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Growth of Juvenile Lake Sturgeon Reared in Tanks at Three Densities

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Abstract.—Juvenile (106-d-old) lake sturgeon *Acipenser fulvescens* were reared at three densities, 150, 300, and 450 fish/m^2 (1.35, 2.5, and 3.75 kg/m^2), for 5 weeks to determine if rearing density affected growth. Feeding rates of fish fed on chironomid larvae (72%, wet weight), brine shrimp *Artemia* sp. (8%), and euphausiids (krill, 20%) ranged from 15% to 34% body weight per day and varied with water temperature and diet. Food conversion (weight of food fed/weight gained) averaged 7.2 during the 5 weeks. Juvenile lake sturgeon increased in mean length from 127 to 169 mm (33%) and in mean weight from 8.5 to 21.1 g (147%). However, changes in length and weight did not differ significantly among the three rearing densities, and patterns of change in length and weight were consistent among the three rearing densities. We conclude that rearing densities of 150–450 fish/m^2 (1.35–3.75 kg/m^2) are equally acceptable for rearing lake sturgeon for stocking.

Techniques to culture lake sturgeon *Acipenser fulvescens* in Wisconsin were first described by Czeskleba et al. (1985). Since the early 1980s, the Wisconsin Department of Natural Resources (WDNR) has collected, hatched, and reared lake sturgeon for research and population restoration within the historic range of the species in Wisconsin, which includes the Great Lakes, Mississippi River, and other major river systems in the state. Eggs and fingerlings have been provided to other midwestern states for research and restoration. Increased demand for juvenile lake sturgeon from the Wild Rose State Fish Hatchery (WRSFH) prompted us to conduct tank-rearing studies to determine if growth was related to rearing density. Juvenile lake sturgeon prefer live food (*Tubifex* spp. and earthworms [Lumbricidae]) over formulated foods, and the initial food offered to lake sturgeon larvae affects their willingness to accept some foods (Czeskleba et al. 1985).

The only lake sturgeon rearing density information available is from the State of Missouri, which rears juvenile (127-mm total length) lake sturgeon at a mean rearing density of 215 fish/m^2 (J. Hamilton, Missouri Conservation Department, personal communication). No studies of rearing densities have been reported for *Acipenser* spp. of North America. Feeding trials have been reported for white sturgeon *A. transmontanus* (Cui et al. 1997) and Atlantic sturgeon *A. oxyrinchus* (Mohler et al. 1996), and the effect of temperature on growth was reported for lake sturgeon (Wehrly 1995). Our objective was to determine if growth and survival of juvenile lake sturgeon were affected by rearing density. This information will help fish culturists determine optimal rearing densities for hatchery production of lake sturgeon.

Methods

A rearing density study was initiated at the WRSFH on August 23, 1993, when lake sturgeon were 106 d old. These juvenile lake sturgeon were produced from eggs taken from spawning adults

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TABLE 1.—Diet composition, amount fed, feeding rate (percent body weight per day, BWD) and food conversion rate (wet weight of food fed/weight gained) over a 5-week study of juvenile lake sturgeon at the Wild Rose State Fish Hatchery, Wisconsin.

	Diet (%)					
Week	Chironomid larvae	Brine shrimp	Krill	Amount fed (kg)	Feeding rate (% BWD)	Food conversion rate
1	67	33		108.6	34	6.9
2	51	5	44	73.5	17	8.6
3	55		45	83.4	17	4.9
4	72		28	91.2	15	8.8
5	100			126.4	19	8.3
Mean	72	8	20	96.6	20	7.2

in the Wolf River, Lake Winnebago system. Most of the lake sturgeon hatched on May 9, 1993. Before the study, juveniles were fed a diet of newly hatched brine shrimp *Artemia* sp., adult brine shrimp, zooplankton, and *Tubifex* spp.

The juvenile lake sturgeon were randomly separated into nine tanks at three densities, 300, 600, and 900 fish/tank, with three tanks per rearing density. Rearing tanks were of equal size, $3.66 \times 0.56 \times 0.61$ m (2.0-m^2, 1.25-m^3) and held 1,136 L of water with a flow-through rate of 38 L/min. The water supply of each tank was independent of the others. Area is considered more important than volume for lake sturgeon because of their benthic orientation. Rearing densities were therefore 150, 300, and 450 fish/m^2 (1.35, 2.50, and 3.75 kg/m^2). Total wet weight (g) was measured at the beginning and end of the study, and a sample of 30 individuals was measured for total length (mm) at the end of the study. At weekly intervals, 25 individuals from each tank were individually measured for total length (mm), and total weight (g) was measured for each tank.

Fish were hand-fed combinations of frozen chironomid larvae, adult brine shrimp, and euphausiids (krill) twice daily for 5 weeks (Table 1). Feeding occurred over a half-hour period, as small amounts of food were provided until the lake sturgeon stopped feeding (fed to satiation). The amount of food was adjusted daily based on the amount that was accepted. Lake sturgeon were considered full when they stopped swimming and began to rest on the bottom. Food conversion rate was determined as the ratio of wet weight of food fed to weight gained (Piper et al. 1992). Water temperature (°C) was recorded at 0800 and 1500 hours each day, and dissolved oxygen (mg/L) of each tank was recorded at the beginning and midpoint of the study. Disease treatments were not needed during the study.

We tested the effect of rearing density on lake sturgeon growth with repeated-measures analysis of variance (ANOVA). We considered individual lake sturgeon to be pseudoreplicates of the treatments and tanks as replicates of the three rearing densities (Hurlburt 1984). The same fish were not measured each week, but weekly estimates of average fish length and weight in each tank were repeated measures of the same fish population in each tank (Neter et al. 1996). We therefore treated average lengths and weights at the start of the study and in five successive weeks as dependent variables and rearing densities as the independent variable (SPSS 1998).

Results

Daily food intake by lake sturgeon was 15–34% body weight per day (BWD; Table 1). Based on a prior study (Czeskleba et al. 1985), frozen food composed of 67% chironomid larvae and 33% brine shrimp was provided at 34% BWD at the start of the study. The diet was adjusted during weeks 2–4, and 28–45% frozen krill was added to the diet at 15–17% BWD. Krill was unavailable during week 5, so 100% chironomid larvae was provided at 19% BWD.

Mean lengths of lake sturgeon did not differ significantly among rearing densities during the 5-week study (density effect, Table 2; Figure 1). Mean lengths increased significantly from 126–129 mm at the start of the study to 168–171 mm after 5 weeks among the three rearing densities (week effect, Table 2). The pattern of mean lengths among the three rearing densities remained similar during the 5 weeks (week × density interaction, Table 2). Growth in length was nearly linear and accounted for nearly 95% of the variation in mean length among weeks ($F = 1{,}916.88$; df = 1, 6; $P \leq 0.001$).

Mean weights of lake sturgeon did not differ significantly among rearing densities (density effect, Table 2; Figure 2). Mean weights increased significantly from 8.3–8.9 g at the start of the study to 20.3–22.1 g after 5 weeks among the three rearing densities (week effect, Table 2). The pattern of mean weights among the three rearing densities remained similar during the study (week × density interaction, Table 2). Growth in weight was nearly linear, accounting for more than 99% of the variation in mean weight among weeks ($F = 860.44$; df = 1, 6; $P \leq 0.001$).

Lake sturgeon gained an average of 4.2% BWD

TABLE 2.—Repeated measures analysis of variance of changes in length and weight of 106-d-old lake sturgeon reared at three densities (150, 300, and 450 fish/tank) in three tanks per density over 5 weeks at the Wild Rose State Fish Hatchery, Wisconsin.

Source	Sum of squares	Degrees of freedom	Mean square	*F*	*P*
Length (mm)					
Between tanks					
Density	26.13	2	13.07	0.077	0.93
Error	1,021.36	6	170.23		
Within Tanks					
Week	12,090.62	5	2,418.12	588	0.00
Week × density	62.91	10	6.29	1.53	0.18
Error	123.45	30	4.11		
Weight (g)					
Between tanks					
Density	15.28	2	7.63	0.54	0.61
Error	84.32	6	14.05		
Within tanks					
Week	965.71	5	193.14	529	0.00
Week × density	2.86	10	0.29	0.78	0.64
Error	10.95	30	0.36		

at all three rearing densities. However, weight gain declined from week 1 (4.9% BWD) to week 5 (2.1% BWD) as water temperature declined from 20°C to 13°C. Weight gain was therefore positively related to water temperature (Figure 3). The largest deviation from the linear correlation occurred in week 2 at 18°C, when krill were added to the diet (Table 1).

Food conversion averaged 7.2 over all rearing densities during the study (Table 1). The average conversion was 7.3 (range, 7.0–8.3) in low-density tanks, 7.1 (range, 6.7–7.5) in medium-density tanks, and 7.2 (range, 6.9–7.4) in high-density tanks. The similar conversion rates among the three rearing densities suggest that fingerling lake sturgeon grew equally in low- and high-density tanks.

Mortality during the 5-week study was insignificant, 0.6% in low-density tanks, 0.0% in medium-density tanks, and 0.1% in high-density tanks. Dissolved oxygen was high throughout the study and averaged 11.5 mg/L (range, 8.3–14.0 mg/L) among

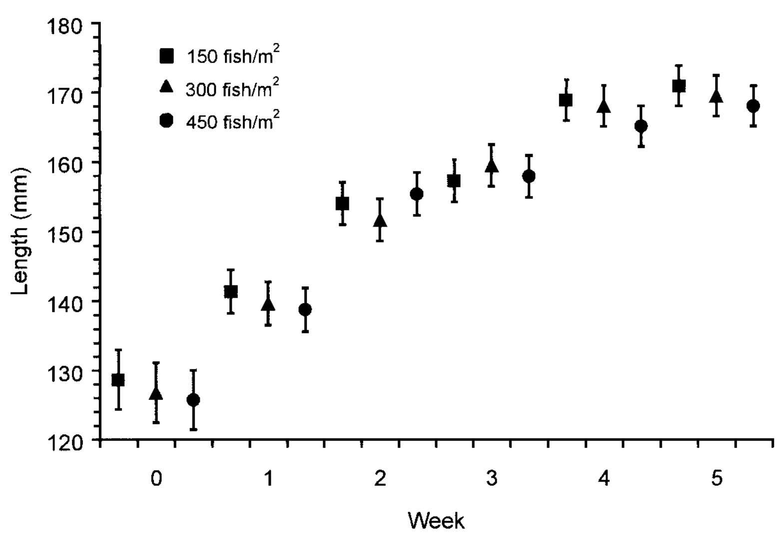

FIGURE 1.—Mean (±SE) length of juvenile lake sturgeon at three rearing densities (150, 300, and 450 fish/m^2) during a 5-week period at the Wild Rose State Fish Hatchery, Wisconsin.

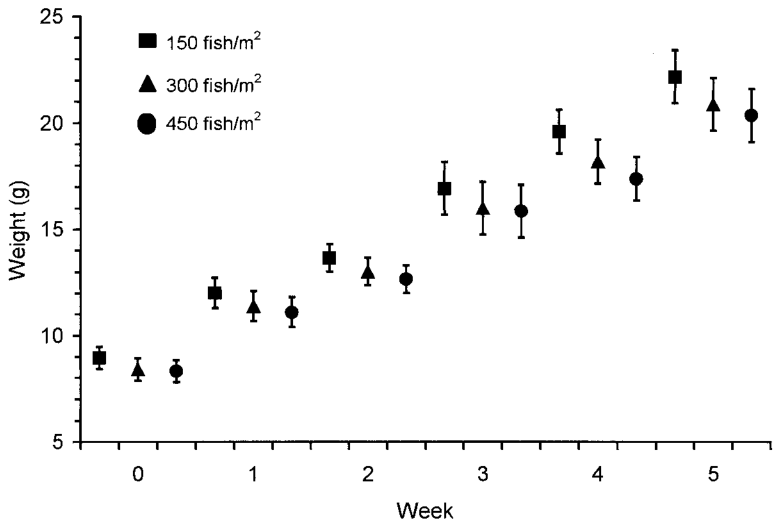

FIGURE 2.—Mean (±SE) weight of juvenile lake sturgeon at three rearing densities (150, 300, and 450 fish/m^2) during a 5-week period at the Wild Rose State Fish Hatchery, Wisconsin.

all the tanks. Dissolved oxygen averaged 11.7 mg/L in low-density tanks, 11.1 mg/L in medium-density tanks, and 11.6 mg/L in high-density tanks.

Discussion

Growth of lake sturgeon was similar at the three rearing densities tested in this study. This suggests that juvenile lake sturgeon (100–140 d, 8–22 g) may be reared at densities of 450 fish/m^2 (3.75 kg/m^2) of tank bottom without sacrificing growth of the fish. Mohler et al. (1996) studied growth of Atlantic sturgeon reared on artificial diets at tank densities of 1.74 kg/m^3, which is considerably lower than our highest tank density (6.0 kg/m^3). We believe that tank area is more critical than tank volume because of the benthic orientation of lake sturgeon. Mohler et al. (1996) reared their fish at 16–18°C, which is similar to temperatures in our study (14–20°C).

Feeding rates and BWD decreased as water temperature decreased. Diet changes during week 2 of the study may have reduced weight gain (BWD)

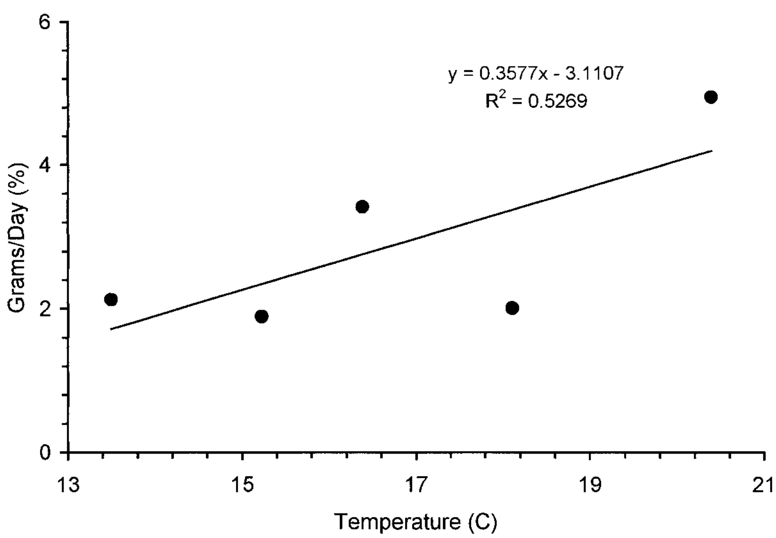

FIGURE 3.—Percent change in body weight per day by juvenile lake sturgeon versus mean water temperature (°C) each week (filled circles) during a 5-week period at the Wild Rose State Fish Hatchery, Wisconsin.

and increased variation in the correlation between water temperature and percent BWD. Normally, lake sturgeon take several days to adjust to diet changes. Therefore, lake sturgeon reared on a uniform diet would probably grow better than those in our study.

Wehrly (1995) reported that lake sturgeon growth increased as water temperature increased from 7°C to 23°C. However, he observed excessive mortality (45%) at 23°C, and concluded that 23°C may be near the upper tolerance limit for juvenile lake sturgeon. Growth increased from 0.71% BWD at 10°C to 1.52% BWD at 23°C (Wehrly 1995). Lake sturgeon grew faster in our study, 4.2% overall BWD, increasing from 1.9% at 15°C to 4.9% at 20°C. In our study, growth was greatest at 20°C, but our study was not designed to determine the optimum temperature for rearing lake sturgeon.

Cui et al. (1997) suggested that juvenile white sturgeon grew best when continuously fed (24 h) small amounts of food by automatic feeders. We hand-fed lake sturgeon to satiation twice daily. This allowed us to visually observe the feeding and rearing condition of the lake sturgeon and also allowed us to adjust the daily feeding rate so there was little waste.

In the future, similar trials should be conducted at higher rearing densities to determine the upper limits of density at which growth may be affected. We do not know if rearing lake sturgeon at a higher density will reduce their survival after release. Survival of lake sturgeon after stocking should be determined for several rearing densities. Studies of other fish species suggests that low rearing densities lead to higher survival after release into the wild. However, if the condition and health of lake sturgeon is not reduced by rearing density, their chances of survival in the wild would probably not be adversely affected.

Acknowledgments

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