and added to the robust redhorse sperm repository held at Warm Springs Fish Technology Center. Due to the low number of embryos produced this year, none were utilized in research projects.

As in year 2000, batches of eggs collected from each female were split into multiple lots and each lot was fertilized with milt from a various males. This protocol is designed to ensure optimal genetic heterogeneity among progeny.

Table 1.1. Information on adult robust redhorse received for spawning at Beaverdam WMA during spring, 2001.

Floy Tag	Floy Tag	PIT Tag	TL	WT	Captured	Sex
01385	01386	4033734309	684	4100	4/30/2001	Female
01418	01419	40337D093E	664	3590	5/14/2001	Female
01387	01388	43040A6411	671	4660	4/30/2001	Male
01360	01601	501A60204B	613	3810	4/30/2001	Male
00082	01391	4033662133	663	4120	4/30/2001	Male
00422	00423	40337C1326, 4034063A25*	648	4380	4/30/2001	Male
00497	00498	403361363F	644	4590	4/30/2001	Male
01389	01390	403400603B	660	4170	4/30/2001	Male
00543	00546	40337A5865	650	4210	4/30/2001	Male
00623	00624	4033797B02	660	4510	5/14/2001	Male
01410	01411	40336B2566	577	3420	5/14/2001	Male
01381	17935	40336B1947	681	3680	5/14/2001	Male

*Only the 1st PIT# recorded on 1st capture (5/12/1997); only the 2nd PIT# recorded on 2nd capture (4/30/2001).

Table 1.2. Spawning matrix for 2001 indicating tag numbers for males and females, dates of mating, number of eggs produced.

Date	Female	Male	# Eggs
4/30/2001	1385/1386	1387/1388	1,656
4/30/2001	1385/1386	1601/1360	2,494
4/30/2001	1385/1386	0082/1391	2,970
5/1/2001	1385/1386	0082/1391	2,407
5/1/2001	1385/1386	0082/1391	1,860
5/1/2001	1385/1386	0422/0423	3,757
5/1/2001	1385/1386	0497/0498	3,478
5/1/2001	1385/1386	1389/1390	3,502
5/1/2001	1385/1386	0543/0546	3,519
5/14/2001	1418/1419	17935/1381	1,326
5/14/2001	1418/1419	1410/1411	947
5/14/2001	1418/1419	623/624	568
TOTAL			28,484

Incubation

Total embryo production for 2001 was 28,484 (compared to 311,809 in spring 2000), with all being shipped to the Warm Springs National Fish Hatchery. 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. By June 4, 2001 all fry were feeding consistently and they were transferred to the Walton State Fish Hatchery for rearing to Phase I fingerling stage. A total of 11,864 fry were shipped and stocked in two earthen ponds. Hatch rates (embryos hatching into fry) for pairings varied from 2-100% with an overall average of 57%. Survival from embryo stage to fry stocking was 42%. Ponds at the Walton State Fish Hatchery were harvested in January, 2002 and overall survival to fingerling stage was quite high (83%). Table 1.3 summarizes the 2001 spawning effort and compares results to previous years, including the numbers of fingerlings ultimately produced from spawned robust redhorse.

Table 1.3. Summary of the number of robust redhorse broodfish 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 - 2001.

Year	Males spawned	Females spawned	Eggs produced	Fry produced	Fingerlings produced
1995	20	20	652,750	71,769	40,468
1996	21	11	477,119	98,089	1
1997	21	12	360,219	189,167	36,285
1998	10	4	142,662	55,683	13,030
1999	13	16	560,227	62,350	23,964
2000	31	13	308,774	82,939	28,600
2001	10	2	28,484	11,864	9,841

Task 2. Reproductive and Recruitment Success of Robust Redhorse in the Oconee River, Georgia.

Introduction

Successful reproduction of robust redhorse *Moxostoma robustum* in the Oconee River has been documented for a limited reach of the river since 1995 (see annual reports for project years 1995-2000); however, reproductive success has been variable. In recent years, efforts have shifted from simply documenting larval production to trying to develop mathematical models that help explain which environmental factors (e.g., flow) may best explain the apparent variability in reproductive success for the period 1995-2000. Interestingly, flow variability during the same period was highly variable and encompassed years with hydropeaking during may (1995-1996) and years with run-of-river flows during May (1997-2000). Those run-of-river flows included a "normal water" year (1997), a flood (1998), and a drought (1999-2000). Evaluation of these data led Jennings et al. (2004b) to hypothesize that low (i.e., maximum May flows < 4,000 cfs) stable flows during the spawning season may promote strong year-classes of redhorses (i.e., robust redhorse and notchlip redhorse *M. collapsum*). The drought conditions that existed during 1999-2000 were forecasted to continue during 2001, which would allow for a field test of the "low-stable flow" hypothesis.

Robust redhorse have been collected as larvae and as adults, but juveniles have not been collected. The absence of juvenile from the catch limits our knowledge of their habitat requirements to conjecture based the habitat preference inhabited by juveniles of other *Moxostoma* spp. In fact, many hypotheses, included ontogenetic shifts in habitat use and gear inefficiency, have been advanced to explain the absence of juveniles from the samples from sampling conducted in the mainstream of the Oconee River. During 1998 and 1999, hoop nets were added to the sampling gear to address the gear inefficiency hypothesis, but juvenile robust redhorse were not caught with this gear. As a result, the "ontogenetic shifts in habitat use" hypothesis was evaluated during 2001 by sampling in off-channel habitats and tributaries.

The background and justification for this work are given in Jennings et al. (1996; 1998; and 2003); however, the overall goal of this study was to continue to 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 robust redhorse in the study reach, 2) evaluate if the number of larval redhorses produced during 2001 is consistent with what would be expected given the maximum flows during May, and 3) determine if juvenile robust redhorse use off-channel habitats or tributaries of the Oconee River.

Materials and Methods

Ichtyoplankton sampling

The Oconee River is part of the Altamaha River basin, which includes the Altamaha, Oconee, and Ocmulgee rivers (Figure 2-1). The Oconee River passes through two large reservoirs, Lakes Oconee and Sinclair. Sinclair Dam, which closes the lower reservoir, is located in Milledgeville, Georgia above the Fall Line at about 235 river kilometers (rkm) from the mouth of the Altamaha River. The study area is located near Toomsboro, Georgia (between Milledgeville and Dublin) and encompasses rkm 145 - 165 (Figure 2-1), which is in the transitional zone between the Piedmont and the Upper Costal Plain physiographic regions.

Sampling began May 16th, 2001 and continued through July 27th, 2001. Gear used to sample larval and juvenile fishes included: push-nets, light traps, benthic light traps, and seines.

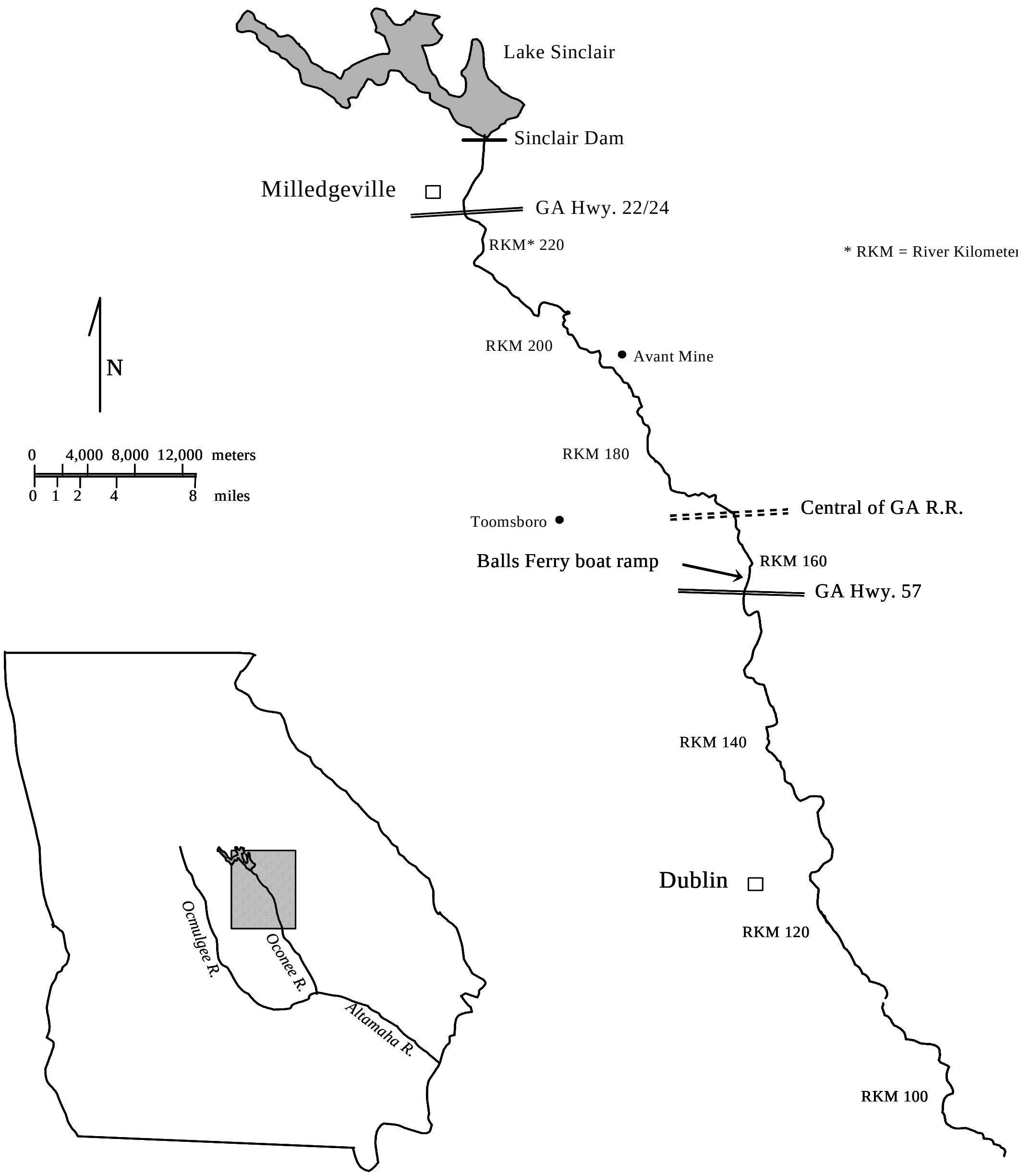


Figure 2-1. Location of study reach (in shaded box) on map of Georgia that shows location of Oconee, Ocmulgee, and Altamaha rivers below the fall line in Georgia; enlarged illustration of study reach between river miles 145 and 165. Sampling was conducted from May - July 2001.

The frequency and duration of sampling as well as habitat sampled with each gear varied in response to expected ontogenetic shifts in habitats by larval robust redhorse. The gear were used in the same general areas and in the same manner as in previous years (see Jennings et al. 2004b). Two-thirds of the samples were preserved in 10% buffered formalin and 1/3 were preserved in 90% ethanol during May and part of June. Beginning the second week in June, all samples were preserved in 90% ethanol. Ethanol was used as the preservative instead of formalin to allow genetic identification of the two species of larval redhorse (i.e., robust redhorse and notch-lip redhorse) that occur in the Oconee River because they are physically indistinguishable at small sizes.

Samples were transferred to University of Georgia to be processed, which included draining and rinsing formalin or ethanol from the samples, extracting fishes from debris, identifying species to lowest possible taxa, and separating redhorse from other fishes. A dissecting scope (10x eye pieces, option for polarized light) was used to identify morphometric (e.g., body depth, melanophores) and meristic (e.g., myomeres, fin rays) characteristics (Hogue et al. 1976; Kay et al.1994) to separate redhorses from other fishes. As in previous years, identification of redhorse species was based on size-at-collection-date. However, this year a sub-sample of larval redhorse were sent to Dr. Ike Wirgin (New York University, Institute of Environmental Medicine) for genetic identification per the assay described in Wirgin et al. (2004). Total length of each redhorse was measured to the nearest 0.1 mm with jaw-type dial calipers. Twenty percent of the processed samples were resorted to assess the efficiency of the extraction of fishes and eggs; the quality assurance resorting was conducted by someone other than the original sorter.

Water quality measurements

Water temperature and dissolved oxygen were measured with a YSI® dissolved oxygen meter, turbidity was measured with a Hach® portable turbidimeter (Model 2100P), flow was measured with General Oceanics® flow meter, and depth was measured with Lowrance® boat-mounted depth finer or a graduated depth pole. These measurements were made immediately after sampling was conducted. Daily river discharge (cfs) for the Oconee River, Georgia (Avant Mine, USGS gauge number 02223056) was downloaded from US Geological Survey website (USGS 2006) at a later date.

Juvenile sampling

During the fall, backpack electrofishers were used to sample previously unsampled areas where juvenile robust redhorse may occur. Sample locations were selected because: they were tributaries of the Oconee River, were accessible to the sampling crew, and were sufficiently shallow (i.e., wadeable) for backpack electrofishing. The upper and lower ends of each reach were closed with block nets, and a three-pass depletion method was used during each sampling event to collect fishes in the reach. Reach length and average width (3-5 widths measured) were measured for each creek sampled. Water quality measurements were collected with the same methods as icthyoplankton sampling, except depth was not measured. Fishes were identified to the lowest possible taxa in the field and released; if a definitive identification could not be made on suckers, the specimens were returned to the lab for definitive identification.

Results and Discussion

Ichtyoplankton sampling

During the 2001 sample season, push-nets, light traps and benthic light traps were twice weekly during May and June. Seine hauls were conducted once a week during May and June and three times a week during July (Table 2-1). The number of samples and fishes collected varied by gear (Table 2-1). Overall, 292 samples containing 12,000 fishes were collected from the study reach. Estimated efficiency with which fishes and eggs were extracted from samples was > 99%. There were 11 families collected in 2001; this number was similar to the numbers (11-12) collected in previous years. The 2001 catch was dominated again by minnows (88%) and within the range observed during previous years (78 - 92%). Throughout the study years, the next most abundant families (not always in this order) have been: shad (Clupidae), suckers (Catostomidae), sunfish/black bass (Centrarchidae), and mosquitofish (Poecilidae). During 2001, the most abundant families were: shad (4%), mosquitofish (3%), sunfish/black bass (2%), and suckers (2%), which was similar to previous years (Table 2-2).

Redhorses (presumably robust as well as notch-lip) successfully spawned during 2001 as is evidenced by 121 larval redhorse collected during the sample period. This number is lower than the total redhorse abundance in 1999 and 2000, but higher than 1995-1998 (Figure 2-2). Whether this catch be attributed to increased sampling efficiency during lower water years or true abundance has not been determined. Jennings (2004b) suggested that stable flows #4,000 cfs during May might produce strong year classes. An exponential-decay, non-linear regression model was used to analyze the abundance of redhorse in relation to maximum May river discharge from 1995 - 2001, fit the data well ($R^2 = 0.74$). The model results are consistent with the hypothesis.

Table 2-1. Gear types, and deployment information for sampling larval and post-larval robust redhorse in the Oconee River, Georgia between May to July 2001.

Gear (mesh µm)	Dates	Effort/ sampling event	Frequency	No. of samples	No. of fishes	Habitat sampled
Push-nets[1] (505)	5-16-01 to 6-27-01	6 tows 2 stations 3 replicates	2 x's /week	53	350	mid-channel (occasionally deep pools)
Light traps[2] (N/A)	5-16-01 to 6-27-01	5-8 traps ~ 2 stations	2 x's /week	64	1,589	slack water habitats off main channel (occasionally mouths of creeks)
Benthic light traps (N/A)	5-16-01 to 6-25-01	3-4 traps ~ 2 stations	2 x's /week	31	42	deeper water, with and without current, locations standard light traps can not fish
Seine nets[3] (800)	5-18-01 to 7-27-01	9 hauls 3 stations 3 replicates	1 x /week May-June 3x/week July	144	10,019	sandbars (occasionally mud-flats)

[1]Mean water volume sampled was 100 m^3

[2]Light traps were fished for an average of 3 hours.

[3]Seine hauls were on average 20 meters long with a distance from shore of 5 - 10 meters

Table 2-2. Number of larval and post-larval fishes, by family (and percent catch composition), collected from the study reach of the Oconee River, Georgia spring and summer, 1995 - 2001.

Year	Number of fishes per family (and % catch composition)														
	Lepis-osteids	Clu-peids	Cyprin-ids	Catost-omids	Ictal-urids	Esocids	Bel-onids	Aphred-oderids	Anth-erinids	Percich-thyids	Centr-archids	Percids	Poeci-liids	Soleids	Un-known
2001	0 (0.0)	455 (3.8)	10,496 (87.5)	179 (1.5)	109 (<1.0)	4 (<1.0)	2 (<1.0)	55 (<1.0)	39 (<1.0)	0 (0.0)	186 (1.6)	131 (1.1)	344 (2.9)	0 (0.0)	0 (0.0)
2000	0 (0.0)	8 (<1.0)	59,416 (90.3)	1,894 (2.9)	58 (<1.0)	3 (<1.0)	1 (<1.0)	0 (0.0)	445 (<1.0)	0 (0.0)	1,217 (1.8)	109 (<1.0)	2,608 (4.0)	1 (<1.0)	60 (<1.0)
1999	4 (<1.0)	82 (<1.0)	74,275 (91.5)	3,685 (4.5)	329 (<1.0)	0 (0.0)	7 (<1.0)	1 (<1.0)	388 (<1.0)	0 (0.0)	1,518 (1.9)	177 (<1.0)	604 (<1.0)	0 (0.0)	60 (<1.0)
1998	3 (<1.0)	323 (1.4)	21,421 (91.0)	999 (4.2)	211 (<1.0)	0 (0.0)	4 (<1.0)	3 (<1.0)	45 (<1.0)	8 (<1.0)	109 (<1.0)	107 (<1.0)	186 (<1.0)	0 (0.0)	236 (<1.0)
1997	2 (<1.0)	938 (4.3)	19,128 (88.6)	261 (1.2)	38 (<1.0)	1 (<1.0)	1 (<1.0)	0 (0.0)	187 (<1.0)	0 (0.0)	169 (<1.0)	143 (<1.0)	680 (3.1)	1 (<1.0)	46 (<1.0)
1996	3 (<1.0)	393 (1.0)	35,373 (91.4)	705 (1.8)	92 (<1.0)	0 (0.0)	6 (<1.0)	0 (0.0)	311 (<1.0)	0 (0.0)	459 (1.2)	151 (<1.0)	688 (1.8)	2 (<1.0)	532 (1.4)
1995	4 (<1.0)	1,041 (2.3)	35,658 (78.0)	3,468 (7.6)	243 (<1.0)	0 (0.0)	16 (<1.0)	0 (0.0)	739 (1.6)	0 (0.0)	2,675 (5.8)	94 (<1.0)	956 (2.1)	1 (<1.0)	282 (<1.0)

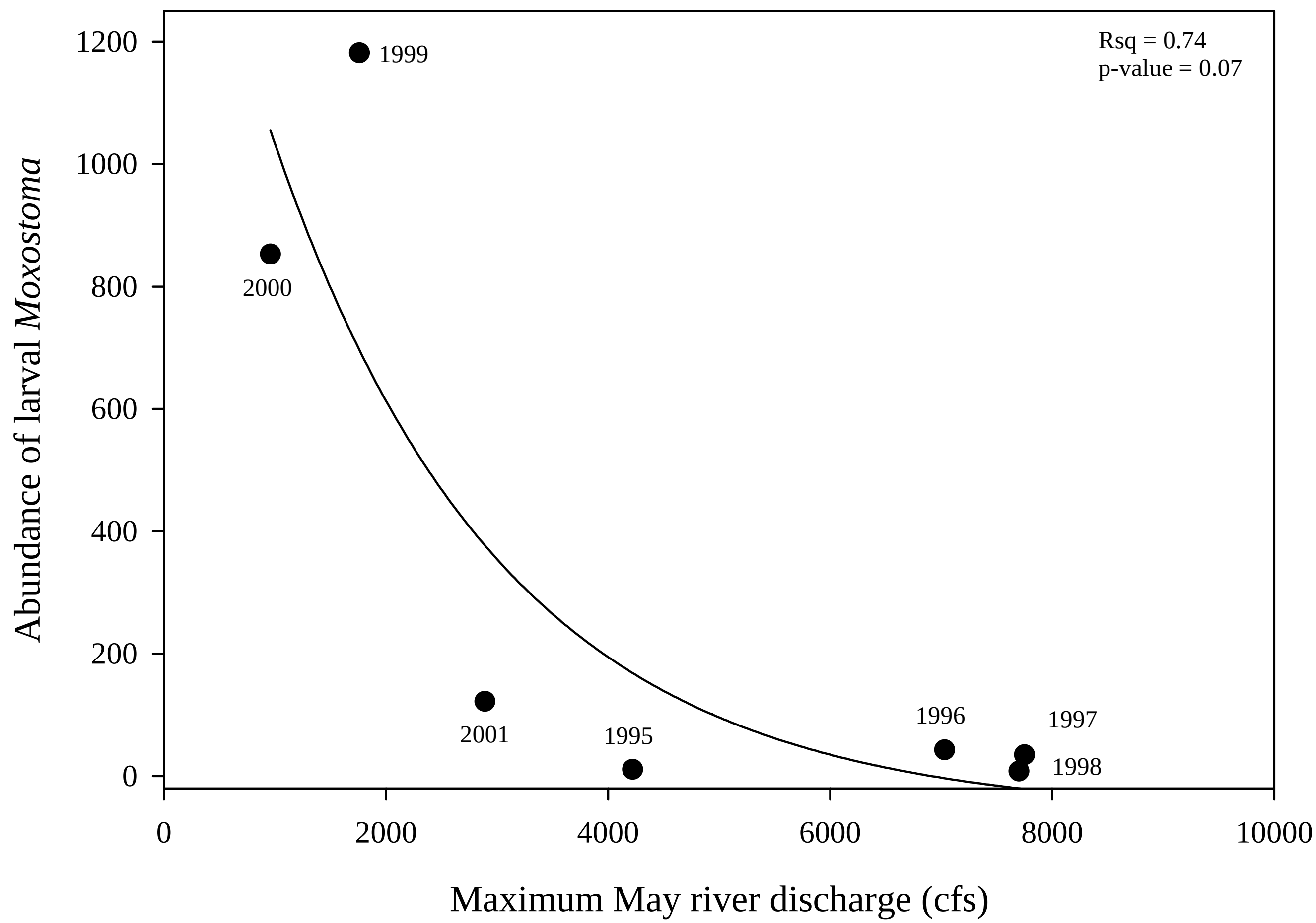


Figure 2-2. Maximum May river discharge (cfs) of the Oconee River recorded at Avant Mine (USGS gauge No. 02223056) and total abundance of larval redhorses during 1995 - 2001.

of lower flows yielding higher abundance of redhorses. Both 1999 and 2000 had stable flows below 4,000 cfs; although most days in 2001 were #4,000 cfs, there were several periods (a 1-day event early June, a 7-day event late June, and a 5-day event in late July) where flows exceeded 4,000 cfs (Figure 2-3). These "high flow" events may have contributed to the comparatively low larval redhorse abundance in 2001 compared to 1999 and 2000. None-the-less, the redhorse abundance was much higher than the numbers produced during 1995-1998. Therefore, the number of redhorses produced during 2001 is consistent with the number expected given the maximum flows during May. Further, the greater abundance during 1999 - 2000 and the "moderate" abundance during 2001 may be indicative of hydrograph-related variability in year-class strength, as was suggested for carpsucker species in the same study reach (Cull Peterson and Jennings, submitted). Such a life-history would allow redhorse to produce a strong year-class every few years, regional hydrograph permitting, and still maintain a viable population.

As in past years (see Jennings et al. 1996, 1998, 2003, 2004a, 2004b, 2005), seine hauls were more effective at collecting larval redhorse than light traps or push-nets (Table 2-3). In 1999, catch of robust redhorse by light traps and push-net was low (2%); however, in 2000 and 2001, catch of larval robust redhorse by these gears increased: push-nets = 5 and 6% respectively; light traps = 15 and 20% respectively. Larval redhorses were not collected in benthic light traps during 2001. As in previous years, redhorses were collected throughout the entire season (Figure 2-4) and were collected in every station sampled (Table 2-4). Sampling at Avant Mine was discontinued because of the poor condition of the primitive boat ramp (i.e., unable to launch boat).

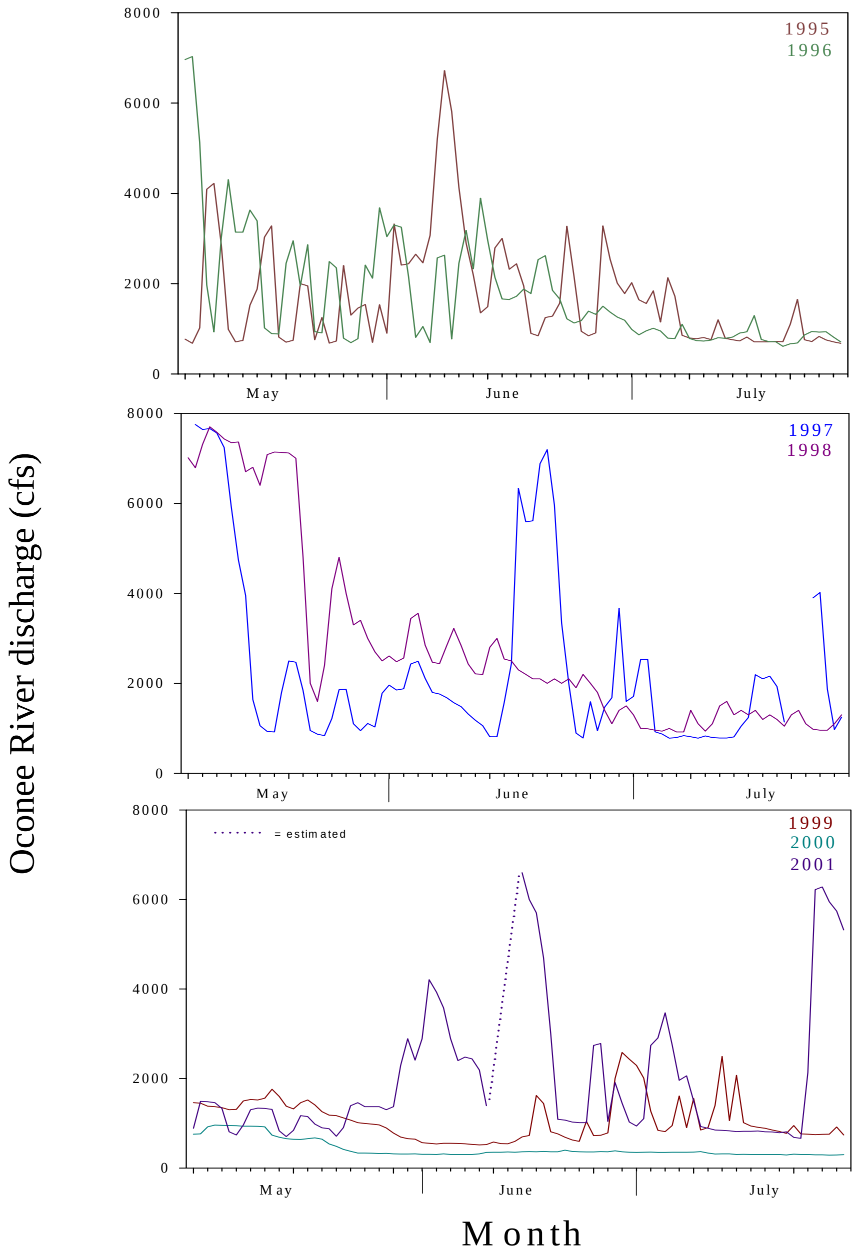


Figure 2-3. Mean daily river discharge (cfs) from Avant Mine (USGS gauge No. 02223056) in the Oconee River, Georgia from May through July 1995 - 2001.

Table 2-3. Number of larval and post-larval Catostomidae collected from the Oconee River, GA during spring and summer 1995 - 2001.

		Species						
Year	Gear	robust[4] redhorse	notch-lip[5] redhorse	spotted sucker	carpsucker[6]	creek chubsucker	northern hogsucker	unknown
2001	benthic light trap	0		0	0	0	0	0
	light trap	24		0	1	0	2	0
	push - net	8		0	1	0	0	0
	seine	89		0	54	0	0	0
2000	benthic light trap	0		0	0	0	1	0
	light trap	125		3	3	0	0	0
	push - net	41		0	2	0	0	0
	seine	684		9	987	0	0	39
1999[7]	benthic light trap	2		0	0	0	0	0
	light trap	4		8	0	0	0	2
	push - net	17		94	1	0	1	5
	seine	1,159		15	2,357	1	0	13
1998	light trap	0	0	0	0	0	0	0
	push - net	6	0	8	3	0	1	0
	seine	0	2	38	941	0	0	0
1997	light trap	1	0	29	1	0	0	1
	push - net	19	5	13	32	1	0	0
	seine	5	5	3	146	0	0	0
1996	light trap	0	0	0	9	0	0	2
	push - net	3	0	0	103	0	0	1
	seine	0	36	0	546	1	0	0
	benthic pump	4	0	0	0	0	0	0
1995	light trap	0	0	1	90	0	0	2
	push - net	5	0	2	243	0	0	26
	seine	0	5	0	3,019	0	0	6

[4] Robust redhorse and notch-lip redhorse were combined since we were unable to distinguish between the two species.

[5] Notch-lip redhorse has previously been referred to as "silver redhorse".

[6] Two undescribed species of carpsucker *Carpoides* occur in the Oconee River. One is related to the quillback carpsucker *C. cyprinus* and the other is related to the highfin carpsucker *C. velifer*.

[7] Six carpsuckers were not included because gear was unknown.

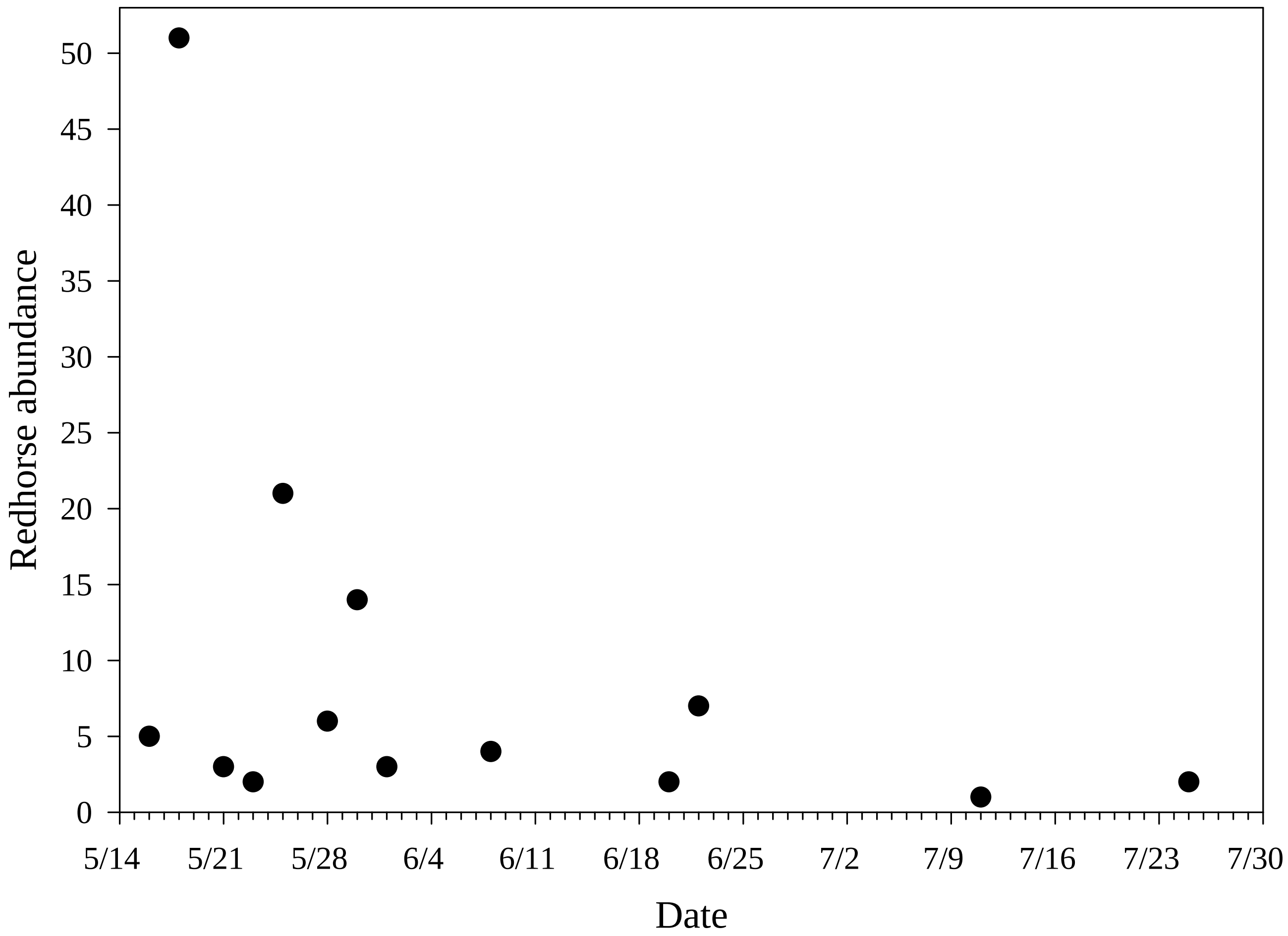


Figure 2-4. Redhorse (notch-lip and robust) abundance by capture date. Collected from the Oconee River, near Toomsboro, Georgia May through July 2001.

Table 2-4. Stations where redhorse were collected. Samples were collected from May through July 2001 from the Oconee River, near Toomsboro, Georgia.

Location	Station	Numbers of redhorse	Number of samples
Ball's Ferry	1	26	8
Ball's Ferry	2	5	3
Ball's Ferry	3	5	5
Ball's Ferry	4	50	6
Ball's Ferry	5	22	6
Aligator Alley	A2-C2[8]	7	3
Unknown station[9]		7	1

[8] A2-C2 is located at Ball's Ferry between boat ramp and station 3

[9] Unknown station is most likely station 1 or 2

The switch to ethanol preservative during 2001 was to allow definitive identification of some of the larval redhorses. Previously, size-at-collection-date was used to discriminate between the two species of redhorse because notch-lip redhorse were thought to spawn at least 4 (and up to 6) weeks before robust redhorse spawned. This spawning pattern resulted in a length-frequency histogram without overlapping tails (Figures 2-5 and 2-6). This spawning pattern was disrupted during the 1999 and 2000 spawning seasons when the spawning of the two species appeared to overlap (Jennings et al. 2005; Figure 2-7). This pattern appears to have occurred again in 2001 and resulted in a length-frequency histogram that was unimodal or a bimodal with overlapping tails (Figure 2-8), which prohibited the morphometric-based identification of the two redhorse species. Consequently, 101 specimens were sent to Dr. Wirgin for genetic identification. Thirty nine of the 101 specimens sent were successfully identified, and all were confirmed to be larval redhorses. The low genetic identification rate was attributed to one of two causes: 1) the specimens were preserved in formalin at the beginning of the sampling season (genetic essays only work for specimens preserved in ethanol) and did not yield usable DNA or 2) the specimen was not a redhorse.

When taxonomic keys were used to identify larval suckers sampled from the Oconee River, there was one couplet of alternative characteristics that identified the specimens as a redhorse or a spotted sucker; another couplet identified the specimen as a redhorse or a northern hogsucker. Whenever such a specimen was encountered during the key-based identification, that specimen was sent to Dr. Wirgin for genetic identification. The non-redhorse specimens may have contributed to the low success rate for all DNA identifications. Of the 39 redhorses identified genetically by Dr. Wirgin: 35 were robust redhorse and 4 were notch-lip redhorse.

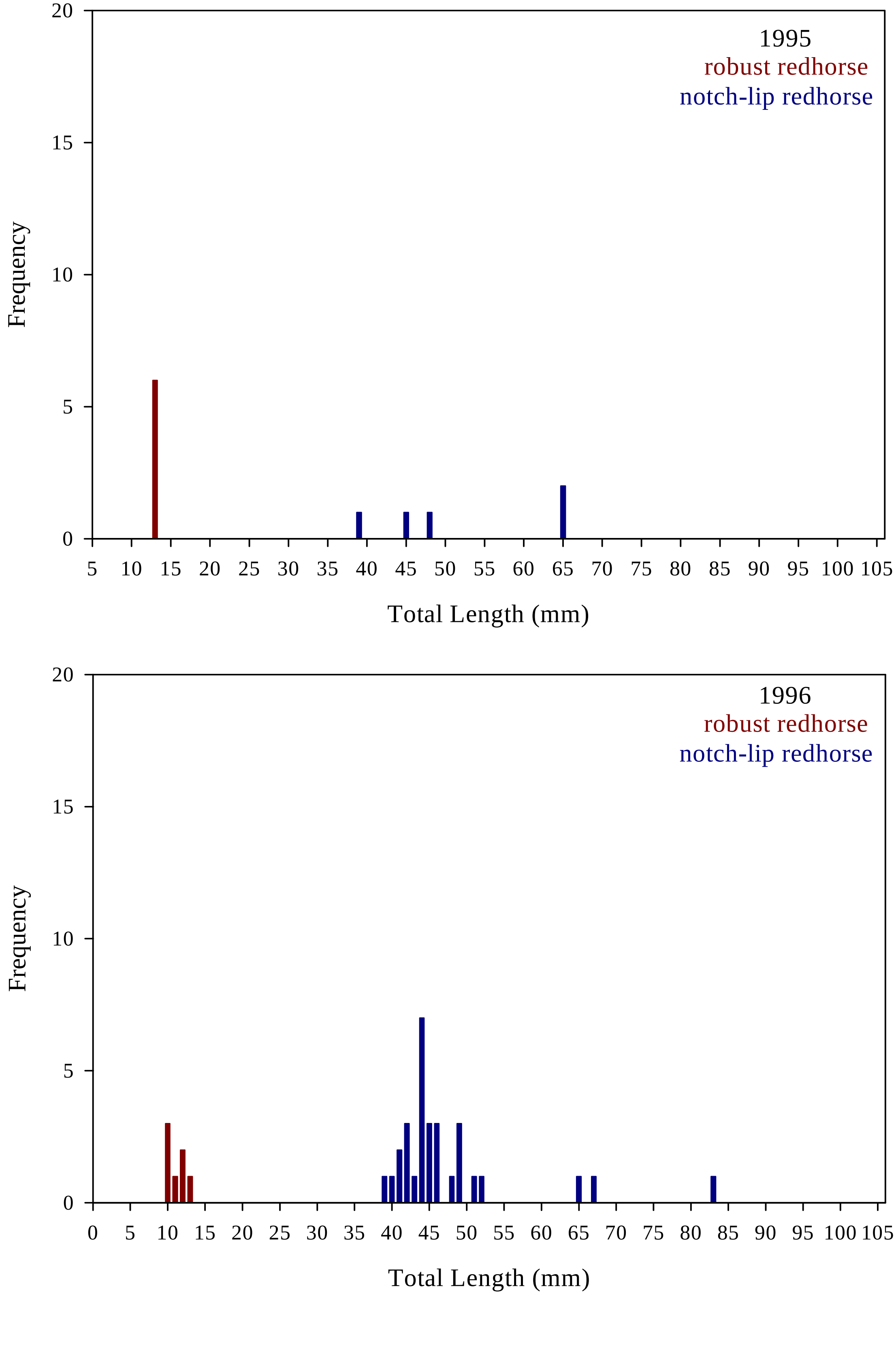


Figure 2-5. Length-frequency histogram of robust and notch-lip redhorses collected from the study area on the Oconee River, Georgia 1995 and 1996.

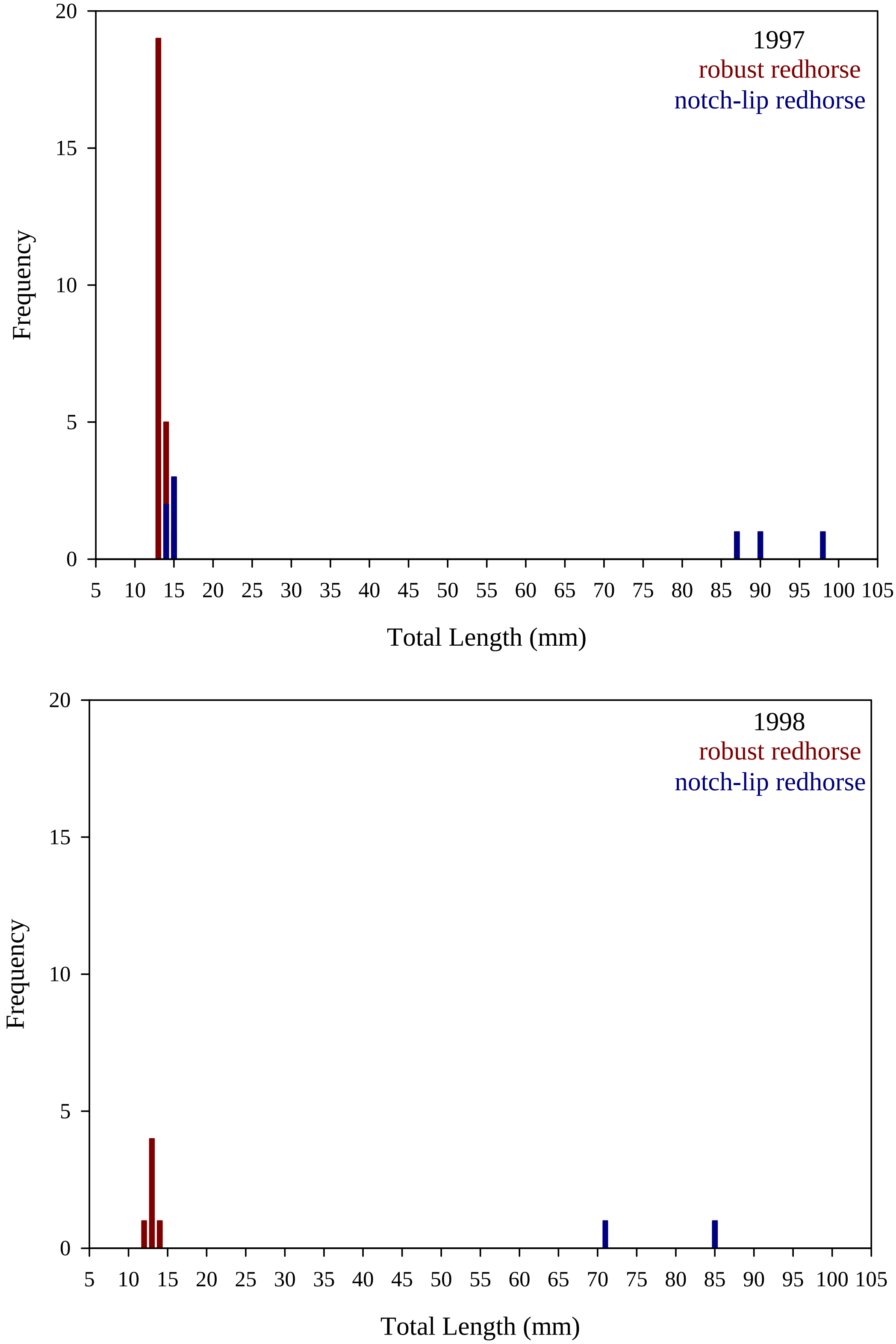
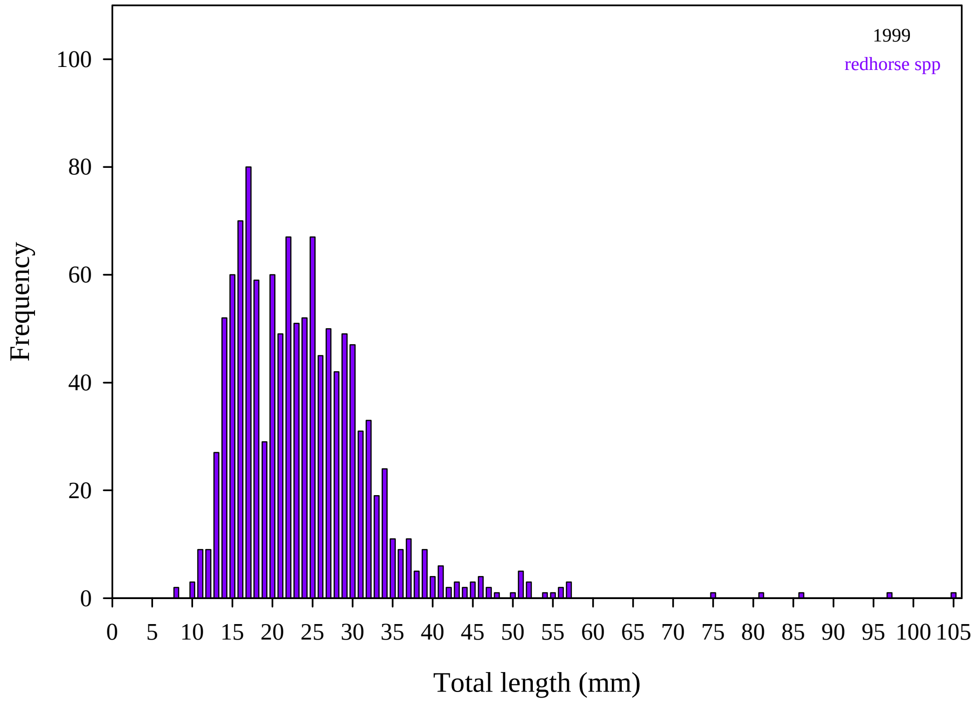


Figure 2-6. Length-frequency histogram of robust and notch-lip redhorses collected from the study area on the Oconee River, Georgia 1997 and 1998.



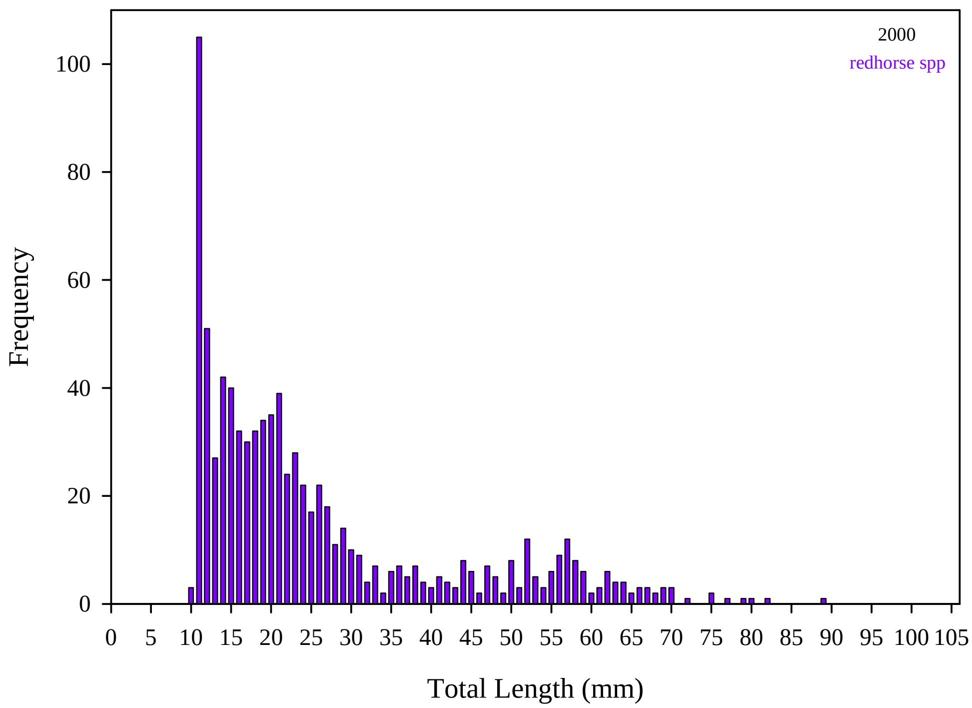


Figure 2-7. Length-frequency histogram of robust and notch-lip redhorses collected from the study reach on the Oconee River, Georgia 1999 and 2000.

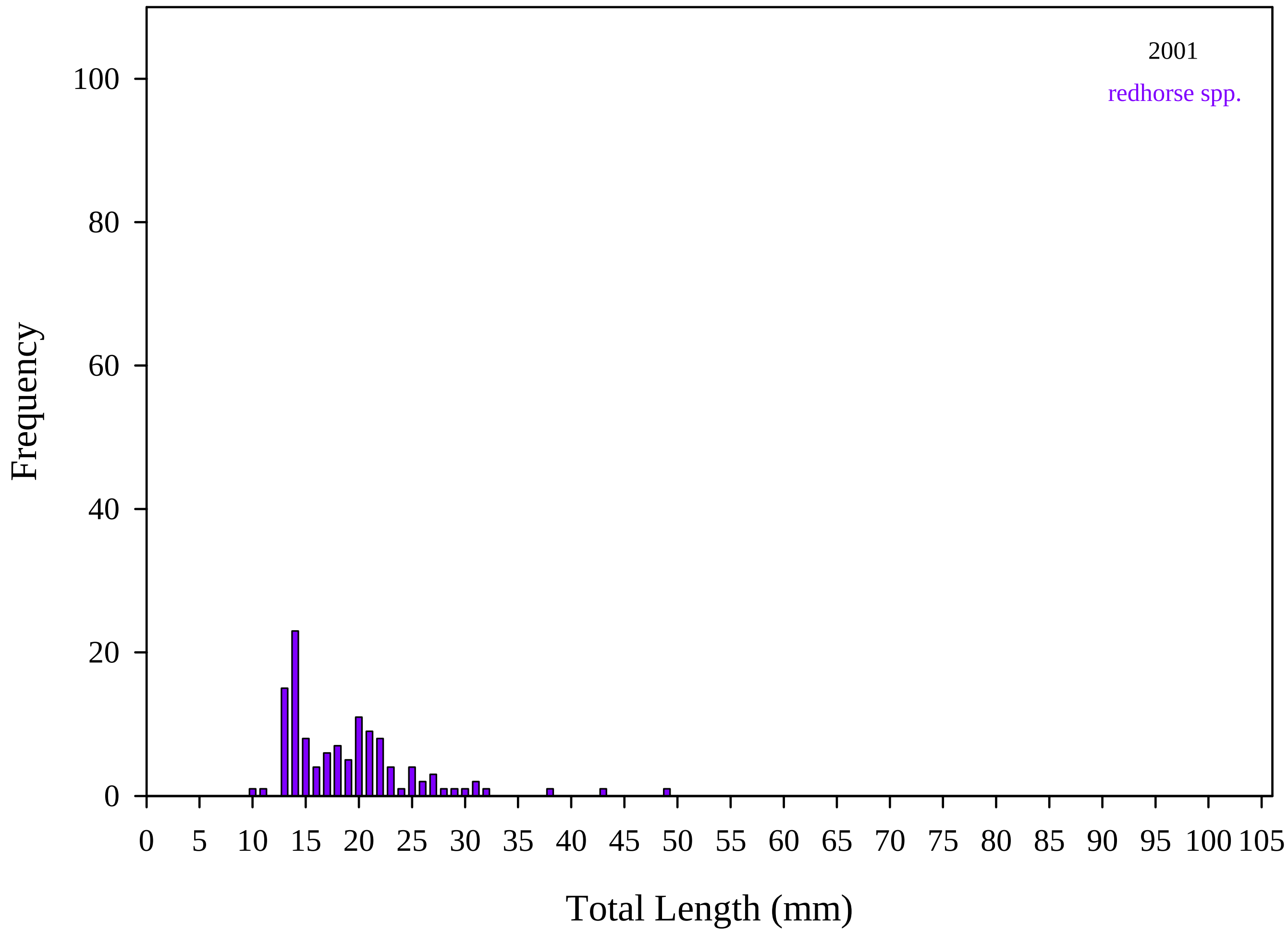


Figure 2-8. Length-frequency histogram of robust and notch-lip redhorses collected from the study reach on the Oconee River, Georgia 2001.

Twenty-three of 39 (59%) genetically identified redhorse were correctly identified by the morphometric- based method (size-at-date-method; Table 2-5). Of the misidentified redhorse, 13 of 16 were identified as notch-lips (size range from 15.7 to 21.6); conversely, 3 of 16 of redhorse were misidentified as robust (size range from 13.9 to 14.3). All the notch-lip redhorse misidentified as robust redhorse were smaller than was expected for notch-lips at that time of the year, and the converse was true for the misidentified robust. Therefore, previous estimates of the numbers of robust redhorse sampled from the study reach may have been lower than the actual abundance.

Water quality measurements

Monthly mean water temperature for May – July 2001 ranged from 24.3 to 27.9 °C, and increased as the season progressed. During study years (1995 - 2001), May mean water temperatures ranged from 21.5 to 25.2 °C, June ranged from 23.9 to 28.2 °C, and July ranged from 27.9 to 31.5 °C (Table 2-6). Monthly mean dissolved oxygen for 2001 varied among sites and days throughout the sample season and ranged from 6.5 to 7.7 mg/l , which is similar to previous study years (Table 2-6). In 2001, mean turbidity ranged from 22.7 to 48.3 ntu's (Table 2-7). 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 (i.e., from rainfall). Monthly mean flow for 2001 ranged from 0.30 to 0.56 m/s (Table 2-7). Although river discharge fluctuated among years (Figure 2-3), low flow areas that provide nursery habitat (Ruetz and Jennings 2000) were generally available each year (Table 2-7).

Table 2-5. Predicted identification (P-ID) and genetic identification (G-ID) for robust and notch-lip (n-lip) redhorse collected in the Oconee River, Ga from May 16th - May 30th 2001.

Sample	P-ID	G-ID	Y/N	length[10]	Sample	P-ID	G-ID	Y/N	length
04A	n-lip	robust	no	18.8	24S	robust	robust	yes	14.5
12	robust	robust	yes	14.1	24T	robust	robust	yes	14.7
24A	robust	robust	yes	13.6	24U	robust	n-lip	no	14.1
24B	robust	n-lip	no	14.3	24V	robust	robust	yes	13.1
24C	robust	robust	yes	14.0	24W	n-lip	robust	no	15.7
24D	robust	robust	yes	15.5	34	n-lip	robust	no	17.8
24E	robust	robust	yes	14.2	56B	robust	robust	yes	14.8
24F	robust	robust	yes	14.2	69B	n-lip	robust	no	20.0
24G	robust	robust	yes	13.8	69C	n-lip	robust	no	18.1
24H	robust	robust	yes	13.9	69E	n-lip	n-lip	yes	20.1
24I	robust	robust	yes	13.7	69F	n-lip	robust	no	21.6
24J	robust	robust	yes	14.7	79A	n-lip	robust	no	20.8
24K	robust	robust	yes	14.0	79B	n-lip	robust	no	19.7
24L	robust	robust	yes	14.0	79E	n-lip	robust	no	16.8
24M	robust	robust	yes	13.5	79F	n-lip	robust	no	18.7
24N	robust	robust	yes	13.5	79G	n-lip	robust	no	20.0
24O	robust	robust	yes	14.1	79I	n-lip	robust	no	19.2
24P	robust	robust	yes	14.4	81D	n-lip	robust	no	21.0
24Q	robust	n-lip	no	13.9	87	robust	robust	yes	15.7
24R	robust	robust	yes	13.7					

[10]Total length (mm)

Table 2-6. Monthly mean (SD) water temperature, and dissolved oxygen for May through July of 1995 - 2001. Measurements were taken during sampling (generally, 3x's/week) in the Oconee River between Milledgeville and Dublin, GA.

	Month					
Year	May		June		July	
	Water Temperature (°C)	Dissolved Oxygen (mg/l)	Water Temperature (°C)	Dissolved Oxygen (mg/l)	Water Temperature (°C)	Dissolved Oxygen (mg/l)
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)
1996	22.2 (1.6)	NM	26.6 (1.2)	7.0 (0.3)	29.2 (0.8)	7.2 (0.6)
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)
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)
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)
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)
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)

NM= No measurement

Table 2-7. Monthly mean (SD) turbidity and flow (current) for May through July of 1995 - 2001. Measurements were taken during sampling (generally, 3x's/week) in the Oconee River between Milledgeville and Dublin, GA.

Year	May		June		July	
	Turbidity (ntu)	Flow (m/s)	Turbidity (ntu)	Flow (m/s)	Turbidity (ntu)	Flow (m/s)
1995	NM	0.24 (0.15)	NM	0.19 (0.18)	NM	0.15 (0.15)
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)
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)
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)
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)
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)
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)

NM= No measurement

Juvenile sampling

Locating sampling areas that fulfilled all requirements for sampling juveniles (i.e., tributaries of the Oconee River, accessible to sampling crew, and appropriate depths for backpack electrofishing) was difficult; therefore, only sections of four creeks were sampled. Sampling was conducted September 8th - 9th and September 13th - 14th, 2001. Sampling locations were located at sections of Turkey, Reedy, Rocky and Cedar creeks (Figure 2-9). Area sampled ranged from 1,200 to 5,000 ft^2, with electrofishing pedal times ranging from 1,926 to 5,938 seconds (Table 2-8). A total of 1,592 fishes from 10 families were collected in these off-channel habitats. Only 10 suckers were collected in these areas, and none were robust redhorse (Table 2-9). Reedy creek had the smallest area sampled and the least amount of electrofishing sampling time, but the most fishes were collected there. Rocky Creek was the largest area sampled with the most shocking time and had the second highest number of fishes collected. Cedar Creek had the fewest fishes collected but had the highest diversity. Both Cedar and Reedy creeks fish assemblages were dominated by sunfish, and Turkey and Rocky creeks fish assemblages were dominated by minnows (Table 2-9). Water temperature ranged from 21.6 to 29.1 °C, dissolved oxygen ranged from 5.4 to 6.9 mg/l, turbidity ranged from 4.0 to 29.2 ntu and flow ranged from 0.01 to 0.51 m/s (Table 2-10).

Juvenile robust redhorse were not collected during fall sampling of tributary creeks. There are several possible reasons why juvenile robust redhorse were not collected during this period. The most obvious reasons are: juveniles are non-existent in the system or if they are, they don’t use tributaries as rearing areas. Additional explanations include the inability of juveniles to access tributaries because the drought created a land barrier between the

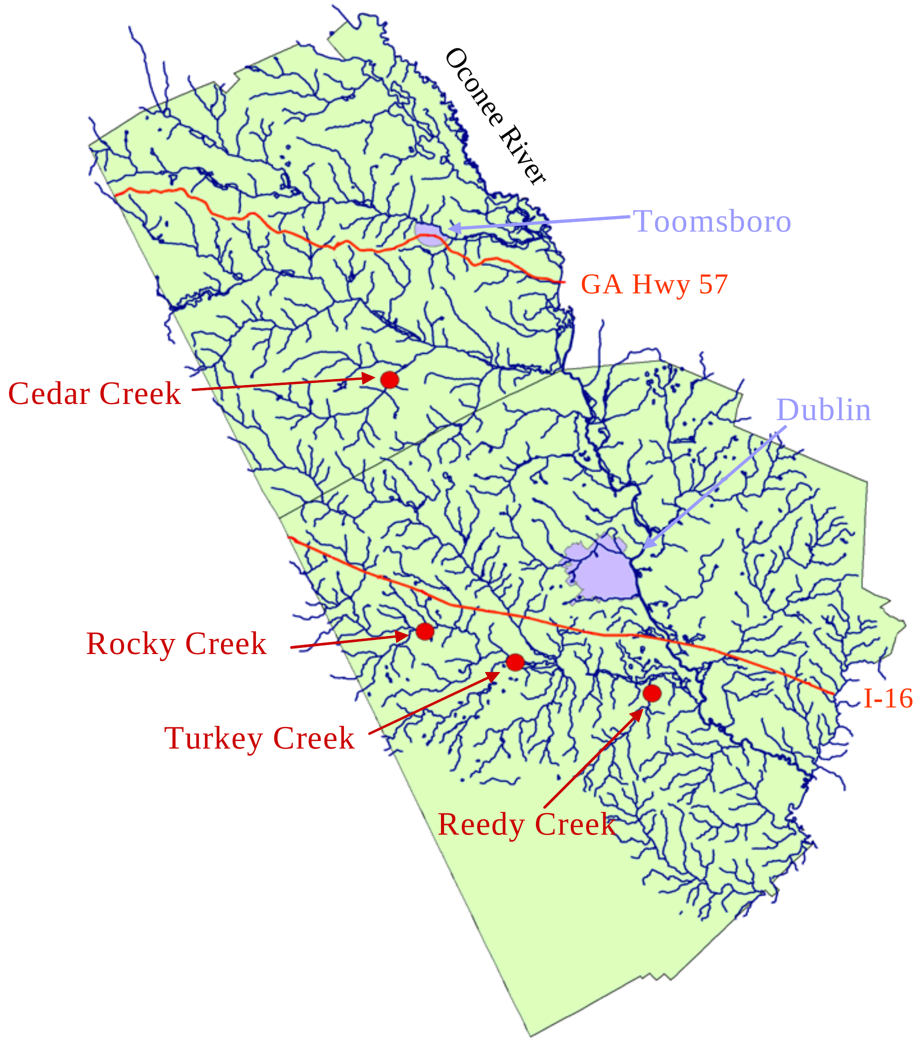


Figure 2-9. Sample locations for backpack electrofishing located in Laurens and Wilkinson counties near Toomsboro and Dublin, Georgia. Creeks were sampled in September 2001 and were tributaries of the Oconee River.

tributary and the river, or the number of tributaries sampled were insufficient to encounter juveniles. Although juveniles were not collected during this study, a few larger (i.e., ~360-400 mm total length) juveniles were collected during broodfish collections conducted by Georgia's Department of Natural Resources (GA DNR) in 2000 and 2001 (DeMeo 2001). These juveniles were both wild and stocked fish that had not been previously collected, and their capture documents that some of the larval robust redhorse produced in the system are recruiting to juvenile stages. Jennings et al. (2004b) references the ongoing debate about whether the lack of juvenile robust redhorse is because of actual abundance or issues with sampling (i.e., gear and habitat sampled) and suggest that sampling inefficiency may contribute to the apparent absences of juvenile robust redhorse in the Oconee River. Information about the habitats used by other juveniles *Moxostoma* is limited, as is our ability to fully explain the scarcity of juveniles in the Oconee River. However, Jennings et al. (2004b) and Mosley (2006) provide examples of catostomids whose adult populations are self-sustaining, but whose juveniles are difficult to sample.

Table 2-8. Summary of backpack electrofishing sampling at sections of four of tributaries of the Oconee River, Georgia during September 2001.

Date	Creek Name	Lat/ Long	Length (ft)	Average width (ft)	Area sampled (ft)	Total shock time (secs)	No. of fishes collected
Sept. 7th	Reedy	32° 26.15 / 82° 52.42	110.8	11.3	1,252	1,926	697
Sept. 8th	Turkey	32° 27.75 / 83° 00.18	124.0	26.4	3,274	5,248	235
Sept. 13th	Rocky	32° 29.34 / 83° 05.31	239.5	20.2	4,838	5,938	512
Sept. 14th	Cedar	32° 42.01 / 83° 07.27	213.2	11.9	2,537	4,654	148

Table 2-9. Family abundance of fishes sampled in sections of four creeks (tributaries of the Oconee River) in middle Georgia during September 2001.

	Creek			
Family	Reedy	Turkey	Rocky	Cedar
Eels (Angullidae)	0	1	2	11
Pikes (Esocidae)	4	0	1	3
Minnows (Cyprinidae)	74	132	179	14
Suckers (Catostomidae)	7[11]	1[12]	0	2[2]
Catfishes (Ictaluridae)	2	13	134	4
Pirate perches (Aphredoderidae)	31	19	4	34
Silversides (Antherididae)	127	0	0	1
Livebearers (Poecillidae)	189	1	0	3
Sunfishes (Centrarchidae)	230	21	96	64
Perches (Percidae)	25	47	96	12
Unknown [13]	8	0	0	0

[11] creek chubsuckers (47 - 59 mm)

[12] spotted suckers (152, 183, 205 mm)

[13] possibly small pirate perch

Table 2-10. Sampling date and creek with water temperature (water temp.), dissolved oxygen (D.O.), turbidity and flow measurements for backpack shocking.

Date	Location	Water temp. (°C)	D.O. (mg/l)	Turbidity (ntu)	Flow (m/s)
09/07/01	Reedy Creek	29.1	5.4	29.2	0.01
09/08/01	Turkey Creek	23.8	6.8	12.1	0.22
09/13/01	Rocky Creek	23.3	6.9	4.0	0.51
09/14/01	Cedar Creek	21.6	6.2	14.5	0.05

Conclusion

Redhorse successfully reproduced during 2001, but their numbers were orders of magnitude below the high abundances documented during 1999 and 2000. Conversely, larval redhorse abundance during 2001 was orders of magnitude above that seen during 1995-1998. Larval redhorse abundance during 2001 was consistent with what would be expected given flows during May and support the "low stable flow" hypothesis advanced by Jennings et al. 2004b. Although the proportion of robust to notchlip is unknown, robust and notchlip redhorse assumed to benefit from similar rearing habitats and conditions since they are congeners.

For the seventh year in a row, juvenile robust redhorse were not collected during summer and fall sampling; however, a the first-ever wild and hatchery-produced juveniles were collected by GA DNR during spring brood stock sampling. Their capture documented that some of the wild-produced larvae as well as stocked, hatchery-reared fingerlings have been recruiting successfully to the juvenile population and suggest eventual recruitment to the adult population. These findings are encouraging and lend support to the continued conservation efforts to maintain and enhance populations of this rare species.

Task 3. Effects of two transmitter attachment methods on the short-term survival of notch-lip redhorse *Moxostoma collapsum*.

Introduction

The utility of radio-telemetry for evaluating the dispersal patterns of stocked, hatchery-reared robust redhorse was evaluated in a pilot project conducted during 1999 (Jennings, unpublished data). Results of this work led to the use of externally-fitted transmitters (hereafter call backpack attachment) during a robust redhorse telemetry project conducted during summer 2000 (Hess et al. 2001). This method of transmitter attachment also was used successfully to attach radio transmitters to striped bass *Morone saxatilis* (Baker 2000). Although some useful movement and habitat use data were obtained from radio-tagged robust redhorse released into the Oconee River, most were dead[14] within two months of being released.

Many factors, including malfunctioning transmitters, handling stress, and environmental conditions may have contributed to the apparently high mortalities observed during the redhorse telemetry study. Suspicion that the backpack attachment may have contributed to the mortalities caused concerns among members of the Robust Redhorse Conservation (RRCC) about the utility of backpack attachment. Further discussion of this matter led the Technical Advisory Group of the RRCC to recommend a thorough evaluation of the methods used to radio-tag suckers. This evaluation was to included literature reviews, consultations with researchers in the western United States who have successfully radio-tagged razorback suckers in the Green and Colorado rivers, and laboratory-based evaluations of the utility (i.e., remaining attached to the fish and not

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[14]The transmitters were equipped with a mortality switch that caused the transmitter to beep at twice the normal rate if the tag was stationary for > 12 hours.

contributing to fish mortality) of various methods of transmitter attachment. The ultimate goal of this assessment was to determine if either of two methods (external attachment or internal placement) caused increased mortality of the tagged fish and assess which might best be used for other radio-tagging studies of juvenile robust redhorse.

Notchlip redhorse *Moxostoma collapsum* were used as surrogate species for robust redhorse because of the scarcity of juvenile robust redhorse and the perceived risk of mortality associated with the surgical procedures required to conduct the evaluation. Notchlip redhorse are congeners of and are closely related to robust redhorse. This species also occur in the Oconee River and were readily available in sufficient numbers to conduct the evaluation.

Materials and Methods

External consultation

Searches of scientific databases (e.g., Web of Science) for articles about radio telemetry of suckers in the western United states identified a few published articles on the subject. Two researchers, Timothy Modde of the U.S. Fish and Wildlife Service's Colorado River Fishery Project (located in Vernal, UT) and Gordon Mueller, of U.S. Geological Survey's Fort Collins Science Center (Fort Collins, CO) were among the more prolific authors identified. Initial contact with T. Modde indicated that he was: 1) enthusiastic and willingly to collaborate on the question of tag location and retention among suckers, and 2) very familiar with G. Mueller's work. An invitation by T. Modde led to a 1-week visit by C. Jennings to the Colorado River Fishery Project to compare telemetry-related methods for studying both species (e.g., robust redhorse and razorback suckers). This comparison included surgical methods and field tracking techniques as well as discussions of G. Mueller's radio telemetry techniques.

Holding pens

Nine holding pens were built to house the fish during the evaluation. Each pen was constructed with one (top) floating frame of 5.1 cm diameter PVC pipe filled with insulating foam, and one (bottom) sinking frame of 1.2 cm diameter PVC pipe left hollow and drilled with holes. For each pen, the top of a 1.2 m X 2.4 m X 1.8 m net pen was secured to a floating frame, and the bottom of each net was held open with an internally fitted sinking frame. Covers for the pens were constructed from 1.2 cm diameter PVC pipe, covered with fine mesh netting, and then secured to the floating frames by zip-ties. The zip-ties were sufficiently loose as to permit the gate to open and close.

Standard-size clay bricks were secured with nylon rope to each corner of the perimeter of each sinking frame and served as anchors for the pens. Each pen was positioned in the study pond at a minimum depth $ 0.9 m and progressed to a maximum depth #than 1.8 m. The net pens were set in the largest of the “Three-sisters” ponds at Whitehall Forest, University of Georgia, Athens.

Fish sampling and surgery

Electrofishing gear was used to collect 90 notchlip redhorse (average weight = 655.6 g; s.d. = 153.2 g) between 16 and 28 November 2001 from the Oconee River in the vicinity of GA Hwy 15 bridge in Oconee County, GA. After each collecting trip, fish were placed inside aerated hauling tanks containing river water, then transported to a research pond of the Whitehall Forest Research Facility at the University of Georgia. Fish were acclimated to the temperature of study pond water by slowly adding pond water to the hauling tank.

Once acclimated, fish were removed from the tanks, anesthetized with a solution of 140 mg tricaine methyl sulfonate (MS-222) per liter of pond water, and then weighed. After each fish was anaesthetized, it was transferred to a surgery cradle slightly inclined inside an ice-chest cooler (Figure 3-1). The cooler contained about 10 liters of pond water at a sedative dose of 70 mg MS-222 per liter and a water pump force the mixture to the fish's gills. After being placed in the cradle, a small tube was fitted into the fish's mouth. This tube led to the water pump, which delivered aerated water containing the sedative dose of MS-222 over the fish's gills throughout surgery (Figure 3-1).

There were three treatments: backpack attachment of an artificial transmitter, an internal artificial transmitter, or transmitter-free (control). Artificial transmitters (weight . 4 g in air) were constructed from Polyvinyl Chloride (PVC) and fitted with a coated wire whip antennas, were used in lieu of real transmitters as a cost-saving measure. The 4 g weight was intended to adhere to the "2% body weight rule" suggested by Winter 1996.

Backpack attachment

A backpack assembly was constructed by tightly fitting transmitter-length plastic tubing over the body of a artificial transmitter. A length of wire was fitted snugly between the transmitter and tubing so that an even length of attachment wire exited from each side the backpack assembly. Each fish receiving a backpack attachment was positioned dorsal-side up on the surgery cradle, and two large hypodermic needles were inserted through the dorsal

Figure 3.1. Image of surgery cradle positioned in a cooler containing a sedative dose of MS_222 (70 mg/l). The tubing for delivering oxygenated, sedative-laden water is evident at the top of the cradle.

musculature between the pterygiophore bones (Figure 3-2). This produced two channels through the fish, about 2.5 cm apart, located just anterior to and about 2.5 cm below the anterior terminus of the dorsal fin. After the needles were inserted, a thin wire was pushed through the interior of each needle to bore out tissue plugs. Next, attachment wires of a backpack assembly were threaded through the sharp ends of the needles and exiting on the other side of the fish. The needles were then drawn out, leaving the attachment wires trailing out the other side of the fish. A small plastic disk was then threaded onto each attachment wire and positioned against the fish. Next, a small plastic bead and a metal crimp were threaded onto the attachment wires. The metal crimp was fitted snugly against the plastic bead, then crimped into place to securely anchor the backpack assembly against the opposite side of the fish (Figure 3-3). Surgery duration was recorded for each fish.

Transmitter implantation method

Each fish receiving an internal transmitter was positioned ventral-side up on the surgery cradle. A Number 11 scalpel was used to make a 2.5 cm incision beginning posterior to the pectoral fins and ending just between them. The scalpel was held cutting side up to avoid cutting internal organs while making the incision.

After the incision was made, the shielded needle technique (Ross 1982) was used to thread a whip antennae through the incision to an exit about 3.5 cm away from the posterior terminus of the incision. The artificial transmitter was coated with a thin film of antibiotic ointment and then placed into the peritoneal cavity (Figure 3-4). The incision was closed with sutures with two interrupted sutures. The sutures were produced with Olsen-Hegar needle

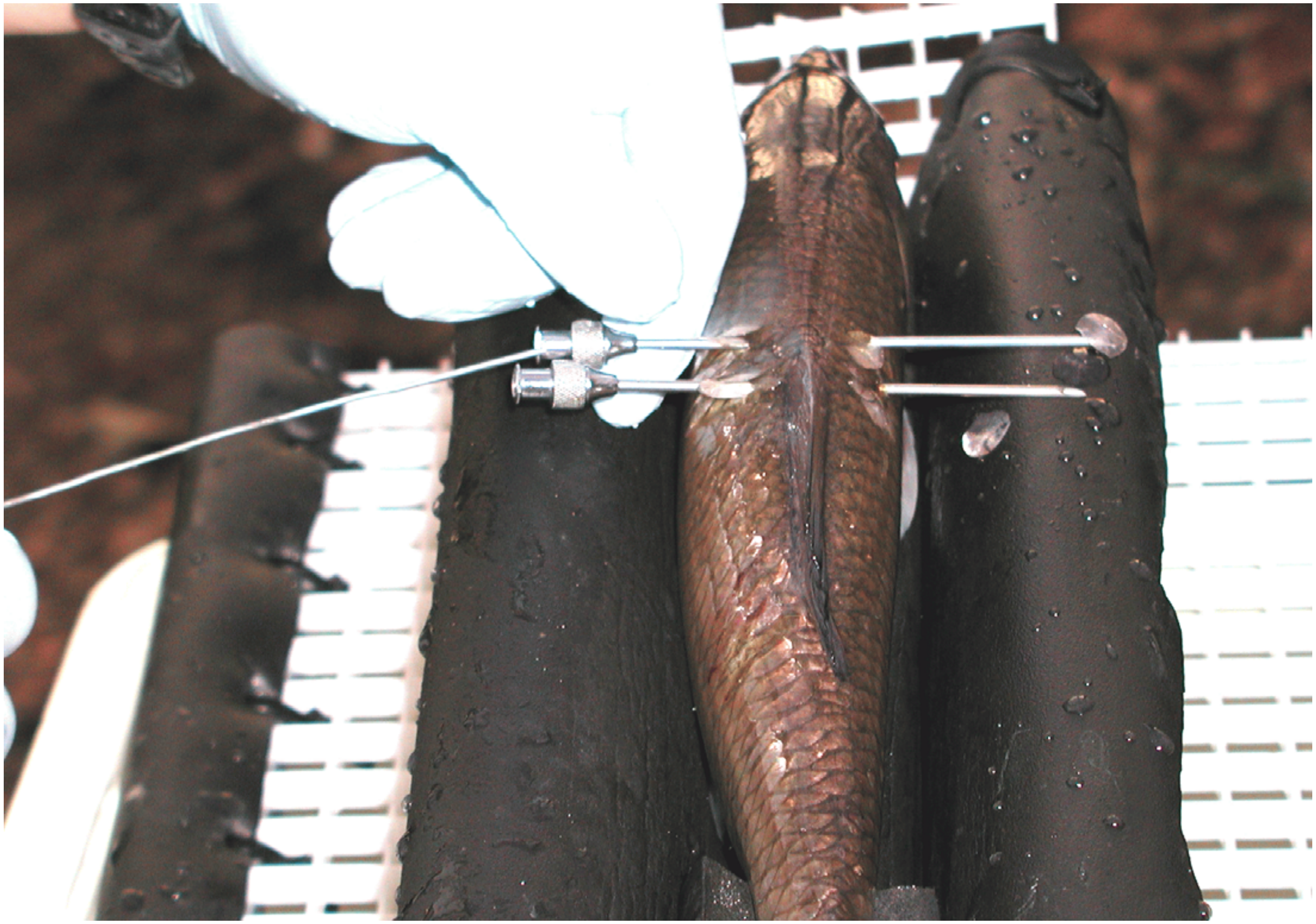

Figure 3.2. Image of large hypodermic needles inserted through the dorsal musculature between the pterygiophore bones of notch-lip redhorse. The needles were used as a conduit to pass transmitter harness through the fish's body.

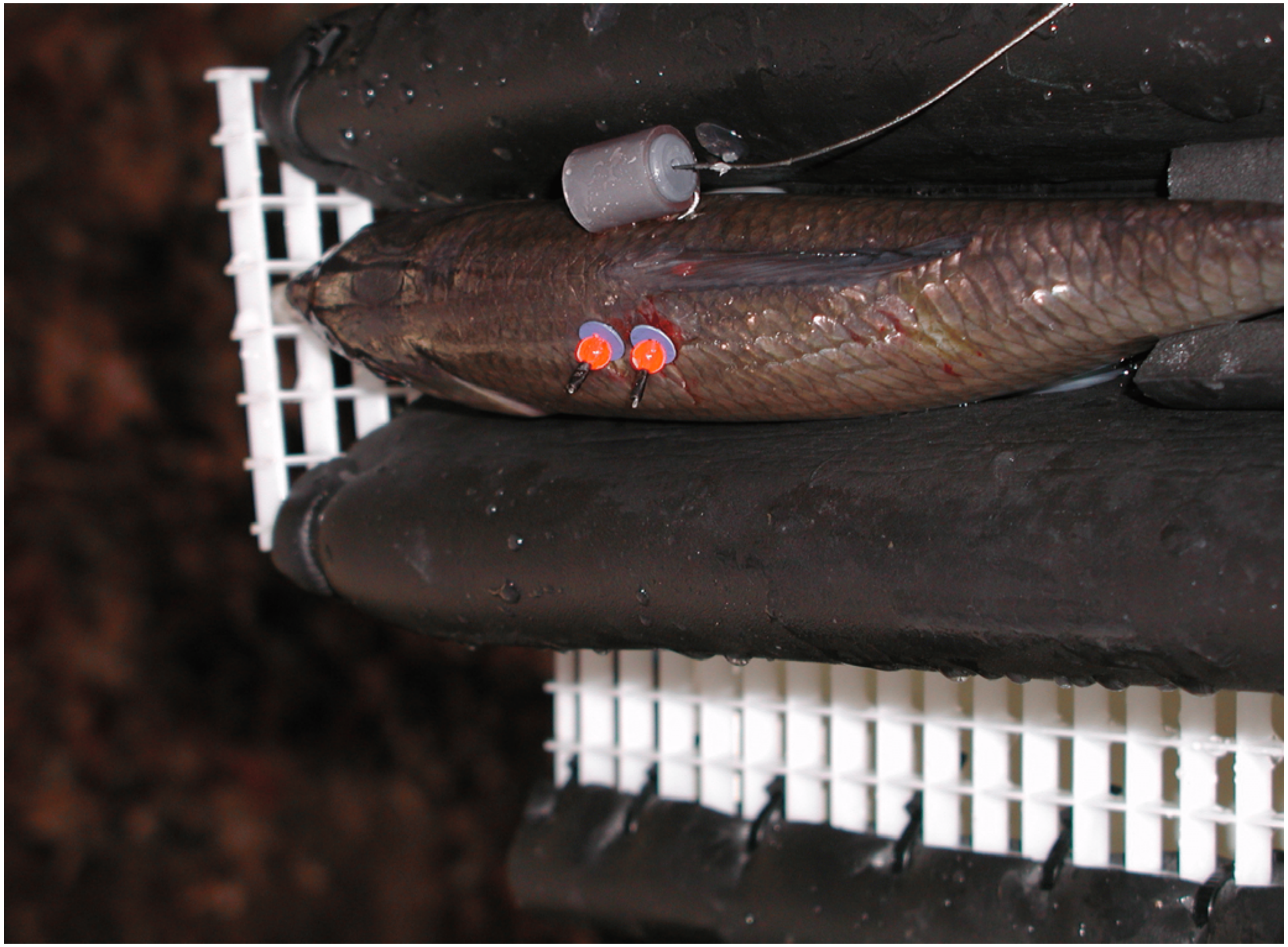

Figure 3.3. Image of artificial radio transmitter attached via the “back-pack” attachment method to the right dorsal side of a notch-lip redhorse.

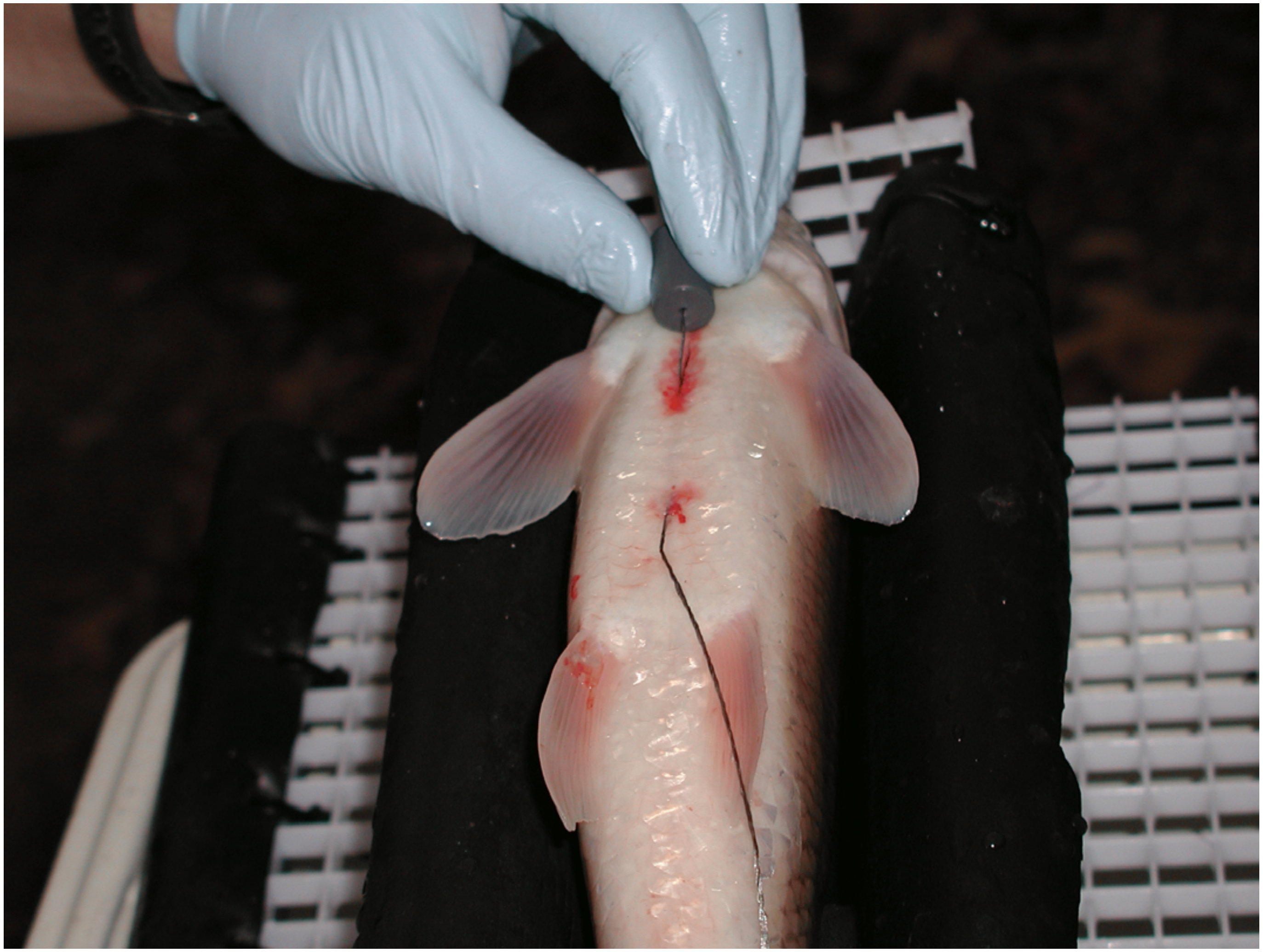

Figure 3.4. Image of artificial transmitter being implanted into the body cavity of notch-lip redhorse. Note that the antenna is exiting the fish through a second incision that is spatially disjoint from terminal point of the primary incision.

holders, a FS-1 cutting needle, and Ethicon 2-0 Polydioxanone II absorbable suture material. Blades and sutures were washed with ethanol after use, and conserved for use on multiple fish. Surgery duration was recorded for each fish.

Transmitter-free fish

Fish that served as controls, (i.e., those fish not receiving backpack attachments or internal transmitters) were subjected to the same stresses of collection, transport, initial MS-222 anesthesia, weighing, pen confinement, and diet as fish receiving transmitter implants or backpack attachments. They were not subjected to invasive (e.g., needle bores) or surgical procedures.

Post surgery distribution, feeding and monitoring of fish

There were three nets per treatment. After each fish was fitted with a transmitter, it was randomly assigned to a floating pen that held fish with similar transmitter attachment method. Eventually, each net contained 10 fish. The first day of the trial began when all 90 fish had been in the pens for a minimum of 24 hours. Fish in the pens received Purina Aquatic Gel Diet for Omnivores® at a rate of 3% of their body weight per day. During feeding, the water temperature in each pen was measured and recorded. The surface water of each pen was observed daily for floating or moribund fish. Occasionally, an Aqua-Vu® camera was used to check for mortalities at the bottom of each pen.

Results

External consultation

The trip to Colorado Fishery Project in Vernal, UT occurred during May 2001 and lasted 5 days. First, T. Modde confirmed that he and G. Mueller had collaborated on many projects and that both used similar approaches and methods for conducting telemetry studies of suckers. Secondly, T. Modde reported that both he and G. Mueller had used internal implantation and external attachment for telemetry projects on suckers, and their experiences suggested that fish survival and medical complications were similar between the tagging method. T. Modde further suggested that their anecdotal observations suggest fish with an internal transmitter retained transmitters longer than fish whose transmitter was attached with the methods.

Surgical duration

Time required for surgery was recorded for 29 of the 30 fish receiving backpack artificial transmitters and for 28 of the 30 fish receiving internal artificial transmitters. Times for transmitter attachment or implanting artificial transmitters were similar. Mean duration of backpack attachment was 5.3 minutes (s.d. = 0.7 minutes) compared to 6.2 minutes (s.d.= 0.9 minutes) required to surgically implant the transmitter. The lightest fish used in this experiment weighed 273g, which resulted in a maximum transmitter-to-body weight ratio of 1.5%. This ratio is below the 2% percent of body weight recommended by Winter (1996).

Artificial transmitter study

None of the fish in the control treatment (i.e., handled, but did not receive a transmitter) or in the back pack attachment treatment died during the abbreviated study (42 days instead of 90 days; explanation given below). Five fish that had internal artificial transmitters died by test day 42. The first two mortalities were observed floating in their respective pens on day 11 and 14 post-surgery, respectively. The final three of these five mortalities were found submerged during observations with an Aqua-vu ® camera; two of these mortalities were found 28 days post-surgery, and one was found 33 days-post surgery. However, because observations with the Aqua-Vu® camera were made infrequently, estimating when (i.e., days post-surgery) moralities 3-5 actually died was difficult. All remaining fish in all treatments were observed with the Aqua-Vu® camera on test day 42 and appeared to be healthy (i.e., without visible signs of disease outbreaks or parasites and in good condition (i.e., not skinny or moribund).

Otter predation and premature study termination

River otters *Lontra canadensis* apparently found the floating cages in the Three Sisters pond at Whitehall Forest, entered the cages, and consumed all the fish. The decimation of the test population, which was discovered on study day 49, resulted in the abrupt termination of the project. An “otter slide” into the lake, partially-eaten fish carcases, and otter scats containing fish scales all point to otters as the probably predator on the study fish.

Discussion

Collaboration with outside experts (i.e., non-RRCC member) conducting radio telemetry studies of suckers elsewhere was effective in resolving differences of opinion among RRCC members about how best conduct radio telemetry studies of robust redhorse in the Oconee River. Based on his experiences and those of G. Mueller, T. Modde suggested that study duration and not health concerns should determine whether to use internally or externally attached transmitters. Ideally, sucker telemetry studies lasting $1 year use internal implantation of transmitter because such transmitter are more difficult for the fish to dislodge; either tagging method may be used on studies # 1 year. Other issues such as fish size and its preferred habitat (e.g., slack vs fast water) may suggest one tagging type over the other (T. Modde, US Fish and Wildlife Service - personal communication). The results of the present study generally support the opinions of T. Modde and G. Mueller. For example, time required to either tagging method was similar and survival among all treatments was very high (83-100%); further, none were close to the 100% observed during the Hess et al. 2001 study.

There were some differences in the backpack attachment method used in the present study compared those used by Hess et al. (2001). The maximum transmitter to body weight ratio in the Hess et al. (2001) study was 2.5%, whereas the maximum transmitter to body weight ratio used in our study was less than 1.5%. The transmitters used by Hess et al. (2001) were purchased to adhere to the “2.0% body weight” advocated by Winter 1996, and the size of the transmitters was determined by RRCC estimates of the size of the robust redhorse available for the implantation. Apparently, the mean weight of the test fish used by Hess et al. (2001) represented the weights of the largest individuals in the pond instead of the mean weight. Also, the method of anesthesia used in this study (MS-222 absorption) differed from the electro-anesthesia method (Orsi and Short 1987; Jennings and Looney 1998) used by Hess et al. (2001).

However, these differences do not explain the difference between the near 100% mortality seen in the Hess et al. (2001) study compared to the 100% survival for fish receiving backpack attachments in our study. One obvious conclusion from these results is that backpack attachment method probably was not a contributing factor to the near 100% mortality observed by Hess et al. (2001).

Hess et al.(2001) reported river temperatures that ranged from 23.9 to 31.4 °C and suggest that the "extreme environmental conditions" may have contributed to the high mortality they observed. High temperature has been identified as a contributing factor in other species receiving radio transmitters. For example, hybrid striped bass (*Morone saxitalis* x *Morone chrysops*) receiving internal transmitters and held at 22-28 °C experienced post-implantation mortality, whereas those internal with the same type of transmitters and held at 12-16 °C did not experience any mortality (Walsh et al. 2000). Water temperature during the current study did not exceed 18 °C and only a few (5 of 30 internally tagged and 0 of 30 externally tagged fish) died. These results support Hess et al. (2001) hypothesis that the high water temperature may have contributed to the high mortality among their test fish.

Bacterial infection

Infections (probably bacterial in original) in and around the wound were evident among all the fish that died during the present study. Internal infection could have subjected these fish to a significant health risk, which may have contributed to the observed mortality. This observation suggest that of the two methods, transmitter implantation may pose significant risk of infection and potential death among test fish. Further, use of this method in the future should implement aseptic protocols aimed at minimizing infection. Examples of eliminating possible sources of infection include the use of broad-spectrum powered or liquid antibiotic instead of the petroleum-based antibiotic. The use of single-use scalpels and sutures instead of reusing scalpel blades and suture materials for multiple surgeries used during the present study should help reduce infection. Also, adding quick-hardening surgical glues (e.g., derma-bond) for ensuring that incisions are water-tight should help reduce the risk of infection among fish receiving surgically internal transmitters.

Otter predation

Whitehall forest is located on peninsula formed by the confluence of the North and Middle Oconee rivers. The Three Sisters pond is located on a small stream that empties into the Middle Oconee River. However, these ponds are farther from the either branch of the Oconee River than most of the ponds and at a much steeper gradient than the other ponds. Otter activity has been reported on other ponds on the Whitehall property, but never on the Three Sisters pond. Accordingly, anti-otter measures such as electrical fences were deemed unnecessary for these ponds, including the one housing the present study. The sudden and unfortunate end to this study by study day 49 suggest that otters posed a bigger threat than was realized at the time and not including anti-predator measure was an serious error.

Conclusions

Backpack attachment and internal artificial transmitters seem adequate for securing transmitters to juvenile robust redhorse. Though some (17%) mortality was observed with the implant method, the rate was relatively low. Further, this risk may be improved by adopting measures such as the use a liquid or powdered antibiotic, cyanoacryllate (i.e., quick bonding) glue in conjunction with sutures to act as a short term-water seal, and the single use of dedicated scalpels and sutures should minimize risk of infection associated with internal implantation of radio transmitters.

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