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Growth and Survival of First-Feeding and Fingerling Atlantic Sturgeon under Culture Conditions

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Abstract.—We performed rearing studies with first-feeding fry and fingerling Atlantic sturgeon *Acipenser oxyrinchus oxyrinchus* produced from streamside spawning of wild Hudson River adults. In all, 20,000 larvae were reared in 54-L circular tanks at initial densities of 3.7–29.6 fish/L (0.06–0.52 g/L). At the onset of exogenous feeding, diet treatments included live brine shrimp *Artemia* sp., frozen brine shrimp, or commercially formulated Biokyowa B-250. At the end of the 26-d study, all treatments but two had survival greater than 93%. Mean specific growth rate (SGR) was inversely proportional to fish density. Fish fed frozen brine shrimp were smaller but had equivalent survival to those fed live brine shrimp. Atlantic sturgeon converted to formulated feed with less than 25% mortality at mean total length and weight of 34.5 mm and 0.18 g in 20–26 d at initial stocking densities of 7.4 fish/L or less. A subsequent study was performed with fingerlings at densities of 0.37–2.22 g/L. These fingerlings were offered Zeigler sturgeon diet at 3% body weight daily. After 28 d, mortality ranged from 4.7% to 13.0%. Atlantic sturgeon from all treatments were similar in weight and total length. Our study showed that first-feeding Atlantic sturgeon under conditions of artificial rearing require low initial stocking densities and 20–26 d of a continuous supply of live brine shrimp to achieve a minimum size necessary for successful conversion to formulated feed. Fingerling Atlantic sturgeon that convert to formulated feed can be stocked at initial densities up to 2.22 g/L and reared for 28 d with resulting feed conversion ratios of 0.50 or better and at least 90% survival.

The Atlantic sturgeon *Acipenser oxyrinchus oxyrinchus* was once a commercially important species with a historical distribution along the Atlantic coast of North America from the Hamilton Inlet in Labrador to the St. Johns River in Florida (Murawski and Pacheco 1977). The Atlantic sturgeon underwent significant distribution decline from historical abundance levels due to overfishing in the late 1800s, and stocks have been further affected by environmental degradation (U.S. Office of the Federal Register 1998). There is considerable interest in restoring Atlantic sturgeon stocks through (1) eliminating harvest and allowing natural population increase and (2) hatchery-based stocking (reintroduction or supplementation) (Waldman and Wirgin 1998). Considering the latter, future hatchery-based stocking or other aquaculture efforts will require reliable information concerning techniques of artificial propagation. However, published information on the culture of Atlantic sturgeon is limited, partly due to the difficulty of capturing adults of both sexes. Varying degrees of success have been reported concerning artificial propagation and rearing of Atlantic sturgeon (Smith et al. 1980, 1981; Mohler et al. 1996; Mohler and Fletcher 1999; P. Soucy and M. Litvak, Canadian Sturgeon Conservation Center, personal communication), but because opportunities for obtaining newly hatched fish have been limited, reliable early culture techniques have not been developed.

Atlantic sturgeon are susceptible to high mortality during early life stages under intensive culture conditions, especially during the transition from endogenous (yolk sac) to exogenous feeding (J. Fletcher, U.S. Fish and Wildlife Service, personal communication). Live brine shrimp *Artemia* sp., along with various other natural and formulated diets, have been used as first feed for Atlantic sturgeon fry, but high mortality has often accompanied these attempts (Smith et al. 1981; M. Hendrix, U.S. Fish and Wildlife Service, personal communication; Soucy, personal communication). Observations of Atlantic sturgeon fry from 1993 to 1997 at the Northeast Fishery Center (NEFC) at Lamar, Pennsylvania, showed that first-feeding fry are substrate feeders and that their food-searching behavior is limited to moving to the tank bottom or vertical surfaces when live brine shrimp are introduced. This is consistent with behavior observed in a subspecies of Atlantic sturgeon, the Gulf sturgeon *A. o. desotoi* (Bardi et al. 1998). In young sturgeon, the search

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for food and feeding are carried out while in constant contact with the bottom; therefore, the size of the feeding area is important in creating optimal conditions for feeding (Sbikin and Budayev 1991). In culture experiments with young paddlefish *Polyodon spathula,* Gershanovich (1983) concluded that high stocking density resulted in competition for space and an increase in fish size variability; a decrease in stocking density led to a decrease in the intensity of competitive relationships, and feeding conditions improved. In rearing experiments with young stellate sturgeon *A. stellatus* and Russian sturgeon *A. gueldenstaedti* (Sbikin and Budayev 1991), fish reared with the largest feeding area (floor space) had greatest growth. Based on these results with other sturgeon species and the closely related paddlefish, it is likely that density is an important factor affecting growth of young Atlantic sturgeon reared under culture conditions. We performed this experiment to (1) examine effects of rearing density on growth and survival of first-feeding and fingerling Atlantic sturgeon, (2) quantify variables related to feeding live brine shrimp to first-feeding fry, and (3) provide growth and survival information for fry during their transition from live to formulated diets.

TABLE 1.—Stocking densities, feed type, and other conditions of tank treatment in first-feeding and fingerling Atlantic sturgeon rearing studies.

Fish/ tank	Fish/L	Weight (g/L)	Brine shrimp type or diet	Other conditions
Fry treatments				
200	3.7	0.07	Live	None
400	7.4	0.13	Live	None
			Frozen	
			BioKyowa B-250	
600	11.1	0.20	Live	None
800	14.8	0.26	Live	None
	29.6	0.52		½ depth water
1,000	18.5	0.33	Live	None
				Extra ration
				Extra substrate
1,200	22.2	0.39	Live	None
Fingerling treatments				
25	0.5	0.37	Zeigler	None
50	0.9	0.63	Zeigler	None
100	1.9	1.43	Zeigler	None
				Extra substrate
150	2.8	1.72	Zeigler	None
175	3.2	2.22	Zeigler	None

Methods

Streamside spawning.—Broodstock (one female and five males) were captured by gill net off the east side of Esopus Island in the Hudson River, New York, on June 16, 1998. Free-flowing eggs were an indication that ovulation was occurring; therefore, artificial spawning procedures were initiated within an hour of capture at a nearby location (Norrie Point Marina, Mils-Norrie State Park, New York State Department of Environmental Conservation). The female was positioned ventral side up with the head submerged in freshwater, and the left oviduct was punctured with a scalpel to remove about 3 L of eggs by hand massaging the abdomen. Eggs were fertilized with pooled milt, de-adhesed with river silt, and transported in a 19-L plastic bucket that was oxygenated to gently roll the eggs during the 6-h transport to NEFC.

First-feeding fry study.—Of the 124,000 larvae produced, about 20,000 were randomly selected for stocking into 54-L circular tanks (0.6-m diameter). Fry were pooled and sampled to determine average initial weights before distribution to culture tanks. Density treatments ranging from 3.7 to 29.6 fish/L (0.07–0.52 g/L) were then assigned randomly to triplicate groups of tanks (Table 1). At the onset of exogenous feeding, most treatments were offered live brine shrimp incubated from cysts (Aquafauna Bio-Marine, Inc., Hawthorne, California). However, one treatment was offered frozen brine shrimp incubated from cysts, and one received a closed-formula dry diet (Fry Feed Kyowa, Type B-250, Biokyowa, Inc., Chesterfield, Missouri) (Table 1). To compare effects of reducing available water column space without reducing horizontal substrate, a treatment of 800 fish/tank was established with three replicates, each containing half the normal water volume (27 L, depth of 12 cm). As a result, density was twofold greater (29.6 fish/L) compared with the treatment with the same number of fish per tank and normal water volume. To compare effects of increasing available horizontal substrate, a counterpart to the density treatment of 18.5 fish/L (1,000 fish/tank), was established with three replicates containing circular, translucent acrylic-plastic platforms, each having a substrate area of 1,045 cm^2 that was elevated about 8 cm off the bottom of the tank. This platform was intended to provide an additional resting and feeding area. Finally, to compare effects of increasing ration, a counterpart to the density treatment of 18.5 fish/L (1,000 fish/tank) was established with three replicates that received an additional 500 mL of saline brine shrimp water daily (Table 1). All tanks contained center standpipe drains that were screened to prevent escapement,

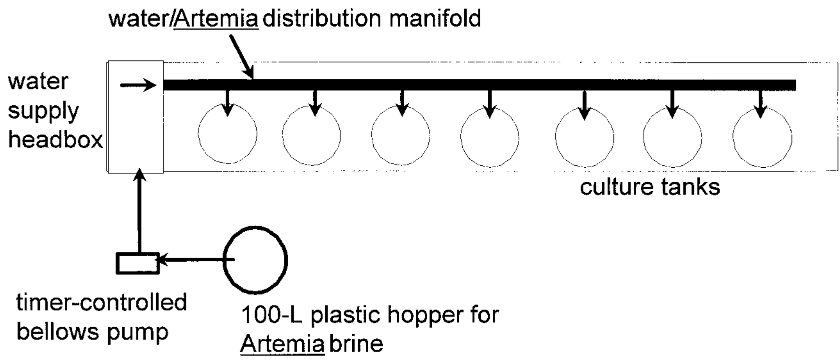

FIGURE 1.—Schematic drawing of live brine shrimp delivery technique used for first-feeding Atlantic sturgeon.

and screened areas were excluded from calculations of tank water volumes. Tank culture conditions during our study were as follows: flow = 3 L/min, temperature = 17.5 ± 0.5°C, pH = 7.3−7.8, and dissolved oxygen = 8.1−8.9 mg/L. Tanks were cleaned daily, and overhead fluorescent lighting was maintained from 0730 to 1600 hours each day.

Brine shrimp cysts were incubated for 24 h in 200-L plastic cylinders using culture variables suggested by Huner and Brown (1985). Brine shrimp were harvested daily by removing the aeration and allowing the nauplii to settle for about 20 min. Subsequently, about 150 L of brine was drained from the cylinder and mixed with 30°C saline water to a volume of 200 L. Aliquots of 50 L each were distributed to plastic hoppers positioned adjacent to headboxes that supplied fresh water (nonsaline) to each row of culture tanks. Saline brine shrimp water was constantly aerated and permitted to drop to room temperature during the feeding period. The brine was delivered through flexible plastic tubing to headboxes for 3 min at 30-min intervals daily via timer-controlled bellows pumps (model 14251-001, Gorman-Rupp Industries, Bellville, Ohio; Figure 1). The number of brine shrimp/mL was calculated daily by sampling all storage hoppers and randomly selected culture tank inflows. Replicates receiving frozen brine shrimp were fed one frozen cube three times daily. Frozen brine shrimp were prepared by concentrating live cultures and freezing in 22 or 30-mL cubes. Brine shrimp counts were performed on randomly selected cubes from each different culture produced. The Biokyowa treatment received a ration at 10% body weight/d via automatic feeders (model A-100; Double A Brand Co., Dallas, Texas) that were modified to dispense feed continuously over 24 h. Mortalities were recorded daily.

After 26 d, brine shrimp supplies were exhausted, and the study was terminated. Biomass of each tank was determined, and 30 individuals from each tank were weighed and measured for total length. Mean weights were used to calculate mean specific growth rate (SGR) expressed as percent gain per day for each treatment using the following equation (Brown 1957):

$$\text{SGR} = (\log_e \text{final weight} - \log_e \text{beginning weight/days}) \times 100.$$

Fingerling study.—Survivors of the first-feeding fry study were offered a closed-formula diet (Zeigler sturgeon diet, number 1 crumbles, Zeigler Brothers, Inc., Gardners, Pennsylvania) at 3% body weight/d. After 25 d, fish that successfully converted to the Zeigler diet were pooled and randomly selected for inclusion into 54-L circular tanks at densities ranging from 0.5–3.2 fish/L (0.37–2.22 g/L; Table 1). To compare effects of increasing available horizontal substrate, six tanks with 1.9 fish/L (100 fish/tank) were established; three had normal tank conditions, and three contained the same plastic platforms used in the first-feeding fry study.

Culture tank conditions during the study were as follows: flow = 4 L/min., temperature = 19 ± 0.5°C, pH = 7.3−7.8, and dissolved oxygen ≥ 8 mg/L. Tanks were cleaned every other day, and overhead fluorescent lighting was maintained from 0730 to 1600 hours each day. Fish were offered Zeigler sturgeon diet (a 1:1 mixture of number 1 and number 2 crumbles) at 3% body weight/d via automatic feeders. Deaths were recorded daily. After 15 d, total biomass was measured and feed amounts were adjusted accordingly. Fish were fed for a total of 28 d, and a final inventory was then performed that included measurement of biomass per tank, as well as individual lengths and weights of 30 fish/tank, if available. Specific growth rate was calculated using initial and final total biomass for each treatment. Feed conversion ratio (FCR), a measurement used to describe the efficiency of fish in converting food to flesh, was calculated from initial and final tank biomass for all treatments using the following

$$\text{FCR} = \text{weight of dry feed offered} \div \text{wet weight gain of fish.}$$

Statistical analyses.—The effects of density on mortality and FCR were analyzed by one-way analysis of variance (ANOVA) with significance between specific treatments determined by the Tukey multiple-comparison test. The relationship between mean SGR and density was explored with stepwise regression. Sigma-Stat statistical software (version 2.01; Jandel Corporation, San Rafael, California) was used for all statistical tests. The significance level chosen was 5% for all comparisons between treatments. Data collected as percentages were arcsine transformed before statistical analysis.

Results

First-Feeding Fry Experiment

After 26 d, mortality was higher in the Biokyowa (87%) and live brine shrimp treatments that contained the submerged platform (65%) than for all other treatments (<10%; Figure 2). Microscopic examination of fish fed Biokyowa revealed starvation as the probable cause of death; the protozoan parasite *Chilodonella* sp. was diagnosed as the agent of mortality in fish reared with the submerged platform.

In all, 8.7 kg of brine shrimp cysts were incubated to rear 20,200 first-feeding Atlantic sturgeon for 26 d at a cost of about $525, excluding labor, electricity, and fuel for heating water. Mean daily amounts of live brine shrimp offered ranged from 3.8×10^5 to 5.7×10^5 nauplii per tank. Tanks supplied with 500 mL supplemental live brine shrimp daily received a greater amount of food (mean = 6.7×10^5 nauplii per tank) than all other treatments, but fish were similar in size to their equivalent density counterparts.

After 26 d, fish reared at a density of 800 fish/tank with half the normal water volume were significantly smaller (27.1 mm and 0.09 g) than their counterparts reared with full water volume (30.3 mm and 0.13 g, $P < 0.05$). Fish fed frozen brine shrimp received similar numbers of food items as counterparts fed live brine shrimp but were 35% smaller even though survival was equivalent (>93%). Mean SGR was inversely proportional to fish density and ranged from 4.9%/d in the high-density treatment to 11.1%/d in the low-density treatment (Figure 3). The line of best fit for stepwise regression analysis of SGR as a function of rearing density was a second-order polynomial described by the quadratic equation

$$\text{SGR} = 12.412 - (4.35^{-1} \cdot X) + (4.29^{-3} \cdot X^2),$$

where X = density in fish/L. Finally, sturgeon converted to Biokyowa type B-400 formulated feed with less than 25% mortality at mean total length and weight (SD) of 34.5 (3.0) mm and 0.18 (0.05) g, respectively. This was achieved with an initial stocking density of 7.4 fish/L or less (Figure 4).

Fingerling Experiment

Mortality of fingerling Atlantic sturgeon increased from 6.7% to 13.0% from the lowest to highest density (0.37–2.22 g/L, respectively). One exception was fish in the treatment containing the submerged platform, which had lower mortality (4.7%) than fish at the same density with no platform (10%), and significantly lower mortality than two treatments having higher densities (1.73 g/L or greater; Figure 5). After 28 d, mean fingerling length and weight (SD) was 90.8 (18.9) mm and 3.2 (1.7) g, with no significant difference between density treatments ($P > 0.05$). Feed conversion ratios ranged from 0.44 in the low-density treatment to 0.56 in the treatment containing additional substrate, with a significant difference between the substrate treatment and all others ($P < 0.05$; Figure 6). Mean SGR ranged from 3.9% to 4.9%/d and was inversely proportional to rearing density (Figure 7), with the exception of the treatment containing the submerged platform, which was not included in the plot of SGR. As with first-feeding fry, fingerling SGR as a function of stocking density was best described by the quadratic equation

$$\text{SGR} = 5.052 - (6.20^{-1} \cdot X) + (1.50^{-1} \cdot X^2),$$

where X = density of fish in g/L (Figure 7).

Discussion

For cultured white sturgeon *A. transmontanus*, Conte et al. (1988) recommends a stocking density of 15–20 yolk sac fry/L. Using these densities for Atlantic sturgeon, our model (Figure 3) predicts

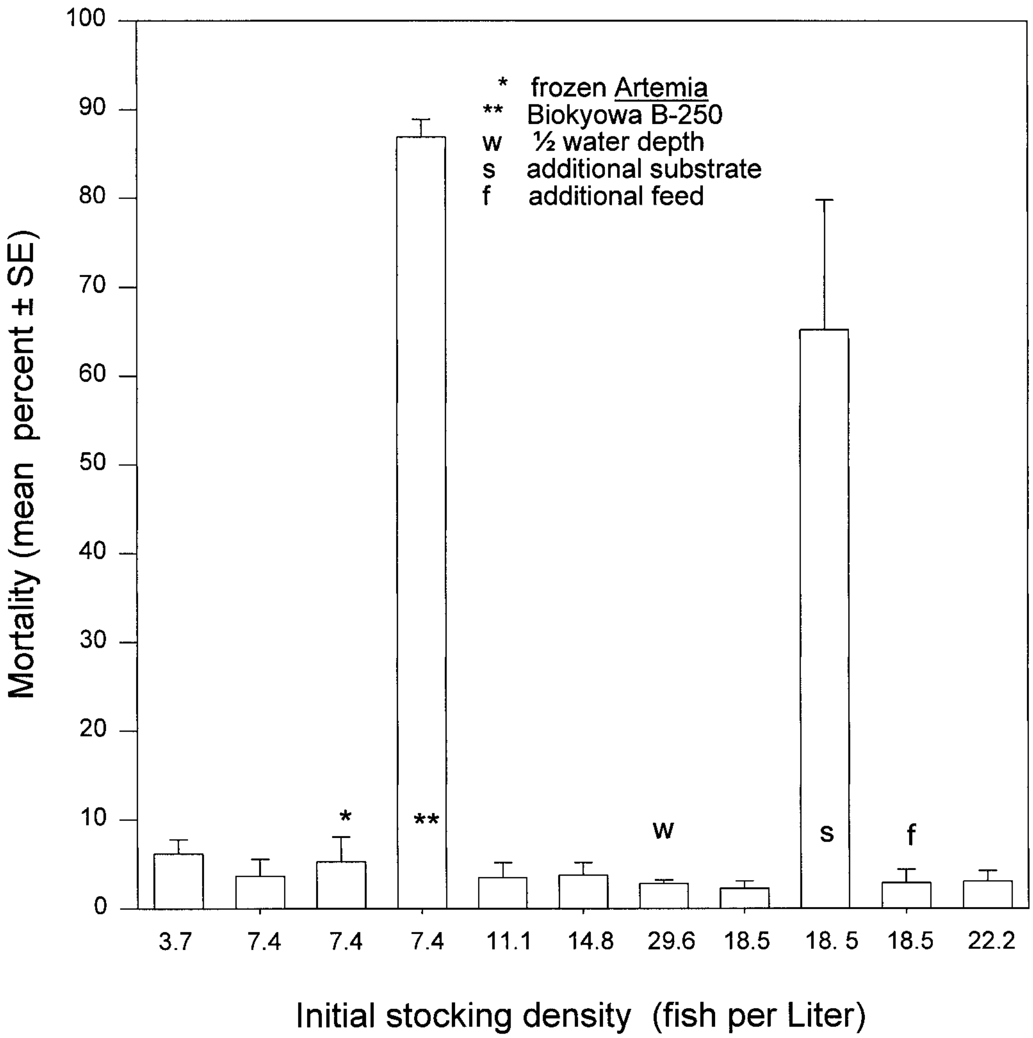

FIGURE 2.—Mean percent mortality of first-feeding Atlantic sturgeon reared for 26 d and offered live brine shrimp, frozen brine shrimp, or Biokyowa B-250 and reared at initial stocking densities of 3.7–29.6 fish/L.

SGRs between 7.32% and 6.45%/d. However, this range of SGRs would not promote the most efficient growth for Atlantic sturgeon to obtain the minimum size necessary for successful conversion to formulated diets (34.5 ± 3.0 mm total length, TL, and 0.18 ± 0.5 g). Of the levels tested, we found that initial stocking densities of less than 7.4 fish/L were required for adequate growth and successful conversion from live to formulated diets for Atlantic sturgeon (Figure 4).

Even though fry that were offered 500 mL of supplemental brine shrimp daily received greater amounts of food than fish held at the same density (18.5 fish/L or 1,000 fish/tank) with lower ration, they were similar in size at the end of the study, suggesting that density had a limiting effect on growth in this treatment regardless of ration. Fish reared at an initial stocking density of 800 individuals/tank with half the normal water volume were smaller after 26 d than their study counterparts with full tank volumes. At first it may seem that reduced water volume and the concomitant increase in fish density alone was responsible for growth differences, but the reduced water volume also served to decrease some grazing area provided by tank sides. Additionally, decreasing tank water volumes also increased the rate of tank water exchange, which probably affected the dynamics of brine shrimp nauplii in the water column and their availability for the fish.

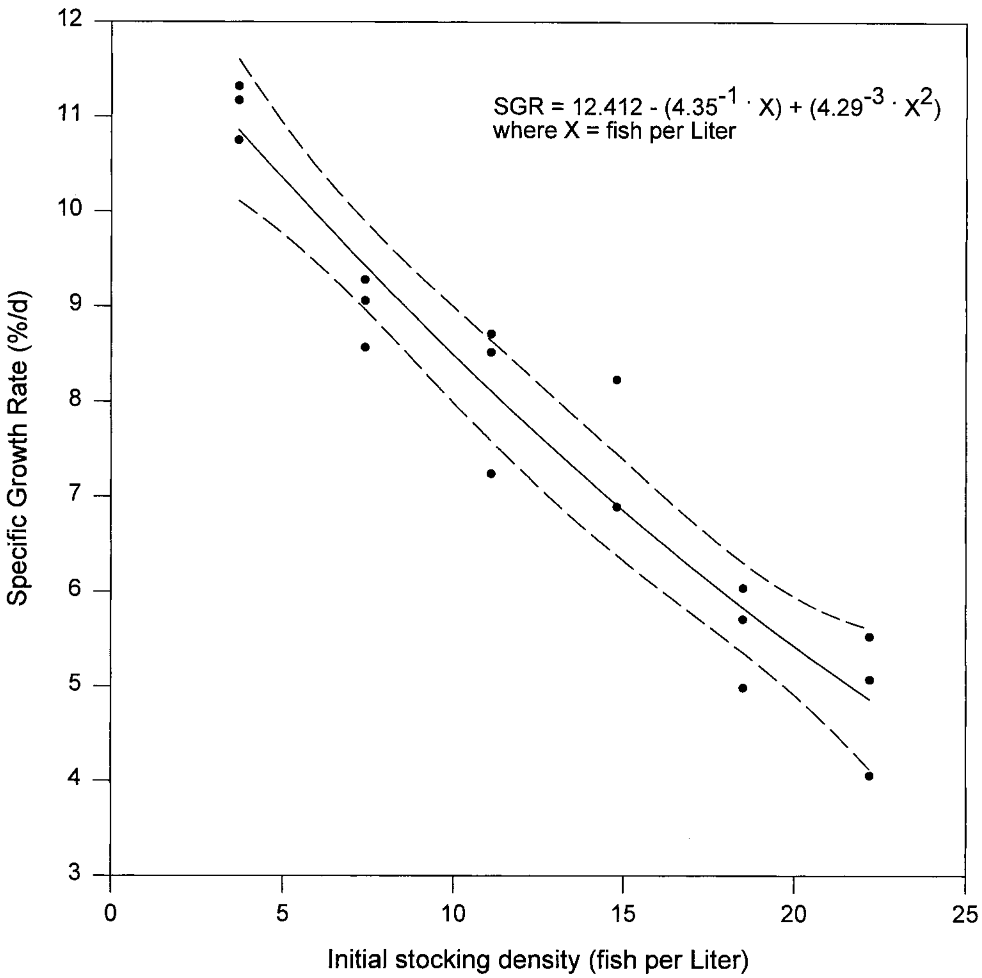

FIGURE 3.—Specific growth rates (SGR as %/d) of first-feeding Atlantic sturgeon reared at stocking densities ranging from 3.7 to 22.2 fish/L and offered equivalent amounts of live brine shrimp for 26 d. Broken lines represent 95% confidence limits for SGR. Only two replicates established for the 14.8 fish per liter treatment.

All formulated diets tested have performed poorly as first feed for Atlantic sturgeon fry (Fletcher, personal communication). For Gulf sturgeon, formulated feeds were also poorly accepted by first-feeding larvae and have resulted in more than 99% mortality by 3 weeks (Bardi et al. 1998). This is supported by our results with Biokyowa, which showed 87% mortality over the first 26 d of exogenous feeding. Although live brine shrimp provided reliable growth and survival for first-feeding Atlantic sturgeon, we found daily culture and feeding of live brine shrimp to be labor intensive for rearing large numbers of fry. It would be advantageous for the culturist to reduce the brine shrimp feeding period by using stocking densities that allow fry to reach a minimum size for efficient conversion to formulated diets as quickly as possible. It may also be beneficial to feed frozen rather than live nauplii to first-feeding Atlantic sturgeon fry because cultures could be produced and frozen well in advance of sturgeon spawning and hatching activities. We found that first-feeding fry offered frozen nauplii survived as well as their counterparts fed live brine shrimp; however, they were smaller after 26 d. The number of frozen versus live nauplii offered was equivalent, but the feeding regimen differed greatly as fish in the frozen brine shrimp treatment received only three feedings daily and the fish fed live brine shrimp received feed for 3 min every half-hour of the day. Cui et al. (1997) found that continuous feeding for 24 h/d was the optimum feeding regimen for ju-

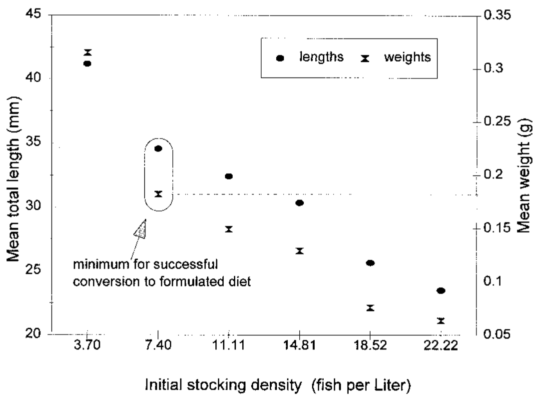

FIGURE 4.—Mean total length (mm) and weight (g) of first-feeding Atlantic sturgeon offered live brine shrimp for 26 d and observed minimum size for successful conversion to formulated diet.

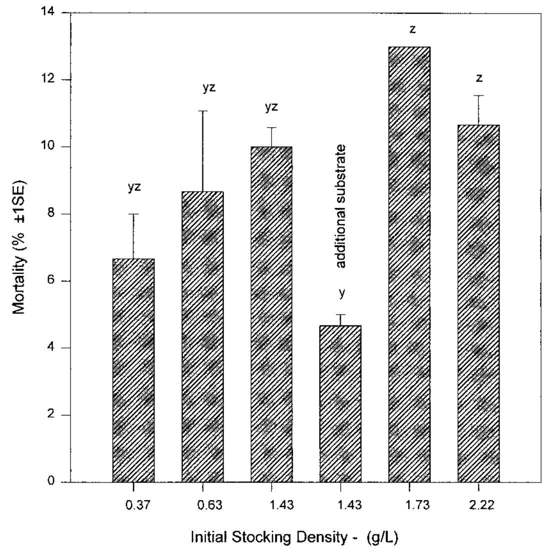

FIGURE 5.—Mean percent mortality of fingerling Atlantic sturgeon reared at densities ranging from 0.37 to 2.22 g/L and offered formulated feed at 3% body weight/d for 28 d. Treatments without a letter in common are significantly different ($P < 0.05$).

venile white sturgeon; those fed only two meals each day showed lower SGR, feed efficiency, and body lipid content. Additional study is necessary to determine if increasing the number of daily feedings of frozen nauplii will improve sturgeon growth equivalent to that obtained with live nauplii.

With first-feeding fry, we found that accumulations of uneaten feed can promote excessive mortality through parasitism by the protozoan *Chilodonella* sp. along with secondary fungal infestation. Fish in all three test replicates containing the submerged feeding platform had excessive mortality in the first 3 days of the experiment. This mortality was attributed to accumulation of uneaten brine shrimp nauplii caused by the submerged platform which promoted a poor drainage flow pattern through the center drain. The protozoan flourished in this environment and was able to parasitize sturgeon fry. *Chilodonella* sp. was controlled by removing submerged platforms and administering one static formalin treatment (Paracide-F, Argent Chemical Laboratories, Redmond, Washington) at 150 mg/L for 1 h.

Some evidence was found that increasing the substrate area of rearing tanks may affect Atlantic sturgeon growth. Sbikin and Budayev (1991) reported that young Russian sturgeon reared with submerged horizontal shelving had greater growth than those reared in a similar-sized normal tank. In our fingerling study, fish reared with a submerged platform showed the lowest SGR of any treatment (3.9%/d), but the platform did appear to have a possible density-related effect on survival. When compared with similar and higher densities, survival was greater in tanks containing platforms than in those with no platforms. It is interesting to note that even though survival was greater in the tanks containing the submerged platform, those fish were significantly less efficient at feed conversion compared with all other treatments ($P < 0.05$; Figure 3). This suggests that the platforms reduced stress and prevented subsequent mortality of weaker individuals by providing an additional resting area as opposed to providing a growth benefit. Random observations of tanks containing platforms showed that about 8% of the population occupied the additional substrate at a given time and that some feeding activity occurred, although no provisions were made to ensure equal distribution of feed to the platform and tank bottom. Therefore, fish using the platform may have been less likely to encounter food items compared with those on the tank bottom.

In summary, we found that first-feeding Atlantic sturgeon fry must attain a minimum size (SD) of 34.5 (3.0) mm TL and 0.18 (0.05) g to convert to a formulated (dry) diet with least mortality. Using water temperature of 17.5°C and water quality characteristics similar to those given, minimum size for conversion can be achieved in 20–26 d by automated continuous feeding of live brine shrimp at a rate of at least 3.8×10^5 nauplii/d in each 54-L culture tank stocked at initial densities of 7.4

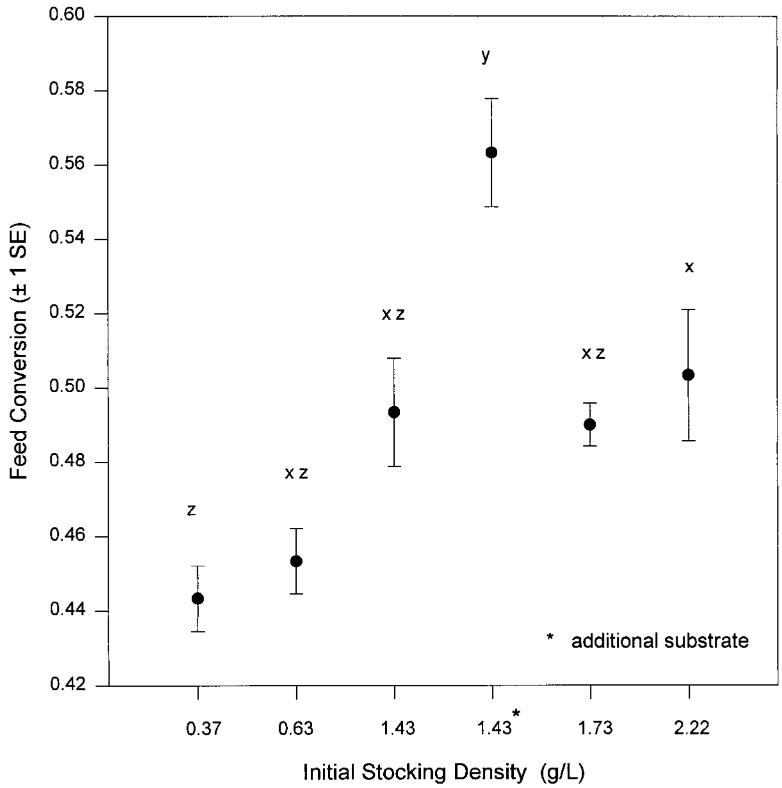

FIGURE 6.—Feed conversion ratios (feed offered/wet weight gain) in fingerling Atlantic sturgeon reared at densities ranging from 0.37 to 2.22 g/L for 28 d. Treatments without a letter in common are significantly different ($P < 0.05$).

fish/L or less. Fry that reach minimum conversion size will readily accept a formulated diet with no weaning period. Once the diet conversion has occurred, fingerlings can be reared at densities up to 2.22 g/L and fed at 3% body weight daily to obtain feed conversions of 0.50 or better with at least 90% survival for 28 d.

Generally, fish that exhibit feed conversion ratios of about 1.0 are considered efficient at using the offered amount of feed for growth; therefore, our reported FCR of 0.50 or less for fingerling-size sturgeon would likely seem extreme. While uncommon for most species, FCR of less than 1.0 have been reported for sturgeon. The best FCR for 8.6-g white sturgeon fed a formulated diet reported by Cui et al (1997) was 0.96 (reported as the reciprocal, feed efficiency). In another study using 30-g white sturgeon fed a formulated diet, Hung et al. (1993) reported FCR equivalent to 0.76–0.91. In our earlier study, we reported FCR of 0.54 for 2.5-g Atlantic sturgeon offered Biokyowa formulated diet for 60 d (Mohler et al. 1996). However, the closed-formula Zeigler sturgeon diet used in our current study outperformed this Biokyowa diet in hatchery trials (M. Kim King, U.S Fish and Wildlife Service, unpublished data).

Even though rearing densities conducive to acceptable growth and survival for first-feeding Atlantic sturgeon were discovered in this study, additional experimentation is needed to (1) further evaluate use of frozen brine shrimp for rearing first-feeding fry, (2) develop strategies to maximize available tank space for rearing large numbers of first-feeding sturgeon, and (3) further refine maximum stocking densities for fingerling-sized and larger Atlantic sturgeon.

Acknowledgments

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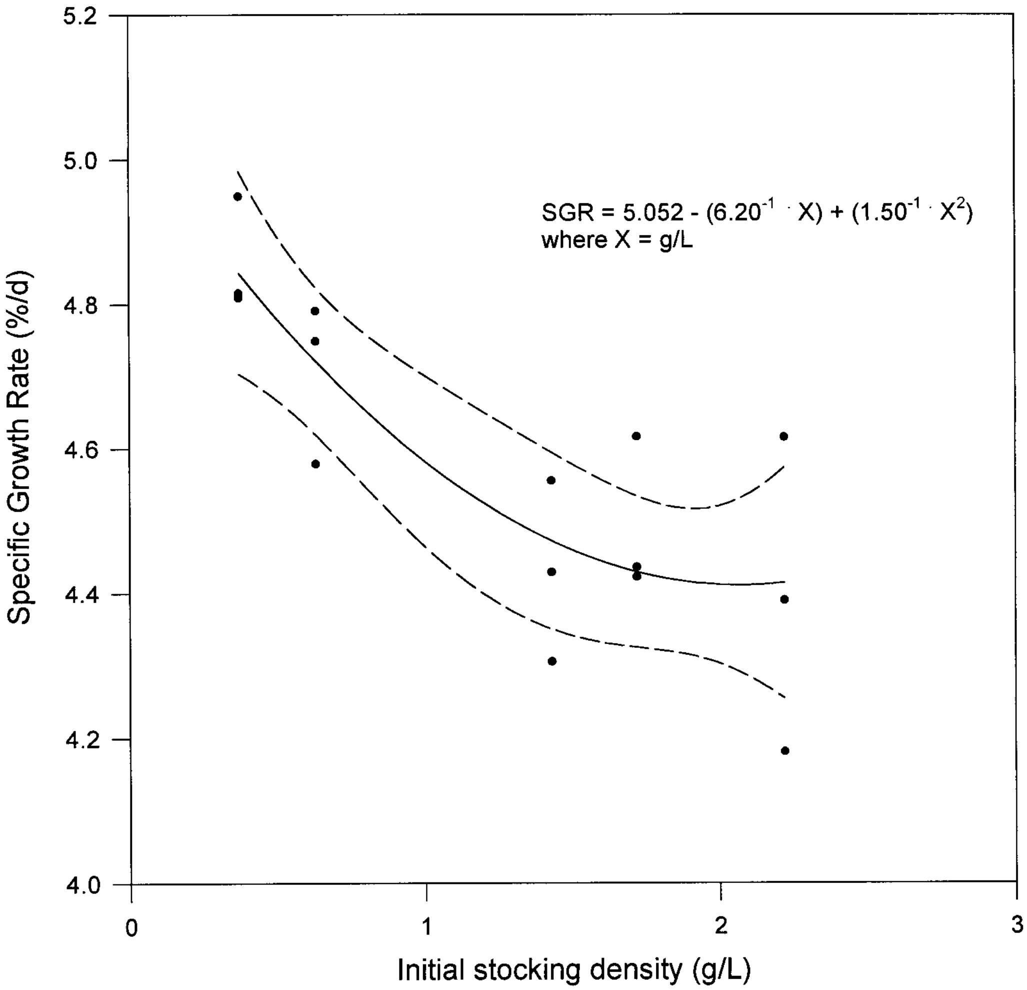

FIGURE 7.—Specific growth rates (SGR as %/d) of fingerling Atlantic sturgeon reared at densities ranging from 0.37 to 2.22 g/L and offered formulated diet for 28 d. Broken lines represent 95% confidence limits for SGR.

support in performing this experiment. In addition, we are grateful to commerical fisherman Doug Bush and his crew for their assistance and guidance in gill-netting mature sturgeon. Finally, a special thanks to Mike Hendrix, Center Director, for encouraging and allowing us to pursue our ideas through experimentation.

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