

TECHNICAL NOTES

The Effects of Stocking Density on Survival, Growth, Condition, and Feed Efficiency of Bluegill Juveniles

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Abstract.—Juvenile bluegills *Lepomis macrochirus* were reared at four densities in indoor aquaria to evaluate the effects of stocking density on growth, survival, condition, and feed efficiency. Fish (mean weight, 1.76 g) were stocked into 100-L aquaria containing 60 L of water at rates of 10, 20, 30, and 40 fish per aquarium (167, 334, 500, and 667 fish/m³, respectively). The growth trial was conducted over an 11-week period during which the fish were offered a 45%-protein commercial ration in slight excess. At the termination of the study, the mean weights as well as the lengths and weights of individual fish in each tank were recorded. Size was inversely related to stocking density. The final weights of the fish decreased significantly as density increased, with fish stocked at a density of 167/m³ having a mean weight of 10.7 g and those stocked at 667/m³ a mean weight of 7.3 g. The percent weight gain and feed efficiency also decreased as stocking density increased. No significant differences in relative condition were found among treatments. The results of this study suggest that density-dependent, nonaggressive competition resulted in reduced growth and feed utilization.

The bluegill *Lepomis macrochirus* is a commercially desirable aquaculture candidate that exhibits good growth and reproductive capacity (Brunson 1983), broad temperature tolerance (Brunson and Robinette 1985), ready acceptance of commercial feeds (Ehlinger 1989), and high palatability (McLarney 1998; Wang et al. 2000). This sunfish is primarily reared as a prey item in production ponds for largemouth bass *Micropterus salmoides* (Masser 1998) and as a recreational game fish (McLarney 1998). Owing to these recreational demands, there is considerable interest in the culture of bluegills. Historical experience with raising bluegills as a prey item provides limited information about their growth response in intensive culture settings and laboratory environments (Bryan et al. 1994).

In most of the published empirical work involving bluegills, the research was unrelated to

culture techniques and thus the exact culture methods are not described. Examples of this research include back-calculation models for estimating growth (Klumb et al. 2001), the effects of hypoxia on RNA–DNA ratios (Aday et al. 2000), and predation by hydra *Hydra* spp. on larval bluegills (Elliott et al. 1997). Moreover, most of the published data on the culture requirements involve the hybrid between the green sunfish *L. cyanellus* and the bluegill. The lack of empirical data concerning the effects of culture density on survival, growth, condition, and feed efficiency has slowed the successful monoculture of bluegills.

McComish (1971) attributed growth depreciation among groups of bluegills to aggressive behavior. Baker and Ayles (1990) reported a positive correlation between culture density and aggressive behavior among hybrid sunfish, while Tidwell and Webster (1992) and Tidwell et al. (1994) found a consistent decrease in growth with increasing stocking density, indicating the possibility of competitively reduced feed utilization. In the present study, we evaluated the survival, growth, condition, and feed efficiency of bluegills maintained in a controlled environment at various stocking densities.

Methods

The study was conducted at the North Auburn University Fisheries Unit in Auburn, Alabama. Twelve 100-L aquaria filled with 60 L of water that were connected to a common biological filter, a rapid-rate sand filter, and a circulation pump were used. Daily water exchange in the aquaria was 30 L/h (12 times daily). Temperature and total ammonia nitrogen were consistently measured at 29 ± 1°C (mean ± SE) and at less than 0.05 mg/L, respectively.

Juveniles (1.76 ± 0.06 g) were obtained from the same pond population, acclimated to laboratory conditions over 2 weeks, and then stocked at 10, 20, 30, and 40 per aquarium, resulting in density treatments of 167, 334, 500, and 667 fish/m³.

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TABLE 1.—Response of juvenile bluegills (initial weight, 1.76 ± 0.06 g [mean \pm SE]) to increasing stocking density over an 11-week growth trial. Data represent the means of three replicates. Based on the Student–Newman–Keuls test, mean values in any column sharing the same lowercase letter are not significantly different ($P < 0.05$).

Density (fish/m ³)	Survival (%)	Initial weight (g)	Final weight (g)	Weight gain ^a (%)	Coefficient of variation ^b	Final length (mm)	Relative condition ^c (%)	Feed efficiency ^d (%)
167	100.0 z	1.70 z	10.67 z	522.9 z	0.33 x	81.20 z	99.08 z	65.39 z
334	100.0 z	1.73 z	9.00 zy	428.1 y	0.44 xy	79.20 y	103.50 z	58.56 zy
500	100.0 z	1.77 z	7.80 y	343.3 yx	0.50 xy	82.10 z	99.44 z	53.22 yx
667	97.5 z	1.87 z	7.30 y	292.5 x	0.55 z	82.80 z	99.66 z	49.58 x
PSE ^e	0.72	0.05	0.54	27.3	0.04393	0.4927	1.15	2.17

^a [(final weight – initial weight) \times 100]/initial weight.

^b SD/mean of the final weights of individual fish within replicates.

^c $(W/W') \times 100$, where W is weight, W' is derived from the equation $\log_{10}W' = a' + b \cdot \log_{10}L_T$, and L_T is maximum total length.

^d (weight gain/offered feed) \times 100.

^e Pool standard error = $\sqrt{\text{Mean square error}/n}$; $n = 3$.

Three replicates were used per treatment. Fish were counted and weighed every 2 weeks. Casual observations of physical condition were made during these weighing periods to detect signs of aggressive activity (i.e., fin nipping or loss of scales). Fish were offered 45%-protein, 10%-lipid, water-stable fingerling starter pellets (Southern States Coop., Richmond, Virginia) twice daily. Feed was offered in slight excess based on the observed consumption, growth, and biweekly feed efficiency for the best-performing group. Rations were offered at 5% of body weight during the first 3 weeks, then reduced gradually to 2.5% during the subsequent 8 weeks.

At the termination of the study, the mean weights as well as the lengths and weights of individual fish in each tank were recorded and the general physical condition noted. Feed efficiency (FE) was calculated by means of the equation

$$\text{FE} = (\text{weight gain/offered feed}) \times 100.$$

The coefficient of variation (CV) of the final weights, defined as SD/mean, was used to standardize the variation between groups.

The relative condition factor (K_n) was employed to describe fish considered to be in good condition. The equation used, as described by Le Cren (1951), was

$$K_n = (W/W') \times 100,$$

where W is the weight of the individual fish and W' is the predicted length-specific mean weight for a fish in the population under study. The weight–length equation used to determine W' for our fish population was

$$\log_{10}W' = a' + b \cdot \log_{10}L_T,$$

where a' is the intercept, b is the slope, and L_T is the maximum total length (mm) of the individual fish (Anderson and Neumann 1996). Individual relative condition indices and individual lengths were pooled by tank prior to analysis.

All statistical analyses were conducted with the Statistical Analysis System (SAS Institute 1999). The initial weight, final weight, final length, percent weight gain, percent survival, FE, coefficient of variation of the final weights of individuals, and relative condition were analyzed by means of one-way analysis of variance to determine significant ($P < 0.05$) differences among treatment means. The Student–Newman–Keuls multiple-range test was used to evaluate significant differences among treatment means. Regression analyses were used to describe the effects of density on the dependent variables (survival, final weight, relative condition, growth, and feed efficiency).

Results

Bluegills were in good health throughout the study. Survival was greater than 97%, with no significant differences among treatments (Table 1). In general, the performance of the fish in terms of growth and feed utilization decreased as stocking density increased (Table 1). Fish grew significantly more at 167/m³ than at the high-density treatments of 500/m³ and 667/m³. Though there were significant differences in final weight among the lowest (167/m³) and highest (500/m³ and 667/m³) density treatments, the treatment with 334/m³ shared significant similarities with each of these groups (Table 1). There was a general increase in the coefficient of variation of the sizes of individuals within replicates as stocking density increased (Table 1). The variation in weights among fish maintained

at 667/m³ was significantly higher than that among fish maintained at 167/m³, but no significant difference in relative condition was found among treatments. Percent weight gain and feed efficiency decreased with increasing stocking density. Regressions of final weight, weight gain, and feed efficiency all showed negative correlations with density ($R^2 > 0.64$). Aggressive social interactions among fish were not apparent during feeding, and no signs of injury were observed on the fish during the biweekly weighing periods or at the end of the study.

Discussion

Stocking densities had no effect on the survival or relative condition of the bluegills in this study. However, a decrease in growth rate and feed efficiency and an increased coefficient of variation in fish weights were related to increased stocking density. McComish (1971) also showed that an increase in stocking density caused a decrease in growth among bluegills maintained in indoor tanks. Wang et al. (2000) reported better growth in aquaria among juvenile hybrid sunfish maintained at 200/m³ than among fish maintained at 800/m³. Moreover, Matthews (2000) found a reduction in the growth rate of bluegills in ponds with increasing stocking densities. The present experiment showed growth depreciation of bluegills maintained in aquaria as stocking densities increased from 167/m³ to 334/m³.

Various authors have reported no effect of stocking density on the survival of sunfish in aquaria or ponds (Tidwell et al. 1994; Wang et al. 2000). In contrast, Matthews (2000) reported better survival in ponds with increasing stocking density. In our study, the increase in size variation among treatments associated with an increase in density and the lack of physical injury to fish suggest non-aggressive competition among bluegills. However, we did not make observations on social behavior. McComish (1971), Baker and Ayles (1990), and Wang et al. (2000) reported detrimental social interactions among sunfish, in which fish growth, performance, and food consumption were reduced because of high fish densities.

Feed efficiency was correlated with stocking density. Wang et al. (2000) also reported a reduced rate of gross growth efficiency with increased density. In their study, the gross growth efficiency of hybrid sunfish declined sharply between the medium- and high-density treatments. However, Tidwell and Webster (1992) and Tidwell et al. (1994) found no effect of stocking density on feed effi-

ciency in hybrid sunfish. Discrepancies between studies might be related to the use of aquaria instead of ponds as well as to differences in diet, water temperature, and stocking density. Furthermore, natural habitats have areas of refuge from aggressive competitive behavior by conspecifics. Lack of refugia and the absence of natural productivity in laboratory settings make the growth and feed efficiency of fish in aquaria different from those of fish in ponds. In summary, increases in the stocking density of juvenile bluegills did not affect survival but did reduce growth rates and feed efficiency.

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