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The Effect of Rearing Density on Growth, Survival, and Feed Conversion of Juvenile Atlantic Sturgeon

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Abstract.—We investigated the effect of rearing density on the growth and survival of juvenile Atlantic sturgeon *Acipenser oxyrinchus* using initial rearing densities ranging from 10 to 30 fish per tank or 3.6–10.9 kg/m^2 of substrate. The mean weight of fish at the start of the trial was 368.7 g. After 7 weeks of rearing, density ranged from 6.5 to 16.3 kg/m^2 (14.7–36.6 g/L). Fish reared at the lowest density had significantly higher mean weight and length at the end of the trial. Growth over the 7-week experiment was modeled as a function of time, and growth rate was inversely proportional to density. The mean increase in total biomass was 63.14%, and the mean daily length gain was 0.23%. Overall survival was 99.7%, and calculated feed conversion rates ranged from 1.93 to 2.65. However, feed conversion rates were likely not at maximum levels due to the selection of a relatively high experimental feeding rate (2.5% of body weight per day).

As a result of excessive commercial harvests, Atlantic sturgeon *Acipenser oxyrinchus* populations experienced dramatic declines in abundance across much of their range throughout the late 1800s. By the 1920s, intense harvests had severely reduced the vulnerable spawning populations (Taub 1990). Recent evidence suggests that between 1977 and 1995 the number of juvenile Atlantic sturgeon in the Hudson River, which supports one of the largest remaining populations in the northeastern United States, declined by approximately 80% (Peterson et al. 2000). In fact, it is now believed that recruitment in the Hudson River is insufficient to sustain the population (Peterson et al. 2000).

The continued decline of Atlantic sturgeon across their historic range has prompted both the Atlantic States Marine Fisheries Commission and the U.S. Fish and Wildlife Service (USFWS) to adopt management plans for the species (Taub 1990; Booker et al. 1993). Both plans call for the development of culture technology and rearing techniques to evaluate the potential for wild population enhancement through the release of hatchery-reared fish, with careful attention to ensuring genetic diversity.

As with the artificial culture of any species, the success of restoration or aquaculture efforts for Atlantic sturgeon will hinge on a knowledge of numerous factors, including growth, survival, and production per unit of culture.

Some information already exists concerning Atlantic sturgeon culture. Smith et al. (1980, 1981) produced fry using wild broodstock from South Carolina and reported that offering various combinations of beef liver, salmon mash, and live brine shrimp *Artemia* sp. resulted in the active feeding and growth of posthatch fry. Unfortunately, unexplained high mortality during both investigations resulted in fish losses of 95−100%. Kelly and Arnold (1999) tested the effect of ration and temperature on growth and determined that for feed rates ranging from 0.5% to 1.5% of body weight (bw) per day, 1.5% provided the greatest growth for 60-g sturgeon at temperatures ranging from 15 °C to 19°C. However, they suggested that maximum growth most likely occurs at some ration beyond 1.5% bw/d because an upward trend in growth was observed at all temperatures as ration was increased to 1.5%. Mohler et al. (1996) evaluated the performance of fingerling Atlantic sturgeon fed four different formulated diets, and Mohler and Fletcher (1999) reported the ability to induce spermiation in wild Atlantic sturgeon held in captivity for up to 6 years by injection of common carp pituitary solution, luteinizing hormone-releasing hormone analog, or a combination of both. But one area of research that has received little attention is that of acceptable culture tank loading densities for rearing juveniles. Mohler et al. (2000) reared Atlantic sturgeon fingerlings at initial densities ranging from 0.37 to 2.22 g/L for 30 d without significant ($P > 0.05$) adverse effects on growth or survival. Additionally, changes in the length and weight of juvenile lake sturgeon *Acipenser fulvescens* (106-d old; initial mean weight, 8.5 g/fish) reared for 5 weeks at densities

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TABLE 1.—Initial and final densities of Atlantic sturgeon reared at five different treatment densities. Densities are expressed as the number of fish per 460-L tank, as biomass (kg) per square meter of tank bottom, and as biomass per liter of water.

Treatment	Fish/tank	Biomass/m^2		Biomass/L	
		Initial	Final	Initial	Final
1	10	3.59	6.54	7.95	14.67
2	15[a]	5.37	8.70	11.91	19.53
3	20	7.18	11.67	15.93	26.17
4	25	9.15	14.56	20.29	32.68
5	30	10.85	16.33	24.06	36.64

[a] One fish died in one of the 15 fish/tank replicates.

of 150, 300, and 450 fish/m^2 (1.35, 2.50, and 3.75 kg/m^2) did not differ among densities (Fajfer et al. 1999). However, information pertaining to the effect of rearing density on growth of age-1 and older Atlantic sturgeon is not available. Elucidation of optimal rearing densities will allow culture of the maximum number of individuals while maintaining acceptable growth and survival. Our investigation examined the effect of five rearing densities on growth, survival, and feed conversion.

Methods

Progeny obtained from an artificial mating of wild Hudson River Atlantic sturgeon (one female and five males) in 1998 were employed for this study. Fish were reared at the Northeast Fishery Center (NEFC) in Lamar, Pennsylvania. At the age of 13 months, 300 fish were randomly distributed into 15 circular fiberglass tanks at stocking densities of 10, 15, 20, 25, and 30 fish per tank. Three replicate tanks were established at each density. Tanks measured 122 cm in diameter at the top and 114 cm at the bottom, and water depth was maintained at 42 cm by adjusting external standpipes. The water volume in each tank was approximately 460 L. All subject fish were measured (TL), weighed, and assigned to tanks in such a manner that the mean lengths and weights did not differ among treatments (analysis of variance [ANOVA]; $P > 0.05$). The mean ($\pm$SE) weight at start-up was 368.7 $\pm$ 3.7 g, resulting in treatments of 3.59, 5.37, 7.18, 9.15, and 10.85 kg/m^2 of substrate, or 7.95, 11.91, 15.93, 20.29, and 24.06 g/L of water, respectively (Table 1). Mean total length per fish was 462 $\pm$ 2 mm. Sbikin and Budayev (1991) reported that sturgeon remain in constant contact with the substrate while searching for food and feeding. They demonstrated that young sturgeon reared in aquaria of equal volume but different substrate area grew in proportion to the area of the bottom feeding surface. This suggests that under artificial conditions, it may be necessary to calculate not only the volume of the rearing units but also the area of the substrate feeding surface. Therefore, we report rearing densities in both kilograms per square meter and grams per liter. After distribution to treatment tanks, fish were allowed 72 h to acclimate before feeding began.

Fish were offered commercially formulated Zeigler Sturgeon Diet (Zeigler Brothers, Gardners, Pennsylvania), which was delivered on a 24-h cycle via time-controlled feeders. This diet was chosen because earlier trials conducted at NEFC demonstrated it to be the most successful of six readily available commercial diets with respect to growth and survival (K. King, USFWS, personal communication). Feed was offered at a rate of 2.5% of total tank biomass per day based on the findings of Kelly and Arnold (1999), who reported that for temperatures ranging from 15 °C to 19°C, the maximum growth of Atlantic sturgeon most likely occurs at some ration beyond 1.5% bw/d. Feed particle diameter was 2.4 mm during the first 5 weeks of rearing and was increased to 3.2 mm during the final 2 weeks to accommodate growth of the fish. Routine water quality readings were taken simultaneously from one tank at each density. Temperature and dissolved oxygen were measured daily using an oxygen meter (YSI model 95; Yellow Springs Instruments, Yellow Springs, Ohio). Ammonia levels and pH were assessed weekly by colorimetric comparison (Ammonia/Nitrogen Test Kit; LaMotte, Chestertown, Maryland) and with a Sentron pH meter (Sentron 1001, Gig Harbor, Washington), respectively. The flow rate for all tanks was 16 L/min and was calibrated weekly.

All fish in each tank were weighed and measured at start-up and once per week for the seven subsequent weeks. Feed rates were adjusted each week to compensate for weight gain. After the weekly data collection, each tank received a prophylactic 1.0% salt treatment. Feed conversion, the efficiency of converting feed to flesh, was calculated as the ratio of weight of feed offered to weight gained by fish. Mortalities were removed and recorded daily, and survival was calculated as the percentage of remaining individuals at the conclusion of the experiment.

The final mean weights and lengths of all fish per density treatment were analyzed with ANOVA. As sample sizes in the final treatment cells were unbalanced, the treatment means were compared with Tukey adjusted *P*-values using the LSMEANS test (SAS Institute 1990; Westfall et

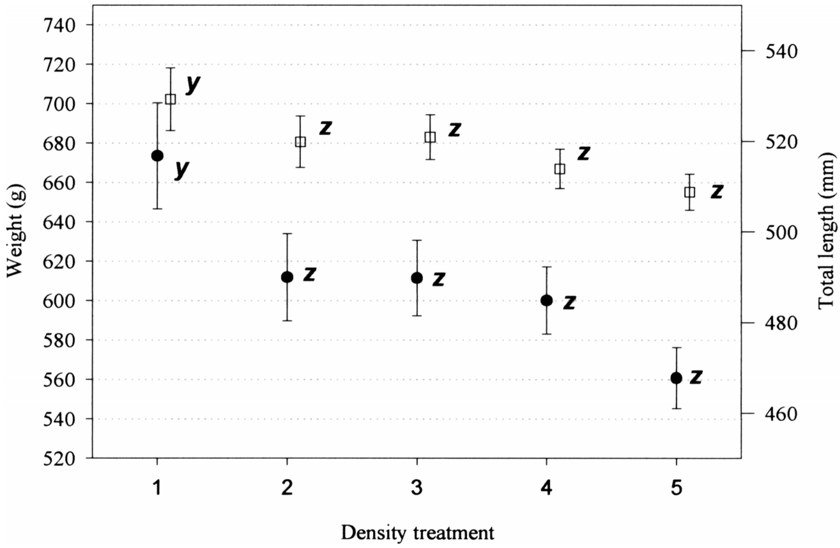

FIGURE 1.—Final mean (±SE) weights (circles) and total lengths (squares) of juvenile Atlantic sturgeon reared at five initial densities (3.59, 5.37, 7.18, 9.15, and 10.85 kg/m² for treatments 1–5, respectively). Values with different lowercase letters are significantly different (adjusted Tukey's test; $P < 0.10$).

al. 1999). We also regressed mean fish weight per tank per treatment on time to assess growth rates over the 7-week period of our experiment. We assumed that growth over 7 weeks was approximately linear. The regression functions for each treatment were then compared with each other via the linear modeling technique of incorporating indicator variables in the model and testing appropriate interaction terms (Neter et al. 1985). ANOVA was used to test for differences in temperature, dissolved oxygen, and pH levels among densities. Differences in final mean lengths among densities was tested at an α-level of 0.10, while all other statistical comparisons were made at an α-level of ≤ 0.05.

Results

After 49 d of rearing, the final mean weights per fish ranged from 560.7 g for fish reared at the highest density to 673.5 g for those reared at the lowest density (Figure 1). This resulted in final densities of 6.54, 8.70, 11.67, 14.56, and 16.33 kg/m² or 14.67, 19.53, 26.17, 32.68, and 36.64 g/L for treatments 1 through 5, respectively (Table 1). Mean lengths ranged from 509 mm at a density of 30 fish/tank to 530 mm for a density of 10 fish/tank (Figure 1). This corresponded to mean total length increases of 15.1, 12.3, 13.1, 11.7, and 9.8% for fish from density treatments 1 through 5, respectively.

There were significant differences in final mean weight ($P = 0.0067$) and final mean length ($P = 0.07$) amongtreatment densities. In particular, the final mean weight of fish reared at the lowest density was higher than that of fish reared at higher densities (Figure 1). The trend in length was identical to that in weight (Figure 1).

Estimated growth rates, as determined from weight gain, differed among treatments (Table 2). The slope of the growth function was highest for fish reared at the lowest density and lowest for those reared at the highest density. Fish reared at the middle three densities exhibited similar growth rates. This indicates that lower rearing densities supported accelerated growth (Figure 2).

Feed conversion rates ranged from 1.93 for fish reared at the lowest density to 2.65 for those reared at the highest density. Mortality during the 7-week trial was not affected by rearing density; there was only one mortality, which occurred in one of the replicates with 15 fish/tank.

Mean temperature, dissolved oxygen, and pH over the course of the investigation were 14.6 ± 0.08°C, 8.2 ± 0.05 mg/L, and 7.9 ± 0.03, respectively. No significant ($P = 0.24$) differences in water quality indicators were found among densities. Furthermore, no detectable levels of ammonia were present in our flow-through system.

Discussion

Our results indicate that growth was significantly affected by initial rearing density. Although

TABLE 2.—Comparison of regression equations representing the change in weight over 7 weeks of Atlantic sturgeon juveniles reared at five initial densities (treatments). Rejection of the null hypothesis is indicated when the adjustment value for the intercept or slope is statistically significant. See Table 1 for initial rearing densities.

Null hypothesis	Parameter	Estimate	*t*-value	*P*
Density 1 = densities 2, 3, 4, 5	Intercept	364.6		
	Adjustment	−11.4	−1.31	0.194
	Slope	32.6		
	Adjustment	11.7	5.66	<0.0001
Density 1 = densities 2, 3, 4	Intercept	361.8		
	Adjustment	−8.6	−0.91	0.365
	Slope	34.0		
	Adjustment	10.3	4.58	<0.001
Density 5 = densities 2, 3, 4	Intercept	361.8		
	Adjustment	11.2	1.28	0.204
	Slope	34.0		
	Adjustment	−5.6	−2.66	0.009
Density 5 = densities 1, 2, 3, 4	Intercept	359.7		
	Adjustment	13.3	1.31	0.193
	Slope	36.6		
	Adjustment	−8.2	−3.34	0.001

survival was high at all densities tested, the best growth occurred at the lowest density. Our results may be specific to the size range of fish that we used, namely, those between 370 and 600 g. In a similar study with age-0 lake sturgeon *Acipenser fulvescens* (8–22 g), Fajfer et al. (1999) reported that rearing densities ranging from 1.35 to 3.75 kg/m^2 had no significant ($P > 0.05$) impact upon growth and survival.

Our feed conversion rates ranged from 1.93 to 2.65 but were likely not at maximum levels due to the selection of a relatively high feeding rate (2.5% bw/d). Hung et al. (1989) described 1.5–2.0% bw/d as the optimal feed rate for 250-g white sturgeon *Acipenser transmontanus* reared at 18°C. Kelly and Arnold (1999) also reported a daily ration of 1.5% as producing the greatest growth for Atlantic sturgeon juveniles (mean weight of 60 g) between temperatures of 15°C and 17°C.

Our study was designed to assess the impacts that rearing density (fish weight per unit volume of water [g/L]) or spatial requirements (tank bottom area [kg/m^2]) had on growth and survival. However, another crucial aspect that may influence growth is loading density (fish weight per unit of water flow [kg/L/min]). Wedemeyer et al. (1990) reported that excessively high loading rates can lead to an accumulation of un-ionized ammonia, which can negatively impact the health and ultimately the growth and survival of fish in culture. Our water inflows were maintained at a uniform delivery rate of 16 L/min for all treatments. A search of the available literature revealed the absence of any published information pertaining to allowable loading densities for sturgeon species. Therefore, our initial (0.23–0.69 kg/L/min) and final (0.42–1.05 kg/L/min) loading density ranges may serve as a guide for other sturgeon culturists and as a baseline for future loading density studies.

Our results provide baseline data concerning permissible stocking and loading density parameters for Atlantic sturgeon. However, this trial was based solely on the progeny of a single female and we did not attempt to address possible genetic variations in performance. Therefore, some caution should be exercised in making general inferences concerning Atlantic sturgeon. Future studies are needed to identify the threshold densities that adversely affect growth and survival for various ages and size-classes of this species. Additionally, because a species' density tolerance may be heavily influenced by a number of other factors, further investigation into these variables and their influence upon sturgeon growth and survival at various rearing densities is warranted. These include genetic variation, the presence of pathogens (LaPatra et al. 1996), water temperature, dissolved oxygen content, feed rate, and loading density or water exchange rate (Piper et al. 1982).

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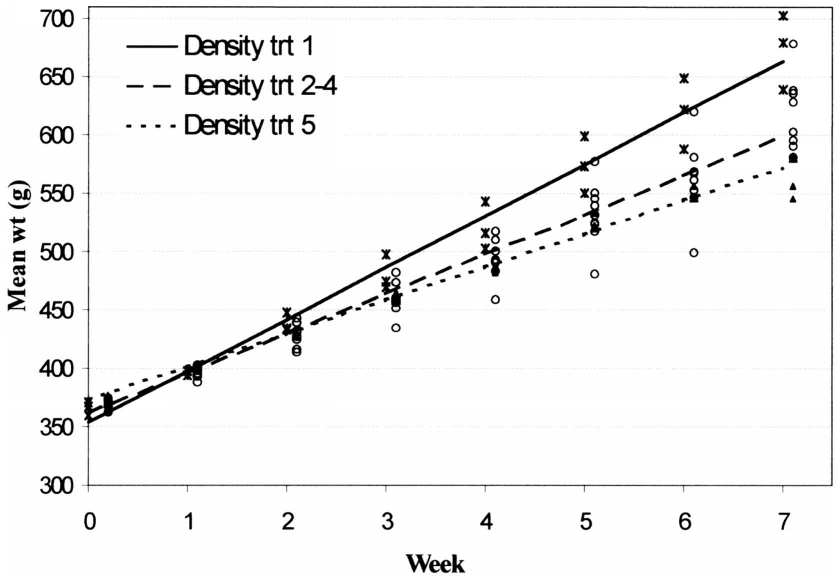

FIGURE 2.—Estimated linear growth of Atlantic sturgeon juveniles reared at five different densities for 7 weeks, as determined from mean weights. As the regression lines for density treatments 2, 3, and 4 were not significantly different from each other, those data were pooled. The observed mean tank values are also shown. Asterisks denote observations for density treatment (trt) 1, circles observations for treatments 2, 3, and 4, and triangles observations for treatment 5.

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