PREFACE

This report describes results of observations on the effects of artificial lake mixing during the period September, 1975 to September 1976. During that interval baseline data were obtained on the limnology and algal biomass of Arbuckle Lake, Oklahoma. These data are used in this report in a comparative manner to access the impact of lake mixing in the previous year, 1975. The 1976 data also form a base for comparison to data collected in 1977, when the lake was experimentally mixed. At this writing (September, 1977) the 1977 data are being analyzed for preparation of a report, which will be available in December, 1977.

Also described are results from 1976, when Ham's Lake was experimentally mixed for the third straight season. Algae data taken during 1975 were analyzed during 1976 using principal component analyses and a resume of the results is presented here. Also, an effort was undertaken in 1976 to investigate the effects of lake mixing in Ham's lake using an experimental approach. Columns of lake water were isolated and the effects of artificial mixing on fish feeding and community were studied.

Principal component analyses were preformed by Dr. Timothy Allen. Dr. Christopher Tooker executed the column experiments and Dr. Barney Venables analyzed the data. Mr. Patrick Downey took data at Arbuckle Lake during 1976 and compared the limnology of the lake between years.

Funds for the research were provided by the Office of Water Research and Technology and the Bureau of Reclamation.

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INTRODUCTION

Anoxic conditions develop in the hypolimnia of deep reservoirs during the summer, as a result of thermal stratification. Anoxic conditions increase reduced compounds (ammonia, hydrogen sulfide, etc.), which lower water quality. Lower water quality increases water treatment costs and restricts fish habitat. Continuous circulation of reservoirs by mechanical pumping is a promising solution to these problems. However, the cost of mechanical pumping has been relatively high and the continuous circulation of large lakes has never been accomplished. A pump designed by Dr. James Garton (Figure 1) holds the promise of low operating cost and the potential of entraining sufficient volumes of water to keep a large lake destratified. This pump was used in 1976 to circulate Ham's Lake (area 40 ha, 9 m deep), Oklahoma, and thus, demonstrate its effectiveness in improving water quality. In addition, the pump had been used to continuously circulate Arbuckle Lake, Oklahoma, (area 950 ha, 27 m deep) during 1975.

Water quality decreases during the summer in both lakes. It was the central goal of this research to determine if the Garton pump could improve water quality in Arbuckle Lake and Ham's Lake. Another goal was to assess the environmental impact of whole lake mixing on the biota. The latter goal is necessary because, for example, it is not clear how lake mixing affects the growth, distribution, and survival of fish and their food supply.

OBJECTIVES

One objective was to determine the effects of lake mixing on water quality and the standing crop of the phytoplankton of Arbuckle Lake. The objectives for Ham's Lake were to determine the long-term effects of lake mixing on water quality and the standing crop of phytoplankton. A further objective for Ham's Lake was to determine the effect of artificial mixing on the distribution of fish and their food supply.

Control water quality and phytoplankton biomass data taken in 1973 and 1976 at Arbuckle Lake are compared to similar data taken in the experimental year, 1975. At Ham's Lake water quality, algal biomass and fish growth for 1973-75 are compared to similar data taken in 1976. The effect of mixing on the food of fishes was investigated experimentally in isolated columns of lake water (limnocorrals) at Ham's Lake.

RESULTS

The results section is organized into four parts. The first part compares the limnology and algal biomass in Arbuckle Lake when the lake was not mixed to years when it was mixed. The second part deals with the long term effects of lake mixing on the limnology, algal standing crop and fishes of Ham's Lake. The third part deals with the effects of mixing on community metabolism and on fish feeding in limnocorrals.

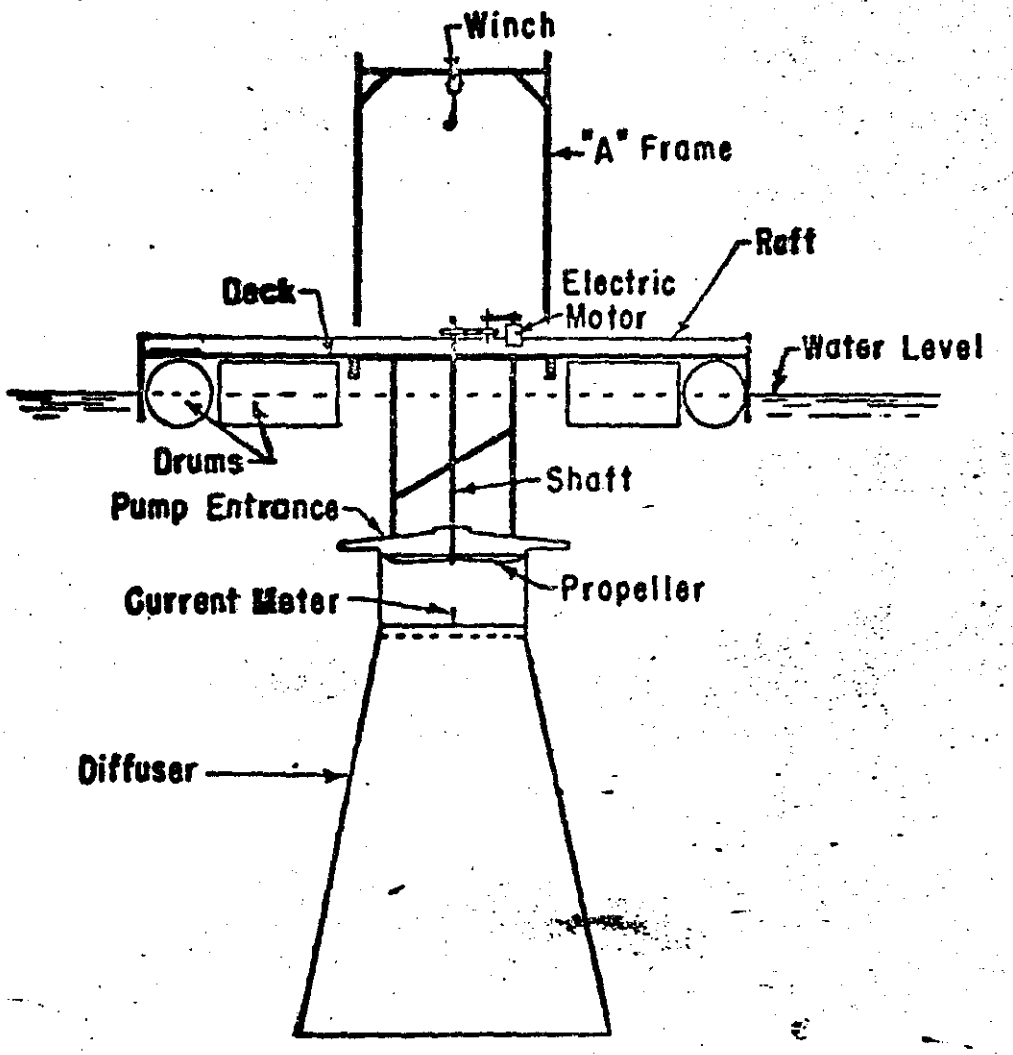

Figure 1. Side view of Garton pump, a scaled up version of which was installed at Arbuckle Lake. The propeller of the device used at Arbuckle Lake was approximately 3m in diameter.

Methods

Pump operation Artificial destratification was attempted on Arbuckle Lake during the summers of 1973 through 1975. The pump used in 1973 was an air "gun" which had virtually no impact on the lake (Toetz, 1975). The Garton pump was in operation in 1974 from July 17 to Sept. 1, and in 1975 from June 2 to Sept. 13.

Field procedures During the summer of 1973 through 1976, water quality parameters were measured at stations 1, 3, 4, 5, and 6* (Figure 2). Temperature and dissolved oxygen (DO) measurements at each station were taken using a YSI 51A temperature and DO oxygen meter and probe. Secchi disc measurements were made with a 20 cm Secchi disc.

In addition, pigments (concentration of chlorophyll a), Secchi disc,and triplicate manganese ($^{1}Mn^{++}$)samples from near the bottom were taken at each station. At station 1, water for chemical analysis was taken at depths of 0, 4, 8, 12, 16, 20, and 24 m using a Van Dorn water sampler. The water for chemical analysis was collected in 4 liter polypropylene bottles and put on ice. Water for sulfide ($S^{=}$) determinations was stored in 125 ml reagent bottles or glass stoppered graduated cylinders and returned on ice to Stillwater for analysis. Pigment samples wer taken by drawing two composite samples of the entire water column at stations 1, 5, and 6 by pooling like aliquots of water taken at one meter intervals with Kemmerer bottle. Two 400 ml subsamples were taken from each composite for pigment analysis. Water for reactive phosphate (PO_4^{-3}) analysis was taken from 0, 4, 8, 12, 16, 20, and 24 m placed on ice in 250 ml polyproylene containers and returned to Stillwater for analysis.

*The stations 1, 5, and 6 are referred to as station 7, 6, 5 respectively in Toetz (1975) and Duffer and Harlin (1971).

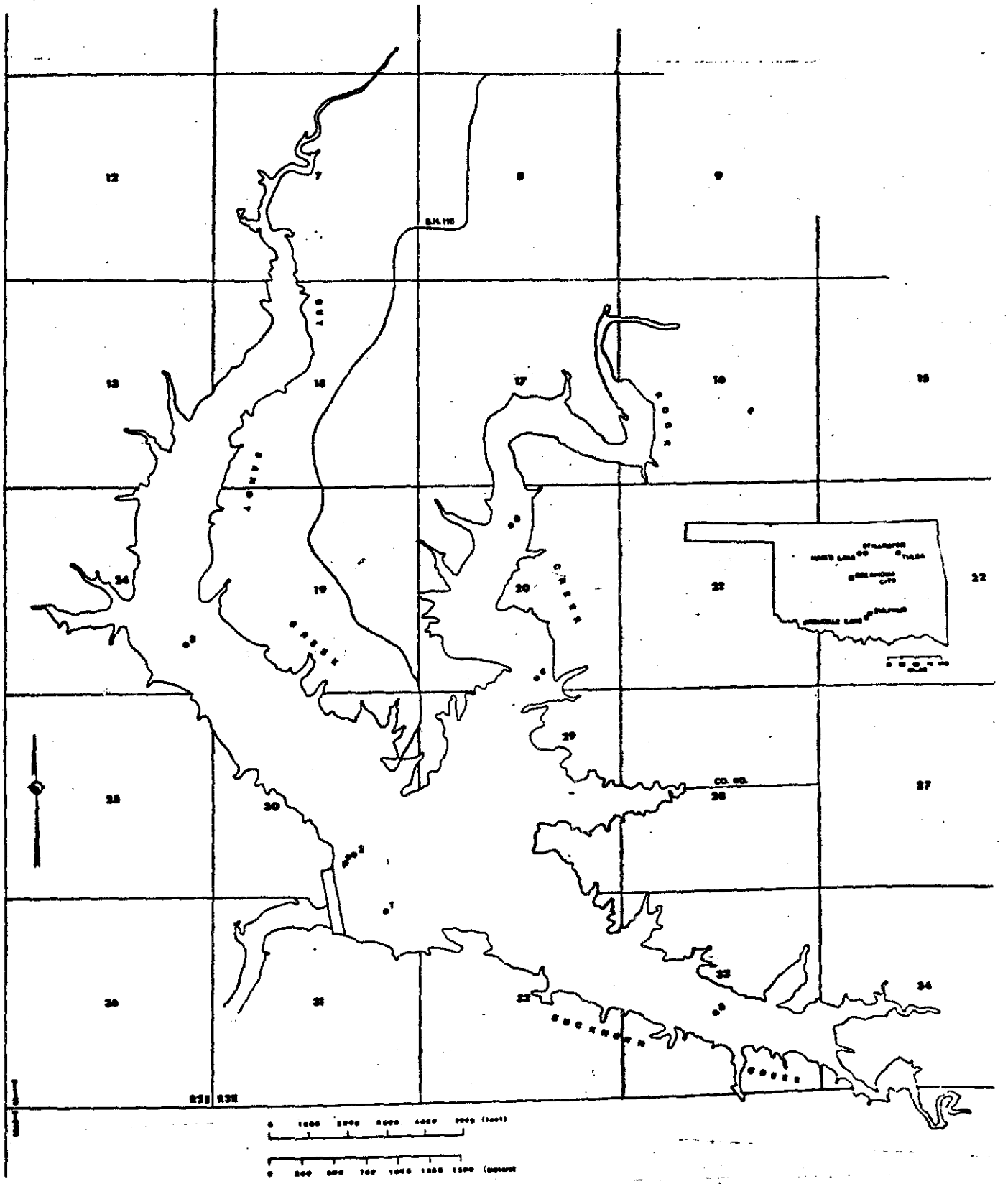

Figure 2. Map of Arbuckle Lake showing location of sampling stations 1,3,4,5, and 6.

The sampling procedures for 1974 through 1975 were basically the same as for 1973 with the following exceptions: Station 3 was added to the routine in 1975 and 1976. Station 4 was used in place of station 6 in 1976. Instead of a Van Dorn or a Kemmerer bottle,an electric bilge pump was used to draw water samples in 1975 and 1976. The reagents for $S^{=}$ determinations were added in the field in 1974 through 1976.

In addition, community metabolism was measured on August 10 and September 11, 1976, at station 1 (McConnell, 1962). Since the sensitivity of the oxygen probe ($\pm$0.5 mg/l) was inadequate, DO was measured using the Alsterberg modification of Winkler method (A.P.H.A., 1965). Water for the DO measurements was drawn at 2 m intervals from the surface to 10 m.

Pigment and algae samples during 1976 were taken at each station by pooling like aliquots of water from 0, 1, 2, 3, and 4 m into a composite sample. Two 400 ml subsamples were taken from the composite sample for pigments analysis and two 150 ml subsamples were taken for enumeration of algae.

The dates on which sampling took place each year are given in Table 1.

Laboratory methods Upon collection, the water samples were taken to a temporary field laboratory where water for nitrate ($NO_3^{=}$), nitrite ($NO_2^{=}$) and ammonia (NH_4^{+}) was filtered through Reeve Angel (RAF) or Gelman glass fiber filters. The filtered samples were then taken to Stillwater for analysis. Storage and preservation methods are given in Table 2, as are literature citations of analytical methods.

Particulate carbon (PC) was extracted by filtering water on muffled Reeve Angle filters and placing the filters in a desiccator. The filtrate thus obtained was used for determination of dissolved organic carbon (DOC). Water for pigment samples was filtered on glass filters and only the filters were retained.

Table 1

Dates on which sampling took place, 1973-1976.
Asterisk indicated days for which only DO, temperature, Mn^{++}, algae, and pigments were analyzed.

1973	_____	6/20	7/10	7/25	8/7	8/23	_____
1974	_____	6/20	7/10	7/25	8/7	____	_____
1975	6/10	6/25	7/8	7/25	8/7	8/30	_____
1976	_____	6/22	7/9*	7/21	8/11*	8/25	9/11

Table 2. Preservation, storage, and analytical techinque for water chemistry analysis.

Parameter	Preservation	Transportation Storage	Storage container	Analysis
$NO_3^{\#}$	none	on ice	polyethylene	Strickland & Parsons, 1968
NO_2^-	none	on ice	polyethylene	Strickland & Parsons, 1968
NH_4^+	none	on ice	polyethylene	Soldranzo, 1969
PO_4^{-3}	none	on ice	polypropylene	Strickland & Parsons, 1968
DOC	2 ml. conc. H_2SO_4	room temp	glass	Beckman 915 Total Organic Carbon Analyzer
Mn^{++}	2 ml. conc. HNO_3	room temp	polyethylene	Varian Techtron Atomic Asorbtion Spectrophotometer
Pigments	90% acetone	on ice	glass	Strickland & Parsons, 1968
$S^=$		room temp in dark	glass	Strickland & Parsons, 1968
BOD_5	none	on ice	dark polypropylene	Strickland & Parsons, 1968

Treatment of the data: The summer of 1975 was considered the experimental year. Data collected during 1975 were compared to those collected by Duffer and Harlin (1971) and those collected during 1973, 1974, and 1976. A t-test was used to compare NH_4^+, $NO_3^=$, NO_2^-, $S^=$, Mn^{++}, PO_4^{-3}, pH, total alkalinity, and DO data. An F-test was used to test for differences in chlorophyll a and near-bottom concentrations of Mn^{++} between years at the same station.

Toetz (1975) has shown that there are two thermoclines present in the lake (Figure 3). The first occurs at about 10 m and the other is found at 20 m. Since the amoont of water in the second hypolimnion is insignificant (less than 1% of the entire volume of the lake), only the part of the hypolimnion between 10 and 20 m will be considered in this discussion.

Results and Discussion

Arbuckle Lake Limnology: Arbuckle Lake is a warm monomictic lake which is normally stratified from early June to mid-October. Water temperatures during stratification range from 15°C at the bottom (24 m) to 30°C at the surface. The depth of the epilimnion ranges from 6 to 15 m. The ratio of the volume of the epilimnion to that of the hypolimnion is approximately 3:2. Lake level remains quite constant, and Secchi disc transparency measurements range from 1.5 to 2.0 m.

Temperature differences between the surface and 20 m for the years 1968 and 1973-1976 are shown in Table 3. Mean hypolimnetic concentrations of PO_4^{-3}, NH_4^{+}, BOD_5, DOC, $NO_3^{=}$, NO_2^{-}, and $S^{=}$ are given in Table 4. A similar table (Table 5) shows mean concentrations of these substances in the epilimnion. Vertical profiles of pH and total alkalinity during late July are seen in Figures 4, and 5, respectively.

The 1976 community metabolism data demonstrated low gross primary productivity for the lake. Results of the August 10 measurements show a production: respiration of 1.28. During September 10, there was less than a half day of overcast. This was sufficient to decrease the ratio to 0.26. Although data were taken on only two occassions, we did work out the exact protocols which were used to measure community metabolism in 1977.

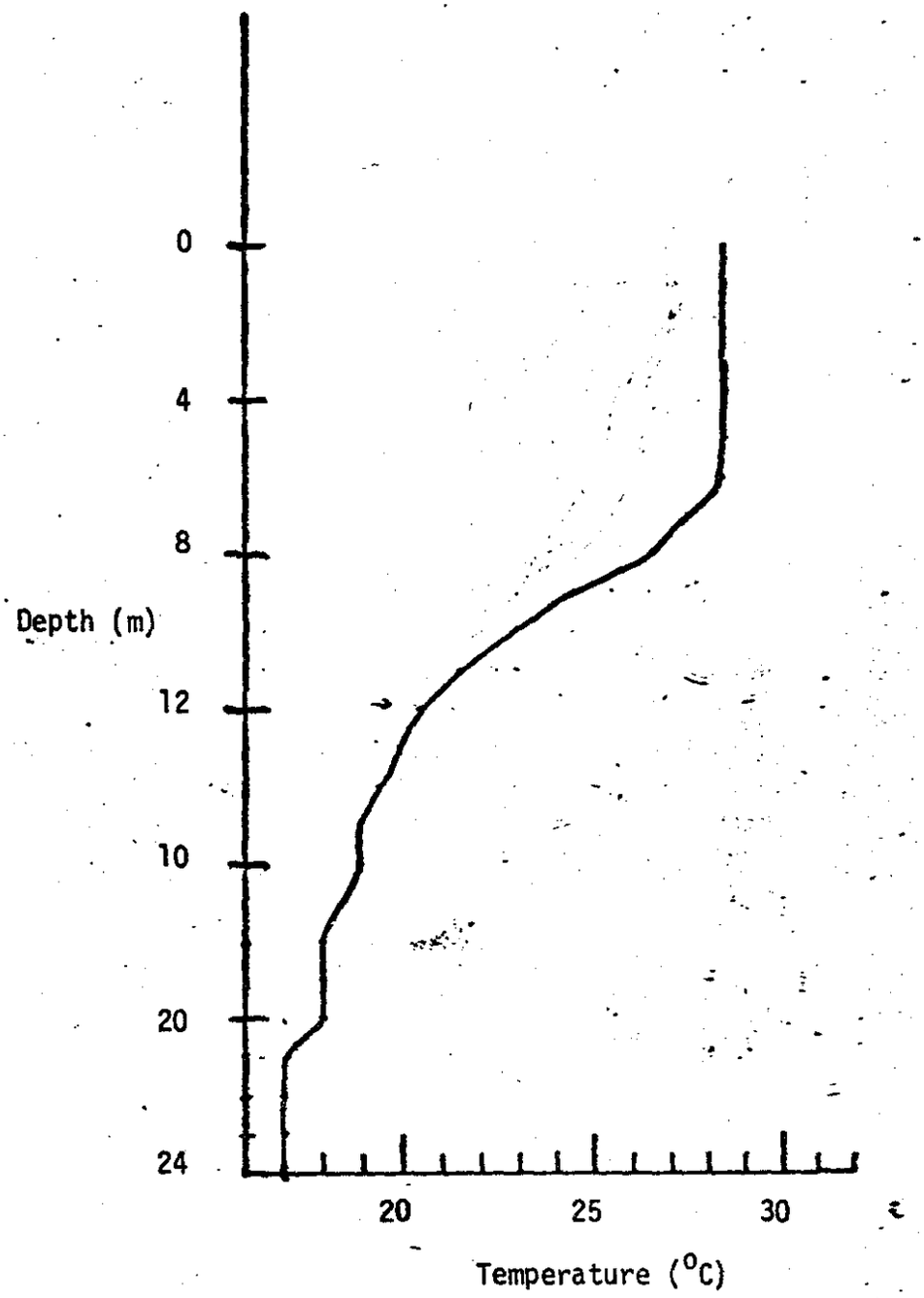

Figure 3. Vertical temperature profile at station 1 in late July, 1976 showing the two thermoclines (at 20 and 8 m) characteristic of Arbuckle Lake.

Table 3. Temperature differences (C^{O}) between the surface and 20 m in Arbuckle Lake. Differences in 1975 are significantly less than for control years ($P < 0.05$). ND = no data.

	DATE				
YEAR	6/20	7/10	7/21	8/7	8/23
1968	10.3	ND	11.0	ND	10.0
1973	7.2	9.0	11.9	8.8	8.1
1974	10.0	11.5	12.7	10.0	ND
1975	6.9	9.6	5.2	5.7	3.3
1976	8.0	8.5	9.0	10.0	9.5

Parameter	1968 x̄	S.D.	n	1973 x̄	S.D.	n	1974 x̄	S.D.	n	1975 x̄	S.D.	n	1976 x̄	S.D.	n
NH_4^+	163	138.39	9	91	50.80	15	73	71.32	12	107	99.89	15	262	231.63	9
$NO_3^=$	6	5.73	9	285	566.15	15	18	20.60	12	34	37.46	15	42	57.6	9
NO_2^-	4	0.44	9	8	10.18	9	6	8.77	12	3	4.93	15	2	3.70	9
PO_4^{-3}	102	88.87	10	8	11.37	12	13	8.43	12	6	5.12	14	26	39.48	9
*BOD_5	1.8	0.73	6	0.6	0.40	10	1.7	0.36	9	2.3	0.72	12	2	0.72	18
$S^=$	217	240.14	6	19	22.94	20	5	6.64	6	29	48.17	15	9	12.33	9
*DOC	ND	--	--	184	173.67	15	23	7.54	8	14	5.47	12	27	7.91	9
*Mn^{++}	0.1	1.00	6	0.1	0.01	12	ND	--	--	0.6	0.45	12	0.6	0.04	12
*Total alkalinity	166	19.00	9	142	131.12	15	145	39.00	12	135	25.27	12	149	20.19	9
pH	7.4	0.95	12	7.3	0.03	15	ND	--	--	7.4	0.02	12	7.8	0.01	6

Table 4. Mean hypolimnetic concentrations (µg/l) of chemical parameters during summer stratification at Arbuckle Lake in 1968 and 1973-1976. Means for 1975 do not include data taken on August 30 when the lake was weakly stratified (see discussion). S.D. = standard deviation, ND = no data, * = BOD_5, Mn^{++}, and total alkalinity means are in mg/l.

Parameter	1968 x	S.D.	n	1973 x	S.D.	n	1974 x	S.D.	n	1975 x	S.D.	n	1976 x	S.D.	n
NH_4^+	38	17.04	9	9	13.46	15	21	20.92	9	37	41.93	15	51	83.26	9
$NO_3^=$	7	2.80	6	44	145.58	15	7	7.87	12	8	8.51	15	6	5.33	9
NO_2^-	4	0.52	6	4	3.27	9	4	5.22	12	1	1.56	15	< 1	0.44	9
PO_4^{-3}	52	26.98	6	2	3.74	12	6	4.97	11	1	1.81	15	3	3.93	9
*BOD_5	1.1	0.21	2	1.0	0.84	13	0.9	0.23	9	1.9	0.83	12	1.7	0.33	18
$S^=$	0	0.0	6	4	6.39	10	0	--	--	0	0.0	15	< 1	0.33	9
*DOC	ND	--	--	176	162.80	15	32	17.61	9	15	3.66	12	26	9.52	9
*Mn^{++}	.5	2.06	9	0.1	0.01	12	ND	--	--	0.0	0.0	12	0.5	0.01	12
*Total Alkalinity	164	59.20	6	135	58.84	15	137	16.00	12	127	75.45	12	132	91.69	9
pH	7.8	0.19	8	7.7	0.09	15	ND	--	--	7.5	0.07	12	8.2	0.09	6

Table 5. Mean epilimnetic concentrations (µg/l) of chemical parameters during summer stratification at Arbuckle Lake in 1968 and 1973-1976. Means for 1975 do not include data taken on August 30 when the lake was weakly stratified (see discussion). S.D.= standard deviation, ND = no data, * = BOD_5, DOC, Mn^{++}, and total alkalinity means are in mg/l.

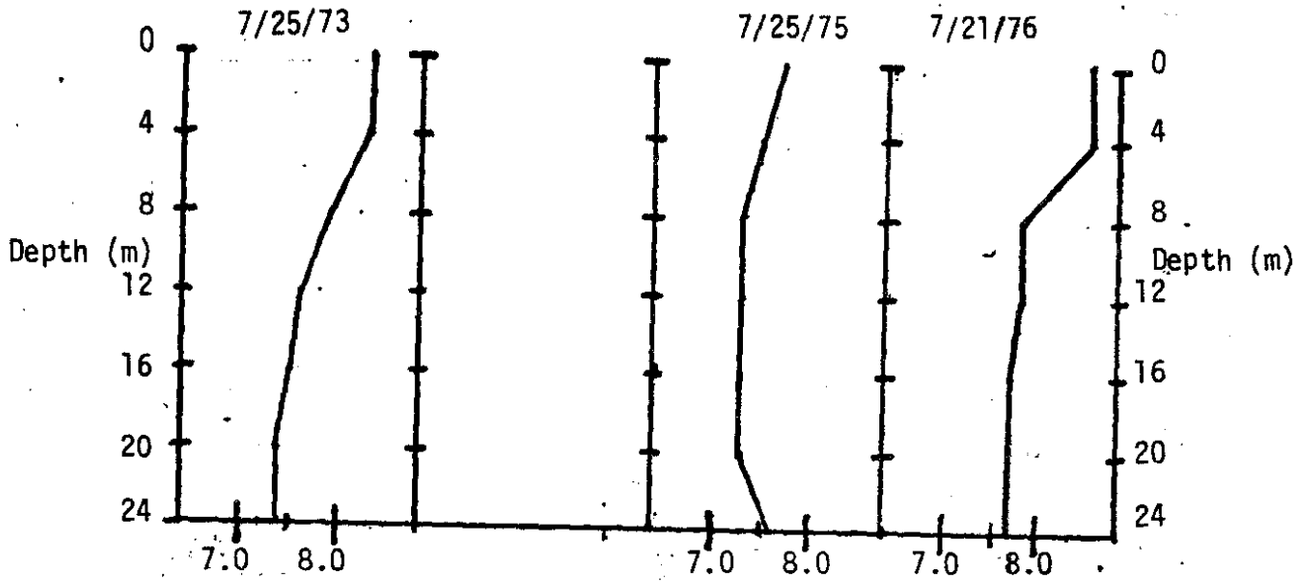

Figure 4. Vertical profiles of pH at station 1. 1974 data not shown.

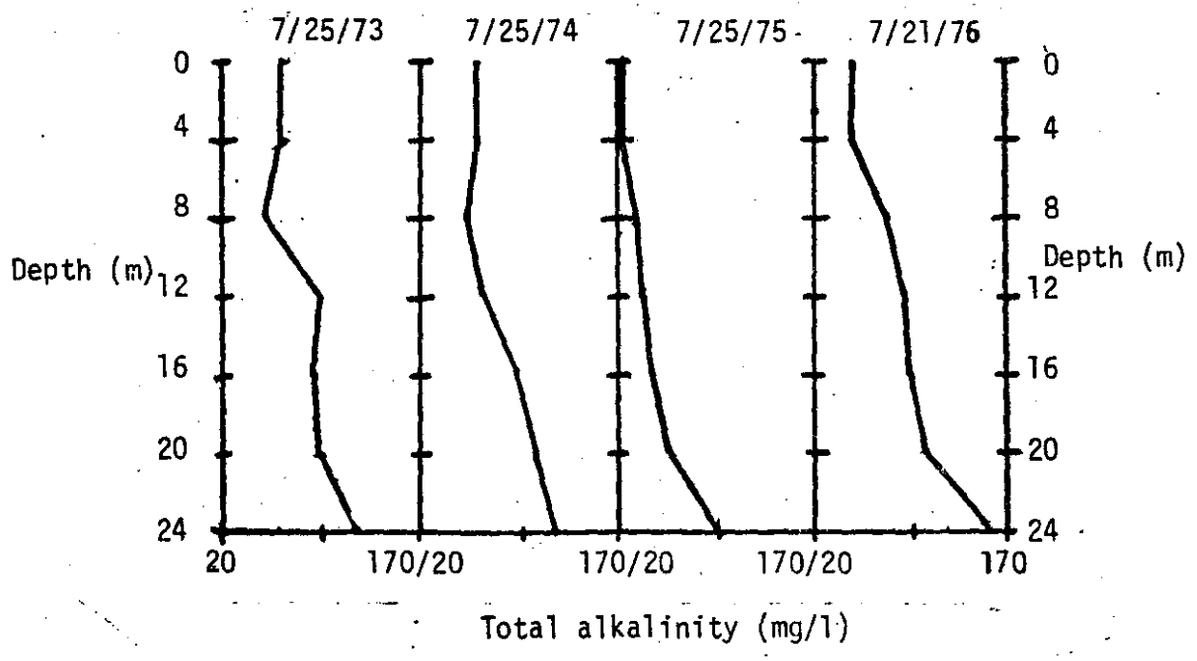

Figure 5. Vertical profile of total alkalinity at station 1 Arbuckle Lake, 1973-1976.

Algal biomass as measured by the concentration of chlorophyll a is given for stations 1 and 5 for the years 1973 through 1975 in Table 6. Due to the method of collection, the 1976 data are not comparable to previous years.

Vertical distribution of NH_4^+ and $S^=$ are seen in Figures 6 and 7, respectively. The eplimnetic concentrations of these chemical species remain low throughout the summer. As reducing conditions in the hypolimnion intensify, the reducing compounds gradually increase in concentration in the hypolimnion.

The data summarized in Tables 3-5, and Figures 4-7 reflect typical patterns of summer stratification. One unexpected characteristic of the limnology of the lake is seen in the vertical distribution of BOD_5 and DOC (Figures 8 and 9). One would expect these parameters, especially BOD_5 to show orthograde distributions. A possible explanation for the BOD_5 and DOC distributions is that organic matter falling through the water column is decomposed by the time it reaches the hypolimnion. This is plausible considering the lake's high epilimnetic temperatures. However, DOC is thought to be composed of largely refractory compounds and thus may not reflect concentrations of organic matter which undergo microbial metabolism. Data taken from 1973 through 1976 did not indicate any noticable trends in terms of changes in the chemistry of the lake.

Table 6. Mean concentrations of chlorophyll a (µg/l) in Arbuckle Lake in late July and early August. Comparisons are made between years within stations. Asterisk denotes significantly different ($P < .05$) mean. Pump operated in 1974 and 1975.

		1973	1974	1975
Station	1	6.3*	4.5	3.7
	5	7.8	7.1	4.8*
	6	8.4	9.4	5.6*

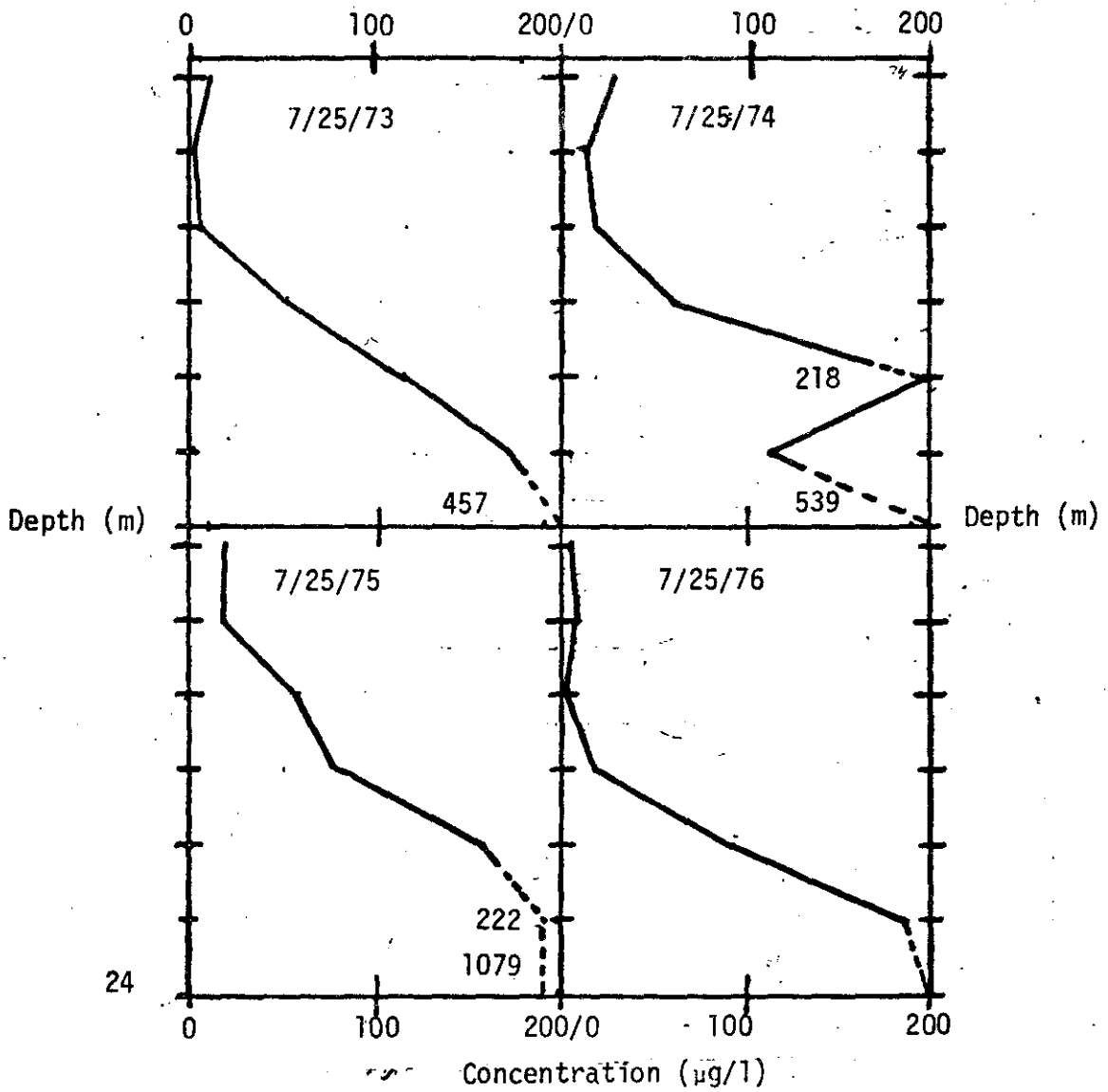

Figure 6. Vertical distribution of NH_4^+ at station 1, Arbuckle Lake, 1973-1976.

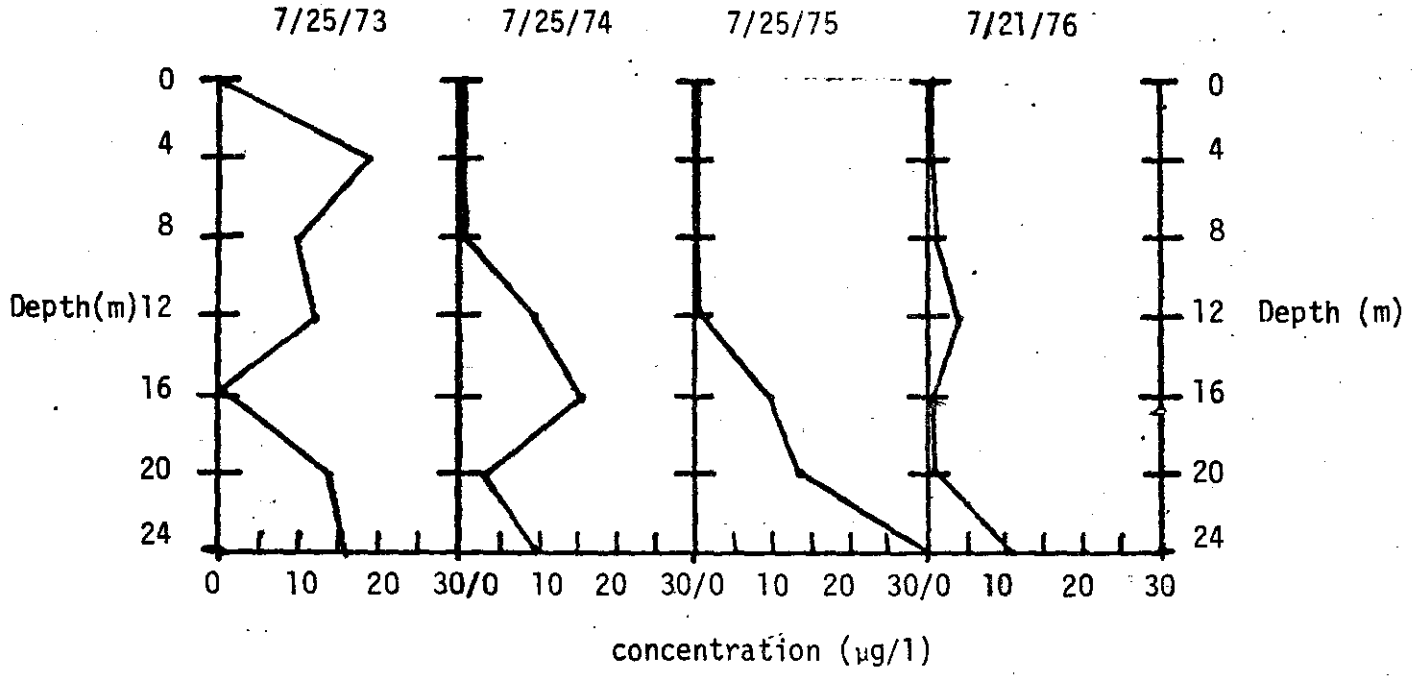

Figure 7. Vertical distribution of $S^{=}$ at station 1, Arbuckle Lake, 1973-1976.

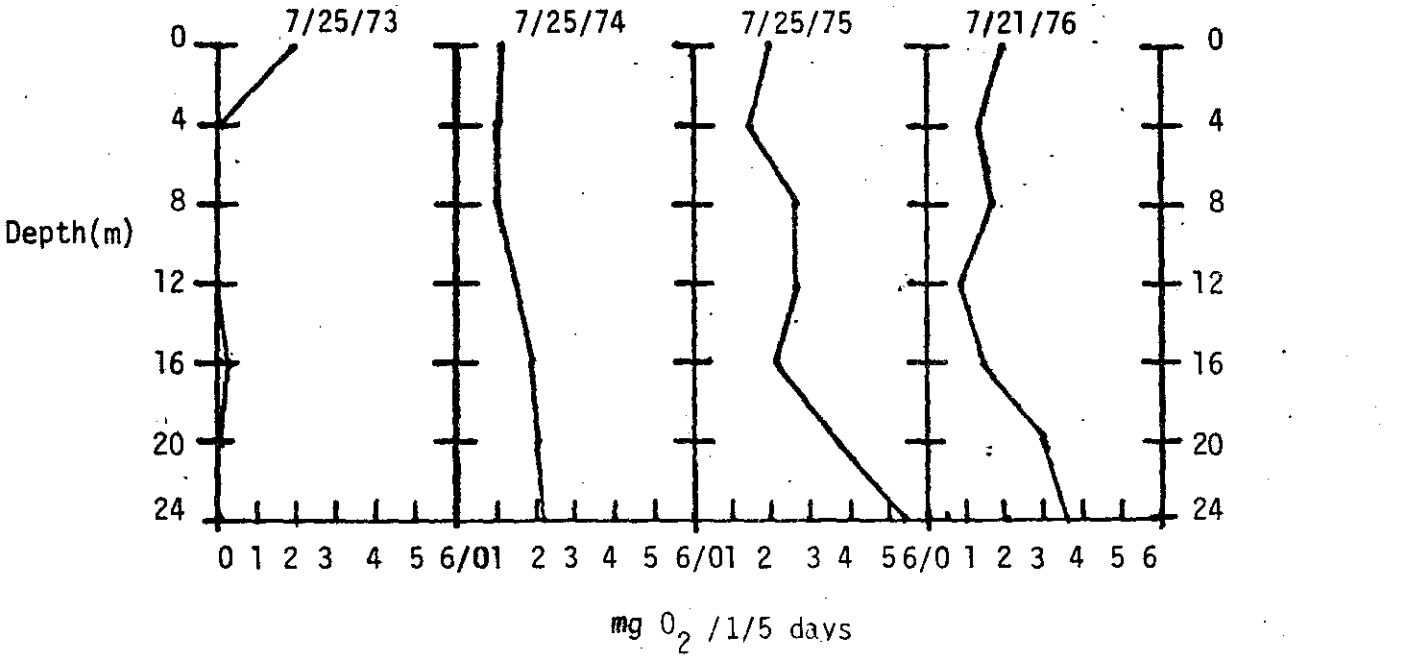

Figure 8. Five-day BOD at station 1 Arbuckle Lake 1973-1976.

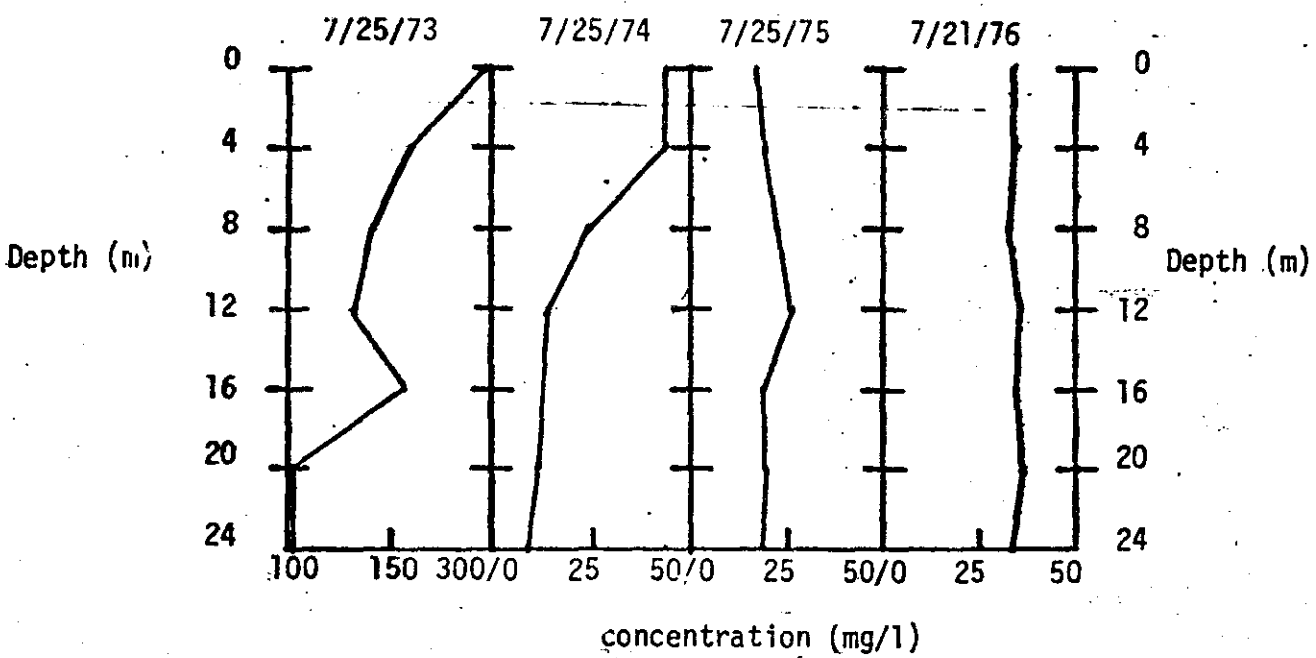

Figure 9. Vertical distribution of DOC at station 1, Arbuckle Lake, 1973-1976.

Impact of the Garton pump: The Garton pump did not destratify the lake in 1975. Statistical analyses did not indicate any yearly differences in water quality concurrent with pump operation. Vertical distribution of NH_4^+, $S^=$, and PO^{-3} as indicated by Tables 4 and 5 did not change in 1975. Likewise, vertical profiles of pH, alkalinity, NH_4^+, $S^=$, BOD_5, and DOC (Figures 4 through 9, respectively) did not change during 1975. The pump had no effect on Secchi disc transparency (Table 7).

The mass of DO in the lake for the years 1968 and 1973 through 1975 is shown in Table 8. No significant changes in the mass of DO in the lake occurred in 1975. Analysis of variance of near bottom concentrations of Mn^{++} at stations 1, 5 and 6 did not reveal any consistent differences that could be attributed to the pump operation (Table 9). There was a significant ($P < 0.05$) decline in total alkalinity in both the epilimnion and the hypolimnion during 1975. No change in pH accompanied this decline. The decrease in total alkalinity could be attributed to the pump operation, if it had occurred only in the hypolimnion. However, since it did not, I believe that the decrease in total aklalinity in 1975 is part of normal yearly variation or systematic analytical error.

There were, however, some noticeable changes in the characteristics of lake stratification which occurred in 1975. The vertical extent of the epilimnion was significantly less during 1975 than in other years (Table 10). This was brought about by a warming of the hypolimnion with no change in the temperature of the epilimnion. This is also consistent with the method of the operation of the pump.

Table 7. Secchi disc transparency (meters) of Arbuckle Lake during 1973-1976. ND = no data.

	YEAR			
	1973	1974	1975	1976
Station				
1	1.87	1.53	1.67	1.92
5	1.75	1.20	1.33	1.60
6	1.57	1.39	1.60	ND

Table 8. Mass of dissolved oxygen beneath 1 m^2 of water at stations 1 and 5 at Arbuckle Lake. Differences between years within stations are not significant ($P > 0.10$). Data from 1974 were not complete enough to include in a balanced AOV.

	1973	1975	1976
Station 1	56.4	45.0	47.1
Station 5	55.7	34.1	45.2

Table. 9. Mean concentrations (mg/l) of Mn^{++} in Arbuckle Lake during 1973-1976. Comparisons of means are made among years within stations. Asterisk indicates means which are significantly different ($P \leq 0.05$) from those of the same station.

		Station		
		1	5	6
Year	1973	1.58	0.52	0.80
	1974	1.74	0.50	0.54
	1975	4.70*	0.27	0.46
	1976	2.09*	no data	0.23*

Table 10. Vertical extent of eplimnion (in meters) at station 1, 5, and 6 during 1973-1976. Values during 1975 are significantly different from other years ($P < 0.05$).

Year/Date	6/22	7/9	7/23	8/8	8/15
			Station 1		
1973	6	6	6	8	8
1974	8	12	12	15	--
1975	9	3	5	4	5(1)
1976	7	7	7	6	8
			Station 6		
1973	9	7	7	8	9
1974	11	12	13	12	--
1975	11	4	5	6	(2)
1976	8	8	8	8	8
			Station 5		
1973	2	7	8	(2)	6
1974	7	4	7	9	--
1975	7	3	6	5	(2)

(1) weakly stratified

(2) destratified

The most significant effect of the pump with respect to improving water quality was the timing of fall overturn. Arbuckle Lake normally turns over in the middle of October. During 1975, however, the lake was very weakly stratified on August 30, at a time when the lake is normally strongly stratified (Figure 10). The lake was completely destratified shortly thereafter, thus decreasing the duration of hypolimnetic water quality problems.

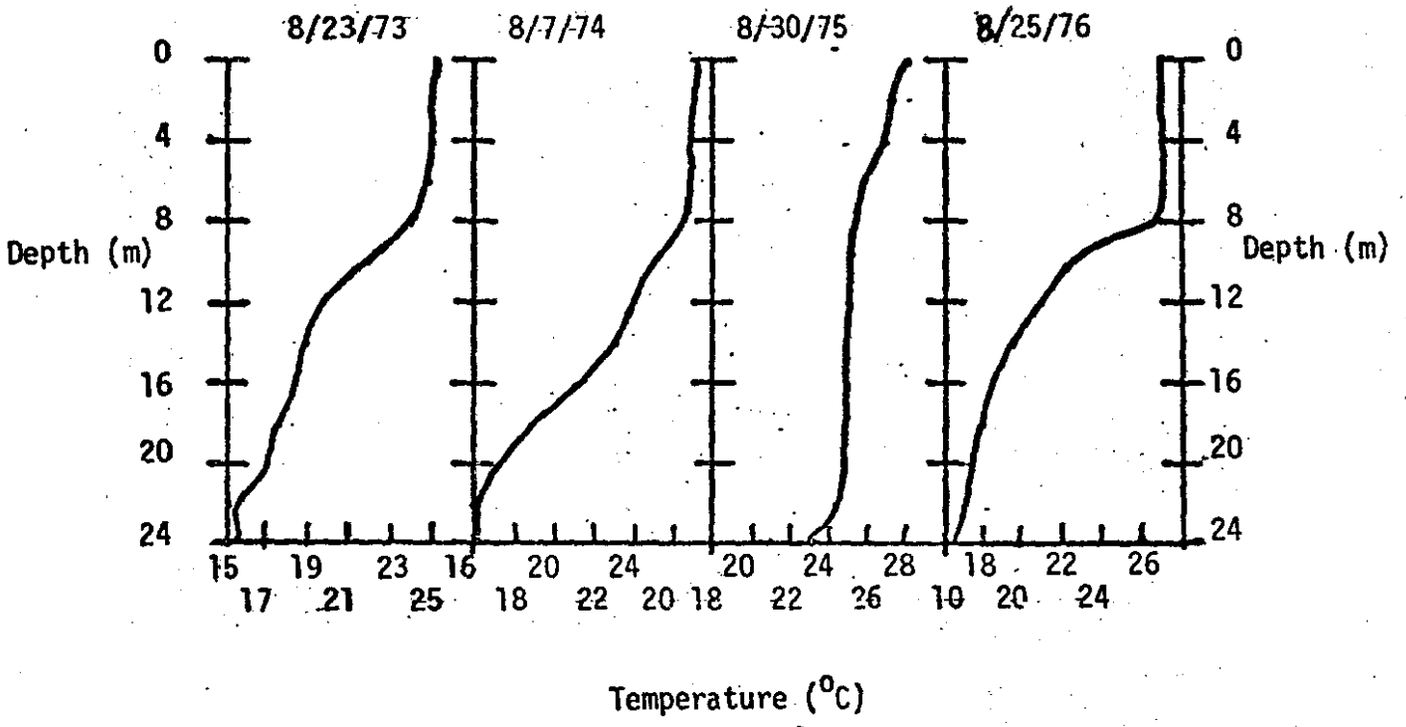

Figure 10. Vertical temperature profiles during late August (early August in 1974) showing weak thermal stratification in 1975.

HAM'S LAKE

Limnology

During 1976 the Garton pump was operated at Ham's Lake in two periods. A six foot pump was operated between June 3 and July 9 and a 3.5 foot pump was operated between July 20 and September 9. No mixing occurred in the period July 10-19.

On June 1 dissolved oxygen (DO) was less than 1.4 mg/l below 4 m. By June 8 the lowest concentration was 2.6 mg/l and by June 15 the water column contained 5.4 mg/l uniformily. Our data do not show a diminution of DO during the period July 10-19, when the pump was not operating. Rather, DO was never below 3.0 mg/l in the hypolimnion. After pumping began again, DO was usually above 5.0 mg/l in the entire water column. Thus, in contrast to previous years, complete hypolimnetic depletion of DO did not occur before pumping began. In spite of the pump being shut down for a short period, morever, oxygen depletion did not occur in the hypolimnion.

Table 11 shows that during mixing in 1976 the concentration of chlorophyll a in Ham's Lake averaged 10.6 micrograms per liter, which is very close to the concentration observed during mixing in 1975 (9.0 micrograms per liter). Before mixing the range of concentration of chlorophyll a was basically the same during 1975 and 1976, although the means are considerably different (Table 11). During July, 1976, when the pump was shut down, the concentration of chlorophyll a was somewhat higher than during mixing, but the ranges of concentration were not. There is no real evidence that lake mixing altered algal biomass in Ham's Lake during 1976. In any event, algal biomass is low in Ham's Lake and algae never developed nuisance blooms.

During 1976 algal samples were taken and temperature, DO, pH, alkalinity and orthophosphate were measured at weekly intervals. These data will be used in a principal component analysis of the phytoplankton community (see below) by Mr. Hong Chau, a graduate student.

Table 11. Range in concentration of chlorophyll a in Hams Lake as micrograms per liter. Values uncorrected for phaeophyton pigments.

1974**	1975*	1975**	1976*	1976**	1976***
8.8-66.3	8.0-10.4	5.9-14.6	2.7-7.8	5.8-19.0	12.3-16.8
$\bar{x}$ = 35.0	$\bar{x}$ = 9.5	$\bar{x}$ = 9.0	$\bar{x}$ = 5.0	$\bar{x}$ = 10.6	$\bar{x}$ = 14.5
3 dates	4 dates	12 dates	4 dates	7 dates	2 dates
surface	0- 3 m	0-3 m	0-3 m	0-3 m	0-3 m

*before mixing
**during mixing
***during shut down of pump in July

Growth of Bluegills and Largemouth Bass

Growth of fishes at Ham's Lake was measured by back calculating lengths from inspection of scales. For all species there was a linear relationship between total body length and the distance from the focus to the marginal radius of the scale. Thus, the Lee equation was used for back calculation.

This scale analysis is based on small numbers of fish. Hence, the results can apply only to parts of the data, i.e. first year growth of each species. Even so, the confidence limits on the back calculated lengths are large (>20%) so that are true differences between years are not likely to be easily discovered. For bluegills, Lepomis macrochirus, the first year growth in 1972, 1973, 1974 and 1975 was identical, averaging about 82.1 mm. Successive years of lake mixing had no apparent effect on growth rate of this species (Table 12).

Good collections of data exist for largemouth bass (Micropterus salmoides) in previous years and the 1976 sampling season enabled us to add to the set of data. The results (Table 13) suggest that the growth of this species is remarkably stable also. Age I fish tended to measure about 128 mm in all years.

This analysis shows that if lake mixing has any effect at all on the growth rate of fish, then the effect is relatively small. Alternatively, it may be the the effect cannot be conveniently measured using our methods.

Table 12. Average calculated total length (mm) and total length at capture of bluegills collected from Ham's Lake, Oklahoma, Spring and Fall 1976.

Date Collected	Year Class	Age Group	No. of fish	1	2	3	4	Average total length at capture
Spring 1976	1975	I	37	85.0(±19.8)				86.5
	1974	II	79	89.4(±17.3)	114.9(±25.0)			121.8
	1973	III	62	83.1(±22.8)	115.8(±23.3)	136.2(±27.9)		146.1
	1972	IV	8	70.7(±12.8)	114.2(±9.1)	145.9(±16.3)	166.1(±17.3)	174.1
	Mean			92.1	115.0	141.0	166.1	
Average annual increment				82.1	32.9	26.0	25.1	
Fall 1976	1975	I	10	83.6(±13.6)				109.1
	1974	II	17	82.8(±15.2)	113.9(±21.3)			150.1
	1973	III	1	82.7	109.2	139.1		164.0
	Mean			83.0	111.5	139.1		
Average annual increment				83.0	28.5	27.6		

Table 13. Mean back-calculated length, in millimeters, of largemouth bass from Ham's Lake, Oklahoma.

Year Class	n	1	2
1975	10	112.2 (28.1)	
1974	31	126.8 (18.5)	197.8 (50.6)
1973	24	127.8 (17.5)	206.4 (27.2)
1972	23	*137.0 (16.8)	204.5 (21.8)
1971	15	128.7 (14.7)	217.5 (16.7)
1970	6	131.7 (13.0)	224.8 (21.9)
1969	3	132.7 (5.1)	210.7 (20.3)
Average		128.1	210.3

* Not significantly different from 1973 or 1971.

(Data in parentheses are one standard deviation of the mean)

Distribution of Adult Bluegills

Vertical gell nets were set out on 4 June 1976 at stations 2 and 5 (mesh size 2.54 cm and 2.2 m wide). The net at station 2 was set over 8 m depth; the one at station 5 was set over a depth of 5 m. Data were obtained on depth of capture, total length, and weight of bluegills.

Table 14 shows bluegills were captured at all depths at station 2 during 1976, where destratification had produced isochemical conditions. At station 5, however, which remained stratified, no bluegills were captured below 4-5 m. Characteristically, dissolved oxygen was depleted at 4-5 m at this station and bluegills avoided these depths. Most bluegills were captured between 1 and 3 m. The bottom of the euphotic zone is about 3 m and the capture at this depth may indicate a dependence of distribution on light.

Table 14. Depth of capture of bluegill sunfish at stations 2 and 5 at Ham's Lake during 1976.

Depth of Capture Meters	Station 2	Station 5	Total
Surface-1	3	1	4
1-2	6	1	7
2-3	3	7	10
3-4	3	2	5
4-5	3	1	4
5-6	1		1
6-7	1		1
7-8	1		1

Phytoplankton Analyses - Ham's Lake

We have also been observing the effects of lake mixing on algal communities in Ham's Lake. Ham's Lake was allowed to stratify normally during 1975 and was destratified through the summer. We sampled algae and measured environmental parameters, before and after the onset of destratification. We have analyzed data collected between May, 1975, and September, 1975. Sampling of algae and environmental parameters continues so that we now have samples and environmental data at weekly intervals from September, 1975, to the present.

Allen, Bartell and Koonce developed a model for community change similar to that employed in chemistry where a certain energy level must be exceeded before a chemical reaction proceeds. Using objective criteria, they showed that the physiochemical environment of plankton in Lake Wingra, Wisconsin, changes in an annual cycle by a series of jumps between patterns of local oscillation. It is these intermittent environmental shifts that appear to produce significant change in the phytoplankton patterns of replacement. The environmental shifts in Lake Wingra are events such as the sudden melting of surface ice, and the resulting water turbulence changes the structure of the phytoplankton community. This environmental change, which is extrinsic to the phytoplankton community, is clearly of the same order as the induced destratification here. From the apparent consistency of the Allen-Bartell-Koonce model it would appear profitable to account for phytoplankton species replacement in terms of the interaction between endogenous forces for floristic continuity and exogenous environmental disturbance.

Analyses of Ham's Lake phytoplankton and environment are supportive of the Allen-Bartell-Koonce model. Between May 28 and September 5, 1975, 26 samples of plankton were taken every fourth day with corresponding environmental estimates. The Garton pump began operation on June 15, 1975,

achieving mixing in two days. Results of the ordinations of environment and species present in state space are found in Figures 11 and 12.

Two days after artificial destratification, the samples represented by point 7 on both ordination diagrams were taken. Apparently the environmental impact of the pump took more than two days to develop its full force. A dramatic shift in the environment is seen with the displacement of point 8 on Figure 11. Even at this date, however, (June 25), the phytoplankton remain relatively unchanged and continue the smooth local cycle of composition that characterizes the first seven samples. Some four days later, however, at sample 9 the phytoplankton appear to have drastically changed according to the displacement of point 9 on the species ordination (Figure 12).

The species composition does not appear to settle in a new circular pattern until some six weeks later in the middle of August. The pump was operating even beyond the end of the periods subjected to ordination.

A first difference ordination, was also applied to the Ham's Lake data. It failed, however, to show an interpretable response of the phytoplankton in this new situation. The failure probably related to three differences between the Wingra study and the preliminary study of Ham's Lake: 1) the size of the universe (the sample period) is shorter in the Ham's Lake data, 2) Ham's Lake was sampled at twice the frequency of Lake Wingra, and 3) because of technical difficulties that will shortly be overcome, only 45 of the 124 species found in Ham's Lake were included in the ordination. The species included were the most variable 45 in species state space. Each of these differences tends to make the Ham's Lake data a finer grained set then that from Lake Wingra. Recently communicated results from Tom Webb III (personal communication) would indicate that fine grain data sets tend to display smaller scale phenomena. Because data transformations

integrate biological information over various periods it is possible to offset the effects of a fine grain data set by using a data transformation that integrates over a longer period. For any given data set the first difference displays finer grain phenomena than the state. The difference in scale between the two data sets appears to be compensated by a shift to a state space ordination in the Ham's Lake data set.

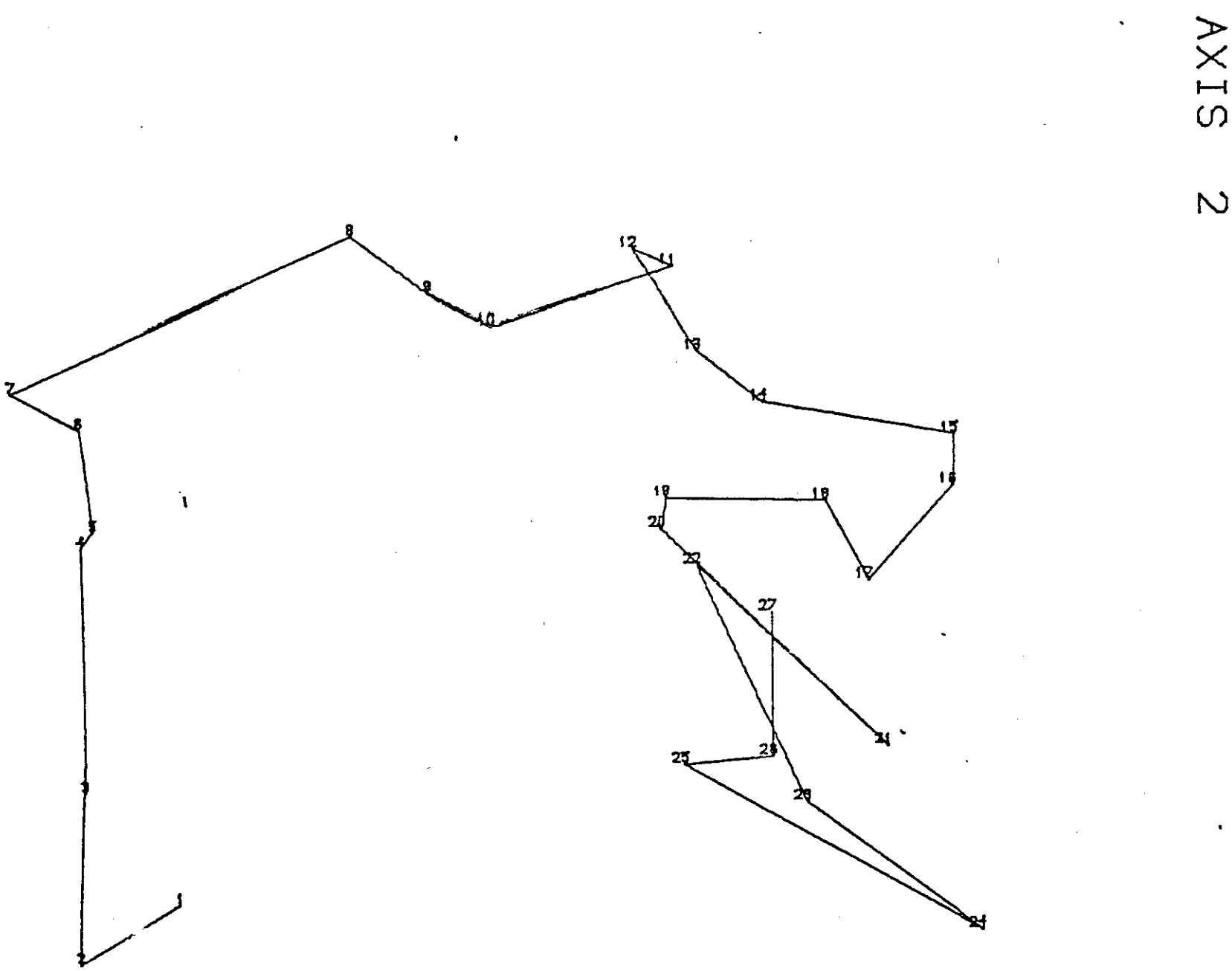

Figure 11. First and second principal componenents of the environmental ordination. The lake was destratified at point 7 but the physicochemistry shows no response until 4 days later at point 8.

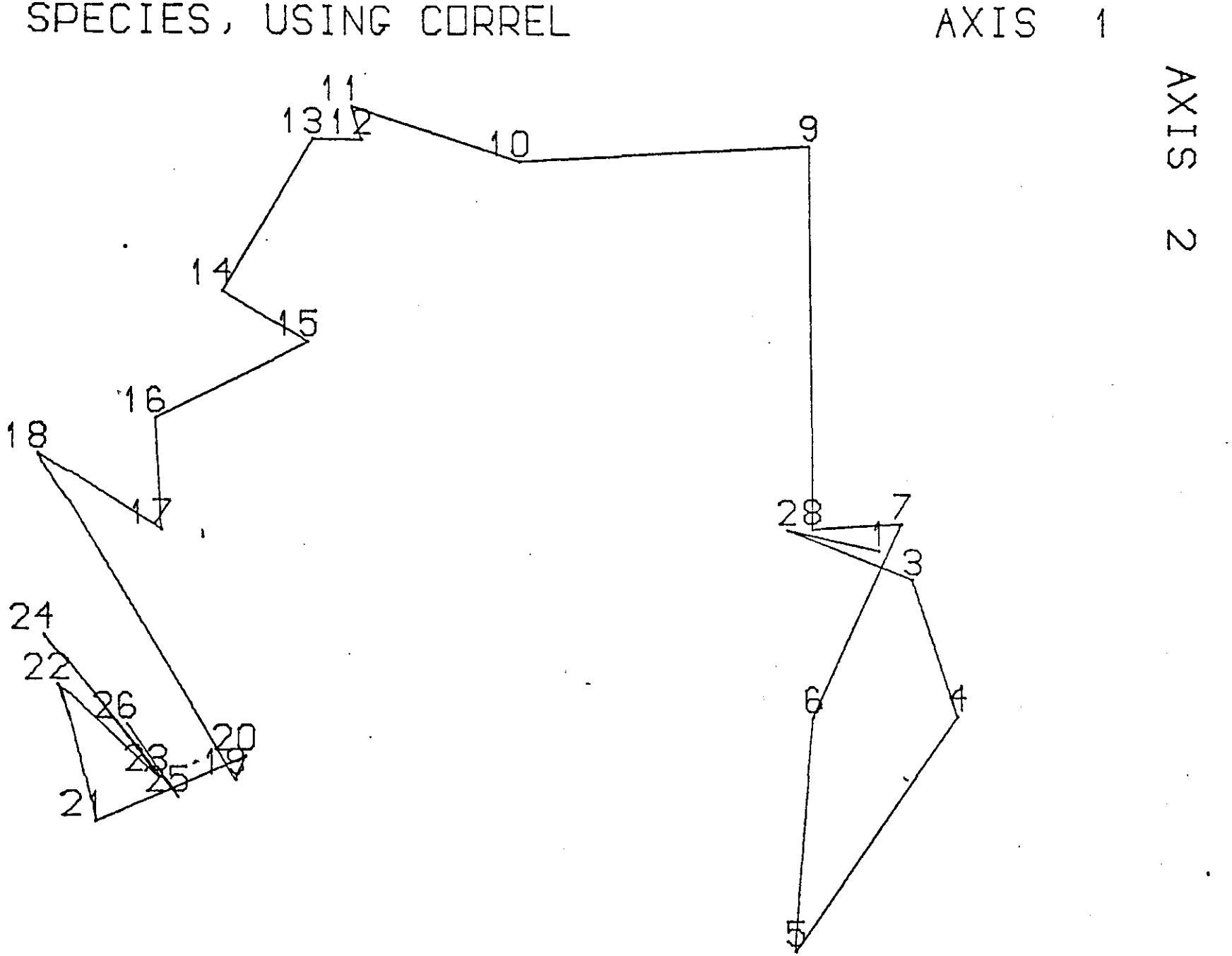

Figure 12. First and second principal components of the plankton ordination. Although the physicochemstry responded to destratification in 4 days, the species composition remains unaffected until sample 9, 8 days later.

Effect of Mixing on Fish Predation on Zooplankton and Community Metabolism

The effect of lake mixing on the complex patterns of fish predation on zooplankton communities is not known. It is well known that fish feed selectively on zooplankton and may have a significant impact on the zooplankton community in terms of density and resulting sizes of plankters.

This problem was investigated experimentally in Ham's lake using columns of lake water (limnocorrals) as experimental units. We sought to learn if mixing altered the density of zooplankton through changes in the feeding rate of fishes, if the fish fed selectively and if patterns of selective feeding were disturbed by artificial mixing.

Data were also taken on the limnology of the columns to determine if artificial mixing altered physicochemistry, biomass of algae and community metabolism.

Column Experiment Procedures

During the month of August, 1976, the column experiment was carried out at Ham's Lake, beginning on 7 August and concluding on 28 August. The experiment involved the suspension of eight plastic tubes (diameter 3.5 ft.) from a floating stationary wooden rectangular frame (Figure 13). The floating support frame (Figure 13) consisted of two levels: a lower rectangular "two by four" frame with cross supports (shaded), and an upper "one by four" frame (unshaded) resting on ½ft. support blocks. Seven styrofoam floats supported the frame, one under each corner, one at each end, and one in the middle. Each tube was seated on the mud bottom, weighted down by eight standard red bricks; the seating of each tube was checked by skin diving and feeling along the bottom of the tube with the hands. The wooden raft was located 40 to 45 meters from shore, and the water under the raft ranged from 5.5 to 6.0 meters in depth. The raft was secured with chain at each end to a steel cable passing over it, and each corner of the raft was secured by a 200 lb. cement weight. Two to three feet of slack was provided in each tube to prevent movement of the tube bottom during high winds or rising water levels. Five tubular plastic support rings (1 in. diameter plastic pipe) were placed in each tube at 5 feet intervals within plastic sleeves sewn into the tube, which lay outside the wall of the plastic column. The middle three rings were air tight to provide buoyancy.

Submersible pumps (Little Giant) were placed in four of the eight tubes (1,4,5,6) to provide for circulation of the water in the column (90 gal./hr). The pumps were attached to flat cinder blocks to provide a solid base, and each was positioned on the mud bottom. Each pump was outfitted with a vertical 2 ft. intake and a 4 ft. exit pipe of 1 inch and 3/4 inches diameter respectively. The top six inches of each pipe contained twelve ¼ inch holes to reduce the pressure on the intake and exit pipes. The intake pipe was capped with hardware

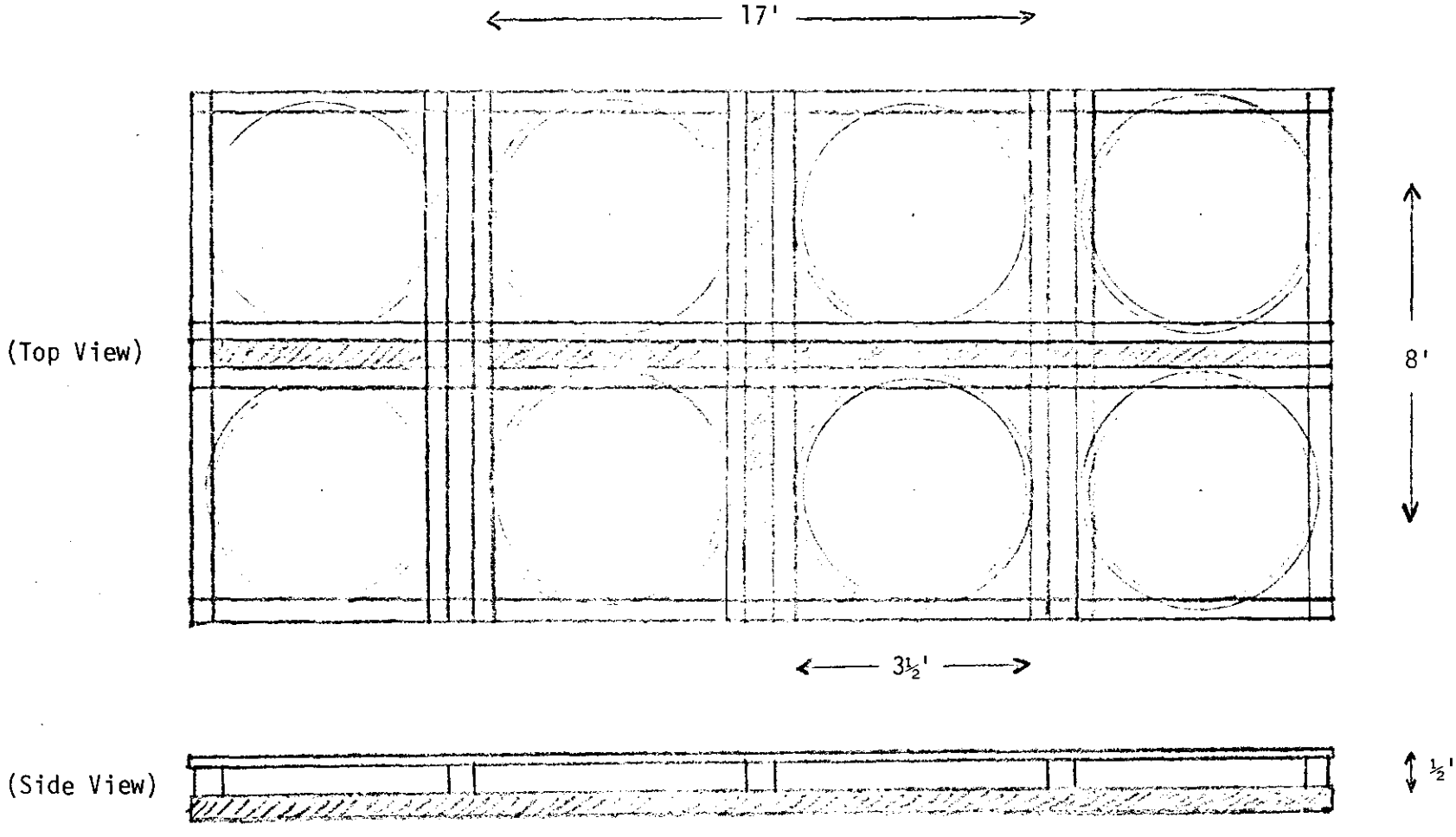

Figure 13. Two-level support frame

cloth (¼ inch squares), and the exit pipe was capped with a size 10-13 elastic cotton sock to diffuse the vertical water jet. The leg portion of the sock was elastic and expandible, and contained holes = 1/16 inch when the pump was functioning. These pump modifications were made to reduce the disturbance of the mud bottom sediments by the circulating action of the pumps.

One day after the experiment was initiated (day 1), eight bluegill sunfish, Lepomis macrochirus, ranging in size (total length) from 69 to 86 mm, were placed in each of four of the tubes (1, 2, 6 and 8) (Table 15). The fish used for this purpose were collected by seine from a local farm pond, and 60 of them were maintained in a wire retaining cage in Ham's Lake for five days before being placed in the columns. On day 4 of the experiment, three bluegill sunfish were removed from each of the four columns (1, 2, 6, and 8), using a 3 ft. diameter drop net. The three fish from each column were measured, and were stored in appropriately labeled water-filled plastic bags in a freezer for later gut content analysis. On day 5, three bluegill sunfish, ranging in size from 55 to 92 mm total length, were placed in each of the four columns (1, 2, 6, and 8).

During the progress of the experiment, eight parameters were measured on a regular schedule (see Table 16). On days 0 and 1, and every other day thereafter, temperature and dissolved oxygen were measured at 1 meter intervals in each of the eight columns and in the lake (outside). An oxygen probe was used for these measurements and was air calibrated according to standard methods before each sampling day began. On days 7 and 14 of the experiment, diurnal oxygen samplings were executed, with three sampling periods (evening, morning and evening). During each sampling period, samples were taken in each column and in the lake at 1 meter intervals. Temperature and dissolved oxygen readings were taken from top to bottom and dissolved oxygen readings were taken again from bottom to top.

Table 15. Bluegill sunfish (Lepomis macrochirus) added to columns. Total length measurements in mm.

Date: 8 August, 1976

Column:	1	2	6	8
	70	85	78	77
	74	84	70	78
	85	76	76	86
	75	70	80	76
	69	76	76	80
	70	72	81	79
	77	69	80	76
	80	75	75	77
Date: 12 August, 1976				
	90	78	72	70
	59	58	75	92
	77	77	55	70

Table 16. Ham's Lake Column Experiment Sampling Schedule August, 1976

Day	Temp	DO	JTU	pH	PO_4	Algae	Pigments	Zoopl	Fish	Diurnal
0 (7 Aug)	✓	✓	✓	✓	✓	✓	✓	✓		
1	✓	✓							(add)	
2										
3	✓	✓								
4										
5	✓	✓						✓	✓	
6										
7(14 Aug)	✓	✓	✓	✓	✓	✓	✓			✓
8										
9	✓	✓								
10										
11	✓	✓								
12										
13	✓	✓						✓		
14(21 Aug)	✓	✓	✓	✓	✓	✓	✓			✓
15										
16	✓	✓								
17										
18	✓	✓								
19										
20	✓	✓	✓	✓	✓	✓	✓			
21(28 Aug)								✓	✓	

Circulated columns = 1, 4, 5, 6 Columns with fish = 2, 6, 1, 8

On days 0, 7, 14 and 20, water samples were taken from each column and in the open lake, using an integrated column water sampler. Each sample was divided as follows:

(1) 100 ml in acid-washed polypropylene bottle stored on ice for subsequent PO_4 analysis.

(2) 1 liter in polyethylene bottle and stored on ice for later analysis of pH, pigments, and Jackson Turbidity Units (JTU's).

(3) 250 ml placed in glass bottle along with eight squirts of Lugols solution for analysis of algae.

On days 0, 4, 13, and 21 of the experiment, zooplankton samples were taken from each of the columns and in the open lake. Samples were taken using a folding net sampler, and three samples were taken first from a depth of 3 meters to the surface, and then three samples were taken from the bottom to a depth of 3 meters. Each of the six samples from each column was washed into a polyethylene bottle with distilled water; 10 to 15 cc of carbonated water was added to each sample to narcotize the zooplankton, and within ten minutes the water volume of the sample was doubled by adding a 20% formalin solution to produce a 10% formalin storage solution.

On day 21 of the experiment the circulating pumps were removed from the columns, and the bluegill sunfish were removed from columns 1, 2, 6 and 8 using the 3 ft. diameter drop net. In only tube #1 were all eight fish successfully removed within three or four seine hauls; ten seine hauls in the other three columns yielded only three to seven bluegill sunfish per column, some small yellow bullheads, Ictalurus natalis, and a black crappie, Pomoxis nigromaculatus.

Results of Column Experiments

Statistical differences among samples were tested by the following formula for the "t" statistic:

1) for the difference between two means,

$$t = \bar{X}_1 - \bar{X}_2 \Big/ \sqrt{\frac{S_1^2}{N_1} + \frac{S_2^2}{N_2}}$$

2) for the difference between a mean and a single value "a"

$$t = \frac{(\bar{X}-a)\sqrt{N}}{S}$$

Where $\bar{X}$ is the sample mean, N is the number of observations and S is the sample standard deviation.

Temperature

Water temperatures varied little during the course of the experiment Vertical stratification ranged from 0-3^{o}C in the open lake as well as the columns. Table 17 lists mean temperatures at 3 depths (0,2 and 6 m) for mixed columns (1,4,5, & 6), unmixed (2,3,7, & 8) and the open water. These means represent temperature taken between 1600 and 1800 hours on 9 seperate days throughout the course of the experiment after the pumps had been turned on (days 3,5,7,11,13,15,17,18, and 20). There were no significant column or mixing effects at any of the depths tested. Surface temperatures were more variable than temperatures at 2 and 6 m and column temperatures were more variable than the open water temperatures.

Table 17. Summary of Temperature Profile Data Temperatures as ^{o}C

Depth (m)	0	2	6
Mixed Columns			
$\bar{X}$	28.3	27.4	27.0
S	1.3	0.9	0.9
N	36	36	36
t(mixed x unmixed)	0.89	0.27	1.95
Unmixed Columns			
$\bar{X}$	28.0	27.3	26.6
S	1.1	1.0	0.9
N	36	36	36
t(mixed x unmixed)	2.30	1.35	0.96
Open Water			
$\bar{X}$	28.8	27.7	26.9
S	0.2	0.7	0.5
N	9	9	9

Dissolved Oxygen

Dissolved oxygen (DO) varied greatly with experimental treatment, depth and time of day throughout the experiment. Table 18 lists mean DO values from 3 depths for mixed columns, unmixed columns, and the open water. Sample dates and times were the same as those listed previously for temperature. Surface DO was greater in the unmixed columns (9.50 ppm) than in either the open lake (8.05 ppm; $P \leq 0.05$, t=4.69, N=9) or the mixed columns (7.09 ppm; $P \leq 0.05$, t=5.92, N=36). This is due primarily to super-saturated values found only in the quiet unmixed water. At 2m, DO was greater in the open water (7.17 ppm) than either the unmixed columns (6.01 ppm; $P \leq 0.1$, t=3.22, N=9) or the mixed columns (4.66 ppm, $P \leq 0.10$, t=3.22, N=9). Similarly at 6 m DO was greater in the open water (5.7 ppm) than in either the unmixed columns (4.81 ppm, $P \leq 0.05$, t=4.05, N-9) or the mixed columns (4.45 ppm; $P \leq .05$, t=6.16, N=9); in the unmixed columns DO was greater at both 0 and 2 m (9.55 and 6.01 respectively) than in the mixed columns (7.09; $P \leq 0.05$, t=5.92, n=36 and 4.66; $P \leq 0.05$, t=11.06, N=36, respectively). Surface DO was more variable in both mixed and unmixed columns than in the open water.

Table 18

Summary of dissolved oxygen as mg/l

Depth (m)	0	2	6
Mixed Columns			
$\bar{X}$	7.09	4.66	4.45
S	1.69	0.60	0.63
N	36	36	36
t(mixed x unmixed)	5.92 *	11.06*	2.10*
Unmixed Columns			
$\bar{X}$	9.55	6.01	4.81
S	1.83	0.42	.81
N	36	36	36
t(unmixed x open)	4.69 *	5.55*	4.05*
Open Water			
$\bar{X}$	8.05	7.15	5.70
S	0.29	0.59	0.52
N	9	9	9
t(mixed x open)	3.22 *	4.03*	6.16*

* significantly different, $P < 0.05$

Turbidity

Turbidity increased 2-3 fold in the mixed columns. Table 19 shows the mean turbidity values for mixed columns, and the open lake. Significant increases in turbidity in the mixed columns are apparent for all days when the pumps were running. Turbidity levels in the unmixed columns were similar to those in the open water. The increase in turbidity was due to the suspension of bottom sediments as there was no appreciable increase in algal biomass after mixing began (see below).

Phosphate

Phosphate values decreased dramatically during the course of the experiment in both the mixed and unmixed columns and the open water. Mean phosphate levels for each of these are shown in Table 20. The only apparent treatment effect is seen on day 7 when phosphate concentrations in the mixed columns (4.28 micrograms per liter) remained higher than the unmixed columns (0.00 micrograms per liter; $p<0.05$, $t=9.5$, $n=4$) or open water(0.05 micrograms per liter). Phosphate concentrations remained low for the remainder of experiment in all treatments.

In spite of the fact that mixing suspended bottom sediments, it did not apparently increase concentrations of phosphate. However, phosphorus has a very short turnover time and concentrations, by themselves, might not be too meaningful.

Table 19

Summary of Turbidity Data

Data given as Jackson Turbidity Units

	Day 0	7	14	20
Mixed Columns				
$\bar{X}$	25.0	70.7	55.7	40.00
S	1.74	12.99	7.94	9.69
N	4	4	4	4
t(mixed x unmixed)	0.00	7.71*	7.97*	4.47*
Unmixed Columns				
$\bar{X}$	25.0	19.7	22.5	17.88
S	0.35	2.49	2.50	2.01
N	4	4	4	4
Open Water	23.5	22.0	21.0	23.0

* significantly different, $P<0.05$

Table 20

Summary of Phosphate Concentrations

Concentrations given as micrograms PO_4-P per liter

	Day 0	7	14	20
Mixed Columns				
$\bar{X}$	9.63	4.28	0.83	0.93
S	1.17	0.90	0.12	0.13
N	4	4	4	4
t(mixed x unmixed)	0.62	9.50*	1.16	0.70
Unmixed Columns				
$\bar{X}$	10.43	0	0.76	0.99
S	2.29	0	0	0.11
N	4	4	4	4
Open Water	7.04	0	0.76	1.06

* significantly different, $P<0.05$

Chlorophyll a

Chlorophyll a concentrations showed no distinct column, mixing or temporal effects. Table 21 lists mean chlorophyll a concentrations for mixed columns, unmixed columns and the open water on days 0,7,14, and 20. The only significant difference is the increase (to 18.8 micrograms per liter) on day 7 in the unmixed columns when compared with the mixed columns (12.87 micrograms per liter; $p<0.05$, $t=3.33$, $n=4$).

pH

Although pH values varied only slightly, some differences are apparent. Table 22 lists mean pH values for mixed columns, unmixed columns and the open water on days 0,7,14 and 20. The mixed columns had lower pH values than either the unmixed columns or the open water on the last 3 dates after pumping had begun. However, the difference is only a few tenths of a pH unit (0.12, 0.23 and 0.18 respectively which may not be analytically significant and certainly not significant to photosynthesis.

Table 21

Summary of chlorophyll a concentration as micrograms per liter

	Day 0	7	14	20
mixed Columns				
$\bar{X}$	12.59	12.87	10.03	10.9
S	0.95	1.07	2.02	2.25
N	4	4	4	4
t(mixed x unmixed)	1.28	3.33 *	1.82	0.43
Unmixed Columns				
$\bar{X}$	11.87	18.8	12.67	10.27
S	0.59	3.39	2.08	1.85
N	4	4	4	4
Open Water	11.73	12.87	13.45	10.87

*significantly different, $P < 0.05$

Table 22. Ham's Lake Column Experiment pH Readings (1976)

Col. \ Date	8/7/76	8/14/76	8/21/76	8/27/76
1	8.51	8.41	8.37	8.38
2	8.55	8.56	8.60	8.54
3	8.60	8.55	8.52	8.50
4	8.62	8.50	8.38	8.39
5	8.68	8.45	8.45	8.39
6	8.62	8.40	8.39	8.30
7	8.60	8.52	8.80	8.60
8	8.65	8.57	8.58	8.58
Lake	8.68	8.60	8.70	8.51

Community metabolism

Three point diel oxygen curves were established for the open water and each column on days 7-8 and 14-15. From these data estimates of gross primary production (P_g), community respiration (R_c) and the ratio of production to respiration (P_g/R_c) were calculated at one-meter intervals for each column and for the open water for both the sampling periods. The depth-specific estimates were plotted against depth and the area under the curve integrated to estimate P_g, R_c and P_g/R_c on the basis of m^2 surface area for each of the two sampling dates (Tables 23 and 24).

The most obvious difference between the two dates is the increase in all values on the second date. Many negative values for both P_g and R_c at various depths on the first date are unexplained and suggest that community metabolism measured on that date may not be accurate.

Mixing and column effects are summarized in Tables 25 and 26. There were no demonstrable effects on the ratio P_g/R_c on either date. It is obvious from the tests on both dates that the columns had both lower P_g and R_c than the open water and that mixed columns had lower P_g and R_c than unmixed columns. Thus, enclosure seems to have reduced biological activity and mixing to have reduced it further.

An additional effect of mixing was evident on the second date (Table 27). It was obvious from the integrated R_c curves that respiration was more evenly distributed with depth in mixed columns than unmixed columns or the open water. The increase in R_c in the upper strata characteristic of unmixed columns or the open water was absent in the mixed columns. Thus, mean R_c values for the 0-3m strata are lower in the mixed columns than in the unmixed columns or in the open water (Table 27).

Table 23

Summary of Day 7-8

Community Metabolism

$g\ O_2/m^2$

Column	$\int P_g$	$\int R_c$	$\int P_g/R_c$
1	2.71	4.33	0.62
2	5.78	6.21	0.93
3	3.95	5.85	0.67
4	0.52	2.79	0.19
5	0.40	2.95	0.14
6	1.59	2.56	0.62
7	1.96	4.84	0.40
8	3.04	5.64	0.54
Open Water	5.85	11.22	0.52

Table 24

Summary of Day 14-15

Community Metabolism

g O_2/m^2

Column	$\int P_g$	$\int R_c$	$\int P_g/R_c$
1	17.08	16.05	1.06
2	20.81	19.71	1.11
3	16.83	16.50	1.02
4	18.85	15.93	1.18
5	19.89	16.95	1.12
6	14.50	13.95	1.04
7	23.43	22.09	1.06
8	19.44	19.14	1.02
Open Water	24.99	23.88	1.05

Table 25

Summary of Mixing effects on day 7-8

Community Metabolism

g O_2/M^2

	$\int P_g$	$\int R_c$	$\int P_g/R_c$
mixed			
$\bar{X}$	1.30	3.16	0.39
S	0.93	0.69	0.23
N	4	4	4
t(open water x mixed)	8.47*	20.23*	0.98
t(unmixed x mixed)	2.83*	5.80*	1.6
t(open water x unmixed)	2.68*	19.36*	1.00
Unmixed			
$\bar{X}$	3.68	5.63	0.63
S	1.40	0.50	0.19
N	4	4	4
Open Water	5.85	11.22	0.52

*significantly different, $P < 0.05$

Table 26

Summary of Mixing effects on Day 14-15

Community Metabolism

g O_2 m^{-2}

Mixed	$\int P_g$	$\int R_c$	$\int P_g/R_c$
$\bar{X}$	17.58	15.72	1.11
S	2.04	1.09	0.06
N	4	4	4
t(mixed x open water)	6.29*	12.97 *	1.73
t(unmixed x mixed)	1.62	2.99 *	1.70
t(unmixed x open water)	3.54*	4.15 *	0
Unmixed			
$\bar{X}$	20.12	19.11	1.05
S	2.38	1.99	0.04
N	4	4	4
Open Water	24.99	23.88	1.05

*significantly different, $P < 0.05$

Table 27

Summary of R_c for the 0-3m strata

Day 14-15

g O_2 m^{-2}

Column	0-m R_c
1	8.14
2	12.12
3	10.95
4	8.25
5	8.55
6	7.00
7	14.28
8	12.06
Open water	14.70

Mixed Columns

$\overline{X}$= 7.98

S= 0.59

N= 4

Unmixed Columns

$\overline{X}$= 12.35

S= 1.20

N= 4

t(mixed x open water) = 19.73 *

t(unmixed x mixed) = 3.39 *

t(unmixed x open water)= 6.54 *

*significantly different, $P < 0.05$

Zooplankton

Zooplankton samples were diluted or concentrated as required to give an initial volume of 100 ml. Five 2-ml subsamples were taken from each original sample (thus 10% of original volume was subsampled). Subsamples were removed with a Hensen-Stempel piston pipette and identified, counted and measured in a plankton wheel. (Identification procedure followed that of McClintock (1976). These data were recorded for each subsample, except those taken from mixed columns on days 13 and 21. It was evident from analysis of data collected from mixed columns on days 1 and 6 that these columns were almose devoid of zooplankton and their analysis was, therefore, reduced to a single 2-ml subsample for the last two sampling dates. Consequently, this discussion is restricted to changes in zooplankton density in the unmixed columns and the open water. Numbers of organisms observed in each 2-ml subsample were converted to a numbers per liter and summarized as means and standard deviations for each column and depth on each date for total zooplankton and each taxon.

Zooplankton were strongly vertically stratified. Table 28 shows the distribution of the total zooplankers in the open water and in the unmixed columns averaged over the entire experiment. The densities in the bottom 3 meters are only about 25% of those in the top 3 meters in both the open water and the columns. Additionally, it is evident that densities in the columns average only about half those of the open water in both the surface and bottom strata. These two general trends were fairly consistent for all taxa. Because of the predictability of the vertical stratification, the remainder of this discussion will focus on the temporal changes in total zooplankton density and the major individual taxa represented in 0-3m samples and their relations to the experimental treatments.

Table 29 shows the temporal changes in total zooplankton density. As noted previously, densities are higher in the open water than in the columns on all dates.

Table 28

Average total numbers of zooplankton per liter in the open water and in unmixed columns.

Depth (m)		Open Water	Unmixed Columns
0-3	$\bar{X}$	201	106
	S.E.	68	68
	N	4	16
3-6	$\bar{X}$	51	28
	S.E.	36	21
	N	4	16

Table 29

Temporal changes in total zooplankton density
in open water and unmixed columns.
(Organisms l^{-1})

Day		Open water	Empty columns	Fish Columns
0	$\bar{X}$	166	93.2	112
	S	30.1	15.5	20.1
	N	15	30	30
5	$\bar{X}$	317	254	148
	S	32.0	66.4	32.0
	N	15	30	30
13	$\bar{X}$	142	39	48
	S	14.8	53.8	12.5
	N	15	30	30
21	$\bar{X}$	180	82	86
	S	20.9	18.4	14.6
	N	15	30	30

There was a gradual decrease in density from day 5 to day 21 in all groups. The increase on day 5 was due primarily to the increase in density of a single taxon (Bosmina) in the columns, while several taxa contributed to the increase in the open water. The only effect of fish on zooplankton density in the columns appears on day 5 when the empty columns had a total mean density of 252 organisms per liter (org. l^{-1}) and those with fish had only 148 org. l^{-1} ($p \leq 0.01$; $t=8.50$, $n=30$). This implies that grazing by fish influenced the density of zooplankton.

Densities of Diaphanosoma in the open water were consistently higher than those in the columns, doubling on day 5 and remaining high through day 21 (Table 30). Densities gradually decreased from 6 to about 1 org. l^{-1} from day 0 to day 21 in both empty columns and those with fish.

Densities of Ceriodaphnia generally decreased throughout the course of the experiment under all conditions (Table 31), although in the open water there was an increase on day 5 similar to that of Diaphanosoma. This general decrease seems to have been somewhat slower in those columns with fish.

Mean densities of Bosmina in the open water peaked on day 5 at 83 org. l^{-1} and declined to only 4 org. l^{-1} on day 21 (Table 32). The columns showed a similar pattern of increase and decrease; however, in the empty columns the absolute density peaked at 186 org. l^{-1} on day 5. This increase on day 5 was dampened (perhaps by predation) in the columns with fish (day 5 mean = 49.3). This was the only taxon that seemed, at least initially, to flourish within the columns.

Densities of Diaptomus were quite variable (Table 33). In the open water they ranged from 4.4 to 50.9 org. l^{-1} but showed no consistent temporal pattern. Individual column means ranged from 0.4 to 37.8.

Copepodite densities were also quite variable (Table 34). Mean values averaged somewhat lower in the columns than the open water but there is no evident effect of the presence of fish. There was an overall tendency for densities to decline in both the open water and the columns.

Nauplii densities showed the greatest stability of any major taxon (Table 35).

Table 30

Summary of temporal changes in the density of Diaphanosoma in the open water and in unmixed columns

(Organisms l^{-1})

Day		Open Water	Empty Columns	Fish Columns
0	$\bar{X}$	15	6.0	7.2
	S	4.2	3.5	4.2
	N	15	30	30
5	$\bar{X}$	30	2.6	11.6
	S	10.0	1.8	7.3
	N	15	30	30
13	$\bar{X}$	27	1.6	3.2
	S	6.7	2.2	2.1
	N	15	30	30
21	$\bar{X}$	29	1.1	0.8
	S	7.1	1.67	0.92
	N	15	30	30

Table 31
Summary of temporal changes in the density of Ceriodaphnia in the open water and unmixed columns
(Organisms l^{-1})

Day		Open Water	Empty Columns	Fish Columns
0	$\bar{X}$	60.0	18.8	37.6
	S	21.0	7.6	22.8
	N	15	30	30
5	$\bar{X}$	92.6	12.3	28.6
	S	12.6	6.6	11.0
	N	15	30	30
13	$\bar{X}$	96.3	1.2	1.1
	S	6.5	1.31	1.28
	N	15.	30	30
21	$\bar{X}$	28.9	0.95	0.15
	S	7.3	1.7	0.4
	N	15	30	30

Table 32

Summary of temporal changes in the density of Bosmina in the open water and unmixed columns (Organisms l^{-1})

Day		Open Water	Empty Columns	Fish Columns
0	$\bar{X}$	26.5	5.8	3.1
	S	10.35	2.76	3.69
	N	15	30	30
5	$\bar{X}$	83.2	186.5	49.3
	S	12.32	71.60	21.90
	N	15	30	30
13	$\bar{X}$	21.9	12.25	22.7
	S	6.61	11.72	15.23
	N	15	30	30
21	$\bar{X}$	4.0	3.0	2.0
	S	3.53	2.94	2.43
	N	15	30	30

Table 33

Summary of temporal changes in the density of *Diaptomus* in the open water and unmixed columns (Organisms l^{-1})

Day		Open Water	Empty Columns	Fish Columns
0	$\bar{X}$	4.4	10.1	8.35
	S	2.71	7.39	5.47
	N	15	30	30
5	$\bar{X}$	50.9	6.9	14.3
	S	13.11	4.84	11.45
	N	15	30	30
13	$\bar{X}$	29.0	19.6	6.0
	S	5.47	21.35	3.89
	N	15	30	30
21	$\bar{X}$	39.5	12.55	5.4
	S	3.80	13.55	4.18
	N	15	30	30

Table 34

Summary of temporal changes in the density of Copepodites in the open water and unmixed columns

(Orgnaisms l^{-1})

Day		Open Water	Empty Columns	Fish Columns
0	$\bar{X}$	20.3	14.2	18.7
	S	5.25	5.83	5.95
	N	15	30	30
5	$\bar{X}$	21.3	8.35	7.95
	S	5.42	3.54	4.12
	N	15	30	30
13	$\bar{X}$	14.5	9.4	11.4
	S	8.55	7.67	5.91
	N	15	30	30
21	$\bar{X}$	13.8	4.05	3.9
	S	4.95	2.48	2.7
	N	15	30	30

Table 35

Summary of temporal changes in the density of nauplii in the open water and unmixed columns

Day		Open Water	Empty Columns	Fish Columns
0	$\bar{X}$	39.6	37.75	35.35
	S	11.06	10.45	6.95
	N	15	30	30
5	$\bar{X}$	32.6	35.35	34.55
	S	4.88	7.14	10.02
	N	15	30	30
13	$\bar{X}$	37.9	34.55	39.85
	S	10.06	18.13	8.91
	N	15	30	30
21	$\bar{X}$	24.7	15.05	28.75
	S	7.68	7.36	10.52
	N	15	30	30

Fish gut analysis

Data has been received for only the first set of fish removed from the columns. These data are incomplete and quite variable. The fish had so few cladocerans or copepods in their guts, that it was not possible to determine if they were feeding selectively. Suprisingly, most feed upon ostracods, when food items were present in the gut.

Discussion

There are several indications from the data presented that enclosure and mixing affected the biota in the columns. Mixing increased turbidity, and generally decreased biological activity as indicated by a decline in daytime DO concentrations. Mixing also decreased both P_g and R_c.

It also is apparent that greatest effects occurred during the first week of the experiment. It was at this point (day 7) that phosphate declined to almost zero in the open water and in the unmixed columns yet remained high in the mixed columns. Chlorophyll _a_ concentrations increased in the unmixed columns above those of the open water and mixed columns, and densities of _Bosmina_ were highest in the unmixed columns.

These column experiments can be used to predict the effects of artificial lake mixing on the biota. For example, if artificial lake mixing increases inorganic turbidity substantially, then algal biomass will decline (as expected). Further, community metabolism will decline but both P_g and R_c will do so simultaneously. The overall ratio of P_g/R_c will remain the same, _i. e._, the system will remain autotrophic as long as producers continue to be present and there will be a strong tendancy for production and respiration to be balanced.

Under the circumstances of this experiment, light was strongly limiting, thus, any effect of resuspending sediments on the phosphorus supply (and its stimulatory effect on primary production) will be negated. However, even mild

resuspension of sediments might result in stimulation of algal productivity in other lakes or reservoirs.

The overall effect of artificial mixing (with attendent increases in turbidity) decreased the dissolved oxygen (DO) concentration in the water column, but did not influence mean water temperature. The overall decrease in DO is probably the result of a decrease in photosynthesis, but concentrations of DO in the mixed columns were sufficient to support fish and aquatic life.

The chief difficulty in extrapolating column behavior to a lake, however, is in correcting for differences between the column and the lake in surface area: volume relationships. Under the circumstances of the surface area: volume relationship and the rate of mixing observed in this experiment, however, lake mixing can be expected to decrease DO.

R_c in the mixed columns was more uniformily distributed than in the unmixed columns, possibly indicating the larger role of bacterial respiration, rather than algal respiration, in a turbid system. Therefore, if lake mixing increases turbidity, the effect should be to decrease the importance of algae as both consumers and producers of DO. The overall DO balance will then be determined by physical factors and bacterial respiration.

The mixing process used in this experiment involved pumping water upward, which is quite different from the action of the Garton pump which moves downward. Preliminary analysis of 1977 data from Ham's Lake suggests that the Garton pump may cause an increase in inorganic turbidity, so some of the conclusions from the above observations are applicable to the probable impact of the Garton pump.

There was some indication that fish feeding influenced the density of zooplankton, since on day 5 columns with fish had less zooplankters than columns without fish. Overall, however, the data are not persuasive. Failure to demonstrate an effect of fish feeding in the control systems, of course,

precludes a demonstration of the effects of fish feeding in the mixed columns. There was a marked vertical stratification of zooplankton, both in the lake (when it was being artificially mixed) and in the unmixed columns. McClintock (1976) found little or no vertical stratification of zooplankton in the same lake during 1975. Our data suggest that under conditions of lake mixing, as practiced with the Garton pump, zooplankton prefer a position in the upper 3 m of the water column in Ham's Lake. Bluegill sunfish also maintain such a position. This strongly suggests that the depth distribution of these organisms is being regulated by light, which reaches the 1% level at 3 to 4 m in Ham's Lake.

Publication

Toetz, D. 1977. Effects of lake mixing with an axial flow pump on water chemistry and phytoplankton. Hydrobiologia 55(2):129-138.

Training

The project provided training for the following graduate students: Hong Chau, Patrick Downey, Steven Halterman and May Yue. Contributions were also made by two undergraduates: Edward Collins and Steven Markham.

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