Culture of Black Bullhead (Ameiurus melas) in Cages and Open Ponds

A Thesis Presented to the Faculty of the Department of Biological Sciences of the State University of New York College at Brockport in Partial Fulfillment for the Degree of Master of Science

by

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May 1993

THESIS DEFENSE

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in Cages and Open Ponds

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ACKNOWLEDGMENTS

I would like to thank Dr. Joseph Buttner, my major advisor, who provided help and advice during my graduate student days. Dr. James Haynes, Dr. Stanley Ross, and Dr. Randall Brummett, served on my graduate committee and reviewed my thesis. A big thank you to Mr. Ted Lewis for all of his time and help with the computer. Special thanks to all the college work-study students and my friends who helped throughout my study. A thank you goes to the U.S. Fish and Wildlife Service Tunison Laboratory of Fish Nutrition for the proximate analyses of the feed. I would like to send very special thanks to Robert Hamdy, my fiance, and my entire family without their love, support, and inspiration, this project would have been much more difficult to complete.

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ABSTRACT

Black bullhead (Ameiurus melas) fingerlings were stocked in three 0.1 ha ponds at a rate of 900 fish/0.1 ha with 150 fish stocked in 1.2 m^3 cages (three cages/pond) and 450 fish stocked free-swimming in each open pond. Fish were simultaneously cultured in cages and open ponds between 4 June 1991 and 28 September 1991. After 117 days, survival rate in all treatments did not differ. Black bullhead reared in open ponds exhibited superior growth and feed conversion when compared to fish reared in cages. Caged fish took longer to double their weight than free-swimming fish. Water quality parameters (D.O., temperature, pH, alkalinity, total ammonia-nitrogen, and Secchi disk visibility) did not differ significantly among cages and open ponds. Results of this study indicate that black bullhead cultured in open ponds outperform bullhead cultured in cages.

INTRODUCTION

The black bullhead (Ameiurus melas; family Ictaluridae) is a scaleless fish found naturally in waters from southern Canada to Mexico, from the Rocky Mountains to the Western slopes of the Appalachians (Smith 1985). It has, however, been stocked in many areas outside of its natural range (Smith 1985). Bullhead are tolerant of swampy, low-oxygen waters (Smith 1985) and grow and survive best in quiet, turbid waters (USFWS 1982, Buttner 1992). Black bullhead usually live for six years or more and reach 203 to 254 mm TL, but can reach 427 mm TL and weigh 1.2 kg (Werner 1980, Smith 1985).

Black bullhead are common to ponds, lakes, and slow flowing water throughout New York State (Werner 1980, Smith 1985). It is one of the most desirable freshwater fishes in New York (Buttner 1992). Many consumers consider it an excellent food fish, with a light and tasty flesh. The availability of bullhead is on the decline due to habitat degradation and management of public waters for other fish (Buttner et al. 1990). Because of increased demand and reduced availability, interest in the aquaculture production of black bullhead is on the rise in New York State.

Aquaculture, in general, is of growing importance. Almost 100 marine and freshwater seafood species are cultured around the world (New York Sea Grant Institute 1985). Aquaculture provides a higher quality product of more uniform size, more consistent flavor and texture than wild stock (New York Sea Grant Institute 1985). Illustrative of the demand and potential for aquacultured fish is that between 1975 and 1991 the channel catfish (Ictalurus punctatus) industry increased production by more than 2400% (USDA 1992). Two forms of aquaculture in which black bullhead have been reared successfully are cage culture and pond culture (Hill 1972, Morris 1990, Buttner 1992).

Most freshwater aquaculture is conducted in ponds. The acreage used in catfish farming as of 1 January 1992 was estimated at over 162 thousand acres (USDA 1992). Earthen ponds have relatively low water requirements and produce some natural food for fish. Ponds differ in origin, structure, location, and water quality. These factors affect stocking density, fish survival, and growth (Chang 1986).

Cage culture of fish is an increasingly important form of aquaculture and its practice is of growing interest (Piper et al. 1982, Beveridge 1987). Cages can be used in a variety of waters that otherwise would be unsuitable for aquaculture (Piper et al. 1982, Stickney 1986, Schwedler et al. 1989, Tucker and Robinson 1990, Buttner et al. 1992). Masser et al. (1991) found channel catfish raised in cages possessed superior taste and quality when compared to fish raised free-swimming in ponds.

There is limited comparative information available for cage versus pond culture of any fish species (Schwedler et al. 1989, Davis et al. 1991, Buttner 1992). The efficiency of pond versus cage culture has not been examined adequately for black bullhead. The objectives of my study were: 1) to determine survival, growth, and feed conversion of black bullhead maintained concurrently in three 0.1 ha ponds as free-swimming or caged fish; 2) to develop predictive equations for growth of black bullhead maintained under culture conditions; 3) to quantify food presented to fish and develop more accurate feeding rates; and 4) to describe water quality in the culture ponds and cages.

MATERIALS AND METHODS

PONDS

Three ponds located on-campus at the State University of New York, College at Brockport (Monroe County, NY) were used in this study. Each earthen pond was approximately 26 m by 40 m (~0.1 ha) and had an average depth of 1.2 m. The deepest point, 1.8 m, was located at the standpipe. Ponds were filled largely by surface runoff. Village water from Lake Ontario (pH = 7.5 - 8.0, alkalinity = 90 - 100 mg $CaCO_3$/L, hardness = 120 - 150 mg $CaCO_3$/L) was added as needed to replace evaporation and seepage losses. Approximately 500 m^3, 700 m^3, and 2,800 m^3 were added during the culture season to ponds 2, 4, and 6, respectively (Table 1).

CAGES

Nine cylindrical cages (1.2 m^3) were constructed and used in the study (Figure 1). Cages were designed to float with 15 cm of mesh exposed above the water surface. A plastic feeding cylinder (19 L bucket, 28 cm in diameter with the bottom cut out) was used to retain feed in the cage. The cylinder was submerged approximately 8 cm in water.

Cages were accessed from a floating dock which minimized fish disturbance and maintenance effort. Distance from the dock to each cage was approximately 1.5 m. Distance between cages was approximately 3 m.

EXPERIMENTAL DESIGN

The study was run in triplicate, three cages floating in each of three ponds. Black bullhead fingerlings (age 1) used in the study were spawned and overwintered in an adjacent pond on-campus. They represented forth and fifth generation of fish selected for good survival and rapid growth when cultured in cages. The fingerlings already accepted pelleted

food before being stocked. Each pond was stocked with 900 fingerlings (TL = 11.4 - 15.2 cm; avg. wt. = 38.5 g). Half of the fish (450) were stocked free-swimming in the pond and the other half (450) were split evenly into three cages floating in each of the ponds. Stocking began when water temperature in the ponds was 25°C in late morning. The cages were stocked on 24 May, 25 May, 29 May, and 30 May 1991. The open ponds were stocked on 28 May, 30 May, and 1 June 1991. Twelve mortalities occurred in cages during the first ten days of the study and were replaced by similarly sized fish.

DAILY ROUTINE

Every morning all cages and ponds were checked for mortalities. If a mortality was observed, the fish was removed and checked for signs of disease. Date, location, and number of mortalities were recorded.

Ponds were checked daily for fry. On several occasions recently hatched bullhead fry were observed in each pond. The fry that could be collected were transferred to a nearby pond that was not involved in the study.

FEEDING ROUTINE

All fish were fed a commercial ration formulated for channel catfish cultured in cages (Table 2). This diet has proven adequate for black bullhead cultured in cages, open ponds, and raceways (Renyaan 1990, Buttner 1992). Feed was measured volumetrically (100 ml ~ 53.5 g). Fingerlings were fed a maintenance diet, which was 1% of their body weight, daily from stocking time until the study began on 4 June 1991. Feed was typically presented around 10:00 a.m. daily between 4 June and 28 September 1991. Fish were not fed on days when cages were sampled or cleaned. Fish in cages were sampled and weighed every 40-50 days to confirm estimated growth and adjust feeding rates, if necessary (Table 3). Fish in

open ponds could not be sampled adequately as the available seine was 1.8 m deep and did not effectively sample the benthic bullhead in the pond. Approximately two hours after food was presented, cages and open ponds were checked. Uneaten pellets in the cages were counted and weight in grams was estimated by 50 pellets = 3.0 g dry weight. The uneaten pellets were not removed from the cages.

Feeding activity was observed daily to check fish condition and to adjust feeding rate. Every 10 days the feeding rate was adjusted to correct for feeding behavior, fish growth and observed mortality. After day 93 (4 September), adjustments were made more frequently as feed consumption steadily decreased, probably due to cooler temperatures.

WATER QUALITY

Dissolved oxygen (D.O.), temperature, alkalinity, total ammonia-nitrogen (TAN), pH, and depth of Secchi disk visibility were measured once each week. When conditions became stressful, D.O. and temperature were measured daily. All water quality parameters were measured within two hours after sunrise by methods described in Table 4. Measurements were taken 0.6 to 0.9 m below the surface of each pond and in one randomly selected cage in each pond. When the Secchi disk was visible on the bottom of the ponds a default reading of 154 cm was recorded and was called a "bottom" reading.

MAINTENANCE

Whenever D.O. levels fell below 3.0 mg/L, supplemental aeration was provided by Leeson Model DT vertical aerators. Aeration was initiated and continued until D.O. levels remained above 4.0 mg/L when measured within two hours after sunrise.

Aquatic vegetation became a problem in late July, particularly in ponds 2 and 4. Mechanical removal (nets, rope and chain pulled through the ponds) was conducted each week and proved effective, though labor intensive.

All cages were cleaned with a brush as needed, typically every 7 days, to remove debris (e.g., algae, fungi) and to maintain good water flow into and out of the cages.

HARVEST

When morning water temperature fell below 17°C on 21 September, feeding activity of caged and free-swimming bullhead became negligible and the fish were considered ready for harvest. Fish were not fed during harvest time. Fish in cages were harvested from 30 September- 3 October 1991. After cages were harvested and removed, ponds were lowered to approximately 0.9 m and seined between 7-10 October and 14-17 October 1991. After most fish had been removed by seining, the ponds were drained by exchanging drain pipes with shorter drain pipes which had a 1.0 cm mesh over the discharge opening to prevent fish loss. When the pond was completely drained, all remaining fish were collected by hand. Weight (g) and total length (mm) of all fish harvested were determined.

STATISTICAL ANALYSES

Water quality data obtained from cages and open ponds were compared by one-way Analysis of Variance (ANOVA). Survival, growth, and feed conversion data obtained from free-swimming and caged fish were compared by Analysis of Variance Randomized Block Design. Fish populations in the three cages floating in each of ponds 2, 4 and 6 were combined and analyzed as cage 2, cage 4, and cage 6 populations, respectively. Predictive growth equations were developed by simple linear regression analyses for fish raised in

cages and for fish raised in open ponds. Analyses followed standard practices used in agriculture (Bender et al. 1989).

The null hypotheses were: (1) that there was no difference in survival, growth, or feed conversion of black bullhead cultured in open ponds (free-swimming) vs. black bullhead cultured in cages; and (2) that there was no difference in water quality in cages and open ponds.

RESULTS AND DISCUSSION

SURVIVAL

Recovery of stocked fish at harvest exceeded 88% in all cages and open ponds (Table 5). No statistically significant differences ($p>0.05$) in percent recovery of farmed bullhead were observed between cages and open ponds (Appendix A). Total amount of bullhead recovered from the ponds was 141, 122, and 127 kg/0.1 ha for ponds 2, 4, and 6, respectively. As in this study, Schwedler et al. (1989) found that survival was similar in cages (97.0% +/- 2.65%) and open ponds (98% +/- 0.5%). The pan-sized channel catfish in the Davis et al. (1991) study also had similar mean survival for all cages (98.6% $\pm$ 0.0) and open ponds (98.6% $\pm$ 0.3). The somewhat lower survival of cultured bullhead may reflect their more recent wild origin vs. the more domesticated channel catfish.

Observed mortalities of bullhead cultured in cages exceeded that for bullhead raised in open ponds. Conversely, the number of bullhead not recovered from open ponds was greater than the number of fish unaccounted for from cages (Table 5). Bullheads missing from open ponds may have been burrowed in the mud during harvest, captured by predators, or removed after death by scavengers. Great blue herons (Ardea herodias) and other predatory birds were frequently observed at the pond site. Also, observed along the pond

banks were footprints of other potential predators and scavengers, such as raccoons and red fox. The percent recovery for caged fish approximates their actual survival. Percent recovery for pond raised fish is a conservative estimate of survival, as missing fish may have been healthy until captured by a predator.

GROWTH

In general, feeding response of fish in cages and open ponds was immediate between days 1-50 (4 June-23 July 1991). After day 50, except for two or three random days, there was little or no immediate feeding activity.

Growth of black bullhead cultured in open ponds was significantly greater ($p<0.05$) than that observed for bullhead cultured in cages (Table 5, Figure 2, Appendix B). Average harvest weights of fish cultured in open ponds 2, 4, and 6 were 215.0 g, 172.8 g, and 191.9 g, respectively. Average harvest weights of caged fish were 116.0 g, 109.3 g, and 98.8 g for cages 2, 4, and 6, respectively. At harvest, all fish cultured in cages had doubled their start weight on average every 84 days, while fish cultured in open ponds had doubled their start weight on average every 53 days. Because of ineffective sampling for open pond fish, it was not possible to record actual growth patterns, as was done for caged fish (Figure 2). Most bullhead cultured in cages and open ponds grew faster than bullhead in wild populations observed by Carlander (1969), which had total lengths (TL) in the second and third years of life ranging from 122-140 mm and 185-201 mm, respectively. In this study, bullhead from cages and open ponds averaged 198 mm and 233 mm TL, respectively. In the study by Schwedler et al. (1989), fish reared in open ponds demonstrated a significantly greater total length at harvest (330 mm +/- 26.8) when compared to fish reared in cages (312 mm +/- 24.0). Davis et al. (1991) showed the average length at harvest for channel catfish cultured

in open ponds was 300 mm +/- 2.5 while fish length in cages was 286 mm +/- 2.4 with no statistically significant differences being observed between ponds and cages. Catfish cultured by Schwedler et al. (1989) obtained weights of 416 g in ponds and 359 g in cages. Davis et al. (1991) obtained fish weights of 297 g in ponds and 274 g in cages, which were not statistically different.

Length/weight relationships were developed for black bullhead cultured in cages and open ponds. Free-swimming fish were consistently plumper than caged fish of the same length (Figure 3). Very scrawny or bloated fish (approximately 6 fish) were excluded from the calculations, based on the assumption that they were sick and did not represent the condition of the rest of the population. These relationships are useful in estimating length or weight for feed projections and market pricing information.

FEED CONVERSION

Feed conversion (FC) for free-swimming fish in ponds [amount of food presented (g) / average weight gained (g)] was significantly better ($p<0.05$) than that observed for fish maintained in cages [FC= amount of food consumed (g) within two hours of presentation/ average weight gained (g)] (Table 5, Appendix C). The feed conversions for open ponds 2, 4, and 6 were 1.4, 1.8, and 1.6, respectively and the feed conversions for cages 2, 4, and 6 were 2.5, 2.5, and 3.0, respectively. Since the free-swimming fish were not efficiently sampled during the study, adjustments of feeding rates may not have been accurate. Catfish in the Schwedler et al. (1989) study which were reared in open ponds showed a significantly better food conversion ratio (1.25 +/- 0.06) than catfish reared in cages (1.38 +/- 0.02). Catfish in the Davis et al. (1991) study showed that feed conversion was significantly better in open ponds (1.23 ± 0.03) than in cages (1.30 ± 0.05).

Bullhead raised in cages did not ingest all feed presented, indicating that original feeding rates (Table 3) were excessive and should be reduced. Recommended feeding rates for black bullhead that weigh between 38-120 g when cultured in cages at ~15-25°C are listed in Table 6 based on the amount of food left in the cages after approximately two hours of feeding. The amount of pelleted food uneaten and the amount of natural food eaten by the free-swimming fish could not be determined.

Fish in cages were confined, crowded, and exposed to greater light intensity than free-swimming fish. Caged fish, having no ports of refuge available, could not relocate and were exposed continuously to stressful conditions (e.g., being handled, seeing people and other animals on pond banks and docks) (Masser 1988). These stressors probably had a negative impact on growth and feed conversion. It has been shown that housing rainbow trout (Oncorhynchus mykiss) in net-pens caused chronic elevations in cortisol (produced by fish in response to stressors) due to restricted volume or depth of the pens used in the study (Kebus et al. 1992).

Schwedler et al. (1989) and Terhune et al. (1992) suggested that fish free-swimming in open ponds had an opportunity to feed on natural food and, as a result, showed superior growth and feed conversion over fish reared in cages. A variety of macrobenthos, such as odonate naiads (Enallagma sp., Anax sp.), were observed in the ponds when seined during the study and at harvest. These aquatic invertebrates probably provided a food supplement to free-swimming fish during the culture period. Only limited natural food was available to caged fish because of their confinement. Terhune et al. (1992) and Webster et al. (1992) suggest a higher percentage of protein be fed to fish reared in cages to compensate for their inability to forage for natural food because of confinement. Webster et al. (1992) found that

caged channel catfish fed a 38% protein diet had better growth, survival, and feed conversion than caged catfish fed a 36% protein diet; the bullhead in this study had a 34% protein diet, from proximate analyses (Table 2).

WATER QUALITY

There were no significant differences in water quality parameters between cages and open ponds. Water quality, except D.O., in all cages and ponds remained at or above levels considered suitable for good fish growth and survival (Table 7) (Thurston et al. 1979). D.O. in pond 6 remained above 3.0 mg/L throughout the study; however, D.O. levels below 3.0 mg/L were observed in pond 2 on days 51-63 (24 July - 5 August) and on days 97-105 (8-16 September), and in pond 4 on days 95-102 (6-13 September). During these times supplemental aeration was provided.

It is unclear why ponds 2 and 4 had low D.O. compared to pond 6. The soil characteristics of ponds 2 and 4 were different than for pond 6. Ponds 2 and 4 had a liner material topped with approximately 30 cm of soil which contained a high concentration of organic detritus while pond 6 had no liner or high nutrient soil. Submergent vegetative growth, predominantly Najas sp. (naiads, often called waterweeds) was most abundant in ponds 2 and 4, covering up to approximately 85% and 60% of the pond, respectively. In contrast, vegetation in pond 6 never covered more than 35% of the pond. More submergent vegetation in ponds 2 and 4 possibly was due to nutrient rich substratum in these ponds compared to pond 6. A canopy effect that prevented light from penetrating to deeper waters limited photosynthesis to the very shallow waters in these ponds. However, there were no statistically significant differences ($p>0.05$) in pond visibility between the time before and the time after pond maintenance and aeration in any of the ponds (Appendix D).

Another possible reason for the low D.O. in ponds 2 and 4 is that there was a greater flush of water into pond 6 than into ponds 2 and 4 (Table 1). This greater inflow of fresh water may have helped maintain the D.O. at a high level.

PRODUCTION

Several incidental organisms (fathead minnows, young bullhead, tadpoles) were observed and collected at harvest from each pond; none were found in cages (Table 5). Biomass of these incidental organisms was 4.5%, 2.2%, and 5.0% of the total biomass in open ponds 2, 4, and 6, respectively. In addition, twenty-seven small bullhead fingerlings, between 14.6 g and 40 g, were harvested from all cages and two ponds (Table 5). It is unclear whether these were young-of-the-year spawned in the pond or stocked fish which lost weight or did not grow. Presence of these incidental organisms indicate that nutrients potentially available to bullhead were incorporated into non-target organisms.

CULTURE IMPLICATIONS

Pond culture of black bullhead has definite advantages over cage culture. Survival, growth, and feed conversion of free-swimming fish were good and reflect a high-quality environment. The bullhead stocking rate used in this study was lower than desired, partially because the fish did not grow as large in cages as expected. Water quality and harvest data from the study indicate that more bullhead fingerlings could have been introduced and maintained in ponds without compromising fish survival, resulting in a larger quantity of marketable fish. Vegetative problems encountered in this study did not occur in holding ponds where our broodstock fish were kept at higher densities. By stocking more fish, vegetative problems and associated water quality problems (e.g., low D.O.) may have been alleviated and the need for aeration may have been eliminated. Vegetation removal and

water aeration not only takes time and money but may also disturb the fish. Culturists interested in growing black bullhead commercially should consider pond culture at high densities where suitable water quality can be maintained and vegetation controlled.

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Table 1. Water added to compensate for evaporation and seepage in ponds during black bullhead study between 4 June and 28 September 1991. Total volume of each pond was ~1250 m^3.

DAY	DATE	WATER ADDED (m^3)		
		POND 2	POND 4	POND 6
21	24 Jun	72		
22	25 Jun		73	
23	26 Jun			89
24	27 Jun	99		
25	28 Jun		72	
26	29 Jun			68
28	1 Jul			140
29	2 Jul	100		
36	9 Jul		99	
37	10 Jul			136
38	11 Jul		75	
39	12 Jul			140
42	15 Jul			164
44	17 Jul			96
46	19 Jul			73
49	22 Jul			98
51	24 Jul			124
60	2 Aug	124		
63	5 Aug		74	
64	6 Aug	102		
65	7 Aug		127	
66	8 Aug			184
70	12 Aug			164
72	14 Aug			190
74	16 Aug			97
77	19 Aug			73
79	21 Aug			73
84	26 Aug			98
86	28 Aug			99
88	30 Aug			150
92	3 Sep			151
95	6 Sep		127	
96	7 Sep		52	
101	12 Sep			74
105	16 Sep			145
108	19 Sep			198
TOTAL		497	699	2,824

Table 2. Composition of commercial ration fed to black bullhead raised in cages and open ponds between 4 June and 28 September 1991. Proximate analyses values are reported within 1%. Proximate analyses was performed by the U.S. Fish and Wildlife Service, Tunison Laboratory of Fish Nutrition, Cortland, NY.

	LABEL VALUES	PROXIMATE ANALYSES
% PROTEIN	not less than 36.0	34.4
% FAT	not less than 4.0	3.5
% ASH	not more than 10.5	8.4
% FIBER	not more than 6.0	----
% WATER	not more than 12.0	12.2
% ADDED MINERALS	not more than 3.0	----

Table 3. Feeding rates for black bullhead raised in cages between 4 June and 28 September 1991. Values were developed from existing information and previous experience. Conversion efficiency was assumed to be 2:1 (2 pounds of feed produce 1 pound of fish).

DAYS	AVERAGE START WT. (g)	BODY WT. FED DAILY (%)	FEED PRESENTED DAILY (g)	AVERAGE END WT. (g)	AVERAGE AIR TEMP. (oC)
1-10	38.5	3.5	1.3	45.2	22.1
11-20	45.2	3.5	1.6	53.1	24.5
21-30	53.1	3.3	1.8	61.9	23.7
31-40	61.9	3.2	2.0	71.8	21.7
41-50	71.8	3.0	2.2	81.5	22.6
51-60	81.5	2.7	2.2	90.3	23.1
61-70	90.3	2.7	2.4	101.3	21.9
71-80	101.3	2.7	2.7	112.2	21.9
81-90	112.2	2.7	3.0	124.3	23.1
91-93	124.3	2.5	3.1	129.0	21.8
94-100	129.0	2.0	2.6	135.5	22.2
101-110	135.5	1.5	2.0	144.6	21.2
111-115	144.6	1.5	2.2	150.0	15.4
116-117	150.0	1.0	1.5	150.8	12.5

Sample Calculation:

(38.5 g) (0.035) = 1.35 g fed per day
(1.35 g per day) (10 days) = 13.5 g fed per 10 days
13.5 g / 2:1 feed conversion = 6.7 g weight gained per 10 days
38.5 g start weight + 6.7 g weight gained = 45.2 g end weight

Table 4. Methods used to monitor water quality in cages and open ponds for culturing black bullhead between 4 June and 28 September 1991.

PARAMETER	PROCEDURE	REFERENCE
Dissolved Oxygen (mg/L)	Polarographic meter	Boyd and Tucker 1992
pH	pH meter	Boyd 1990
Temperature (°C)	pH meter	------
Alkalinity (mg/L $CaCO_3$)	Potentiometric titration	APHA 1980
Nitrogen-Ammonia (mg/L)	Nesslerization	HACH 1985
Visibility (cm)	Secchi disk	Boyd and Tucker 1992

Table 5. Survival and growth of black bullhead raised in cages (cage) and free-swimming in ponds (pond) between 4 June and 28 September 1991.

		CAGE 2	POND 2	CAGE 4	POND 4	CAGE 6	POND 6
PERCENT	MEAN %	93.6	88.5	96.2	92.7	91.8	92.7
HARVESTED	SD	1.6	---	2.6	---	2.2	---
OBSERVED	n	25	1	18	2	32	1
MORTALITIES	%	5.6	0.2	4.0	0.4	7.1	0.2
UNACCOUNTED	n	4	51	-1[a]	31	5	32
FISH	%	0.9	11.3	-0.2	6.9	1.1	7.1
WEIGHT	MEAN	77.5	176.5	70.8	134.3	60.3	153.4
GAINED(g)	SD	40.3	51.1	30.5	50.4	28.2	41.4
FEED	MEAN	2.5	1.4	2.5	1.8	3.0	1.6
CONVERSION	SD	0.1	---	0.3	---	0.1	---
NON-TARGET	GRAMS	---	6,382.9	---	2,745.6	---	6,381.9
BIOMASS [b]	%	---	4.5	---	2.2	---	5.0
BULLHEAD	n	11	0	3	5	7	1
FINGERLINGS	%	2.6	0.0	0.7	1.2	1.7	0.2
(<40.0 g)							

[a] The one extra fish in cage 4 is probably due to a miscount when stocking.
[b] Includes fathead minnows, tadpoles, and young bullhead.

Table 6. Recommended feeding rates for black bullhead cultured in cages at 15-25°C. Rates are from the amount of food ingested by black bullhead raised in cages between 4 June and 28 September 1991. Values were determined by linear regression for bullhead sampled on days 1, 53, 87, and 117 [weight = 0.643871(day) + 44.83430]. Conversion efficiency is assumed to be 2:1 (2 pounds of feed produce 1 pound of fish).

DAYS	AVERAGE START WT. (g)	BODY WT. FED DAILY (%)	FOOD PRESENTED DAILY (g)	AVERAGE END WT. (g)
1-10	38.5	3.5	1.3	51.3
11-20	51.3	2.7	1.4	57.7
21-30	57.7	3.0	1.7	64.2
31-40	64.2	2.6	1.7	70.6
41-50	70.6	2.3	1.7	77.0
51-61	77.0	1.0	0.8	83.5
61-70	83.5	1.8	1.5	89.9
71-80	89.9	1.8	1.6	96.3
81-90	96.3	1.7	1.6	102.8
91-93	102.8	3.0	3.1	104.7
94-100	104.7	1.3	1.3	109.2
101-110	109.2	1.4	1.6	115.7
111-115	115.7	0.4	0.4	118.9
116-117	118.9	0.4	0.6	120.2

Table 7. Water quality in cages (cage) and open ponds (pond) used to culture black bullhead between 4 June and 28 September 1991. There are no significant differences ($p>0.05$) between cages and ponds for any water quality parameter.

PARAMETER		CAGE 2	POND 2	CAGE 4	POND 4	CAGE 6	POND 6
	MEAN	4.3	4.6	5.0	5.0	6.9	7.0
D.O.	SD	1.5	1.4	1.5	1.6	1.6	1.6
(mg/L)	MIN	2.2	2.4	2.8	2.8	4.7	4.8
(N=16)	MAX	7.1	6.9	7.4	7.4	9.4	9.6
	MEAN	21.4	21.6	21.6	21.7	22.0	22.2
TEMP	SD	2.4	2.5	2.5	2.5	2.7	2.8
(°C)	MIN	12.7	12.6	12.7	12.7	12.4	12.3
(N=16)	MAX	23.4	24.3	23.8	24.2	24.2	25.1
	MEAN	8.0	8.0	8.2	8.1	8.4	8.4
pH	SD	0.5	0.5	0.5	0.5	0.4	0.4
(N=16)	MIN	7.6	7.6	7.6	7.6	7.8	7.8
	MAX	9.3	9.3	9.1	9.1	9.3	9.3
	MEAN	83	82	84	83	86	86
ALK	SD	15	14	22	22	19	20
(mg/L)	MIN	60	58	54	52	52	52
(N=15)	MAX	110	108	121	114	118	128
TOTAL	MEAN	0.10	0.09	0.08	0.07	0.05	0.05
AMMONIA-NITROGEN	SD	0.05	0.05	0.04	0.05	0.03	0.02
(mg/L)	MIN	0.01	0.02	0.02	0.02	0.01	0.02
(N=15)	MAX	0.18	0.18	0.17	0.19	0.09	0.10
	MEAN		104		113		136
VISIBILITY	SD		34		27		25
(cm)	MIN		56		68		79
(N=14)	MAX		154		154		154
	BOTTOM		2		3		10

Figure 1. Materials and methods used to construct cages to culture black bullhead between 4 June-28 September 1991.

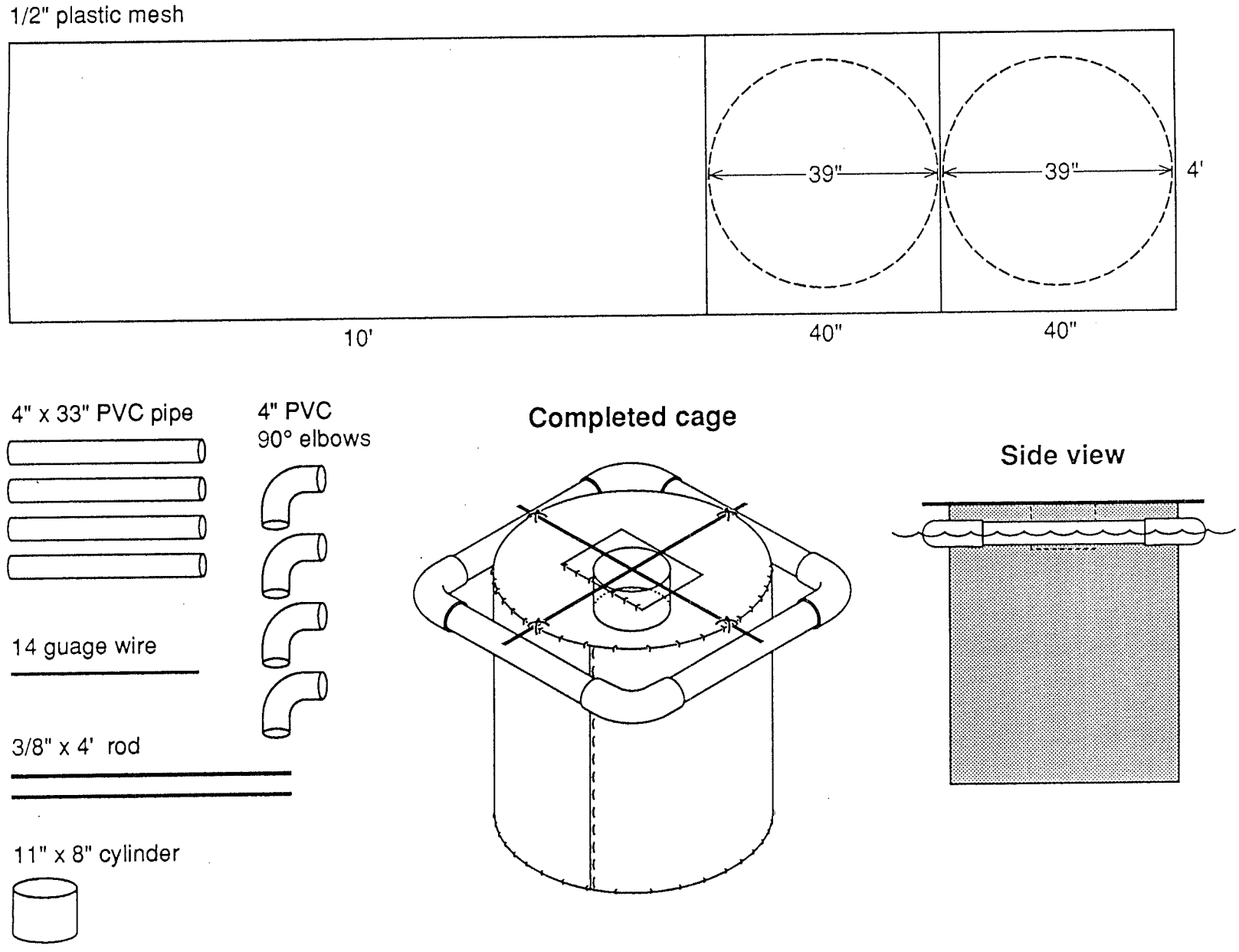


Figure 2. Average weight of black bullhead raised in cages and open ponds sampled on selected days between 4 June and 28 September 1991.

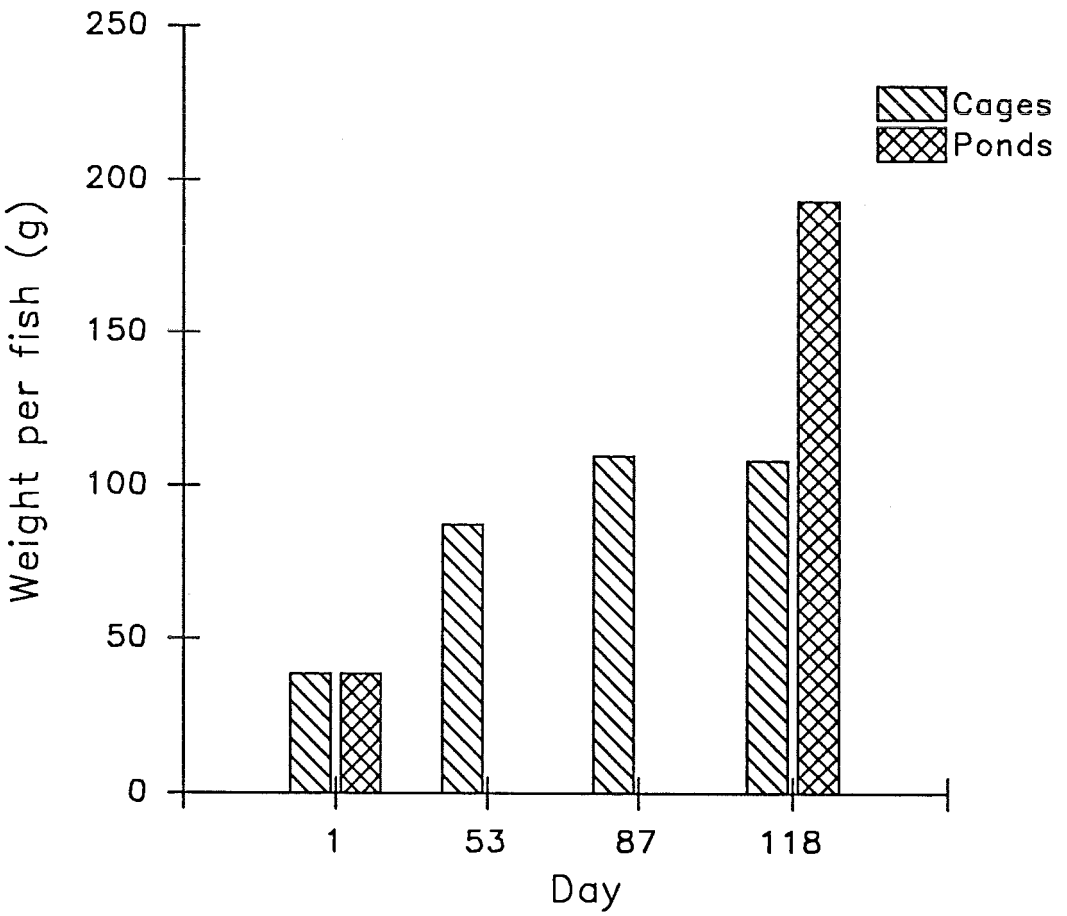
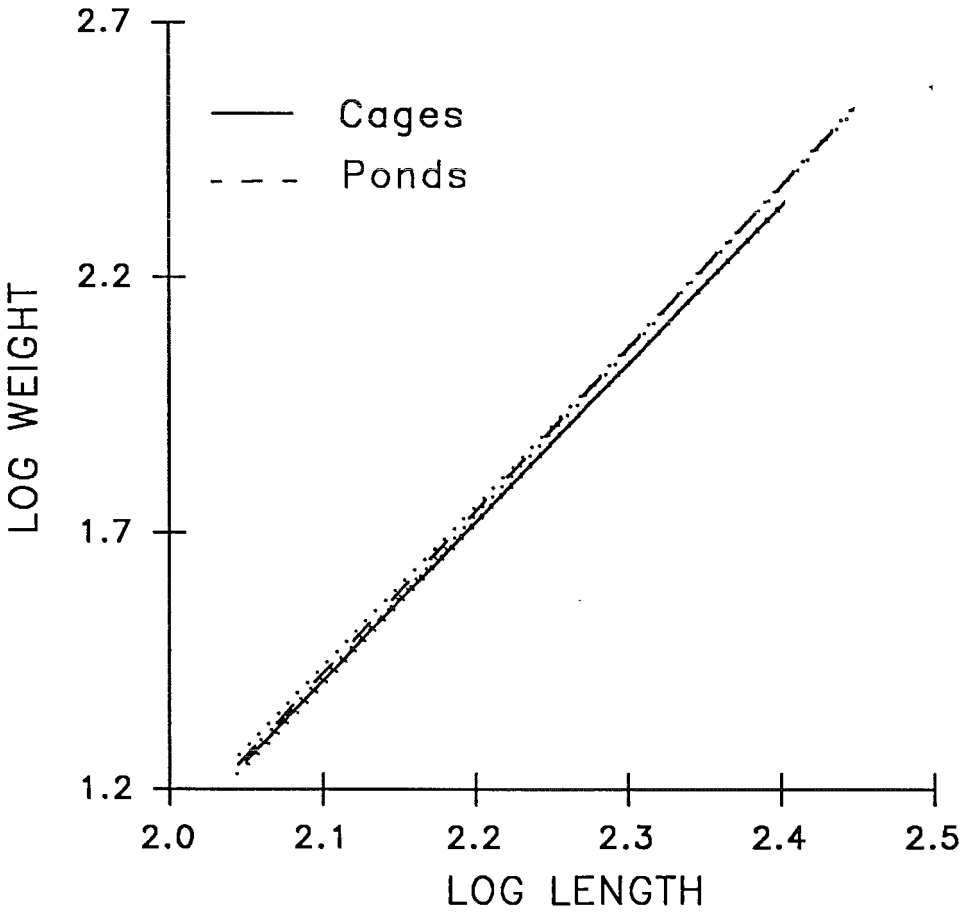


Figure 3. Length/weight relationships at harvest for black bullhead raised in cages and open ponds between 4 June and 28 September 1991. Dotted lines (...) represent 95% confidence intervals.

Cages: $\log W = 3.089 (\log L) - 5.075$; $r^2 = 0.927$
Ponds: $\log W = 3.171 (\log L) - 5.234$; $r^2 = 0.924$



APPENDIX A

Statistical Analysis for Percent Recovery

Table A-1. Percent recovery for black bullheads raised in cages and open ponds between 4 June and 28 September 1991.

WHERE	# STOCKED	# RECOVERED	# DOCUMENTED DEATHS	# NOT ACCOUNTED FOR	% RECOVERED
CAGE 2A	150	137	10	3	91.3
CAGE 2B	150	142	8	0	94.7
CAGE 2C	150	142	7	1	94.7
CAGE 4A	150	139	11	0	92.7
CAGE 4B	150	146	3	1	97.3
CAGE 4C	150	148	4	-2[a]	98.7
CAGE 6A	150	137	11	2	91.3
CAGE 6B	150	142	7	1	94.7
CAGE 6C	150	134	14	2	89.3
POND 2	452	400	1	51	88.5
POND 4	450	417	2	31	92.7
POND 6	450	417	1	32	92.7

[a] The extra fish in cage 4C are probably from miscounting when stocking.

Table A-2. The randomized block design for percent recovery for black bullhead cultured in cages (caged) and open ponds (free) between 4 June and 28 September 1991.

TREATMENTS		PONDS (BLOCKS) 2	4	6	TOTALS
	CAGED	93.6	96.2	91.8	281.6
	FREE	88.5	92.7	92.7	273.9
	TOTALS	182.1	188.9	184.5	555.5

Table A-3. Analysis of variance table for the randomization block design for percent recovery for black bullhead cultured in cages (caged) and open ponds (free) between 4 June and 28 September 1991.

SOURCE	SS	DF	MS	$F_{COMPUTED}$
TREATMENTS	9.92	1	9.99	2.06
BLOCKS	11.93	2	5.96	1.24
ERROR	9.62	2	4.81	
TOTALS	31.47	5		

RESULTS:

No differences between treatment means (caged vs. free); $p>0.05$.

No differences between block means (ponds 2 vs. 4 vs. 6); $p>0.05$.

APPENDIX B

Statistical Analysis for Weight Gained

Table B-1. Weight gained (g) for black bullheads raised in cages and open ponds between 4 June and 28 September 1991.

WHERE	AVERAGED STOCKED WEIGHT (g) PER FISH	# OF FISH HARVESTED	AVERAGE HARVEST WEIGHT (g) PER FISH	TOTAL BULLHEAD HARVEST WEIGHT (g)	AVERAGE WEIGHT GAINED (g) PER FISH
CAGE 2A	38.5	137	114.9	15,747.7	76.4
CAGE 2B	38.5	142	121.2	17,213.0	82.7
CAGE 2C	38.5	142	111.7	15,854.6	73.2
CAGE 4A	38.5	139	112.6	15,655.6	74.1
CAGE 4B	38.5	146	112.9	16,476.6	74.4
CAGE 4C	38.5	148	102.5	15,174.6	64.0
CAGE 6A	38.5	137	99.8	13,676.7	61.3
CAGE 6B	38.5	142	97.6	13,862.8	59.1
CAGE 6C	38.5	134	99.0	13,272.2	60.5
POND 2	38.5	400	215	85,984.9	176.5
POND 4	38.5	417	172.8	72,060.1	134.3
POND 6	38.5	417	191.9	80,006.0	153.4

Table B-2. The randomized block design for weight gained (g) for black bullhead cultured in cages (caged) and open ponds (free) between 4 June and 28 September 1991.

		PONDS (BLOCKS)			
		2	4	6	TOTALS
TREATMENTS	CAGED	77.5	70.8	60.3	208.6
	FREE	176.5	134.3	153.4	464.2
	TOTALS	254.0	205.1	213.7	672.8

Table B-3. Analysis of variance table for the randomization block design for weight gained (g) for black bullhead cultured in cages (caged) and open ponds (free) between 4 June and 28 September 1991.

SOURCE	SS	DF	MS	$F_{COMPUTED}$
TREATMENTS	10,888.56	1	10,888.56	60.18
BLOCKS	681.54	2	340.77	1.88
ERROR	361.87	2	180.94	
TOTALS	11,931.97	5		

RESULTS:

There are statistically significant differences between treatment means (caged vs. free); $p<0.05$.

No differences between block means (ponds 2 vs. 4 vs. 6); $p>0.05$.

APPENDIX C

Statistical Analysis for Feed Conversion

Table C-1. Feed conversion for black bullheads raised in cages and open ponds between 4 June and 28 September 1991.

WHERE	FOOD CONSUMED (g)	WEIGHT GAINED (g)	FEED CONVERSION
CAGE 2A	26,175	10,473	2.5
CAGE 2B	27,272	11,746	2.3
CAGE 2C	26,981	10,388	2.6
CAGE 4A	26,102	10,304	2.5
CAGE 4B	24,344	10,856	2.2
CAGE 4C	25,909	9,477	2.7
CAGE 6A	25,729	8,402	3.1
CAGE 6B	24,420	8,396	2.9
CAGE 6C	25,341	8,113	3.1
POND 2	99,069	70,585	1.4
POND 4	99,708	56,006	1.8
POND 6	99,069	63,952	1.6

Table C-2. The randomized block design for feed conversion for black bullhead cultured in cages (caged) and open ponds (free) between 4 June and 28 September 1991.

		PONDS (BLOCKS)			
TREATMENTS		2	4	6	TOTALS
	CAGED	2.5	2.5	3.0	8.0
	FREE	1.4	1.8	1.6	4.8
	TOTALS	3.9	4.3	4.6	12.8

Table C-3. Analysis of variance table for the randomization block design for feed conversion for black bullhead cultured in cages (caged) and open ponds (free) between 4 June and 28 September 1991.

SOURCE	SS	DF	MS	$F_{COMPUTED}$
TREATMENTS	1.70	1	1.70	28.33
BLOCKS	0.12	2	0.06	1.00
ERROR	0.13	2	0.06	
TOTALS	1.95	5		

RESULTS:

There are statistically significant differences between treatment means (caged vs. free); $p<0.05$.

No differences between block means (ponds 2 vs. 4 vs. 6); $p>0.05$.

APPENDIX D

Statistical Analysis for Visibility

Table D-1. Visibility (cm) for ponds 2, 4, and 6 before (pop. 1) and after (pop. 2) pond maintenance and aeration was initiated during black bullhead study 4 June and 28 September 1991.

WHERE	POP. 1 (cm)	POP. 2 (cm)
POND 2	63	154
	69	132
	126	81
	134	114
	154	110
	135	106
		61
		65
		56
POND 4	68	93
	154	154
	154	146
	117	105
	114	110
	124	89
		95
		92
		82
POND 6	154	121
	154	154
	79	154
	154	154
	91	154
	97	133
		154
		154
		154

Table D-2. Analysis of variance tables for visibility for ponds 2, 4, and 6 before and after pond maintenance and aeration was initiated during the black bullhead study 4 June and 28 September 1991.

	SOURCE	SS	DF	MS	F	p
POND 2						
	FACTOR	903	1	903	0.17	0.41
	ERROR	16,475	13	1,267		
	TOTAL	17,378	14			
POND 4	FACTOR	757	1	757	0.95	0.35
	ERROR	10,313	13	793		
	TOTAL	11,070	14			
POND 6	FACTOR	2528	1	2,528	4.26	0.06
	ERROR	7711	13	593		
	TOTAL	10,240	14			

RESULTS:

No differences between before and after pond maintenance and aeration in any of the three ponds; $p>0.05$.