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Growth and Survival of Juvenile Robust Redhorse *Moxostoma robustum* Fed Three Different Commercial Feeds

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Abstract.—The name *Moxostoma robustum* has been transferred to a recently rediscovered large catostomid, the robust redhorse. The only known population of this species currently exists in the Oconee River in east central Georgia, and efforts are underway to restore it to its historic range. Our study objective was to identify which of three commercial diets, Fry Feed Kyowa C-700 (diet B), Shrimp Production 45/10 (diet SP), or Salmon Starter (diet SS), would provide the best survival and growth of juvenile robust redhorse. Two experiments were conducted, and a completely randomized design was used within each experiment. The two experiments differed in tank color (green; black), length of study (60 d; 30 d), and initial size of fish (27.1 and 44.8 mm total length). Growth was best with diet B; diets B and SP produced the highest survival; and diet SP cost less than the others. We were unable to determine whether the significant differences in growth and survival among fish fed the three diets was a result of differences in particle size, nutrient composition, or palatability. We recommend that consideration be given to the relative benefits of diets B and SP, such as cost versus growth differences, before selecting the diet for an intensive culture program.

The robust redhorse *Moxostoma robustum*[2] is a large catostomid, the only known population of which currently exists in an 85-km stretch of the Oconee River in east central Georgia. The historic range of the fish is believed to include both Piedmont and upper Coastal Plain streams along the Atlantic slope from the Altamaha River drainage in Georgia to the Pee Dee River in North and South Carolina (Evans 1994). For several years, the fish was thought to be an undescribed species represented by only a few specimens. However, recent investigations indicate that the naturalist E. D. Cope described the species in 1870 from a specimen collected in the Yadkin River, North Carolina (Evans 1994). Cope's original specimen was lost, and the name *M. robustum* was applied erroneously to another species (the smallfin redhorse); an attempt to correct this mistake and formalize the nomenclature for robust redhorse is currently underway (Jenkins and Burkhead 1994). Efforts to locate other populations within the historic range have been unsuccessful, although five adults were captured recently in the Savannah River near Aiken, South Carolina. Consequently, most experts have predicted the fish could become extinct unless recovery efforts are initiated immediately.

The recovery effort, initiated in the spring of 1992, is a cooperative endeavor between the Georgia Wildlife Resources Division, U. S. Fish and Wildlife Service, the U. S. Geological Survey, the University of Georgia, and the Georgia Power Company. The goals of the recovery effort are to first establish refugial populations to serve as future broodstock and eventually to develop reproducing populations within the species' known historic range. One requirement for achieving these goals included the development of techniques to propagate (Barrett 1997) and subsequently culture the offspring to stockable sizes. This paper focuses

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[2] Once thought to be a rare Atlantic slope population of the river redhorse *Moxostoma carinatum,* this species has been rediscovered and renamed the robust redhorse; its scientific name, *M. robustum*, was transferred by Jenkins and Burkhead (1994). The species previously recognized as *M. robustum*, the smallfin redhorse, represents an undescribed species of jumprock sucker (R. E. Jenkins, Roanoke College, personal communication).

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on the culture aspects. The specific objective of our study was to identify which of three commercial fish feeds might provide the best growth and survival of juvenile robust redhorse.

Because this fish was thought to have been extinct for many years, only recently has it been the subject of relevant research. We know of no published studies identifying the effects of feeds on the growth and survival of the species. Studies involving the culture of other catostomids have included an evaluation of the effects of five formulated diets on the growth and survival of larval razorback suckers *Xyrauchen texanus* (Tyus and Severson 1990) and a description of the methodology used for rearing copper redhorse *Moxostoma hubbsi* (Branchaud and Gendron 1993).

This study consisted of two feeding study experiments conducted in nine 38.0-L (internal wetted-surface area) circular tanks arranged in a completely randomized design. The nine tanks were part of a single recirculating-water culture system. Water from each tank drained by gravity into a common sediment–biological filter, where particulate matter and dissolved gases were removed; the clean water was pumped back into the culture tanks. Each of three treatments was replicated three times within each experiment, for a total of nine experimental units.

Experiment 1.—Robust redhorse were spawned artificially; the eggs were hatched in the University of Georgia's Whitehall Fisheries Laboratory (Barrett 1997); and the fry were held in aquaria for approximately 150 d. Initially, all fish received daily ad libitum proportions of nauplii of brine shrimp *Artemia* sp. until they were approximately 130 d old. Before initiation of the experiment, each tank of fish received daily ad libitum feedings of a mixture containing equal amounts of the treatment feeds.

Twelve samples of 30 robust redhorse each were taken from the holding aquaria. Nine of these samples were assigned randomly to a culture tank (culture tanks were green) and allowed to acclimate for 5 d before initiation of the experiment. The remaining three samples were used to estimate the mean initial length of fish in the experiment. Each fish in the three remaining samples was sacrificed and measured to the nearest millimeter total length (TL). Mean initial lengths of fish did not significantly differ among the three samples (analysis of variance, ANOVA; $P > 0.05$), and these means were used to estimate the mean initial length of fish in the experiment (27.1 mm, SE = 1.3 mm).

TABLE 1.—Nutrient analysis (percent, by weight; from data supplied by feed manufacturers) of three commercial diets (B = Fry Feed Kyowa C-700, BioKyowa, Inc.; SP = Shrimp Production 45/10, Rangen, Inc.; SS = Salmon Starter, Rangen) fed to robust redhorses. Values for protein, fat, and phosphorus represent minimum guaranteed levels, those for fiber and ash represent maximum guaranteed levels.

Diet	Protein	Fat	Fiber	Ash	Phosphorus
B	55.0	10.0	4.0	17.0	0
SP	45.0	9.0	4.0	15.0	1.0
SS	50.0	16.0	5.0	12.0	1.0

During the 60-d experimental periods, each tank received 9.6% of initial total fish biomass per day of one of three diets: Fry Feed Kyowa C-700 (diet B; BioKyowa, Inc.), Shrimp Production 45/10 (diet SP; Rangen, Inc.), or Salmon Starter (diet SS; Rangen). A high feeding rate was chosen to ensure ad libitum consumption throughout the experiment. A sample of 150 food particles from each diet was measured with a compound microscope equipped with an ocular micrometer. Average dry particle size was 744 μm (SE = 20 μm) in diet B, 877 μm (SE = 28 μm) in diet SP, and 1,069 μm (SE = 35 μm) in diet SS. Information regarding nutrient content for each diet was obtained from the manufacturer (Table 1). To avoid handling-induced mortality of the fish, feeding rate was adjusted for mortality during the study by maintaining a rate of 9.6% of the initial body weight, calculated for the number of fish remaining in each tank. Feed was dispersed in two feedings at about 1000 and 1400 hours daily.

Temperature, dissolved oxygen (DO), and pH were measured three times per week, and ammonia was measured once per week in each tank; a Yellow Springs Instruments model 55 temperature–DO meter, a Hach model FF-1A Test Kit, and a Fisher Accumet 925 pH meter were used to make the measurements.

Experiment 2.—This experiment followed a protocol similar to the first, except for differences in initial size and age of the fish, number of fish per tank, tank color, and duration of the experiment. The robust redhorses used in this experiment were from the same cohort as those in experiment 1. During the interim between the two experiments, fish received daily ad libitum feedings of brine shrimp and the three treatment feeds. They were approximately 270 d old and consequently were larger (mean TL = 44.8 mm, SE = 1.9 mm) than fish used in the first experiment (mean = 27.1 mm;

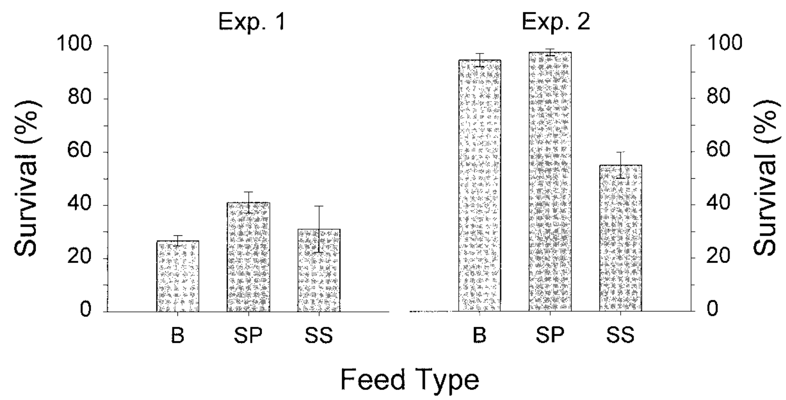

FIGURE 1.—Means and standard error bars of the percent survival of robust redhorse fed three commercial diets (B = Fry Feed Kyowa C-700; SP = Shrimp Production 45/10; SS = Salmon Starter) during two experiments.

SE = 1.3 mm). We used 20 fish per tank, for a total of 180 fish. Black culture tanks were used in this experiment. A mechanical failure in the culture system caused this experiment to end prematurely at 30 d. All other procedures were similar to those used during the first experiment.

At the end of each experiment, all fish in each tank were sacrificed, counted, and measured for total length (nearest millimeter). Survival, expressed as a percentage, was determined by dividing the number alive at the end of the experiment by the number alive at the beginning of the experiment and multiplying by 100. Relative growth was calculated as

$$G_r = (L_2 - L_1)/L_1, \tag{1}$$

where G_r is the relative rate of increase in length during each experiment (expressed as a percent of the initial length), L_1 is the length at the beginning of the experiment and L_2 is the length at the end of the experiment (Ricker 1975).

All data were tested for homogeneity of variances with the $F_{\max}$-test (Sokal and Rohlf 1981) and tested for normality with the Shapiro–Wilk test (SAS Institute 1990). Temperature data within both experiments were $\log_e X$-transformed, where X = temperature, and the survival and ammonia data within each experiment were transformed with the arcsine transformation. To determine the effects of the three feeds on survival and growth, mean percent survival and average relative growth among treatments in each experiment was compared with one-way ANOVA (SAS Institute 1990). Tukey's multiple-comparison test was used to identify significant differences among feeds for the growth and survival analyses. Repeated-measures ANOVA of the water quality variables displayed no significant variation over time; consequently, each variable was averaged over time and evaluated with one-way ANOVA (SAS Institute 1990). The significance of all statistical tests were evaluated at an alpha level of 0.05.

Neither growth, survival, nor any of the water quality variables differed significantly among treatments during experiment 1. Average percent survival ranged from 26% to 41% (Figure 1) but was not significantly different among diets (P = 0.27). Mean relative growth did not significantly differ among treatments (P = 0.19), and values ranged from 45% to 62% of initial length (Figure 2). Overall mean temperature, dissolved oxygen, pH, and percent un-ionized ammonia were each similar among treatments ($P > 0.09$ for each analysis).

Mean relative growth and survival of robust redhorse in experiment 2 were both significantly different among diets, whereas none of the water quality variables differed. Survival rates of fish consuming diets B (95%) and SP (98%) were significantly higher (P = 0.001) than the rate of those fed diet SS (55%; Figure 1). Relative growth ranged from 5% to 16% of initial lengths (Figure 2). Growth of fish fed diet B was significantly higher (P = 0.048) than for those fed the other two diets. Relative growth did not differ between fish that consumed diets SP and SS.

None of the water quality variables differed significantly among treatments during either experiment. We expected nominal difference in specific variables (e.g., temperature) among treatments, because each experiment was conducted within a

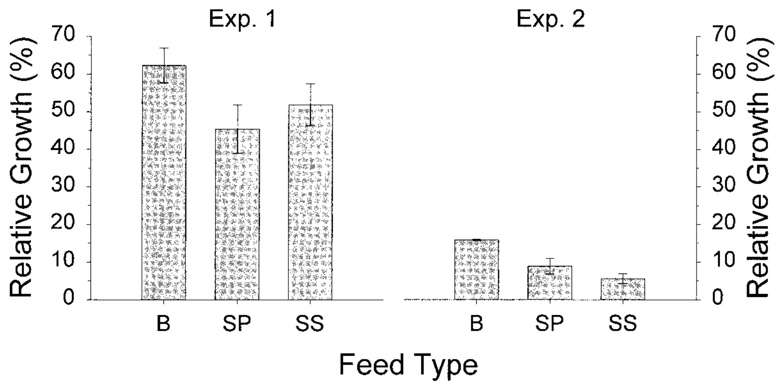

FIGURE 2.—Means and standard error bars of the relative growth of robust redhorse fed three commercial diets (B = Fry Feed Kyowa C-700; SP = Shrimp Production 45/10; SS = Salmon Starter) during two experiments.

common recirculating-water culture system. Though optimal water quality requirements for this species are unknown, the means and ranges of the variables (Table 2) were within the recommended levels for most warmwater fishes (Piper et al. 1982) and probably did not affect the survival or relative growth of fish in the study.

Results of experiment 2 indicated that survival was highest for fish fed diets B and SP, and growth was highest for those fed diet B; whereas differences in growth or survival were not evident in experiment 1. We made no attempt to compare results between the two experiments because of differences in initial size and age of the fish, number of fish per tank, and duration of the experiment. Further, we were unable to determine whether the differences in growth and survival among fish fed the three diets was the result of differences in particle size, nutrient composition, or palatability of the diets. Future studies should be designed to examine the effects of these factors upon growth and survival of this species.

Survival, growth, and feed costs are three criteria commonly used to select an effective commercial feed for intensive fish culture. The robust redhorse recovery effort is predicated upon establishing large numbers of reproducing fish within the historic range of the species; thus, optimum growth and high survival of cultured fish are both important factors in achieving this goal. The choice of feeds will depend on the goals of the culturist. The use of diet B will result in fastest growth and high survival, but at a relatively high cost ($15.00/kg at 1996 prices). Feeding diet SP to these fish will produce equally high survival and cost less ($1.04/kg) than diet B, but will yield slower growth. The culturist should weigh the relative benefits of the two feeds, such as cost versus growth differences, before selecting one for an intensive culture program.

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TABLE 2.—Overall means (and SEs) of water quality variables in each experiment.

Experiment	Temperature (°C)	Dissolved oxygen (mg/L)	pH	Un-ionized ammonia (%)
1	22.5 (0.05)	7.4 (0.01)	7.66 (0.01)	0.0122 (0.0007)
2	20.9 (0.10)	8.2 (0.02)	7.37 (0.02)	0.0096 (0.0019)

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