LIMNOLOGY AND POLLUTION

IN LAKE VALENCIA, VENEZUELA

by

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INTRODUCTION

Lake Valencia is the largest natural freshwater lake in Venezuela.

The lake is located in one of the most populated areas in the country and its

watershed possesses approximately 8% of the total population, with a density of

350 persons/km^2.

Increasing population in the watershed, coupled with rapid expansion of

industry and agriculture, has caused gross environmental contamination in Lake

Valencia. Once known for its great beauty and potential natural resources, Lake

Valencia water quality is currently undergoing a rapid deterioration.

The eutrophication of Lake Valencia has long been accelerated by the

pronounced natural desiccation and greatly enhanced by modern human activity in

the lake basin.

The desiccation phenomenon and its effect on lake hydrological balance was

first reported by von Humbolt (1856) and more recently by Bockh (1956), Cartaya

and Montano (1969), and MARNR (1980). Although several investigations have been

devoted to pollution problems in the lake (INOS 1971, Torrealba and Cardenas

1972, AVIS 1973, and Fuchs and Mosqueda 1975), little effort has been made to

obtain more basic and comprehensive limnological information.

As most available documents on eutrophication and pollution in the

freshwater environment were obtained from the northern temperate region, the

problems and consequences associated with those processes in tropical lakes are

relatively unfamiliar. Therefore, investigation on the fundamental limnological

features in Lake Valencia would generate valuable scientific information which,

in turn, may provide a practical guideline for improving water quality and

managing the resources of this aquatic ecosystem.

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Several specific objectives were set in the present project:

1. To measure the velocity and direction of water movement. This information is essential in order to understand the mixing process of the water mass and dispersion patterns of contaminants from point sources.

2. To measure the light penetration and transparency in the lake water. The light regime in the water column is of primary importance for determining the depth of the euphotic zone which governs phytoplankton production.

3. To analyze major nutrients, trace metals, and organic contaminants in lake water.

4. To document the community composition and succession of planktonic organisms and their environmental factors.

5. To survey the submerged and emerged macrophytes.

6. To survey the pollutant inputs of three major tributary inflows: Rio los Guayos, Rio Guey, and Caño Central.

GENERAL PROJECT PLAN

To meet the project objectives, six cruises were conducted approximately bimonthly from January to December 1978. The exact schedule and activities for each cruise are listed in Table 1. All the cruises were carried out with a 24-ft Rotork boat. A normal cruise required five persons on shipboard to undertake all research activities.

The general survey was conducted at 40 stations distributed evenly on a grid of 3 km between neighbor stations (Fig. 1). Several field parameters were measured at each of the 40 stations, and 17 of those stations were selected for chemical and biological sampling. Those samples were delivered to either the field laboratory in Valencia or the central laboratory in El Hatillo.

Each cruise included four types of investigations: (1) monitoring and sampling for physical-chemical properties and plankton, (2) measuring primary productivity of phytoplankton, (3) monitoring dissolved oxygen, current, and diurnal cycle of temperature, (4) monitoring pollutant dispersion in Rio Los Guayos and Rio Guey.

Measurement of primary productivity of phytoplankton was carried out _in situ_ at three fixed stations (17, 20, and 23), located in the western, central, and eastern parts of the lake respectively. The diurnal changes of pH, dissolved oxygen, temperature, and current were monitored throughout the water column during 12-24 hours at the central location of the lake (station 20). The last part of each cruise involved the monitoring of the dispersion of the two major tributary inflows: Rio Los Guayos in the west part and Rio Guey in the east part of the lake proper. Measurements of temperature, light, current, dissolved oxygen, and chemical samplings were made at nine stations adjacent to each river mouth covering an area of 9 km^2 on a 3 km x 3 km grid.

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TABLE 1. Cruise schedules and activities.

Cruise No.	Date	Activity
1	Jan. 11-14	Routine 40 stations
	Jan. 25-27	Primary productivity, station 20
		Pollution dispersion
2	Feb. 7-10	Routine 40 stations
	Feb. 21-23	Primary productivity, station 20
		Pollution dispersion
3	Apr. 23-28	Routine 40 stations
	May 23-25	Primary productivity, station 20
4	Jul. 17-26	Routine 40 stations
		Primary productivity, station 20
		Pollution dispersion
5	Sep. 29-Oct. 6	Routine 40 stations
		Primary Productivity, station 20
		Pollution dispersion
6	Nov. 21-24	Routine 40 stations
		Primary productivity, station 20
		Pollution dispersion

MATERIALS AND METHODS

A. Physical Parameters

  1. Water movement -

    The velocity and direction of current flows were measured
    with a Braystoke current flow meter with 5" diameter im-
    peller. At each station the measurement was made at 5-m
    intervals starting from the surface. At station 20 the
    measurement was made at 3-hr intervals throughout the en-
    tire depth over 12 hours. Current velocity is expressed in
    cm/sec and direction in degrees of compass.

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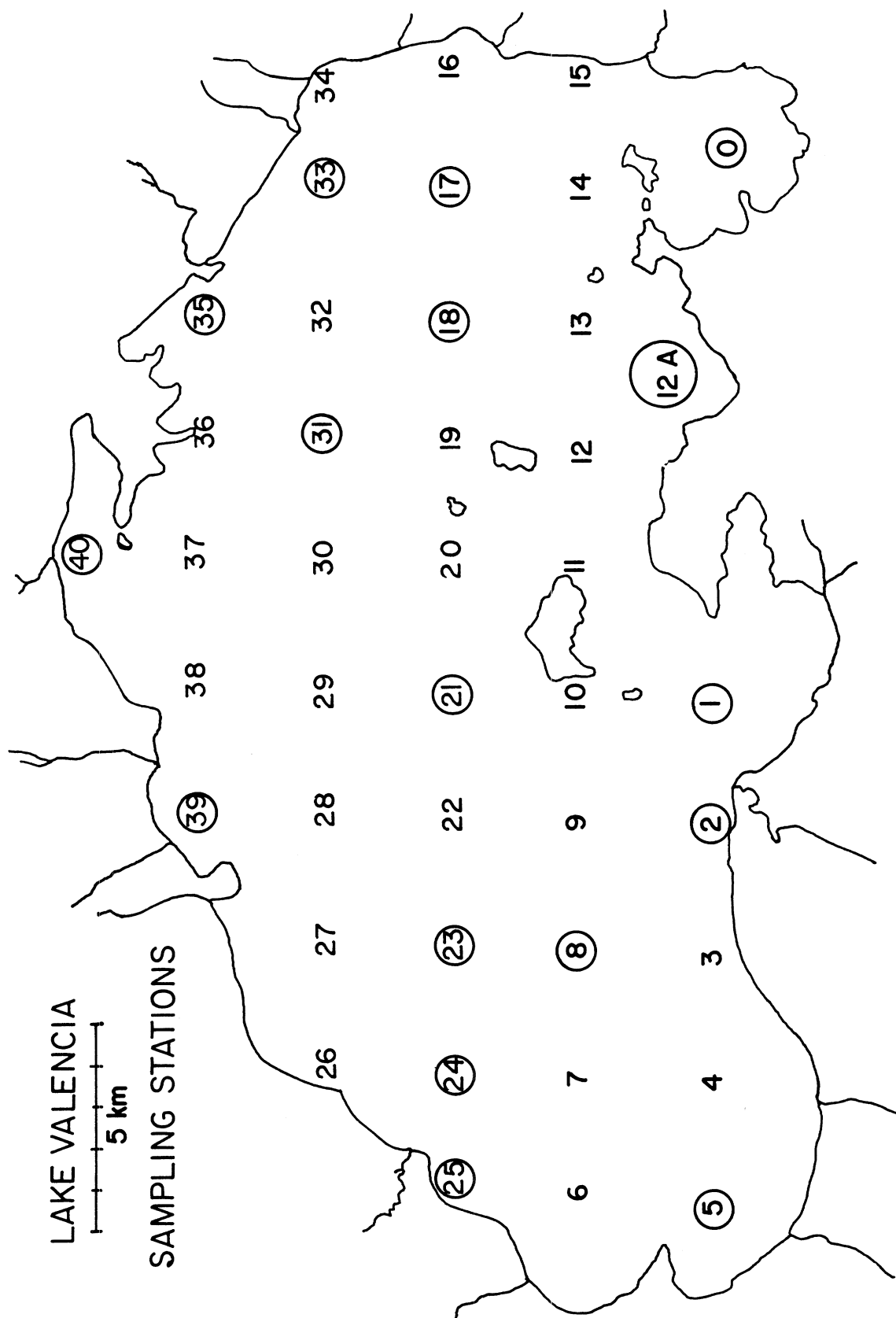
FIG. 1. Monitoring stations for physical, chemical, and biological parameters. Circled stations indicate the locations where samples were taken for laboratory analysis of chemicals, phytoplankton, and zooplankton. Distance between two adjacent stations is approximately 3 km.

2. Light penetration and transparency –

Photosynthetic light regime was measured using LAMBDA underwater quantum meter (Lincoln, Nebraska) at 0, 0.5, 2, and 10 meters at each station. Light level is expressed in μ Ein m^{-2} sec^{-1}, and penetration was calculated as percent of surface light intensity. Transparency was determined at all stations with a standard black and white Secchi disc.

3. Hydrolab parameters –

Other limnological measurements made _in situ_ were depth, temperature, pH, specific conductance, and dissolved oxygen, using a Hydrolab Surveyor Model 6D Water Quality Analyzer (Hydrolab®, Austin, Texas). Measurements were made at a series of depth intervals throughout the water column at all stations. Diurnal variations of those parameters were recorded at station 20.

B. Biological Methods

1. Aquatic macrophytes –

Aquatic macrophytes growing along the coastal region of the lake and islands were sampled for species identification and their distributions were recorded on a map. Submerged plants were collected by hand or hooks. The distribution of emerged vegetation was surveyed from the lake by a small boat and from land on foot. Several collections were made to determine the vegetative and reproductive growth cycle throughout the year. Specimens collected were pressed dry for species identification.

2. Phytoplankton –

   Phytoplankton samples were collected at selected stations
   (0, 1, 2, 5, 8, 12A, 17, 18, 21, 23, 24, 25, 31, 33, 35,
   39, and 40). At each station, a composed sample was taken
   from surface (0.5 m), mid, and maximum depths of the water
   column using a centrifugal pump. At station 31, a series
   of profile samples was taken from 0.5, 5, 10, 20, and 30 m.
   The 250-mL phytoplankton sample taken from each station was
   immediately preserved with 5 mL of Lugol solution and
   subsequently concentrated to 25 mL by settling. The
   phytoplankton taxa were identified at the generic level and
   all numbers of each taxonomic entity were counted using an
   inverted microscope.

3. Chlorophyll _a_ –

   A 250 to 500 mL phytoplankton sample, taken from each
   station and from various depths at station 31, was filtered
   through a GFC filter. The chlorophyll _a_ was extracted with
   10 mL of 90% acetone in an opaque vial in ambient cold for
   a minimum of 24 hours. The chlorophyll _a_ concentration was
   determined by spectrophotometric method (Strickland and
   Parsons 1969).

4. Zooplankton –

   Twenty liters of sample composed equally of surface, mid, and
   bottom lake water were filtered through a #25 plankton net
   (mesh size 65 μm). The sample was concentrated to 300 mL and
   preserved with 5% formalin. Species of major genera were
   identified and numbers of each taxon were enumerated.

5. Primary productivity of phytoplankton -

Phytoplankton productivity was measured several times at four locations in 1978, using the light-dark bottle dissolved oxygen exchange method. Water samples taken from surface, 0.5, 2, 3, 5, and 10-m depths were enclosed in 300-mL Winkler bottles (two light and two dark bottles for each depth). Those bottles were suspended for 4 hours (1000-1400 hours) in the water column in respect to the original sampling depths. The dissolved oxygen concentrations in those incubation bottles were measured at the beginning and the end of the incubation period. The productivity was calculated by the following formulae:

net productivity $= c_3 - c_1$

gross productivity $= c_3 - c_2$

where c_1 = initial concentration of dissolved oxygen

c_2 = final concentration of dissolved oxygen in dark bottle.

c_3 = final concentration of dissolved oxygen in light bottle.

To determine the specific productivity, phytoplankton standing crop in each incubation bottle was filtered to determine chlorophyll _a_ concentration.

6. Coliform bacteria -

Sampling locations. To determine the sources and distribution of total and fecal coliform in the lake,

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twelve sample stations were chosen. Six were near the
outfalls of major tributaries and the remaining six
stations represent open lake water. Those locations are
designed as A, B, F, H, I, P, 5, 6, 12A, 31, 33, and 39.
Stations A and B are located at the mouths of Rio Los
Guayos and Caño Central, respectively. Stations 5 and 6
are adjacent to B and A on the open lake side. Another
heavily polluted area is the western end of the lake in the
vicinity of Rio Guey outfall where stations H and 33 are
located. Stations F, I, P, and 39 are situated near the
shore of plantations representing non-point source
discharges, and occasional discharges from cattle and pig
farms. Station P is located in the vicinity of Puenta
Palmita, which is the most popular bathing area for local
residents. Station 12 represents the least contaminated
area, remote from any point and non-point sources of
domestic and industrial waste. Station 31 represents the
major mass of lake water because it is the deepest and most
turbulent area of the lake.

Sample logistics. Bacterial samples were taken from the
12 stations in the morning and completed within 2 hours.
At each station, triplicate samples were taken from surface
water and put in pre-sterilized bacterial sample bottles.
Those samples were transported to the field laboratory in
Valencia immediately after collection.

Laboratory procedures for determination of total and fecal coliform density in the samples were according to the multiple-tub fermentation procedures to obtain the Most Probable Number (MPN) index. The details of the method are in Standard Methods (APHA 1975).

C. Chemical Procedures

1. Water samples were collected at 17 selected stations (Fig. 1) using a centrifugal pump. The water sample taken from each station was composed of an equal mixture of surface, mid, and bottom water, except for station 31 where water samples were taken separately from five depths at 0.5, 5, 10, 20, and 30 m.

   The sampling scheme, volume, and preservation for water chemistry are shown in Figure 2. Chemical parameters analyzed in the laboratory were chloride, heavy metals (As, Cd, Cu, Fe, Pb, Mn, Zn, Hg, and Cr), nitrogen (ammonium, nitrite, nitrate, and total Kjeldahl), pH, phosphorus (soluble reactive othophosphate, total dissolved phosphate, and total phosphate), solids (total, total dissolved), and sulfate. Analytical procedures used for quantitative determination of the chemical parameters were based on Standard Methods (APHA 1975). Trace metals were analyzed with a Beckman atomic absorption spectrophotometer, phosphorus and nitrogen with a Technicon autoanalyzer. Sulfate was determined by the turbidimetric method and solids by the gravimetric method.

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SAMPLING SCHEME, VOLUME, PRESERVATION
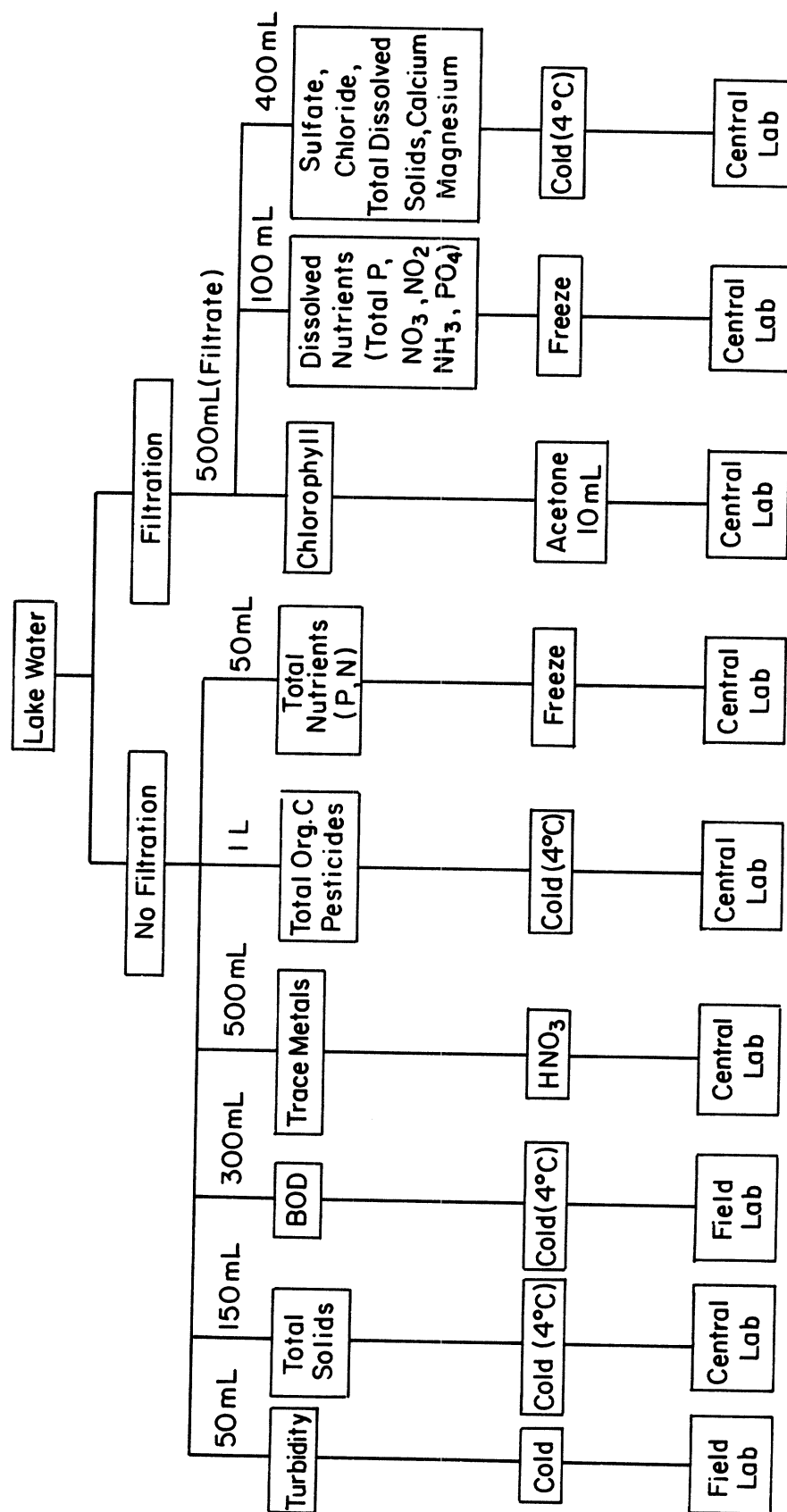
FIG. 2. Sampling scheme, volume, and treatment of water samples for water quality analysis.

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MORPHOLOGY AND BATHYMETRY

Lake Valencia occupies a drainage basin of 3,000 km^2 in northern central Venezuela. Geologically, the lake basin is situated on metamorphic basal rocks and was formed by a relatively narrow depression (a graben) between two fault scarps running WSW - ENE (Peeters 1968). The depression has been gradually filled with Pleistocene and Holocene sediments. Accumulation of the sediments blocked the drainage outlet of the Rio Paito to the Orinoco basin when the lake elevation dropped to 429 m above sea level around the year 1727. Since then the lake has become a closed system.

The modern lake morphometry is listed in Table 2. The surface area of the lake is 356 km^2, approximately 12% of the water shed area (Fig. 3). There are 16 tributaries distributed throughout the watershed (Table 3), but the lengths of most tributaries are less than 30 km and originated from steep Andean mountains in the north. Most of those rivers carry a considerable amount of silts from surface runoff during the rainy season and have little flowing water during the dry season. Only those rivers such as Los Guayos, Caño Central, and Rio Guey, which drain domestic and industrial waste water, have continuous flow throughout the year.

The most recent bathymetric map (Fig. 4) was made in 1963 and the depth contour and shoreline have since altered considerably. The maximum depth has been reduced from 40 m to 37 m, and Champego Island is now connected to adjacent land. The lake was relatively shallow at the western portion and the drop in water level has created an extensive soft, muddy shore. The deeper part (35 m) of the lake extends between Punta Palmita and Macapo-Yuma shore. Table 4 shows

TABLE 2. Morphometry.

Altitude	405 m (asl)
Maximum length (L)	30 km
Maximum width (b)	17.8 km
Mean width (b)	12.7 km
Area (A)	356 km^2
Volume (V)	6,740 X 10^6 m^3
Maximum depth (Zm)	37 m
Mean depth (Z)	18 m

TABLE 3. Major tributaries and their lengths and areas.

Tributaries	Length (km)	Area (km^2)
Aragua	58.7	360.0
Turmero	41.2	245.1
Guigue	22.5	119.3
Paya	21.25	77.0
Guayabita	17.7	54.1
Limon	21.2	78.6
Maracay	27.7	126.6
Guey	14.5	33.0
Tocoron	23.5	140.1
Noguera	28.0	118.0
Guacara	30.5	111.2
Guaica	7.5	15.1
Los Guayos	31.5	102.9
San Joaquin	10.5	17.7
Mariara	10.0	14.5
Cura	14.0	41.6
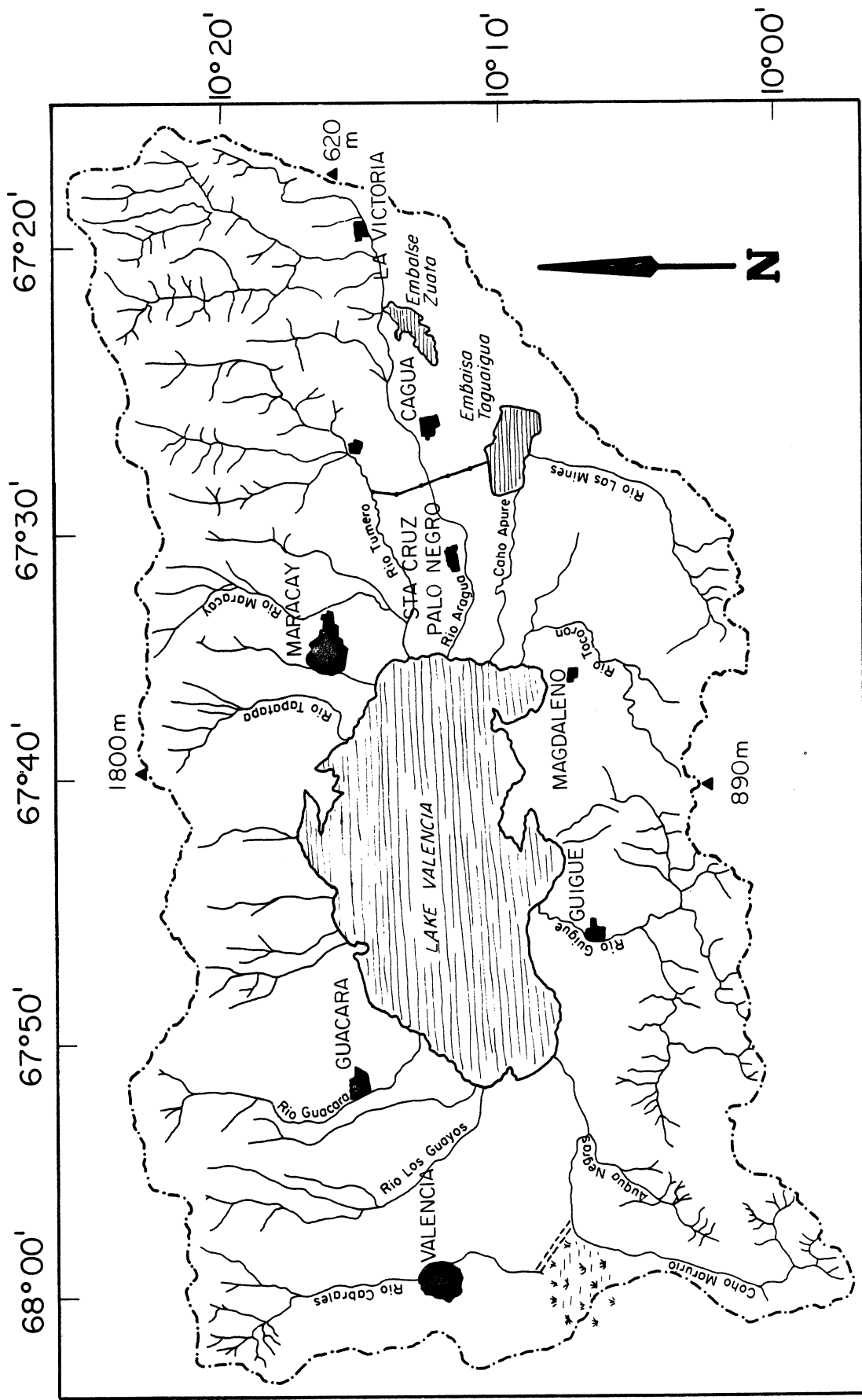
FIG. 3. Watershed boundary of Lake Valencia and tributaries.

FIG. 4. Bathymetric map of water column in Lake Valencia (contour in 5-m depth intervals).

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TABLE 4. Areas (A) and volumes (V) in 5-m depth intervals.

Depth (m)	A (km^2)	A%	Vz (10^{6}m^3)	Va (10^{6}m^3)
0	356	100	0	0
5	286	80	1,602	1,602
10	243	68	1,321	2,923
15	215	60	1,144	4,067
20	177	49	978	5,045
25	132	37	769	5,814
30	99	27	575	6,389
35	45	13	351	6,740

the water volumes at 5-m depth intervals, and the decrease of surface area may be estimated by the loss of corresponding water volume as indicated in Figure 5.

Decrease of water level has been a historical and most serious problem in Lake Valencia. As a rough estimate, the average annual water loss has been 60×10^6 m^3 in the past 170 years (Apmann 1973). The recent accelerated desiccation has most probably been due to the destruction of forests, the slash and burn land cleaning, and agricultural and industrial consumptions of both surface and underground water in the lake basin. Figure 6 shows the decreasing trend of lake elevation from 406 m in 1962 to 403 m in 1976. The water loss was particularly pronounced between 1971 and 1976 during which the lake level dropped 2 m. The annual fluctuation between 1978 and 1979 is shown in Figure 7. In this yearly cycle the water level dropped 50 cm from the end of rainy season in October 1978 to February 1979, but a large rise occurred starting in May 1979. The rise of water level in 1979 was accelerated by the diversion of Rio Cabrales which added 4-5 m^3/sec of water from sources outside the watershed.
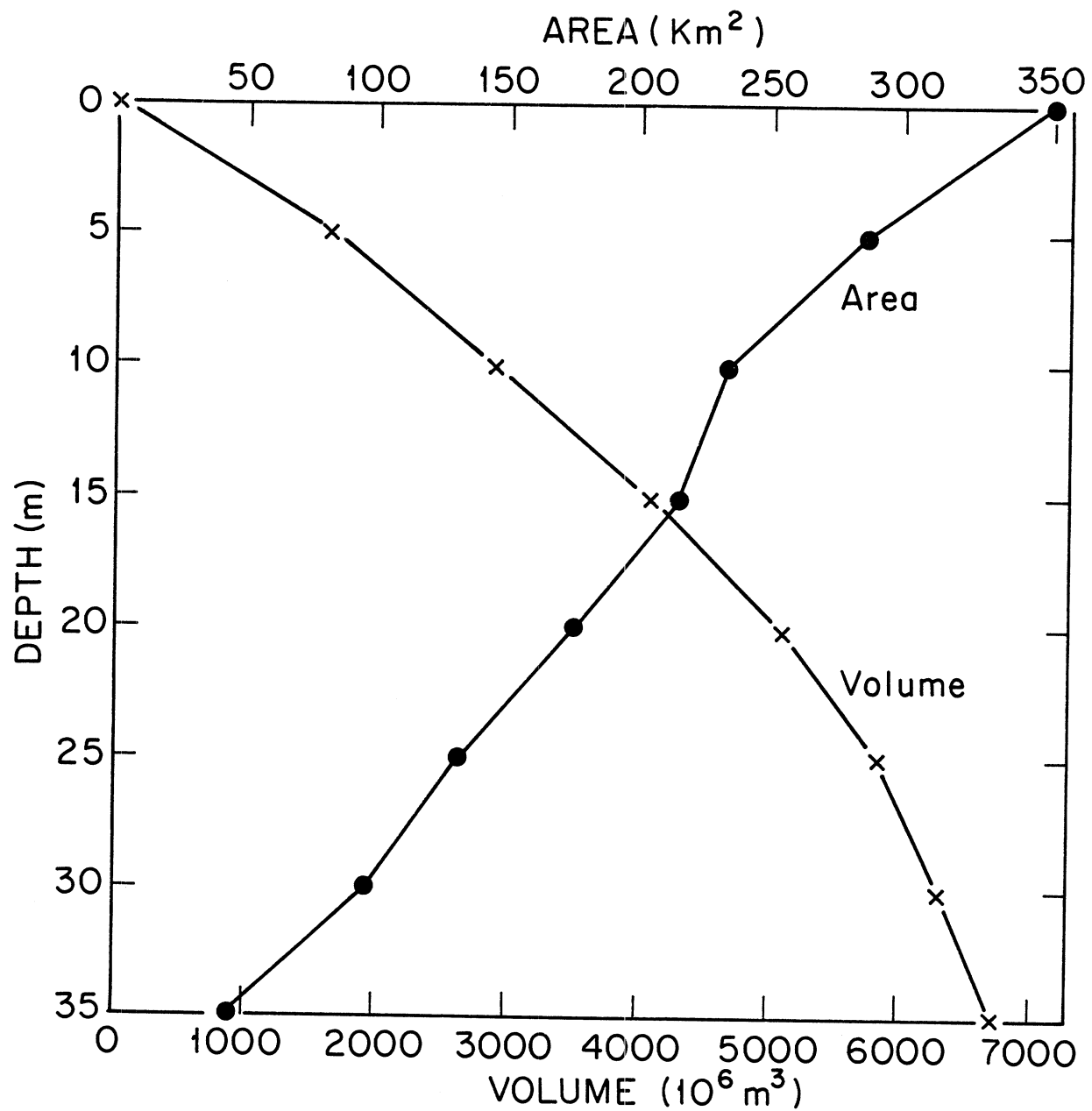
FIG. 5. Lake surface area and volumes corresponding to depth intervals.

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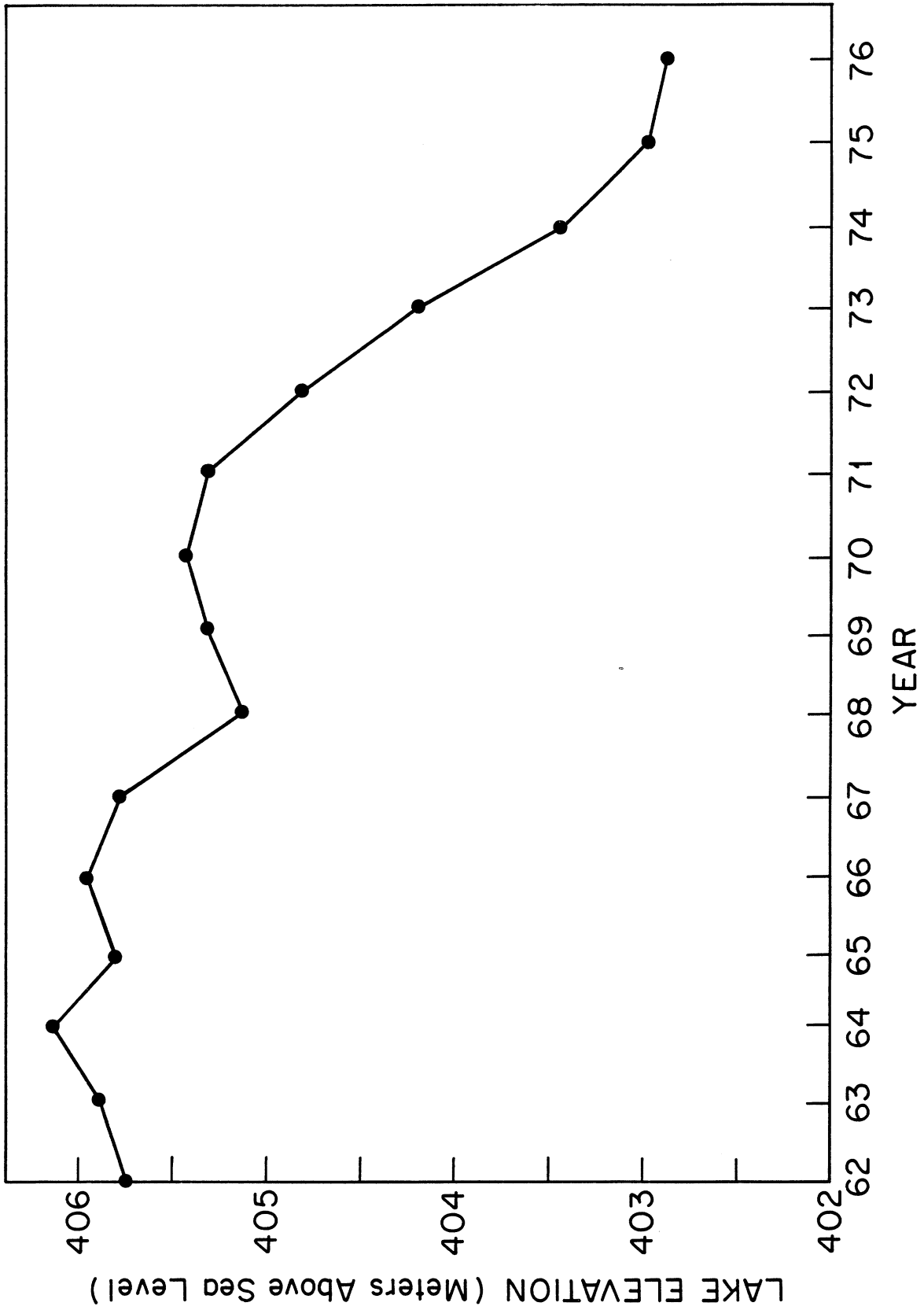
FIG. 6. Water levels recorded between 1962 and 1976.
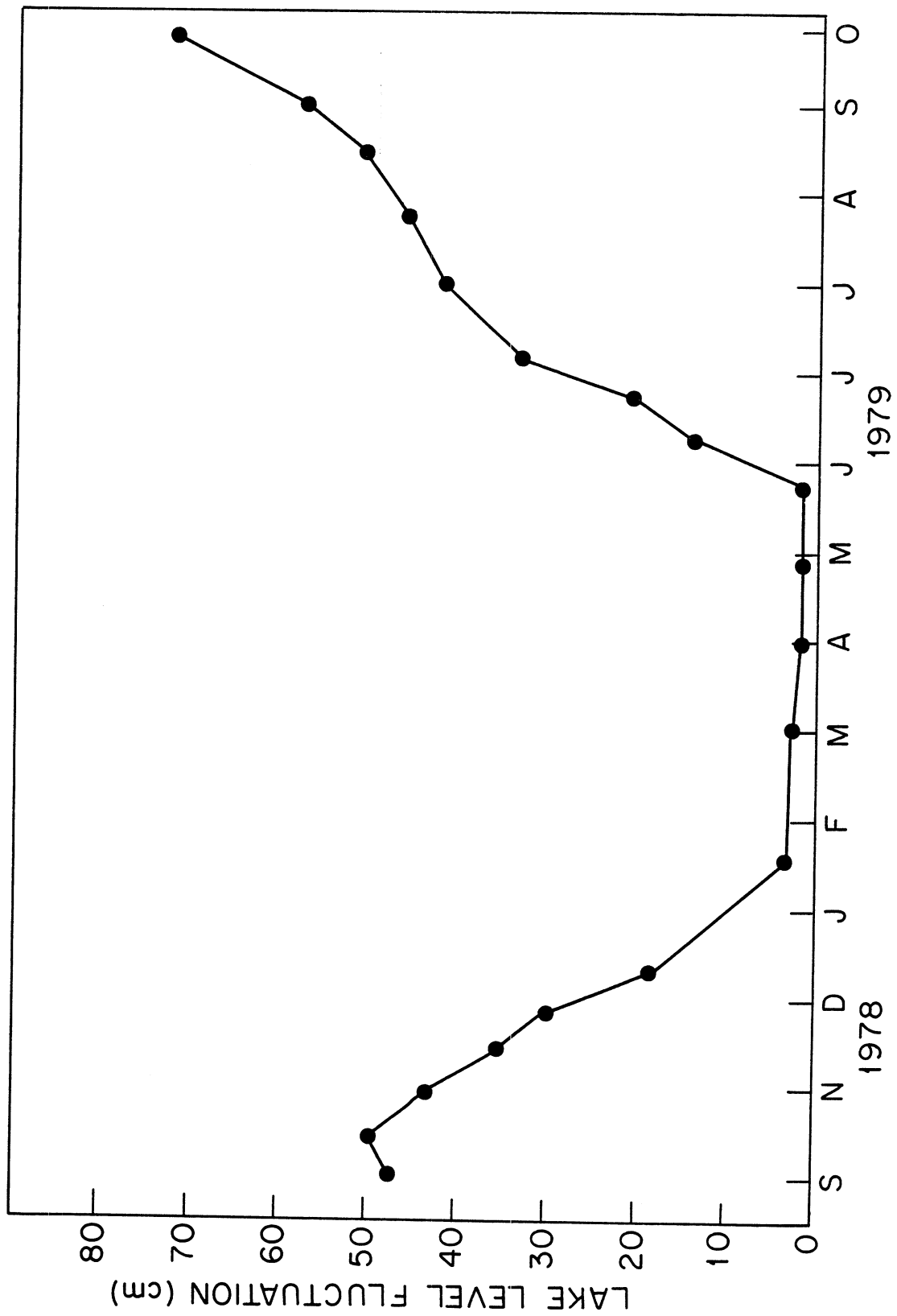
FIG. 7. Water level fluctuation recorded in 1978.

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The solar radiation on Lake Valencia's surface on an average day is 12 hours with a maximum intensity of approximately $2,000 \pm 500$ µEin m^{-2} sec^{-1} near mid-day. Figure 8 shows the distribution of light intensity throughout a typical clear day in February. Day length and light intensity in this low latitude (10° N) are relatively constant throughout the year. Typical light attenuation in the water column at several transect stations is shown in Figure 9.

The depth of light penetration in Lake Valencia is extremely shallow. As shown by Secchi disc transparency (Fig. 10), the visibility ranged from 23 cm to 284 cm, with the majority of values between 100 and 150 cm. The greatest transparency occurred in January and the lowest in July. Lakewide, the central area between Punta Palmita and Isla Otama had greater transparency than other areas of the lake. There were two areas where water visibility was persistently poor, with values less than 50 cm during most cruises. The poor transparency in those areas was mainly caused by the heavy loading of suspended matter from Rio Los Guayos and Caño Central in the southwest and Rio Guey in the northeast. The turbidity, resulting from sediment resuspension, also contributed to low transparency in the shallow waters (<2 m) of the western basin. The variation of transparency in open water near the center of the lake was largely due to the phytoplankton blooms.

Attenuation of photosynthetic light intensity as measured by quantum is highly correlated to Secchi disc transparency values (Fig. 11), and the calculated depth of 1% light penetration (Fig. 12) reached 5 m in the central basin. The major portion of the lake received this light at 3 m. In situ
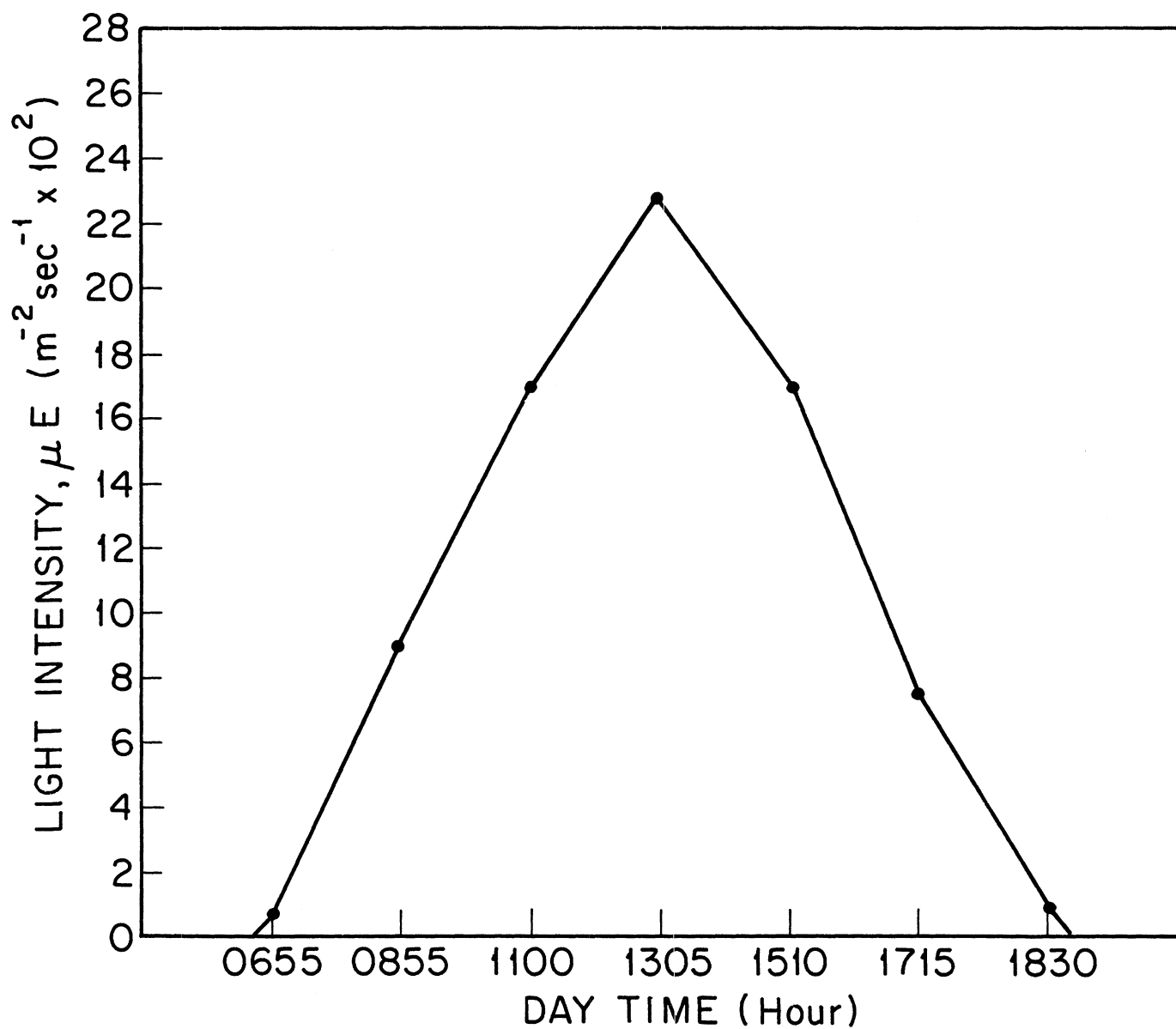
FIG. 8. Incident solar radiation on lake surface recorded on a clear day in February, 1978.
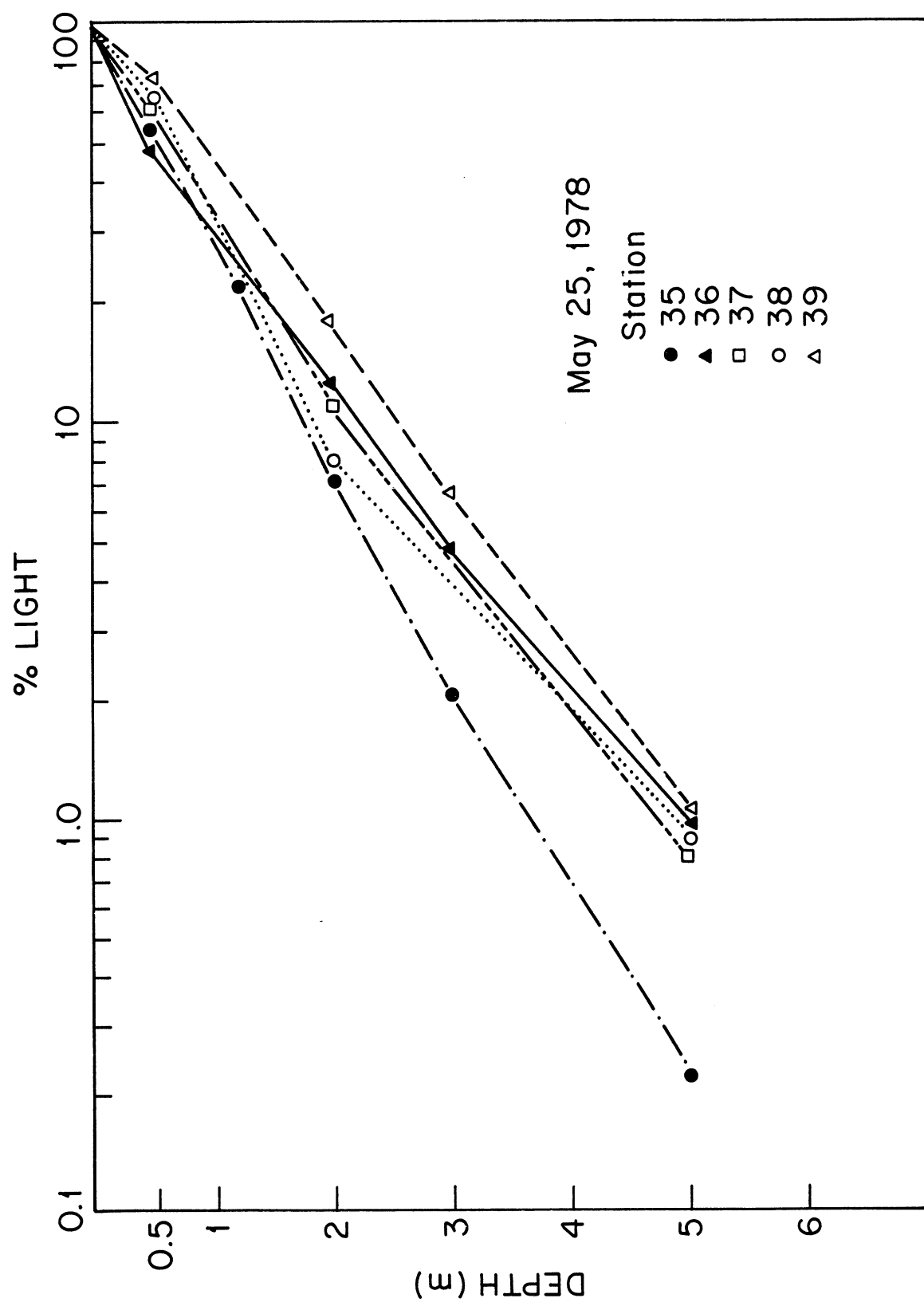
FIG. 9. Depths (m) of light penetration in water column at stations along a transect on May 25, 1978.

JULY 17-21

OCTOBER 2-6

JAN. 10-14, 1978

APRIL 24-28
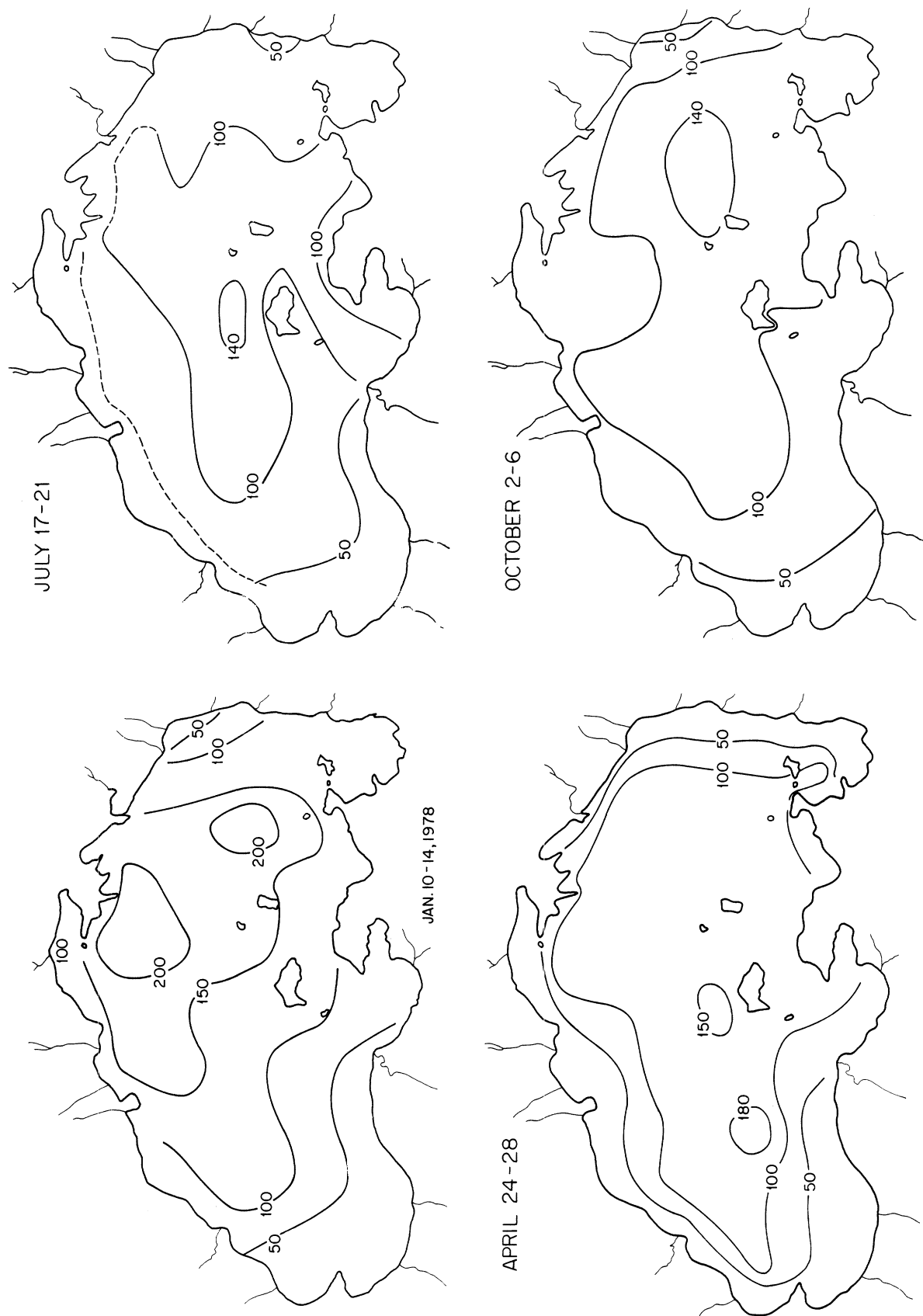
FIG. 10. Depth contour (cm) of Secchi disc transparency during four cruise periods in 1978.

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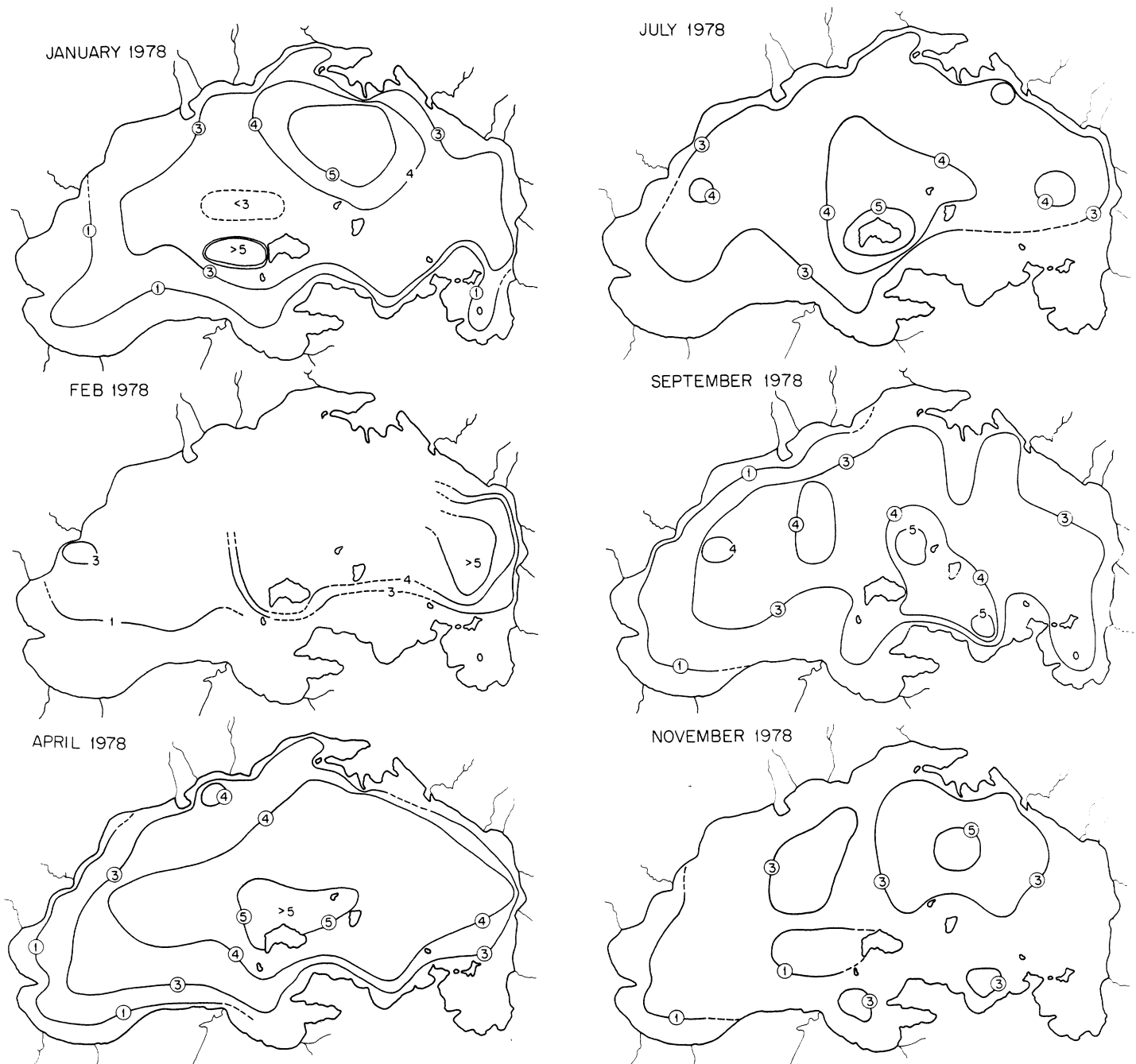
FIG. 11. Depth contour (m) of 1% light penetration during six cruise periods in 1978.
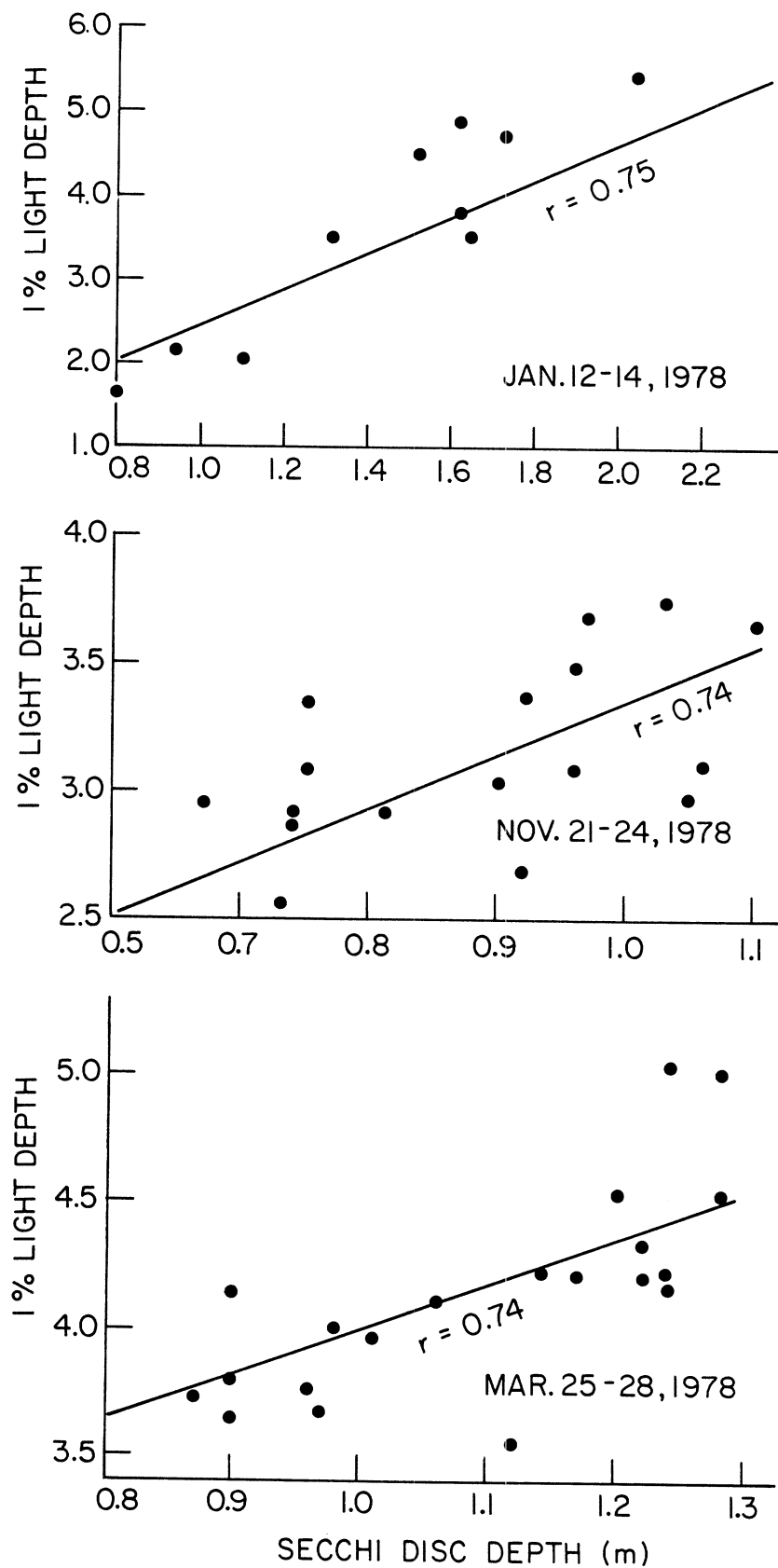
FIG. 12. Correlation between depths (m) of 1% light penetration and Secchi disc transparency.

measurements of oxygen production and consumption indicate that 1% light level is a critical compensation zone where photosynthetic and respiratory activities are nearly equal.

WATER CURRENT AND VELOCITY

Current direction and velocity of water mass in Lake Valencia are illustrated for four cruise periods by Figure 13. The maximum velocity observed during those cruise periods frequently reached 50 cm/sec or greater; occasionally up to 100 cm/sec was recorded. The current directions were extremely variable and durations of any given direction were normally no more than a few hours. Large numbers of islands located in the southern half of the lake complicated the current flow pattern as the velocity and direction of surface current exhibited great regional differences.

The greatest surface currents often occurred in the central, eastern, and western basins when the wind blew directly from the opposite end of the lake.

Several observations were made for the duration of current throughout the water column, over a period of 12 hours or longer, at station 20 near the geographical center of the lake (Fig. 14). Those observations indicate that the movement of water mass was extremely responsive to wind stresses over the lake surface. On February 21, a gust of wind (20 kph) occurred during the night. The velocity of the water column was measured at 0650 hr on the following day. At most depths, the current velocity reached 40 cm/sec. At depths greater than 20 m, the velocity was reduced to 25 cm/sec. The surface current direction was east-north-east and shifted to east-south-east in the lower half of the water mass. The current velocity normally dampened within a few hours, from 40 cm/sec

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CURRENT
DIRECTION VELOCITY
DEPTH (m)
FEB 7-10,1978

20 cm/s

CURRENT
DIRECTION VELOCITY
DEPTH (m)
SEPT 29-OCT 6,1978

20 cm/s

CURRENT
DIRECTION VELOCITY
DEPTH (m)
JAN 10-13,1978

20 cm/s

CURRENT
DIRECTION VELOCITY
DEPTH (m)
APR 25-28,1978

20 cm/s
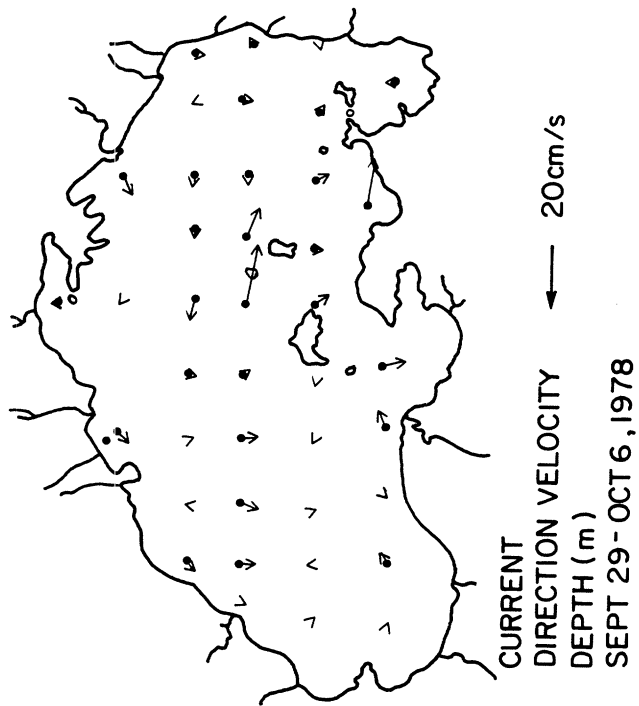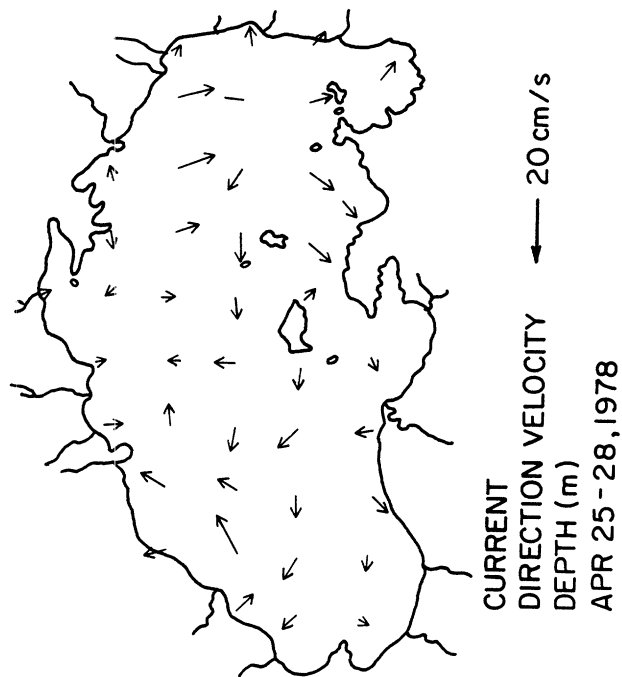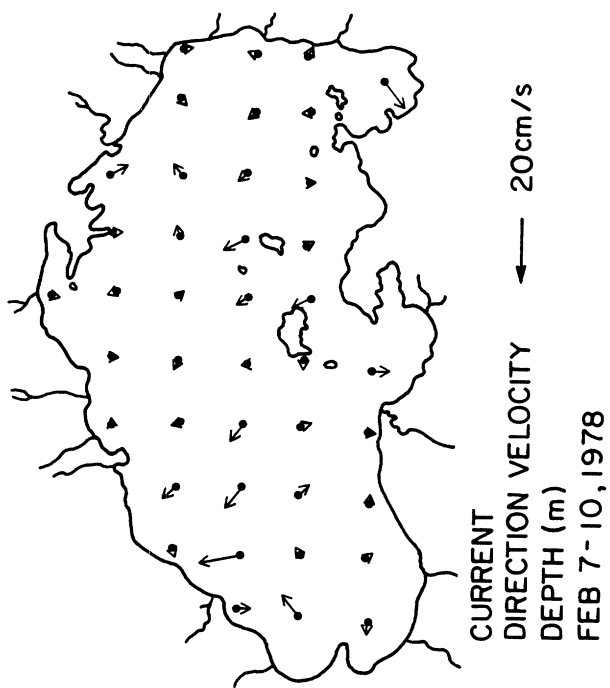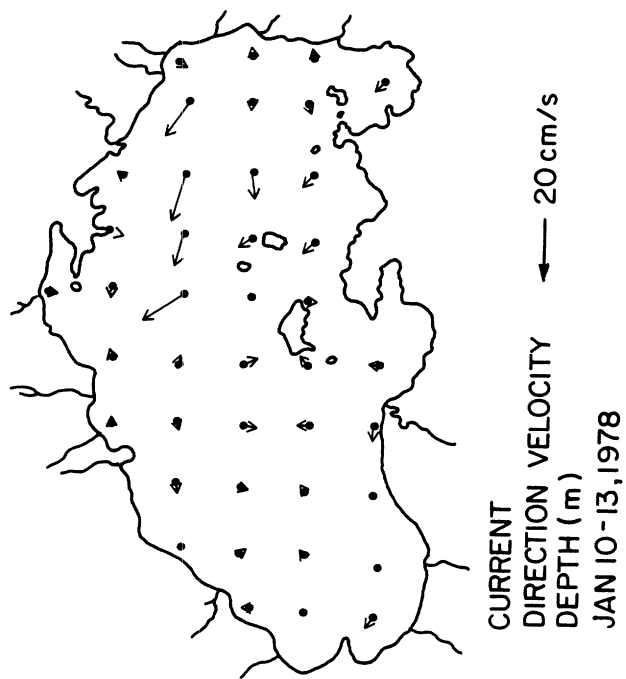
FIG. 13. Current direction and velocity in surface water (0.5 m) during four cruise periods in 1978.

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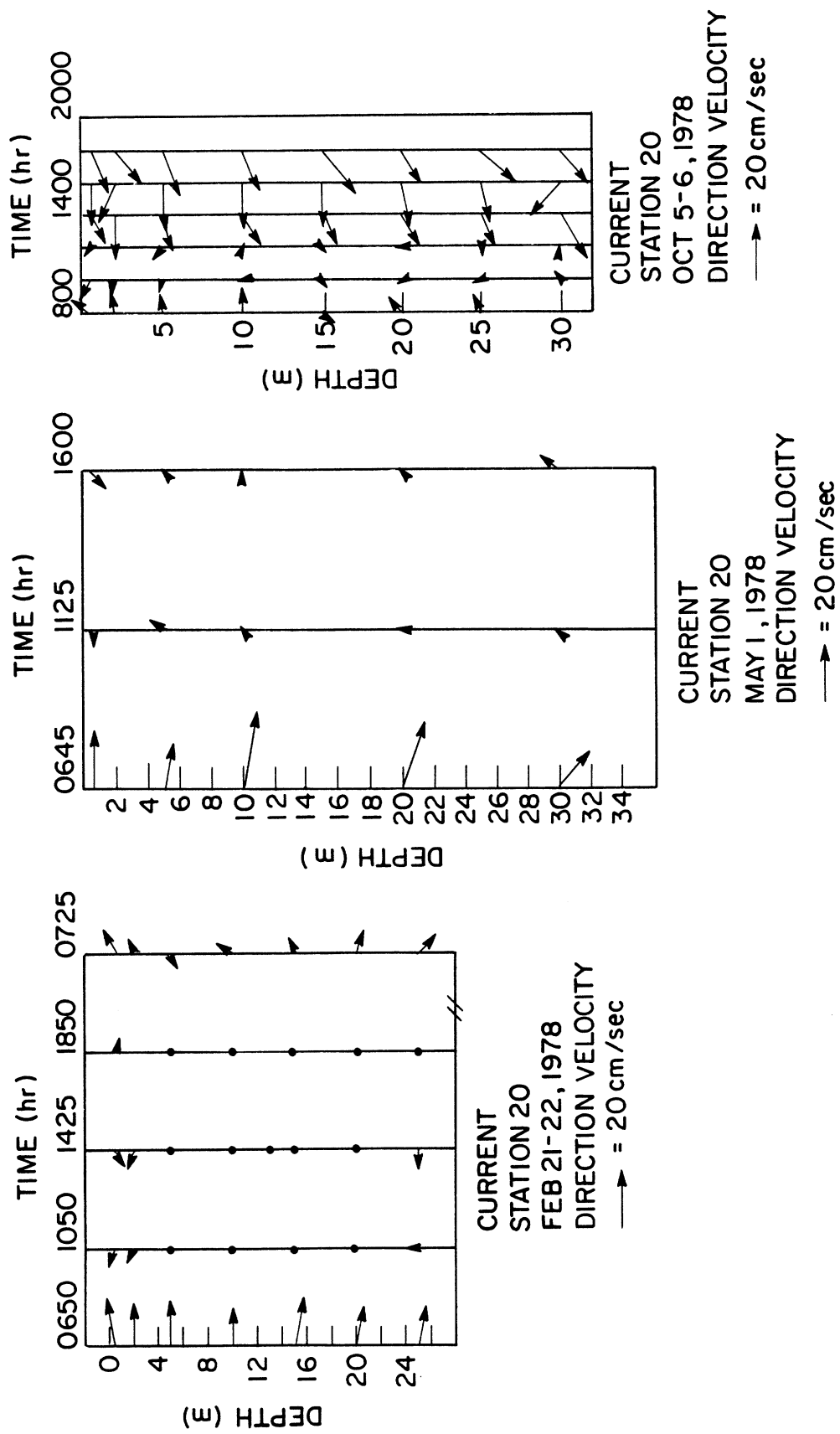
FIG. 14. Variations in direction and velocity of water current recorded at various depths at station 20 on three dates in 1978.

to a standstill in 4 hours on Feb. 21, and from 60 cm/sec to 0 flow in 5 hours on May 1.

The wind data, collected from a northwestern lake shore weather station (Base Sucre) by the Venezuelan Air Force, show most of the maximum wind velocity was recorded in the afternoon and evening. Frequent changes in wind direction throughout the day caused the velocity and direction of water current to be extremely irregular and unpredictable.

Langmuir circulation appeared to be a common water movement pattern in surface water as indicated by frequent occurrence of streaks. These streaks, ranging from 0.5 to 2 m wide, contained mostly phytoplankton, aquatic macrophytes, and invertebrate residues.

TEMPERATURE

The annual thermal variation in Lake Valencia is shown in Figure 15. The maximum temperature (30°C) occurred in surface water during June and the minimum temperature occurred in subsurface water during January and April. In general, the low temperature (26°C) of the water mass prevailed in the early part of the annual cycle and was relatively uniform throughout most of the water column. The water temperature increased progressively from April to July and it reached 27°C in the deep water toward the end of the year.

Although the vertical thermal differential in the lake was small, approximately 5C°, the formation of transient thermal stratifications occasionally occurred during June and October (Fig. 16). Thorough mixing of the water column, as indicated by the isothermal conditions of the water mass, occurred in December. Pronounced diurnal variations in water temperature occurred mostly at the surface. For instance, on February 21, 1978, the surface water temperature

29
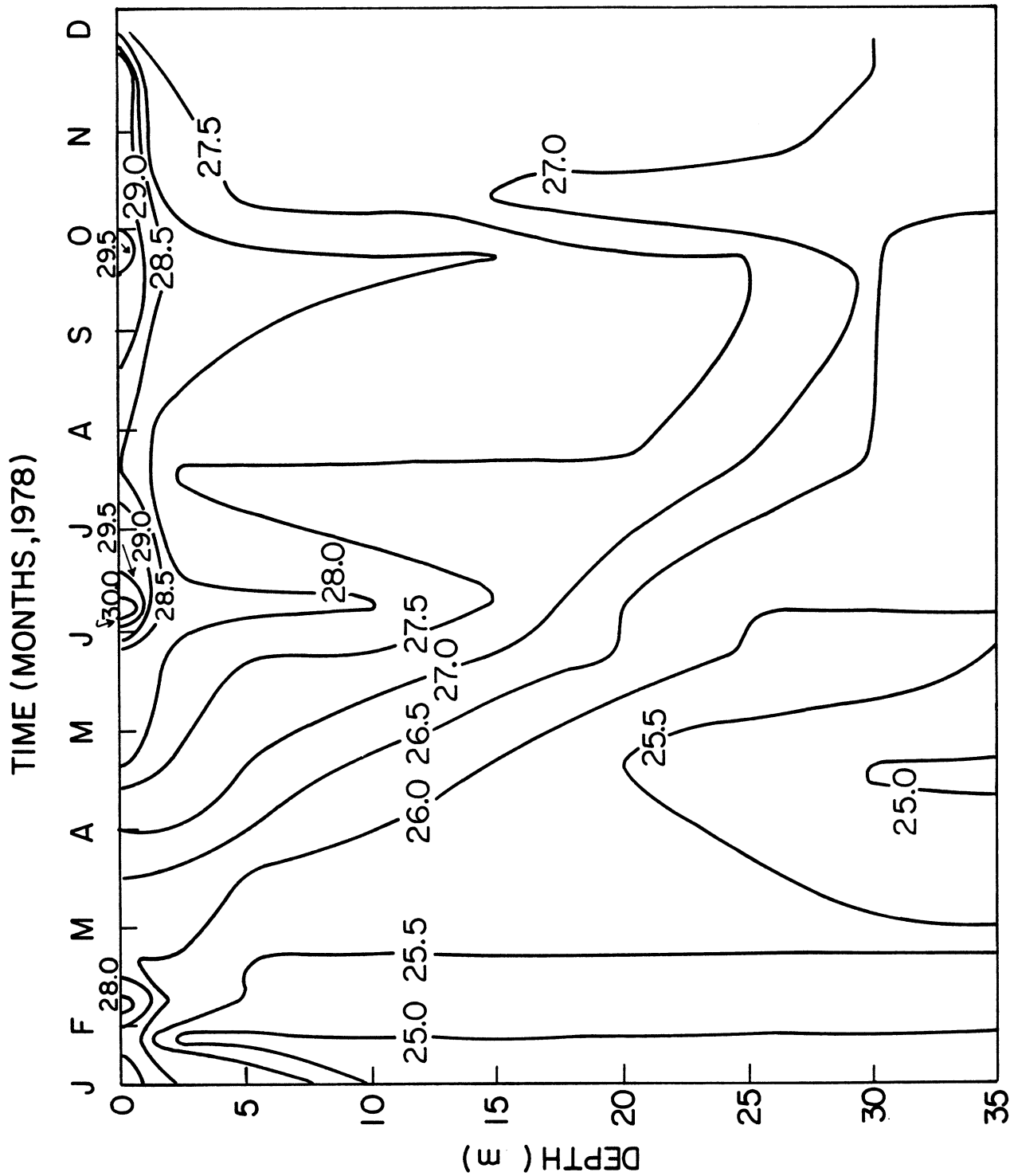
FIG. 15. Annual isothermal variation (°C) of water temperature recorded from station 20 during 1978.
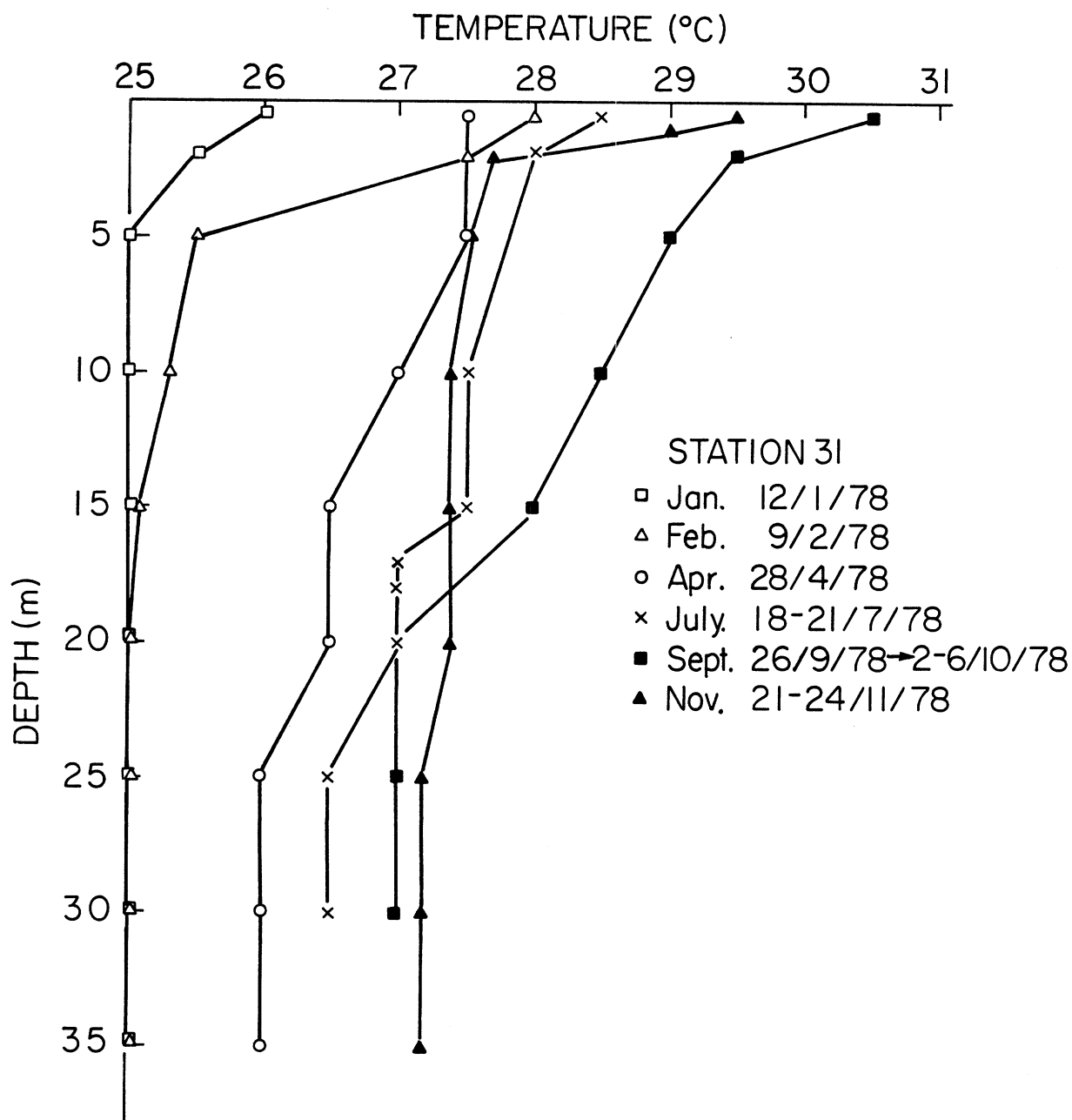
FIG. 16. Vertical temperature profile recorded at station 31 during six cruise periods.

in the morning was less than 26°C and it rose to 28°C in late afternoon (Fig. 17). The heat that accumulated in the surface water was quickly dissipated during the night. The temperature of the water mass below 3 m remained stable at 25.5°C. The cool water mass in the subsurface upwelled during the night, which may possibly have resulted from surface cooling at night.

DISSOLVED OXYGEN

Annual Variation

The annual variation of DO in the water column near the geographical center of the lake is extremely dynamic (Fig. 18). Oxygen stratification, from supersaturated to anoxic conditions, prevailed during most of the year. Supersaturation frequently occurred near the surface (<2 m), and severe oxygen depletion deficit (<50% saturation) constantly occurred below 10 m depth. During December-March the lake water was well mixed as indicated by the isothermal condition. The oxygenation reached the maximum depth of the lake. Although the mixing process effectively replenished the DO in the anoxic deep water, the oxygen deficit in the entire water column became pronounced. On January 22, 1978, the DO level in the surface water was depleted as low as 3 ppm. This event of extreme DO deficit, coupled with extensive H_2S released from premixing in the anoxic zone, caused a massive fish mortality. The strong oxygen stratification began in early April, and a rapid DO depletion followed during May and June. The extensive anoxic depth occurred below 20 m in mid-April and surfaced to 8 m in October. The largest DO gradient in the water column was observed between 5 to 15 m, particularly in May and October during which the DO decreased from 9 ppm at the surface to 6 ppm at 5 m and to 0 ppm at 10 m. Such a large change in DO gradient appeared to be related to a large
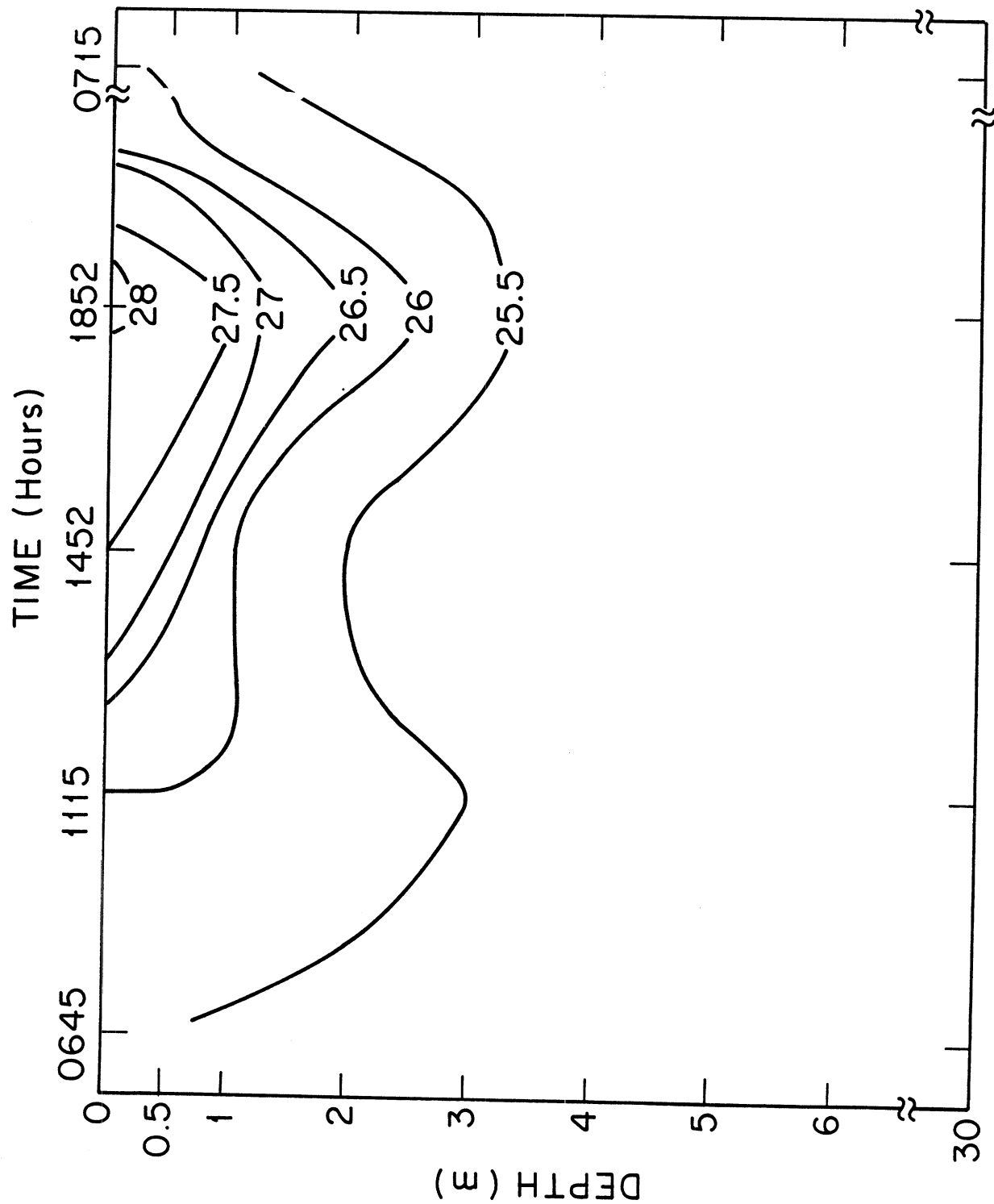
FIG. 17.   Depth-time isopleths of daily temperature variation at station 20 on February 21, 1978.

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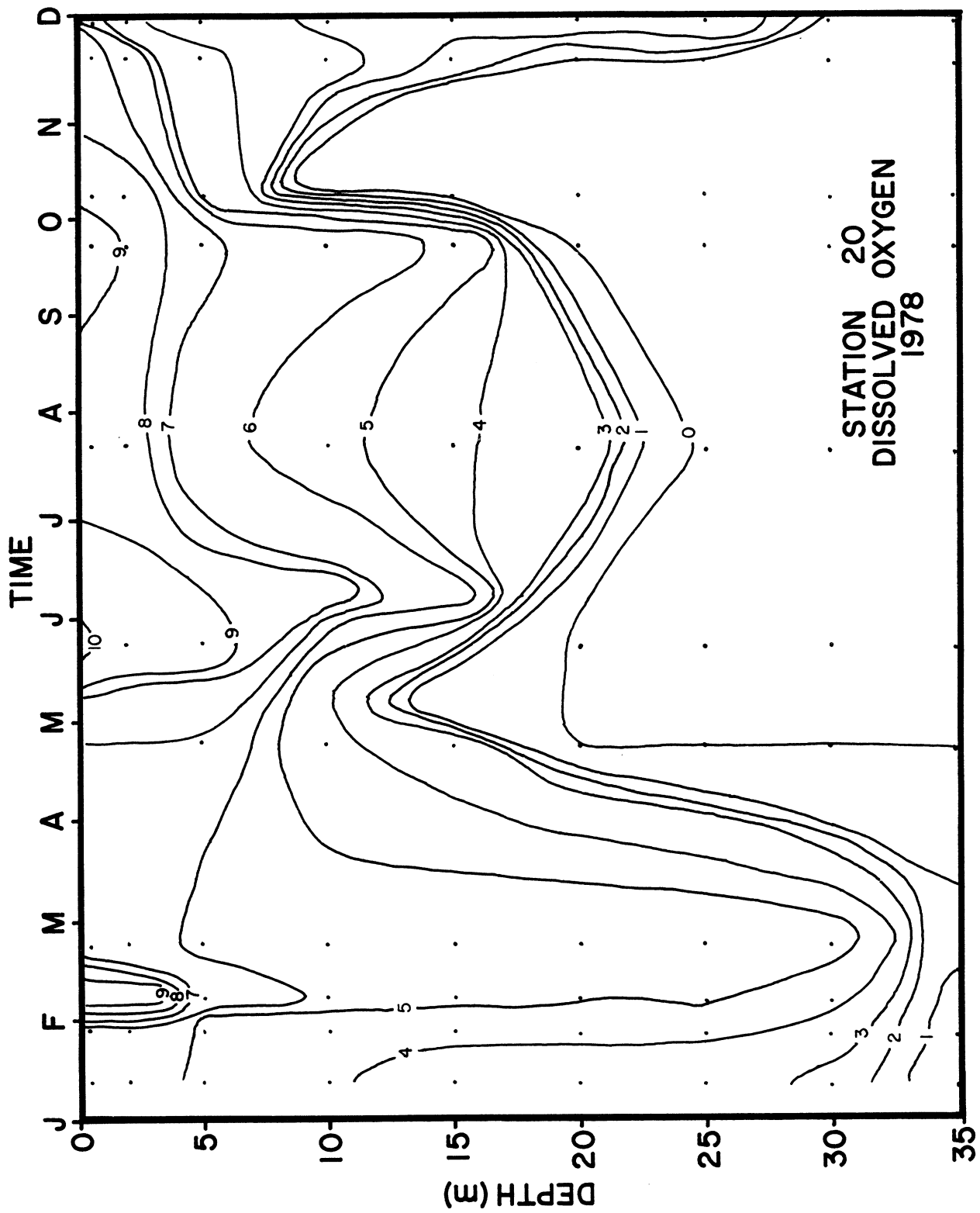
FIG. 18. Depth-time isopleths of dissolved oxygen concentration (mg/L) at station 20 during 1978.

phytoplankton biomass buildup in the euphotic zone as a result of calm weather.

The DO profiles measured during six cruise periods are shown in Figure 19. The greatest fluctuation of DO content in the water column occurred between January and February, increasing from 5 to 12 ppm at the surface 5 m. A similar distribution pattern, typical clinograde, was observed during April, July, September, and November.

Daily Variation

The DO concentration exhibited in diurnal variation was often episodic and the amplitude of variation depends primarily on rates of photosynthetic production, respiratory consumption, and mixing depth. Figures 20 and 21 illustrate two specific dates showing two different DO variation patterns in the water column during the day. On February 21 a relatively uniform DO distribution was recorded from the surface (6.0 ppm) to the bottom (5.5 ppm) in the morning, and became highly stratified in the late afternoon. The greatest DO reduction occurred between 3 and 5 m, with DO reducing from 9 to 6 ppm at 7 pm. The photosynthetic oxygen production was 3 g O_2/m^3/day in the surface and the compensation depth was at 3 m; at that depth no apparent increase in net DO production occurred. A rapid destratification of DO followed during the evening. On September 11, when the anoxic layer was extensively developed (below 15 m depth), the DO fluctuated between 8 and 10 ppm in the top 5 m and drastically reduced to 0 between 10 and 15 m. The mixing event had rarely extended to the pyncnocline (anoxic zone).

The budget of DO in the water column was measured in several cruises (Fig. 22). On January 25 and March 23, there were net gains of DO throughout the water column, but during the remaining dates various degrees of DO deficit

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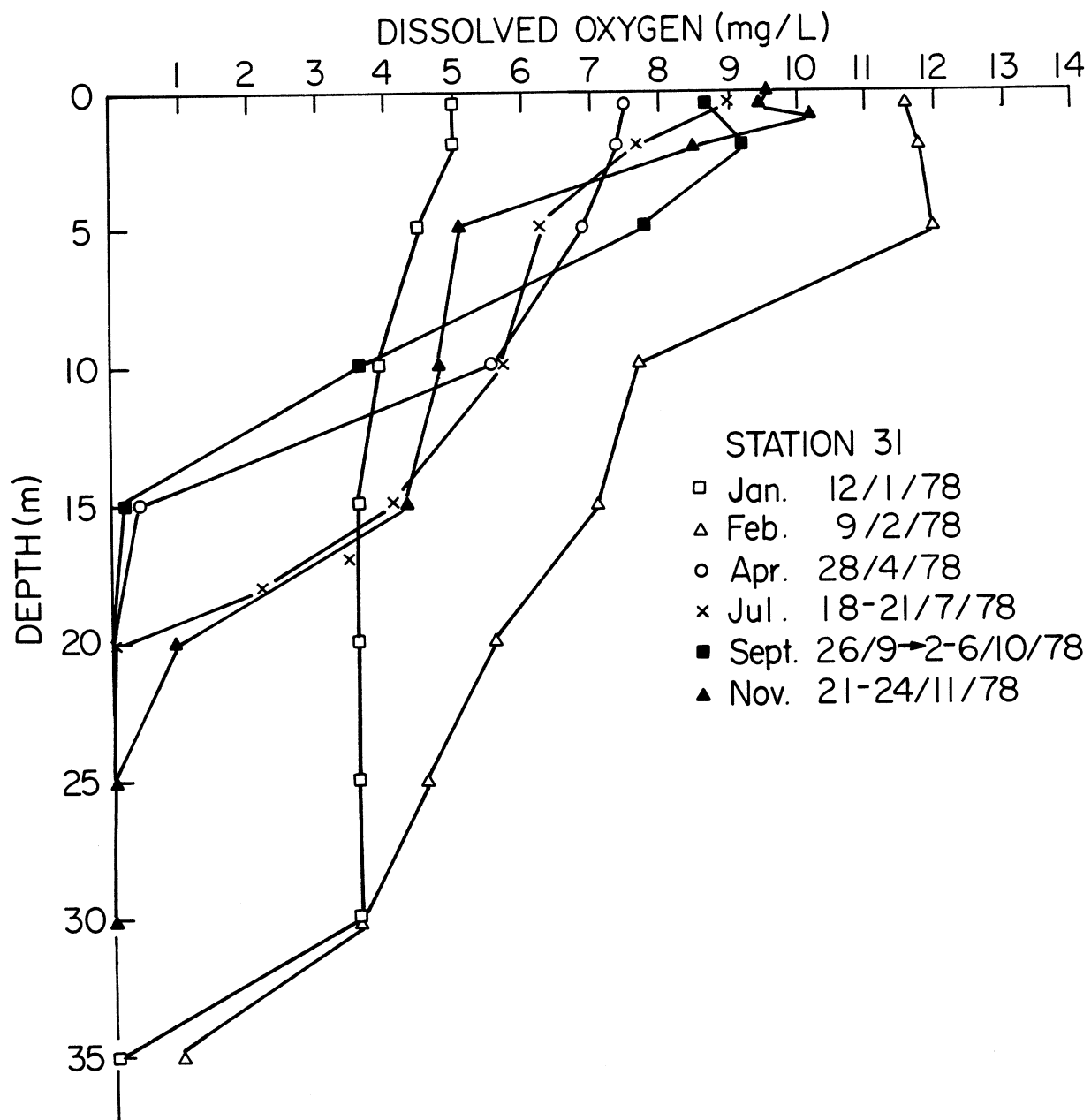
FIG. 19. Vertical distribution of dissolved oxygen at station 31 recorded on six dates in 1978.
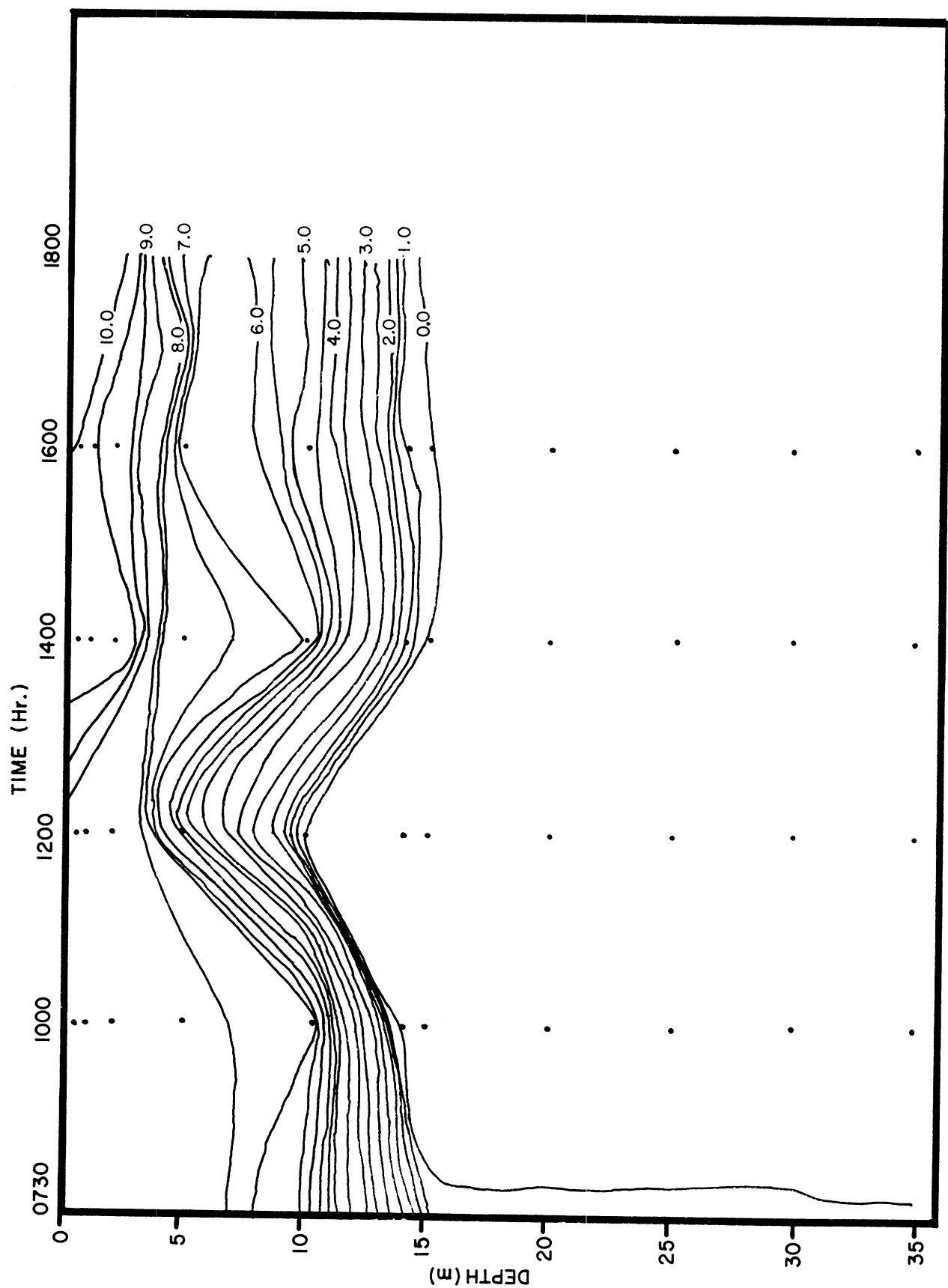
FIG. 20. Depth-time isopleths of dissolved oxygen concentration (mg/L) during day hours on February 21, 1978.

37
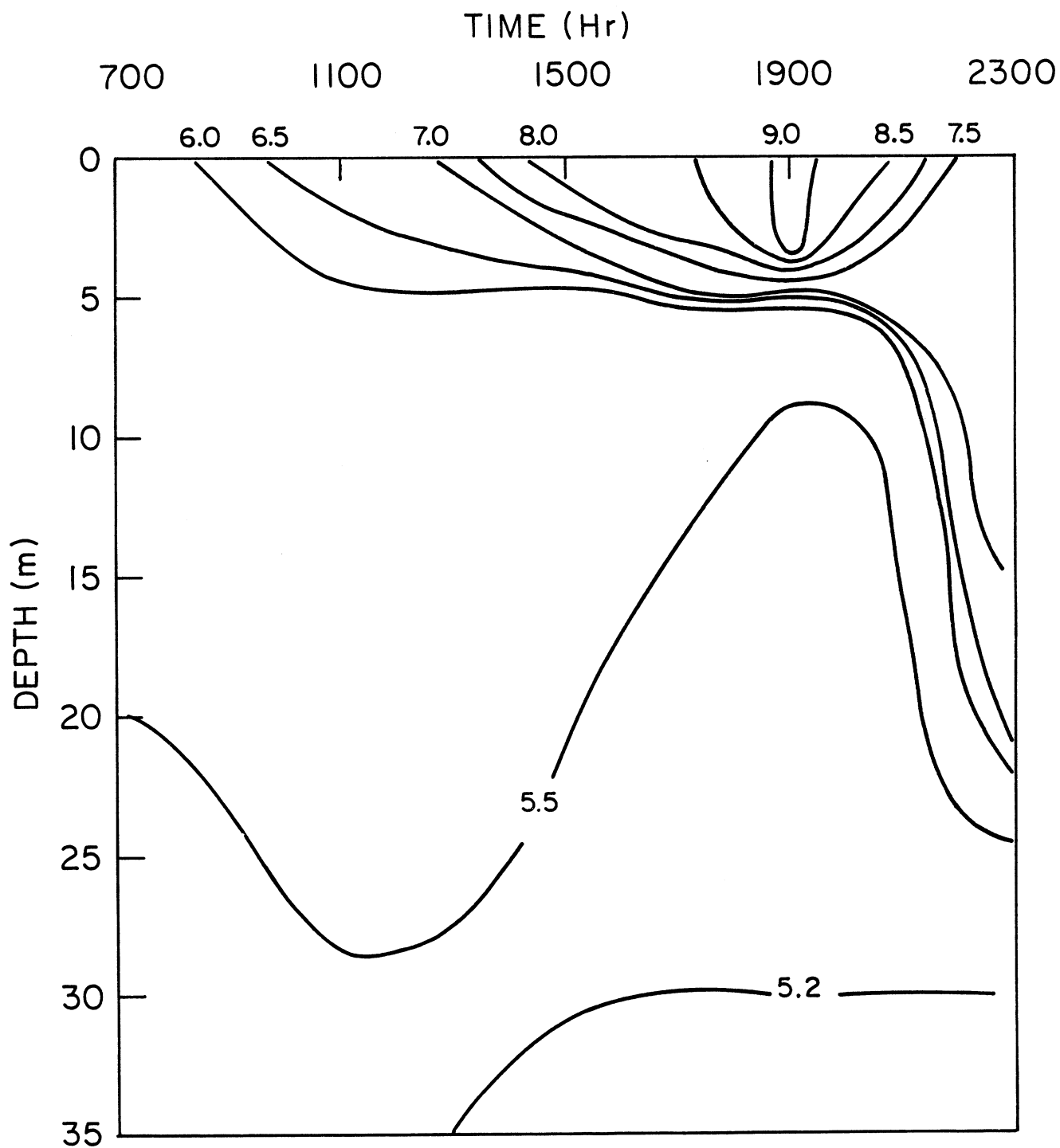
FIG. 21. Depth-time isopleths of dissolved oxygen concentrations (mg/L) on September 11, 1978.
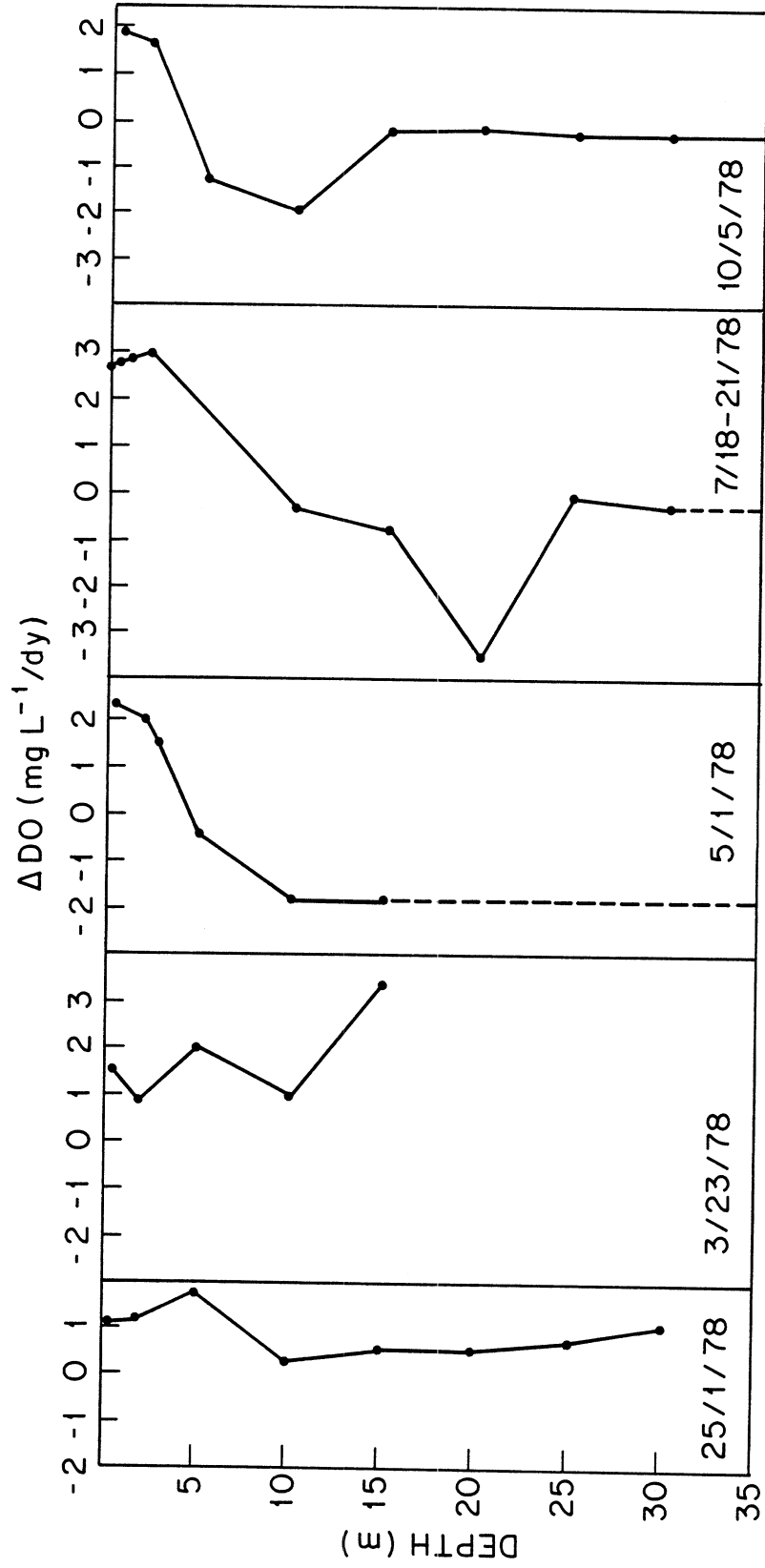
FIG. 22. Changes of dissolved oxygen concentration throughout the water column at station 20 during 12-hr daytime on five dates in 1978.

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prevailed in the subsurface water. As indicated in Figure 18, the lake remained totally oxygenated during the early part of the year and the pyncnocline developed from May throughout the rest of the year. The oxygen depletion in subsurface water during the anoxic period was most probably enhanced by the greater organic loading from surface runoff during the rainy season (from May to November), and the greater phytoplankton standing crop (shown by chlorophyll level in Fig. 33) reduced the light penetration and contributed dead biomass in the aphotic zone.

Lakewide DO Distribution

The horizontal distribution of DO in the lake water varies a great deal depending on the depth of the water column, the land use of the shoreline, the influence of tributary inflow, the photosynthetic production, the respiratory consumption of oxygen, and the mixing effectiveness by wind action. Figure 23 shows the lakewide DO distribution at depths of 0.5, 5, 10, 20, and 30 m during the April cruise. The maximum DO value in the surface water (0.5 m) was 10 ppm near the west and south portions, and gradually decreased to 7.5 ppm near the center of the lake. The DO concentration was above saturation level in most of the surface water except nearshore of the northeastern region where DO sagged to 4 ppm (50%). It is expected that the DO content progressively decreased in the deeper water, and a major portion of the zone below 20 m was free of oxygen during this period.

The horizontal and vertical DO distributions along the north-south transect during six cruises in 1978 are shown in Figure 24, and the east-west transect in Figure 25. During the January-February period the entire lake was oxygenated, with the maximum DO of 13 ppm and minimum at 1 ppm. The low values were

40
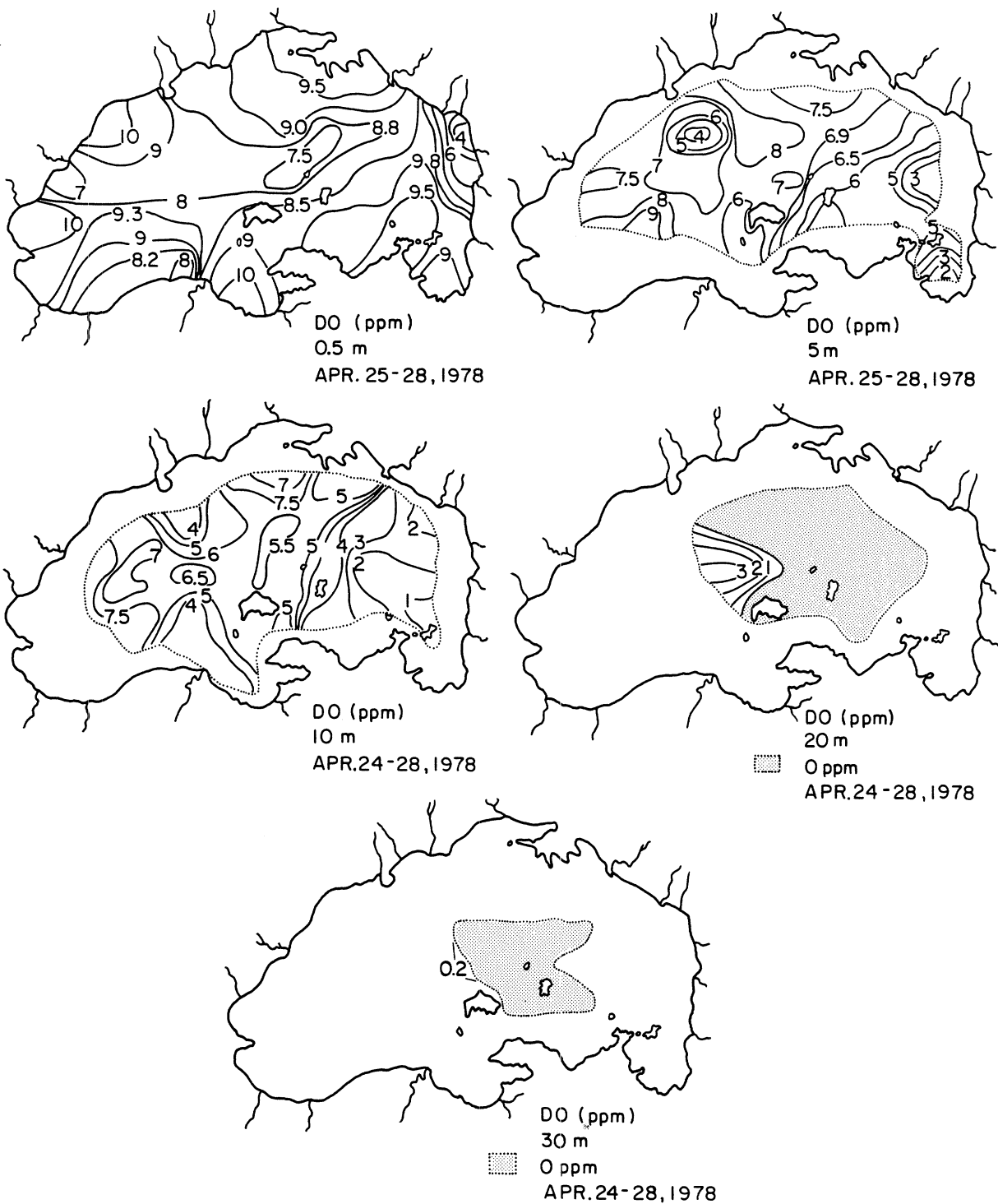
FIG. 23. Horizontal distributions of dissolved oxygen concentration at five different depths during April 24-28, 1978.
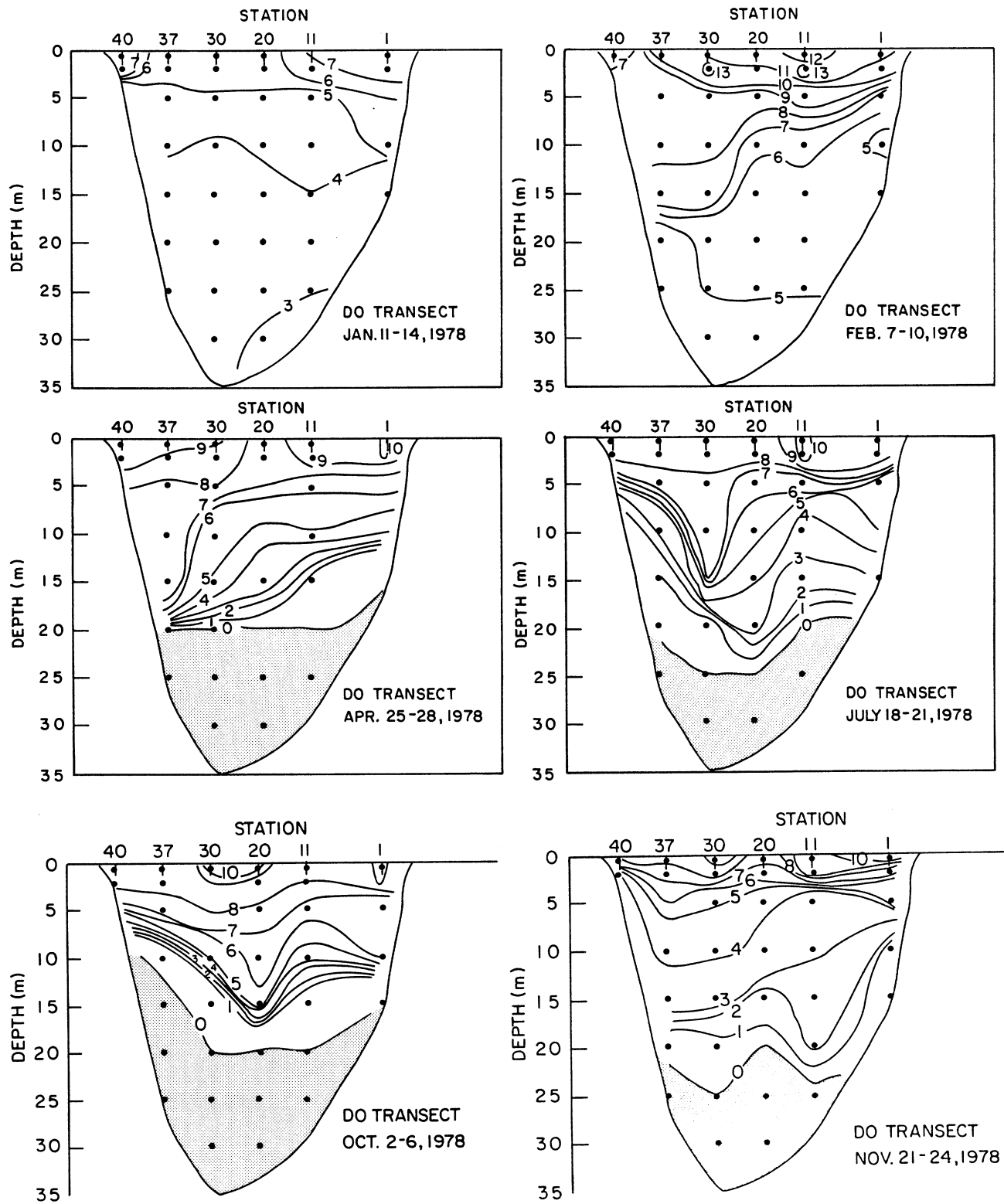
FIG. 24. Vertical gradient of dissolved oxygen concentration (mg/L) in north-south transect during six cruise periods in 1978.

42
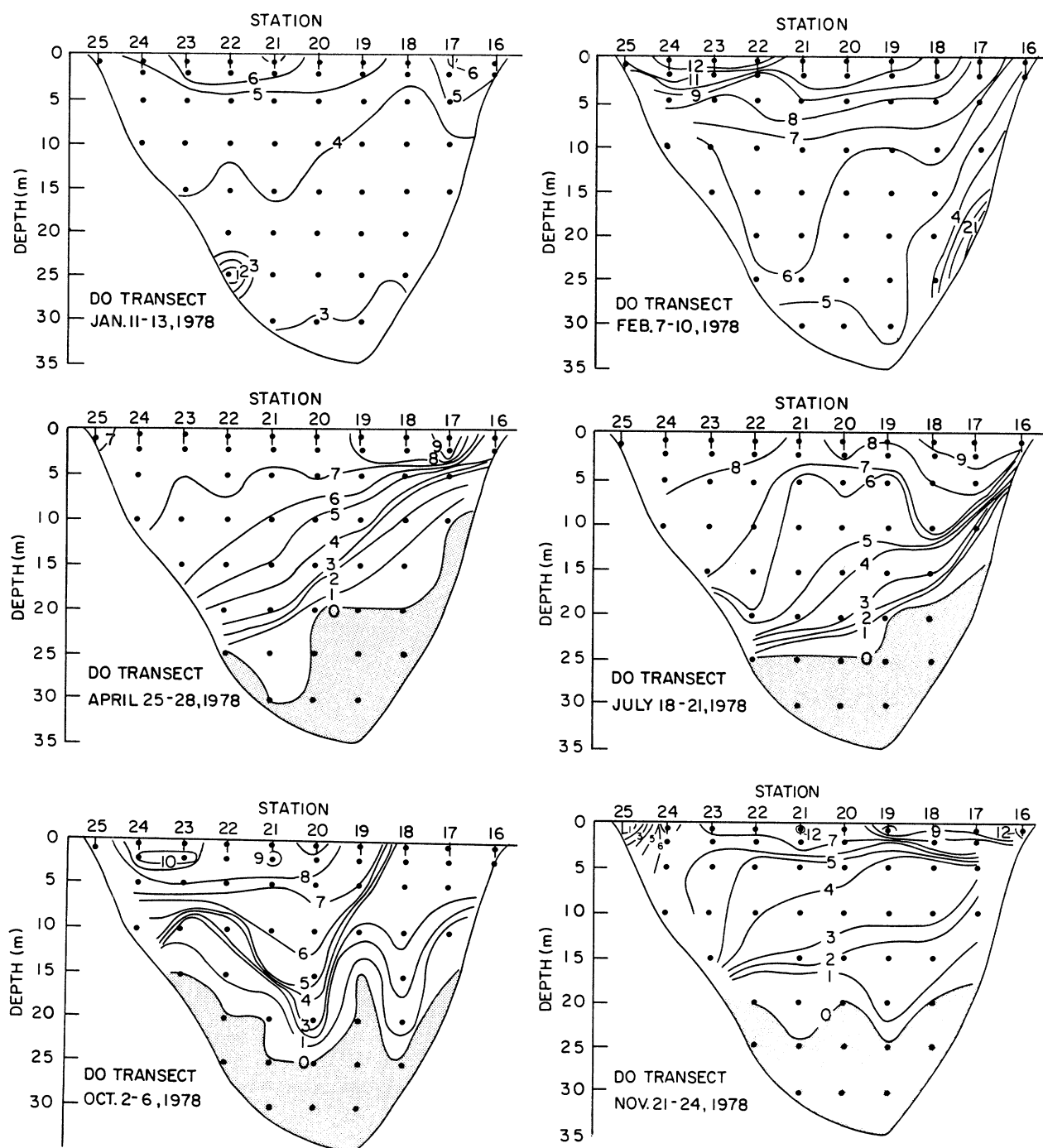
FIG. 25. Vertical gradient of dissolved oxygen concentration (mg/L) in east-west transect during six cruise periods in 1978.

recorded from the water mass near the bottom (20-25 m) at stations 22 and 23 in January and stations 16 and 17 in February. Those stations were adjacent to either end of the east-west transect receiving the outfalls of the Rio Los Guayos and Rio Guey, respectively. The continuous deoxygenation trend which developed on the eastern shore encroached into the entire lower strata of the lake basin.

The persistent long-term oxygen depletion in subsurface Lake Valencia presents a very serious water quality problem. Under unaerobic conditions, the production of H_2S and methane became prevalent, and regeneration of nutrients was enhanced. Several major factors responsible for the oxygen depletion in Lake Valencia are the external input of organic matter through tributaries, the respiratory consumption of planktonic organisms (phytoplankton, zooplankton, and bacteria), and sediment oxygen demand. In order to accurately assess the oxygen budget in the lake, these major processes involved in oxygen loss must be investigated.

PH AND ALKALINITY

Several measurements of alkalinity made in Lake Valencia during 1978 ranged between 300 and 350 mg/L $CaCO_3$. The seasonal and spacial variations in alkalinity were relatively small (Fig. 26).

The pH value in lake water ranged from 7.4 to 9.2, with high values in the surface and low ones near the bottom. Seasonal pH variation in surface water was minimal (Fig. 26). However, the pH in the bottom water was lowered to 7.6 and 7.4 in April and November, respectively.

44
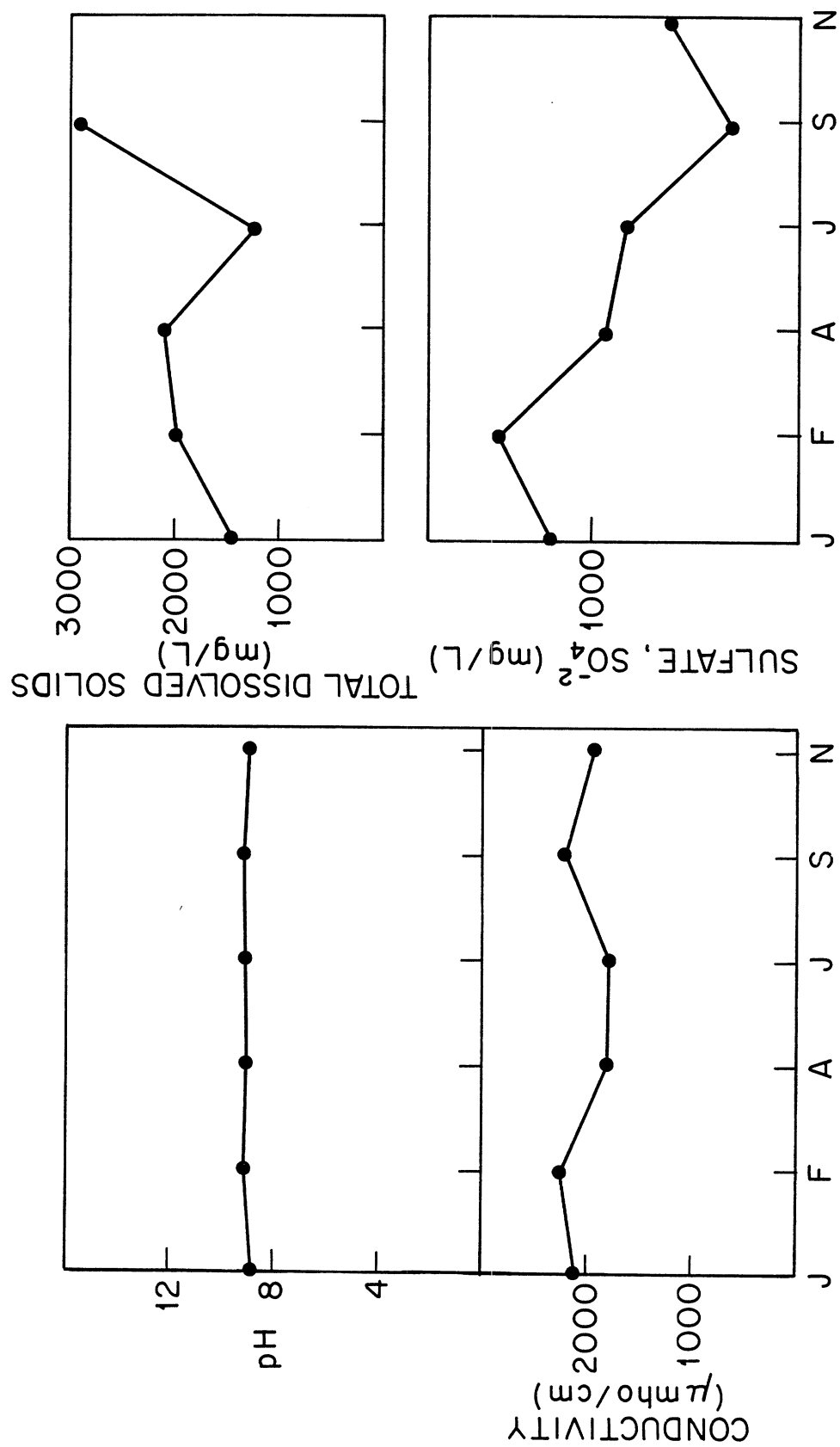
FIG. 26. Seasonal variations in pH, conductivity, and concentration of sulfate total dissolved solids in surface water at station 31.

SPECIFIC CONDUCTANCE

Specific conductance in Lake Valencia ranged from 1,200 to 2,300 μmho/cm, with mean value around 1,900 μmho/cm. The seasonal fluctuation in the surface water of the main water mass remained relatively constant, with high values (>2,000) recorded during February and September (Fig. 26). Vertical variation at most stations also showed a great uniformity, with differences less than 200 μmho/cm, or 10%, between surface and bottom at the central deep station. There were no persistent seasonal and horizontal variations in the surface water (Fig. 27). During April 24-29, the maximum value (2,000 μmho/cm) was observed in the northwest region of the lake, and gradually lowered to 1,200 μmho/cm in the southern and eastern portions. During the September-October cruise period, the value in most parts of the lake was 2,000 μmho/cm or greater.

The specific conductance of the common bicarbonate type freshwater lake is closely proportional to concentrations of total dissolved solids, approximated by the equation:

Sp. Conductance (μmhos/cm 25°C) x A = total dissolved solids.

A is the coefficient obtained experimentally. The factor A is generally between 0.55 and 0.75. However, the analyses of Lake Valencia data on specific conductance and total dissolved solids show little correlation.

TOTAL DISSOLVED SOLIDS

The lakewide distribution of total dissolved solids (TDS) in 1978 ranged

SP CONDUCTANCE
JULY 17-21, 1978

2000
2000-1700
1700-1200

SP. CONDUCTANCE
APR. 24-29, 1978

> 2000
2000-1700
1700 - 1200
< 1200

SP. CONDUCTANCE
SEPT. 26 - OCT. 6, 1978
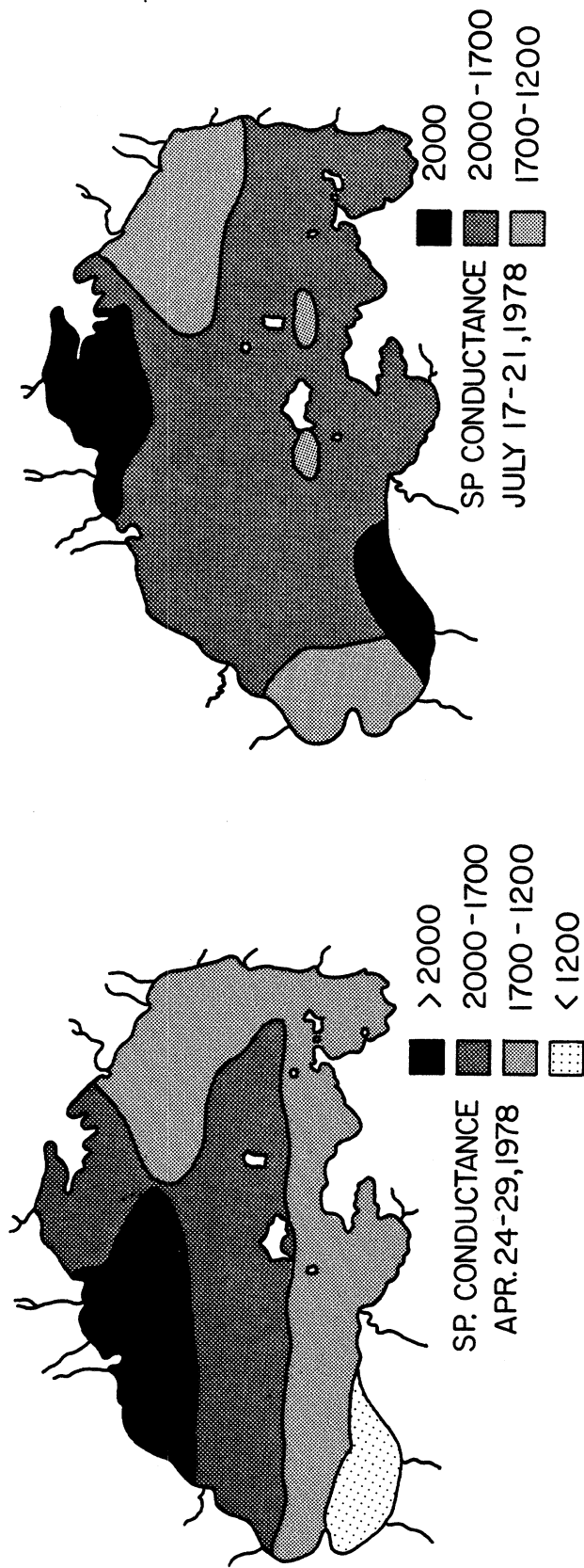
2000
2000-1700

FIG. 27.   Distribution of specific conductance (µmho/cm @ 25°C) recorded during three cruise periods in 1978.

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mostly between 1,500 and 3,000 mg/L, with an average value around 2,000.

Concentration in the surface water at the central station rose from 1,500 mg/L

in January to 2,000 mg/L in July, and reached a maximum of 3,000 mg/L in

September (Fig. 26). Dissolved solids in Lake Valencia consist mainly of

sulfate, magnesium, calcium, chloride, sodium, potassium, carbonate, and

bicarbonate. In the 1978 investigation, sulfate and chloride were analyzed in

all six cruise periods, and other constituents were less frequently analyzed.

Their relative quantitative relationship which prevailed in Lake Valencia was:

Cations: $Mg > Ca > Na$

Anions: $SO_4 > CO_3 > Cl$

The measurements made on November 22 show that Mg:Ca ranged from 2-10. The most

uncommon feature of the chemical constituents in Lake Valencia is the unusually

high sulfate concentration, comprising approximately 30 to 50% of dissolved

solids.

From a health standpoint the TDS concentration in Lake Valencia has already

reached a harmful level of 2,000 mg/L (National Academy of Science 1973). It

was reported that when the sum of the Mg and SO_4 content exceeds 1,000 mg/L, or

TDS content is above 2,000 mg/L, the water has a laxative effect on most

persons. A similar effect also occurs in domestic animals if the drinking water

contains TDS above 1,000 mg/L. It is important to note that water which

contains a high concentration of TDS may conceivably have toxic effects on many

individual organisms. Water containing a high TDS concentration is

objectionable in industrial uses because it may cause formation of boiler scale,

accelerate corrosion, and interfere with the clearness and color of finished

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products (McKee and Wolf 1963).

The rapid increase in TDS over time is one of the most indicative features of deterioration of water quality in Lake Valencia. From a simple input-output model, Apmann (1973) estimated that the TDS concentration was 348 mg/L in 1727 and rose to 1,332 in 1970. The most rapid increase occurred after 1960 and the value observed in 1978 rose above 2,000 mg/L, which was greater than that predicted by Apmann's model (1,700 mg/L in 1980). The difference may result from the desiccation of the lake, which was not included in Apmann's model.

The major external sources of TDS inputs to Lake Valencia are tributary inflows, weathering of soil and rock in the lake basin, and atmospheric precipitation and fallout. Examination of the existing chemical data on Lake Valencia shows that the rapid increase in SO_4 concentration contributed the single largest component in TDS's loading budget during the past few years. Desiccation in this closed lake was undoubtedly an important causal factor in the rapid increase in TDS concentration.

SULFUR

Two major forms of sulfur present in Lake Valencia are sulfate and sulfide. The sulfate concentration reported by INOS (1971) was less than 400 ppm. In this study in 1978, the value ranged from 400 to 1,500 ppm. Figure 26 shows the concentration measured for surface water in the center of the lake, with high concentrations (>1,000 ppm) occurring during the January-February period and decreasing gradually throughout the remaining periods. However, the lakewide horizontal variation was rather large (Fig. 28). The major factors causing large seasonal and regional changes may be the degree of sulfur reduction and

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SULFATE (mg/L)
JULY 17-21, 1978

> 900 ppm
800-900 ppm
700-800 ppm
600-700 ppm

SULFATE (mg/L)
OCT 2-6, 1978

700-800 ppm
600-700 ppm
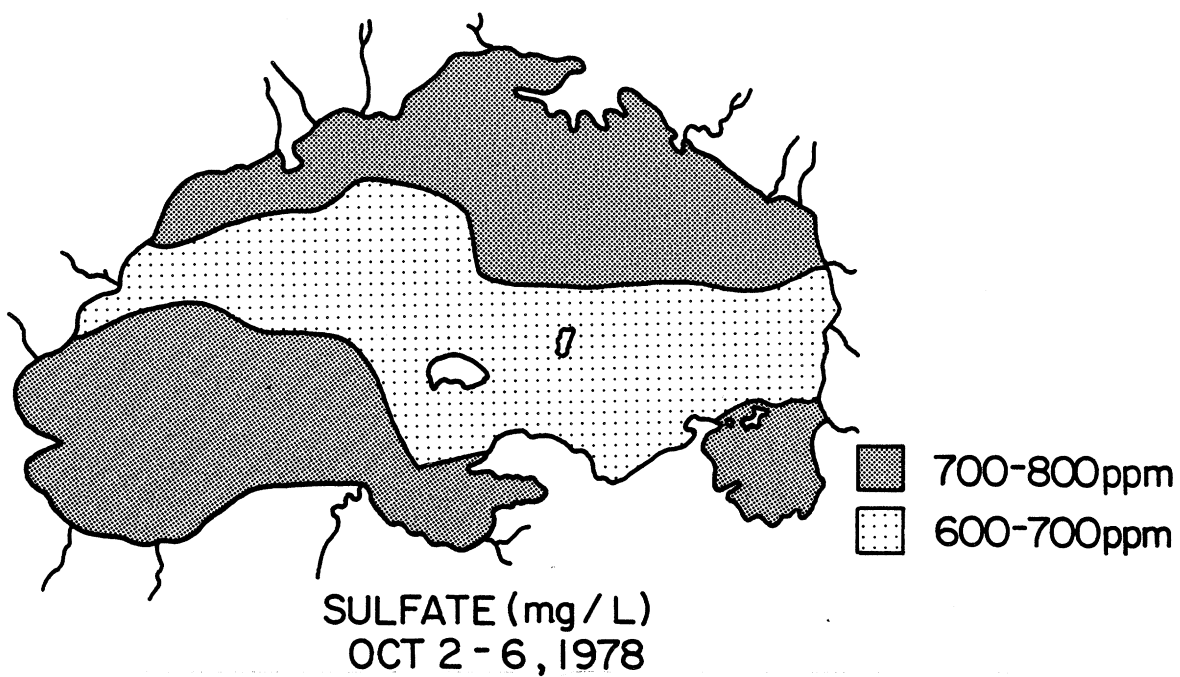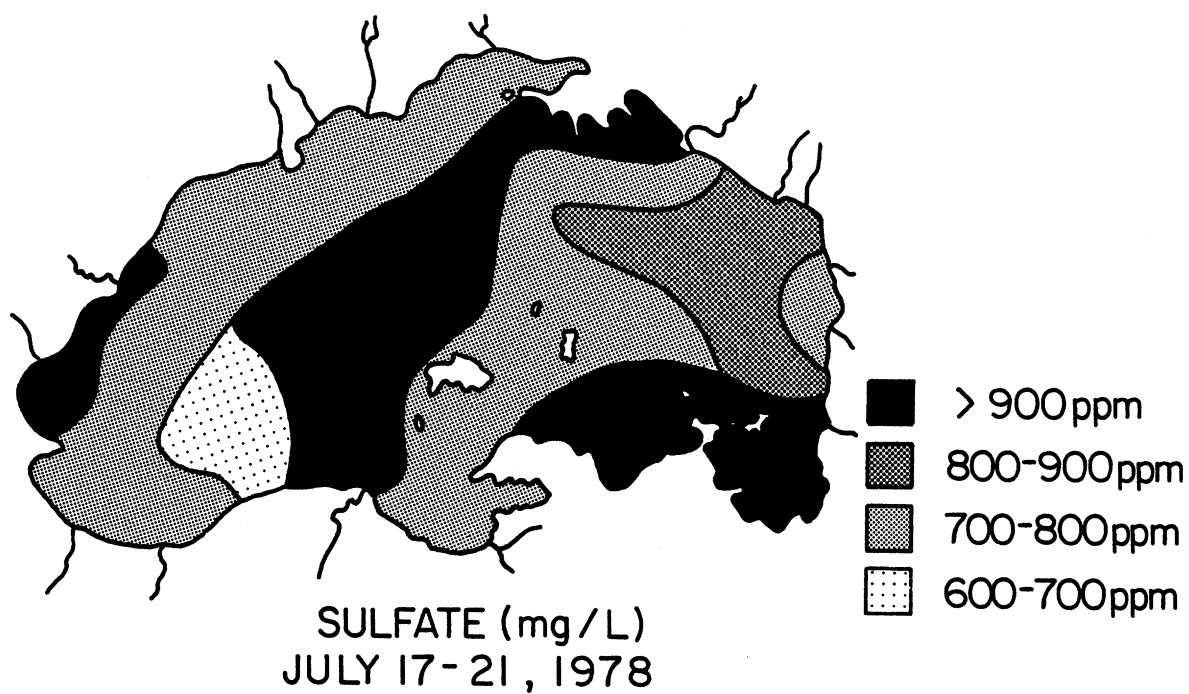
FIG. 28. Distribution of sulfate concentration (ppm) recorded during two cruise periods in 1978.

stagnation in the subsurface water where anoxic situations prevailed frequently during the year. Planktonic organisms may also influence the sulfate concentration in the lake due to the mineralization of organic cellular sulfur content. There are many sources of sulfate input to Lake Valencia. In addition to natural weathering and erosion of sulfur-containing soil and rocks in the watershed, human activities (through sewage and industrial discharges) probably contribute a major input of sulfate to the lake. The preliminary data on sulfate input from tributaries show an extremely high value. For example, the sulfate concentration in Rio Guey during March through May ranged from 60 to 100 ppm, with an estimated total daily input of 6,000-10,000 Kg.

Sulfide (H_2S) is expected to be a dominant form of sulfur in the anoxic zone. Although we did not measure the actual H_2S concentration in the lake water sample, we did notice the powerful rotten egg odor in water devoid of dissolved oxygen. In the February cruise, the obnoxious sulfide odor was pronounced even in the surface water. Presumably the complete mixing during that period brought up the sulfide from deep water. A massive fish kill was also observed at that time of the year. Sulfides are known to be extremely toxic to aquatic organisms. A concentration of total sulfides greater than 0.002 mg/L is unsafe for all aquatic organisms, including fish (National Academy of Science 1973). The extent to which sulfides cause the fish mortality in Lake Valencia remains an important feature for investigation.

PHOSPHORUS

The phosphorus was measured in three forms: total phosphorus (TP) that includes dissolved and particulate, organic and inorganic; total dissolved

phosphorus (TDP) that includes organic and inorganic forms filterable with 0.45 μm pores; and inorganic orthophosphate (PO_4-P) that is the simplest and most available form in the lake water.

The annual fluctuation of phosphorus contents in those three forms, as integrated throughout the depth at station 20, is presented in Figure 29. During the early part of the year, the concentrations were lowest at 3,000 mg/m^2, 200 mg/m^2, and 1,500 mg/m^2 for TD, TDP, and PO_4-P, respectively. Those concentrations increased steadily until they reached their maxima in October at 5,500 mg/m^2, 4,500 mg/m^2, and 4,000 mg/m^2, respectively. Comparisons between the TP and TDP show that the TP content contained 60-90% TDP. In other words, the particulate P, including organic and inorganic forms, constituted less than 50% of the TP.

The vertical variation of TP, TDP, and PO_4-P concentrations in the deepest part of the lake during the annual six cruises are shown in Figure 30. In general, the three forms of phosphorus followed close patterns in their vertical distribution, and in most cases their concentrations were lower toward the surface and greater in the deeper water column. Such a pattern was particularly pronounced during the July-October period. For example, during September-October concentrations of TP, TDP, and PO_4-P were 129, 29, and 13 μg/L in the surface water, compared to 289, 285, and 283 μg/L at the 30-m depth, respectively. During this period, while the TP concentration was relatively comparable with the rest of the year (100-150 μg/L), the concentrations of TDP and PO_4-P (<30 μg/L) were much lower than other periods (>50 μg/L). The most homogeneous concentrations of those phosphorus forms in the water column occurred in the period between November and March.

In general, the TP content in non-polluted natural waters in the world
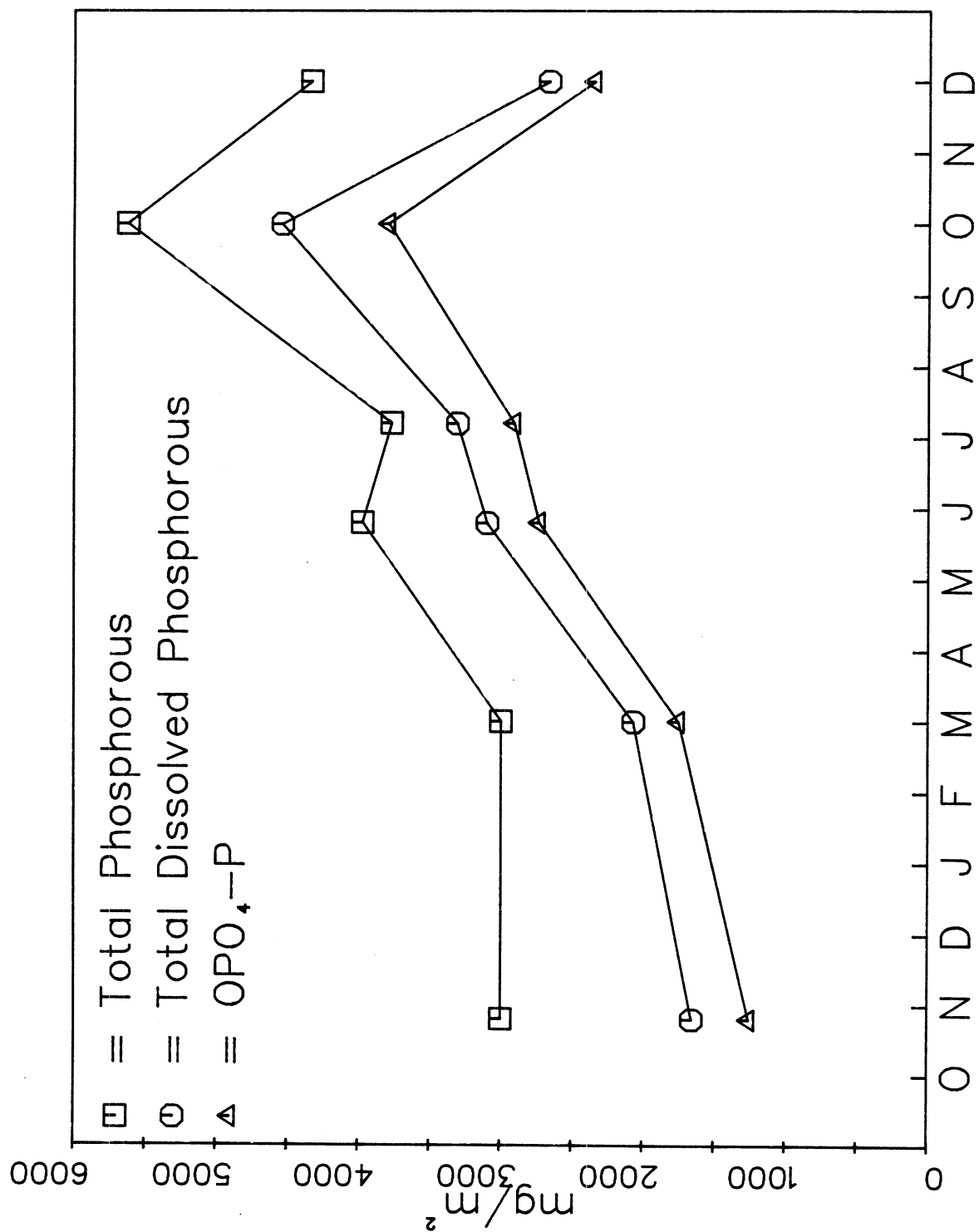
FIG. 29. Annual variation in total phosphorus, total dissolved phosphorus, and inorganic soluble orthophosphate at station 20, 1980. Values are presented by surface area.
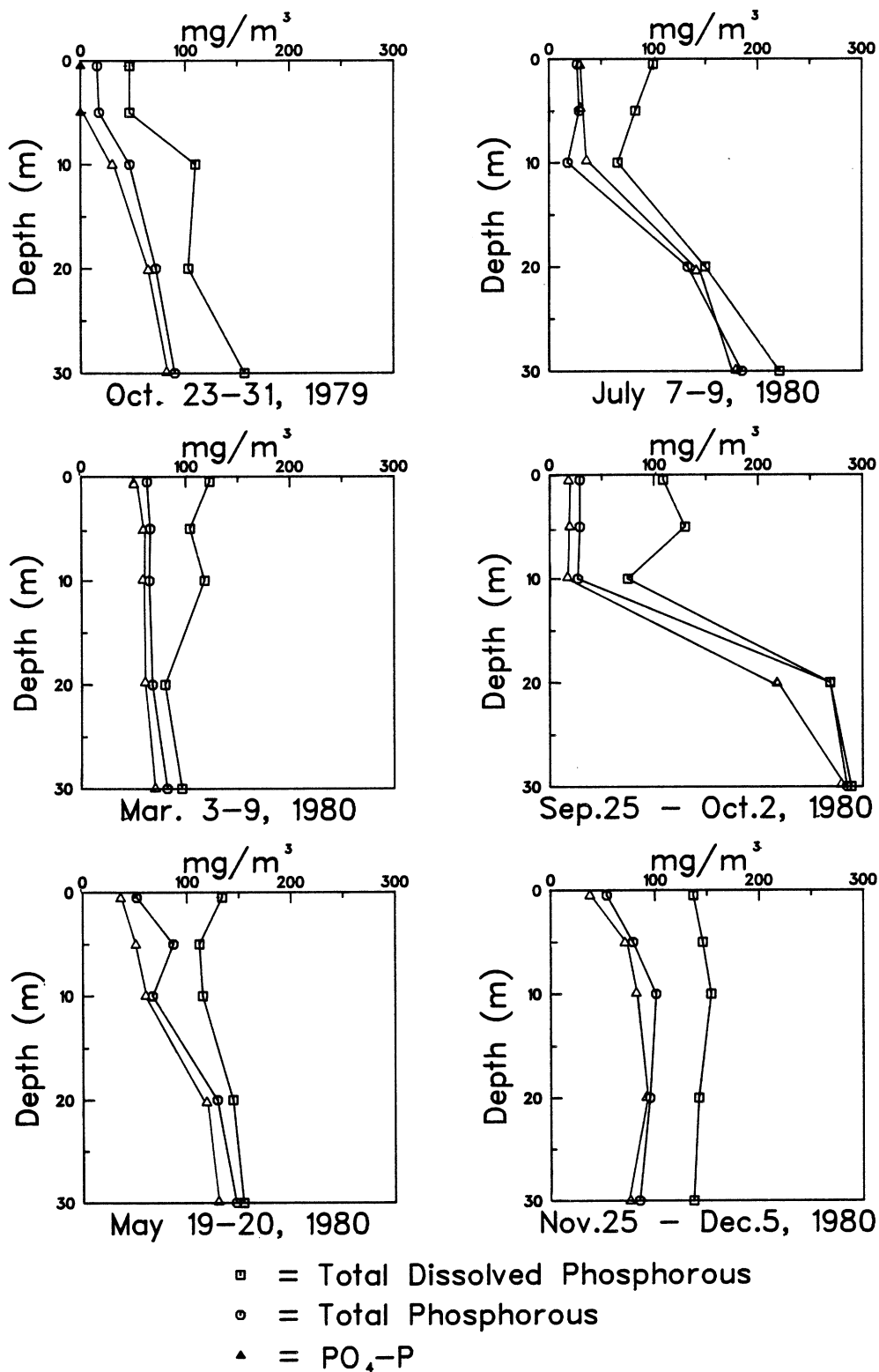
FIG. 30. Vertical distributions of total dissolved phosphorus, total phosphorus, and orthophosphate at station 20 during six cruises in 1979-80.

extends over a wide range from <1 µg/L to >100 mg/L, but the majority of them are between 10 and 50 µg/L. Separation of TP into inorganic and organic fractions in a large number of lakes in the temperate region indicate that a great proportion of the TP is in the organic phase (>85%) (Wetzel 1975). Of the total organic P, about 70% or more is in the particulate organic fraction, and the remainder is present as dissolved and colloidal forms.

In a detailed treatment on phosphorus and productivity of lakes, Vollenweider (1968) demonstrated that the amount of TP generally increases with the algal productivity. Lakes with TP ranging from 30-100 µg/L are considered eutrophic, and those greater than 100 µg/L are hypereutrophic.

Total Phosphorus. Figure 31 shows the lakewide distribution of TP concentration in Lake Valencia. With few exceptions, the total P concentration is well above 100 µg/L in most areas during most times of the year. Persistently higher concentrations were found near the western and eastern ends of the lake. During the annual cycle, the lower TP concentrations occurred in October 1979 with lakewide concentrations ranging from 28 to 228 µg/L; the majority of values during the rest of the year were between 100 and 200 µg/L. At the western end of the lake, total P content ranged from 250 to 1,500 µg/L.

The annual cycle of TP concentration varied considerably with time and depth (Fig. 32). It clearly shows that the TP concentration was relatively homogeneously distributed throughout the water column during the period from January through March, with the majority of concentrations ranging from 100-200 µg/L. It also varied very slightly around 120 µg/L in the surface 5 m during the annual course. However, a marked gradient, increased from 80 µg/L at 10 m to a concentration greater than 200 µg/L at 30 m, prevailed from June throughout the end of the year.

Oct. 23–31, 1979

July 7–9, 1980

Mar. 3–9, 1980

Sep.25 — Oct.2, 1980

May 19–20, 1980
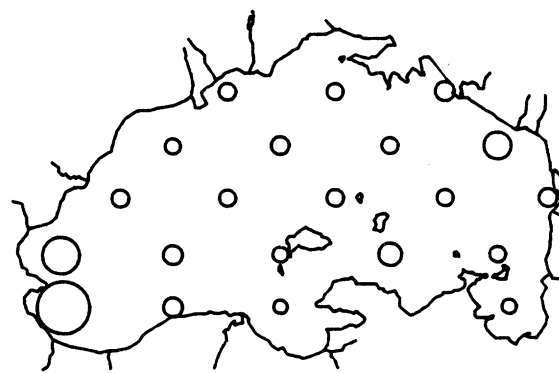
Nov.25 — Dec.5, 1980

∘ = 100mg/m³ Total Phosphorous

FIG. 31. Horizontal distribution of total phosphorus during six cruise periods.
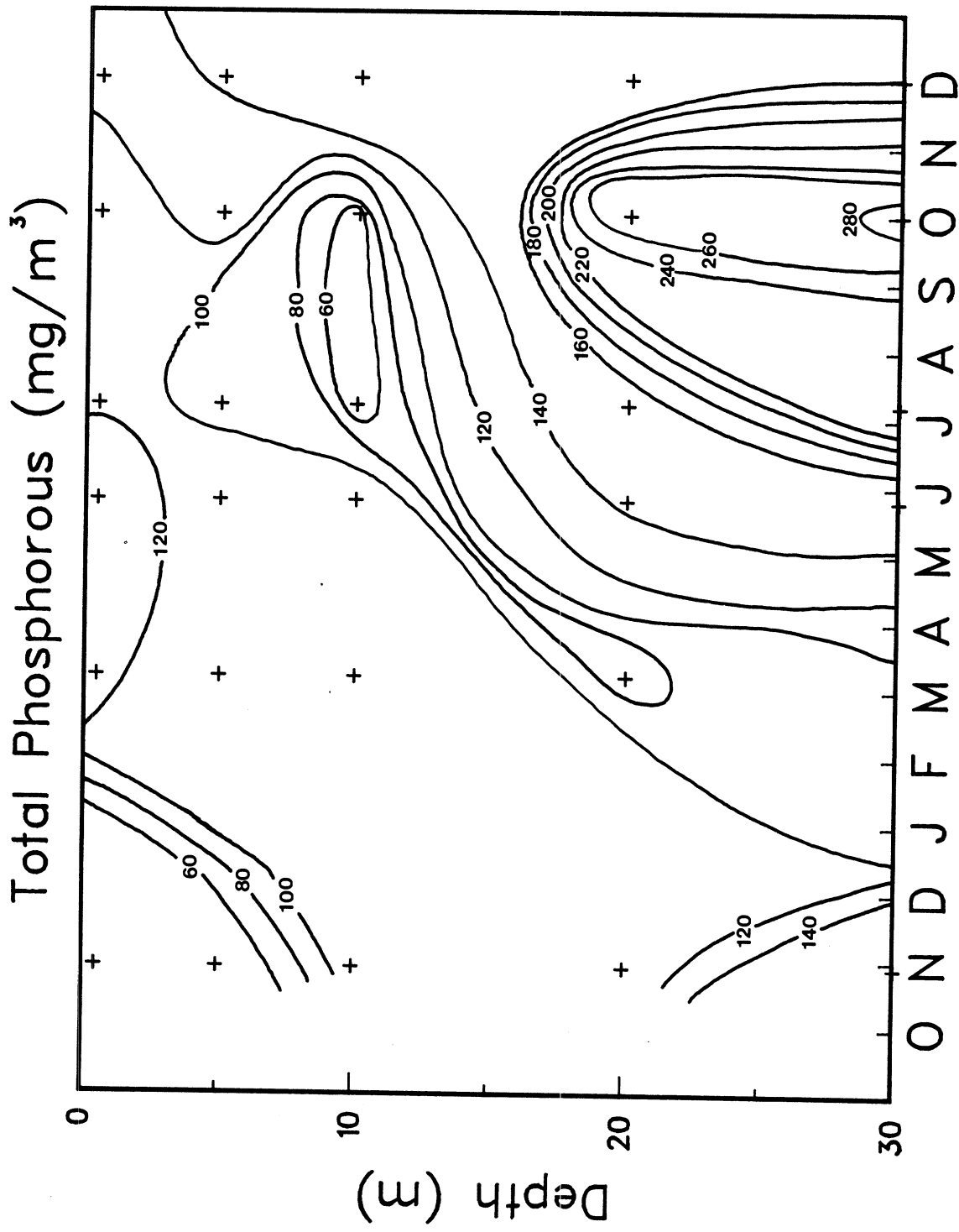
FIG. 32. Time-depth distribution of total phosphorus concentrations, in 20 µg/L gradient contour, during 1980.

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Total Dissolved Phosphorus. Distribution of total dissolved P (TDP), as shown in Figure 33, exhibits a pattern similar to that of TP. The low values, ranging from 13 to 90 µg/L, occurred in October 1979; high values ranging from 52 to 117 µg/L occurred in May 1980. Concentrations ranging from 50 to 150 µg/L prevailed in the lake water during most of the year. On a few occasions the TDP content was greater than 300 µg/L.

The pattern of annual depth variation of TDP concentration in the central part of the lake was somewhat similar to that of TP (Fig. 34). The TDP concentration in the surface 10 m was much smaller than TP, but the difference narrowed with increasing depth. In the surface water, large portions of phosphorus were present in particulate form, especially in phytoplankton cells, which are capable of accumulating dissolved phosphorus from the surrounding water. As phytoplankton cells sink to the aphotic depth, the phosphorus is released back to the water medium upon decomposition of algal cells.

Orthophosphate. Inorganic orthophosphate (PO_4-P) distribution in lake water is presented in Figure 35. In October 1979, most areas in the lake contained PO_4-P less than 10 µg/L, but the concentration increased considerably throughout the 1980 sampling periods, with the majority of the values exceeding 30 µg/L. Particularly high PO_4-P content (>100 µg/L) was widespread from July through October, 1980. The annual variation of vertical distribution of PO_4-P concentration determined for station 20 is shown in Figure 30. The PO_4-P concentration in the upper 10 m of lake water was 20 µg/L or less during the beginning and second half of 1980 and reached 40 µg/L from February to June. A considerably higher concentration of PO_4-P persisted in the deeper water column, i.e., the concentration was greater than 60 µg/L in the water below 20 m throughout the year. Pronounced accumulation of PO_4-P in deep water occurred

Oct. 23–31, 1979   July 7–9, 1980

Mar. 3–9, 1980   Sep.25 — Oct.2, 1980

May 19–20, 1980   Nov.25 — Dec.5, 1980

○ = 100mg/m³ Total Dissolved Phosphorous

FIG. 33. Horizontal distribution of total dissolved phosphorus during six cruise periods.

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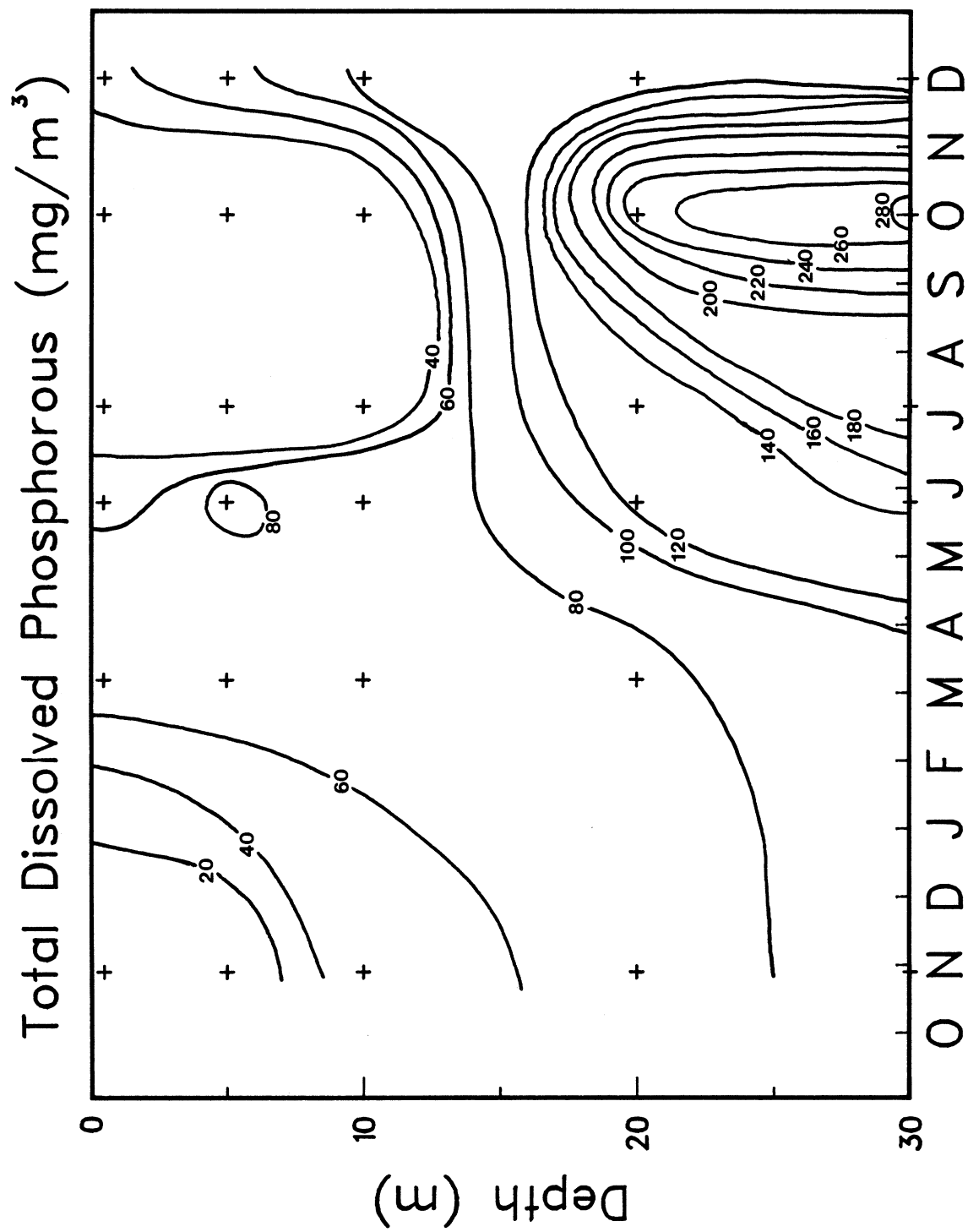
FIG. 34. Time-depth distribution of total dissolved phosphorus, in 20 µg/L gradient contour, during 1980.

Oct. 23–31, 1979

July 7–9, 1980

Mar. 3–9, 1980

Sep.25 — Oct.2, 1980

May 19–20, 1980

Nov.25 — Dec.5, 1980

$\circ = 100mg/m^3\ PO_4-P$

FIG. 35. Horizontal distribution of orthophosphate during six cruise periods.

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during the period from April throughout November, and it reached the maximum concentration of 280 µg/L at 30 m in October (Fig. 36). This pronounced buildup of PO_4-P superimposed on the anoxic event in the lake water presents a classic example demonstration of the mobilization of PO_4-P in an anoxic hypolimnion. As the oxygen in the hypolimnion is removed by active decomposition of organic matter, which in turn releases soluble phosphate, the reductions of iron and manganese are expected to increase markedly. With the reduction of ferric hydroxides and complexes, ferrous ions and absorbed phosphates are mobilized and appear in the water. The existence of hydrogen sulfide in the anoxic water column may further enhance the PO_4-P accumulation in deep water. It has been shown that in very productive lakes, where the decomposition of organic matter produces anoxic conditions and hydrogen sulfide in the hypolimnion, ferrous sulfide (FeS) precipitation occurs. If FeS precipitation is sufficiently large to remove large proportions of the iron, phosphorus may be kept and accumulated in solution.

NITROGEN

Four major chemical groups of nitrogen compounds were analyzed for Lake Valencia water. They are total ammonia (NH_3), nitrite (NO_2), nitrate (NO_3), and total Kjeldahl nitrogen (TKN). Nitrogen compounds may vary their chemical forms throughout the water column depending on the degree of prevailing oxidation and reduction process at a given specific depth. To accurately estimate the total quantity of the various nitrogen compounds from surface to the bottom of the lake, values integrated over the depth for TKN, NH_3, and NO_3 + NO_2 are shown in Figure 37. Content of TKN was relatively stable in comparison with either total
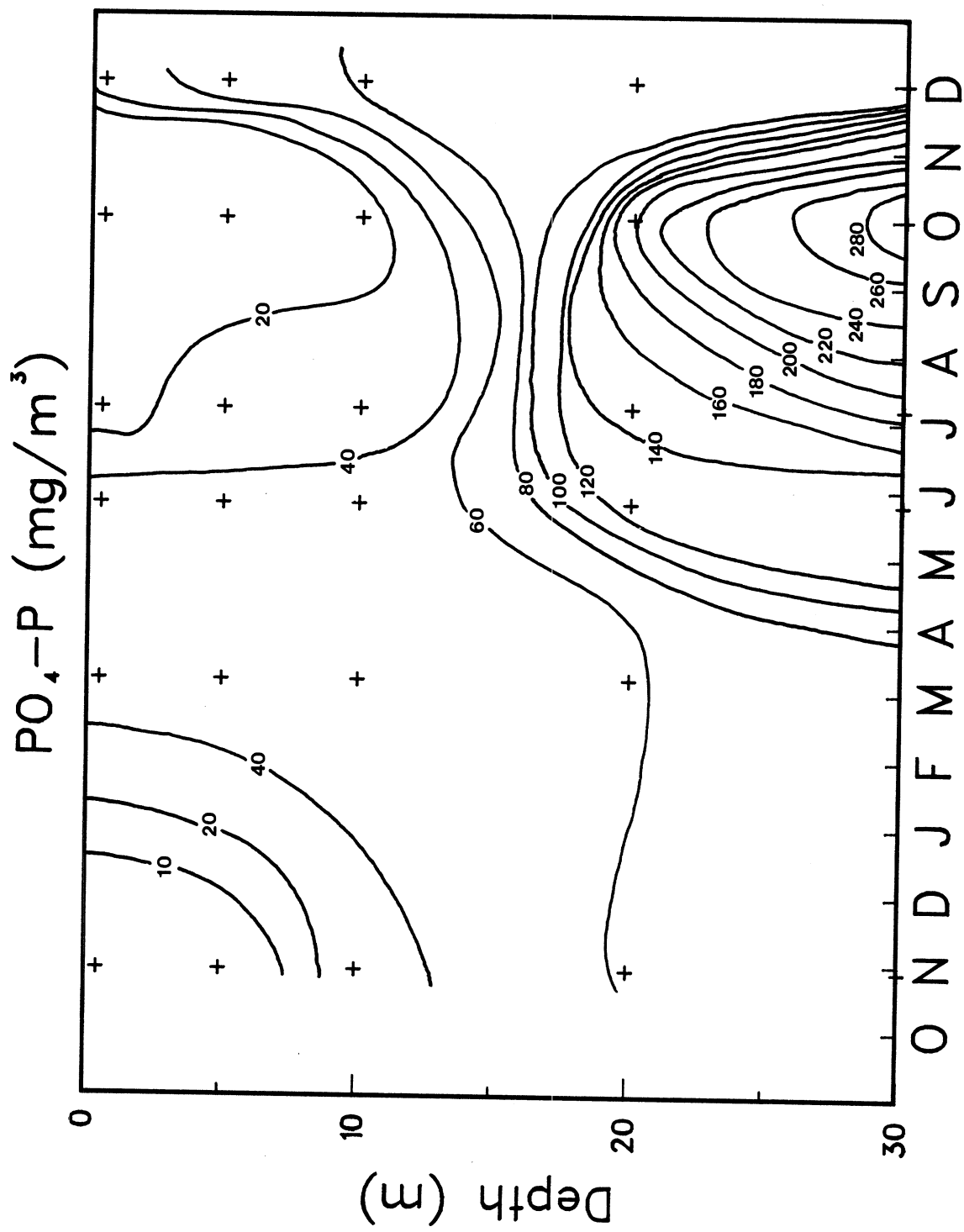
FIG. 36. Time-depth distribution of orthophosphate concentration during 1980.
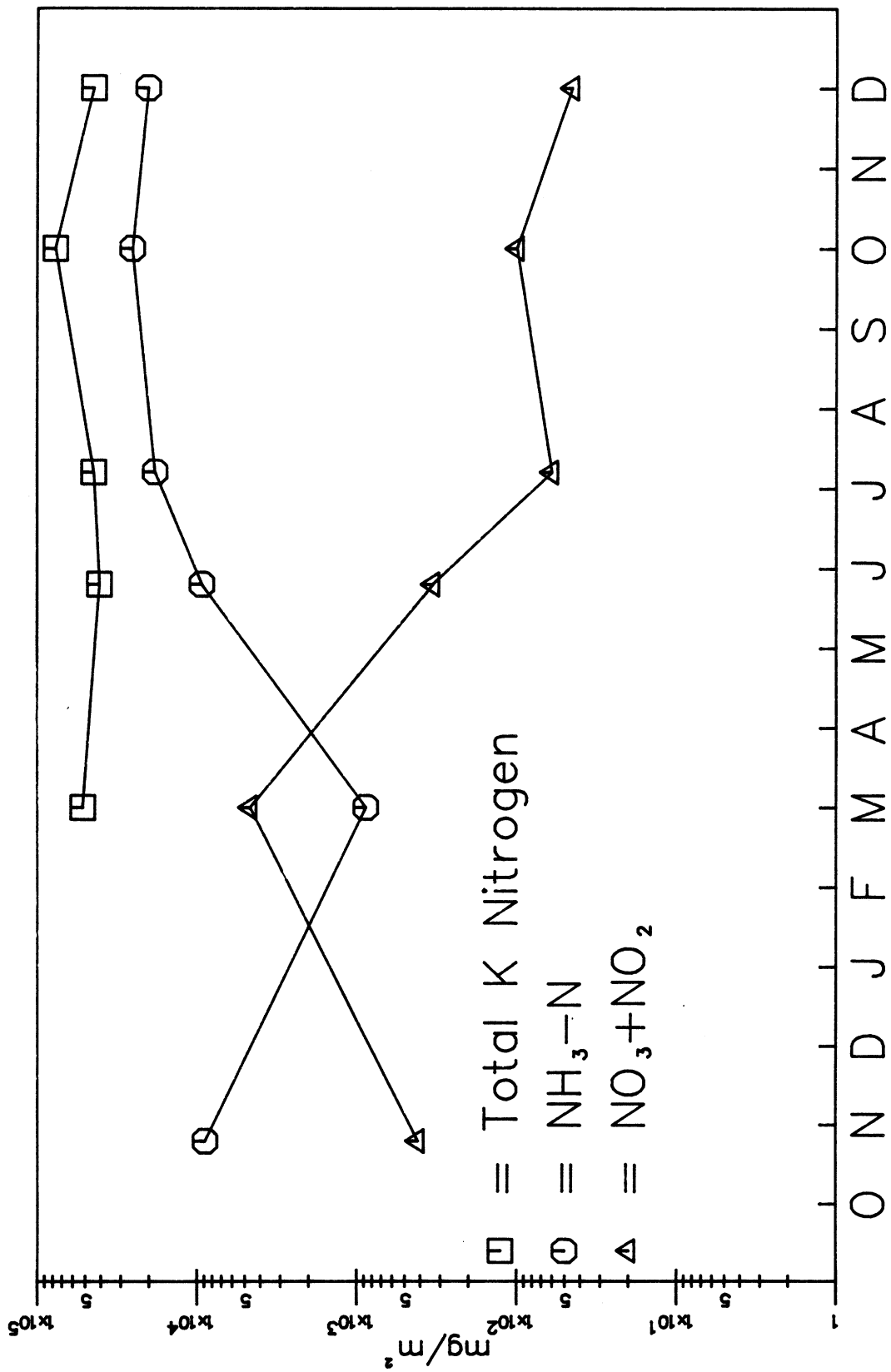
FIG. 37. Annual variation in total K nitrogen, $NH_3 - N$, and $NO_3 + NO_2$ concentrations at station 20.

NH_3 or $NO_3 + NO_2$. While the concentration of NH_3 increased from around 800

mg/m^2 in March to near 2×10^4 mg/m^2 in October, the concentration of $NO_3 + NO_2$

declined steadily from 4,000 mg/m^2 in March to 50 mg/m^2 in December. The

concentrations of NH_3 and $NO_3 + NO_2$ clearly fluctuated in a mirror image

pattern. During the early part of the annual cycle, the NH_3 content was lower

and the $NO_3 + NO_2$ was higher as the lake water was mixed and oxygenated

throughout the water column. However, as the prevailing deoxygenation increased

in depth during the second half of the year, the nitrogen transformed to the

reduced form, NH_3.

Vertical variations of TKN, NH_3, and $NO_3 + NO_2$ concentration are shown in

Figure 38. There were two sampling periods, March and November-December, during

which all three nitrogen forms were distributed more or less homogeneously in

the water column. TKN concentration ranged between 1,000 and 3,000 $\mu g/L$.

Except for the March period, the $NO_3 + NO_2$ concentration was relatively low,

often below our detectable level at 4 $\mu g/L$. Such a low value most likely

resulted from phytoplankton uptake.

Total Kjeldahl Nitrogen (TKN). The lakewide horizontal TKN distribution

ranged from 200 to 4,500 $\mu g/L$, with the majority of the values exceeding

1,000 $\mu g/L$ (Fig. 39). In general, the higher concentrations were persistently

observed at the western basin of the lake where values ranged between 2,000 and

3,000 $\mu g/L$.

Annual vertical variation of TKN content in the water column is shown in

Figure 40. The concentrations were between 1,000 and 2,000 $\mu g/L$ in the upper

10 m throughout the year, and in the entire water column from March to

September. During the period from September to November, a marked vertical

concentration gradient prevailed, increasing from 1,000 $\mu g/L$ at 30 m.
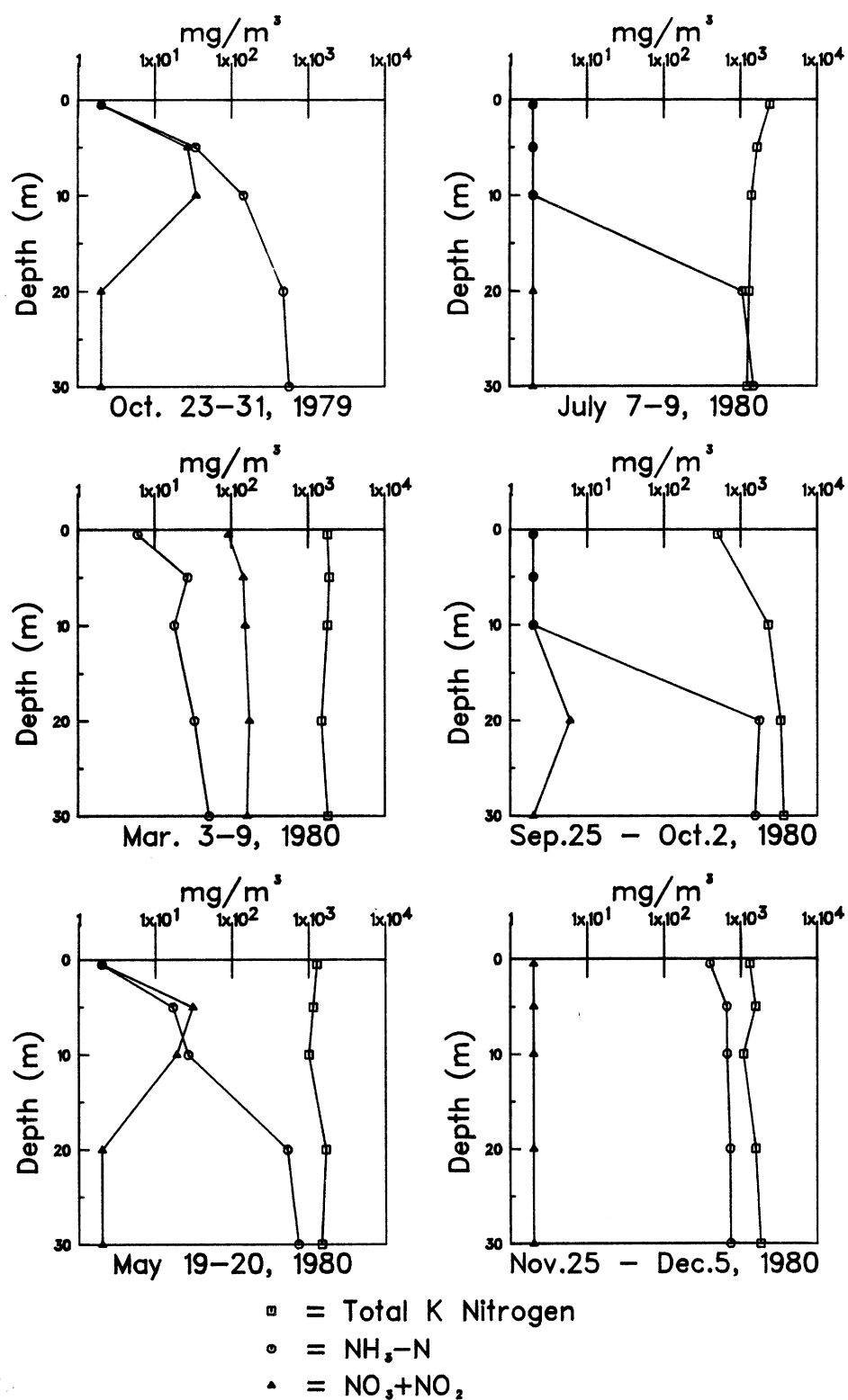
FIG. 38. Vertical distributions of total K nitrogen, $NH_3 - N$, and $NO_3 + NO_2$ at station 20 during six cruise periods.

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Oct. 23–31, 1979
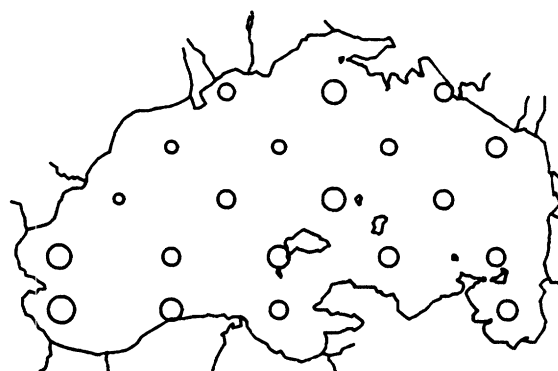
July 7–9, 1980

Mar. 3–9, 1980

Sep.25 — Oct.2, 1980

May 19–20, 1980

Nov.25 — Dec.5, 1980

o = 1 mg/L Total K Nitrogen

FIG. 39. Horizontal variation in total K nitrogen at selected stations during six cruise periods.

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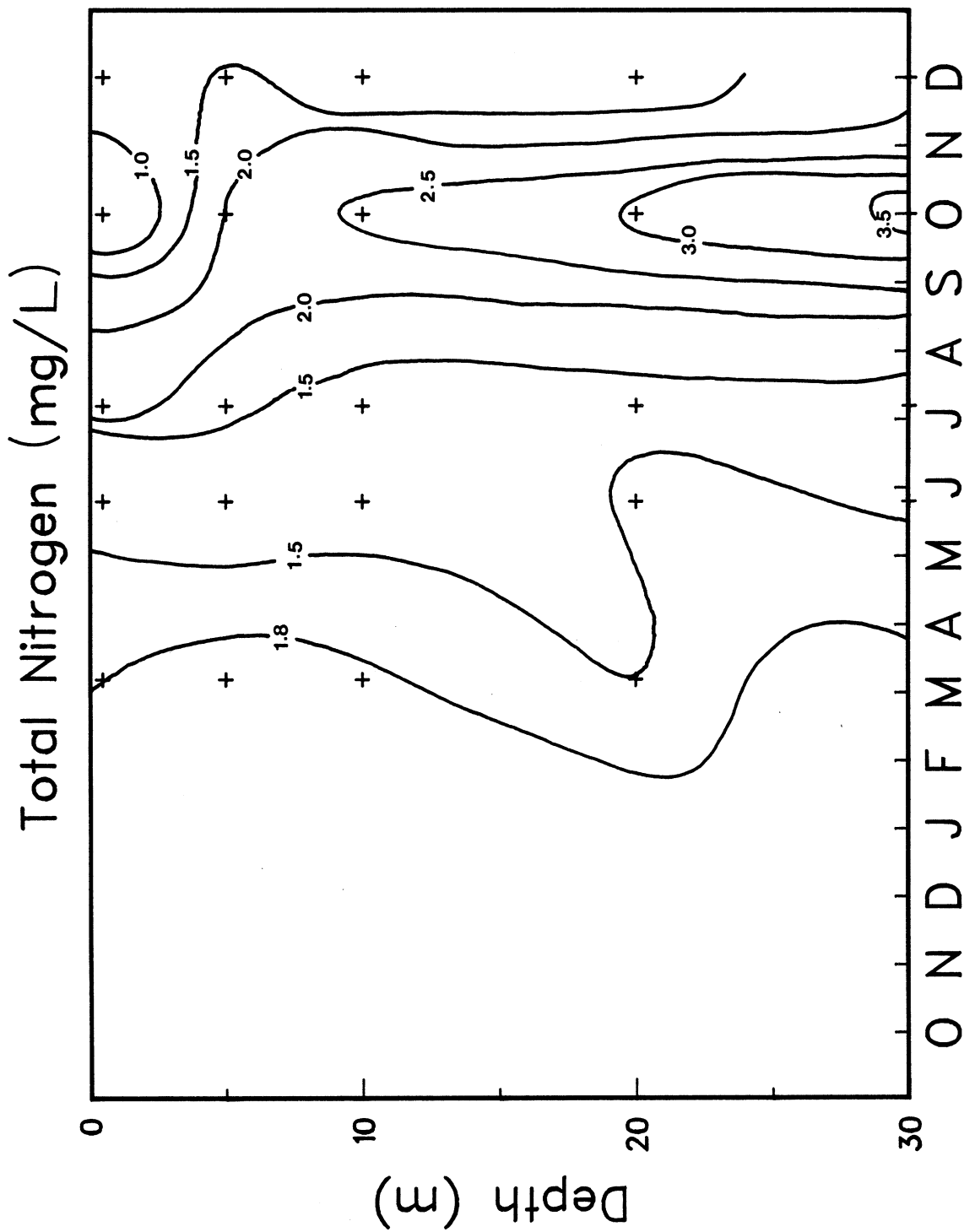
FIG. 40. Time-depth distribution of total K nitrogen at station 20 in 1980.

Destratification of the lake water normally occurred between December and March, during which the TKN content showed a great degree of homogeneity.

Nitrite (NO_2) and Nitrate (NO_3). The lakewide horizontal distribution of the oxidized nitrogen, $NO_3 + NO_2$, as shown in Figure 41, is highly variable although the concentrations are generally very low. With few exceptions, concentrations were below 100 μg/L and the contents of many samples, in fact, were less than 4 μg/L. Among the six sampling periods, the overall concentration was highest in March, with values ranging from 6 to 172 μg/L. Unlike other nutrients, the $NO_3 + NO_2$ concentrations were generally lower in the vicinity of point contamination sources, i.e., tributary discharges, as the effluents and lake water in those regions often contained little oxygen. As nitrate is the major nitrogen form assimilated by phytoplankton, the content is expected to be lower in surface water where there is a large algal standing crop. Figure 42 shows the vertical distribution of $NO_3 + NO_2$ in the lake water. The peak concentration was built up in March (100-160 μg/L), and was followed by a sharp decline to the lowest level at 4 μg/L from June throughout the rest of the year. As the rapid deoxygenation occurred in the water column after March, the NO_3 was denitrified to NH_3 in the anoxic zone. The combination of prevailing denitrification in the subsurface water and phytoplankton uptake in the surface euphotic zone resulted in the disappearance of NO_3 in the lake water.

Ammonium (NH_3-N). Ammonium is an important, prevailing form of nitrogen in Lake Valencia. Its seasonal and partial distribution in the lake water was extremely variable. Figure 43 shows the lakewide horizontal distribution of NH_3. Concentrations were lowest at the beginning of the year (March), ranging from 6 to 51 μg/L, and were highest during the September-November period, with most values greater than 100 μg/L. The vertical distribution of NH_3 in an

Oct. 23–31, 1979

July 7–9, 1980
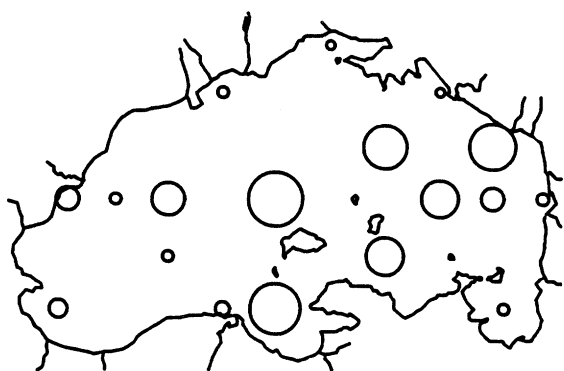
Mar. 3–9, 1980
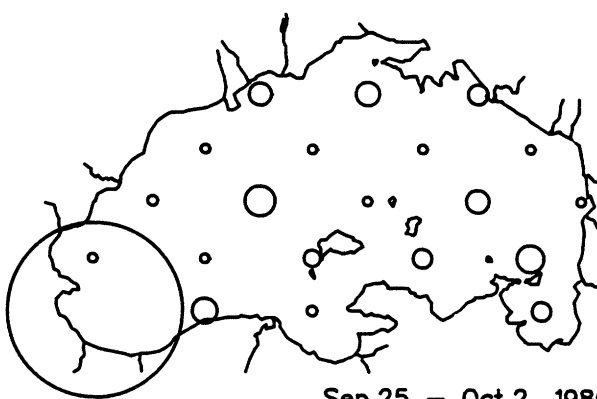
Sep.25 — Oct.2, 1980

May 19–20, 1980

Nov.25 — Dec.5, 1980

$$\bigcirc = 100 mg/m^3 \ NO_3 - NO_2$$

FIG. 41. Horizontal variation in $NO_3 - NO_2$ concentration at selected stations during six cruise periods.
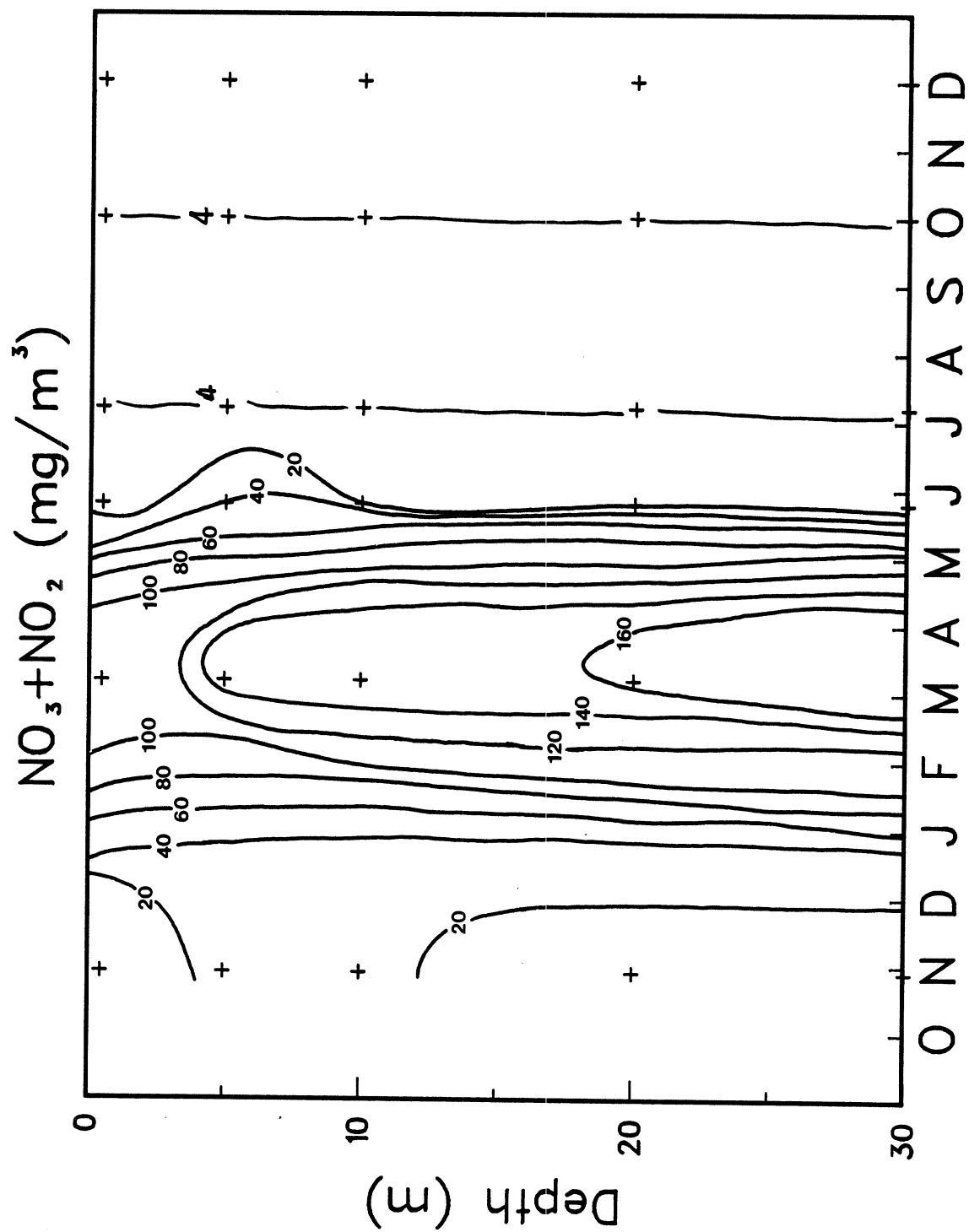
FIG. 42. Vertical variation in $NO_3 - NO_2$ concentration at station 20 during 1980.

Oct. 23–31, 1979
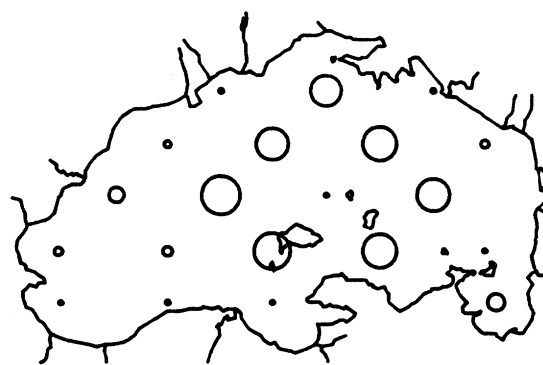
July 7–9, 1980

Mar. 3–9, 1980
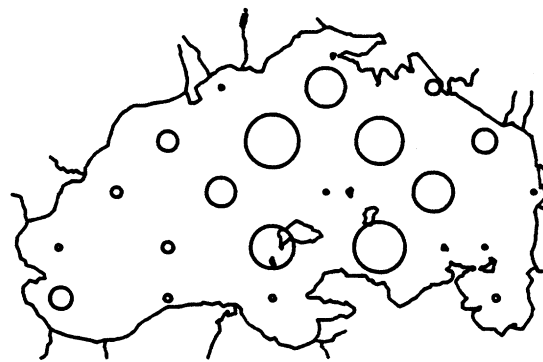
Sep.25 — Oct.2, 1980
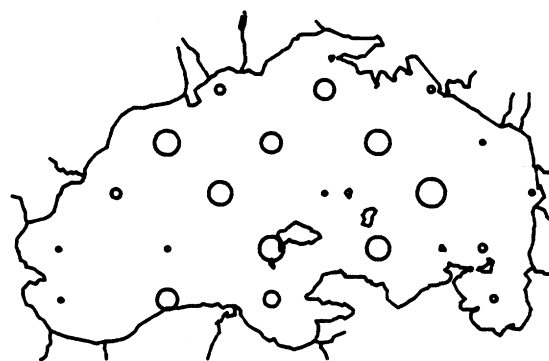
May 19–20, 1980
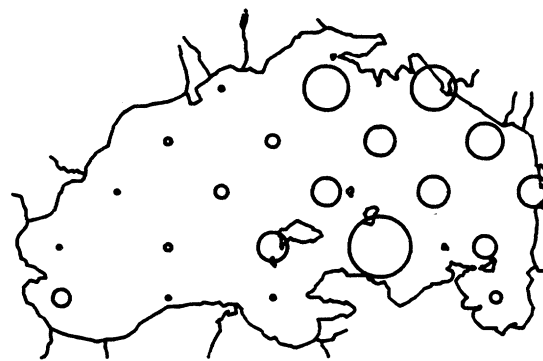
Nov.25 — Dec.5, 1980

$\circ$ = 100mg/m^3 NH$_3$–N

FIG. 43. Horizontal variation in NH$_3$ – N concentration at selected stations during six cruise periods.

annual cycle is shown in Figure 44. Very low NH_3 (<100 µg/L) appeared in the surface 10 m from January to October. A pronounced vertical concentration gradient began to establish below the 10 m depth after June and reached the greatest level at 1,700 µg/L near 20 m in October. The development of the NH_3 gradient was closely related to the oxygen depletion pattern in the hypolimnion.

<div align="center">TRACE METALS</div>

The concentrations of several heavy metals were analyzed at several depths at station 20 (Fig. 45). During January, when the lake water mass was well mixed, a greater degree of homogeneity in vertical concentrations occurred.

Iron. Iron concentration was 50 µg/L from the surface to 20 m and 200 µg/L at 30 m. During the lake turnover period (December to March) the lake water was thoroughly oxidized. It is expected that the ferric ion would be the predominant form that in turn precipitates to the sediment as a hydoxide, $Fe(OH)_3$. In the anoxic water during the remainder of the year the presence of H_2S probably removed iron in the form of ferrous sulfide (FeS), which resulted in the production of black mineral muds.

Nickel. Nickel concentration was 100 µg/L throughout the water column. High concentrations of nickel were reported to be toxic to plant life (>500 µg/L) and to fish reproduction (>700 µg/L). However, concentrations at or below 100 µg/L have no apparent harmful effects on aquatic organisms.

Lead. Lead concentration ranged between 40 and 50 µg/L, which is the permissible level for domestic water supply in the USA. It was shown that 30 µg/L concentration caused reproductive impairment in Daphnia magna (Biesinger and Christensen 1972).
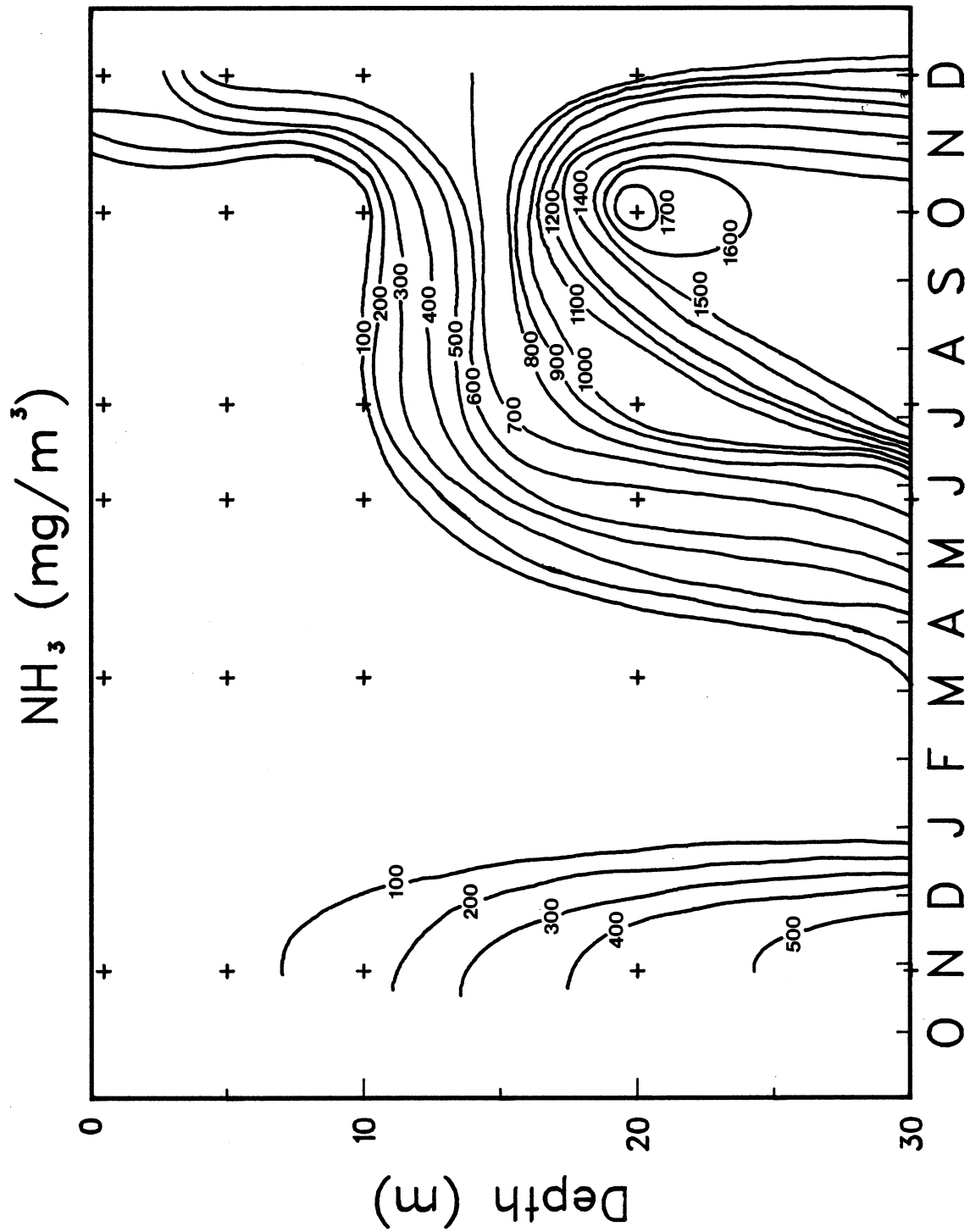
FIG. 44. Vertical variation in NH$_3$ – N concentration at station 20 during 1980.
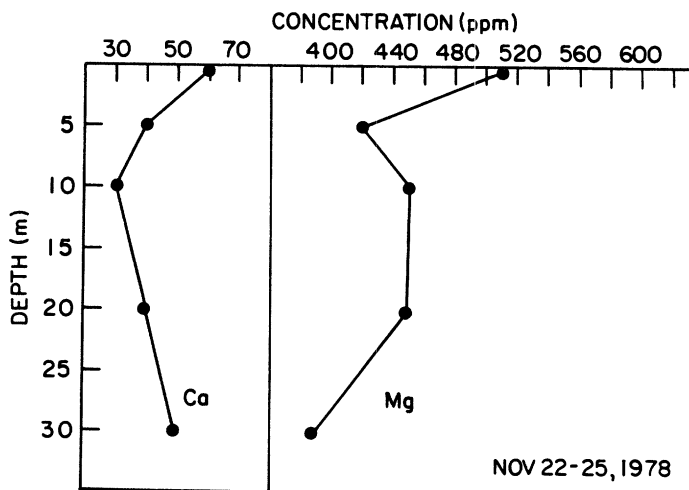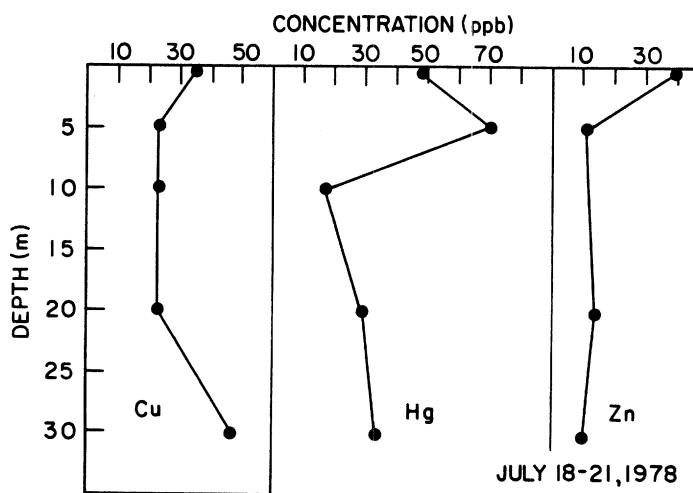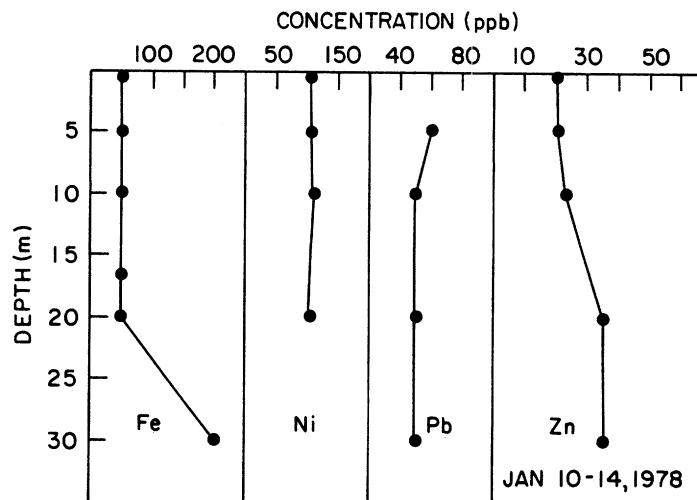
FIG. 45. Vertical distribution of iron, nickel, lead, zinc, copper, mercury, calcium, and magnesium concentrations.

Zinc. Zinc concentration ranged from 20 to 40 µg/L and from 10 to 35 µg/L in July 1979. Those concentrations were relatively low compared to the mean concentration (64 µg/L) in U.S. waterways. Numerous bioassays have been conducted to test the toxic effect on all levels of aquatic organisms. Zinc is also an essential trace metal required by all kinds or organisms (Bowen 1966, Underwood 1971). Minimum concentration required for optimal algal growth was reported at 50 µg Zn/L (Eyster et al. 1958). Zinc concentrations toxic to human are quite high (>5 mg/L). The test for chronic effects of zinc on fathead minnow reproduction showed that 30 µg/L had no effect, whereas 180 g/L caused a 93% reduction in fecundity.

Copper. Copper concentration was between 20 and 50 µg/L at station 20 in Lake Valencia. The vertical profile shows that the highest concentration was at 30 m. All organisms require minute quantities of copper for growth. Free copper ions at concentrations greater than 50 µg/L have an adverse effect on phytoplankton species. The copper toxicity to algae depends on the temperature and alkalinity of the water. Deleterious effects of free copper concentrations on fish and zooplankton were greater than 18 µg/L in soft water (<30 mg/L $CaCO_3$) and 30 µg/L in hard water (>200 mg/L $CaCO_3$) (Mount 1968).

Mercury. Mercury concentration from the surface to 30 m ranged between 15 and 70 µg/L at station 20 in July 1978. The toxicity of mercury has been known to man for a long time. Although it may exist in inorganic (Hg^o and Hg^{+2}) and organic forms in the environment, the organic methyl mercury ($HgCH^3$) is 50 times more toxic to organisms than inorganic forms (Schroeder 1974). Algae and aquatic plants accumulate mercury by surface adsorption, and fish take it up both directly from the water and from food (Hannerz 1968). The accumulation rate was shown to be fast while the elimination rate was slow, leading to

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concentration factors of 3,000 fold and higher. Concentration factors by fish

in excess of 10,000 times that in the surrounding water have been reported

(McKim 1974), and 1 µg/L of mercury showed a distinct effect on marine

organisms. Two chronic toxicity tests on Daphnia magna showed that mercury as

mercuric chloride and methylmercuric chloride caused significant reproductive

impairment at concentration of 2.7 and 0.04 µg/L mercury, respectively

(Biesinger 1974).

To detect the mercury level in fish in Lake Valencia, samples of Tilapia

mossambica, the most abundant species in the lake, were taken for analysis.

Table 5 shows the mercury content in fish muscle and viscera. Mercury content

in fish muscle and viscera ranged from 20 to 70 µg/kg of fish in wet weight.

The levels of mercury in those fish samples were relatively low, compared to the

safety levels (500 µg/kg) in livestock recommended for human consumption. The

accumulation factor from lake water appears to be extremely small. One

explanation would be that the mercury in Lake Valencia water reacted with the

prevalent hydrogen sulfide, forming extremely insoluble precipitates which make

it unavailable to organisms for uptake.

CHLOROPHYLL a

The chlorophyll a concentration fluctuated widely over depth, time, and

location. Figure 46 shows that at the beginning of 1978, at station 20, the

chlorophyll concentration was low (10-20 mg/m^{-3}) and relatively homogeneous

throughout the water column. As indicated by the depth profiles of temperature

and dissolved oxygen, the water mass was well mixed during the January-February

period. Chlorophyll a concentration in the upper 10 m increased progressively

TABLE 5. Mercury content in muscle and viscera of _Tilapia mossambica_, sampled at Turmero rivermouth and Macapo in Lake Valencia.

Sample No.	Muscle	Viscera
Turmero 2	0.02	0.04
Turmero 4	0.03	0.03
Turmero 6	0.03	0.07
Turmero 8	0.03	0.04
Turmero 10	0.04	0.05
Turmero 12	0.03	0.07
Macapo 5	0.02	0.05
Macapo 6	0.06	--
Macapo 7	0.02	0.07
Macapo 9	0.07	--
Macapo 11	0.02	0.02
Macapo 13	0.02	0.02
Macapo 15	0.04	--

and the vertical gradient became pronounced toward the latter part of the year (Fig. 46). The maximum concentration in the surface water (5 m) occurred in October with value greater than 50 mg/m^3 and less than 10 mg/m^3 at 25 m. Chlorophyll level remained relatively low and constant at approximate 10 mg/m^3 in the deep water below 20 m. As this depth was far below the euphotic zone (<5 m), chlorophyll was not expected to carry out photosynthetic activity. But the chlorophyll appeared to be healthy and functional as indicated by a high chlorophyll/phaeophytin ratio.

The lakewide chlorophyll distribution during six cruise periods showed large regional variation throughout the year (Fig. 47). In general, high concentrations occurred in the southwestern portion of the lake, and this pattern was particularly pronounced from July to November. During the January-April period, a major portion of the lake contained chlorophyll at 10-20 mg/m^3

CHLOROPHYLL (mg/m^3)
ST. 31, 1978
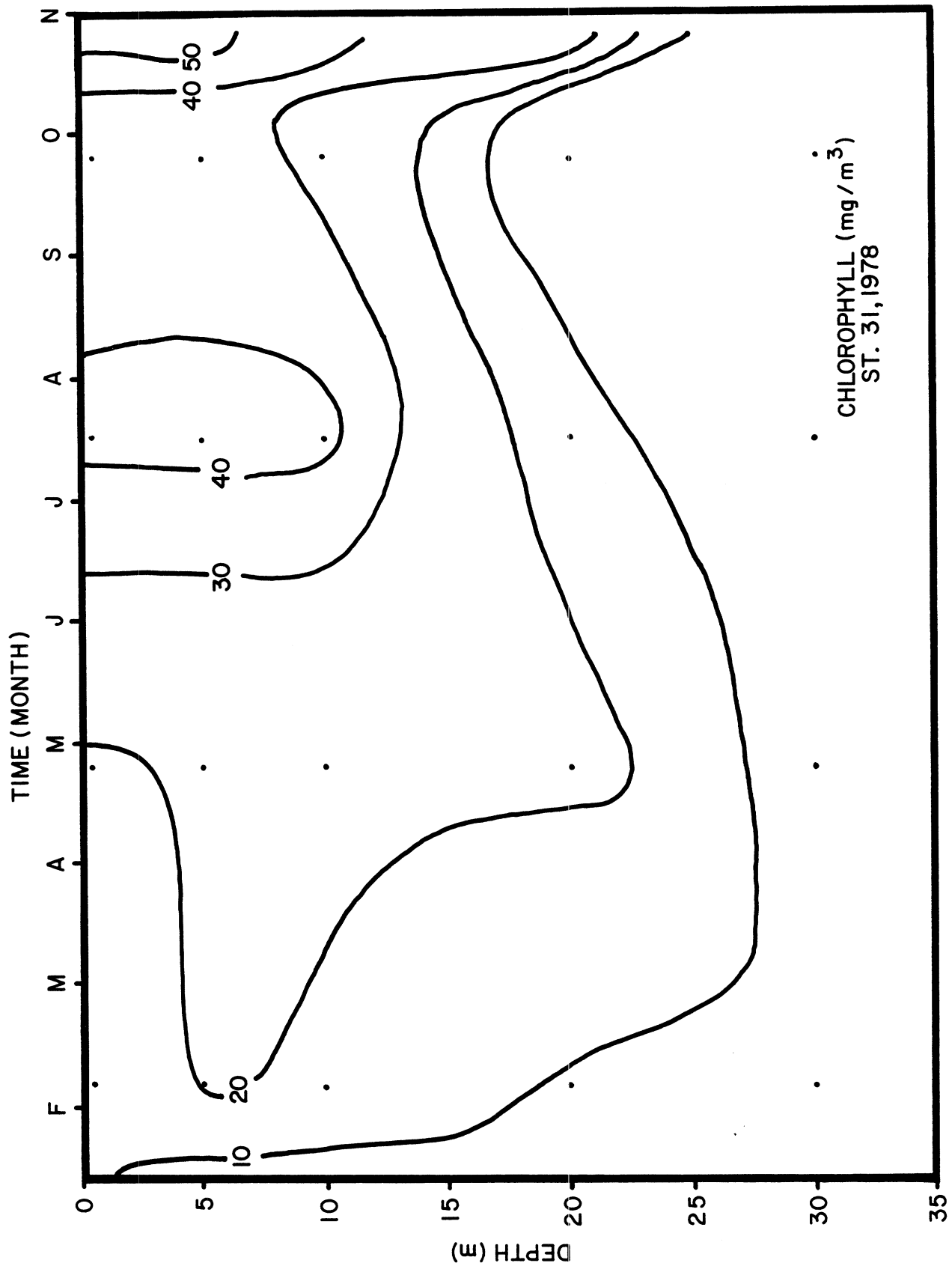
FIG. 46. Depth-time isopleths of chlorophyll a concentration at station 31 in 1978.

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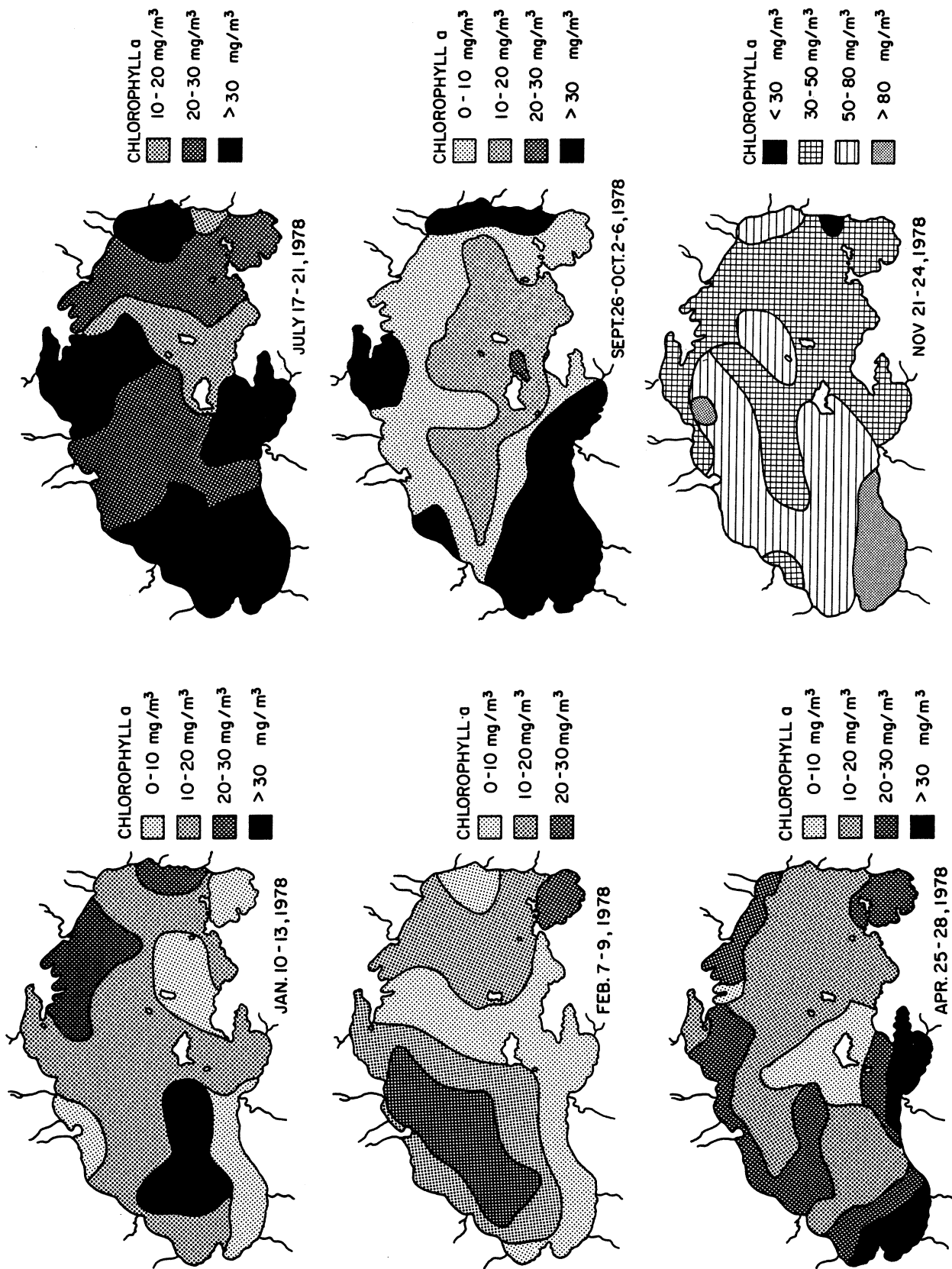
FIG. 47. Lakewide distribution of chlorophyll a (mg/m^3) during six cruise periods in 1978.

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with considerable shifting, and maximum concentration (>30 mg/m^3) occurred only in a small area. During the July–October period the chlorophyll concentration increased considerably, with values in the major portion of the lake greater than 20 mg/m^3. Annual maximum chlorophyll production occurred in November, during which approximately half of the lake contained >50 mg/m^3 chlorophyll. The most productive region was located in the extreme southwestern sector where the maximum chlorophyll content was 176 mg/m^3 (station 5).

The most obvious factors that cause the spatial heterogeneity of chlorophyll distribution in lakes are variation in nutrient concentrations, herbivore grazing pressure, water movement pattern, and sinking rate. However, the nutrient levels (phosphorus and nitrogen) in Lake Valencia were sufficiently high to support optimal chlorophyll production within the limited euphotic zone. As the predominant phytoplankton species in Lake Valencia was Microcystis aeruginosa, the heterogeneity caused by zooplankton grazing and the sinking process is expected to be minimal. Wind action appeared to be the most significant factor in mixing and redistributing the surface-inhabiting Microcystis aeruginosa.

The chlorophyll heterogeneity also occurred in the euphotic zone at all locations over a short time. Figure 48 shows the changing chlorophyll concentration in surface water (5 m) at station 20 on a clear, calm February 22, 1978. At 0700 hr, the depth profile of chlorophyll in the euphotic zone was 10–11 mg/m. As the day progressed, the chlorophyll content in the immediate surface water decreased and the maximum value (16 mg/m^3 at 1900 hr) occurred at 3 m.
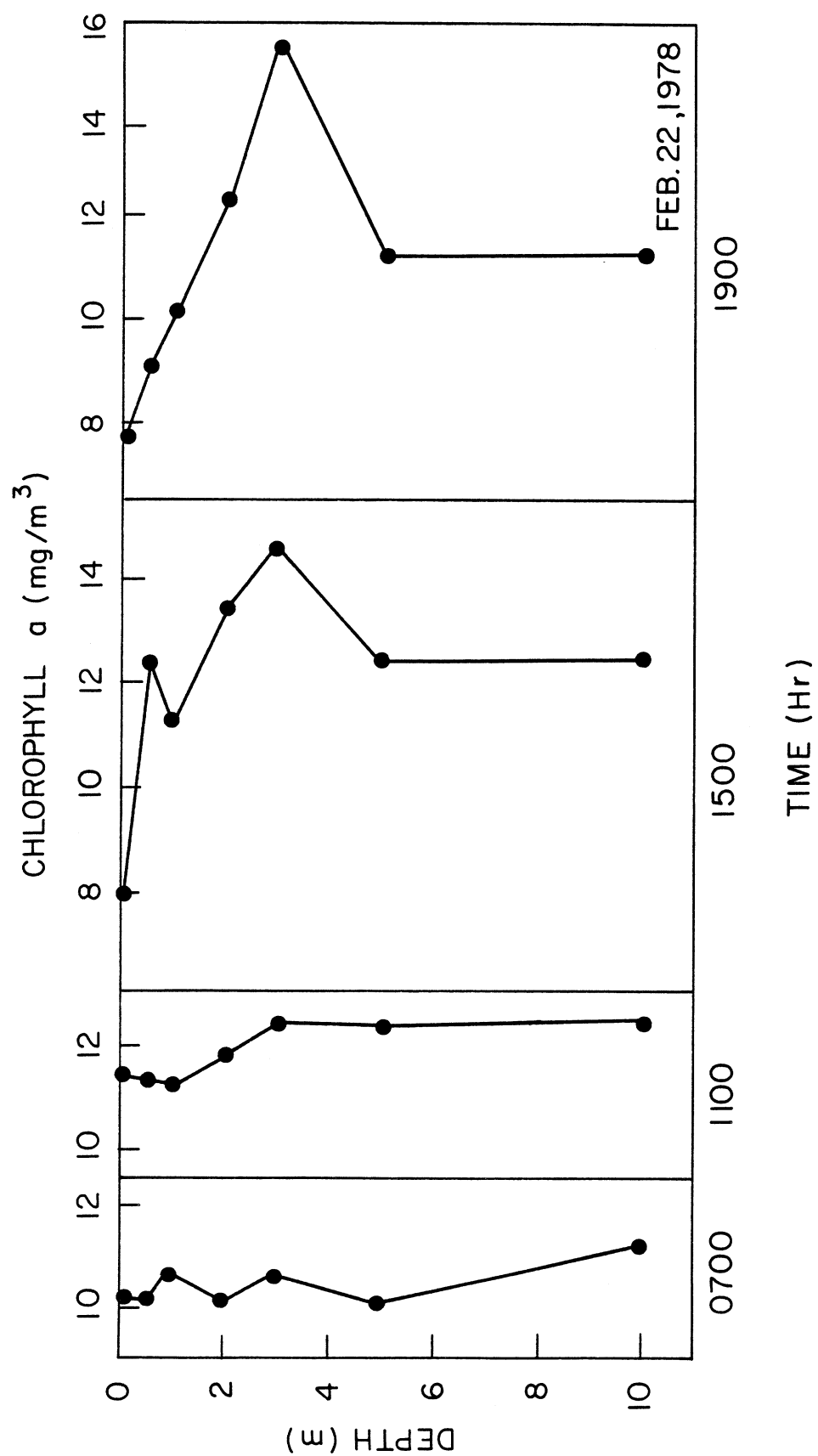
FIG. 48. Vertical variation in chlorophyll _a_ concentration at station 20 on February 22, 1978.

PRIMARY PRODUCTIVITY AND RESPIRATION

The gross productivity measured by oxygen production at station 20 on five
dates in 1978 is shown in Figure 49. Maximum productivity mostly occurred in
the surface 1 m, ranging from 2-5 g $O_2/m^3/day$. On July 27 and November 29, the
productivity at the immediate surface (10 cm) was less than that at 0.5 m,
presumably inhibited by excessive solar radiation that caused chlorophyll
damage. Comparison of the productivity integrated throughout upper 10 m per m^2
per day (Σ P in Fig. 49) shows that the highest production (16 g $O_2/m^2/day$)
occurred on November 29, and the lowest (1.42 g $O_2/m^2/day$) on February 21.

The specific productivity based on unit weight of chlorophyll a shows that
the maximum value was 184 mg O_2/mg Chl a/day at station 17 at 10 cm on July 27
and the value decreased to 25 mg O_2/mg Chl a/day at 5 m; and the gross
productivity in unit surface area at stations 17, 20, and 23 were 13.07, 13.30,
and 13.55 g $O_2/m^2/day$, respectively. The vertical variation in specific
productivity was strikingly different among those stations.

The respiratory oxygen consumption measured at station 20 on five discrete
dates is shown in Figure 50. Respiration rate at the surface was less than
0.5 g $O_2/m^3/day$ and the consumption increased toward the aphotic zone (>5 m) in
most cases. Total DO consumption rates integrated over depth at station 20 were
0.94, 4.47, 16.11, 4.55, and 2.77 g $O_2/m^2/day$ on February 21, May 25, July 27,
October 5, and November 29, respectively. Net oxygen productivity in the top
50 m water from photosynthesis and respiration at station 20 during those five
dates were 0.77, 5.56, -2.81, 5.25, and 13.23 g $O_2/m^3/day$, respectively.

Oxygen contributed by phytoplankton production is the largest source of
dissolved oxygen in Lake Valencia. A rough estimate based on the average

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GROSS PRODUCTIVITY (gO₂/m³/dy)
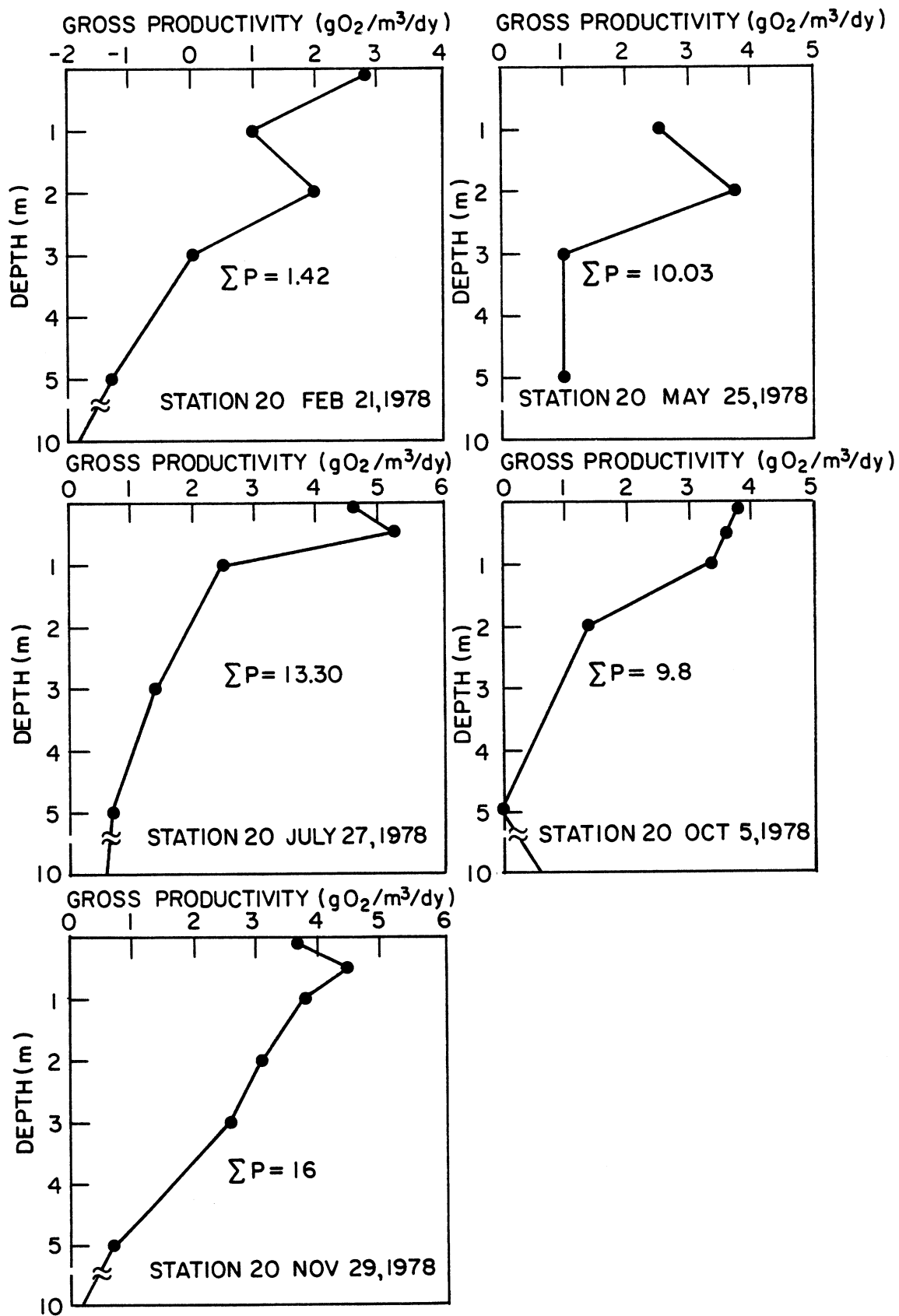
FIG. 49. Vertical distribution of primary productivity in the euphotic zone at station 20 on five dates in 1978.

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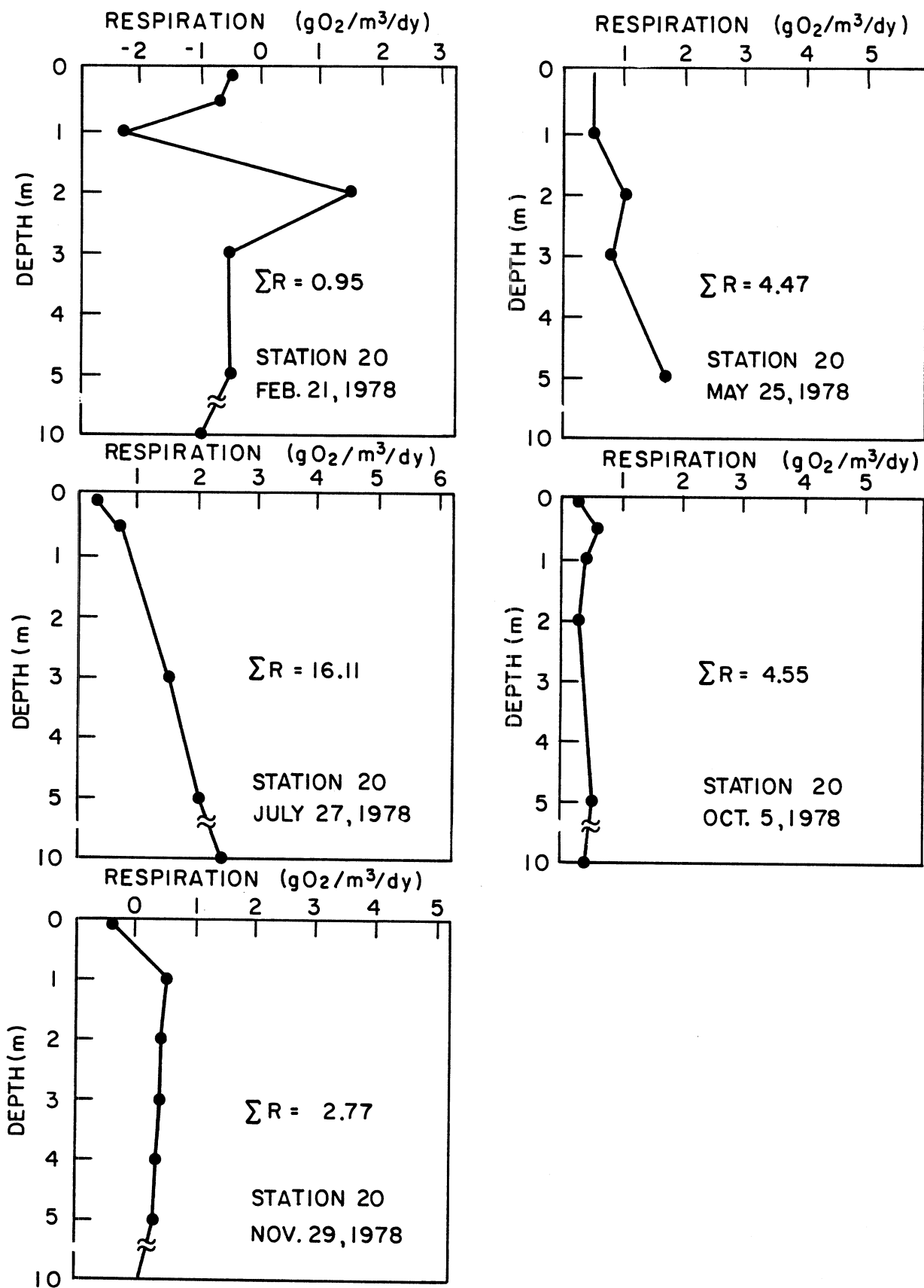
FIG. 50. Vertical distribution of respiration in the euphotic zone at station 20 on five dates in 1978.

observed photosynthetic rates at stations 17, 20, and 23 in five discrete measurements showed that the gross oxygen production in the top 10 m over the whole lake ranged from 1.5×10^9 to 5.7×10^9 g O_2/day, with an annual average of 2×10^9 g O_2/day. Oxygen generated in the eutrophic zone diffuses downward by a mixing process to replenish DO in the deeper water. In comparison, the oxygen influx from external aeration into Lake Valencia is relatively small. Apmann (1973) estimated that the transfer rates from air to water over Lake Valencia were $10-30 \times 10^9$ g/yr assuming a reaeration coefficient of 0.1 g/m^2/hr under various hydrodynamic conditions.

PHYTOPLANKTON

Phytoplankton taxa and their quantitative distribution in Lake Valencia during six cruise periods in 1978 were identified to a total of 37 genera belonging to Chlorophyta, Cyanophyta, Chrysophyta, and Pyrrhophyta. Population density of the phytoplankton community among lake-wide stations during the study period ranged from 28,210 to 572,880 cells/mL. As those samples were composed of surface, mid, and lower depth at each station, the actual density is expected to be larger in the surface and smaller in the bottom water. The seasonal variation of total phytoplankton and Microcystis cell numbers, shown in Figure 51, indicates that the maximum standing crop occurred in January and the minimum in October. During most of the year, Microcystis occupied more than 90% of the total cell counts, and the minority species were in significant proportion only in January. Figure 52 illustrates the vertical distribution of total phytoplankton at station 31 on six discrete sampling dates. In January and February large populations ($28-45 \times 10^5$ cells/mL) occurred in the surface
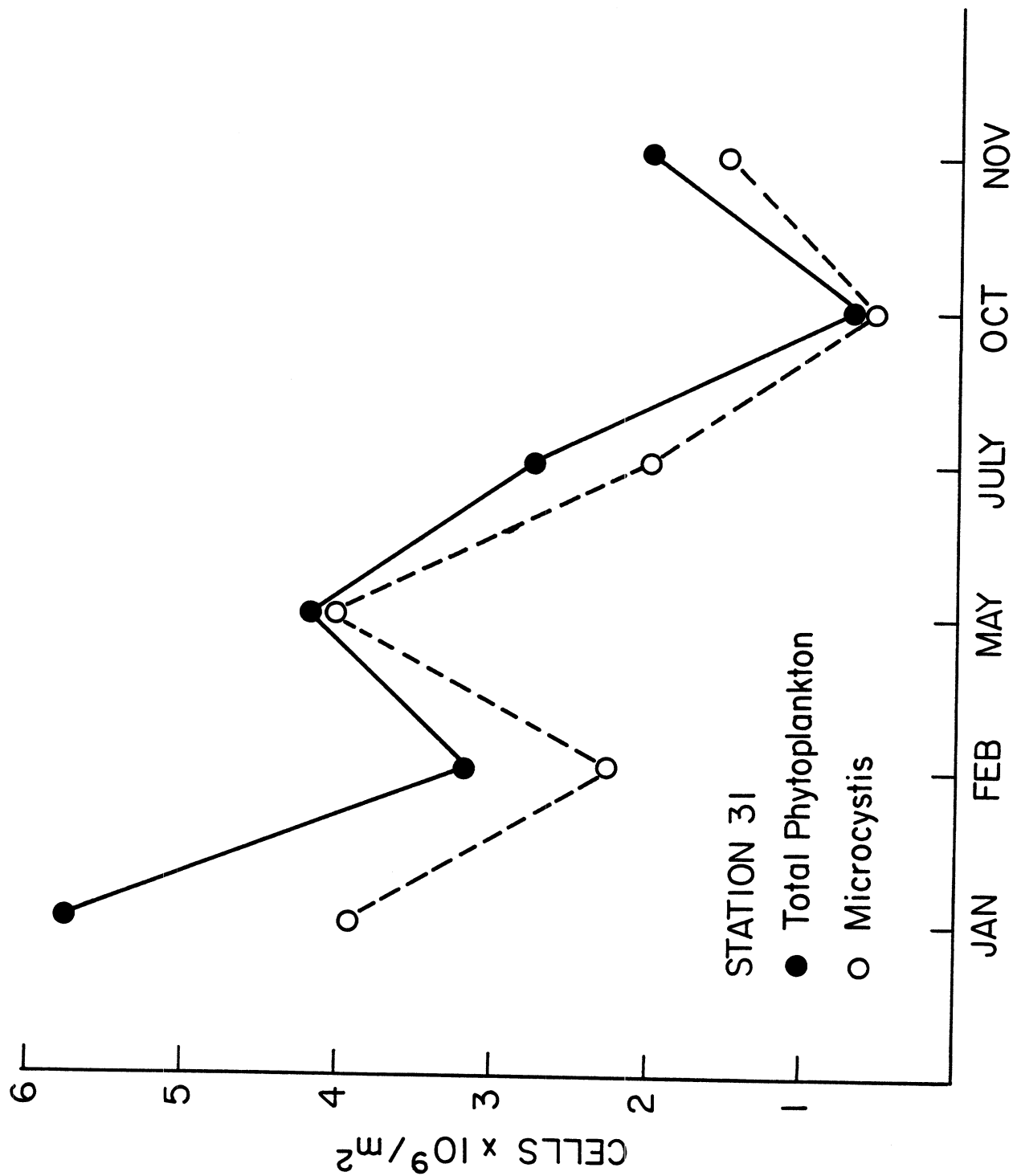
FIG. 51. Seasonal variation in total cell numbers of phytoplankton and _Microcystis_ at station 31 in 1978.
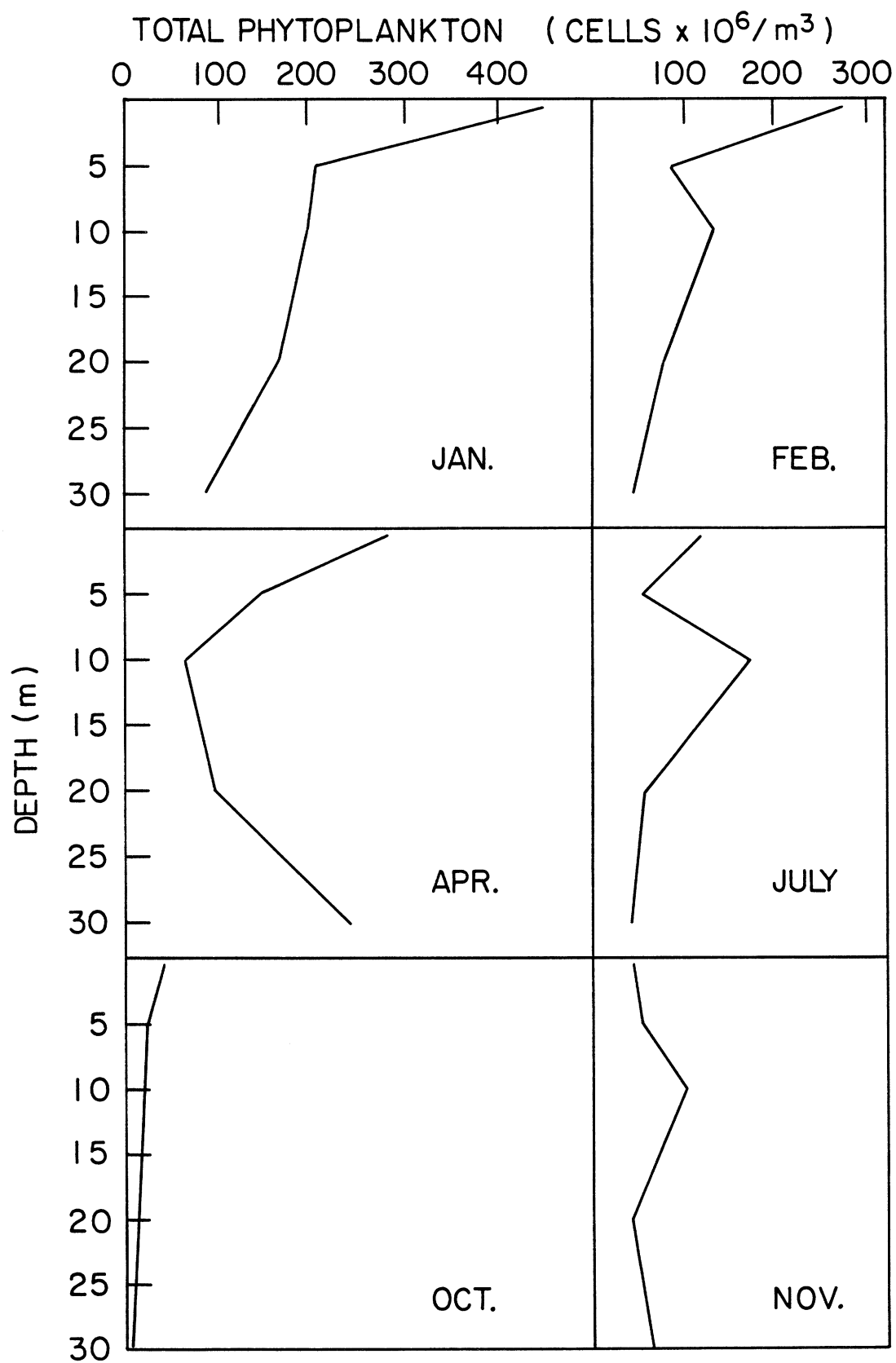
FIG. 52. Vertical distribution of total phytoplankton during six cruise periods in 1978.

(1 m) and decreased drastically at/below 5 m. But the variation was relatively

small in other sampling periods. As Microcystis bloomed persistently, its

vertical distribution dominated the community vertical distribution pattern

(Fig. 53).

In January, Ankistrodesmus and Nitzschia populations reached 36,022 and

28,210 cells/mL in the surface water, respectively, and constituted the second

and third largest phytoplankton populations.

Lake-wide quantitative distribution of predominant phytoplankton genera

during six cruises in 1978 is shown in Figure 54. The major species of

Cyanophyta were Microcystis, Anabaena, Oscillatoria, and Spirulina. Among those

entities, Microcystis and Oscillatoria were particularly abundant.

As Microcystis is well adapted to flotation the size, shape, and patchiness

of its colonies are dependent on water movement and wind action. This blue-

green alga bloomed during most of the year, with population density ranging from

20,000 to 500,000 cells/mL. Oscillatoria was most abundant during February,

with a maximum population density of 10^5 cells/mL, and had a relatively low

profile ($<10^4$ cells/mL) during the rest of the year. Like Oscillatoria, the two

genera of nitrogen fixer, Anabaena and Anabaenopsis, never developed a

population competitive with that of Microcystis. Chlorophyta, although

numerically much smaller than Cyanophyta, consisted of diverse taxa. In January

and February there were 10-12 genera present, and the composition became more

complex during the remainder of the year. There were 20 genera in September.

Among those entities, Ankistrodesmus and Cosmarium were most abundant in

January, but became sporadic during the rest of the year. No other genera of

green algae developed any significant population size.
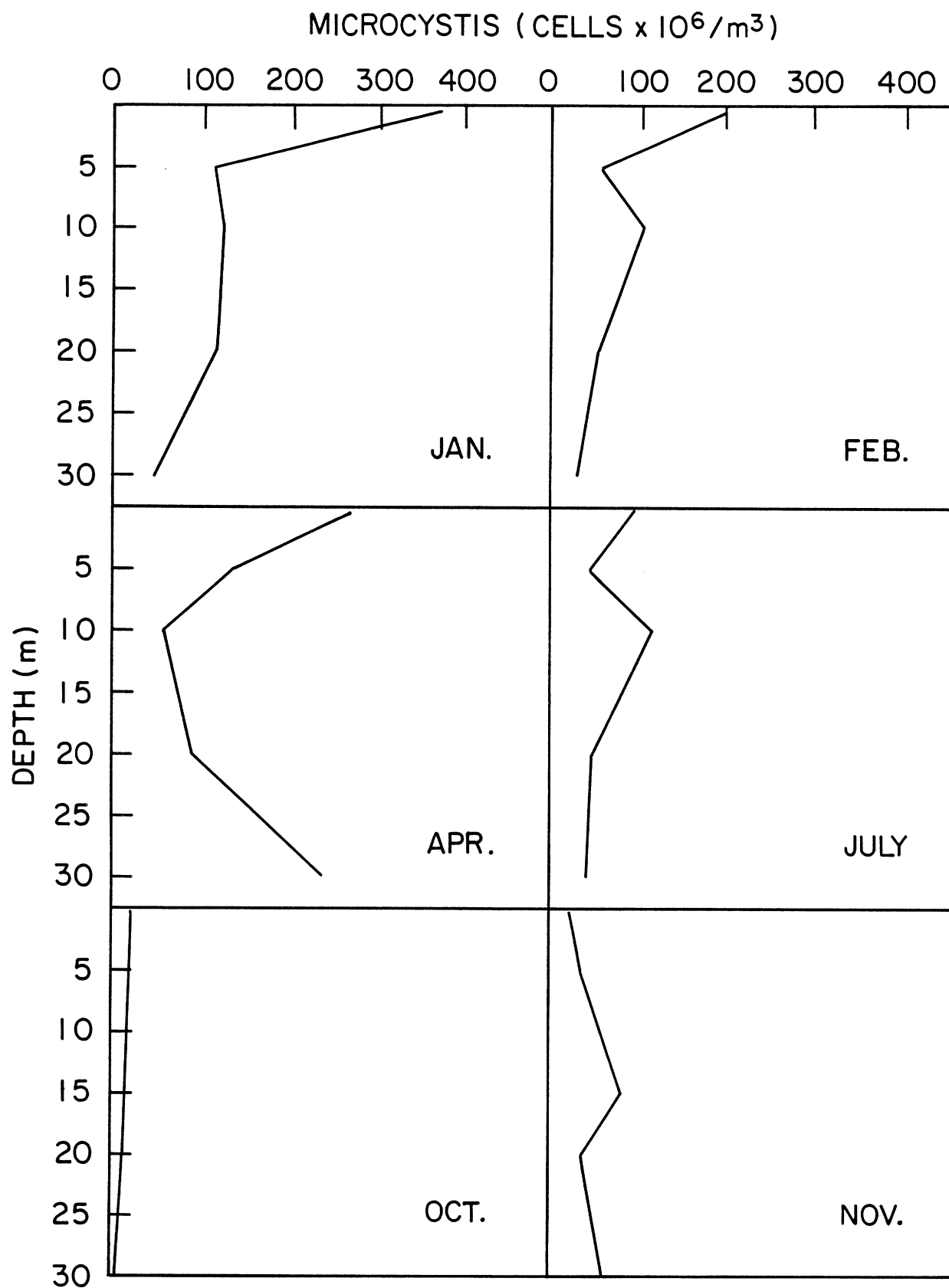
FIG. 53. Vertical distribution of _Microcystis_ during six cruise periods
in 1978.
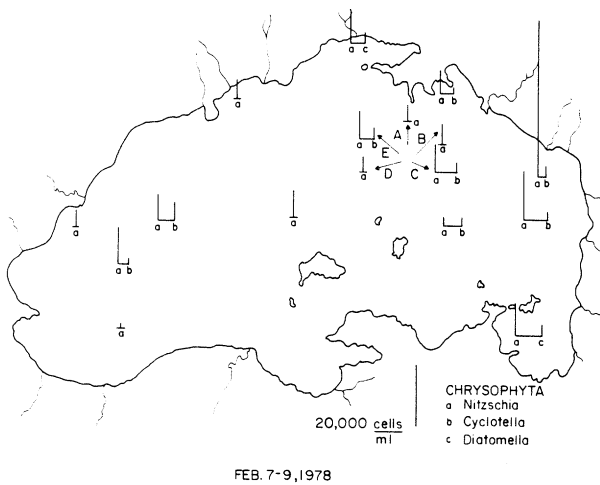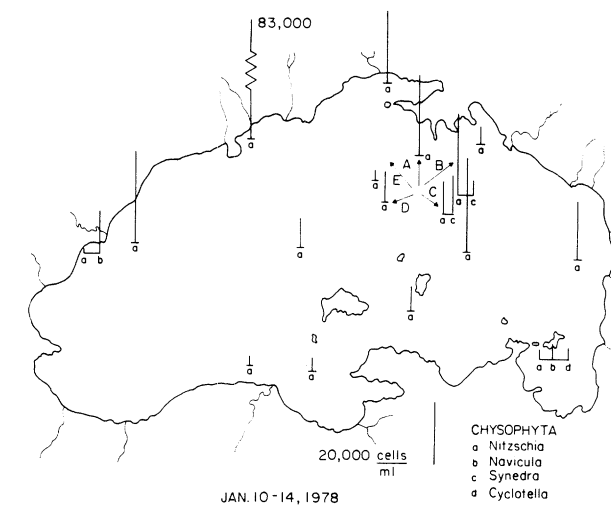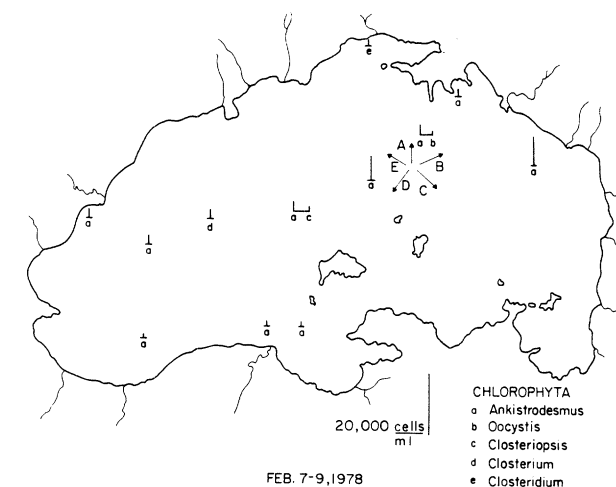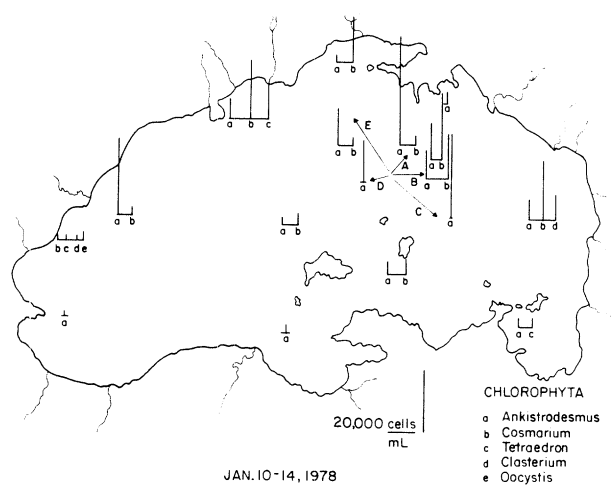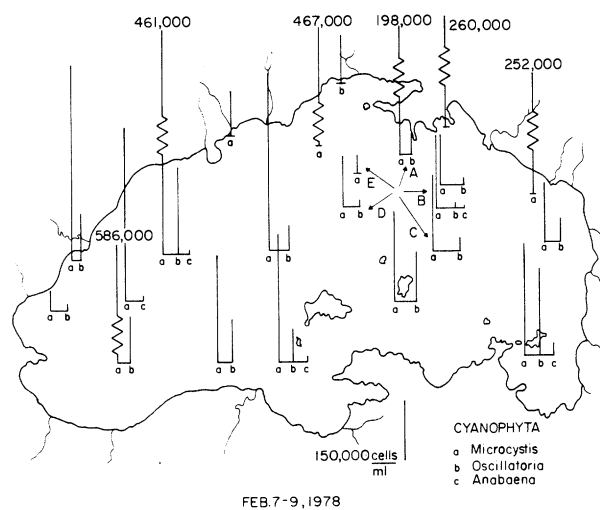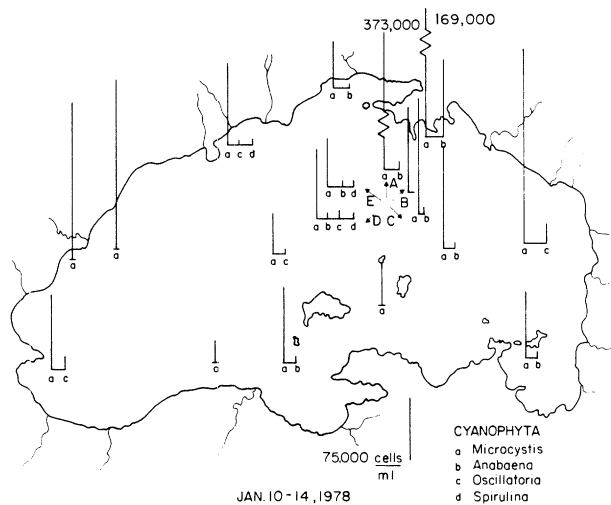
FIG. 54. Horizontal distribution of predominant genera of three major phytoplankton classes during six cruise periods in 1978.

CYANOPHYTA
a Microcystis
b Oscillatoria
c Anabaena
d Lyngbya
e Anabaenopsis

75,000 cells/ml

APR. 25-28, 1978

CYANOPHYTA
a Microcystis
b Oscillatoria
c Anabaena
d Anabaenopsis
e Lyngbya
f Spirulina

75,000 cells/ml

JULY 18-21, 1978

CHLOROPHYTA
a Tetraedron
b Chlorococcum
c Glenodinium
d Coelastrum
e Ankistrodesmus

20,000 cells/ml

APR. 25 - 28, 1978

CHLOROPHYTA
a Ankistrodesmus
b Tetraedron
c Elakatothrix
d Chroococcus

20,000 cells/ml

JULY 18 - 21, 1978

CHYSOPHYTA
a Nitzschia
b Cyclotella

20,000 cells/ml

APR. 25 - 28, 1978

CHRYSOPHYTA
a Nitzschia
b Cyclotella

20,000 cells/ml

JULY 18 - 21, 1978

FIG. 54. (continued).

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CYANOPHYTA

a Microcystis
b Oscillatoria
c Anabaena
d Spirulina
e Anabaenopsis

20,000 cells/ml

SEP. 26 - OCT. 2, 1978

CYANOPHYTA

a Microcystis
b Oscillatoria
c Anabaena
d Spirulina
e Anabaenopsis

75,000 cells/ml

NOV. 21 - 24, 1978

CHLOROPHYTA

a Tetraedon
b Chlorella
c Treubaria
d Oocystis

20,000 cells/ml

SEP. 26 - OCT. 2, 1978

CHRYSOPHYTA

a Nitzschia
b Cyclotella

20,000 cells/ml

NOV. 21 - 24, 1978

CHYSOPHYLA

a Nitzschia
b Cyclatella

20,000 cells/ml

FIG. 54. (continued).

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Diatoms consisted of 5-10 genera in Lake Valencia. Only one entity, Nitzschia sp., occurred persistently throughout the year with population size ranging from 10^3 to 10^4 cells/mL. This species was particularly abundant during January, February, and July. Other genera occurred sporadically in relatively low numbers.

Three genera of dinoflagellates recorded were Glenodinium, Gymnodinium, and Peridinium. None of those entities developed to a significant percentage of phytoplankton populations.

Assessment of standing crop and succession pattern of phytoplankton communities in Lake Valencia is difficult because of the great heterogeneity in horizontal distribution. Any attempt based on a few selected stations is inadequate to draw lake-wide information on phytoplankton.

In an attempt to use the species diversity of phytoplankton communities to indicate trophic state (Margalef 1958), the Shannon-Weaver index (Shannon and Weaver 1963) was calculated based on the following equation:

$$H = - \sum_{i=1}^{n.\ sp} Pi \log Pi$$

Where Pi is the probability of occurrence of the i th species. In lakes, H values normally range from slightly greater than 0 to as high as 4.5. Margalef (1958) used the diversity index to define the trophic state as follows: oligotrophic, >3.5; mesotrophic, 2.5-3.5; and eutrophic, <2.5. The values calculated for each station during all cruise periods ranged from 0.4 to 1.7. Those extremely low diversity indexes undoubtedly indicate that Lake Valencia is in a highly eutrophic state.

ZOOPLANKTON

Zooplankton samples taken during 1978 cruises were mostly used for preliminary taxonomical identification. The zooplankton results presented in this report are samples taken during October 1979 cruises.

A total of 18 taxa were recorded for the zooplankton community (Table 6), including three species of copepods, two species of cladocerans, six species of rotifers, and seven species of ostracods. Among them, the rotifers were most abundant, particularly Branchionus calyciflorus and B. havanaensis whose populations consistently constituted 50% or greater of the zooplankton community (Fig. 55). The total zooplankton individuals ranged from 100 to 1,926 organisms/L among 23 sample locations, and a population density greater than 1,000 org/L occurred in the shallow water along the southern and northern shores (Fig. 56). It is noteworthy that the greatest densities were found at stations 5 and 33 with 1,837 and 1,926 org/L, respectively.

Those two stations are respectively situated near the mouths of Caño Central and Rio Guey, which are major point sources of contamination in Lake Valencia. The zooplankton community in those regions was dominated by rotifer populations, which comprised more than 80% of the community.

Another interesting aspect is that many taxa of ostracoda exist, although in low number. It is speculated that those ostracods found in plankton samples were actually benthic dwellers stirred up along with sediment resuspension at those shallow stations.

Figure 57 shows the vertical distribution of predominant zooplankton entities at station 31 in October 1979. The largest population density (313 org/L) occurred at the surface and the lowest (24) near the bottom.

TABLE 6. Species composition and population density of the zooplankton community in October, 1979.

OCTOBER, 1979

Organisms & Taxa	STATIONS															
	0	1	3	4	5	6	7	8	10	12	14	16	18	20	22	24
COPEPODA																
Cyclops spp.	58	403	180	93	232	24	140	68	29	54	47	20	36	59	32	85
Nauplios	66	12	97	55	103	17	60	20	49	32	7	41	56	41	38	39
Notodiaptomus venezolanus	17	3	-	5	-	-	14	2	7	-	-	-	-	7	-	-
Total	141	418	277	153	335	41	214	90	85	86	54	61	92	107	70	124
CLADOCERA																
Ceriodaphnia cornuta	-	3	-	3	-	-	9	-	13	-	3	-	23	-	-	-
Moina micrura	3	3	13	10	12	-	6	2	-	-	7	3	-	-	-	-
Total	3	6	13	13	12	0	15	2	13	0	10	3	23	2	0	0
ROTIFERA																
Asplanchna sp.	-	-	-	-	-	3	-	-	-	-	-	-	-	-	-	-
Brachionus calyciflorus	506	56	172	315	788	93	123	38	49	25	224	313	40	22	18	58
Brachionus havanaensis	791	93	594	753	616	41	131	59	26	36	17	35	23	113	12	51
Brachionus plicatilis	259	-	2	5	-	59	3	-	3	-	3	-	13	-	-	-
Keratella americana	-	19	130	13	78	-	3	-	-	-	-	-	-	2	-	-
Trichocerca sp.	-	3	9	3	-	3	-	-	-	-	-	-	-	-	-	-
Total	1,556	171	907	1,089	1,482	199	260	97	78	61	244	348	76	137	30	109
OSTRACODA																
Ostracoda sp. #1	-	-	-	3	8	-	-	-	3	-	-	-	-	-	-	-
Ostracoda sp. #2	-	-	2	-	-	-	-	-	-	-	-	-	-	-	-	-
Ostracoda sp. #3	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Ostracoda sp. #4	-	-	24	-	-	-	-	-	-	-	-	-	-	-	-	-
Ostracoda sp. #5	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Ostracoda sp. #6	-	3	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Ostracoda sp. #7	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Total	0	3	26	3	8	0	0	0	3	0	0	0	0	0	0	0
GRAND TOTAL	1,700	598	1,223	1,258	1,837	240	489	189	179	147	308	412	191	246	100	233

* a, b, c, d, and e indicate depths at 0.5, 5, 10, 20 and 30 m respectively.

TABLE 6. (continued).

OCTOBER, 1979

Organisms & Taxa	STATIONS										
	27	29	31a*	31b*	31c*	31d*	31e*	33	35	37	39
COPEPODA											
Cyclops spp.	43	50	6	33	28	3	9	49	65	73	62
Nauplios	23	15	39	-	2	-	4	155	32	33	35
Notodiaptomus venezolanus	13	6	-	10	2	-	-	9	-	7	-
Total	79	71	45	43	32	3	13	213	97	113	97
CLADOCERA											
Ceriodaphnia cornuta	-	4	-	-	9	3	-	-	-	-	-
Moina micrura	-	-	-	-	2	-	-	4	-	-	8
Total	0	4	0	0	11	3	0	4	0	0	8
ROTIFERA											
Asplanchna sp.	-	-	-	-	-	-	-	36	-	-	-
Brachionus calyciflorus	69	19	82	55	19	-	7	463	112	62	39
Brachionus havanaensis	99	42	170	20	7	6	9	1,136	558	216	408
Brachionus plicatilis	43	10	8	-	-	3	-	-	-	-	-
Keratella americana	-	-	2	-	-	-	-	16	43	-	146
Trichocerca sp.	-	-	-	-	-	-	-	23	-	-	-
Total	211	71	262	75	26	9	16	1,674	723	278	593
OSTRACODA											
Ostracoda sp. #1	-	12	6	3	-	-	-	34	-	-	208
Ostracoda sp. #2	-	2	-	-	-	-	-	-	-	-	19
Ostracoda sp. #3	-	6	-	-	-	-	-	5	-	4	89
Ostracoda sp. #4	-	-	-	-	-	-	-	-	-	-	-
Ostracoda sp. #5	3	-	-	-	2	9	-	-	-	-	-
Ostracoda sp. #6	-	-	-	-	-	-	-	-	-	-	-
Ostracoda sp. #7	-	10	-	-	-	-	-	-	-	-	-
Total	3	30	6	3	2	9	0	39	0	4	316
GRAND TOTAL	293	176	313	121	71	24	29	1,926	820	395	1,014
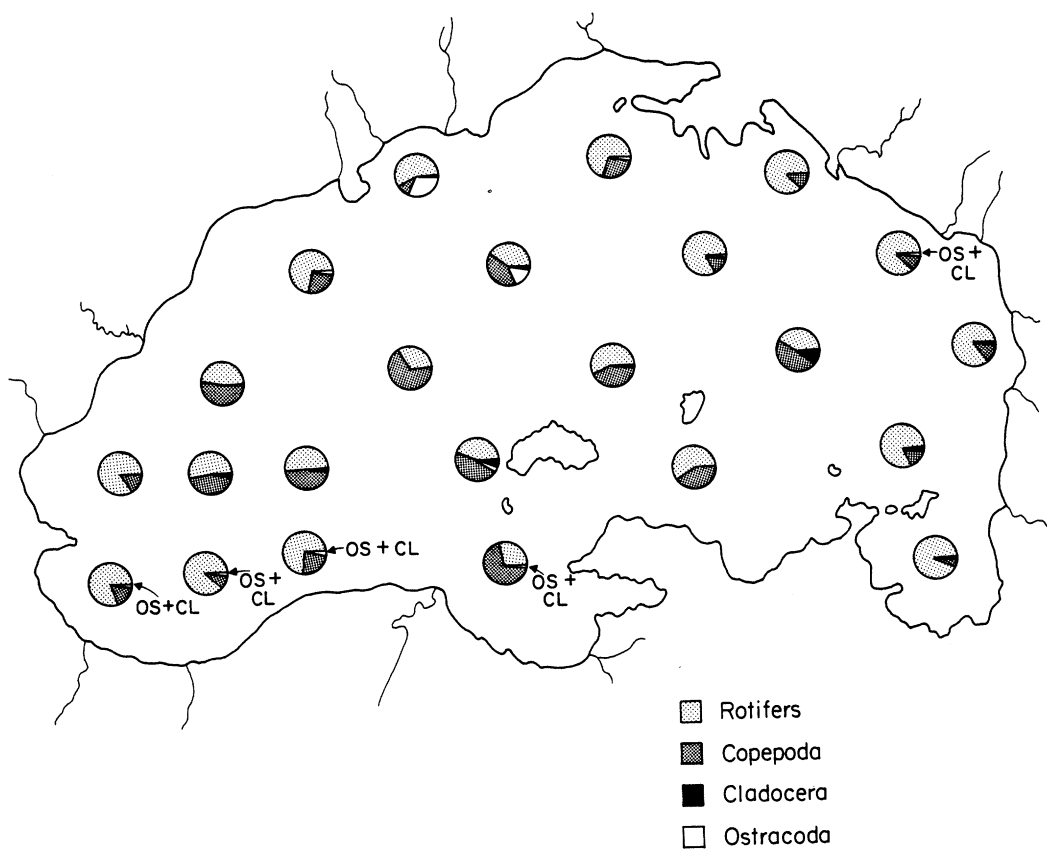
FIG. 55. Variation in zooplankton composition during October 1979.
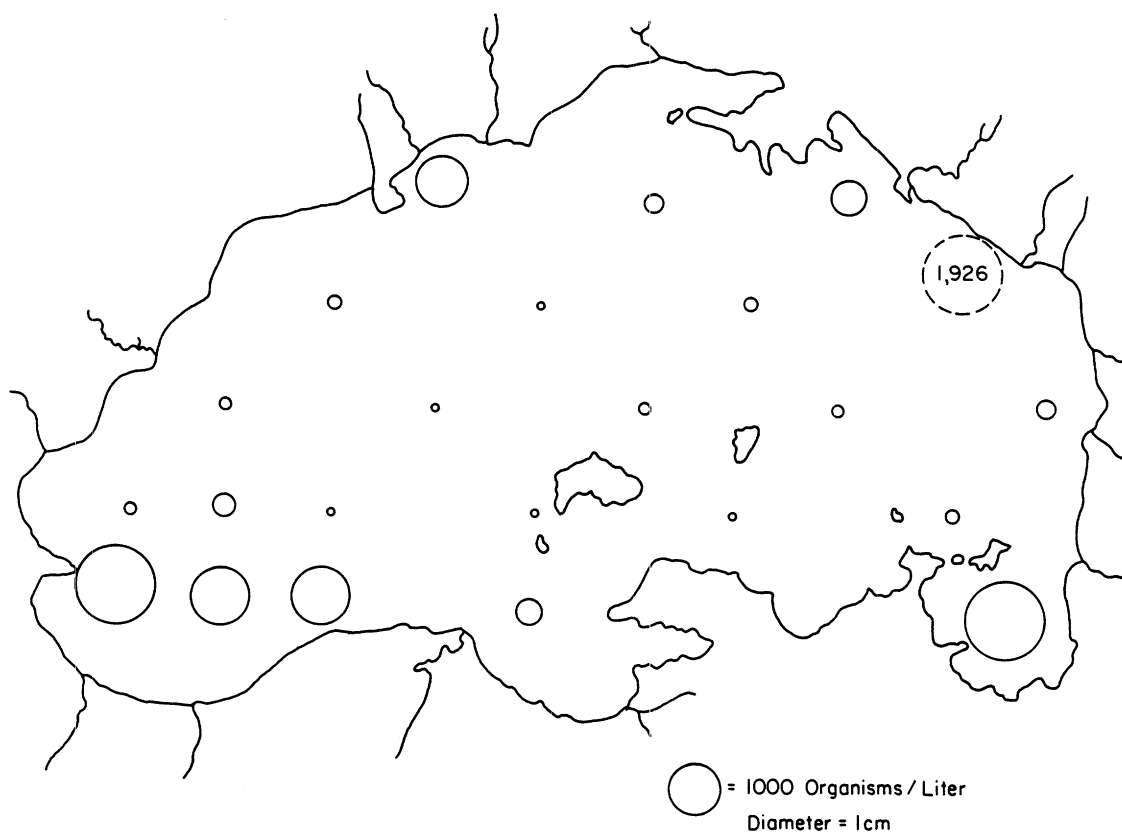
FIG. 56. Horizontal variation in total zooplankton numbers during
October 1979.

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Cyclops   Brachionus calyciflorus   Brachionus havanaensis   Total

1cm = 50organisms/liter
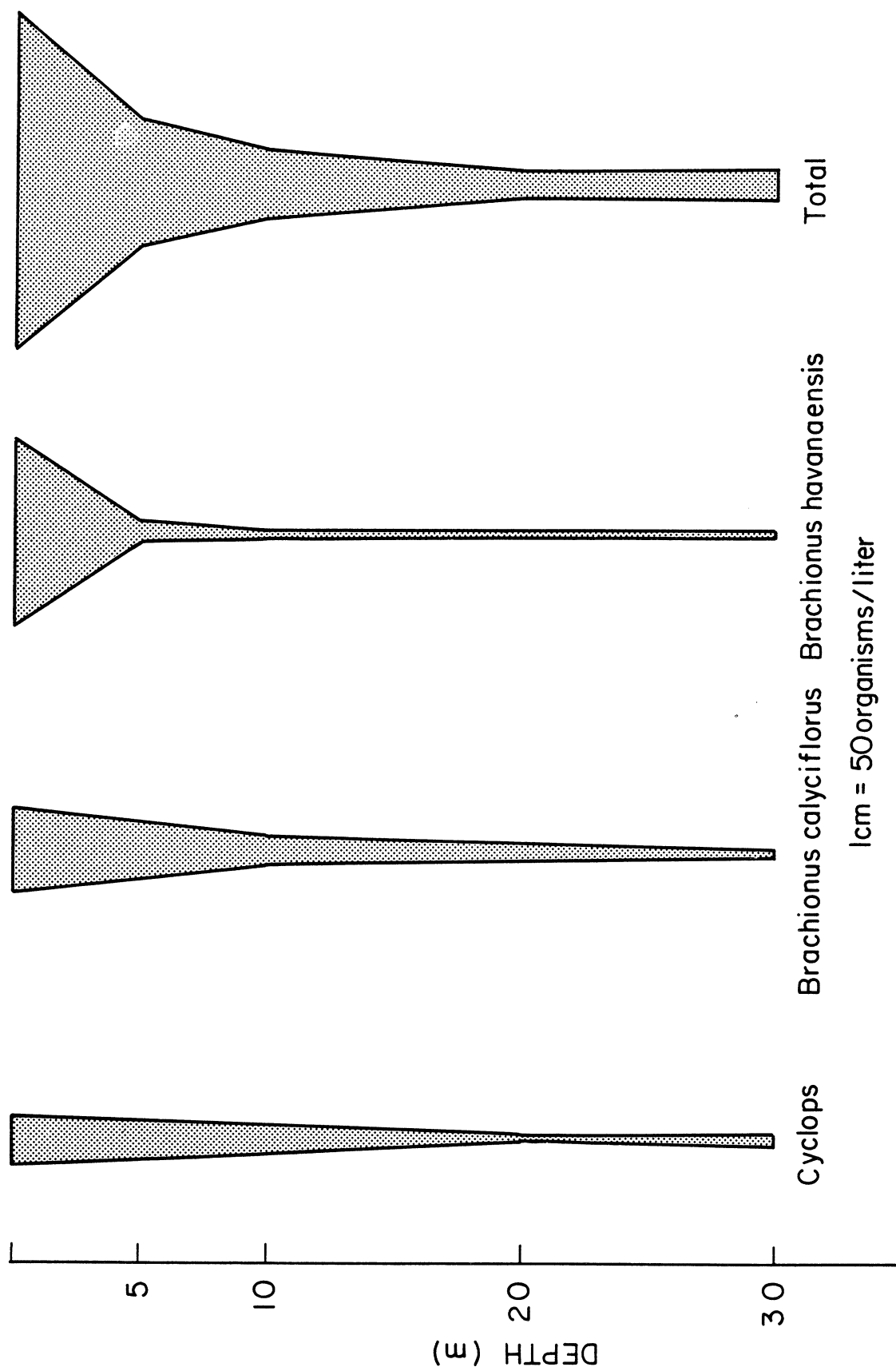
STATION 31 OCT., 1979

FIG. 57. Vertical distribution of major zooplankton taxa at station 31 during October 1979.

DEPTH (m)

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<u>Branchionus</u> <u>havanaensis</u>, the most abundant species, showed the most distinct

density gradient in its vertical distribution.

COLIFORM BACTERIA

Table 7 shows the densities of total and fecal coliform at 12 sampling

stations during three different periods in 1980. Highest densities (MPN/100 m)

were found persistently at stations A and B adjacent to the outfalls of Rio

Los Guayos and Caño Central. At station A, the total coliform bacteria ranged

from 1.4×10^6 to 8.4×10^6 MPN/100 mL, and fecal coliform from 9.3×10^5

to 3.7×10^6. Those high bacteria densities declined drastically in a short

distance toward the open lake. For example, in May the density of total

coliform at station 5 was reduced to 1.2×10^6 MPN/100 mL, less than 20% of that

of station B at a distance of 2 km. Similar reductions also occurred during

other sampling periods and other locations (Fig. 58).

The second most contaminated area in the lake was at the western end near

the outfall of Rio Guey, represented by stations H and 33. The total coliform

index at stations H and 33 ranged from 5.3×10^5 to 9.3×10^6 and from 4.6×10^5

to 7.6×10^6. On most occasions, the fecal coliform densities were the major

component of the total coliform in this area.

In the areas where there was no apparent adjacent contamination source, the

bacteria density was relatively low. At stations F, P, 12, and 39, located on

the fringe of farm land, the total coliform index was often less than 500

MPN/100 mL. The density at open lake station 31, representing the major water

mass of the lake, was less than 1,300 MPN/100 mL for total coliform, and fecal

coliform was persistently less than 300 MPN/100 mL.

TABLE 7. Density of total and fecal coliform (MPN/100 mL) sampled at 12 stations on three dates in 1980.

Station	May		July		October	
	Total	Fecal	Total	Fecal	Total	Fecal
A	2,400,000	93,000	8,420,000	3,600,000	8,410,000	3,740,000
B	6,800,000	1,215,000	7,630,000	3,000,000	2,450,000	1,326,000
F	1,830	<300	9,300	680	230,000	230,000
H	930,000	47,000	9,300,000	9,300,000	530,000	530,000
I	24,000	24,000	68,000	6,800	400	<300
P	3,500	790	<300	<300	<300	<300
5	1,210,000	195,000	680,000	585,000	680,000	68,000
6	4,300	<300	3,300	530	680,000	530,000
12	<300	<300	6,800	<300	<300	<300
31	1,260	<300	530	<300	<300	<300
33	1,250,000	1,250,000	7,600,000	3,000,000	460,000	330,000
39	<300	<300	1,910	<300	<300	<300
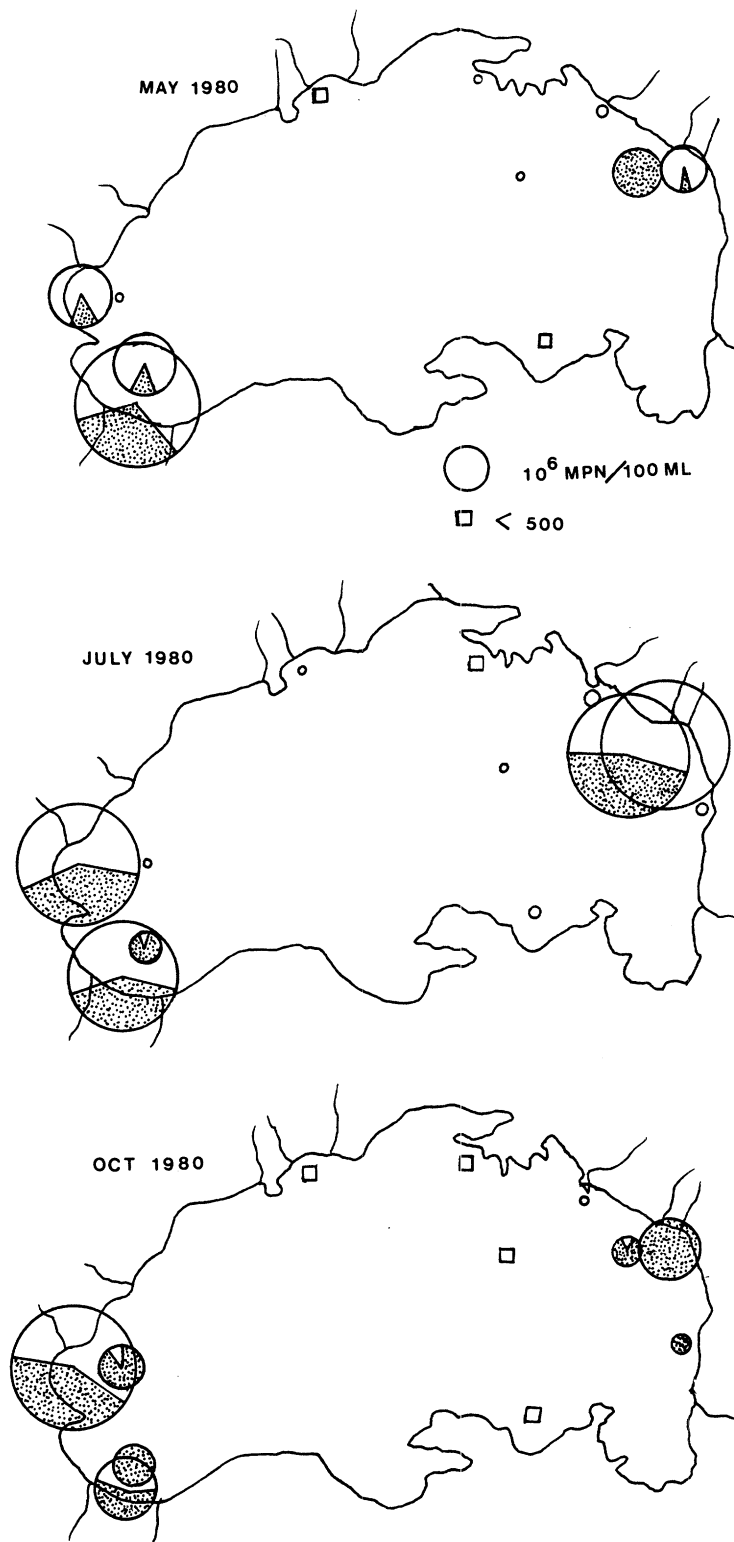
FIG. 58. Density of coliform bacteria at sample stations in May, July, and October 1980. Blank circles and squares indicate total coliform, and dotted symbols indicate fecal coliform.

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The coliform group reported here was unusually high in the vicinities of tributary discharges, where the MPN index is in the range of municipal sewage bacterial density (5-50 x 10^6). The extreme degree of contamination in Lake Valencia undoubtedly indicates that the river water entering the lake consisted of concentrated waste water from domestic and industrial sources.

The concentration of waste water in the tributaries fluctuated considerably throughout the year depending on the dilution of the storm runoffs. Accurate estimates of the bacteria density should consider the pattern of flow volumes of the tributaries. The drastic decrease in bacterial density in the open lake water probably resulted from dilution of the river discharges as they disperse in the open lake.

Although the coliform bacteria data are mainly used to indicate the degree of contamination from human and animal wastes, coliform group bacteria include a pathogenic genus, Klebsiella. Large concentration of Klebsiella often occur in certain industrial wastes such as pulp and paper, sugar, and food processing effluents. The presence and implications of this group of bacteria are yet to be determined.

POLLUTANT INPUTS FROM THREE MAJOR TRIBUTARIES

In general, the external loadings of contaminants to Lake Valencia originated from three major sources: point, non-point, and atmospheric inputs. The point source input from tributary discharges contributes the largest quantity of pollutants into the lake.

Lake Valencia receives discharges from 16 tributaries (Fig. 3), which carry heavy silt loads from surface runoff during the rainy season. Most of those tributaries have little flow during the dry season, and only three maintain measurable flow throughout the year. The source of those flows during the dry season are domestic and industrial effluents, which become the most serious contamination inputs to Lake Valencia. Those three tributaries are Rio Guey, Rio Los Guayos, and Caño Central.

To estimate the quantity of pollutant discharge received by the lake and its effects on water quality, it is necessary to obtain information on the variety and quantity of contaminants in those tributaries. During 1979-80, water samples were taken from each of those three tributaries for analysis of a large inventory of pollutants, including organic compounds, solids, inorganic nutrients, heavy metals, and coliform bacteria. The analyses were mostly carried out by DIA laboratory personnel in Valencia and at El Hatillo.

Description of Tributaries

As shown in Figure 3, the Rio Guey receives drainage from the area northeast of the lake basin including the city of Maracay. The Rio Guey discharges into the lake through a relatively short, steep, and deep channel with a forceful plume. There was little marsh or shoal featuring the river mouth.

The Rio Los Guayos drains the west side of the lake basin, receiving runoff from a large area of agriculture land and the waste water of the city Los Guayos. Adjacent to the Rio Los Guayos, the Caño Central enters the lake at the southwest corner. Caño Central drains a relatively large catchment area and has a long flowing course. Since the beginning of 1979, the tributary has received a large volume of flow from Rio Cabrales that was previously emptied into a

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different watershed, Cachinche. Rio Cabrales collects drainage from the city of Valencia and Central Tacarigua, and the present diversion of this river into Lake Valencia has become a serious source of contamination to the lake.

Unlike the Rio Guey, the inflows of Rio Los Guayos and Caño Central enter the lake through a large area of marshes and extensive shoal.

The chemical nature of the industrial effluents is diverse. Table 8 shows the contaminants that are commonly found in the effluents of light industries in the Lake Valencia basin.

Pollutant Loadings

The original results of tributary study were obtained by the Tributary Group of the Lake Valencia Research Project and some of the data were presented in Weber's report (Weber 1981).

Table 9 shows the annual means of physical and chemical parameters of the discharge from Rio Guey, Los Guayos, and Caño Central. Based on the discharge of each tributary and mean annual values of pollutant content, the total yearly inputs of the major contaminants are presented in Table 10.

Discharge volume. The largest flow among the three tributaries came from Caño Central with the total annual flow of 1.5×10^8 m^3 and a mean of 4.8 m^3/sec, ranging from 2.3 to 11.9 m^3/sec. Rio Guey and Rio Los Guayos discharged 6.28×10^7 m^3 and 5.48×10^7 m^3/year, respectively. The flows in those tributaries fluctuate 5 to 10 fold between low and high water levels. In fact, during the rainy season, the flow regime was in a plug and flow phenomenon because the short course of the river bed and steep terrain of the surrounding mountains and hills flush out runoff in short periods of time after rains.

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TABLE 8. Typical contaminants discharged by agricultural industries in Lake Valencia basin.

Type of Industry	Contaminants
Animal Feed	Oil and grease, detergents, sewage, solids, acids, bases
Soft Drink	Oil and grease, detergents, sewage, solids, acids, bases
Alcoholic Beverage	Oil and grease, detergents, sewage, solids, acids, bases
Rubber Industry	Oil and grease, detergents, sewage, solids, acids, bases
Soap Products	Oil and grease, detergents, sewage, solids, acids, bases
Fruit and Vegetables	Detergents, solids, sewage
Flour Mill	Solids, sewage
Milk Products	Solids, sewage, acids, bases
Wood and Paper Products	Solids, sewage, acids, oil and grease, sulfates, and sulfites
Agricultural Chemicals	Solids, sewage, dyes, detergents, pesticides, fertilizers, trace metals
Tannery	Acids, bases, solids, sewage
Textiles	Acids, bases, oil and grease, solids, detergents, dyes, trace metals, sewage, chloride
Tobacco	Solids, sewage

TABLE 9. Chemical and physical parameters of discharges of three major tributaries in the Lake Valencia basin.

RIO GUEY	Conc.		
Parameters	$\overline{X}$	S.D.	Conc. Range
Flow budget (m^3/sec)	1.99	1.14	0.71 — 8.00
Temperature (°C)	29.83	1.96	26 — 33
BOD (ppm)	241.67	121.92	68.8 — 930
COD (mg/L)	386.20	166.55	150 — 768
DO (ppm)	1.72	1.88	0.0 — 6.3
pH	7.88	1.37	2.1 — 9.5
Turbidity (J.U.)	240.83	60.77	130 — 330
Cyanide (mg/L)	0.10	0.07	0.01 — 0.27
Alkalinity (mg/L)	216.33	60.05	50 — 300
Total organic carbon (mg/L)	119.07	48.19	38 — 192
Oil and grease (mg/L)	89.92	110.89	2.4 — 534
Chloride (mg/L)	79.87	48.01	25 — 188
Sulfate (mg/L)	60.73	29.80	13 — 104
Detergents ABS (mg/L)	0.66	0.41	0.09 — 1.32
Color (C.U.)	135	99.49	20 — 300
Phenols (mg/L)	0.34	0.35	0.032 — 1.824
Total solids (mg/L)	695.43	150.55	388 — 964
Dissolved solids (mg/L)	533.17	169.13	272 — 848
Suspended solids (mg/L)	152.27	77.14	40 — 292
Sedimental solids (mg/L)	4.64	2.27	0.7 — 8.2
Total nitrogen (mg/L)	24.17	14.94	4.2 — 64.4
Organic nitrogen (mg/L)	24.00	15.16	2.8 — 64.4
NO_2-N (mg/L)	0.037	0.052	0.002 — 0.302
NO_3-N (mg/L)	0.31	0.15	0.13 — 0.66
Total phosphorus (mg/L)	6.72	3.89	2.03 — 15.39
Total dissol. P (mg/L)	5.09	3.21	0.43 — 12.45
PO_4-p (mg/L)	3.34	1.95	0.23 — 6.90
Total hardness (mg/L)	132.23	65.54	35 — 345
Magnesium hardness (mg/L)	47.70	52.07	0.0 — 270
Calcium hardness (mg/L)	84.87	28.18	30 — 185

(continued)

TABLE 9. (Continued).

| RIO LOS GUAYOS | Conc. | | |
Parameters	X̄	S.D.	Conc. Range
Flow budget (m^3/sec)	1.737	0.892	0.686 – 4.419
Temperature (°C)	28.22	1.95	25 – 31
BOD (ppm)	410.88	216.78	165.2 – 975
COD (mg/L)	615.31	436.04	150 – 2,704
DO (ppm)	1.13	1.31	0.0 – 4.9
pH	7.00	0.47	6.1 – 8.5
Turbidity (J.U.)	369.22	185.95	150 – 950
Cyanide (mg/L)	0.198	0.210	0.022 – 0.94
Alkalinity (mg/L)	182.87	69.18	30 – 330
Total organic carbon (mg/L)	164.09	100.86	2 – 387
Oil and grease (mg/L)	84.26	93.80	2 – 725
Chloride (mg/L)	132.93	82.67	32 – 382
Sulfate (mg/L)	46.37	30.29	3 – 174
Detergents ABS (mg/L)	0.32	0.26	0.01 – 0.99
Color (C.U.)	67.27	70.90	15 – 300
Phenols (mg/L)	1.024	1.147	0.032 – 4.420
Total solids (mg/L)	1,286.25	992.89	520 – 6,480
Dissolved solids (mg/L)	900.34	910.95	232 – 6,240
Suspended solids (mg/L)	412.06	312.94	64 – 1328
Sedimental solids (mg/L)	12.26	14.97	0.1 – 98
Total nitrogen (mg/L)	19.03	11.73	6.3 – 56
Organic nitrogen (mg/L)	18.97	11.84	5.6 – 56
NO_2-N (mg/L)	0.015	0.016	0.002 – 0.079
NO_3-N (mg/L)	0.22	0.09	0.06 – 0.46
Total phosphorus (mg/L)	–	–	0.97 – 16.04
Total dissol. P (mg/L)	3.02	2.11	0.75 – 9.25
PO_4-p (mg/L)	1.88	1.45	0.23 – 6.94
Total hardness (mg/L)	139.06	40.22	65 – 250
Magnesium hardness (mg/L)	47.81	36.63	5 – 140
Calcium hardness (mg/L)	91.25	26.98	45 – 145

(continued)

TABLE 9.   (Continued).

CAÑO CENTRAL	Conc.			
Parameters	X̄	S.D.	Conc. Range	
Flow budget (m³/sec)	4.808	2.17	2.334 −	11.90
Temperature (°C)	27.24	2.03	24 −	31
BOD (ppm)	70.70	74.47	3.8 −	250
COD (mg/L)	166.78	187.31	26 −	792
DO (ppm)	0.68	0.76	0.0 −	2.6
pH	6.90	0.42	6.0 −	7.5
Turbidity (J.U.)	59.62	40.52	1.4 −	163
Cyanide (mg/L)	1.30	1.79	0.011 −	7.1
Alkalinity (mg/L)	182.33	44.27	110 −	300
Total organic carbon (mg/L)	24.65	9.06	10 −	48
Oil and grease (mg/L)				
Chloride (mg/L)	58.73	29.44	21 −	178
Sulfate (mg/L)	87.24	52.65	20 −	187
Detergents ABS (mg/L)	0.58	0.36	0.08 −	1.28
Color (C.U.)	82.73	57.69	10 −	200
Phenols (mg/L)	0.11	0.11	0.004 −	0.560
Total solids (mg/L)	618.87	262.26	400 −	2,144
Dissolved solids (mg/L)	516.67	230	332 −	2,076
Suspended solids (mg/L)	109.20	100.58	8 −	400
Sedimental solids (mg/L)	0.75	0.51	0.2 −	1.7
Total nitrogen (mg/L)	10.53	7.48	4.2 −	33.3
Organic nitrogen (mg/L)	8.90	6.36	2.8 −	28
NO_2-N (mg/L)	?	?	? −	?
NO_3-N (mg/L)	0.114	0.107	0.01 −	0.71
Total phosphorus (mg/L)	2.21	0.92	0.97 −	3.88
Total dissol. P (mg/L)	1.53	0.78	0.68 −	2.90
PO_4-p (mg/L)	1.617	1.079	0.52 −	4.19
Total hardness (mg/L)	195.13	63.64	125 −	445
Magnesium hardness (mg/L)	71.80	64.82	5 −	330
Calcium hardness (mg/L)	129.50	25.03	100 −	195

TABLE 10. Annual flows and discharges of contaminants from three major tributaries to the Lake Valencia basin.

Parameters	Rio Guey	Los Guayos	Caño Central	Total
Flow (m^3/yr)	6.28×10^7	5.48×10^7	1.52×10^8	2.70×10^8
POLLUTANTS (Kg/yr)				
BOD	1.52×10^7	2.25×10^7	1.07×10^7	4.84×10^7
COD	2.43×10^7	3.37×10^7	2.53×10^7	8.33×10^7
TOC	7.48×10^6	8.99×10^6	3.74×10^6	2.02×10^7
Cl^{-1}	5.02×10^6	7.28×10^6	8.91×10^6	2.12×10^7
SO_4^{-2}	3.81×10^6	2.54×10^6	1.32×10^7	1.95×10^7
SOLIDS				
Total	4.37×10^7	7.05×10^7	9.38×10^7	2.08×10^8
Dissolved	3.35×10^7	4.93×10^7	7.83×10^7	1.61×10^8
Suspended	9.56×10^6	2.25×10^6	1.65×10^6	3.37×10^7
Sedimental	2.91×10^5	6.71×10^5	1.14×10^4	9.73×10^5
Total N	1.52×10^6	1.04×10^6	1.60×10^6	4.16×10^6
Organic N	1.51×10^6	1.04×10^6	1.35×10^6	3.90×10^6
$NO_2 + NO_3$	2.18×10^4	1.29×10^4	---	3.37×10^4
Total P	4.22×10^5	2.00×10^5	3.35×10^5	9.57×10^5
Total dis. P	3.20×10^5	1.65×10^5	2.32×10^5	7.17×10^5
PO_4-P	2.10×10^5	1.03×10^5	2.45×10^5	5.58×10^5
Hardness (Ca)	5.33×10^6	5.00×10^6	1.96×10^7	2.99×10^7
Hardness (Mg)	3.00×10^6	2.62×10^6	1.09×10^7	1.65×10^7
Cyanide	6.34×10^3	1.08×10^4	1.98×10^4	3.40×10^4
Oil and Grease	5.64×10^6	4.62×10^6	3.74×10^5	1.06×10^7
Detergent	4.14×10^4	5.48×10^3	8.81×10^3	1.05×10^5
Phenols	2.14×10^4	5.61×10^4	1.67×10^3	7.92×10^4
Cr	6.28×10^3	1.19×10^4	---	1.82×10^4
Cu	6.28×10^3	1.51×10^4	---	2.14×10^4
Ni	3.14×10^3	2.51×10^3	---	5.65×10^3
Pb	1.19×10^4	4.08×10^4	---	5.27×10^4
Zn	8.16×10^3	9.92×10^4	---	1.07×10^5
COLIFORM BACTERIA (MPN/100 mL x 10^7)				
Total	2.7	3.0	0.9	6.6
Fecal	0.7	0.7	0.5	1.9

Dissolved oxygen. Extremely low mean DO content was recorded for all three tributaries throughout the year. The mean DO values were 1.7, 1.1, and 0.6 mg/L for Rio Guey, Los Guayos, and Caño Central, respectively. The water in those rivers was occasionally anoxic. Because of the short running course and large volumes of untreated sewage, those rivers merely function as open sewers that carry waste water to the lake.

Biochemical oxygen demand (BOD). The total BOD loading from those three tributaries amounted to 4.8×10^7 kg/yr, with an average of 179.25 mg/L. The annual input from Caño Central was 1.07×10^7 kg/yr and the mean value 70.7 mg/L. Rio Guey and Los Guayos, despite the fact that the flow volume was much smaller than that of Caño Central, contributed 1.52×10^7 and 2.25×10^7 kg/yr of BOD into the lake.

Chemical oxygen demand (COD) and total organic carbon (TOC). The total COD loading from the three rivers was 8.33×10^7 kg/yr, approximately twice the BOD input. The total organic carbon input from the three tributaries was 2.02×10^7 kg/yr.

BOD, COD, and TOC are all important parameters for measuring the potential requirement of dissolved oxygen from receiving water. BOD in a sample of raw water is due almost entirely to microbial oxidation of carbonaceous organic matter, which is mostly contained in the TOC. However, BOD loadings resulted in depressing dissolved oxygen concentrations to levels harmful to aquatic organisms. The average content of BOD_5 in effluents from secondary treatment of municipal waste water in the United States is 25 mg/L (Weinberger et al. 1966). In sharp contrast, the mean content of BOD was 70.7 mg/L in Caño Central, and 410.8 mg/L in Rio Guey. The BOD determination has shortcomings, including the

oxygen demand of reducing inorganic compounds and inhibition of toxic substances to microorganisms.

Total organic carbon (TOC) content is the sum of particulate and dissolved organic carbon. Particulate organic carbon (POC) is composed of living and non-living particles, which provide substrate for microorganisms and food for zooplankton and fish. Dissolved organic carbon (DOC) includes large varieties of compounds of both natural and anthropogenic sources. In the tributary effluents of Lake Valencia, the major organic pollutants contain cyanide (3.4×10^4 kg/yr), phenols (7.9×10^4 kg/yr), detergent (1.05×10^5 kg/yr), and oil and grease (1.06×10^7 kg/yr). Quantitatively, the content of oil and grease account for one half of the TOC (2.02×10^7 kg/yr) input. As shown in Table 8, the oil and grease contamination in Lake Valencia's tributaries came from a large variety of agricultural industries. Among those pollutants, cyanide and phenols are highly toxic to aquatic organisms. For instance, fish were killed by water containing phenols greater than 0.5 ppm (USEPA 1974). The levels of phenols in Rio Guey, Los Guayos, and Caño Central were 0.34, 1.02, and 0.11 ppm, respectively. The safety limit of cyanide to freshwater organisms is set at 5 ppb in U.S. waters, and the levels found in Rio Guey, Los Guayos, and Caño Central were 0.1, 0.2, and 1.3 ppm, respectively. However, the cyanide ion combines with many heavy metal ions to form metallocyanide complexes which are often extremely stable in the aquatic environment.

Heavy metals. The five metals which were sampled and analyzed for Rio Guey and Los Guayos are listed in Table 6. Relatively high concentrations of Zn and Pb were found in Los Guayos with 150 and 650 µg/L, respectively. The total annual inputs of Cr, Cu, Ni, Pb, and Zn from those two rivers were 1.82×10^4, 2.14×10^4, 5.65×10^3, 5.27×10^4, and 1.07×10^5 kg, respectively.

Phosphorus. The input of total phosphorus (TP) from the three major tributaries was 9.57 x 10^5 kg/yr, with annual mean concentrations of 6.72, 3.65, and 2.21 mg/L in Rio Guey, Los Guayos, and Caño Central, respectively. Those values are much higher than the permissible P concentration (2 mg/L) in the effluents of many municipal sewage treatment plants in the United States. To prevent the development and control of nuisance algal blooms, total P should not exceed 50 µg/L in any stream at the point entering the lake or reservoir. However, the amount of annual input of total P from those three major tributaries alone would increase the mean P concentration of the lake water in Lake Valencia by 0.106 mg/L/yr.

Total dissolved phosphorus (TDP). A high proportion of the TP content in those tributary waters is in dissolved form, including both organic and inorganic. The annual input of TDP was 7.17 x 10^5 kg, which was approximately 75% of the TP. The largest input was from Rio Guey, with a mean concentration of 5.09 mg/L and a total annual input of 3.02 x 10^5 kg; Los Guayos had a mean value of 3.02 mg/L and an annual total of 1.65 x 10^5 kg; and Caño Central had a mean of 1.53 mg/L and a total of 2.32 x 10^5 kg.

Orthophosphate (PO$_4$-P). The total input of PO$_4$-P from those tributaries was 5.58 x 10^5 kg/yr, approximately 78% of the TDP and 58% of the TP. Caño Central contributed the largest annual input at 2.45 x 10^5 kg, followed by Rio Guey at 2.10 x 10^5 kg. However, the mean annual concentrations in these three waters were 1.62, 3.34, and 1.88 mg/L, respectively.

Most of the phosphorus content in those tributaries undoubtedly originated from domestic waste. The physiological level of phosphorus excretion for adult humans is estimated 1.5 g P/day (Fair et al. 1968). In recent years, domestic use of detergents containing polyphosphate, such as pyrophosphate and

tripolyphosphate, may have increased the P content in sewage as much as four times over sewage containing human excreta only (Stumm and Morgan 1962).

Nitrogen. Three forms of nitrogen were determined in Lake Valencia tributary water samples. The input of total nitrogen was 4.16×10^6 kg/yr, with 1.52×10^6, 1.04×10^6, and 1.60×10^6 kg/yr from Rio Guey, Los Guayos, and Caño Central, respectively. Most nitrogen was in organic form, with an annual input of 3.96×10^6 kg, approximately 94% of total N. The highest organic nitrogen concentration was found in Rio Guey at 24.17 mg/L and the lowest in Caño Central at 8.9 mg/L; Los Guayos was measured at 18.97 mg/L. The input of inorganic nitrogen ($NO_3 + NO_2$) was 3.37×10^4 kg/yr, less than 1% of total N. Annual mean concentration was highest in Rio Guey with 0.34 mg/L. The ammonia content, although not measured, is expected to be high because the tributary waters were often deprived of oxygen. Most organic nitrogen is released by human and animal wastes. Microbial decomposition of organic nitrogenous compounds is rapid and releases ammonia.

Solids. The total solids, including dissolved, suspended, and sedimental fractions, were measured. A large quantity, 2.08×10^8 kg (2.08×10^5 tons), of total solids was discharged by the three tributaries into Lake Valencia annually. Caño Central contributed the largest amount with 9.38×10^7 kg/yr, Los Guayos was second with 7.05×10^7 kg/yr, and Rio Guey was the smallest at 4.37×10^7 kg/yr. Total dissolved solids were 1.61×10^8 kg/yr, which constitutes 78% of the total solids in the tributary discharges. The dissolved solids mainly consisted of chloride, organic carbon, sulfate, calcium, magnesium, carbonate, oil and grease, and detergent. Other substances, such as phosphorus, nitrogen, and metals, were minor constituents.

Calcium was the largest item among the major dissolved solids, and annual input from the three tributaries was 2.99×10^7 kg, followed by chloride at 2.02×10^7 kg/yr, sulfate at 1.95×10^7 kg/yr, and magnesium at 1.65×10^7 kg/yr. The total dissolved solids discharged by those tributaries would increase the concentration in the lake water by approximately 24 mg/L/yr. This amount appears to be much lower than the apparent increases during the last few years. It is likely that the remaining large input of total dissolved solids has come from other sources, such as the atmosphere, non-point runoff, and other tributaries. The drastic increase in TDS during the past few decades has also been attributed to concentration resulting from the chronic desiccation.

MACROPHYTES AND MARSH SYSTEM

Wetland is a transitional zone formed between terrestrial and aquatic systems, which resulted from deposition of surface runoff from the land phase. The substrates of wetlands are often rich in nutrients and support dense growth of semi-aquatic vegetation that forms marshes. The accumulation of detrital materials resulting from seasonal succession of marsh vegetations may in turn form a thick layer of peat-like substrate.

Marshes are ecologically important for a number of reasons. The dense growth of vegetation provides habitat for wildlife. Marshes are also important in relation to the water quality of their adjacent aquatic environment, because the thick substrates may function in several ways to improve water quality. (1) They intercept siltation from terrestrial runoff and settle out particulate matter. (2) They process decomposition of organic matter and absorb inorganic nutrients. Recognizing those functions, marshes have been used in recent years as biological treatment systems for sewage effluents (Tilton et al. 1976).

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However, most of those practices are experimented with in temperate climates where the vegetative growth is disrupted during the winter. In tropical climates, growth is continuous all year around and it may be even more practical to use marshes for purification of sewage effluents.

Marsh System in Lake Valencia

The formation of marsh land around Lake Valencia is prominent due to two major processes. First is the continuing long-term desiccation that causes the level of lake water to drop more than 10 cm a year. Consequently, the surface area of the lake is reduced and the emerged aquatic macrophytes invade the shallow zone along the lake shore. The second process is the sediment deposition caused by surface runoff in the watershed. This process is particularly significant near the mouths of major tributaries, which carry a heavy load of organic and inorganic particulates during the rainy season.

The existence and distribution of marshes around the Lake Valencia basin is extremely dynamic. It is expected that the continued drop in lake water level will shift the marsh lakeward, and the outer zone will become part of the terrestrial system. The distribution of marshes has been progressively destroyed by channelization of the tributaries and development of farmland.

The seasonal succession of the marsh vegetation is primarily regulated by the dry-rainy cycle. Marsh land expands during the rainy season and reduces during the dry period. The vital biomass of the vegetative growth also responds according to such a cycle.

Figure 59 shows the species distribution of emerged macrophytes around the lake shore. The most predominant macrophytes were species of Typha and Chemopodium. Those species are most densely developed on the east and

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southwestern shores during the wet season from June to November. A smaller

stand remained toward the water's edge during the dry period.

At present there are substantial marsh lands along the eastern and western

shores of the lake (Fig. 59). Those marshes are particularly valuable as they

receive the outflow of several tributaries (Los Guayos, Caño Central, Rio Guey,

and Rio Aragua) that constitute major point sources of pollution in Lake

Valencia. Because the formation of marshes will be a prominent feature of the

lake ecosystem as the severe siltation and desiccation take place in the

lacustrine environment, protection of the wetland and creation of a green belt

around the lake will be a measure urgently needed to stall the accelerated

eutrophication in Lake Valencia. Full utilization of the marshes for

purification and removal of contaminants from sewage effluent will be a highly

appropriate technology for the social-economical-environmental system in the

Lake Valencia watershed.

Submerged Macrophytes

The distribution of submerged aquatic macrophytes is limited to shallow

water around islands and the southern shore where the substrates are sandy or

gravelly. In the soft, muddy portion of the lake very little submerged

vegetation was observed. In shallow muddy areas, vigorous sediment resuspension

caused great turbidity and siltation which provided poor conditions for

macrophyte growth. In addition to the turbidity problem, the large seasonal

fluctuation in water level made the immediate shore zone undergo an expose-flood

cycle, creating unfavorable growth conditions for submerged vegetation.

o Typha
x Chenopodium
+ Shrub
- Grass
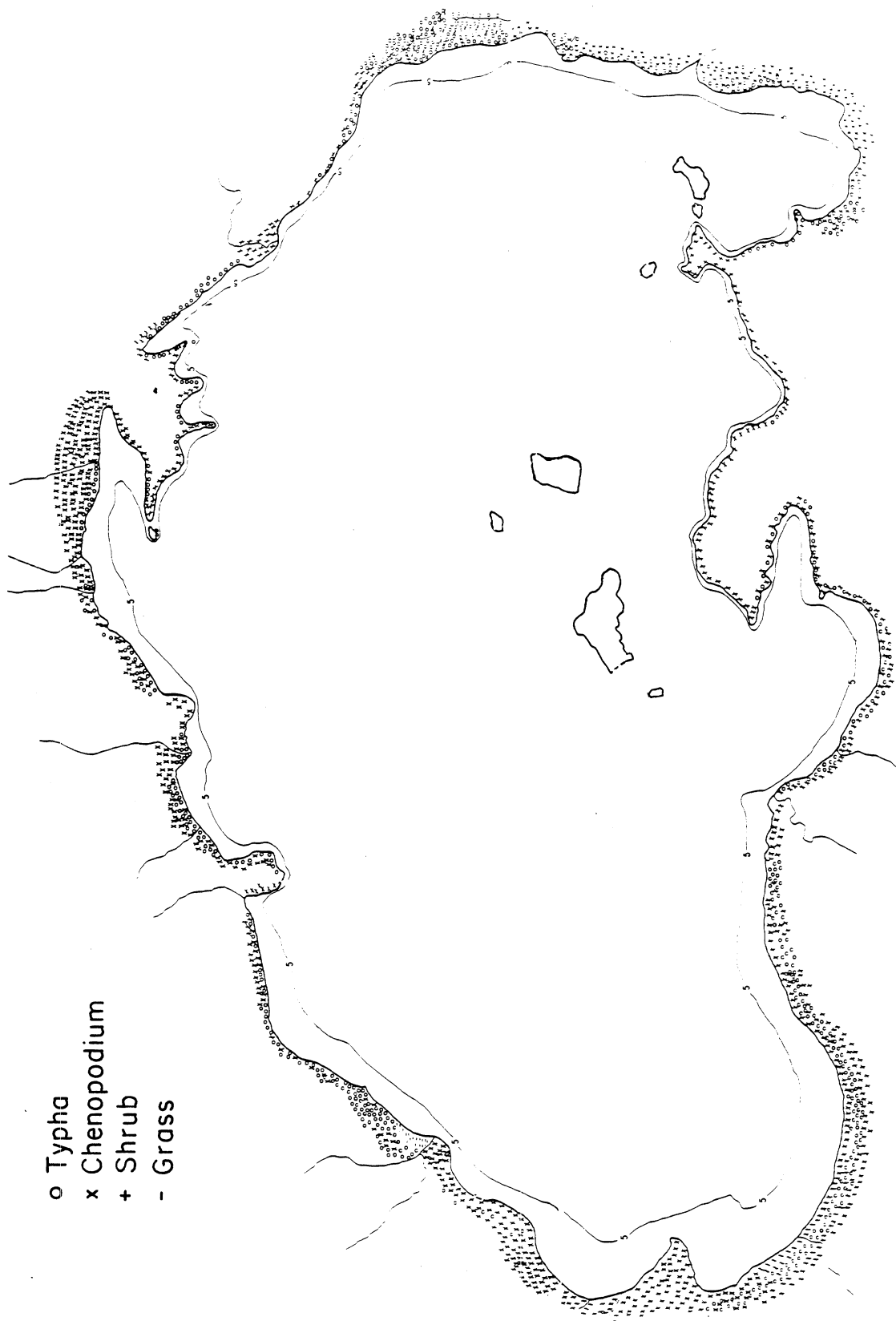
FIG. 59. Distribution of major emerged macrophytes on the lake shore.

The submerged macrophyte species composition is dominated by <u>Chara</u> sp. and <u>Potamogeton</u> sp.

<u>Chara</u> sp.

One or more species of <u>Chara</u> (Characeae) occurs sparsely in the shallow water, often found less than 1/2 m deep in the sandy or gravel bed. They commonly occur around the south shore and around the islands, where the water quality is relatively good.

The plant appears in vivid green and each plant grows in tufts of half a dozen to a dozen shoots which converge at the base. Shoots are unbranched, 5-10 cm high. No reproductive structure was observed during the survey.

<u>Potamogeton</u> <u>latifolius</u> (Robbins) Morong.

This is the most abundant submerged plant found in Lake Valencia. It grows almost continuously around the lakeshore and islands, except where the water has high turbidity and/or there are badly polluted river mouths. The most dense growth is found along the south shore of the lake and around the islands, but there is little growth at the east and west ends of the lake.

The plant is distributed in the littoral zone from 0.5 to 4 m deep, and the length of the plant varies considerably with the depth of the water column in which it grows. In shallow water, the plants average 20-40 cm in length, while in deep zones they reach over a meter in length. The predominant flowering season is not certain and only a small number of the plants bore flowers during the period of this survey.

A filamentous alga (Chlorophyceae), its species yet to be identified, is commonly associated with the upper shoots of <u>Potamogeton</u>. This association is

extremely productive as indicated by the abundant tiny air bubbles evolving from the vegetation beds.

In addition to submerged species, a floating species, _Eichhornia crassipes_ (Mart.) Solms., was observed to grow near the river mouth, and individual plants were occasionally dispersed to the open lake. A dense growth occurred on the north side of the Rio Guey mouth. The environmental conditions that prevent this plant from becoming wide spread are not known.

DISCUSSIONS AND CONCLUSIONS

The physical features of Lake Valencia have been undergoing a rapid change due to chronic desiccation which results in the rapid reduction of surface area, volume, and depth.

The lake has dwindled to an enclosed stagnant system that accumulates and condenses incoming soluble and insoluble substances. Results of the present study indicate that the depth of the water column has decreased to a level sufficiently shallow to allow frequent circulation to the maximum depth of the water column. As the wind action in the Lake Valencia basin is extremely variable in direction and velocity, the movement of water masses driven by wind stress shows little persistent pattern. The results also indicate that the water movement is so episodic and ephemeral that it does not appear to exert an effective vertical mixing mechanism, as indicated by dissolved oxygen during most of the year. It was difficult to obtain a simultaneous lakewide water movement pattern as the measurements were made using one current meter over several days during each cruise. More comprehensive features of the lakewide water movement pattern in Lake Valencia may be obtained by simultaneous measurements using a number of current meters at several stations in the lake,

or by continuous monitoring of water movement at several depths near the center of the lake.

The light regime in Lake Valencia plays a very important role in governing the phytoplankton ecology. Despite the high intensity of incident light in the tropical climate, the attenuation of light penetration in Lake Valencia is extremely great and the maximum depth of Secchi disc transparency is less than 2 m. Accordingly, the maximum depth of the euphotic zone extends to approximately 5 m, and on a volume basis only 25% of the lake water is autotrophic and 75% heterotrophic. In reality, the proportion of the auto-trophic and heterotrophic zones is much smaller as the average transparency in most areas is much less than 2 m during most of the year. Accumulation of phytoplankton biomass on the surface water is apparently the major cause of the shallow euphotic zone.

The dynamics of dissolved oxygen in Lake Valencia present the complex limnological processes in a single parameter, and the severe oxygen depletion imposes a most serious managerial problem. The major source of dissolved oxygen in the lake is phytoplankton photosynthesis. Input through atmospheric diffusion is expected to be insignificant because the surface lake water is frequently supersaturated with dissolved oxygen that prevents efficient air diffusion into the lake water.

On the other hand, the dissolved oxygen is consumed by several major components in the lake system, i.e. respiration of phytoplankton, zooplankton, and fish; sediment oxygen demands; chemical oxygen demands; and biochemical oxygen demands of the large quantity of organic materials from tributary inputs. Those processes result in a negative dissolved oxygen budget in Lake Valencia and create a severe oxygen depletion in the aphotic zone where an anoxic state

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prevails in a large proportion of the water column. Predictably, the continuous external loading of organic substances from tributaries will demand a greater quantity of the dissolved oxygen produced by phytoplankton and drive the anoxic layer upward to the surface.

Further understanding of the dynamic role of dissolved oxygen in Lake Valencia will require systems analysis and development of a numerical mass balance model. This type of model is essential for any managerial attempt to improve oxygen tension in the lake.

Water chemistry in Lake Valencia is probably far more complex than any general survey can comprehend.

The exceedingly high concentrations of total dissolved solids ($\approx$2,000 mg/L) with sulfate as a major constituent (500-1,000 mg/L) represent an unusual case in freshwater lakes of this size. Unlike most natural lakes with relatively long-term stable chemical characteristics which are governed largely by the geological features of the lake basin, the major chemical constituents in Lake Valencia are anthropogenic. The composition and quantity of those chemical constituents are constantly changing with increasing population and land use patterns in the lake basin. The concentration of total dissolved solids has risen progressively since the lake became a closed body of water: it has been increasing exponentially during the last two decades. According to a mass balance predictive equation (Apmann 1973), the total dissolved solids will rise to 6,000 by the year 2020. During recent years, the increase of total dissolved solids has paralleled a rise in sulfate concentration. Although sulfate is generally considered a conservative ion in the aquatic environment, the effects of exceedingly high concentrations on aquatic biota are not well known. Certainly, sulfate is the most available form to be reduced to sulfide in the

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prevailing anaerobic subsurface water in Lake Valencia. The formation of sulfide in lake water may have a significant impact on the chemistry of heavy metals as the sulfide of heavy metals forms notoriously insoluble precipitates. Theoretical treatment indicates that the insolubility of ferrous sulfide in the sediment prevents release of certain metals such as copper, silver, lead, and cadmium to lake water (Hutchinson 1957). The oxidation of hydrogen sulfide during the mixing period may also enhance the oxygen depletion in the lake water.

The nutrient data presented in this report indicate that the levels of phosphorus and nitrogen were in excessive supply for phytoplankton growth. A large proportion of those nutrients was in the organic or particulate forms, presumably retained mostly by the phytoplankton cells. The internal loading of nutrient through organismal cycling and sediment regeneration is likely to be an important source of nutrient supply in Lake Valencia. Under the prevailing anoxic conditions in the sediment and deep water, a substantial quantity of nutrients might be regenerated and released to the euphotic zone. Therefore, the analysis of sediments is an important tool for the study of the chemical and biological functions of the overlying water body. Transfer of dissolved matter between sediments and overlying water is of considerable importance in the control of the chemical processes taking place in the sediments and interstitial and basin waters. Some of the primary concerns are those of the role of sediments in the cycling of nutrients and as a sink of oxygen. These processes are governed by complex biochemical mechanisms. One of these processes is sediment oxygen demand (SOD). In Lake Valencia, incorporating SOD into a quantitative model will be indispensable to predict mass balance of dissolved oxygen for lake restoration.

Source of phosphorus (P) and nitrogen (N) released from the sediment to the overlying waters is expected to be of critical importance for successful prediction of the effects on lake trophic status resulting from the removal of nutrients by treatment.

The external loadings through tributary discharges constitute the largest pollutant input to Lake Valencia. As those loadings contain mostly untreated domestic and industrial discharges and silts from surface runoffs, the lake proper adjacent to the tributary outfalls acts as a treatment which may be conveniently termed a self-purification system for the pollutant. Several processes are involved in the system: sedimentation of solid material, decomposition of organic substances, and release of inorganic nutrients. As a result, those areas of the lake show a large sedimentation rate, severe oxygen depletion, and high nutrient concentrations.

Thus, the chemical constituents of the pollutants, the physical features of the treatment area, and the biological responses are primary factors involved in the self-purification capacity. Our previous investigation indicates that the river mouth of Caño Central exhibits a great capacity of self-purification. Such a process is particularly important in this area because it receives the largest quantity of domestic discharge to Lake Valencia. Physically, the extensive shallow contour provides efficient aeration which results in the active aerobic decomposition of organic materials. The nutrients released from organic forms stimulate massive phytoplankton blooms. Population density of the zooplankton community has been found greater here than in other parts of the lake, particularly the density of rotifers which are believed to be bacteria feeders. Ostracods are also commonly found in this area. The pollutant discharge, dispersion pattern, and heterotrophic and autotrophic processes in

the Caño Central region should be another focus for future research.

Results of this investigation indicates that excessive nutrient loading and severe oxygen depletion present the most urgent issues in Lake Valencia. To estimate nutrient and oxygen budgets in the lake water, we must consider both external and internal loadings. The external sources of nutrients and biochemical oxygen demand are primarily contributed by tributary discharges which are being thoroughly investigated. The internal loading of nutrient and oxygen involves uptake and release by various constituents in the water column as well as in the sediment. However, the magnitude of uptake and release of nutrients and oxygen through internal compartments of the lake is virtually unknown in Lake Valencia. The dynamics of nutrient and oxygen concentrations are governed by physical, chemical, and biological processes, and to understand the complexity of those processes requires system analysis and numerical modeling.

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