THE EFFECT OF ARTIFICIAL DESTRATIFICATION ON PHYSICO-CHEMICAL PARAMETERS AND PHYTOPLANKTON IN HAM'S LAKE, OKLAHOMA

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TABLE OF CONTENTS

Chapter | Page

LIST OF TABLES

LIST OF FIGURES

Figure		Page

CHAPTER I

INTRODUCTION

The majority of lakes in the temperate regions are thermally stratified during the summer. This condition results in a stagnant hypolimnion which loses its oxygen to heterotrophic respiration. Anaerobic bacteria accumulating at the bottom of the anoxic water cause a further deterioration of water quality (Irwin et al., 1966).

Artificial circulation helps to alleviate anoxic conditions in the hypolimnion by extending the oxic epilimnion or completely destratifying the lake where complete circulation is possible. Artificial destratification improves the water quality in lakes. Hydrogen sulfide concentrations decrease due to artificial circulation (Irwin et al., 1966) as well as ammonia concentrations (Symons et al., 1967; Brezonik et al., 1969; and Leach and Harlin, 1971). Another possible beneficial effect of artificial circulation is the decline in the biomass of blue-green algae.

Artificial circulation provides an opportunity to study the effect of an environmental perturbation on the physico-chemical parameters of the lake and the phytoplankton standing crop as measured directly through cell numbers or indirectly by measurement of the concentration of chlorophyll. Knowledge of the effect of environmental changes has important implications for lake management. The purpose of this research was to study the effect of this perturbation on the physico-chemical parameters and phytoplankton standing crop in a small lake, Ham's Lake, Oklahoma.

Ham's Lake was destratified by mechanical mixing during the summers of 1976 and 1978, but not in 1977. The sampling periods were from the middle of May to the end of September of each year. Artificial mixing provided an opportunity to study the physico-chemical changes and phytoplankton standing crop in a perturbed environment (1976, and 1978) as opposed to an unperturbed one (1977).

The objectives of this study were as follows:

1. Describe changes in the physical parameters (temperature and transparency) due to artificial mixing.
2. Describe changes in the chemical parameters (dissolved oxygen, pH, alkalinity, nitrate, nitrite, ammonia, orthophosphate, and sulfide) due to artificial mixing.
3. Describe changes in the phytoplankton standing crop (cell numbers and chlorophyll a) due to artificial mixing.
4. Determine changes in the horizontal variability between sampling sites to evaluate the adequacy of the design of the data collection.

Toetz et al. (1972) indicated that the value of artificial mixing in the reduction of blue-green algae and in reducing eutrophication needed further study. Long-term study is likely to avoid the problems of interpreting data when there is apt to be short-term natural fluctuations. The present study was a continuation of a long-term research project at Ham's Lake to determine the impact of artificial destratification.

Knowledge of the variability among composite samples and samples from individual stations is essential in designing sampling methods. The extent of variability of phytoplankton data in composite samples as compared to the samples from each station is a measure of the feasibility of using composite samples in Ham's Lake to characterize water chemistry or algal biomass. Comparisons among stations indicate which station or stations are representative of the lake. The information obtained on sampling variability is used here to determine how accurately my data characterize the lake and to provide other workers with insights into the protocols needed to sample other lakes similar to Ham's Lake.

CHAPTER II

LITERATURE REVIEW

Ecology of Freshwater Phytoplankton

The literature on the ecology of freshwater phytoplankton is voluminous. Fritsch (1931) introduced a broad classification of algal communities. He also discussed the effects of the environment, lake types, and pH on algae. Lund (1965) emphasized physical, chemical, and biological factors which influenced algal populations: light and temperature, weather, water movements, inorganic nutrients, general ionic environment, organic matter, perennation, herbivory, and parasitism.

The association of phytoplankton populations and lake types as well as light and temperature was discussed by Hutchinson (1967). The author stated that diatoms made up the major portion of the flora of eutrophic lakes except at the warmest time of the year. A similar attempt was made by Whitford (1968) in studying the effects of temperature, light, and water current on 50 species of freshwater algae. Happey (1970) observed that *Asterionella formosa* was the predominant species in the spring while *Stephanodiscus rotula* was the predominant species in summer and autumn.

Diversity in freshwater phytoplankton was discussed by Moss (1973b). Seasonal changes and mean values of diversity, calculated by the Shannon formula, were given for the phytoplankton communities of three freshwater lakes. In the more eutrophic lakes, diversity increased in summer and decreased in winter. Zaika and Andryushchenko (1969) found diversity of phytoplankton was higher during warm periods than cold periods. Williams (1964) found that a high standing crop of algae was associated with low diversity and was indicative of eutrophication. Diversity of phytoplankton decreased with increasing stream order (Seyfer, 1976). Alkalinity due to calcium hardness has been shown to be correlated positively to high algal densities but negatively correlated to diversity (Rawson, 1960; Williams, 1964). Woelkerling and Gough (1976) observed that high diversity of desmids was correlated with low conductivity, low calcium concentrations and alkalinity, acid pH of 5.1 to 7.0, and the presence of free carbon dioxide. Patrick (1968) found that under favorable conditions there was a high degree of uniformity in the population of most diatom species. Under less favorable conditions, the more tolerant species survived at the expense of the less tolerant species and resulted in a large variation of the sizes of populations. Edden (1971) stressed that both the number of species and equitability should be measured in determining diversity of phytoplankton. Under similar ecological conditions, 95.5% to 98.0% of the algal species were the same (Patrick, 1968).

Temperature

Temperature affects growth and photosynthesis of algae. The maximum photosynthetic rate at excess phosphate concentration is governed by temperature (Ichimura, 1967). The doubling time of *Asterionella formosa* was found to be 9.6 hours at 20°C under laboratory conditions but was 5 to 7 days in the colder lake (Lund,1950). Temperature was found to regulate photosynthesis in temperate Pacific phytoplankton when nutrients were not limiting (Parsons and Takahashi, 1973). According to Precott (1968) it is possible that the same species of phytoplankton may have different optimum temperatures for photosynthesis, metabolism, and reproduction. Water temperature was found to be a more important factor in predicting chlorophyll *a* content than chemical factors (Schwartzkopf and Hergenrader, 1978). Water temperature was considered to be a likely phytoplankton regulator by Stewart and Blinn (1976), because it was positively correlated to phytoplankton cell number in 7 out of 13 cases studied.

Algal species have different ranges of temperature tolerance (Hutchinson, 1967). Diatoms can tolerate generally lower temperature whereas the blue-green algae are more tolerant of higher temperature. Whitford (1968) distinguished the chrysophyceae as low temperature algae that grew best below 15°C. The chlorophyceae, bacillariophyceae, and xanthophyceae grew best between 15°C to 20°C; whereas, the cyanophyceae grew best between 20°C to 30°C. Algal species including *Diatoma elongatum*, *Diatoma* vulgare, and many Fragilaria species were found to prefer low temperatures (Williams, 1964). However, Shear et al. (1976) found that Melosira species showed marked preference for high temperatures (18-23°C) in some Canadian lakes. According to Nalewajko (1967), temperature was a factor affecting the distribution of algae in Lake Ontario. An increase of temperature from an average of 2.8°C to 10°C increased the number of species in the community (Patrick, 1971). An increase of temperature from 10°C to 22°C resulted in an increase in equitability. Lin (1972) reported that the sequence of a blue-green algal bloom was closely related to the change in water temperature. Aphanizomenon flos-aquae became incompatible with Microcystis aeruginosa when the temperature fluctuated over a wide range.

Light

Steemann-Nielsen et al. (1962) observed that Chlorella grew more efficiently at low rather than at high illumination. The greater efficiency of cells growing at a low illumination was explained by their relatively higher chlorophyll content. A similar finding was made by Ryther and Menzel (1959). Rodhe (1948) considered the production of Melosira helvetica to be dependent on the intensity of light and the length of illumination as well as the temperature. Yentsh and Ryther (1957) concluded that the rate of photosynthesis was affected by the chlorophyll content of the organisms and light intensity. In laboratory culture, the growth rates of Nitzschia closterium and Tetraselmus sp. increased at high light intensity and high nutrient concentrations (Maddux and

Jones, 1964). Day-length was considered to be the most significant factor affecting photosynthesis (Lorenzen, 1963). Increasing day-length favored more efficient photosynthesis (Pechlaner, 1970). The chlorophyceae and cyanophyceae were categorized as the "sun" species whereas the bacillariophyceae, xanthophyceae, and chrysophyceae were regarded as needing medium light. Light was found to be the most important factor limiting the growth of phytoplankton (Javornicky, 1966). Reynolds (1973) concluded that growth of diatoms was typically subjected to physical rather than chemical factors. Light duration of 6.3 to 6.8 hours per day was critical in determining the onset of growth and ultimate density of diatoms. It was suggested that the rate of increase of the diatom, Asterionella, was related to the interaction of light, turbulence, and temperature. Light intensities below 150 f.c. were found to limit the growth of Chlamydomonas reinhardi (McCombie, 1960). The rate of nitrogen fixation in Anabaena increased with irradiation (Dugdale and Dugdale, 1962). Under natural conditions light intensities also influenced the vertical migration rhythm of diatoms, as these organisms moved to the surface in the morning and moved downward in the afternoon (Fisher et al., 1977).

Wind and Turbidity

Wind-initiated circulation is common in relatively shallow lakes. Wind has a tremendous effect on the internal heat flux of a lake by creating turbulent eddies and vertical mixing (Dutton and Bryson, 1962). Small (1963) and George and Edwards (1976) considered wind as one of the most important factors influencing the horizontal and vertical distribution of phytoplankton in open inland lakes. These authors also analyzed the effect of wind speed and direction on chlorophyll a distribution. Leach (1972) found that the amount of mixing was dependent on wind direction and velocity. Gran and Braarud (1935) pointed out that the rate of vertical mixing determined whether the algae could stay in the euphotic zone and maintain growth through photosynthesis. Lund (1954; 1955) showed that the seasonal cycle of diatom Melosira italica was correlated with the turbulence of water. He concluded that vertical mixing enhanced the production of a large population of Melosira in the euphotic zone. Moed et al. (1976) recorded a single sudden 30% increase of Melosira and a reappearance of Diatoma elongatum after a severe storm. Wind stress was positively correlated with algal population size partly due to its effect on circulation of nutrients (Haertel, 1976). Nonmotile algal species were dominant when the water column was relatively turbulent while motile species dominated during stratification or when the effect of wind was minimal (Moss, 1969). A decrease in turbulence during stratification has also been observed by Nalewajko (1967). According to Bryson and Ragotzkie (1960), internal waves probably played a role in the vertical transfer of heat in a stratified lake. However, in a study by Billington and Jones (1976), the authors were not able to relate the variation in algal numbers to wind history and wind conditions since such parameters fluctuated too rapidly.

Turbidity inhibits photosynthesis. High turbidity retarded the growth of algae by decreasing the amount of available light (Javornicky, 1966). The depth at which the maximum rate of photosynthesis occurs varies with the transparency of water, which in turn is a function of the concentration of dissolved and/or particulate organic matter (Wetzel, 1975). Schwartzkopf and Hergenrader (1978) observed that turbidity was significantly related to the concentration of chlorophyll a.

Lake Level

Legovich et al. (1973) observed that a reduction in lake level resulted in an increase in the oxygen deficit in the hypolimnion during summer, an earlier onset of autumnal circulation, a reduction in Secchi disc transparency, and changes in algal species composition. Serruyg and Pollingher (1977) found that lake level was strongly correlated to the biomass of the major groups of phytoplankton. An increase in lake level was associated with an increase of biomass. In this study a reduction of cell size of Peridinium was believed to be caused by a high rate of growth. Mitchell (1975) observed an increase in phytoplankton productivity with an increase of water level due to large input of phosphorus from agricultural runoff. A similar result was also noted by Heron (1961). Billington and Jones (1976) considered water movement due to drawdown as the major physical factor affecting the distribution of algae in a reservoir.

Chemical Parameters

Phosphorus is a limiting nutrient and is rapidly assimulated by phytoplankton (Brydges, 1971; Megard, 1972). Soluble phosphorus exists as soluble inorganic phosphate or orthophosphate and soluble organic phosphate. Hutchinson (1957) reported 9.5% of total phosphorus was in the soluble inorganic form and 28.6% of total phosphorus was in the soluble organic form. Rigler (1969) reported 25-32% of the total phosphorus to be the soluble organic phosphate. Undetectable amounts of soluble phosphate in lake water was not uncommon (Gruendling and Malanchuk, 1974). The specific rates of movement of phosphorus among its biologically important forms in lake water have been demonstrated (Lean, 1973; Lean and Rigler, 1974). Soluble phosphorus increased drastically when water became anoxic (Burns and Ross, 1971).

Total phosphorus concentrations were shown to be directly proportional to chlorophyll _a_ concentrations (Lorenzen, 1963; Brydges, 1971). A regression line was constructed by Dillon and Rigler (1974) to predict average summer chlorophyll _a_ concentration from a single measurement of total phosphorus concentration at spring overturn. Megard (1972) observed a linear relationship between the concentration of total phosphorus and chlorophyll concentration in summer but not in spring and autumn. Regression analysis revealed a good relationship between total phosphorus concentration and chlorophyll concentration (Schindler, 1978). An increase in primary productivity was related to an increase in phosphorus concentration (Moss, 1973c).

An increase in algal cell number was observed to correspond to an increase in phosphate concentration (Haertel, 1976). However, Stewart and Blinn (1976) did not find a significant correlation between orthophosphate and total number of cells. Stoermer et al. (1978) observed a large increase in a phytoplankton population when the phosphorus concentration was 5-15 mg/m^3. An increase in phosphorus concentration caused changes in phytoplankton composition only when silicon was depleted. Dugdale and Dugdale (1962) observed a bloom of _Anabaena_ due to a large influx of phosphorus from incoming sewage. Bush and Welch (1972) used a ratio of phosphate concentration in water to chlorophyll _a_ concentration to compare different algal species assemblages. The ratio was 10:1 in a blue-green algal assemblage and 2:1 in a green algal assemblage.

Several important generalities regarding nutrient availability and phytoplankton periodicity were established in some English lakes (Pearsall, 1930; 1932). The high nutrient concentration in spring was responsible for the spring diatom bloom. _Asterionella formosa_ was observed to appear before _Tabellaria fenestrata_ due to a difference in its nutrient requirement. An increase in the N/P ratio and the silicon level was essential for a diatom bloom, but a low ratio favored green algae. Reynolds (1976) observed that the depletion of nitrate in the epilimnion roughly coincided with the decline of green algae. A decline in the density of blue-green algae occurred when nitrogen was exhausted. Total nitrogen was highly correlated to phytoplankton production (Brylinsky and Mann, 1973). However, Lorenzen (1963) and Maulood et al. (1978) observed an inverse relationship between nitrate concentration and chlorophyll _a_ concentration. Horne et al. (1972) found that nitrogen fixation was significantly and positively correlated to _Anabaena_ heterocyst number, organic nitrogen, and chlorophyll _a_ concentration.

A high pH reflects a high concentration of bicarbonate and carbonate ions (Moore, 1939). Hutchinson (1957) stated that a high pH could be caused by a high photosynthetic rate. The concentration of carbon dioxide decreased as the rate of photosynthesis increased (Crane and Summerfeld, 1976), causing an increase in pH. Ho (1979) attributed an increase of pH to nine or higher to the high rate of photosynthesis of _Potamogeton_ and _Enteromorpha_. Moss (1973a) speculated that eutrophic algal species could grow at high pH and bicarbonate concentrations because of their abilities to use both free carbon dioxide and bicarbonate at very low levels. High pH is favorable to the growth of blue-green algae (Sharpiro, 1973; Viner, 1977). Rao (1953) and Woelkerling (1976) found diatoms to be very common in acid ponds. Acid pH, low conductivity and free carbon dioxide were conditions favorable for desmids (Woelkerling and Gough, 1976).

The presence of a high concentration of silicon was demonstrated to be essential for diatom growth (Pearsall, 1923). Lund (1950) and Lund et al. (1963) reported a decline in the diatom, _Asterionella_, with a decrease in dissolved silicon concentration below 0.5 mg/l. Kilham (1971) examined the literature in order to relate ambient silicon concentration to numerical dominance of freshwater diatoms. The mean silicon concentration (mg/l) during dominance of the respective species was found to be: *Stephanodiscus astraea*, 0.6; *Tabellaria flocculosa asterionelloides*, 0.9; *Asterionella formosa*, 1.7; *Melosira granulata*, 13.4. Declining ambient silicon concentrations might influence the sequence of seasonal succession. When silicon became depleted, diatoms became scarce. Lin (1972) found that deficiency of silicon and a rise in water temperature caused the decline of a spring pulse of diatoms. High summer water temperatures and high concentrations of organic matter favored blue-green algae.

Seasonal Succession

Changes in phytoplankton populations were illustrated in terms of percent wet weight among the major groups in a Swedish lake (Rodhe et al.,1958). Diatoms were dominant in spring and were followed by a bloom of flagellates. The summer months favored the growth of blue-green algae and *Peridineae*. A second pulse of diatoms dominated in the autumn months. Studies on Ham's Lake with respect to an artificial circulation (Steichen, 1974) showed that in June, flagellates, especially *Euglena*, predominated. The blue-green algae Anabaena and Anacystis were dominant in late June. The diatoms *Cyclotella* and *Melosira* were common in August.

It is the combination of light, temperature, and nutrients that triggers the increase or decline of natural populations of algae (Golterman, 1975). When irradiation and day length increased significantly, *Asterionella* began to grow exponentially to a maximum population density of about 10^7 cells/liter (Lund, 1950).

The decomposition of dead *Anabaena* cells was observed to play an important part in the development of subsequent blooms of other blue-green algae (Lin, 1972). The same study suggested that blue-green algal blooms were inhibitory to the growth of the non-blue-green algae.

Artificial Destratification

A 30 cm diameter axial-flow pump operated at 2,000 rpm and with a velocity of discharge at 2.52 mps successfully destratified four lakes ranging from 3.2 ha to 42 ha (Irwin et al., 1966). Temperature, pH, dissolved oxygen (DO), and carbon dioxide were uniform from the surface to the bottom and also from one location of the lake to another. The fall bloom of blue-green algae was inhibited although the total number of algae remained the same. The rate of destratification was found to be proportional to the rate of oxygen demand. It was concluded that prevention of stratification rather than destratification was a better approach to impoundment management.

Artificial destratification by aeration distributed oxygen to all depths of the lake (Fast, 1968). The heat budget increased. Artificial aeration of the hypolimnion caused a reduction in the standing crop of phytoplankton but had little apparent effect on the rest of the biota.

Lund (1971) reported a late summer increase of *Melosira italica* caused by artificial destratification and favorable nutrient conditions. He suggested that the time of the initiation of artificial destratification, the duration of destratification and weather conditions affected the population of the diatom. Haynes (1975) studied the ecological effects of artificial circulation on a small eutrophic lake. After the start of of artificial circulation, the population of green algae declined but was followed by an increase of the blue-green algae Aphanizomenon flos-aquae.

In Ham's Lake Anabaena and Microcystis predominated before mixing, but the blue-green algae Dactylococcopsis became dominant at the onset of mixing (Steichen, 1974). The diameter of the propellar of the pump used in this study was about 1.07 m and the speed of the propeller shaft was between 33 to 56 rpm. The Garton pump destratified Ham's Lake in three days (Toetz, 1977). During stratification, algal biomass declined, the number of green algae increased, but the number of species of blue-green algae did not decrease. Anabaena, Aphanizomenon, and two species of Microcystis were observed during the period between mid June to early September.

Hooper et al. (1952) reported the use of a centrifugal pump which displaced 20.7% of the lake volume in 10 days during midsummer and successfully increased the epilimnion by 49.9%. During pumping, conductivity and alkalinity increased. An increase in the concentration of total phosphorus in the epilimnion accounted for the increase in the volume of phytoplankton for three weeks after termination of pumping. Although the species composition of the phytoplankton changed little during pumping, the increase in the volume of phytoplankton was caused by an increase in the size and number of colonies of the predominant alga, Chroococcus.

Brezonik et al. (1969) successfully destratified a 39 ha lake by using six aerator guns. At 3 m DO increased from 0 to 3.9 mg/l during the first week of pumping. A sharp increase in nitrite concentration (from 1 to 14 µg/l) occurred in the entire water column one month after the initial pumping. A decrease in Kjeldahl nitrogen (organic nitrogen and ammonia) was detected at the bottom. Artificial destratification also caused a reduction in the concentration of hypolimnetic manganese.

Symons et al. (1967) showed that mechanical pumping had little effect on the DO concentration at the surface, but raised that of the bottom water. A more homogenous temperature profile was observed due to warming of the water mass below 9 m. While mixing had little effect on the nitrogen and total phosphorus concentrations both at the surface and bottom, the process eliminated sulfide at 14 m in about one week. Mixing did not cause an algal bloom. However, the study showed that the reduction in the population of blue-green algae was more than that of green algae.

Horizontal Variability

George and Edwards (1976) attributed the horizontal distribution of algae to wind. Maximum horizontal patchiness occurred at moderate wind speeds of 100 cm/sec, but decreased as wind speed increased. The authors also observed a considerable horizontal heterogeneity in the distribution of the more buoyant blue-green algae, but a fairly homogeneous distribution of green algae and diatoms. Haffner (1977) observed horizontal heterogeneity of diatoms populations. However, the spatial distribution varied dramatically over the study period of two years.

Gruendling and Malanchuk (1974) detected higher total phosphate and nitrate concentrations in shallower sampling stations. They did not study the distribution of phytoplankton. The concentration of nutrients has a significant effect on the horizontal distribution of phytoplankton. A high density of phytoplankton was observed in regions of major nutrient input and upwelling in Lake Ontario (Munawar and Nauwerk, 1971). The inshore regions were characterized by high densities and irregular distribution of phytoplankton while the central waters had low densities and homogeneous distribution of phytoplankton. Robertson et al. (1971) observed higher chlorophyll a concentrations near large cities than in offshore waters of Lake Michigan. On the same lake, the number of diatoms near shore was twice as much as that offshore (Holland and Beeton, 1972). In Lake Erie the concentration of chlorophyll a was seven times higher in the western basin than in the eastern basin during summer (Glooschenko et al., 1974).

CHAPTER III

MATERIALS AND METHODS

During summer and autumn of 1976 and 1977, weekly collections and Secchi disc transparency measurements were made at Ham's Lake at stations 2, 4, 6, 7, and 8 (Figure 1). Temperature was recorded at station 2 at meter intervals. Chlorophyll samples and algal samples were taken in duplicate from one pooled sample made by combining water from stations 2, 4, 6, 7, and 8, from the top 2.5 m of the water column. Chemical parameters (DO, alkalinity, pH, and phosphate) were determined weekly at station 2. Nitrate, nitrite, and ammonia samples were determined monthly at station 2. Dissolved oxygen was measured at meter intervals; all other chemical parameters at the surface, 4 m, and 8 m or bottom. During 1978 samples were taken weekly as in 1976 and 1977. Two additional sampling stations (11, 22) were set up to more adequately characterize distribution patterns (Figure 1). Sampling started in the second week of May and continued to the end of September. Water samples were stored on ice during transit and refrigerated in the laboratory if analyses were delayed.

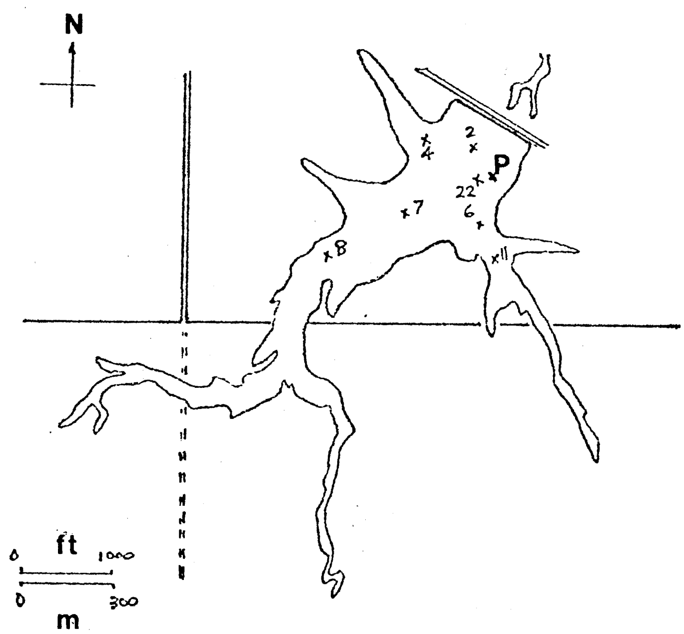

Figure 1. Map of Ham's Lake, Oklahoma, Showing Sampling Stations and Location of Pump (P)

Physical Parameters

During 1978 temperature was taken weekly at station 2 at meter intervals from the surface to the bottom of the lake with a thermister telethermometer. Quadruplicate Secchi disc measurements were made weekly at station 2, 4, 6, 7, and 8. Lake level was measured weekly as distance below spillway level using a permanent pole gauge. These measurements were made in the same manner and frequency in 1976 and 1977.

Measurements for horizontal comparisons during 1978 were made as follows: temperature was recorded monthly in triplicate at all seven stations at 1 m. Four measurements of Secchi disc transparency were taken monthly at all seven stations.

Chemical Parameters

Dissolved oxygen, pH, alkalinity, carbon dioxide, phosphate, nitrate, nitrite, and ammonia were measured weekly at station 2. Water samples were collected with a Kemmerer water sampler and analyzed in duplicate. Dissolved oxygen was determined at meter intervals from the surface to the bottom of the lake with a galvanic oxygen probe and meter. Estimates of DO were also made by the Winkler method for calibration of the probe. One sample was taken weekly for all other parameters at 0 m, 4 m, and 8 m or bottom. Determination of pH was done in duplicate with a Corning field pH meter. Alkalinity was determined in duplicate by titration (APHA, 1975). Concentrations of carbon dioxide were read from a nomograph with known pH and alkalinity values (APHA, 1975).

Nitrate and nitrite were analyzed following Strickland and Parsons (1968). Ammonia samples were analyzed by the method of Solórzano (1969). Phosphate was analyzed in duplicate by the stannous chloride method (APHA, 1975).

Monthly chlorophyll a determinations were made on one sample collected from each of the five stations and from each of two pooled samples containing equal portions of water from stations 2, 4, 6, 7, and 8. At each station, a composite of the top 2.5 m of the water column was collected with a weighted rubber hose. Measurements on each sample were made in triplicate. Extraction procedures and spectrophotometric determinations followed those of Strickland and Parsons (1968). Both chlorophyll a and phaeo-pigments were determined.

Horizontal comparisons of water chemistry were made by collecting monthly samples for determination of pH, alkalinity, phosphate, nitrate, and ammonia from all seven stations. For each of the above parameters, one sample from each station was collected as composite of the top 2.5 m of the water column with a weighted rubber hose. Each sample was analyzed in triplicate for each parameter.

Water was collected at least once a month with the weighted rubber hose above from all seven stations to determine the representativeness of the pigment samples.

Phytoplankton

I collected two pooled samples (composite samples) containing equal portions of water from stations 2, 4, 6, 7, and 8 weekly from the top 2.5 m of the water column with a weighted rubber hose. This procedure for sample collection was used in 1976, 1977, and 1978.

Phytoplankton samples were preserved with Lugol's solution (Vollenweider, 1979). An appropriate volume of sample was concentrated on a known surface area by filtering through Millipore membrane filters of 0.22 μ pore size (APHA, 1975). The filters were cleared with immersion oil. Identification and counting were done from 20 randomly selected fields of the same magnification and known area. Taxonomic texts by Prescott (1951; 1970) were used as references for the identification of algae. Organisms were identified to genus. Based on the assumption that the algae are evenly distributed on the surface of the filter, an estimate of the total cell number as well as the number of the dominant genera were made by proportionality. Cell counts were recorded as cells/ml.

Station Comparisons

Data for the physico-chemical parameters and phytoplankton standing crop were categorized according to sampling stations, sampling dates, and years (i.e. 1976 and 1978 experimental versus 1977 control). I compared means among corresponding sampling dates of the three years, as well as among the different sampling dates within a year. I compared station variability using data collected in 1978. I used a one-way analysis of variance as the method of statistical analysis (Steel and Torrie, 1960). A calculated F value larger than the 1% tabulated F value indicated significant differences among station means. I also used a multiple range test to make comparisons among stations (Murphy, 1973). Determination of the representativeness of the pooled samples as opposed to samples collected at each station was made using the same multiple range test.

Study Site

Ham's Lake is located in Payne County, 9.6 m west of Stillwater. The dam impounds Harrington Creek, a tributary of Stillwater Creek and several unnamed creeks. The lake was built in 1965 and has a surface area of 40 ha and a volume of about 115 ha-m at spillway elevation. The maximum depth of the lake is about 9.5 m, and the mean depth is about 3 m. The epilimnion is about 4 m. The lake is stratified between May and October with temperatures ranging from 25^{o}C to 29^{o}C. Blue-green algae, diatoms, and green algae are the predominant algae.

Station 2 is located near the dam, in the open area of the lake (Figure 1). The depth of this station is about 6 m to 8 m depending on the water level. During earlier destratification attempts this station had been destratified with temperature and DO profiles similar to those at the pump site (Steichen, 1974).

CHAPTER IV

RESULTS

Temperature

Data for temperature in Ham's Lake during 1976 are shown in Table VI of the Appendix. The surface temperature of 17.5°C on the first sampling date, May 2, was the lowest for the entire season. The lake was well mixed on that day. The temperature difference between the surface and the bottom (8 m) was only 1.6°C. From May 10 to June 8, as temperature at the surface increased, the thermocline fluctuated between one and three meters. The temperature difference between the surface and the bottom increased from 5.0°C to 7.5°C during that period. The temperature at the bottom of the lake was near 16.0°C before artificial mixing started on June 3.

The action of the pump was very dramatic. The temperature at the bottom of the lake increased from 16.5°C to 21.5°C in the first week the pump was running. Temperatures at 4 m also increased 3.0°C in the same period. The temperature difference between the surface and the bottom was only 5.3°C, despite a sharp increase of temperature at the surface as the summer progressed. The lake was mixed in less than two weeks after the pump started. The temperature difference between the surface and the bottom was only one degree on June 15. The lake remained mixed during the rest of the summer up to September (Figure 2). The temperature difference between the surface and the bottom stayed well within three degrees. In fact, on most sampling days, the difference was only two degrees or less.

Data for temperature during the 1977 sampling season (control) are shown in Table VII of the Appendix. On May 4, the temperature at the surface and the bottom was 24.0^{o}C and 18.0^{o}C, respectively. During May, the surface temperature stayed between 24.0^{o}C and 25.0^{o}C, and the temperature at the bottom remained at 18.0^{o}C. The surface temperature climbed to 29.0^{o}C by June 15 and the temperature at the bottom still remained at 28.0^{o}C. For nearly two whole months up to August 10, the surface temperature was within 29.0 $\pm$ 1.0^{o}C and that at the bottom was within 18.0 $\pm$ 1.0^{o}C (Figure 2). The lake was thermally stratified from May to August. For most of the summer the differences in the surface and bottom temperatures were about 11.0^{o}C. Temperatures at the bottom of the lake gradually increased towards the end of August. On August 31 the surface temperature was 27.0^{o}C and the temperature at the bottom was 22.8^{o}C, setting the stage for rapid destruction of thermal stratification. Rapid cooling of the upper portion of the lake during the period September 7 and 14 established an isothermal condition. The temperature difference between the surface and the bottom did not exceed 2.0^{o}C for the rest of the month after autumnal circulation began.

Ham's Lake was mixed artificially in 1978. The temperature data are shown in Table VIII of the Appendix. A 1.1 m pump was

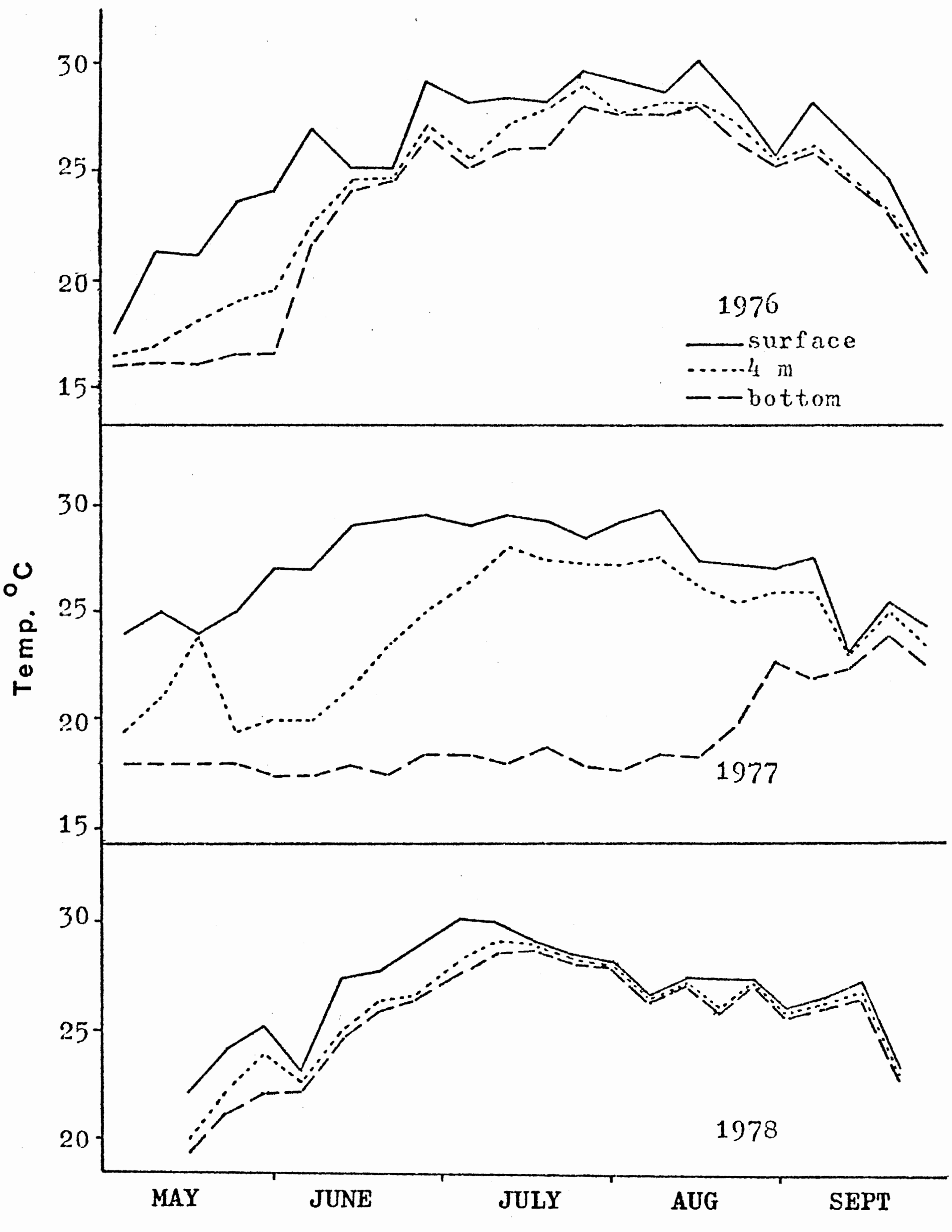

Figure 2. Temperatures at the Surface, 4 m, and the Bottom of Station 2 in Ham's Lake During 1976, 1977, and 1978

used from April 19 to July 6. Data taken in the first day of the sampling on May 16 indicated the lake was fairly well mixed. The surface temperature was 22.0^{o}C and that at the bottom was 19.2^{o}C. As the surface temperature increased to 25.0^{o}C by May 30, the temperature difference between the surface and the bottom was only 2.2^{o}C. On June 6 the surface temperature dropped to 23.0^{o}C. For the rest of the month of June and on to July 11, the temperature difference was below 3.0^{o}C. On July 4 and 11 the surface temperature was 30.0^{o}C and 29.8^{o}C, respectively. From July 11 to September 9, Ham's Lake was mixed artificially by a 1.6 m pump. The lake was well mixed and was isothermal throughout the remaining sampling season (Figure 2).

Secchi Disc Transparency

Data for Secchi disc transparency are shown in Table IX of the Appendix. In 1976 there were only slight fluctuations in Secchi disc transparency. On May 18, the value was 0.90 m (Figure 3). The transparency improved a little between May 25 and June 9 when the readings were between 1.15 m and 1.34 m. From June 15 to July 27, readings were mainly between 0.90 m and 1.05 m. A further decrease in Secchi disc transparency occurred between August 3 and September 7. The readings were between 0.70 m and 0.80 m. The lowest Secchi disc transparency reading was 0.70 m recorded on August 24. The sharpest increase in Secchi disc transparency occurred after the first week of September. The deepest Secchi disc transparency of the 1976 sampling season was 1.43 m recorded on September 21.

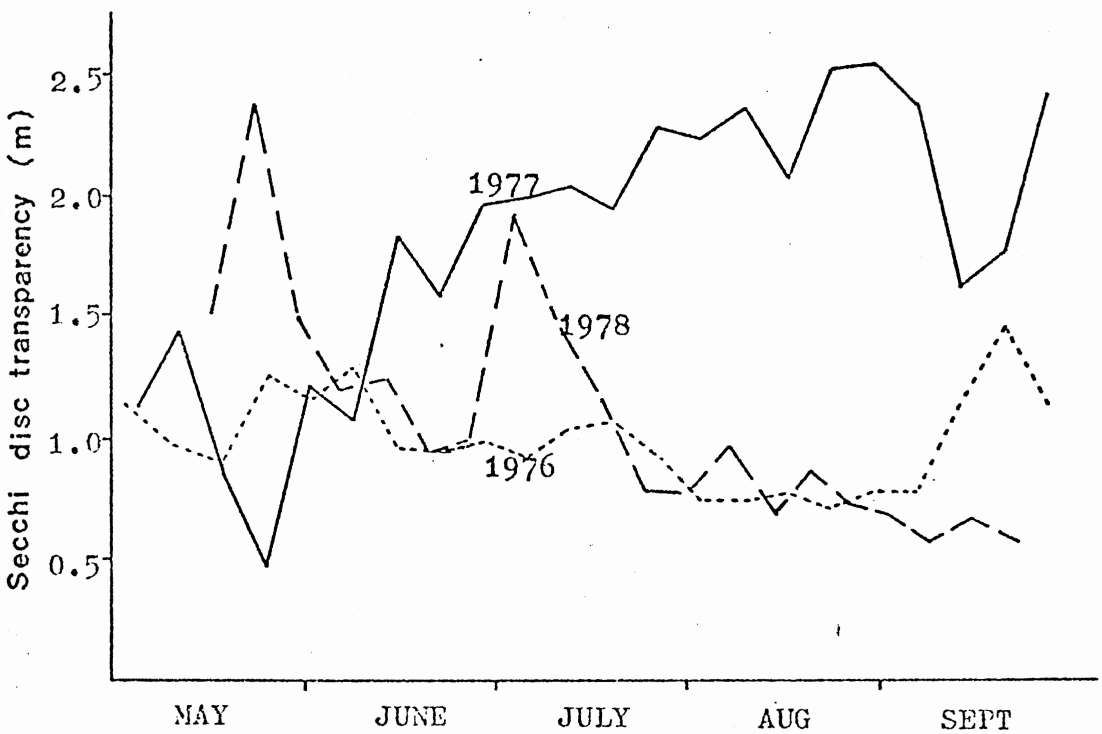

Figure 3. Mean Secchi Disc Transparency at Station 2 in Ham's Lake During 1976, 1977, and 1978

Readings for Secchi disc transparency during the 1977 sampling period were characterized by extraordinary values and sharp changes (Figure 3). During the first two sampling dates on May 4 and 11, the lake was relatively clear with Secchi disc transparency values of 1.11 m and 1.44 m, respectively. Transparency dropped below 1.00 m on May 18 and reached the lowest value of 0.46 m on May 25. This period of high turbidity did not continue for long. The value changed sharply to 1.20 m by June 1. Another equally rapid increase in Secchi disc transparency was recorded on June 15. The value changed from 1.05 m to 1.82 m in a week. From June 15 to the end of the sampling season, the Secchi disc transparency readings never fell below 1.50 m. The trend was toward an increase in transparency readings. The deepest Secchi disc transparency was recorded on August 31 with a reading of 2.52 m. A significant decrease to 1.60 m occurred on September 14 but by the end of September the depth of the Secchi disc was 2.40 m.

Sharp fluctuations in Secchi disc transparency readings also occurred in 1978 (Figure 3). The lake was relatively clear in May with Secchi disc transparency readings of 1.50 m or above. The deepest reading of the year was recorded on May 23 with a reading of 2.38 m. In June the readings declined a little with high readings near 1.20 m and low readings not less than 0.90 m. The depth of Secchi disc increased to 1.90 m on July 4. The readings stayed above 1.00 m for another two weeks in July but fell below 1.00 m toward the end of the month and into September. The lowest Secchi disc transparency readings were recorded in September and ranged between 0.56 m and 0.69 m.

Lake Level

All measurements of lake level were made from the same mark which corresponded to 15.2 feet on the permanent lake gauge. All measurements are reported as meters below this mark (Figure 4). The lake level on May 2, 1976, was 1.20 m (Table X of Appendix). The water level increased only slightly to its highest point of the year on June 1 with a value of 1.17 m. The water level came down very gradually throughout the summer. The last reading recorded on September 7 was 1.91 m. In the period between June 1 and September 7, the rate of decline in lake level was approximately 0.05 m per week.

The lake level during the first half of May, 1977, was very low (2.50 m) (Figure 4). A very drastic change occurred between May 18 and 25 when the lake level rose 1.54 m. The highest water level of the year was recorded on June 1. The lake level declined gradually during the summer except for a brief period between June 22 and July 6. On the last sampling date on September 28, the water level was 1.60 m. The difference between the highest level and the lowest level was 0.70 m. The rate of decline was similar to that in 1976 (Figure 4). During the latter part of May to September, the lake level was about 0.25 m higher in 1977 than that in the same period in 1976.

In 1978, the lake level was 1.92 m below the reference frame on May 16 (Figure 4). It declined to 1.98 m on May 23. Between May 23 and June 6, the lake level rose to 1.55 m. From that time onwards, the lake level declined gradually through September. The reading recorded on September 23 was 2.38 m. Again the rate of

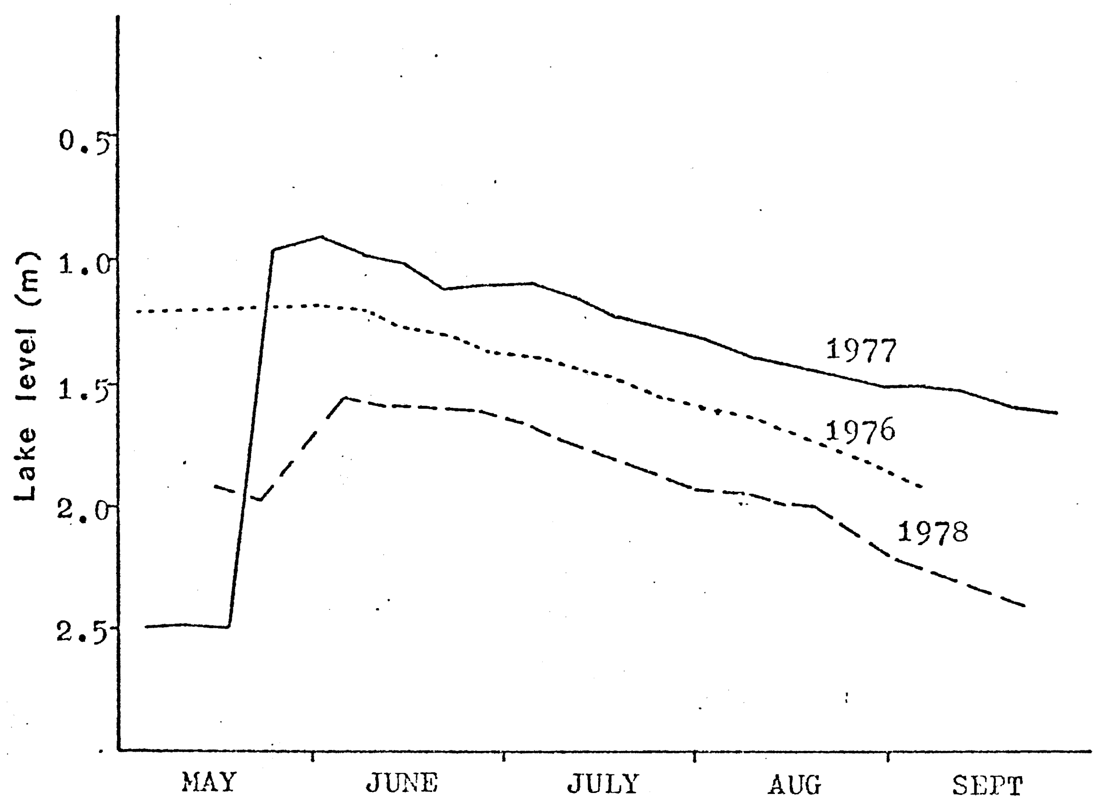

Figure 4. Lake Levels in Ham's Lake During 1976, 1977, and 1978 as Meters Below the Reference Mark (Reference Mark was Equivalent to 15.2 Feet on the Permanent Gauge)

decline in lake level was similar to that of the previous two years. The lake level in 1978 was the lowest among the three years. The reading on May 23 was 1.98 m and was about 0.80 m less than that in corresponding periods in 1976 and 1977, respectively (Figure 4). Throughout the summer months and September, the lake level in 1978 was about 0.30 m and 0.55 m less than that in corresponding periods in 1976 and 1977, respectively.

Dissolved Oxygen

Data for dissolved oxygen for 1976 are given in Table XI of the Appendix. The lake was well aerated during the first three sampling dates. On May 10 and 18, the concentration of DO at the surface and the bottom was 7.5 mg/l and 7.0 mg/l, respectively (Figure 5). A significant decrease in the concentration of DO occurred at all depths on May 25. The concentration of DO at the bottom was 1.3 mg/l. The lowest value of 0.6 mg/l was recorded on June 1. The action of artificial circulation alleviated anoxic conditions. On June 15 the lake was well mixed, since DO at the surface and the bottom was 5.6 mg/l and 5.2 mg/l, respectively. There was a decline in DO at the bottom between July 9 and July 20 when the pump was shut off, despite an increase in DO at the surface and 4 m. One week after the pump was operational, the DO at the bottom increased to 5.0 mg/l. For the rest of the month of August to the first week of September, the lake was fairly well mixed. Dissolved oxygen at the bottom stayed between 4.9 mg/l to 6.4 mg/l and from 6.6 mg/l to 8.0 mg/l at the surface. The difference in values between the surface and the bottom was about 1.0 to

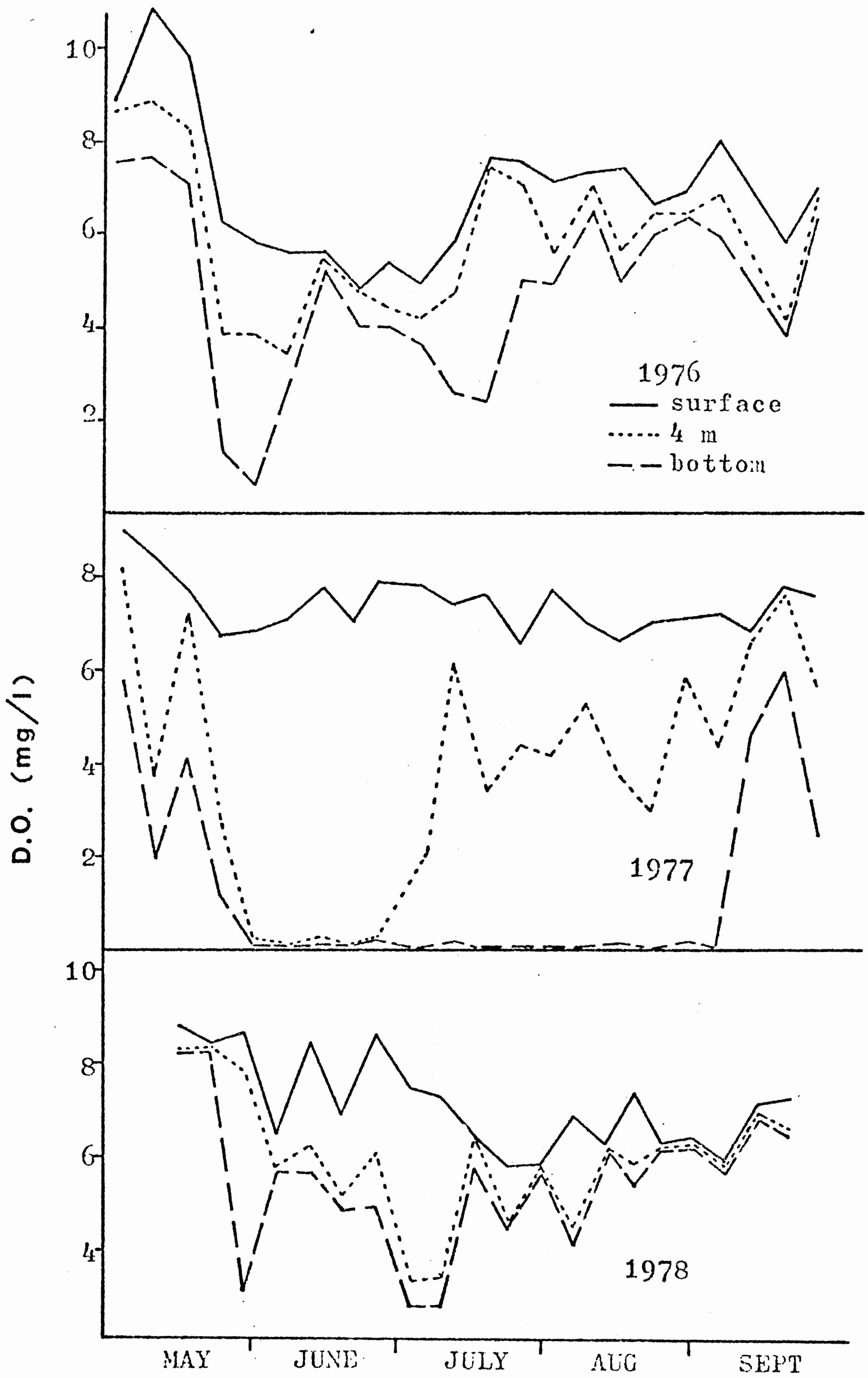

Figure 5. Dissolved Oxygen at the Surface, 4 m, and the Bottom of Station 2 in Ham's Lake During 1976, 1977, and 1978

2.0 mg/l. The concentrations of DO decreased at all depths on September 21 (Figure 5) only to increase again by September 28.

No artificial mixing took place in Ham's Lake during 1977. The concentration of DO at the surface reached 9.0 mg/l on May 4, the first sampling date, and gradually declined to 6.7 mg/l by the end of the month (Figure 5). The concentration of DO between 3 m and the bottom fluctuated drastically during the same period. On two occasions, May 11 and 25, DO at the bottom was 1.9 mg/l and 1.2 mg/l, respectively. From June to September, DO values at the surface were about 7.0 mg/l (range: 6.5 mg/l to 7.9 mg/l). The bottom of the lake remained anoxic for more than three months from June 1 to September 7 (Figure 5). The bottom returned to an oxic condition by September 14; DO reached 6.0 mg/l on September 21. Large fluctuations in the concentration of DO were evident. The most severe stress in terms of concentration of DO was recorded during the month of June. Dissolved oxygen was depleted below 4 m.

Data for concentrations of DO in 1978 are presented in Figure 4. Artificial mixing began early that year, on April 19. On the first two sampling dates (May 16 and 23) the lake was well circulated and the concentration of DO at all depths was above 8.0 mg/l. On May 30 while the concentration of DO at the surface remained above 8.0 mg/l and that at 4 m 7.6 mg/l, there was a significant decrease to 3.0 mg/l at the bottom. By June 6 the concentration of DO was 5.6 mg/l, but at the surface it was only 0.8 mg/l higher. The concentration of DO at the bottom stayed between 5.6 mg/l and 4.8 mg/l in June, while that at the surface fluctuated between 6.4 mg/l and 8.6 mg/l.

Between July 6 and 11, the pump was temporarily out of operation. Two days prior to the mechanical failure on July 4, the concentration of DO in the whole water column decreased. The value at the bottom declined to 2.7 mg/l from a previous reading of 4.9 mg/l, and from 6.0 mg/l to 3.3 mg/l at 4 m; while that at the surface declined from 8.6 mg/l to 7.4 mg/l. The situation was similar on July 11.

On July 18, one week after a 1.6 m pump was put into operation, there was a tremendous increase in DO at 4 m and at the bottom (Figure 5). The concentration of DO was homogeneous from the surface to 4 m with a value of 6.5 mg/l; at the bottom it was 5.7 mg/l. From the latter half of July to the end of September, the DO concentration was more homogeneous than that in the period from May to the first half of July. The concentration of DO at the bottom stayed above 5.0 mg/l for most of the sampling dates and ranged from a low of 4.0 mg/l on August 8 to a high of 6.8 mg/l on September 15.

pH

The pH values obtained at the surface of Ham's Lake generally stayed above 8.0. A pH value of 8.2 was recorded at the surface on June 29, 1976. Fluctuations of pH values among successive sampling dates were slight and generally either increased or decreased by one tenth of a pH value (Table XIV of Appendix). The pH values obtained from July through September were about 8.5 (mean) with a range of 8.2 and 8.7 (Figure 6). The mean pH value at the bottom of the lake in 1976 was 8.4.

In 1977 pH values were generally lower than those of 1976. The mean pH value at the surface of the lake from May to September was 8.1 (range: 7.6 to 8.5) (Figure 6). The mean pH value at the bottom of the lake was 7.9. Large fluctuations of pH values of 0.4 of a pH unit or larger were recorded at the surface, 4 m, and the bottom of the lake. Fluctuations of pH values were especially obvious in the month of May, June, and July.

During the 1978 sampling season, the mean pH value at the surface was 8.3 (Figure 6). Fluctuations of pH values as much as 0.5 or more of a pH unit occurred in May and June. The range of pH values during the two months were from 7.8 to 8.9, but fluctuations in pH values were less from July through September. The pH values at the surface stayed between 8.0 and 8.5. This period of relative stability corresponded to the second period of artificial mixing in that year. From May to September the average pH value at 4 m, and at the bottom was 8.3 and 8.2, respectively.

I subtracted the pH value at the bottom from that at the surface to determine the impact of the pump. These differences, ΔpH, are very sensitive in reflecting the effect of artificial mixing. When artificial mixing is most effective, ΔpH will be very small or zero. Between June 29 and July 6, 1976, the pH values at the surface and at the bottom of the lake were identical and ΔpH was zero (Figure 7). Values for ΔpH increased to 0.5 on July 13 reflecting the unstable situation when mechanical circulation was temporarily halted. From the latter part of July to September, ΔpH was no larger than 0.1. In 1978, the differences

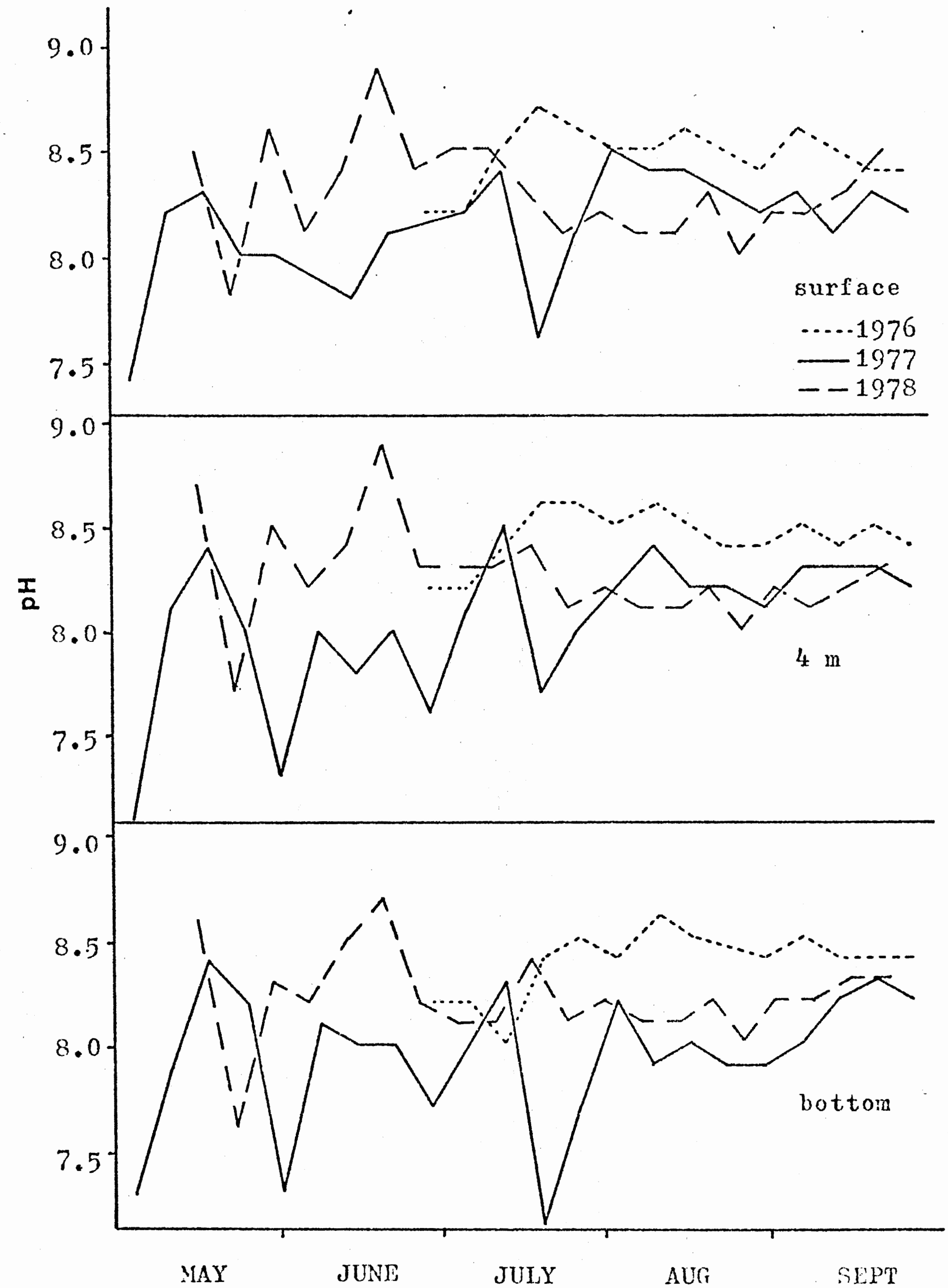

Figure 6. Mean pH Values at the Surface, 4 m, and the Bottom of Station 2 in Ham's Lake During 1976, 1977, and 1978

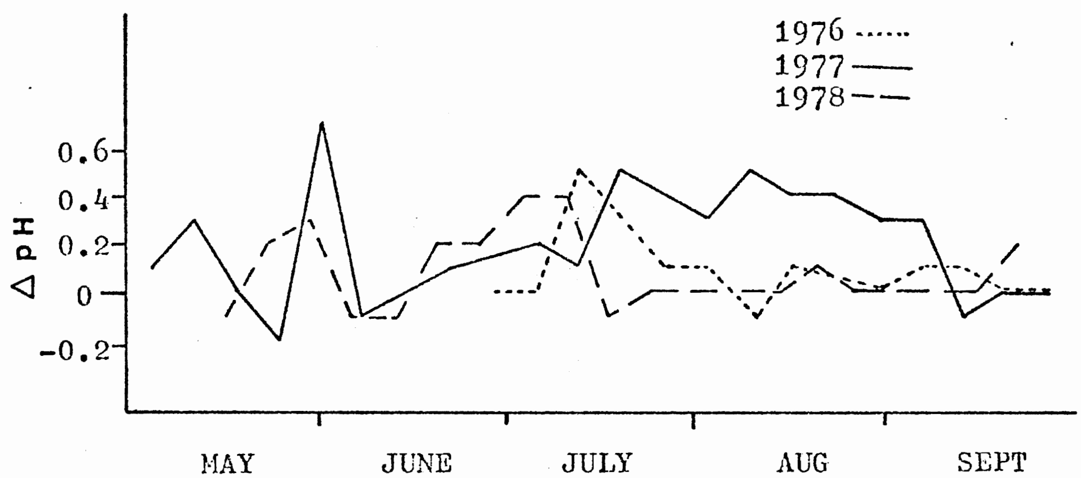

Figure 7. Differences in the Mean pH Values Between the Surface and the Bottom (ΔpH) of Station 2 in Ham's Lake During 1976, 1977, and 1978

were more pronounced from May to the first half of July than for the remainder of the year. Differences of 0.4 of a pH unit were recorded on July 4 and on July 11, a period when the pump was not operational. The ΔpH diminished towards the latter half of July and remained small into September (Figure 7). During the control year (1977) the differences were more pronounced compared to the two experimental years. On June 1, 1977, ΔpH reached a high of 0.7, while from July 20 to September 7 ΔpH remained between 0.3 to 0.5. Such differences were significantly larger and extended over a longer period of time compared to corresponding periods in the other two years.

There were occasions when the ΔpH was negative. Usually one expects an alkaline pH at the surface due to the removal of carbon dioxide by algae during photosynthesis, and a relatively more acid pH at the bottom due to decomposition and accumulation of carbon dioxide. However, sometimes in Ham's Lake the pH at the surface was lower than that near the bottom. Such a phenomenon can be explained by both physical and climatic conditions. Rain may have lowered pH at the surface as recorded on September 14, 1977 and on June 5, 1978 since rain water is acidic. Cloudy weather can also cause accumulation of carbon dioxide at the surface due to algal respiration. Such a condition might explain the negative ΔpH difference recorded on June 13, 1978, when the weather was cloudy.

Total Alkalinity

Bicarbonate alkalinity constitutes the major portion of the total alkalinity in Ham's Lake. The average total alkalinity in 1976 was the highest of the three years. The average value at the surface was 162 mg/l with a range of 147 mg/l and 177 mg/l (Table XV of Appendix). The average value at the bottom was 164 mg/l with a range of 150 mg/l and 196 mg/l. In 1977, the average total alkalinity value at the surface was 139 mg/l with a range of 122 mg/l and 163 mg/l. The average value at the bottom was only 119 mg/l with a range of 68 mg/l and 166 mg/l. The values recorded in May and the most of June were higher than those recorded in subsequent months. A drastic decrease in the values of total alkalinity occurred at all depths of the lake on June 1, 1977 (Figure 8). This period of decline in the values of total alkalinity corresponded to the massive inflow of water into the lake. In 1978, the average total alkalinity value at the surface was 123 mg/l and ranged from a low of 116 mg/l to a high of 130 mg/l. The average value at the bottom was 122 mg/l and ranged from 109 mg/l to 130 mg/l.

Carbonate alkalinity values were generally higher at the surface of the lake than at the bottom in 1978, but not in other years. The average carbonate alkalinity value at the surface was 4 mg/l or 3.2% of the average total alkalinity value. The average carbonate alkalinity value at the bottom was 2 mg/l or only 1.6% of the average total alkalinity value. The formation of carbonate in the trophogenic zone is caused by the dissociation of bicarbon-

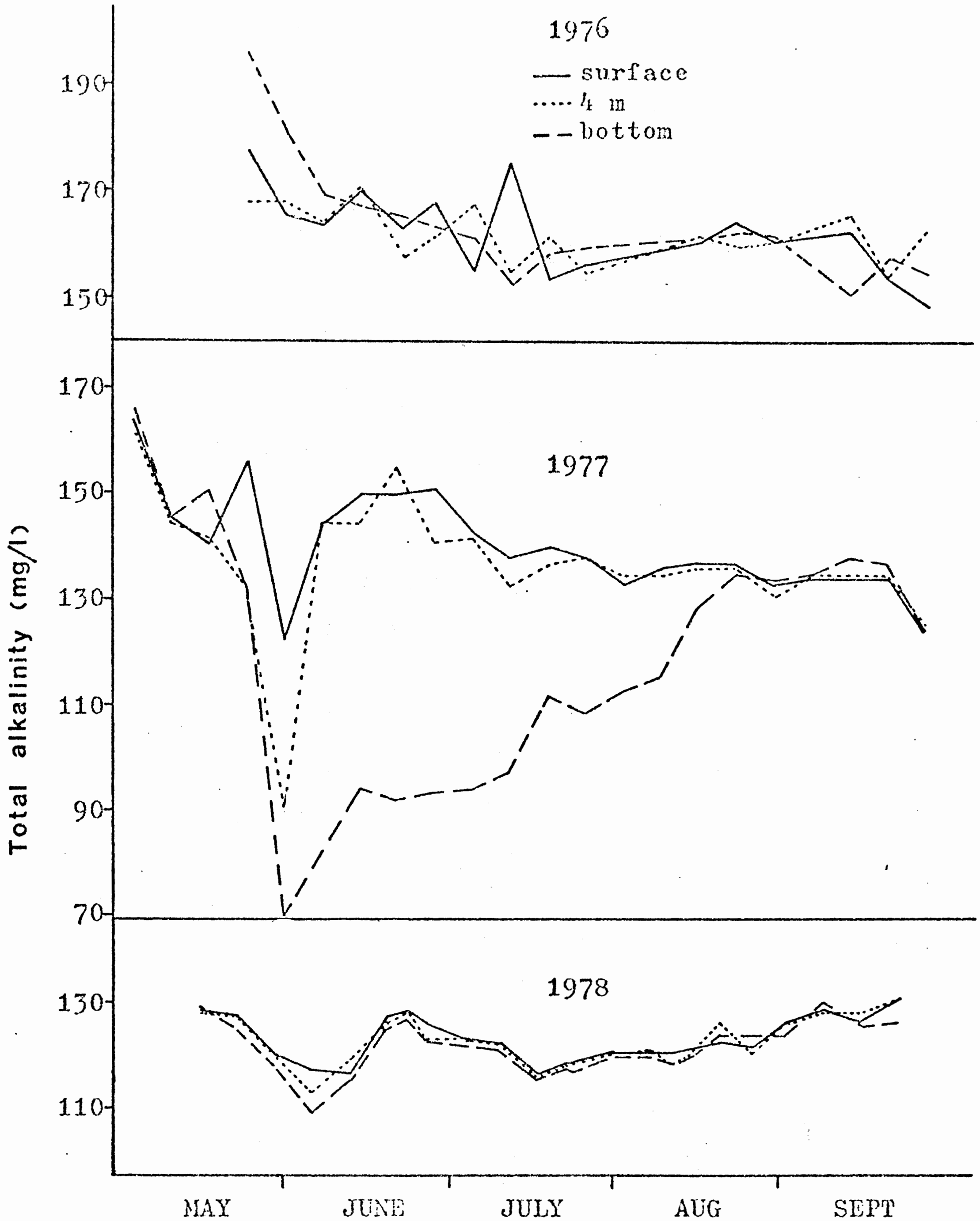

Figure 8. Mean Total Alkalinity Values at the Surface, 4 m, and the Bottom of Station 2 in Ham's Lake During 1976, 1977, and 1978

ate to replenish the supply of free carbon dioxide used in photosynthesis.

I subtracted the value of total alkalinity at the bottom from that at the surface (Δtotal alkalinity) on each sampling date to assess the effect of artificial mixing on the lake, as I did with the pH data. In 1976 and 1978, values of Δtotal alkalinity were near zero indicating that the pump successfully mixed the lake (Figure 9). One large value for Δtotal alkalinity, recorded on July 13, 1976, indicated heterogeneity between the surface and the bottom of the lake at a time when the pump was temporarily halted. During the control year, 1977, Δtotal alkalinity values were positive and greater than zero from the latter part of May to early August, showing that the lake was stratified. The large Δtotal alkalinity values resulted from the decline in total alkalinity at the bottom of the lake. The lowest bottom value, 68 mg/l, was recorded on June 1 and for most of June and July, the total alkalinity was below 110 mg/l (Figure 8).

Free Carbon Dioxide

Free carbon dioxide (carbon dioxide) was present during 1977 but not in 1976 and 1978. The distribution of carbon dioxide at the surface, 4 m, and the bottom is recorded in Table XVI of the Appendix. The presence of carbon dioxide at the surface was detected on several occasions. A high value of 12 mg/l was recorded on May 4. Values ranging from 2 mg/l to 4 mg/l were recorded consistently from May 25 to June 13 (Figure 10). Carbon dioxide was not detected at the surface in August and September.

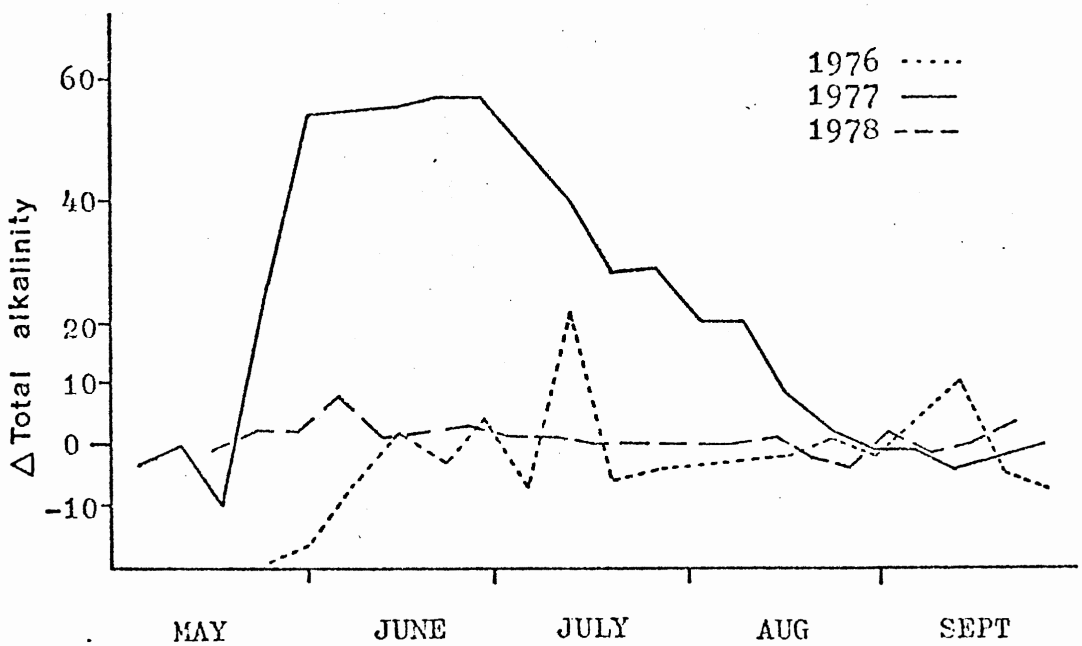

Figure 9. Differences in the Mean Total Alkalinity Values (Δ Total Alkalinity) Between the Surface and the Bottom of Station 2 in Ham's Lake During 1976, 1977, and 1978

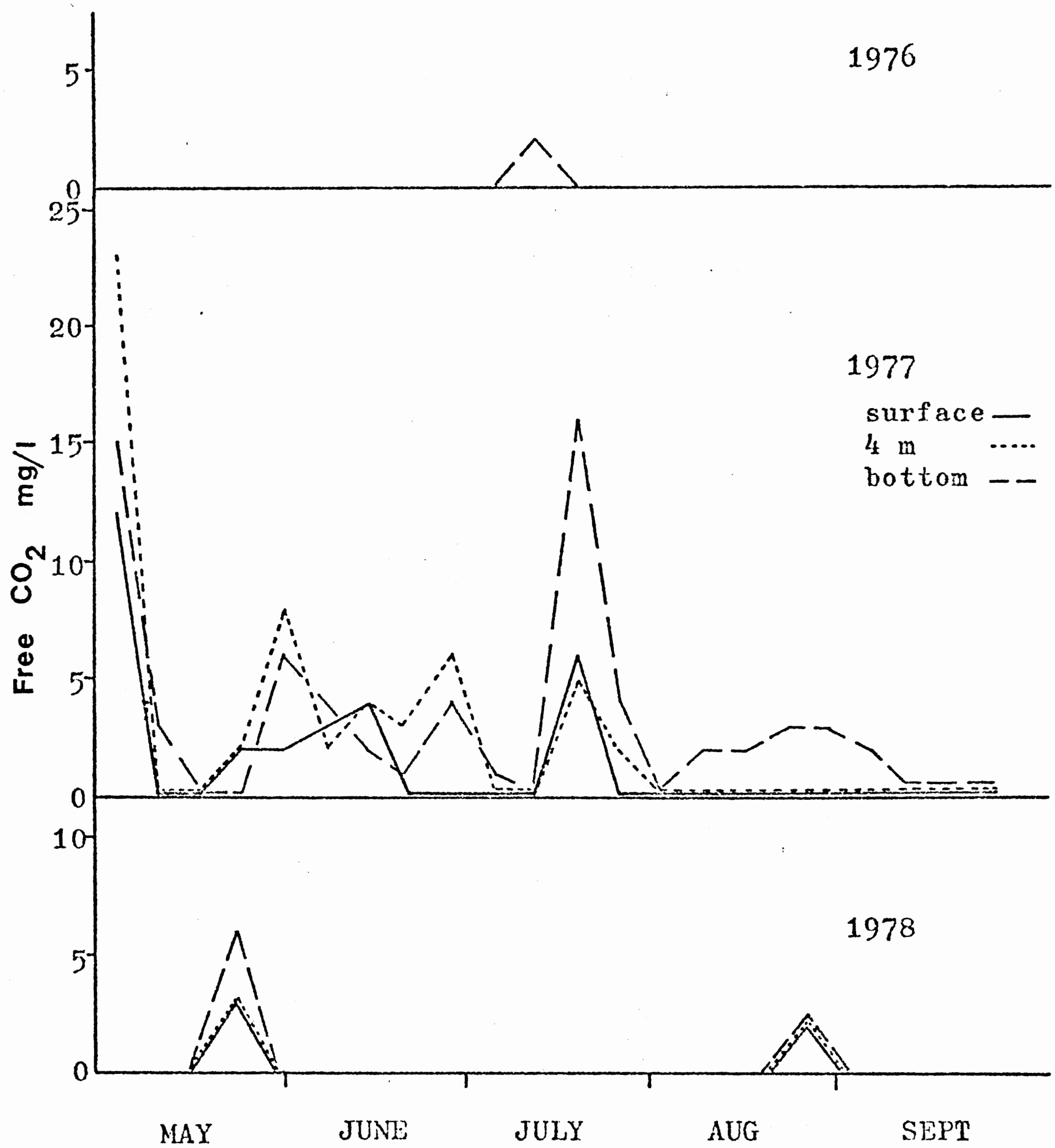

Figure 10. Mean Free Carbon Dioxide Concentrations at the Surface, 4 m, and the Bottom of Station 2 in Ham's Lake During 1976, 1977, and 1978

The concentrations of carbon dioxide at 4 m were generally higher than that at the surface. The value recorded for May 4 was 23 mg/l. Carbon dioxide was either not present or present in small quantities for the rest of May. Throughout the month of June the concentration of carbon dioxide at 4 m varied between 4 to 6 mg/l. During that period, dissolved oxygen was not detected at 4 m. Between 5 mg/l and 2 mg/l of carbon dioxide was present in the latter part of July. Again carbon dioxide was not present at 4 m in August and September.

Carbon dioxide was also present at the bottom. The initial reading recorded on May 4 was 15 mg/l but then it decreased to 3 mg/l on May 11. Carbon dioxide was not detected at the bottom on May 18 and 28 when a massive amount of water flowed into the lake. An average of about 3 mg/l of carbon dioxide was detected at the bottom in June and early July, but the value obtained was less than that obtained at 4 m. From July 7 to mid September, there was an accumulation of carbon dioxide at the bottom. The values obtained during this period were higher than that at 4 m (Figure 10). The value increased to 16 mg/l on July 20. The lake was destratified by September 15.

Nitrate

Data on nitrate-nitrogen (nitrate) concentrations were obtained at monthly intervals during the sampling seasons in 1976 and 1977 but at weekly intervals during the sampling season in 1978 (Table I). Nitrate concentrations showed an inverse clinograde distribution on June 1, 1976, just before artificial mixing

TABLE I

MEAN CONCENTRATIONS OF NITRATE NITROGEN AT THE SURFACE, 4 m, AND THE BOTTOM OF STATION 2 IN HAM'S LAKE DURING 1976, 1977, AND 1978

1976			1977			1978		
DATE	DEPTH (m)	µg/l	DATE	DEPTH (m)	µg/l	DATE	DEPTH (m)	µg/l
6-01	0	4	4-27	0	4	5-16	0	32
	4	44		4	2		4	30
	8	71		8	3		8	34
6-29	0	2	5-25	0	105	5-23	0	4
	4	5		4	87		4	15
	8	3		8	177		8	N.D.*
7-28	0	24	6-29	0	1	5-30	0	16
	4	9		4	N.D.		4	21
	8	22		8	13		8	50
8-31	0	5	7-27	0	2	6-06	0	13
	4	5		4	1		4	35
	8	28		8	2		8	42
			8-31	0	4	6-13	0	2
				4	3		4	13
				8	3		8	15
			9-28	0	6	6-20	0	7
				4	18		4	10
				8	13		8	13
						6-27	0	3
							4	11
							8	12
						7-04	0	N.D.
							4	28
							8	27
						7-11	0	N.D.
							4	2
							8	4

TABLE I (Continued)

1976			1977			1978		
DATE	DEPTH (m)	µg/l	DATE	DEPTH (m)	µg/l	DATE	DEPTH (m)	µg/l
						7-18	0	N.D.
							4	N.D.
							8	N.D.
						7-25	0	3
							4	6
							8	7
						8-01	0	6
							4	3
							8	5
						8-08	0	N.D.
							4	3
							8	3
						8-12	0	5
							4	5
							8	5
						8-21	0	3
							4	3
							8	4
						8-27	0	3
							4	2
							8	2
						9-02	0	4
							4	4
							8	6
						9-16	0	7
							4	7
							8	7
						9-23	0	10
							4	7
							8	7

*N.D. = Not detected.

began. The concentration recorded at the surface and bottom was 4 µg/l and 72 µg/l, respectively. On June 29, nitrate concentrations at all depths were low and essentially alike. During July the value of nitrate at the surface and the bottom was 24 µg/l and 22 µg/l, respectively; while that at 4 m was 9 µg/l. By August 31, nitrate was evenly distributed between the surface and 4 m with a value of 5 µg/l. The value at the bottom was 28 µg/l.

Low concentrations of nitrate between 2 µg/l and 4 µg/l were recorded during pre-season sampling on April 27, 1977. On May 25, nitrate concentrations reached a record high for all three years due to the massive inflow of water into the lake. The value at the surface was 105 µg/l, at 4m 87 µg/l, and at the bottom 177 µg/l. On June 29 there was 1 µg/l and 13 µg/l of nitrate at the surface, and at the bottom, respectively. The concentration of nitrate in July and August did not exceed 4 µg/l at the depths sampled (Table I). On September 28, nitrate was essentially isochemical with respect to depth.

In 1978 the concentration of nitrate appeared to be lower than the previous two years. The highest level recorded in May or June was 50 µg/l as compared to 72 µg/l in 1977, and 177 µg/l in 1976. Nitrate was isochemical with respect to depth on May 16 with a concentration of 30 µg/l. There was a drastic decline in the concentration of nitrate at the surface and the bottom on May 23 (Table I). There was a significant increase in the concentration of nitrate between May 30 and June 6, corresponding to an increase in lake level of approximately 0.4 m. From the end of May to July 25, the distribution of nitrate was basically inverse clinograde with higher concentrations of nitrate detected at the bottom (Table I). From July 11 to the end of the sampling season on September 23, the distribution of nitrate was essentially the same. At this time the concentration of nitrate was rather low as it was in 1977. On most occasions, the concentrations of nitrate detected during this period were well below 10 µg/l.

Nitrite

Data collected in the sampling season of 1976 showed that on the average, the nitrite-nitrogen (nitrite) concentration found at the surface was 5 µg/l, at 4 m it was 7 µg/l, and at the bottom it was 8 µg/l. Data collected four weeks after artificial mixing began showed a slight decline of nitrite concentration at all depths sampled (Table II). This was also true for nitrate concentration as indicated earlier. The concentration of nitrite increased slightly in July and August but declined in September.

Monthly data collected between April and September of 1977 showed that the concentrations of nitrite did not exceed 8 µg/l at the surface and at 4 m (Table II). At both depths, the average nitrite concentration was 4 µg/l. A higher average value of 9 µg/l was observed at the bottom. A concentration of nitrite of 8 µg/l was observed both at the surface and at 4 m on May 25. However, nitrite was not detected at the bottom on that date. On June 29, 3 µg/l of nitrite was recorded at the surface and at 4 m. The value at the bottom increased to a high of 32 µg/l but decreased to 10 µg/l on July 27 and to 3 µg/l on August 31 (Table II).

TABLE II

MEAN CONCENTRATIONS OF NITRITE NITROGEN AT THE SURFACE, 4 m, AND THE BOTTOM OF STATION 2 IN HAM'S LAKE DURING 1976, 1977, AND 1978

1976			1977			1978		
DATE	DEPTH (m)	µg/l	DATE	DEPTH (m)	µg/l	DATE	DEPTH (m)	µg/l
6-01	0	5	4-27	0	4	5-16	0	N.D.*
	4	12		4	4		4	N.D.
	8	9		8	4		8	N.D.
6-29	0	4	5-25	0	8	5-23	0	N.D.
	4	5		4	8		4	2
	8	6		8	N.D.		8	2
7-27	0	7	6-29	0	3	5-30	0	2
	4	7		4	3		4	2
	8	15		8	32		8	2
8-31	0	8	7-27	0	4	6-06	0	4
	4	8		4	3		4	4
	5	9		8	10		8	4
9-28	0	3	8-31	0	2	6-13	0	N.D.
	4	3		4	2		4	N.D.
	8	4		8	3		8	N.D.
			9-28	0	1	6-20	0	N.D.
				4	2		4	N.D.
				8	7		8	N.D.
						6-27	0	N.D.
							4	2
							8	6
						7-04	0	N.D.
							4	10
							8	13
						7-11	0	N.D.
							4	5
							8	5

TABLE II (Continued)

1976			1977			1978		
DATE	DEPTH (m)	µg/l	DATE	DEPTH (m)	µg/l	DATE	DEPTH (m)	µg/l
						7-18	0	N.D.
							4	N.D.
							8	N.D.
						7-25	0	N.D.
							4	N.D.
							8	N.D.
						8-01	0	1
							4	1
							8	N.D.
						8-08	0	N.D.
							4	2
							8	3
						8-12	0	2
							4	2
							8	2
						8-15	0	2
							4	2
							8	2
						8-21	0	N.D.
							4	2
							8	2
						8-27	0	N.D.
							4	N.D.
							80	N.D.
						9-02	0	N.D.
							4	N.D.
							8	N.D.
						9-09	0	N.D.
							4	N.D.
							8	3

TABLE II (Continued)

1976			1977			1978		
DATE	DEPTH (m)	µg/l	DATE	DEPTH (m)	µg/l	DATE	DEPTH (m)	µg/l
						9-16	0	N.D.
							4	N.D.
							8	N.D.
						9-23	0	N.D.
							4	N.D.
							8	N.D.

*N.D. = Not detected.

A weekly sampling schedule for nitrite was adopted in 1978. No nitrite was detected on May 14. Only 2 µg/l of nitrite was detected at 4 m and the bottom, but none at the surface on May 24 (Table II). From the end of May until June 21, nitrite was evenly distributed in the lake. A small quantity (4 µg/l) was detected at all depths on June 6. From June 27 to July 11, nitrite was detected at 4 m and at the bottom but not at the surface. The concentration of nitrite increased on July 4, two days before the pump was temporarily stopped, when concentrations of nitrite at 4 m and at the bottom rose to 10 µg/l and 13 µg/l, respectively. Only 5 µg/l of nitrite was observed at the bottom on July 11 (Table II). A small quantity of nitrite was detected from the latter part of July to the end of September.

Ammonia

Very large quantities of ammonia-nitrogen (ammonia) were observed on June 1, 1976. One day before artificial mixing began, the distribution was inverse clinograde (Table III). The values of ammonia recorded on June 29, about a month after artificial mixing began, were considerably lower. Only 13 µg/l of ammonia was found at the surface. At 4 m the value was 35 µg/l, and at the bottom it was 62 µg/l. The pump did not appear very effective in reducing the concentrations of ammonia near the bottom in subsequent sampling dates as there was a considerable amount of ammonia present in July and August when the pump was operating (Table III). The concentration of ammonia at the surface increased considerably after the June sampling. The value at the

TABLE III

MEAN CONCENTRATIONS OF AMMONIA NITROGEN AT THE SURFACE, 4 m, AND THE BOTTOM OF STATION 2 IN HAM'S LAKE DURING 1976, 1977, AND 1978

1976			1977			1978		
DATE	DEPTH (m)	µg/l	DATE	DEPTH (m)	µg/l	DATE	DEPTH (m)	µg/l
6-01	0	130	4-27	0	13	5-16	0	2
	4	208		4	13		4	9
	8	278		8	29		8	24
6-29	0	13	5-25	0	27	5-23	0	N.D.*
	4	35		4	39		4	38
	8	62		8	145		8	42
7-27	0	77	6-29	0	15	5-30	0	N.D.
	4	66		4	15		4	N.D.
	8	123		8	250		8	24
8-31	0	85	7-28	0	11	6-06	0	8
	4	57		4	14		4	16
	8	107		8	148		8	20
9-28	0	149	8-31	0	49	6-13	0	N.D.
	4	18		4	38		4	25
	8	64		8	75		8	30
			9-28	0	14	6-20	0	12
				4	38		4	45
				8	105		8	49
						6-27	0	N.D.
							4	18
							8	35
						7-04	0	N.D.
							4	27
							8	44
						7-11	0	N.D.
							4	7
							8	7

TABLE III (Continued)

1976			1977			1978		
DATE	DEPTH (m)	µg/l	DATE	DEPTH (m)	µg/l	DATE	DEPTH (m)	µg/l
						7-18	0	N.D.
							4	N.D.
							8	N.D.
						7-25	0	N.D.
							4	10
							8	15
						8-01	0	N.D.
							4	N.D.
							8	3
						8-08	0	N.D.
							4	22
							8	35
						8-12	0	N.D.
							4	N.D.
							8	4
						8-15	0	N.D.
							4	N.D.
							8	2
						8-21	0	N.D.
							4	4
							8	7
						8-27	0	3
							4	3
							8	3
						9-02	0	N.D.
							4	N.D.
							8	N.D.
						9-09	0	N.D.
							4	10
							8	11
						9-16	0	39
							4	36
							8	44

TABLE III (Continued)

1976			1977			1978		
DATE	DEPTH (m)	µg/l	DATE	DEPTH (m)	µg/l	DATE	DEPTH (m)	µg/l
						9-23	0 4 8	N.D. 6 6

*N.D. = Not detected.

surface exceeded that at the bottom on September 29.

During 1977 the ammonia profile was characterized by relatively low concentrations of ammonia at the surface and at 4 m, but high concentrations at the bottom. The concentration gradient was moderate between the surface and 4 m but very steep between 4 m and the bottom. On May 25, 27 µg/l of ammonia was detected at the surface, 39 µg/l at 4 m, and 145 µg/l at the bottom. While there was a slight decline of ammonia both at the surface and 4 m on June 29, there was an accumulation of ammonia at the bottom (Table III). Ammonia at the bottom decreased by July 28, when 148 µg/l was detected. Some mixing of the water column occurred toward the end of August. By August 31 the concentration gradient was less steep, due to increases of ammonia at the surface and at 4 m to 49 µg/l and 38 µg/l, respectively, coupled with a decrease of ammonia at the bottom (75 µg/l). Such a condition did not last long. There was considerable amount of ammonia detected at the bottom by the end of September. Data collected on September 28 showed that the profile of ammonia distribution was typically inverse clinograde (Table III).

A more extensive survey involving weekly sampling of ammonia was adopted in 1978 (Table III). Artificial mixing began early that year (April 19). On the average, values obtained in 1978 were significantly lower than those obtained at corresponding depths in the two previous years. On most sampling dates, ammonia was not even detected at the surface (Table III). There were some slight fluctuations in the amount of ammonia detected at the surface from May 16 to the end of June but the mean was only 3 µg/l.

Relatively more ammonia was detected from the latter part of May to early July than in the rest of July and August. The values at the bottom varied from a low of 20 µg/l to a high of 49 µg/l. The mean value from May 16 to July 4 was 33 µg/l. The mean value at 4 m during the same period was 22 µg/l. A small amount of ammonia was present between the latter part of July and September 9. Although ammonia was detected occasionally at 4 m and at the bottom, the concentrations were usually low. Only on one occasion, August 8, was a fairly large concentration of ammonia detected at the bottom. About 40 µg/l of ammonia was found in all three depths of the lake on September 16 (Table III), but this situation did not persist. During the last sampling date on September 23, no ammonia was detected at the surface while the concentration at 4 m and at the bottom was 8 µg/l.

Sulfide

Artificial mixing reduced the concentration of sulfide-sulfur (sulfide) in Ham's Lake. Lower concentrations of sulfide were detected in 1976 and 1978 than in 1977. On June 1, 1976, low concentrations of sulfide (4 µg/l) were detected at each of the three depths (Table XVII of Appendix). Higher concentrations of sulfide were found by the end of June. On June 29 there was 13 µg/l at the surface and 26 µg/l at the bottom. On July 27, 30 µg/l of sulfide was detected at the surface and at 4 m. The value at the bottom, however, was 12 µg/l. Sulfide concentrations decreased drastically by the end of August and none was detected in September (Figure 11).

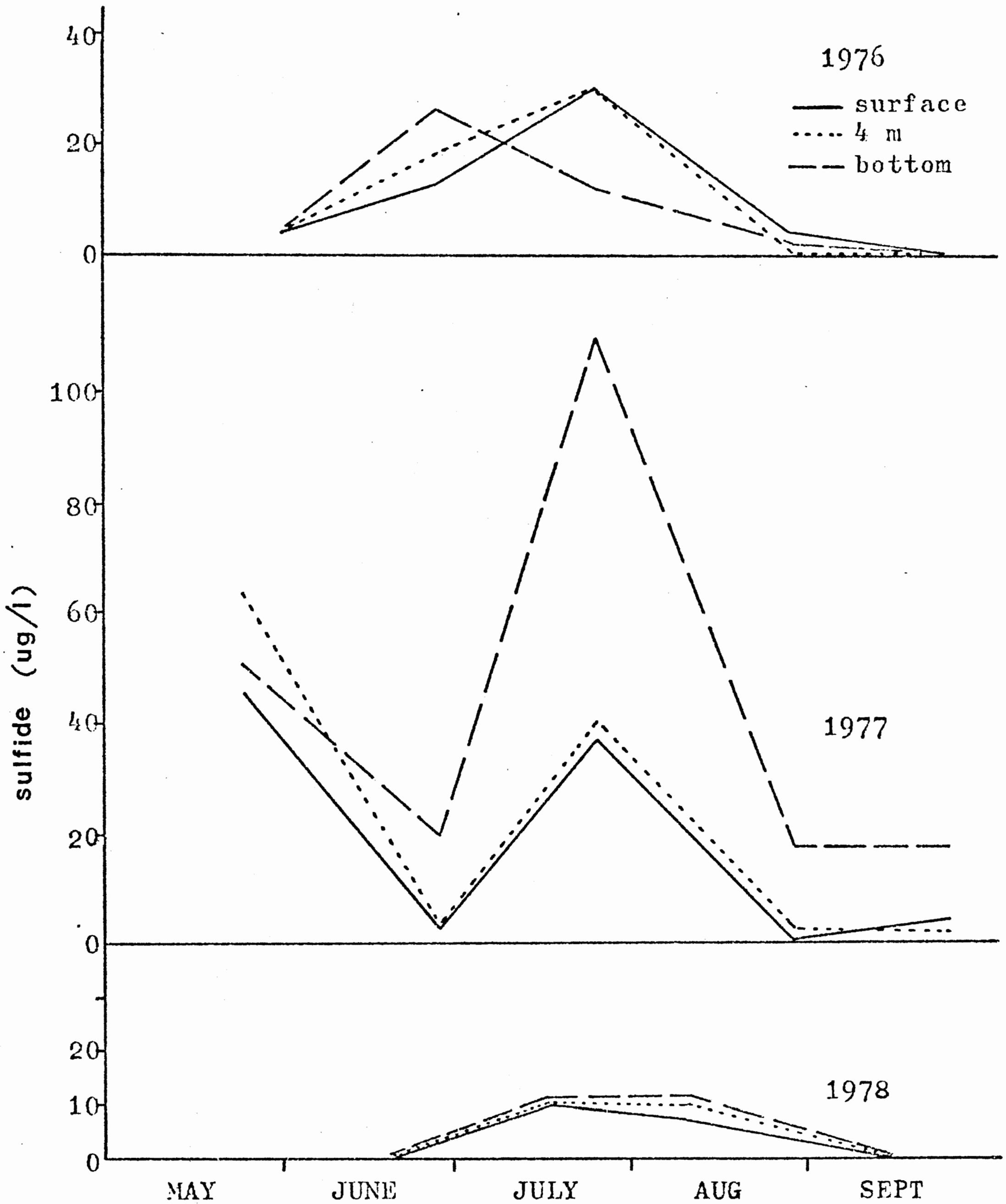

Figure 11. Mean Concentrations of Sulfide at the Surface, 4 m, and the Bottom of Station 2 in Ham's Lake During 1976, 1977, and 1978

A positive heterograde distribution of sulfide was observed on May 25, 1977. There was 45 µg/l of sulfide at the surface, 63 µg/l at 4 m, and 50 µg/l at the bottom. The concentration of sulfide decreased in June. Only 2 µg/l of sulfide was present at the surface and at 4 m. However, the value at the bottom was 19 µg/l. The concentration of sulfide increased significantly on July 27. There was 36 µg/l of sulfide at the surface, but 109 µg/l at the bottom (Figure 11). While the concentrations of sulfide in the epilimnion were not above 4 µg/l in August and September, the concentrations in the hypolimnion were considerably higher.

The concentrations of sulfide detected during the sampling season in 1978 were very low. Sulfide was not detected in May, June, or September. A small amount of sulfide was present in July and August. Only 11 µg/l of sulfide was detected at the bottom on July 18, when the lake was well mixed. The difference in sulfide concentration between the surface and the bottom was only 2 µg/l. The condition was very much the same on August 12. Again, 11 µg/l of sulfide was detected at the bottom. Only 7 µg/l was detected at the surface. The homogeneity in the vertical distribution of sulfide during the summer months of July and August indicated that the pump was effective in mixing the lake.

Phosphate

Orthophosphate-phosphate (phosphate) was readily detected in the experimental years, 1976 and 1978, but not in the control year, 1977. The concentrations of phosphate detected in 1976 were the highest of the three years. Two thirds of the time when phosphate was detected, there was more than 6 µg/l present. Phosphate was detected in three out of four sampling dates in June and in the first week of July, with concentrations at the surface ranging from 8 µg/l to 12 µg/l. Nevertheless, phosphate was not detected during the rest of July. No phosphate was detected during the period from July 9 to 20 when the pump was turned off temporarily. On August 2, 8 µg/l of phosphate was detected at the bottom but none was detected at the surface or 4 m. However, the reverse was true on August 24 when 6 µg/l of phosphate was detected at the surface but none was detected at other depths. Phosphate concentrations reached high values on August 31 when 20 µg/l was detected at the surface and 23 µg/l was measured at 4 m and the bottom (Figure 12).

Phosphate was not detected at the surface during the entire sampling season of 1977. However, there were few instances during July and August when phosphate was detected at 4 m and at the bottom of the lake. On July 13, 7 µg/l of phosphate was detected at 4 m but none was detected at the bottom. On August 4, only the bottom contained measurable phosphate (5 µg/l). On August 10, there was 7 µg/l of phosphate at 4 m and the bottom. On August 17, 4 µg/l of phosphate was found at 4 m only. In summary, there were only four instances in the 1977 control year when phosphate was detected (Figure 12).

There were eleven instances in the 1978 experimental year when phosphate as detected. As in 1976, phosphate was not only present in the lower depths, but it also occurred at the surface.

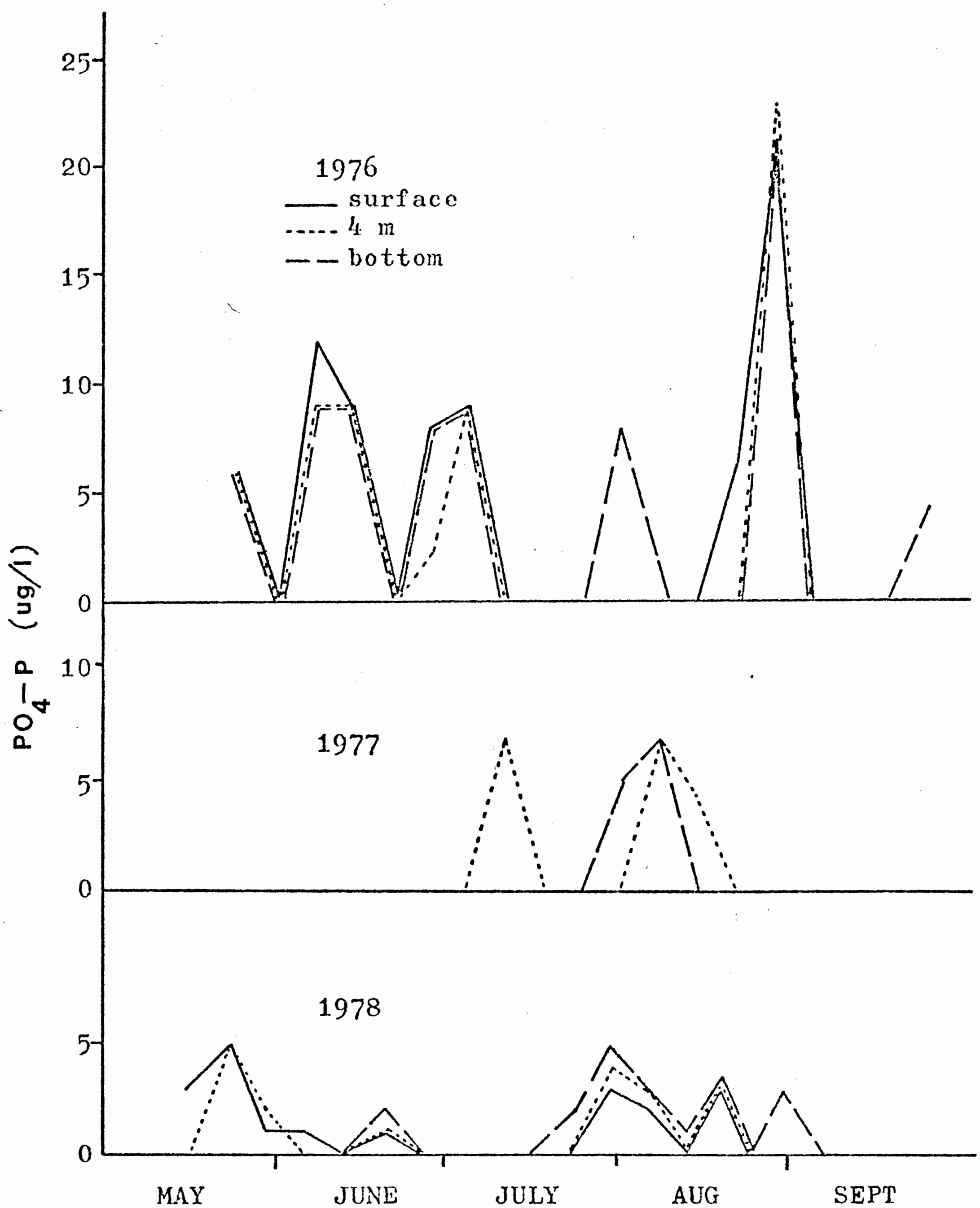

Figure 12. Mean Concentrations of Phosphate at the Surface, 4 m, and the Bottom of Station 2 in Ham's Lake During 1976, 1977, and 1978

Low concentrations of phosphate not exceeding 5 µg/l, were detected at the surface from May 15 to June 6, 1978. Phosphate was not detected at the bottom during this period. Low concentrations of phosphate not exceeding 2 µg/l, were observed at all three depths on June 21. Between June 21 and July 25, no phosphate was detected. Again, phosphate was not detected during the period from July 6 to 11 when the pump was shut down. Between the latter part of July until early September the concentration of phosphate was higher at the bottom. On July 25, August 15, and September 1, phosphate was detected only at the bottom.

Chlorophyll a

Chlorophyll a data are reported in Table XIX of the Appendix and Figure 13. Chlorophyll a samples were collected as composite samples from the top 2.5 m of the euphotic zone. On May 24, 1976, the concentration of chlorophyll a was 5 mg/m^3, increasing to 8 mg/m^3 on June 1, and then decreasing to 4 mg/m^3 on June 8, five days after the pump started. The concentration of chlorophyll a was 10 mg/m^3 and 9 mg/m^3 on June 15 and 23, respectively. From June 29 and August 10, the average chlorophyll a concentration was 8 mg/m^3 (range: 7 mg/m^3 to 9 mg/m^3). On August 17 when surface temperatures reached 30.0°C, the concentration of chlorophyll a was 12 mg/m^3. From August 24 to 31, concentrations were 11 mg/m^3. As the water temperature cooled in September there was a gradual decline in the chlorophyll a concentration. During the last sampling date on September 28 the concentration increased sharply to 13 mg/m^3, an possible indication of an early fall

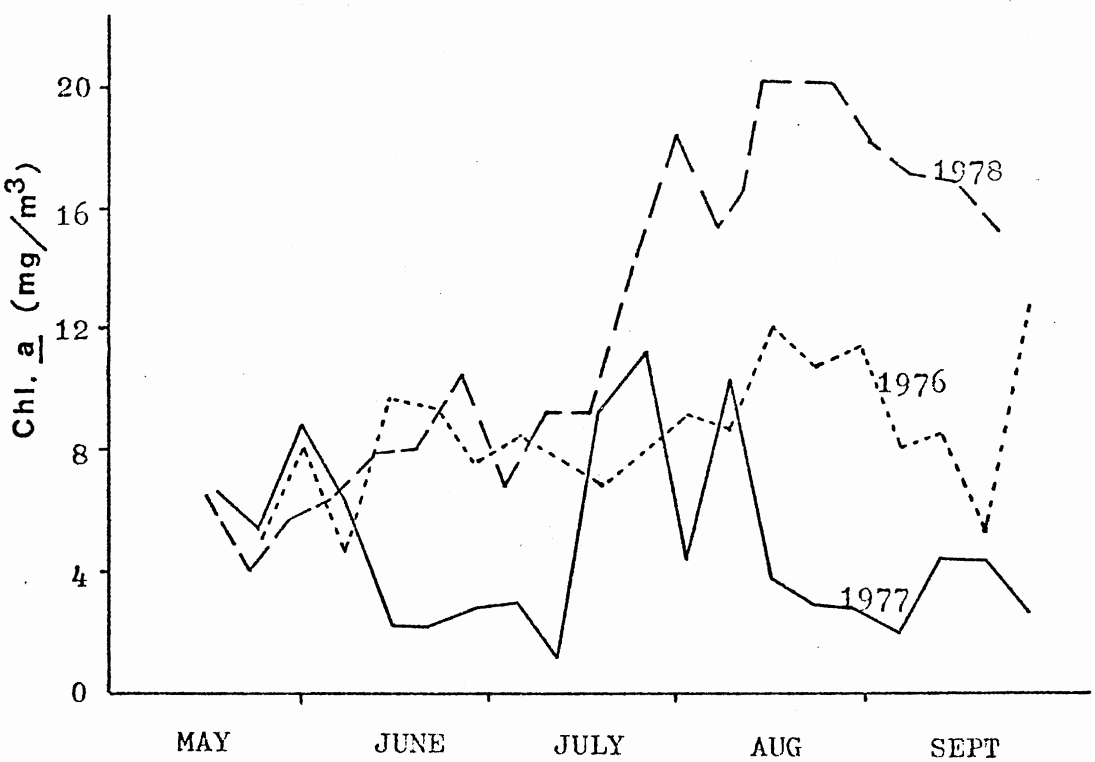

Figure 13. Mean Concentrations of Chlorophyll a in the First 2.5 m of the Water Column of Station 2 in Ham's Lake During 1976, 1977, and 1978

bloom (Figure 13).

Chlorophyll a values were low in 1977 (control year). From May 18 to June 8, the average concentration of chlorophyll a was 7 mg/m^3 and it ranged from 5 mg/m^3 on May 25 to 9 mg/m^3 on June 1. From June 16 to July 13, the average chlorophyll a value was only 2 mg/m^3. A very sharp increase in the concentration of chlorophyll a occurred on July 20 (Figure 13). Large fluctuations, between 4 mg/m^3 and 10 mg/m^3, occurred during the first two weeks of August. The concentration of chlorophyll a was constant between August 17 and the end of September, 3 mg/m^3 (range: 2 mg/m^3 to 4 mg/m^3).

During the experimental year (1978), the concentration of chlorophyll a increased gradually from May to August. From May 16 to June 6, the average chlorophyll a value was 6 mg/m^3 (range: 4 mg/m^3 to 7 mg/m^3). A gradual increase occurred between June 13 and July 18 with an average value of 9 mg/m^3 (range: 7 mg/m^3 to 11 mg/m^3). Up to this time, the temporal variation of chlorophyll a in 1978 was similar to that of 1976 (Figure 13). From July 25 onward to the end of September, the concentration of chlorophyll a was much higher than during the two previous years, reaching 19 mg/m^3 on August 1 and remaining at a high of 20 mg/m^3 from August 15 to August 27. The concentration of chlorophyll a gradually declined in September from 18 mg/m^3 on September 2 to 15 mg/m^3 on September 23.

I plotted the concentration of chlorophyll a versus the inverse of Secchi disc transparency (1/S.D.) and a linear equation was constructed for each of the three years (Figure 14). In 1976, the linear equation was 1/S.D. = 0.54 + 0.06(chlorophyll a), where S.D. is the Secchi disc transparency in meters and chlorophyll a is the concentration of the chlorophyll a in mg/m^3. As the concentration of chlorophyll a increased, there was a proportionate increase in 1/S.D., or a decrease in S.D. In 1976 the presence of algal biomass contributed to a significant reduction in Secchi disc transparency. Based on the equation, 5 mg/m^3 of chlorophyll a corresponded to a S.D. value of 1.19 m while 10 mg/m^3 of chlorophyll a corresponded to a S.D. value of 0.87 m. In the hypothetical situation when the chlorophyll a value was equal to zero, the S.D. reading was 1.85 m.

During 1977 the concentration of chlorophyll a was low and Secchi disc transparency was high. The majority of the chlorophyll a values were less than 5 mg/m^3 with corresponding Secchi disc transparency of 1.67 m (1/S.D. = 0.6) or more. After deleting three extreme sets of values, two with high chlorophyll a values and high Secchi disc transparency and one with low chlorophyll a value but low Secchi disc transparency, the adjusted linear equation for 1977 was 1/S.D. = 0.38 + 0.05(chlorophyll a). A chlorophyll a value of 5 mg/m^3 corresponds to a S.D. value of 1.59 m while another value of 10 mg/m^3 equals to a S.D. value of 1.14 m.

The equation for 1/S.D. versus chlorophyll a for 1978 was similar to that of 1977. The linear equation was 1/S.D. = 0.35 + 0.06(chlorophyll a). Highest concentrations of chlorophyll a were actually observed in 1978, not in 1977.

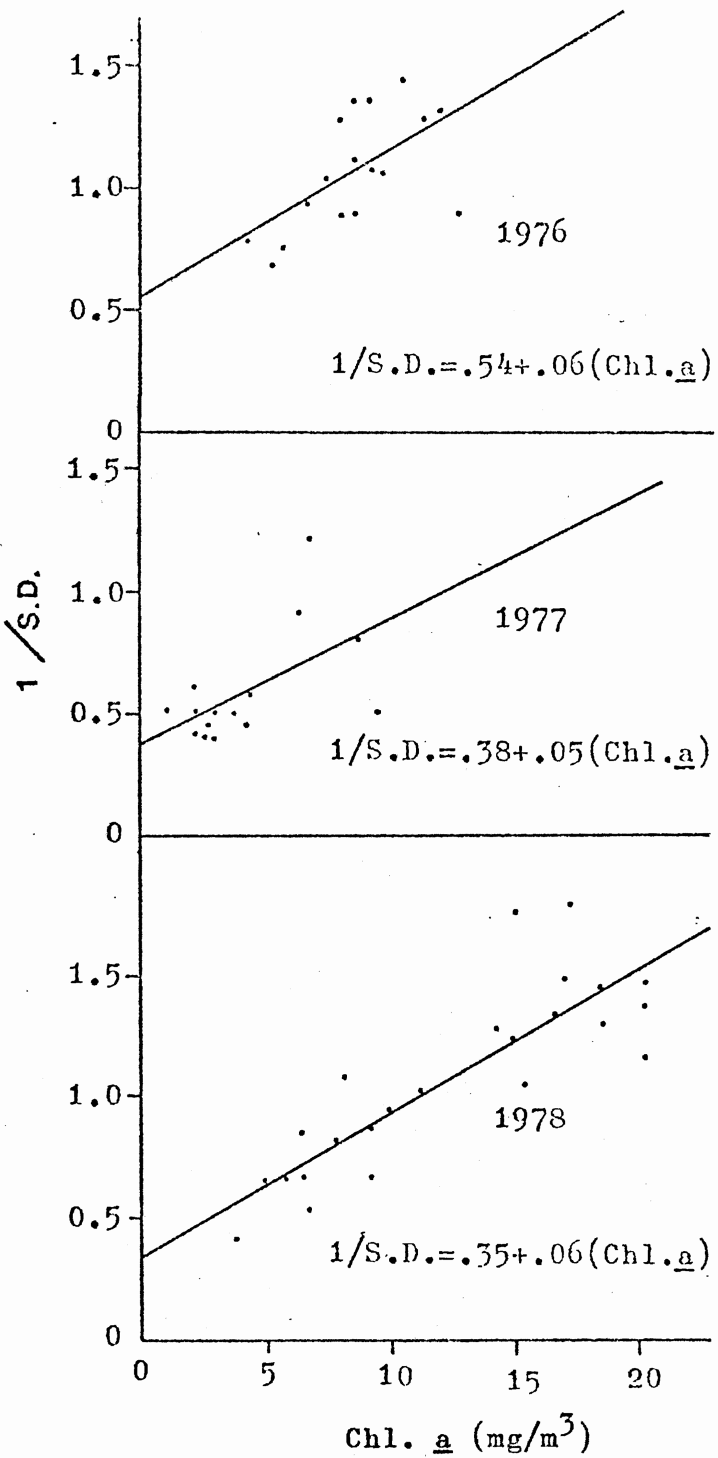

Figure 14. Plot of Chlorophyll a Concentrations Versus the Inverse of Secchi Disc Transparency Values at Station 2 in Ham's Lake, 1976, 1977, and 1978

Phytoplankton

Table IV shows the densities of the 39 genera found in Ham's Lake during the sampling period, May to September, 1977. The diatoms were the predominant group of algae with 19 genera observed. The green algae were the next largest group with 12 genera. There were six genera of blue-green algae, one genus of a dinoflagellate and one genus of a euglenoid. Among the diatoms, the genera Cyclotella and Navicula were most commonly encountered and occurred in greater abundance than the other genera. Among the green algae, Coelastrum was most common. The dominant blue-green algae was Microcystis.

Seasonal variability of algal composition and algal densities occurred in 1977. Relatively few genera were observed in May, when only three genera of green algae were encountered. The green alga Coelastrum showed a seasonal high on May 11. Colonies of the blue-green algae Microcystis and Aphanothece were present in moderate numbers. Cyclotella and Navicula were among the six genera of diatoms present in May. The dinoflagellate Ceratium occurred mainly in May. From June to July, the algal composition as well as the densities of the diatoms increased. The number of genera of diatoms increased from six in May to 13 on June 29. The dominant diatoms, Cyclotella, Navicula, and Synedra reached maximum densities during the period from the latter part of June to the first half of July (Table IV). The euglenoid, Trachelomonas, also increased in density in June and July. The rest of the algal flora showed very little change during that period. All the algal

TABLE IV

DENSITIES OF ALGAL GENERA (CELL/ML, OR COLONY/ML, OR FILAMENT/ML) IN HAM'S LAKE DURING 1977

DIVISION GENERA	5-11	5-25	6-15	6-29	7-13	7-27	8-10	8-24	9-07	9-27
Chlorophyta										
Ankistrodesmus									154	11
Asterococcus									22	
Chlorococcum					1				70	
Closteriopsis										
Coelastrum	71	42	50	14	4	35	28	17	28	
Crucigenia									22	6
Elakatothrix									42	
Gloeocystis	4					3			123	11
Keriochlamys										
Kirchneriella										
Pandorina									3	
Pediastrum	4		6	3	4					
Quadrigula										
Radiofilum										
Scenedesmus										
Sphaerocystis									241	
Staurastrum							1			
Ulothrix							1			
Cyanophyta										
Anabaena			1	1			3	3	160	414
Aphanothece	21		3	3	6	1				
Chroococcus						6			19	6
Merismopedia			1						87	
Microcystis	42	8	15	29	21	35	14	109	585	39
Oscillatoria										
Spirulina									3	
Chrysophyta										
Amphipleura			1	20	6	11	11	6	6	11
Amphora					3					
Brebissonia										
Cocconeis				7	3		1			
Cyclotella	92	8	15	101	144	52	62	11	14	106
Cymbella	4	8	7	4	7	1	4			
Diatoma							1		11	
Diploneis			3	6	3	6	3		3	6
Epithemia							3			17
Fragilaria			4	6	4	3	1		8	
Gomphoneis							1			
Gyrosigma						1				
Melosira			24	6	7					
Meridion						1	1			
Navicula	13	17	31	42	10	15	6	6	56	17
Nitzschia	4		6	6		1		3	6	6
Pinnularia		8		1						
Rhopalodia	8			10	17	3	8	6		
Surirella				1	3					
Synedra			6	39	42	11	14	8	6	
Pyrrophyta										
Ceratium	46	8	1				4			
Euglenophyta										
Trachelomonas	25		7	29	20	17	8			

taxa except the blue-green algae declined in number of genera and in density toward the latter part of August. *Coelastrum* was the only genus of green algae observed. Six genera of diatoms, but no dinoflagellates or euglenoids were observed. On the other hand, the blue-green algae, *Microcystis*, increased in density to 109 colonies/ml on August 24. By September the number of genera and algal densities increased in the green algae, diatoms, and blue-green algae. For example, there were nine genera of green algae in September as opposed to three in August. *Ankistrodesmus*, *Gleocystics*, and *Sphaerocystis* being the most numerous. The diatoms *Navicula* and *Cyclotella* increased in density in the first half of September and in the latter part of September, respectively. Blue-green algae were very abundant in September. On September 7, a total of five genera of blue-green algae was observed. *Microcystis* was the dominant genus with a density of 585 colonies/ml and *Anabaena* next with a density of 160 filaments/ml. By the end of September there was a shift of dominance. The density of *Microcystis* was only 39 colonies/ml, while that of *Anabaena* was 414 filaments/ml.

Table V shows the algal densities of the various algae found in Ham's Lake during the period from May to September, 1978. A total of 40 algal genera was observed. I observed 17 genera of diatoms, two less than in the same period in 1977; 15 genera of green algae, an increase of three; six genera of blue-green algae and one genus each of a dinoflagellate and an euglenoid.

Although there was a decline of the number of diatom genera in 1978, the mean density actually increased from 129 cells/ml in

TABLE V

DENSITIES OF ALGAL GENERA (CELL/ML, OR COLONY/ML, OR FILAMENT/ML) IN HAM'S LAKE DURING 1978

DIVISION GENERA	5-16	5-30	6-13	6-27	7-11	7-25	8-08	8-21	9-02	9-23
<u>Chlorophyta</u>										
Ankistrodesmus										
Asterococcus										
Chlorococcum										
Closteriopsis	1			4						
Coelastrum			14	54	35	15	15	8	6	14
Crucigenia	3		1	1	1					
Elakatothrix		11	7	6		18				3
Gloeocystis	1	23	84	5		14				
Keriochlamys				35	1					
Kirchneriella				1						
Pandorina			1							
Pediastrum	1		7	1		1	3	3		3
Quadrigula			6			1				
Radiofilum			1							
Scenedesmus		4	1		1	1				
Sphaerocystis	1	3	12	8		1				
Staurastrum			1	1	3	1	1	3		3
Ulothrix		1			1			6	1	
<u>Cyanophyta</u>										
Anabaena	3	4	43	16	29	113	34	39	8	3
Aphanothece			24	1		7	1			
Chroococcus	4		8	10	1	29	1	7		
Merismopedia			2							
Microcystis	28	22	43	28	42	105	41	20	11	3
Oscillatoria								3		
Spirulina										
<u>Chrysophyta</u>										
Amphipleura					4	4	7	8	3	6
Amphora	1									
Brebissonia		1		1				1		
Cocconeis	1		5	5	3		3	3	1	
Cyclotella	225	277	200	43	74	342	56	475	2105	375
Cymbella	1	6		2	1				1	
Diatoma					1			3		
Diploneis					1	4		3		8
Epithemia	1									3
Fragilaria		5		2	6	7	6	1		
Gomphoneis										
Gyrosigma				1					2	
Melosira	3	1	1	13	31	104	104	99	126	666
Meridion						1				
Navicula	20	15	19	34	11	8	11	25	14	11
Nitzschia		1				3	3	7	1	
Pinnularia										
Rhopalodia					6	4		3	1	3
Surirella										
Synedra	8	1	5	1	1	4	14	3	11	8
<u>Pyrrophyta</u>										
Ceratium	18			5	1					
<u>Euglenophyta</u>										
Trachelomonas									17	28

1977 to 570 cells/ml in 1978. This was due to significant increase in the densities of the genera Cyclotella and Melosira (Table V). The genus Navicula remained one of the major diatom genera.

There were some slight changes in the algal composition among the green algae. The genera Keriochlamys, Kirchneriella, Quadrigula, Radiofilum and Scenedesmus were observed in the 1978 experimental period while the genera Ankistrodesmus, Asteriococcus, and Chlorococcum were not. The genus Keriochlamys occurs in Kansas. Its presence in Oklahoma has not been documented (Prescott, 1970). In the present study, Keriochlamys was observed on two occasions, June 27, and July 11. The densities observed on these two dates were 35 cells/ml and one cell/ml, respectively.

The mean density of blue-green algae declined significantly during the experimental year of 1978 when the lake was artificially circulated. During 1977 and 1978 the mean density was 164 colonies and/or filaments/ml and 73 colonies and/or filaments/ml, respectively. The genera Microcystis and Anabaena remained dominant. When compared to 1977, the densities of Microcystis were lower on most occasions in 1978 (Table V). More importantly, there was no major bloom of Microcystis in 1978 as occurred in September, 1977 (Table V). Anabaena occurred on more occasions in 1978 than in 1977. However, the densities in 1978 never reached the magnitude as that recorded on September 27, 1977 (Table IV).

Seasonal variabilities in algal composition and density also occurred in 1978. The green algae were higher in density in June than at any other time during the sampling season. A total of 14 genera of green algae was observed in June alone and their densities were relatively high. With the exception of September, all months during the sampling season in 1978 had more genera than the corresponding months in 1977. The diatoms Cyclotella and Melosira were the dominant algae during the sampling season of 1978. Cyclotella had high densities from May through the first half of June, in the latter part of July, and from the latter part of August through the end of September, attaining an extremely high density of 2105 cells/ml on September 2 (Table V). The genus Melosira was dominant from the latter part of July to the end of September, reaching a density of 666 cells/ml on September 23. A small bloom of blue-green algae, consisting mainly of Microcystis and Anabaena, occurred on July 25. But the bloom was of smaller magnitude and did not last as long as the one that took place from the end of August through September of 1977. The dinoflagellate, Ceratium, was more numerous in early May, as was the case in 1977. The euglenoid, Trachelomonas, was observed only in September and not before as in 1977.

Station Comparisons

Station comparisons were made in 1978 using a Murphy's studentized range maximum gap test for the following parameters: Secchi disc transparency, total alkalinity, pH, ammonia, nitrate, nitrite, and chlorophyll a (Murphy, 1973). The 1% significant level was used for all comparisons.

Data for Secchi disc transparency collected at different stations on each sampling date were compared. Figure 15 shows the results of the comparisons. Each arrow indicated significant difference between two groups of stations at the 1% significance level. With the exception of the first two sampling dates, the Secchi disc transparency at station 4 was always significantly higher than that at other stations. No other consistent patterns can be seen among the other stations.

Comparisons of total alkalinity data between stations were made monthly from June to August (Figure 16). The results for June and July showed that there was no significant difference between the various stations. The results for August showed that while station 4 and 2 were not significantly different from each other, they were as a group significantly higher in total alkalinity than the rest of the stations.

Comparisons of pH data between stations were also made monthly from June to August (Figure 16). In June, station 4 with an average pH value of 9.7 was significantly different from stations 6, 7, 8, 11 and 22, each of which had a pH value of 9.3. However, stations 6, 7, 8, 11, and 22 were significantly different from station 2 which had an average pH value of 9.2. The pH values for all stations were identical in July. In August, station 4 with an average pH value of 8.2 was significantly different from the rest of the stations, which had an average pH value of 8.3.

Figure 17 shows the results of station comparisons using monthly ammonia data from June to September. In June station 7, 22, 2, 4, and 8, which had average ammonia concentrations less than 2 $\mu g/l$, were significantly different from station 6 with an

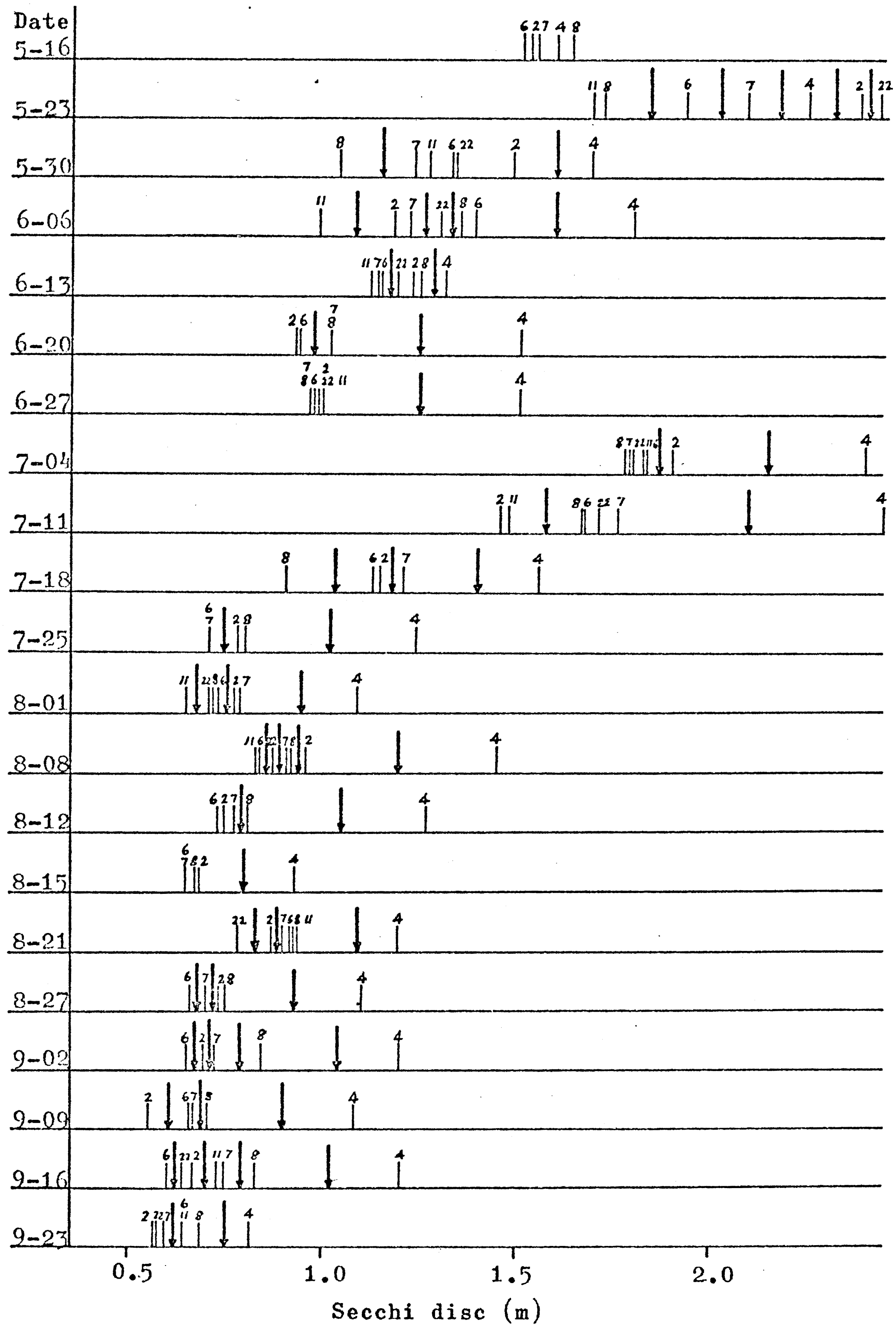

Figure 15. Results of Station (Numbered Bars) Comparisons at Ham's Lake in 1978 Based on Secchi Disc Transparency Arranged Along a Depth Gradient (Arrow Indicates Significant Difference at the 1% Level)

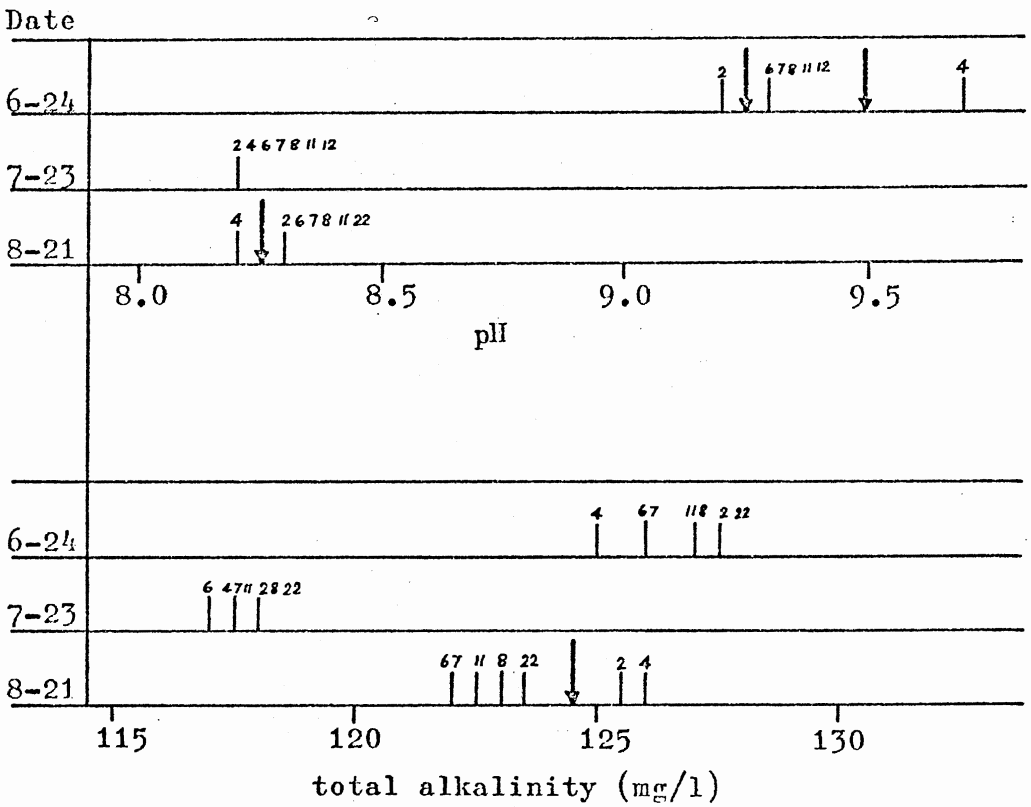

Figure 16. Results of Station (Numbered Bars) Comparisons at Ham's Lake in 1978 Based on pH and Total Alkalinity Arranged Along Concentration Gradients (Arrow Indicates Significant Difference at the 1% Level)

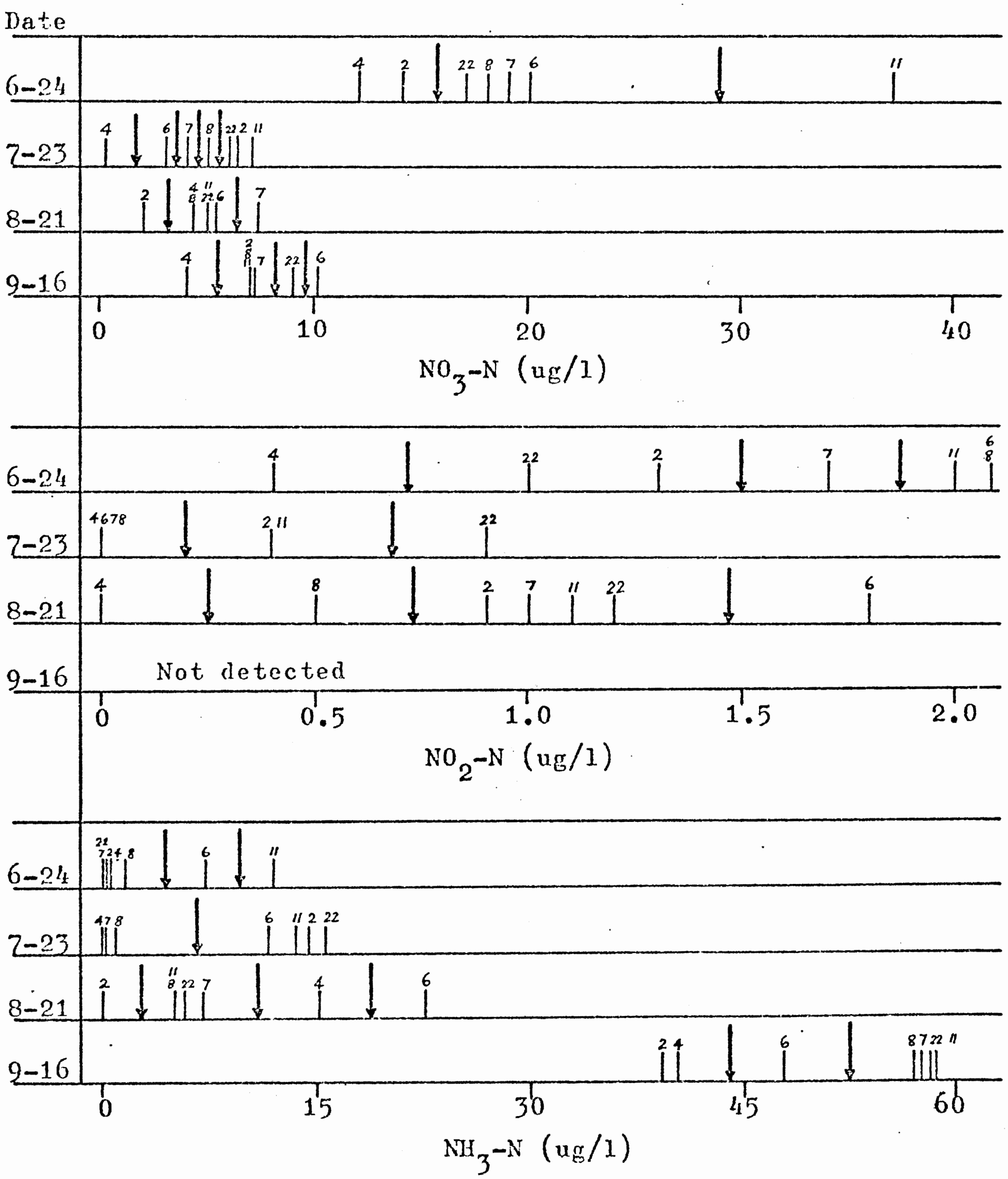

Figure 17. Results of Station (Numbered Bars) Comparisons at Ham's Lake in 1978 Based on Nitrate, Nitrite, and Ammonia Arranged Along Concentration Gradients (Arrow Indicates Significant Difference at the 1% Level)

average concentration of 8 µg/l. The average for station 6 was again significantly lower than that of station 11, which showed an average ammonia concentration of 13 µg/l. In July station 4, 7, and 8, which had concentrations less than 2 µg/l, were significantly different from stations 6, 11, 2, and 22, which had concentrations ranging from 13 µg/l to 18 µg/l. Results for August showed that the various stations were segregated into five groups. Station 2 with no ammonia detected occupied one end of the continuum and station 6 with an average of 23 µg/l the other end. The result of the September comparison showed that the stations could be divided into three groups. Station 2 and 4 were considered as one group with an ammonia concentration of about 40 µg/l. Station 6 was significantly different from all others with an average ammonia concentration of 48 µg/l. Station 8, 7, 22, and 11 constituted another group with ammonia concentrations of about 58 µg/l. The results of these four monthly comparisons indicated that station 2 and 4 tended to have relatively low ammonia concentrations. On the other hand, station 11, tended to have relatively high ammonia concentrations.

Results of the monthly station comparisons of nitrate are shown in Figure 17. Again station 2 and 4 tended to occupy the low end of the concentration continuum during each comparison. Station 11 had 37 µg/l of nitrate in June and was significantly higher than those of the other stations. Station 11 had a relatively high concentration of nitrate in July but not in August and September. No definite pattern of station differences was detected for the other stations.

Results of the monthly station comparisons for nitrite are shown in Figure 17. The highest concentration of nitrite detected at any station was 2 µg/l. Station differences were demonstrated statistically. However, the concentrations of nitrite detected at the various stations were too low to render the comparisons to be of practical significances.

Station comparisons based on chlorophyll a concentrations were made for eleven sampling dates from May to September (Figure 18). Station differences were demonstrated on each sampling date. There were six occasions when the chlorophyll a concentrations at station 4 were relatively low. On the other hand, there were six occasions when the concentrations at station 8 were relatively high. No definite pattern of station differences was detected in the other stations.

The chlorophyll a concentration of composite samples, obtained by pooling equal volumes of water samples from stations 2, 4, 6, 7, and 8, were compared to the chlorophyll a concentrations at other stations (Figure 18). In most cases, the concentration of chlorophyll a in the composite samples was close to the average of all the other stations, indicating that the composite samples were representative of Ham's Lake.

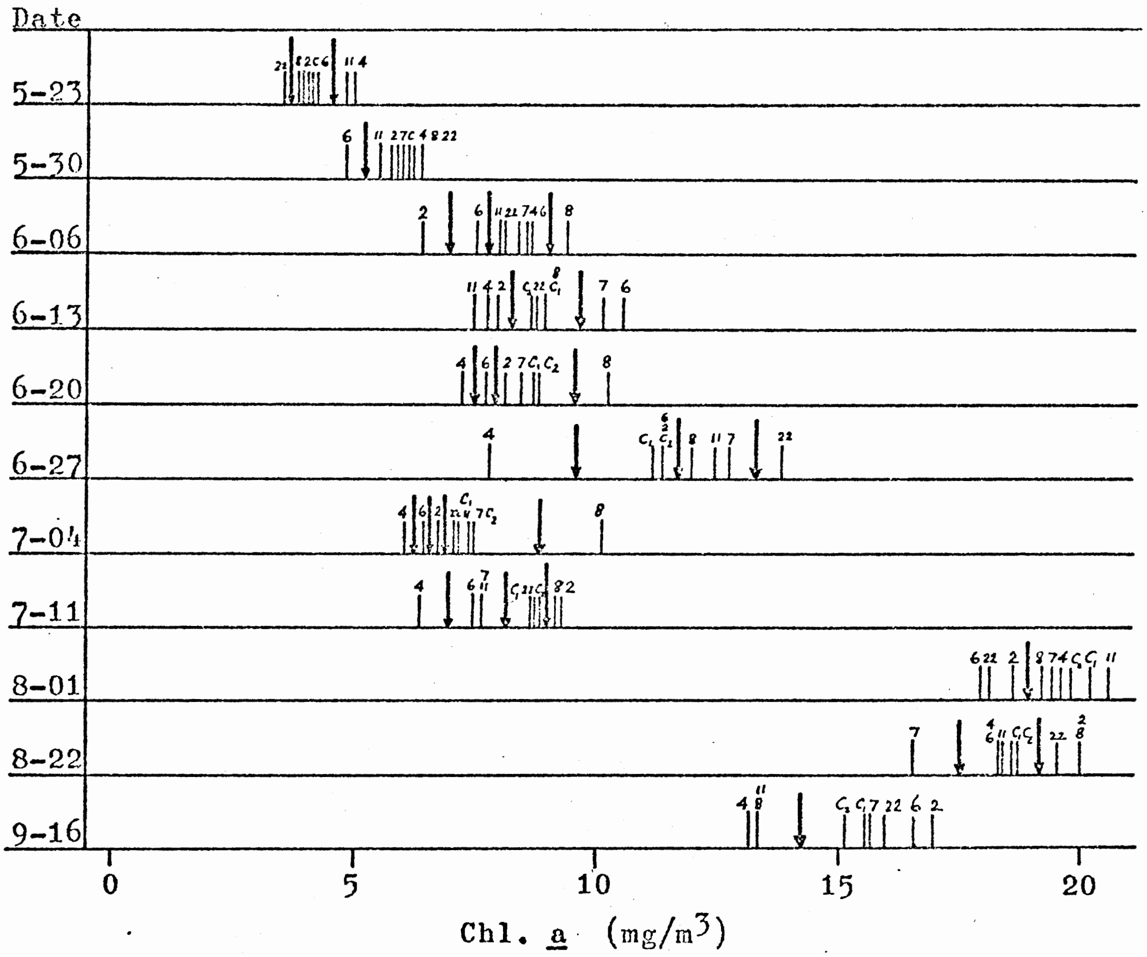

Figure 18. Results of Station (Numbered Bars) Comparisons at Ham's Lake in 1978 Based on Chlorophyll a Arranged Along a Concentration Gradient (C_1 and C_2 are Two Composite Samples from Stations 2, 4, 6, 7, and 8; Arrow Indicates Significant Difference at the 1% Level)

CHAPTER V

DISCUSSION

Temperature

Artificial destratification changed the distribution of heat in Ham's Lake in the experimental years of 1976 and 1978, when the lake was uniformly mixed. Temperature differences between the surface and the bottom did not exceed three degrees centigrade. In 1976 the lake became thermally mixed within two weeks after artificial destratification began (Figure 2). Ham's Lake was stratified during the sampling season in 1977 when no mechanical mixing was applied. Artificial destratification increased the temperature at the bottom of Ham's Lake by six or more degrees centigrade during the months of July and August. Fast (1968), Robinson et al. (1969), and Haynes (1973) also observed warming of the bottom water due to artificial destratification.

The diameter of the axial flow pump affected the vertical distribution of temperature. In 1978 the larger axial flow pump of 1.6 m in diameter destratified Ham's Lake more adequately than the one of 1.1 m in diameter. One week after the large pump started to run on July 11, the lake became isothermal and remained so until the end of September.

Secchi Disc Transparency

Observations of Secchi disc transparency during 1976 to 1978 showed that the values in the experimental years of 1976 and 1978 were lower than those of 1977 with the exception of the date collected in May (Figure 3). The average for 1976 and 1978 was 0.98 m and 1.06 m, respectively, in sharp contrast to the 1977 average of 1.79 m. The low values of the Secchi disc during the period, May 11 to 25, 1977, and May 23 to June 6, 1978, can be attributed to increases in runoff and resulting turbidity. During this period, turbidity was largely due to inorganic particulate matter associated with runoff. Latter in the season the transparency of the water was influenced by the density of the algal cells. The present study at Ham's Lake has shown that Secchi disc transparency was very sensitive to the concentration of chlorophyll _a_ (Figure 14). Artificial destratification reduced the Secchi disc transparency in Ham's Lake by somehow increasing algal biomass (see below).

Lake Level

The lake level in 1978 was the lowest of the three years. In 1977 the lake level rose more than 1.5 m between May 18 and 25. A rapid increase in lake level produced a rapid decline in the values of Secchi disc in 1977 and 1978 (Figure 3 and 4), demonstrating the relationship between high runoff and inorganic particulate turbidity mentioned above.

The present study indicates that high lake level is not necessarily associated with high phytoplankton standing crop as observed by Heron (1961), Mitchell (1975), and Seruyg and Pollingher (1977). I believe that phytoplankton standing crop in Ham's Lake is related to the concentrations of phosphate and other physical factors than the lake level alone.

Dissolved Oxygen

The immediate effect of artificial mixing on Ham's Lake in 1976 was an increase in the concentration of DO at the bottom. The concentration of DO at the bottom rose from less than 1 mg/l to more than 5 mg/l in less than twelve days (Figure 5). The concentration of DO at the bottom decreased immediately when the pump was temporarily stopped from July 9 to 20. An anoxic condition developed in the hypolimnion in 1977, when no mixing occurred. Due to an early start in the operation of the pump in 1978, the concentration of DO at the bottom of the lake did not fall below 3 mg/l on any of the sampling date. Hooper et al. (1952), Fast (1968), and Haynes (1973) also observed consistently higher concentrations of DO at the bottom during years when artificial mixing occurred than during control years.

pH, Total Alkalinity, and Carbon Dioxide

The pH values at the surface and the bottom of Ham's Lake were higher during the experimental years (1976 and 1978) than the control year (1977). The concentrations of carbon dioxide at the surface and bottom of the lake were low during the experimental years and were higher in the control year. The results suggest high rates of photosynthesis in the surface waters during the experimental years as pH was high and carbon dioxide was often low. The high pH values and much lower concentrations of carbon dioxide at the bottom during the experimental years indicated that carbon dioxide was eliminated by artificial mixing. This result agrees with the conclusions of Fast (1971) and Haynes (1973). The present study shows that artificial mixing resulted in the reduction of differences in the pH values at the surface and at the bottom (Figure 8). Weiss and Breedlove (1973) observed the same phenomenon. Results of this study also indicated that overcast weather caused a reduction in the pH at the surface.

Total alkalinity at the surface and the bottom of Ham's Lake was higher in 1976 than in 1977. However, slightly lower average total alkalinity values were recorded at the surface in 1978 than in 1977. Fast (1971) reported a marked decrease in bottom alkalinity due to artificial aeration. The results of the present study did not support that finding.

Nitrogen

Just before artificial mixing began in 1976, nitrate was readily detectable at the bottom with concentrations up to 70 µg/l. The concentration of nitrate declined throughout the water column by the end of June and then slowly increased by the end of July and August. Artificial mixing apparently increased the concentration of nitrate in 1976 but not in 1978. I speculate that such a difference was due to a high demand for nitrate by algae in 1978. Johnson (1966), Brezonik et al. (1969), and Haynes (1973) observed an increase of nitrate due to artificial mixing. On the other hand, Weiss and Breedlove (1973) reported decreases in nitrate and nitrite in the hypolimnion. Toetz (1977) reported decreases in nitrate and nitrite due to artificial mixing. During the control year (1977), nitrate concentrations did not increase.

Nitrite was generally higher in concentration in 1976 than in 1977. Brezonik et al. (1969) reported increases in nitrite at all levels of the water column after artificial mixing was in progress. High concentrations of nitrite can be caused also by nitrification, when ammonia is oxidized to nitrite and then to nitrate (Hutchinson, 1957). Nitrite concentrations in 1978 were low compared to those in 1977.

There was a reduction in the concentrations of ammonia in 1976 after artificial mixing began. However, the concentrations of ammonia in 1976 were comparatively higher than those in 1977. Concentrations of ammonia in 1978 were the lowest of the three years. A reduction in the concentrations of ammonia at the bottom occurred in July and August, 1978. Irwin et al. (1969), and Toetz (1979) also reported a reduction in ammonia following artificial mixing.

Sulfide

Artificial mixing reduced concentrations of sulfide in Ham's Lake. During 1976, 10 $\mu g/l$ to 30 $\mu g/l$ of sulfide was detected in the water column. Small quantities of sulfide (not more than 11 $\mu g/l$) were distributed homogeneously in July and August, 1978. During May and July of 1977, much higher concentrations of sulfide were detected. The increase of DO at the bottom of the lake helped reduce the sulfide concentration significantly when the lake was experimentally mixed, because sulfide is easily oxidized to sulfate in an oxic environment. In addition, the increase of pH at the bottom of the lake, due to artificial mixing, did not favor the accumulation of sulfide (Wetzel, 1975).

Phosphate

Artificial mixing increased the number of occasions when phosphate was detected in Ham's Lake. In 1976 phosphate was detected on eleven occasions and in 1978 eight occasions. The concentrations of phosphate detected in 1976 were higher than those detected in 1977. The highest concentration detected on August 31 was 23 $\mu g/l$. The highest concentration detected in 1978 did not exceed 5 $\mu g/l$. An increase in the concentrations of phosphate, due to artificial mixing, was observed by Haynes (1973). Wirth and Dunst (1967) reported that phosphate tended to be distributed uniformly in the water column after artificial aeration. Such a tendency was also observed in the present study.

Chlorophyll *a*

Concentrations of chlorophyll *a* were high in the experimental years of 1976 and 1978, but were comparatively low in 1977. The results indicate that artificial mixing created a chemical environment favorable for the growth of phytoplankton. Among these conditions, the increase in phosphate and the various forms of nitrogen may have been the most important. Secchi disc transparency was lower in the experimental years, probably because of increased algal turbidity, since the phytoplankton standing crop was higher in those years than in 1977.

The increases in chlorophyll *a* concentrations in July and August, 1977, corresponded approximately to increases in the density of diatoms. The small peak of chlorophyll *a* in September, 1977, was probably caused by increases in populations of green algae and blue-green algae. The large increase in chlorophyll *a* concentration from July to September, 1978, can be attributed to a bloom of diatoms. Haynes (1973) also observed an increase in the concentrations of chlorophyll *a* during artificial mixing.

Phytoplankton

Artificial mixing encouraged the growth of diatoms but discouraged blue-green algae. In 1977 the two dominant diatoms were *Cyclotella* and *Navicula*. Most diatom genera were observed from late June to early August of that year. *Coelastrum* was the most common green alga. A short-lived increase in the number of green algal genera occurred in early September. A significant bloom of blue-green algae consisting mainly of *Microcystis* and *Anabaena* took place from late August to the end of September. In 1978 Ham's Lake was dominated by diatoms from May to September. The most abundant genera were *Cyclotella*, *Melosira*, and *Navicula*. The total densities of *Cyclotella* and *Melosira* encountered in 1978 were higher than those encountered in 1977 by 85% and 97%, respectively. Highest numbers of genera of green algae were encountered in June, 1978, in contrast to 1977 when highest numbers of genera occurred in September. A small bloom of Anabaena and Microcystis did occur in 1978, but it was only one-third the magnitude of that in 1977 and definitely did not last as long.

The observation that blue-green algae competed less favorably under conditions created by artificial mixing agrees with that of Bernhardt (1967). Wirth and Dunst (1967) speculated that reduction in the epilimnetic temperature due to artificial mixing might have slowed down the growth of blue-green algae. Evidence from this study also points in that direction, although the differences (1.0 to 3.0°C) were not large (Table VI, VII, and VIII of Appendix). Further studies along this line would be fruitful. Lund (1971) showed that artificial mixing increased the population of Melosira italica in late summer. In the present study, Melosira was one of the common genera observed in 1978.

Station Comparisons

I observed considerable horizontal variability in physical and chemical parameters in Ham's Lake. Station 4 was consistantly different from the other stations in terms of the various parameters used in the comparison of stations. This unique characteristic was probably caused by an old submerged dam across the old creek channel situated at the mouth of the north arm of the lake. This dam is an underwater barrier which separates the north arm from the main body of the lake. Also, dense growths of aquatic macrophytes along the littoral of the cove near the mouth of the north arm probably prevented water in the main body of the lake from mixing freely with water in the cove.

Station 11 tended to have higher values of nitrogen, possibly due to agricultural runoff into the south-eastern arm of the lake. Variability between other stations appeared to be random.

George and Edwards (1976) attributed the horizontal patchiness of algae to wind, but the lack of consistent patterns in the distribution of chlorophyll a observed here suggests that wind generated currents did not always operate in the same way in Ham's Lake.

The composite samples of chlorophyll a had values close to the means of other stations and were considered to be representative of the lake. The use of composite samples for other chemical analyses in Ham's Lake appears to be an efficient approach to sampling.

CHAPTER VI

SUMMARY

I observed physico-chemical parameters of water quality and the standing crop of phytoplankton during three comparable periods in 1976, 1977, and 1978 in Ham's Lake, Oklahoma. My objective was to determine the ecological effect of artificial mixing on Ham's Lake. The lake was artificially mixed during 1976 and 1978, but not in 1977. The major findings of this reseach were as follows:

1. Artificial mixing created isothermal conditions by raising the temperature between the bottom and 4 m.
2. The larger axial flow pump of 1.6 m destratified the lake better than the smaller one of 1.1 m (diameter).
3. Artificial mixing reduced the transparency of the Secchi disc.
4. Anoxic conditions in the hypolimnion were eliminated by artificial mixing.
5. Artificial mixing reduced free carbon dioxide at the bottom of the lake causing an increase in pH. Free carbon dioxide at the surface did not increase, probably due to higher rates of photosynthesis.
6. Total alkalinity was isochemical with respect to depth during mixing.

7. The concentration of nitrate was slightly higher during experimental years than during the control year.

8. The concentration of ammonia was lower in 1978 than in 1976.

9. The concentration of sulfide decreased during artificial mixing.

10. Phosphate was detected more often during the experimental years than during the control year.

11. Concentrations of chlorophyll *a* were higher during the experimental years than during the control year, demonstrating that artificial mixing created an environment favorable for the growth of phytoplankton.

12. Artificial mixing encouraged the growth of the diatoms, *Cyclotella*, *Melosira*, and *Navicula* but discouraged the blue-green algae, *Microcystis* and *Anabaena*.

13. Horizontal variability in water quality parameters and chlorophyll *a* was observed at Ham's Lake. However, the patterns of variation between stations were apparently random. The use of composite samples (pooled samples from several stations) in Ham's Lake appears to be an efficient approach to sampling.

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APPENDIX

TABLE VI

DEPTH DISTRIBUTION OF TEMPERATURE (^{o}C) AT STATION 2 IN HAM'S LAKE DURING 1976

DEPTH	MAY				JUNE			
(M)	2	10	18	25	1	8	15	23
0	17.5	21.2	21.0	23.5	24.0	26.8	25.0	25.0
1	17.2	20.5	20.0	23.0	23.2	26.3	24.9	25.0
2	17.0	18.3	19.5	23.0	22.6	24.0	24.8	24.9
3	16.8	17.3	19.0	21.0	21.0	23.0	24.5	24.9
4	16.5	16.9	18.1	19.0	19.5	22.5	24.5	24.6
5	16.2	16.5	17.2	18.0	18.5	22.2	24.3	24.6
6	16.1	16.3	16.8	17.5	17.5	22.0	24.2	24.6
7	16.0	16.1	16.4	17.0	17.0	21.8	24.2	24.6
8	15.9	16.0	16.0	16.5	16.5	21.5	24.0	24.5

DEPTH (M)		JULY				AUG		
	29	6	13	20	27	3	11	17
0	29.0	28.0	28.2	28.0	29.5	29.0	28.5	30.0
1	29.0	26.0	28.0	28.0	29.3	29.0	28.5	29.8
2	28.0	25.7	28.0	28.0	29.0	28.0	28.2	29.2
3	27.5	25.5	27.8	28.0	29.0	27.8	28.0	28.5
4	27.0	25.3	27.0	27.8	28.9	27.5	28.0	28.0
5	27.0	25.3	26.5	27.0	28.5	27.5	28.0	28.0
6	27.0	25.2	26.0	26.2	28.0	27.5	27.8	28.0
7	26.8	25.1	26.0	26.0	28.0	27.5	27.5	27.9
8	26.5	25.0	25.8	26.0	27.9	27.5		

DEPTH (M)			SEPT		
	24	31	7	21	28
0	28.0	25.5	28.0	24.5	21.0
1	27.5	25.5	27.5	24.0	21.0
2	27.0	25.3	26.5	23.5	21.0
3	27.0	25.3	26.0	23.5	21.0
4	27.0	25.3	26.0	23.0	21.0
5	26.5	25.1	26.0	23.0	21.0
6	26.5	25.0	26.0	23.0	20.5
7	26.2	25.0	25.8	23.0	20.5
8					

TABLE VII

DEPTH DISTRIBUTION OF TEMPERATURE (°C) AT STATION 2 IN HAM'S LAKE DURING 1977

DEPTH (M)	MAY 4	11	18	25	JUNE 1	8	15	22
0	24.0	25.0	24.0	25.0	27.0	27.0	29.0	29.2
1	23.0	24.0	24.0	25.0	26.8	26.5	29.0	29.2
2	23.0	23.5	24.0	25.0	24.5	26.5	29.0	29.0
3	23.0	23.0	24.0	20.5	21.5	26.5	26.0	29.0
4	19.5	21.0	24.0	19.5	20.0	20.0	21.5	23.5
5	18.5	19.0	20.5	18.5	19.7	19.0	20.0	19.5
6	18.0	18.0	18.0	18.0	18.2	18.0	18.5	18.5
7				18.0	17.5	17.5	18.0	17.5
8								

DEPTH (M)	29	JULY 6	13	20	27	AUG 3	10	17
0	29.5	29.0	29.5	29.2	28.5	29.3	29.8	27.3
1	29.5	29.0	29.2	29.2	28.5	29.2	29.5	27.1
2	29.0	28.5	29.0	29.1	28.1	29.0	29.1	27.1
3	28.0	28.5	29.0	29.1	28.0	28.0	28.0	26.8
4	25.0	26.5	28.0	27.4	27.2	27.2	27.5	26.2
5	21.0	21.5	23.0	22.9	24.0	24.8	26.8	26.0
6	19.5	19.5	19.5	18.8	18.9	19.6	20.0	26.0
7	18.5	18.5	18.1	18.8	18.0	17.8	18.5	18.5
8								

DEPTH (M)	24	31	SEPT 7	14	21	28
0	27.2	27.0	27.5	23.2	25.5	24.5
1	27.0	27.0	27.0	23.2	25.5	24.5
2	26.7	27.0	26.5	23.2	25.2	24.5
3	26.0	26.9	26.0	23.2	25.1	24.0
4	25.5	25.9	26.0	23.2	25.0	23.5
5	24.9	25.1	25.0	23.2	25.0	23.0
6	21.9	22.8	22.0	22.5	24.0	22.7
7	19.8					
8						

TABLE VIII

DEPTH DISTRIBUTION OF TEMPERATURE (^{o}C) AT
STATION 2 IN HAM'S LAKE DURING 1978

DEPTH (M)	MAY 16	23	30	JUNE 6	13	20	27	JULY 4
0	22.0	24.0	25.0	23.0	27.2	27.5	28.7	30.0
1	21.5	24.0	24.5	23.0	27.0	27.2	28.4	29.8
2	21.0	23.7	24.0	23.0	25.5	26.9	28.0	28.8
3	20.2	23.5	24.0	22.8	25.0	26.5	26.6	28.3
4	19.8	22.0	23.8	22.5	24.8	26.2	26.5	28.0
5	19.5	21.5	23.0	22.5	24.8	26.0	26.4	28.0
6	19.2	21.0	22.8	22.0	24.5	25.8	26.2	27.8
7								
8								

DEPTH (M)	11	18	25	AUG 1	8	12	15	21
0	29.8	28.9	28.3	28.0	26.8	26.8	27.1	27.2
1	29.6	28.9	28.3	28.0	26.7	26.8	27.1	27.0
2	29.1	28.9	28.1	27.9	26.4	26.8	27.1	26.8
3	29.0	28.9	28.0	27.9	26.3	26.8	27.1	26.4
4	28.9	28.9	28.0	27.9	26.2	26.8	27.1	25.9
5	28.8	28.9	28.0	27.9	26.2	26.8	27.1	25.9
6	28.5	28.6	28.0	27.9	26.1	26.8	27.1	25.7
7								
8								

DEPTH (M)	27	SEPT 2	9	16	23
0	27.2	25.7	26.3	27.0	23.0
1	27.2	25.7	26.2	27.0	23.0
2	27.2	25.6	26.1	26.8	23.0
3	27.1	25.5	26.0	26.7	22.8
4	27.1	25.5	26.0	26.6	22.7
5	27.1	25.4	26.0	26.5	22.7
6	27.1	25.3	26.0	26.4	22.6
7					
8					

TABLE IX

MEAN SECCHI DISC TRANSPARENCY VALUES (METER) AT STATION 2
IN HAM'S LAKE DURING 1976, 1977, AND 1978

1976		1977		1978	
DATE	METER	DATE	METER	DATE	METER
4-24	0.81	5-04	1.11	5-16	1.50
5-02	1.14	5-11	1.44	5-23	2.38
5-10	0.97	5-18	0.85	5-30	1.49
5-18	0.90	5-25	0.46	6-06	1.18
5-25	1.34	6-01	1.20	6-13	1.23
6-01	1.15	6-08	1.06	6-20	0.93
6-08	1.29	6-15	1.82	6-27	0.99
6-15	0.95	6-22	1.58	7-04	1.90
6-23	0.94	6-29	1.95	7-11	1.46
6-29	0.98	7-06	1.98	7-18	1.15
7-06	0.91	7-13	2.02	7-25	0.78
7-13	1.02	7-20	1.93	8-01	0.77
7-20	1.07	7-27	2.27	8-08	0.96
7-27	0.92	8-03	2.21	8-12	0.75
8-03	0.74	8-10	2.34	8-15	0.68
8-11	0.74	8-17	2.05	8-21	0.87
8-17	0.77	8-24	2.50	8-27	0.73
8-24	0.70	8-31	2.52	9-02	0.69
8-31	0.78	9-07	2.35	9-09	0.56
9-07	0.78	9-14	1.60	9-16	0.67
9-14	1.12	9-21	1.75	9-23	0.57
9-21	1.46	9-28	2.40		
9-28	1.12				

TABLE X

LAKE LEVEL OF HAM'S LAKE DURING 1976, 1977, AND 1978

1976		1977		1978	
DATE	METER+	DATE	METER	DATE	METER
4-24	1.20	5-04	2.49	5-16	1.92
5-02	1.20	5-11	2.48	5-23	1.98
5-10	1.20	5-18	2.49	5-30	1.76
5-25	1.18	5-25	0.95	6-06	1.55
6-01	1.17	6-01	0.90	6-13	1.58
6-08	1.20	6-08	0.97	6-20	1.58
6-15	1.27	6-15	1.01	6-27	1.60
6-23	1.30	6-22	1.11	7-04	1.65
6-29	1.36	6-29	1.09	7-11	1.73
7-06	1.39	7-06	1.09	7-18	1.79
7-13	1.48	7-13	1.14	7-25	1.85
7-20	1.47	7-20	1.22	8-01	1.92
7-27	1.54	7-27	1.27	8-08	1.94
8-11	1.63	8-03	1.32	8-12	1.97
8-31	1.84	8-10	1.38	8-15	1.98
9-07	1.91	8-17	1.42	8-21	2.00
		8-24	1.46	8-27	2.10
		8-31	1.50	9-02	2.20
		9-07	1.50	9-09	2.27
		9-14	1.52	9-16	2.32
		9-21	1.58	9-23	2.38
		9-28	1.60		

+Meters below reference mark (reference mark was equivalent to 15.2 feet on the permanent gauge)

TABLE XI

DEPTH DISTRIBUTION OF DISSOLVED OXYGEN AT STATION 2 IN HAM'S LAKE DURING 1976

DEPTH	MAY				JUNE			
(M)	2	10	18	25	1	8	15	23
0	8.8	10.8	9.8	6.2	5.8	5.6	5.6	4.8
1	8.8	10.6	9.2	6.2	6.0	5.4	5.4	4.8
2	8.6	9.8	9.6	6.0	5.8	4.8	5.5	4.8
3	8.8	9.2	9.4	5.3	4.6	3.8	5.4	4.8
4	8.6	8.8	8.2	3.8	3.8	3.4	5.4	4.8
5	8.4	8.6	8.0	2.8	2.2	3.2	5.4	4.6
6	8.2	8.4	7.2	2.5	1.4	3.0	5.4	4.3
7	8.0	8.2	7.0	2.0	1.0	3.0	5.4	4.2
8	7.5	7.6	7.0	1.3	0.6	2.6	5.2	4.0

DEPTH (M)		JULY				AUGUST		
	29	6	13	20	27	3	11	17
0	5.4	4.9	5.8	7.6	7.5	7.1	7.3	7.4
1	5.4	4.7	5.9	7.6	7.5	7.1	7.3	7.4
2	5.0	4.5	5.8	7.6	7.2	5.9	7.0	7.4
3	4.5	4.4	5.8	7.5	7.1	5.7	7.0	5.6
4	4.4	4.2	4.7	7.4	7.0	5.5	7.0	5.6
5	4.3	4.1	4.1	4.4	6.1	5.4	7.0	5.5
6	4.2	4.1	3.6	3.6	5.2	5.1	6.8	5.1
7	4.1	3.9	3.1	3.0	5.1	5.0	6.4	4.9
8	4.0	3.6	2.6	2.4	5.0	4.9		

DEPTH (M)			SEPT.		
	24	31	7	21	28
0	6.6	6.9	8.0	5.8	7.0
1	6.6	6.7	8.0	5.7	7.0
2	6.6	6.5	7.1	5.7	7.0
3	6.3	6.5	6.9	5.6	6.8
4	6.4	6.4	6.8	4.1	6.7
5	6.3	6.4	6.5	3.6	6.6
6	6.2	6.4	6.2	5.0	6.4
7	5.9	6.3	5.9	3.8	6.4
8					

TABLE XII

DEPTH DISTRIBUTION OF DISSOLVED OXYGEN AT STATION 2 IN HAM'S LAKE DURING 1977

DEPTH	MAY				JUNE			
(M)	4	11	18	25	1	8	15	22
0	9.0	8.4	7.7	6.7	6.8	7.1	7.8	7.0
1	9.0	8.7	7.7	6.7	6.8	7.0	7.8	6.9
2	9.0	8.0	7.4	6.5	6.4	7.1	7.8	6.8
3	9.0	7.6	7.2	3.1	0.2	7.1	3.4	6.8
4	8.2	3.7	7.2	2.8	0.2	0.1	0.3	0.1
5	6.8	3.4	7.2	2.6	0.2	0.1	0.2	0.1
6	5.7	1.9	4.2	2.2	0.0	0.0	0.2	0.1
7				1.2	0.0	0.0	0.1	0.1
8								

DEPTH		JULY				AUGUST		
(M)	27	6	13	20	27	3	10	17
0	7.9	7.8	7.4	7.6	6.5	7.7	7.0	6.6
1	7.9	7.8	7.3	7.6	6.1	7.5	7.0	6.6
2	-	-	6.8	7.4	5.8	7.5	6.9	5.5
3	-	-	6.7	7.4	6.0	6.4	6.3	4.5
4	0.2	2.0	6.1	3.4	4.4	4.2	5.3	3.8
5	-	-	0.5	0.0	0.1	0.7	3.1	2.5
6	-	-	0.2	0.0	0.0	0.0	0.1	0.2
7	0.2	0.0	0.2	0.0	0.0	0.0	0.1	0.2
8								

DEPTH			SEPT.			
(M)	24	31	7	14	21	28
0	7.0	7.1	7.2	6.8	7.8	7.6
1	7.0	7.2	7.1	6.8	7.8	7.6
2	6.1	7.1	6.8	6.8	7.8	7.4
3	4.9	7.1	5.6	6.8	7.7	6.5
4	3.0	5.8	4.3	6.8	7.7	5.6
5	1.4	4.4	1.1	6.4	7.6	3.8
6	0.0	0.2	0.0	4.6	6.2	2.4
7	0.0				6.0	
8						

TABLE XIII

DEPTH DISTRIBUTION OF DISSOLVED OXYGEN AT STATION 2 IN HAM'S LAKE DURING 1978

DEPTH	MAY			JUNE				JULY
(M)	16	23	30	6	13	20	27	4
0	8.8	8.4	8.6	6.4	8.4	6.8	8.6	7.4
1	8.8	8.4	8.4	6.0	-	6.8	8.4	7.7
2	8.8	-	8.4	-	-	6.1	8.0	7.2
3	8.8	-	8.4	-	-	5.3	-	4.4
4	8.3	8.2	7.8	5.7	6.2	5.1	6.0	3.3
5	-	-	6.0	-	-	5.1	-	3.0
6	-	-	5.4	5.6	-	4.8	4.9	2.7
7	8.3	8.2	3.0	-	5.6	4.8		
8								

DEPTH				AUG				
	11	18	25	1	8	12	15	21
0	7.2	6.4	5.7	5.8	6.8	5.6	6.2	7.3
1	7.2	6.3	5.4	5.8	6.4	5.4	6.0	7.2
2	6.6	6.5	5.6	5.8	4.7	5.6	6.1	7.0
3	3.7	6.5	5.6	5.8	4.8	5.6	6.1	6.5
4	3.4	6.5	4.5	5.8	4.4	5.6	6.1	5.8
5	2.8	6.2	4.5	5.8	4.4	5.6	6.1	5.3
6	2.8	5.7	4.3	5.8	4.0	5.4	6.1	5.3
7								
8								

DEPTH		SEPT			
	27	2	9	16	23
0	6.2	6.3	5.8	7.1	7.3
1	6.2	6.2	5.8	7.0	7.0
2	6.2	6.3	5.8	6.8	7.1
3	6.2	6.3	5.8	7.0	7.0
4	6.2	6.2	5.8	6.8	6.5
5	6.2	6.2	5.6	6.8	6.4
6	6.2	6.1	5.6	6.8	6.5
7					
8					

TABLE XIV

MEAN pH VALUES AT THE SURFACE, 4 m, AND THE BOTTOM OF STATION 2 IN HAM'S LAKE DURING 1976, 1977, AND 1978

1976			1977			1978		
DATE	DEPTH (m)	pH	DATE	DEPTH (m)	pH	DATE	DEPTH (m)	pH
6-29	0	8.2	5-04	0	7.4	5-16	0	8.5
	4	8.2		4	7.1		4	8.7
	8	8.2		8	7.3		8	8.6
7-06	0	8.2	5-11	0	8.2	5-23	0	7.8
	4	8.2		4	8.1		4	7.7
	8	8.2		8	7.9		8	7.6
7-13	0	8.5	5-18	0	8.4	5-30	0	8.6
	4	8.4		4	8.4		4	8.5
	8	8.0		8	8.4		8	8.3
7-20	0	8.7	5-25	0	8.0	6-06	0	8.1
	4	8.6		4	8.0		4	8.2
	8	8.4		8	8.2		8	8.2
7-27	0	8.6	6-01	0	8.0	6-13	0	8.4
	4	8.6		4	7.3		4	8.4
	8	8.5		8	7.3		8	8.5
8-03	0	8.5	6-08	0	7.9	6-20	0	8.9
	4	8.5		4	8.0		4	8.9
	8	8.4		8	8.0		8	8.7
8-11	0	8.5	6-15	0	7.9	6-27	0	8.4
	4	8.6		4	7.8		4	8.3
	8	8.6		8	7.9		8	8.2
8-17	0	8.6	6-22	0	8.1	7-04	0	8.5
	4	8.5		4	8.0		4	8.3
	8	8.5		8	8.0		8	8.1
8-24	0	–	6-29	0	–	7-11	0	8.5
	4	8.4		4	7.6		4	8.3
	8	–		8	7.7		8	8.1
8-31	0	8.4	7-06	0	8.2	7-18	0	8.3
	4	8.4		4	8.1		4	8.4
	8	8.4		8	8.0		8	8.4

TABLE XIV (Continued)

1976			1977			1978		
DATE	DEPTH (m)	pH	DATE	DEPTH (m)	pH	DATE	DEPTH (m)	pH
9-07	0	8.6	7-13	0	8.4	7-25	0	8.1
	4	8.5		4	8.5		4	8.1
	8	8.5		8	8.3		8	8.1
9-14	0	8.5	7-20	0	7.6	8-01	0	8.2
	4	8.4		4	7.7		4	8.2
	8	8.3		8	7.1		8	8.2
9-21	0	8.4	7-27	0	8.1	8-08	0	8.1
	4	8.5		4	8.0		4	8.1
	8	8.4		8	7.7		8	8.1
9-28	0	8.4	8-03	0	8.6	8-12	0	8.1
	4	8.4		4	8.2		4	8.1
	8	8.4		8	8.3		8	8.1
			8-10	0	8.4	8-15	0	8.1
				4	8.4		4	8.1
				8	7.9		8	8.1
			8-17	0	8.4	8-21	0	8.3
				4	8.2		4	8.2
				8	8.0		8	8.2
			8-24	0	8.3	8-27	0	8.0
				4	8.2		4	8.0
				8	7.9		8	8.0
			8-31	0	8.2	9-02	0	8.2
				4	8.1		4	8.2
				8	7.9		8	8.2
			9-07	0	8.3	9-09	0	8.2
				4	8.3		4	8.1
				8	8.0		8	8.2
			9-14	0	8.1	9-16	0	8.3
				4	8.3		4	8.2
				8	8.2		8	8.3
			9-21	0	8.3	9-23	0	8.5
				4	8.3		4	8.3
				8	8.3		8	8.3

TABLE XIV (Continued)

1976			1977			1978		
DATE	DEPTH (m)	pH	DATE	DEPTH (m)	pH	DATE	DEPTH (m)	pH
			9-28	0	8.2			
				4	8.2			
				8	8.2			

TABLE XV

MEAN TOTAL ALKALINITY VALUES AT THE SURFACE, 4 m, AND THE BOTTOM OF STATION 2 IN HAM'S LAKE DURING 1976, 1977, AND 1978

1976			1977			1978		
DATE	DEPTH (m)	mg/l	DATE	DEPTH (m)	mg/l	DATE	DEPTH (m)	mg/l
5-25	0	177	5-04	0	163	5-16	0	128
	4	168		4	161		4	128
	8	196		8	166		8	129
6-01	0	165	5-11	0	145	5-23	0	127
	4	168		4	144		4	128
	8	181		8	145		8	125
6-08	0	163	5-18	0	140	5-30	0	120
	4	164		4	141		4	120
	8	169		8	150		8	118
6-15	0	169	5-25	0	155	6-06	0	117
	4	171		4	131		4	113
	8	167		8	131		8	109
6-23	0	162	6-01	0	122	6-13	0	116
	4	157		4	90		4	119
	8	165		8	68		8	115
6-29	0	167	6-08	0	143	6-20	0	127
	4	161		4	144		4	126
	8	163		8	-		8	125
7-06	0	154	6-15	0	149	6-24	0	128
	4	167		4	144		4	128
	8	161		8	94		8	127
7-13	0	174	6-22	0	149	6-27	0	126
	4	154		4	154		4	123
	8	152		8	92		8	123
7-20	0	152	6-29	0	150	7-04	0	123
	4	161		4	140		4	123
	8	158		8	93		8	122

TABLE XV (Continued)

1976			1977			1978		
DATE	DEPTH (m)	mg/l	DATE	DEPTH (m)	mg/l	DATE	DEPTH (m)	mg/l
7-27	0	155	7-06	0	142	7-11	0	122
	4	154		4	141		4	122
	8	159		8	94		8	121
8-03	0	-	7-13	0	137	7-18	0	116
	4	-		4	132		4	116
	8	-		8	97		8	116
8-11	0	-	7-20	0	139	7-23	0	118
	4	-		4	136		4	118
	8	-		8	111		8	118
8-17	0	159	7-27	0	137	7-25	0	118
	4	161		4	137		4	118
	8	161		8	108		8	117
8-24	0	163	8-03	0	132	8-01	0	120
	4	159		4	134		4	120
	8	162		8	112		8	120
8-31	0	159	8-10	0	135	8-08	0	120
	4	160		4	134		4	121
	8	161		8	115		8	120
9-07	0	-	8-17	0	136	8-12	0	120
	4	-		4	135		4	118
	8	-		8	128		8	119
9-14	0	161	8-24	0	136	8-15	0	121
	4	165		4	135		4	120
	8	150		8	134		8	120
9-21	0	152	8-31	0	132	8-21	0	122
	4	153		4	130		4	126
	8	157		8	133		8	124
9-28	0	147	9-07	0	133	8-27	0	120
	4	162		4	134		4	120
	8	154		8	134		8	124
			9-14	0	133	9-02	0	126
				4	134		4	126
				8	137		8	124

TABLE XV (Continued)

1976			1977			1978		
DATE	DEPTH (m)	mg/l	DATE	DEPTH (m)	mg/l	DATE	DEPTH (m)	mg/l
			9-21	0	133	9-09	0	128
				4	134		4	128
				8	136		8	130
			9-28	0	124	9-16	0	126
				4	125		4	128
				8	124		8	126
						9-23	0	130
							4	130
							8	127

TABLE XVI

MEAN FREE CARBON DIOXIDE CONCENTRATIONS AT THE SURFACE, 4 m, AND THE BOTTOM OF STATION 2 IN HAM'S LAKE DURING 1977

DATE	DEPTH (m)	mg/l	DATE	DEPTH (m)	mg/l	DATE	DEPTH (m)	mg/l
5-04	0	12	7-06	0	0	9-07	0	0
	4	23		4	0		4	0
	8	15		8	1		8	2
5-11	0,4	0	7-13	0,4,8	0	9-14	0,4,8	0
	8	3						
5-18	0,4,8	0	7-20	0	6	9-21	0,4,8	0
				4	5			
				8	16	9-28	0,4,8	0
5-25	0	2						
	4	2	7-27	0	0			
	8	0		4	2			
				8	4			
6-01	0	2						
	4	8	8-03	0,4,8	0			
	8	6						
			8-10	0	0			
6-08	0	3		4	0			
	4	2		8	2			
	8	-						
			8-17	0	0			
6-15	0	4		4	0			
	4	4		8	2			
	8	2						
			8-24	0	0			
6-22	0	0		4	0			
	4	3		8	3			
	8	1						
			8-31	0	0			
6-29	0	0		4	0			
	4	6		8	3			
	8	4						

TABLE XVII

MEAN CONCENTRATIONS OF SULFIDE AT THE SURFACE, 4 m, AND THE BOTTOM OF STATION 2 IN HAM'S LAKE DURING 1976, 1977, AND 1978

1976			1977			1978		
DATE	DEPTH (m)	μg/l	DATE	DEPTH (m)	μg/l	DATE	DEPTH (m)	μg/l
6-01	0	4	4-27	0	18	5-23	0	N.D.*
	4	4		4	18		4	N.D.
	8	4		8	17		8	N.D.
6-29	0	13	5-25	0	45	6-20	0	N.D.
	4	17		4	63		4	N.D.
	8	26		8	50		8	N.D.
7-27	0	30	6-29	0	2	7-18	0	10
	4	30		4	2		4	10
	8	12		8	19		8	11
8-31	0	4	7-27	0	37	8-12	0	7
	4	N.D.*		4	40		4	10
	8	2		8	109		8	11
9-28	0	N.D.	8-31	0	0	9-16	0	N.D.
	4	N.D.		4	2		4	N.D.
	8	N.D.		8	17		8	N.D.
			9-28	0	4			
				4	2			
				8	17			

*N.D. = Not detected.

TABLE XVIII

MEAN CONCENTRATIONS OF PHOSPHATE AT THE SURFACE, 4 m, AND THE BOTTOM OF STATION 2 IN HAM'S LAKE DURING 1976, 1977, AND 1978

1976			1977			1978		
DATE	DEPTH (m)	µg/l	DATE	DEPTH (m)	µg/l	DATE	DEPTH (m)	µg/l
5-25	0 4 8	6 6 6	5-04	0,4,8	N.D. *	5-16	0 4 8	3 N.D. N.D.
6-01	0,4,8	N.D.	5-11	0,4,8	N.D.	5-23	0 4 8	5 5 N.D.
6-08	0 4 8	12 9 9	5-18	0,4,8	N.D.	5-30	0 4 8	1 2 N.D.
6-15	0 4 8	9 9 9	5-25	0,4,8	N.D.	6-06	0 4,8	1 N.D.
6-23	0,4,8	N.D.	6-01	0,4,8	N.D.	6-13	0,4,8	N.D.
6-29	0 4 8	8 2 8	6-08	0,4,8	N.D.	6-21	0 4 8	1 1 2
7-06	0 4 8	9 9 9	6-15	0,4,8	N.D.	6-27	0,4,8	N.D.
7-13	0,4,8	N.D.	6-22	0,4,8	N.D.	7-04	0,4,8	N.D.
7-20	0,4,8	N.D.	6-29	0,4,8	N.D.	7-11	0,4,8	N.D.
7-27	0,4,8	N.D.	7-06	0,4,8	N.D.	7-18	0,4,8	N.D.
8-03	0,4 8	N.D. 8	7-13	0 4 8	N.D. 7 N.D.	7-25	0,4 8	N.D. 2
8-11	0,4,8	N.D.	7-20	0,4,8	N.D.	8-01	0 4 8	3 4 5
8-17	0,4,8	N.D.	7-27	0,4,8	N.D.			
			8-03	0,4 8	N.D. 5			
			8-10	0 4 8	N.D. 7 7			
			8-17	0 4 8	N.D. 4 N.D.			

TABLE XVIII (Continued)

1976			1977			1978		
DATE	DEPTH (m)	µg/l	DATE	DEPTH (m)	µg/l	DATE	DEPTH (m)	µg/l
8-24	0	6	8-24	0,4,8	N.D.	8-08	0	2
	4,8	N.D.					4	3
			8-31	0,4,8	N.D.		8	3
8-31	0	20						
	4	23	9-07	0,4,8	N.D.	8-12	0	N.D.
	8	23					4	2
			9-14	0,4,8	N.D.		8	2
9-07	0,4,8	N.D.						
			9-21	0,4,8	N.D.	8-15	0,4	N.D.
9-14	0,4,8	N.D.					8	1
			9-28	0,4,8	N.D.			
9-21	0,4,8	N.D.				8-21	0	3
							4	3
9-28	0,4	N.D.					8	3
	8	4						
						8-27	0,4,8	N.D.
						9-02	0,4	N.D.
							8	3
						9-09	0,4,8	N.D.
						9-16	0,4,8	N.D.
						9-23	0,4,8	N.D.

* N.D. = Not detected

TABLE XIX

MEAN CONCENTRATIONS OF CHLOROPHYLL <u>a</u> IN THE FIRST 2.5 m OF THE WATER COLUMN OF STATION 2 IN HAM'S LAKE DURING 1976, 1977, AND 1978

1976		1977		1978	
DATE	µg/l	DATE	µg/l	DATE	µg/l
5-25	5	5-18	7	5-16	7
6-01	8	5-25	5	5-23	4
6-08	4	6-01	9	5-30	6
6-15	10	6-08	6	6-06	6
6-23	9	6-16	2	6-13	8
6-29	8	6-22	2	6-20	8
7-06	9	6-30	3	6-27	11
7-20	7	7-06	3	7-04	7
8-03	9	7-13	1	7-11	9
8-10	9	7-20	9	7-18	9
8-17	12	7-27	11	7-25	14
8-24	11	8-03	4	8-01	19
8-31	11	8-10	10	8-08	15
9-07	8	8-17	4	8-12	17
9-14	9	8-24	3	8-15	20
9-21	5	8-31	3	8-22	20
9-28	13	9-07	2	8-27	20
		9-14	5	9-02	18
		9-21	4	9-09	17
		9-28	3	9-16	17
				9-23	15

VITA

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