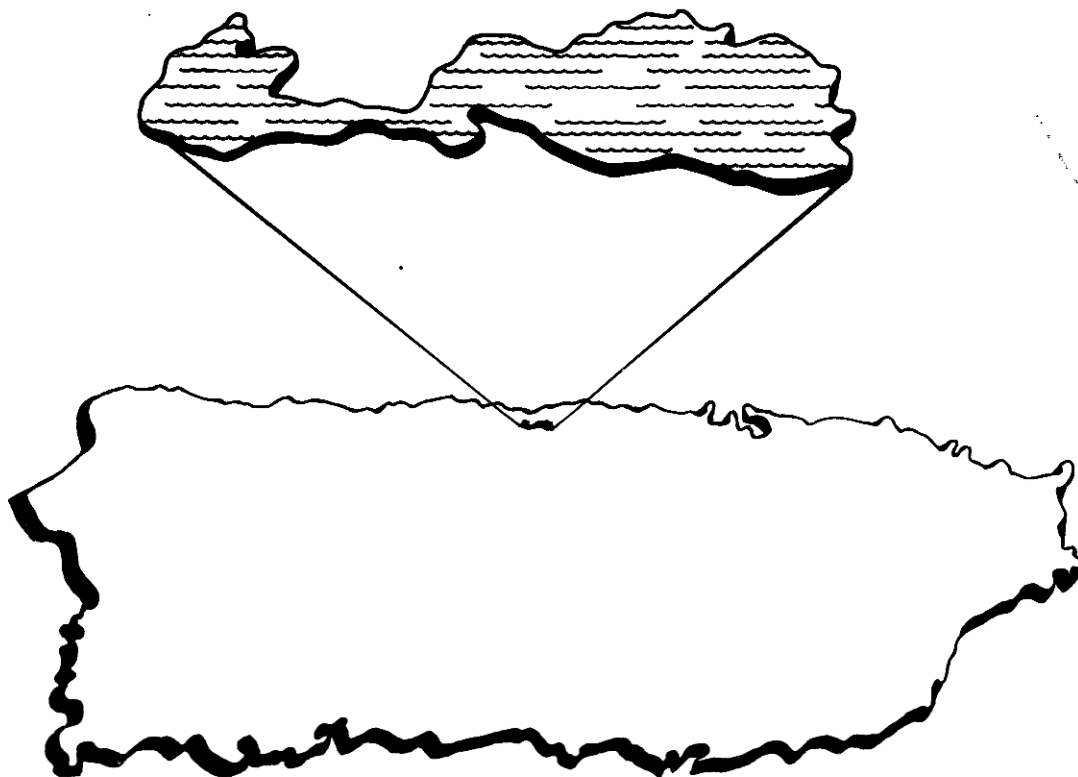


**LIMNOLOGY OF LAGUNA TORTUGUERO,  
PUERTO RICO**

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**U.S. GEOLOGICAL SURVEY  
Water Resources Investigation 77-122**



**Prepared in cooperation with the  
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March 1978

UNITED STATES DEPARTMENT OF THE INTERIOR

CECIL D. ANDRUS, Secretary

GEOLOGICAL SURVEY

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## CONTENTS

	Page
Abstract . . . . .	1
Introduction . . . . .	2
Purpose and scope . . . . .	2
Methods and procedures . . . . .	4
Lagoon characteristics . . . . .	6
Hydrology of Laguna Tortuguero . . . . .	9
Precipitation and evaporation . . . . .	9
Runoff . . . . .	9
Water budget . . . . .	12
Chemical and physical characteristics . . . . .	13
Common ions and related physical characteristics . . . . .	13
Nutrients and nutrient budget . . . . .	20
Heavy metals and pesticides . . . . .	28
Dissolved oxygen . . . . .	32
Temperature . . . . .	35
Sediments . . . . .	35
Biological characteristics . . . . .	44
Bacteria . . . . .	44
Phytoplankton and periphyton . . . . .	44
Zooplankton . . . . .	54
Fish . . . . .	62
Aquatic plants . . . . .	64
Community productivity . . . . .	64
Chemical, physical and biological interactions in Laguna Tortuguero . . . . .	68
Summary and conclusions . . . . .	73
Selected references . . . . .	76
Glossary . . . . .	79

## ILLUSTRATIONS

Figure	Page
1 Map showing Laguna Tortuguero and sampling stations . . . . .	3
2 Bathymetric map of Laguna Tortuguero . . . . .	7
3 Bar graph showing seasonal precipitation and pan evaporation near Laguna Tortuguero . . . . .	8
4 Photograph showing canal outlet . . . . .	10
5 Graph showing seasonal fluctuation in the water-surface elevation in Laguna Tortuguero (west end) . . . . .	11
6 Graph showing daily mean discharge at the canal outlet . . . . .	11
7 Diagram showing water budget, July 1974 to June 1975 . . . . .	12
8 Graph showing seasonal fluctuation in the main chemical and physical characteristics for stations 1, 4 and 5 in eastern Laguna Tortuguero . . . . .	14

# ILLUSTRATIONS--Continued

Figure		Page
9	Graph showing seasonal fluctuation in the main chemical and physical characteristics at station 2 in western Laguna Tortuguero . . . . .	15
10	Map showing chloride concentrations throughout Laguna Tortuguero on November 14, 1974 and June 24, 1975 . . . .	17
11	Graph showing seasonal fluctuation in the chloride concentration and specific conductance at stations 2 and 5 . . . . .	19
12	Graph showing seasonal fluctuation in the concentration of the principal nitrogen and phosphorus forms for the average of stations 1, 4, and 5 at the east part of Laguna Tortuguero . . . . .	22
13	Graph showing seasonal fluctuation in the concentration of the principal nitrogen and phosphorus forms at station 2 in the west part of Laguna Tortuguero . . . . .	23
14	Diagram showing nutrient budget, July 1974 to June 1975 . .	29
15	Graph showing seasonal fluctuation in the dissolved oxygen concentration at stations 2 and 5 . . . . .	33
16	Graph showing diurnal fluctuation in the dissolved oxygen concentration at 0.5-meter depth . . . . .	34
17	Photograph showing waves on the east part of Laguna Tortuguero . . . . .	36
18	Graphs showing seasonal fluctuation in temperature at stations 2 and 5 . . . . .	37
19	Map showing generalized thickness of bottom sediments	38
20	Graph showing seasonal fluctuation in the number of total coliform bacteria, fecal coliform bacteria, and fecal streptococcal bacteria at stations 1, 2 and 5 . . . . .	45
21	Graph showing seasonal fluctuation in the number of phytoplankton cells at stations 2, 4 and 5 . . . . .	46
22	Graph showing seasonal fluctuation in the percentage dominance of phytoplankton genera at station 2 . . . . .	50
23	Graph showing seasonal fluctuation in the percentage dominance of phytoplankton genera at station 5 . . . . .	51
24	Photograph showing <u>Navicula</u> sp. . . . .	52
25	Photograph showing periphyton . . . . .	53
26	Graph showing seasonal fluctuation in the number of zooplankton organisms at stations 2, 4, and 5 . . . . .	58
27	Graph showing diurnal fluctuation in the number of zooplankton at stations 2, 3, 4 and 5, Nov. 26, 1976 . . . .	58
28	Graph showing percentage dominance of the principal species at stations 2 and 5 . . . . .	59
29	Photograph showing <u>Diaptomus</u> sp. . . . .	60
30	Photograph showing <u>Diaphanosoma brachyurum</u> . . . . .	61

## ILLUSTRATIONS--Continued

Figure	Page
31 Photograph showing fish from Laguna Tortuguero . . . . .	66
32 Photograph showing <u>Typha domingensis</u> Pers, the dominant aquatic plant in Laguna Tortuguero . . . . .	67
33 Graph showing dissolved oxygen curve and complementary information used for community primary productivity computations at station 5 . . . . .	69
34 Diagram showing simplified model of the principal interactions in the lagoon . . . . .	70

## TABLES

Table	Page
1 Stations throughout Laguna Tortuguero . . . . .	5
2 Physical characteristics of Laguna Tortuguero . . . . .	8
3 Nutrients essential to algal life . . . . .	21
4 Selected physical and chemical characteristics of rainfall near Laguna Tortuguero . . . . .	26
5 Concentration of selected heavy metals in the waters throughout Laguna Tortuguero . . . . .	30
6 Concentration of selected pesticides and organic chemicals in the water at stations 1, 2 and 5 . . . . .	31
7 Concentration of selected metals, organic carbon and nutrients in the bottom sediments . . . . .	40
8 Concentration of organic carbon, iron, manganese, total nitrogen and total phosphorus in sediment cores from stations 4 and 5 . . . . .	42
9 Species of mollusks identified from a bottom sediment core from Laguna Tortuguero . . . . .	42
10 Concentration of selected pesticides and organic chemicals in the bottom sediments at stations 2 and 5 . . . . .	43
11 Genera of phytoplankton identified throughout Laguna Tortuguero . . . . .	48
12 Species of periphytic algae identified in Laguna Tortuguero . . . . .	55
13 Species of zooplankton identified in Laguna Tortuguero . . . . .	57
14 Species of fish identified in Laguna Tortuguero in 1971 . . . . .	63
15 Species of fish identified in Laguna Tortuguero during December 1975-January 1976 . . . . .	65

In recognition of the general trend toward the adoption of the metric system of measurements (SI or System Internationale), metric units are used in this report. Within the Commonwealth of Puerto Rico, both the SI and English systems are used extensively. The following factors may be applied for conversion of metric values (SI) to English values:

	<u>Multiply</u>	<u>By</u>	<u>To obtain</u>
<u>Length</u>			
millimeters (mm)		.03937	inches (in)
meters (m)		3.281	feet (ft)
kilometers (k)		.6214	miles (mi)
<u>Area</u>			
square meters (m <sup>2</sup> )		10.764	square feet (ft <sup>2</sup> )
square kilometers (km <sup>2</sup> )		.3861	square miles (mi <sup>2</sup> )
<u>Volume</u>			
cubic meters (m <sup>3</sup> )		35.31	cubic feet (ft <sup>3</sup> )
<u>Weight</u>			
grams (g)		.03527	ounces (oz)
tonnes (t)		1.1025	tons (T)
<u>Flow</u>			
cubic meters per second (m <sup>3</sup> /s)		22.827	million gallons per day (Mgal/d)

L I M N O L O G Y    O F

L A G U N A        T O R T U G U E R O ,

P U E R T O    R I C O

by Ferdinand Quiñones-Márques and Luis A. Fusté

ABSTRACT

Laguna Tortuguero, located on the north coast of Puerto Rico, is the largest freshwater lagoon on the island. It has a surface area of 2.24 square kilometers with a volume of about 2.68 million cubic meters and a mean depth of 1.2 meters.

Water entering the lagoon from 1974-75 included 3.41 million cubic meters from precipitation and 19.7 million cubic meters from ground water and surface flows. About 20.1 million cubic meters was discharged to the sea through the north canal outlet and 2.85 million cubic meters was lost by evapotranspiration.

The quality of the water in the lagoon depends on the inflow of seawater and on circulation patterns. Seawater flows contribute about 5 percent of the water in the lagoon. Chloride and sodium are the most abundant ions, ranging in concentration from 300 to 700 and from 150 to 400 milligrams per liter, respectively. Among the nutrients, nitrogen concentrations average 1.7 milligrams per liter, while phosphorus average 0.01 milligram per liter. About 70 percent of the nitrogen is organic or ammonia nitrogen. Total nitrogen inputs to the lagoon were about 33.2 tonnes and about 34.0 tonnes was discharged to the ocean, suggesting a near equilibrium in the system.

Dissolved oxygen concentrations average 8.2 milligrams per liter, increasing toward the bottom as a result of high oxygen production by periphyton. Wind mixing contributes to maintain high oxygen concentrations throughout the lagoon.

The bottom sediments in the lagoon average about 2.0 meters deep, with a volume of about 4.5 million cubic meters, or twice the water volume. Organic

carbon in the sediment averages about 6.8 percent by weight while nitrogen and phosphorus average 0.8 and 0.014 percent by weight, respectively.

Bacteria counts throughout the lagoon are very low, indicating excellent sanitary conditions. Phytoplankton concentrations average 6,000 cells per milliliter. Of 47 genera of phytoplankton identified, 16 were diatoms and 12 blue-green algae. Anacystis was the dominant alga 90 percent of the time. Zooplankton concentrations average 100,000 organisms per cubic meter. A total of 17 species were identified, among which Diaptomus dorsalis, Diaphanosoma brachyurum and Filinia opoliensis are dominant.

The lagoon, as a whole represents a near steady-state system approaching natural eutrophic conditions. Water flows, nutrients and the dissolved-oxygen concentrations are the most important factors in the present steady-state conditions. The bottom sediments are a potential source of nutrients to the lagoon. Land-use changes in the immediate area of the lagoon could result in increases in the water and nutrient flows, which could shift the present equilibrium toward a more biologically productive system.

## INTRODUCTION

### Purpose and Scope

Laguna Tortuguero, located between the Río Cibuco and the Río Grande de Manatí, and about 35 km west of San Juan (fig. 1), is the largest natural freshwater lagoon in Puerto Rico. The lagoon is a valuable natural resource which has been maintained in a near natural condition. Except for a drainage channel dug by the U.S. Army in 1940, no other works have disturbed the lagoon. The lagoon and the immediate area around it are sanctuaries for a diversity of species of fish, other aquatic organisms, birds, and several endemic plants (Reyes de Ruiz, 1971). The area is a source of recreation for sportsmen and fishermen and provides additional sources of food and income to a number of dwellers in the vicinity. Recently a number of private and government interests have proposed developments in the immediate vicinity of the lagoon. Several major urban development projects have been proposed on its southern slopes. Plans for a power generating unit in the area are contemplated. A permit to extract sand for industrial uses from the area north of the lagoon was recently approved. The potential impact of these projects on the overall water quality and hydrology of the lagoon may be significant.

At the request of the Department of Natural Resources of the Commonwealth of Puerto Rico, the U.S. Geological Survey initiated a comprehensive study of the limnology of the lagoon. The purposes of the 1-year study were to obtain baseline information as to the overall chemical, physical and biological conditions in the lagoon and to analyze the hydrologic factors in the lagoon system. The investigation was conducted from July 1974 to June 1975 under the cooperative program between the Commonwealth of Puerto Rico and the U.S. Geological Survey.



Figure 1.--Laguna Tortuguero and sampling stations.



We gratefully acknowledge the assistance of Juan Carvajal Zamora, Microbiologist, Department of Natural Resources of the Commonwealth of Puerto Rico, for his aid in the biological work of the study. We are also grateful to W. J. Byas, Division of Mollusks of the U.S. National Museum, in identifying mollusk specimens collected during the study. The hydrologic analysis of the lagoon could not have been performed without the data obtained by Roberto Ramírez, a hired observer.

### Methods and Procedures

Sampling stations throughout the lagoon were established as shown in figure 1 and listed in table 1. Samples for chemical, physical, biochemical and bacteriological properties were collected monthly (except during December 1974) from stations 1 through 5. Station 1 (canal outlet) was also a flow-measuring station from which daily observations of gage heights were made. Discharge measurements were made at station 1 about once every 2 weeks. Continuous water-level recorders were installed at station 6 and in the vicinity of station 4. A standard rain gage and a recording class "A" evaporation pan were installed in the vicinity of station 6. Samples of rainfall were collected from the rain gage for chemical and physical analyses.

Nutrient samples were chilled to 4°C and analyzed within 4 days of collection. Samples collected for whole water chemical analyses of common ions, nutrients, pesticides, heavy metals and phytoplankton were analyzed at the U.S. Geological Survey Central Laboratory in Doraville, Georgia. Samples collected for determination of zooplankton, bacteria, and periphyton were analyzed at the U.S. Geological Survey Field Service Laboratory in San Juan. Chemical, physical, and biochemical analyses were performed in accordance with methods described by Brown and others (1970), and the American Public Health Association and others (1971). Biological (plankton) and bacteriological analyses were performed as described by Greeson and others (1973), Ward and Whipple (1959), and Smith (1950). Taxonomic keys described by Reimer (1966), Davis (1955), and Prescott (1970) were utilized in the periphyton analyses.

On site determinations at each station were made of the dissolved-oxygen concentration (DO), pH, specific conductance, temperature, and Secchi disk transparency. Vertical profiles were determined for the DO concentration and temperature.

Bottom sediment samples for the analysis of pesticides and heavy metals were collected at stations 2 and 5 once during the study. An Ekman dredge suspended from a line was used for the collection of the samples. Cores of the bottom sediments were collected with a PVC pipe piston-type core sampler. Bottom sediment samples were frozen prior to the analyses. Mollusks identified from the cores were removed from segments not exposed to freezing. Depths of bottom sediments were measured with a calibrated PVC pipe.



Table 1.--Sampling stations in Laguna Tortuguero,  
Puerto Rico.

<u>Station number</u>	<u>Name</u>	<u>Latitude</u>	<u>Longitude</u>
50038190	Laguna Tortuguero No. 6	18°27'46"	66°28'01"
50038191	Laguna Tortuguero No. 2	18°27'53"	66°27'50"
50038192	Laguna Tortuguero No. 3	18°27'50"	66°27'16"
50038193	Laguna Tortuguero No. 4	18°27'55"	66°26'40"
50038194	Laguna Tortuguero No. 5	18°27'52"	66°25'50"
50038200	Laguna Tortuguero No. 1 (Outlet near Vega Baja)	18°28'29"	66°26'50"

A diel study of the community productivity in the lagoon utilizing the oxygen evolution method was conducted November 26, 1974. Methods described by Slack and others (1973) were used during the study.

A bathymetric survey of the lagoon was conducted during May 1975. A fathometer coupled to an Ott current meter mounted on a moving boat was used to measure depths and distances (Smoot and Novak, 1969). Bearings were maintained with a compass and the use of land controls. Data from the bathymetric study were used for computations of the capacity of the lagoon (Eakin and Brown, 1939; and Heinemann and Dvorak, 1970).

## LAGOON CHARACTERISTICS

Laguna Tortuguero is unique not only because of its near natural state, but also because it is fed from a series of freshwater and saline-water springs that make it slightly saline. Geologically, the lagoon is probably very recent. Meyerhoff (1933) and Bennett and Giusti (1972) suggest that "it is probably the arrested preliminary stage of a line of interconnected sinks and haystacks which are typical of the karst in the area." Test borings in the lagoon area indicate a sequence of peat, sand, and clay overlying an irregular limestone surface. The limestone surface in the lagoon proper is well below the general water table. There is no longer a downward movement of rainwater but an upwelling of water into the lagoon from the underlying aquifer. The upwelling is the sole reason for the existence of Laguna Tortuguero. Ground water in a coastal aquifer is not static but is part of a dynamic system. As freshwater moves toward the sea, there is a corresponding movement of seawater inland along the bottom part of the aquifer. Eventually the seawater moves upward and back toward the sea. The freshwater moving seaward is also carried upward, mingling with the seawater to form a mixing zone along the contact between freshwater and seawater. It is this upwelling of seawater which accounts for the slightly salty quality of Laguna Tortuguero (Bennett and Giusti, 1972). The lagoon is, in effect, a window through which part of the flow mechanism of freshwater and saltwater in a coastal aquifer can be observed.

At present the freshwater-seawater system can be considered to be in a dynamic balance. Bennett and Giusti (1972) indicate that prior to 1940, before the drainage canal was dug, the lagoon water level was probably 0.5 to 1 m higher. A balance similar to the present one but probably at a different point in the dynamic system, existed prior to the lowering of the lagoon level. Changes in the lagoon's natural system caused by the lowering in the canal should have been recorded in the lagoon itself.

The surface area of the lagoon is about 2.24 km<sup>2</sup>, of which about two-thirds is on the east part. The lagoon is relatively shallow, averaging about 1.2 m in depth. A bathymetric map of the lagoon is shown in figure 2. The map shows that the east part is generally deeper than the west part. Equal depth lines for the canal that joins both parts of the lagoon are not shown because of the scale. The canal in this area is about 1.5 m deep. The deepest part of the lagoon (2.8 m) was measured near the west end of the canal.

The bathymetric map of the lagoon shows the depth from the water surface to the bottom sediment layer. It will be shown in a later section that the consistency and depth of the sediments may have a bearing on the actual depth.

The physical characteristics of the lagoon are summarized in table 2. The development of shoreline ratio (DL) is an index of the morphology of a lake, produced by the ratio of the length of the shoreline to the length of the circumference of a circle of area equal to that of the lake. The ratio gives an insight into the origin and behavior of lakes (Hutchinson, 1957). Irregular lakes or lagoons exhibit development of shoreline ratios higher than 1.5.

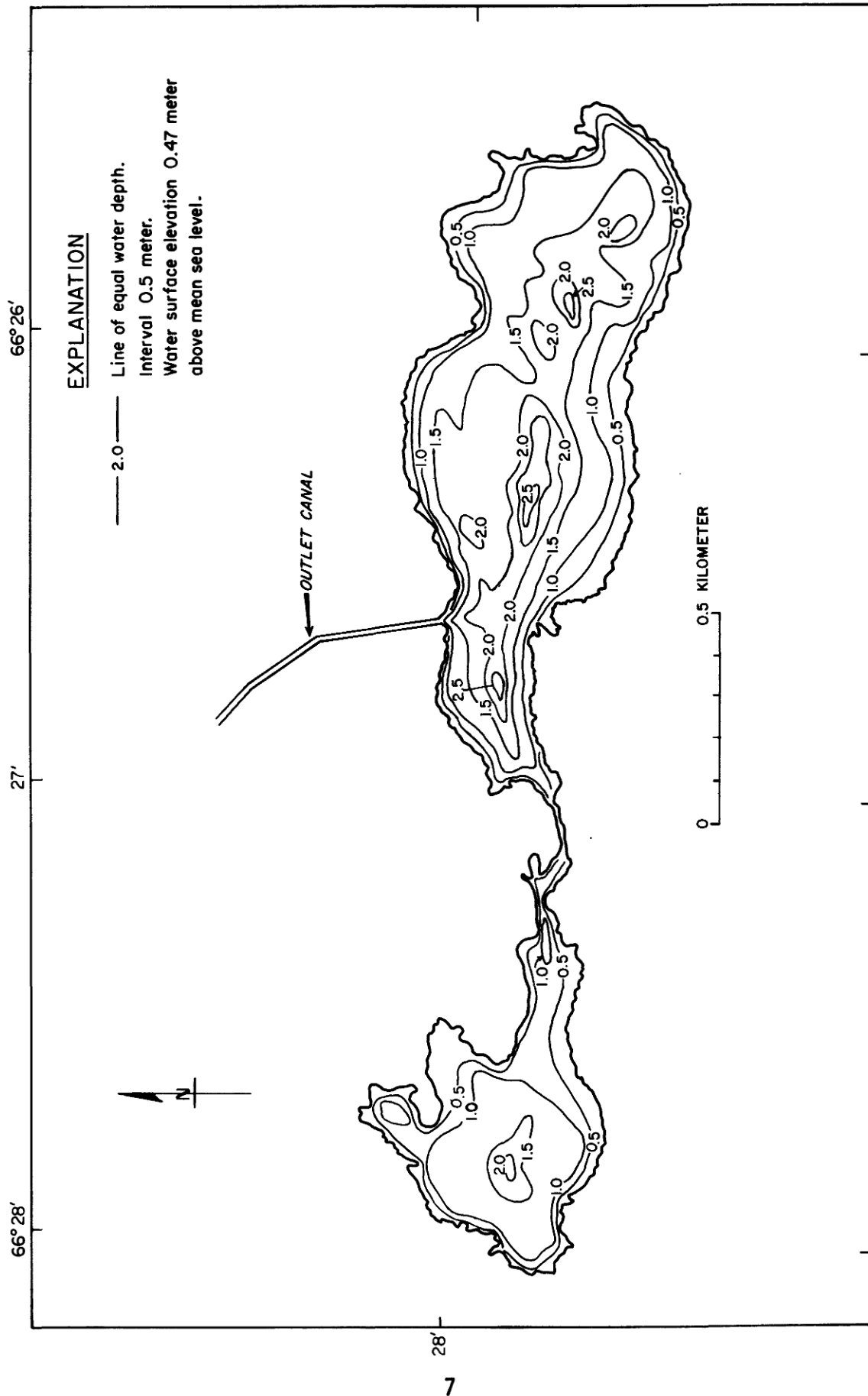


Figure 2.--Bathymetric map of Laguna Tortuguero. Surveyed May 1975.

Table 2.--Physical characteristics of Laguna Tortuguero.

Area (A)	2.24 km <sup>2</sup>
Volume (V)	2.68 Mm <sup>3</sup>
Mean depth $\frac{V}{A}$	1.2 m
Maximum depth	2.8 m
Maximum length (east to west end)	4.6 km
Maximum width (east end)	.9 km
Maximum width (west end)	1.0 km
Shoreline length (L)	15.3 km
Development of shoreline	
$D_L = \frac{L}{2 \sqrt{\pi A}}$	2.9

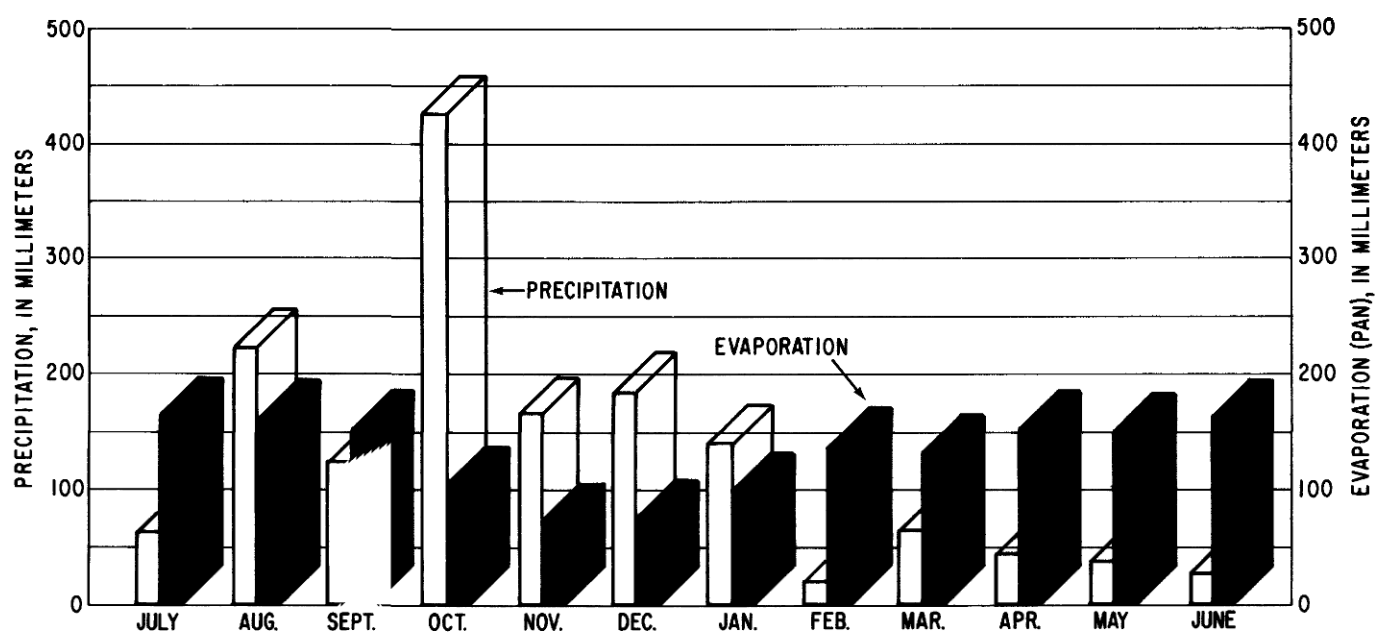


Figure 3.--Seasonal precipitation and pan evaporation near Laguna Tortuguero.

## HYDROLOGY OF LAGUNA TORTUGUERO

### Precipitation and Evaporation

Precipitation along the north coast of Puerto Rico is characterized by a drought period from February through March and increasing rainfall thereafter. The average precipitation in the vicinity of Laguna Tortuguero is about 1,600 mm per year (Colón, 1970).

A standard 8-in (203 mm) nonrecording precipitation gage was located on the western shore of the lagoon. Daily observations were made. Monthly totals of the amount of precipitation measured are shown in figure 3. A total of 1,521 mm of rainfall was recorded during the year of study, which contributed 3.41 Mm<sup>3</sup> to Laguna Tortuguero.

Evaporation data collected at the weather station are also shown in figure 3. A total of 1,592 mm of pan evaporation was recorded during the study period. If a pan-to-evapotranspiration (ET) coefficient for the lagoon of 0.8 is assumed (Pruitt, 1966), total evapotranspiration from the lagoon can be estimated as about 1,274 mm. This is equivalent to a volume of 2.85 Mm<sup>3</sup> evapotranspiration from Laguna Tortuguero during the study period.

The data in figure 3 show that through half of the year of study there was a deficit between precipitation and evaporation in the area. Even when evaporation rates are adjusted to reflect evapotranspiration, a deficit would be shown for most of the months after February 1975. The overall balance between precipitation and evapotranspiration shows a net input of 247 mm. Most of the excess precipitation occurred during October 1974, when a total of 245 mm was recorded.

### Runoff

Runoff into Laguna Tortuguero occurs only during periods of intense storms. Whenever precipitation in the area exceeds percolation rates, some overland runoff, mainly from the southern slopes, may flow directly into the lagoon. Although no samples were collected during storms, areas in the vicinity of station 3 (fig. 1) showed some evidence that overland runoff had occurred.

Outflow from Laguna Tortuguero is only through the north canal outlet. The canal (fig. 4), reportedly dug by the U.S. Army in 1940, is about 0.6 km in length (to the ocean), about 8.5 m wide and about 1 m deep. Although the canal is affected by backwater from the ocean tide, it flows continuously. The common belief that seawater flows through the canal into the lagoon is not correct. There were no observations of flows in the direction of the lagoon, nor did specific conductance measurements indicate seawater encroachment during the study period.



Figure 4.--Canal outlet, looking south.

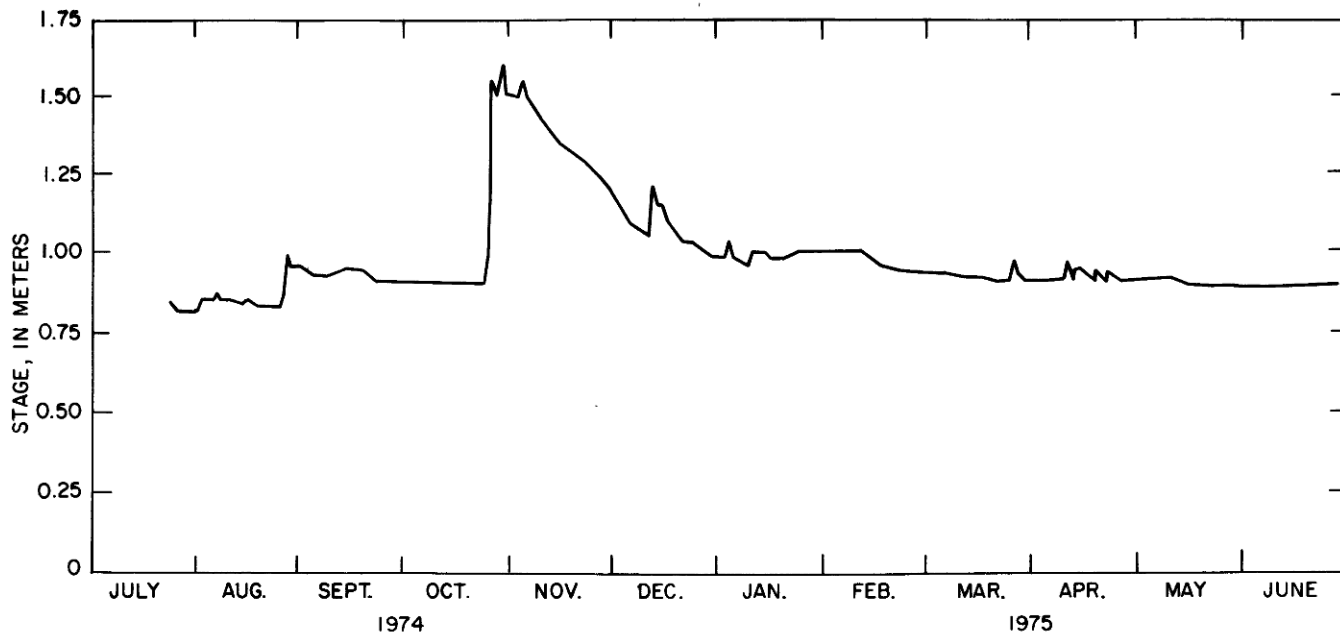


Figure 5.--Seasonal fluctuation in the water-surface elevation in Laguna Tortuguero (west end).

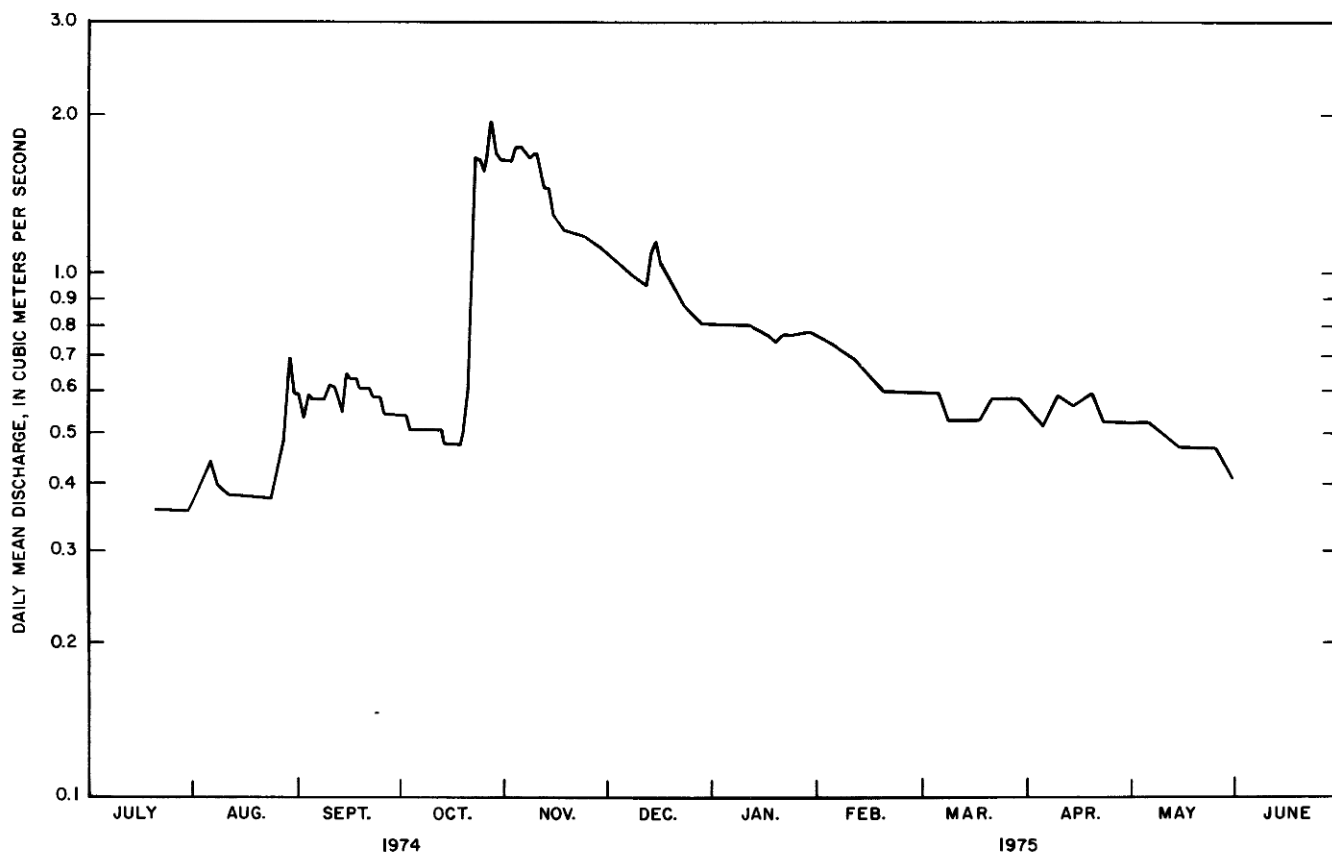


Figure 6.--Daily mean discharge at canal outlet.

Discharge measurements through the canal outlet ranged from 0.26 to 1.95 m<sup>3</sup>/s. The lowest measurements were made in July 1974 when the study was initiated, while the highest were made during October 1974. The storm of October 24-25, 1974, resulted in a rapid increase in the water level throughout the lagoon. The water level, shown for the west end in figure 5, rose about 0.6 m during the storm. At the canal outlet, the water level increased about 0.4 m. Daily discharges increased at the canal outlet from 46,500 m<sup>3</sup> on October 23 to about 171,000 m<sup>3</sup> on October 29.

Daily mean discharges at the canal outlet are shown in figure 6. A total of 20.1 Mm<sup>3</sup> was discharged during the period of study; the equivalent to a mean daily discharge of about 0.64 m<sup>3</sup>/s. This is in agreement with an estimated 0.6 m<sup>3</sup>/s reported by Bennett and Giusti (1972) as the base flow from the lagoon to the sea.

### Water Budget

The water budget for Laguna Tortuguero during the study period is summarized in figure 7. Ground- and surface-water inflows were computed on the basis of the other known flows. The overall change in storage in the lagoon was the result of a higher water level at the end of the study.

The volume of water discharged through the canal outlet results in a high flushing rate in Laguna Tortuguero. Flushing rates are an important aspect of lake hydraulics and the degree of eutrophication of lakes.

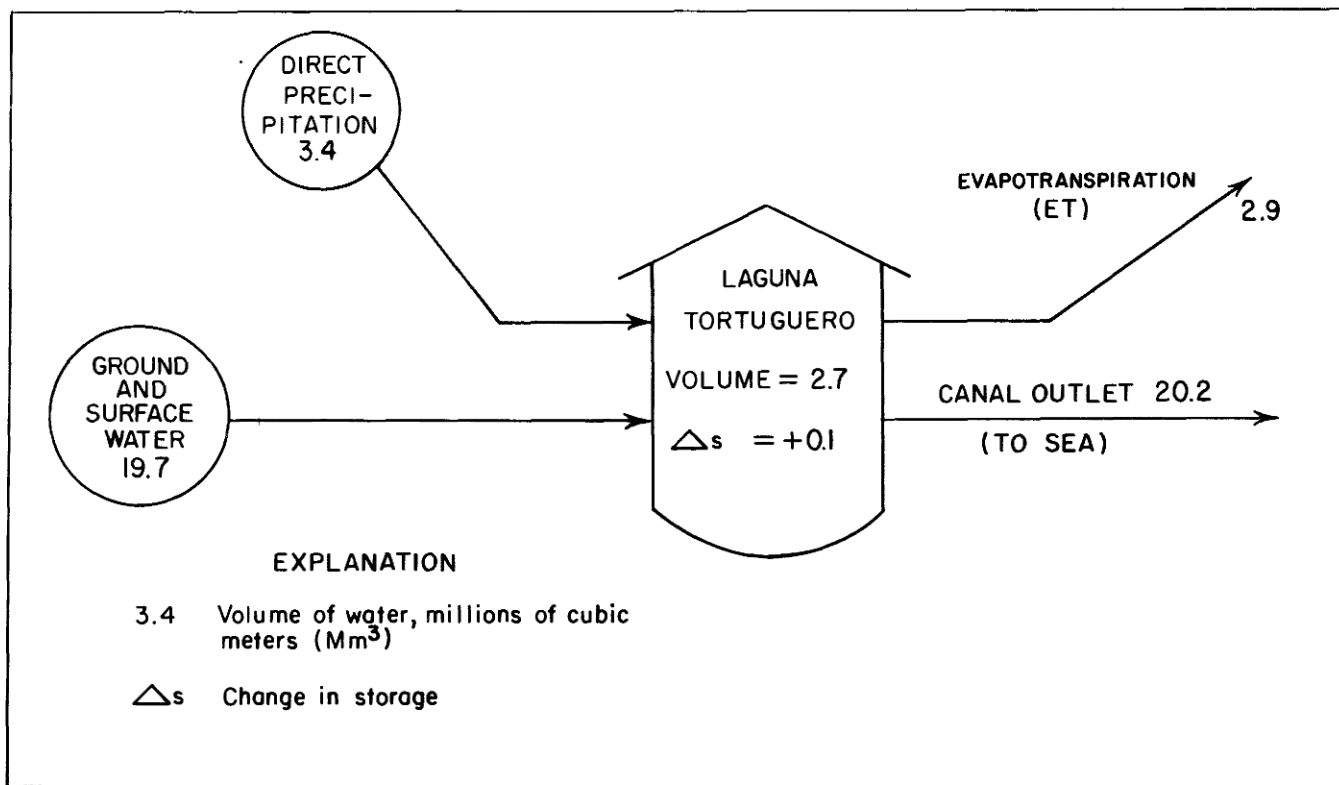


Figure 7.--Water budget, July 1974 to June 1975.



The flushing rate of Laguna Tortuguero during the study period was 7.5 per year. Dillon (1975) has reported that lakes with flushing rates higher than 1 per year are able to tolerate higher nutrient loadings. It will be shown later that this plays an important role in the limnology of Laguna Tortuguero.

## CHEMICAL AND PHYSICAL CHARACTERISTICS

### Common Ions and Related Physical Characteristics

Chemical analyses were made for calcium, magnesium, sodium, potassium, iron, manganese, chloride, sulfate, and bicarbonate, as well as physical measurements of pH, temperature, and specific conductance.

There are significant differences between the concentrations of some of the ions in samples collected from the eastern and those from the western parts of the lagoon. For common ions and other data in the report, stations 2 and 5 (fig. 1) are used as index stations as these represent the extremes of the conditions in the lagoons. Stations 4 and 5 in the east end and station 1 (canal) represent nearly similar water-quality conditions, and the average of these is reported at times. The average was assumed to represent the quality of water in the eastern part of the lagoon.

The seasonal fluctuation in the average of the main chemical and physical characteristics at stations 1, 4 and 5 is shown in figure 8. Concentrations and values for station 2 are shown in figure 9. With very few exceptions, the concentrations of the different ions declined significantly after the rains of October 1974. The large inflow of surface runoff, probably very low in the concentration of ions, diluted the concentration of those in the lagoon. Most of the concentrations of the different ions analyzed did not recover at the end of the study to the values measured at the beginning of it.

Chloride and sodium are the principal ions in the waters of Laguna Tortuguero. The concentration of chloride ranged from 300 to 700 mg/L, while that of sodium ranged from 150 to 400 mg/L. The ratio of sodium to chloride resembled that of seawater during the periods prior to the flood of October 1974 and after the recovery period.

The areal concentration of chloride during two periods is shown in figure 10. On November 14, 1974, after the flood of October, the average chloride concentration in the east part of the lagoon was about 400 mg/L, while in the west part it was about 540 mg/L. On June 24, 1975, at the end of the study and after the lagoon had recovered nearly to its normal stage condition, the average chloride concentration in the east part was about 640 mg/L, while in the west part it was close to 800 mg/L.

Comparison of the two surveys indicates a change in chloride concentration of about 250 mg/L throughout the lagoon. This change in the amount of chloride in the water, as well as other ions, could have a significant effect on some of the aquatic communities in the lagoon.

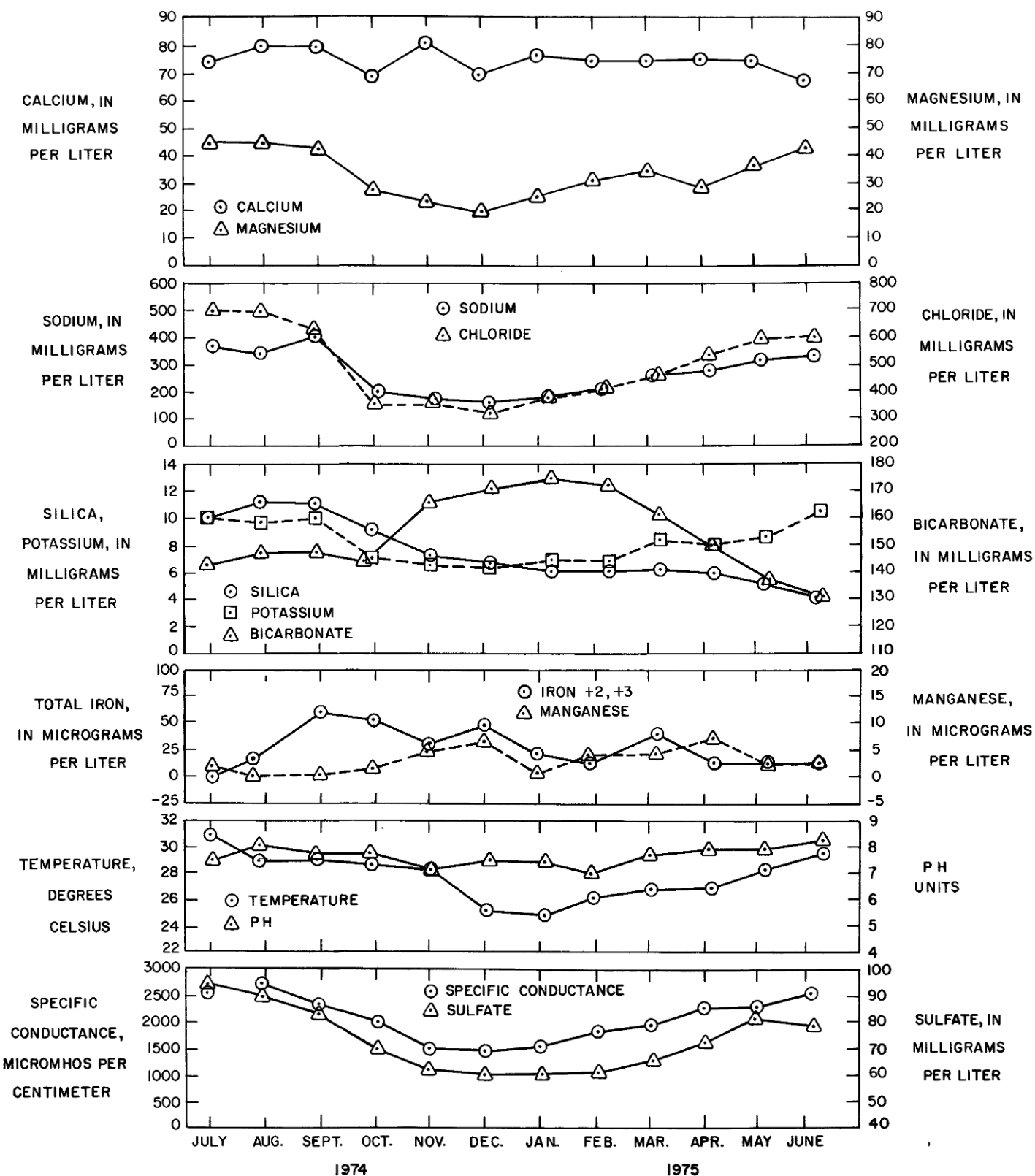


Figure 8.--Seasonal fluctuation in the main chemical and physical characteristics for the average of stations 1, 4 and 5 in eastern Laguna Tortuguero.

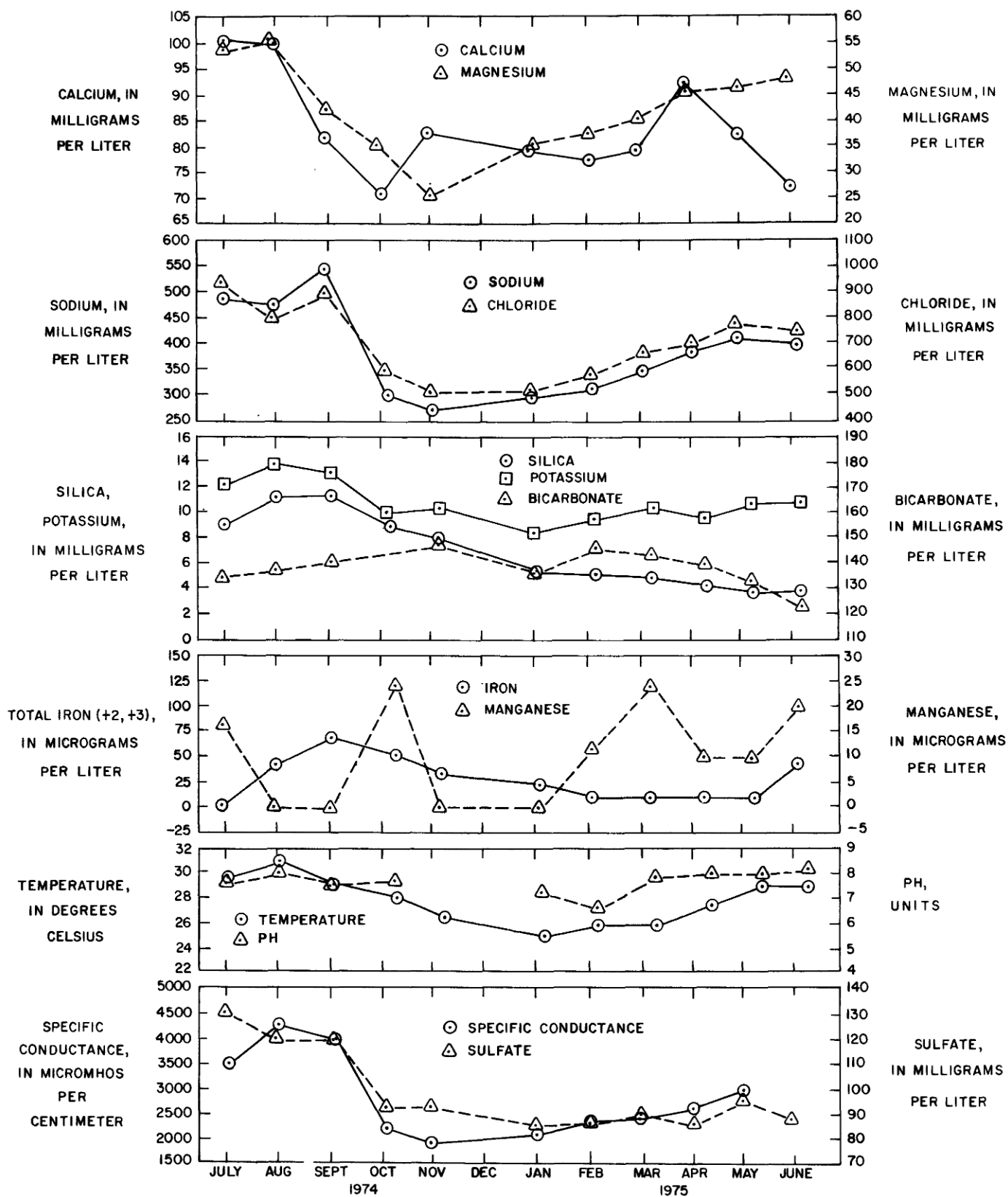


Figure 9.--Seasonal fluctuation in the main chemical and physical characteristics at station 2 in western Laguna Tortuguero.

Chloride and sodium are the principal ions in the waters of Laguna Tortuguero. The concentration of chloride ranged from 300 to 700 mg/L, while that of sodium ranged from 150 to 400 mg/L. The ratio of sodium to chloride resembled that of seawater during the periods prior to the flood of October 1974 and after the recovery period.

The areal concentration of chloride during two periods is shown in figure 10. On November 14, 1974, after the flood of October, the average chloride concentration in the east part of the lagoon was about 400 mg/L, while in the west part it was about 540 mg/L. On June 24, 1975, at the end of the study and after the lagoon had recovered nearly to its normal stage condition, the average chloride concentration in the east part was about 640 mg/L, while in the west part it was close to 800 mg/L.

Comparison of the two surveys indicates a change in chloride concentration of about 250 mg/L throughout the lagoon. This change in the amount of chloride in the water, as well as other ions, could have a significant effect on some of the aquatic communities in the lagoon.

Sulfate, calcium and magnesium follow in order of abundance among the ions in Laguna Tortuguero. The sulfate concentrations in the east part of the lagoon ranged from 60 to 95 mg/L, while those in the west part ranged from 85 to 130 mg/L. Magnesium concentrations ranged from 20 to 45 mg/L and 25 to 55 mg/L for the east and west parts, respectively.

The average ratio of sodium to sulfate ( $\text{Na}^+/\text{SO}_4^{=}$ ) throughout the lagoon is about 4, which is similar to the ratio of these ions in seawater. This ratio and that of sodium to chloride indicate seawater input to the lagoon from the underlying aquifer.

The calcium concentration throughout Laguna Tortuguero fluctuated from 70 to 100 mg/L in the east part but remained nearly constant at about 75 mg/L in the west part. Seawater has a concentration of up to 400 mg/L of calcium (Hem, 1970). If only about 5 percent of the water in Laguna Tortuguero is of seawater origin (based on the percentage of chloride), and if there were no other source of calcium to the lagoon, a dilution in the calcium concentration to about 20 mg/L would occur. However, the primary source of water to Laguna Tortuguero is ground water from the Aymamón aquifer (Bennett and Giusti, 1972), which is either saturated or supersaturated with calcium (Giusti, 1974). The chemical equilibria of these waters maintain in solution concentrations of calcium of as much as 100 mg/L. Calcium plays an important role in the sediments in Laguna Tortuguero. This will be discussed in connection with the sediments in the lagoon.

The concentration of silica in Laguna Tortuguero ranged from 3 to 11 mg/L, decreasing from the beginning to the end of the study. There were no significant differences in concentration between the east and west parts of the lagoon.



Silica in ground waters along the north coast averages about 10 mg/L (Guisti, (1974)). Prior to the flood of October 1974, silica concentrations in the lagoon were about 11 mg/L. Concentrations then declined steadily not only after the flood, but continued to decline during the period when recovery in the concentrations of other ions occurred. Bicarbonates in the lagoon followed a similar pattern. Silica plays an important role in the metabolism of diatoms. The decline in silica during the spring and summer could be related to the diatom populations in the lagoon. These interactions will be covered in the biological part of the report.

Specific conductance values at 25°C ranged from 1,500 to 2,800  $\mu\text{mho/cm}$  in the eastern part of Laguna Tortuguero and from 2,000 to 4,300  $\mu\text{mho/cm}$  in the western part (figs. 8 and 9). Higher values were recorded on the northern tip of the western part of the lagoon (6,500  $\mu\text{mho/cm}$ ), but these are not typical of the lagoon. The proximity of the ocean to this area accounts for the higher values.

The relation between the specific conductance and chloride concentration, their seasonal fluctuations and the comparisons between the two parts of the lagoon are shown in figure 11. A correlation between the two parameters shows that chloride concentrations throughout the lagoon may be estimated accurately by multiplying the specific conductance times 0.25. Because the field measurement of specific conductance may be accomplished with a high degree of precision, chloride ion concentrations in the lagoon may be monitored with minimum effort and expense.

The pH of the water in Laguna Tortuguero did not change significantly during the period of study. It ranged from 6.8 to 8.2 units; however, the mode was about 8.0 units. The high calcium and bicarbonate concentrations provide an alkaline buffer system that maintains the pH nearly unchanged.

Concentration of ions is higher in the western than in the eastern part of the lagoon (figs. 8 and 9). This difference may be caused by several factors. The west end of the lagoon does not have an open drainage system to the ocean such as the canal of the eastern part. As a result, flushing of the lagoon occurs principally in the eastern part, while in the western part the water is more "stagnant." Also, because the general wind pattern in Laguna Tortuguero is from east to west, the winds act as an additional force that reduces the flow from the western to the eastern end. With limited drainage in the west, evaporation further concentrates the ions. Upwelling of seawater into the western end is bound to occur at a higher rate than in the east because the western part of the lagoon is closer to the ocean.

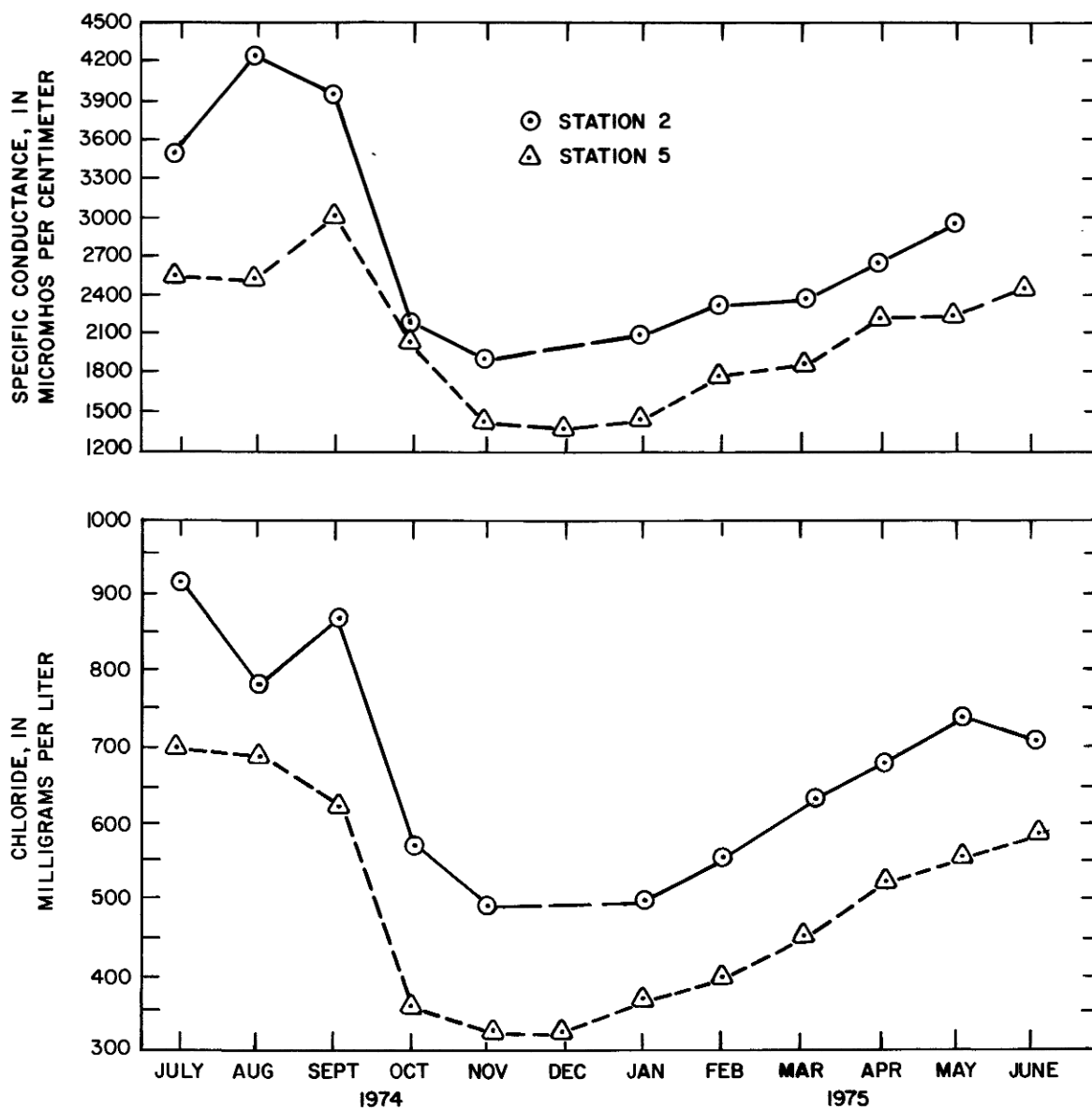


Figure 11.--Seasonal fluctuation in the chloride concentration and specific conductance at stations 2 and 5.







































































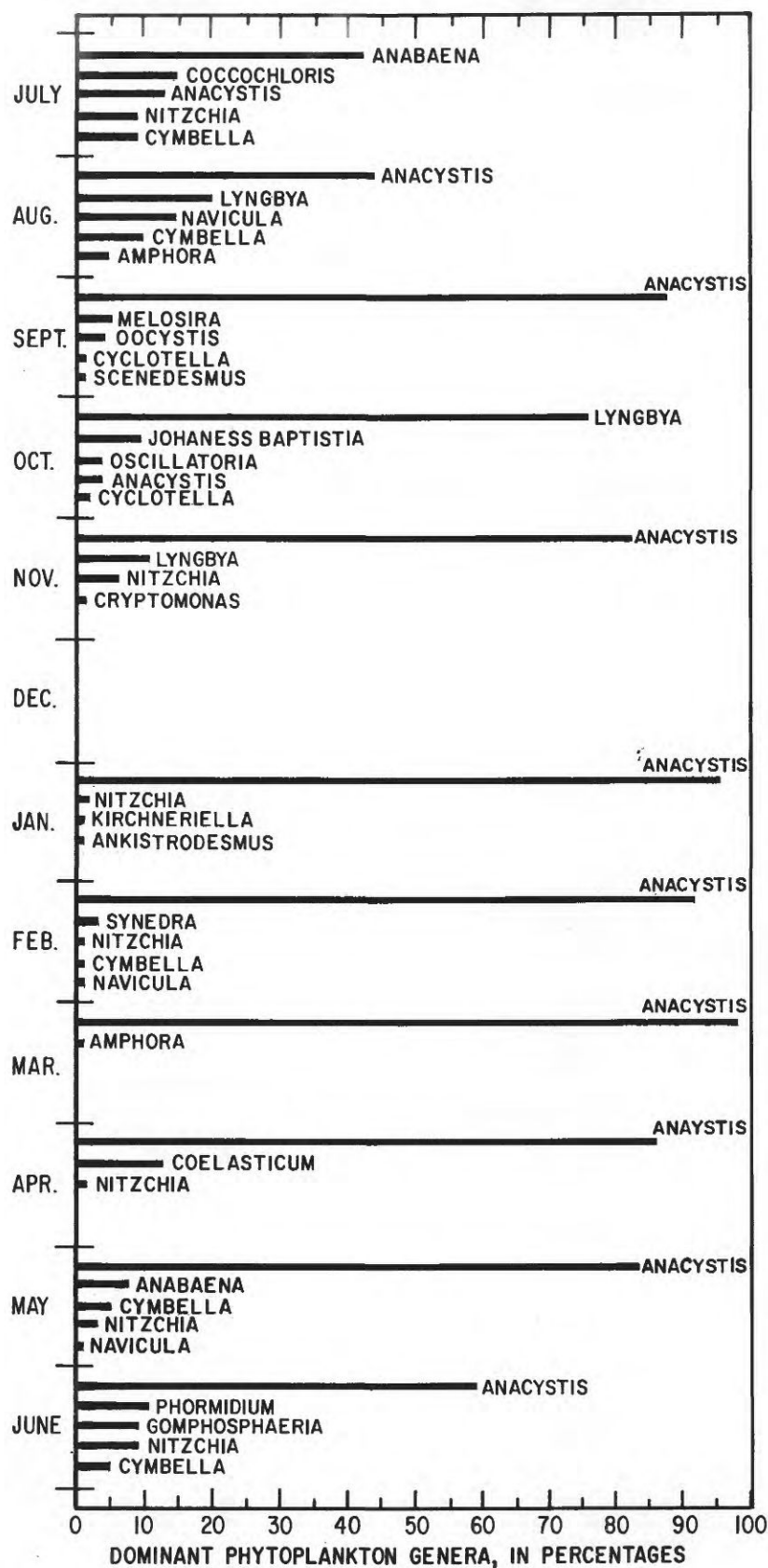


Figure 23.--Seasonal fluctuation in the percent dominance of phytoplankton genera at station 5.

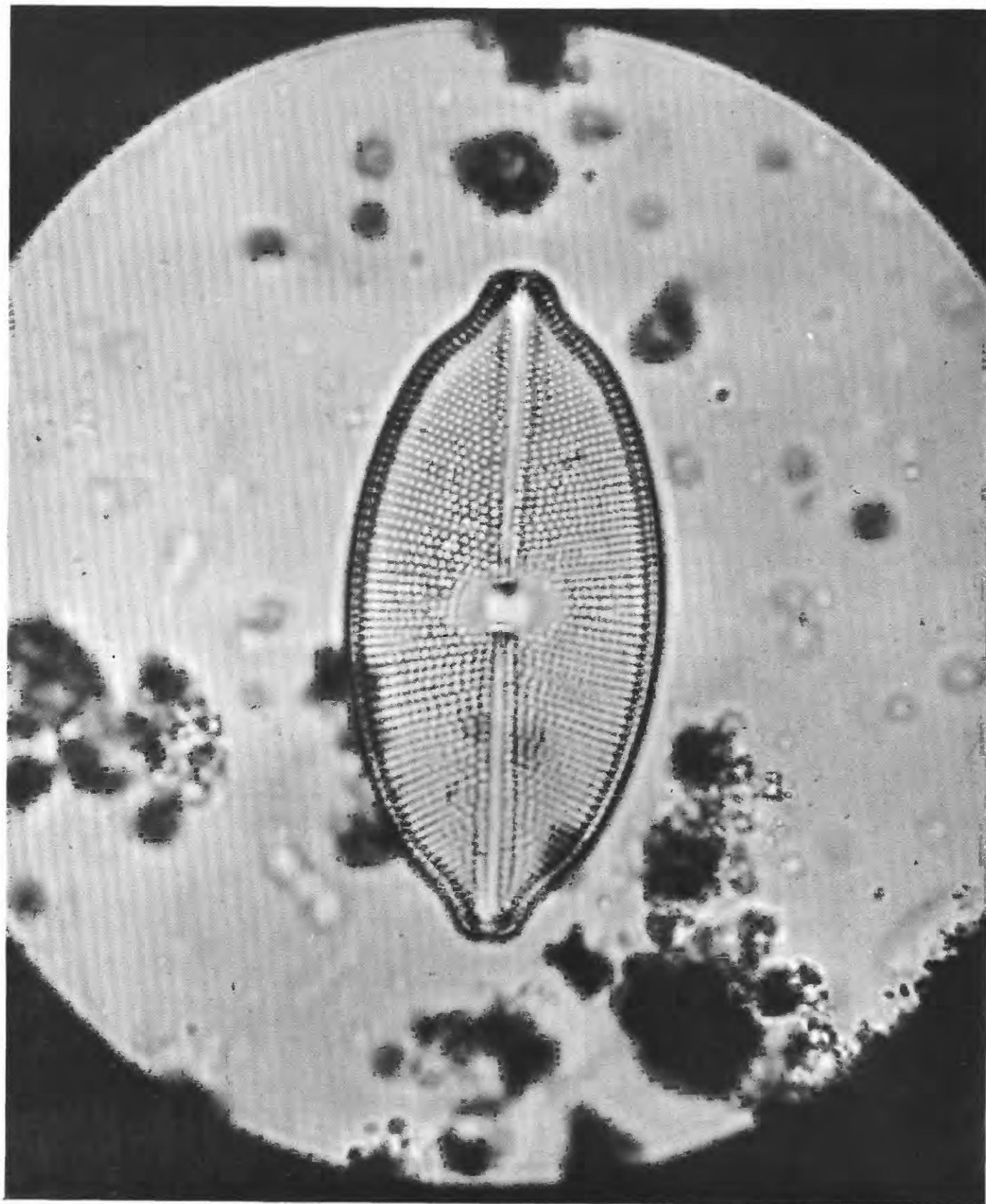


Figure 24.--Navicula sp.



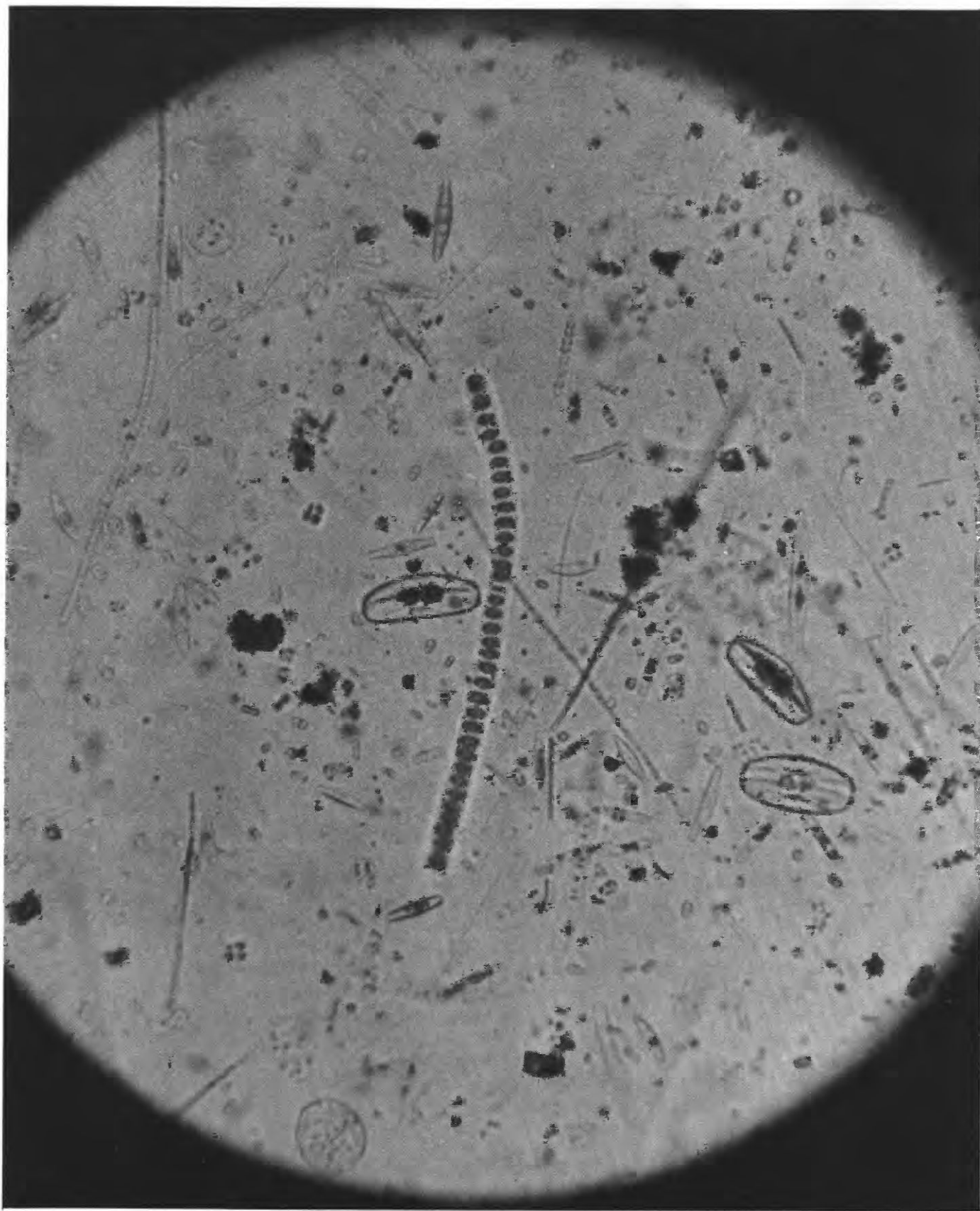


Figure 25.--Periphyton.

The periphyton of Laguna Tortuguero is closely associated with the phytoplankton but it is much more abundant and diverse. The entire bottom of the lagoon is covered by a thick layer of periphytic algae. As previously shown, these algae are responsible for the higher dissolved oxygen concentrations near the bottom as compared with the upper layers in the water column. These mats also may have an effect on redox reactions and possibly pump nutrients from the sediments into the water.

The species of periphyton identified from the lagoon are shown in table 12. Sixty-five species were identified, of which 44 were Chrystophyta (diatoms) and 20 were Cyanophyta (blue-green). An example of the density and diversity of these populations is shown in figure 25. In addition to the diatom species identified, there were many subspecies that could not be identified. Although only qualitative analyses were made of the periphyton, it is obvious that a high diversity exists among these organisms. The pennate diatoms comprise more than 75 percent of all the organisms observed. Future studies in Laguna Tortuguero should include a more detailed investigation of the periphyton.

### Zooplankton

The zooplankton are the animal component of the plankton. Zooplankton feed on bacteria, smaller organisms, detritus and algae. They are a link in the food chain, grazing on other organisms and being consumed by fish. Large populations are characteristic of productive systems. High diversity is typical of ecologically balanced systems, while low diversity implies stresses.

The zooplankton studies in Laguna Tortuguero included identification of most of the species collected, determination of population densities, dominance and seasonal fluctuation. Only those species in the water (swimming or floating) were investigated, although composites of vertical hauls were also collected.

The different zooplankton species identified in Laguna Tortuguero are shown in table 13. Seventeen species were observed, of which 12 were properly identified. Some of the zooplankters shown in table 13 were observed only during short periods during the study. Only Diaptomus dorsalis, Diaphanosoma brachyurum and Filinia opoliensis were collected during each sampling (no samples were collected during December 1974).

The number of zooplankton species identified by Candelas (1974) was 10. Candelas further concluded that the diversity of zooplankton in the lagoon was low. The opposite is shown from this study, more specifically upon consideration of the percent dominance of the principal species.

The number of zooplankton organisms per unit volume is shown in figure 26. Concentrations ranged from 20,000/m<sup>3</sup> to 380,000/m<sup>3</sup>, averaging about 100,000/m<sup>3</sup>. There are no significant differences between stations 2, 4 and 5. The concentrations increased slightly after February 1975, as did the phytoplankton populations (fig. 21). Zooplankton also increased after October.

Table 12.--Species of periphytic algae identified in Laguna Tortuguero,  
Chrysophyta (diatoms)

Navicula

Navicula palpebralis  
Navicula braunii  
Navicula viridis  
Navicula pupula var. capitata  
Navicula inaculata  
Navicula circumtexta  
Navicula decurrens  
Navicula radiosa  
Navicula scutum  
Navicula pseudo. sentiformis

Cymbella

Cymbella lanceolata  
Cymbella cymbiformis  
Cymbella pusilla

Denticula

Denticula thermalis

Asterionella spp.

Amphora

Amphora proteus

Dipeoneis

Dipeoneis elliptica

Cyclotella

Cyclotella meneghiniana

Terpsinoe

Terpsinoe musica

Coratoneis

Coratoneis arcus

Cyrtopleura

Cyrtopleura gibba

Gomphonema spp.

Stauroneis

Stauroneis anceps

Scoliopleura spp.

Eunotia

Eunotia paralella

Anomoeoneis

Anomoeoneis sphaerophora

Mastogloia

Mastogloia smithii  
Mastogloia smithii var.  
lacustris

Neidium

Neidium dubium

Pinnularia

Pinnularia rupestris  
Pinnularia spp.

Synedra

Synedra tabulata  
Synedra ulna  
Synedra delicatissima  
Synedra fasciculata  
Synedra minuscula  
Synedra spp.

Table 12.--Species of periphytic algae identified in Laguna Tortuguero.--  
Continued.

Chrysophyta (diatoms)

Homocladia (Nitzschia)

Homocladia linearis  
Homocladia anuphioxys  
Homocladia fasciculata  
Homocladia spp.

Fragilaria

Fragilaria crotonensis  
Fragilaria spp.

Amphiprora spp.

Cyanophyta (Blue-green)

Gomphosphaeria spp.  
Eucapsis spp.  
Oscillatoria forosa  
Oscillatoria geminata  
Aphonothece spp.

Symploca thermalis  
Coclosphaerium spp.  
Glocothece spp.  
Synechococcus spp.  
Anacystis dimidiata

Anacystis cyanea  
Chroococcus spp.  
Borzia trilocularis  
Aphanoupsa spp.  
Spirulina principis

Glococapsa spp.  
Arthrospira khanuae  
Arthrospira gomontiana  
Phormidium subfuscum  
Johanesbaptistia pellucida

Chlorophyta (Green algae)

Staurostrum furcigerum

Table 13.--Species of zooplankton identified in Laguna Tortuguero.

Species	1974												1975					
	Jul	Aug	Sep	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun						
<u>Brachionus stylifer</u>	x				x	--					x							
<u>Calanoida spp.</u>	x	x	x	x		No samples												
<u>Ceriodaphnia reticulata</u>				x	x		x		x		x							
<u>Cladocera spp.</u>	x				x	No samples		x	x		x	x						
<u>Diaptomus dorsalis</u>	x	x	x	x	x		x		x	x	x	x						
<u>Diaptomus purpureus</u>		x	x	x	x		x		x	x	x	x						
<u>Diaphanosoma brachyurum</u>	x	x	x	x	x		x	x	x	x	x	x						
<u>Filinia opoliensis</u>	x	x	x	x	x		x	x	x	x	x	x						
<u>Halicyclops spp.</u>					x		x	x		x								
<u>Hexarthra mira</u>				x	x		x	x		x	x	x						
<u>Huntemannia lacustris</u>	x	x	x	x					x		x	x						
<u>Keratella americana</u>	x	x	x	x	x			x	x									
<u>Keratella cochlearis</u>	x	x	x	x	x		x	x	x		x	x						
<u>Latonopsis occidentalis</u>		x	x		x		x	x	x	x	x	x						
<u>Ostracoda spp.</u>	x	x		x	x		x	x	x	x	x	x						
<u>Paracyclops fimbriatus</u>																		
<u>Paracyclops sp.</u>								x										

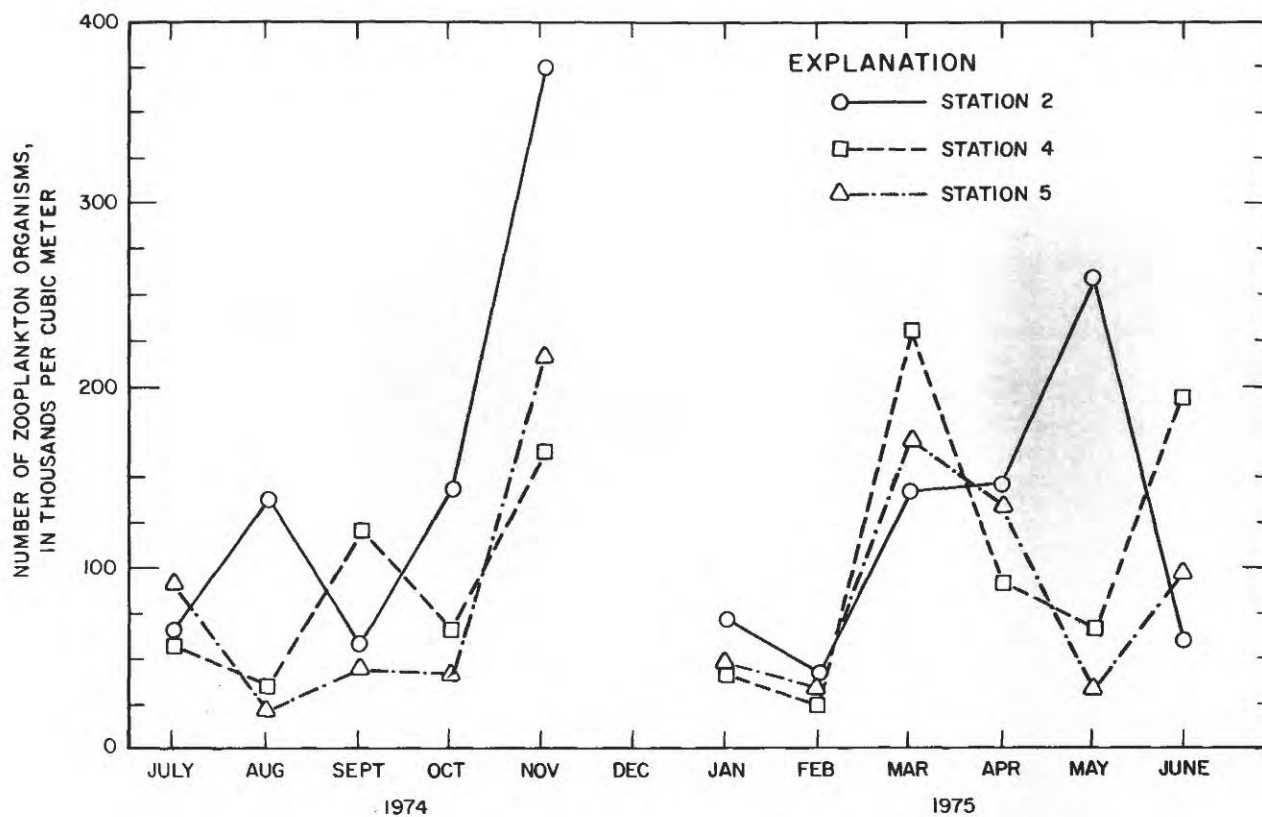


Figure 26.--Seasonal fluctuation in the number of zooplankton organisms at stations 2, 4, and 5.

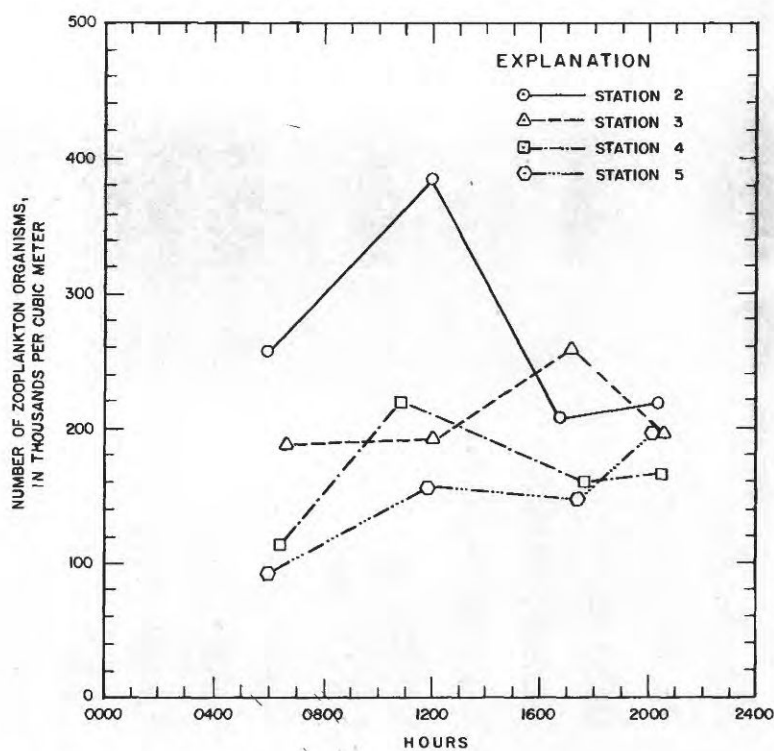


Figure 27.--Diurnal fluctuation in the number of zooplankton at stations 2, 3, 4, and 5, Nov. 26, 1976.



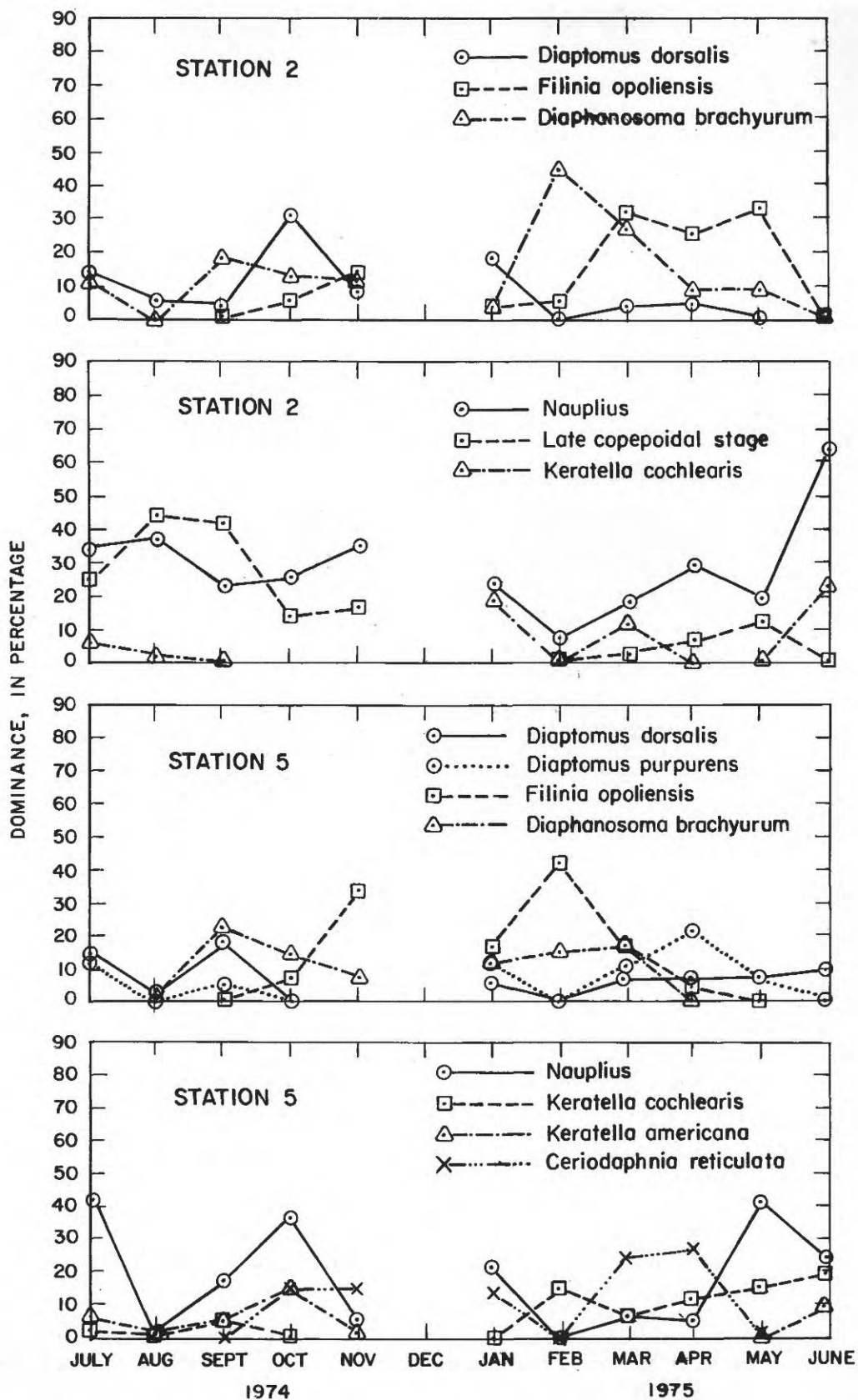


Figure 28.--Percentage dominance of the principal species, nauplius and copepoidal stages of zooplankton at stations 2 and 5.

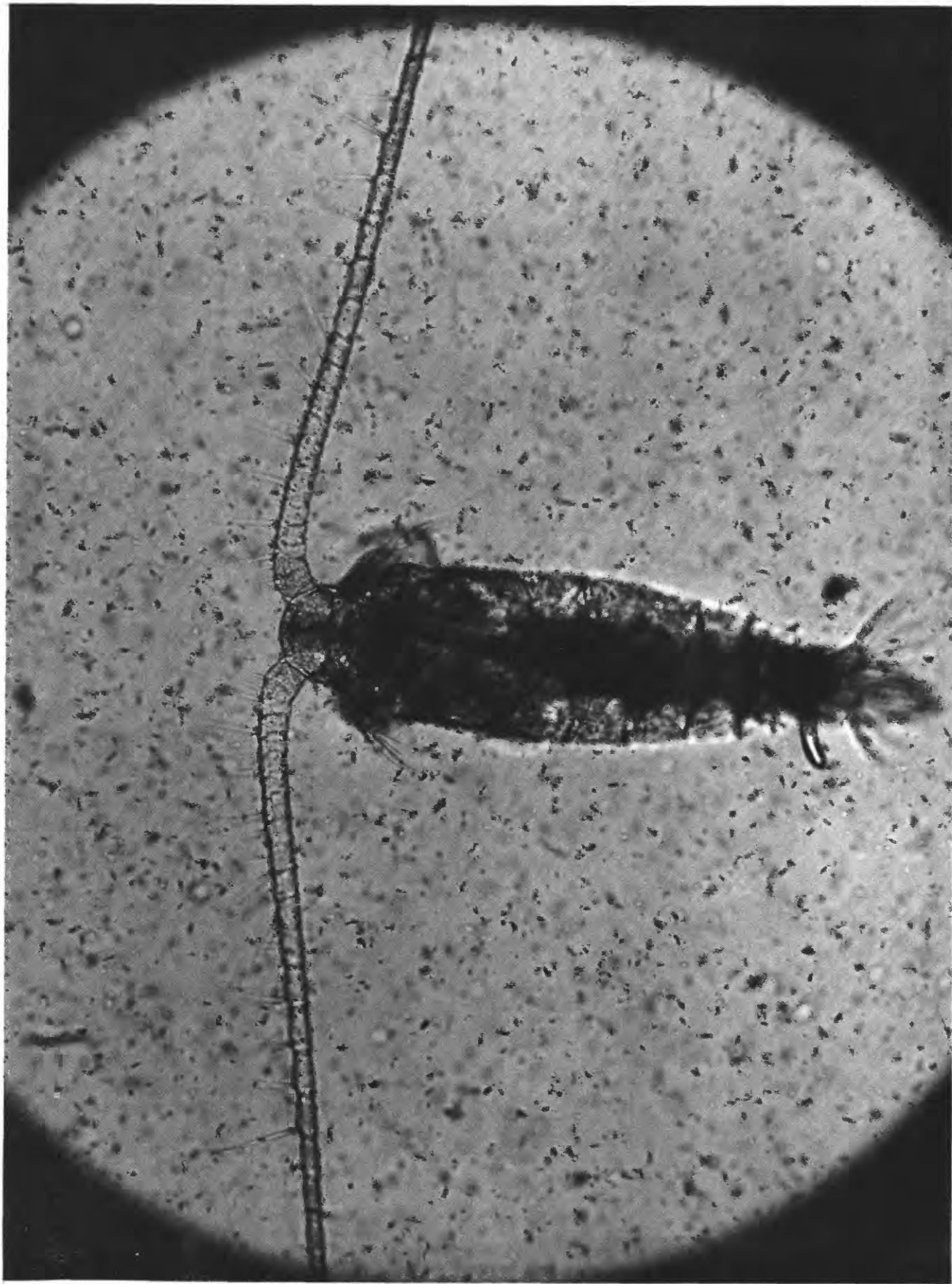


Figure 29.--Diaptomus sp.



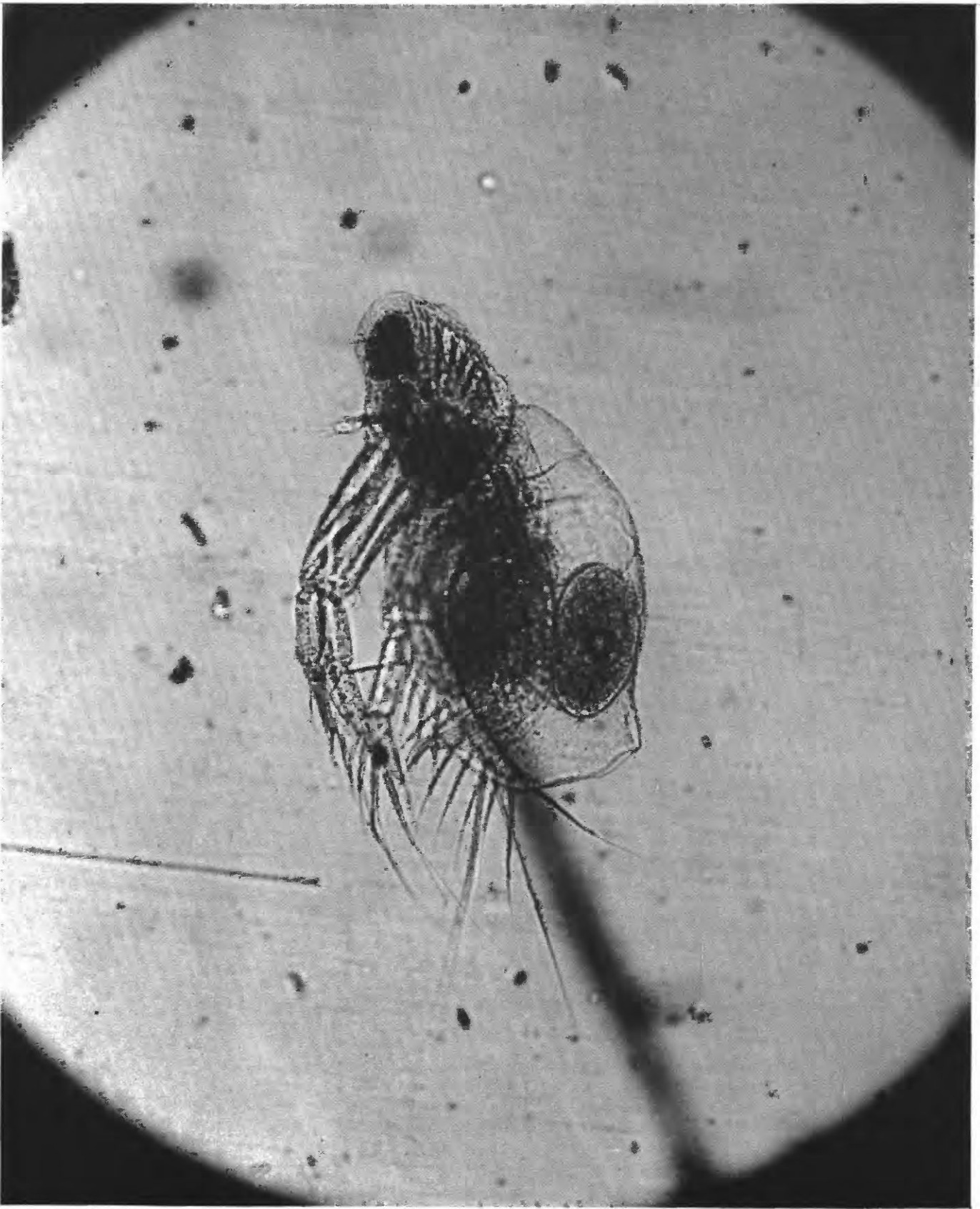


Figure 30.--Diaphanosoma brachyurum.

The zooplankton concentrations in Laguna Tortuguero are typical of productive systems. Similar studies in Lago Loíza, Puerto Rico (written commun., Quiñones, 1976) a very eutrophic lake, showed that the zooplankton concentrations averaged about 1 million/m<sup>3</sup>, ranging from 200,000/m<sup>3</sup> to 3.7 million/m<sup>3</sup>. Although the concentrations in the lagoon are lower than in Lake Loíza, they are much higher than those reported in oligotrophic systems by Brinson (1973).

Of the species shown in table 13, the rotifers comprise nearly one-half of the organisms observed. Rotifers feed mainly on small organic matter particles that are captured by the action of their coronal cilia. The abundance of organic matter in Laguna Tortuguero probably benefits the rotifer population.

Diurnally there were no significant changes in the density of zooplankton throughout the lagoon on November 26, 1974 (fig. 27). In general, higher concentrations were observed at station 2. Although the study did not include the main night hours, a general increase in the number of organisms occurred from the early morning hours to the first night hours. Vertical migrations probably do not occur due to mixing of lagoon water by the wind.

Several species of zooplankton dominate in the lagoon. The percentage dominance of the principal forms is shown in figure 28. None of these were dominant during the entire study period. Only on rare occasions did more than 30 percent of the total population consist of a single species. This suggests a high index of diversity among the zooplankton.

The data in figure 28 show that more species were dominant or codominant in the east part (station 5) than in the west part (station 2). Some species identified in the eastern part were not present in the western part of the lagoon. Throughout the lagoon, Filinia opoliensis and the two species of Diaptomus (fig. 29) are the dominant zooplankters. Filinia, a rotifer, is cosmopolitan in distribution. Diaptomus, a calanoid copepod, includes a large number of species of worldwide distribution. Both Filinia and Diaptomus are characteristic of warm waters, mainly undisturbed systems (Hutchinson, 1967). A specimen of Diaphanosoma brachyurum, also a common cladoceran, is shown in figure 30.

### Fish

The fisheries of Laguna Tortuguero were studied by Reyes de Ruiz (1971), and more recently a reconnaissance was conducted by the Department of Natural Resources of the Commonwealth of Puerto Rico (unpub. rept., 1976). Both studies are qualitative, indicating only the species collected during short runs.

In her 1971 study, Reyes de Ruiz identified 18 species in the lagoon. These are shown in table 14. Some of these (Micropterus salmoides and Tilapia mossambica) were introduced to the lagoon by the Commonwealth Department of Agriculture.

Table 14.--Species of fish identified in Laguna Tortuguero in 1971.

Species	Common name
<u>Anguila rostrata</u>	Anguila
<u>Belonidae spp.</u>	Agujón
<u>Megalops atlantica</u>	Sábalo
<u>Mugil curema</u>	Jarea
<u>Mugil trichodon</u>	Jarea
<u>Agonostomus monticola</u>	Dajao
<u>Centropomus undecimalis</u>	Róbalo
<u>Caranx latus</u>	Jurel ojón
<u>Eleotris pisonis</u>	Morón
<u>Gobiomorus dormitor</u>	Guavina
<u>Dormitatur maculatus</u>	Mapiro
<u>Eucinsotomus pseudogula</u>	Muníama
<u>Gerres cinereus</u>	Rayado
<u>Diapterus rhombeus</u>	Mojarreta
<u>Diapterus plumeri</u>	Mojarra
<u>Micropterus salmoides</u>	Lobina
<u>Lepomis microlophus</u>	Chopa
<u>Tilapia mossambica</u>	Tilapia

The species identified during the 1975-76 reconnaissance are shown in table 15. A total of 14 species were positively identified in the lagoon during the recent reconnaissance. Gerres cinereus was the most common species, accounting for about 93 percent of the fish captured with nets.

Large numbers of fish were not observed during the reconnaissance. The dominance by the Gerres spp. does not indicate a low diversity among the fish, but probably reflects conditions created by continuous fishing with large nets in the lagoon. The overall picture is that there has been no significant change in the fish populations in Laguna Tortuguero since the study in 1971 by Reyes de Ruiz. Some specimens captured by local fishermen during one of our field runs are shown in figure 31.

### Aquatic Plants

The aquatic plants around Laguna Tortuguero were studied in detail by Reyes de Ruiz (1971). During this study only a reconnaissance of the most important plants was made.

Typha domingensis Pers ("eneas," or cattail) is the dominant aquatic plant around the lagoon (fig. 32). Large colonies occupy almost the entire perimeter and even isolated "islands." Typha probably contributes most of the organic matter to the lagoon. Decaying plants abound in the bottom, not only near the shore but throughout the lagoon.

Blechnum indicum and Chara spp. were observed in between the Typha colonies. In terms of abundance these were minor compared with the Typha.

The water hyacinth (Eichornia crassipes), common to most of the lakes in Puerto Rico, was not observed in Laguna Tortuguero. In her study, Reyes de Ruiz reported growing colonies of Eichornia and expressed concern for the possibility that the hyacinth could spread over the lagoon. Eichornia spp. is known to proliferate in systems of high nitrogen and phosphorus concentrations and low salinities. Perhaps the low phosphorus and relatively high chloride concentrations in Laguna Tortuguero check the development of blooms of Eichornia spp. Algal assays to determine the growth potential of Eichornia spp. in waters from Laguna Tortuguero should be made during future studies.

### Community Productivity

The metabolism of plant and animal organisms in an aquatic system produces changes in the concentration of dissolved substances, primarily oxygen and carbon dioxide. The amount of oxygen produced, or organic carbon fixed, may be used as an indicator of the degree of productivity of the system and indirectly as a measure of the extent of eutrophication (Hooper, 1969 and Odum, 1971).

Gross primary productivity of the lagoon community was computed following the methods described by Greeson and others (1970) using the diel data shown in

Table 15.--Species of fish observed in Laguna Tortuguero during December 1975-January 1976.

Species	Common name
<u>Awaous taia</u> sica	Saga
<u>Caranx</u> latus	Jurel ojón
<u>Dormitator</u> maculatus	Mapiro
<u>Diapterus</u> plumieri	Mojarra
<u>Gerres</u> cinereus	Rayado
<u>Gobiomorus</u> dormitor	Guavina
<u>Lepomis</u> microlophus	Chopa
<u>Lophogobius</u> cyprinoides	Morón
<u>Lutjanus</u> apodus	Pargo rubio
<u>Megalops</u> atlantica	Sábalo
<u>Mugil</u> liza	Liza
<u>Mugil</u> curema	Jarea
<u>Pimephales</u> promelas	Mino
<u>Tilapia</u> rendalli	Tilapia



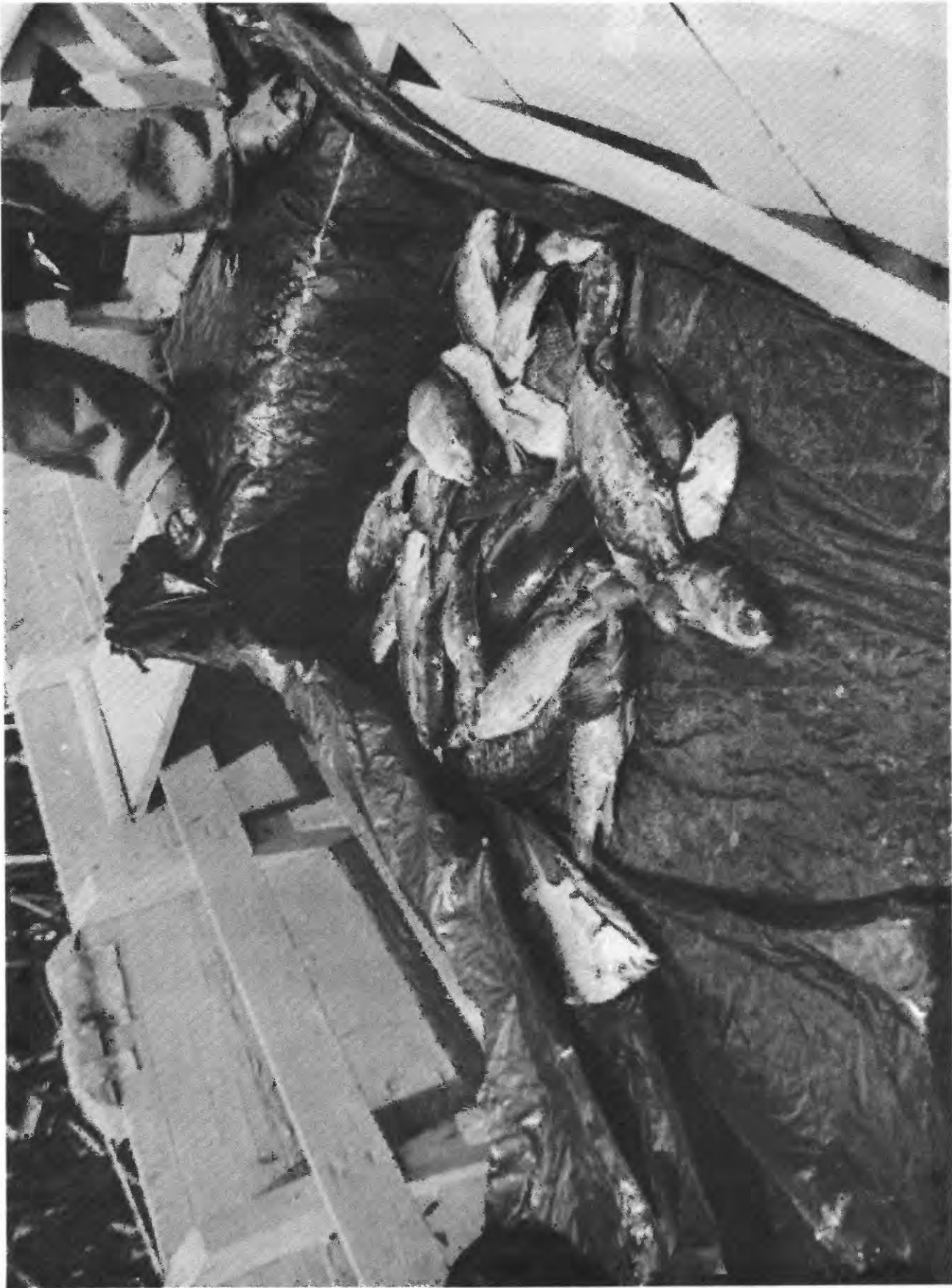


Figure 31.--Fish from Laguna Tortuguero.



Figure 32.--Typha domingensis Pers, the dominant aquatic plant in  
Laguna Tortuguero.

figure 16. On the basis of field observations during the study, a gas transfer coefficient (K) of 2 (g/m<sup>2</sup>)/h was estimated. No corrections were made to the computations for the salinity of the lagoon because this was considered small. Parts of the night hours not included in the study were estimated on the basis of measurements after sunrise and before sunset. Respiration during those hours was estimated as an average between the observed sunrise and sunset hours, or about 0.35 g/m<sup>3</sup>/hr. The data for station 5, including the dissolved oxygen, temperature and oxygen rate curves are shown in figure 33. Computations were based on principles described by Odum and Hoskins (1958) and Greeson and others (1977). Similar results were obtained at stations 2, 3, and 4.

The computations in figure 33 show that respiration on November 26, 1974 in Laguna Tortuguero exceeded gross production by a factor of almost 2. The difference between the oxygen produced and consumed must be supplied from the air by diffusion and air-water mixing due to the wind effect.

#### CHEMICAL, PHYSICAL AND BIOLOGICAL INTERACTIONS IN LAGUNA TORTUGUERO

Laguna Tortuguero is a very complex system reacting to a series of chemical, physical and biological factors. In order to understand these interactions a systems analysis approach must be applied. The scope of this report does not include a complex systems analysis of the lagoon. However, a conceptual model of the most important interactions can be developed as a first step in a possibly more complex model that could be used as a management tool.

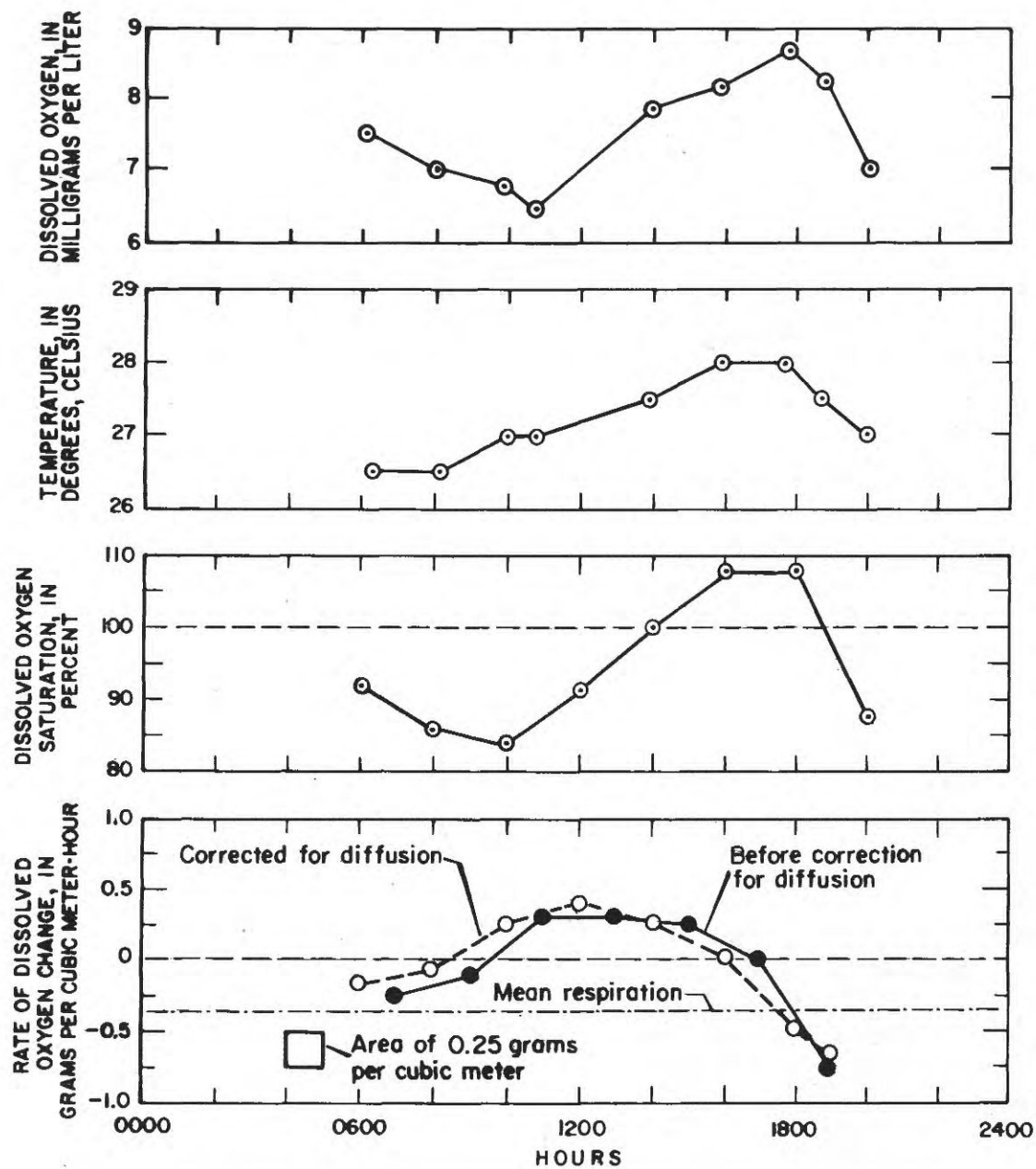
A simplified model of the Laguna Tortuguero system is shown in figure 34. The model is based on concepts described by H. T. Odum (1971). Only the most important flowpaths are shown; otherwise the model would become too complex.

The model shows that the principal external factors that influence Laguna Tortuguero are the wind, solar energy, and flows of water and materials. The wind is an important factor in maintaining a high dissolved-oxygen concentration in the lagoon and in mixing nutrients and organisms. High respiration by the consumers (zooplankton and nekton) and oxygen required to oxidize organic matter would deplete the dissolved oxygen in the lagoon unless replenished by diffusion.

The wind is also an important element in the lagoon's circulation. It blows most of the time in a westerly direction, restricting the movement of water from the western to the eastern part of the lagoon.

The sun provides the necessary energy to maintain the lagoon's producers in constant activity. Although the lagoon has a low phytoplankton population, periphyton is abundant and diverse. The transparency of the waters in the lagoon allows light transmission to the periphyton layer, promoting high productivity.





Depth=2.0 meters

Gross productivity=9.8 grams of oxygen per cubic meter per day

Respiration=16.8 grams of oxygen per cubic meter per day

Figure 33.--Dissolved oxygen curve and complementary information used for community primary productivity computations at station 5. Data for Nov. 26, 1974.

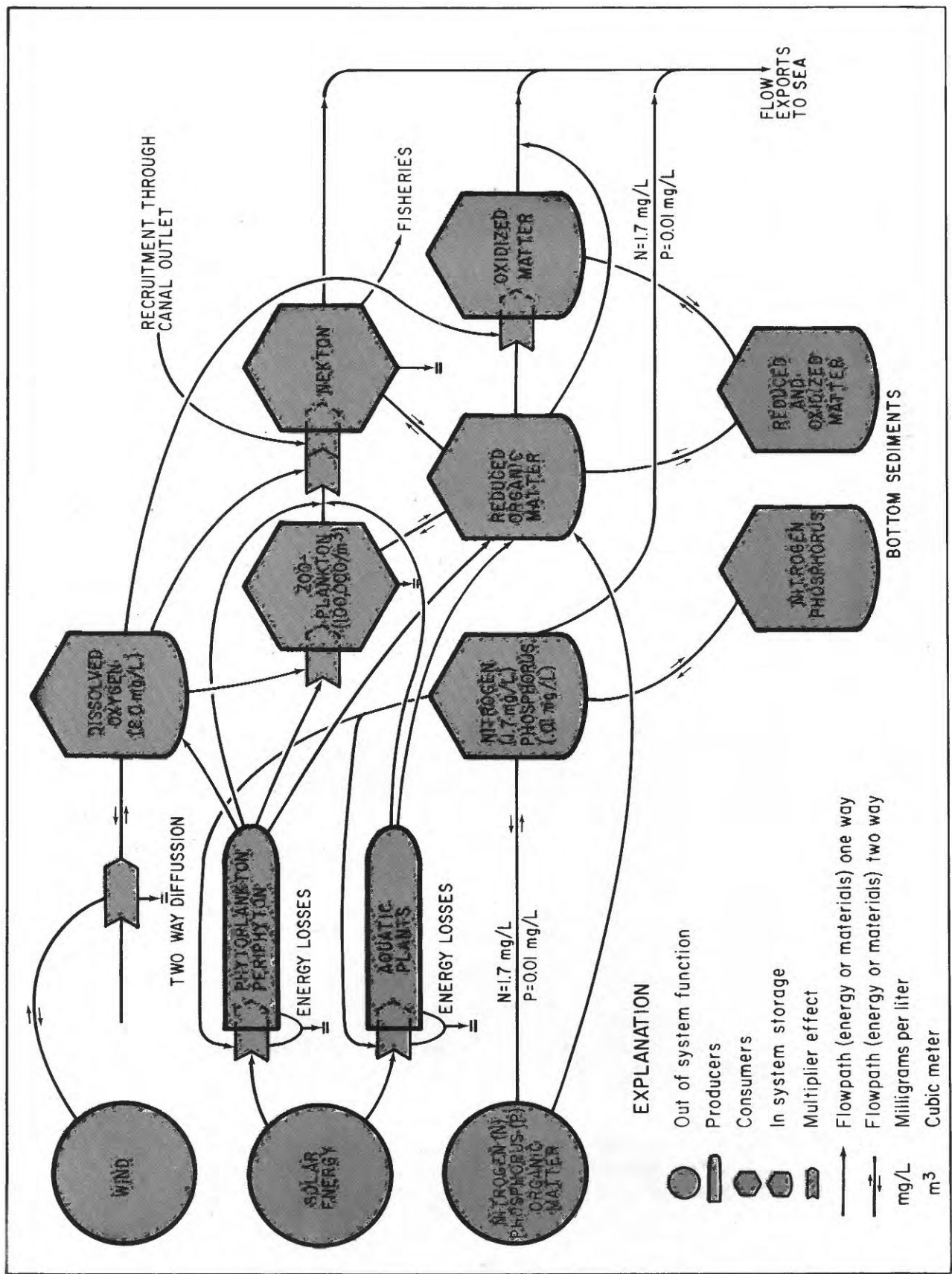


Figure 34.--Simplified model of the principal interactions in the lagoon.

The flow of materials into and out of Laguna Tortuguero is regulated by other factors not shown in the model, such as precipitation, ground-water flow, and so forth. The water-budget model shown in figure 7 details some of these components.

The external forces on Laguna Tortuguero interact to maintain the present system. Nutrients flowing into the lagoon maintain high nitrogen but low phosphorus concentrations in the water. The nutrients are utilized by the phytoplankton, periphyton and macrophytes. Some of the nutrients in the water precipitate and are stored in the sediments. The model shows a two-way flow between the water and the sediments. This exchange between water and sediments can be prompted by several conditions, among which are the availability of reactive cations (iron and manganese), their oxidation state, biochemical reactions, and so forth. The oxidation states of the ions may be regulated by the dissolved oxygen concentration in the water. The model does not show the interaction between dissolved oxygen and nutrients exchange with the sediments. Details of this mechanism are discussed by Stumm and Leckie (1970). The sediments constitute a nutrient sink that, under the proper conditions, can be triggered to release these to the water.

Most of the nutrients flowing into Laguna Tortuguero are discharged to the ocean and the concentration in the "nutrient pool" is maintained nearly constant. Short-circuiting of this flowpath, or the one providing nutrients to the plankton or macrophytes would most likely cause an increase in the nutrients in the water. This would in turn probably promote rapid increase in the algal populations. Community productivity would then increase, but so would the consumer populations. The fish population would also increase as a result of the more abundant plant and animal food sources. These potential developments are checked by a factor limiting the system's productivity. Phosphorus is probably the limiting factor. A more detailed model would show the present phosphorus concentration connected to a threshold sensor which in turn would operate a "switch" in the system. The threshold would be the phosphorous concentration beyond which increased productivity occurs. Concentrations exceeding the threshold value would prompt the switch to activate and induce the changes outlined.

The dissolved-oxygen subsystem of the model is important to our understanding of the conditions in the lagoon and aids in the prediction of what may happen if changes are induced. Oxygen flows into the lagoon from the air and is produced on site by phytoplankton and periphyton. Zooplankton (in large numbers) and fish (in relatively small numbers) are the primary consumers. The dissolved oxygen "tank" is connected to the organic matter subsystem. Oxygen is utilized to oxidize the organic matter in the lagoon deposited by macroscopic aquatic plants. At present, the amount of organic matter in the water is low. Biochemical oxygen demands (BOD-5) average less than 2.0 mg/L. However, the oxygen demand may be higher than what the BOD tests indicate. Respiration rates measured during the BOD tests do not account for high turnover rates.

Total organic carbon (TOC), a measure of the amount of carbonaceous material in the water, averages about 10 mg/L. Systems with high organic loading from sewage exceed TOC concentrations of 50 mg/L (Colston, 1974). The amount of dissolved oxygen, therefore, required to oxidize the organic matter is proportionally low.

A combined balance around the dissolved-oxygen pool in the lagoon would show that the wind is the primary source and the consumers are the primary sinks. If the organic loading to the lagoon were increased, a shift in the "level" in the oxygen "tank" would occur. If the organic-matter oxygen requirements were to reach a disproportionally high level, the wind "subsidy" would not be adequate to supplement the on site production. Instead of an average of 8.0 mg/L of dissolved oxygen, the system would attain a steady state at a lower level. If the organic loading is high enough, the equilibrium dissolved oxygen concentration can be lower than the minimal required for certain organisms. Dominance of the most tolerant ones, with loss of diversity would then follow. Low dissolved-oxygen concentration would also trigger the release of nutrients from the sediments as the oxidized insoluble precipitates were reduced to more soluble forms.

The nekton in the lagoon are affected by imports and exports through the canal outlet. Species capable of high tolerance in the nearly fresh waters in the lagoon migrate from and to the ocean. They graze on the plant communities (phytoplankton, periphyton and aquatic plants) and zooplankton. Insects and small organisms, also a source of food to the nekton, are not shown in the model.

The impact of other changes in the lagoon and its vicinity could be analyzed from the model. If considerable land around the lagoon were disturbed, increasing the amount of suspended sediment flowing into it, several changes could occur. Turbidity would increase in proportion to the amount of particles suspended. The transparency of the lagoon's water would be reduced, decreasing the transmission of light and the productivity of the periphyton. The "oxygen pool" could be lowered, affecting all the other communities in the lagoon.

The model does not consider the interrelation of the ground water and drainage system, but a separate model could be designed and coupled to it. Changes in the drainage system could have a severe impact on the lagoon. If the outlet channel were to be deepened (as proposed by a now defunct harbor project for the lagoon) seawater would flow in large quantities into the lagoon. The entire system would change from a nearly fresh to a brackish environment. Only the most tolerant freshwater species would survive and a succession of marine organisms (or those adapted to brackish systems) would dominate the lagoon. During intense storms, salinities would probably change drastically, exposing the organisms in the lagoon to nearly freshwater. Only a few organisms are capable of adapting rapidly to these changes. Species diversity would undoubtedly be reduced.

Only major interferences with the ground-water system in the lagoon would cause a significant impact on it. The magnitude of the ground-water discharges into the lagoon is large enough to withstand some disturbances. But if interception is large enough, the salinities in the lagoon would increase in proportion to the reduction in freshwater inflow. The changes already described would probably occur.

Proposed urban developments in the vicinity of Laguna Tortuguero could also trigger drastic changes in the lagoon's subsystems. Urban developments are characterized by increases in runoff. Fertilizers applied to lawns are partially leached and carried away by runoff. Colston (1974) reported average total phosphorus concentrations ranging from 0.3 to 1.5 mg/L in urban runoff in North Carolina. As previously shown, phosphorus is probably limiting the algal growth in the lagoon. If urban runoff from proposed developments is discharged into the lagoon, the potentially ample phosphorus supply could induce the development of algal blooms to nuisance levels. The water hyacinths, now absent from the lagoon environment, likely could proliferate with the added nutrients.

Finally, the model does not include the impact of chemical pollutants, such as organics or heavy metals. Discharges of organics or heavy metals into the lagoon would have an impact proportional to the concentration of the pollutants. Both organics and heavy metals accumulate in living tissue. Death of some organisms occurs due to extremely high concentrations of these components (National Academy of Science, 1972).

#### SUMMARY AND CONCLUSIONS

A comprehensive study of the limnology of Laguna Tortuguero was conducted from July 1974 to June 1975 by the U.S. Geological Survey in cooperation with the Commonwealth of Puerto Rico.

The lagoon has a surface area of 2.24 km<sup>2</sup>, with a volume of about 2.68 Mm<sup>3</sup> (water-surface elevation of 0.47 m above mean sea level) and mean depth of 1.2 m. The shoreline length is about 15.3 km while the maximum length is 4.6 km and the maximum width 1.0 km.

During the study period a total of 1,521 mm of precipitation was recorded near the lagoon, contributing about 3.41 Mm<sup>3</sup> of water to it. Evapotranspiration from the lagoon was estimated as 1,274 mm, or about 2.85 Mm<sup>3</sup>.

The lagoon is drained through a canal on its north side. The canal, about 0.6 km long, 8.5 m wide and 1.0 m deep discharges an average of 0.64 m<sup>3</sup>/s. Total discharge during the year of study of 20.1 Mm<sup>3</sup> is equivalent to a flushing rate of 7.5/yr. The high flushing rate is a factor in the export of nutrients and organic matter from the lagoon.

Chemical analyses throughout the lagoon show higher concentrations of ions in the western part than in the eastern part. Poor circulation in the west as compared with the east, as well as evaporation, results in the concentration of ions.

Chloride and sodium are the principal ions in the water. Seawater flowing into the lagoon from the zone of diffusion contributes most of the chloride and sodium, as well as sulfate and magnesium. The chloride concentration ranged seasonally from 300 to 700 mg/L, while that of sodium ranged from 150 to 400 mg/L. The large fluctuations were due to extreme dilution during the storm of October 1974. Specific conductance values, a measure of the dissolved solids, ranged from 1,500 to 2,800  $\mu\text{mho/cm}$  at 25°C in the eastern part and from 2,000 to 4,300  $\mu\text{mho/cm}$  in the western part. The pH of the water in the lagoon fluctuated seasonally from 6.8 to 8.2 units.

Nitrogen is the principal nutrient in the water in Laguna Tortuguero, exceeding phosphorus by a weight ratio of about 170:1. Total nitrogen concentrations averaged 1.7 mg/L, while phosphorus averaged 0.01 mg/L, suggesting that phosphorus is probably the limiting factor in the phytoplankton growth in the lagoon.

The nutrient budget of the lagoon shows that precipitation contributed about 1.9 tonne of nitrogen and 0.35 tonne of phosphorus. A total of about 31.3 tonne of nitrogen and 0.31 tonne of phosphorus was contributed to the lagoon from ground and surface-water flows. The lagoon exported to the sea 34.0 tonne of nitrogen and 0.42 tonne of phosphorus.

Concentrations of selected heavy metals in the lagoon fluctuated during two samplings from zero to a maximum of 67 micrograms per liter for nickel. Pesticides were not detected in the waters, but residues of DDT, DDD and dieldrin were detected in the sediments.

The dissolved oxygen concentration throughout the lagoon exceeds saturation values most of the time. Monthly measurements ranged from 7 to 11 mg/L, averaging about 8.2 mg/L. The dissolved-oxygen concentration increases toward the bottom as a result of oxygen production by periphyton. Diurnally, concentrations fluctuated from 6 to 11 mg/L. The wind plays an important role in diffusing oxygen into the lagoon's water.

Temperatures throughout the lagoon fluctuate seasonally from about 24 to 31 degrees Celsius. There are no vertical temperature gradients.

The bottom sediments in Laguna Tortuguero occupy a volume of about 4.5  $\text{Mm}^3$ , or 1.7 times the water volume. The sediments are composed primarily of calcium carbonate precipitated from ground water flowing from the Aymamón aquifer. Organic carbon averages about 6.8 percent by weight of the sediments. Decaying littoral plants are the primary source of organic material to the sediments. Among the nutrients, nitrogen comprises about 0.8 percent of the sediments, while phosphorus averages about 0.014 percent. The sediments constitute a sizable nutrients storage area.

Bacterial counts among the coliform group are very low throughout the lagoon, indicating excellent sanitary conditions. Small numbers of fecal coliform and fecal streptococci are contributed from cattle grazing in the vicinity of the lagoon.

Phytoplankton concentrations throughout the lagoon are low compared with other systems in Puerto Rico. Concentrations average about 6,000 cells/mL. A total of 47 genera of phytoplankton were identified, 16 of which were diatoms and 12 blue-green algae. Anacystis, a blue-green algae typical of eutrophic systems is the principal algae, dominating or codominating during about 90 percent of the observations.

Periphyton covers the entire lagoon bottom. A total of 65 species of periphyton were identified. Among these 44 were pennate diatoms, while 20 were blue-green algae.

The zooplankton in the lagoon are characterized by average concentrations of 100,000 organisms/m<sup>3</sup>, mostly rotifers. A total of 17 species were identified, among which Diaptomus dorsalis, Diaphanosoma brachyurum and Filinia opoliensis are dominant. A high diversity among the zooplankton was indicated from relative percent dominance studies.

Data from the Commonwealth Department of Natural Resources show a high diversity among the fish in the lagoon. Fourteen species were identified during December 1975, although a single species (Gerres cinereus) dominated the populations.

Typha dominguensis Pers ("eneá") is the dominant emergent aquatic plant throughout the lagoon, occupying about 90 percent of its shoreline. Typha contributes most of the organic load to the lagoon.

Community productivity studies indicate that the lagoon's total respiration exceeded gross productivity by a 2 to 1 factor on November 26, 1974. Prevailing east to northeast winds promote diffusion of oxygen into the lagoon's water. The overall productivity of the lagoon is comparable to that of eutrophic systems. Most of the productivity is from the periphyton layer.

A systems analysis of the lagoon shows that many factors are interacting in it. Water flow, nutrients, and the dissolved oxygen concentration are the most important factors. Changes in the hydraulic system, increases in the phosphorus load, or reduction of the dissolved oxygen concentration could cause dramatic changes in the lagoon's populations. To maintain its present steady state, disturbances of the lagoon should be kept to a minimum.

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## GLOSSARY

Alga, algae (n), algal (adj).--A group of plants, mostly aquatic, single-celled, colonial, or multicelled, containing chlorophyll and lacking roots, stems and leaves.

Algal bloom (n).--A large number of a particular algal species, often amounting to 0.5 to 1 million cells per liter.

Allochthonous (adj).--Originating outside the area under consideration. See also Autochthonous.

Amino acid (n).--A class of nitrogen-containing organic compounds, large numbers of which become linked together to form proteins.

Anaerobe (n), anaerobic (adj).--An organism living or growing in the absence of free oxygen.

Aquatic (adj).--Pertaining to water; aquatic organisms, such as phytoplankton or fish, live in or on water.

Average flow.-- The average yearly discharge at a particular station, obtained from the sum of the annual total discharges of n years divided by the same number of years.

Bacterium, bacteria (n), bacterial (adj).--Microscopic unicellular organisms, typically spherical, rod-like, or spiral and thread-like in shape, often clumped into colonies. Some bacteria cause disease, others perform an essential role in the recycling of materials; for example, by decomposing organic matter into a form available for reuse by plants.

Biochemical oxygen demand (BOD).--The amount of oxygen required by bacteria while stabilizing decomposable organic matter under aerobic conditions. BOD-5 is a 5-day determination of the oxygen requirement for a known volume of water.

Biology (n), biological (adj).--The science or study of organisms.

Bloom (n).--See Algal bloom.

Carnivore (n).--An organism that obtains its nourishment by consuming other animals; includes many fishes and aquatic insects.

Clinograde.--The stratification curve of temperature or of a chemical substance in water that exhibits a sloping profile from the surface downward into deeper water.

## GLOSSARY--Continued

Coliform bacteria (n).--A particular group of bacteria used as indicators of possible sewage pollution. They are formally characterized as aerobic, and facultative anaerobic, gram-negative, nonspore-forming, rod-shaped bacteria which ferment lactose with gas formation within 48 hours at 35°C.

Convective.--Flow originated by heat differentials. Climatologically it implies precipitation which originates when warm air rises against the windward side of a mountain, and upon contact with the colder upper layers.

Cultural eutrophication.--The acceleration of the natural process of nutrient enrichment in a lake as a result of man's activities.

Detritus (n).--Fragmented material of inorganic or organic origin.

Diatom (n).--A unicellular or colonial alga having a siliceous shell.

Diel (adj).--Relating to a 24-hour period that usually includes a day and the adjoining night.

Diurnal (adj).--Relating to daytime or something recurring every day, often used as a synonym for diel.

Diversity.--The abundance in numbers of species in a specified location.

Drainage basin.--A part of the surface of the earth that is occupied by a drainage system, which consists of a surface stream or a body of impounded surface water together with all tributary surface streams.

Ecology (n), ecologic(al) (adj).--The science or study of the relation of organisms or groups of organisms to their environment.

Ecosystem (n).--The community of plants and animals interacting together with the physical and chemical environment.

Environment (n).--The sum of all the external physical, chemical, and biological conditions and influences that affect the life and development of an organism.

Epilimnion (n).--The upper, relatively warm, circulating zone of water in a thermally stratified lake.

Euphotic zone (n).--That part of the aquatic environment in which the light is sufficient for photosynthesis; commonly considered to be that part of a water body in which the intensity of underwater light equals or exceeds 1 percent of the intensity of surface light.

## GLOSSARY--Continued

Eutrophication (n), eutrophic (adj).--Enrichment of water, a natural process that may be accelerated by the activities of man; pertaining to waters in which primary production is high as a consequence of a large supply of available nutrients. See also Oligotrophic.

Evapotranspiration.--Water withdrawal from the soil, a body of water, etc., by evaporation and plant transpiration.

Fecal coliform bacteria (n).--That part of the coliform group that is present in the gut or the feces of warmblooded animals; they are indicators of possible sewage pollution.

Fecal streptococcal bacteria (n).--A particular group of bacteria found in the gut of warmblooded animals; their presence in natural waters is considered to verify fecal pollution. They are formally characterized as gram-positive, cocci bacteria which are capable of growth in brain-heart infusion broth either at 45°C and 10°C (the enterococci species) or at 45°C only (Streptococcus bovis and S. equinus).

Flushing rate.--The ratio between the annual discharge into a lake (or other water body) and the lake volume.

Genus, genera (n), generic (adj).--The taxonomic categories below family, consisting of species; the first part of the scientific name of organisms. See also Taxonomy.

Gross primary productivity (n).--The total rate at which organic matter is formed by photosynthesis, including the organic matter used up in respiration within the period of measurement. The term is synonymous with gross primary production, total photosynthesis, and total assimilation.

Habitat (n).--The place where an organism lives.

Herbicide.--Chemical or a mixture of chemicals intended to control or destroy vegetation.

Hypolimnion (n).--The lower, relatively cold, noncirculating water zone in a thermally stratified lake.

Limnology (n).--The area of science concerned with the characteristics of inland waters, the forces and procedures which mold and maintain the integrity of these waters, the interrelationship between water and basin, and the community of living organisms inhabiting the environment.

Macrophyte (n).--Large plants that can be seen without magnification, includes mosses and seed plants.

## GLOSSARY--Continued

Mean annual flow.--The average daily discharge at a particular station, obtained from the sum of the daily discharges in a year divided by the number of days in the same year.

Mean depth.--The volume of the lake divided by its area.

Membrane filter (n).--A thin microporous material of specific pore-size used to filter bacteria, algae, and other very small particles from water.

Metabolism (n).--The chemical processes of living cells by which energy is derived and material is assimilated.

Net community productivity (n).--The rate of storage of organic matter not used by the organisms in the environmental area under study during the period of measurement; net primary productivity minus heterotrophic utilization.

Niche (n).--The location and ecological function of an organism in the environment.

Nutrient (n).--Any chemical element, ion, or compound that is required by an organism for the continuation of growth, for reproduction, and for other life processes.

Periphyton (n).--The entire community of microorganisms that are attached to or live upon submerged solid surfaces. Includes algae, bacteria, fungi, protozoa, rotifers and other small organisms.

Pesticide.--Any substance used to kill plants, insects, algae, fungi, and other organisms; includes herbicides, insecticides, algacides, fungicides, and other substances.

pH.--The negative logarithm of the hydrogen-ion concentration, expressed as a number from 0 to 14. A pH of 7 is neutral, a pH of less than 7 is acidic, and a pH of greater than 7 is basic.

Photosynthesis (n), photosynthetic (adj).--A biochemical synthesis of carbohydrates from water and carbon dioxide in the chlorophyll-containing tissues of plants in the presence of light.

Phytoplankton (n), phytoplanktonic (adj).--The plant part of the plankton.

Plankter (n).--An individual planktonic organism.

Plankton (n), planktonic (adj).--The community of suspended or floating organisms which drift passively with water currents.

## GLOSSARY--Continued

Pollution (n).--"an undesirable change in the physical, chemical, or biological characteristics of our air, land, and water that may or will harmfully affect human life or that of other desirable species, our industrial process, living conditions, and cultural assets; or that may or will waste or deteriorate our raw material resources." (Natl. Research Council, Comm. on Pollution, 1966, p. 3).

Population (n).--A group of interacting and interbreeding individuals of the same type living in a common habitat and having little reproductive contact with other groups of the same species.

Primary productivity (n).--The rate at which radiant energy is stored by photosynthetic and chemosynthetic activity of producer organisms (chiefly green plants) in the form of organic substances which can be used as food materials (Odum, 1971, p. 43). See also Gross primary productivity and Net community productivity.

Production (n).--The total amount of living matter produced in an area per unit time regardless of the fate of the living matter.

Respiration (n).--A life process in which carbon compounds are oxidized to carbon dioxide and water and the liberated energy is used in metabolic processes.

Sample (n).--A small separated part of something that is representative of the whole.

Secchi disk.--A circular metal plate, 20 centimeters in diameter, the upper surface of which is divided into four equal quadrants painted black and white. Variations in size and painted only in white are used. (The disk is lowered into the water and the average depth at which it is no longer visible is denominated as the "secchi disk transparency.")

Sediment (n).--Fragmental material, both mineral and organic, that is in suspension or is being transported by the water mass or has been deposited on the bottom of the aquatic environment.

Species (n, sing. and pl.).--The basic unit for the classification of organisms; the taxonomic category below genus, and the second part of the scientific name of an organism. See also Taxonomy. The biological concept of species, in contrast to the purely taxonomic concept, has been defined by Mayr (1940) as ". . . a group of actually or potentially interbreeding organisms reproductively isolated from other such groups of interbreeding organisms."

Suspended sediment (n).--Fragmental material, both mineral and organic, that is maintained in suspension in water by the upward components of turbulence and currents or by colloidal suspension.







