THE USE OF *TILAPIA AUREA* (STEINDACHNER) (CICHLIDAE) TO CONTROL AQUATIC VEGETATION IN SMALL PONDS

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PREFACE

Excessive growth of aquatic vegetation has detrimental effects on fish populations, sport fishing, and water quality. The use of herbivorous fish is a popular method of controlling overabundant vegetation. The objective of this research was to determine the effectiveness of *Tilapia aurea* as a biological vegetation control agent. Funds were provided by the Langston University Research Program (CSRS-OKLX-8085-15-5) through the Department of Agriculture in cooperation with the Oklahoma Cooperative Fishery Research Unit and Oklahoma State University.

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To my wife, Elsa, I extend my gratitude for her patience and understanding during my graduate studies. This thesis is dedicated to my father, Nathan Schwartz.

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CHAPTER I

INTRODUCTION

A common and integral component of many ponds is the presence of emergent, submersed, and floating-leaved macrophytic plants. Aquatic plants provide a direct food source for some fish, birds, and mammals, provide shade, cover, and spawning sites for other species, and support invertebrate populations upon which many fish feed (Fassett 1957). However, excessive vegetation causes a variety of fishery management problems. These problems include (1) stunting of fish populations probably due to excessive cover (hence excessive survival) for juvenile gamefish and forage fish, (2) reduction in recreational fishing success, (3) elimination or reduction of the phytoplankton based food chain and dissolved oxygen producing potential of phytoplankton, and (4) overall dissolved oxygen deficiencies (Boyd 1979).

Stunting of predatory and forage fish is perhaps the most common problem of excessive vegetation growth (Bennett 1948, 1954; Mraz and Cooper 1957; Heman et al. 1969; Cope et al. 1970; Judd and Taub 1973). For example, Hickman and Congdon (1974) attributed slow growth of largemouth bass (Micropterus salmoides) and bluegill (Lepomis macrochirus) in Missouri lakes to overabundant vegetation. They concluded the vegetation prevented the bass from locating the bluegill. The bass therefore suffered from a reduced food supply, while the bluegill overpopulated the vegetation beds and also grew slowly. Similarly, the mean size of fish in Currituck Sound, North Carolina, decreased from 20 g to 8 g during a period of infestation by the water-milfoil, Myriophyllum (Borowa et al. 1979).

Excessive vegetation has also been shown to result in a depressed K-factor (condition factor) among fish. The K-factor is a measure of relative well-being or "plumpness" (Bennett 1970). Bennett (1948) reported a marked improvement in largemouth bass condition after a vegetation dieoff in Fork Lake, Illinois. He attributed this improved growth to increased availability of forage fish. Another similar example is given by the results from Lake Wales, Florida, where a dramatic decrease of Hydrilla resulted in an increased mean K-factor (0.95 to 1.10) among bass less than 250 mm. This increase in condition was also attributed to increased prey availability (Colle and Shireman 1980).

The effects of dense plant stands on fish production, i.e., number and weight per unit area, do not appear to be consistent. Swingle (1945) and Moorman (1956) observed little impact of vegetation on total production. However, Borowa et al. (1979) reported a fourfold increase in the density of fish in Currituck Sound during a period of water-milfoil infestation, although no corresponding increase in total weight was observed.

Fishing success is also reduced in heavily vegetated ponds and lakes, and control results in fishery improvement. Swingle (1945) reported an increase in bass and bluegill catch from 18.4 kg/ha to approximately 60 kg/ha after Najas (naiad) was controlled by increased turbidity. In Fork Lake angling hours increased by 56% during a period of expansion by Potamogeton foliosus (pondweed), yet yield decreased by

45% due to vegetation interference (Bennett 1948).

Perhaps the most serious problem which may be attributed to aquatic macrophytes is reduction in dissolved oxygen concentrations. Oxygen deficiencies are most likely to occur in small, shallow, clear ponds. The conditions in such ponds encourage plant growth, especially of those plants which float on the surface (duckweeds) or tend to fill the entire water column with vegetation, e.g., *Chara* (muskgrass), *Najas*, and *Potamogeton*. These macrophytes compete with phytoplankton for light and nutrients, thus limiting oxygen production within the pond (Boyd 1979). Dobbins and Boyd (1976) observed that gross primary productivity, measured as oxygen produced, was typically greatest in ponds with the least macrophyte cover. Vegetation also limits pond circulation, therefore reducing the mixing of oxygen rich surface waters with oxygen deficient bottom layers (Rottman 1977).

As a result of these problems it frequently becomes necessary to control aquatic vegetation. Vegetation control may be accomplished by mechanical, chemical, or biological methods. Mechanical methods cannot totally eliminate problem species, and rapid regrowth often occurs (Stickney 1979). In addition fish can become entangled in plants harvested mechanically, and this loss results in an economic and sport fishery loss (Haller et al. 1980). Chemical treatments, i.e., herbicides, are expensive (Rottman 1977) and potentially toxic to fish. Also, plant decay may lead to further oxygen depletion (Stickney 1979). Additionally, macrophytes will become reestablished if phytoplankton blooms are not encouraged (Boyd 1979).

Biological control of aquatic vegetation offers a viable alternative to mechanical and chemical controls. Advantages include low program costs, ready supply sources, ease of application of techniques, absence of the necessity for special equipment or skilled personnel, and relative permanence of treatments because the biological agent resists reinfestations (Butler et al. 1968).

Tested biological agents include unicellular organisms, insects, snails, turtles, fish, birds, and mammals (Schuytema 1977). Most research in the United States has been directed toward the use of fish as biological controls, particularly the grass carp (*Ctenopharyngodon idella*).

Since its introduction in 1963, the grass carp has become popular as an aquatic vegetation control agent. It has been introduced into more than 100 lakes in Arkansas, where it has been effective in controlling vegetation with no measurable impact on resident fish populations (Bailey 1978; Henderson 1978). Similar results have also been reported from other areas (Mitzner 1980). However, as Avault et al. (1968) has predicted, widespread concern over the effects of grass carp on natural systems has prevented total acceptance.

At present it is illegal to privately own or transport grass carp in Oklahoma; therefore, a pond owner is limited in his or her choice of an herbivorous fish for vegetation control. One potential herbivorous fish presently established in the state is the blue tilapia, *Tilapia aurea* (Family Cichlidae).

A native of Africa, *T. aurea* normally displays food preferences for zooplankton (Spataru and Zorn 1978), phytoplankton (Manooch 1972), organic detritus (Hendricks and Noble 1979; Leventer 1981), and particularly among smaller fish, insects (McBay 1961; Shell 1962). Although one food source typically dominates the diet as a result of environmental abundance, the diet of _T. aurea_ is varied (McBay 1961; Williamson and Smitherman 1975; Hendricks and Noble 1979).

When stocked at high density, _T. aurea_ consumes filamentous algae and macrophytes. The level of control attained is dependent upon size, density, survival, and reproduction of stocked fish; predator abundance; physical factors such as temperature; and species of plants present.

McBay (1961) reported that _T. aurea_ would consume the filamentous alga, _Pithophora_, and Shell (1962) observed control at 2470/ha in some experiments. Similarly, Avault (1965) stated that _T. aurea_ successfully controlled _Pithophora_ in ponds if stocked at 2470/ha to 4940/ha. However, in some experiments stocking rates up to 4940/ha did not prove successful, probably due to small individual size (Shell 1962). Even higher densities of tilapia may be necessary to control filamentous algae in some situations, e.g., if tilapia are preyed upon by largemouth bass (Childers and Bennett 1967). In Oklahoma previous studies have failed to demonstrate filamentous algae control by tilapia. Summers (1980, 1981) reported no significant reduction of filamentous algae by _T. aurea_ in American Horse Lake, although algae were the predominant food item. This failure to control algae was attributed to low survival and reproduction. In addition, it is probable that the stocking densities employed (100/ha in 1979; 250/ha in 1980) were insufficient to provide control.

T. aurea has typically been reported to prefer filamentous algae over macrophytes, and the potential for this species to control macrophytes has been widely debated. Shell (1962) stated that _T. aurea_ stocked at 4940/ha controlled _Eleocharis_ (spikerush) and _Najas_ after filamentous algae removal. Avault (1965) similarly reported some reduction of Eleocharis, Najas, and Potamogeton in pools stocked at 5074/ha. Glass (unpublished data) observed control of Chara at densities as low as 1000/ha in Oklahoma State University experimental ponds. In a similar study T. aurea stocked at 2210/ha and 3980/ha effectively controlled vegetation, while in two other ponds stocked at 1240/ha and 6020/ha there was no visible macrophyte reduction (Sartin unpublished data). Pierce and Yawn (1965) found that T. aurea stocked at 1235/ha did not reduce Najas or Ruppia (widgeon grass). However, their ponds contained largemouth bass. As a result of these studies Pierce and Yawn (1965) concluded that tilapia were not a satisfactory means of controlling undesirable macrophytes in ponds containing established fish populations.

The biology and life history of T. aurea present legitimate concerns to the pond owner attempting to employ it for vegetation control. A prolific mouthbreeder such as T. aurea will readily overpopulate a pond during a growing season in the absence of predation. Pagan (1969) reported that tilapia stocked at densities of 7,000/ha to 15,000/ha ultimately reached densities of 250,000/ha to 346,000/ha by the end of the season. In addition the ability of tilapia to withstand crowding and to compete for food and nesting sites with native fishes (Buntz and Manooch 1968; Noble et al. 1976; Germany 1977; Hendricks and Noble 1979) would probably be detrimental in ponds where sport fishing is practiced.

Another limitation is that T. aurea requires temperatures above 10 C for survival (Germany 1977); therefore, in Oklahoma, annual restocking would be required to maintain adequate vegetation control. This natural temperature control may be advantageous, however, to a pond owner attempting to eradicate the tilapia and return a pond to its natural state.

The objectives of this study were (1) to test the effectiveness of *T. aurea* as a biological vegetation control agent in small ponds when stocked at 500/ha and 2500/ha, (2) to test feeding preferences of *T. aurea* among the five dominant plants occurring in the experimental ponds, and (3) to determine if there were any effects on water temperature, dissolved oxygen (DO) and turbidity levels resulting from vegetation control.

CHAPTER II

METHODS

Vegetation Control

Study Site Description

Field studies during 1980 and 1981 were conducted at nine Oklahoma Cooperative Fishery Research Unit experimental ponds located 12 km west of Stillwater, Oklahoma, near Lake Carl Blackwell. All ponds were 0.1 ha with depth gradually increasing from 0.5 m to 1.3 m (mean depth approximately 1.0 m).

Pond level was maintained by perodically piping water from Lake Blackwell. Inlet pipes were covered with 3 mm wire mesh screen to prevent wild fish immigration. The ponds were drained during the winters of 1979-80 and 1980-81 and refilled each spring approximately one month prior to research initiation.

Vegetation Sampling and Experimental Design

Aquatic macrophytes and filamentous algae were sampled monthly from July through October, 1980, and May through October, 1981. For convenience, these periods are referred to as seasons. The 1980 samples provided baseline data for 1981 vegetation control research.

Flag markers along the bank divided each pond into 1-m^2 sections. Eight randomly chosen sections in each pond were sampled at mid-month.

Vegetation was sampled by driving a 0.15 m^2 sheet metal tube into the sediments (once per section) and removing all living rooted and floating vegetation.

In 1980 emergent shore zone vegetation, i.e., Typha (cattails), Sagittaria (arrowhead), and Eleocharis (spikerush), were included in the samples, but analysis of these communities was eliminated in 1981. This decision was based upon the failure of T. aurea to effect these species in preliminary qualitative pond studies conducted during 1980 (personal observation). Therefore in 1981 sampling was concentrated on the submersed vegetation.

Samples were refrigerated at 1 C in individual plastic bags until analyzed. All samples were thoroughly washed in a porcelain tray to remove mud, detritus, and invertebrates. Wash effluent was poured through a 0.6 mm sieve and all plant fragments were integrated with the remainder of the sample. Samples were then divided by species unless plant entanglement prohibited separation within one to two hours. Species composition of entangled samples was estimated by selecting a random subsample representing 10% to 20% of the total sample and separating it by species. All samples were hand-squeezed dry, placed in ventilated paper bags, and dried in a forced-air plant drying oven at 55 C for 144 hr. After removal the plants were weighed to the nearest 0.01 g on a Mettler Type H6 balance, and final results were expressed as g dry weight/m^2. Total species weights in subsampled collections were calculated from the subsample proportions. A test of the subsampling procedure revealed no significant difference between species weights determined by subsample or whole sample methods.

Plants were identified to the lowest practicable taxon, typically to species. Identification of macrophytes was confirmed by Dr. Ronald J. Tyrl, curator of the Oklahoma State University herbarium, and a reference collection was maintained. Filamentous algae were not separated by taxa in either year, but in 1981 dominant genera were identified in May, July, and September.

The baseline data collected in 1980 revealed the ponds to be densely vegetated with either Najas guadalupensis or the macrophytic alga, Chara sp.. Potomogeton nodosus and P. pectinatus were secondarily abundant in several ponds. Filamentous algae occurred in low density in most ponds. Treatments were assigned in 1981 based upon 1980 mean vegetation density and species composition in a randomized block design with replication (Table 1). The data were analyzed by analysis of variance (ANOVA) and the test of least significant differences (LSD).

Tilapia Stocking and Harvest

On May 8, 1981, approximately 1000 T. aurea were seined at Horseshoe Lake in Harrah, Oklahoma, and transported to the experimental ponds. The fish were held until May 18 to allow mortality of any stressed or diseased individuals. On May 18, 50 tilapia (500/ha) were stocked in ponds 6, 13 and 16 (low density ponds = LDP), and 250 tilapia (2500/ha) were stocked in ponds 7, 12, and 15 (high density ponds = HDP). No fish were stocked in control ponds 8, 9, and 11 (CP).

Ten fish sampled at random were individually weighed and measured from each low density pond and 25 individuals from each high density pond. The remaining fish were batch weighed. Among all ponds the mean total length (subsampled tilapia only) was 236 mm and mean weight (including batch weighed fish) was 242 g. ANOVA revealed no significant

Table 1. Mean[1] vegetation density (g dry wt./m^2) and dominant genera during 1980 in experimental ponds.

Pond	1980 mean vegetation density	Dominant genera	1981 treatment
9, 6, 7	232.9 (84.8)	*Najas*, *Chara*	0, 500, 2500 tilapia/ha
11, 13, 12	183.3 (40.6)	*Najas*	0, 500, 2500 tilapia/ha
8, 16, 15	154.7 (64.5)	*Najas*, *Potamogeton*	0, 500, 2500 tilapia/ha

N = 96/pond.

[1]Mean (standard deviation).

difference in mean length, weight, or K-factor of individually sampled *T. aurea* in LDP versus HDP at stocking. The K-factor is a measure of relative well-being or "plumpness" (Bennett 1970) and may be expressed by the equation:

$$\text{K-factor} = \frac{W \times 10^5}{L^3}$$

where K-factor = coefficient of condition,

W = weight in grams, and

L = total length in millimeters.

The ponds were drained and harvested from October 20 to 29. Individual measurements and batch weighing were performed in a manner identical to that used at stocking.

Temperature, Dissolved Oxygen (DO), and Turbidity

Temperature and DO were measured weekly in all ponds from May 24 through October 13, 1980. Measurements were made at the surface, middle (0.6 m) and bottom (1.2 m) of the ponds with a YSI model 51B polarographic DO meter and thermistor. All measurements were made between 0900 and 1100 hr. Weekly measurements of surface turbidity were also made from June 24 through October 13 with a Hellige optical turbidimeter. In 1981 all variables were measured twice per week from May 15 through October 8. The data were analyzed by ANOVA and the LSD test.

Tilapia Feeding Preference

The feeding preference of *T. aurea* for *N. guadalupensis*, *Chara* sp., *P. pectinatus*, *P. nodosus*, and filamentous algae, predominantly

Cladophora sp., was tested in two replicated experiments, A and B (Table 2).

Tilapia were maintained in the laboratory in aerated holding tanks and fed a daily ration of 32% protein floating catfish feed. Test fish were selected at random from the stock and a single fish weighing approximately 100 to 175 g was placed in each of ten, 75-l opaque plastic aquaria. The mean weight of fish among treatments within each experiment was kept as similar as practicable. The aquaria were aerated, filtered, and heated to approximately 25 C (24.9 ± 0.8 C in experiment A; 24.7 ± 0.5 C in experiment B).

The test fish were starved for 48 hr to allow clearing of the digestive tract and then offered randomly assigned individual plants (experiment A) or one of ten possible paired combinations (experiment B) (Table 2). Fresh plants were collected from the experimental ponds for each replicate. The plants were rinsed and dried on paper towels before weighing (wet weight), and approximately 25 g of each plant was offered at the start of a 48 hr feeding period (preliminary testing indicated that consumption would not exceed 25 g for any species). Lead plant anchors were fastened at the base of each sample lot to prevent the plants from floating when placed in the aquaria. At the end of the test period all uneaten plants and plant fragments were removed and weighed to determine the amount ingested.

Each individual tilapia was used in only one feeding trial, i.e., new fish were used in each replicate of both experiments. All aquaria were thoroughly cleaned, new filter material was added, and water partially changed before the start of each feeding test.

The data from experiment A were analyzed by ANOVA and a Duncan's

Table 2. Experimental design[1] for the tilapia feeding preference study.

Experiment	Replicate number	Aquarium 1	2	3	4	5	6	7	8	9	10
A	1 and 2	C	B	D	A	E	A	C	D	B	E
	3 and 4	A	E	C	D	B	D	E	A	C	B
B	1	BD	AC	CD	AE	DE	BE	BC	CE	AB	AD
	2	BC	CE	BD	AE	BE	AC	CD	AD	DE	AB
	3	BE	AD	AE	AB	AC	BD	CE	DE	CD	BC

[1]A = *N. guadalupensis* B = *Chara* sp. C = Filamentous algae D = *P. pectinatus* E = *P. nodosus*.

multiple range test. Treatment effects in experiment B were measured by using a paired t-test. In addition, individual plant consumption means in experiment B were analyzed by ANOVA and a Duncan's multiple range test.

CHAPTER III

RESULTS

Vegetation Control

Survival, Growth, and Reproduction of Tilapia

Survival of tilapia in HDP ranged from 79.6% to 95.6% (Table 3). Survival in LDP ranged from 92.0% to 94.0%.

Tilapia in both LDP and HDP showed significant growth (Tables 4 and 5). There was a significant increase in mean length ($P = 0.0103$) and weight ($P = 0.0271$) among fish in LDP, although mean K-factor decreased significantly ($P = 0.0183$). A similar increase in length ($P = 0.0029$) and weight ($P = 0.0006$) was observed among fish in HDP. However, there was no significant change in K-factor ($P = 0.8840$).

Stocking density appeared to have little effect on tilapia growth during the year. Mean individual fish weight gain exceeded 90 g in all ponds with the exception of Pond 12 (Table 3). There was no significant difference in length ($P = 0.6002$), weight ($P = 0.8178$), or K-factor ($P = 0.3985$) of harvested fish between LDP and HDP (Table 5).

Extensive reproduction occurred in all stocked ponds throughout the study period. Females with mouth-broods were observed at stocking, and initial nest building activity occurred within one week after stocking. Schools of fry were observed in all ponds by June 15. Although many fry and fingerlings were probably lost as the ponds were

Table 3. Percent survival and growth[1] (g) of tilapia in LDP and HDP.

Tilapia/ha	Pond	Number of tilapia stocked	Number of tilapia harvested	Percent survival	Mean weight stocked	Mean weight harvested	Mean growth
500	6	50	---[2]	---[2]	246.9	---[2]	---[2]
	13	50	47	94.0	219.9	314.8	94.9
	16	50	46	92.0	235.2	328.0	92.8
2500	7	250	239	95.6	236.6	328.2	91.6
	12	250	199[3]	79.6[3]	228.5	305.8	77.3
	15	250	217	86.8	233.4	326.6	93.2

[1]Includes subsampled and batch weighed tilapia.

[2]Broken drain valve precluded harvest.

[3]Includes 25 dead tilapia removed in late September.

Table 4. Mean length (mm), weight (g), and K-factor for tilapia in LDP and HDP at stocking and harvest. Variable means were considered significantly different if $P < 0.05$.

Tilapia/ha	Variable	Stocking	Harvest	ANOVA		
				MSE[1]	F	Prob > F
500	Length	234.7	264.8	326.8	33.34	0.0103
	Weight	238.7	328.6	5900	16.42	0.0271
	K-factor	1.855	1.739	0.00735	22.01	0.0183
2500	Length	237.0	261.1	517.3	41.99	0.0029
	Weight	242.6	324.8	2633	96.14	0.0006
	K-factor	1.807	1.802	0.05058	0.02	0.8840

N = 30 for LDP at stocking, 20 at harvest.
75 for HDP at stocking and harvest.

[1]Variance among ponds within stocking and harvest.

Table 5. Mean length (mm), weight (g), and K-factor for tilapia at stocking and harvest in LDP and HDP. Variable means were considered significantly different if $P < 0.05$.

Stocking or harvest	Variable	Tilapia/ha 500	Tilapia/ha 2500	ANOVA MSE[1]	ANOVA F	ANOVA Prob > F
Stocking	Length	234.7	237.0	282.1	0.42	0.5530
	Weight	238.7	242.6	4403	0.08	0.7977
	K-factor	1.855	1.807	0.00730	6.59	0.0622
Harvest	Length	264.8	261.1	640.4	0.34	0.6002
	Weight	328.6	324.8	3538	0.06	0.8178
	K-factor	1.739	1.802	0.06506	0.96	0.3985

N = 30 for LDP at stocking, 20 at harvest.
75 for HDP at stocking and harvest.

[1]Variance among ponds within treatments.

drained at harvest, young tilapia literally covered the bottom near the drainage basin in each pond. Densities were estimated to be approximately 100,000/ha in both LDP and HDP. A difference was possibly present between the LDP and HDP, but could not be quantitatively verified. The great majority of young tilapia in all ponds were less than 50 mm and 5 g at harvest. A qualitative sampling of the largest fingerlings revealed a similar maximum size in both LDP and HDP of approximately 100 mm to 125 mm and 15 g to 35 g.

Vegetation Seasonal Mean Densities, 1980 and 1981

In 1980 mean seasonal (July through October) total vegetation density (range from 185.0 g/m^2 to 193.8 g/m^2) was similar among treatments (Table 6). *Najas guadalupensis* and *Chara* sp. were the predominant species and accounted for 74.1% to 97.4% of total plant density. *Potamogeton* spp. and emergent species were secondarily abundant in several ponds. Density of filamentous algae was consistently low in all treatments.

During the same period in 1981 mean density of plants among CP was 148.6 g/m^2. Values were lower than in 1980 for *Najas* (23.7 g/m^2), *Potamogeton* (20.6 g/m^2), and filamentous algae (5.8 g/m^2). However, *Chara* density was higher in 1981 by 22.0 g/m^2. Mean densities among LDP (66.1 g/m^2) and HDP (31.0 g/m^2) were substantially lower than corresponding values in the same ponds in 1980. Densities of all plants in LDP and HDP were reduced in 1981 with the exception of negligible increases of *Potamogeton* in both treatments.

During 1981 mean seasonal (May through October) total vegetation

Table 6. Mean plant densities (g dry wt./m^2) in experimental ponds during July through October 1980[1] and 1981.

	Tilapia/ha					
	0		500		2500	
Plant category	1980	1981	1980	1981	1980	1981
Najas guadalupensis	138.8	115.1	154.5	64.7	145.0	25.0
Chara sp.	4.7	26.7	33.9	0.8	36.0	3.8
Filamentous algae[2]	7.7	1.9	4.1	0.4	3.9	0.1
Potamogeton spp.[3]	29.5	4.9	0.0	0.2	0.0	2.1
Emergents[4]	13.1	----	0.1	----	0.1	----
Total vegetation	193.8	148.6	192.6	66.1	185.0	31.0

N = 96/treatment/year.

[1] 1980 means calculated according to the 1981 design for purposes of comparison only. No tilapia were stocked in 1980.

[2] Filamentous algae predominantly *Cladophora* sp..

[3] *P. pectinatus* and *P. nodosus*.

[4] Only sampled in 1980 and includes *Typha* spp., *Sagitarria latifolia*, *S. platyphyla*, *Eleocharis macrostachya*, and unidentified species A, probably a Scrophulariaceae.

density was significantly different among treatments. Values ranged from 121.5 g/m^2 in CP to 61.4 g/m^2 and 33.7 g/m^2 among LDP and HDP, respectively (Table 7). Najas density exhibited a similar pattern, although there was no significant difference between LDP and HDP. Chara density was greater in CP (19.9 g/m^2) than in LDP (0.9 g/m^2) or HDP (4.1 g/m^2), but differences were not significant. Najas and Chara accounted for 94.2%, 97.1%, and 91.2% of the total vegetation densities among CP, LDP, and HDP, respectively. Filamentous algae (1.6 to 2.3 g/m^2) and Potamogeton (0.0 to 4.8 g/m^2) densities were low and were not significantly different among treatments.

Vegetation Monthly Mean Densities, 1981

In May total vegetation density within all treatments was approximately 20 g/m^2 (Table 8, Figure 1). Density increased through June and July to 142.5 g/m^2 in LDP and CP and 91.2 g/m^2 in HDP. During this period up to 50% of vegetation density within samples from LDP and HDP was composed of uprooted, floating plants. No floating vegetation was observed in samples from CP. Density of plants was significantly greater in CP than HDP in June, but the difference was not significant in July. Although not significantly different, density in HDP was approximately 50 g/m^2 less than in either LDP or CP during July.

Total density of all plants among CP increased to approximately 150 g/m^2 in August and remained constant through October. A significant decline in plant densities occurred in both LDP and HDP after July. Mean total vegetation densities in LDP and HDP decreased to 77.3 g/m^2 and 20.8 g/m^2 in August, 29.8 g/m^2 and 12.1 g/m^2 in

Table 7. Mean seasonal (May to October) plant densities in (g dry wt./m^2) in experimental ponds during 1981. Means of plant categories with a common superscript were not significantly different at $P < 0.05$ as determined by the LSD test.

Plant category	Tilapia/ha 0	Tilapia/ha 500	Tilapia/ha 2500	ANOVA MSE[1]	ANOVA F	ANOVA Prob > F
Najas guadalupensis	94.5^{a}	58.7^{b}	26.6^{b}	14524	11.41	0.0090
Chara sp.	19.9^{a}	0.9^{a}	4.1^{a}	19078	0.78	0.4999
Filamentous algae[2]	2.3^{a}	1.6^{a}	1.6^{a}	158.92	0.15	0.8622
Potamogeton spp.[3]	4.8^{a}	0.1^{a}	1.4^{a}	694.72	1.22	0.3600
Total vegetation	121.5^{a}	61.4^{b}	33.7^{c}	4462.5	64.95	0.0001

N = 144/treatment.

[1]Variance among ponds within treatments.

[2]Filamentous algae predominantly *Cladophora* sp..

[3]*P. pectinatus* and *P. nodosus*.

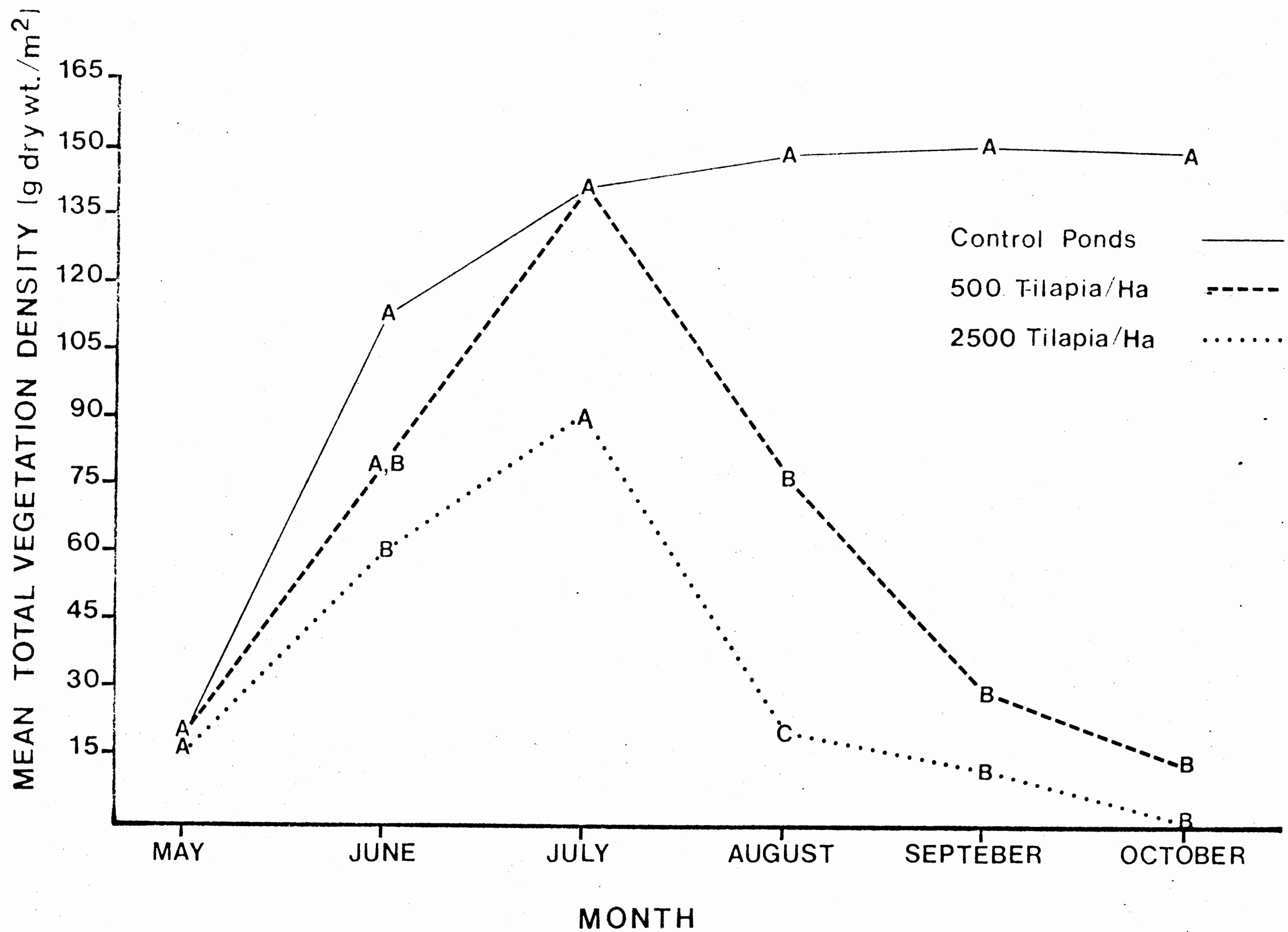
Table 8. Mean monthly total vegetation density (g dry wt./m^2) in experimental ponds during 1981. Monthly means with a common superscript were not significantly different at $P < 0.05$ as determined by the LSD test.

Month	Tilapia/ha			ANOVA		
	0	500	2500	MSE[1]	F	Prob > F
May	20.8^{a}	22.8^{a}	16.6^{a}	680.1	0.35	0.7162
June	113.5^{a}	$80.8^{a,b}$	61.3^{b}	2906	5.75	0.0404
July	142.5^{a}	142.5^{a}	91.2^{a}	4889	4.30	0.0694
August	149.8^{a}	77.3^{b}	20.8^{c}	3065	32.77	0.0006
September	152.1^{a}	29.8^{b}	12.1^{b}	1662	83.94	0.0001
October	150.0^{a}	14.9^{b}	0.1^{b}	4562	35.89	0.0005

N = 24/treatment/month.

[1]Variance among ponds within treatments.

Figure 1. Mean monthly total vegetation density (g dry wt./m^2) in experimental ponds during 1981. Monthly means designated by the same letter were not significantly different at $P < 0.05$ as determined by the LSD test. Sample size was 24/treatment/month.


MEAN TOTAL VEGETATION DENSITY (g dry wt./m2)
165
150
135
120
105
90
75
60
45
30
15
MAY
JUNE
JULY
AUGUST
SEPTEBER
OCTOBER
MONTH
Control Ponds
500 Tilapia/Ha
2500 Tilapia/Ha
A
A
A
A,B
B
A
A
A
A
B
C
A
B
B
A
B
B

September, and 14.9 g/m^2 and 0.1 g/m^2 in October. Density was significantly lower among HDP than among LDP in August. Vegetation reduction was most evident in Pond 7, where no vegetation was recorded during September or October (Appendix A).

Najas abundance followed a similar temporal pattern (Table 9). By October densities had declined to 14.6 g/m^2 and 0.1 g/m^2 among LDP and HDP, respectively, while exceeding 100 g/m^2 in CP. Abundance of filamentous algae and *Potamogeton* were limited and were not significantly different among treatments throughout 1981 (Tables 10 and 11). *P. nodosus* continued to cover small (1-m^2 to 10-m^2) areas in both LDP and HDP after all other vegetation had declined. When present, filamentous algae in all ponds were always dominated by *Cladophora* sp.. *Spirogyra* sp. and *Zygnema* sp. were secondarily abundant in the spring. *Chara* density among CP increased in July and fluctuated between 20 g/m^2 and 30 g/m^2 from July through October. However, the density of this species was not significantly greater in CP than in LDP or HDP (Table 12).

Temperature, Dissolved Oxygen (DO), and Turbidity Seasonal Means, 1980 and 1981

There was no significant difference among treatments with respect to seasonal (May to October) mean temperature, DO, and turbidity in 1980 (Table 13). However, in 1981 there was a consistent and significant difference among treatment means for all three variables (Table 14). Seasonal mean temperatures and DO values at all depths were significantly greater in LDP and HDP than in CP, and, in addition, high density pond values exceeded those for LDP. The differences

Table 9. Mean monthly density of *Najas guadalupensis* (g dry wt./m^2) in experimental ponds during 1981. Monthly means with a common superscript were not significantly different at $P < 0.05$ as determined by the LSD test.

Month	Tilapia/ha			ANOVA		
	0	500	2500	MSE[1]	F	Prob > F
May	13.2^a	16.9^a	10.7^a	409.7	0.57	0.5945
June	93.1^a	76.8^a	49.2^a	5103	2.32	0.1789
July	110.4^a	138.7^a	76.5^a	5993	3.89	0.0827
August	117.3^a	75.9^a	19.8^b	4561	12.58	0.0071
September	123.3^a	29.5^b	3.6^b	3769	25.24	0.0012
October	109.5^a	14.6^b	0.1^b	1216	69.70	0.0001

N = 24/treatment/month.

[1]Variance among ponds within treatments.

Table 10. Mean monthly density of filamentous algae[1] (g dry wt./m^2) in experimental ponds during 1981. Monthly means with a common superscript were not significantly different at $P < 0.05$ as determined by the LSD test.

Month	Tilapia/ha			ANOVA		
	0	500	2500	MSE[2]	F	Prob > F
May	3.5^a	5.7^a	5.4^a	328.3	0.10	0.9033
June	2.8^a	2.3^a	3.3^a	117.7	0.05	0.9479
July	0.4^a	1.7^a	0.6^a	14.44	0.86	0.4701
August	0.6^a	0.0^a	0.0^a	2.801	1.00	0.4219
September	$<0.1^a$	0.0^a	0.0^a	0.00500	1.00	0.4219
October	6.4^a	0.0^a	0.0^a	115.2	2.83	0.1362

N = 24/treatment/month.

[1]Filamentous algae predominantly *Cladophora* sp..

[2]Variance among ponds within treatments.

Table 11. Mean monthly density of *Potamogeton* spp.[1] (g dry wt./m^2) in experimental ponds during 1981. Monthly means with a common superscript were not significantly different at $P < 0.05$ as determined by the LSD test.

Month	Tilapia/ha			ANOVA		
	0	500	2500	MSE[2]	F	Prob > F
May	2.9^{a}	0.0^{a}	0.0^{a}	49.46	1.39	0.3192
June	6.4^{a}	0.0^{a}	0.0^{a}	332.2	1.00	0.4219
July	7.7^{a}	0.0^{a}	0.0^{a}	332.3	1.44	0.3084
August	2.6^{a}	0.8^{a}	0.0^{a}	45.07	0.95	0.4391
September	5.4^{a}	0.0^{a}	8.5^{a}	710.4	0.63	0.5657
October	3.8^{a}	0.1^{a}	0.0^{a}	67.61	1.70	0.2607

N = 24/treatment/month.

[1]*P. nodosus* and *P. pectinatus*.

[2]Variance among ponds within treatments.

Table 12. Mean monthly density of Chara sp. (g dry wt./m^2) in experimental ponds during 1981. Monthly means with a common superscript were not significantly different at $P < 0.05$ as determined by the LSD test.

Month	Tilapia/ha 0	Tilapia/ha 500	Tilapia/ha 2500	ANOVA MSE[1]	ANOVA F	ANOVA Prob > F
May	1.1[a]	0.3[a]	0.5[a]	6.231	0.83	0.4796
June	11.1[a]	1.7[a]	8.8[a]	1482	0.39	0.6936
July	23.9[a]	2.0[a]	14.2[a]	6144	0.47	0.6480
August	29.4[a]	0.6[a]	1.0[a]	6915	0.95	0.4395
September	23.4[a]	0.3[a]	0.0[a]	4372	0.99	0.4259
October	30.2[a]	0.2[a]	0.1[a]	7315	0.99	0.4243

N = 24 treatment/month.

[1]Variance among ponds within treatments.

Table 13. Mean seasonal (May to October) temperature (C), DO (mg/1) and turbidity (JTU) in experimental ponds during 1980[1]. Variable means with a common superscript were not significantly different at $P < 0.05$ as determined by the LSD test.

Variable	Tilapia/ha			ANOVA		
	0	500	2500	MSE[2]	F	Prob > F
Surface temperature	25.23[a]	25.44[a]	25.70[a]	3.480	0.80	0.4980
Middle temperature	24.76[a]	25.07[a]	25.36[a]	6.057	0.76	0.5144
Bottom temperature	24.11[a]	24.35[a]	24.89[a]	17.86	0.49	0.6413
Water column mean temperature	24.70[a]	24.95[a]	25.32[a]	7.980	0.63	0.5699
Thermal stratification[3]	1.12[a]	1.08[a]	0.80[a]	6.708	0.27	0.7757
Surface DO	4.67[a]	5.34[a]	6.01[a]	32.15	0.72	0.5327
Middle DO	3.31[a]	4.05[a]	4.40[a]	28.16	0.53	0.6173
Bottom DO	2.55[a]	3.29[a]	3.56[a]	25.44	0.53	0.6209
Water column mean DO	3.51[a]	4.23[a]	4.66[a]	26.16	0.64	0.5679
DO stratification[3]	2.13[a]	2.05[a]	2.45[a]	11.72	0.23	0.8008
Turbidity	5.56[a]	5.86[a]	5.94[a]	29.82	0.05	0.9494

N = 42 (CP), 62 (LDP), and 63 (HDP), for temperature and DO; 34 (CP), 51 (LDP), and 50 (HDP) for turbidity. No temperature/DO value was recorded for Pond 6 on July 21 due to a meter malfunction; similarly, no turbidity value was available on July 8 for Pond 12 due to a broken sample bottle. Pond 11 was not included in the analyses due to constant leakage.

[1]1980 means analyzed according to the 1981 design for purposes of comparison only. No tilapia were stocked in 1980.

[2]Variance among ponds within treatments.

[3](Surface value minus bottom value).

Table 14. Mean seasonal (May to October) temperature (C), DO (mg/1), and turbidity (JTU) in experimental ponds during 1981. Variable means with a common superscript were not significantly different at $P < 0.05$ as determined by the LSD test.

Variable	Tilapia/ha 0	500	2500	ANOVA MSE[1]	F	Prob > F
Surface temperature	23.62^a	24.00^b	24.30^c	0.4726	24.90	0.0025
Middle temperature	23.48^a	23.91^b	24.29^c	0.9019	18.83	0.0047
Bottom temperature	22.67^a	23.48^b	24.22^c	1.016	61.09	0.0003
Water column mean temperature	23.26^a	23.80^b	24.27^c	0.7415	35.66	0.0011
Thermal stratification[2]	0.95^a	0.53^b	0.08^c	0.3024	65.73	0.0003
Surface DO	5.01^a	5.30^b	5.69^c	0.5307	23.85	0.0028
Middle DO	3.90^a	4.47^b	5.40^c	1.304	47.56	0.0006
Bottom DO	2.44^a	3.12^b	4.68^c	1.616	90.74	0.0001
Water column mean DO	3.78^a	4.30^b	5.26^c	0.9137	67.20	0.0002
DO stratification[2]	2.57^a	2.18^b	1.01^c	0.9525	77.61	0.0002
Turbidity	4.43^a	11.02^b	12.82^b	92.56	19.74	0.0042

N = 86 (CP) and 129 (LDP and HDP) for temperature and DO; 82 (CP) and 123 (LDP and HDP) for turbidity. Turbidity was not measured during the week of July 27 due to a turbidimeter malfunction. Pond 11 was not included in the analyses due to constant leakage.

[1]Variance among ponds within treatments.

[2](Surface value minus bottom value).

among treatments increased with depth, reaching maximum levels of difference at the bottom of the ponds. Mean seasonal bottom temperatures and DO concentrations in HDP exceeded those in CP by 1.55 C and 2.24 mg/1, respectively.

In 1981 seasonal thermal stratification (surface temperature minus bottom temperature) was significantly different in ponds in each of the treatments (HDP = 0.08 C, LDP = 0.53 C, and CP = 0.95 C). Mean thermal stratification among all ponds in 1980 (0.99 C) was similar to the data for the 1981 CP (0.95 C).

During 1981 seasonal surface DO concentrations exceeded 5.0 mg/1 in ponds in all treatments. Strong stratification (surface DO minus bottom DO) was evident only in CP (2.57 mg/1) and LDP (2.18 mg/1). Values in these ponds were comparable to 1980 levels for all ponds (2.22 mg/1). Surface to bottom DO values declined by an average of only 1.01 mg/1 among HDP.

An inverse relationship between thermal stratification and DO concentration was observed both during 1980 and 1981. There was a highly significant negative correlation between mean seasonal thermal stratification and both middle ($r = -0.8529$; $P < 0.01$) and bottom ($r = -0.7611$; $P < 0.01$) mean DO values for combined 1980 and 1981 data (Table 15). A negative but non-significant ($r = -0.4616$; $P > 0.05$) correlation also existed between mean seasonal thermal stratification and mean surface DO concentration.

In 1981 there was no detectable difference in mean seasonal turbidity among LDP (11.02 JTU) and HDP (12.82 JTU), but turbidity in CP (4.43 JTU) was significantly lower than in either LDP or HDP (Table 14). Values for CP in 1981 were similar to the 1980 mean for all

Table 15. Correlation between mean seasonal (May to October) thermal stratification (surface temperature C minus bottom temperature C) and mean seasonal surface, middle, and bottom DO (mg/1) in experimental ponds for combined 1980 and 1981 data.

Abscissa (X)	Ordinate (Y)	Regression equation	Correlation coefficient (r)
Mean thermal stratification	Mean surface DO	$\hat{Y} = -0.7729691X + 5.9620439$	-0.4616 NS
Mean thermal stratification	Mean middle DO	$\hat{Y} = -1.5885093X + 5.4904253$	-0.8529 **
Mean thermal stratification	Mean bottom DO	$\hat{Y} = -1.5122706X + 4.4690961$	-0.7611 **

N = 18 (9 ponds x 2 years).

NS = not significant, $P > 0.05$.

** = highly significant, $P < 0.01$.

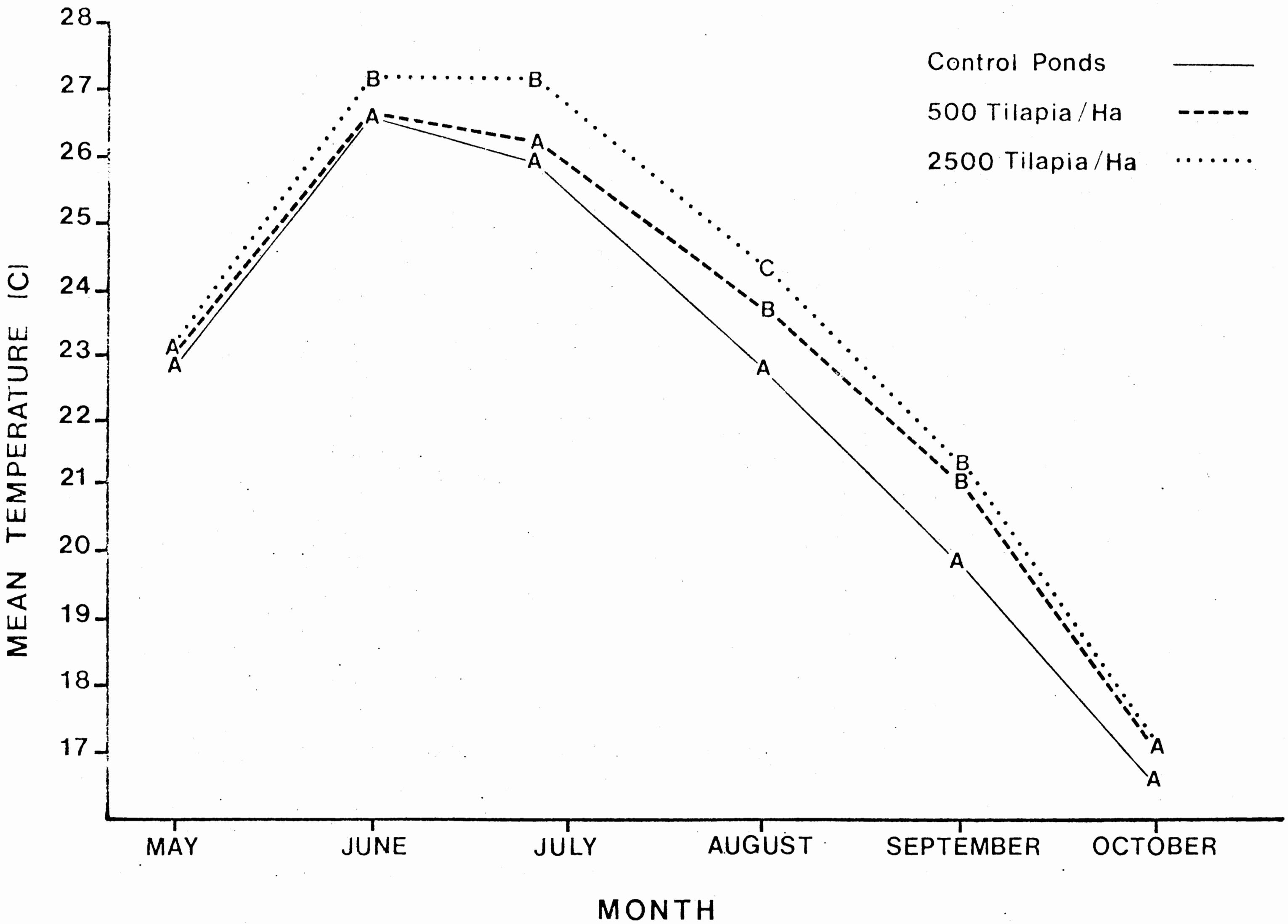
ponds (5.81 JTU).

Temperature, Dissolved Oxygen (DO), and Turbidity Monthly Means, 1981

There was no significant treatment effect upon water column (surface to bottom) mean temperatures in May or October (Figure 2). However, mean temperature in HDP were significantly greater than in either LDP or CP from June through August and June through September, respectively. The maximum difference between HDP and LDP (0.87 C) and between HDP and CP (1.52 C) occurred during July and August, respectively. Mean temperatures in HDP exceeded those in CP by greater than 1 C throughout the summer, and reached a maximum difference of 2.27 C on August 17. The temperature difference between LDP and CP gradually increased from July (0.28 C) through August (0.91 C) and September (1.22 C). Differences were significant in the latter two months.

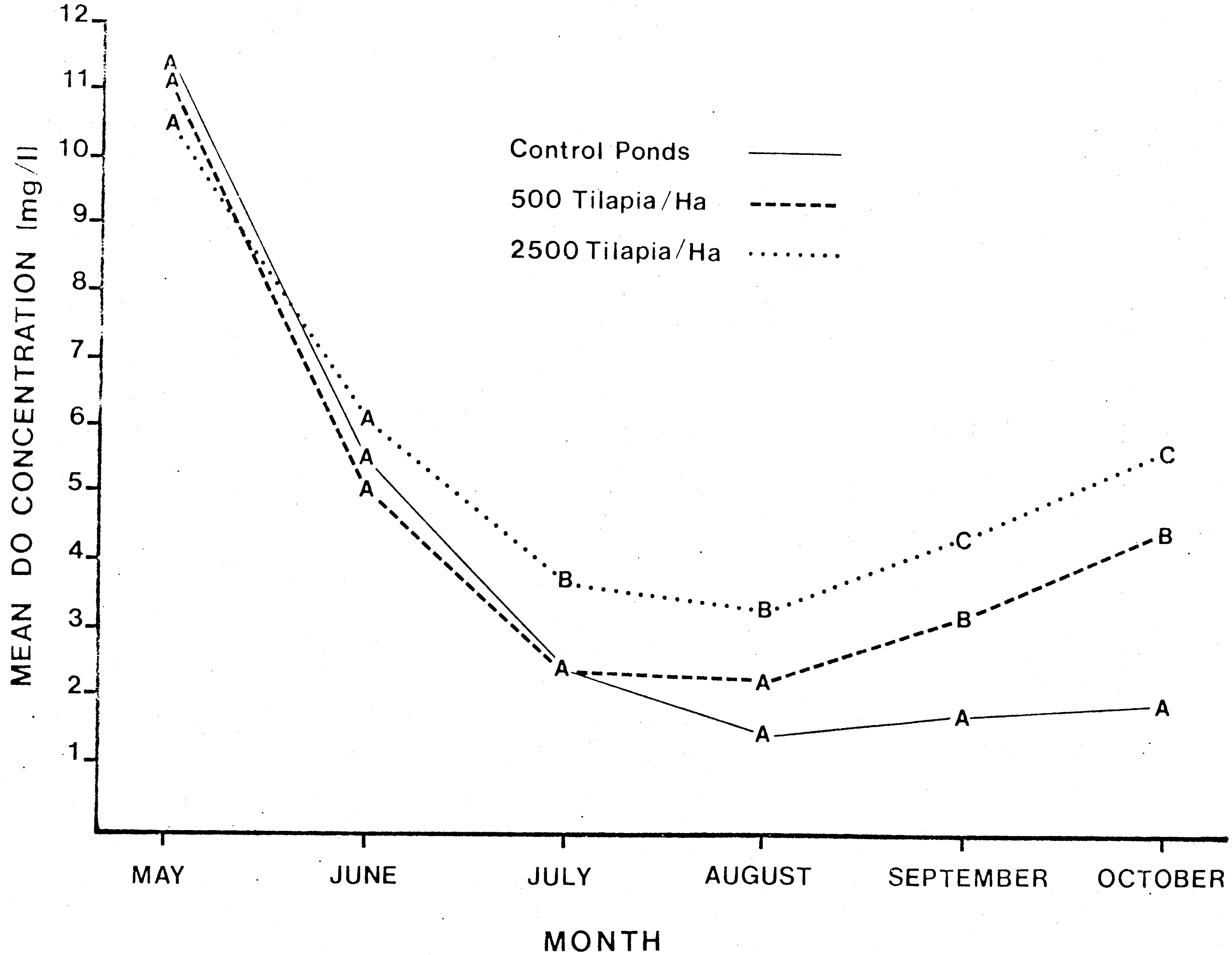
Mean surface to bottom DO concentrations were similar among all treatments in May and June (Figure 3). Values declined from approximately 10-11 mg/1 in May to 5-6 mg/1 in June. DO concentrations in CP and LDP continued to rapidly decline through July, when they reached less than 2.5 mg/1. DO levels also declined in HDP, but values were significantly greater in July (3.79 mg/1) in HDP than in either LDP or CP. Mean water column DO in CP fluctuated between 1.5 and 2.0 mg/1 throughout the remainder of the summer and early fall, and was significantly less in CP than in LDP or HDP during September through October and August through October, respectively. Minimum monthly DO levels occurred among HDP in August (3.37 mg/1) but increased

Figure 2. Mean monthly temperature (C) (mean of surface, middle and bottom values) in experimental ponds during 1981. Monthly means designated by the same letter were not significantly different at $P < 0.05$ as determined by the LSD test. Sample size/treatment was 15 (May), 27 (June), 27 (July), 24 (August), 27 (September), and 9 (October).



Control Ponds
500 Tilapia/Ha
2500 Tilapia/Ha
MEAN TEMPERATURE (C)
28
27
26
25
24
23
22
21
20
19
18
17
MAY
JUNE
JULY
AUGUST
SEPTEMBER
OCTOBER
MONTH

Figure 3. Mean monthly DO concentration (mg/1) (mean of surface, middle, and bottom values) in experimental ponds during 1981. Monthly means designated by the same letter were not significantly different at $P < 0.05$ as determined by the LSD test. Sample size/ treatment was 15 (May), 27 (June), 27 (July), 24 (August), 27 (September), and 9 (October).


Control Ponds
500 Tilapia/Ha
2500 Tilapia/Ha
MEAN DO CONCENTRATION (mg/l)
12
11
10
9
8
7
6
5
4
3
2
1
A
B
C
MAY
JUNE
JULY
AUGUST
SEPTEMBER
OCTOBER
MONTH

subsequently to 5.69 mg/1 by October. DO levels in LDP also increased in September and October, and exceeded 4.50 mg/1 at the end of the study. Early fall values in the LDP remained significantly lower than values in the HDP.

Perhaps the most important difference between treatments occurred in bottom DO levels. Anoxic bottom DO conditions were approached in CP from July through September (Figures 4-6). Similarly, bottom DO concentration declined to less than 1.0 mg/1 in LDP during July and August. Minimum bottom DO concentration in HDP also occurred during July and August, but monthly means exceeded 2.4 mg/1 throughout the study.

Differences in thermal stratification among treatments were most evident during the summer months (Figures 4-10). Thermal stratification developed rapidly in CP and LDP in June, reached a maximum (2.19 C and 1.38 C, respectively) in July, and declined through October. There was little difference between surface and bottom temperature (maximum 0.16 C in July) in HDP throughout the study.

Conditions of DO stratification followed a pattern similar to that of thermal stratification over time (Figures 4-7, 9-11). Values were comparable among all treatments and less than 1.0 mg/1 during May and October. However, differences greater than 2.0 mg/1 between surface and bottom DO levels occurred in CP and LDP throughout the summer and early fall. Peak DO stratification during July corresponded to maximum thermal stratification and reached 4.47 mg/1 and 3.50 mg/1 among CP and LDP, respectively. DO stratification in HDP exceeded 1.0 mg/1 only during July and August.

Turbidity was similar among CP, LDP, and HDP in May (Figure 12). However, turbidities in HDP and LDP began to increase in June and

Figure 4. Depth profiles of mean temperature (C) and DO concentration (mg/1) in experimental ponds during July, 1981. Within depth means designated by the same letter were not significantly different at $P < 0.05$ as determined by the LSD test. Sample size was 27/treatment at each depth.

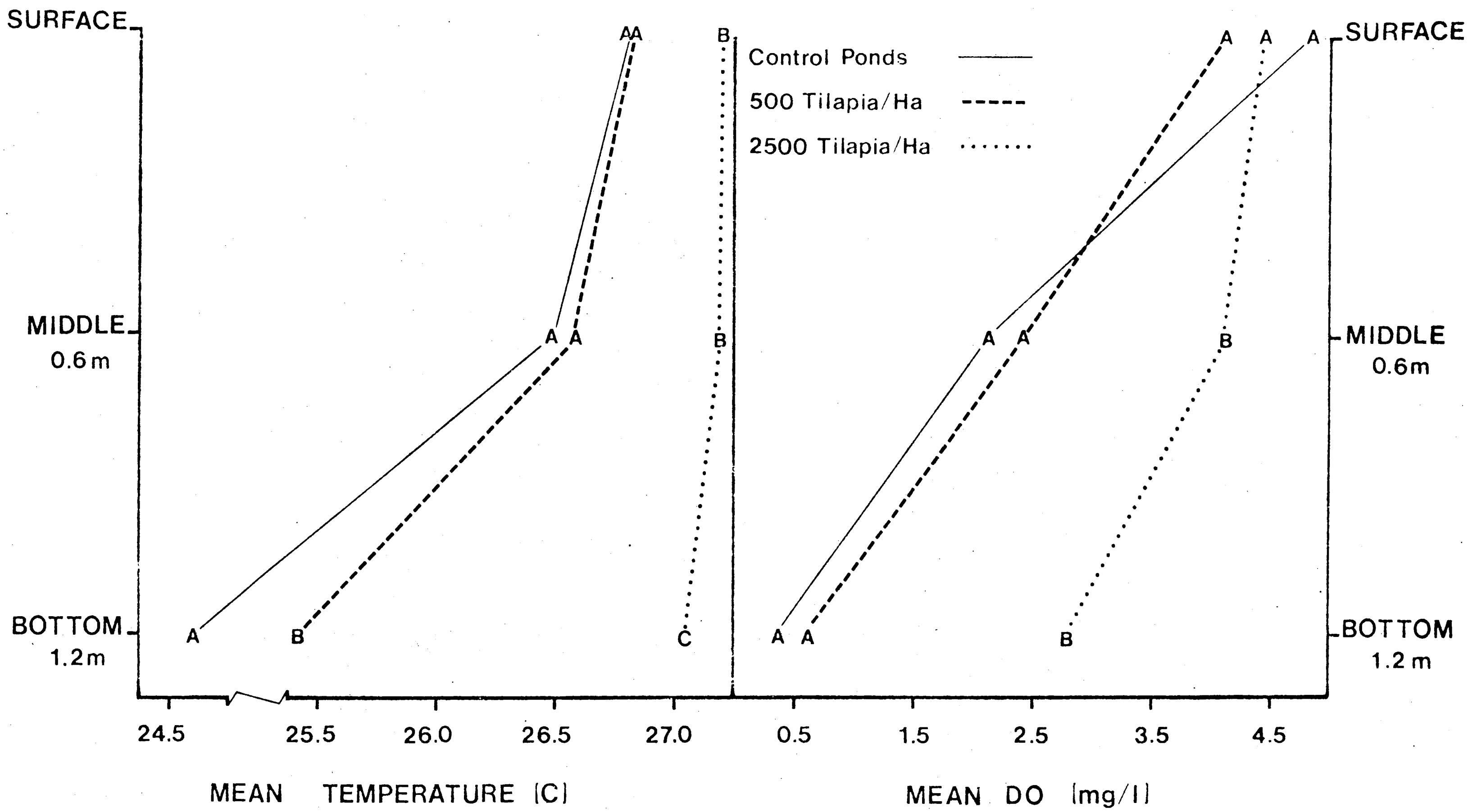
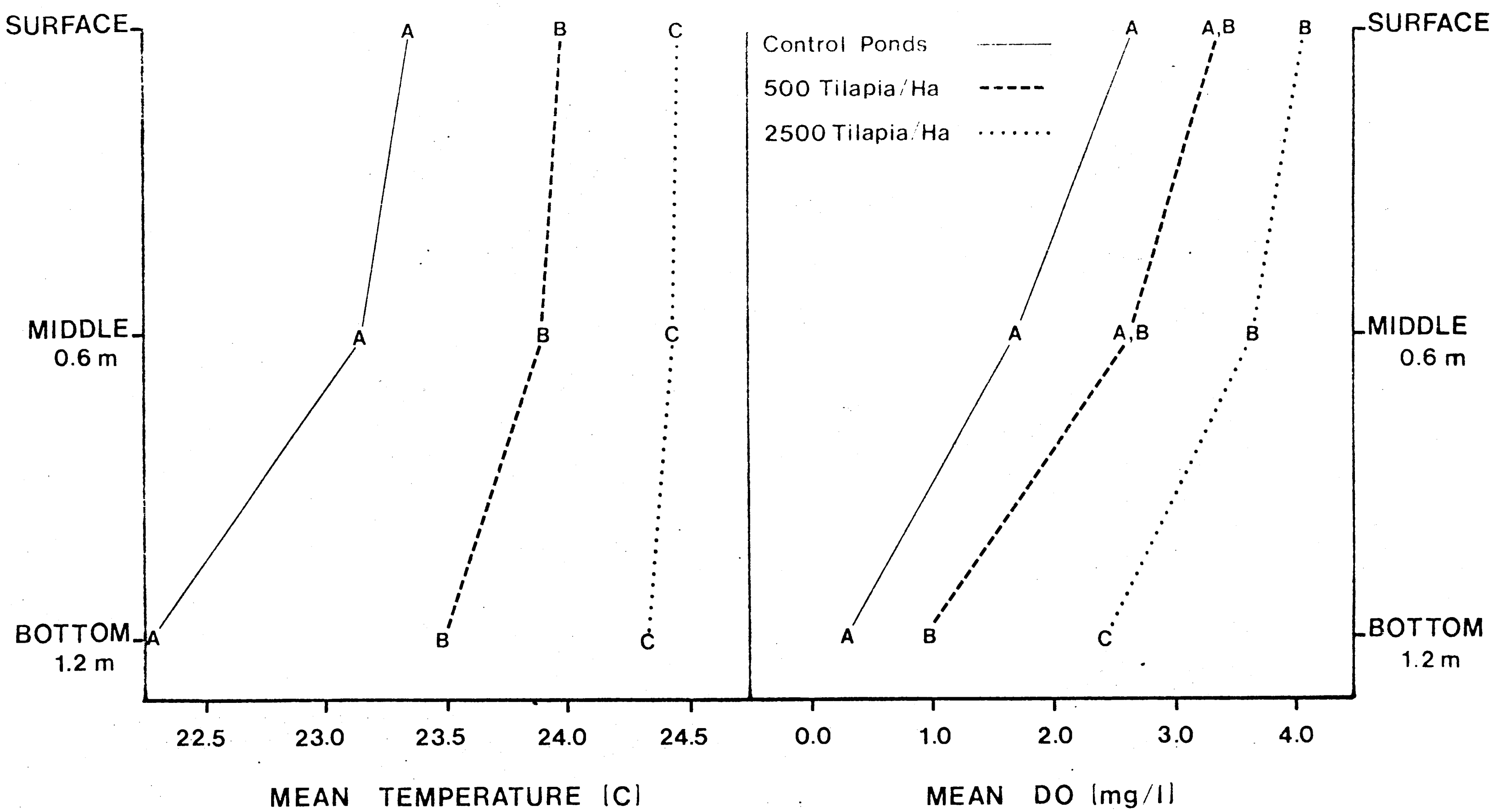

SURFACE
MIDDLE
0.6 m
BOTTOM
1.2 m
Control Ponds
500 Tilapia/Ha
2500 Tilapia/Ha
24.5
25.5
26.0
26.5
27.0
0.5
1.5
2.5
3.5
4.5
MEAN TEMPERATURE (C)
MEAN DO (mg/l)

Figure 5. Depth profiles of mean temperature (C) and DO concentration (mg/1) in experimental ponds during August, 1981. Within depth means designated by the same letter were not significantly different at $P < 0.05$ as determined by the LSD test. Sample size was 24/treatment at each depth.



SURFACE
MIDDLE
0.6 m
BOTTOM
1.2 m
Control Ponds
500 Tilapia/Ha
2500 Tilapia/Ha
A
B
C
A,B
22.5
23.0
23.5
24.0
24.5
0.0
1.0
2.0
3.0
4.0
MEAN TEMPERATURE (C)
MEAN DO (mg/l)

Figure 6. Depth profiles of mean temperature (C) and DO concentration (mg/1) in experimental ponds during September, 1981. Within depth means designated by the same letter were not significantly different at $P < 0.05$ as determined by the LSD test. Sample size was 27/treatment at each depth.

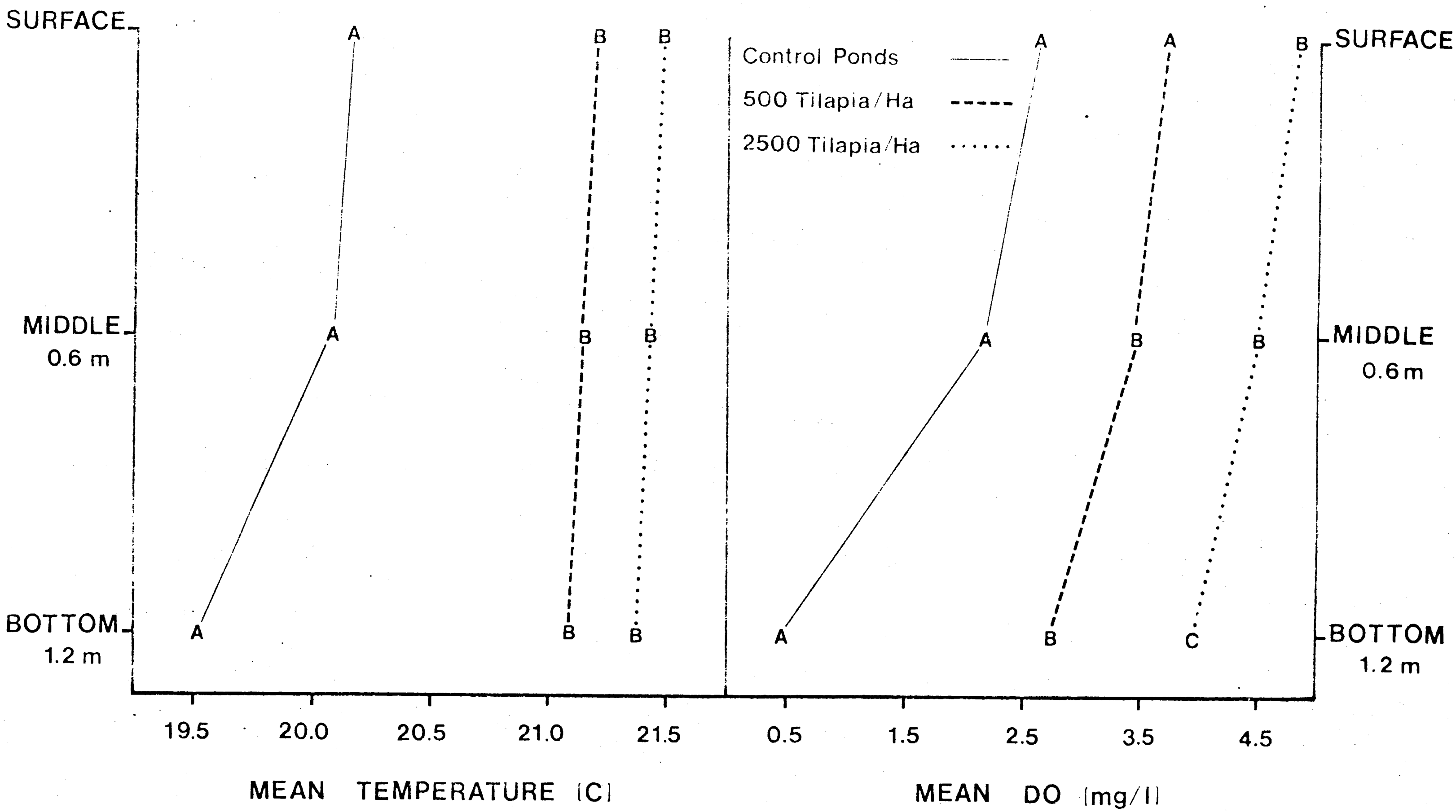

SURFACE
MIDDLE
0.6 m
BOTTOM
1.2 m
Control Ponds
500 Tilapia/Ha
2500 Tilapia/Ha
A
B
C
19.5
20.0
20.5
21.0
21.5
0.5
1.5
2.5
3.5
4.5
MEAN TEMPERATURE (C)
MEAN DO (mg/l)

Figure 7. Depth profiles of mean temperature (C) and DO concentration (mg/1) in experimental ponds during June, 1981. Within depth means designated by the same letter were not significantly different at $P < 0.05$ as determined by the LSD test. Sample size was 27/treatment at each depth.

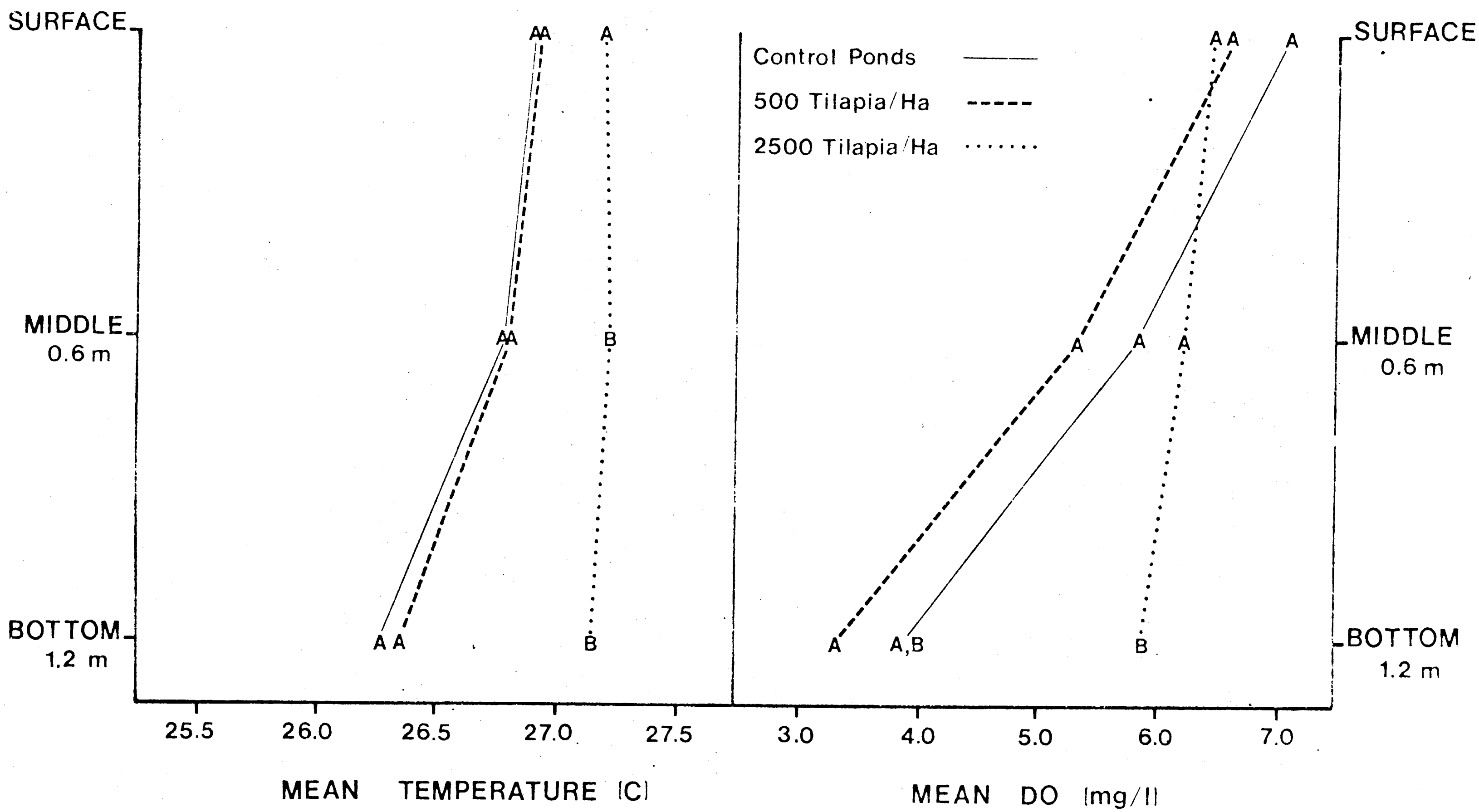
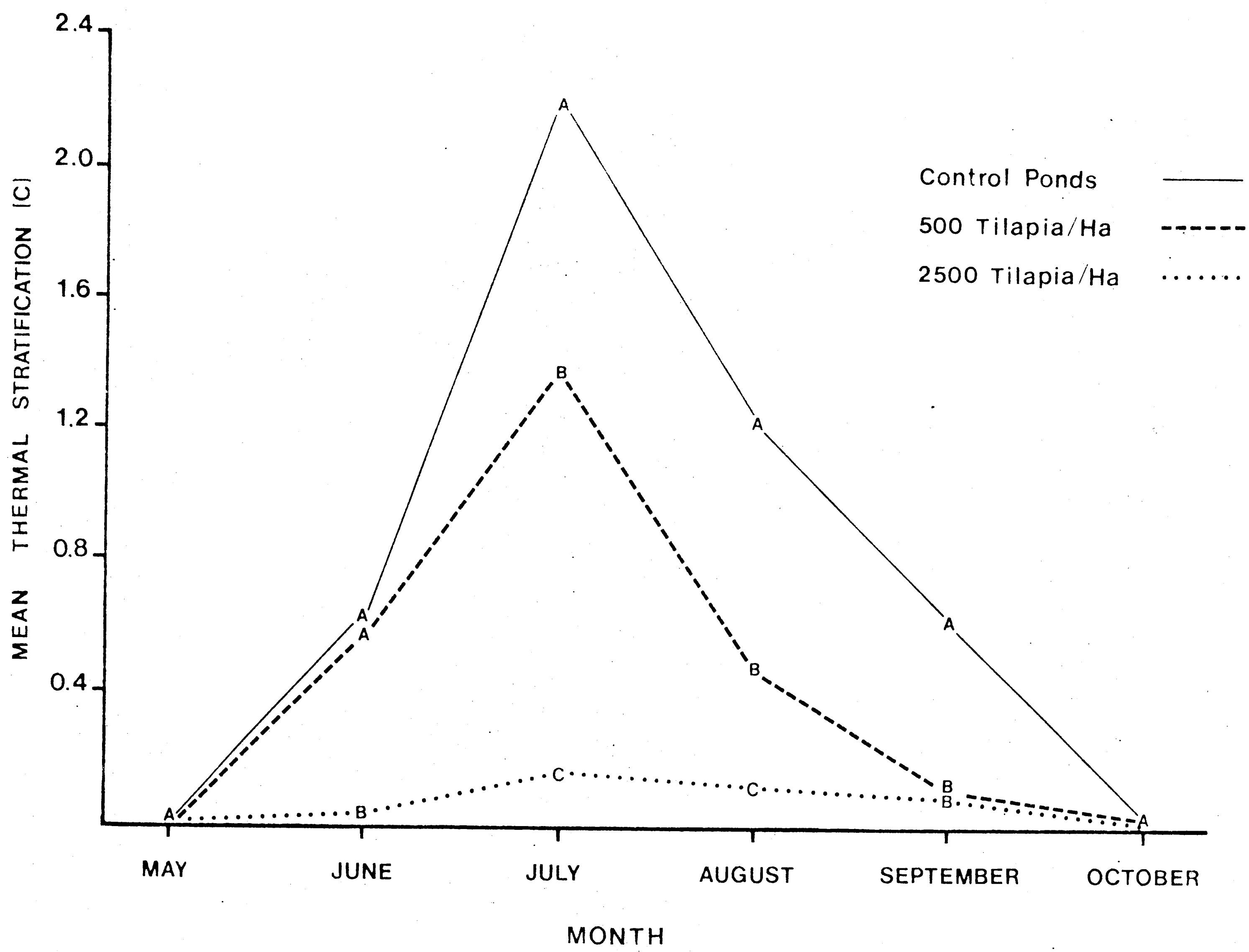

SURFACE
MIDDLE
0.6 m
BOTTOM
1.2 m
Control Ponds
500 Tilapia/Ha
2500 Tilapia/Ha
25.5
26.0
26.5
27.0
27.5
3.0
4.0
5.0
6.0
7.0
MEAN TEMPERATURE (C)
MEAN DO (mg/l)
A
B
A,B

Figure 8. Mean thermal stratification (C) (surface temperature minus bottom temperature) in experimental ponds during 1981. Monthly means designated by the same letter were not significantly different at $P < 0.05$ as determined by the LSD test. Sample size/treatment was 15 (May), 27 (June), 27 (July), 24 (August), 27 (September), and 9 (October).



Control Ponds
500 Tilapia/Ha
2500 Tilapia/Ha
MEAN THERMAL STRATIFICATION (C)
2.4
2.0
1.6
1.2
0.8
0.4
A
B
C
MAY
JUNE
JULY
AUGUST
SEPTEMBER
OCTOBER
MONTH

Figure 9. Depth profiles of mean temperature (C) and DO concentration (mg/1) in experimental ponds during May, 1981. Within depth means designated by the same letter were not significantly different at $P < 0.05$ as determined by the LSD test. Sample size was 15/treatment at each depth.

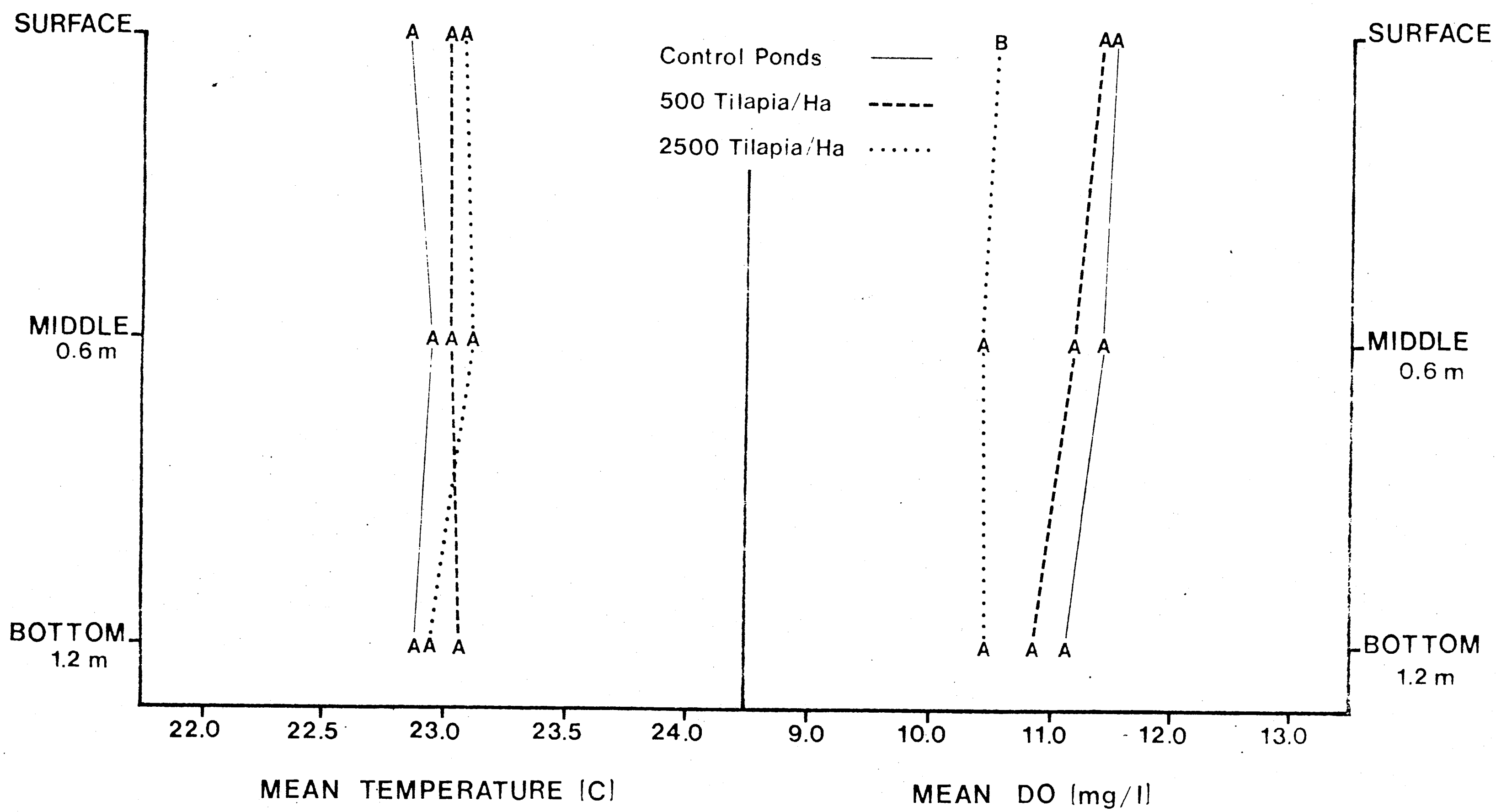
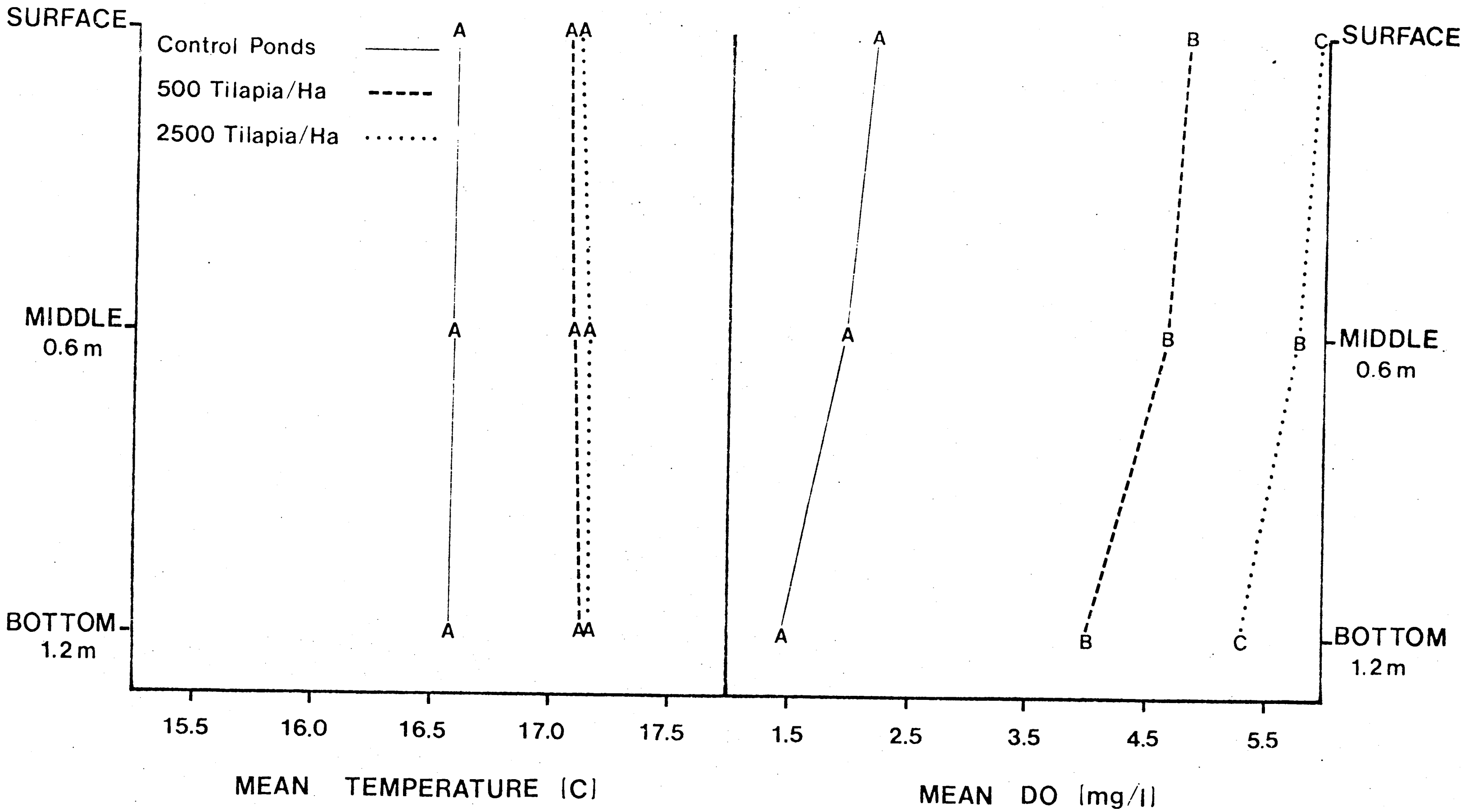
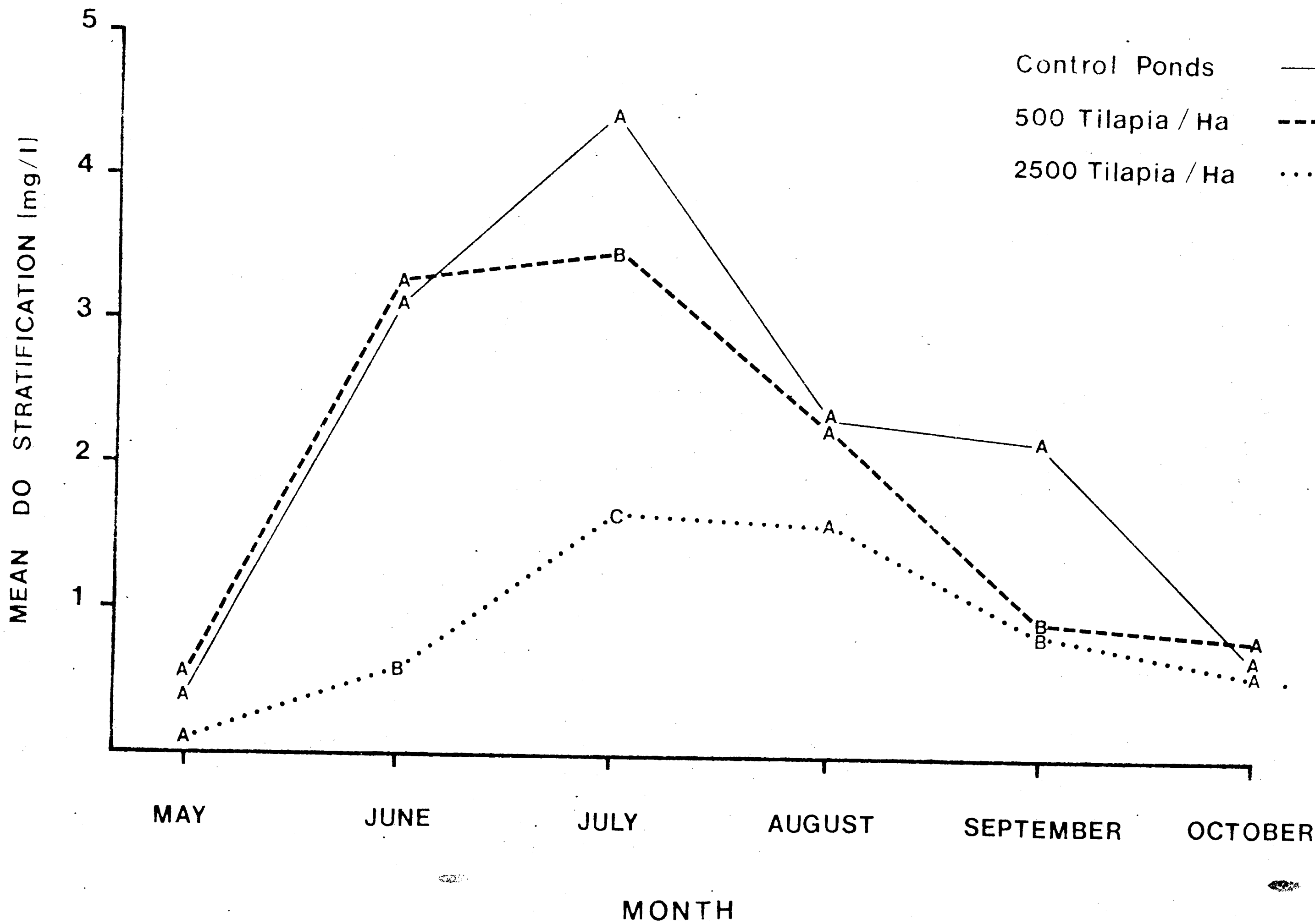

SURFACE
MIDDLE
0.6 m
BOTTOM
1.2 m
Control Ponds
500 Tilapia/Ha
2500 Tilapia/Ha
22.0
22.5
23.0
23.5
24.0
9.0
10.0
11.0
12.0
13.0
MEAN TEMPERATURE (C)
MEAN DO (mg/l)

Figure 10. Depth profiles of mean temperature (C) and DO concentration (mg/1) in experimental ponds during October, 1981. Within depth means designated by the same letter were not significantly different at $P < 0.05$ as determined by the LSD test. Sample size was 9/treatment at each depth.



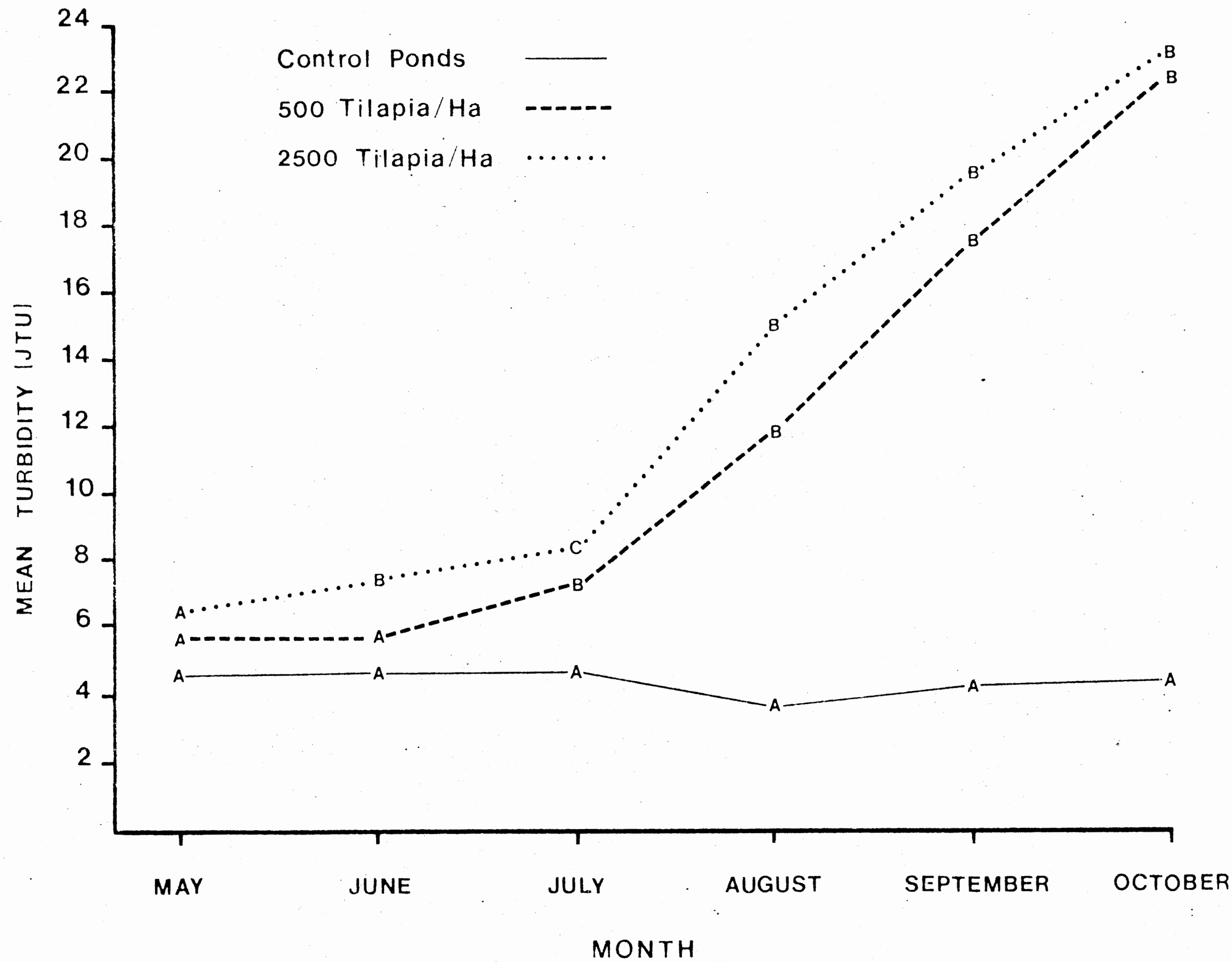
SURFACE
MIDDLE
0.6 m
BOTTOM
1.2 m
Control Ponds
500 Tilapia/Ha
2500 Tilapia/Ha
A
AA
B
C
15.5
16.0
16.5
17.0
17.5
1.5
2.5
3.5
4.5
5.5
MEAN TEMPERATURE (C)
MEAN DO (mg/l)

Figure 11. Mean monthly DO stratification (mg/1) (surface value minus bottom value) in experimental ponds during 1981. Monthly means designated by the same letter were not significantly different at $P < 0.05$ as determined by the LSD test. Sample size/treatment was 15 (May), 27 (June), 27 (July), 24 (August), 27 (September), and 9 (October).



Control Ponds
500 Tilapia / Ha
2500 Tilapia / Ha
MEAN DO STRATIFICATION (mg/l)
5
4
3
2
1
A
B
C
MAY
JUNE
JULY
AUGUST
SEPTEMBER
OCTOBER
MONTH

Figure 12. Mean monthly turbidity (JTU) in experimental ponds during 1981. Monthly means designated by the same letter were not significantly different at $P < 0.05$ as determined by the LSD test. Sample size/treatment was 15 (May), 27 (June), 21 (July), 24 (August), 27 (September), and 9 (October).


Control Ponds
500 Tilapia/Ha
2500 Tilapia/Ha
MEAN TURBIDITY (JTU)
24
22
20
18
16
14
12
10
8
6
4
2
MAY
JUNE
JULY
AUGUST
SEPTEMBER
OCTOBER
MONTH

July respectively, and were significantly greater than turbidity values in CP throughout the remainder of the study. All ponds stocked with tilapia had a brown clay color and organic stain during the summer and fall, with turbidity exceeding 20 JTU in October. There was no significant difference between turbidity in LDP and HDP from August through October. Turbidity was consistently low in CP, ranging from approximately 4.0 JTU to 5.0 JTU. No color or stain was observed in any month among CP.

Tilapia Feeding Preference

In experiment A mean consumption of *Najas* (17.48 g) and *Chara* (17.95 g) were equivalent, and both were consumed in greater quantities than any other plant (Table 16). A significant decline in preference was obvious when comparing consumption of these two species with that of filamentous algae (14.03 g), *Potamogeton pectinatus* (9.10 g) and *P. nodosus* (0.40 g).

The observed preferences among plant pairs in experiment B were in agreement with predicted responses based upon the results of experiment A (Table 17). There was a significant difference among five pairs ($P = 0.0031$ to 0.0425), and in four additional pairs there was an appreciable though non-significant ($P = 0.0641$ to 0.2407) difference. When *Najas* and *Chara* were offered simultaneously there was no preference observed ($P = 0.8226$). A comparison of individual plant consumption means, irrespective of pairing, resulted in a preference ranking identical to that in experiment A.

Maximum mean consumption of any individual plant over a 48 hr period was approximately 18 g, regardless of whether one or two plants

Table 16. Mean[1] consumption (g) of four macrophytic plants and filamentous algae[2] by T. aurea in experiment A. Means with a common superscript were not significantly different at $P < 0.05$ as determined by a Duncan's multiple range test. Mean fish weight was 138.3 g.

Plant category						ANOVA	
Najas guadalupensis	Chara sp.	Filamentous algae	Potamogeton pectinatus	Potamogeton nodosus	MSE[3]	F	Prob > F
17.48^{a}	17.95^{a}	14.03^{b}	9.10^{c}	0.40^{d}	5.123	41.13	0.0001

[1]Mean of four replicates.

[2]Filamentous algae predominantly Cladophora sp..

[3]Variance among replicates within plant categories.

Table 17. Mean[1] consumption (g) of four macrophytic plants and filamentous algae[2] by _T. aurea_ in experiment B. Within plant pair means were considered significantly different if $P < 0.05$ as determined by a paired t-test. Individual plant means with a common superscript were not significantly different at $P < 0.05$ as determined by a Duncan's multiple range test. Mean fish weight was 106.3 g.

Plant pair	Plant category: _Najas guadalupensis_	_Chara_ sp.	Filamentous algae	_Potamogeton pectinatus_	_Potamogeton nodosus_	T-test: T	Prob > T
NG - C	15.73	14.10	---	---	---	0.25	0.8226
NG - FA	17.80	---	8.37	---	---	1.65	0.2407
NG - PP	15.30	---	---	3.53	---	2.41	0.1372
NG - PN	16.13	---	---	---	0.00	4.70	0.0425
C - FA	---	17.97	10.27	---	---	3.76	0.0641
C - PP	---	15.33	---	4.57	---	11.79	0.0071
C - PN	---	16.30	---	---	0.00	14.13	0.0050
FA - PP	---	---	8.17	3.67	---	2.45	0.1338
FA - PN	---	---	9.07	---	0.23	17.29	0.0031
PP - PN	---	---	---	5.00	0.07	5.01	0.0375
Mean[3]	16.24[a]	15.93[a]	8.97[b]	4.19[c]	0.08[d]	---	---

NG = _N. guadalupensis_ C = _Chara_ sp. FA = Filamentous algae PP = _P. pectinatus_ PN = _P. nodosus_
[1]Mean of three replicates.
[2]Filamentous algae predominantly _Cladophora_ sp..
[3]ANOVA: MSE = 11.67 (variance among replicates within plant categories); F = 52.46; Prob > F = 0.0001.

were offered. However, in experiment B total consumption, i.e., the total amount eaten of both plants within a pair, exceeded 25 g among the pairs representing the most preferred plants (*Najas* - *Chara*, *Najas* - filamentous algae, and *Chara* - filamentous algae). Conversely, mean total consumption among the least preferred pair, *P. pectinatus* - *P. nodosus*, was only 5.07 g.

CHAPTER IV

DISCUSSION

Tilapia Growth and K-factors

The growth of stocked tilapia (range from 91.6 g to 94.9 g in five of six ponds) was similar at each of the densities employed. Apparently the food supply was not limiting, or was equally limiting, in both LDP and HDP. Vegetation was greatly reduced in HDP after July. Therefore it appears the tilapia were able to switch to an alternate food base, e.g., plankton, or by some other mechanism were able to maintain their weight gains through the fall.

Relative condition as measured by K-factors seems to have been only marginally affected by stocking density. Although there was a measurable difference in mean K-factor among densities at harvest (1.739 vs. 1.802), differences of this magnitude may not be biologically significant given the many variables which affect condition (Everhart et al. 1975). Similarly, the decreased condition of tilapia in LDP at harvest (K-factor = 1.739) versus condition at stocking (K-factor = 1.855) is probably not biologically significant. Supporting evidence is provided by Germany (1977), who reported similar ranges in three year mean K-factors for an established population of _T. aurea_ in Lake Trinidad, Texas (1.73 to 1.88).

Vegetation Control

In this study *T. aurea* stocked at 500 or 2500 adults/ha in small ponds successfully controlled submersed vegetation dominated by *Najas* and *Chara*. The speed and degree of control were proportional to density, with effective control observed in LDP and HDP within 120 and 90 days, respectively.

Feeding activities, including ingestion, plant uprooting, and leaf stripping during periphyton removal probably accounted for most vegetation control. Although ingestion rates were not measured in the field, both *Najas* and *Chara* were actively eaten in laboratory tests.

During the summer months large floating beds of uprooted *Najas* were evident in all stocked ponds. In addition many of the plants in these floating beds were partially or totally stripped of leaves. These floating beds probably resulted from the feeding activities of *T. aurea*. Leaf removal resulted from direct ingestion and grazing upon attached periphyton. Fingerlings as small as 25 mm were often observed feeding upon leaf surfaces. The latter observation does not agree with the observation of Shell (1962), who reported that *T. aurea* was primarily insectivorous until 125 mm in length. Similarly, McBay (1961) stated that the alga *Pithophora* was utilized extensively only by fish 125 mm or larger. However, Lahser (1967) observed that ingestion of macrophytes of *T. mossambica* (75 mm to 125 mm) was secondary to periphyton removal, and that most vascular plant material passed through the digestive tract relatively intact.

Increased turbidity levels and corresponding reduction of light penetration as a result of plant uprooting and nest building probably also contributed to reduced vegetation densities in LDP and HDP. Nest building by T. aurea had been observed to increase turbidity in small ponds (Noble et al. 1976), and Lahser (1967) reported that vegetation control by T. mossambica was partially the result of elevated turbidity from nest building.

Herbivorous fish, including tilapia (Lahser 1967) and grass carp (Avault et al. 1968; Cross 1969; Opuszyinski 1972; Hestand and Carter 1978; Fowler and Robison 1978) have been shown to favor softer, more easily masticated and digestible plant species in feeding preference tests. In the present study leaf and stem size appeared to be the most important factors in determining preference. The fine leaves and stems of Najas and the short branches of the calcareous encrusted Chara were ripped apart whereas the larger stems and leaves of Potamogeton, particularly P. nodosus, were avoided. Field data supported avoidance of Potamogeton since P. nodosus persisted in both LDP and HDP throughout the study.

Filamentous algae, e.g., Pithophora, have typically been reported as preferred over macrophytes by T. aurea (McBay 1961; Shell 1962; Avault 1965; Pierce and Yawn 1965; Avault et al. 1968; Summers 1980). In the present feeding studies preference for filamentous algae, predominantly Cladophora sp., was weaker than that for Najas and Chara, and field data did not reveal a preference for filamentous algae over macrophytes. This difference from previously published observations may have resulted because of different genera involved in the studies. Feeding preference for Cladophora has not been previously tested.

Survival of stocked adults was excellent in most ponds and this survival was also probably an important element in vegetation control. Summers (1981) reported a 50% to 75% mortality of stocked T. aurea in

American Horse Lake, Oklahoma, and concluded that the remaining fish were unable to control the filamentous alga, *Oedogonium*.

Reproductive success and lack of predation on fingerling tilapia were also factors contributing to vegetation control. Lack of reproduction by *T. aurea* in initial stockings at American Horse Lake was an additional factor in the failure of tilapia to control filamentous algae in the reservoir (Summers 1980). Childers and Bennett (1967) reported excellent vegetation control by *T. mossambica* (standing crop 26,745 fish/ha) in a predator free farm pond. However, control was substantially reduced in succeeding years when predation by largemouth bass limited standing crops to 27/ha and 405/ha. These authors concluded that, " . . . until tilapias are present in substantial numbers, their feeding activities on algae and rooted vegetation will be too insignificant to eliminate nuisance problems caused by this vegetation . . ." Pierce and Yawn (1965) similarly observed that *T. aurea* fingerlings stocked at 1976/ha controlled *Pithophora* in the absence of predation, but an identical density stocked with largemouth bass was unsuccessful. The lack of vegetation control by established populations of *T. aurea* in Florida (Ware et al. 1975) may potentially be attributed to predator control of standing crop.

Temperature and Dissolved Oxygen (DO)

Vegetation control by *T. aurea* resulted in significantly greater temperature and DO levels in experimental ponds. In addition stratification was reduced in experimental ponds during the summer months. It is unlikely that increased light penetration and primary productivity accounted for the observed effects since clay turbidity probably limited the depth of light penetration. It is probable that increased wind mixing is responsible for increased oxygen levels and reduced stratification since Rottman (1977) reported that excessive plant growth can impair oxygen levels through circulation inhibition. In the present study elimination of *Najas* and *Chara* beds would have allowed increased wind mixing between the surface and bottom layers in LDP and HDP, which would have tended to produce a more homogenous water column. Average wind velocities of 12 km/hr to 18 km/hr were recorded during the summer of 1981 in north-central Oklahoma, and velocities of 29 km/hr to 61 km/hr occasionally occurred (National Oceanic and Atmospheric Administration 1981a, 1981b, 1981c).

The strong inverse correlation between thermal stratification and DO levels at the middle and bottom of the ponds (Table 15) is further evidence of the impact of reduced wind mixing on oxygen depth profiles. However, extensive plant cover and density was also important in maintaining low DO levels, particularly in CP during the late summer and fall. As support for the latter conclusion it was observed that thermal stratification declined among CP after July, and isothermal conditions occurred by October. In spite of the lack of thermal stratification, DO concentrations at all depths exhibited little change throughout the period (Figures 3, 5, 6, 8, and 10). Total vegetation density in CP was also constant from July through October (Table 8, Figure 1).

Maintenance of adequate DO concentrations is critical to the growth, survival, and successful reproduction of pondfish, and the increased DO levels exhibited in the LDP and HDP was probably the most important measured effect of vegetation control. Although DO concentrations were not exceptionally high in any treatment, the removal of dense beds of submersed vegetation in both LDP and HDP resulted in significantly increased DO levels.

DO levels in the "critical" range for bluegill, largemouth bass, and channel catfish, i.e., approximately 0.5 mg/1 to 1.0 mg/1 (Moss and Scott 1961) were common near the bottom of CP from July through October (Figures 4-6, 10). Similar values were observed in LDP during July and August. Such values did not occur in any month in HDP.

The "desired" DO concentrations for the maintenance of warmwater pondfish are above 5 mg/1 (Swingle 1969). At DO values of 2 mg/1 to 4 mg/1 there are significant effects on growth, survival, and reproduction. Survival of largemouth bass embryos (25 C) was significantly reduced below 2.8 mg/1 (Dudley and Eipper 1975), while growth of juveniles was depressed at any level below saturation (Stewart et al. 1967). No channel catfish embryos hatched at 1.7 mg/1 (25C), and survival was significantly reduced at 2.4 mg/1 to 4.2 mg/1 (Carlson et al. 1974). Juvenile channel catfish fed ad libitum at 26.6 C exhibited significantly reduced growth at 36% and 64% DO saturation (Andrews et al. 1973). A 50% reduction in the DO habitat suitability index for bluegill and adult largemouth bass occurred at 3.2 mg/1 and 3.3 mg/1, respectively (Gebhart et al. 1981; Stuber et al. 1982).

Based upon the DO levels observed in the present study, adverse effects on an indigenous pondfish population would probably have occurred in CP during July through October, in LDP during July through September, and during July and August in HDP.

Potential Impact on Resident Fish Populations

In this study *T. aurea* was stocked alone in small ponds and therefore no measure of its direct or indirect impact on resident fishes is available. Based upon the data collected, several potential positive effects upon indigenous fish populations may be predicted in ponds where *T. aurea* is used for vegetation control. These effects include (1) elevation of DO concentrations, (2) provision of eggs, larvae, and fingerling tilapia as a food source for predators, (3) elimination of escape cover for forage and juvenile predators, and (4) increased area of the pond available for sport fishing.

T. aurea has been shown to have significant adverse effects on natural systems. The most prominent of these negative effects is competition for food and nesting sites with native fishes, including centrarchids (Buntz and Manooch 1968; Noble et al. 1976), clupeids (Germany 1977; Hendricks and Noble 1979) and cyprinids (Germany 1977). In addition, the crowding resulting from extensive reproduction by *T. aurea* may inhibit spawning in largemouth bass (Noble et al. 1976).

Potential positive and negative interactions will, of course, be unique to each aquatic system. In general, however, the stocking of *T. aurea* for vegetation control is not recommended in environments where unanticipated adverse interactions with natural fish populations cannot be tolerated.

CHAPTER V

SUMMARY

Excessive aquatic vegetation causes a variety of fishery management problems in lakes and ponds, including lowered DO concentrations, stunting of fish populations, and reduction in sport fishing success. Biological vegetation control offers several advantages over chemical or mechanical controls. Most research on biological vegetation control has been directed towards the use of fish, particularly the grass carp. However, use of the grass carp is prohibited in Oklahoma. A possible alternative presently established in the state is the blue tilapia, *Tilapia aurea* (Family Cichlidae).

In this study *T. aurea* at various densities was tested as a biological vegetation control agent in small (0.1 ha), densely vegetated ponds. Fish were stocked alone at 0 (CP), 500 (LDP), and 2500 (HDP) adults/ha in replicate ponds. *Najas guadalupensis* was the dominant submersed macrophyte in all ponds, while *Chara* sp., *Potamogeton* spp., and filamentous algae, predominantly *Cladophora* sp., were less abundant. Feeding preferences of tilapia among the dominant plant species were tested in two experiments. The effects of vegetation control on temperature, DO concentrations, and turbidity in the experimental ponds were also measured.

Growth of stocked tilapia was similar over all densities, ranging from 91.6 g to 94.9 g in five of six ponds. Mean K-factors ranged

from 1.739 to 1.855 during the course of the study. These values were similar to values previously reported for an established population.

T. aurea significantly reduced total vegetation abundance at both stocking densities. Mean vegetation density (dry weight) for the May to October study period declined from 121.5 g/m^2 in CP to 61.4 g/m^2 in LDP and 33.7 g/m^2 in HDP. Effective control was observed in 90 days at a density of 2500 tilapia/ha, and within 120 days at a density of 500 tilapia/ha. Feeding activities, including ingestion, plant uprooting, and leaf stripping during periphyton removal were the most important plant control mechanisms. Increased turbidity levels as the result of nest building probably also contributed to vegetation control.

The control observed in this study may be attributed to dominance in the ponds of plant species that are preferred by tilapia, high survival of stocked adults, high reproductive success, and lack of predation on fingerlings.

Feeding tests showed tilapia preferred plants in the following order: Najas guadalupensis = Chara sp. > Filamentous algae (Cladophora sp.) > Potamogeton pectinatus > P. nodosus. This ranking was consistent with field observations and, to a large degree, explains the successful control observed in the field.

Significant effects on turbidity, temperature, and DO concentrations were observed in both LDP and HDP. Turbidity in these ponds was significantly greater than it was in the CP. Temperature and DO levels at all depths were significantly higher in LDP and HDP than in CP, while thermal and oxygen stratification were significantly reduced. All temperature and DO effects were most evident at a density of 2500 tilapia/ha. The observed differences in temperature and DO regimes were probably predominantly due to wind induced surface to bottom mixing in ponds where vegetation was controlled. Excessive plant cover and density were also important in the maintenance of low DO concentrations in CP.

The use of T. aurea for vegetation control offers several potential positive effects in resident fish populations, including (1) elevation of DO concentrations, (2) provision of eggs, larvae and fingerlings as a food source for predators, (3) elimination of escape cover for forage and juvenile predatory populations, and (4) provision of increased pond area for sport fishing.

However, T. aurea is also known to have adverse impacts on native fishes. The most important of these factors is competition for food and nesting sites. As a result of these negative effects, stocking T. aurea for vegetation control is not recommended where unanticipated adverse interactions with natural fish populations cannot be tolerated.

Recommendations for future studies include (1) further feeding preference tests with common submersed and floating-leaved macrophytes, e.g., additional Potamogeton spp., Myriophyllum, and Ceratophyllum, (2) vegetation control studies in ponds dominated by species not favored in feeding preference tests, (3) determination of the speed and effectiveness of vegetation control at densities greater than 2500/ha, and (4) most importantly, studies in natural or experimental ponds containing known populations of representative pondfish, e.g., largemouth bass-bluegill-channel catfish combinations in various ratios.

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APPENDICES

APPENDIX A

MEAN MONTHLY PLANT DENSITIES AMONG INDIVIDUAL EXPERIMENTAL PONDS DURING 1980 AND 1981

Table 18. Mean monthly plant densities (g dry wt./m^2) among individual experimental ponds during 1980 and 1981.

Pond	Plant category	Year	Month: May	June	July	August	September	October
6	N. guadalupensis	1980	----	----	69.73	86.06	154.33	219.31
		1981	20.80	85.87	139.15	92.36	48.97	28.59
	Chara sp.	1980	----	----	120.56	179.96	63.21	7.28
		1981	0.64	2.53	6.12	1.89	0.92	0.58
	Filamentous algae[1]	1980	----	----	1.13	5.38	6.84	6.34
		1981	1.29	0.47	0.18	0.00	0.00	0.00
	P. nodosus	1980	----	----	0.00	0.00	0.00	0.00
		1981	0.00	0.00	0.00	0.00	0.00	0.23
	P. pectinatus	1980	----	----	0.00	0.00	0.00	0.00
		1981	0.00	0.00	0.00	0.00	0.00	0.00
	Typha spp.	1980	----	----	0.00	0.00	0.00	0.00
		1981	*	*		*	*	*
	E. macrostachya	1980	----	----	0.00	0.00	0.00	0.00
		1981	*	*	*	*	*	*
	S. latifolia	1980	----	----	0.00	0.00	0.00	0.00
		1981	*	*	*	*	*	*
	S. platyphyla	1980	----	----	0.07	0.00	0.08	0.00
		1981	*	*	*	*	*	*
	Unidentified species A[2]	1980	----	----	0.00	0.00	0.00	0.00
		1981	*	*	*	*	*	*
	Total vegetation	1980	----	----	191.48	271.40	224.46	232.92
		1981	22.73	88.87	145.44	94.25	49.88	29.40

Table 18. Continued.

Pond	Plant category	Year	Month: May	June	July	August	September	October
	N. guadalupensis	1980	-----	-----	33.81	112.97	127.07	146.59
		1981	16.74	56.99	84.92	10.32	0.00	0.00
	Chara sp.	1980	-----	-----	79.43	67.56	138.12	146.61
		1981	1.38	26.42	42.10	2.86	0.00	0.00
	Filamentous algae[1]	1980	-----	-----	4.53	23.67	1.97	0.31
		1981	3.44	1.32	0.15	0.00	0.00	0.00
	P. nodosus	1980	-----	-----	0.00	0.00	0.00	0.00
		1981	0.00	0.00	0.00	0.00	0.00	0.00
	P. pectinatus	1980	-----	-----	0.00	0.00	0.00	0.00
7		1981	0.00	0.00	0.00	0.00	0.00	0.00
	Typha spp.	1980	-----	-----	0.00	0.00	0.79	0.00
		1981	*	*	*	*	*	*
	E. macrostachya	1980	-----	-----	0.00	0.00	0.00	0.00
		1981	*	*	*	*	*	*
	S. latifolia	1980	-----	-----	0.00	0.00	0.00	0.00
		1981	*	*	*	*	*	*
	S. platyphyla	1980	-----	-----	0.30	0.22	0.00	0.00
		1981	*	*	*	*	*	*
	Unidentified species A[2]	1980	-----	-----	0.01	0.00	0.00	0.00
		1981	*	*	*	*	*	*
	Total vegetation	1980	-----	-----	118.06	204.41	267.94	293.51
		1981	21.56	84.73	127.17	13.18	0.00	0.00

Table 18. Continued.

Pond	Plant category	Year	May	June	July	August	September	October
			Month					
8	*N. guadalupensis*	1980	-----	-----	90.50	44.20	51.94	27.43
		1981	18.34	89.30	102.98	129.84	126.33	124.13
	Chara sp.	1980	-----	-----	0.00	0.00	0.00	0.00
		1981	2.49	1.54	0.00	0.01	0.00	0.00
	Filamentous algae[1]	1980	-----	-----	0.00	0.00	0.00	0.00
		1981	0.00	0.00	0.00	0.00	0.00	13.13
	P. nodosus	1980	-----	-----	78.46	102.60	36.12	28.62
		1981	1.56	7.16	4.94	2.17	5.98	0.11
	P. pectinatus	1980	-----	-----	54.87	19.16	31.67	0.86
		1981	6.32	12.18	15.59	5.00	7.36	1.83
	Typha spp.	1980	-----	-----	0.00	2.55	0.00	0.14
		1981	*	*	*	*	*	*
	E. macrostachya	1980	-----	-----	0.00	0.00	0.00	0.00
		1981	*	*	*	*	*	*
	S. latifolia	1980	-----	-----	0.00	0.00	0.00	0.00
		1981	*	*	*	*	*	*
	S. platyphyla	1980	-----	-----	0.00	0.00	0.00	0.00
		1981	*	*	*	*	*	*
	Unidentified species A[2]	1980	-----	-----	0.00	0.00	0.00	0.00
		1981	*	*	*	*	*	*
	Total vegetation	1980	-----	-----	223.83	168.51	119.73	57.05
		1981	28.71	110.18	123.52	137.02	139.67	139.21

Table 18. Continued.

Pond	Plant category	Year	Month: May	June	July	August	September	October
9	N. guadalupensis	1980	-----	-----	181.56	173.99	173.50	241.37
		1981	19.95	137.21	154.66	139.27	154.29	111.84
	Chara sp.	1980	-----	-----	5.35	0.00	0.00	0.00
		1981	0.00	0.00	0.00	0.00	0.01	0.00
	Filamentous algae[1]	1980	-----	-----	40.53	17.60	3.69	0.00
		1981	8.98	2.50	1.13	1.78	0.08	6.03
	P. nodosus	1980	-----	-----	0.00	0.00	0.00	0.00
		1981	0.00	0.00	0.00	0.00	0.00	0.00
	P. pectinatus	1980	-----	-----	0.00	0.00	0.00	0.00
		1981	0.00	0.00	0.00	0.00	0.00	0.00
	Typha spp.	1980	-----	-----	0.00	21.61	10.24	49.52
		1981	*	*	*	*	*	*
	E. macrostachya	1980	-----	-----	0.00	0.80	3.64	0.00
		1981	*	*	*	*	*	*
	S. latifolia	1980	-----	-----	0.00	50.63	16.58	0.00
		1981	*	*	*	*	*	*
	S. platyphyla	1980	-----	-----	0.00	0.00	0.00	0.00
		1981	*	*	*	*	*	*
	Unidentified species A[2]	1980	-----	-----	0.00	0.00	0.00	0.00
		1981	*	*	*	*	*	*
	Total vegetation	1980	-----	-----	227.44	264.63	207.66	290.89
		1981	28.94	139.71	155.79	141.04	154.37	117.87

Table 18. Continued.

Pond	Plant category	Year	Month: May	June	July	August	September	October
	N. guadalupensis	1980	----	----	129.86	163.95	176.93	210.95
		1981	1.23	52.89	73.69	82.70	89.21	92.66
	Chara sp.	1980	----	----	33.38	18.18	0.00	0.00
		1981	0.93	31.79	71.57	88.14	70.13	90.72
	Filamentous algae[1]	1980	----	----	10.45	16.71	3.15	0.10
		1981	1.56	5.98	0.19	0.00	0.00	0.00
	P. nodosus	1980	----	----	0.00	0.00	0.00	0.00
		1981	0.00	0.00	0.00	0.00	0.00	0.00
	P. pectinatus	1980	----	----	0.00	0.82	0.00	0.99
11		1981	0.92	0.00	2.67	0.62	2.96	9.53
	Typha spp.	1980	----	----	0.00	0.00	0.00	0.00
		1981	*	*	*	*	*	*
	E. macrostachya	1980	----	----	0.00	0.00	0.00	0.00
		1981	*	*	*	*	*	*
	S. latifolia	1980	----	----	0.00	0.00	0.00	0.00
		1981	*	*	*	*	*	*
	S. platyphyla	1980	----	----	0.00	0.00	0.00	0.00
		1981	*	*	*	*	*	*
	Unidentified species A[2]	1980	----	----	0.00	0.00	0.00	0.00
		1981	*	*	*	*	*	*
	Total vegetation	1980	----	----	173.69	199.66	180.08	212.04
		1981	4.63	90.66	148.12	171.46	162.30	192.90

Table 18. Continued.

Pond	Plant category	Year	Month: May	June	July	August	September	October
12	N. guadalupensis	1980	----	----	143.06	183.19	180.61	189.70
		1981	6.74	41.83	92.11	45.84	10.81	0.33
	Chara sp.	1980	----	----	0.00	0.00	0.00	0.00
		1981	0.00	0.02	0.09	0.00	0.00	0.03
	Filamentous algae[1]	1980	----	----	3.88	0.00	6.36	0.00
		1981	11.55	8.72	1.44	0.00	0.00	0.00
	P. nodosus	1980	----	----	0.00	0.00	0.00	0.00
		1981	0.00	0.00	0.00	0.00	0.00	0.00
	P. pectinatus	1980	----	----	0.00	0.00	0.00	0.00
		1981	0.00	0.00	0.00	0.00	0.00	0.00
	Typha spp.	1980	----	----	0.00	0.00	0.00	0.00
		1981	*	*	*	*	*	*
	E. macrostachya	1980	----	----	0.00	0.00	0.00	0.00
		1981	*	*	*	*	*	*
	S. latifolia	1980	----	----	0.00	0.00	0.00	0.00
		1981	*	*	*	*	*	*
	S. platyphyla	1980	----	----	0.00	0.00	0.00	0.00
		1981	*	*	*	*	*	*
	Unidentified species A[2]	1980	----	----	0.00	0.00	0.00	0.00
		1981	*	*	*	*	*	*
	Total vegetation	1980	----	----	146.94	183.19	186.97	189.70
		1981	18.29	50.57	93.63	45.84	10.81	0.37

Table 18. Continued.

Pond	Plant category	Year	Month: May	June	July	August	September	October
	<u>N</u>. <u>guadalupensis</u>	1980	----	----	154.33	165.30	170.35	208.20
		1981	12.43	74.76	149.36	76.13	24.56	15.18
	<u>Chara</u> sp.	1980	-----	----	4.98	0.00	0.00	0.00
		1981	0.00	0.00	0.00	0.00	0.00	0.08
	Filamentous algae[1]	1980	----	----	10.45	0.00	19.17	0.00
		1981	15.40	6.48	4.14	0.00	0.00	0.00
	<u>P</u>. <u>nodosus</u>	1980	----	----	0.00	0.00	0.00	0.00
		1981	0.00	0.00	0.00	1.98	0.00	0.00
	<u>P</u>. <u>pectinatus</u>	1980	----	----	0.00	0.00	0.00	0.00
13		1981	0.00	0.00	0.00	0.00	0.00	0.00
	<u>Typha</u> spp.	1980	----	----	0.00	0.00	0.00	0.00
		1981	*	*	*	*	*	*
	<u>E</u>. <u>macrostachya</u>	1980	----	----	0.00	0.00	0.00	0.00
		1980	*	*	*	*	*	*
	<u>S</u>. <u>latifolia</u>	1980	----	----	0.00	0.00	0.00	0.00
		1981	*	*	*	*	*	*
	<u>S</u>. <u>platyphyla</u>	1980	----	----	0.00	0.00	0.00	0.00
		1981	*	*	*	*	*	*
	Unidentified species A[2]	1980	----	----	0.00	0.00	0.00	0.00
		1981	*	*	*	*	*	*
	Total vegetation	1980	----	----	169.76	165.30	189.52	208.20
		1981	27.83	81.23	153.50	78.10	24.56	15.26

Table 18. Continued.

Pond	Plant category	Year	Month: May	June	July	August	September	October
	N. guadalupensis	1980	----	----	163.60	133.68	155.44	170.49
		1981	8.67	48.64	52.39	3.33	0.00	0.00
	Chara sp.	1980	----	----	0.00	0.22	0.00	0.00
		1981	0.00	0.00	0.37	0.00	0.00	0.00
	Filamentous algae[1]	1980	----	----	0.00	0.00	0.90	4.91
		1981	1.34	0.00	0.08	0.00	0.00	0.00
	P. nodosus	1980	----	----	0.00	0.00	0.00	0.00
		1981	0.00	0.00	0.00	0.00	25.53	0.00
	P. pectinatus	1980	----	----	0.00	0.00	0.00	0.00
15		1981	0.00	0.00	0.00	0.00	0.00	0.00
	Typha spp.	1980	----	----	0.00	0.00	0.00	0.00
		1981	*	*	*	*	*	*
	E. macrostachya	1980	----	----	0.00	0.00	0.00	0.00
		1981	*	*	*	*	*	*
	S. latifolia	1980	----	----	0.00	0.00	0.00	0.00
		1981	*	*	*	*	*	*
	S. platyphyla	1980	----	----	0.00	0.00	0.00	0.00
		1981	*	*	*	*	*	*
	Unidentified species A[2]	1980	----	----	0.00	0.00	0.00	0.00
		1981	*	*	*	*	*	*
	Total vegetation	1980	----	----	163.60	133.90	156.34	175.40
		1981	10.01	48.64	52.83	3.33	25.53	0.00

Table 18. Continued.

Pond	Plant category	Year	May	June	July	August	September	October
			Month					
	N. guadalupensis	1980	----	----	122.26	149.96	176.79	177.74
		1981	17.48	69.82	127.56	59.33	14.85	0.00
	Chara sp.	1980	----	----	18.79	7.84	2.35	2.11
		1981	0.11	2.59	0.00	0.00	0.00	0.00
	Filamentous algae[1]	1980	----	----	0.00	0.00	0.00	0.00
		1981	0.36	0.00	0.90	0.00	0.00	0.00
	P. nodosus	1980	----	----	0.00	0.00	0.00	0.00
		1981	0.00	0.00	0.00	0.32	0.00	0.00
	P. pectinatus	1980	----	----	0.00	0.00	0.00	0.00
16		1981	0.00	0.00	0.00	0.00	0.00	0.00
	Typha spp.	1980	----	----	0.00	0.00	0.00	0.00
		1981	*	*	*	*	*	*
	E. macrostachya	1980	----	----	0.00	0.00	0.00	0.00
		1981	*	*	*	*	*	*
	S. latifolia	1980	----	----	0.00	0.00	0.00	0.00
		1981	*	*	*	*	*	*
	S. platyphyla	1980	----	----	0.00	0.00	0.00	0.00
		1981	*	*	*	*	*	*
	Unidentified species A[2]	1980	----	----	0.00	0.00	0.00	0.00
		1981	*	*	*	*	*	*
	Total vegetation	1980	-----	-----	141.05	157.80	179.14	179.85
		1981	17.94	72.41	128.46	59.65	14.85	0.00

N = 8/pond/month. No samples were collected during May and June, 1980.
* = Not included in 1981 samples.
[1]Filamentous algae predominantly Cladophora sp..
[2]Probably a Scrophulariaceae.

APPENDIX B

MEAN MONTHLY TEMPERATURE, DO, AND TURBIDITY AMONG INDIVIDUAL EXPERIMENTAL PONDS DURING 1980 AND 1981

Table 19. Mean monthly temperature (C), DO (mg/1), and turbidity (JTU) among individual experimental ponds during 1980 and 1981.

Pond	Variable	Year	May	June	July	August	September	October
			Month					
	Surface temperature	1980	24.60	28.70	30.47	27.28	23.14	16.40
		1981	22.80	26.87	26.74	23.74	20.94	17.10
	Middle temperature	1980	24.05	28.53	30.20	27.08	23.08	16.40
		1981	22.86	26.74	26.49	23.56	20.91	17.20
	Bottom temperature	1980	22.90	28.45	30.10	26.70	22.52	16.35
		1981	22.80	26.48	25.39	23.18	20.82	17.17
	Water column mean temperature	1980	23.85	28.56	30.26	27.02	22.91	16.38
		1981	22.82	26.70	26.21	23.49	20.89	17.17
	Thermal stratification[1]	1980	1.70	0.25	0.37	0.58	0.62	0.05
6		1981	0.00	0.39	1.36	0.56	0.12	-0.07
	Surface DO	1980	6.15	8.68	8.50	5.40	3.80	6.30
		1981	11.04	7.17	4.52	3.34	3.32	4.47
	Middle DO	1980	6.15	8.35	6.67	3.55	2.72	5.90
		1981	10.70	6.14	2.80	2.39	3.03	4.30
	Bottom DO	1980	5.20	8.18	6.17	2.78	1.80	5.50
		1981	10.44	3.97	0.64	0.80	1.98	3.80
	Water column mean DO	1980	5.83	8.40	7.11	3.91	2.77	5.90
		1981	10.73	5.76	2.66	2.18	2.78	4.19
	DO stratification[1]	1980	0.32	0.50	2.33	2.63	2.00	0.80
		1981	0.60	3.20	3.88	2.54	1.34	0.67
	Turbidity	1980	-----	4.50	3.75	4.75	4.80	5.00
		1981	5.40	5.11	7.00	10.38	17.78	23.33

Table 19. Continued.

Pond	Variable	Year	Month: May	June	July	August	September	October
7	Surface temperature	1980	24.10	28.75	30.53	27.23	23.24	16.10
		1981	22.96	27.38	27.39	24.35	21.28	16.87
	Middle temperature	1980	23.85	28.50	30.25	27.00	23.08	16.10
		1981	23.04	27.39	27.42	24.25	21.31	16.87
	Bottom temperature	1980	23.05	28.40	30.15	26.93	22.62	16.05
		1981	22.98	27.29	27.30	24.11	21.27	16.83
	Water column mean temperature	1980	23.67	28.55	30.31	27.05	22.98	16.08
		1981	22.99	27.35	27.37	24.24	21.29	16.86
	Thermal stratification[1]	1980	1.05	0.35	0.38	0.30	0.62	0.05
		1981	-0.02	0.09	0.09	0.24	0.01	0.03
	Surface DO	1980	6.45	7.98	8.73	4.68	5.16	6.50
		1981	10.92	6.87	4.66	3.75	4.86	5.67
	Middle DO	1980	6.35	7.75	6.68	3.45	3.76	6.20
		1981	10.76	6.73	4.44	3.25	4.43	5.40
	Bottom DO	1980	6.15	7.38	6.30	2.63	2.32	5.20
		1981	10.66	6.29	3.30	2.54	3.91	5.13
	Water column mean DO	1980	6.32	7.70	7.23	3.58	3.75	5.97
		1981	10.78	6.63	4.13	3.18	4.40	5.40
	DO stratification[1]	1980	0.30	0.60	2.43	2.05	2.84	1.30
		1981	0.26	0.58	1.36	1.21	0.94	0.53
	Turbidity	1980	-----	5.50	4.75	4.50	4.00	5.50
		1981	5.80	7.00	7.43	18.50	25.56	27.33

Table 19. Continued.

Pond	Variable	Year	May	June	July	August	September	October
			Month					
	Surface temperature	1980	24.80	27.23	27.43	25.13	23.10	12.15
		1981	22.90	26.93	26.70	23.18	19.98	16.37
	Middle temperature	1980	24.75	26.45	26.15	24.70	22.88	17.20
		1981	22.98	26.73	26.31	22.86	19.82	16.30
	Bottom temperature	1980	24.60	25.65	24.03	23.13	22.42	17.20
		1981	22.90	26.23	24.32	21.89	19.19	16.30
	Water column mean temperature	1980	24.72	26.44	25.87	24.32	22.80	17.18
		1981	22.93	26.63	25.78	22.64	19.66	16.32
	Thermal stratification[1]	1980	0.20	1.58	3.40	2.00	0.68	-0.05
8		1981	0.00	0.70	2.38	1.29	0.79	0.07
	Surface DO	1980	6.95	4.83	2.68	0.80	1.64	4.55
		1981	11.68	7.47	4.70	2.63	2.02	1.93
	Middle DO	1980	6.90	3.25	0.30	0.23	1.42	4.35
		1981	11.66	6.30	1.86	1.41	1.58	1.70
	Bottom DO	1980	6.90	2.43	0.00	0.00	0.84	4.05
		1981	11.58	4.00	0.27	0.20	0.33	1.33
	Water column mean DO	1980	6.92	3.50	0.99	0.34	1.30	4.32
		1981	11.64	5.92	2.27	1.41	1.31	1.66
	DO stratification[1]	1980	0.05	2.40	2.68	0.80	0.80	0.50
		1981	0.02	3.47	4.43	2.43	1.69	0.60
	Turbidity	1980	-----	5.50	6.75	5.00	5.40	9.00
		1981	4.20	5.67	4.86	3.75	3.78	3.67

Table 19. Continued.

Pond	Variable	Year	Month: May	June	July	August	September	October
	Surface temperature	1980	24.85	28.65	30.05	26.95	23.14	16.65
		1981	22.80	26.88	26.94	23.53	20.33	16.80
	Middle temperature	1980	24.70	28.10	29.15	26.63	22.86	16.55
		1981	22.92	26.83	26.67	23.43	20.34	16.87
	Bottom temperature	1980	24.70	27.85	28.58	26.33	22.48	16.55
		1981	22.88	26.32	24.93	22.35	19.86	16.87
	Water column mean temperature	1980	24.75	28.20	29.26	26.63	22.83	16.58
		1981	22.87	26.68	26.18	23.10	20.18	16.84
	Thermal stratification[1]	1980	0.15	0.80	1.48	0.63	0.66	0.10
9		1981	-0.08	0.56	2.01	1.18	0.48	-0.07
	Surface DO	1980	8.20	8.70	9.23	4.08	3.60	4.70
		1981	11.34	6.60	4.97	2.65	3.18	2.43
	Middle DO	1980	8.20	6.90	5.15	2.45	2.18	4.60
		1981	11.24	5.33	2.40	1.95	2.78	2.23
	Bottom DO	1980	8.45	5.60	2.60	1.63	1.34	4.10
		1981	10.70	3.83	0.46	0.34	0.63	1.57
	Water column mean DO	1980	8.28	7.07	5.66	2.72	2.37	4.47
		1981	11.09	5.26	2.61	1.65	2.20	2.08
	DO stratification[1]	1980	-0.25	3.10	6.63	2.45	2.26	0.60
		1981	0.64	2.77	4.51	2.31	2.54	0.87
	Turbidity	1980	-----	4.50	5.50	4.25	5.20	6.00
		1981	5.20	3.89	4.71	3.88	4.56	5.33

Table 19. Continued.

Pond	Variable	Year	May	June	July	August	September	October
			Month					
	Surface temperature	1980	24.60	28.58	29.75	27.38	23.80	16.85
		1981	23.20	27.20	27.28	24.76	21.63	17.57
	Middle temperature	1980	24.50	28.13	29.10	27.15	23.62	16.80
		1981	23.26	27.21	27.38	24.90	21.72	17.57
	Bottom temperature	1980	24.10	27.63	28.18	27.03	23.46	16.50
		1981	23.24	27.19	27.20	24.74	21.68	17.53
	Water column mean temperature	1980	24.40	28.11	29.01	27.18	23.63	16.72
		1981	23.23	27.20	27.29	24.80	21.68	17.56
	Thermal stratification[1]	1980	0.50	0.95	1.58	0.35	0.34	0.35
11		1981	-0.04	0.01	0.08	0.03	-0.04	0.03
	Surface DO	1980	8.45	9.33	7.80	5.65	5.30	8.40
		1981	10.90	8.48	7.70	5.78	6.02	8.10
	Middle DO	1980	8.40	8.10	4.85	4.53	4.08	7.95
		1981	10.92	8.18	7.59	5.50	5.94	8.07
	Bottom DO	1980	8.45	7.83	2.68	3.85	2.72	7.55
		1981	11.00	8.19	6.34	4.51	5.54	8.17
	Water column mean DO	1980	8.43	8.42	5.11	4.68	4.03	7.97
		1981	10.94	8.28	7.21	5.26	5.84	8.11
	DO stratification[1]	1980	0.00	1.50	5.13	1.80	2.58	0.85
		1981	-0.10	0.29	1.36	1.26	0.48	-0.07
	Turbidity	1980	-----	10.00	5.00	4.25	4.80	4.00
		1981	5.00	4.00	2.43	7.75	9.33	5.00

Table 19. Continued.

Pond	Variable	Year	May	June	July	August	September	October
	Surface temperature	1980	25.00	29.00	29.80	26.60	22.48	16.25
		1981	23.16	27.07	27.10	24.61	21.64	17.43
	Middle temperature	1980	25.00	28.23	28.28	26.08	22.32	16.25
		1981	23.20	27.13	27.06	24.61	21.59	17.50
	Bottom temperature	1980	25.00	27.68	26.53	24.75	21.96	16.25
		1981	23.16	27.11	26.90	24.50	21.58	17.47
	Water column mean temperature	1980	25.00	28.30	28.20	25.81	22.25	16.25
		1981	23.17	27.10	27.02	24.58	21.60	17.47
	Thermal stratification[1]	1980	0.00	1.33	3.28	1.85	0.52	0.00
12		1981	0.00	-0.04	0.20	0.11	0.07	-0.03
	Surface DO	1980	7.35	10.15	8.38	4.35	3.36	5.70
		1981	10.48	7.06	4.96	3.80	4.39	5.60
	Middle DO	1980	7.15	7.63	1.90	1.60	1.80	5.50
		1981	10.46	6.84	4.73	3.46	4.14	5.47
	Bottom DO	1980	7.30	6.33	1.03	0.05	1.56	5.60
		1981	10.66	6.76	2.83	2.24	3.68	5.10
	Water column mean DO	1980	7.27	8.03	3.77	2.00	2.24	5.60
		1981	10.53	6.89	4.17	3.17	4.07	5.39
	DO stratification[1]	1980	0.05	3.83	7.35	4.30	1.80	0.10
		1981	-0.18	0.29	2.12	1.56	0.71	0.50
	Turbidity	1980	-----	4.00	6.00	5.75	4.80	7.50
		1981	6.80	7.78	8.71	12.13	14.00	18.67

Table 19. Continued.

Pond	Variable	Year	May	June	July	August	September	October
	Surface temperature	1980	24.85	28.30	29.48	26.83	23.16	16.75
		1981	23.20	26.89	26.80	23.99	21.38	17.27
	Middle temperature	1980	24.85	27.95	28.43	26.63	23.04	16.70
		1981	23.16	26.72	26.48	23.95	21.34	17.30
	Bottom temperature	1980	24.70	26.98	27.30	26.28	22.74	16.60
		1981	23.10	26.20	25.22	23.35	21.30	17.30
	Water column mean temperature	1980	24.80	27.74	28.40	26.58	22.98	16.68
		1981	23.15	26.60	26.17	23.76	21.34	17.29
	Thermal stratification[1]	1980	0.15	1.33	2.18	0.55	0.42	0.15
		1981	0.10	0.69	1.58	0.64	0.08	-0.03
13	Surface DO	1980	8.35	8.53	4.90	2.83	1.94	5.10
		1981	11.80	6.28	3.80	2.79	3.88	5.37
	Middle DO	1980	8.25	6.28	1.73	1.78	1.54	4.95
		1981	11.82	4.98	1.71	2.20	3.76	5.23
	Bottom DO	1980	8.35	4.28	0.30	0.73	1.26	4.80
		1981	11.68	2.54	0.43	0.74	3.44	4.73
	Water column mean DO	1980	8.32	6.36	2.31	1.78	1.58	4.95
		1981	11.77	4.60	1.98	1.91	3.69	5.11
	DO stratification[1]	1980	0.00	4.25	4.60	2.10	0.68	0.30
		1981	0.12	3.73	3.37	2.05	0.43	0.63
	Turbidity	1980	-----	6.00	5.75	5.75	8.80	10.00
		1981	6.40	6.44	7.00	11.25	14.67	15.33

Table 19. Continued.

Pond	Variable	Year	May	June	July	August	September	October
	Surface temperature	1980	25.20	28.58	29.48	26.75	23.32	16.75
		1981	23.10	27.13	27.09	24.36	21.44	17.00
	Middle temperature	1980	25.05	27.90	29.08	26.75	23.30	16.70
		1981	23.12	27.14	27.07	24.38	21.30	17.10
	Bottom temperature	1980	25.05	26.38	28.70	26.70	23.28	16.70
		1981	23.06	27.07	26.91	24.35	21.27	17.10
	Water column mean temperature	1980	25.10	27.62	29.08	26.73	23.30	16.72
		1981	23.09	27.11	27.02	24.36	21.34	17.07
	Thermal stratification[1]	1980	0.15	2.20	0.78	0.05	0.04	0.05
15		1981	0.04	0.07	0.18	0.01	0.18	-0.10
	Surface DO	1980	8.35	9.25	5.78	1.85	2.14	6.15
		1981	10.24	5.43	3.81	4.61	5.22	6.63
	Middle DO	1980	8.15	6.25	3.40	1.48	2.02	6.05
		1981	10.14	5.07	3.18	4.18	4.88	6.50
	Bottom DO	1980	8.10	4.03	1.43	0.85	1.70	5.90
		1981	10.08	4.58	2.23	2.51	4.23	5.70
	Water column mean DO	1980	8.20	6.51	3.53	1.39	1.95	6.03
		1981	10.15	5.02	3.07	3.77	4.78	6.28
	DO stratification[1]	1980	0.25	5.23	4.35	1.00	0.44	0.25
		1981	0.16	0.86	1.58	2.10	0.99	0.93
	Turbidity	1980	-----	8.00	5.75	5.75	10.40	8.00
		1981	7.00	7.56	8.86	14.50	19.56	24.00

Table 19. Continued.

Pond	Variable	Year	May	June	July	August	September	October
			Month					
	Surface temperature	1980	25.00	22.55	28.40	25.95	23.12	16.70
		1981	23.02	27.03	26.83	24.16	21.26	16.83
	Middle temperature	1980	24.95	27.13	26.78	25.30	22.90	16.65
		1981	23.04	26.89	26.74	24.19	21.12	16.93
	Bottom temperature	1980	24.60	26.22	24.53	23.58	21.90	16.65
		1981	22.92	26.37	25.62	23.89	21.12	16.97
	Water column mean temperature	1980	24.85	26.97	26.57	24.94	22.64	16.67
		1981	22.99	26.76	26.40	24.08	21.29	16.91
	Thermal stratification[1]	1980	0.40	1.33	3.88	2.38	1.22	0.05
16		1981	0.10	0.67	1.21	0.28	0.13	-0.13
	Surface DO	1980	8.15	5.88	5.55	2.00	3.74	7.55
		1981	11.38	6.39	4.03	3.78	3.89	4.70
	Middle DO	1980	8.10	4.33	1.70	0.50	3.12	7.35
		1981	11.08	4.89	2.83	3.29	3.58	4.63
	Bottom DO	1980	7.90	4.00	0.08	0.00	2.14	7.25
		1981	10.46	3.49	0.79	1.30	2.82	3.47
	Water column mean DO	1980	8.05	4.73	2.44	0.83	3.00	7.38
		1981	10.97	4.92	2.55	2.79	3.43	4.27
	DO stratification[1]	1980	0.25	1.88	5.48	2.00	1.60	0.30
		1981	0.92	2.90	3.24	2.48	1.07	1.23
	Turbidity	1980	-----	9.50	3.75	5.50	6.60	5.50
		1981	5.20	5.56	7.43	14.00	20.89	28.67

N/pond/month: 1980: May (2 except no turbidity samples collected); June (4 except 2 turbidity); July (4 except 3 turbidity Pond 12, 3 DO/temperature Pond 6); August (4); September (5); October (2).

1981: May (5); June (9); July (9 except 7 turbidity); August (8); September (9); October (3).

[1](Surface value minus bottom value).

APPENDIX C

PLANT CONSUMPTION, TILAPIA WEIGHT, AND MEAN TEMPERATURE AMONG INDIVIDUAL REPLICATES IN EXPERIMENT A

Table 20. Plant consumption (g), tilapia weight (g), and mean temperature (C) among individual replicates in experiment A.

Plant category	Replicate number	Tilapia weight	Mean temperature	Plant consumption
N. guadalupensis	1	141	24.3	18.8
	2	166	25.5	16.4
	3	146	26.0	14.4
	4	113	25.0	20.3
Chara sp.	1	130	23.8	16.3
	2	176	25.0	18.3
	3	118	24.7	15.7
	4	140	24.9	21.5
Filamentous algae[1]	1	159	26.1	15.6
	2	145	25.7	15.4
	3	124	24.8	15.9
	4	139	24.8	9.2
P. pectinatus	1	162	23.0	10.0
	2	147	24.3	9.7
	3	110	24.9	9.3
	4	112	24.2	7.4
P. nodosus	1	152	25.5	1.0
	2	138	25.7	0.0
	3	126	24.5	0.6
	4	122	24.6	0.0

[1]Filamentous algae predominantly *Cladophora* sp..

APPENDIX D

PLANT CONSUMPTION, TILAPIA WEIGHT, AND MEAN TEMPERATURE AMONG INDIVIDUAL REPLICATES IN EXPERIMENT B

Table 21. Plant consumption (g), tilapia weight (g), and mean temperature (C) among individual replicates in experiment B.

Plant pair	Replicate number	Tilapia weight	Mean temperature	Plant consumption
	1	106	24.9	5.5 - 16.4
NG - C	2	98	24.7	24.7 - 14.5
	3	108	24.3	17.0 - 11.4
	1	98	25.3	12.1 - 12.6
NG - FA	2	122	23.9	22.9 - 3.6
	3	97	24.2	18.4 - 8.9
	1	119	25.3	13.6 - 6.2
NG - PP	2	118	24.5	24.3 - 2.8
	3	110	24.5	8.0 - 1.6
	1	105	25.1	16.3 - 0.0
NG - PN	2	108	24.5	22.0 - 0.0
	3	98	24.6	10.1 - 0.0
	1	130	25.1	20.9 - 11.1
C - FA	2	98	25.0	18.4 - 8.7
	3	102	25.7	14.6 - 11.0
	1	128	24.9	13.9 - 4.5
C - PP	2	99	24.8	18.6 - 6.1
	3	105	25.5	13.5 - 3.1
	1	96	23.9	14.1 - 0.0
C - PN	2	99	24.5	16.8 - 0.0
	3	100	23.8	18.0 - 0.0
	1	108	24.7	7.5 - 3.5
FA - PP	2	123	24.5	7.8 - 6.2
	3	94	24.7	9.2 - 1.3
	1	97	24.7	8.7 - 0.7
FA - PN	2	100	24.9	9.7 - 0.0
	3	107	23.9	8.8 - 0.0
	1	101	24.9	6.7 - 0.0
PP - PN	2	104	24.2	5.0 - 0.2
	3	110	25.8	3.3 - 0.0

NG = *N. guadalupensis* C = *Chara* sp. FA = Filamentous algae (predominantly *Cladophora* sp.)
PP = *P. pectinatus* PN = *P. nodosus*.

VITA

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