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I am submitting herewith a thesis written by Larry R. Hilton entitled "Effects of Tilapia Densities on Growth of Channel Catfish in Flow-through Polyculture." I recommend that it be accepted in partial fulfillment of the requirements for the degree of Master of Science, with a major in Wildlife and Fisheries Science.

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EFFECTS OF TILAPIA DENSITIES ON GROWTH OF CHANNEL CATFISH IN FLOW-THROUGH POLYCULTURE

A Thesis
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Degree
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ABSTRACT

The purpose of this study was to determine the feasibility of polyculturing channel catfish (Ictalurus punctatus) and tilapia (Tilapia aurea) in a high-density, flow-through culture system. Three densities of tilapia (3.0, 6.0, and 12.0 g/l) were polycultured with a common density of catfish (12.0 g/l). A monoculture treatment of catfish (12.0 g/l) was used for comparison. The effects of tilapia densities on catfish growth and condition were determined.

The fish were stocked in tanks containing 180 liters of water and having a flow rate of 2.0 l/min. Fish were individually weighed and measured at stocking and on day 90 at study's end. Gross weights of catfish and tilapia were taken for each tank every 14 days. Water quality parameters monitored were pH, temperature, dissolved oxygen, ammonia, and nitrate-nitrites. All data was analyzed using computer programs for nested analysis of variance and Duncan's multiple range test.

The growth and condition of channel catfish was significantly reduced in all polyculture treatments as compared to the catfish monoculture treatment. The mean weight gain after 90 days for monocultured catfish was approximately 49%. The best polyculture catfish growth was approximately 2% and occurred with 3 g/l of tilapia. Growth and condition of tilapia was reduced only at the

highest stocking density. Decreased catfish growth in the polyculture treatments was the result of competition for food. As the density of tilapia was increased, the competition for food was increased.

Water quality parameters other than dissolved oxygen concentrations were not significantly different between the treatments. Dissolved oxygen concentrations were significantly lower in the polyculture treatments, at times reaching levels which might have suppressed growth. Ammonia and nitrate-nitrite concentrations were low over the duration of the experiment and should not have affected growth.

It was concluded that polyculture of catfish and tilapia in a flow-through system is not practical for the densities studied. The significant decrease in growth and condition of the catfish in polyculture resulted in fish which were not marketable. Therefore it is recommended that commercial fish farmers not use the method described.

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I. INTRODUCTION

Aquaculture, the rearing of fish under some measure of human control, dates back thousands of years. This is in evidence from many sources such as Egyptian bas-reliefs which depict scenes of fish being reared in ponds. In addition, since 1100 B.C., Chinese literature has presented accounts of the culture of different fishes. Since those early attempts at fish culture, new methods and techniques have been employed to include many species of fish, shellfish, and crustaceans.

Monoculture, the production of a single species in a system, is the major method of producing fish in the United States. Among the culture systems being used are ponds, raceways, tanks, cages, and silos. A commercially prepared diet is often used to supplement the natural foods of ponds and promote more rapid growth. The more highly intensive systems such as cages, raceways, and tanks require a complete, balanced commercial diet since natural foods are not abundant or absent.

Channel catfish (*Ictalurus punctatus*) is the primary warmwater species cultured in the United States today. The commercial culture of catfish is a comparatively young industry having begun about 20 years ago. Although ponds provide the greatest percentage of catfish production, highly intensive systems such as those already mentioned are also employed. The ready acceptance of commercially prepared diets by catfish has influenced their culture success to a large degree. In general, catfish require water temperatures of 23 C to 30 C, dissolved oxygen daily minimum of 2-3 ppm, and a pH of 6.5-8.5 for good growth (Stickney 1979). Toxic wastes must also be kept at low levels to prevent mortalities and inhibition of growth.

Because of catfish culture success, studies have recently been done on culturing catfish with other species such as carps, buffalofish, and tilapias. The practice of culturing two or more species together is known as polyculture and has been conducted in many foreign countries for the production of food fish (Buck 1977). General environmental conditions, growth increment of the species cultured, and the mutual relations among the species based on competition for food are important factors to consider when attempting polyculture (Yashouv 1969).

Tilapia, grass carp, mullet, and various species of carp (common, bighead, silver) have been polycultured in ponds with supplemental feeding, most notably in Israel (Buck 1977). Of the tilapias, *Tilapia aurea* is the most commonly cultured in Israel (Brown 1977). These species have worked well in polyculture because they occupy different niches and utilize different foods. Species of different trophic levels also work well in polyculture with supplemental feeding. Species utilizing high protein food sources high on the trophic level do not conflict with primary level consumers such as carp which feed on detritus or plants.

Fish of the genus *Tilapia* are endemic to Africa, but were widely distributed for culture during the 1950's (Lovshin and Da Silva 1975). They are presently found in most tropical and subtropical areas suitable for their growth and reproduction; populations of *T. aurea* now exist in several Florida lakes (Langford et al. 1978). The general environmental conditions required for catfish culture also apply to *T. aurea*. Temperatures of 26-30 C promote good growth whereas the lower lethal limit is approximately 9 C (Kirk 1972). Tilapia are more tolerant of low dissolved oxygen concentrations than catfish, and have survived and grown well in heavily fertilized ponds with a dissolved oxygen concentration of 0.5 ppm (Kohler and Pagan-Font 1978). The acute toxicity levels for ammonia are similar to those for catfish, but exposure to sublethal levels can result in a built-up resistance to ammonia (Stickney 1979).

The food habits of *T. aurea* have been studied extensively in both wild populations and intensive polyculture conditions. In lakes and ponds *T. aurea* feed primarily on plankton and detritus, utilizing phytoplankton to a large extent (McBay 1961; Spataru 1976; Spataru and Zorn 1978). Their food habits are similar when polycultured in ponds with channel catfish except that catfish feces and pelleted feed, up to 62% of the diet, are also consumed (Smith 1971; Williamson and Smitherman 1975). The diversity of foods utilized by T. aurea and their reduced water quality requirements make them suitable for polyculture with channel catfish.

Several studies have shown that tilapia and channel catfish can be successfully polycultured in ponds (Kilgen 1969; Smith 1973; Williamson and Smitherman 1975; Malca 1976; Behrends et al. 1978). Two species of tilapia have been reared in divided raceways receiving waste materials from cultured channel catfish (Ray 1978). Very few studies have been done on polyculture of catfish and tilapia in raceways or other high density, flow-through systems (Allen and Carter 1976).

The lack of information for such systems and the compatability of T. aurea and channel catfish in ponds prompted this investigation. The purpose of the study was to determine the feasibility of high density polyculture of tilapia (T. aurea) and channel catfish in a flow-through system. The effects of various stocking densities on growth and condition of catfish were assessed. In addition, certain water quality parameters were monitored to determine the practicality of the method.

II. LITERATURE REVIEW

Although several pond studies have been done, the only raceway study conducted involved catfish, _T. aurea_, and hybrid buffalo in divided compartments (Allen and Carter 1976). The presence or absence of tilapia and/or hybrid buffalo had no significant effect on ammonia levels in the downstream catfish compartment. Also no significant differences were observed for survival, growth, or food conversion between the upstream and downstream catfish populations.

Results from studies to determine the effects of _T. aurea_ on production of channel catfish in ponds have been quite varied. Kilgen (1969) stocked 49,420 catfish and 19,768 _T. aurea_ per hectare in ponds. He found that tilapia exerted a benificial effect, greatly increasing the production and food conversion rate for catfish when compared with an equal density of monocultured catfish. A comparison of ammonia concentrations between polyculture and monoculture ponds indicated no significant difference.

Smith (1973) found that catfish production in ponds was not significantly different when the same monoculture density of 24,700 catfish was stocked with 14,280 _T. aurea_ per hectare. He did conclude that competition reached a harmful degree at these stocking densities and recommended that no more than 7,410 _T. aurea_ per hectare initially be stocked. An analysis of _T. aurea_ stomachs revealed the utilization of supplemental catfish ration in addition to catfish feces and plankton. Thus he doubled his feeding rate for 14,280 tilapia per hectare with catfish, since tilapia were consuming the supplemental ration and removing waste products. This reduced the degree of competition for food and allowed increased production of catfish.

Williamson and Smitherman (1975) found that production of catfish stocked at 7,410 per hectare was significantly decreased by a density of 1,235 tilapia per hectare while 618 tilapia per hectare did not significantly reduce catfish yields (0.05 probability). Entomostraca and unicellular algae were the primary natural foods while pelleted ration comprised up to 62% of the tilapia's diet. At similar densities (618 tilapia and 4,949 catfish per hectare), Malca (1976) found no significant decrease in catfish yield due to the presence of tilapia.

Catfish production was not significantly reduced when cultured with all-male populations of *T. aurea* at densities of 84 kg/hectare catfish and 76 kg/hectare tilapia (Behrends et al. 1978). As part of the study, tilapia were also marketed locally in Alabama to determine consumer acceptability; tilapia were found to be as desirable as channel catfish.

Water quality parameters, particularly ammonia, play an important part in growth. Several studies on toxicity values of ammonia have been conducted (Knepp and Arkin 1973; Colt and Tchobanoglous 1976; Robinette 1976; Tomasso et al. 1980); most recommended that total ammonia be kept below

30 ppm for channel catfish. Dissolved oxygen can also be a problem with growth of channel catfish being suppressed at levels less than 36% of air saturation (Andrews et al. 1973).

Both growth and water quality can be correlated with density of fish in a flow-through system (Andrews et al. 1971; Allen 1974). With a 2.5-hour exchange rate and minimal aeration, channel catfish grew well in circular tanks at densities of 5.5-16.5 g/l which correspond to 2-6 fish per cubic foot (Andrews et al. 1971). Both ammonia and dissolved oxygen were found to be highly correlated with the density of fish. Allen (1974) determined that densities of 180-360 catfish per cubic meter of water were optimal in circular tanks with a total exchange every 1.5 hours and having adequate aeration.

III. METHODS AND MATERIALS

Twelve fiberglass tanks, 100 cm x 40 cm x 55 cm high, were housed on a floating barge at Norris Dam Marina, Norris Reservoir, Tennessee. Surface draining 25.4 mm inside diameter (ID) standpipes were used to maintain a constant water volume of 180 liters in all tanks. A ½-horsepower continuous-duty well pump supplied lake water at a rate of approximately 47 liters per minute. The 38 mm ID ring-reinforced intake hose was positioned to draw water from approximately 2 m below the lake surface. After initial priming through a tee fitting on the discharge, a foot valve was used to prevent loss of prime during a power interruption. The 38 mm ID discharge was immediately reduced to a 19 mm ID PVC pipe which discharged into two headtanks.

Two headtanks, 105 cm x 44 cm x 50 cm high, were used to provide an even water flow to the culture tanks. Each was fitted with two 19 mm ID bottom drains and a 19 mm ID standpipe, 45 cm high, to remove excess water. The bottom of each head tank was 45 cm above the water level in the culture tanks. Each bottom drain was fitted with 19 mm ID PVC pipe and 3 PVC valves to allow control of water flow into each culture tank. The original flow rate of 1.5 liters per minute, 2-hour exchange rate per tank, was spilled onto the tank surface through the cover screen. After 30 days the flow was adjusted to 2.0 liters per minute, 1.5-hour exchange rate per tank, and the flow was discharged at the tank bottom. This was done in an effort to prevent low dissolved oxygen concentrations which inhibit growth from occurring.

A 12-volt electrical back-up system was employed to maintain continuous water flow in the event of a power failure. Four small transfer pumps were powered by two 90-amp auto batteries. The pumps were suspended 30 cm below the lake surface through an access in the barge floor; each pump supplied water at about 12 liters per minute against a 2.0 m head pressure through 13 mm ID garden hose. Two pumps, each on a different battery, supplied each head tank. A snap-action switch with fishing floats and leads was used to activate the pumps if the water level in a head tank fell to a critical level. The floats were set in such a manner that each pump for a head tank was activated at a different critical water level. Thus if a pump failed or the battery grew weak then the second pump on a fresh battery would be activated.

Tilapia aurea were obtained from Southern Fish Culturists, Leesburg, Florida. Channel catfish fingerlings were obtained from a local catfish farmer's pond. Tilapia were stocked at three densities (3.0, 6.0, and 12.0 g/l), each replicated three times, on 5 and 6 of July, 1979. The densities 3.0, 6.0, and 12.0 g/l correspond to stocking rates of 270, 540, and 1080 g/l/min respectively. Catfish were stocked 6-12 July in all twelve tanks at a rate of

12 g/l (1080 g/l/min). Tank covers of fiberglass screen were used to prevent loss of fish from jumping. Three tanks contained only catfish for comparison with catfish in the three polyculture treatments. The tanks were randomly selected for each replicate. The average weight and length at stocking of tilapia and catfish for each treatment is summarized in Table 1.

On day 6 and every 14 days thereafter gross weights of catfish and tilapia in each tank were taken. A treatment of 100 ppm Formalin was applied to each tank after weighings to prevent external disease problems from handling. All fish were individually weighed and measured on day 90.

Purina floating catfish cage-culture ration, 36% protein, was fed once daily to the fish in each tank. The feeding rate was originally 4% of the total weight of all catfish with the ration equally divided among the tanks. After 34 days the feeding rate was changed to 4% of the actual weight of the catfish in a particular tank. The amount of feed was adjusted every 14 days when gross weights were taken. The fish were fed every day except Sunday and on days when gross weights were taken.

Weekly water quality samples were taken in the morning from each culture tank and head tank. All samples were frozen and analyzed at the end of data collection. Total nitrogen due to ammonia ($N\text{-}NH_3$) and nitrogen due to nitrate plus nitrite ($N\text{-}NO_2 + NO_3$) were determined

TABLE 1. Mean weight (g), mean total length (mm), and number of fish (N) at stocking for each tank in a density treatment

Treatment (g/l) Catfish:Tilapia	Tank Number	Catfish N	Catfish Mean Total Length (Range)	Catfish Mean Weight (Range)	Tilapia N	Tilapia Mean Total Length (Range)	Tilapia Mean Weight (Range)
12 : 0	2	47	185.2 (135-250)	45.9 (17-102)	--	--	--
12 : 0	3	52	179.4 (140-242)	41.5 (19-106)	--	--	--
12 : 0	7	84	152.4 (135-223)	25.7 (16-72)	--	--	--
12 : 3	1	50	181.1 (135-226)	43.4 (18-79)	17	116.9 (70-185)	31.9 (5-102)
12 : 3	5	56	174.0 (140-245)	38.6 (15-112)	19	109.0 (67-195)	28.4 (5-132)
12 : 3	9	48	185.9 (146-245)	45.2 (18-102)	16	117.5 (77-187)	33.8 (5-102)
12 : 6	4	48	179.0 (133-258)	45.0 (14-126)	23	134.0 (85-193)	47.1 (9-111)
12 : 6	8	49	181.4 (142-236)	44.2 (20-95)	25	127.6 (70-214)	43.0 (6-158)
12 : 6	12	55	177.3 (146-234)	39.5 (20-94)	27	125.8 (70-191)	40.1 (5-117)
12 : 12	6	48	178.6 (138-251)	41.7 (14-132)	49	127.5 (74-191)	44.1 (6-119)
12 : 12	10	43	189.4 (138-254)	50.0 (18-114)	75	113.9 (75-191)	29.0 (5-114)
12 : 12	11	49	178.2 (136-254)	44.2 (17-125)	59	122.3 (69-209)	36.6 (5-146)

using a Technichon Auto Analyzer. At this time pH was also measured with a Fisher Accumet pH meter.

Water temperature was recorded daily with an Adkins recording thermometer. Dissolved oxygen concentrations were monitored on varying days with a portable dissolved oxygen meter. Daily cleaning of tanks was initiated on day 15, ending day 69. Settleable solids were siphoned from each tank into a 200-mesh brass seive and subsequently rinsed into a funnel with filter paper. The filter paper and waste products were frozen and later oven dried at about 50 C and weighed to the nearest 0.1 g.

The change in the average weight of fish, condition factors, dissolved oxygen concentrations, pH, $N\text{-}NH_3$, $N\text{-}NO_2 + NO_3$, and weights of filtered solids were compared using a nested one-way analysis of variance to detect significant difference between the treatments. Duncan's multiple range test was applied when significant differences existed between treatment means. Also weight change, dissolved oxygen, stocking density, $N\text{-}NH_3$, and $N\text{-}NO_2 + NO_3$ were examined with the appropriate regression and correlation analyses. These tests were performed by computer using standard SAS computer programs. A probability of 0.05 was used in determining significance for all analyses.

IV. RESULTS

As the stocking density of tilapia was increased, the growth of catfish was significantly decreased in all polyculture treatments in comparison to growth of monocultured catfish (Table 2). Monocultured catfish gained about 49 % of their initial body weight while catfish of equal density stocked with 12 g/l of tilapia lost about 22 % of their original body weight. Also, the condition of the catfish was significantly decreased as the stocking density of tilapia was increased (Table 2).

Growth and condition of tilapia was significantly less only at their highest stocking density of 12 g/l (Table 3). The tilapia gained well in all polyculture treatments with a much larger percent weight gain than the monocultured catfish (Figure 1). Due to the more rapid growth of the tilapia, the weight ratios in the treatments changed drastically after 90 days from the initial stocking weight ratios (Figure 2).

No significant differences were detected between treatments for pH, ammonia, and combined nitrate-nitrites (Table 4). Also there was no significant difference between treatments for settleable solids. A significant difference between the catfish monoculture treatment and the polyculture treatments did occur for dissolved oxygen (Table 4). However, no significant differences occurred for dissolved oxygen levels between polyculture treatments. Water

TABLE 2. Comparison of treatment means for catfish growth and condition at 90 days. The letter after a mean denotes its rank in comparison to other means at 0.05 level of probability, (SD) denotes standard deviation.

Treatment (g/l) Catfish:Tilapia	Mean Weight (g) (Range) Day 1	Mean Weight (g) (Range) Day 90	Mean Percent Weight Change (SD)	Mean Condition Factor (Range) Day 1	Mean Condition Factor (Range) Day 90
12 : 0	33.5 (16-106)	49.4 (16-177)	48.8 a (26.1)	0.70 (0.59-0.86)	0.74 a (0.42-0.91)
12 : 3	42.2 (15-112)	42.7 (11-140)	1.9 b (24.9)	0.68 (0.53-0.82)	0.61 b (0.32-0.90)
12 : 6	42.8 (14-126)	36.8 (15-86)	-14.0 c (17.2)	0.68 (0.51-0.80)	0.58 c (0.42-0.72)
12 : 12	44.9 (14-132)	34.7 (14-73)	-22.3 c (15.3)	0.71 (0.56-0.90)	0.53 d (0.41-0.65)

TABLE 3. Comparison of treatment means for tilapia growth and condition at 90 days. The letter after a mean denotes its rank in comparison to other means at 0.05 level of probability, (SD) denotes standard deviation.

Treatment (g/l) Catfish:Tilapia	Mean Weight (g) (Range)		Mean Percent Weight Change (SD)	Mean Condition Factor (Range)	
	Day 1	Day 90		Day 1	Day 90
12 : 3	31.2 (5-123)	89.5 (25-286)	186.7 a (58.4)	1.59 (1.40-1.82)	1.87 a (1.70-2.05)
12 : 6	43.2 (5-158)	100.9 (31-216)	133.1 a (57.6)	1.58 (1.35-1.83)	1.82 a (1.43-2.03)
12 : 12	35.5 (5-146)	71.4 (12-225)	101.3 b (35.9)	1.58 (0.95-1.99)	1.76 b (0.72-3.07)

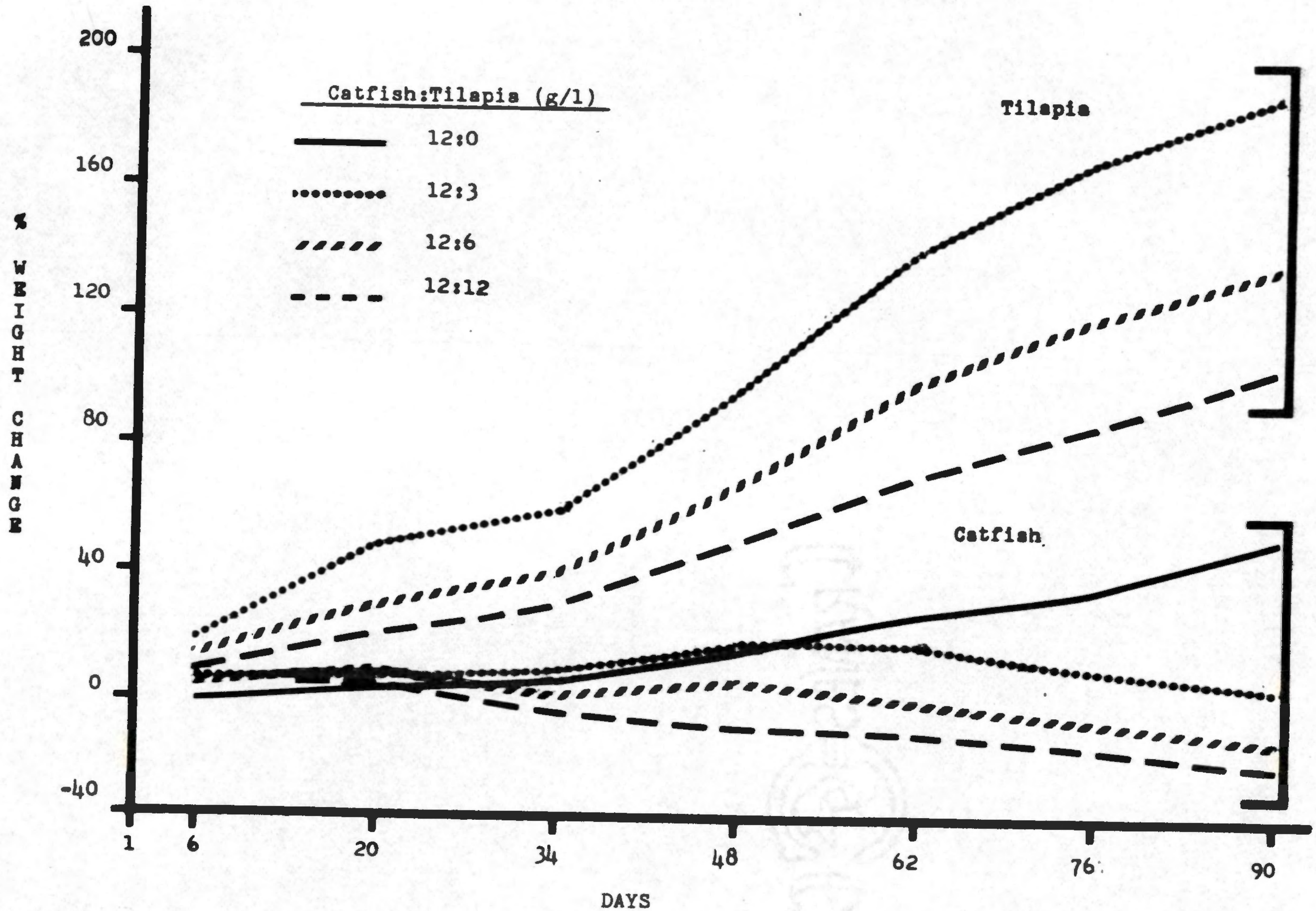

FIGURE 1. Relative change in weight over time for Tilapia and Catfish.

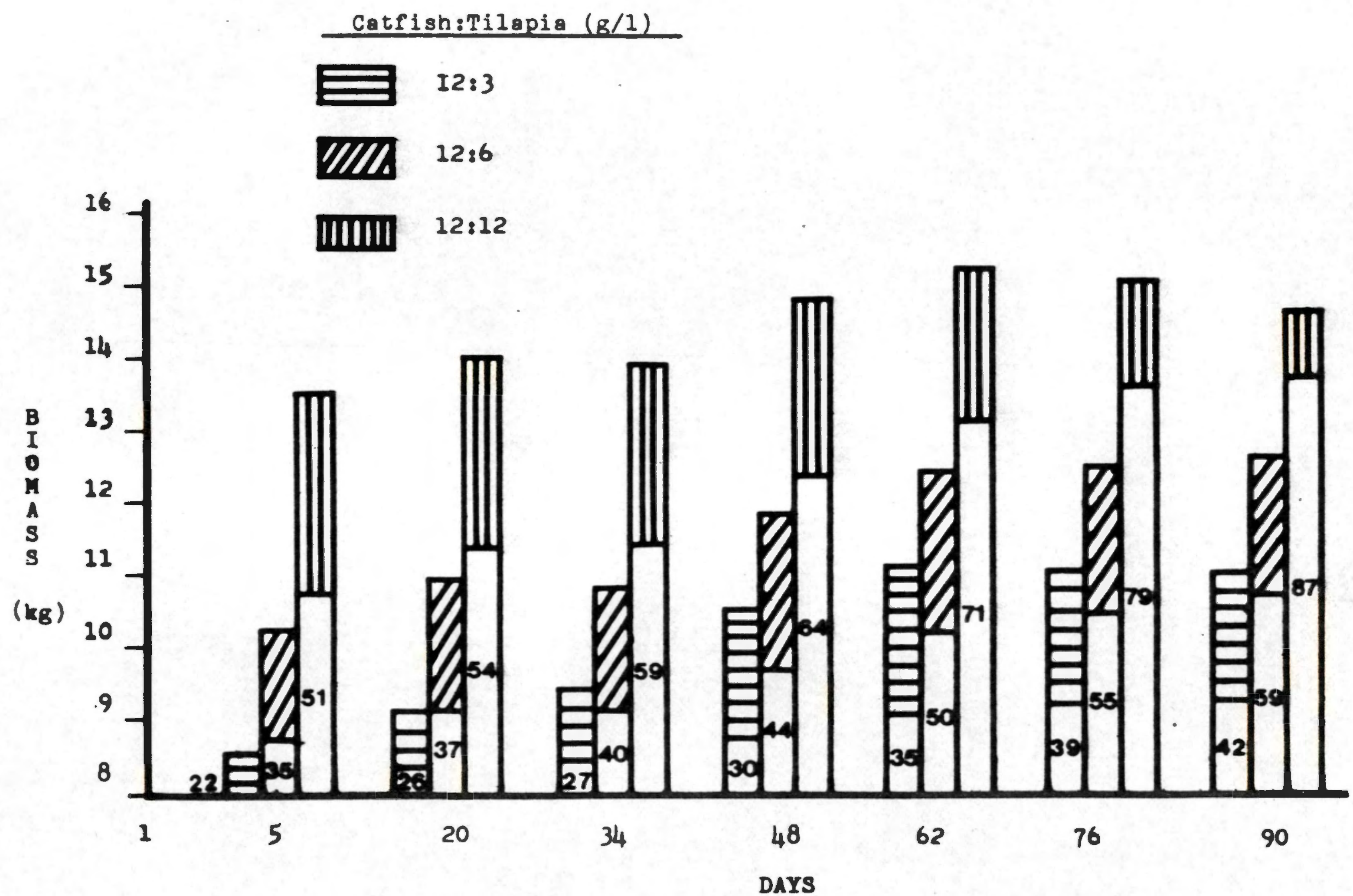

FIGURE 2. Relative change in biomass and weight ratios over time for Tilapia and Catfish. The number in the clear area of a bar represents the percent of the biomass which is tilapia weight.

TABLE 4. Comparison of water quality parameters between treatments. The letter after a mean denotes its rank in comparison to other means at 0.05 level of probability, N denotes sample size.

Parameter Measured	N	Treatment (g/l) Catfish:Tilapia 12:0	12:3	12:6	12:12
Dissolved Oxygen (mg/l)	24	3.4 a	2.5 b	2.0 b	1.7 b
(Range)		(1.0-5.5)	(1.1-4.2)	(1.0-4.1)	(0.8-3.4)
Nitrate-Nitrites (mg/l)	11	0.20a	0.18a	0.18a	0.19a
(Range)		(0.1-0.7)	(0.1-0.3)	(0.1-0.3)	(0.1-0.3)
Ammonia (mg/l)	11	0.25a	0.26a	0.29a	0.28a
(Range)		(0.1-0.6)	(0.1-0.6)	(0.1-0.7)	(0.1-0.7)
pH	11	7.2	7.2	7.3	7.4
(Range)		(6.3-7.8)	(6.1-8.1)	(6.5-8.2)	(6.8-8.4)

temperature ranged from 20-29 C and remained above 23 C until day 86.

On day 16 mortalities in two of the monoculture tanks occurred. Continued mortalities of catfish in the one tank revealed a disease problem which was later diagnosed at Auburn University as *Edwardsiella tarda*. Terramyacin-coated feed was originally used in treatment until diagnosis showed the bacteria was resistant to terramyacin. Treatment was then changed to Furacin-coated feed which was given to all fish. One catfish monoculture tank was completely lost.

V. DISCUSSION

Several factors such as dissolved oxygen, ammonia, density of fish, and species competition for food affect growth of both catfish and tilapia. The varying interactions between these factors often make it difficult to determine their individual effect on growth. Species competition, which is related to the densities of the species in polyculture, plays a major role (Yashouv 1969). As the density of tilapia was increased so was the degree of competition. From visual observation, tilapia stocked at 12 g/l were much more aggressive at feeding time than the lesser densities of tilapia. Tilapia at that density fed before the catfish and waited at the tank's surface for food whenever the tank cover was removed. Biting of catfish during feeding was observed also, which limited the amount of food consumed by the catfish. The increased competition with an increase of tilapia density was also evident from the percent weight changes which occurred for the catfish (Table 2). Catfish stocked with 12 g/l tilapia lost weight steadily for most of the 90 days. When stocked with 6 g/l tilapia the catfish slowly lost weight over the 90 days and with 3 g/l tilapia they didn't lose weight until after 45 days (Figure 1). At the same time tilapia in all treatments steadily gained weight over the 90 days. These results are comparable to those obtained in ponds by Smith (1973). When the density of

T. aurea polycultured in ponds with catfish was increased, competition was increased and reached a harmful degree at his highest density of 24,700 catfish and 14,820 tilapia per hectare. Williamson and Smitherman (1975) and Malca (1976) also obtained similar results in ponds for slightly lower densities of both species. In contrast no significant reduction in catfish production was experienced when 84 kg per hectare of catfish and 76 kg per hectare of male *T. aurea* were polycultured in ponds (Behrends et al. 1978).

Correlation of species densities and growth of catfish resulted in a significant negative relationship (Table 5). Similar correlation results for stocking density and percent gain have been demonstrated in high density tank culture of channel catfish (Andrews et al. 1971). While this does not establish a definite cause and effect relationship, it is suggested by the correlation analysis that as density is increased the amount of weight gain is decreased.

Condition factors of channel catfish were significantly different for each treatment, decreasing as the density of tilapia increased (Table 2). This was also an indication of the increased competition between the species as density was increased. Only tilapia at 12 g/l had a condition factor significantly lower than the others. This was partially due to the reduced amount of feed received toward the end of the 90 days as a result of an ever decreasing weight of catfish. Even so, the tilapia still gained weight.

TABLE 5. Growth, density, and water quality relationships from Pearson correlation coefficients. Numbers larger than 0.5 indicate significant correlation between factors.

	Weight Change	Tilapia Density	Nitrate-Nitrites	Ammonia	Dissolved Oxygen
Weight Change	--	-0.74	0.21	0.04	0.80
Tilapia Density	--	--	-0.13	-0.07	-0.83
Nitrate-Nitrites	--	--	--	0.07	0.83
Ammonia	--	--	--	--	-0.18

Other than possible effects of low dissolved oxygen concentrations, water quality was not significantly different between treatments (Table 4). This was in keeping with results obtained in ponds by Kilgen (1969) and in raceways by Allen and Carter (1976). Ammonia concentrations were not significantly different between treatments and did not reach toxic levels (Willingham 1973). Sublethal levels of ammonia capable of inhibiting growth (0.12 to 0.13 ppm unionized ammonia) were encountered on occasion and should have had a minimal effect on growth (Robinette 1976). The positive correlation found by Andrews et al. (1971) for stocking density and ammonia concentrations was not experienced (Table 5). Ammonia concentrations and nitrate-nitrite concentrations were not significantly correlated to density. Nitrate-nitrite levels were low enough not to have been toxic or have had an inhibitory effect on growth.

Since dissolved oxygen concentrations of 36% air saturation or less will inhibit growth (Andrews et al. 1973), there were times the dissolved oxygen was low enough in the polyculture treatments to possibly have had an effect on growth. In ponds, Kilgen (1969) found that dissolved oxygen levels were improved due to removal of waste by T. aurea. Correlation analysis revealed a significant negative relationship between dissolved oxygen concentrations and density (Table 5). The same relationship was found to exist for stocking density and dissolved oxygen by Andrews et al. (1971). Thus, stocking densities could possibly influence growth through decreased oxygen concentrations as density is increased.

Growth of catfish and tilapia may also have been influenced to a degree by disease problems and tilapia reproduction. The slow growth from days 20-34 in Figure 1 correspond to the period when an infection of Edwardsiella tarda was being treated. Medicated feed did not appear to be as readily accepted by the fish. In addition diseased fish which were lethargic did not feed well. This would partially explain why growth was slowed during those 14 days. Also during this time reproduction by tilapia occurred in five tanks with stocking densities of 3 and 6 g/l of tilapia. The use of energy for reproduction and mouth brooding of eggs and yolk-sac larvae by females might have had an effect on growth rates also.

It was concluded from this study that stocking T. aurea at densities equal to or greater than 25% of the weight of stocked catfish in a flow-through system with a high density of catfish is not practical. Due to competition with the tilapia, the decreased growth and condition of catfish would result in a nonmarketable fish. A feeding rate greater than that used would probably not be effective in producing favorable growth, since the aggressive behavior of biting catfish by the tilapia intimidated them during feeding. It was apparent that competition was the limiting factor in this study.

LIST OF REFERENCES

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Allen, K.O. 1974. Effects of stocking density and water exchange rate on growth and survival of channel catfish *Ictalurus punctatus* (Rafinesque) in circular tanks. Aquaculture 4:29-39.

Allen, K.O., and R.R. Carter. 1976. Polyculture of channel catfish, tilapia, and hybrid buffalo in divided raceways. The Progressive Fish-Culturist 38(4):188-191.

Andrews, J.W., L.H. Knight, J.W. Page, Y. Matsuda, and E.E. Brown. 1971. Interactions of stocking density and water turnover on growth and food conversion of channel catfish reared in intensively stocked tanks. The Progressive Fish-Culturist 33:197-203.

Andrews, J.W., T. Murai, and G. Gibbons. 1973. The influence of dissolved oxygen on the growth of channel catfish. Transactions of the American Fisheries Society 102:835-838.

Behrends, L., K. Crawford, H. Mandanhar, R.O. Smitherman, E.W. McCoy, M. Hopkins, and D. Dunseth. 1977. The effects of all-male tilapia and silver carp on fish production, oxygen concentrations, phytoplankton communities, and economics of channel catfish culture. Unpublished manuscript, Auburn University, 20 pp.

Brown, E.E. 1977. World Fish Farming: Cultivation and Economics. The AVI Publishing Company, Inc., Westport, Connecticut. 397 p.

Buck, J.D. 1977. The integration of aquaculture with agriculture. Fisheries 2(6):11-16.

Colt, J., and G. Tchobanoglous. 1976. Evaluation of the short-term toxicity of nitrogenous compounds to channel catfish, *Ictalurus punctatus*. Aquaculture 8:209-224.

Kilgen, R.H. 1969. Fishes as bio-filters for improvement of pond water quality. Unpublished Ph.D. dissertation. Auburn University, Auburn, Alabama. 122 p.

Kirk, R.G. 1972. A review of recent developments in *Tilapia* culture, with special reference to fish farming in the heated effluents of power stations. Aquaculture 1:45-60.

Knepp, G.L., and G.F. Arkin. 1973. Ammonia toxicity levels and nitrite tolerance of channel catfish. The Progressive Fish-Culturist 35:221-224.

Kohler, C.C., and F.A. Pagan-font. 1978. Evaluations of rum distillation wastes, pharmaceutical wastes and chicken feed for rearing Tilapia aurea in Puerto Rico. Aquaculture 14:339-347.

Langford, F.H., F.J. ware, and R.D. Gasaway. 1978. Status and harvest of introduced Tilapia aurea in Florida lakes. Pages 102-108 in R.O. Smitherman, W.L. Shelton, and J.H. Grover, eds. Culture of exotic fishes symposium proceedings. Fish Culture Section, American Fisheries Society, Auburn, Alabama.

Lovshin, L.L., and A.B. Da Silva. 1975. Culture of monosex and hybrid Tilapias. FAO/CIFA Symposium on Aquaculture in Africa. 15 p.

McBay, L.G. 1961. The biology of Tilapia nilotica Linneaus. Southeastern Association of Game and Fish Commissioners 15:208-218.

Malca, R.P. 1976. Polyculture systems with channel catfish as the principal species. Ph.D. dissertation, Auburn University, Auburn, Alabama. 202 p.

Ray, L.E. 1978. Production of Tilapia in Catfish Raceways Using Geothermal Water. Pages 86-89 in R.O. Smitherman, W.L. Shelton, J.H. Grover, eds. Culture of exotic fishes symposium proceedings. Fish Culture Section, American Fisheries Society, Auburn, Alabama.

Robinette, H.R. 1976. Effects of selected sublethal levels of ammonia on the growth of channel catfish (Ictalurus punctatus). The Progressive Fish-Culturist 38:26-29.

Smith, P.L. 1973. Effects of Tilapia aurea (Steindachner), cage culture, and aeration on channel catfish Ictalurus punctatus (Rafinesque), production in ponds. Ph.D. dissertation, Auburn University, Auburn, Alabama. 223 p.

Spataru, P. 1976. Natural feed of Tilapia aurea in poly-culture with supplementary feed and intensive manuring. Bamidgeh 28(3):57-63.

Spataru, P. and M. Zorn. 1978. Food and feeding habits of Tilapia aurea (Steindachner) (Cichlidae) in Lake Kinneret (Israel). Aquaculture 13:67-79.

Stickney, R.R. 1979. Principles of warmwater aquaculture. John Wiley & Sons, Inc., New York, New York. 375 p.

Tomasso, J.R., C.A. Goudie, B.A. Simco, and K.B. Davis. 1980. Effects of environmental pH and calcium on ammonia toxicity in channel catfish. Transactions of the American Fisheries Society 109:229-234.

Williamson J., and Smitherman, R.O. 1975. Food habits of hybrid buffalo fish, tilapia, Israeli carp and channel catfish in polyculture. Southeasters Association of Game and Fish Commissioners 28:86-91.

Willingham, T. 1973. Ammonia toxicity and its removal from waste waters. Environmental Protection Agency. 93 p.

Yashouv, A. 1969. Mixed fish culture in ponds and the role of tilapia in it. Bamidgeh 21(3):75-92.

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