

Do Channel Catfish Stockings Affect Growth and Size Structure of Bluegills in Small Impoundments?

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Abstract.—Channel catfish *Ictalurus punctatus* are commonly stocked into small impoundments and may become abundant in these waters. When channel catfish are abundant, they may compete with bluegills *Lepomis macrochirus* for macroinvertebrate prey, resulting in reduced growth and size structure of bluegills. I determined whether bluegill growth and size structure were related to the varying abundance of channel catfish by means of two experimental pond studies and small-lake survey data. In the first pond experiment, 16 ponds were stocked with bluegills at 39.5 kg/ha and with channel catfish at a rate of 10, 30, 50, or 100 kg/ha (4 ponds/treatment). In the second pond experiment, 12 ponds were stocked with one of four bluegill–channel catfish biomass combinations (3 ponds/treatment): 15 and 70 kg/ha, 15 and 130 kg/ha, 70 and 70 kg/ha, or 70 and 130 kg/ha. Bluegill growth increments (both length and mass) did not decrease with increases in channel catfish biomass in either experiment, but both fish species exhibited density-dependent growth. Macroinvertebrate biomass did not differ among treatments for either experiment. Bluegill proportional stock density, relative stock density for fish of 203 mm total length (TL) or more, relative weight, and mean TL at ages 3 and 4 for females and males did not differ among lakes stocked with 12, 37, or 74 channel catfish fingerlings·ha⁻¹·year⁻¹. However, channel catfish abundance varied greatly among lakes within a given stocking rate. When bluegill population characteristics were compared with channel catfish catch per unit effort (CPUE; fish/tandem hoop-net series), there was a general pattern in which bluegill variables were highly variable at low to moderate channel catfish CPUE but consistently low at high channel catfish CPUE (>200 fish/tandem hoop-net series). Thus, bluegill growth and size structure may only be reduced when channel catfish are highly abundant.

Channel catfish *Ictalurus punctatus* (usually large fingerlings >175 mm total length [TL]) are commonly stocked to maintain populations in many small impoundments (hereafter termed lakes) in the Midwest and southern United States (Michaletz and Dillard 1999). Natural recruitment of channel catfish is often negligible in these systems because of predation by largemouth bass *Micropterus salmoides* and other predators (Marzolf 1957; Krummrich and Heidinger 1973; Spinelli et al. 1985; Storck and Newman 1988). Consequently, channel catfish biomass is usually very low in the absence of stocking but can reach high levels in annually stocked lakes (Hill 1984; Mitzner 1999).

High biomass of channel catfish may lead to reduced growth rates of channel catfish and other fishes through competition for food resources (Mitzner and Middendorf 1976; Hubert 1999). Growth of channel catfish is often density dependent (Hubert 1999; Mitzner 1999), implying that intraspecific competition may occur. There is also some evidence that interspecific competition between channel catfish and other species occurs. Crance and McBay (1966) found that the average mass

of bream (mostly bluegills *Lepomis macrochirus*) in the first year of fishing in small ponds was about 30% lower in ponds stocked with channel catfish at a rate of 371 fish/ha than in ponds stocked at 124 fish/ha, suggesting that channel catfish may have competed with bluegills for food. Bluegill growth rates and body condition decreased after initiation of a channel catfish stocking program in Williamson Pond, Iowa (Mitzner and Middendorf 1976). Hill (1984) found that growth rates and body condition of both bluegills and channel catfish were poor in Slip Bluff Lake, Iowa, where biomass of channel catfish was 614 kg/ha. Mitzner (1989) suspected competition between channel catfish and bluegills in a lake with low macroinvertebrate biomass (1 g/m²) due to copper sulfate treatments. Both channel catfish and bluegills exhibited slow growth rates and poor body condition. These studies suggest that channel catfish may compete with bluegills for food resources when channel catfish biomass is high and when macroinvertebrate biomass is low; both channel catfish and bluegills rely heavily on macroinvertebrates for food (Werner et al. 1983; Schramm and Jirka 1989; Hubert 1999; Michaletz, in press). However, the level of stocking and abundance of channel catfish at which adverse effects on bluegills occur is unknown but probably depends on many

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factors, including the abundances of both species relative to their shared prey resources (Connell 1983; Schoener 1983).

Bluegills provide important fisheries in many small lakes, and recent management efforts have focused on increasing the size of bluegills through angler harvest restrictions (Coble 1988; Muoneke 1992; Beard et al. 1997; Kruse 1997; Reed and Parsons 1999). If channel catfish do compete with bluegills for food resources, then fisheries managers may need to adjust their management strategies accordingly. If the management goal for a small lake is to produce large bluegills, stockings of channel catfish may have to be reduced or eliminated in order for bluegills to grow fast enough to achieve this goal.

Because there is much uncertainty about whether and under what conditions channel catfish negatively affect bluegills, I determined whether bluegill growth rates and size structure were related to the varying abundance of channel catfish that is commonly found in small lakes. To accomplish this objective, I used a combination of experimental pond studies and small-lake surveys to compare growth and size structure of bluegills with channel catfish abundance. I used lake productivity (indexed by total chlorophyll α concentration [CHLA]) as a covariate in the small-lake analyses because it can influence macroinvertebrate community structure and biomass (Mosher 1999; Michaletz et al. 2005) and, ultimately, fish growth (Mosher 1999).

Methods

Pond experiments.—Experiments were conducted in 0.2-ha research ponds located at Little Dixie Lake Conservation Area near Millersburg, Missouri, to evaluate whether bluegill growth was related to differences in channel catfish biomass (1999) or channel catfish and bluegill biomass (2000). These drainable, rectangular ponds were all similar in morphometry and contained concrete catch basins with a maximum depth of about 3 m. Prior to the experiments, ponds were completely drained and all resident fish were removed. Then the ponds were refilled with filtered lake water from nearby Little Dixie Lake to reduce the likelihood of contamination by unwanted fish.

For the 1999 experiment, 16 ponds were stocked with 28 kg/ha (mean number of fish per pond \pm SE = 144 ± 1.5) of age-2 bluegills (mean TL \pm SE = 128 ± 0.2 mm) and 11.5 kg/ha (about 640 fish/pond) of age-1 bluegills (63 ± 0.6 mm TL) during March 2–4, 1999. The bluegills were obtained from Hunnewell Hatchery, located near Hunnewell, Missouri. Bluegill biomass in the ponds was on the low end of the range of biomasses

found in small lakes (Hackney 1978). However, I expected bluegills to reproduce and substantially increase their biomass during the experiment. On March 11, 1999, ponds were stocked with channel catfish (270 ± 1.4 mm TL) from Chesapeake Hatchery, Mount Vernon, Missouri, at either 10 (mean number of fish per pond \pm SE = 11 ± 1.0), 30 (32 ± 1.8), 50 (54 ± 2.3), or 100 (110 ± 5.6) kg/ha (four ponds assigned to each treatment). These treatments were considered to constitute low (L), medium (M), high (H), and very high (VH) channel catfish biomass, respectively. These biomasses spanned the range commonly found in small lakes (Hackney 1978) and approximated the biomasses that would occur with stocking rates of 12, 37, 74, and 125 fish·ha⁻¹·year⁻¹ given a 50% annual survival rate.

Prior to stocking, fish were held in a single raceway for each species to allow for mixing of all fish. A single length–mass equation was developed for both species by measuring (nearest mm TL) and weighing (nearest g for channel catfish and age-2 bluegills; nearest 0.1 g for age-1 bluegills) 50 individuals; the equation was then used to estimate mass of all stocked fish. Total lengths of all stocked age-2 bluegills and channel catfish were measured immediately before stocking. Only TLs of age-1 bluegills in a single subsample ($N = 212$ fish) were individually measured to lessen handling stress. Because of high mortality, the measured individuals were not stocked but were instead used to estimate the length distribution of age-1 bluegills in all of the ponds. Age-1 green sunfish *L. cyanellus* and hybrid sunfish (green sunfish \times bluegill) were mixed in with age-1 bluegills and could not be easily separated; therefore, they were stocked into the ponds along with the bluegills. They represented about 5% of the fish in the subsample of age-1 bluegills. There were no significant differences in TL of stocked age-2 bluegills (analysis of variance [ANOVA]: $F = 0.56$; $df = 3, 2,294$; $P = 0.64$) or channel catfish ($F = 0.43$; $df = 3, 824$; $P = 0.74$) among treatments or in TL of age-2 bluegills among ponds ($F = 1.64$; $df = 15, 2,282$; $P = 0.06$). The significant difference ($F = 2.66$; $df = 15, 812$; $P = 0.006$) in channel catfish TL among ponds was probably due to chance because of the low numbers of fish in L ponds. The maximum difference in mean TL among ponds was 31 mm.

Water quality and zooplankton data were collected monthly during April through October from each pond. Water quality parameters included temperature ($^{\circ}$ C), dissolved oxygen (mg/L), Secchi depth (m), turbidity (nephelometric turbidity units [NTU]), and CHLA (μ g/L). Temperature and dissolved oxygen were measured with a meter at the surface and at 1-m intervals to the bottom (about 3 m deep) of the catch basin. Turbidity and CHLA were measured from surface water samples

using a turbidity meter and by ethanol extraction and spectrophotometry (APHA 1985), respectively. Measurements of CHLA were taken for two samples and averaged. Zooplankton was collected with two vertical tows of an 80- μm Wisconsin plankton net. Tows were made from the bottom to the surface in the catch basin of each pond and were processed separately.

Zooplankton samples were subsampled, and all organisms within the subsample were identified and counted. Zooplankton was identified as cyclopoid copepods, calanoid copepods, copepod nauplii, rotifers, or to genus for cladocerans. Counts within subsamples were used to estimate zooplankton density (number/L). At least 100 randomly selected individuals were measured for length with procedures in Culver et al. (1985) for each pond and date. Individual dry mass was estimated by converting length measurements to dry mass using length–dry mass relationships (Dumont et al. 1975; Rosen 1981; Culver et al. 1985) and adjusting for preservation effects (Giguère et al. 1989). Total zooplankton biomass (dry mass; mg/L) was estimated by multiplying the average dry mass per taxon by the corresponding density estimate and summing these estimates over all taxa. Rotifers and copepod nauplii were excluded from biomass estimates because they were not found in channel catfish or bluegill stomachs (P.H.M., unpublished data).

Macroinvertebrates were collected in May, July, and September by pushing a 0.25-m² column sampler (0.5 m long \times 0.5 m wide \times 1.2 m high) into the substrate to delineate the sampling area; a 500- μm mesh dip net was then used to collect macroinvertebrates within the column sampler. When the sampler was placed in the substrate, it completely sealed off the entire water column, thus preventing escape by macroinvertebrates. The dip net was used to disturb the substrate and collect all macroinvertebrates and vegetation within the sampler. Three samples were collected from randomly chosen locations within the shallow two-thirds of each pond. It was not possible to sample the deep one-third because of steeply sloping banks and deep (>1.2-m) water. Macroinvertebrate samples were preserved in a 10% formalin solution.

In the laboratory, macroinvertebrates were removed from vegetation and sediment, identified to order or family, and counted. Vegetation was separated into periphyton and vascular plants, blotted dry, and weighed to the nearest 0.01 g. For each pond and date, 10 randomly selected individuals from each macroinvertebrate taxon were measured for length (exclusive of setae and spines), and dry mass (excluding shells or cases) was estimated using length–dry mass equations (Leeper and Taylor 1998; Benke et al. 1999; P.H.M., unpublished data; G.

Mittelbach, Michigan State University, Kellogg Biological Station, Hickory Corners, unpublished data). The average dry mass of *Hydra* spp. was assumed to be 5 μg (D. Pascoe, Cardiff University, Cardiff, UK, personal communication). Biomass of all benthic invertebrates (dry mass, g/m²) was estimated by multiplying the average dry mass per taxon by the corresponding density estimate and summing these estimates over all taxa.

Fish were removed from the ponds after draining during October 25 through November 1, 1999. All fish were removed from the ponds except for a few small age-0 sunfish *Lepomis* spp. that were stranded in vegetation in the pond basin. One channel catfish was lost down the outlet of one H pond. Large fish (≥ 100 mm TL) were counted and weighed in aggregate by species. All large fish were usually measured (TL), and either all or a subsample of fish (≥ 30 fish) were individually weighed. In one pond, measurements were not taken from all large bluegills because of the presence of large numbers of 100–115-mm individuals. Small bluegills, green sunfish, and hybrid sunfish (<100 mm TL) were weighed together, and a subsample was taken to determine the total number of each species in the pond. Small sunfish within the subsample were individually measured and weighed. Length–mass equations were developed for each species in each pond and were used to estimate mass of fishes that were not individually weighed.

The effect of treatments (varying channel catfish biomass) on water quality, vegetation (periphyton and vascular plants), zooplankton, macroinvertebrates, bluegill and channel catfish growth and survival, and final fish biomass was analyzed with ANOVA. In addition to total zooplankton biomass, biomasses of *Daphnia* spp., *Bosmina* spp., cyclopoid copepods, and calanoid copepods were analyzed separately. Likewise, the biomasses of chironomids, nonmollusk macroinvertebrates, and mollusks were analyzed separately and in combination. Replicate samples in each pond were averaged, and these means were used in the analysis. Water quality, vegetation, zooplankton, and macroinvertebrate variables were log_e transformed prior to analysis with repeated-measures ANOVA. The significance level for these and all statistical tests was set at 0.05. One-way ANOVA (followed by Tukey's Studentized range test for significant ANOVAs) were used to analyze treatment effects on fish growth, survival, and final biomass. Bluegill and channel catfish growth were determined by measuring the average change in length (mm) and mass (g) from the start to the end of the experiment. It was not possible to separate age-1 from age-0 bluegills based on length-frequency distributions in several ponds, so

growth was only determined for age-2 fish; there was minimal overlap in length-frequency distributions between age-1 and age-2 bluegills. In most cases, only a few individuals could not be clearly separated into ages 1 and 2, but in three ponds (two M ponds and one H pond) about 10–15 individuals could not be clearly separated. These fish were assigned to age 2 if they were at least 130 mm TL based on observed shifts in modes of age-2 fish. Additionally, I assigned age 2 to all 120-mm TL and larger bluegills (this included all of the questionable fish) for these three ponds and compared the results with those generated by the 130-mm criterion to determine the potential effects of incorrectly assigning fish to age-classes. Survival was estimated as the proportion of fish surviving the experiment and was arcsine square root transformed prior to ANOVA.

For the 2000 experiment, bluegills and channel catfish obtained from ponds in the 1999 experiment were used to stock ponds. After the 1999 experiment, both species were allowed to overwinter in ponds (separate ponds for each species) and were then transferred to a single raceway for each species during the following spring to ensure mixing of fish prior to stocking. Twelve ponds were stocked in late March and early April 2000 with one of four bluegill–channel catfish biomass treatments: low bluegill–low channel catfish (LBLC; 15 and 70 kg/ha), low bluegill–high channel catfish (LBHC; 15 and 130 kg/ha), high bluegill–low channel catfish (HBLC; 70 and 70 kg/ha), and high bluegill–high channel catfish (HBHC; 70 and 130 kg/ha). Three ponds were assigned to each treatment. Ten grass carp *Ctenopharyngodon idella* (200–250 mm TL) were added to each pond to control aquatic vegetation. For bluegills, an average of 104 (SE = 3) and 500 (SE = 13) individuals were stocked into low- and high-biomass ponds, respectively. For channel catfish, an average of 42 (SE = 1) and 79 (SE = 3) individuals were stocked into low- and high-biomass ponds, respectively. At stocking, bluegills averaged 117 mm TL (SE = 0.4) and stocked channel catfish averaged 354 mm TL (SE = 2). Prior to stocking, a single length–mass equation was developed for each species by measuring (nearest mm TL) and weighing (nearest g) 50 individuals and was used to estimate mass of all stocked fish except for bluegills stocked into one LBHC pond. Because of a shortage of bluegills, some bluegills from nearby Little Dixie Lake were stocked into this LBHC pond to supplement those from the raceway. Although bluegills from Little Dixie Lake were of similar lengths to those in the raceway, they were slightly heavier than raceway fish. Prior to stocking, bluegills from Little Dixie Lake were mixed with the remainder of the bluegills held in the raceway.

Fish were then randomly selected from this mixture to develop a single length–mass equation for the LBHC pond. Total lengths of all stocked bluegills and channel catfish were measured immediately before stocking. Also, bluegills were marked with a partial pectoral fin clip so that stocked individuals could be distinguished from those produced in the pond. Stocked bluegill TL did not differ among treatments ($F = 1.03$; $df = 3$, 3,620; $P = 0.38$), and channel catfish TL did not differ among treatments ($F = 1.29$; $df = 3$, 725; $P = 0.28$) or among ponds ($F = 1.06$; $df = 11$, 717; $P = 0.39$). There was a significant difference ($F = 2.46$; $df = 11$, 3,612; $P = 0.005$) in bluegill TL among ponds, but the range in mean lengths was less than 7 mm.

Pond preparation, data collection, pond draining, and sample processing followed the same procedures outlined for the 1999 experiment. The only exceptions were that all bluegills larger than 80 mm TL were checked for fin clips, and the TLs of all age-1 and older bluegills were measured. Ponds were drained during October 30 to November 1, 2000. Due to the 2×2 factorial design of the 2000 experiment, fish variables were analyzed with a two-way ANOVA that employed bluegill biomass and channel catfish biomass as main effects and included the interaction between bluegill and channel catfish biomass. Water quality, vegetation, and invertebrate data were transformed and analyzed with repeated-measures ANOVA as in 1999.

Small lakes.—Bluegill population characteristics were compared among small lakes stocked annually since 1998 with 12, 37, or 74 channel catfish fingerlings (mean TL = 230–250 mm) per hectare. Twenty-two lakes were randomly assigned to each of the two lower stocking rates, and 16 lakes were randomly assigned to the highest stocking rate. The study lakes were scattered across much of the state of Missouri but were concentrated in the northwestern quarter. They varied in size from 5 to 332 ha (mean = 42 ha) and ranged widely in productivity (CHLA mean = 30 ($\mu\text{g/L}$), range = 2–161 ($\mu\text{g/L}$); J. Jones, unpublished data; Missouri Department of Conservation [MDC], unpublished data). Fish communities consisted primarily of bluegills, largemouth bass, and channel catfish. Crappies *Pomoxis* spp., gizzard shad *Dorosoma cepedianum*, redear sunfish *L. microlophus*, and common carp *Cyprinus carpio* were also common in some lakes.

Bluegills were sampled in the study lakes in 2002 (two lakes), 2003 (two lakes), 2004 (42 lakes), and 2005 (14 lakes) using standardized spring (late April–early June, depending upon latitude) electrofishing surveys (Kruse 1993) conducted by MDC biologists. All sizes of bluegills were collected as the electrofishing boat (rectified DC) sampled shoreline areas of each

lake during the day ($N = 39$ lakes) or night ($N = 21$ lakes). Daytime sampling was conducted mostly in turbid lakes, whereas nighttime sampling was used for most clear lakes. Differences in bluegill size structure estimates derived from springtime day and night electrofishing samples appeared to be minimal for stock size (>75 mm TL) and larger fish, especially in turbid lakes (Dumont and Dennis 1997; Pierce et al. 2001), but catch rates of bluegills may be higher at night (Dumont and Dennis 1997; Pierce et al. 2001). Electrofishing effort averaged 1.0 h (SE = 0.06), and catch per unit effort (CPUE; fish/h) of stock-size and larger bluegills was computed. All bluegills were counted and measured, and proportional stock density (PSD) and relative stock density (RSD) for 203-mm and larger fish were computed for each bluegill population sample (Anderson and Gutreuter 1983). An average of 126 bluegills (SE = 15.4) was used to estimate PSD and RSD. Size structure indices of bluegills were compared among the three channel catfish stocking rates by use of ANOVA; CHLA and the interaction between stocking rate and CHLA were used as covariates. Bluegill CPUE was compared among channel catfish stocking rates by use of ANOVA. Both bluegill PSD and RSD (first expressed as decimal equivalents) were arcsine square root transformed, and CHLA and bluegill CPUE were $\log_e x$ transformed.

Although channel catfish abundance increased overall with stocking rate, it varied at least 10-fold among lakes assigned to a given stocking rate (P.H.M., unpublished data). Hence, bluegill variables may be more closely related to channel catfish abundance than stocking rate. Stepwise linear regression was used to examine relationships between channel catfish abundance and bluegill PSD and RSD, and CHLA was used as a potential covariate. Channel catfish abundance was indexed as the grand mean CPUE (fish/tandem hoop-net series) derived from standardized tandem hoop-net sampling in 2001, 2003, and 2005, except that CPUE was averaged over 2001 and 2003 for the four lakes that were sampled for bluegills in 2002 or 2003. This index represents the average condition that bluegill populations experienced throughout the study period. Bluegill variables and CHLA were transformed as for ANOVA, and channel catfish CPUE was \log_e transformed. Channel catfish CPUE was estimated by sampling each lake in May or June using four to eight series of tandem hoop nets (Michaletz and Sullivan 2002). Each series consisted of a string of three 25-mm-mesh hoop nets baited with waste cheese and fished for 3 d (Michaletz and Sullivan 2002).

Mean TL at age and relative weight (W_r) of bluegills were compared among the three channel catfish

stocking rates using 10 randomly selected lakes for each stocking rate. For this analysis, otoliths were removed from up to 10 bluegills per centimeter group for fish collected during the standardized surveys, except for one lake where bluegills were collected for aging in late October. In addition to being measured, bluegills used for aging were also weighed (nearest 0.1 g) and sexed. Relative weight (Anderson and Gutreuter 1983) was computed for each fish, and the mean W_r was computed for all weighed stock size and larger fish (both sexes combined) for each sampled population. Relative weight was computed for only 27 lakes because weight data were unavailable for two lakes and was not computed for the lake that was sampled in the fall because fall W_r may not represent spring W_r . Whole otoliths were aged with the aid of a dissecting microscope. An age-length key was developed for each sex and applied to the entire sample to estimated mean TL for each age. I assumed the sex ratio of the aged fish was representative of the entire sample. The von Bertalanffy growth equation was applied to mean TL-at-age data separately for each sex to predict mean TL at ages 3 and 4 for bluegills by use of FAST 2.0 software (Slipke and Maccina 2001). These ages were used to assess influences of channel catfish on bluegill growth because older ages were not present in several lakes. Predicted mean TL of bluegills was used because for some lake-sex combinations year-classes were missing or because sample sizes for a particular age were low. In most cases, the same mean TL for ages 1 and 2 was used for both sexes because these fish were mostly immature and did not exhibit sex-related differential growth (Aday et al. 2003). The von Bertalanffy growth equation provided a good fit to bluegill mean TL-at-age data (r^2 range = 0.86–0.99; all $P < 0.04$), except that the growth equation could not be solved for females from one lake and for males from another lake. Predicted mean TL at ages 3 and 4 for male and female bluegills and W_r were compared among the three stocking rates of channel catfish by ANOVA, in which CHLA and the interaction between stocking rate and CHLA were employed as covariates. Additionally, stepwise linear regression was used to compare bluegill mean TL-at-age data and W_r to channel catfish CPUE, and CHLA was used as a potential covariate. Relative weight (first expressed as a decimal equivalent) was \log_e transformed prior to all analyses, while mean TL-at-age data were not transformed.

In many cases, the strength of relationships between two variables may vary greatly across the range of observed values. In these situations, regression analysis may not be the most appropriate test (Garvey et al. 1998). Consequently, a two-dimensional Kolmogorov–

Smirnov (2DKS) test (recommended by Garvey et al. 1998) was also used to test relationships between channel catfish CPUE and bluegill PSD, RSD, W_p , and mean TL at age. Untransformed data were used for these analyses.

Bluegill growth, size structure, and condition may be more strongly related to bluegill abundance than channel catfish abundance because these variables are often density dependent (Wiener and Hanneman 1982; Tomcko and Pierce 2005). To test for this possibility, linear regression was used to compare bluegill PSD, RSD, W_p , and mean TL at age with bluegill CPUE. Bluegill PSD, RSD, W_p , and CPUE were transformed as for previous tests. Because day–night differences in sampling could affect these relationships, I included a dummy variable representing day or night sampling in the regression analyses. I also compared bluegill CPUE between lakes sampled during the day and night with ANOVA to determine whether time of sampling affected CPUE overall.

Results

Pond Experiments—1999

Increases in channel catfish biomass led to decreases in the growth of channel catfish but did not reduce the growth of bluegills. Both the mean length ($F = 4.88$; $df = 3, 12$; $P = 0.02$) and mean mass ($F = 5.40$; $df = 3, 12$; $P = 0.01$) increments of channel catfish declined with increasing channel catfish biomass (Figure 1). The effect of channel catfish biomass on bluegill growth was ambiguous. While treatment effects were significant for both length ($F = 8.49$; $df = 3, 12$; $P = 0.003$) and mass ($F = 9.04$; $df = 3, 12$; $P = 0.002$) increments of bluegills, neither were significantly different between L and VH ponds (Figure 1), and mean increments were lower for M and H ponds. Analyses including all fish that could not be clearly designated as age 2 produced the same results. Thus, there was no clear evidence that increasing channel catfish biomass reduced growth of bluegills.

Survival of channel catfish ($F = 1.40$; $df = 3, 12$; $P = 0.29$) and age-2 bluegills ($F = 0.23$; $df = 3, 12$; $P = 0.87$) did not vary among treatments. Survival among ponds was consistently high for channel catfish (mean \pm SE = $97 \pm 1\%$; range = 90–100%) but was more variable for age-2 bluegills (mean \pm SE = $78 \pm 4\%$; range = 46–100%).

There were no significant differences in the biomass of fish among treatments except for channel catfish ($F = 44.38$; $df = 3, 12$; $P = 0.0001$) when ponds were drained. Biomass of age-0 and age-1 bluegills combined, age-2 bluegills, green sunfish and hybrid sunfish combined, and other species did not differ among

treatments (ANOVA: all $P > 0.21$). Three ponds (one H pond and two VH ponds) contained other species, including redear sunfish, white crappies *Pomoxis annularis*, bluntnose minnow *Pimephales notatus*, gizzard shad, and a topminnow *Fundulus* sp. These species represented minor portions of total fish biomass.

Water quality, vegetation biomass, and invertebrate prey biomass were similar among treatments (repeated-measures ANOVA: all $P > 0.07$). All variables varied significantly with time (all $P < 0.01$) except for chironomid biomass ($P = 0.48$), but no interactions between time and treatment effects were evident (all $P > 0.05$). Total macroinvertebrate biomass was highly variable both within and among treatments but was lowest in September for all treatments (Figure 2).

Pond Experiments—2000

As in the 1999 experiment, there was no evidence that high channel catfish biomass suppressed the growth of bluegills (Figure 1). Bluegills grew more in length (bluegill effect: $F = 44.22$, $df = 1, 8$, $P = 0.0002$; channel catfish effect: $F = 0.00$, $df = 1, 8$, $P = 0.96$; interaction: $F = 0.30$, $df = 1, 8$, $P = 0.60$) and mass (bluegill effect: $F = 54.04$, $df = 1, 8$, $P < 0.0001$; channel catfish effect: $F = 0.00$, $df = 1, 8$, $P = 0.96$; interaction: $F = 0.57$, $df = 1, 8$, $P = 0.47$) in ponds with low bluegill biomass than in ponds with high bluegill biomass regardless of channel catfish biomass. Growth of channel catfish was highly variable within treatments (Figure 1), and neither length increments (bluegill effect: $F = 1.71$, $df = 1, 8$, $P = 0.23$; channel catfish effect: $F = 1.96$, $df = 1, 8$, $P = 0.20$; interaction: $F = 0.01$, $df = 1, 8$, $P = 0.91$) nor mass increments (bluegill effect: $F = 0.89$, $df = 1, 8$, $P = 0.37$; channel catfish effect: $F_{1,8} = 1.13$, $P = 0.32$; interaction: $F = 0.06$, $df = 1, 8$, $P = 0.81$) differed among treatments.

Survival did not significantly vary among treatments for either bluegills (bluegill effect: $F = 1.15$, $df = 1, 8$, $P = 0.31$; channel catfish effect: $F = 0.13$, $df = 1, 8$, $P = 0.72$; interaction: $F = 2.98$, $df = 1, 8$, $P = 0.12$) or channel catfish (bluegill effect: $F = 0.05$, $df = 1, 8$, $P = 0.83$; channel catfish effect: $F = 0.66$, $df = 1, 8$, $P = 0.44$; interaction: $F = 0.06$, $df = 1, 8$, $P = 0.81$). Survival among ponds was consistently high for channel catfish (mean \pm SE = $94 \pm 1\%$; range = 86–100%) but was lower and more variable for bluegills ($73 \pm 2\%$; range = 62–84%).

In addition to the fish stocked into the ponds, age-0 bluegills and a few individuals of other species (mostly redear sunfish) were found upon pond draining. Biomass of age-0 bluegills did not differ among treatments (ANOVA: $P = 0.09$). Fish other than channel catfish, bluegills, and grass carp represented less than 1% of the fish biomass in infested ponds.

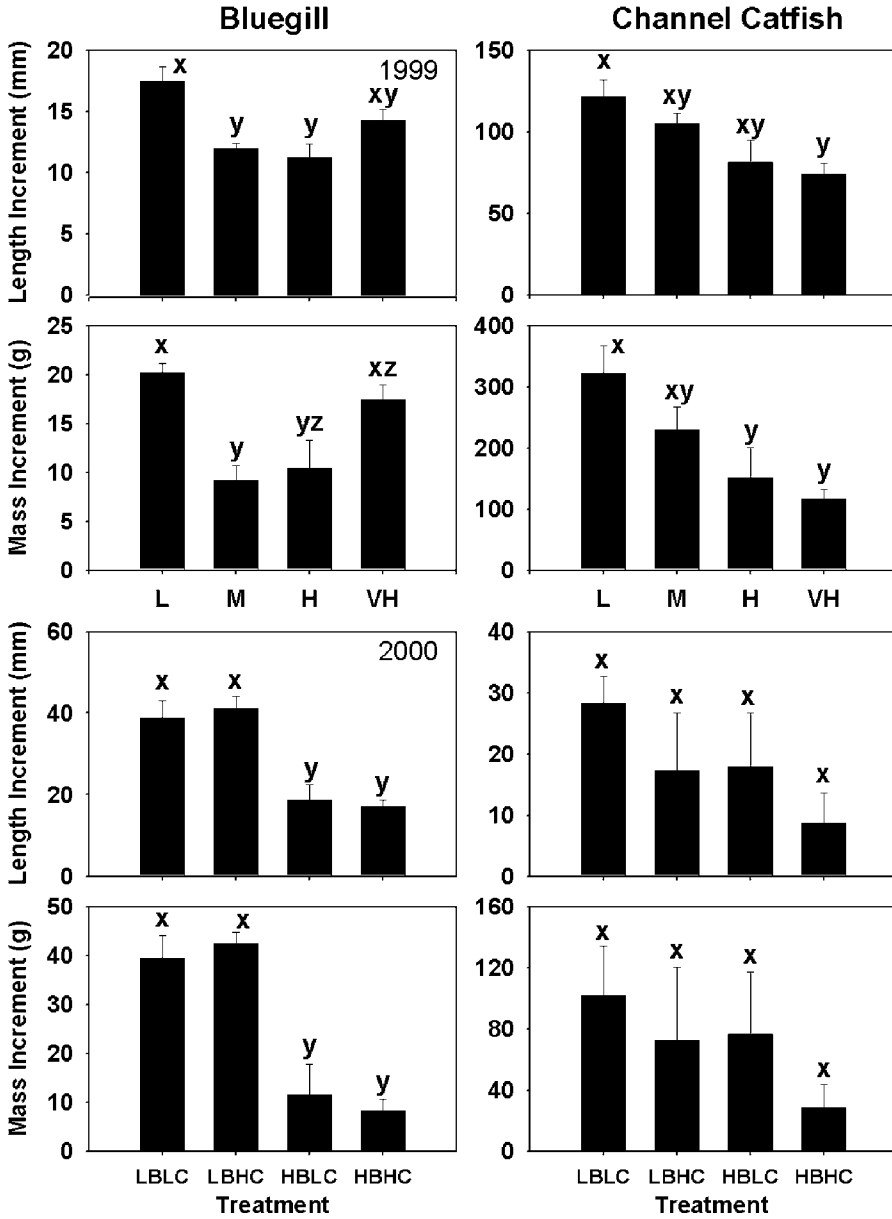


FIGURE 1.—The upper four panels show the mean + SE length and mass increments for bluegills and channel catfish in experimental ponds stocked with channel catfish at 10 (low [L]), 30 (medium [M]), 50 (high [H]), or 100 (very high [VH]) kg/ha in 1999. Each pond was also stocked with age-2 bluegills at 28 kg/ha and age-1 bluegills at 11.5 kg/ha. The lower four panels depict length and mass increments in ponds subjected to four bluegill–channel catfish biomass treatments during 2000: low bluegill–low channel catfish (LBLC; 15 and 70 kg/ha), low bluegill–high channel catfish (LBHC; 15 and 130 kg/ha), high bluegill–low channel catfish (HBLC; 70 and 70 kg/ha), and high bluegill–high channel catfish (HBHC; 70 and 130 kg/ha). Within a panel, bars that lack common letters are significantly different ($P \leq 0.05$).

Water quality, vegetation biomass, and invertebrate prey biomass were similar among treatments (repeated-measures ANOVA: all $P > 0.12$) except for total zooplankton biomass ($P = 0.03$). Total zooplankton biomass was significantly higher in HBLC ponds than

in LBLC ponds in May. All variables varied seasonally ($P \leq 0.01$) except for *Daphnia* biomass ($P = 0.16$), periphyton biomass ($P = 0.49$), vascular plant biomass ($P = 0.34$), and mollusk biomass ($P = 0.47$). No interactions between treatment and time were signifi-

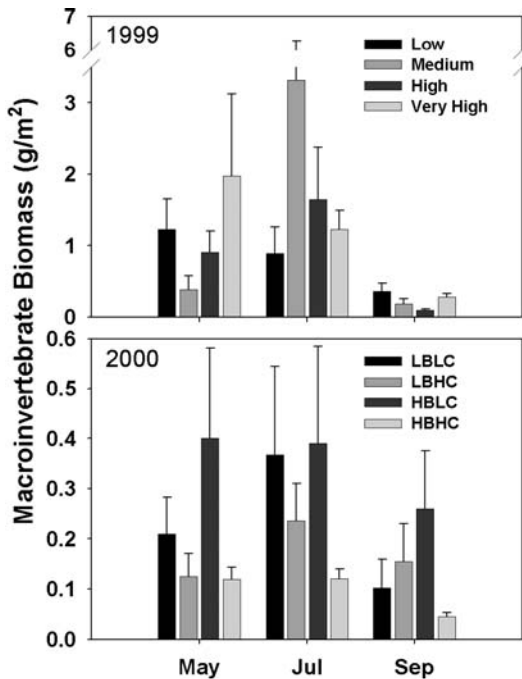


FIGURE 2.—The upper panel shows mean + SE macroinvertebrate biomass (dry mass) in experimental ponds stocked with channel catfish at 10 (low), 30 (medium), 50 (high), or 100 (very high) kg/ha in 1999. Each pond was also stocked with age-2 bluegills at 28 kg/ha and age-1 bluegills at 11.5 kg/ha. The lower panel depicts macroinvertebrate biomass in ponds subjected to four bluegill–channel catfish biomass treatments during 2000: low bluegill–low channel catfish (LBLC; 15 and 70 kg/ha), low bluegill–high channel catfish (LBHC; 15 and 130 kg/ha), high bluegill–low channel catfish (HBLC; 70 and 70 kg/ha), and high bluegill–high channel catfish (HBHC; 70 and 130 kg/ha).

cant (all $P > 0.08$) except for CHLA ($P = 0.02$). As was the case for 1999, macroinvertebrate biomass was lowest in September (Figure 2).

Small Lakes

Bluegill CPUE, size structure, mean TL at age, and condition did not differ with channel catfish stocking rates, but some were related to CHLA. Bluegill CPUE, PSD, RSD, mean TL at ages 3 and 4 for females and males, and W_r were similar (ANOVA: all $P > 0.25$) among channel catfish stocking rates. Similarly, the interaction term between channel catfish stocking rate and CHLA was never significant (all $P > 0.19$). Mean TL at age 3 for female ($F = 5.82$; $df = 1, 23$; $P = 0.02$) and male ($F = 5.30$; $df = 1, 23$; $P = 0.03$) bluegills were related to CHLA. All other bluegill variables were unrelated to CHLA (all $P \geq 0.10$).

A general pattern was evident in which estimates of

bluegill size structure, condition, and mean TL at age were highly variable at low to moderate channel catfish CPUE but consistently low at high channel catfish CPUE (Figure 3). Stepwise linear regression models explained little of the variation in bluegill variables. Bluegill PSD was marginally related to channel catfish CPUE ($r^2 = 0.06$; $P = 0.059$; $N = 60$) and RSD was significantly but weakly related to channel catfish CPUE ($r^2 = 0.08$; $P = 0.03$; $N = 60$). The CHLA variable did not enter into either model. Mean TL at ages 3 and 4 for female bluegills was significantly related to both channel catfish CPUE (–) and CHLA (+) (age 3: $R^2 = 0.35$, $P = 0.003$, $N = 29$; age 4: $R^2 = 0.30$, $P = 0.01$, $N = 29$). Mean TL at ages 3 and 4 for males was not significantly related to either channel

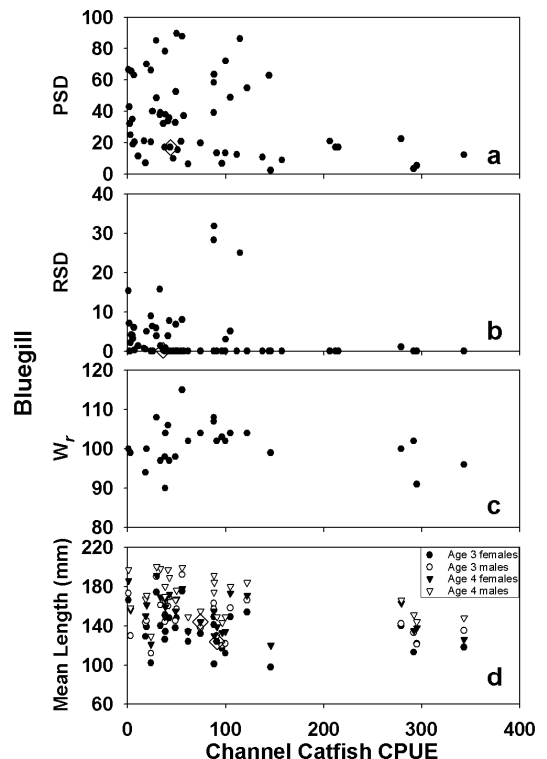


FIGURE 3.—Scatterplots showing the relationships between channel catfish catch per unit effort (CPUE; fish/tandem hoop-net series) in small lakes and bluegill (a) proportional stock density (PSD), (b) relative stock density (RSD) for 203-mm total length (TL) and larger fish, (c) relative weight (W_r), and (d) mean TL at ages 3 and 4. For significant two-dimensional Kolmogorov–Smirnov tests, the values producing the maximum differences in the integrated probabilities for the two observed bivariate distributions are denoted by large open diamonds. For (d), the leftmost diamond is associated with age-4 female bluegills and the rightmost diamond is for age-3 females.

catfish CPUE or CHLA. Bluegill W_r was positively related to CHLA ($r^2 = 0.21$; $P = 0.02$; $N = 27$).

Because variability in bluegill variables decreased across the range of channel catfish CPUEs (Figure 3), data were more appropriately analyzed using 2DKS tests (Garvey et al. 1998). These tests revealed significant relationships between channel catfish CPUE and bluegill PSD (the maximum differences in the integrated probabilities for the two observed bivariate distributions [D_{BKS}] = 0.08; $P = 0.048$), RSD (D_{BKS} = 0.13; $P = 0.0002$), mean female TL at age 3 (D_{BKS} = 0.12; $P = 0.03$), and mean female TL at age 4 (D_{BKS} = 0.12; $P = 0.03$). These tests were not significant between channel catfish CPUE and bluegill W_r (D_{BKS} = 0.09; $P = 0.18$), mean male TL at age 3 (D_{BKS} = 0.08; $P = 0.40$), or mean male TL at age 4 (D_{BKS} = 0.09; $P = 0.19$).

Bluegill growth, size structure, and condition were not significantly density dependent among the study lakes. Bluegill CPUE was not different between lakes sampled during the day and night ($F = 0.08$; $df = 1, 58$; $P = 0.78$). The dummy variable representing day or night sampling was never significant (all $P > 0.11$) in initial models and was not included in the final regression models. Bluegill PSD ($P = 0.15$), RSD ($P = 0.16$), W_r ($P = 0.17$), mean TL at age 3 for females ($P = 0.96$) and males ($P = 0.19$), and mean TL at age 4 for females ($P = 0.84$) and males ($P = 0.29$) were not significantly related to bluegill CPUE.

Discussion

There was no evidence that channel catfish competed with bluegills in experimental ponds or in most study lakes. Bluegill growth was unrelated to initial biomasses of channel catfish ranging from 10 to 130 kg/ha in experimental ponds. The potential for competition was most apparent for lakes where channel catfish CPUE exceeded 200 fish/tandem hoop-net series; in these lakes, bluegill size structure and growth rates were consistently poor. Biomass of channel catfish in the lakes was not measured, so it is unknown if biomass exceeded those in the experimental pond studies where there was no measurable effect of channel catfish on bluegill growth. It does appear that channel catfish need to be highly abundant in order to reduce size structure and growth of bluegills (Crance and McBay 1966; Mitzner and Middendorf 1976; Hill 1984; this study). Apparently, for most situations channel catfish stockings at rates used during this study (12–74 fingerlings·ha⁻¹·year⁻¹) did not harm bluegill populations.

The association between high abundance of channel catfish and poor size structure and growth of bluegills may have been coincidental. Many variables influence

size structure and growth of bluegills, including their population density (Wiener and Hanneman 1982; Tomcko and Pierce 2005), variation in life history strategies (Ehlinger 1997; Ehlinger et al. 1997), vegetation abundance (Savino et al. 1992; Unmuth et al. 1999), lake productivity (Cross and McNerny 2005), predator density and size structure (Novinger and Legler 1978; Paukert et al. 2002), presence or absence of gizzard shad (Aday et al. 2003; Michaletz and Bonneau 2005), and angling (Coble 1988; Beard et al. 1997). One or more of these variables may be more important than channel catfish even when channel catfish are abundant. While data were not available to assess all of these variables, indices were available for bluegill abundance (CPUE; this study), predator (largemouth bass) abundance (CPUE; fish/h of electrofishing; MDC, unpublished data) and size structure (PSD and RSD; Anderson and Gutreuter 1983; MDC, unpublished data), lake productivity (CHLA; this study), vegetation abundance (indexed as absent, moderate, or abundant; Michaletz and Bonneau 2005), and gizzard shad (presence or absence; Michaletz and Bonneau 2005). The CPUE of stock-size bluegills (range = 52–424 fish/h) –and stock-size (≥ 203 -mm TL) largemouth bass (range = 19–68 fish/h), size structure of largemouth bass (PSD range = 11–72%; $RSD_{381\text{ mm}}$ range = 0–68%), CHLA (range = 10–102 $\mu\text{g/L}$), vegetation abundance (five lakes with no vegetation, two lakes with abundant vegetation), and gizzard shad presence or absence (present in five of seven lakes) were not consistent among the seven lakes where channel catfish exceeded 200 fish/tandem hoop-net series. Thus, none of these variables were associated with the consistently poor size structure and growth of bluegills in these lakes. The only measured variable that was consistent among the seven lakes was the high abundance of channel catfish.

At high abundances, channel catfish may affect bluegill size structure and growth by reducing macroinvertebrate prey abundance. Mitzner and Middendorf (1976) reported a 53% decline in macroinvertebrate densities and a concurrent 75% increase in channel catfish biomass in an Iowa pond. Dipteran biomass was consistently low in small Missouri lakes where channel catfish were highly abundant (Michaletz et al. 2005). However, reductions in macroinvertebrate biomass with increases in channel catfish biomass were not observed in the experimental pond studies possibly because of insufficient study duration, high variation in macroinvertebrate biomass within treatments, or insufficient biomass of channel catfish. Dipterans, along with other soft-bodied macroinvertebrates (excluding mollusks), are important prey for both bluegills and channel catfish (Schramm and Jirka 1989; Hubert 1999; Michaletz, in

press), and reductions in their abundance may lead to reduced growth rates of bluegills. Given that most of the lakes used in the study by Michaletz et al. (2005) were also part of this study, macroinvertebrate abundance estimates were available to compare with bluegill growth rates for some of the lakes. Data were available for three of the seven lakes where channel catfish CPUE exceeded 200 fish/tandem hoop-net series. Soft-bodied macroinvertebrate biomass in these three lakes averaged 452, 523, and 2,021 mg/m², respectively, numbers which were lower than the average of 2,834 mg/m² for the 30 small lakes (Michaletz et al. 2005). Bluegill mean TLs at ages 3 and 4 for both sexes were strongly correlated with soft-bodied macroinvertebrate biomass (Pearson's correlation coefficient $r=0.77-0.90$; all $P < 0.009$; $N = 10$ lakes), indicating that reductions in macroinvertebrate abundance could indeed reduce bluegill growth. While it is possible that high abundances of bluegills could reduce macroinvertebrate abundance as well, bluegill abundance was actually positively related to macroinvertebrate abundance in these small lakes (Michaletz et al. 2005).

Not only is macroinvertebrate abundance lower in lakes with high abundances of channel catfish, but diet overlap between channel catfish and bluegills is more likely to occur (Michaletz, in press). In these lakes, channel catfish grow slowly and remain small due to density-dependent effects (Hubert 1999; Mitzner 1999). Small channel catfish have diets similar to those of bluegills, feeding mostly on macroinvertebrates (Hubert 1999; Michaletz, in press), which may result in high diet overlap. In lakes where channel catfish grow faster, diet overlap with bluegills is less because larger channel catfish incorporate more non-macroinvertebrate prey (e.g., fish, crayfish, and plant material) into their diets (Hubert 1999; Michaletz, in press).

Lake productivity as indexed by CHLA did not appear to strongly influence most relationships between channel catfish and bluegills in the study lakes. I expected that as lake productivity increased, negative interactions between channel catfish and bluegills would lessen at a given level of fish abundance due to increased food production. Studies have shown positive relationships between lake productivity and macroinvertebrate abundance (Hanson and Peters 1984; Rasmussen and Kalff 1987; Rasmussen 1988) and between lake productivity and fish growth and production (Jones and Hoyer 1982; Downing et al. 1990; Mosher 1999; Tomcko and Pierce 2005). However, in my study lakes, total macroinvertebrate biomass was not strongly related to productivity (Michaletz et al. 2005). Abundance of some macroinvertebrate taxa (e.g., Diptera) did increase with lake

productivity, whereas others (Ephemeroptera, Odonata) decreased with productivity. Lake productivity effects on fish interactions were probably masked by these complex relationships with macroinvertebrates as well as by other factors such as varying abundances of fish and differences in fish community structure.

Situations where channel catfish abundance is high enough to reduce the growth and size structure of bluegills are probably uncommon in small lakes managed for sport fisheries. Managed lakes are frequently surveyed to assess growth, size structure, and relative abundance of sport fish species. Poor growth and size structure of channel catfish would be observed in lakes with abundant channel catfish before harmful effects on bluegills would occur. The experimental pond studies provided evidence that intraspecific competition among channel catfish occurs at abundances lower than what would be necessary to affect bluegills. Channel catfish in one LBHC pond during the 2000 experiment actually lost mass, yet bluegills grew well. In lakes where channel catfish grow slowly, managers will probably reduce stocking rates of channel catfish in an attempt to improve their growth and size structure. In Missouri, channel catfish stocking rates were reduced from about 74–124 fingerlings/ha in the 1960s and 1970s to about 25–49 fingerlings/ha in the 1980s and 1990s in an effort to improve growth rates and size structure of channel catfish populations (Eder et al. 1997). Six of seven lakes used in this study where channel catfish CPUE exceeded 200 fish/tandem hoop-net series were stocked at a rate of 74 fingerlings/ha, which is higher than most stocking rates currently used in Missouri. However, one lake was only stocked at a rate of 37 fingerlings/ha, indicating that appropriate stocking rates may vary among lakes.

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