

EFFECTS OF CAGED CATFISH CULTURE ON WATER QUALITY AND COMMUNITY METABOLISM OF A LAKE

Rex L. Eley, Joe H. Carroll, and Doyle DeWoody

U. S. Army Corps of Engineers, Tulsa, Oklahoma, Department of Zoology, Oklahoma State University, Stillwater, Oklahoma, and Department of Biological Science, Southern State College, Magnolia, Arkansas¹

Effects of commercial caged catfish culture on water quality and community metabolism of White Oak Lake, Arkansas, were studied during the summers of 1970 and 1971. Statistically significant increases in turbidity, alkalinity, total and phosphate phosphorus, organic nitrogen, biochemical oxygen demand, bacteria, community metabolic rates, and dominant invertebrates were observed in the culture area as compared to other lake areas. Significant decreases in dissolved oxygen, nitrate, chlorophyll *a*, and gross primary production/total community respiration (P_g/R_t) ratios were observed in the culture area.

The caged catfish industry is growing rapidly in the southern United States. In the past unconfined culture in ponds or raceways has been the most common method of catfish farming. Rearing catfish fingerlings to marketable size in floating cages is a newer method which is showing significant commercial potential. Usually fingerlings of *Ictalurus punctatus* are stocked at densities of about 1,000 fish per (1.2 x 1.2 x 2.4 m) cage in the spring and are fed floating pellets until they reach a harvestable size (350 to 700 g) in the fall.

While the maximum recommended stocking rate for unconfined culture in ponds without artificial aeration normally is 5 - 6 thousand fingerlings per hectare (personal communication with Arkansas Game and Fish Commission), stocking rates in cages of 300-600 fingerlings per cubic meter have been successfully employed in lakes where sufficient water exchange is available. Cages do not reduce the volume of water required to support the culture of a given number of fish, but they do allow the culture to be confined to a smaller area, thereby facilitating feeding, periodic checks on weight gains and health, and harvesting. Theoretically, increases in fertility as a result of excess food and of fish excrement produced during high density culture would be expected to stimulate productivity of natural populations in oligotrophic lakes, but these conditions could pose

potential water quality problems in eutrophic lakes.

In 1970 the Arkansas Game and Fish Commission began leasing portions of state-owned lakes to commercial fish farmers in return for 5% of the gross weight of catfish raised, with these fish to be used for stocking public waters (1). The first such contract in Arkansas leased four hectares (ha) of White Oak Lake, Ouachita County, to a commercial fish farmer for experimental caged culture of channel catfish.

White Oak Lake was created in 1960 by impounding White Oak Creek, a tributary of the Little Missouri River, near Camden, Arkansas (Figure 1). A dam in the middle of the lake forms two separate bodies of water, an upper portion of 417 ha and a lower portion of 666 ha. The lake has an average depth of 2.4 m and a maximum depth of 5.5 m; it is equipped with a draw-down structure and a spillway (2). Limited clearing prior to impoundment resulted in the formation of extensive areas of dead timber in the lake.

In the spring of 1970, 150-170 thousand fingerling catfish were placed in 160 cages at densities ranging from 400 to 2,400 fish per 1.2 x 1.2 x 2.4 m cage. The cages were floated in four lines of about 40 cages each by attachment to steel cables anchored in a cleared area in the lower portion of the lake (Figure 1). Approximately 59 metric tons of floating pellets were fed during the growing season of 1970. The project was not a financial success during the initial year of operation, largely because of losses

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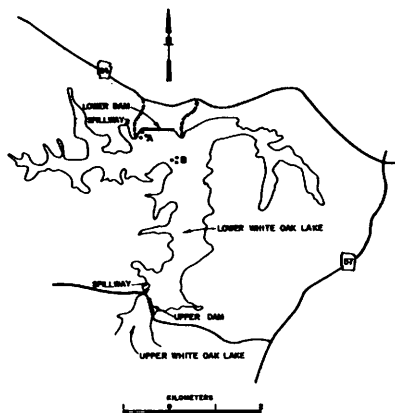


FIGURE 1. Lower White Oak Lake, Ouachita County, Arkansas. The three dots designated "A" indicate the location of sampling stations among cages of catfish; dots designated "B" indicate the location of sampling stations in the control area.

of fish from damaged cages and vitamin C deficiencies resulting from improperly prepared feed. In 1971 the White Oak project was expanded by stocking 300,000 channel catfish fingerlings, ranging in size from 5 to 25 cm, at densities of 1-6 thousand fish per cage. Approximately 181 metric tons of commercial floating pellets were fed during the 1971 growing season, with feeding rates ranging from 0.3 metric tons per day at the beginning of the growing season up to 1.8 metric tons per day in July when a selective harvest began.

Although a large volume of literature concerning catfish culture is available, little is known about the quality or quantity of wastes produced by commercial caged catfish culture or about the effects of these wastes on water quality and biota of lakes. Problems of oxygen depletion and excessive plankton blooms associated with pond catfish culture have been reviewed by Tackett (3) and Avault (4). Collins (5) reported that there was no measurable difference in dissolved oxygen concentrations inside cages of catfish and elsewhere in a lake. Murphy and Lipper (6) studied wastes produced by channel catfish in laboratory tanks and concluded that catfish produce more biochemical oxygen demand (BOD) per unit of live weight than other commercial animals, such as chickens, swine, and cattle.

The objective of this study was to determine if commercial caged catfish culture significantly affected the water quality and community structure and function of White Oak Lake.

METHODS

Six permanent sampling stations were established by anchoring three buoys approximately 100 m apart in the form of a triangle among the fish cages and three buoys in a control area located about 0.8 km upstream from the culture area (Figure 1). The prevailing water movement, as determined by free drags, was past the control sampling area toward the culture area, which was located near the lake's outlet structures. All six sampling stations were located in water about 5 m deep. Measurements of pH, turbidity, alkalinity, phosphorus, nitrogen, biochemical oxygen demand (BOD) and chemical oxygen demand (COD) were made by standard methods (7) at 0.5 and 4.5 m depth at each sampling station twice during the summer of 1970 and biweekly during the summer of 1971. Temperature and dissolved oxygen were determined *in situ*, at each meter of depth at 3-hr intervals for a 24-hr period on each sampling date, using a galvanic cell oxygen-analyzer and tele-thermometer. A modification of the O_2 curve method of Odum and Hoskin (8) was used to estimate rates of community metabolism from diurnal oxygen changes (9). Total numbers of bacteria at 0.5 and 4.5 m depth were determined by the standard plate count method (7). Concentrations of chlorophyll *a* at 0.5 and 4.5 m depth were measured by filtering water samples through 0.45μ membrane filters and following the methods of Richards with Thompson (10) and Parsons and Strickland (11). The abundance of dominant invertebrates per square meter of lake surface was estimated by combining counts of benthic macroinvertebrates obtained from Ekman dredge samples with counts of planktonic invertebrates obtained from vertical plankton net tows made from the bottom to the surface of the lake. Analyses of variance and tests for statistically significant differences (*t*ad) between culture and control areas, between depths within areas, and among sampling dates were made using a factorial arrangement of treatments with variation among triplicate sampling stations located within each area

servicing as an estimate of experimental error (12).

RESULTS AND DISCUSSION

White Oak Lake was thermally stratified during the summers of 1970 and 1971 (Figure 2). No significant difference in

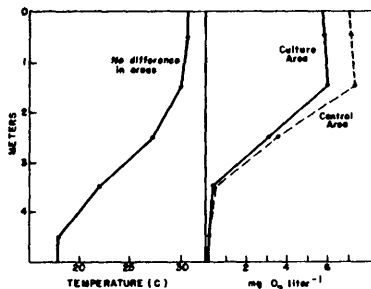


FIGURE 2. Comparison of average temperature and dissolved oxygen profiles in an area of caged catfish culture and a control area in White Oak Lake, Arkansas, during the summers of 1970 and 1971.

the degree of stratification was observed between culture and control areas or between years (Figure 2). Stratification did intensify slightly from June to August of each year as the average surface temperature (at 0.5 m) increased from about 29 to 31 C. No significant changes in the temperature of bottom waters (4.5 m) were observed during June, July, and August.

Dissolved oxygen (DO) exhibited a clinograde distribution (Figure 2). Oxygen concentrations in the upper 3 m of water were significantly lower in the culture area than in the control area (Table 1). No

significant differences were observed between oxygen concentrations below 3.5 m during 1970 and 1971. Average oxygen concentrations in the surface waters progressively decreased from June to August from 7.7 to 6.7 mg liter⁻¹ in the control area and from 6.6 to 5.1 mg liter⁻¹ in the culture area.

The consistently lower oxygen concentrations in the upper 3 m of the culture area, as compared to control areas during 1970 and 1971, are contrary to observations made by Douglas Rogers (personal communication) on surface samples collected from White Oak Lake during 1970. Rogers concluded that only when the water temperature was in excess of 30 C was a difference noted, and then it was 1 mg liter⁻¹. The discrepancy between our conclusions probably is because Rogers collected unreplicated surface samples and "DO was determined to the nearest ppm."

Statistical comparison of physiochemical data, for culture and control areas averaged over sampling depth and time, revealed significant decreases in dissolved oxygen, pH, and nitrate-nitrogen in the culture area (Table 1). Reductions in oxygen and pH probably were a result of biochemical decomposition of fish wastes and feed residue. The slight reduction in nitrates in the culture area may have been due to a greater percentage of the total inorganic nitrogen existing as nitrite or ammonia associated with lower oxygen concentrations. Turbidity, alkalinity, orthophosphate, total phosphorus, organic nitrogen, and 5-day biochemical oxygen demand were significantly higher in the culture area than in the control area (Table 1). All of these in-

TABLE 1. Effect of caged catfish culture on physiochemical parameters in White Oak Lake, Arkansas.

Parameter ^a	Control area \bar{X}	Culture area \bar{X}	Probability of significant difference (%)
Temperature (C)	25.7	25.5	—
Dissolved oxygen (at 0.5 m)	7.1	5.8	99
pH units	6.4	6.1	—
Turbidity units	6	10	90
Total alkalinity (as CaCO ₃)	87	91	75
PO ₄ -P	0.03	0.48	99
Total P	0.06	1.01	95
NO ₃ -N	0.6	0.5	75
Organic N	1.2	4.0	90
BOD ^b (5-day)	1.0	1.6	99
COD ^c	17	17	—

^a Expressed as mg liter⁻¹ unless otherwise noted.

^b Biochemical oxygen demand.

^c Chemical oxygen demand.

creases are consistent with the hypothesis that fish excrement and feed residue added to the fertility and oxygen demand of the culture area. No significant difference in chemical oxygen demand was observed between sampling areas. Turbidity, pH, and nitrates decreased with depth, while alkalinity, phosphate, total phosphorus and organic nitrogen increased with depth. No significant differences among depths were observed for BOD and COD.

Changes in water quality as a result of fish culture produced significant effects on all biological parameters studied (Table 2). Total numbers of bacteria and dominant invertebrates and rates of community metabolism were significantly higher in the culture area. These increases probably were caused by allochthonous organic matter and nutrients added for catfish culture. Significant decreases in concentrations of chlorophyll *a* and in the ratios of gross primary production (P_g) to total community respiration (R_t) were observed in the culture area. Change in the state of the aquatic community from autotrophic in the control area to heterotrophic in the culture area would be expected because of the large influx of allochthonous organic matter in the form of fish food. However, the difference in average chlorophyll *a* concentration between the control area (116 mg m^{-3}) and the culture area (72 mg m^{-3}) is difficult to explain. An increase in chlorophyll *a* concentration might be expected in the culture area due to the increase in nutrient concentrations, despite a significant but small increase in turbidity.

A decrease in chlorophyll *a* from 354 to 80 mg m^{-3} was observed in a laboratory experiment in which ten channel catfish fingerlings (approximately 0.9 kg total

weight) were placed in an aquarium (0.2 m^3) under Grow-Lux lights and changes between the fish aquarium and a control aquarium (0.2 m^3) were observed for two weeks. In the laboratory experiment, however, there was a much larger increase in turbidity, as a result of fish excrement and food residues, than in White Oak Lake. Extremely inefficient food conversion by catfish in the aquarium prevented conclusions that were applicable to the commercial project. Low efficiency of food conversion by fish in confined culture also may well have caused Murphy and Lipper (6) to over-estimate actual values for the biochemical oxygen demand (BOD) rates of catfish. These investigators obtained conversion ratios of 2.35 to 3.34 for catfish in a tank of approximately 0.9 m^3 , whereas conversion ratios for caged catfish in lakes normally are less than 1.5.

Both the culture and control areas of White Oak Lake were characterized by low diversity of benthic and planktonic macroinvertebrates. Chaoborinae made up over 95% of all benthic macroinvertebrates collected. Chaoborinae composed 22% of the larger planktonic invertebrates, while cladocerans accounted for 26% and copepods for 49%.

The success of sport fishing in the culture area, as compared to other areas of White Oak Lake, indicated that natural fish populations were attracted to the cage area because of food wastes and increases in natural fish food organisms.

Based on a conservative food conversion ratio of 1.5 and a total feed input of 240 metric tons during the summers of 1970 and 1971, approximately 160 metric tons of feed were converted to fish biomass and about 80 metric tons were added to

TABLE 2. Effect of caged catfish culture on biological parameters in White Oak Lake, Arkansas.

Parameter	Units	Control area \bar{x}	Culture area \bar{x}	Probability of significant difference (%)
Bacteria	No. ml ⁻¹	14,800	38,200	75
Dominant invertebrates				
Chaoborinae	No. m ⁻²	3,467	9,887	95
Cladocera	No. m ⁻²	3,269	4,338	75
Copepoda	No. m ⁻²	3,596	8,654	90
Chlorophyll <i>a</i>	mg m ⁻³	116	72	90
Gross primary production	g O ₂ m ⁻² day ⁻¹	12.5	18.4	97
Community respiration	g O ₂ m ⁻² day ⁻¹	12.4	21.4	99
P_g/R_t ^a	—	1.01	0.86	90

^a Gross primary production/ total community respiration.

the lake. These calculations assume that all of the feed was consumed by catfish with no waste. However, it is probable that most of the feed that escaped the cages was consumed by natural fish populations.

The lack of statistically significant differences in nutrients and potential oxygen demand between the summers of 1970 and 1971 indicates that, in lakes such as White Oak, the effects of commercial catfish projects of moderate size may not drastically affect the long-term rate of eutrophication. However, in this study the location of cages near the lake's outlet probably prevented cumulative effects on water quality due to water exchange. Caged catfish culture apparently did affect water quality in the immediate project area during the growing season, but during the winter the waste residues were dissipated through decomposition and water exchange. This pattern probably would hold even if a caged fish population remained throughout the winter because the metabolic rate decreases and feeding practically ceases as the lake cools in the fall.

Rates of community metabolism in the control area of White Oak Lake ($P_g = 12.5 \text{ g O}_2 \text{ m}^{-2} \text{ day}^{-1}$ and $R_t = 12.4 \text{ g O}_2 \text{ m}^{-2} \text{ day}^{-1}$) are comparable to rates of P_g ($12.6 \text{ g O}_2 \text{ m}^{-2} \text{ day}^{-1}$) and R_t ($12.1 \text{ g O}_2 \text{ m}^{-2} \text{ day}^{-1}$) obtained in August, 1971 in Lake Greason on the Little Missouri River, Arkansas. Lake Greason is characterized by lower nutrient concentrations than White Oak and is representative of oligotrophic lakes in Arkansas. In lakes such as Greason, and even White Oak, a controlled quantity of commercial caged catfish culture would appear to be an effective management tool for stimulating production of natural fish populations and for the development of excellent sport fishing areas. However, caution would have to be exercised in allowing the establishment of a significant number of commercial projects in White Oak Lake and especially in more eutrophic lakes such as Lake Millwood. Dissolved oxygen concentrations in the surface waters of the culture area of White Oak Lake frequently dropped to near 4 mg liter^{-1} at sunrise during the summer. During extended periods of cloudy weather or drought, water quality in culture areas could quickly deteriorate sufficiently to cause mortality of both caged and natural fish populations.

Future studies of the effects of caged catfish culture should include estimates of nutrient flux between water and bottom muds and more quantitative estimates of the effects of wastes on water quality and natural fish populations. Wire enclosures placed over areas of bottom sediment could be used to estimate the indirect contribution of catfish culture to the production of natural fish populations through stimulation of benthic macroinvertebrate populations. The use of a clear plastic sleeve to isolate a known volume of water around a cage of catfish for short periods of time would be an effective method of estimating the quantity of fish excrement and feed residue produced under actual field conditions.

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