AN ABSTRACT OF THE THESIS OF

Teresa G. Donoso for the degree of Master of Science in Botany and Plant Pathology presented on January 9, 1984.

Title: The Phytoplankton and Limnological Characteristics of Lago Rupanco, Osorno, Chile

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Lago Rupanco is located in the central plain of Chile (Borgel, 1964) at 40° 50' S; 72° 30' W. It lies at 117 m above sea level, and corresponds to type 28c of Hutchinson's (1967) classification. Lago Rupanco is a warm, monomictic lake, with winter circulation and summer stratification. Physical, chemical and biological parameters of this lake were studied during a cycle of 18 months for the first time in 1981-1982. Lago Rupanco has a maximum depth of 160 m. The euphotic zone was sampled and the temperature ranged from 10 to 18 C with an oxygen content between 9 and 11 mg/l. This lake had small amounts of nitrate-nitrogen and phosphate-phosphorous, as is characteristic of oligotrophic lakes. The phytoplankton was analyzed qualitatively and quantitatively. A total of 84 taxa was identified. Maximum and minimum values of phytoplankton relative abundance occurred in spring and fall, respectively. The phyto-planktonic biomass was at its maximum in summer and at its minimum in fall. Four species were the most abundant, *Melosira granulata*, *Sphaerocystis schroeteri*, *Botryococcus braunii* and *Dinobryon divergens*. Seasonal succession among the Bacillariophyceae, Chlorophyceae and Chrysophyceae was observed. The relationships between abiotic factors and the phytoplankton standing crop are discussed.

# THE PHYTOPLANKTON AND LIMNOLOGICAL CHARACTERISTICS OF LAGO RUPANCO, OSORNO, CHILE

by

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Typed by LaVon Mauer for Teresa G. Donoso

DEDICATED TO

My Husband

Jose D. Núñez

and

My Sons

Felipe and Gerardo

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TABLE OF CONTENTS

LIST OF FIGURES

## LIST OF TABLES

# THE PHYTOPLANKTON AND LIMNOLOGICAL CHARACTERISTICS OF LAGO RUPANCO, OSORNO, CHILE

## INTRODUCTION

The southern glacial lakes of Chile and Argentina are the only large, deep oligotrophic lakes in South America that occur near sea level. The most characteristic zone is located between 39° and 42° S latitude, and is referred to in Chile as the Lagos Region. Despite the unique character and economic importance of these lakes, basic physical and chemical parameters of the lakes have not been measured and the study of annual cycles of phytoplankton and other biota have not been attempted by investigators. The purpose of this investigation was to measure basic chemical and physical parameters of one lake, Lago Rupanco, over a year and to relate these to phytoplankton populations measured over the same time span.

Limnological information on the Lagos Region of Chile is limited to the investigations of Loeffler (1960), Thomasson (1963), and Campos et al. (1974, 1977). The Argentine lakes east of the Andes in the same latitudes were studied by Drago (1974) and Thomasson (1959-1963). All of the investigations have been primarily concerned with physical and chemical studies, the biota, except for fish, have been ignored. Loeffler (1960) and Thomasson (1963) stated that

Lago Rupanco was dominated by *Melosira*, but used only one sample taken during the summer months to reach this conclusion. Clearly a time series of phytoplankton samples combined with information concerning the changing physical and chemical properties is needed to characterize a lake and its phytoplankton populations.

The southern region of Chile has a rapidly increasing populations, and a growing economy. These changes will probably result in an increased eutrophication of all lakes in the Lagos Region. It is important to describe the limnological characteristics of at least a few of these lakes so that any general degradation of the lakes can be documented, and so that management of developments may be planned to reduce the impact of man's activities on the conditions of the lakes. For these reasons, the Instituto Professional de Osorno established a Limnological Station on Lago Rupanco in 1980. The clear, deep lakes of the Lagos Region represent one of the most valuable economic resources of Chile, but without evidence of the conditions of the lakes and surrounding watersheds, they may be ruined unwittingly during development.

Phytoplankton populations respond quickly to eutrophication. A time series of quantitative and qualitative analyses defining the trophic status of Lago Rupanco can be used to establish the pristine conditions of the lake.

# MATERIALS AND METHODS

## STUDY AREA

Lago Rupanco is located at 40°50'S; 72°30'W at 117 m above sea level. This lake was formed by glacial scouring of a valley that was later dammed with volcanic flows (Bruggen 1946, 1950; Aguirre and Levi, 1964; Mercer, 1972). The last glaciation (19,400 years B.P.) covered Lago Rupanco and the final lake formation probably occurred less than 10,000 years B.P. The drainage into Lago Rupanco comes directly from 57 andean streams, and there is only one outlet, the Rio Rahue. The watershed is characterized by granitic rocks low in calcium and streams of the region have pH concentration ranging from 6.5 to 7.5 (Vila et al. 1978).

The basin surrounding Lago Rupanco is relatively undeveloped. The soil is thin and underlain by granite. Small farms raise cattle and sheep and cultivate small plots of potatoes. Forestry provides the main income for residents around the lake, small steam operated saw mills are found around the lake. Despite a growing population and some development, large scale erosion is not in evidence.

The weather and climate characteristic of this zone corresponds to the type Csb of Koeppen (1958), with warm, dry summers and mild, moist winters. Although during the winter time the minimum temperatures reach the freezing point, none of the lake freezes, due to the high heat budget of the lake and the strong wind action. Only small farm ponds show an ice cover, but the ice is not strong enough to support the weight of a person. The winter rains and snowmelt in spring determine the maximum flows of the streams coming into the lake.

## SAMPLING

The studies of Lago Rupanco were performed from the Limnological Station of the Instituto Profesional de Osorno, located on the northern side of the lake approximately 5 Km from its outlet. The physical and chemical samples were obtained monthly from July 1981 to December 1982. All the samples were taken in the euphotic zone at an index station located at the point of maximum depth on the western side of the lake (Figure 1). A single station was considered adequate because it had been determined that there were not significant differences between measurements made at this station and at sites on the eastern side of the Islote peninsula, where the influence of the tributaries were expected to be considerable. The large volume of the lake coupled with mixing of the lake acts to reduce localized variations in the water column. The water samples were taken with Van Dorn bottles of 3 and 6 liters capacity. Chemical analyses were performed in accordance with the Standard Methods (APHA, 1975). The inverted microscope

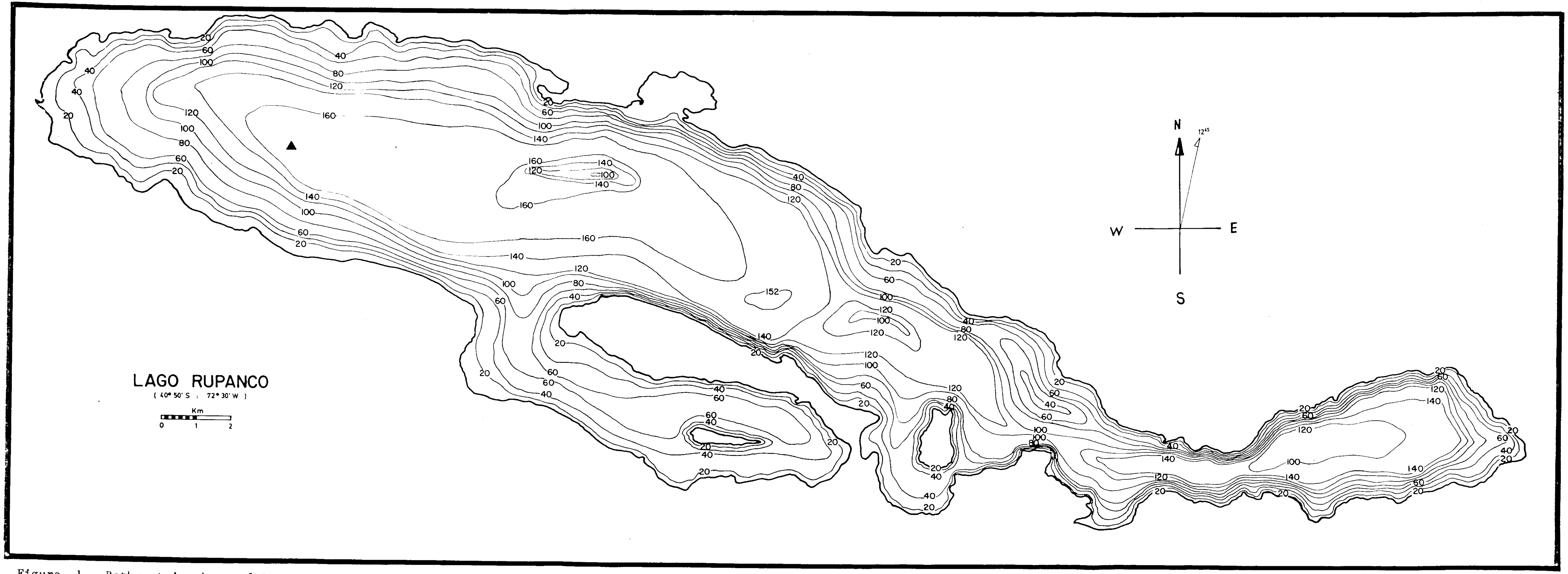


Figure 1. Bathymetric chart of Lago Rupanco, Osorno, Chile. Isobaths at 20 m intervals. Δ : Sampling station.

technique of Lund et al. (1958) was used for phytoplankton analysis.

MORPHOMETRY

The bathymetric chart was based on 20 parallel transects selected to cover the lake surface uniformly. The transects were selected on the basis of information derived from aerial photogrammetric charts (1:50,000) from the Instituto Geografico Militar de Chile (1973). The depth along each transect were estimated from Echosounder Simrad-EL strip recording made while traversing the transect at a constant low speed of ca. 7 Km/h. A magnetic compass and a telescope were used for navigation. The transects were oriented on a North-South axis, correcting for magnetic deviation of 12°43'E. Depth profiles were registered in fathoms and converted to meters. Considering the regular features of the vertical profiles observed on the echograms, contour intervals of 20 m were judged to be adequate to characterize the gross morphology of the lake. The isobaths were drawn by the procedure recommended by Welch (1948).

Morphometric parameters were calculated from the bathymetric chart by following Hutchinson's (1957) methodology. The area (A) and the shoreline (L) were measured by using a polar planimeter and a cartometer, respectively. The hypsographic and volume curves were plotted by following the procedure recommended by Welch

(1948). The exchange rate of the lake was calculated from average outflow of 107.75 $m^3$/sec as estimated by Thomasson (1963) and Endesa (1981).

## PHYSICAL AND CHEMICAL MEASUREMENTS

Light penetration in Lago Rupanco was measured with a standard sized (20 cm) Secchi disk. Additional light data were obtained with a LI-COR, LI-185B, quantum sensor, with a quantum response between 400-700 nannometers. Light was measured as photosynthetically active radiation at the surface and underwater in microeinsteins/$m^2$ sec. Percentages of the surface incident radiation transmitted through the water column were graphed at uniform intervals of 20% of attenuation (Wetzel and Likens, 1979). The main objective of measuring light attenuation was to be able to estimate the photosynthetically active photic zone at 1% level of irradiance.

Temperature of the air and surface water were measured with a mercury thermometer (-20 to 100 C). A Kahlsico bathythermograph was used to obtain the temperature profiles of the water column. Temperature data were plotted at uniform intervals of 2 C (Wetzel and Likens, 1979). These measurements were made to determine the periods of thermal stratification or circulation of the lake.

The oxygen content was measured using the azide modification of the Winkler method. The percentage of oxygen saturation was calculated from Wetzel's (1975) nomogram. The pH was measured in the field with a portable Beckman pH-meter. Carbon dioxide was estimated by titration with 0.005N NaOH and phenolphtalein indicator. The bicarbonate alkalinity was estimated by titration with 0.01N HCl and 0.1% W/V methyl-orange. Total hardness was measured by the EDTA titrimetric method with the addition of the dye Eriochrome black T. The calcium content was evaluated by the EDTA titration with murexide (ammonium purpurate) indicator. The concentration of magnesium was calculated from the EDTA calcium hardness titration.

The phenate method was used to estimate ammonia-nitrogen. Nitrate and nitrite-nitrogen were measured by the cadmium reduction method. The nitrate was reduced in alkaline buffered solution to nitrite by passing the sample through a coperized cadmium metal fillings. This method is more sensitive for concentrations less than 0.1 mg $NO_3$-N/l. The ascorbic acid method was most appropriate for phosphate-phosphorous measurements. This method is applicable in a range of 1-500 μg $PO_4$-P/l. The molybdosilicate method was used to estimate dissolved silica. This method is accurate to at least ±0.02 mg/l. All the inorganic nutrients already mentioned were measured with a PYE-Unicam digital spectrophotometer.

To evaluate total dissolved solids (TDS) and total suspended solids (TSS) the samples were filtered. To determine TDS concentration, the filtrate was evaporated at 105 C, and the residue weighed (Boyd, 1979). For the concentration of TSS, the samples were filtered through tared glass fiber filters, dried at 105 C and then the filter reweighed (Strickland and Parson, 1968).

To determine the organic and inorganic fractions of the total suspended solids, the filters were incinerated in a muffle furnace at 550 C for 30 minutes. The weight loss represented the organic matter.

PHYTOPLANKTON

The phytoplankton was sampled with No 25 mesh nets (60 µm diameter pore) and with Van Dorn water bottles. Plankton nets were towed horizontally through the surface water for 10 minutes. For qualitative study, net plankton was analysed before being fixed. For quantitative evaluation only the Van Dorn samples were considered. A sub-sample of 100 ml of the content of the water-bottle was put into the appropriate plastic flask provided with a double lid. Sufficient Lugol's solution was added to each flask to equal 1% v/v for fixation and preservation of the samples (Vollenweider, 1974).

Identification of the phytoplankton was accomplished primarily with the aid of Bourrelly, Les Algues d'eau douce (1966-1970) and the Manual Taxonomico del Fitoplancton de Aguas Continentales by Oscar O. Parra et al. (1982-1983).

The counting of the phytoplankton was carried out with a Leitz Inverted Microscope. Compound sedimentation chambers of 25 mm diameter and 100 ml capacity were used. The time allowed to ensure sedimentation of phytoplankton was 20 hours minimum (Lund et al., 1958). The chambers were examined at a magnification of 400X to 1000X depending on the size of the organisms. As the time to count an entire chamber is excessive, the count was restricted to a portion of the bottom surface of the chamber. Two strips perpendicular to each other, over the middle of the bottom of the chamber were always counted. It was considered necessary to count ca. 100 individuals of each of the more important species in the sample in order to obtain a sufficient degree of statistical accuracy (Lund et al., 1958). By means of the mechanical stage of the microscope other strips located at an angle of 90° to one another were counted. In the calculation of the number of cells per unit volume, the volume of the chamber, its diameter and the area counted were considered. These three elements (volume, diameter and area) determined a factor which permitted the expression of the number of cells per liter.

Assuming a normal distribution of organisms in the sample and hence in the lake, the abundance of the phytoplankton was expressed as number of cells per liter (Schwoerbel, 1970). To estimate the relative density of different species the following criteria were used: 100-61% very abundant (VA), 60-41% abundant (A), 40-16% common (C), 15-1% rare (r), if a taxon was present only occasionally a single specimen (x), or absent (-).

In determining the biomass of the phytoplankton, the volume of each of the more abundant species was calculated from the mean dimensions of ten cells. It was assumed that the form of the cells corresponded roughly to some simple geometric body (Vollenweider, 1974), and their volume calculated. The specific gravity of the organisms was taken as unity. Thus, the volume corresponded approximately to the wet weight. The number of individuals of each species multiplied by the average cell volume was an estimate of the biomass of the phytoplankton per unit volume.

Spherical curves were used as a means of comparing the vertical distribution of phytoplankton. In order to reduce population numbers to a manageable size, the numbers of organisms found at each depth were not given in absolute numbers of cells per liter but were presented as the cube root of that number divided by 4.19 ($R = k \sqrt[3]{n/4.19}$), where R = radius of spherical curve, and k = scaling constant (Thomasson, 1963). Seasonal changes of the vertical distribution of the biovolume of populations were represented by using Nauwerck's (1963) method.

# RESULTS

## PHYSICAL FACTORS

From the bathymetric chart, it should be noted that the long axis of Lago Rupanco lies in an approximate SE-NW direction and the greatest depths occur along this axis (Figure 1). The basin has a relatively flat bottom that is interrupted in the central part by the Islote peninsula and 2 small islands (Ciervos and Cabras).

The results of morphometric calculations from the bathymetric chart (Table 1) yielded an hypsographic curve (Figure 2) revealing a U-shaped profile of the basin, with steep slopes, a flat bottom and poor development of the littoral zone. The volume curve (Figure 3) exhibits a strong convexity, confirming the characteristics clearly shown in the area curve (Figure 2). The average of the exchange rate in the lake was 7.5 years.

The values for transparency obtained with the Secchi disk were between 10 and 20 m. The maximum transparency observed was 20 m in December 1981 and the minimum value was 10 m in August 1981 (Figure 4). Measurements of photosynthetically active radiation at the surface and underwater showed that the illumination had been reduced to 1% of its surface value around 20-30 m, except for the months of November and December when that depth was 50 and 60 m respectively. This stratum of 0-60 m was considered

Table 1. Morphometric values of Lago Rupanco, Osorno, Chile.

| Parameters | Symbols and Formulas | Results |
|---|---|---|
| Length | l | 40.425 Km |
| Breadth | b | 9.075 Km |
| Area | A | 247.530 $Km^2$ |
| Maximum depth | Z m | 160 m |
| Mean depth | $\bar{Z} = V/A$ | 94 m |
| Relative depth | $Z_r = 50\ Zm \sqrt{\pi} / \sqrt{A}$ | 0.92% |
| Depth of crypto depression | Zc | 43 m |
| Volume | $V = {}^h/_3 (A_1 + A_2 + \sqrt{A_1 A_2})$ | 25.124 $Km^3$ |
| Shore line | L | 141.3 Km |
| Shore line development | $D_L = L/2\sqrt{\pi A}.$ | 2.59 |
| Ratio of mean to maximum depth | $(\bar{Z}:Zm)$ | 0.59 |

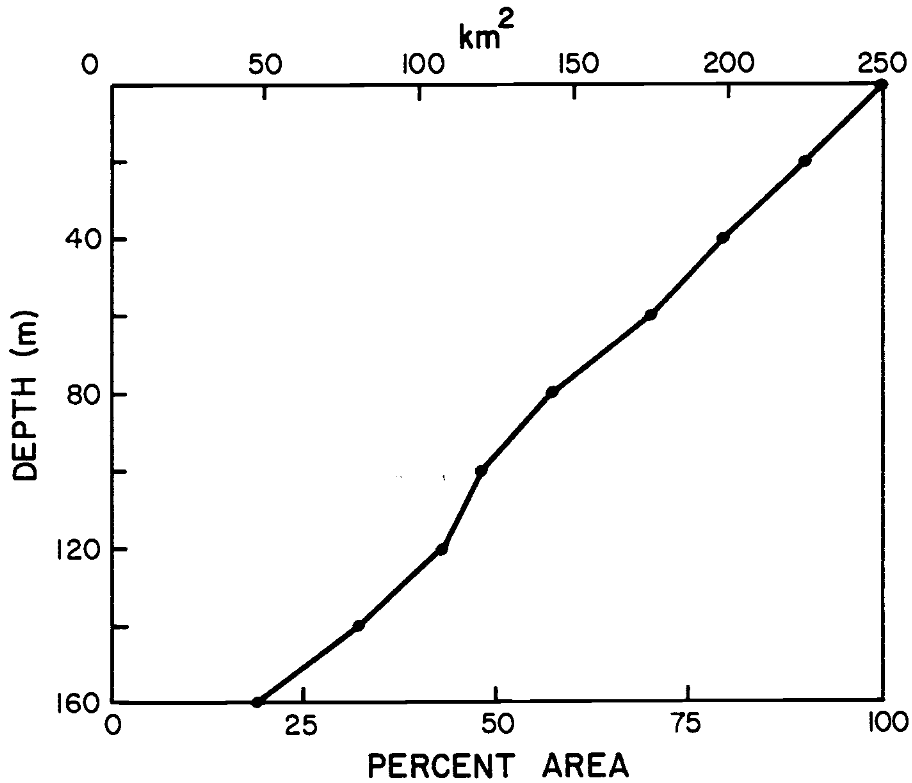


Figure 2. Hypsographic curve of Lago Rupanco and its percent distribution.

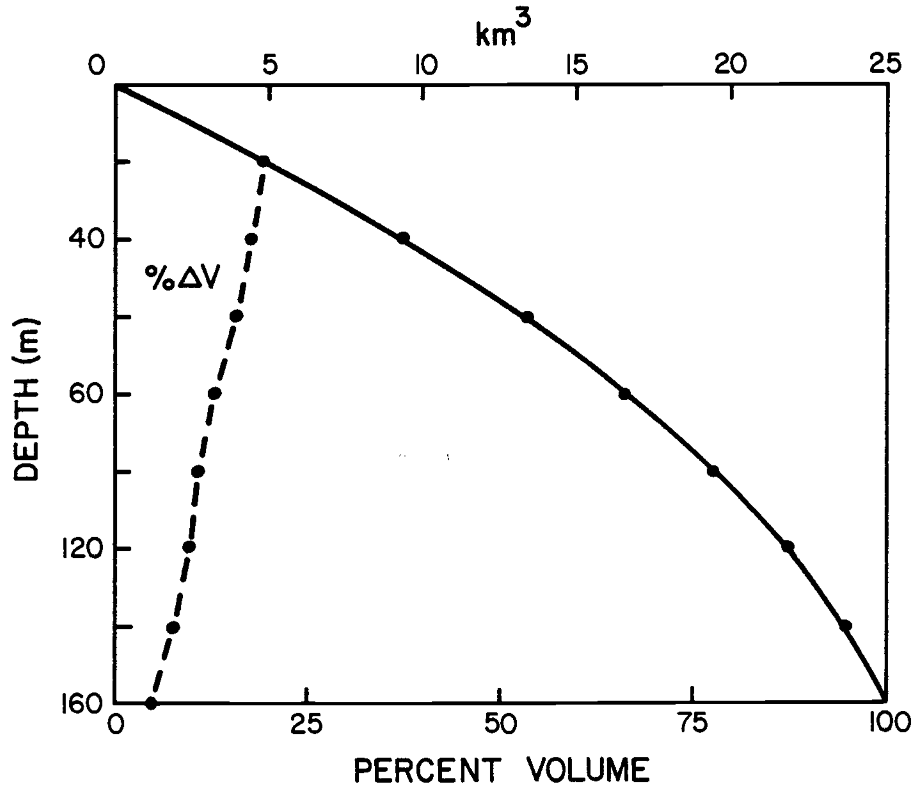


Figure 3. Depth-volume curve of Lago Rupanco and its percent distribution.

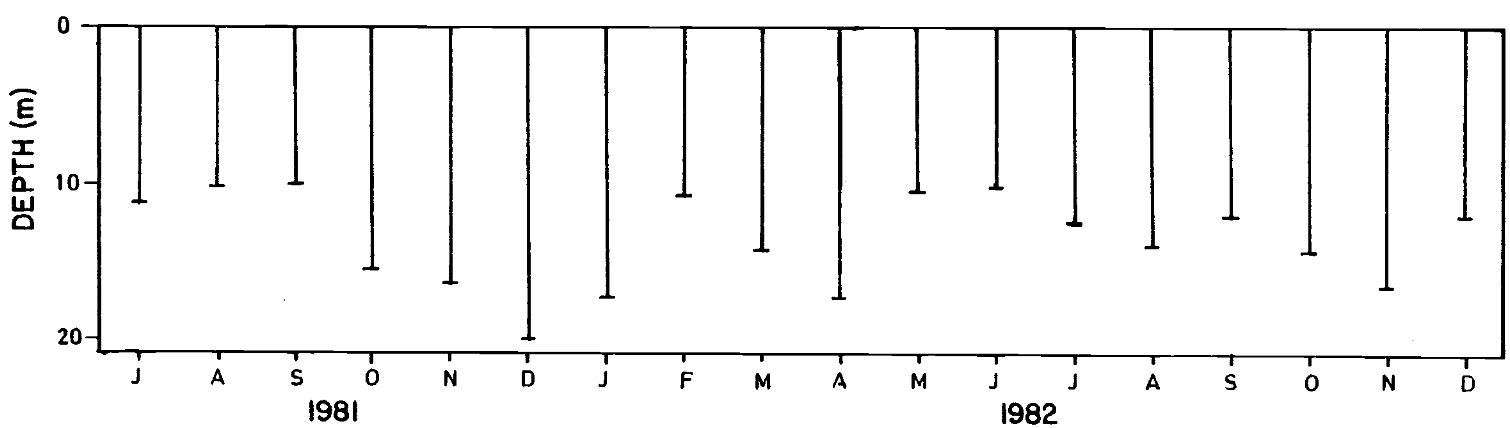


Figure 4. Secchi disk transparency in Lago Rupanco.

the photic zone or the zone where photosynthesis takes place and from this zone the samples were obtained (Figure 5).

During the period analyzed, the temperatures recorded showed a vertical isothermy of 10 C (±0.2) during the winter time (July to Sept.) down to the maximum depth measured of 100 m. In spring time (Oct. to Dec.) there was an increase in the temperature of the surface layers of 2 to 4 degrees. At the end of this period, thermal stratification was established (Figure 6). Stratification continued through all the summer (January to March). The bathythermograph record in December 1981 showed the metalimnion lying between 20 and 50 m with the temperatures of 15.8 C to 11.2 C, respectively. In March 1982, temperatures went from 16 C to 11 C between 22 to 33 m; and in April 1982, temperatures were between 14.5 and 11 C at 30 to 35 m, respectively. After May the metalimnion started to disappear as the temperature of the water decreased to 12 to 13 C, until it reached 10 C from surface to the maximum depth measured in September of both 1981 and 1982 (Figure 6).

At the surface of the lake, the temperature ranged from 10 C in winter to 18 C in summer. The epilimniom increased in depth from February to May and its temperature decreased from 18 to 13 C, while the metalimnion went down 40 to 50 m deep. In the hypolimnion the temperature varied between 11.2 and 9.8 C. This last temperature was the minimum registered in this zone at 100 m depth in April 1982.

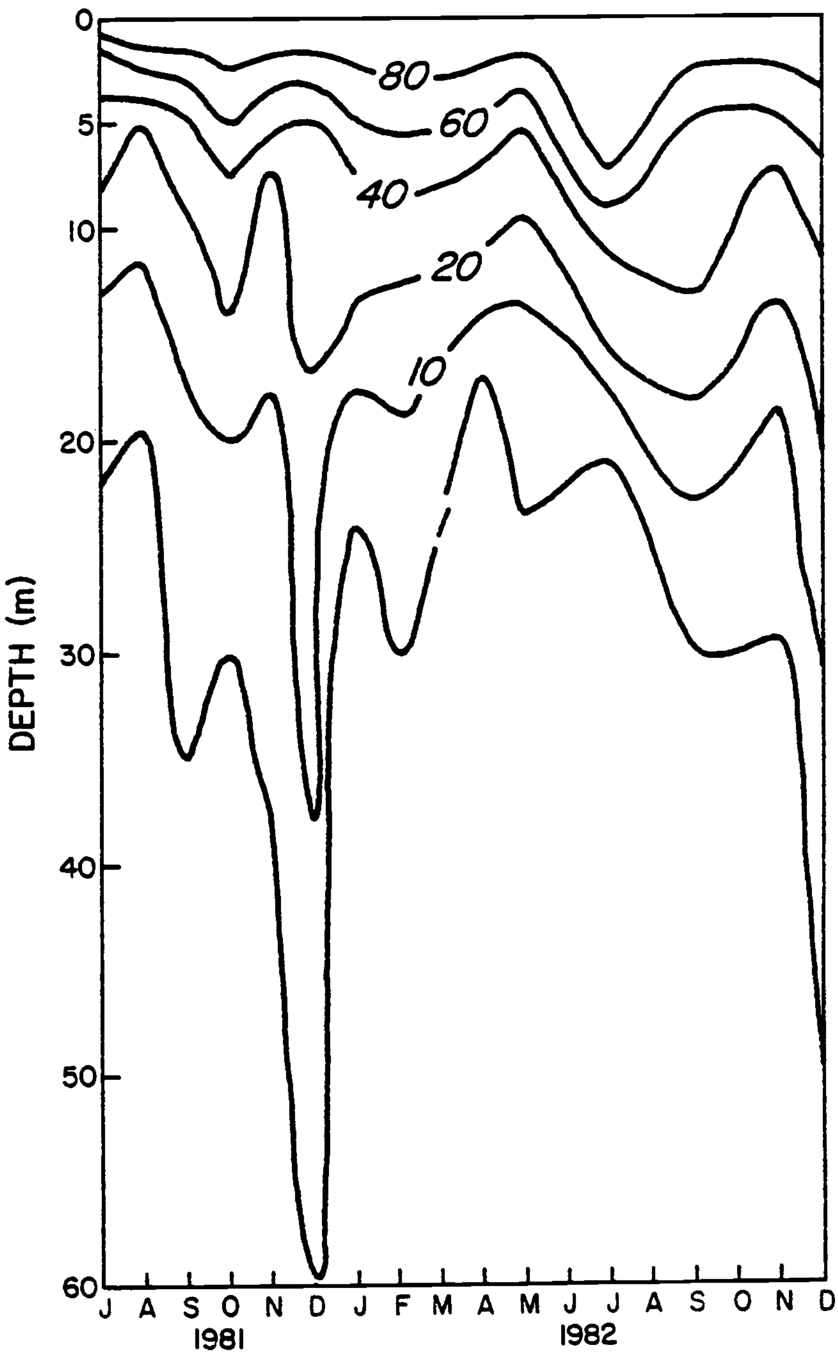


Figure 5. Isopleths of the percentage transmission of light underwater in Lago Rupanco.

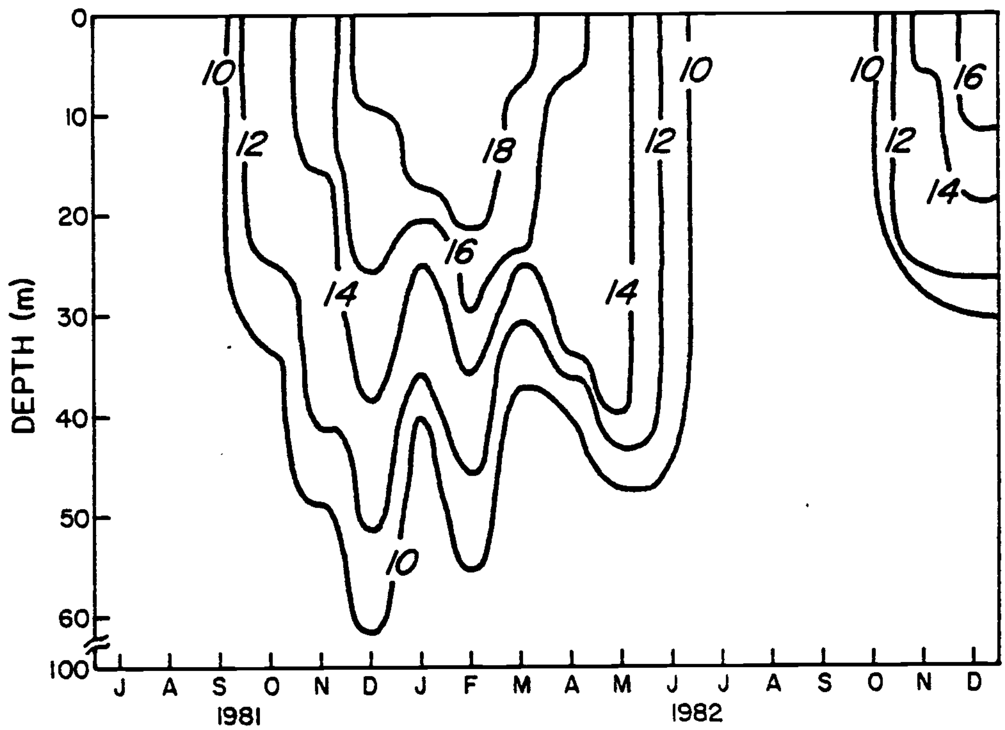


Figure 6. Chronological distribution of isotherms (C) in Lago Rupanco.

The isopleth of water temperatures at uniform intervals of 2 C, showed the temperatures of the epilimnion fluctuating between 12 and 18 C, the metalimnion between 11 and 16 C and the hypolimnion between 10 and 11 C (Figure 6).

The temperature variations at different depths through the period studied showed that the upper stratum (0-20 m), the middle stratum (20-50 m) and the deepest one, had different thermal behavior. The surface layers increased their temperatures from the end of the winter to the summer time, reaching a maximum in February and decreasing through the fall. The intermediate stratum showed a constant increase in temperature from the end of winter until the end of summer, with a decrease in the fall. On the other hand, the deepest stratum was the most stable and uniform during the cycle analysed.

The predominant winds in the region are from the North in the winter time and the S.E. and S.W. from September through the summer time. These last 2 types of wind have a great influence in the dynamics of the lake.

Considering the thermal characteristics described, this lake corresponds to a warm monomictic lake with the period of circulation during the winter.

## CHEMICAL FACTORS

The vertical distribution of dissolved oxygen showed that practically all the water column had uniform characteristics in relation to the concentration of this gas through all the year. The concentrations were between 9.0 and 11.0 mg/l (±0.2) (Figure 7). The lowest value was 8.81 mg/l in April at 17 m. In summer the concentration of dissolved oxygen was lower in the surface layers than in the deepest ones. This situation was reversed during the fall. In the winter there was a concurrent decrease of the temperature of the water and an increase in the dissolved oxygen concentration. But the higher values were found at the early spring, 11.27 mg/l. In general, the results gave an orthograde oxygen distribution with the percentage of saturation always above 100% (Figure 8).

The hydrogen ion concentration ranged from 6.8 to 7.2 (Figure 9). A great seasonal variation was not observed although the higher values were found mostly in spring.

The carbon dioxide concentration ranged from 1 to 8 mg/l (Figure 10). The minimum value found was 0.77 mg/l in January. The maximum was in spring, 8.4 mg/l. May also presented high values ranging from 4 to 8 mg/l. During the winter time the concentration was lower. The vertical distribution showed that carbon dioxide was evenly distributed from the surface to the deeper layers during most of the year, except in May.

The alkalinity consisted entirely of bicarbonate. It ranged from 0.4 to 0.6 meq/l (Figure 11). The lowest concentration occurred in late spring and the highest during

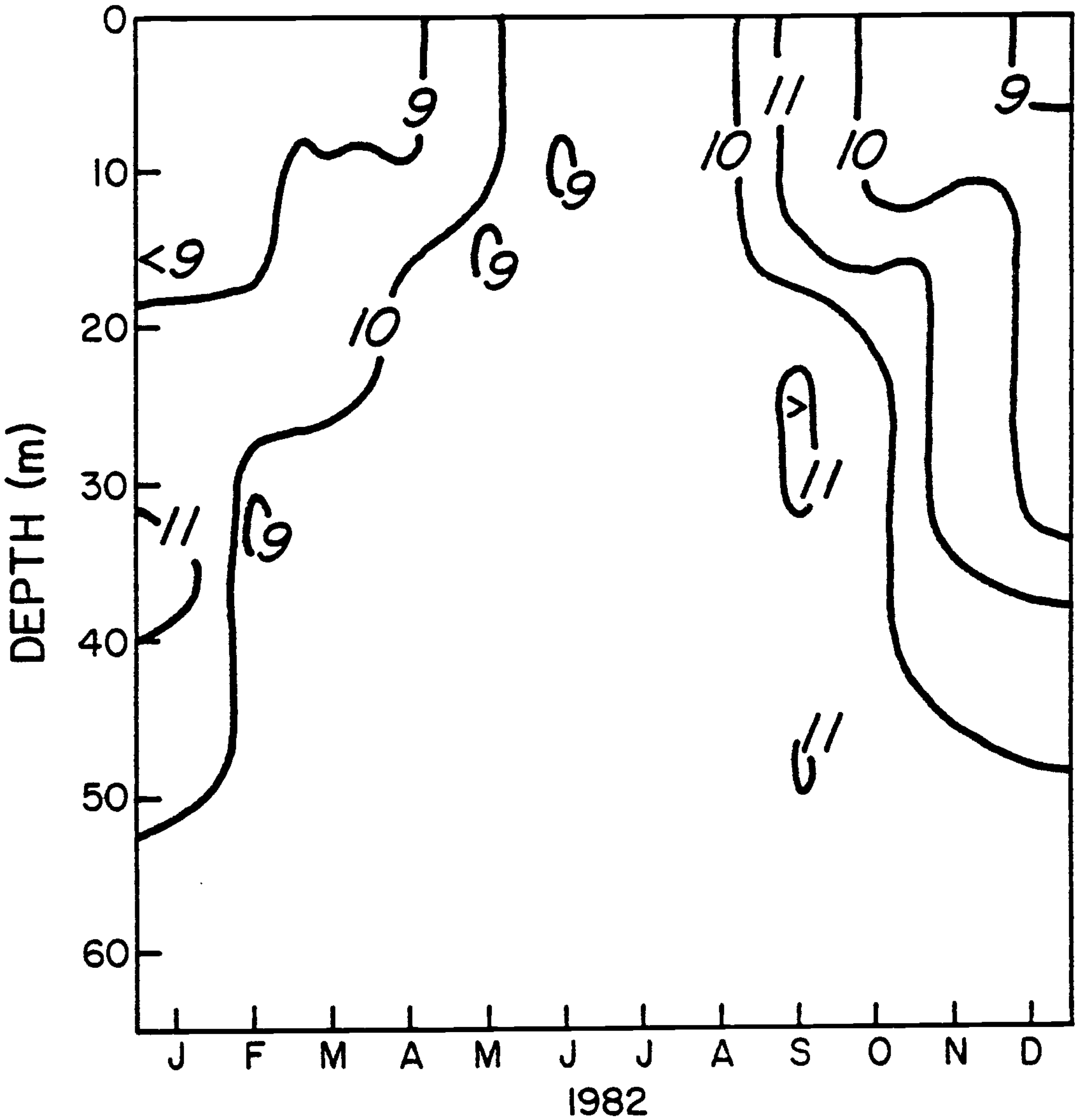


Figure 7. Chronological distribution of isopleths of dissolved oxygen (mg/l) in Lago Rupanco.

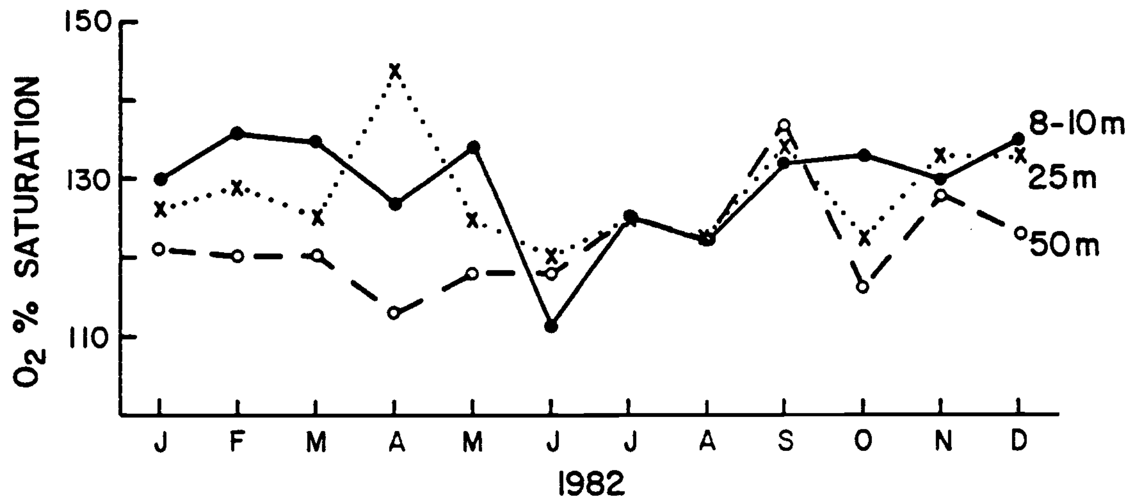


Figure 8. Percentage saturation of dissolved oxygen concentration measured at different depths in Lago Rupanco.

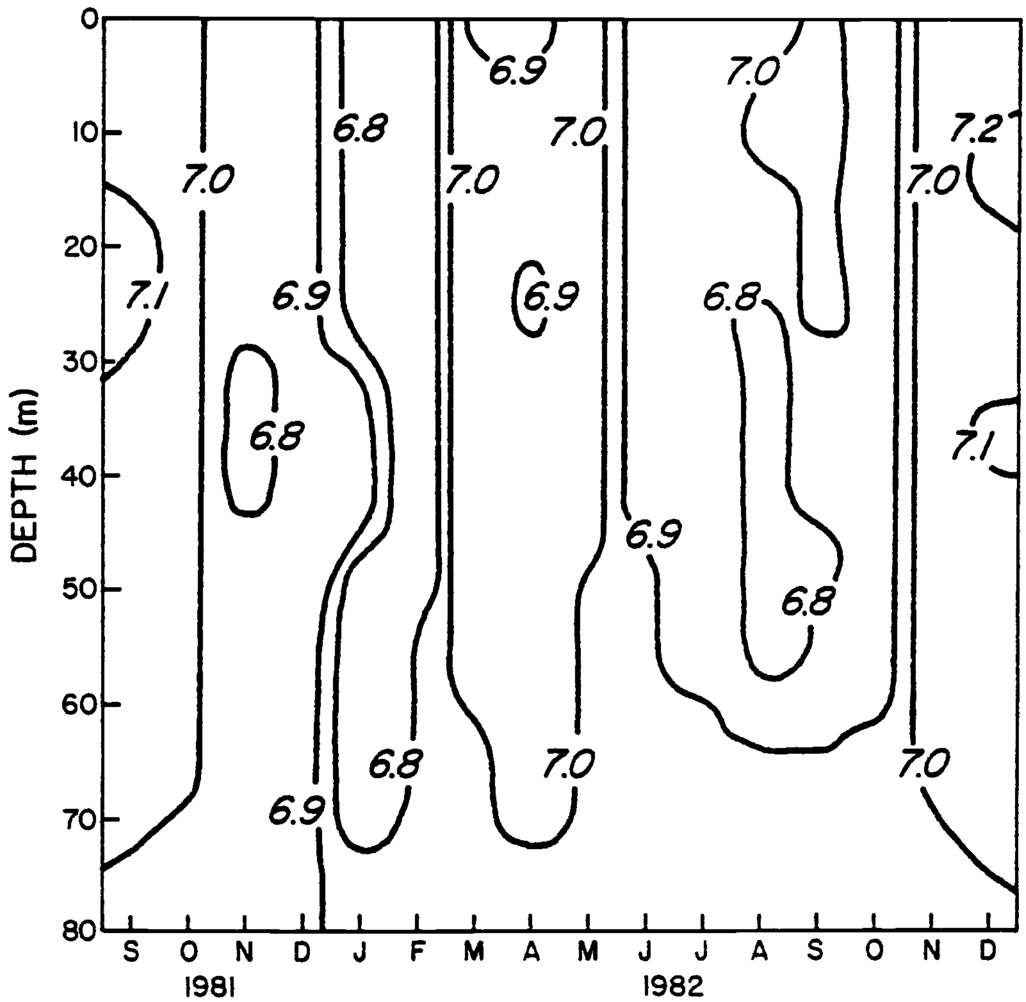


Figure 9. Chronological distribution of isopleths of hydrogen ion concentration in Lago Rupanco.

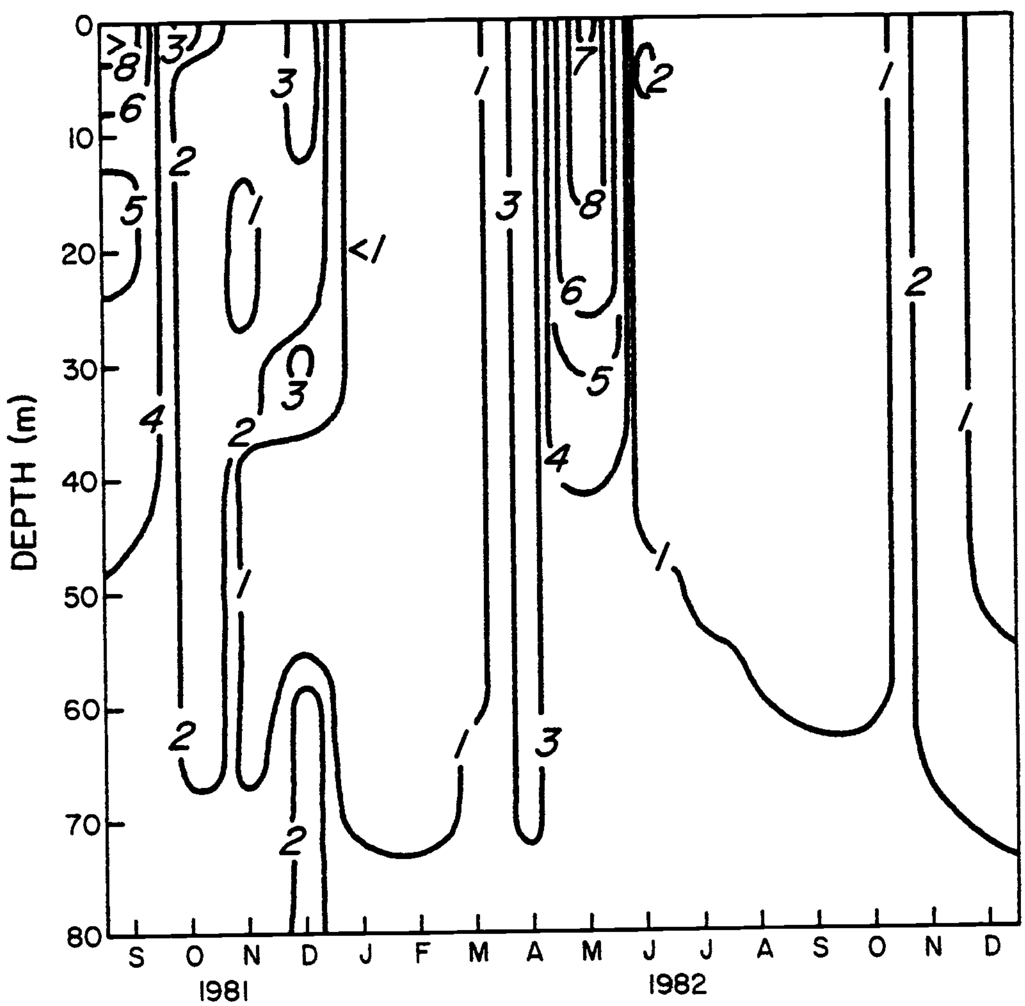


Figure 10. Chronological distribution of isopleths of carbon dioxide concentration in Lago Rupanco.

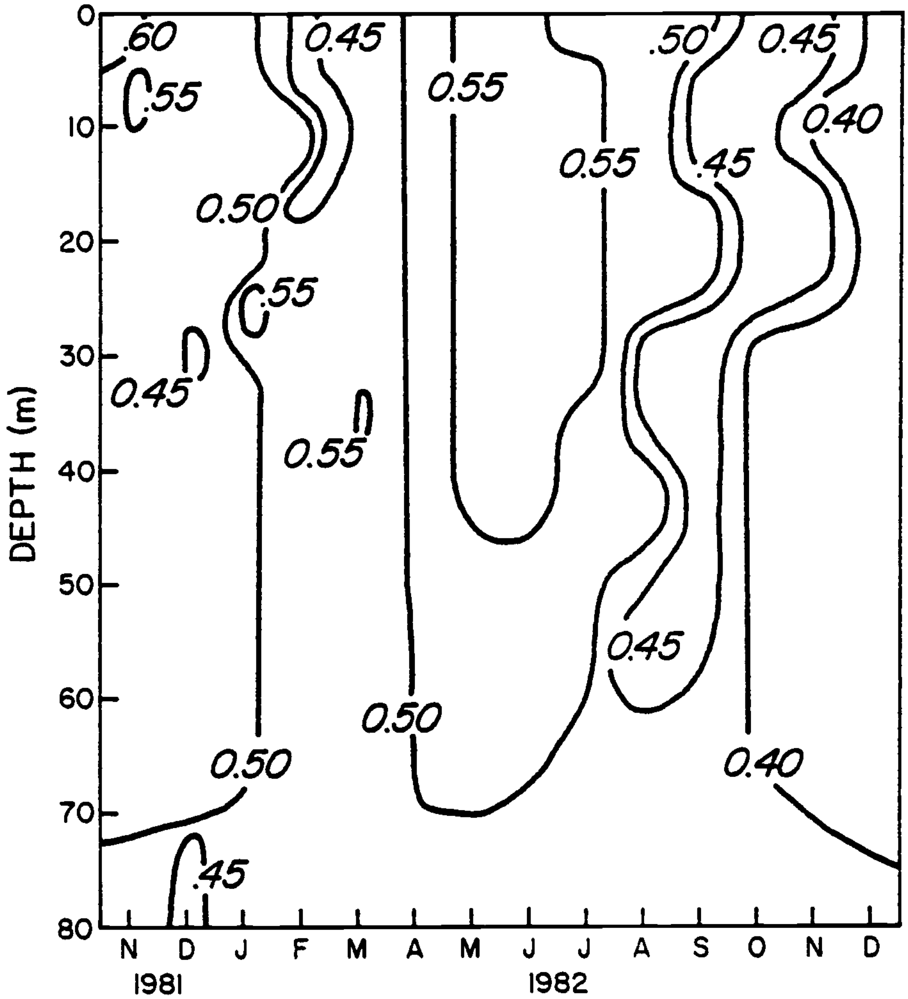


Figure 11. Chronological distribution of isopleths of total alkalinity (meq/l $CaCO_3$) in Lago Rupanco.

the winter circulation period, with the vertical profile almost uniform. The amount of hardness (Ca + Mg) was less than bicarbonate alkalinity. Maximum concentrations were found in spring-summer, 20 to 29 mg/l $CaCO_3$, and the minimum in autumn-winter of 17 to 19 mg/l $CaCO_3$ (Figure 12). The vertical distribution was quite uniform with a slight decrease in the deeper zone. These values according to Boyd (1979), are characteristics of a soft water.

The concentration of ammonia-nitrogen ranged from 0 to 21 µg/l in 1982. The vertical distribution showed seasonal differences in concentration (Figure 13). The maximal values were found in the spring-summer time, 10 to 20 µg/l, and the minimal ones were observed during the fall. Results for the winter of 1982 were not recorded. Besides these seasonal variations there was also noticed a great concentration in the surface and in the deepest layers during the summer. This situation was reversed through the fall.

Analysis of nitrite-nitrogen was negative. The concentration of nitrate-nitrogen ranged from 2 to 48 µg/l. The isopleths demonstrated that the period of lower concentration of 2 to 15 µg/l was during late summer (Figure 14). During the autumn there was an increase of nitrates at the surface where the maximum value of 48 µg/l was recorded. In the winter time, the nitrate was almost uniformly distributed in the water column, with average levels of 20 to 25

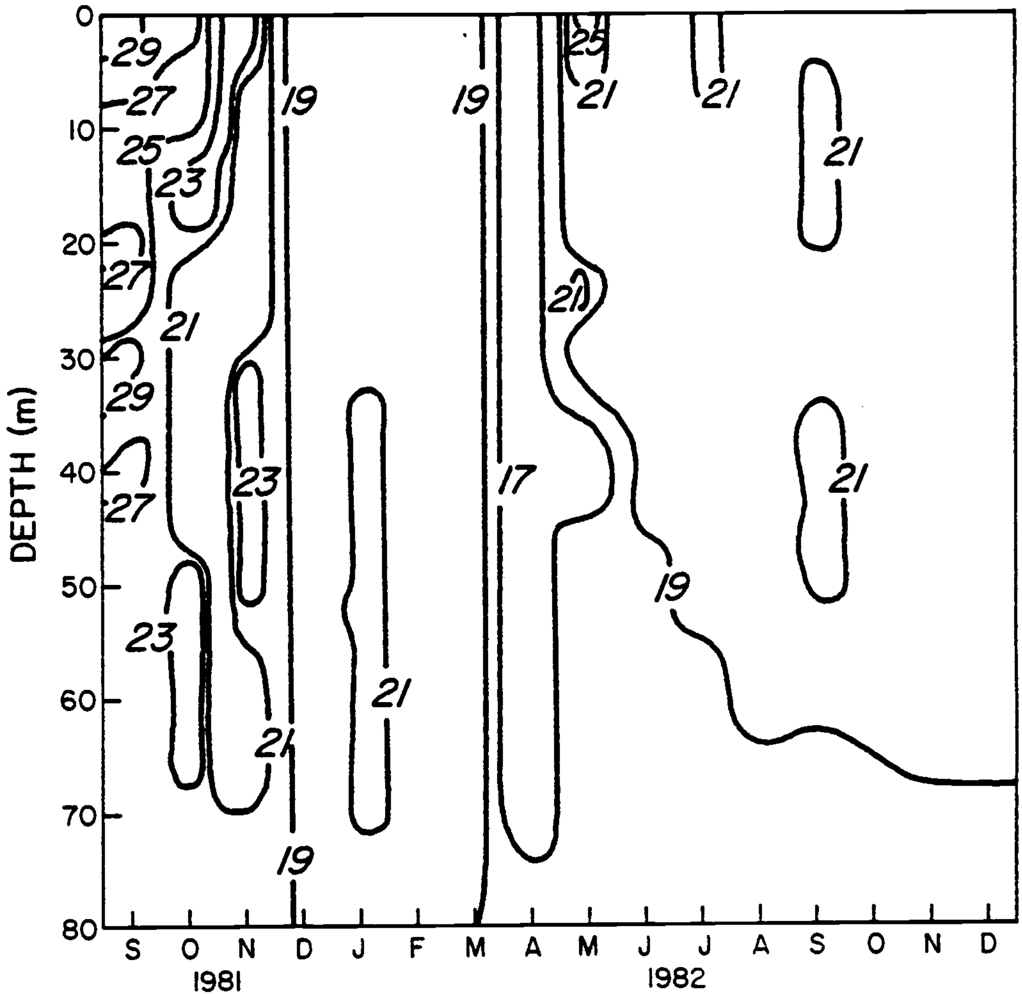


Figure 12. Chronological distribution of isopleths of total hardness (mg /l $CaCO_3$) in Lago Rupanco.

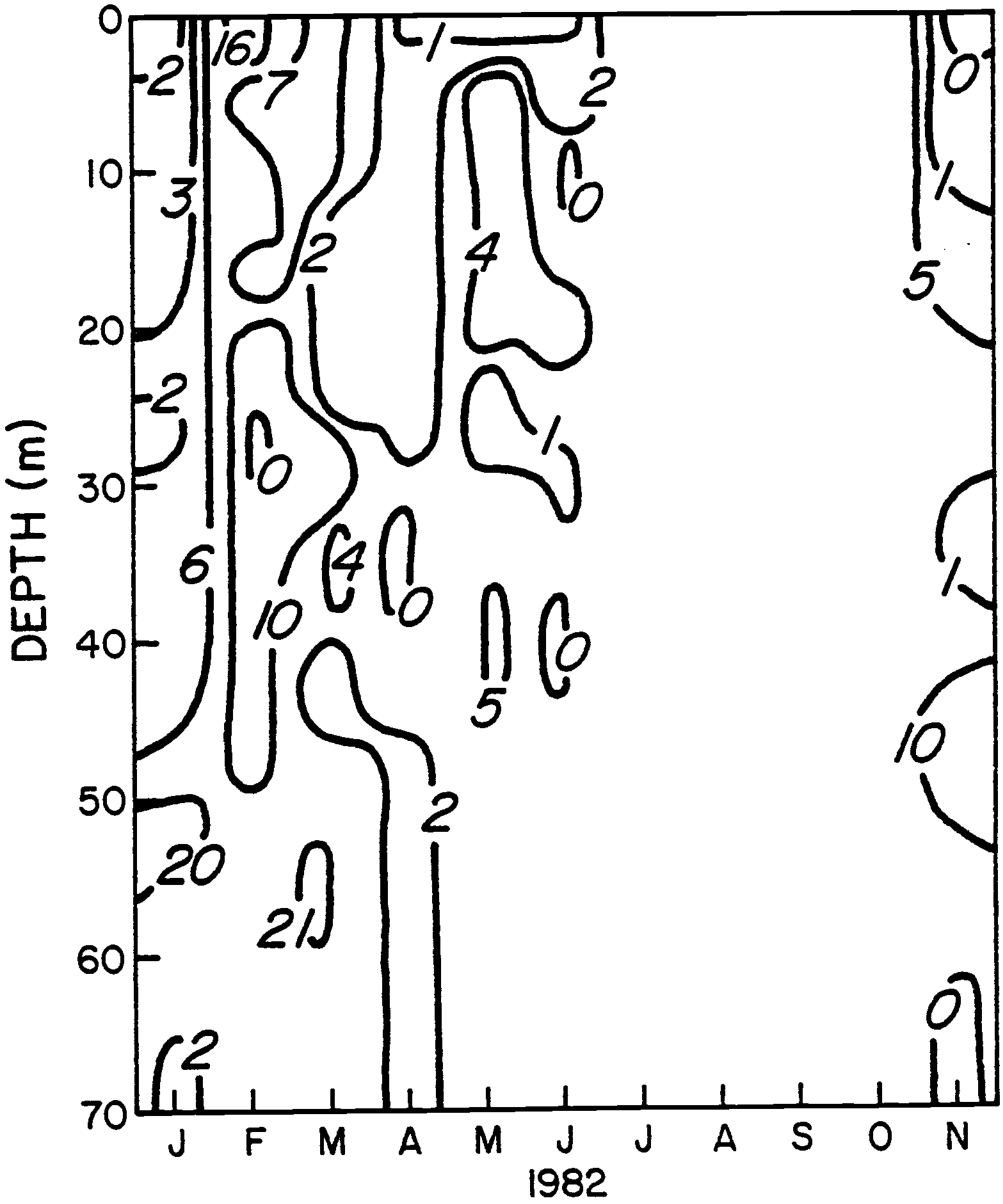


Figure 13. Chronological distribution of isopleths of ammonia-nitrogen (μg/l) in Lago Rupanco.

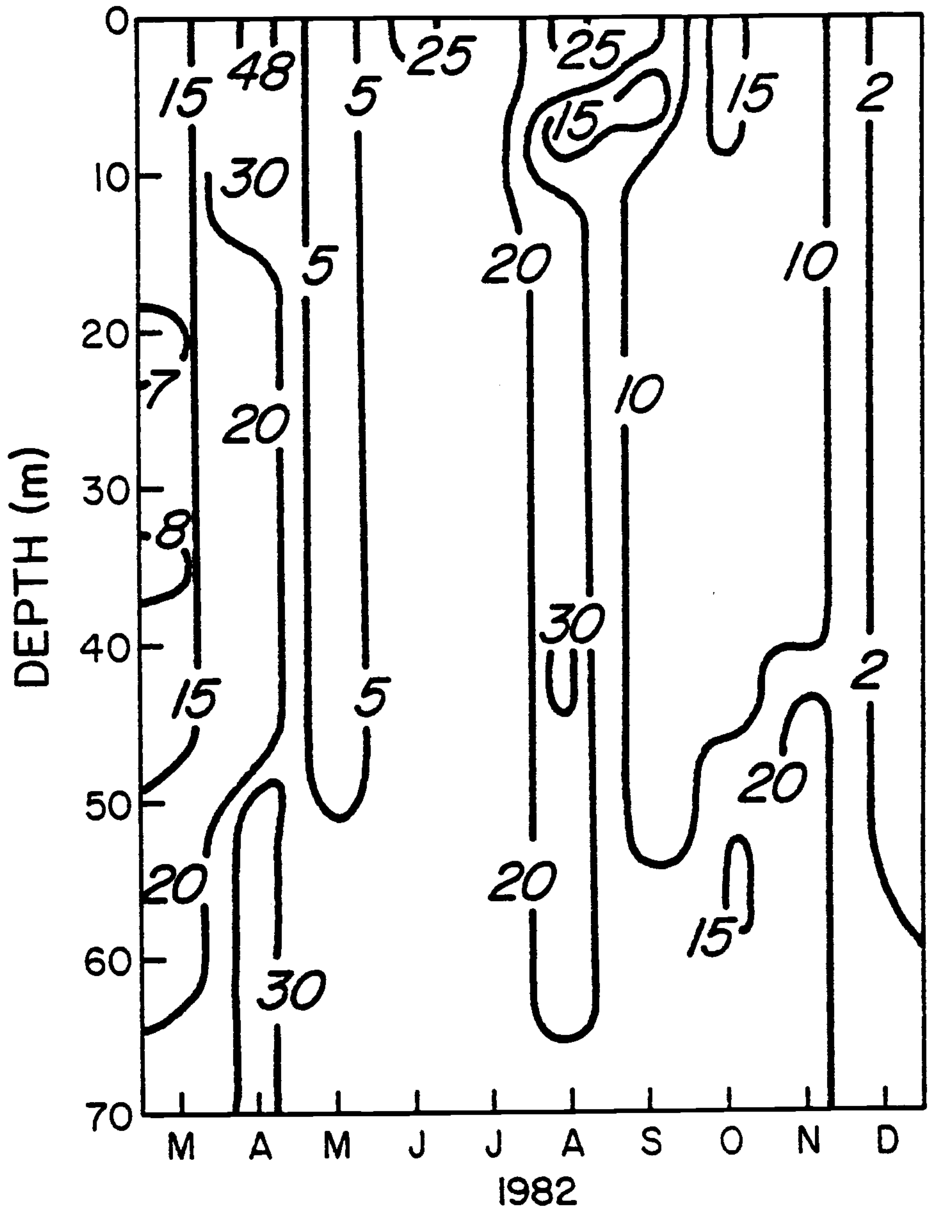


Figure 14. Chronological distribution of isopleths of nitrate-nitrogen (μg/l) in Lago Rupanco.

μg/l. In spring the values decreased and remained low until late summer (March). There was noted a difference in concentration between the surface and deeper strata. In autumn and winter the surface presented the greater values. These concentrations decreased through the spring until the early summer. On the other hand, in the deeper layers the reverse was true. These seasonal and vertical variations of nitrate concentrations were presumeably associated with the rainfall during autumn and winter, and with the main production of phytoplankton in spring and summer.

The concentration of phosphate-phosphorous ranged from 0 to 50 μg/l. This nutrient showed a clear seasonal distribution (Figure 15). In the summer the concentrations were variable and ranged from 0 to 25 μg/l. During autumn the highest values, 30 to 50 μg/l, were found mainly in the surface layers. In the winter, there was a decrease in the concentration of this nutrient to below analytical detectability, 0 μg/l in August. In the spring there was a new increase in the concentration of phosphate. Presumably these variations in nutrient concentrations were related to the rainfall and the agricultural activities on some areas around the lake. The vertical distribution was almost uniform except during the period of stratification.

The diatoms are the organisms that are frequently considered in relation to the concentrations of silica. Dissolved silica is assimilated in large quantities by

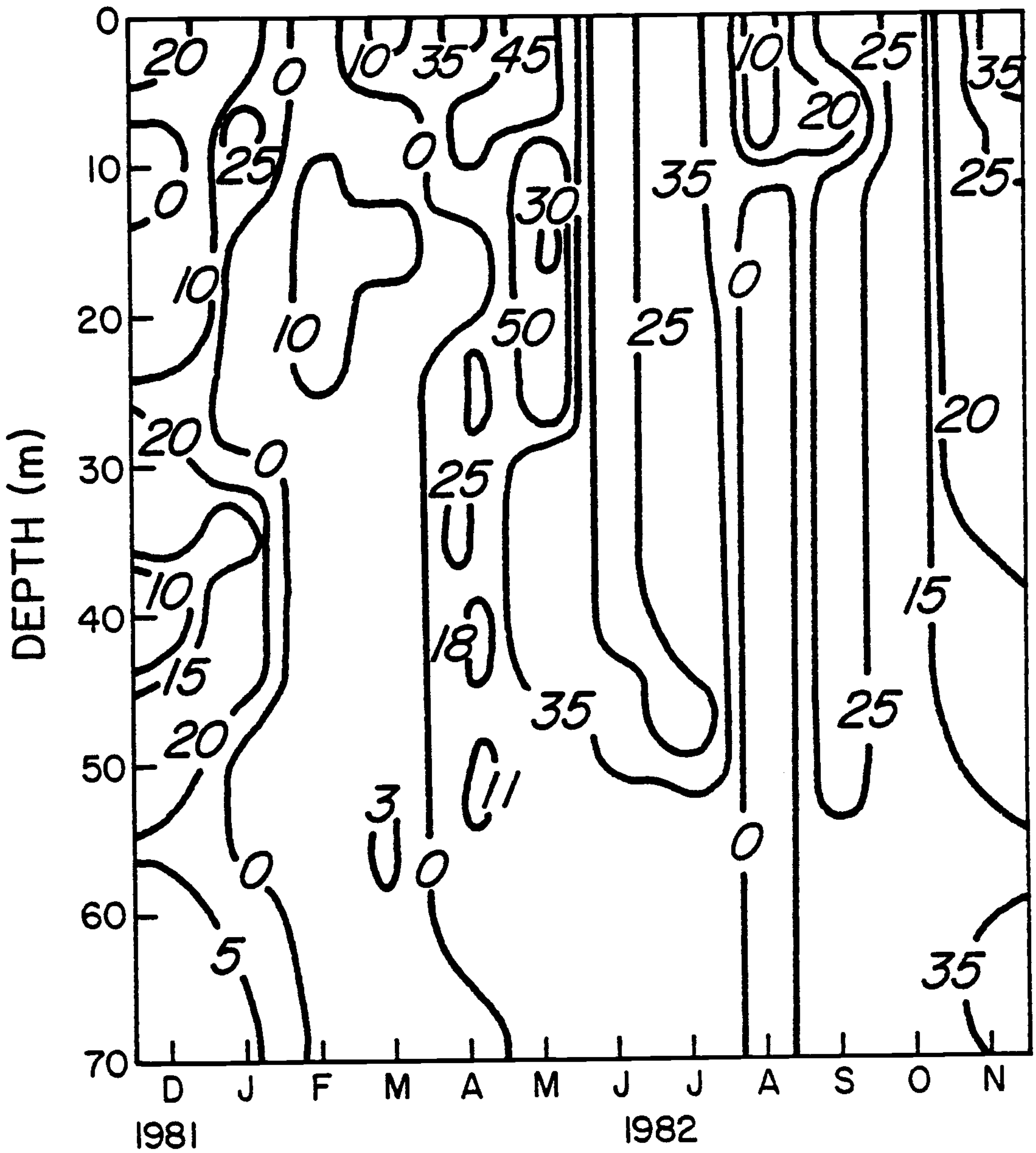


Figure 15. Chronological distribution of isopleths of phosphate-phosphorous (μg/l) in Lago Rupanco.

diatoms in the synthesis of their cell walls or frustules. Therefore, utilization by diatoms can modify greatly the concentrations and flux rates of dissolved silica in a lake. In Lago Rupanco the isopleths exhibited slight variations in seasonal and spatial distribution (Figure 16). The concentrations of this nutrient were approximately 10 mg/l from the end of summer until early spring. During late spring these values decreased and then they increased to their maximum concentrations during the summer time. At the same time it was also noted that the epilimnion and metalimnion had slightly higher concentrations compared with the hypolimnion. This situation could be explained considering that during summer time, Lago Rupanco was stratified. Silica concentrations usually increase in the tropholitic zones of lakes during periods of stratification (Wetzel, 1975).

The solids represent the portion of a water sample which is not lost upon evaporation. Solids include dissolved organic matter, particulate organic matter, dissolved inorganic substances except gases and the $CO_2$ contained in bicarbonate and particulate inorganic substances (Boyd, 1979).

Total dissolved solids (TDS) corresponds to the total residue remaining after evaporation of a water sample which was first filtered to remove suspended matter. The higher concentrations of TDS in Lago Rupanco occurred during summer

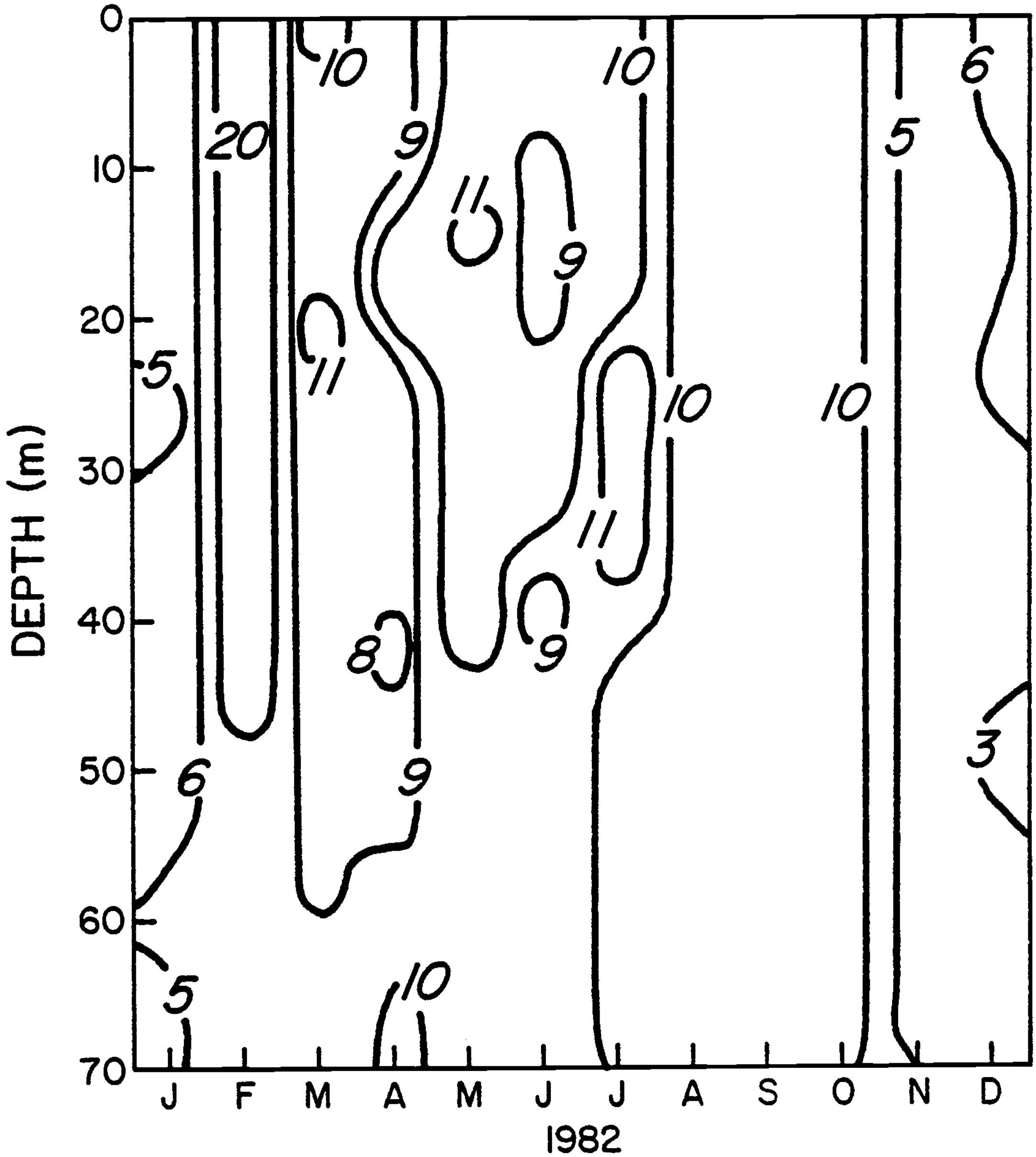


Figure 16. Chronological distribution of isopleths of dissolved silica (mg/l) in Lago Rupanco.

stratification and in early fall (Figure 17). During winter through spring the values decreased until they reached minimal concentrations in October, and increased a little by the end of spring. Also the distribution at different levels showed that during the time of higher values, they occurred mainly in surface layers and in the season when the concentrations were lower they occurred in deeper layers.

Total suspended solids (TSS) corresponds to total particulate matter or dry weight of matter that is retained on a fine filter. This fraction includes inorganic particles and living and dead organic matter. In Lago Rupanco the concentrations of TSS were very low, from April to December, the monthly averages ranged from 0.05 to 1.24 mg/l. Data for summer time (Jan. to March) was not recorded. The seasonal distribution observed had higher values in early fall (Figure 18). The lowest concentrations were found in the early spring and they began to increase through November and December. During the winter the values were more or less stable between 0.2 and 0.3 mg/l. The spatial distribution of TSS showed that the highest values occurred in deeper layers. This situation is opposite to that observed from the TDS.

To determine the organic and inorganic fractions of the total suspended solids, the filters were incinerated in a muffle furnace at 550 C for 30 minutes. The weight loss

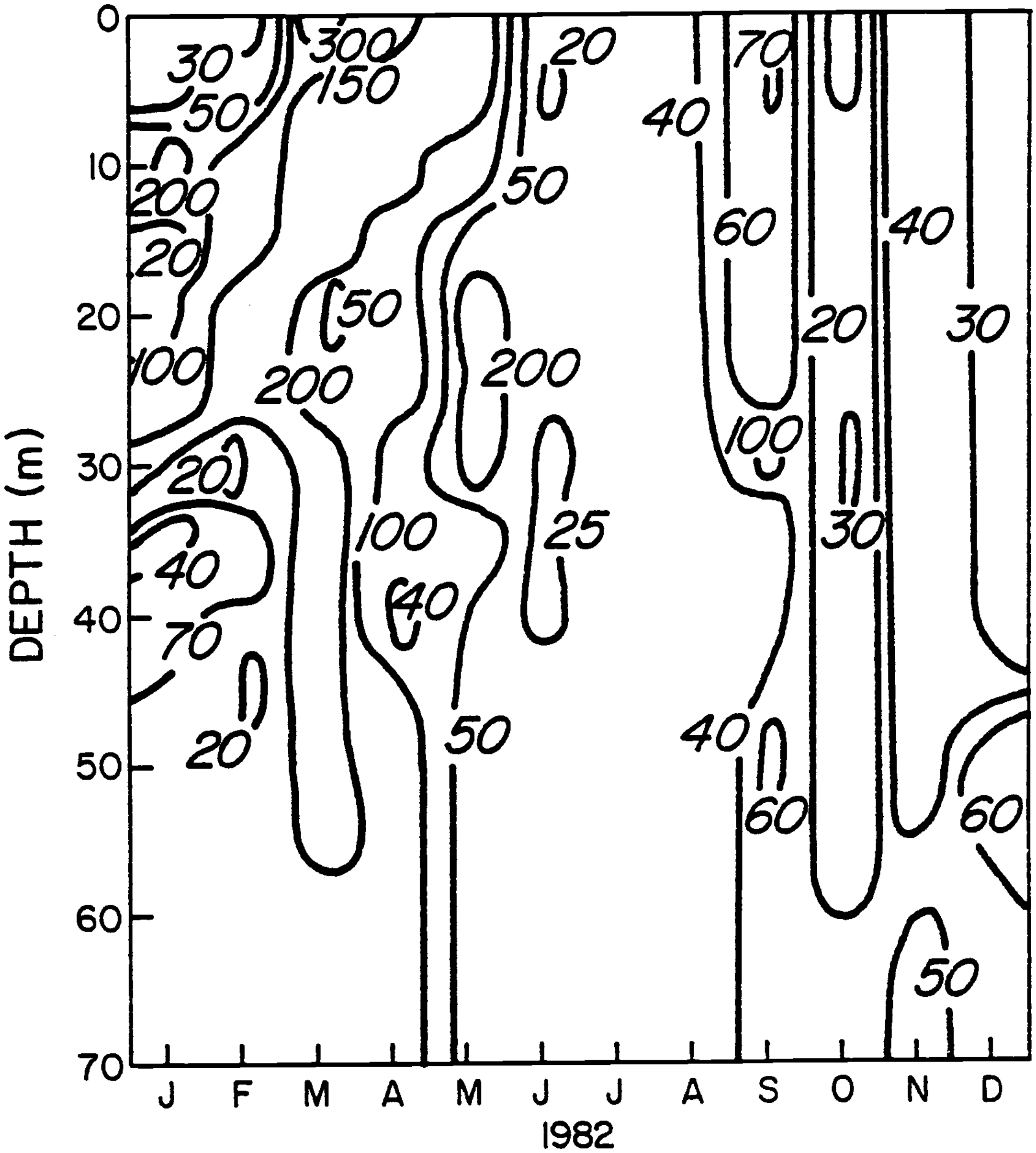


Figure 17. Chronological distribution of isopleths of total dissolved solids (mg/l) in Lago Rupanco.

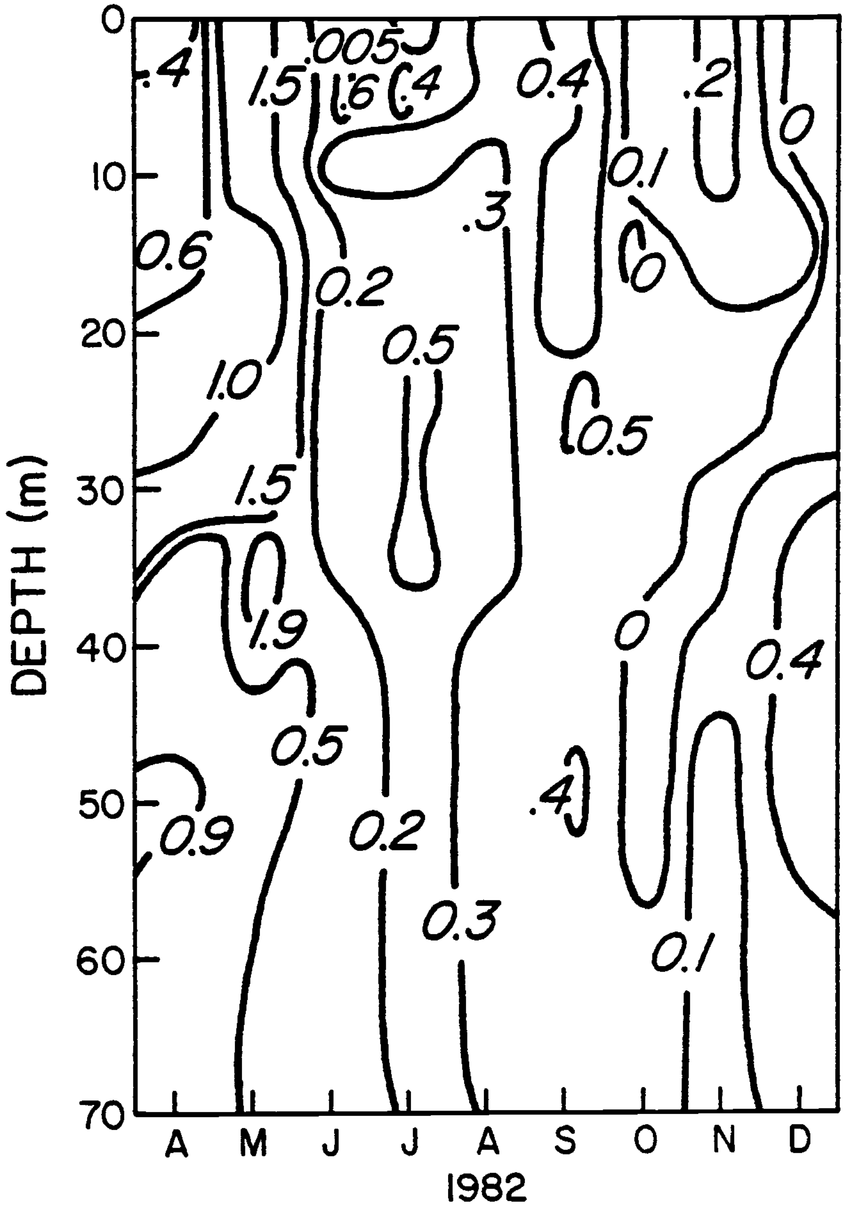


Figure 18. Chronological distribution of isopleths of total suspended solids (mg/l) in Lago Rupanco.

represented the organic matter (Boyd, 1979). This fraction was very difficult to determine in this study because the differences in weight were very slight except during the winter time. From this it could be assumed that most of the particulate matter of Lago Rupanco was organic matter, except in the surface layers during the winter.

PHYTOPLANKTON, SPECIES COMPOSITION AND ABUNDANCE

A total of eighty four taxa were identified in samples taken from Lago Rupanco. In Table 2, the general taxonomic list is presented together with the monthly distribution in abundance. Two classes were best represented, the Chlorophyceae by 38 species and the Bacillariophyceae by 29 species. *Botryococcus braunii* and *Sphaerocystis schroeteri* were the most abundant green algae, followed by *Staurastrum tetracerum*, *Dictyosphaerium ehrenbergianum* and *Monoraphidium contortum*. The most abundant diatoms were *Melosira granulata* followed by *Rhizosolenia eriensis*, *Synedra ulna* and *Cyclotella meneghiniana*. The Chrysophyceae was represented by 2 species, *Dinobryon divergens* being the dominant one. Among the 3 species of Dinophyceae, *Peridinium cinctum* was the most frequent species. Eight species of Cyanophyceae, 1 Cryptophyceae and 3 Euglenophyceae were present occasionally with a frequency equal to or less than 7%.

Table 2. List of monthly distribution in abundance of phytoplankton species collected in Lago Rupanco 1981-1982. The relative density is given by the symbols:

VA (Very abundant, 61 to 100% frequency)
A (Abundant, between 41 to 60%)
C (Common, between 16 and 40%)
r (rare, between 1 and 15%)
x (present occassionally, single specimen)
- (absent)

| | 1981 | | | | | | 1982 | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | J | A | S | O | N | D | J | F | M | A | M | J | J | A | S | O | N | D |
| CYANOPHYCEAE | | | | | | | | | | | | | | | | | | |
| *Chroococcus minutus* | - | - | - | - | - | - | - | - | - | - | x | - | - | - | - | - | - | - |
| *Microcystis aeruginosa* | - | - | - | - | - | - | - | - | r | - | - | - | - | - | - | - | - | x |
| *Rhabdoderma lineare* | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | x | x |
| *Anabaena sp.* | - | x | - | - | - | - | - | x | r | r | - | - | - | - | - | - | - | - |
| *Rhaphidiopsis curvata* | - | - | - | - | - | - | - | - | - | - | x | x | - | - | x | - | - | - |
| *Oscillatoria curviceps* | x | x | - | - | - | - | - | - | x | - | - | - | - | - | - | - | - | - |
| *O. limosa* | - | - | - | - | - | - | - | - | - | - | - | - | - | x | - | - | - | - |
| *Spirulina meneghiniana* | x | - | x | - | - | - | - | - | - | - | - | - | - | - | x | - | - | - |
| CRYPTOPHYCEAE | | | | | | | | | | | | | | | | | | |
| *Rhodomonas ovalis* | - | - | - | - | - | x | - | x | x | x | x | r | x | - | x | r | r | x |

Table 2. Continued

| | 1981 | | | | | | 1982 | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | J | A | S | O | N | D | J | F | M | A | M | J | J | A | S | O | N | D |
| CHRYSOPHYCEAE | | | | | | | | | | | | | | | | | | |
| <u>Dinobryon divergens</u> | r | r | r | r | r | A | A | VA | A | C | C | r | x | x | x | x | r | C |
| <u>Mallomonas sp.</u> | - | - | - | - | - | - | - | - | - | x | - | - | - | - | - | - | - | - |
| DINOPHYCEAE | | | | | | | | | | | | | | | | | | |
| <u>Peridinium sp.</u> | x | x | - | - | x | - | x | x | x | x | x | - | - | - | - | - | x | x |
| <u>P. cinctum</u> | x | x | - | - | x | r | r | r | r | x | x | x | - | - | - | x | x | r |
| <u>Gymnodinium fuscum</u> | - | - | x | x | r | x | x | x | x | - | - | - | - | - | - | - | x | x |
| EUGLENOPHYCEAE | | | | | | | | | | | | | | | | | | |
| <u>Trachelomonas spinulosa</u> | - | - | - | - | - | - | x | - | - | - | - | - | - | - | - | - | - | x |
| <u>T. volvocina</u> | x | - | - | - | - | x | x | x | x | x | - | - | - | - | - | - | - | x |
| <u>T. sydneyensis</u> | - | - | - | - | - | - | x | - | - | - | - | - | - | - | - | - | - | - |
| BACILLARIOPHYCEAE | | | | | | | | | | | | | | | | | | |
| <u>Cyclotella meneghiniana</u> | x | r | x | x | r | x | x | x | x | - | x | r | r | r | r | r | r | r |

Table 2. Continued

| | 1981 | | | | | | 1982 | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | J | A | S | O | N | D | J | F | M | A | M | J | J | A | S | O | N | D |
| *Stephanodiscus astraea* | - | - | - | x | x | x | x | x | x | x | x | r | r | r | r | r | r | x |
| *Melosira granulata* | r | r | x | r | A | r | A | C | r | r | C | C | A | VA | C | C | r | x |
| *M. italica* | - | - | - | - | x | x | x | x | x | x | r | r | r | r | x | x | x | x |
| *M. hustedti* | - | - | - | - | - | - | - | x | x | - | - | - | x | x | - | - | - | - |
| *M. pseudogranulata* | - | - | - | - | - | - | - | x | - | x | - | - | - | - | - | - | - | - |
| *Rhizosolenia eriensis* | C | r | r | r | r | r | r | r | r | r | r | C | r | r | r | r | x | x |
| *Asterionella formosa* | x | - | - | - | x | - | x | - | - | - | x | - | - | - | - | - | - | - |
| *Ceratoneis arcus* | - | - | - | - | x | x | - | - | - | - | - | - | - | - | - | - | x | x |
| *Diatoma hiemale* | x | - | - | - | x | - | - | - | x | - | - | - | - | - | - | - | - | - |
| *Fragilaria construens* | x | x | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - |
| *Fragilaria sp.* | - | - | - | - | - | - | x | r | x | x | r | x | r | x | x | x | x | x |
| *Synedra ulna* var. *ulna* | x | r | r | r | r | r | r | x | x | x | x | x | r | r | r | C | r | r |
| *S. ulna* var *oxyrhynchus* | - | x | - | x | x | - | - | - | - | - | x | - | - | - | - | - | - | - |
| *Achnanthes sp.* | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | x | x |

Table 2. Continued

| | 1981 | | | | | | 1982 | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | J | A | S | O | N | D | J | F | M | A | M | J | J | A | S | O | N | D |
| *A. clevei* | x | x | x | x | x | x | x | x | x | x | x | x | x | x | x | - | - | - |
| *Amphora* aff. *fontinalis* | - | - | - | - | x | - | x | - | - | x | x | - | x | - | - | - | x | x |
| *Cymbella cistula* | - | - | - | x | x | - | x | x | x | - | x | x | x | x | x | x | x | x |
| *Diploneis* aff. *subovalis* | - | - | - | - | - | x | x | x | x | x | x | x | x | - | x | x | x | x |
| *Gomphonema sp.* | x | - | - | x | - | - | x | - | - | - | - | - | x | x | x | x | x | x |
| *Gyrosigma sp.* | - | - | - | - | - | - | x | x | x | x | - | - | x | x | - | - | x | - |
| *Navicula sp. 1* | x | x | x | x | x | x | x | x | x | x | x | x | x | x | x | x | x | x |
| *Navicula sp. 2* | - | - | - | x | x | x | x | x | x | x | x | x | x | x | x | x | x | x |
| *Pinnularia sp.* | - | - | - | - | x | - | x | x | x | - | - | x | x | x | - | - | x | - |
| *Nitzchia sp.* | x | - | - | - | x | - | x | - | - | - | x | - | - | - | - | - | x | x |
| *Epithemia sp.* | - | - | - | - | - | - | - | - | - | - | - | x | - | - | - | - | - | - |
| *Eunotia sp.* | x | x | - | - | - | x | x | - | x | - | - | - | - | - | - | - | - | - |
| *Stauroneis sp.* | - | x | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | x |
| *Pennatae* indet. | - | - | - | - | - | - | - | - | x | - | - | - | - | - | - | - | - | - |

Table 2. Continued

| | 1981 | | | | | | 1982 | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | J | A | S | O | N | D | J | F | M | A | M | J | J | A | S | O | N | D |
| CHLOROPHYCEAE | | | | | | | | | | | | | | | | | | |
| *Eudorina elegans* | r | x | x | - | - | - | - | - | - | - | - | r | x | x | x | x | - | - |
| *Chlamydocapsa bacillus* | x | x | - | x | x | - | x | x | x | x | r | r | - | - | x | x | x | x |
| *C. planctonica* | - | - | - | - | - | - | - | - | x | x | - | - | - | - | x | x | - | - |
| *Tetraspora sp.* | - | - | - | x | - | - | - | - | x | r | r | r | - | - | - | - | - | - |
| *Gloeocystis sp.* | - | - | x | - | x | r | r | r | x | x | x | - | - | - | x | x | x | x |
| *Paulschulzia tenera* | x | x | - | - | - | - | - | - | - | - | r | x | x | - | - | - | x | - |
| *Tetraedron minimum* | r | r | x | x | x | x | - | - | - | - | - | - | - | - | - | - | - | - |
| *Sphaerocystis sp.* | - | - | - | - | - | x | - | - | - | - | - | r | r | r | r | r | r | r |
| *S. schroeteri* | x | r | x | - | x | x | - | x | - | x | x | r | r | x | x | r | r | A |
| *Chlorella sp.* | - | - | x | - | - | - | - | x | x | x | - | - | - | x | x | x | - | r |
| *Oocystis lacustris* | x | r | x | x | x | r | r | r | x | x | x | r | x | x | x | x | x | x |
| *O. parva* | - | - | - | - | - | - | - | - | - | - | - | x | - | - | x | - | x | - |
| *Nephrocytium sp.* | - | - | - | - | - | - | - | - | - | - | x | - | - | - | - | - | - | x |

Table 2. Continued

| | 1981 | | | | | | 1982 | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | J | A | S | O | N | D | J | F | M | A | M | J | J | A | S | O | N | D |
| N. limneticum | - | - | x | x | x | x | x | x | x | x | x | - | - | - | x | - | - | - |
| Kirchneriella sp. | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | x | - | x |
| K. lunaris | - | x | - | - | - | - | - | - | - | - | - | r | - | x | - | r | x | - |
| Ankistrodesmus sp. | x | x | x | x | x | - | - | - | - | - | - | - | x | - | - | - | - | - |
| Monoraphidium contorum | C | C | C | C | C | C | r | x | r | r | x | r | r | r | r | r | r | r |
| Micractinium sp. | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | x |
| Botryococcus braunii | C | C | A | A | r | r | - | r | x | C | C | - | - | - | - | - | A | r |
| Dictyosphaerium ehrenbergianum | - | - | r | r | r | r | r | r | r | r | x | r | r | r | r | r | x | x |
| D. pulchellum | - | x | r | r | x | x | r | r | r | r | r | x | r | - | r | r | x | x |
| Coelastrum cubicum | - | x | x | r | x | r | x | x | x | - | x | - | - | - | - | x | - | x |
| Elakatothrix gelatinosa | r | r | x | x | r | x | x | x | x | x | x | x | x | x | x | r | r | x |
| Ancylonema sp. | x | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - |
| Cosmarium sp. 1 | - | x | x | x | x | x | x | - | - | x | x | r | r | x | x | x | x | - |
| C. leave var octangulare | - | - | - | x | - | - | - | - | - | - | - | - | - | - | - | - | - | - |

Table 2. Continued

| | 1981 | | | | | | 1982 | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | J | A | S | O | N | D | J | F | M | A | M | J | J | A | S | O | N | D |
| Cosmarium sp. 2 | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | x |
| Staurodesmus sp. | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | x | - | - |
| S. patens | - | x | - | - | x | x | - | x | x | x | x | x | x | x | x | x | x | x |
| Staurastrum tetracerum | - | x | x | x | x | x | x | r | r | r | r | r | r | r | r | r | x | x |
| S. gracile | x | x | x | x | x | x | x | x | x | x | r | x | x | x | x | x | x | x |
| S. rotula | x | x | - | - | - | x | x | x | x | x | x | x | x | x | x | x | x | x |
| S. muticum | - | - | - | - | - | - | - | - | - | x | x | - | x | x | - | x | x | x |
| Closterium acutum var variabili | r | r | r | x | x | x | x | x | x | x | x | r | x | x | x | x | - | x |
| Closterium sp. | - | - | - | - | - | - | x | - | - | - | - | - | - | - | - | - | - | - |
| Radiofilum sp. | r | r | x | r | x | r | - | - | x | x | x | - | x | - | - | - | - | - |
| Ulothrix sp. | - | - | - | x | - | x | - | r | x | x | - | - | x | x | x | - | x | - |

The green algae had a high relative abundance throughout the year, ranging between 8.63% in January, 56.80% in May and 93.31% in September. The abundance of diatoms was also high, it ranged between 5.35% in December and 79.91% in August. The Chrysophyceae had a minimum relative abundance of 0.09% in August-September and maximum of 62.60% in February. The relative abundance of Dinophyceae ranged from the minimal winter values of 0.0% to the highest of 1.26-2.75% during the spring and summer time. The blue greens had a maximum relative abundance in March with 6.26%, 0.3-0.8% in July-August, and were absent in spring. The Cryptophyceae reached the relative abundance of 2.54% in October, the other values ranged from 0.3 to 1.5% to being absent in the winter. The relative abundance of Euglenophyceae was very low, it did not reach 0.5% (Figure 19).

## PHYTOPLANKTON, VERTICAL DISTRIBUTION

The variation in vertical distribution of the more abundant species of phytoplankton was recorded monthly (Figure 20-25). During the winter (July-September) of 1981, *Dinobryon divergens* showed slight differences in numbers between the surface and the deeper layers with a tendency to reduced numbers below 20 m by the end of the season. The diatom, *Rhizosolenia eriensis* was more abundant between 5 and 15 m and the green algae *Monoraphidium contortum* and

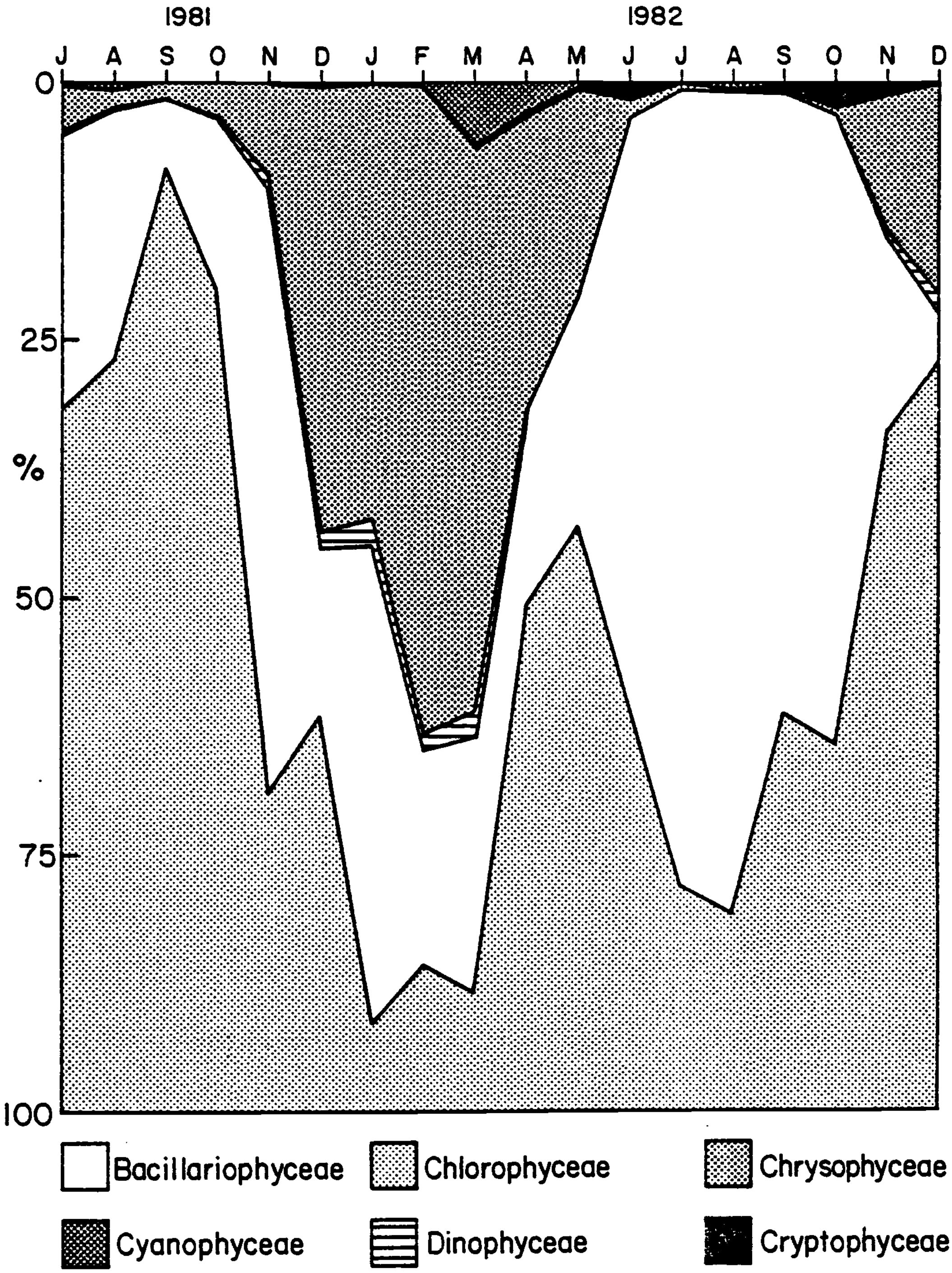


Figure 19. Relative abundance of each algal class by the month in Lago Rupanco.

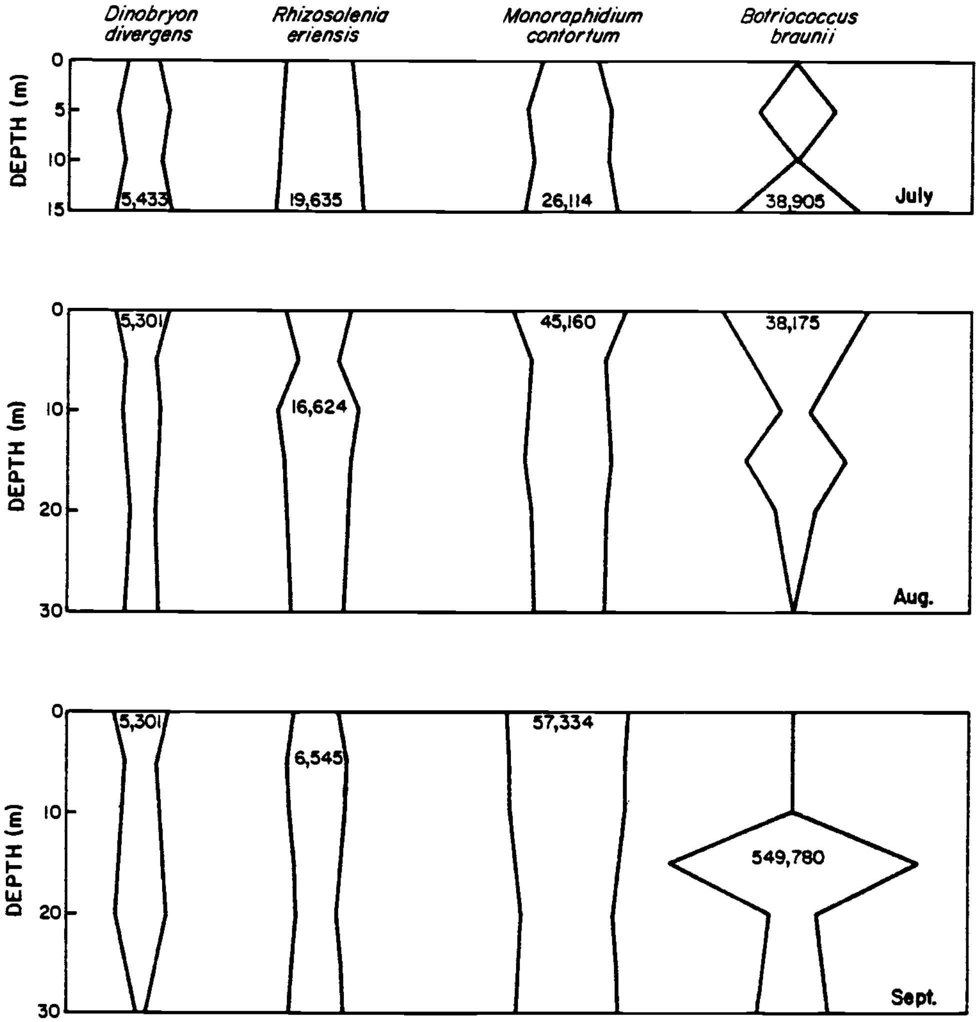


Figure 20. Vertical distribution of some phytoplankters during winter 1981 in Lago Rupanco.

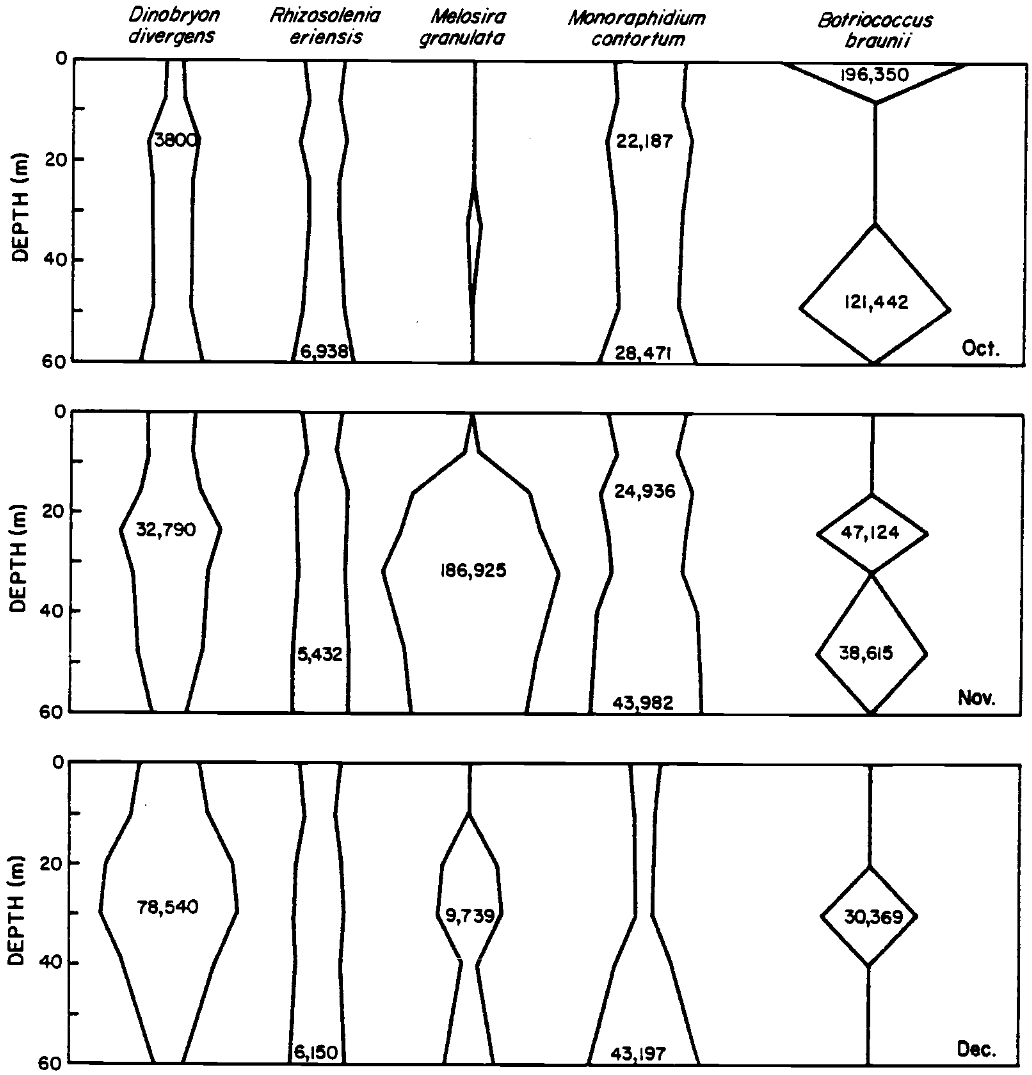


Figure 21. Vertical distribution of some phytoplankters during spring 1981 in Lago Rupanco.

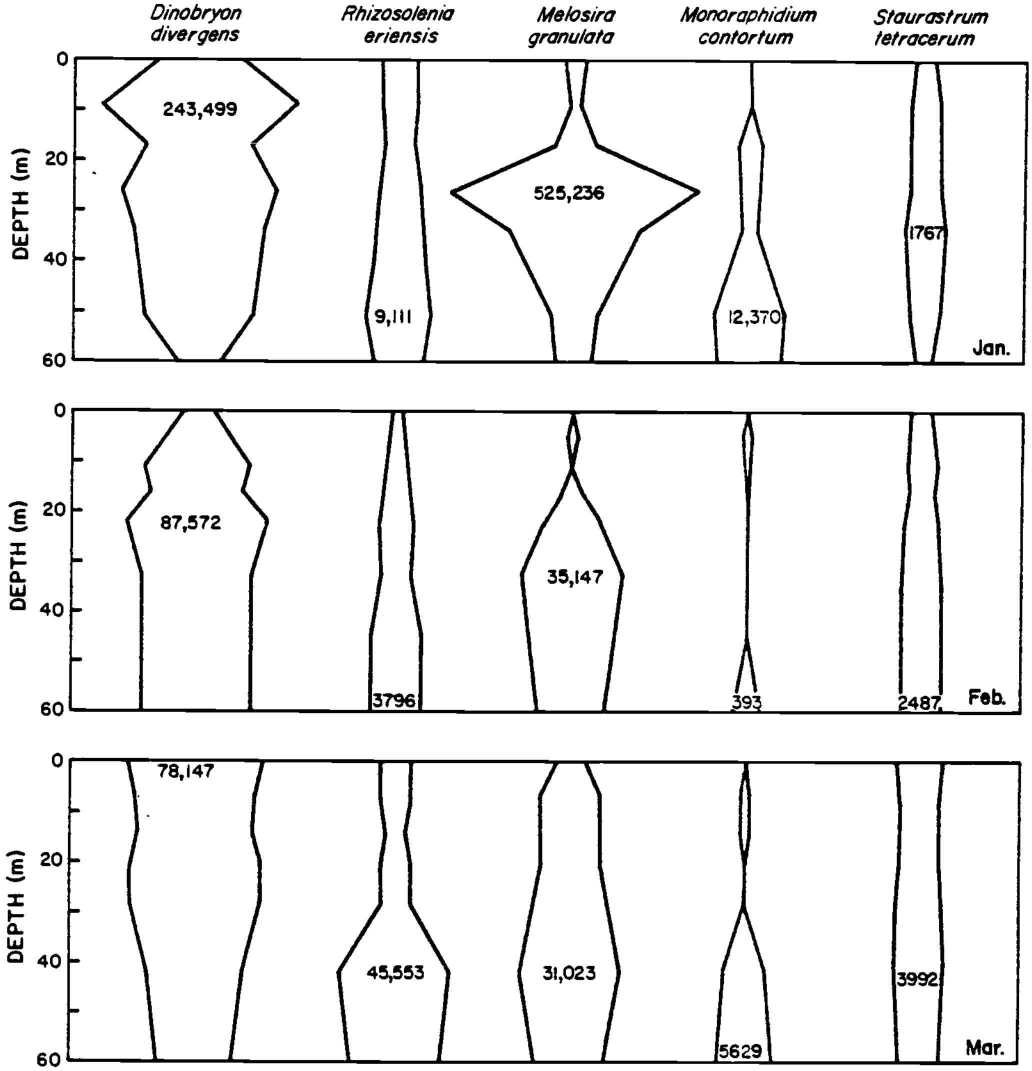


Figure 22. Vertical distribution of some phytoplankters during summer 1982 in Lago Rupanco.

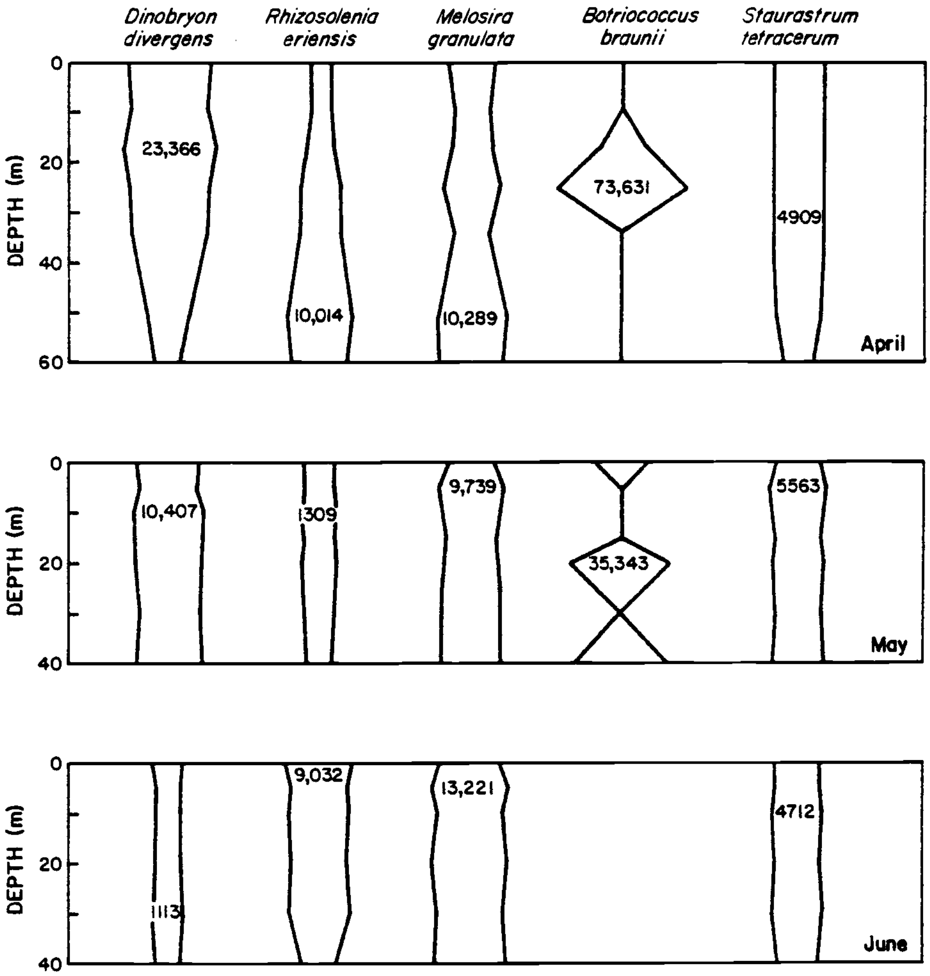


Figure 23. Vertical distribution of some phytoplankters during autumn 1982 in Lago Rupanco.

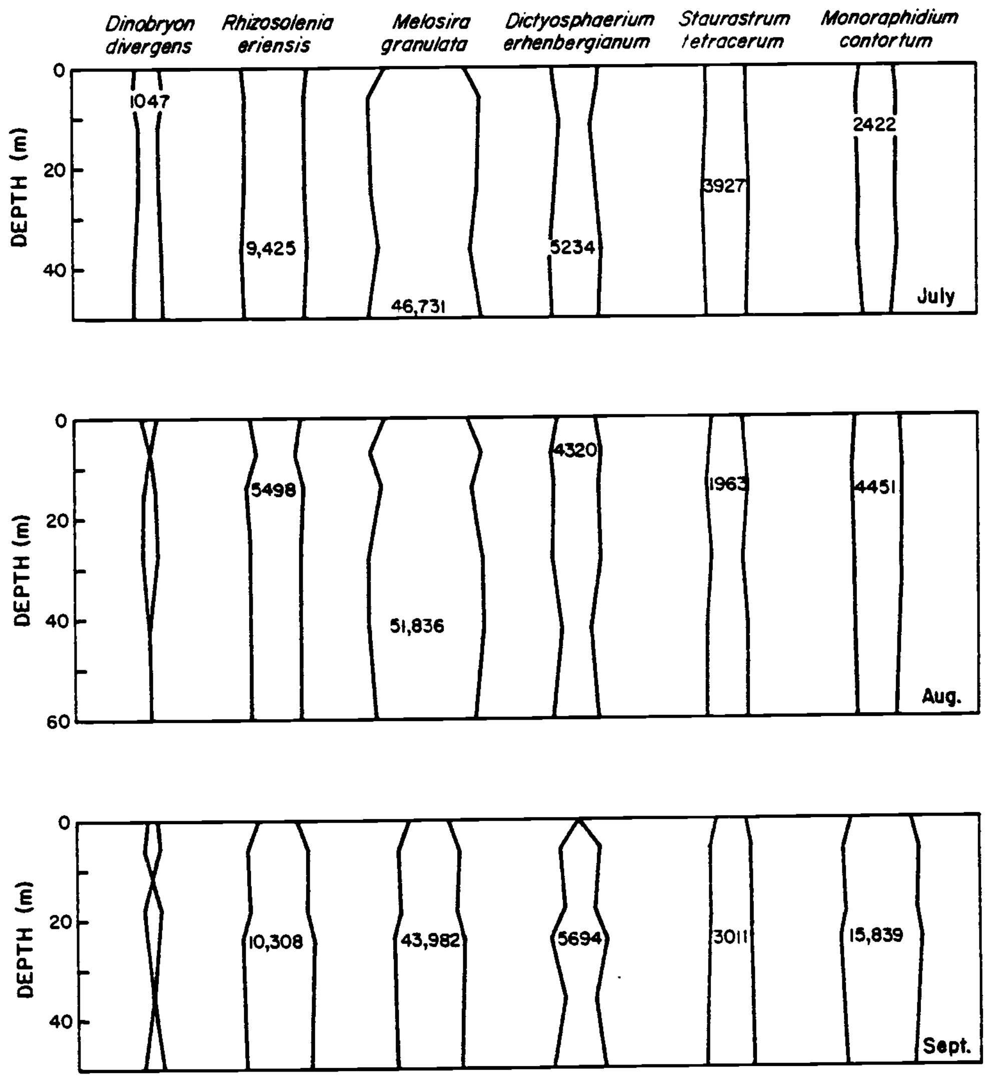


Figure 24. Vertical distribution of some phytoplankters during winter 1982 in Lago Rupanco.

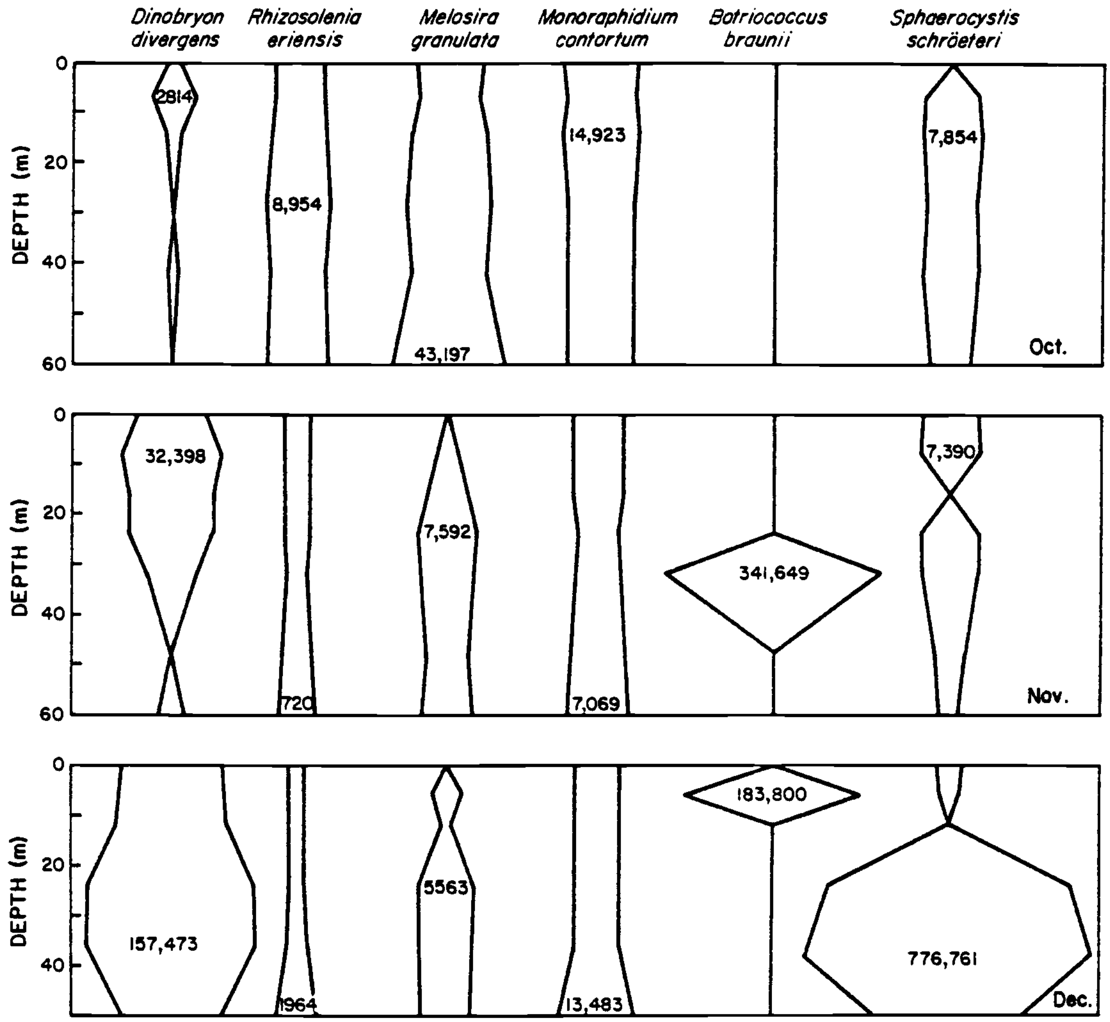


Figure 25. Vertical distribution of some phytoplankters during spring 1982 in Lago Rupanco.

*Botryococcus braunii* were distributed from 0 to 15 m (Figure 20). In the winter of 1982, the behavior of these 4 species was very similar but besides these species another diatom and 2 additional green algae reached high abundance levels: *Melosira granulata* dominated with its greatest abundance from 5 to 50 m, and *Dictyosphaerium ehrenbergianum* with *Staurastrum tetracerum* were more abundant in the stratum from 10 to 35 m (Figure 24).

In the spring time (October-December) of both years, *Dinobryon divergens* moved from the surface layers to 10 and 35 m depth and increased significantly in abundance in the deeper layers by the end of the season. *Rhizosolenia eriensis* decreased through this season and the highest concentrations were found below 30 m. *Melosira granulata* dominated during part of this season with an abundance at and below 30 m greater than in the surface layers. *Monoraphidium contortum*, *Botryococcus braunii* and *Sphaerocystis schroeteri* were more abundant from 0-40 m (Figures 21 and 25).

During the summer (January-March), *Dinobryon divergens* dominated in the surface stratum from 0 to 25 m. *Rhizosolenia eriensis* showed a greater abundance below 40 m than above 40 m and *Melosira granulata* had a peak at 25 m in January and after that was more abundant below 30 m. The green algae at this time had a very low abundance and also occurred around the 40 m depth (Figures 22).

In the fall (April-June), Dinobryon divergens decreased in numbers, its abundance being greater between 10 to 20 m depth. Diatoms also decreased in abundance in April and were located at 50 m. But in May and June these algae were found in the surface layers in increasing abundance. The Chlorophyceae increased in abundance in the stratum between 20-30 m in April and May and became concentrated in the surface layers with lower abundance occurring by the end of the season (Figure 23).

PHYTOPLANKTON, ANNUAL CYCLE AND SEASONAL VARIATIONS

Cell numbers often are not representative of true biomass because of considerable variation in sizes of cells among algal species (Vollenweider, 1974). Therefore, it was considered appropriate to calculate the cell volume of the most abundant species as a means of estimating the biomass of each one (Table 3). The relative biomass of the main groups of the phytoplankton showed a general annual pattern similar to that of the relative cell abundances (Figure 26). But this pattern showed marked fluctuations in the less abundant groups. The Dinophyceae, for example, had a relatively high biomass compared with the number of cells due to the large volume of Peridinium cinctum.

During the winter, the Bacillariophyceae was the dominant group with a biomass of 400.42 μg/l in 1981 and 1,528.99 μg/l in 1982. These values corresponded to a

Table 3. Calculated mean volumes of the most abundant species of Lago Rupanco.

| Species | Volume ($\mu m^3$) |
|---|---|
| *Anabaena* sp. | 230 |
| *Oscillatoria curviceps* | 427 |
| *Raphidiopsis curvata* | 3250 |
| *Rhodomonas ovalis* | 150 |
| *Dinobryon divergens* | 960 |
| *Peridinium cinctum* | 21160 |
| *Gymnodinium fuscum* | 2160 |
| *Cyclotella meneghiniana* | 147 |
| *Melosira granulata* | 6760 |
| *Rhizosolenia eriensis* | 1250 |
| *Synedra ulna* var *ulna* | 2055 |
| *Sphaerocystis schroeteri* | 14 |
| *Monoraphidium contortum* | 40 |
| *Botryococcus braunii* | 500 |
| *Dictyosphaerium ehrenbergianum* | 54 |
| *Staurastrum tetracerum* | 1350 |

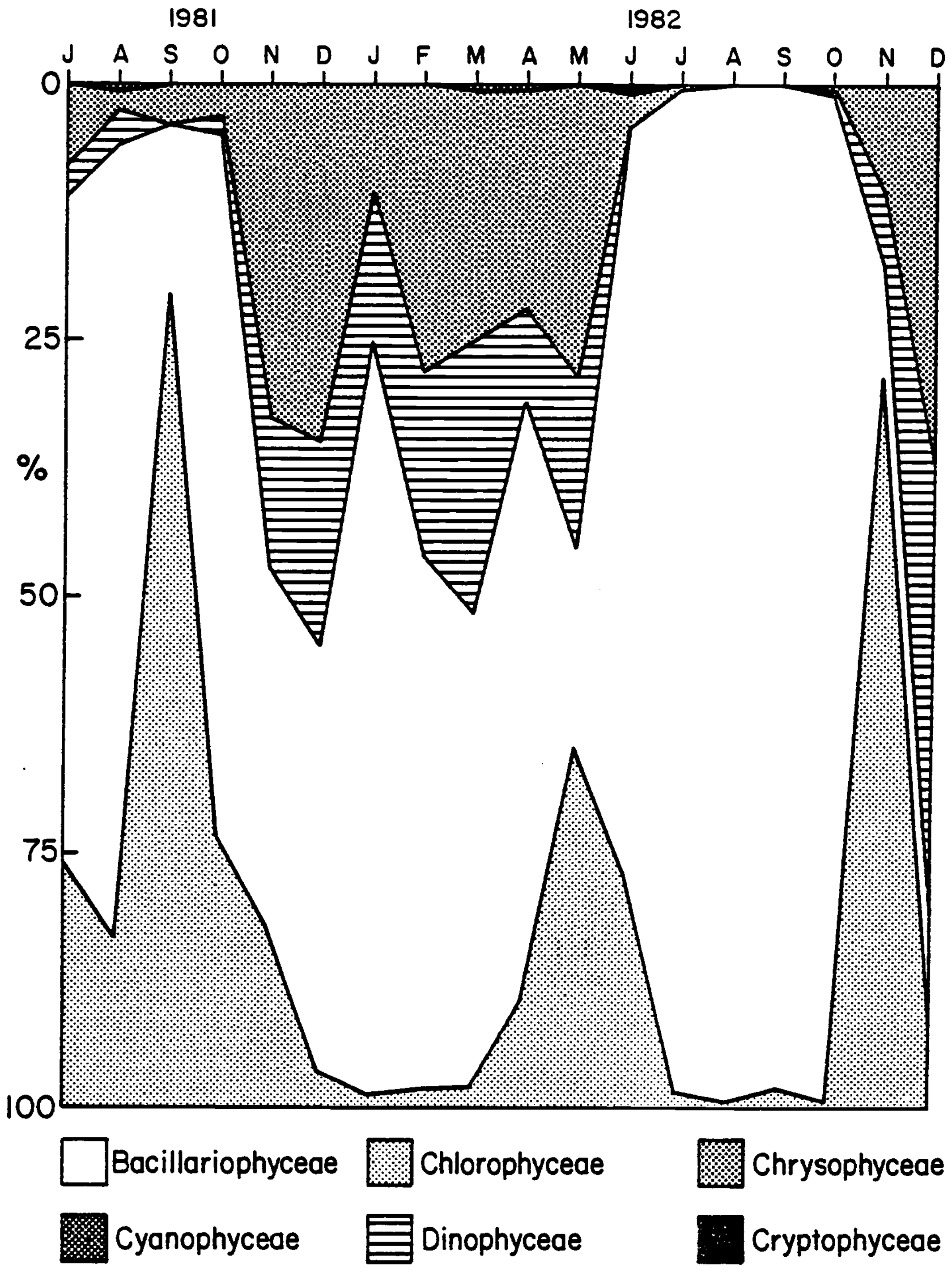


Figure 26. Relative biomass of each algal class by the month in Lago Rupanco.

relative biomass of 77.52-99.62%, respectively. At the end of this season in 1981, as diatoms decreased, the green algae increased reaching 79.52% of the total biomass. In 1982, diatoms dominated during the whole winter. Considering the biovolume of the 4 most abundant species, Melosira granulata, Rhizosolenia eriensis, Synedra ulna and Cyclotella meneghiniana, a winter time bloom occurred with a maximum biomass of 1.7 $mm^3/l$ (Figure 27-A). The highest concentrations were evenly distributed in the water column from 0-60 m (Figure 27-B). This bloom was primarily composed of Melosira granulata (Figure 27-C). The maximum values for the other 3 species were below 0.25 $mm^3/l$. In 1982 the Chlorophyceae showed low levels of relative biomass, between 0.1 and 1.5%. Considering the 5 main species of this class: Botryococcus braunii, Staurastrum tetracerum, Monoraphidium contortum, Sphaerocystis schroeteri and Dictyosphaerium ehrenbergianum, the biovolume ranged from 0.01 to 0.03 $mm^3/l$ (Figure 28-A). The vertical distribution of this biovolume was approximately uniform from 0 to 60 m. At the end of the season the highest values were located at the intermediate level (20 to 40 m) (Figure 28-B). Staurastrum tetracerum (Desmidiaceae) was the species involved during winter (Figure 28-C). At the same time the biomass of Chrysophyceae was very low and was composed of Dinobryon divergens (Figure 29-A). The biovolume values were below 0.01 $mm^3/l$ and were evenly

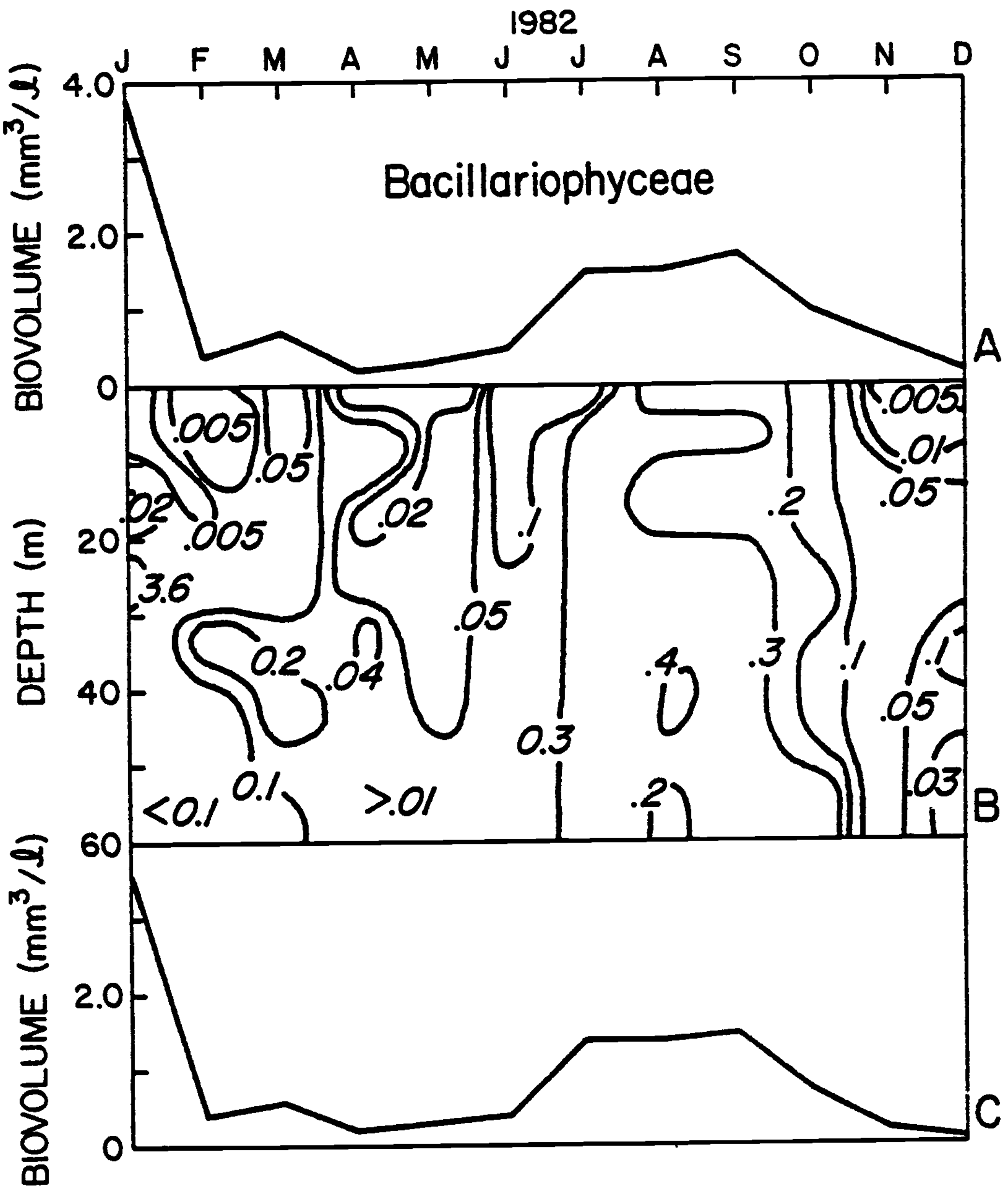


Figure 27. Chronological distribution of biovolume of the (A and B) Bacillariophyceae. (C) *Melosira granulata*.

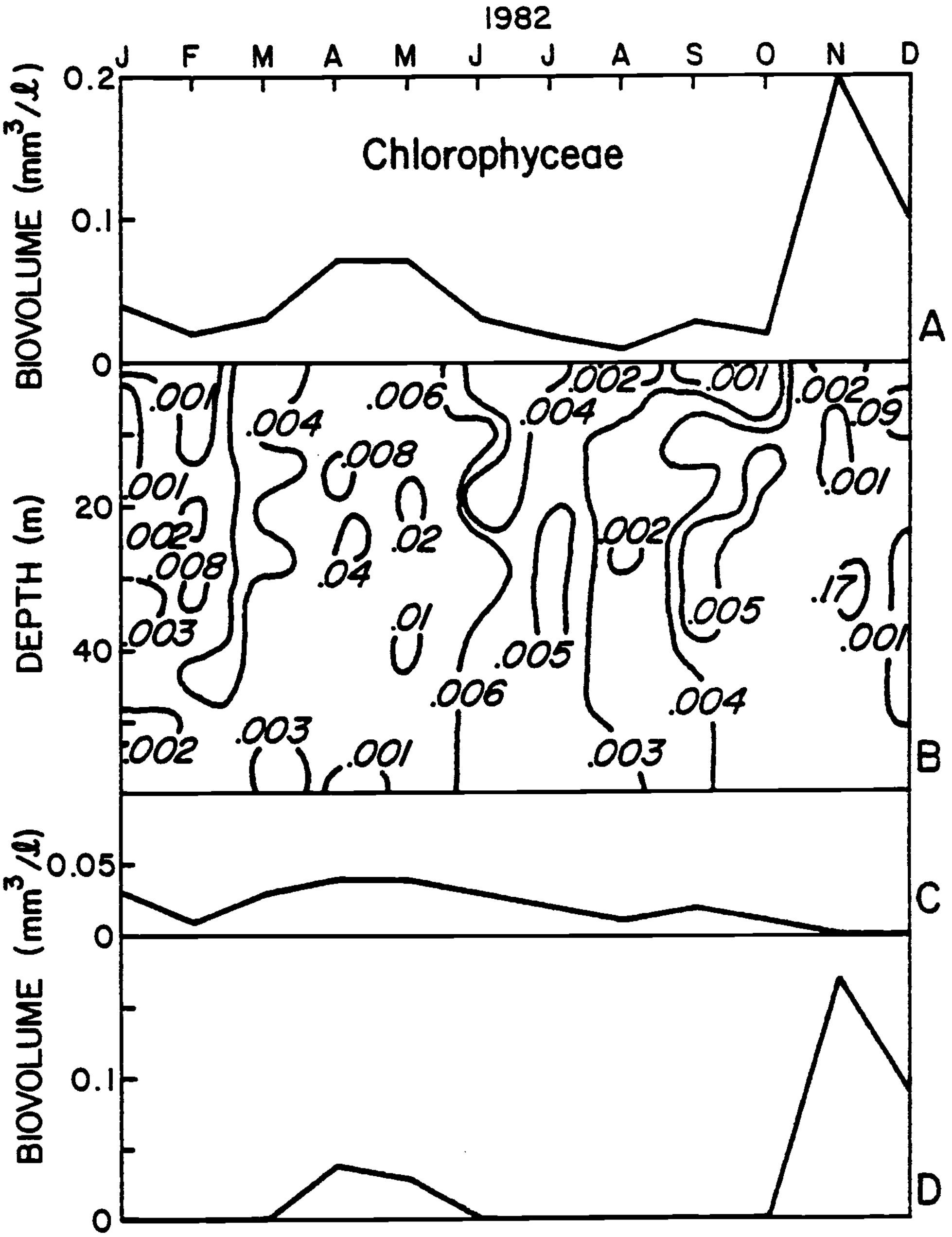


Figure 28. Chronological distribution of biovolume of the (A and B) Chlorophyceae. (C) Staurastrum tetracerum (D) Botryococcus braunii.

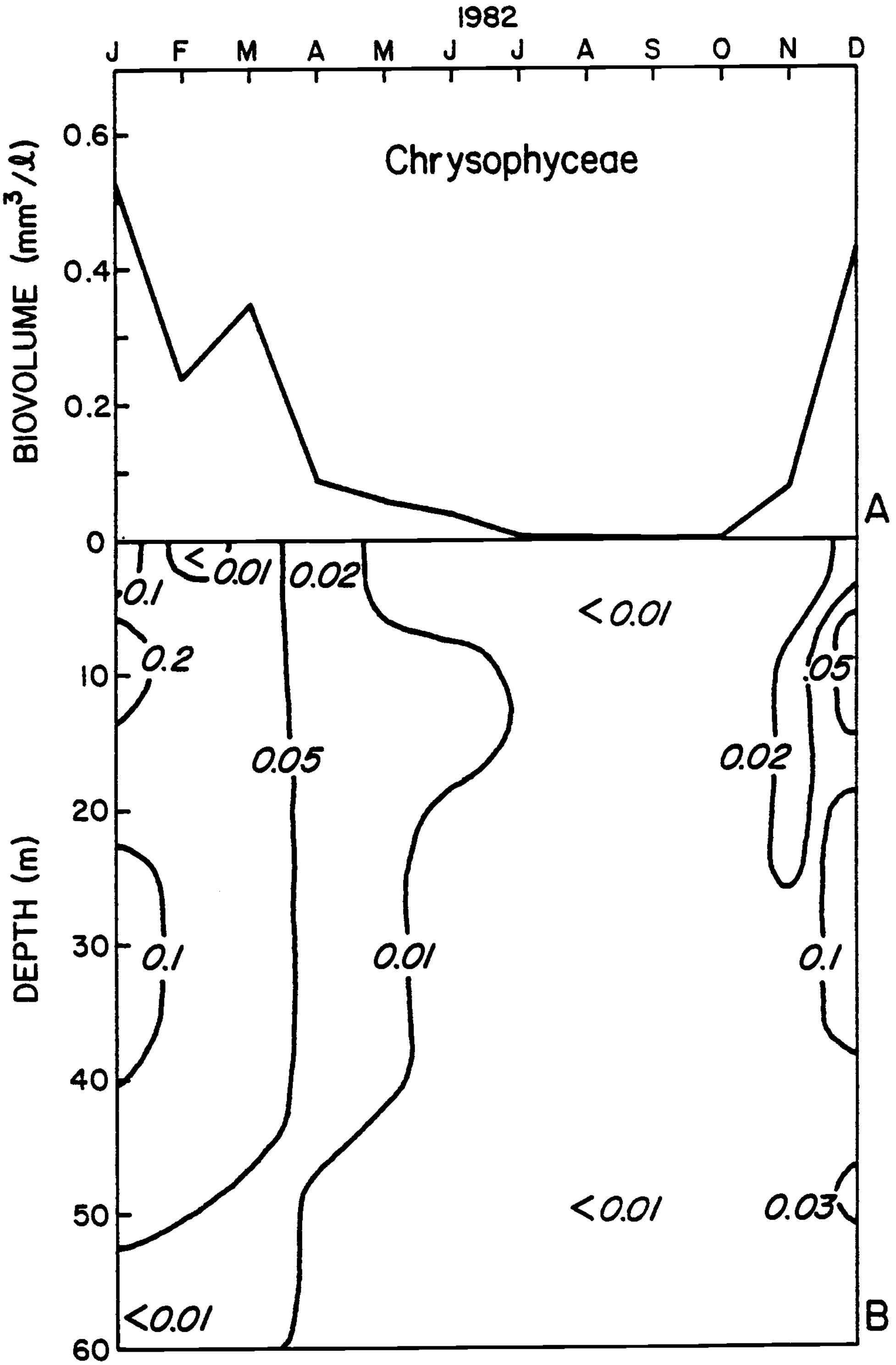


Figure 29. Chronological distribution of biovolume of the (A and B) Chrysophyceae: Dinobryon divergens.

distributed in the water column (Figure 29-B). In 1981 the relative biomass of D. divergens ranged from 1.9 to 7.6% and in 1982 from 0.02 to 0.2%. During the winter of 1981 the relative biomass of Dinohyceae varied from 3.4% to zero by the end of the winter and in 1982 they were absent. The other algal classes were present occasionally and the biomass ranged between 0.001 and 4.0% (Figure 26).

In the spring, the biomass of Bacillariophyceae decreased, this was more evident in 1982 than in 1981. This decrease from a maximum of 981.77 μg/l, 98.54% of the total biomass, in October to a minimum of 117.85 μg/l (9.67%) in December, was accompanied by the development of the bloom of Chlorophyceae (Figure 26). The same relationship occurred in 1981 when the green algae had a bloom in early spring. The decline in the biovolume of the 4 main species of the Diatoms which occurred throughout the spring, was more evident in the upper 20 m whereas and the greater concentrations occurred between 20 and 40 m (Figure 27-A and B). Again a population of Melosira granulata (Figure 27-C) exhibited the same pattern. The spring bloom of Chlorophyceae produced a biomass of 293.11 μg/l (79.52%) in 1981 and 577.89 μg/l (71.42%) in 1982 (Figure 26). The composite biovolume of the 5 most abundant species of green algae is presented in Figure 28-A. The maximum biomass of this group at this season was observed at 32 m (Figure 28-B). The species involved in this peak was Botryococcus braunii (Figure 28-D). At the end of spring, the biomass of Chrysophyceae and Dinophyceae increased from the minimal levels in winter to 35.99 and 45.23%, respectively (Figure 26). The vertical distribution of Dinobryon divergens biovolume showed the greatest concentrations between 20 and 40 m (Figure 29-A and B). At this time, Peridinium cinctum had the major biomass in the upper stratum between 0 and 15 m (Figure 30-A and B).

During the summer time the dominant taxa or taxon were not as easily determined as in the other seasons. The most numerous member of the Chrysophyceae was Dinobryon divergens with 41% abundance (Figure 19). But its average biomass was only ca. 20% (Figure 26). The diatom Melosira granulata was the subdominant species in number of cells but had the greater biomass of over 50% (Figure 26). Dinophyceae also were represented rarely, but Peridinium cinctum was the species with highest volume, reaching a biomass between 15 to 25% of the total (Figure 26). The Chlorophyceae were present with a low biomass ranging between 66.51 and 16.15 µg/l (1.31 to 1.94%). The Cyanophyceae plus Cryptophyceae relative biomass ranged from 0.01 to 0.45% (Figure 26). The biovolume of the Bacillariophyceae reached a maximum of 3.8 $mm^3/l$ in January (Figure 27-A). This concentration occurred at 26 m and in general, the biomass was concentrated in the stratum from 20 to 40 m while the surface layers were poor in diatoms (Figure 27-B). The species that contributed to

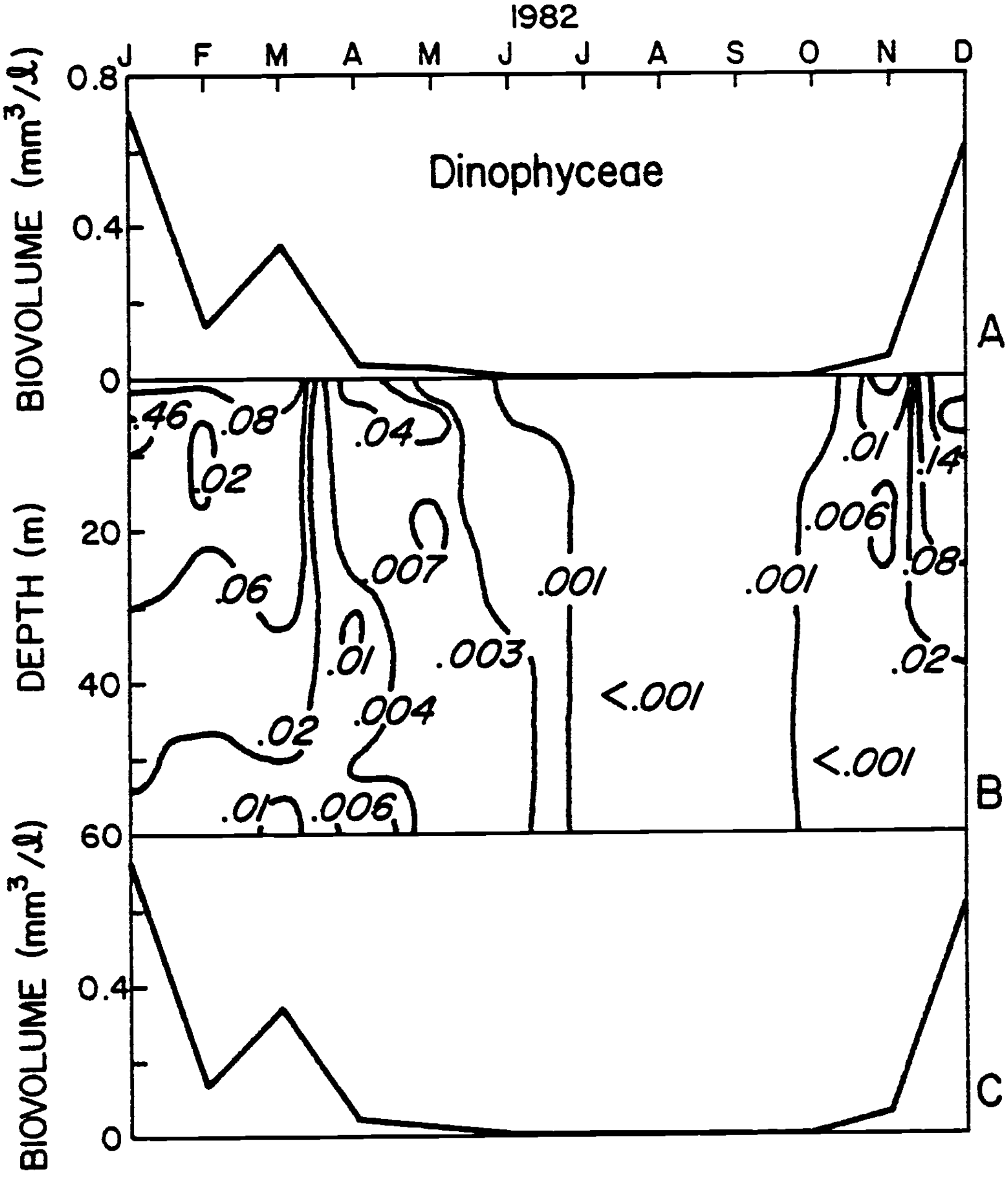


Figure 30. Chronological distribution of biovolume of the (A and B) Dinophyceae. (C) Peridinium cinctum.

the peak was Melosira granulata (Figure 27-C). The biovolume of Chlorophyceae showed a smooth curve during the summer, with very low concentrations in all the water columns analyzed (Figure 28-A and B). The species present was a desmid, Staurastrum tetracerum (Figure 28-C). The biovolume of Chrysophyceae, represented by the species Dinobryon divergens showed its maximum biomass during the summer (Figure 29-A). This higher biomass was found in the surface layers at the beginning of the season but sank to the metalimnion by the end of the season (Figure 29-B). The large biovolume of Peridinium cinctum indicated that the Dinophyceae had an important biomass during the summer (Figure 30-A). The highest values occurred in the surface layers (Figure 30-B).

During autumn, the Bacillariophyceae maintained a relatively high biomass with a decline in May when the green algae reached their maximum concentration (Figure 26). The biovolume of the diatoms increased from the end of summer to the end of fall in the upper stratum (0 to 20 m) (Figure 27-A and B). The main species involved was Melosira granulata (Figure 27-C). The biomass of the Chlorophyceae was 69.53 μg/l (35.30%) (Figure 26). During the fall the biovolume increased very notably (Figure 28-A), between 20 and 40 depth (Figure 28-B). The dominant species in this bloom were Botryococcus braunii and Staurastrum tetracerum (Figures 28-C and D). The biovolume of the Chrysophyceae decreased from its summer maximum to the end of the fall (Figure 29-A). In the early fall the highest concentrations of Dinobryon divergens were close to the surface and by the end of the season, the values were lower and distributed evenly in the water column (Figure 29-B). The biomass of the dinoflagellate, Peridinium cinctum decreased during this season, reaching minimal values by the end of fall (Figure 30-A). The highest concentrations were recorded at the surface layers, 0 to 8 m (Figure 30-B). The biomass of Cyanophyceae and Cryptophycae, at this time, was very low, ranging from 0.04 to 0.52%.

# DISCUSSION

Lakes in the northern Hemisphere have been studied for many years from the Arctic to the subtropical and tropical regions (Hutchinson, 1957). The corresponding sequence in the southern Hemisphere is less well known. However, man's rapidly increasing demands for water and power are leading to new interest in research on the management of lotic and lentic waters in the southern Hemisphere.

The sequence of lake types from the Antarctic northward is as yet poorly defined. Lake Miers in Antarctica is permanently ice covered and undoubtedly amictic (Fish, 1970). The Swedish Limnological Expedition 1953-1954 to South America made brief surveys of many lakes, mainly within the Lagos Region of southern Chile. Nearly all the lakes studied were warm monomictic lakes (Hutchinson, 1957), except Lago Quillehue at 1,200 m in the Andean mountains which is dimictic (Thomasson, 1964). The lakes located east of the Andes are also warm monomictic, except Lake Frias (770 m above sea level) which is probably dimictic (Thomasson, 1964). The New Zealand lakes of the South Island provide another comparable region. The mild oceanic climate of New Zealand supports a large number of warm monomictic lakes (Jolly, 1968). In general, the field of limnology in the southern Hemisphere, mainly in the southern part of South America and New Zealand, is largely explored as yet, and the present study may be useful for comparing lakes at similar latitudes in the two hemispheres.

The southern lakes of Chile were considered by Loeffler (1960), to be warm monomictic lakes. Campos et al. (1974) confirmed that Lago Rinihue, a Chilean lake of the Lagos Region was of this type. The thermal characteristics of Lago Rupanco also conform to Loeffler's (1960) classification. The general morphometric features observed in the bathymetric chart place Lago Rupanco in type 28c of Hutchinson's (1957) classification. The average renewal time for Lago Rupanco is ca. 7.5 years. This average depends on the occurrence of maximum and minimum rainfall and melted snow which determine the high or low flow of the influent streams.

The physical and chemical parameters exhibited seasonal fluctuations due to high winter precipitation and spring-summer radiation. During the winter, the euphotic zone was restricted to 20-25 m depth with a transparency of 10 m. The water column was isothermic at 10 C and the percentage saturation of dissolved oxygen reached high values at that temperature. The carbon dioxide concentrations were low and bicarbonate decreased corresponding to high flow from tributaries and low photosynthesis. Ammonia and nitrate-nitrogen concentrations were greater in winter than in the spring Silica remained almost the same concentration but phosphate-phosphorous showed a marked decrease. Under these conditions the diatoms and some rare groups, such as the Cyanophyceae were present, the assumption being that phosphorous is the nutrient primarily responsible for the development of the latter group. In the spring, the limit of euphotic zone increased to 60 m and the surface layers showed a slow warming. This was followed by an increase in concentration of carbon dioxide and of phosphate-phosphorous and a decrease in the amount of silica and nitrogen-nutrients. These new physico-chemical conditions caused the increased biomass of Chlorophyceae in the spring.

During the summer stratification, the euphotic zone was restricted to 24-30 m in depth. The metalimnion was between 20 and 50 m and it was defined as the depth where the rate of temperature change with depth is greatest and is not restricted to that zone having a change of 1 C per meter of depth. This means that the volume of the hypolimnion, during this period of time, was 4-5 times greater than that of the epilimnion. As been pointed out by Loeffler (1960), the lakes in the Chilean Lagos Region reach high stratification stabilities during the summer. However, the temperature of the hypolimnion is high; during the summer in 4 different lakes between 110 and 200 m temperatures were 7.86 to 10.27 C (Thomasson 1964). For the Argentinean Lago Nahuel Huapi (764 m above sea level), the surface water ranged from 7.25 to 15.8 C and the bottom water, 7.02 to 7.55 C (Thomasson, 1959). During the summer the increase in temperature and in the concentrations of all the chemical factors in Lago Rupanco, except carbon dioxide, was related to the increase of the total phytoplanktonic biomass, at which time *Dinobryon divergens* was most abundant. *D. divergens* is also the most abundant species during the summer in the plankton of Lago Nahuel Huapi (Thomasson, 1959).

In the fall, there was an increase of the nitrogen and phosphorous nutrients and a decrease in silica. The other measured parameters did not change notably. Under these conditions the diatoms decreased and Chlorophyceae showed a new increase. The data concerning total dissolved and suspended solids are of limited value because they indicate nothing of the qualitative composition of the material. The values included both dissolved and particulate inorganic and organic matter (Wetzel and Likens, 1979). The highest concentrations of TDS in Lago Rupanco occurred concurrently with maximum biomass of phytoplankton during the summer.

The physico-chemical and biological regimes of Lago Rupanco, with a deep basin, orthograde oxygen distribution, low concentration of nutrients and a low standing crop of phytoplankton, makes it similar to other oligotrophic lakes (Thomasson, 1964). The main source of nutrients seems to be from the tributary streams which are mainly influenced by rainfall and snowmelt water. Generally, the nutrients in oligrotrophic lakes show orthograde distributions. In many ways the South American lakes at about latitude 40° S are similar to lakes in New Zealand. These lakes are general oligotrophic, with water that is soft and of poor nutrient content (Fish, 1970). From the morphometric point of view, the Araucanian lakes are almost comparable to the large Italian prealpine lakes (Thomasson, 1964).

In oligotrophic lakes the availability of orthophosphate and nitrate limits the productivity of many phytoplanktonic species (Golterman, 1975). The low concentrations (0 to 50 μg/l) of both nutrients in Lago Rupanco and the exhaustion of orthophosphate in the trophogenic layers can be the cause of the decline from the maximum phytoplanktonic biomass. Silica is another important nutrient which determines the abundance of diatoms in the lake. Silica levels in Lago Rupanco were moderate to high (10 to 20 mg/l) in summer, fall, and winter, but low, 5 mg/l, in spring. In this season the diatoms could not effectively compete and were replaced by Chlorophyceae.

The phytoplankton of Lago Rupanco was represented by members of the Cyanophyceae, Cryptophyceae, Chrysophyceae, Dinophyceae, Euglenophyceae, Bacillariophyceae and Chlorophyceae. Of the 84 taxa of specific or subspecific ranks identified, 4 species were important for the density that they reached (> 41%): Melosira granulata, Sphaerocystis schroeteri, Botryococcus braunii and Dinobryon divergens. The majority of the species were rare (1-15%) or were present occasionally. These last 2 species, *Botryococcus braunii* and *Dinobryon divergens* were also found to be dominant by Thomasson (1959) in the lakes located east of the Andes. Thomasson (1963), in a study of the same lakes, stated that the predominant plankter was *Melosira granulata*, subdominant were *Rhizosolenia eriensis*, *Synedra ulna* and *Dictyosphaerium pulchellum*. Thomasson (1963) separated the southern Chilean lakes into 2 main types, *Dinobryon*-lakes and *Melosira*-lakes. *Dinobryon*-lakes were poor in available dissolved nutrient minerals and *Melosira*-lakes were those lakes with a more favorable nutrient supply. Thomasson (op. cit.) also pointed out that Lago Rupanco did not conform to this classification. In the present study both species were found to be dominant but at different seasons. *Dinobryon* was more abundant during the summer and *Melosira* during the winter. The dominance of *Dinobryon* does correspond to an oligotrophic lake but *Melosira* is also common to eutrophic waters (Hutchinson, 1967; Wetzel, 1975). This disagreement in relation to the typical species of oligotrophic or eutrophic conditions has been discussed by Hutchinson (1967), who considered that the abundance of *Melosira granulata* in Lago Rinihue, suggested a relatively eutrophic locality. Hustedt (1945) believes *Melosira granulata* to be the planktonic diatom most characteristic of eutrophic waters in Europe. The Cyanophyceae is another group related to eutrophy, but in Lago Rupanco even when they were represented by 7 species the abundance was always low, 1 to 15% of the total algae present. Prescott (1962) stated that the abiotic conditions that are related to the presence of blue-green algae are high concentrations of nitrate, a relatively large amount of orthophosphate and high temperatures. In Lago Rupanco nitrates were high in comparison to phosphate, but water temperatures were lower than in many situations where blue-green algae are abundant. The Cyanophyceae were found mainly in summer but also were present in winter. Smith (1983), suggests that the relative proportion of blue-green algae in the epilimnetic phytoplankton is primarily dependent on the epilimnetic ratio of the total nitrogen to total phosphorous and that the occurrence of blue-green alge is independent of temperature. Cyanophyceae tends to be rare when this ratio exceeds 29 to 1 by weight.

The more abundant Chlorophyceae were represented by _Botryococcus braunii_ and _Sphaerocystis schroeteri_. _B. braunii_ appeared as a dominant associated with oligotrophic organisms such as _Dinobryon_ and _Staurodesmus_ (Thomasson, 1955). Ordinarially _S. schroeteri_ appears associated with Desmidiaceae in oligotrophic plankton (Hutchinson, 1967).

The composition of plankton in Lago di Como of Italy reflects a higher trophic level in comparison with that of Lago Nahuel Huapi of Argentina. The plankton of Lago di Como seems to be more related to the plankton of the preandean lakes in the Chilean Lagos Region. Probably, the similar temperature is of some importance in regard to the similarity in plankton composition between Italian and Chilean lakes (ca. 20 C) in comparison to the lower temperature of Lago Nahuel Huapi (Thomasson, 1959).

The seasonal succession of phytoplankton in Lago Rupanco, in general, follows the pattern for temperate oligotrophic lakes (Hutchinson, 1967). In these lakes, the populations of phytoplankton which develop a first maximum in the spring and a second in the fall, both usually predominantly of diatoms, are often low throughout the summer. Then in winter they decline to the minimum. In Lago Rupanco a maximum phytoplanktonic biomass was present during the summer as occurs in lakes of high latitudes and polar regions (Wetzel, 1975), and the minimum phytoplanktonic biomass was in the fall. The disparity seems to be related to the choice of analyses. Older analyses were based solely on number of organisms, which is quite a biased indicator in comparison to biomass, because of great differences in size among algae (Vollenweider, 1974).

Hutchinson (1967) suggests the use of dominant groups in order to characterize the plankton. Considering this criteria, Lago Rupanco can be characterized as an oligo-eutrophic diatom plankton, followed by a *Botryococcus*-plankton and by a Chrysophycean-plankton.

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