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CAGE CULTURE OF CHANNEL CATFISH, ICTALURUS PUNCTATUS
(RAFINESQUE), IN A TERTIARY WASTEWATER TREATMENT POND
AND A PRIVATE POND IN SOUTHERN MICHIGAN

presented by

Daniel Joseph Duffield

has been accepted towards fulfillment
of the requirements for

MASTER OF SCIENCE degree in FISHERIES

Howard E. Johnson
Major professor

Date August 27, 1979



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(RAFINESQUE), IN A TERTIARY WASTEWATER TREATMENT POND
AND A PRIVATE POND IN SOUTHERN MICHIGAN

By

Daniel Joseph Duffield

A THESIS

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ABSTRACT

CAGE CULTURE OF CHANNEL CATFISH, ICTALURUS PUNCTATUS (RAFINESQUE), IN A TERTIARY WASTEWATER TREATMENT POND AND A PRIVATE POND IN SOUTHERN MICHIGAN

By

Daniel Joseph Duffield

Channel catfish were reared in 0.8 m^3 cages in a southern Michigan farm pond and a pond which received secondary treated domestic waste water. Cages were stocked in May with 117 mm fingerlings at densities of 50, 100 and 150 fish per cubic meter.

The fish production in the farm pond was approximately 44.8 kg/m^3 compared with 12.5 kg/m^3 in the wastewater pond. The lower production in the wastewater pond was probably due to adverse water quality conditions including high pH, low dissolved oxygen and high concentrations of un-ionized ammonia. Total mortality of the fish in the wastewater pond occurred in September when dissolved oxygen levels declined to less than 1.0 mg/l . Fish production was not significantly affected by different stocking densities.

The results indicate that cage culture is not suitable in highly enriched wastewater ponds with extensive plant growth but successful cage culture may be practiced in southern Michigan farm ponds.

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Finally, I wish to thank my wife, Gloria, for her moral support, patience and understanding during the last two years. I would like to dedicate this thesis to Gloria and our daughter, Amy.

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INTRODUCTION

The culture of channel catfish, Ictalurus punctatus (Rafinesque), is commercially important in the Mississippi river areas of the United States. This success has generated interest in culturing channel catfish in other locations including the northern areas of the nation.

Cage culture of channel catfish is an intensive culture method that has received considerable attention due to the ease of observing, feeding, and harvesting the fish (Schmittou 1969). Experimental cage culture of channel catfish has been reported by various authors. Kilambi et al. (1976) and Collins (1970) reported results of cage culture of channel catfish in Arkansas. Schmittou (1969) utilized cages to rear channel catfish in Alabama. Douglass and Lackey (1972) reported that the production of marketable channel catfish in cages was both economically and biologically feasible in Virginia. Lewis and Wehr (1976) described a fish rearing system in Illinois which incorporated cages, controlled water circulation and solid waste removal. They felt that their system had the potential for increasing fish production in ponds, avoiding loss of fish due to oxygen depletion, and permitting polyculture.

In cage culture, stocking densities vary with differences in pond size and characteristics (Douglass and Lackey 1973). Collins (1970) reported the optimum stocking density to be between 200 and 300 fish per cubic meter for cages placed in a shallow 0.04 ha bay. Kilambi et al. (1976) reported that the stocking rates of 144, 235 and 366 fish per cubic meter had no effect on growth or feed conversion of channel catfish. Schmittou (1969) suggested a stocking rate of 500 fish per cubic meter of cage for ponds between 0.5 and 4.2 ha in size.

In Michigan there is a relatively high interest and demand among pond owners for information on channel catfish culture. The large number of private farm ponds in Michigan represents a potential for the production of fish. In addition, there is an increasing interest in developing ponds for the treatment of agricultural and domestic wastewater which may also have a potential for intensive fish culture. Consequently, there is a need to develop information on the growth and production potential of catfish in north temperate climates.

The purpose of this study was to determine the potential for cage culture of channel catfish in Michigan ponds. Two types of ponds were used: (1) a tertiary wastewater treatment pond that is part of the Michigan State University wastewater management project and (2) a private pond that is typical of farm ponds in southern Michigan.

The specific objectives were as follows:

1. To determine the growth rate and growth efficiency of channel catfish in cages in Michigan.

2. To compare the efficiency and production of channel catfish in a wastewater treatment system with a typical farm pond.

Description of Study Areas

Lake Four has a surface area of 4.4 ha and an average depth of 2 m. It is the terminal pond in a series of four ponds designed to provide tertiary treatment of domestic waste water from the City of East Lansing. The waste water management project is located approximately 3.2 kilometers south of the main part of Michigan State University's campus near East Lansing, Michigan. The waste water system, first operated in 1973, received unchlorinated, secondary treated waste water from the East Lansing sewage treatment plant at intermittent periods until 1976. During 1976 and 1977 there was very little waste water added to Lake Four and none was received in the lake during the study period or during the first part of 1978. Lake Four contained extensive vegetation (mostly Elodea sp.) during most of its history and part of the management scheme for the treatment system included the harvest and removal of these plants as a method to remove nutrients. During 1978, periphyton growth was more extensive than Elodea sp. for the first time. Because of this heavy plant density, the water quality in Lake Four was characterized by high pH values, low dissolved oxygen levels and low free CO₂ levels. Lake Four was stocked with largemouth bass (Micropterus salmoides) and fathead minnows (Pimephales promelas) in 1975.

Martin Pond is a privately owned pond approximately 2.4 kilometers south of the waste water treatment ponds. It has a surface area of 0.36 ha and an average depth of 1.5 m. It originated from a cut-off oxbow of Sycamore Creek, Ingham County. The water source consisted of run-off water and a few small springs. The pond was primarily used for recreational purposes. The aquatic vegetation was primarily periphyton around the pond margin and some aquatic macrophytes extending out into the pond. Martin Pond contained populations of bluegills (Lepomis macrochirus), largemouth bass (Micropterus salmoides) and fathead minnows (Pimephales promelas).

MATERIALS AND METHODS

The cages were cylinders (0.91 m diameter x 1.22 m height) constructed of 127 mm mesh plastic netting (E. I. Dupont Denemours & Co. Vexar) secured to 3 fiberglass hoops and covered with a hinged plywood top. The total cage volume was 0.80 m^3 . Blocks of styrofoam (10 cm x 15 cm x 30 cm) attached near the top on the cage sides floated the cages at the water surface. A 32 mm mesh plastic screen lining around the upper 305 cm inside the cage acted as a feeding ring to retain floating food pellets within the cage. A screen covered feeding port in the cage top allowed feeding without opening the cages.

Nine cages were placed in each pond. Each cage was attached at 1 m intervals to a main anchor rope which was secured to shoreline stakes (in Martin Pond) or to concrete block anchors (in Lake Four). In Lake Four the cages were arranged in two rows (4 and 5 cages in each) with the rows spaced approximately 10 m apart. The cages were positioned in a single row of 9 cages in Martin Pond. All cages were located in water that had a depth of at least 1.5 m.

The cages were stocked with channel catfish fingerlings averaging 117 mm total length and 12.3 gm in weight. The fish were purchased from a commercial fish farm and were

stocked directly from the transport tank into the cages on May 12, 1978. Three stocking densities (40, 80 and 120 fish per cage) each in triplicate were used in each pond. These densities were equivalent to 50, 100 and 150 fish per cubic meter. Densities for each cage were assigned by random selection.

Feeding was initiated on May 15, 1978 and continued on a 6 day per week basis at approximately 1000 to 1200 hours. The fish were fed Purina Floating Trout Chow (developer size) which had a guaranteed analysis of crude protein greater than or equal to 40.0%, crude fat greater than or equal to 4.0%, crude fiber less than or equal to 4.0%, ash content less than or equal to 13.0% and added minerals less than or equal to 4.0%. The food for each day was weighed to the nearest gram and placed in separate, labeled containers for each cage.

The fish were fed to satiation. To adjust the feeding rate, the amount of food fed was increased until after 10 minutes a few pellets remained uneaten in at least a few cages. This new feeding rate was then maintained until all of the food fed was consumed in all of the cages within the allotted time. When this occurred, the amount of food fed was gradually increased (about 3 grams per day per 40 fish) until the satiation level was again attained.

A subsample of 10 fish per cage (30 fish per treatment) was weighed and measured on the 14th of each month to ensure an adequate sample size throughout the study. Prior to stocking a statistical test (Gill 1978) was performed in order to

estimate the required sample size needed to detect a mean difference in fish growth. It was calculated that a mean difference of 6 grams could be detected for a 0.05 significance level with a sample size of 10 fish per treatment.

Fish were anesthetized with MS-222 (ethyl m-aminobenzoate methanesulphonate), weighed to the nearest gram (Ohaus Dial-O-Gram scale-1600 gram capacity) and measured to the nearest millimeter. One fish from each cage (3 per stocking density) was killed on June 14, July 14 and August 14 and the stomachs from these fish were preserved in 10% formalin. The stomach contents were analyzed to determine the contribution of natural food to the catfish diet. The general condition of the skin and fins of the fish and their gills were examined and noted. Sections of the gill filaments were examined under a microscope for gill tissue damage and hyperplasia.

Surface water temperature and wind velocity were recorded 6 days per week. Wind velocity was estimated according to categories of 0-5, 5-10, 10-15, 15-20, 20-25 and 25-30 mph. Water samples were taken next to various cages at 1.0 to 1.3 m depth with a 1-liter Kemmerer sampling bottle and transported to the laboratory in 2-liter polyethylene bottles.

Ammonia measurements were initiated on June 20 and were continued 4 days per week shortly thereafter according to the method recommended by Harwood and Kuhn (1970) and further modified by Gravitz and Gleye (1975). Un-ionized ammonia was determined using tables by Thurston et al. (1974).

Alkalinity was measured approximately bi-weekly by acid titration with mixed brom-cresol green-methyl red indicator solution (APHA 1975). Free CO_2 levels were calculated from tables utilizing pH, temperature and alkalinity (Dr. D. King, Institute of Water Research, Michigan State University, unpublished data).

Dissolved oxygen was determined 6 days per week from a single sample taken next to a cage from each body of water utilizing the Azide modification of the Winkler method (APHA 1975). Additional dissolved oxygen determinations were made at dawn and dusk when the routine daytime (1000 to 1200 hours) dissolved oxygen levels decreased below 5.0 mg/l or when about 2 weeks had elapsed since the previous dawn and dusk samples.

The pH was measured on site at each pond with a Beckman Chem-mate model 72 pH meter at the time the water samples were taken. Average pH values were determined by calculating the hydrogen ion concentration and then averaging those values. The average hydrogen ion concentrations were then expressed as an average pH value.

The catfish growth data were analyzed by a two-way analysis of variance (pond and density as main effects) (Nie, N.H. et al. 1975) using an IBM 6500 computer. Students' t-test was used to test means of the water quality data (Gill 1978). Significance levels of statistical tests were expressed at the 0.05 level, unless otherwise noted.

The fish were subsampled on the 14th of each month with the data being analyzed according to the following sample periods:

First period---May 15 to June 14
Second period--June 15 to July 14
Third period---July 15 to August 14
Fourth period--August 15 to September 14
Fifth period---September 15 to October 6

RESULTS

Physical and Chemical Parameters

There were major differences between the water quality parameters of the two study ponds. The observed trends in some of the water quality values reflected differences in the plant community. In Martin Pond pH values and free CO₂ levels were variable indicating frequent changes in the plant community. Lake Four, however, had consistently high pH values and low free CO₂ values indicating high photosynthetic activity. High photosynthetic activity reduced the free CO₂ and tended to increase the pH. These conditions in Lake Four continued until the periphyton collapsed in August which increased free CO₂ values and decreased pH values. The die-off of plants reduced the demand for free CO₂ which resulted in lower pH values. In addition, the decomposition of the plants combined with the loss of photosynthetic activity resulted in lower dissolved oxygen levels. This was illustrated by the fact that low dissolved oxygen levels paralleled low pH recordings in both ponds. Therefore, lower pH values, lower dissolved oxygen levels, higher free CO₂ levels and higher alkalinities were indicative of reduced photosynthesis and increased respiration.

The sample means of water quality parameters are given in Table 1. Mean temperatures for both ponds were in the 21-25°C range during the study period but the temperature was consistently higher in Martin Pond (Figure 1). During the final period the mean temperature in Martin Pond decreased to about 19°C. Bi-weekly dawn and dusk temperature measurements revealed that the temperature in both ponds varied by 2-5°C (Appendix Tables A1 and A2). The mean temperature in Martin Pond was significantly greater than that for Lake Four during the second and third periods of the study. The first and fourth period mean temperatures were not significantly different.

The mean dissolved oxygen level was significantly greater in Martin Pond in all but the third period. The lowest dissolved oxygen level recorded was 0.1 mg/l in Lake Four while Martin Pond had 4.5 mg/l as its lowest level. Dissolved oxygen in both ponds varied by 1-3 mg/l between dusk and dawn (Appendix Tables A1 and A2).

The pH values were consistently higher in Lake Four than in Martin Pond. During the first three periods all values in Lake Four were above 9.0 (Table 1 and Figure 1). During the first two periods in Martin Pond a high percentage of pH values were above 9.0 but in the third and fourth periods the pH was usually less than 9.0. The pH varied about 0.1 units between dawn and dusk for both ponds (Appendix Tables A1 and A2).

Table 1. Monthly means, standard errors and ranges of temperature, dissolved oxygen, total ammonia, un-ionized ammonia and pH for Martin Pond and Lake Four.

Pond	Period	Temp. °C.	D.O. (mg/l)	Total NH ₃ (mg N/l)	Un-ionized NH ₃ (mg N/l)	pH
MP	1	22.7 ± 0.7 (16.0-28.0)	8.7 ± 0.2 (5.9-10.2)			8.80 (8.2-9.7)
MP	2	25.2 ± 0.3 (22.0-28.0)	8.4 ± 0.3 (5.6-11.5)	0.180 ± 0.064 (0.010-0.400)	0.060 ± 0.021 (0.001-0.226)	8.90 (8.3-10.0)
MP	3	25.8 ± 0.3 (24.0-29.0)	6.4 ± 0.3 (4.5-10.2)	0.070 ± 0.015 (0.010-0.230)	0.002 ± 0.001 (0.001-0.008)	7.62 (7.2-8.5)
MP	4	24.9 ± 0.3 (21.0-27.0)	7.9 ± 0.2 (6.2-9.9)	0.040 ± 0.004 (0.020-0.110)	0.009 ± 0.001 (0.002-0.019)	8.51 (8.0-9.0)
MP	5	19.0 ± 0.8 (11.5-25.0)	7.9 ± 0.2 (5.0-9.0)	0.060 ± 0.009 (0.010-0.120)	0.002 ± 0.001 (0.001-0.004)	7.89 (7.5-8.3)
LF	1	21.2 ± 0.7 (14.5-27.0)	5.8 ± 0.2 (4.5-7.8)			10.30 (10.0-10.5)
LF	2	23.7 ± 0.4 (19.0-27.0)	6.9 ± 0.3 (4.9-10.6)	0.110 ± 0.037 (0.010-0.430)	0.091 ± 0.033 (0.009-0.383)	9.91 (9.5-10.3)
LF	3	24.9 ± 0.3 (23.0-28.0)	6.9 ± 0.2 (5.2-8.9)	0.050 ± 0.015 (0.010-0.290)	0.040 ± 0.013 (0.007-0.244)	9.86 (9.7-10.0)
LF	4	24.5 ± 0.2 (21.0-27.0)	4.2 ± 0.5 (0.1-9.2)	0.030 ± 0.004 (0.010-0.070)	0.011 ± 0.004 (0.001-0.033)	7.69 (6.7-10.3)
Mean ± Standard Error (Range)						

Figure 1. Sample period means of temperature, pH and dissolved oxygen for Martin Pond and Lake Four.

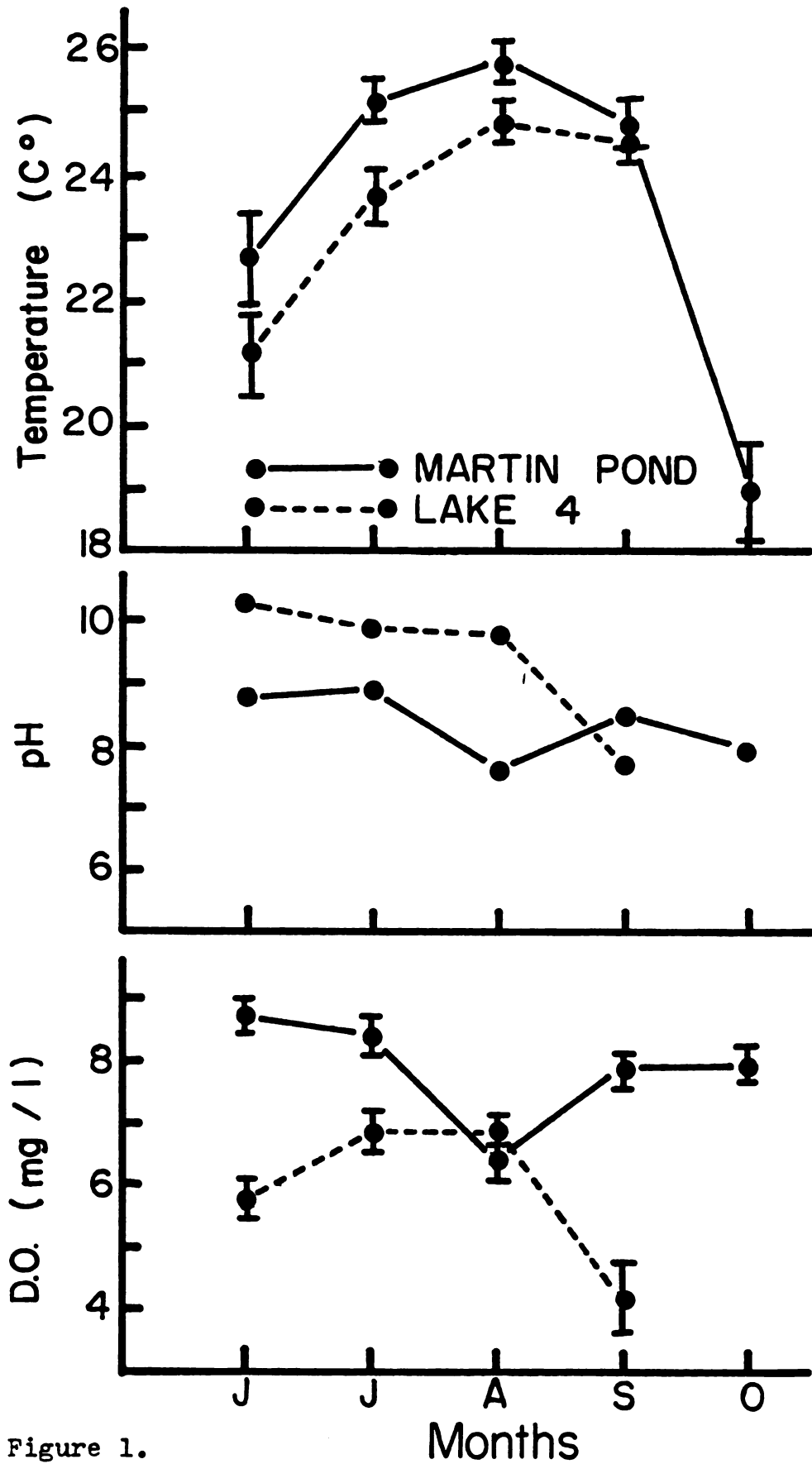


Figure 1.

The free CO_2 was quite variable in Martin Pond (Appendix Table A1). This variability reflected several algal blooms and subsequent die-offs. In Lake Four the free CO_2 was less variable (Appendix Table A2) and remained below $2.0 \mu\text{mol/l}$ from the beginning of the study period until August 25 when it increased to $1329.55 \mu\text{mol/l}$ due to a die-off of the periphyton. This tremendous increase coincided with a decrease in both pH and dissolved oxygen and with a slight increase in alkalinity indicating that respiration was the dominant process.

The alkalinity was also variable in Martin Pond with high alkalinities representing periods of dominant respiration (Appendix Table A1). The alkalinity decreased from an initial level of 106 mg/l as CaCO_3 to a low of 56 mg/l as CaCO_3 near the end of June and then varied between 82 and 106 mg/l as CaCO_3 for the remainder of the study.

In Lake Four the alkalinity was quite constant (Appendix Table A2). Between May 24 and August 25 the alkalinity varied from 111 to 123 mg/l as CaCO_3 . After the major mortality of fish and plants in September, the alkalinity increased to 145 mg/l as CaCO_3 .

Sample period means of total ammonia for both ponds were essentially equivalent ranging between 0.03 and 0.18 mg N/l (Table 1). For both ponds the highest total ammonia values occurred during the second period and the lowest values were in the fourth period. The total ammonia was

significantly greater in Martin Pond only during the fourth period.

During the fourth period the un-ionized ammonia concentration was significantly greater in Lake Four than in Martin Pond. Lake Four, however, consistently had a high percentage of un-ionized ammonia values greater than 0.02 mg N/l whereas in Martin Pond un-ionized ammonia levels only exceeded 0.02 mg N/l during the second period.

There was evidence of a higher rate of exchange of water through the cages in Lake Four. Wind velocity at Lake Four was 5-10 mph or greater on a majority of days while at Martin Pond wind velocities were usually less than 5-10 mph (Appendix Table A3). On days when the wind was greater than 15 mph, the wind induced water circulation was great enough to strip the periphyton growth from the outside of the cages in Lake Four. In Martin Pond the periphyton remained intact on the cages at all times and had to be manually stripped from the cages.

Catfish Feeding

The initial feeding rate for the fish in both ponds was 0.7% of the fish body weight (Table 2). The feeding rates remained the same for both ponds until June 1, 1978. At that time the Martin Pond fish continued to increase their feeding rate much more rapidly than the Lake Four fish. For the remainder of the study the Martin Pond fish fed more

vigorously than the Lake Four fish.

The highest feeding rate was 3.58% on June 14 in Martin Pond. Martin Pond fish had higher feeding rates than the Lake Four fish until September when the feeding rate of the fish in Lake Four exceeded that of the fish in Martin Pond.

Table 2. The average weight and the calculated biomass and feeding rate for catfish at each sampling date in Martin Pond and Lake Four.

Pond	Date	Average Weight(gm)	Calculated Biomass(kg)	Calculated Feeding Rate(% body weight)
MP	5-15	12.3	9.262	0.70
MP	6-14	36.6	27.560	3.58
MP	7-14	56.5	42.036	2.71
MP	8-14	84.6	62.181	1.92
MP	9-14	137.8	99.905	1.44
MP	10-6	160.9	116.653	0.77
LF	5-15	12.3	8.856	0.70
LF	6-14	27.9	20.088	1.34
LF	7-14	32.2	22.894	1.57
LF	8-14	46.4	32.480	1.66
LF	9-10	55.8	38.558	1.54

The contribution of natural food to the diet of the fish was similar for both ponds. Of the 54 fish sacrificed, 32 fish contained some form of natural food while the remaining were empty. The frequency of occurrence of natural food in stomachs was approximately the same for both ponds on June 14 and July 14 (Table 3). On August 14, the percentage of stomachs containing natural food decreased below 50% for both ponds.

The average number of food items per fish was essentially

equivalent for both ponds for June and August sample dates. The number of food items was initially high on June 14 and then decreased to 0.4 food items per fish by August 14. Only the July 14 stomach samples were noticeably different with the Lake Four fish having the largest average number of food items per fish.

Table 3. Frequency of occurrence of food items in fish stomach samples from Martin Pond and Lake Four.

Food Item	Frequency of Occurrence as %					
	June		July		August	
	MP	LF	MP	LF	MP	LF
Diptera adult	22	33	11	11		
Diptera pupa	44	22				11
Diptera larva	22	33		33		
Ephemeroptera (immature)	22					
Odonata (immature)	11	11		11		
Hemiptera	11					
Coleoptera adult				22		
Coleoptera larva			11	22		
Amphipoda				11		
Water mite				11		
Algae			56		44	33
Unident. Insect Parts				22		
Percent empty	22	33	33	33	56	67
Average Items/fish	2.1	2.6	0.8	2.9	0.4	0.4

Dipterans were the most abundant item for fish in both ponds on June 14. Algae became the predominate natural food item for Martin Pond on both July 14 and August 14 and for Lake Four on August 14. Coleopterans and dipterans were the most frequent item in fish stomachs in Lake Four on July 14.

When the sacrificed fish were examined no evidence of gill tissue damage was found in fish from either pond. The incidence of external parasites was low with only an occasional Trichodina sp. being found.

Cage Culture Fish Production

The study period started May 15, 1978 and ended September 14 and October 6, 1978 for Lake Four and Martin Pond respectively. The study terminated prematurely in Lake Four when 100% mortality of the fish occurred due to low dissolved oxygen levels. Survival was greater than 90% in both ponds until September when the total mortality occurred in Lake Four.

The growth rate of the fish in Martin Pond exceeded the growth rate in Lake Four for all stocking densities. The growth rate was fairly uniform in Martin Pond for the first three periods (Figure 2). It increased the fourth period and then decreased the fifth. In Lake Four the growth rates in the first and third periods exceeded those in the second and fourth periods. The average weight gain per day in Martin Pond ranged from 0.66 to 1.72 gm/day while in Lake Four it ranged from 0.14 to 0.50 gm/day. There were no differences in growth rates between stocking densities in either pond (Figure 3).

As of September 14 when the total mortality of catfish occurred in Lake Four, the biomass had increased 9 to 10 fold in Martin Pond but only about 3 fold in Lake Four (Table 4).

Overall, the production was 3 to 4 times greater in Martin Pond as that recorded for fish in Lake Four (Table 5). Even at the lowest stocking density of Martin Pond total production exceeded the highest production value for fish of Lake Four for the study period.

Table 4. Calculated biomass of catfish for each stocking density in Martin Pond and Lake Four at each sample date.

Pond	Stocking Density	Biomass (kg/m ³)				
		May 15	June 14	July 14	Aug. 14	Sept. 14
MP	LOW	0.620	1.810	2.714	4.198	6.799
MP	MEDIUM	1.296	3.595	5.792	8.933	14.248
MP	HIGH	1.942	6.285	9.212	12.356	19.425
LF	LOW	0.615	1.325	1.604	2.179	2.507
LF	MEDIUM	1.230	2.920	3.298	4.222	5.207
LF	HIGH	1.845	4.215	4.507	7.257	8.468

By utilizing the values of initial and final total lengths and weights, condition factors were calculated for fish at each stocking density (Table 5). The condition factor for all fish was initially 0.77. Final condition factors exceeded 1.0 for the Martin Pond fish and were less than 1.0 for the fish in Lake Four.

Food conversion efficiencies (Table 5) were calculated by dividing the weight (gm) of dry food fed by the gain in biomass. The gains in biomass were greater for each stocking density in Martin Pond than for the same stocking densities in Lake Four, but food conversion efficiencies were approximately the same for fish in both ponds.

Figure 2. Growth rates of catfish (all stocking densities combined) in the two study ponds for the entire study period.

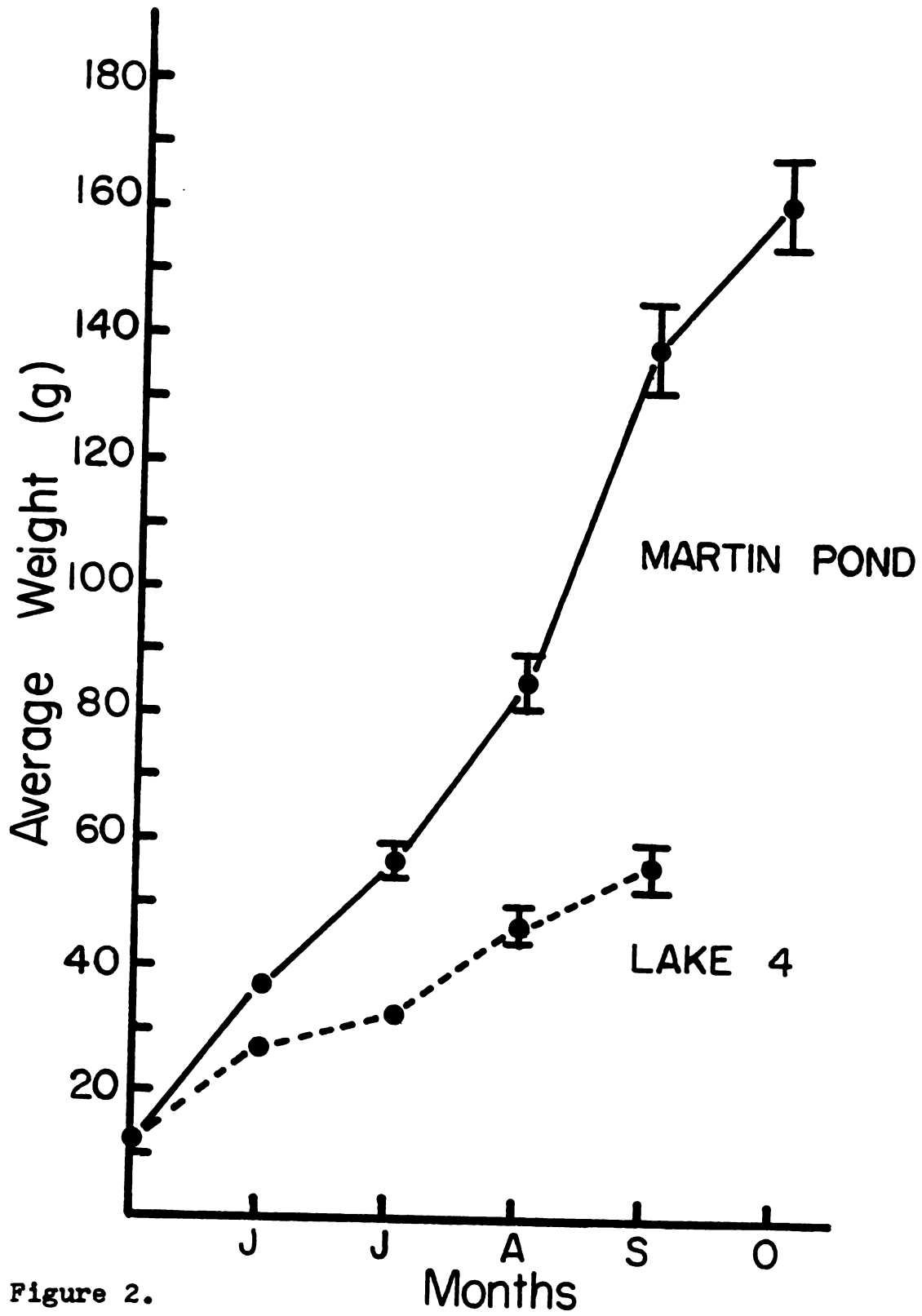


Figure 2.

Figure 3. Growth rates of catfish for each stocking density in Martin Pond and Lake Four.

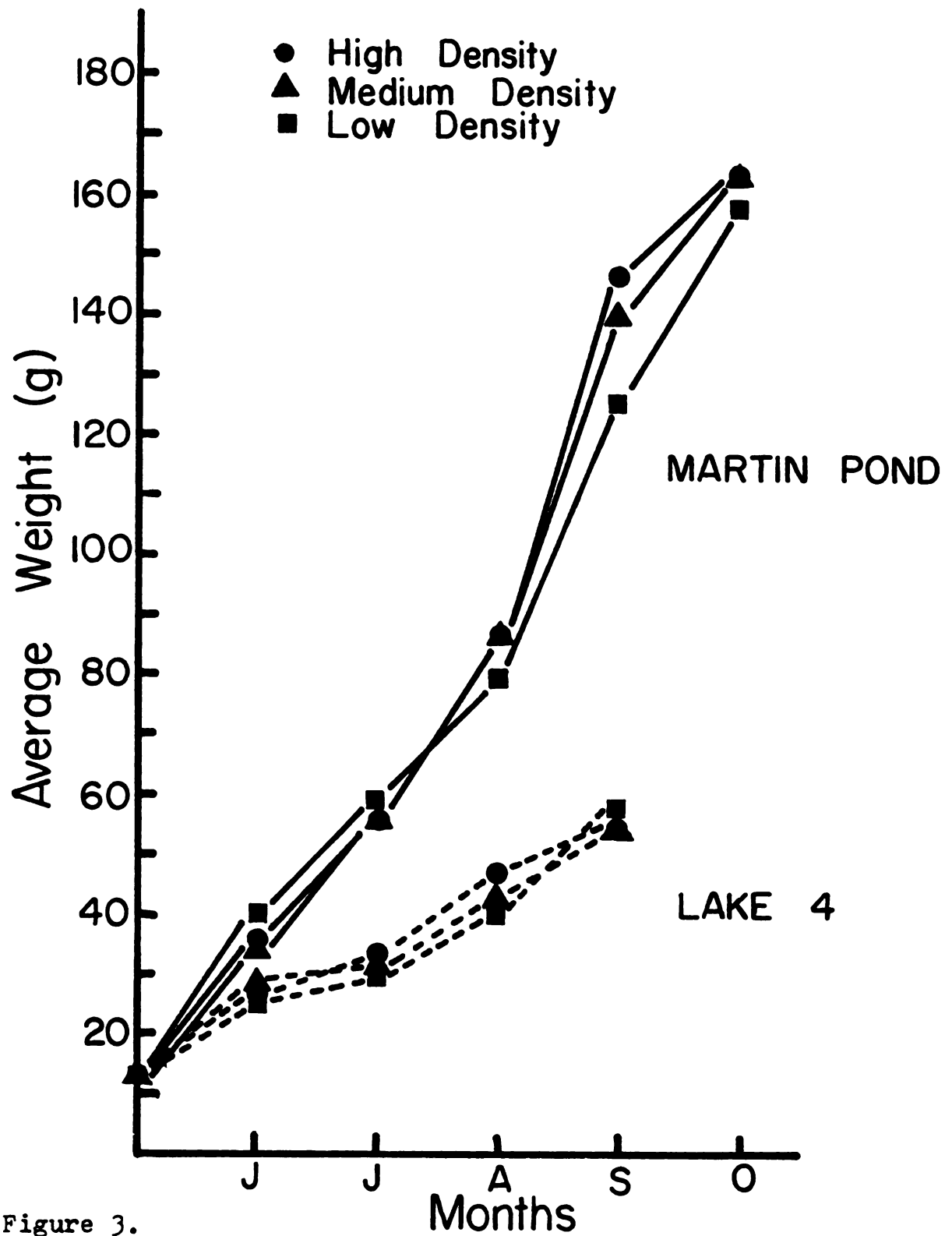


Figure 3.

Table 5. Average lengths and weights, condition factors, total gain in biomass, total production and food conversion efficiencies (F.C.E.) for each stocking density of channel catfish in Martin Pond and Lake Four.

Pond	Stocking Density	Average Length (mm)		Average Weight (gm)		Condition Factor	Total Gain in Biomass (kg)	Total Prod. ³ (kg/m ³)	F.C.E.
		Initial	Final	Initial	Final				
MP	LOW	117	250	12.3	165	1.05	16.782	20.978	1.17
MP	MEDIUM	117	251	12.3	164	1.04	36.904	46.130	1.07
MP	HIGH	117	248	12.3	158	1.03	53.724	67.155	1.13
LF	LOW	117	181	12.3	55	0.93	4.541	5.676	1.23
LF	MEDIUM	117	178	12.3	54	0.96	9.545	11.931	1.16
LF	HIGH	117	184	12.3	58	0.93	15.895	19.869	1.06

There was a significant difference ($p < 0.01$) of both total length and weight between fish in Martin Pond and Lake Four for each period of the study. The differences between stocking densities within each pond were not significant. There was no significant interaction between the two main effects (pond and stocking density).

DISCUSSION

Since the main difference between the two ponds was that of water quality, it seems probable that one or more factors of the water environment were responsible for the observed difference in growth of fish. The lower production in Lake Four was probably due to adverse water quality conditions including low dissolved oxygen, high pH and high concentrations of un-ionized ammonia. These adverse water quality conditions probably served to lower the feeding rates of the fish in Lake Four which resulted in decreased growth of the fish.

The feeding rates of fish in the two ponds were different and followed different patterns. Lovell (1977) reported a typical spring-summer-fall feeding schedule for channel catfish (initial size of 127 mm) stocked in ponds in the southeastern United States. In this feeding schedule, the feeding rate (as percent of fish weight per day) increased from 2.0% in April to 3.0% in June. During the remainder of the schedule, the feeding rate decreased to 1.1% by October. In Martin Pond a similar pattern was followed. The feeding rate increased to a maximum value of 3.58% of the fish body weight per day in June and then gradually decreased as the fish increased in size. In Lake Four, however, the initial feeding rate increased throughout the study but the highest level attained was only 1.66%.

The lower feeding rate of fish in Lake Four resulted in decreased growth. The most efficient utilization of food occurs at rates equal to 2-4% of the body weight with levels below 2% resulting in decreased growth rates (Douglass and Lackey 1973). Andrews and Page (1975) reported that optimal growth and food efficiency were obtained when fish were fed to satiation 2 times per day. Collins (1970) reported the satiation level to be a 2.5-3.0% body weight feeding level.

Natural food did not contribute to the observed feeding behavior differences. During June, July and August the fish in Martin Pond were feeding at 2 to 3% of their body weight while those in Lake Four were feeding at 1.34 to 1.66%. However, the stomach analysis revealed that the percentage of stomachs which contained natural food followed the same trend in both ponds. The quantity of food items in the fish stomachs was small in comparison to the quantity of artificial food offered to each fish.

Water temperatures were consistently 1°C higher in Martin Pond which may have influenced the observed difference in growth. In the two study ponds water temperatures seldom reached the optimum temperature range for growth of channel catfish (Andrews et al. 1972).

In general, Martin Pond had higher dissolved oxygen values than Lake Four which may have influenced the observed differences in feeding and growth of the fish. Andrews and Matsuda (1975) reported that oxygen consumption rates

of fish in all feeding states were reduced as the available oxygen decreased. A further reduction in oxygen consumption was noted when the fish were fasted. Increases in water temperature over the range of 24 to 30°C resulted in increased oxygen consumption (Andrews and Matsuda 1975).

Various authors have related growth to dissolved oxygen levels. Andrews et al. (1973) noted that growth rates and food consumption rates were higher for channel catfish that were fed to satiation and maintained in water which had an oxygen content of 100% saturation than those that were maintained at 60% or 30% of the saturation level. Andrews and Matsuda (1975) went on to describe an "incipient limiting level". This level was 7.0 mg/l and was defined as the dissolved oxygen point where a further reduction in dissolved oxygen resulted in metabolic rate restriction. In Martin Pond a majority of dissolved oxygen values were above 7.0 mg/l while a majority of values were below 7.0 mg/l in Lake Four.

Dahlberg et al. (1968) noted that the growth rate of the largemouth bass was restricted when dissolved oxygen levels were less than or equal to 8 mg/l. They also reported that the food conversion ratio remained stable down to 3 and 4 mg/l. The food consumption of the bass was progressively restricted throughout the total range of oxygen in question.

Fish subjected to pH extremes must exert more energy to maintain their homeostasis. During the study period the pH

was usually 1 to 2 units higher in Lake Four than Martin Pond with a large portion of the pH values above 9.0. The optimum pH for fish growth and health is generally accepted to be in the range of 6.0 to 9.0 (FWPCA 1968, Wedemeyer 1974).

The higher pH in Lake Four was also important in that it affected the portion of total ammonia which was in the un-ionized form. When the pH is increased, the amount of un-ionized ammonia is also increased. Because of lipid solubility and lack of charge of the free base (NH_3), it is able to diffuse across cell membranes more easily than the ammonium ion (NH_4) which is hydrated, charged and has a low solubility (Fromm and Gillette 1968). Therefore the pH would have a great effect on the toxicity of the ammonia solution since the un-ionized form (NH_3) is the toxic form to fish (Wuhrmann and Woker 1948).

Fromm and Gillette (1968) reported that rainbow trout subjected to increased concentrations of total ammonia had increasing levels of total ammonia in the blood. The blood NH_3 showed direct linear correlation with the water NH_3 level. They found that the blood concentrations of total and un-ionized ammonia were higher than those in the water that the fish had been in. As the ammonia concentration in the water was increased, the values for total nitrogen excretion and ammonia excretion both decreased. They further noted that a reduction of the blood-water NH_3 gradient caused a decrease in the rate of ammonia excretion. This suggested to them that ammonia is excreted passively.

Brockway (1950) found a correlation in increased in ambient ammonia with a reduction in the dissolved oxygen level of the blood. He suggested that ammonia affects the oxygen transport ability of fish blood. He reported that the oxygen content of trout blood decreased to about 1/7 of its normal level and the carbon dioxide blood level increased about 15% when ammonia in the water was increased to 1 mg/l. He felt that increased ammonia lessened the ability of hemoglobin to combine with oxygen or liberate carbon dioxide.

Fromm and Gillette (1968), however, showed that the ability of oxygen to combine with hemoglobin is not affected by ammonia. They suggested that alterations in the gas content of the blood resulted from increased oxygen usage and carbon dioxide production.

McLean and Frazer (1974) observed nitrogen excretion patterns of fish in their study. They noted that ammonia excretion patterns followed a diurnal rhythm. Ammonia output was minimum in the early morning and maximum in the afternoon. Nitrogen excretion was found to increase during periods of low dissolved oxygen and during forced activity. They also suggested that external factors which cause sudden shifts to protein catabolism would tend to decrease the fish growth rates and increase the ambient ammonia concentrations.

Burrows (1964) reported that reduced growth rate and reduced physical stamina resulted from long-term exposure of salmonids to sublethal levels of un-ionized ammonia.

He indicated that continuous exposure to concentrations as low as 0.003 mg/l un-ionized ammonia for 6 weeks produced extensive hyperplasia in gill epithelium of fingerling chinook salmon (Oncorhynchus tshawytscha). He also noted that these same fish could tolerate un-ionized ammonia levels as high as 0.35 mg/l for one hour per day without apparent harm.

Robinette (1976) found that sublethal levels of un-ionized ammonia at which no growth occurred were about 1/3 of the threshold value of ammonia toxicity to rainbow trout and several other fish. He observed no growth at levels of 0.12 to 0.13 mg/l $\text{NH}_3\text{-N}$ while toxicity levels were about 0.29 to 0.41 mg/l. Wedemeyer and Wood (1974) reported 0.02 mg/l as the upper limit for continuous exposure conducive to optimum health of both warmwater and coldwater species.

It should be noted that Lake Four had both a high pH and low concentration of CO_2 which would tend to increase the toxicity values of un-ionized ammonia. CO_2 respired at the gill surface has a pronounced depressing effect on the pH of the water in contact with the gill if the free CO_2 level is low in the water (Lloyd and Herbert 1960, Fromm and Gillette 1968). Therefore there would be greater conversion of NH_3 to NH_4 than that which would occur when the free CO_2 content was higher in the water (Fromm and Gillette 1968). Toxicity values determined under such conditions may be as much as 5 times greater than values determined in water with a high CO_2 concentration and low pH (Lloyd 1970).

A few authors have reported the relationship of the dissolved oxygen to various levels of un-ionized ammonia. Smith (1972) reported that as long as 5 mg/l dissolved oxygen was maintained, trout growth was not significantly reduced until the average total ammonia concentration increased to 1.6 mg/l (0.033 mg/l un-ionized ammonia) and then only after continuous exposure of at least 6 months.

Merkens and Downing (1957) noted that ammonia toxicity in trout was greatly increased at low dissolved oxygen concentrations. Minimum dissolved oxygen levels of 5.0 mg/l or greater have been suggested to alleviate the ammonia effect (Smith and Piper 1975). Smith and Piper (1975) also reported that the maximum safe level for un-ionized ammonia was 0.0125 mg/l. Downing and Merkins (1955) experimentally illustrated that the survival time of rainbow trout increased significantly with increased dissolved oxygen concentrations at 3 levels of un-ionized ammonia. In addition, they found that the increase in survival time due to increased dissolved oxygen levels was the greatest in the lowest concentration (0.60 mg/l) of un-ionized ammonia.

Alkalinity values reflected major changes in photosynthetic and respiratory activity. Minimum alkalinities were reached during algal blooms due to CO_2 and bicarbonate ion uptake. Minimum values were lower for Martin Pond but were never less than the 20 mg/l as CaCO_3 recommended by FWPCA (1968).

Wedemeyer et al. (1976) recommended a level of 3 mg/l or less of free total CO₂ for the minimum water quality necessary to support a mixed fish population. The free CO₂ was well below that level in both Lake Four and Martin Pond for almost the entire study period.

Fry (1971) noted that under natural conditions oxygen lack is a much more likely limiting factor than CO₂ excess since free CO₂ reaches major levels ordinarily only under anaerobic conditions.

Wind velocities were generally greater on the surface of Lake Four during the entire study period. These higher wind velocities would have tended to increase circulation of Lake Four water. The result of this enhanced circulation would have been an increased water exchange through the Lake Four cages. This water exchange probably aided the fish in Lake Four by making more oxygen available to them and by removing waste products from the cages.

The present study indicates that intensive cage culture may not be useful in a wastewater system. Water quality may frequently be less than the optimum needed for intensive culture. In a cage culture system the fish are confined and unable to migrate to more favorable water quality conditions.

The results in Martin Pond are probably more typical of Michigan ponds than Lake Four. The Martin Pond results were similar to a study conducted with the yellow bullhead (Ictalurus natalis) (McIarney and Parkin 1979). During a 127 day

study period they utilized densities of 57, 103 and 147 fish per cubic meter and attained final cage biomass densities similar to those in Martin Pond. Final biomass densities of 8.532, 16.131 and 23.130 kg/m³ were recorded. The yellow bullheads grew from an initial mean weight of 54.4 grams to a final mean weight of 158.6 grams. The food conversion rates ranged between 2.24 and 2.57. The production per cubic meter was 5.599, 10.398 and 15.038 kg/m³ for low to high stocking densities respectively.

The food conversion efficiencies of the present study were lower than most other values reported. Kilambi et al. (1977) reported a value of 1.5. Collins (1970) calculated a food conversion of 1.32 for his study. Douglass and Lackey (1972) reported values ranging from 2.28 to 4.19. Then, in a later study they reported values ranging from 1.81 to 3.22 (Douglass and Lackey 1973). Hurst (1973) found that Purina floating trout chow gave significantly increased growth and feed conversions than Purina floating catfish chow. Therefore, the use of Purina trout chow may account for the more efficient food conversion of the present study.

Kilambi et al. (1977) found that stocking densities (144, 235 and 366 fish/m³) had no apparent effect on channel catfish growth or feed conversion. This seems consistent with the results obtained in the present study.

The growth rate as weight gain per day in Martin Pond was low in comparison to those of Lewis et al. (1978).

Under experimental conditions attempting to utilize hydroponics to maintain water quality for channel catfish in a recirculation system, they achieved growth rates of 1.26 to 3.63 grams per day per fish for water temperatures of 21° to 25°C.

SUMMARY

There were major differences between the water quality parameters of the two study ponds. Lake Four had higher pH values, lower dissolved oxygen levels and higher un-ionized ammonia levels in comparison to Martin Pond.

The feeding rate of fish in Martin Pond followed a typical pattern while the feeding rate of fish in Lake Four did not. The feeding rate of fish in Lake Four was always less than 2% of their body weight. In Martin Pond the feeding rate of the fish exceeded 3% of their body weight for a portion of the study period.

The contribution of natural food to the diet of the fish was similar for both ponds and therefore was not a likely cause for the observed feeding rate differences.

The growth rate of the fish in Martin Pond exceeded the growth rate of fish in Lake Four for all stocking densities. There was a significant difference ($p < 0.01$) of both total length and weight between fish in Martin Pond and Lake Four for each period of the study.

The gains in biomass were greater for each stocking density in Martin Pond than for the same stocking densities in Lake Four, but food conversion efficiencies were approximately the same for fish in both ponds.

Final condition factors exceeded 1.0 for the Martin Pond fish and were less than 1.0 for fish in Lake Four.

The lower production in Lake Four was probably due to adverse water quality conditions including high pH, low dissolved oxygen and high concentrations of un-ionized ammonia. These adverse water quality conditions probably served to lower the feeding rates of the fish in Lake Four which resulted in decreased growth.

There was no significant difference in growth between stocking densities of either pond among the range tested.

Comparison of growth data between Martin Pond and other studies revealed that the growth in Martin Pond was less than that achieved in more southerly areas. The most probable reason for this is that during most of the study period the optimum temperatures for growth of channel catfish were rarely attained. This combined with the shorter growing season resulted in less growth.

APPENDIX

APPENDIX

Table A1. Values of temperature, dissolved oxygen, alkalinity and free carbon dioxide taken at various times in Martin Pond.

Date	Time	Temp. °C	Dissolved Oxygen(mg/l)	pH	Alkalinity (mg CaCO ₃ /l)	Free CO ₂ *
5-24	2110	24	8.1		106	
5-25	600	21	9.0		103	
5-25	2120	26	9.4		104	
6-12	2045	24	10.9	9.7	70	0.45
6-13	640	22	8.1	9.6	70	0.63
6-13	2100	23	10.3	9.7	68	0.45
6-28	2050	29	8.0	9.4	57	0.81
6-29	700	27	8.4	9.3	56	1.07
7-13	2100	25	7.3	8.3	74	16.74
7-14	510	24	6.1	8.4	75	13.65
7-31	2110	27	8.0	7.6	100	113.51
8-1	510		6.0			
8-3	540		4.2			
8-25	1650	27	9.0	8.8	90	6.10
8-26	610		8.4			
8-29	650		7.5			
9-11	940	26	8.6	9.0	82	3.45
9-28	1420	20	8.1	8.3	99	24.40
10-6	1400	15	7.9	7.8	106	89.18
10-9	1400	12	9.0	7.5	107	193.06

* Free CO₂ levels are expressed as $\mu\text{mol/l}$.

Table A2. Values of temperature, dissolved oxygen, alkalinity and free carbon dioxide taken at various times in Lake Four.

Date	Time	Temp. °C	Dissolved Oxygen(mg/l)	pH	Alkalinity (mg CaCO ₃ /l)	Free CO ₂ *
5-24	2040	23	6.2		111	
5-25	530	21	5.6		116	
5-25	2100	25	7.6		116	
6-12	2130	22	7.6	10.5	120	0.05
6-13	600	20	5.0	10.4	116	0.07
6-13	2130	20	7.3	10.4	117	0.08
6-28	2130	28	7.9	10.0	115	0.27
6-29	630	26	8.9	10.0	112	0.26
7-13	2140	23	6.5	10.1	120	0.21
7-14	540	23	6.5	9.7	121	0.79
7-31	2050	25	6.3	10.0	120	0.29
8-1	530		5.5			
8-3	520		5.8			
8-25	1630	26	6.2	9.5	123	1.02
8-26	550		4.8			
8-29	630		2.6			
9-11	915	25	0.1	6.7	145	1329.55

* Free CO₂ levels expressed as $\mu\text{mol/l}$.

Table A3. Percentage of daily wind velocity estimates in each category during each sample period for Martin Pond and Lake Four.

Pond	Period	Percentage of daily estimates				
		0 mph	0-5 mph	5-10 mph	10-15 mph	15-20 mph
MP	1	46	42	8	4	0
MP	2	38	62	0	0	0
MP	3	71	29	0	0	0
MP	4	15	63	22	0	0
MP	5	14	67	19	0	0
LF	1	8	31	46	12	4
LF	2	8	16	44	28	4
LF	3	0	33	50	17	0
LF	4	0	8	64	24	4

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