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ICHTHYOFAUNA RECONSTRUCTION FOR THE MANAGEMENT OF PHYTOPLANKTON

by

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CONTENTS

Executive Summary

Experimental ponds were used to test the hypothesis that bighead carp, a filter-feeding fish, could improve water quality and reduce the excessive growth of nuisance algae in Lake Apopka. Six experimental ponds were built adjacent to the lake and received water from Lake Apopka. Four ponds were stocked with bighead carp. Two ponds were not stocked and used as control ponds.

Out of sixteen physico-chemical parameters measured, seven were significantly different between Lake Apopka and the ponds. Secchi disk visibility was greatest in the ponds, along with higher values of specific conductance. Total alkalinity in the fish stocked ponds was higher than in the lake, but no difference was found between the control ponds and the lake. Total nitrogen, total phosphorus, total chlorophyll _a_, and filtered chlorophyll _a_ were higher in the lake.

No differences in plankton abundance were found between the lake and the control ponds for blue-green algae, _Botryococcus Braunii_, total algae number, rotifers, copepods, and total zooplankton number groups. These parameter values, however, were significantly lower in the ponds stocked with bighead carp than in the lake. It suggests that bighead carp exerted some effect on the pond ecosystem, but this effect was not large enough to cause significant differences between the stocked and unstocked ponds. The algal community in the ponds and lake was characterized by an extreme dominance of blue-green algae, reduced number of total algal species, and a clear dominance by several algal species (_Spirulina lesissuna_, _Lyngbya contorta_, _L. limnetica_, _L. lagerheinii_ and _Microsystis incerta_). A large green algae, _Botryococcus Braunii_, despite low numerical occurrence, constituted an important component of the algal biomass (more than 45% at the lake intake site and more than 25% in the ponds, based on chlorophyll _a_ determination). Bighead carp fed selectively on _B. Braunii_, which comprised 66 to 70% of the volume and 50 to 60% of the dry weight of the fish food. Bighead carp did not reduce algal numbers in the ponds but did decrease the ratio of blue-green/green species in the pond algal community. Using the data collected in this study, we calculated that a biomass of 750 kg/ha of bighead carp would be needed to cause a significant reduction in _B. Braunii_ abundance in Lake Apopka within 8 days. This biomass was not achieved during the study due to the slow growth and high mortality of stocked fish, and short

experimental time period. The small size of the fish also contributed to their inability to reduce the algal biomass.

FIGURES

FIGURES

TABLES

TABLES

ABSTRACT

This study was conducted to determine if bighead carp, (Hypophthalmichthys nobilis), an asiatic filter feeding fish, could reduce the abundance of nuisance algae in Lake Apopka. Six 0.2 hectare experimental ponds adjacent to Lake Apopka received water from the lake by gravity flow. Water clarity in Lake Apopka was significantly lower than in the ponds throughout the study. Lake water concentrations of total nitrogen, total phosphorus and chlorophyll a were also greater. This last constituent reflects algal biomass in water. Bighead carp had no statistically proven influence on any of the water quality parameters tested, except for a decreased ratio of blue-green/green algal species. Algal species collected in both the ponds and lake were similar, although algal abundance in the lake was greater.

The biomass of bighead carp needed to impact the algae was not achieved in our experiment due to slow growth and high mortality of stocked fish and the short experimental time. Therefore, the hypothesis that bighead carp would reduce nutrients and change the algal community was not fully tested. Bighead carp selectively ate Botryococcus Braunii, a large green algal species present in Lake Apopka. We postulated that a biomass of about 750 kg/ha of bighead carp could alleviate this nuisance algae in the lake in 8 days. This biomass figure is probably overestimated because small fish and low algal densities were used for the calculations.

INTRODUCTION

Shapiro et al. (1975) originally defined the term biomanipulation as "the management of aquatic communities by controlling natural populations of organisms aimed at water quality improvement". Verigin (1979) proposed that balanced ecosystems could be developed by changing the fish populations in lakes. He termed this "ichthyofauna reconstruction". Although biomanipulation has been largely ignored as a management and restoration technique (Shapiro 1979a), experiments in Israel (Leventer 1979, 1972), Europe (Opuszynski 1979), and the United States (Henderson 1978, 1979) indicate that the method might be used to reduce nutrients and algae. Shireman et al. (1979), Shireman and Maceina (1981) and Shireman et al. (1983) demonstrated that grass carp (Ctenopharyngodon idella) can be used to manage excessive growths of aquatic plants. This is the first step in alleviating one of the problems of eutrophication, because macrophytes in abundance may be unacceptable to the general public.

The potential for using biomanipulation, particularly ichthyofauna reconstruction and management, for improving game-fish populations through the removal of rough-fish was first suggested in early fish management programs in the upper midwest (Ricker and Gottschalk 1941; Moyle 1949; Threinen 1949; Rose and Moen 1952). Test seining in hypereutrophic East Okoboji Lake (Iowa) in 1940 showed the lake had a very large population of rough-fish including bigmouth buffalo (Ictiobus cyprinellus), carp (Cyprinus carpio), and freshwater drum (Aplodinotus grunniens), and relatively few game-fish (Rose and Moen 1952). In addition, the lake was subject to dense blooms of blue-green algae, particularly Aphanizomenon sp. and Microcystis sp., which greatly reduced water clarity. After extensive removal of rough-fish by use of haul seines, Rose and Moen (1952) showed that game-fish populations improved significantly. Aquatic macrophytes, particularly submersed plants, returned to the lake in abundance. Dense growths of blue-green algae were greatly limited, which significantly improved water clarity. Similar changes also occurred in other lakes (Ricker and Gottschalk 1941; Moyle 1949; Threinen 1949), suggesting the changes represented a general response pattern in lakes. In addition, the process is reversible. Studies by Bachmann and Jones (1974) and Canfield (1979) showed that East Okoboji Lake had lost its macrophyte community and redeveloped dense blooms of blue-green algae by the 1970s after rough-fish removal programs were discontinued in the 1950s.

Although changes in the overall quality of lakes have long been correlated with changes in fish populations, only recently have hypotheses been developed to explain the causal mechanisms. Many scientists contend the influence of fish is directly related to their effect on zooplankton grazing. Lake studies have shown that small fish of all species and obligate zooplanktivorous fish can, through their feeding activities, alter not only the abundance, but size-distribution and species composition of the zooplankton community (Hrbacek et al. 1961, Brooks and Dodson 1965, Galbraith 1967, Hutchinson 1971). Studies by Anderson et al. (1978) and Lynch (1979) showed that the addition of zooplanktivorous fish to enclosures in northern lakes reduced zooplankton levels and increased algal levels, whereas the removal of zooplanktivorous fish resulted in increased zooplankton abundance and reductions in algal abundance. There is evidence, however, that zooplankton sometimes have little effect on algal biomass in some northern lakes and many southern lakes (Hoyer and Jones 1983, Canfield and Watkins 1984). Other studies also suggest that the zooplankton size-efficiency hypothesis is not as simple as once believed. As suggested by Shapiro (1979a,b), the phytoplankton population response to grazing by large zooplankters is not uni-directional, but depends on the community structure and species composition of the initial algal assemblage. For example, increased daphnid populations resulted in a shift in algal dominance from blue-greens to greens, chrysophytes, diatoms, and euglenoids in Severson Lake (Schindler and Comita 1972) and Wirth Lake, Minnesota (Shapiro 1979a). The appearance of similar daphnid populations in Lake Washington (Shapiro 1979b), caused blue-green populations, especially Aphanizomenon, to increase. This seemingly unpredictable phytoplankton response is probably controlled by the biochemically induced formation of large colonies unsuitable for zooplankton grazing, such as observed for Aphanizomenon in the presence of large Daphnia (Hrbacek 1964, Shapiro 1979a,b). Thus, the complex response of phytoplankton to an alteration of trophic levels remains poorly known (Crisman 1986).

Manipulations of fish populations for the management of nuisance growths of aquatic plants received increased attention during the 1970s. Several phytophagous fish including Tilapia aurea, Tilapia galilia, silver carp, (*Hypophthalmichthys molitrix*), and bighead carp, (*Hypophthalmichthys nobilis*), were identified (see Shireman (1984) for a review of the literature). Of the known phytophagous species, only the Chinese carp (i.e., silver carp, bighead carp, and grass carp) have been routinely used for the control of nuisance growths of phytoplankton and aquatic macrophytes (Vovk 1973, Leventer 1979 and 1987, Verigin 1979, Shireman & Maceina 1981, Shireman 1984, Shireman and Hoyer 1986).

Silver carp and bighead carp have been used primarily to consume phytoplankton (Moskul 1977) and detritus (Moskul 1977, Vovk 1973). Henderson (1978, 1979) reported that grazing of plankton in Arkansas oxidation ponds by silver and bighead carp reduced ammonia nitrogen levels by 27% and phosphate levels by 2.72%. Organic loads (BOD_5) were reduced by 96% and total suspended solids were reduced by 78% (Henderson 1983). These ponds contained 2280 pounds of silver carp/acre and 156 pounds of bighead carp/acre. The advantage of using bighead carp over silver carp for phytoplankton control, however, has been that bighead carp consume larger algae (Huisman and Hogendoorn 1979) and utilize greater amounts of blue-green algae (Lazareva et al. 1977, Aliyev 1976, Verigin 1979), which often leads to increased fish production (Verigin 1979).

This research project has been aimed to test the hypothesis (Leventer 1979, Verigin 1979) that ichthyofauna reconstruction and management (biomanipulation-Shapiro 1975) could be used to manage many of the deleterious effects (e.g. excessive growths of phytoplankton) of lake eutrophication. Although Leventer (1972, 1979) used this technique to reduce nuisance macrophytes, algae, and nutrients in Israeli reservoirs, the technique has not been used to manage total lake ecosystems in the U.S. The objective of the project was to determine the potential impact of bighead carp on algal biomass and composition, and water quality in Lake Apopka.

STUDY SITE

Lake Apopka

Lake Apopka is a large hypereutrophic lake located in Orange and Lake counties (latitude 28° 37′ N and longitude 81° 38′ W). Lake Apopka is the first lake in the Oklawaha chain of lakes (Figure 1) with a drainage basin of 31,100 ha. Population centers within the basin are Winter Garden, Ocoee, Apopka, Montverde, Tavares, Mont Dora, Eustis, and Leesburg. The basin is characterized by undulating hills underlain with limestone of the Florida aquifer (Brezonik et al. 1978). Muck farming is restricted to the northern end of the lake (Figure 2). Prior to recent freezes, citrus groves also abounded around the lake. Many of these groves are no longer in production.

Lake Apopka has a surface area of 12,467 ha, mean depth of 1.5 m, maximum depth of 4.9 m and a shoreline development (SLD) of 1.39[1]. The lake bottom consists primarily of unconsolidated muck averaging 1.8 m deep, (Danik and Tomlinson 1989). These sediments are relatively consistent in appearance (black-brown) and have a water content ranging from 67-95%. (Schneider and Little 1968).

Experimental Ponds

Six ponds were constructed adjacent to Lake Apopka by the Zellwood Drainage and Water Control District (Figure 3). Each pond had an area of approximate 0.2 ha and depths ranging from 91 to 104 cm. In order to prevent percolation, the ponds were lined with high-density polyethylene fabric. The plastic liners were covered with 15 cm of organic soil.

Lake Apopka water was used to fill the ponds and for flow-through water. Gravity-flow water entered the ponds through valved inflow pipes and left through outflow pipes. However, when adequate pond water levels could not be achieved by gravity flow, water was pumped into the ponds from Lake Apopka.

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[1] $SLD = \frac{S}{2\sqrt{a\pi}}$, where S = length of shoreline,

a = area of lake

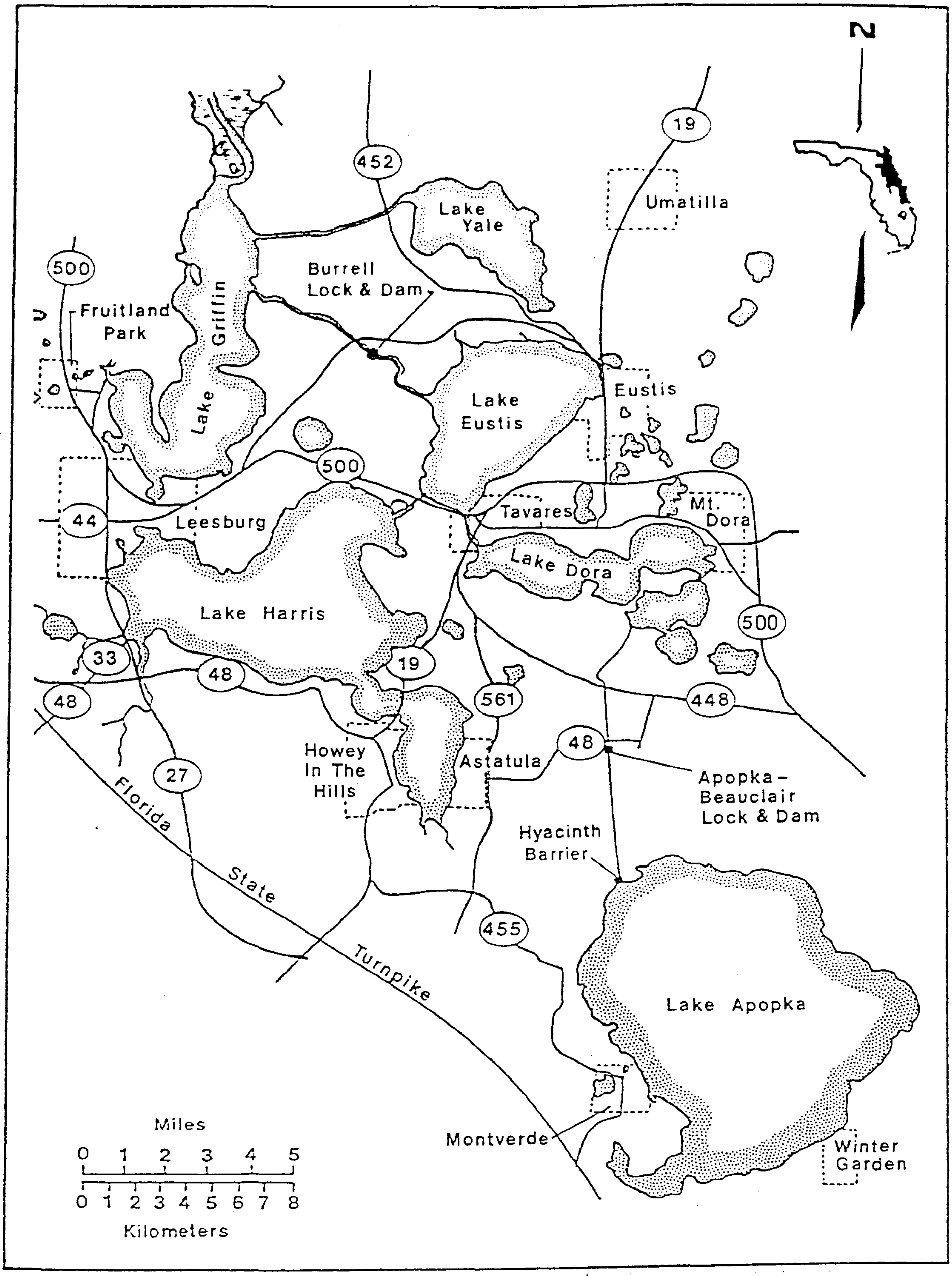

Figure 1. Location of Lake Apopka in the Oklawaha Chain of Lakes.

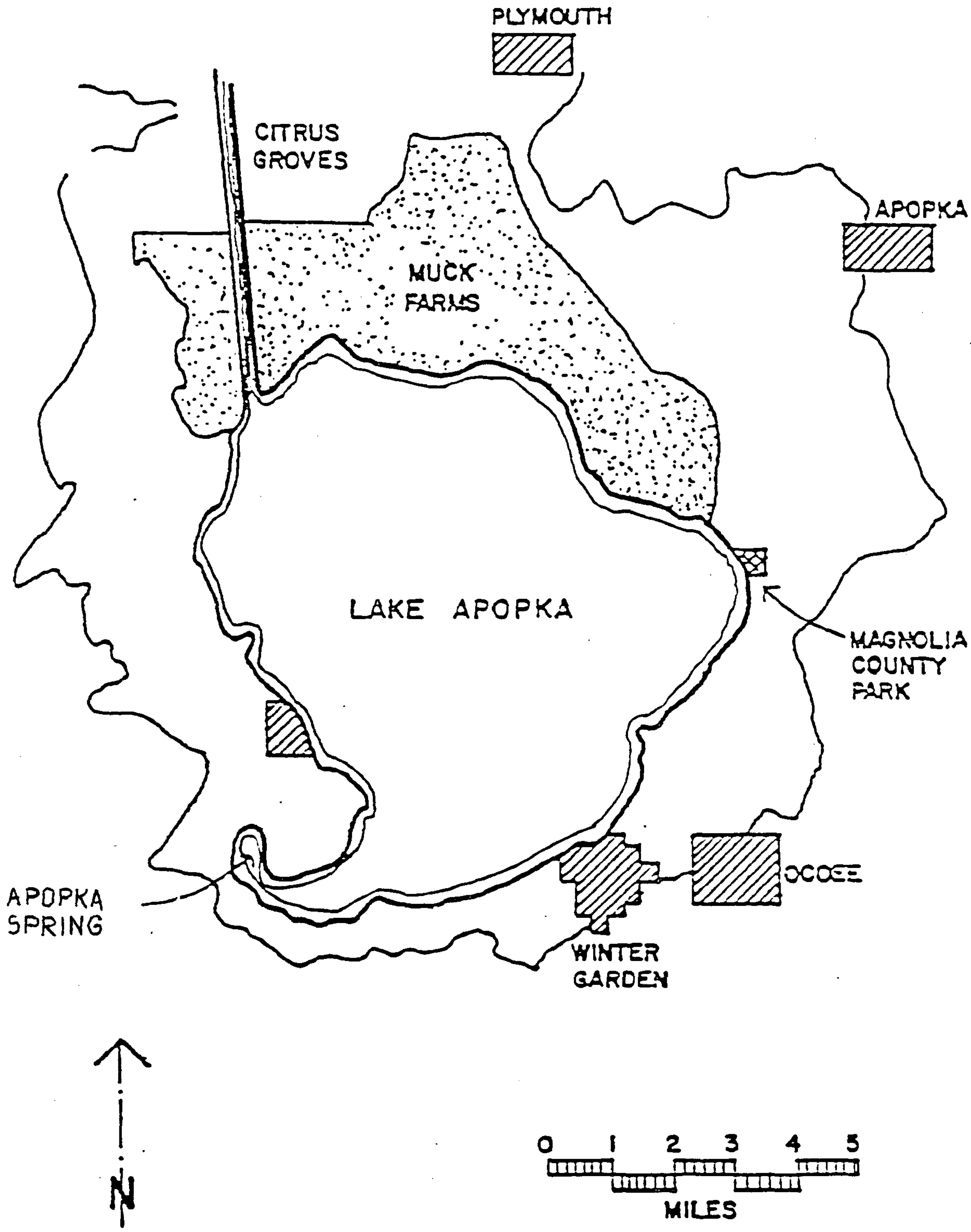

Figure 2. Land use distribution in the Lake Apopka watershed (modified from Brezonik et al. 1978).

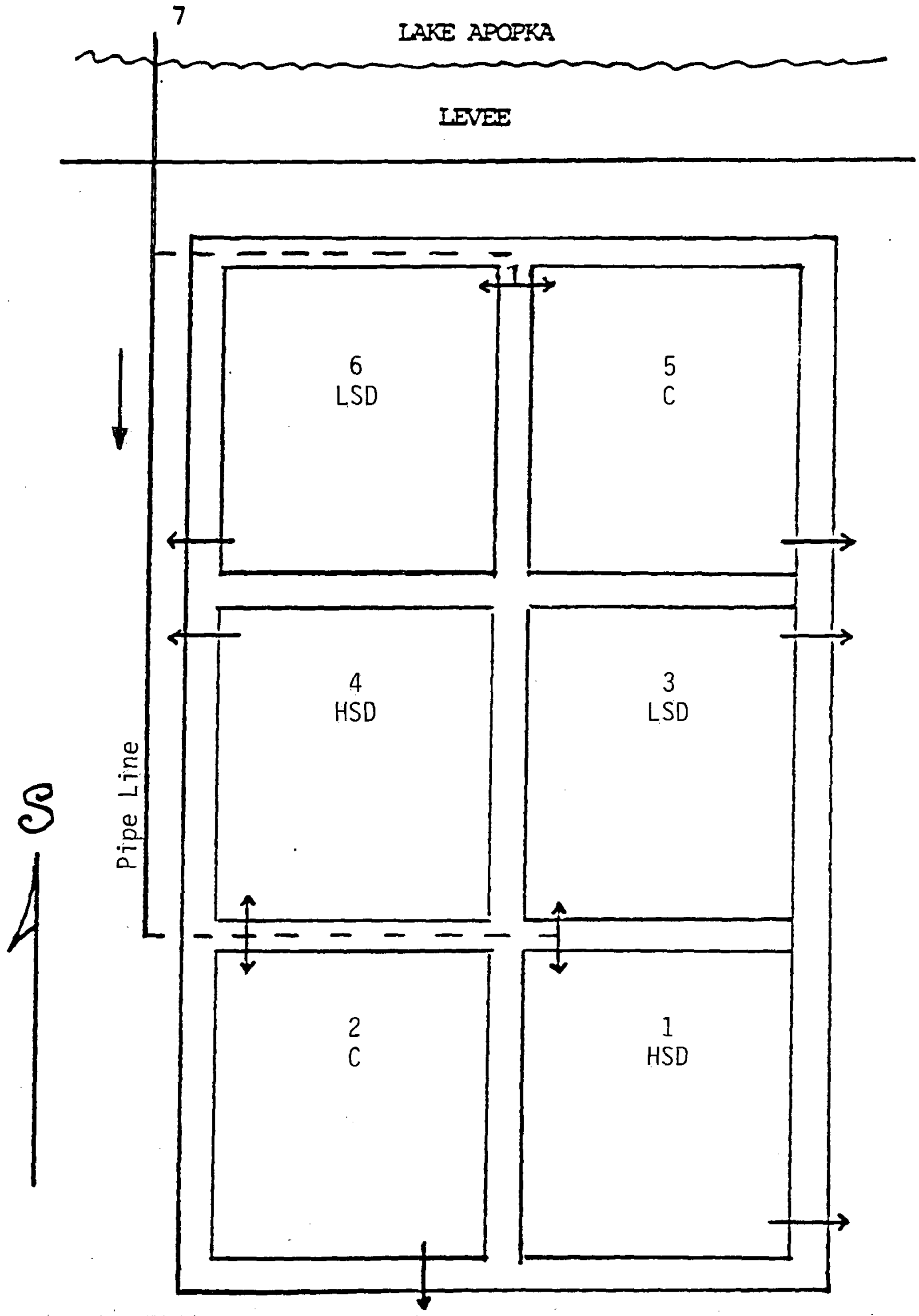

Figure 3. Relationship of experimental ponds to Lake Apopka (arrows indicate direction of water flow; numbers indicate pond number and water sampling stations). LSD = low stock density, and HSD = high stock density ponds. C = control ponds.

METHODS

Experimental Design and Fish Stocking

Ponds were selected randomly for three experimental groups. Ponds 2 and 5 were not stocked with bighead carp and were used as control ponds. Ponds 3 and 6 were low stock density (LSD) bighead carp ponds, and ponds 1 and 4 were high stock density (HSD) ponds. Pond stocking commenced on January 4, 1990, and continued until June 20, 1990. Completion of pond stocking was significantly delayed due to slow growth of the fish, problems with the ploidy verification procedure, and the cold winter of 1989/90 which caused heavy mortality of fish in holding tanks. The number and biomass of stocked fish was 2,564 and 28.4 kg in the HSD ponds and 425 and 4.6 kg, in the LSD ponds (Table 1). The stocking values calculated per hectare were 12,671 fish and 141 kg in the HSD ponds, and 2,100 fish and 23 kg in the LSD ponds.

All ponds were stocked with grass carp to control macrophytes. Different numbers of grass carp were stocked into each pond to keep macrophytes in check during the growing season (Table 2). All fish used for the experiment were sterile triploids to prevent the possibility of their reproduction in case of escape into the lake.

Physico-chemical Water Quality Parameters

Water quality, phytoplankton, zooplankton, and fish samples used for preparation of this report were collected following fish stocking from February 27, 1990 to August 22, 1990.

Surface water samples (0.5 meter depth) for physico-chemical analyses were collected biweekly (twice monthly) from a midpond station in each of the experimental ponds and at the Lake Apopka inlet site. The following parameters were determined for the ponds: temperature, dissolved oxygen, Secchi disk visibility, depth, water inflow and outflow rate, pH, total alkalinity, specific conductance, calcium, magnesium, sodium, potassium, chloride, total nitrogen, total phosphorus, total chlorophyll _a_ and filtered chlorophyll _a_ (filter mesh size = 35 µm). The same parameters, excluding water depth and flow rate, were determined simultaneously for the Lake Apopka inlet site.

Table 1. Total number and average weight (g) at stocking of bighead carp in experimental ponds.

	PONDS							
	1 (HSD)		4 (HSD)		3 (LSD)		6 (LSD)	
Date	number	Avg. weight	number	Avg. weight	number	Avg. weight	number	Avg. weight
01/04/90	870	11.1	870	11.1	100	11.1	100	11.1
01/12/90	48	11.1	48	11.1				
01/19/90	346	11.1	346	11.1				
01/26/90	236	11.9	236	11.9	150	11.9	150	11.9
04/10/90	540	12.0	540	12.0				
05/15/90	503	10.0	503	10.0				
06/18/90					175	10.0	175	10.0
06/20/90	21	10.0	23	10.0				
	2564	11.1	2566	11.1	425	11.0	425	11.0

Note: LSD and HSD - low and high stocking density ponds.

Table 2. Grass carp stocking rates (number of fish per pond) in experimental ponds.

Date	Pond 1	Pond 2	Pond 3	Pond 4	Pond 5	Pond 6
09/15/89	4	4	4	4	4	4
10/18/89	10	10	10	10	10	10
10/25/89			14			
11/09/89	5		7	5	6	5
05/15/90	1					
05/25/90	2	2	2	10	2	2
06/14/90				28		
06/20/90		5				
07/10/90		20		20		20
07/30/90		5		5		5
08/16/90		47		47		
Total	22	93	37	129	22	46

Water temperature and dissolved oxygen concentrations were determined using a YSI oxygen-temperature probe. Water transparency was measured with a Secchi disk. Water inputs and outputs through inflow and outflow pipes were measured by collecting water in a calibrated cylinder and timing with a stop-watch. All other chemical parameters were determined following standard methods (APHA 1980).

Phytoplankton

One liter surface water (0.5 meter depth) samples for phytoplankton were collected biweekly from each pond and the lake. Algal abundance, as indicated by chlorophyll a concentrations, was determined using the methods of Richards and Thompson (1952) and Yentsch and Menzel (1963). Water samples were also filtered through a 35 µm nitex screen to determine the relative abundance of net and nanoplankton components. However, as shown in Table 3, this method mainly allowed separation of *Botryococcus Braunii*[2] from other algal species. Larger *B.B.* colonies were retained by the 35 µm screen, whereas smaller *B.B.* colonies together with the bulk of other algae passed through the screen. Therefore, this method underestimated the percentage of *B.B.* in the phytoplankton biomass.

Algae samples were collected monthly for quantitative and qualitative analyses. Samples were preserved in Lugol's solution immediately after collection and were transported in a cooler filled with ice. Quantitative analysis of algae was made using the Edmondson (1971) method, whereas species composition was determined using Smith (1950), Prescott (1982), and Whitford and Schumacher (1984) keys.

Zooplankton

Initially, zooplankton samples were collected by three vertical net tows with an 80 µm Wisconsin plankton net. This method proved to be impractical in the shallow ponds, and was replaced beginning in October 1989 with a 3-liter capacity water sampler. Four samples were collected and composited from each pond. Zooplankton were preserved in 4% formalin solution, enumerated, and identified to species using Edmonton (1976), Pennak (1978) and Stemberger (1979).

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[2]We followed Prescott's (1982) capitalization of the species name to commemorate Alexander Braun. However, lower case (*B. braunii*) is also used (e.g., Whitford and Schumacher 1984).

Table 3. Qualitative and quantitative analysis of algae retained by and prefiltered through a 35 µm nitex screen (ind./ ml of water)

Species	Retained	Prefiltered
08-08-90 Lake Apopka		
Macrocistis incerta	2420	209330
Spirulina laxissima	3630	164560
Lyngbya contorta	1210	21780
L. limnetica	0	27800
L. lagerheimii	0	10890
Total algae exc. Botryococcus	7260	434360
Botryococcus	17	2
Botryococcus mean size (µm)	133	40
Botryococcus mean volume (µm3)	1988177	83369
Botryococcus total volume (µm3)	33799014	191749
08-08-90 Pond 4		
Macrocystis incerta	0	37507
Spirulina laxissima	0	10486
Merismopedia tenuissima	0	1210
Lyngbya contorta	0	3630
Chroococcus sp.	0	3226
Merismopedia sp.	0	2823
Lyngbya limnetica	0	6049
L. lagerheimii	0	2016
Microcystis aeruginosa	403	806
Ankistrodesmus falcatus	0	4840
Aphanothece nidulans	0	403
Total algae exc. Botryococcus	403	72996
Botryococcus	6	3
Botryococcus mean size (µm)	75	46
Botryococcus mean volume (µm3)	335918	66603
Botryococcus total volume (µm3)	1948324	193149
08-08-90 Pond 5		
Macrocystis incerta	0	39927
Spirulina laxissima	6049	172612
Lyngbya limnetica	2016	41137
L. lagerheimii	0	6049
L. contorta	403	7259
Scenedesmus quadricauda	0	403
Aphanocapsa delicatissima	0	403
Merismopedia tenuissima	0	1210
Diatoms	0	403
Tetraedron sp.	0	403
Chroococcus sp.	403	403

Total algae exc. *Botryococcus*	8871	270209
Botryococcus	8	4
Botryococcus mean size (μm)	72	40
Botryococcus mean volume (μm3)	474438	58982
Botryococcus total volume (μm3)	3937835	265419

Fish Food Habits and Growth

When possible, 10 fish were collected monthly from each pond. They were killed immediately after capture and transported on ice to the laboratory. The fish were measured, weighed, and their alimentary tracts (AT) dissected. Each AT was divided into three equal sections and the degree of filling was determined according to a five-degree scale (Pavlovskij 1961). Food was removed carefully from all AT and weighed to determine wet biomass. Index of filling (wet weight of food expressed in percentage of fish body weight) was used to compare quantity of food in the AT of different size fish. All food from each AT was mixed in a known volume of 4% formalin solution and a subsample equal to 9/10 of the total volume was taken to determine dry food weight. This total subsample was used for analysis when food was in a small quantity. Two aliquots of the first subsample were taken when food was present in great quantity. The smallest subsample volume was 2.5 ml. This sample was filtered through a fiber glass filter (Gelman A/E) and the residue dried at 103°C. The remaining 1/10 of AT content from individual fish was mixed and qualitative and quantitative determinations of the contents were made according to the methods previously described for phytoplankton and zooplankton examinations. The food of fish smaller and larger than the mean of a sample was examined separately when the sizes of fish in a sample were different.

Phytoplankton and zooplankton were identified to species when possible, and the number of organisms eaten was calculated. Using these data the ratio of blue-green/green algae in the fish food was calculated. The proportion of different food categories was also determined using the volumetric method. The bulk of the food was divided into three groups: 1) zooplankton, 2) *Botryococcus Braunii* (*BB*), and 3) phytoplankton/detritus. Volumetric proportions of each group in the AT were estimated. Volumetric proportions were calculated as a mean of twenty 10 x 4 power microscopic fields examined. The volumetric method is a subjective one, because it consists of visual determination of the proportion of different food items in a sample. We found it possible to separate *BB* from the other food items by sedimentation. This alga floated to the surface in a 4% formalin solution, whereas the other food items sank to the bottom. Therefore, *BB* could be separated by syphoning. Using this technique, the dry weight fraction of BB in the food was determined. It allowed us to compare the results of the volumetric analysis with the more objective weight method. The results of both methods proved to be in good agreement as characterized by a statistically significant correlation coefficient $r = 0.71$ (Figure 4).

Food selectivity was measured using Ivlev's (1961) index (Ei), calculated as $E_i = [z_i - p_i] / [z_i + p_i]$ where z_i = the proportion of food type i in the AT, and p_i = the proportion of the food type i in the environment. Values for this index range between -1 and +1, where -1 indicates complete avoidance of a given food item, and +1 indicates complete preference.

Statistical Analyses

Data were analyzed according to statistical tests shown in Table 4.

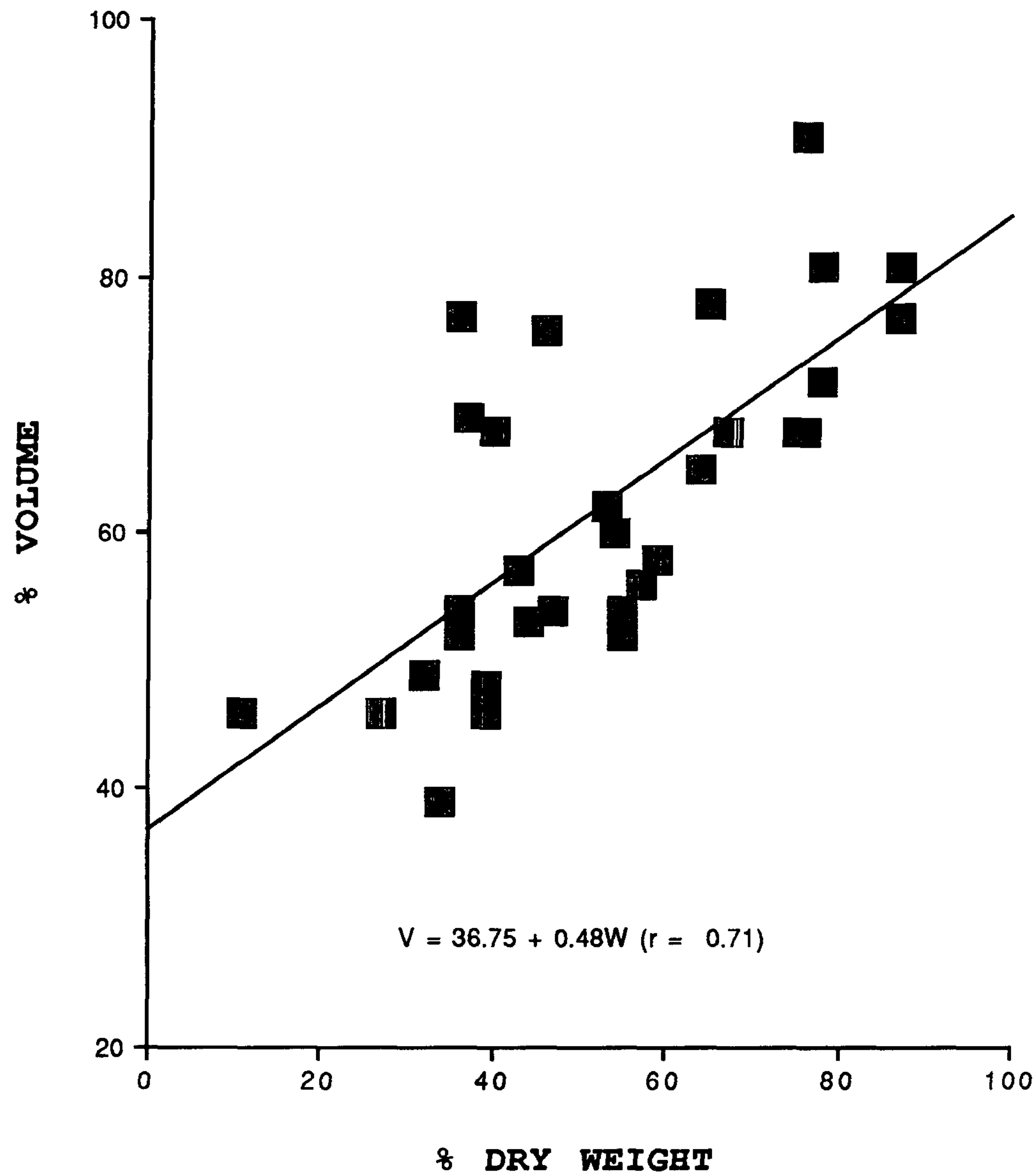

Figure 4. Relationship between percentage of Botryococcus Braunii in fish food estimated by volume (V) and dry weight (W) methods.

Table 4. Statistical tests performed.

Data set	Statistical procedure
1. Pond differences - water	Analysis of variance (ANOVA) Scheffe multiple-range test
2. Control pond and Lake differences - water	Student "t" test
3. Differences between treatment groups (control and experimental ponds)	Student "t" test

RESULTS

Water Quality

Mean temperature, dissolved oxygen, calcium, magnesium, sodium, potassium, and chloride values were not significantly different between the ponds and the lake (Table 5). Mean values for individual ponds for the study period are shown in Table 6.

Secchi disk. Mean secchi disk readings were from 36 cm to 72 cm in the ponds and 24 cm in Lake Apopka (Table 6). The values among ponds were not significantly different; however, all pond values were significantly higher than Lake Apopka values (Table 5). The readings were more consistent in the lake, showing little seasonal variability (Figure 5).

pH. Mean pH values were from 8.5 to 8.9 in the ponds (Table 6) and 9.0 in the lake, and were significantly different between the ponds and the lake (Table 5). Seasonal pH variation was greatest in Lake Apopka (Figure 6).

Total Alkalinity. Mean values ranged from 117 mg $CaCo_3$/l to 145 mg $CaCo_3$/l in the ponds and 124 mg $CaCo_3$/l in Lake Apopka (Table 6). The control ponds were not significantly different from the lake, whereas the experimental ponds were different from the lake (Table 5). Seasonal dynamics of the alkalinity values is shown on Figure 7.

Specific Conductance (SC). Mean SC in the ponds was from 408 μmhos/cm to 460 μmhos/cm (Table 6). Mean SC values for the lake were significantly lower (409 μ mhos/cm; Table 5). SC values were lower in the lake than in the ponds during the summer months and higher during the winter months (Figure 8). These seasonal trends were similar to those found by Brezonik et al (1978).

Table 5. Statistical analysis of the differences between the experimental pond groups and Lake Apopka for the period 02-27-90 to 08-22-90. Mean values ± S.D. are listed.

Parameter	Lake	Control (2, 5)	Experimental (1, 3, 4, 6)
Temperature (°C)	28.0±5.0[a]	26.5±4.1[a]	26.7±4.0[a]
Dissolved Oxygen (mg/l)	9.4±1.9[a]	8.5±2.1[a]	8.5±2.0[a]
Secchi Disc (cm)	24.4±3.5[a]	51.9±20.2[b]	53.5±17.4[b]
Water inflow rate (l/sec)	0.53±0.24[b]	0.55±0.38[b]	
pH	9.0±0.5[a]	8.7±0.4[b]	8.7±0.4[b]
Total alkalinity (mg/l $CaCo_3$)	124±18[a]	133±14[ab]	135±14[b]
Specific conductance (µmhos/cm)	409±26[a]	440±30[b]	442±38[b]
Calcium (mg/l)	33.6±8.7[a]	35.2±5.7[a]	35.8±5.8[a]
Magnesium (mg/l)	20.0±2.8[a]	20.4±1.3[a]	20.5±1.8[a]
Sodium (mg/l)	19.7±3.0[a]	19.8±2.2[a]	19.7±2.0[a]
Potassium (mg/l)	13.2±0.7[a]	13.4±1.0[a]	13.7±1.2[a]
Chloride (mg/l)	48.5±2.4[a]	49.7±3.9[a]	50.0±3.6[a]
Total nitrogen (mg/l)	5.01±0.72[a]	3.33±0.72[b]	3.27±0.73[b]
Total phosphorus (mg/l)	0.174±0.065[a]	0.070±0.026[b]	0.067±0.021[b]
Chlorophyll a (µg/l)	116.4±29.1[a]	30.8±11.0[b]	31.4±10.3[b]
Filtered chlorophyll a (µg/l)	64.3±11.1[a]	23.2±7.6[b]	24.7±8.3[b]
Blue-green Algae/ ml x 1000	272.3±96.4[a]	145.3±143.9[ab]	128.5±105.7[b]
Green Algae/ml	1108±1032[a]	3866±8876[a]	2297±3016[a]
Botryococcus/ml	12±7[a]	6±7[ab]	7±4[b]
Total Algae/ml x 1000	274.8±95.6[a]	150.1±141.3[ab]	131.4±105.2[b]
Rotifers/l	1096±1802[a]	187±188[ab]	144±142[b]
Nauplii & Copepodids/l	197±165[a]	156±112[a]	95±107[a]
Copepods/l	20±30[a]	5±5[ab]	3±5[b]

Table 5. (Cont'd)

Parameter	Lake	Control (2, 5)	Experimental (1, 3, 4, 6)
Cladocera/l	323±356[a]	221±444[a]	100±234[a]
Other Zooplankton/l	0±0[a]	0.1±0.5[a]	0.2±0.7[a]
Total Zooplankton/l	1640±1683[a]	569±523[ab]	342±355[b]

Note: Means with the different letters are statistically different (P=0.05)

Table 6. Mean values and standard deviation of physical-chemical parameters for the period 02-27-90 to 08-22-90.

Parameter	LSD 3	LSD 6	HSD 1	HSD 4	C 2	C 5	Lake
Temperature (°C)	26.7± 4.1	26.8±4.2	.4±4.1	26.8±4.1	26.6±4.1	26.5±4.2	28.0±5.0
Dissolved oxygen (mg/l)	9.1±1.9	8.2±2.0	8.5±1.5	8.2±2.7	7.9±2.4	9.1±1.6	9.4±1.9
Secchi disc reading (cm)	36±9	59±7	47±13	72±13	68±19	38±6	24±3
Depth (cm)	102±7	108±2	109±3	99±10	108±3	106±4	
Water inflow rate(l/sec)	0.49±0.20	0.45±0.19	0.45±0.19	0.79±0.64	0.55±0.19	0.51±0.30	
pH	8.9±0.3	8.5±0.2	8.7±0.3	8.7±0.5	8.5±0.4	8.9±0.3	9.0±0.5
Total alkalinity (mg Co.Co_3/l)	135±6	142±7	145±7	117±15	124±7	141±15	124±18
Specific conductance (μmhos/cm)	439±22	460±29	60±26	408±46	430±17	450±38	409±26
Calcium (mg/l)	35±4	39±3	40±1	29±6	32±4	39±4	34±9
Magnesium (mg/l)	21±2	21±2	21±2	19±1	20±1	21±1	20±3
Sodium (mg/l)	20±3	20±2	20±2	19±2	19±2	20±2	20±3
Potassium (mg/l)	14±1	14±1	14±1	13±1	13±1	14±1	13±1
Chloride (mg/l)	50±4	50±4	51±4	48±3	49±4	50±4	48±2
Total nitrogen (mg/l)	3.64±0.66	3.17±0.75	3.27±0.66	3.02±0.77	3.10±0.77	3.57±0.61	5.01±0.72
Total phosphorus (mg/l)	0.092±0.023	0.053±0.012	0.067±0.011	0.055±0.009	0.056±0.025	0.084±0.018	0.174±0.065
Total chlorophyll a (μg/l)	41.5±9.1	26.2±7.3	31.1±5.5	27.6±11.5	24.4±9.9	37.2±8.0	116.4±29.1
Filter chlorophyll a (μg/l)	32.3±5.3	22.1±7.7	23.3±4.3	21.2±10.2	18.1±4.4	28.3±6.8	64.3±11.1

Note: C - control ponds, LSD - low stocking density and HSD - high stocking density ponds.

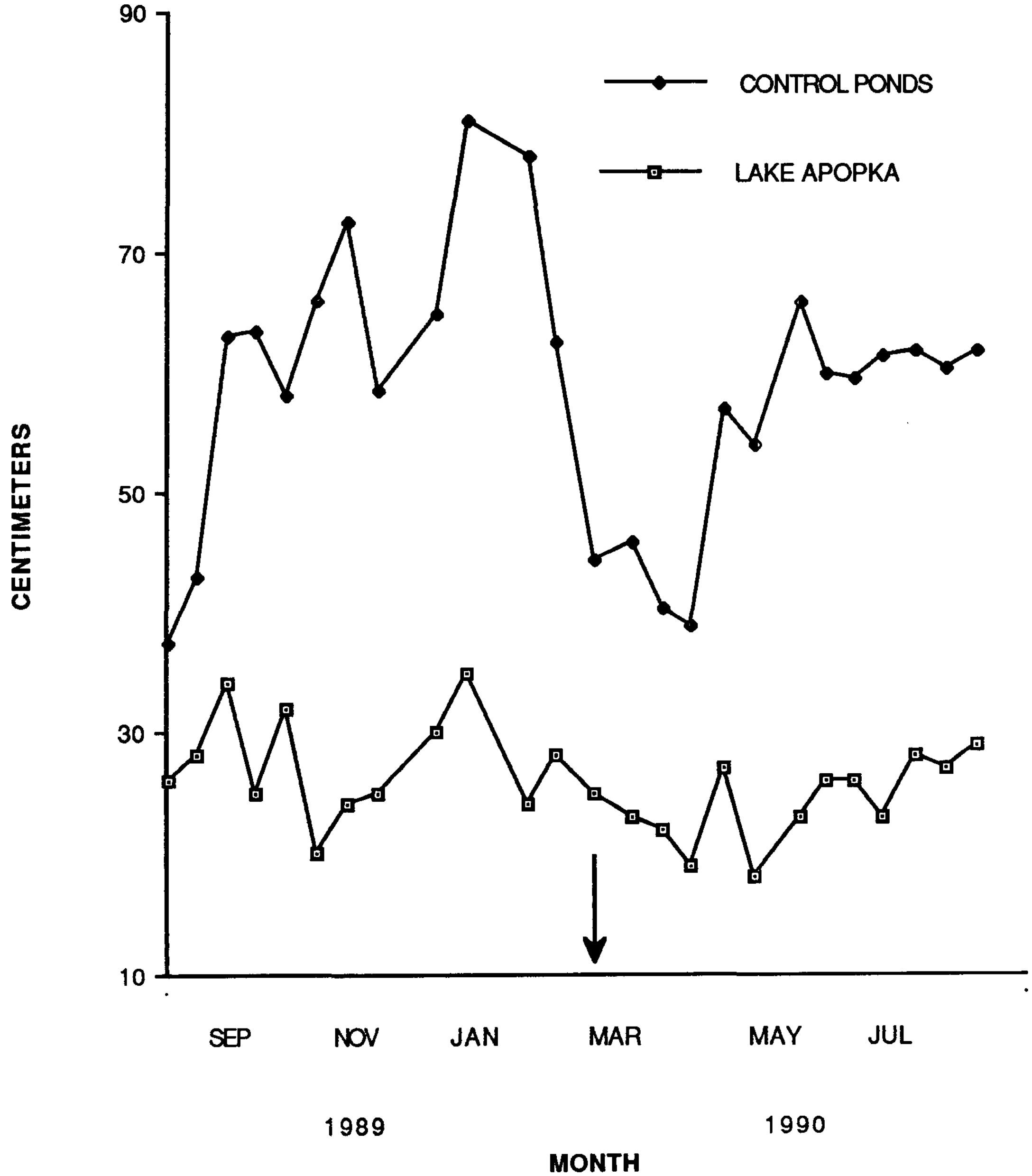

Figure 5. Secchi disc depths in control ponds and Lake Apopka. The arrow shows beginning of the period included in the present analysis.

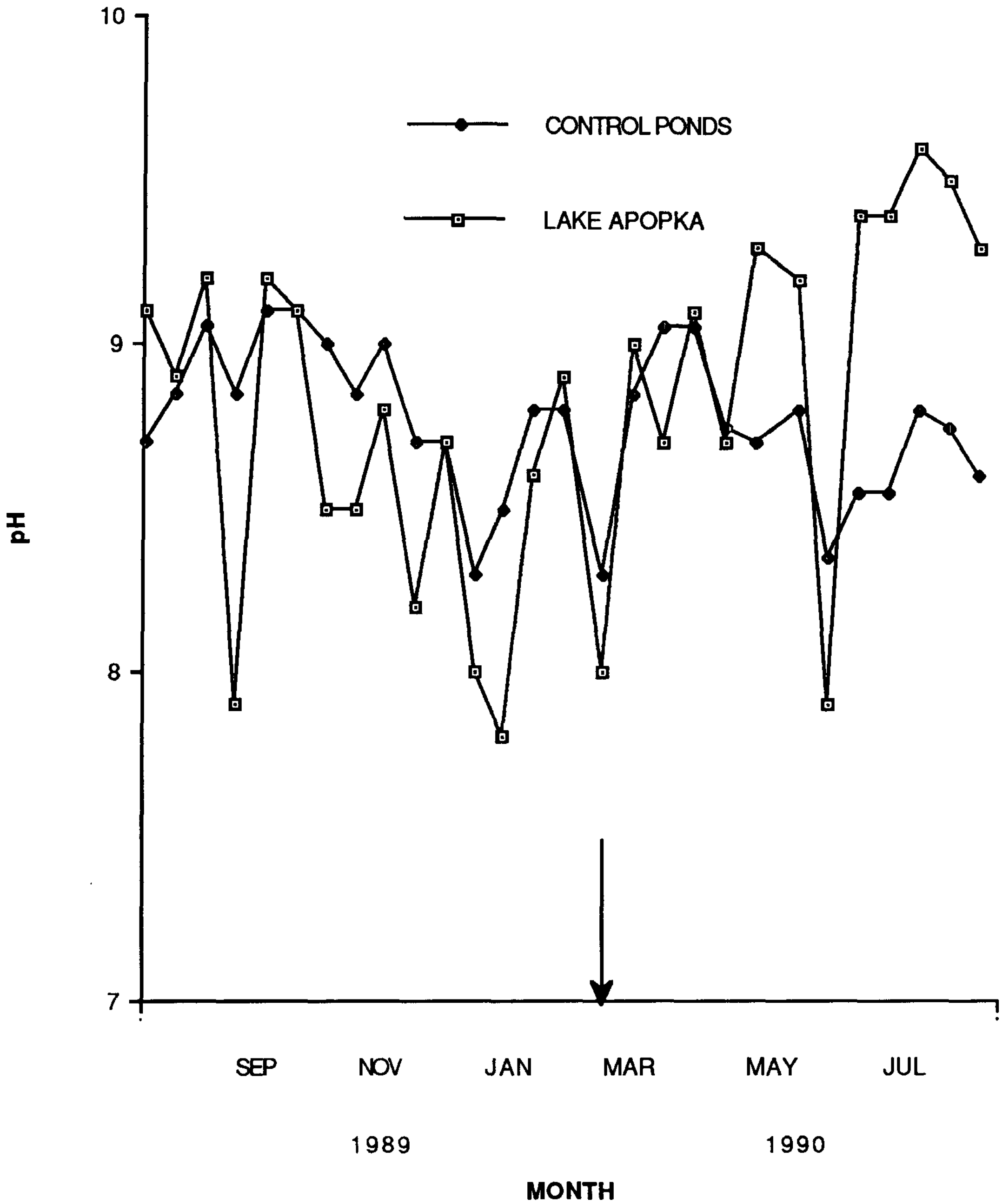

Figure 6. Seasonal pH values for the control pond group and Lake Apopka (the arrow - See Figure 5).

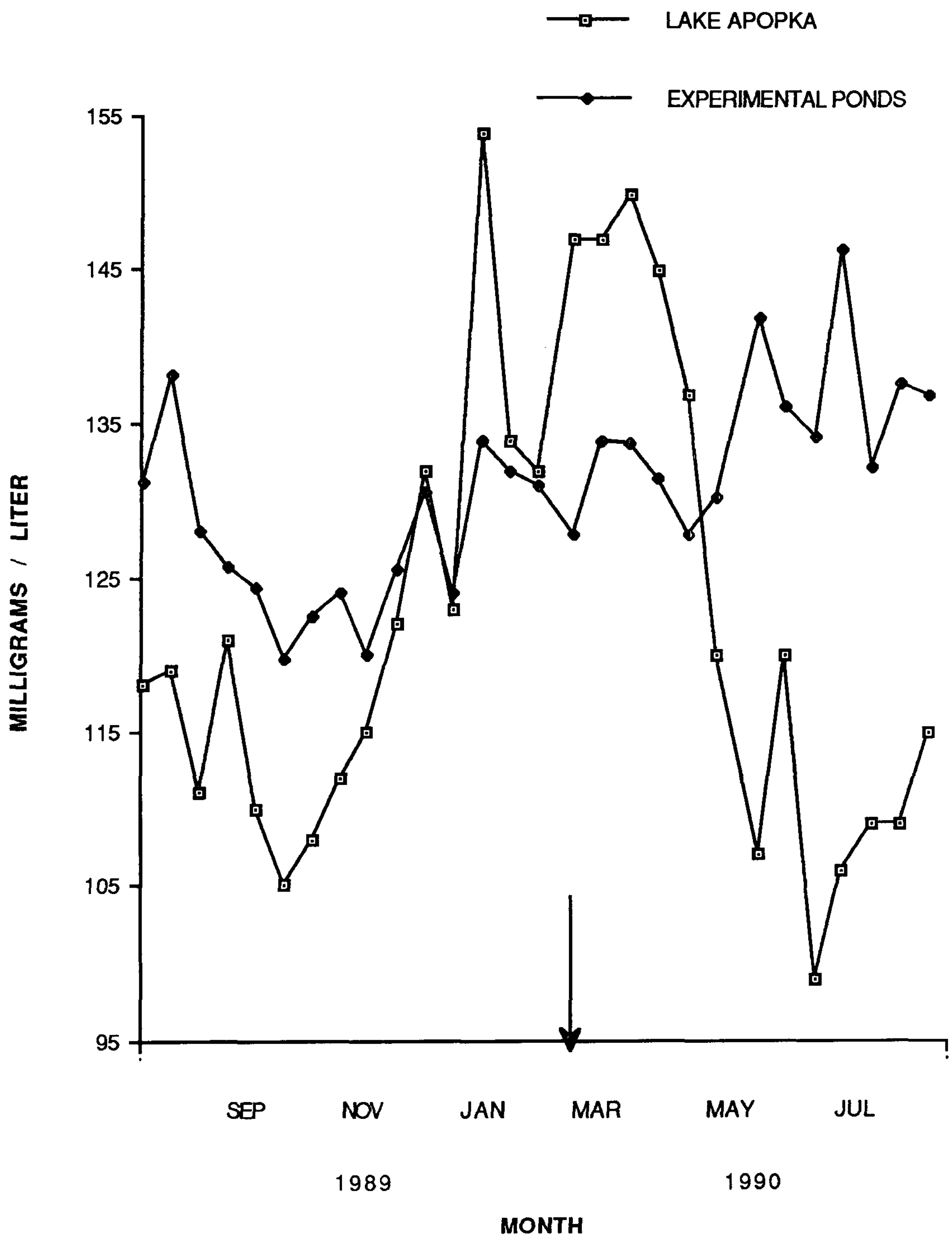

Figure 7. Seasonal total alkalinity values for the experimental pond group and Lake Apopka (the arrow - See Figure 5).

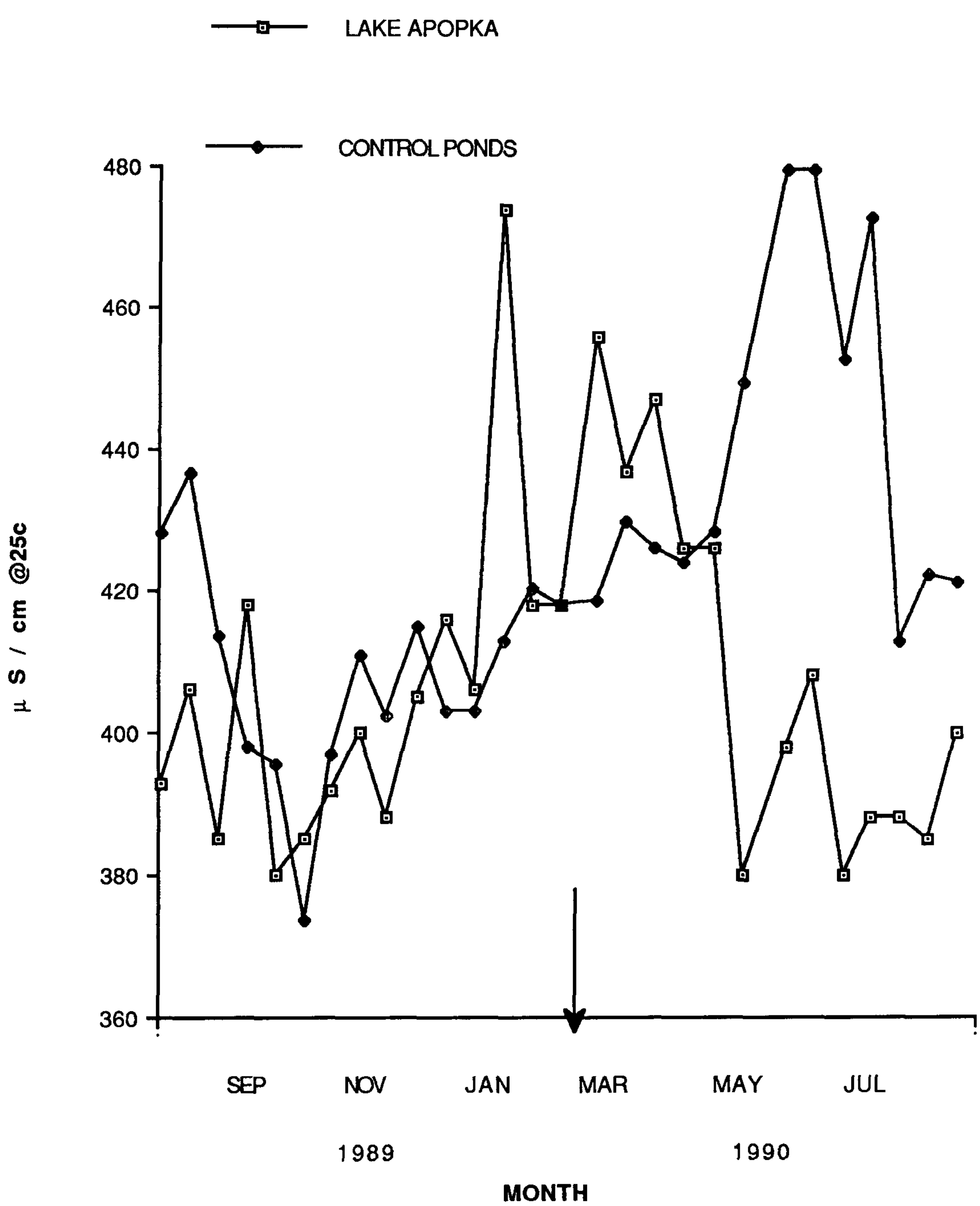

Figure 8. Seasonal specific conductance values for the control pond group and Lake Apopka (the arrow - See Figure 5).

Total Nitrogen (TN). Mean TN values were from 3.0 mg/l to 3.64 mg/l in the ponds. These values were significantly lower than the 5.0 mg/l mean value for Lake Apopka (Tables 5 and 6). All seasonal values for Lake Apopka were higher than those in the ponds (Figure 9). Seasonal variations in the ponds and lake were very similar even though the mean lake values were significantly higher. TN was highest during Oct.-Nov., 1989, and Feb.-March, 1990. Lowest values were recorded during July-September, 1989, and July and August, 1990. These seasonal relationships are common to many Lakes and are similar to Brezonik et al. (1978) results. Pond values were lowest during winter months (Dec. - Feb., 1989-90) highest during May, 1990, and lower during the summer.

Total Phosphorous (P). Mean total P values were from 0.053 mg/l to 0.092 mg/l in the ponds. The mean value for the lake was significantly higher (0.174 mg/l; Tables 5 and 6). Seasonally P values was very similar in all experimental ponds with little variation in the data. Lake fluctuation was greater (Figure 10) with maxima in November, February, June and August. During the other months values remained near 0.15 mg/l.

Total Chlorophyll a. Mean total chlorophyll a values were from 24.4 µg/l to 41.5 µg/l in the ponds and 116.4 µg/l in Lake Apopka (Table 6). All pond values were significantly lower than lake values (Table 5). Similarly, as in the case of P, the dynamics of this parameter were very similar in the experimental pond group with little variation among ponds. Seasonal variation in lake samples was much greater (Figure 11). Maximum values occurred from December to May. Minimum values occurred from July through September, 1989, and from July through August, 1990.

Filtered Chlorophyll a. Mean seasonal values were from 18.1 µg/l to 32.3 µg/l in the ponds and 64.3 ug in the lake (Table 6). The mean lake value was significantly higher than for all the experimental ponds (Table 5). The difference between total chlorophyll a and the

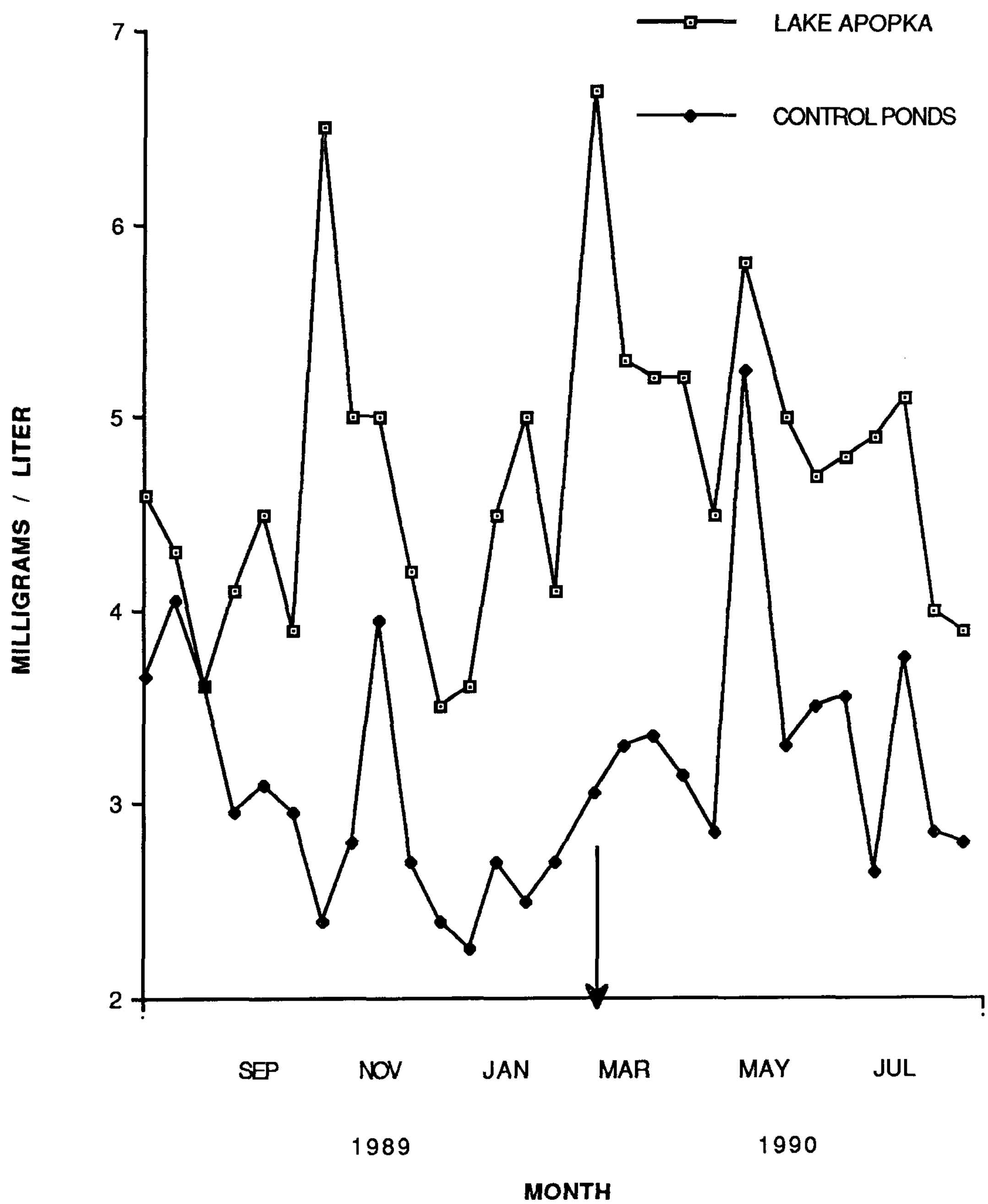

Figure 9. Seasonal total nitrogen values for the control pond group and Lake Apopka (the arrow - See Figure 5).

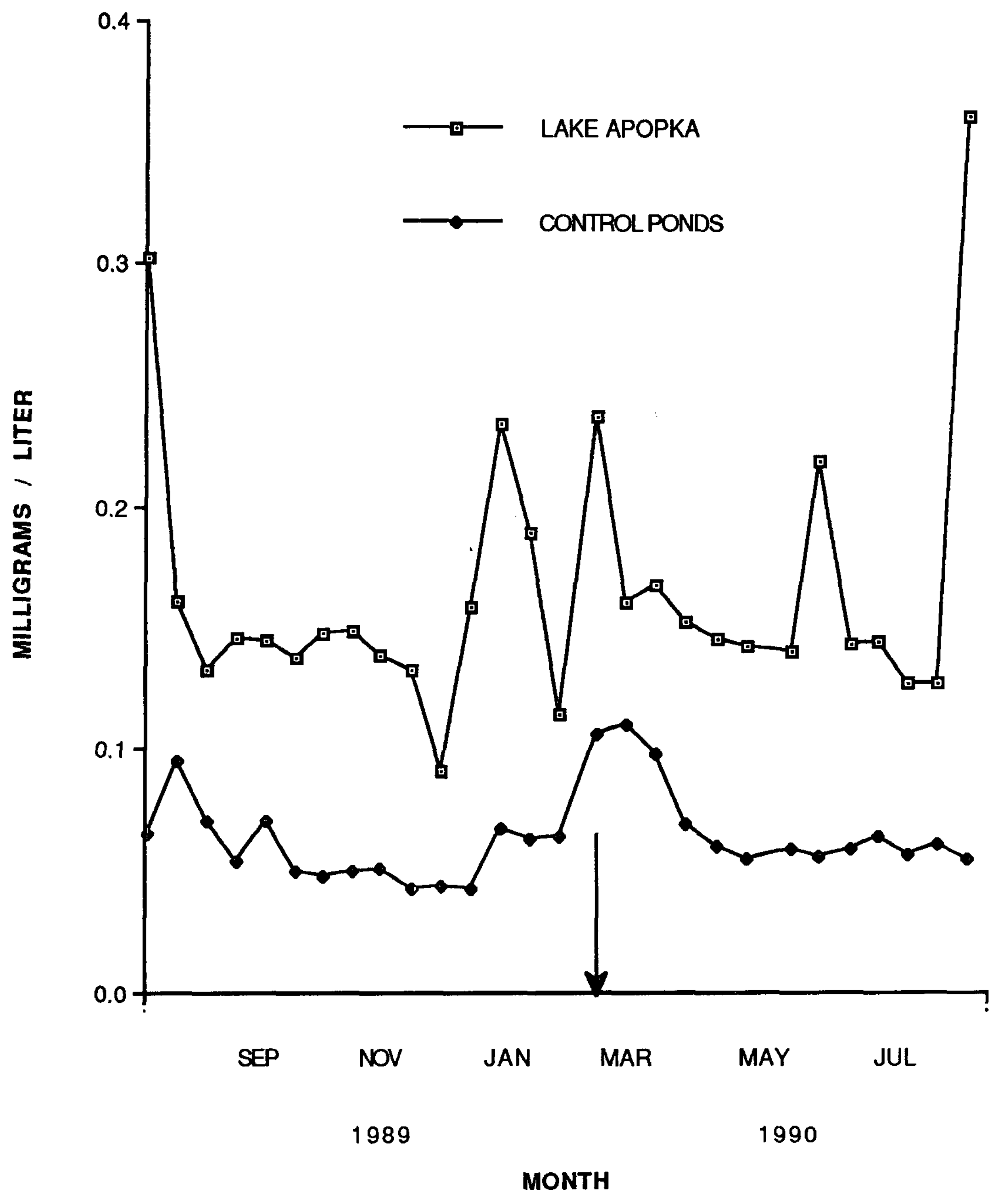

Figure 10. Seasonal total phosphorus values for the control pond group and Lake Apopka (the arrow - See Figure 5).

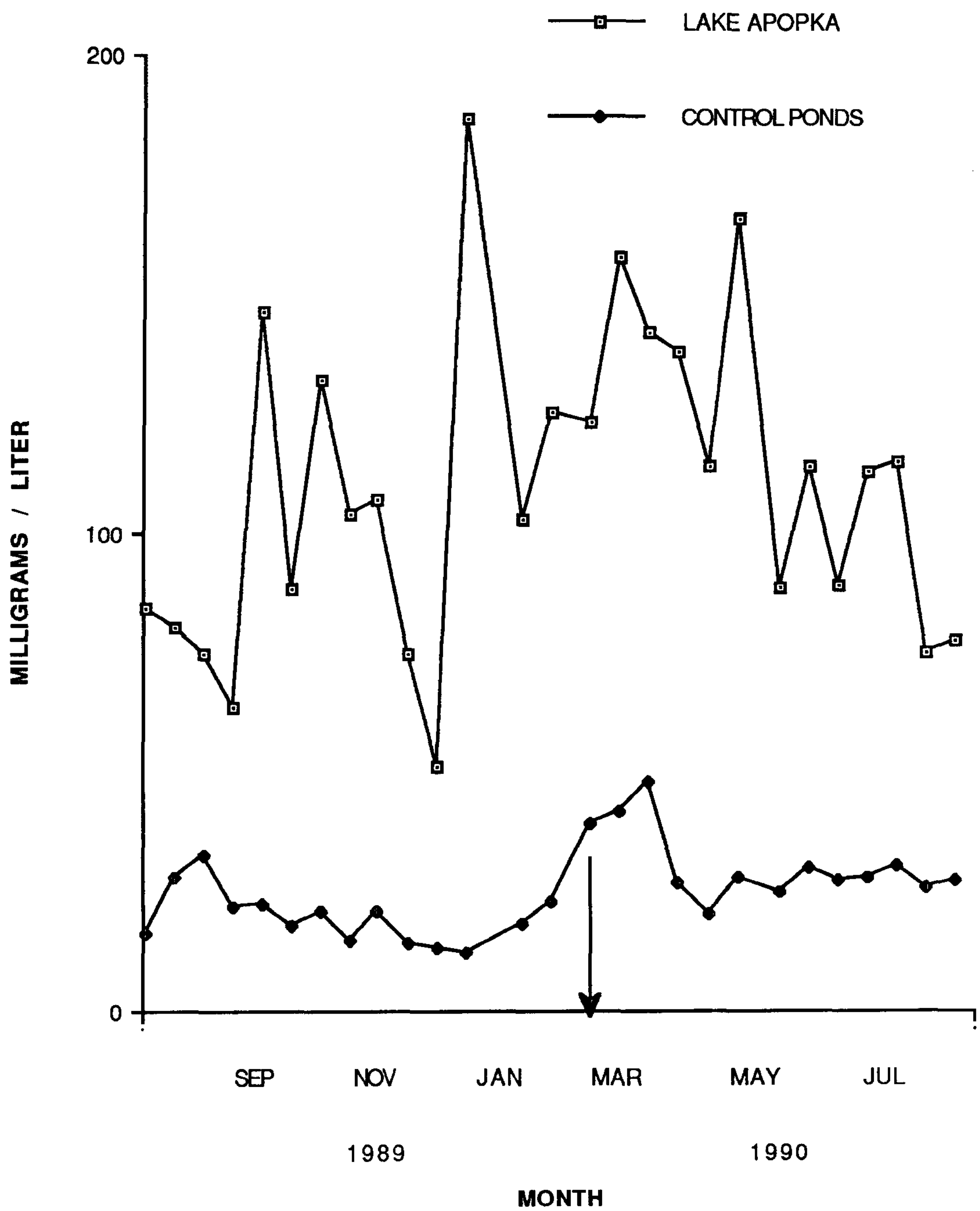

Figure 11. Seasonal total chlorophyll a values for the control pond group and Lake Apopka (the arrow - See Figure 5).

chlorophyll a retained by a 35 µm screen (retained chlorophyll a is calculted as the difference between total chlorophyll a and filtered chlorophyll a, see Methods section p. 14) indicates the relative amount of BB and other "net" plankton in each sample. In the ponds, the amount of retained chlorophyll a amounted to 21 to 25% of the total chlorophyll values, whereas in the lake the retained chlorophyll a amounted to 45% of the total chlorophyll value. This indicates that the share of BB and other "net" plankton in the lake was about 20% higher.

Water and Nutrient Budget

Water budget. Water inflow from Lake Apopka was the main source of water to the ponds. The highest seepage in pond 4 was reflected in the smallest outflow. This pond needed an increased inflow to maintain an appropriate water level (Table 7).

Nutrient budget. Water inflow from Lake Apopka was the main source of nitrogen and phosphorus in the ponds. About 50% of the nitrogen and 65% of the phosphorus was retained in the ponds (Figure 12). There were no apparent differences in nutrient retention between the control and fish-stocked ponds. This is understandable considering the negligible proportion of nutrients in the fish biomass (Table 8 and 9).

Phytoplankton

Bluegreen algae (BG). Mean total number of BG algae ranged from 58 x 10^3 to 233 x 10^3 individuals/ml in the ponds (Table 10). The mean lake value was 272 x 10^3 individuals/ml, which was significantly greater than the experimental pond values but not greater than the control pond values (Tables 5 and 10). BG algal numbers increased in all the experimental pond groups during the study. Maximum pond values were recorded in June, 1990. This was contrary to the situation observed in the lake where two peaks (October, 1989 and June, 1990) of algal abundance occurred during the season. Algal levels in the ponds

Table 7. Water budget for the period 02-27-90 to 08-22-90 (m^3/ha).

Ponds		1	2	3	4	5	6
Sources	I	47,020	52,390	51,965	68,870	44,795	46,765
of	R	6,875	6,875	6,875	6,875	6,875	6,875
Water	Total	53,895	59,265	58,840	75,745	51,670	53,640
	O	7,660	13,930	4,805	355	9,055	11,620
Output	E	12,465	12,465	12,465	12,465	12,465	12,465
	S	33,770	32,870	41,570	62,925	30,150	29,555

I - inflow, R - rainfall (data from Sanford Station)
O - outlet, E - evaporation (data from Lisbon Station; data for July and August are for 1989
S - seepage (calculated as the differance between total income and the outlet plus the evaporation).

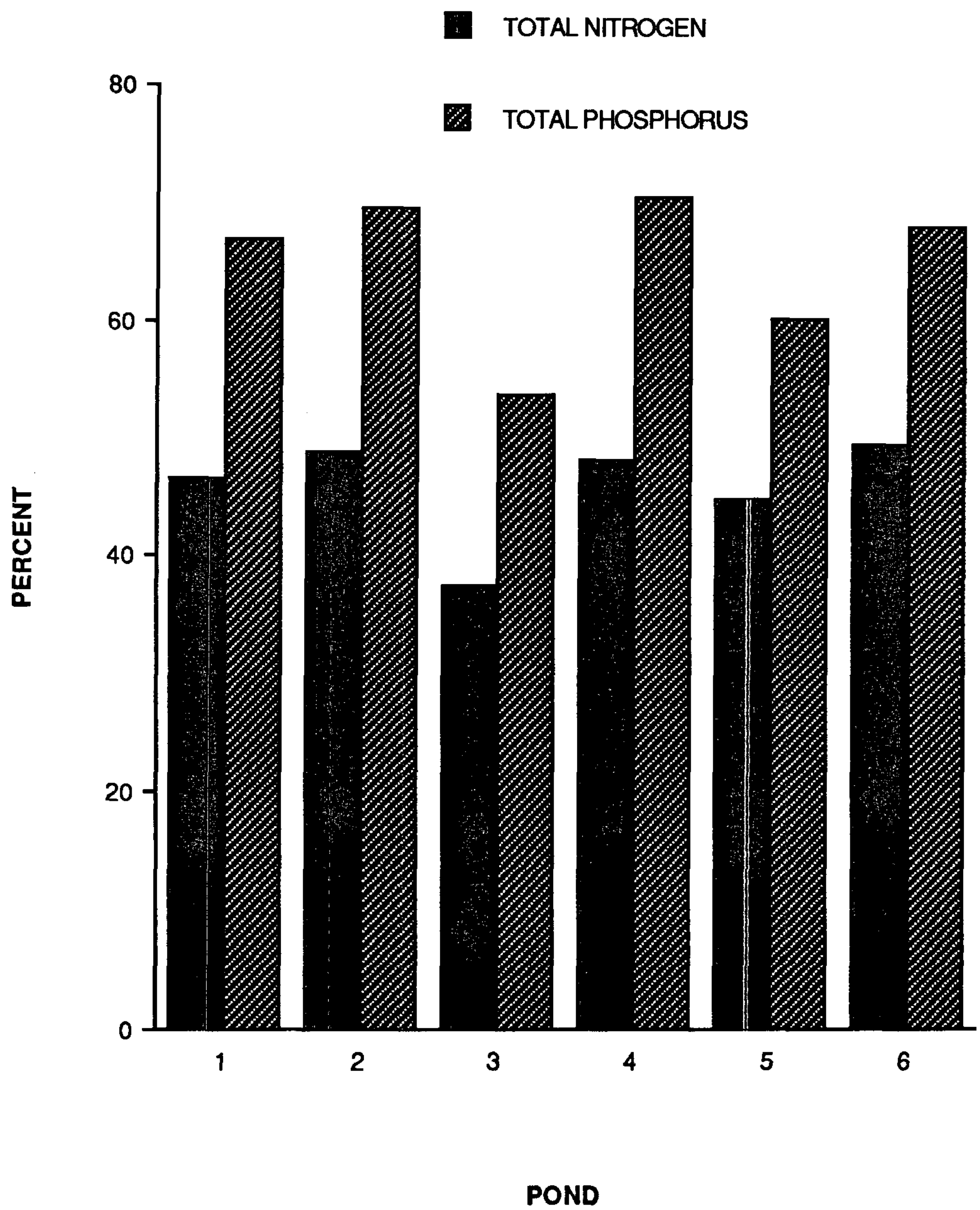

Figure 12. Nutrients retained in the ponds in percentage of the total input.

Table 8. Nitrogen budget for the period 02-27-90 to 08-22-90 (Kg N_T/ha).

Ponds		1	2	3	4	5	6
Sources	I	235.5	261.0	255.5	345.5	229.0	235.0
of	P	8.5	8.5	8.5	8.5	8.5	8.5
Nitrogen	Total	244.0	269.5	264.0	354.0	237.5	243.5
	O	22.2	42.0	16.0	1.2	29.5	32.5
Output	S	108.0	96.5	148.0	182.5	102.5	89.5
	F	0^x	-	1.2	0^x	-	1.0
	Total	130.2	138.5	165.2	183.7	132.0	123.0
$\blacktriangle N = T_{in} - T_{out}$		113.8	131.0	98.8	170.3	105.5	120.5

I - inflow, P - precipitation (data from Brezonik et al. 1979)
O - outflow, S - seepage
F - nitrogen in fish tissue, 0^x - no fish biomass increase

Table 9. Phosphorus budget for the period 02-27-90 to 08-22-90 (Kg P_T/ha).

Ponds		1	2	3	4	5	6
Sources of Phosphorus	I	7.77	8.66	8.76	11.62	7.53	7.63
	P	0.32	0.32	0.32	0.32	0.32	0.32
	Total	8.09	8.98	9.08	11.94	7.85	7.95
Output	O	0.50	1.02	0.33	0.02	0.79	0.66
	S	2.18	1.72	3.45	3.50	2.34	1.53
	F	0_x	–	0.42	0_x	–	0.35
	Total	2.68	2.74	4.20	3.52	3.13	2.54
$\Delta P = T_{in} - T_{out}$		5.41	6.24	4.88	8.42	4.72	5.41

I - inflow, P - precipitation (data from Brezonik et al. 1979)
O - outflow, S - seepage
F - phosphorus in fish tissue, 0^x - no fish biomass increase

Table 10. Mean values and standard deviation of the phytoplankton data for the period 02-27-90 to 08-22-90.

Parameter	LSD 3	LSD 6	HSD 1	HSD 4	C 2	C 5	Lake
Blue-green Algae /ml x 1000	224±121	74±34	174±96	42±17	58±35	233±160	272±96
Green Algae/ml	3753±5552	1618±1633	1968±1824	1850±866	7148±12043	585±728	1108±1032
Botryococcus/ml	8±4	5±5	8±2	6±2	3±3	9±9	12±7
Total Algae/ ml x 1000	228±117	76±29	176±97	45±17	66±32	234±161	275±96
% Blue-green Algae	96.1±6.2	96.3±5.1	98.6±1.0	93.2±3.3	81.4±26.2	99.4±0.5	98.9±0.8
% Green Algae	3.5±6.2	.8±3.4	1.1±0.9	4.4±2.4	14.3±25.5	0.2±0.2	0.4±0.4
% Botryococcus	0.00±0.00	0.00±0.00	0.00±0.00	0.00±0.00	0.00±0.00	0.00±0.00	0.00±0.00

Note: C - control ponds, LSD - low stock density, HSD - high stock density ponds.

gradually approached the levels observed in the lake (Figure 13). The major species in both the ponds and lake were Spirulina laxissima, Lyngbya contorta, L. liminetica, L. lagerheimii and Microcystis incerta. These species were also reported as the major BG species by Brezonik et al. (1978).

Green algae (GA). Mean total number of GA ranged from 585 to 7,148 individuals/ml in the ponds, and 1,108 individuals/ml in the lake (Table 10). No significant differences existed among the ponds or the lake (Table 5).

BB. Mean total number of BB ranged from 3 to 9 individuals/ml in the ponds and 12 individuals/ml in Lake Apopka. No significant differences existed between the control ponds and the lake, whereas a difference was found between the lake and the experimental ponds (Tables 5 and 10). All values for the lake and ponds were similar except for one sample date in December, 1989, when a very high level of BB was observed in the lake (Figure 14). Although the numbers of BB are relatively low, it constitutes an important component of the algal biomass (see Chlorophyll section).

Total Algae (TA). The mean number of TA ranged from 62 x 10^3 to 158 x 10^3 /l. In the lake this value was 275 x 10^3/l., which was significantly higher than experimental pond group values (Table 5 and 10). The seasonal TA dynamics is shown in Figure 15.

Blue-green/green algal group ratio. Differences in the numerical proportion of blue-green/green algae were found between the experimental pond groups and the control ponds. This proportion was lower in HSD ponds and also lower in LSD ponds than in the unstocked control ponds (Table 11). However, the differences in algal group ratios can not be explained by the mean differences in algal group abundance. Differences in numerical occurrence were not found in blue-green and green algae when the control and experimental pond groups were compared (Table 5).

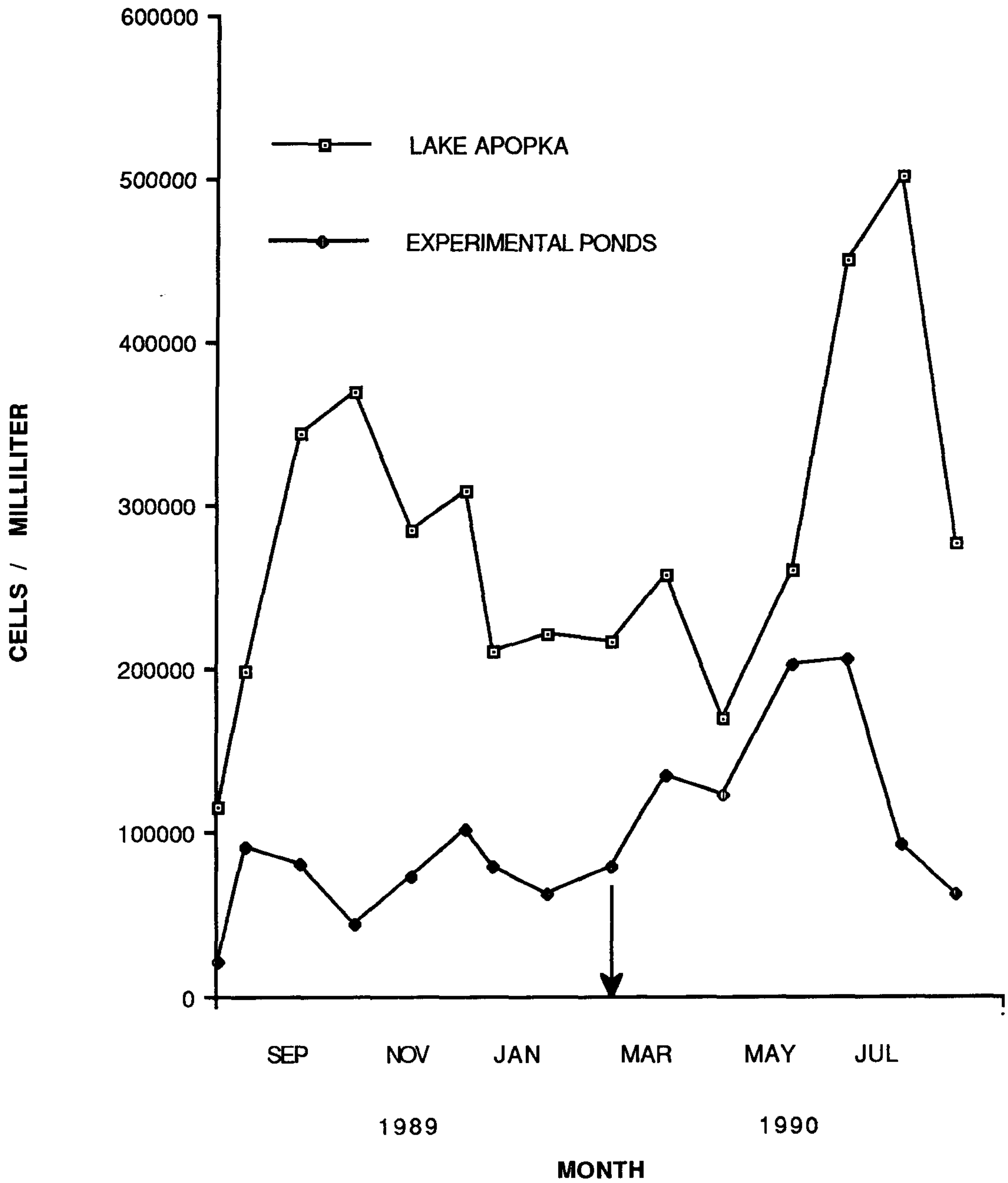

Figure 13. Seasonal bluegreen algae numbers for the experimental pond group and Lake Apopka (the arrow - See Figure 5).

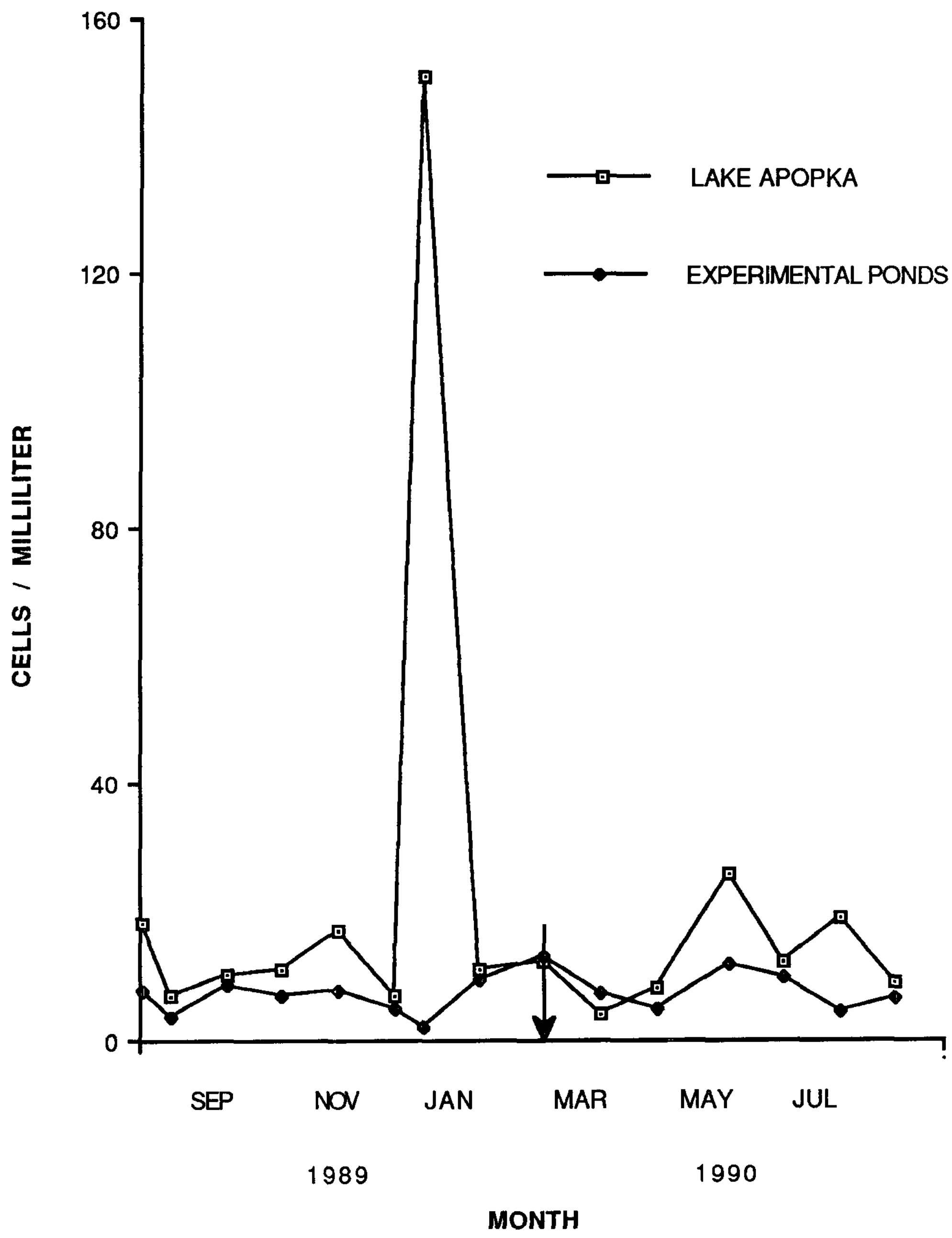

Figure 14. Seasonal <u>Botryococcus</u> <u>Braunii</u> numbers for the experimental pond group and Lake Apopka (the arrow - See Figure 5).

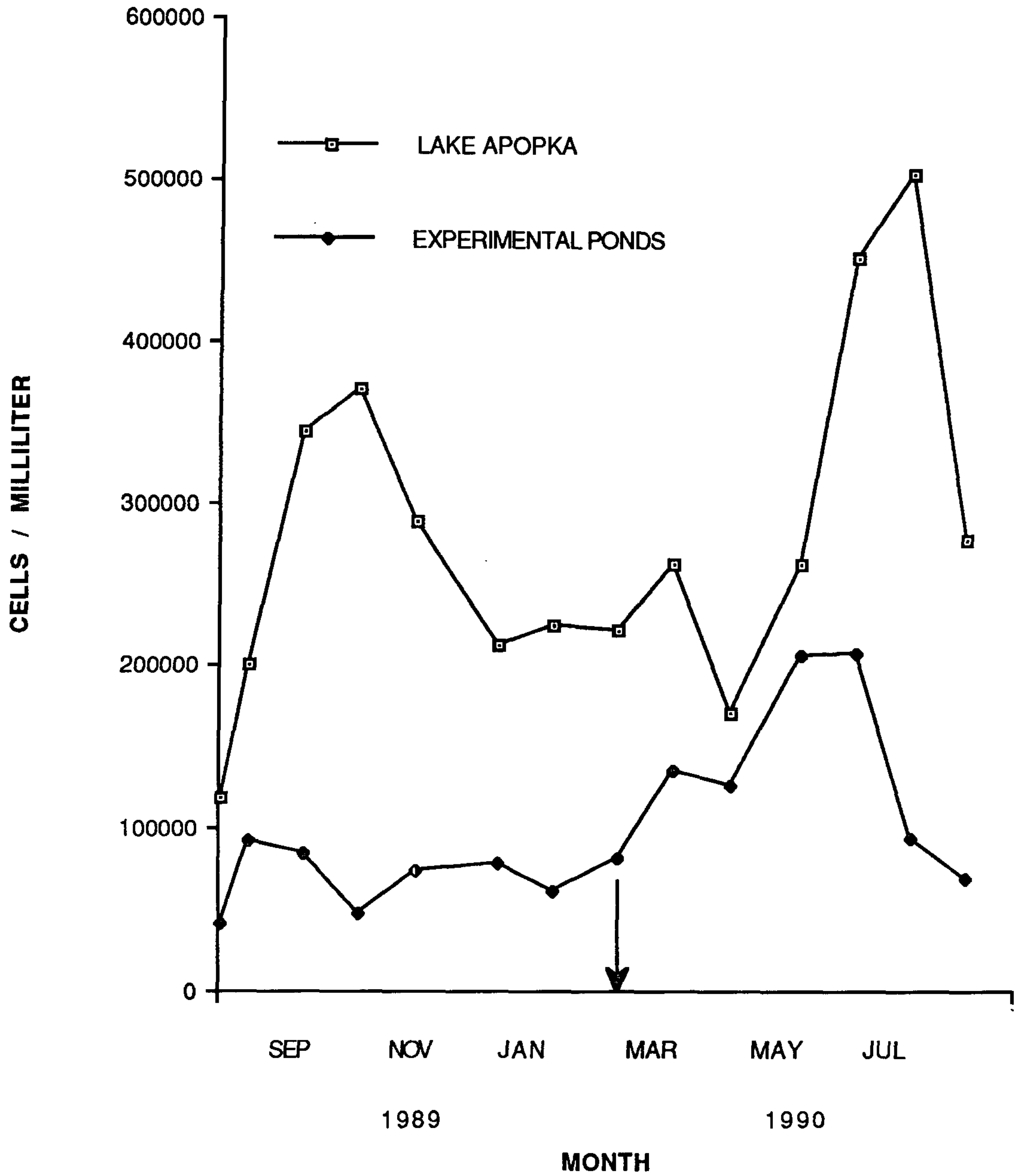

Figure 15. Seasonal total algae numbers for the experimental pond group and Lake Apopka.

Table 11. The ratio of blue-green/green algae from the lake and ponds

Date	02-27-90	03-27-90	04-25-90	05-30-90	06-27-90	07-25-90	08-22-90	Mean
Control								
Pond 2	66	262	39324	2	18015	17343	0.4	
Pond 5	3092	536	33274	216	273	318	29577	10164
LSD								
Pond 3	16	345	500	164	797	157	5	
Pond 6	21	1726	38	226	157	55	9	301
HSD								
Pond 1	267	49	36	121	255	90	171	
Pond 4	20	17	28	38	23	10	54	84
Lake	521	80	139	211	551	609	30922	4719

Note: LSD - low stocking density ponds, HSD - high stocking density ponds.
The differences between C-LSD and C-HSD are significant (t-Student's test, $P<0.05$)

Zooplankton

The zooplankton community in both the ponds and lake was dominanated by rotifers and copepods (nauplii, copepodids and adults). Cladocerans were poorly represented. The major rotifer species were (body size in µm and S.D. are given in parenthesis): Keratella cochlearis (184±17), Brachionus havanaensis (243±35), B. quadridentata (305±41), B. caudatus (191±45), B. calyciflorus (274±38), Filinia longiseta (124±19), Monostyla sp (119±13), Hexarthra sp. (150±23) and Trichocerca longiseta (200±29). Diaptomus dorsalis (♂ 1130-1200, ♀ 1130-1375, mean 1188±117) was the most numerous copepod representative. The cladoceran assemblage was dominated by two small species, Bosmina sp. (364 ± 87) and Chydorus sphaericus (250±41). The larger cladoceran species, Daphnia ambigua (772±105), was found in significant numbers only in the samples on January 26, 1990. Because larger cladoceran species were not present in most of the samples, and adult copepods were found only in token numbers (Table 12), the zooplankton assemblage consisted of the same small species, both in the treatment pond group and in the lake.

The total number of zooplankton (TZ) was highest in Lake Apopka. Significant differences existed between the experimental pond group and the lake (Table 5). The seasonal dynamics of rotifers, copepods, and TZ numbers is shown in Figure 16, 17 and 18.

Fish Food Habits

The materials eaten by bighead carp were divided into three general categories, zooplankton, phytoplankton/ detritus (excluding BB), and BB.

Zooplankton. The amount of zooplankton in the AT consisted of 1% of the total volume of food (Table 13). Zooplankton eaten by the fish consisted mainly of small forms, primarily rotifers and young copepod stages.

Table 12. Mean values and standard deviation of the zooplankton data for the period 02-27-90 to 08-22-90.

Parameter	L S D		H S D		C		Lake
	3	6	1	4	2	5	
Rotifers/l	231±258	111±66	165±32	67±28	92±36	282±232	1096±1802
Nauplii & copepodids/l	159±108	117±159	82±50	21±10	123±137	190±76	197±165
Copepods/l	5±7	4±7	1±1	1±1	4±5	6±5	23±30
Cladocera/l	207±426	98±200	45±47	51±64	206±421	236±500	323±356
Other zooplankton/l	0.0±0.0	0.3±0.7	0.3±0.7	0.4±1.1	0.3±0.7	0.0±0.0	0.0±0.0
Total zooplankton/l	603±539	330±362	294±104	141±79	424±531	714±511	1640±1683
% Rotifers	45.1±30.1	50.9±24.0	61.7±19.0	54.4±22.1	46.4±27.4	46.8±25.8	46.7±37.7
% Nauplii & Copepodids	32.2±19.2	31.5±14.0	25.4±9.5	16.0±3.1	32.5±12.7	31.7±12.5	16.9±16.0
% Copepods	1.0±0.7	0.8±0.8	0.3±0.4	0.6±0.8	1.0±1.7	0.9±0.3	2.5±3.8
% Chadocera	21.6±25.4	16.4±14.9	12.5±10.7	28.7±21.5	19.6±27.0	20.6±26.6	33.8±30.9
% Other zooplankton	0.0±0.0	0.4±1.0	0.0±0.00	0.2±0.6	0.4±1.0	0.0±0.0	0.0±0.0

Note: C - control ponds, LSD - low stock density and HSD - high stock density ponds.

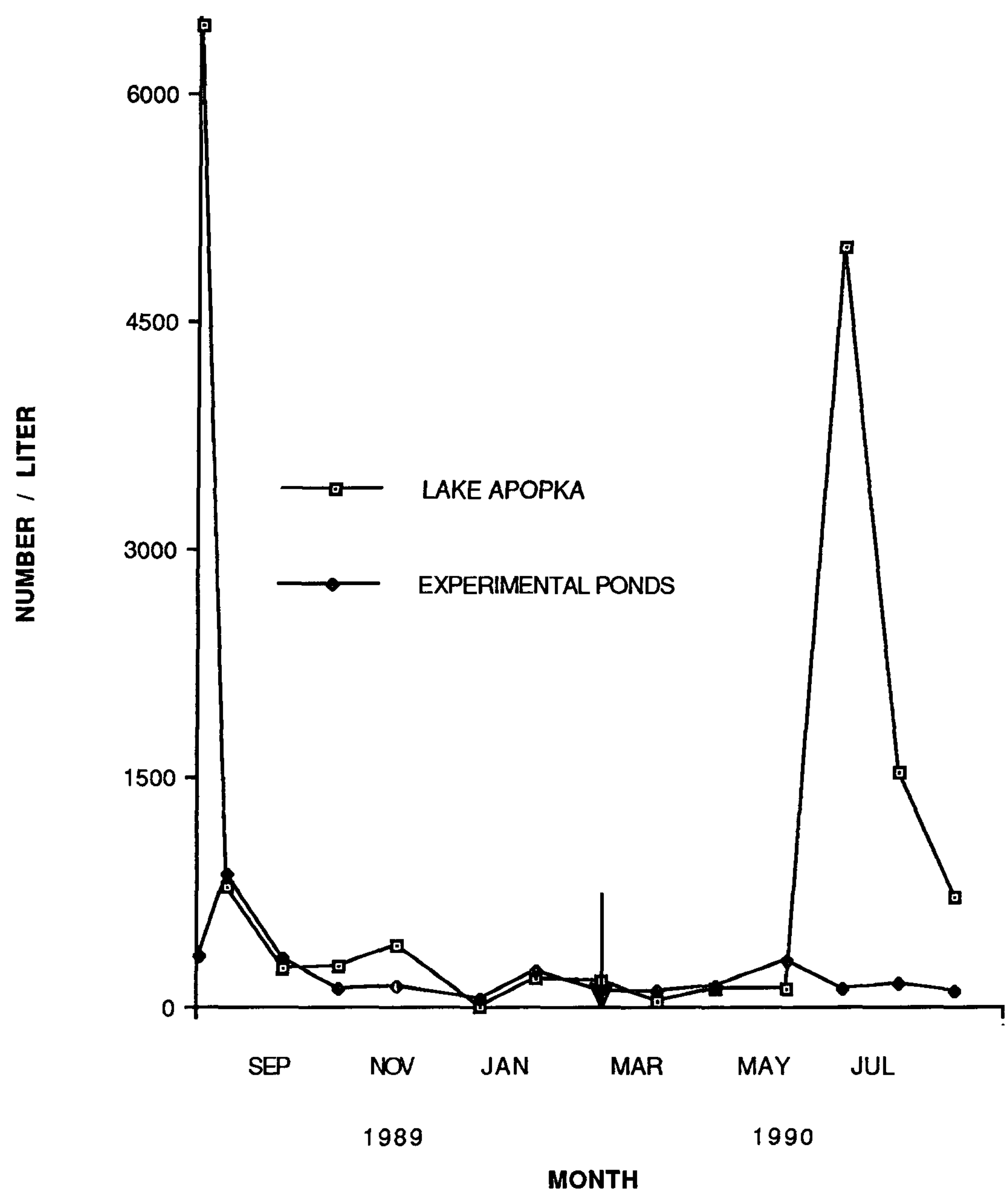

Figure 16. Seasonal rotifer number for the experimental pond group and Lake Apopka.

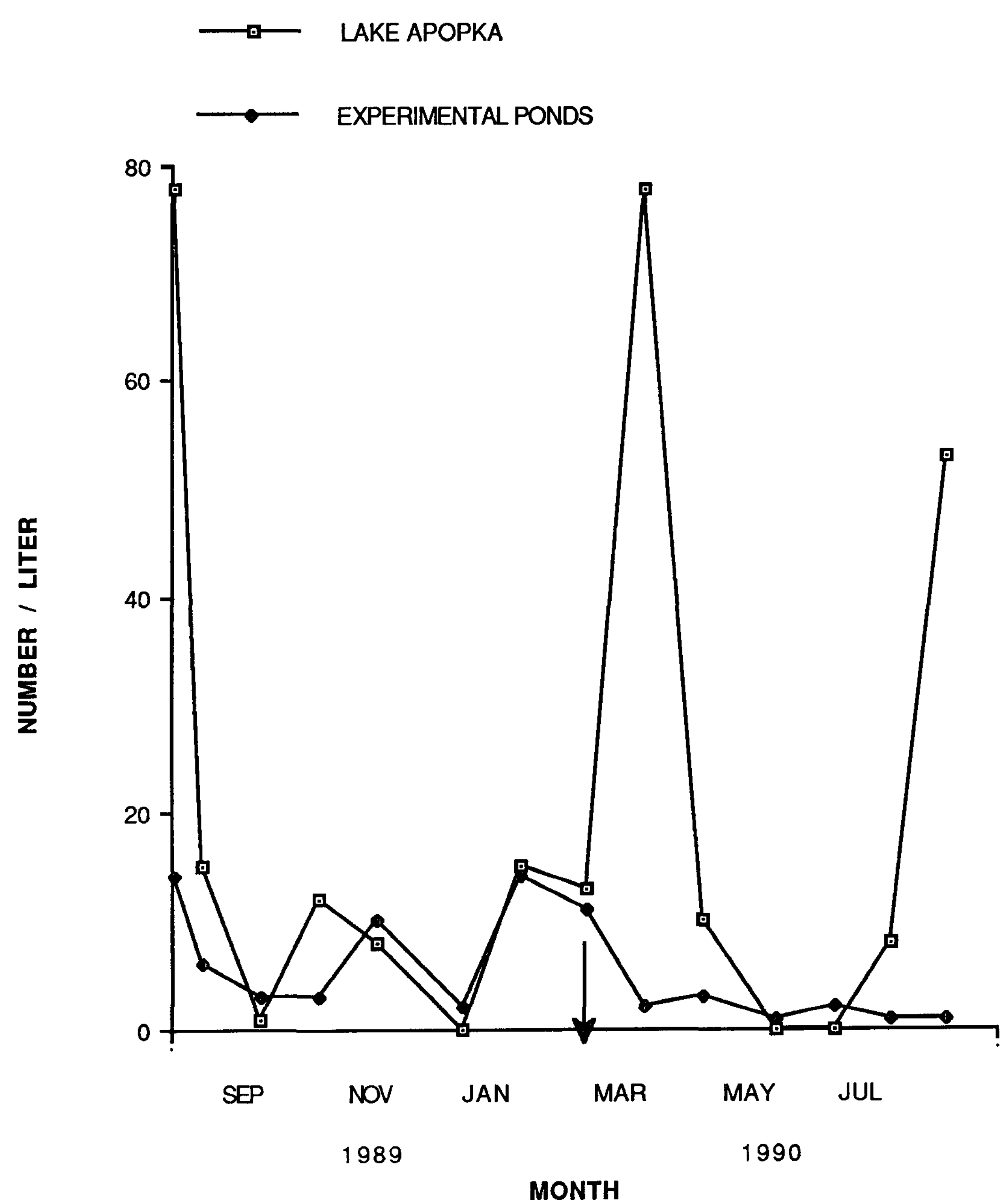

Figure 17. Seasonal copepod numbers for the experimental pond group and Lake Apopka.

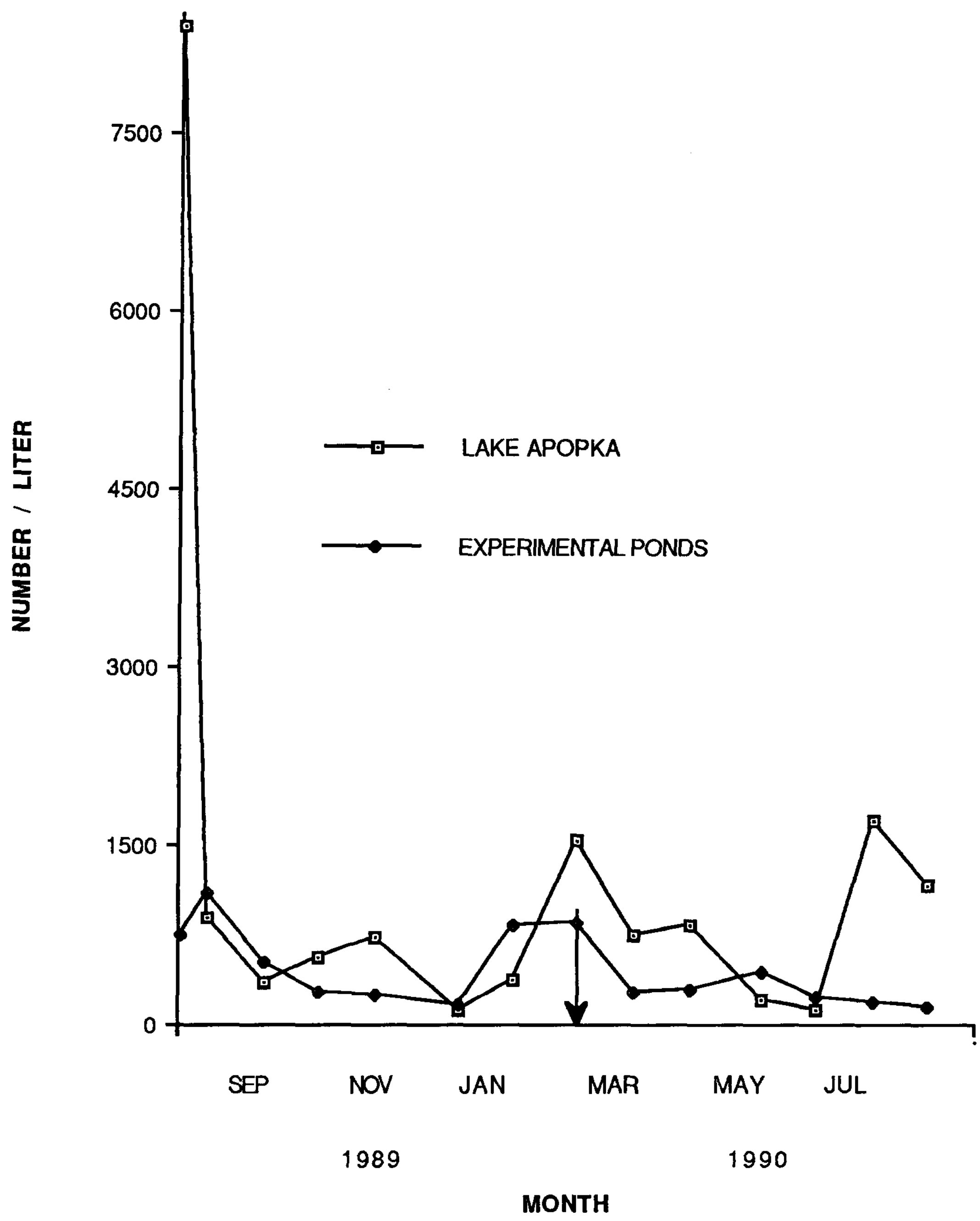

Figure 18. Seasonal total zooplankton numbers for the experimental pond group and Lake Apopka.

Phytoplankton/ Detritus (P/D). The present volume of P/D was 32 and 28% in the AT of small and large fish, respectively (Table 13). Algal species most often found in the AT were the common BG species in the ponds.

BB. The percent volume of BB found in fish AT was 66 and 70 in small and large fish, respectively. On a dry weight basis the volume of BB amounted to 50 and 60% in the AT of small and large fish, respectively. From these data it can be seen that the percentage of BB in the fish food increased slightly with the size of the fish (Table 14).

In addition to the percent volume of food consumed, the total number of each item eaten was also determined. The number of BB colonies eaten by small fish was 4.8×10^3/g of fish body weight and 15.3×10^3/g of fish body weight in the larger fish (Table 15). This relationship between fish size and consumption of BB is unusual because, as a general rule, larger fish consume less food/g of body weight than smaller ones (Webb 1978).

Total Algal Consumption: Small fish ate an average of 426×10^3 algal colonies/g of fish body weight whereas this number was 712×10^3 for larger fish. The same relationship as pertained to fish size existed for the total amount of algae consumed (Table 15).

Blue-green/green algal group ratio. The proportion of blue-green/green algae in the fish food was 24 and 29 in LSD and HSD ponds, whereas the same proportion in the pond water was 301 and 84, respectively (Table 11 and 16). The algal group proportion in fish food was significantly lower than in the ponds (t-test, P=0.05).

Food Selectivity: BB and zooplankton were highly preferred by bighead carp. This was confirmed by Ivlev's selectivity index. In all samples the index for both was close to +1 (x = +0.99) in small and large fish (Table 15). Zooplankton biomass was low in the ponds and made up only a small portion of the fish food. Selectivity for other algae was variable.

Table 13. Characteristics of bighead carp food, percentage of zooplankton and phytoplankton & detritus (by volume).

Date	Pond No.	Zooplankton			Phytoplankton & detritus		
		s	m	l	s	m	l
02-28-90	1		15			8	
02-28-90	4		11			8	
02-28-90	6		24			8	
04-26-90	1	1		2	43		33
04-26-90	4	0		0	43		38
05-31-90	1	1		1	23		17
05-31-90	4	0		1	10		8
06-28-90	1			1		27	
06-28-90	3	1		2	21		30
06-28-90	4		1			45	
06-28-90	6	5		1	27		22
07-26-90	1	1		0	41		32
07-26-90	3	1		3	39		43
07-26-90	4		1			53	
07-26-90	6	0		1	46		30
Mean ± SD			1±1.5		1±1	32±12.6	28±11

Note: s - small fish, l - large fish, m - fish not divided into either small or large fish.

Table 14. Characteristics of bighead carp food, percentage of Botryococcus Braunii (by volume and by dry weight).

Date	Pond No.	% of B. Braunii (volume)			% of B. Braunii (dry weight)		
		s	m	l	s	m	l
02-28-90	1		77			87	
02-28-90	4		81			87	
02-28-90	6		68			75	
04-26-90	1	56		65	57		64
04-26-90	4	57		62	43		53
05-31-90	1	76		81	46		78
05-31-90	4	90		91	42		76
06-28-90	1		72			68	
06-28-90	3	78		68	65		76
06-28-90	4		54			36	
06-28-90	6	68		77	40		36
07-26-90	1	58		68	59		67
07-26-90	3	60		54	54		55
07-26-90	4		46			11	
07-26-90	6	54		69	47		37
Mean $\pm$ SD		66 ± 12.5		70 ± 11	50 ± 8.7		60 ± 16

Note: s - small fish, l - large fish, m - fish not divided into size groups.

Table 15. Characteristics of bighead carp food, number of algae ($x10^3$ g fish body weight^{-1}) and selectivity for B. Braunii.

Date	Pond No.	B. Braunii			Other			Ivlev's index		
		s	m	l	s	m	l	s	m	l
2-28-90	1		18.4			141			+1.00	
2-28-90	4		18.5			180			+1.00	
2-28-90	6		5.6			17			+1.00	
4-26-90	1	7.6		15.4	584		505	+1.00		+1.00
4-26-90	4	8.5		9.4	309		413	+0.99		+0.99
5-31-90	1	3.0		33.1	139		1050	+1.00		+1.00
5-31-90	4	1.8		23.5	77		681	+0.98		+0.99
6-28-90	1		15.1			663				
6-28-90	3	0.6		4.3	29		221	+1.00		+1.00
6-28-90	4		5.2			1607			+0.97	
6-28-90	6	7.2		6.3	1386		1311	+0.99		+0.99
7-26-90	1									
7-26-90	3									
7-26-90	4									
7-26-90	6									
Mean ± SE		4.8±3.4		15.3±11.5	421±514		697±411	+0.99		+0.99

Note: s = small fish, l = large fish, m = fish not divided into size groups

Table 16. The ratio of blue-green algae in the fish food.

Date	02-38-90	04-26-90	05-31-90	06-28-90	07-26-90	08-23-90	Mean
LSD							
Pond 3				19	40	17	
Pond 6	0.6			50	13	26	24
HSD							
Pond 1	4	44	20	43	34	88	
Pond 4	7	7	14	23	36		29

Index of Filling: Only a few fish in all samples were found to have empty AT. However, AT were not uniformly filled with food. Usually, the first part of AT contained the smallest amount of food or was empty, whereas the last part contained the largest amount (Table 17). The index of filling averaged 2.8 and 3.8 in HSD and 2.3 and 3.2 in LSD (Table 18). This index was calculated on a food wet weight basis in order to make our data comparable with the literature. Determination of wet weight can not be done as accurate as determination of dry weight. However, the high correlation between wet and dry food weight determinations obtained in our study indicates high accuracy of the measurements (Figure 19).

Fish Growth: From the data collected it is difficult to describe growth of the fish (Table 19). It was noticed immediately that two sizes of fish existed, which added to sample variation. This variance could have been reduced if larger samples were taken, but during the experiment, we determined that fish survival and fish food habits were of most importance. Seining during the summer when water temperatures were warm caused mortalities; therefore, we decided not to collect large samples for length and weight measurements. The larger samples of fish were collected between 12-21-90 and 01-02-91. Weight class distribution of the sample of 100 fish from each pond is shown in Figure 20. This distribution is clearly a negative bionomial as the variance values (between 3261 and 6736) are many times greater than the mean weight of fish. There is not a

Table 17. Fullness of the three sections of bighead carp alimentary tracts.

	Pond 1			Pond 3			Pond 4			Pond 6		
Date	I	II	III	I	II	III	I	II	III	I	II	III
02-28-90	1.2	2.4	3.0				1.0	1.9	2.7	0.0	0.5	1.0
04-26-90	0.8	1.8	2.6				0.9	1.9	2.6			
05-31-90	0.4	0.9	1.5				0.2	0.5	1.6			
06-28-90	0.1	0.5	1.4	0.3	0.6	2.1	0.5	1.0	1.5	0.1	0.5	2.0
07-26-90	1.9	1.9	2.7	0.0	0.6	2.1	1.2	1.4	1.2	0.2	1.6	2.8
08-23-90	0.9	1.4	2.5	0.0	0.4	1.9				0.0	1.3	2.4

Note: 0 = no food, 1 = little, 2 = medium, 3 = much, and 4 = very much food.
I, II, III - first, second, and third section of the alimentary tract.

Table 18. Quantity of food in intestinal tracts.

Date	Pond	Number of fish	Mean fish total length	Mean fish weight g	Wet weight food g	Mean Dry weight food g	Wt. of food[1/] as % of Body wt.
2/28/90	1	10	114.0	14.5	0.758	0.137	5.0
2/28/90	4	10	94.6	8.1	0.392	0.070	4.9
2/28/90	6	2	120.0	18.8	0.390	0.039	1.5
4/26/90	1	10	136.4	28.7	0.891	0.106	3.0
4/26/90	4	10	147.8	35.9	0.972	0.122	2.4
5/31/90	1	10	148.7	34.3	1.164	0.525	1.9
5/31/90	4	10	150.0	46.1	1.832	1.093	1.8
6/28/90	1	10	147.7	24.2	0.545	0.049	2.0
6/28/90	3	10	181.4	57.2	1.390	0.381	1.9
6/28/90	4	4	115.5	12.1	0.298	-	2.4
6/28/90	6	10	196.1	74.6	1.679	0.202	2.1
7/26/90	1	10	181.0	71.7	4.100	0.438	5.9
7/26/90	3	10	206.5	85.3	2.227	0.281	2.4
7/26/90	4	5	103.6	9.1	0.210	-	2.3
7/26/90	6	10	224.3	123.3	5.418	0.574	4.1
8/23/90	1	10	185.8	72.2	3.122	-	5.3
8/23/90	3	10	214.1	95.1	3.002	-	2.7
8/23/90	6	10	231.3	124.7	6.727	-	3.7

[1/] index of filling

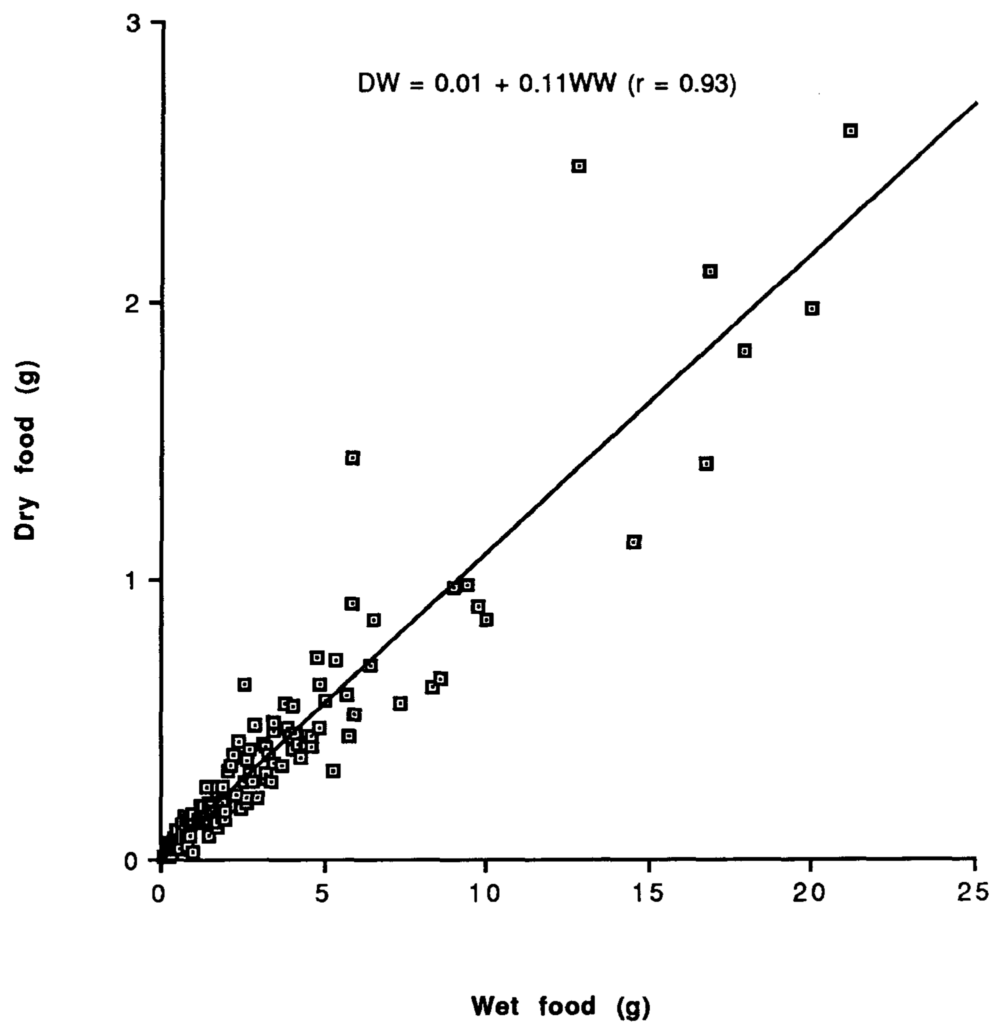

Figure 19. Relationship between dry (DW) and wet weight (WW) of bighead carp food.

Table 19. Mean weight of fish collected each date and used for food analysis.

Date	Pond	Mean weight (G) and range	Mean weight (g) S	L
02-28-90	1	14(8- 20)		
04-26-90	1	29(9-105)	13	93
05-31-90	1	34(7-113)	14	82
06-28-90	1	24(14- 37)		
07-26-90	1	72(22-148)	48	126
08-23-90	1	72(21-211)	27	140
06-28-90	3	57(15-106)	35	79
07-26-90	3	85(46-134)	71	118
08-23-90	3	95(62-177)		
02-28-90	4	8(7- 8)		
04-26-90	4	36(9-100)	21	97
05-31-90	4	46(7-237)	10	130
06-28-90	4	12(10- 13)		
07-26-90	4	9(8- 10)		
02-28-90	6	18(10- 26)		
06-28-90	6	75(43-124)	54	122
07-26-90	6	123(37-358)	57	189
08-23-90	6	125(43-313)	74	200

S = small fish, L = large fish

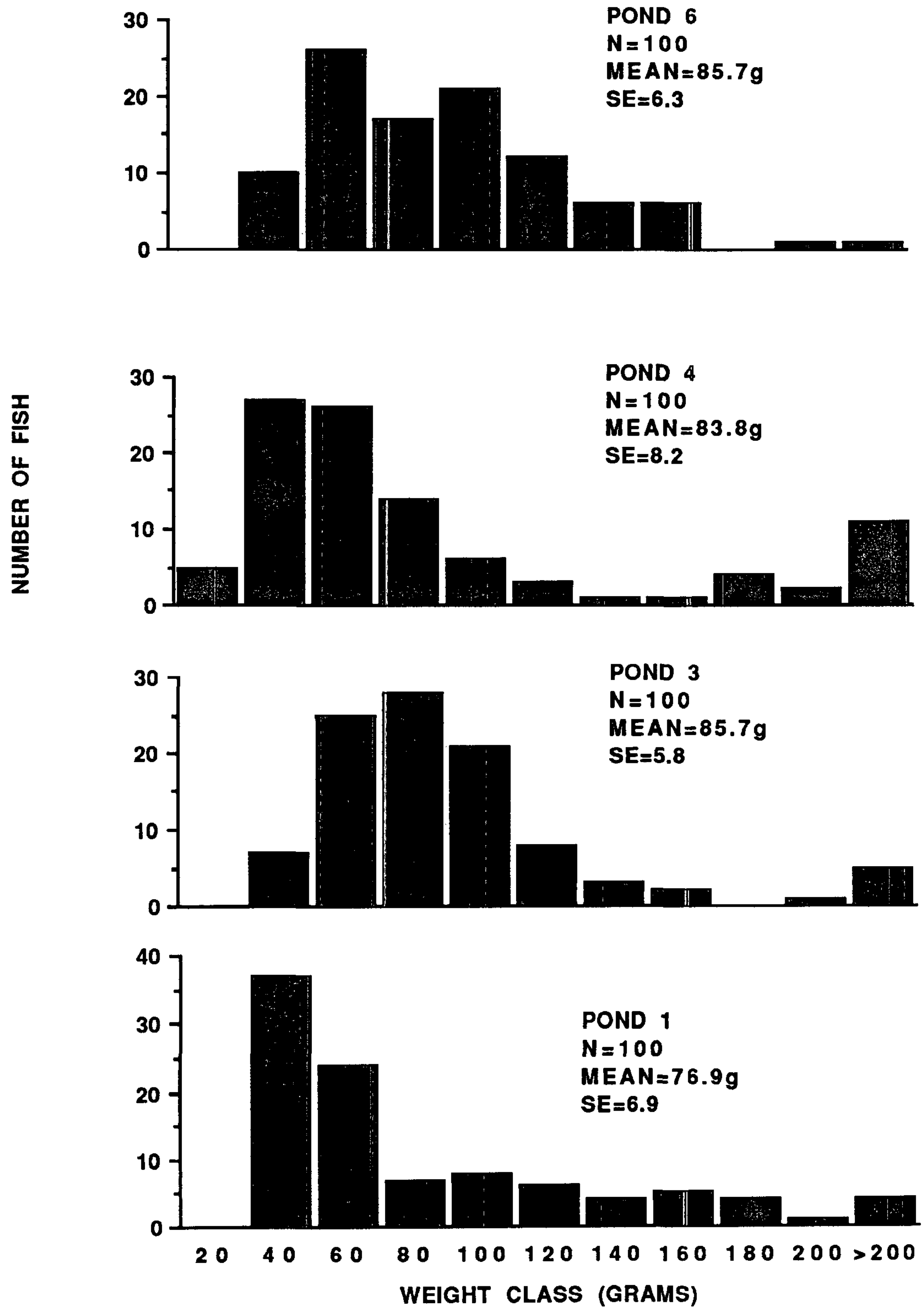

Figure 20. Weight-class distribution of bighead carp from the ponds (12-21-90 to 01-02-91).

definitive answer for these growth differences, but it might be related to the triploid production technique.

Fish survival and biomass: Fish survival and final biomass was determined between 12-21-90 and 01-02-91 using mark-and-recapture procedures (Ricker 1975). Because of slow fish growth and high mortality, especially in HSD ponds, the final biomass of fish was low (Table 20). Fish production in the HSD ponds was lower than the initial stocked biomass of fish.

Table 20. Fish survival rate and biomass estimated by mark - recapture procedures (12-21-90 - 01-02-91).

Pond no.	Fish weight (g) Mean ± S.E.	Fish survival (%) and 95% C.I.	Fish biomass (kg/ha) and 95% C.I.
3 (LSD)	85.7±5.8	44(33-62)	80(59-111)
6 (LSD)	85.7±6.3	39(33-47)	71(60-85)
1 (HSD)	76.9±6.9	10(8-12)	97(81-116)
4 (HSD)	83.8±8.2	6(5-7)	60(50-74)

Note: LSD - low stock density ponds, HSD - high stock density ponds.
1) Ricker's (1975) method was used to calculate 95% confidence interval (C.I.).

DISCUSSION

Water temperature during the study period followed typical seasonal trends for Lake Apopka as described by Brezonik et al. (1978), and for other Central Florida Lakes (Shireman et al. 1979, 1983). Minimum temperatures were found in December and January. Maximum temperatures occurred in August, 1989 and 1990. The lake and ponds had similar seasonal changes in water temperature. Dissolved oxygen concentrations were high in the ponds and lake and remained favorable for fish life throughout the study.

Water clarity as measured by Secchi disk was extremely poor in Lake Apopka during our studies. This has been a long lasting and stable phenomenon in the lake. Similar Secchi disk readings were reported in 1977 by Brezonik et al. (1978). Water clarity in all experimental ponds was greater than in the lake, indicating less suspended materials or algae in the ponds.

An important issue of this study is whether the control pond group was comparable to Lake Apopka. If the pond group does not compare with the lake, the results of the bighead carp experiments in the ponds may not be applicable to Lake Apopka. There were significant differences between the lake and the control ponds in some water quality parameters, such as Secchi disk visibility, pH, total nitrogen, total phosphorus, and chlorophyll _a_. No differences in plankton abundance were found between the lake and the control ponds in blue-green algae, _B.B._, total algal number, rotifers, copepods, and total zooplankton number.

The ponds stocked with bighead carp occupy an intermediate position between Lake Apopka and the control pond group in all plankton abundance parameters. These parameter values are not different between the control and bighead carp stocked ponds, but there are significant differences between the bighead carp ponds and the lake. It suggests that bighead carp exerted some effect on the pond ecosystem, but the effect was not large enough to cause significant differences between the stocked and unstocked ponds.

Despite the differences in algal abundance between the lake and the ponds, the structure of the algal community remained the same in the compared water bodies. This structure was characterized by extreme dominance of blue-green algae (> 90 percent), a reduced number of total algal species, and a clear dominance of several algal species (approximately 10 species), which remained relatively constant during the study period.

Clear differences in zooplankton assemblages were not found among the lake and the ponds. A zooplankton peak occurred shortly after filling the ponds, but for the most part zooplankton numbers averaged between 300 and 600/l, which is close to the zooplankton numbers found in Lake Apopka in 1977 and 1978 (Brezonik et al. 1978). Zooplankton abundance in Lake Apopka averaged about 1600/l, which is almost three times as high as reported by Brezonik et al. (1978). Zooplankton species composition found in our study was similar to that reported earlier. Dominance of small cladocerans, (Bosmina sp., Chydorus sphaericus), and small-bodied rotifer species is indicative of eutrophic conditions (Edmondson 1985).

Lower concentrations of nutrients were found in the experimental ponds probably because of the low inflow of nutrient-rich lake water into the ponds and/or was possibly due to lack of resuspension of nutrients from the pond sediments. Brezonik et al. (1978) stated that internal loading from the sediments contributed to higher nutrient concentrations in the lake water. The mean inflow rate averaged between 0.53 and 0.55 l/sec, which would be indicative of a total water volume exchange in the ponds about every 43 days.

Fish food samples included in this report were collected between February and August, 1990. They represent fish feeding habits from the coolest and warmest parts of the season. No distinctive seasonal change in food composition was found. Although zooplankton were highly preferred they were not an important constituent in the fish diet. The zooplankton share in fish food averaged 1%, except for the February, 1990, sample when it ranged from 15 to 24% in the individual ponds. The minor importance of zooplankton in bighead diets may have been due to the low zooplankton density in the ponds. When the density of zooplankton was highest, as in February 1990, the share of zooplankton in the diet increased. This finding is in agreement with literature data. All the authors dealing with food habits of bighead carp concluded that this fish feeds mainly on zooplankton (Bobrova 1966, Voropaev 1968, Danchenko 1971, Cremer and Smitherman 1980, Opuszynski 1981, Spataru et al. 1983). However, the same authors stated that the amount of zooplankton in the fish diet depends on the zooplankton density. When zooplankton density decreased, bighead carp fed on phytoplankton and detritus. These two components constituted the bulk of bighead carp food in our study. BB was especially important among the algal species eaten by the fish. The share in the diet was 66 to 70% of volume and 50 to 60% of the dry weight (Table 14), even though the numerical percentage of this species in the total number of algae was smaller than 1% (Table 10). High selectivity of BB was due to its large size. For example, the average size of a colony measured in pond 4 on April 25, 1990 was 112 µm, ranging from 55 to 220 µm. The space between the gill rakers of bighead carp ranges from 20 - 80 µm (Voropaev 1968, Spataru et al. 1983); therefore, most of the BB colonies were probably retained by the filtering apparatus. Small algae apparently pass through the gill rakers.

If the index of filling is known, the daily food ration of bighead carp can be calculated. The daily food ration or, in other words, the daily food consumption (D) is given by the formula: $D=A(24/n)$, where A is the average amount of food in the intestines, and n is the food evacuation rate, i.e. the number of hours necessary for complete intestinal evacuation. Assuming the evacuation rate equaled 10 hours (Opuszynski and Shireman in press), the mean daily food ration of bighead carp ranged from 5.5% of fish body weight in pond 3 to 9.1% in pond 4. These values are higher than those (2% to 5.7%) reported by Opuszynski and Shireman (in press) for bighead carp kept in cages. No other literature values for bighead carp food rations were found. Daily food ration data are available, however, for silver carp, a species closely related to bighead carp. Savina (1965) found that daily food rations of silver carp were 0.02 - 1.1% of fish body weight. Omarov (1970) and Moskul (1977) reported significantly higher values of 17.2 and 20.9%, respectively. Bialokoz and Krzywosz (1981) studied the seasonal feeding habits of silver carp in a Polish lake where daily rations ranged from 5.7 to 11.7% during summer months and dropped to 0.007 to 0.076% in the winter. If the winter data from Bialokoz and Krzywosz (1981) are excluded, their results are very close to the results reported in our studies. Gerking (1984) estimated a maintenance ration of 5.6 to 5.9% for another herbivorous fish, *Sarpa salpa*, fed on a green algae under laboratory conditions.

In order to determine the stocking rate of bighead carp needed to consume BB in Lake Apopka, the quantity of BB in both the lake water at the intake site and AT of the carp was determined. The food evacuation rate determined by Opuszynski and Shireman (in press) was used in the calculations. We calculated that a fish biomass of 750 kg/ha would consume 13% of the BB standing crop/day (Table 21). Therefore, a fish stocking rate of 750 kg/ha would consume the total standing crop of BB in Lake Apopka in 8 days (Table 21). These stocking rates are probably inflated because the calculations were based on the consumption of small fish. The fish in our study were not large enough to have reached their maximum efficiency.

The consumption rate calculated for BB for bighead carp is probably underestimated, because the consumption rates were calculated according to the diets of pond fish. The quantity of BB in the ponds was 3-6 times lower than in the lake (Table 10). Bearing in mind that the consumption rate of filter-feeding fish is algae-density-dependent (Drenner et al. 1984), the consumption of BB by bigheads, if stocked in Lake Apopka, may be more than twofold greater than our calculated values. The influence of bighead carp grazing on BB populations, however, is difficult to predict accurately, because the P/B ratio (production to biomass) of BB is unknown. The P/B value (turnover rate) of an organism, or group of organisms, is the ratio of production to biomass. When calculated on a growing season basis it serves as a general index of the rate of organic substance synthesized relative to standing stock (biomass). Smaller organisms are expected to have greater P/B values. This ratio averages 113 for phytoplankton, but ranges broadly from 8.9 to 359 (LeCren and Lowe-McConnell, 1980). If the P/B ratio of BB is low, which is probable considering the large size of this alga, the influence of bighead grazing would be greater. Even though bighead carp prefer BB, our study did not show a significant effect of the fish on the population of this algae in the experimental ponds. The probable reason seems to be the small biomass of fish. This biomass (60-97 kg/ha) is still considerably below that which may be needed to significantly decrease BB in Lake Apopka. Higher fish biomass was not achieved because of the short experimental period and slow growth and high mortality of the stocked fish. Pond stocking began on January 4, 1990, and was continued until June 20, 1990. Data were collected until August, 1990. Estimation of fish survival rate and biomass was made between December 21, 1990 and January 2, 1991.

Table 21. Hypothetical *Botryococcus* consumption per hectare-meter by different stock densities of bighead carp for Lake Apopka.

Bighead carp Stock density (kg/ha)	No. of *Botryococcus* eaten per day (colonies x 10^5)	% of *Botryococcus* standing crop eaten per day	No. of days needed for standing crop consumption
1	527	0.017	5882
100	52,700	1.7	59
250	131,750	4	23
500	263,500	8	12
750	395,250	13	8
1000	527,000	17	6

No. of *Botryococcus*/ml in Lake Apopka = 31 (see Table 6)
No. of *Botryococcus*/g fish body weight = 18,500 (see Table 10, February, 1990)
Bighead carp food evacuation rate = 8.4 h (Opuszynski and Shireman, in press)

The reasons for the slow fish growth and high mortality are not clear and need further investigation. The fish population was differentiated soon after stocking into two groups of fish. The growth rate of the first group was apparently retarded, whereas the second group of fish grew reasonably well (Figure 16). The differential growth rates might have been caused by the sterilization technique. The triploid production technique involves exposing fish eggs to high water pressure, about 8000 lbs/square inch (Aldridge et al. 1990). This technique has been used for several years to produce sterile triploids of the Asiatic grass carp. It is well known that grass carp triploids grow slower and more abnormally developed individuals can be found among them in comparison to normal diploid fish. The production of triploid bighead carp is a relatively new procedure developed at our laboratory. Thus, the fish are not generally available from commercial sources. To date not enough experience has been gained to evaluate the influence of the sterilization technique on the quality of the fish. Furthermore, it is difficult to say whether this pattern of growth is typical for triploid bighead carp or if it was specifically due to the batch of fish used in this experiment.

Due to low fish biomass, the question as to whether the bighead carp would be able to change the structure of the phytoplankton community in Lake Apopka was not fully answered. The data collected, however, clearly substantiate that bighead carp fed selectively on BB, and that this algae constituted the bulk of the fish food. Moreover, despite low fish biomass, some changes in the phytoplankton community structure were evident, as indicated by the lower ratio of blue-green/green algae in the bighead stocked ponds. Therefore, we continue to hypothesize that bighead carp could have exerted more pronounced changes in phytoplankton community structure with a larger fish biomass. This can be confirmed by experiments with other filter-feeding fish (Drenner and Taylor 1984, Drenner et al. 1984). These fish were able to suppress populations of large-sized algae, providing the algal species were large enough to be effectively ingested by the fish.

Although bighead carp do consume large algae and would probably change the algal community to smaller forms, additional fish species should be used to improve water quality. For example, Henderson (1978, 1979) reported that grazing of plankton by silver and bighead carp reduced ammonia nitrogen levels by 27% and phosphate levels by 2.72% in Arkansas oxidation ponds. Organic loads (BOD_5) were reduced by 96% and total suspended solids by 78% (Henderson 1983). These ponds contained 2,280 pounds of silver carp/acre and 156 ponds of bighead carp/acre. Leventer (1972, 1979) studied the effects of introducing a number of different species (polymanipulation) to reduce algae and nutrients. This was done in a large water reservoir in Israel. Generally, algae and nutrients were reduced by approximately 25%. These studies indicate that the polymanipulation method has definite potential. Preliminary results from this study confirm that bighead carp consume large algae, but in order to fully investigate the technique additional time and fish species are needed in the experiments.

CONCLUSIONS

1. The experimental ponds adjacent to Lake Apopka were generally less eutrophic than the Lake, possibly because of low inflow rates of the nutrient-rich lake water into the ponds and less bottom mixing by the wind.

2. The dynamics of physical/chemical parameters and structure of plankton communities in the ponds were similar to those in the Lake, which made the ponds a suitable experimental site for the Lake Apopka ichthyofauna reconstruction project.

3. Bighead carp had no statistically significant effects on any of the water quality parameters tested.

4. Botryococcus Braunii, in spite of a low numerical occurrence, was an important component of the algal biomass. This alga, because of its large size, is not consumed by zooplankton.

5. BB was selectively eaten by bighead carp.

6. Bighead carp did not cause a reduction in BB number, but they changed the ratio of blue-green to green algae in the experimental ponds.

7. No significant changes resulted from the use of bighead carp at the densities achieved in this study. However, because the biomass and size of fish were less than desired, the hypotheses were not fully tested at the 750 kg/ha biomass level.

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