REC-ERC-82-7

STUDIES OF THE EFFECTS OF OPERATING THE MT. ELBERT PUMPED-STORAGE POWERPLANT ON TWIN LAKES, COLORADO: 1980 REPORT OF FINDINGS

December 1981

Engineering and Research Center

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16. ABSTRACT

A series of studies is being performed to qualify and quantify changes that occur in the limnological features of Twin Lakes, Colo. because of the Mt. Elbert Pumped-Storage Powerplant, which began operation in August 1981. This report presents the results of studies done in 1980. These results, along with those from other studies done since 1971 when the project began, are being used to define the preoperational limnology of Twin Lakes. The lakes are a pair of dimictic, connected, montane, drainage lakes of glacial origin. Based on seven limnological parameters, the lakes are classified as oligotrophic lakes.

Maximum water temperatures were recorded in August 1980 for the upper and lower lakes and were about 17 and 18 °C, respectively. The lowest measured dissolved oxygen concentration during 1980 was 1.3 mg/L at the bottom of the lower lake in October. The pH ranged between 6.3 and 8.3, and the conductivity levels were between 64 and 90 µS/cm. Total phosphorous concentrations never exceeded 2 µg/L during 1980, while nitrate nitrogen ranged from less than 10 to 90 µg/L. Average daily primary productivity rates ranged from a low of 1.6 mg C/($m^2 \cdot d$) in the upper lake during January to a high of 143.5 mg C/($m^2 \cdot d$) in the lower lake during November. Chlorophyll *a* concentrations during 1980 ranged from 0.6 mg/m^3 below 15 m in the lower lake during April to 18.0 mg/m^3 near the bottom of the epilimnion in the upper lake during September. Average phytoplankton and zooplankton densities reached maximums of just over 13 000 and 125.8/L, respectively, during August in the lower lake. Phytoplankton populations were dominated by diatoms and dinoflagellates, while zooplankton populations were dominated by copepods, oppossum shrimp, and various species of rotifers. Large pelagic cladocerans are notably absent from the lakes. The benthos of Twin Lakes is dominated by chironomids, oligochaetes, and fingernail clams reaching maximum densities, respectively, of 2922, 800, and 974/m^2 in the lower lake, and 1969, 2813, and 173/m^2 in the upper lake.

17. KEY WORDS AND DOCUMENT ANALYSIS

a. *DESCRIPTORS--* / *limnology/ *pumped storage/ *reservoirs/ *ecology/ chemical properties/ primary productivity/ chlorophyll/ phytoplankton/ zooplankton/ benthos/ fauna/ aquatic environment/ powerplants/ *lakes/ shrimp/ lake currents/ meteorological factors/ wind/ surface currents/ fish/ lake trout/ spawning/

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Division of Research
Engineering and Research Center
Denver, Colorado

SI METRIC

UNITED STATES DEPARTMENT OF THE INTERIOR ★ BUREAU OF RECLAMATION

METHODS AND MATERIALS

Table 1 is a summary of the limnological field surveys done during 1980 at Twin Lakes. During each of the surveys, data were collected in the same manner. The following subsections give a brief description of the methods used to collect data for the activities listed in table 1.

Physical-Chemical Factors

Temperature, dissolved oxygen, conductivity, hydrogen ion concentration (pH), and oxidation-reduction potential were measured with a Hydrolab Corporation System 8000 multiparameter probe. Water samples were collected from the surface, mid-depth, and bottom of the lake water column with a Van Dorn water sampler. Grab type water samples were collected from the inflow and outflow. Water samples were subjected to the following analyses:

- Major ions
- Trace metals (copper, zinc, iron, manganese, and lead)
- Plant nutrients (orthophosphate phosphorus, total phosphorus, total Kjeldahl nitrogen, nitrate nitrogen, nitrite nitrogen, ammonia nitrogen, and silica.)

Samples for the trace metal analysis were preserved immediately after collection with about 1 mL of concentrated nitric acid per 240 mL of water. The nutrient analysis samples were frozen immediately following collection. All samples were analyzed according to procedures in the *National Handbook of Recommended Methods for Water Data Acquisition* [20]. Light penetration was measured using both a standard Secchi disk and a limnophotometer. Light extinction coefficients were calculated from the limnophotometer measurements.

Primary Productivity

The rate of net primary production by carbon dioxide uptake using radioactive carbon (^{14}C) was done following the methods in Wood (1975) [21]. Measurements were always made during

Table 1. — *Field surveys at Twin Lakes during 1980*

Date of survey[1]	Activity performed						
	Physical factors	Chemical factors	Primary productivity	Chlorophyll	Phytoplankton	Zooplankton	Benthos
Jan. 9-11	x	x	x	x	x	x	x
Feb. 13-15	x	x	x	x	x	x	x
Mar. 11-14	x	x	x	x	x	x	x
Apr. 14-16	x	x	x	x	x	x	x
Apr. 24	x	x					
May 19-21	x	x	x	x	x	x	x
May 28	x	x			x	x	
June 11-13	x	x	x	x	x	x	x
June 18-19	x						
June 27	x						
July 14-16	x	x	x	x	x	x	x
Aug. 11-13	x	x	x	x	x	x	x
Sept. 8-9	x	x	x	x	x	x	x
Sept. 24-26	x	x	x	x	x	x	x
Oct. 8-10	x	x	x	x	x	x	x
Oct. 20-22	x	x	x	x	x	x	x
Nov. 3-5	x	x	x	x	x	x	x
Nov. 19-21	x	x	x	x	x	x	x
Dec. 18		[2]x					

[1] Includes surveys of Twin Lakes and Lake Creek inflow and outflow (physical-chemical only).
[2] Only inflow and outflow sampled.

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INTRODUCTION

The ongoing ecological studies of Twin Lakes began in 1971. The purpose of the studies is to learn more about the interrelationships of an acquatic ecosystem that is being influenced by operations of a pumped-storage powerplant and, in particular, about these interrelationships at Twin Lakes, Colo. and the Mt. Elbert Pumped-Storage Powerplant. Reports on the studies prior to this report can be found in references [1 through 17].[1] In addition, quarterly activity reports have been prepared since 1976 as Applied Sciences Referral Memorandums and are on file at the Bureau of Reclamation, Engineering and Research Center, Denver, Colo. Sartoris et al., (1977) [10], present a comprehensive report on the physical and chemical limnology of Twin Lakes through 1976. Reports on the biological limnology of Twin Lakes since 1971, excluding the fishery, are now being prepared. The data presented in this report are almost exclusively from calendar year 1980. Since the Mt. Elbert Pumped-Storage Powerplant only began operation in August 1981, all the report data presented has been for preoperation conditions. The same limnological studies will be repeated for a minimum of 3 years after commencement of powerplant operation. In this manner, a comprehensive and relatively accurate analysis of the effects of operating the powerplant on the aquatic ecology of Twin Lakes can be made. The present plan is to continue the field studies at Twin Lakes through 1984.

APPLICATION

Results of this study will be combined with other preoperational data on the physical, chemical, and biological limnology of Twin Lakes for comparison with postoperation conditions to assess the impact of Mt. Elbert Powerplant. Information from these studies is already being used by the Bureau in preparing designs and plans for other pumped-storage facilities. Those involved in environmental effects of pumped-storage powerplants will find data from these studies useful. Results of these studies will also be of interest to anyone involved in the study of lake ecosystems, especially those located in montane regions.

[1] Numbers in brackets refer to entries in the Bibliography.

GENERAL DESCRIPTION

The Twin Lakes are located on Lake Creek at the eastern front of the Sawatch Range in the upper Arkansas River Valley of central Colorado (fig. 1). The lakes are 2802 m above mean sea level. The present topography of the western side of the Arkansas River Valley in the Twin Lakes area is largely the result of glacial action on earlier alluvial deposits (Buckles, 1973 [18]). Twin Lakes probably originated with the moranic damming of Lake Creek (Sartoris et al., 1977 [10]). The shoreline and bottom topography of Twin Lakes are shown on figures 2 and 3, respectively.

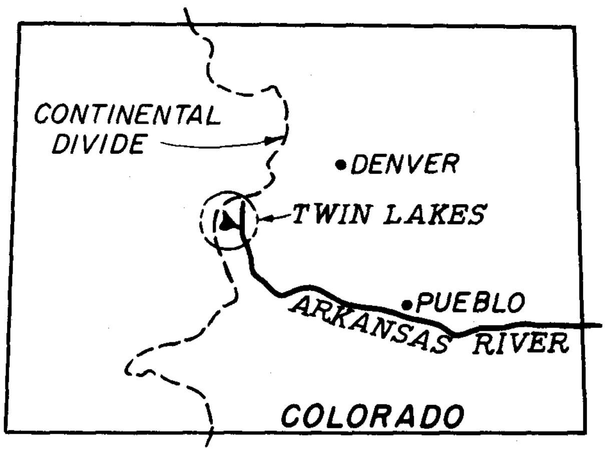

Figure 1.—General location map of Twin Lakes, Colo.

The lower lake is the largest natural mountain lake in Colorado (Pennak, 1966 [19]). Present maximum water surface areas are about 263.4 ha for the upper lake and 736.5 ha for the lower lake, with corresponding depths of about 28 and 27 m, respectively. Sartoris et al., (1977) [10], summarize the literature reporting results of studies done from 1873 to 1977; LaBounty et al., (1980) [16], update this summary. The physical and biological changes of Twin Lakes during the past 100 years are also discussed in [10].

The installation of the outlet control works, dredging of the channel between the two lakes, human activities in the area, and the introduction of rainbow trout *(Salmo gairdneri)*, lake trout *(Salvelinus namaycush)*, and mysis shrimp *(Mysis relicta)* have altered the original ecology of Twin Lakes and produced the present system. In late 1980, use of the recently constructed Twin Lakes Dam began; full use of this structure is planned for 1982.

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ACKNOWLEDGMENTS

The study is a cooperative effort involving the Bureau of Reclamation, Colorado Division of Wildlife, and the Fish and Wildlife Service's Colorado Cooperative Fishery Research Unit at Colorado State University. Funding for this project (DR-331) is provided by the Fryingpan-Arkansas Project, Lower Missouri Region, and the Division of Research of the Bureau of Reclamation. Work on this study is being performed under the supervision of N. E. Otto, Head, Environmental Sciences Section, and L. O. Timblin, Jr., Chief, Applied Sciences Branch. Contributions to both the field and laboratory portions of this study by R. A. Roline, S. G. Campbell, J. R. Boehmke, and S. D. Hiebert are gratefully acknowledged. The Chemistry, Petrography, and Chemical Engineering Section performed the chemical analyses.

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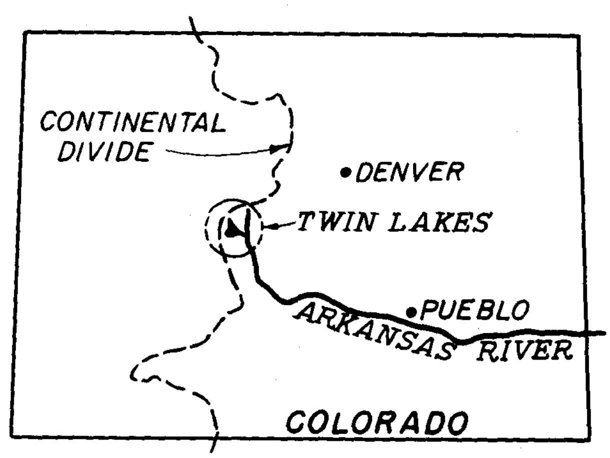

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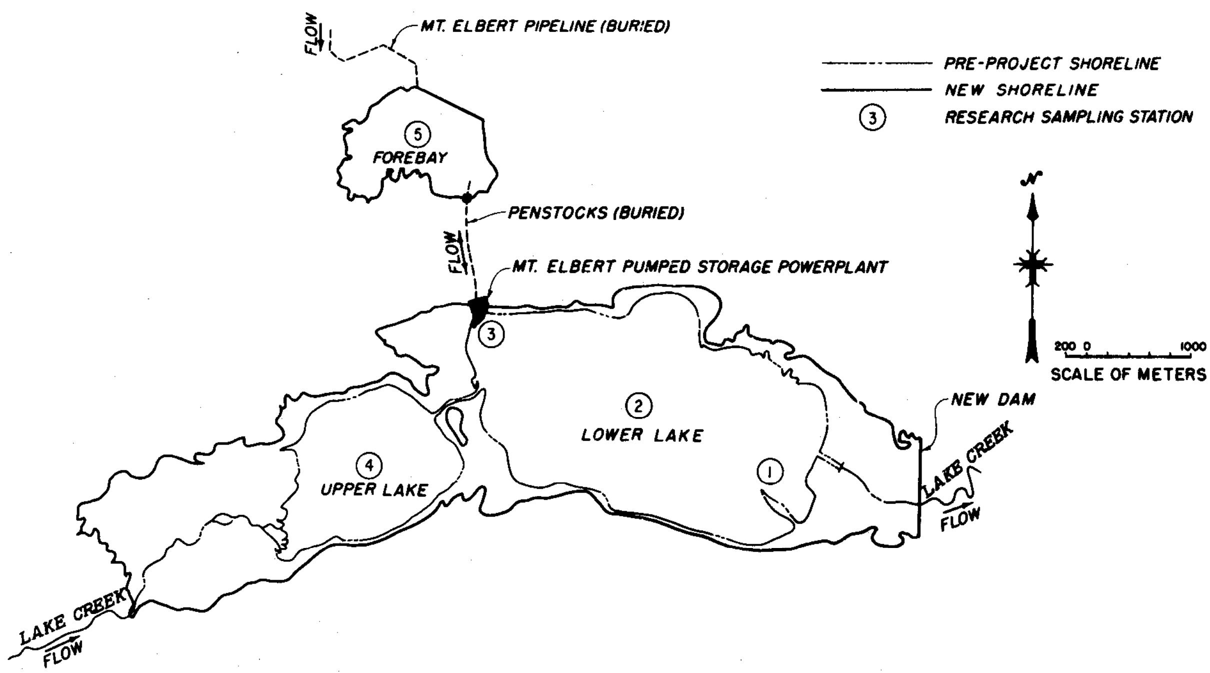
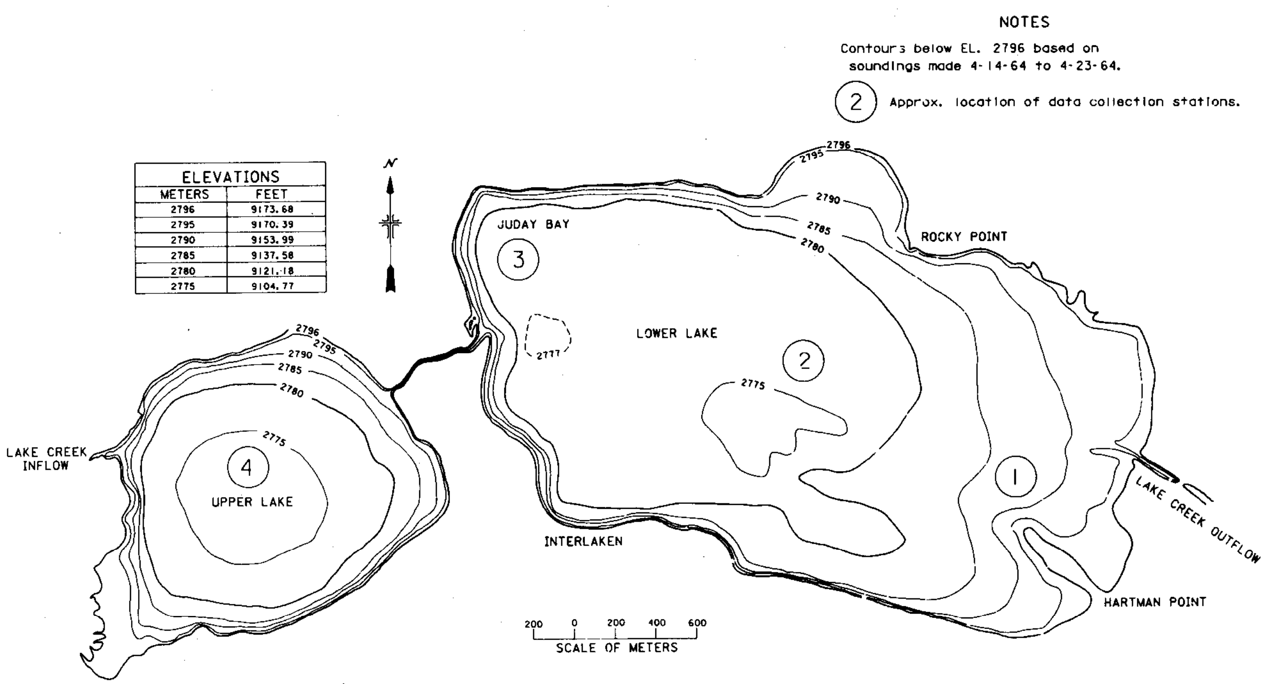


Figure 2.—Twin Lakes shoreline.



ELEVATIONS	
METERS	FEET
2796	9173.68
2795	9170.39
2790	9153.99
2785	9137.58
2780	9121.18
2775	9104.77

Figure 3.—Bottom topographic map of Twin Lakes.

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May 19-21	x	x	x	x	x	x	x
May 28	x	x			x	x	
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Sept. 24-26	x	x	x	x	x	x	x
Oct. 8-10	x	x	x	x	x	x	x
Oct. 20-22	x	x	x	x	x	x	x
Nov. 3-5	x	x	x	x	x	x	x
Nov. 19-21	x	x	x	x	x	x	x
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[1] Includes surveys of Twin Lakes and Lake Creek inflow and outflow (physical-chemical only).
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peak daylight hours. In March, primary production rates were measured in a series of samples that were spiked with luxuriant concentrations of phosphate phosphorus and nitrate nitrogen. Results of the special studies done in March will be presented in a separate report.

Chlorophyll

Samples for chlorophyll analysis were collected at 0.1-, 1-, 3-, 5-, 9-, and 15-m depths in each lake. Following collection, 750-mL samples were filtered through Millipore glass filter pads. Chlorophyll extraction and analysis were done according to methods outlined in Parsons and Strickland (1963) [22].

Phytoplankton and Zooplankton

Plankton were collected with a closing net having a No. 20 (mesh opening = 0.076 mm) silk net and bucket. Vertical hauls were made from 0 to 5 m, 5 to 10 m, 10 to 15 m, and from 15 m to the lake bottom. Samples were preserved with a 2 percent formalin solution for laboratory analysis. Laboratory methods follow those of Welch (1948) [23].

Benthos

Two or three samples of benthic muds were collected from each station using an Ekman dredge. These samples were screened through a U.S. Standard Series No. 30 sieve size (sieve opening = 0.589 mm) and then preserved in a 10 percent formalin solution for laboratory analysis. All specimens were identified according to type, and then counted and weighed. Both the wet and dry biomass were obtained by methods from APHA (1971) [24].

Meteorological-Limnological Instrumentation

Specially designed meteorological-limnological monitoring instrumentation was purchased and put into operation at Twin Lakes during 1980. These instruments were designed and constructed by Hydrolab Corporation. Instrument packages for three stations in the lower lake, one station in the upper lake, and one station in the forebay were received and basically tested during 1980. All of the instrument packages are mounted on anchored rafts. Instruments at stations 2 (lower lake) and 4 (upper lake) monitor underwater parameters at two depths. Station 1 instrumentation, located at the east end of the lower lake, monitors underwater parameters at one depth. The instruments on station 3, near the tailrace in the lower lake, and station 5, in the center of the forebay, monitor underwater parameters at one depth in addition to selected meteorological parameters. Underwater parameters are temperature, dissolved oxygen, pH, and oxidation-reduction potential (redox or ORP). Meteorological parameters are air temperature, average hourly windspeed, and brightness (light). Data from the instrumentation are not completely presented in this report because most of the units were received late in the year. The meteorological and underwater unit at station 3 operated successfully for most of the ice-free season. Also, the older Sierra Corporation instrument that monitors air and water temperatures and average hourly windspeed was operated successfully for the ice-free season. A complete analysis of the data collected by these instruments will be presented in a separate report. For purposes of this report, only selected meteorological data are summarized in the following section.

RESULTS AND DISCUSSION

Light

Figure 4 is a plot of the 5-day average ambient light flux measured between 0900 and 1500 hours daily at Twin Lakes from June 26 through November 13, 1980. The dashed line on figure 4 connects points representing 5-day periods that were nearly or completely cloud free; thus, this line represents the theoretical maximum light curve. The maximum average insolation of about 44 g-cal/($cm^2 \cdot h$) occurred over the 5-day period July 16-20, 1980. From that period on, the theoretical curve declines to a low average insolation of about 26 g-cal/($cm^2 \cdot h$) during the 5-day period November 9-13, 1980. The solid line on figure 4 connects the measured 5-day average light fluxes. These data points indicate the extreme variability in the amount of light during the June-November period. For example, the average insolation during the 5-day period September 9-13 was about 22 g-cal/($cm^2 \cdot h$). Theoretically, if the skies had been mostly clear during that period, the insolation value would have been about 40 g-cal/($cm^2 \cdot h$). This means that nearly 50 percent of the potential light was shaded; that is, there was less light available

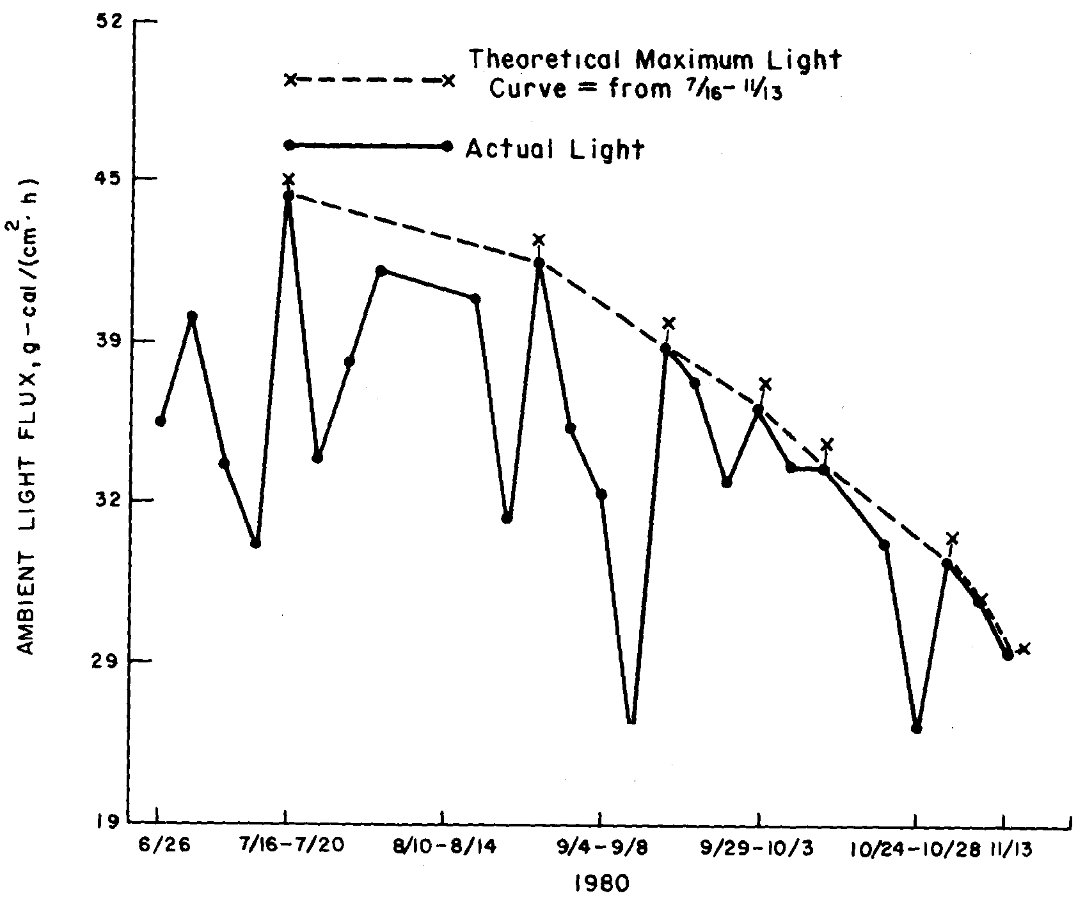


Figure 4.—Five-day average ambient light flux at Twin Lakes, June-November 1980.

September 9-13 than on a clear day at the end of November. Variations in cloud cover are characteristic of the area; however, for extreme variations, such as the one just described, there is a significant loss of energy for primary production in the lakes.

Two instruments to monitor light will be placed in operation in 1981; one on the forebay and one on station 3 near the tailrace channel in the lower lake. From the data collected by these instruments, we should be able to estimate the daily energy input to both the forebay and Twin Lakes.

Wind

Wind is another very important meteorological factor affecting the ecology of Twin Lakes. Wind is partly responsible for the timing of ice formation, break-up of spring ice, length of time the lakes continuously mix during spring turnover, time and severity of fall turnover and mixing, amount of mixing in the epilimnion during summer, and the amount of snowpack on the ice.

Figure 5 shows the 5-day average wind velocities from May 28 through November 13, 1980. The average wind velocity over that time was about 10 km/h. There is much variability in average windspeed at Twin Lakes just as there is with light; however, the average wind was never below 8 km/h. The highest wind velocities occurred after mid-September particularly during late October and November. The average wind velocity during late October and early November was 12.8 km/h. This was at the time when the lakes were subject to fall turnover. Thus, the greater the wind velocity, the more mixing that occurs, and the more nutrients that are brought into the water column from the sediments and made available for primary productivity.

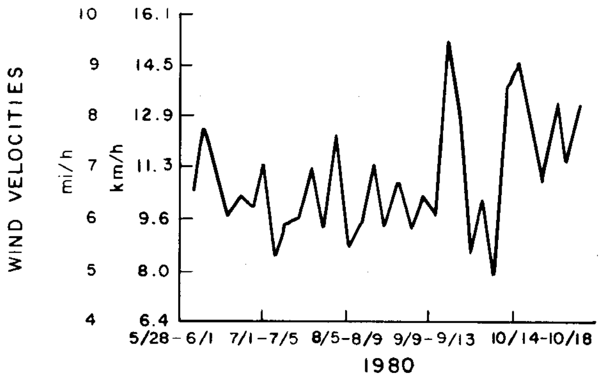
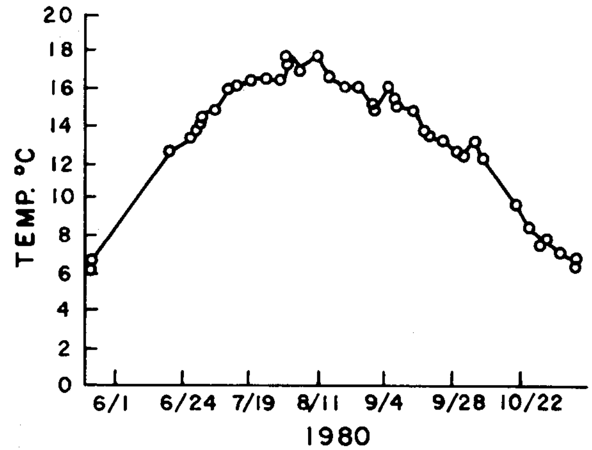


Figure 5.—Five-day average wind velocities at Twin Lakes, May-October 1980.

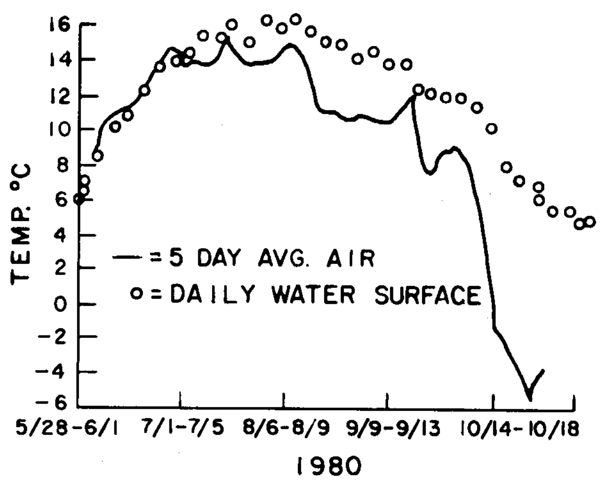
During 1981, wind velocities will be monitored both in the tailrace area of the lower lake and in the center of the forebay (sta. 5).

Temperature

Both air and water temperatures were monitored at stations 2 and 3 in the lower lake from late May to mid-November 1980. Temperature data from station 2, center of lower lake, are shown on figure 6. Water surface temperatures are daily averages, and air temperatures are 5-day averages. Average air temperatures ranged from about -6 °C in early November to almost 16 °C in mid-July. Even though some variation in average air temperature exists, these variations are not nearly as great as with wind and light. By averaging the temperatures, the variation was reduced somewhat. With light and wind, averaging the values did not change the variation much. Average water surface temperatures at station 2 ranged from about 4 °C in early November, when the lake was isothermal, to just over 16 °C in early to mid-August. The time of turnover is evident from the drop in average water temperature from above 10 °C to below 6 °C during mid-October. Other than that variation, the curve remains quite smooth. Average daily water surface temperatures from station 3, near the tailrace channel, are also shown on figure 6. Average temperatures ranged from about 6 °C in late May and early November to just under 18 °C in early to mid-August. Fall turnover is again indicated by the drop in average surface temperatures in mid-October. Average water surface temperatures were somewhat warmer at station 3 because it is more sheltered from prevailing westerly and northern winds, and it is somewhat shallower than station 2. However, the average water surface temperature at station 3 was influenced by the inflow from the upper lake and took longer (mid-July) to warm up to above 14 °C.



(a) Daily average water surface temperatures at station 3.



(b) Average air and water surface temperatures at station 2.

Figure 6.—Temperature data for lower lake during May-October 1980.

During 1981, air temperatures will be monitored at station 3 and in the forebay. Water temperatures will be monitored at station 3 (surface), forebay (surface), station 1 (east end of lower lake — surface), station 2 (middle of lower lake — surface and hypolimnion), and station 4 (middle of upper lake — surface and hypolimnion).

Physical-Chemical Profiles

Temperature. — Figures 7 and 8 present 1980 water temperature isopleths for both the lower and upper lakes, respectively. The lakes were ice free from May 15 to December 9, or 208 days. Also, the lakes were thermally stratified during this period from about May 25 to about October 20, or about 148 days. This means that the lakes remained subject to turnover for about 10 days in the spring and 50 days in the fall. During 1980, the lakes were not ice free for as long as any of the previous 9 years of this study. A prolonged cold spell in late April and early May kept temperatures so low that the ice cover melted more slowly than normal. Ice formation in 1980 occurred about December 9, which was the latest date that ice formed during the 9 years of study. This was because of mild weather experienced in the area during early winter. The weather remained so mild that the ice cover was not strong enough to work on through all of December. This event is not related to the late date of ice melting during the spring of 1980.

Figures 7 and 8 show that both lakes were strongly stratified during the summer with peak stratification occurring during the second week of August. Water temperatures in the epilimnion were warmer than those of recent years. Between mid-July and mid-August, surface water temperatures in early August were 18 °C to a depth of 3 meters. The epilimnion was generally above 16 °C from late June to early September. During most of the recent years of this study, the maximum sustained water surface temperature was 16 °C. The 16 °C surface temperature in the upper lake was sustained from mid-July to early September; the maximum surface temperature measured was 17.7 °C. This maximum surface temperature remained from late July to late August, or about 30 days. The epilimnion of the upper lake was warmer during 1980 than in previous years. In addition, stratification in the upper lake was stronger during 1980 than in previous years. There have been years when classical thermocline formation in the upper lake did not occur. Because of the relatively strong stratification in both lakes during 1980, the hypolimnia of both lakes remained comparatively cool. Bottom temperatures in the lower lake remained below 9 °C all year and below 8 °C until late September. Bottom temperatures in the upper lake remained below 6 °C all year. Since lake trout prefer 10 °C and below, there was a great volume of optimum space for them in both lakes. Although fall turnover usually occurs by the second week in October at the lakes, it was the last week in October 1980 before both lakes were mixed completely.

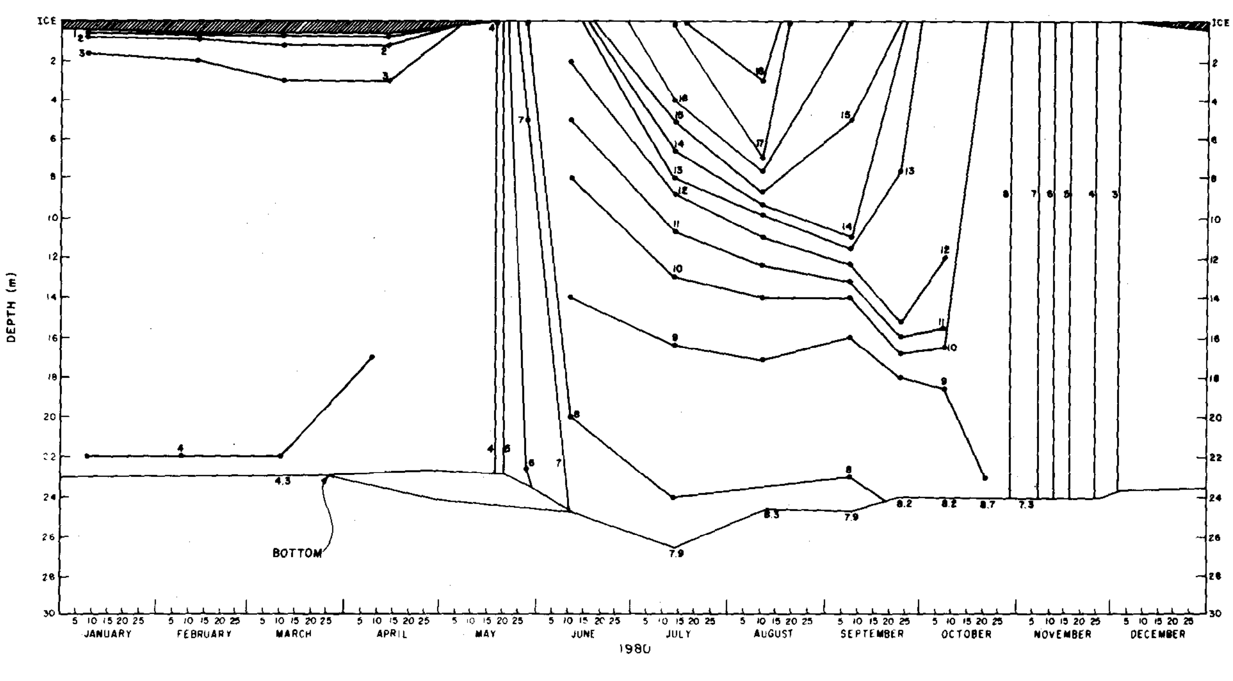


Figure 7.—Temperature (°C) isopleths at station 2 on lower lake during 1980.

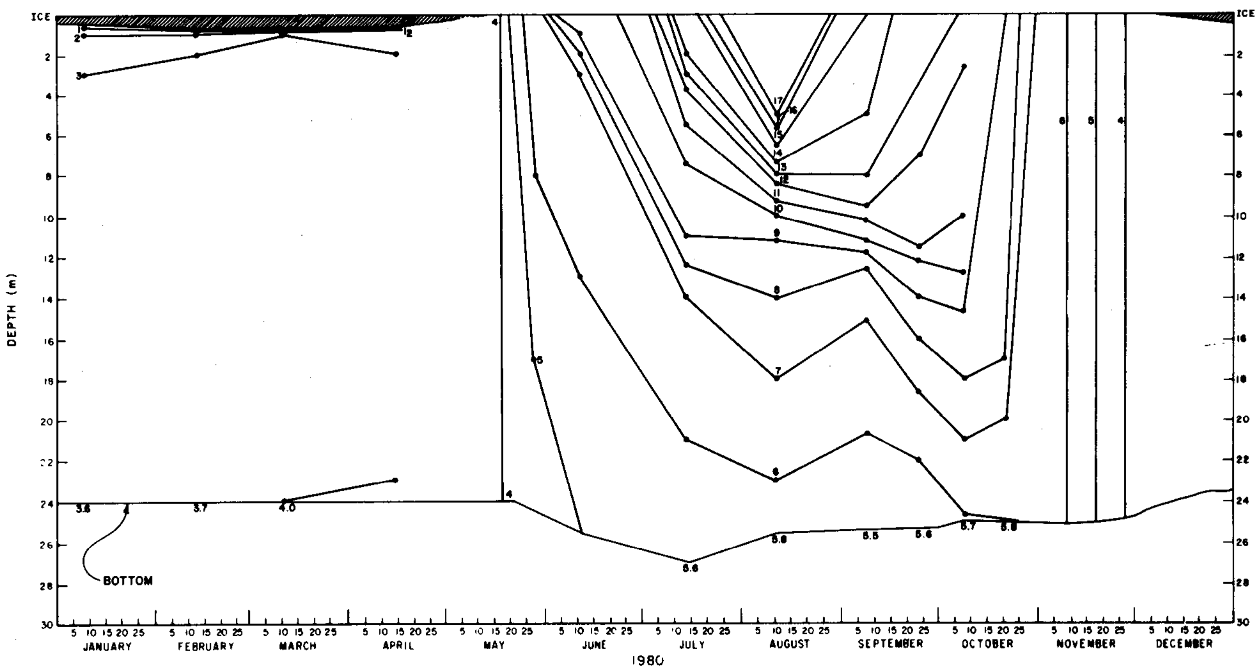


Figure 8.—Temperature (°C) isopleths at station 4 on upper lake during 1980.

Figure 9 plots average monthly water temperatures for both lakes during 1980. Also shown on this figure are the 1974-79 average monthly water temperatures. The monthly average was calculated by including all water temperature data from all depths and for all surveys done during that month. These data indicate that, on the average, both lakes were about 1 °C warmer during the months when the lakes were covered with ice. This was due to an early ice formation in the fall of 1979 when the ice formed before the cold fall winds supercooled the lake to 1 to 2 °C as usually happens. Thus, the lakes began the winter a degree or two warmer than in previous years. Although both lakes were somewhat warmer in July, their temperatures were close to the 1974-79 average. However, the averages do not adequately reveal the exact conditions in the lakes. As previously stated, the lakes were strongly stratified in 1980 which made them warmer on the surface and cooler on the bottom. The average temperatures can be somewhat deceptive unless the degree of stratification is also considered.

Dissolved Oxygen. — Figures 10 and 11 present dissolved oxygen data from Twin Lakes during 1980. The highest dissolved oxygen readings of 12 mg/L occurred during the winter under the ice when water temperatures were coldest. Both lakes had low readings of between 3- and 4-mg/L (about 40 percent saturation) during April near the bottom. During previous winters, the concentrations were much lower at the bottom, especially in the upper lake. The reasons for these differences in dissolved oxygen levels between winters are the amount of snow cover in March and April, time of ice-on, amount of nutrient input, volume of inflow, and degree of winter thermal stratification. The lowest concentration measured in 1980 was 1.3 mg/L (about 15 percent saturation) on October 21 in the lower lake. Concentrations were below 3 mg/L in this lake from at least late August to late October. The lowest concentration during the summer in the upper lake was 4 mg/L (35 percent saturation). The concentrations in both lakes during the summer of 1980 were about the same as in previous years, except that the relatively late mixing of the lakes resulted in lower values near the bottom later into October.

Hydrogen Ion Concentration. — Figures 12 and 13 present the hydrogen ion concentration (pH) isopleths for Twin Lakes during 1980. The pH values for both lakes show the normal reflection of thermal stratification. In January and February, the pH ranged from 7.6 to 7.8 near the water surface, and from 6.6 to 6.7 near the lake bottom in March and April. During the summer,

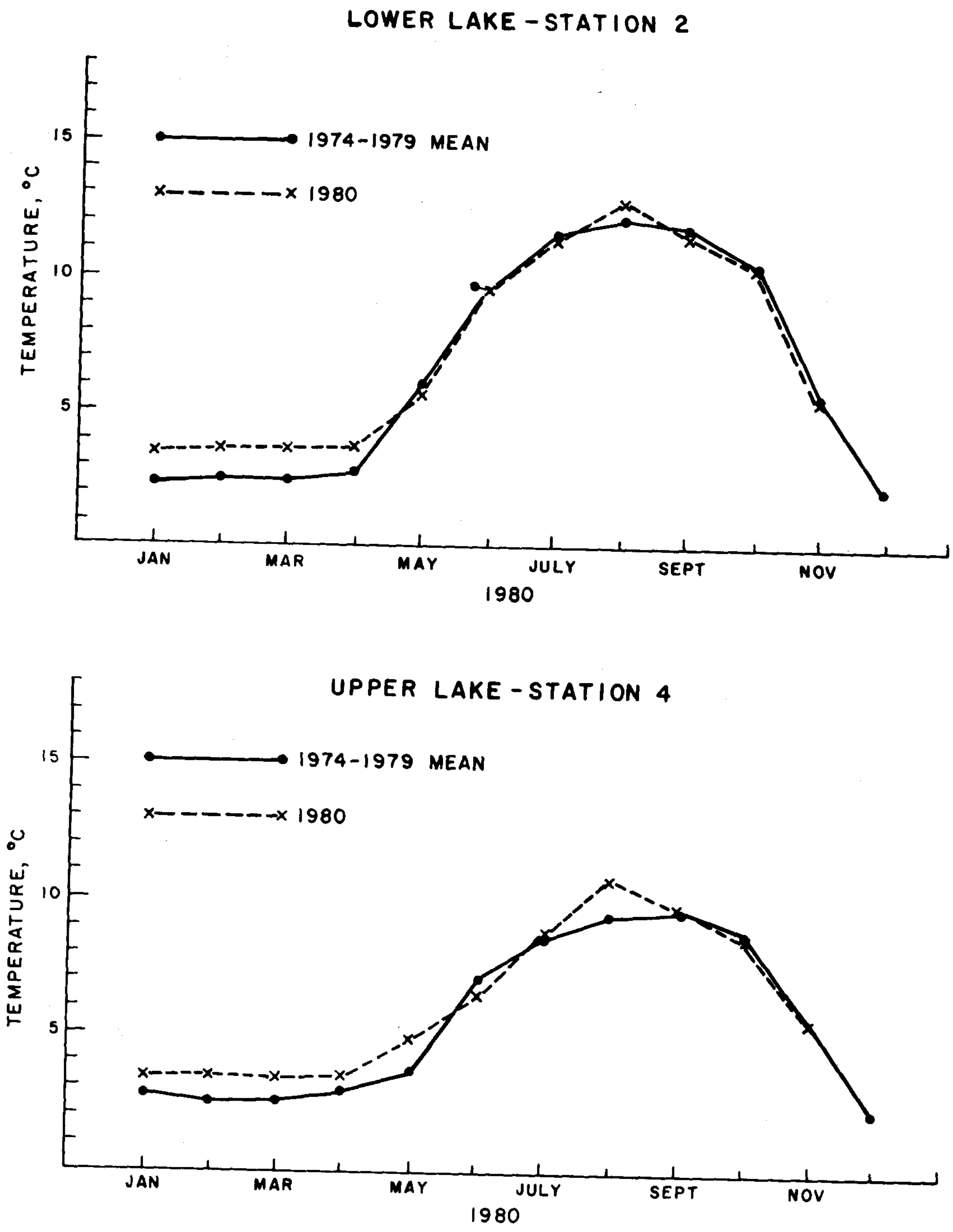


Figure 9.—Average monthly water temperatures for Twin Lakes.

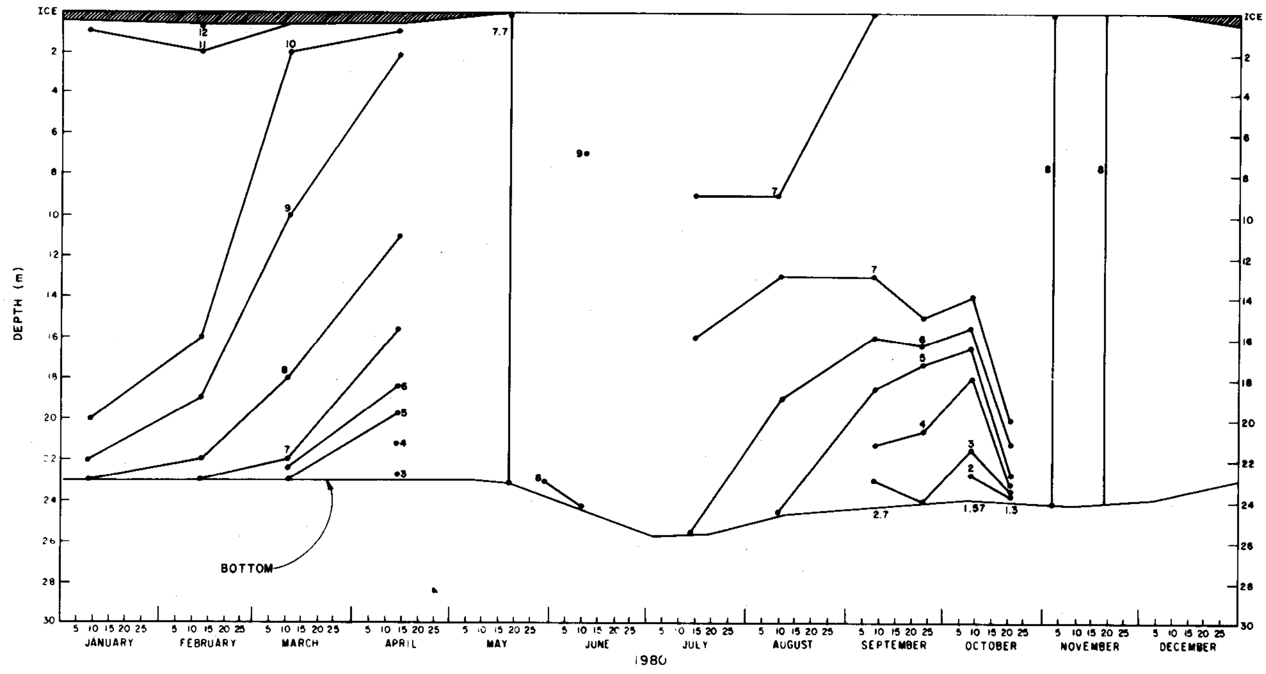


Figure 10.—Dissolved oxygen isopleths at station 2 on lower lake during 1980.

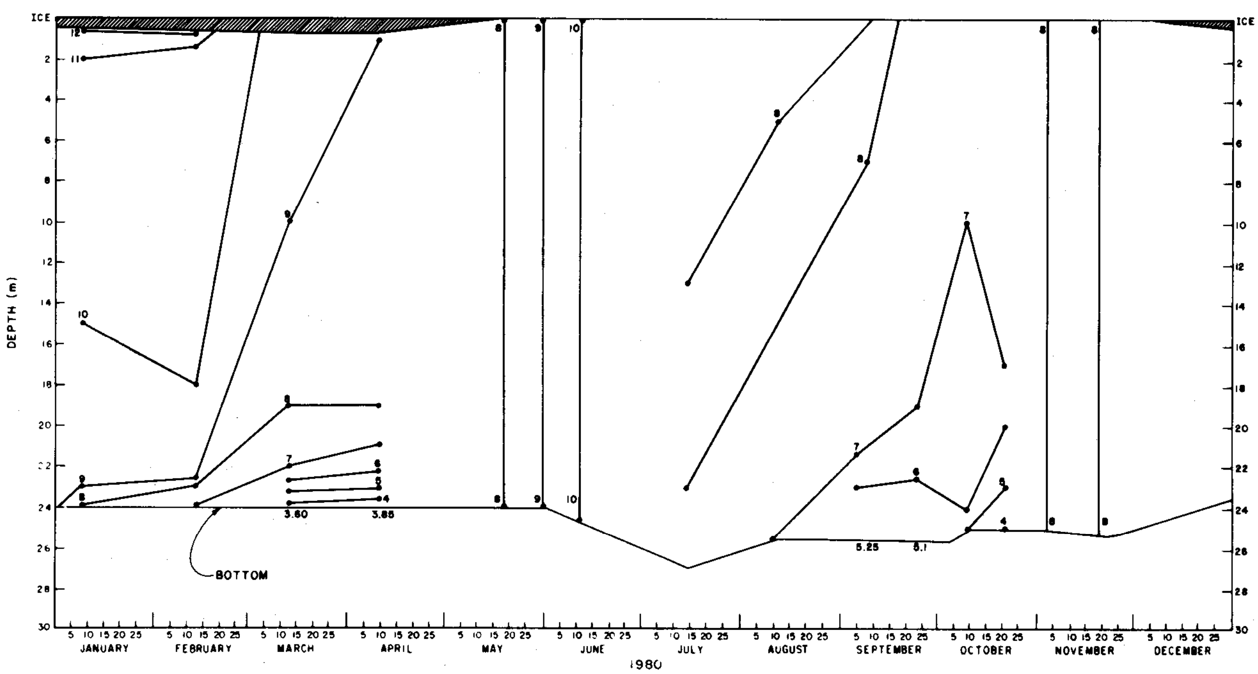


Figure 11.—Dissolved oxygen isopleths at station 4 on upper lake during 1980.

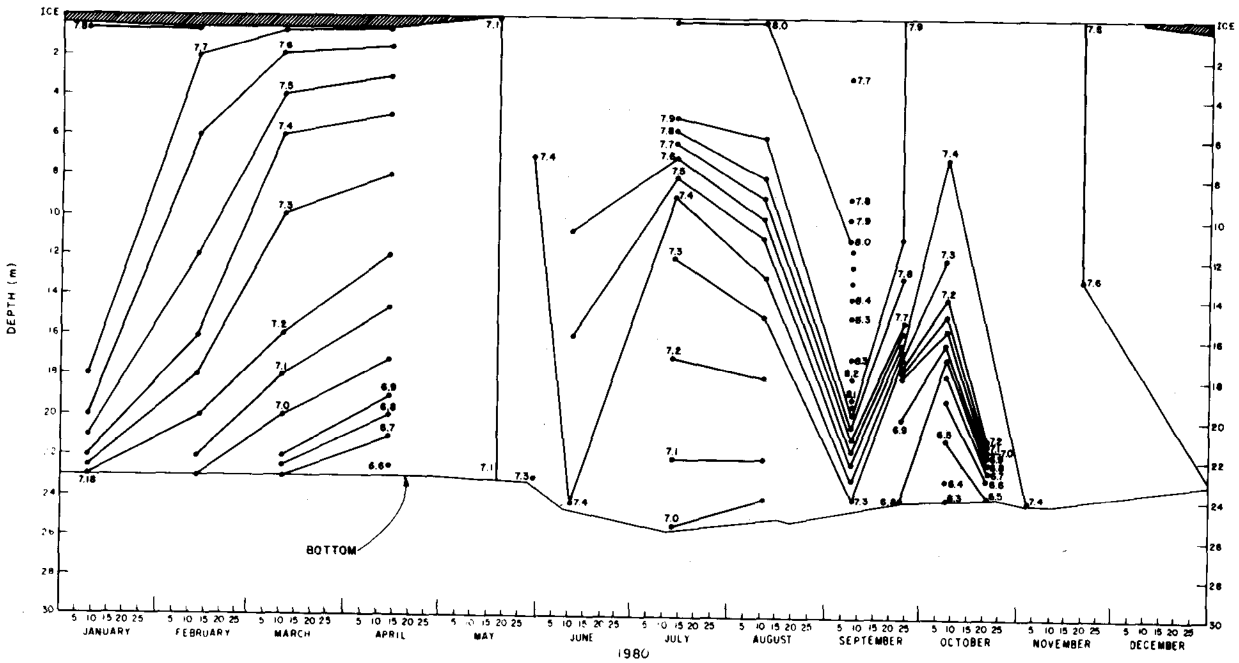


Figure 12.—Hydrogen ion concentration (pH) isopleths at station 2 on lower lake during 1980.

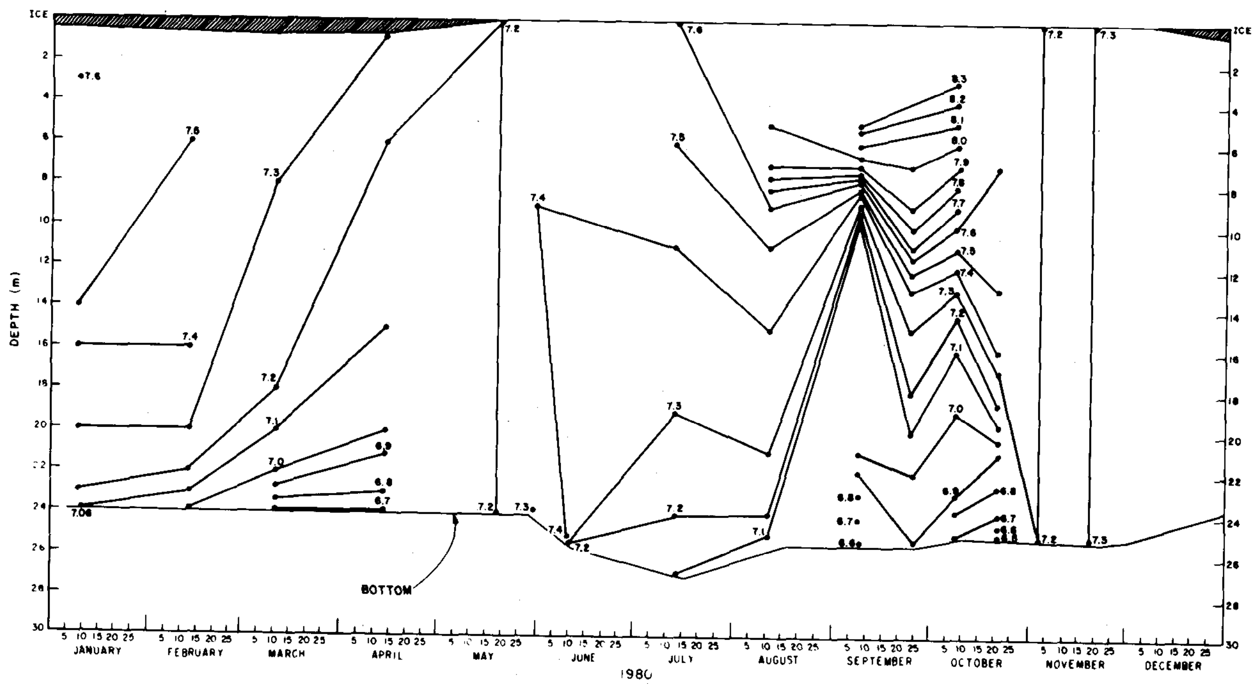


Figure 13.—Hydrogen ion concentration (pH) isopleths at station 4 on upper lake during 1980.

the range of pH values was much greater. The lowest values of 6.3 and 6.5 in October for the lower and upper lake, respectively, were at the bottom of the hypolimnion where dissolved oxygen concentrations were lowest, and where decomposition rather than photosynthesis is likely to occur. The highest pH values of 8.0 to 8.4, which occurred mostly in September and October, reflect times of maximum stratification. Twin Lakes water at this time has relatively low conductance (less than 90 μS/cm) which makes it poorly buffered. Generally, the pH varies greatly because of the amount of biological activity in this poorly buffered water. Biological activity at Twin Lakes greatly influences the carbonate-bicarbonate shift. Upon turnover, the pH decreases (7.2 to 7.5) and is relatively uniform from surface to bottom; the resuspension of material from the hypolimnion may be responsible for this uniformity. This has also occurred during previous years of this study. Import of material by way of Lake Creek during peak runoff also results in decreased pH. As soon as runoff subsides and thermal stratification is established, pH values in the epilimnion increase.

Conductivity. — Figure 14 presents average conductivity data for Twin Lakes during 1980. Values were averaged from surface to bottom for each sampling date and the average plotted. The values ranged from 62 to 90 μS/cm, in the upper lake and from 66 to 88 μS/cm in the lower lake. The data (fig. 14) indicate the influence of runoff on conductivity, especially in the upper lake. After the runoff slowed, average conductivity began to increase slowly, reaching a peak during the winter in the upper lake. Beginning in late May, this increased inflow to the upper lake meant that its water, which in mid-May had a conductance of 90 μS/cm, was "pushed" into the lower lake and mixed. This resulted in an average conductance of 86 μS/cm for the lower lake in late May. By the second week in June, runoff was sufficient to "dilute" the conductance in both lakes to less than 75 μS/cm. The average of all conductivity measurements during 1980 was 74 and 77 μS/cm for the lower and upper lakes, respectively. The 1974-79 average conductivity for all measurements made was 68 and 74 μS/cm for the lower and upper lakes, respectively. Thus, the average conductivity was 6 and 3 μS/cm higher in 1980 for the lower and upper lakes, respectively. This difference is not statistically significant.

Oxidation-Reduction Potential. — Figure 15 shows the average oxidation-reduction potential measured at the bottom of the lakes during 1980. The values ranged between 350 and 550 mV for the upper lake and between 350 and 500 mV for the lower lake. There is no obvious biological significance to any differences in these data. The bottom of the lakes remained in an oxidizing state during the entire year. During some previous years, significantly low redox values have been measured at the bottom of the lakes, indicating that conditions were approaching or had reached a reducing state. A reducing state was not approached anywhere in the water column during 1980.

Monthly Inflow Volume

Figure 16 presents the total monthly inflow volume to Twin Lakes by way of Lake Creek. The dashed line indicates 1980 inflow volumes, and the solid line indicates average monthly inflow volumes for 1971-80. The total volume of inflow during 1980 from Lake Creek, which includes both natural flows and diverted western slope flows, was close to the 10-year average for total volume. However, inflow was slightly less in 1980 than the 1971-80 average and was also more concentrated in June. Volumes in May, July, and August 1980 were 15 to 50 percent lower than the 1971-80 average, while June was found to be average. The pattern of inflow during 1980 was normal; that is, monthly volumes for January through April remained less than 2 million cubic meters. During May, the volume of inflow was 15 million cubic meters, almost eight times that for January-April. June is usually the peak runoff month, and the volume of inflow during June 1980 was about 75 million cubic meters, almost 40 times that for January-April. During this peak runoff, nutrients are brought into the lakes. Usually, most of these nutrients are flushed through the upper lake to the lower lake where they are generally utilized. However, during years of low runoff these nutrients are used to a greater extent in the upper lake because they more readily accumulate there. The volume of inflow in July dropped to almost 25 million cubic meters, which was about one-third that of June. In August and September, inflow volumes were below 5 million cubic meters. In summary, the runoff begins to build during May, peaks sharply in June, and then drops quickly through September. The timing

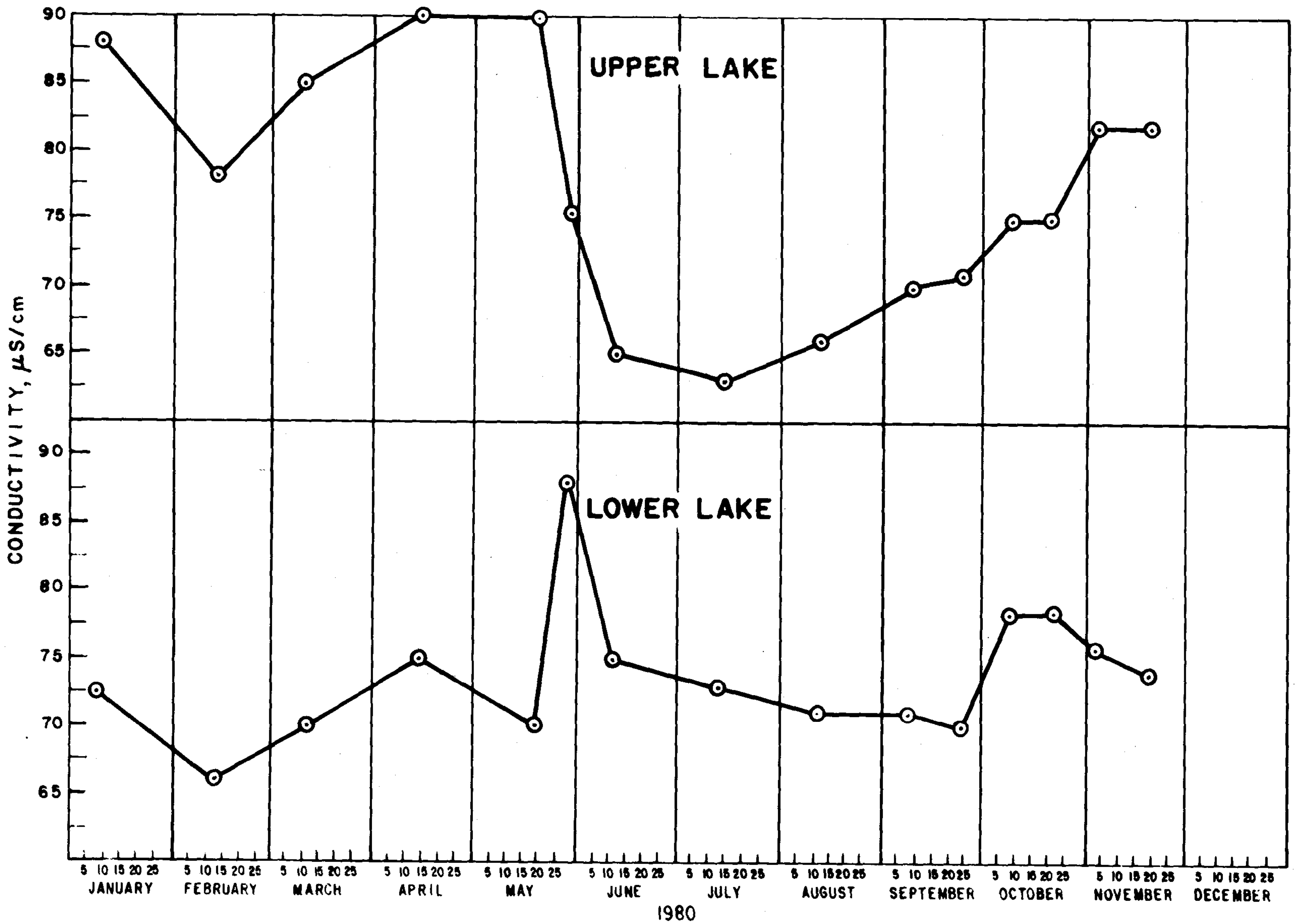


Figure 14.—Average conductivity for Twin Lakes during 1980.

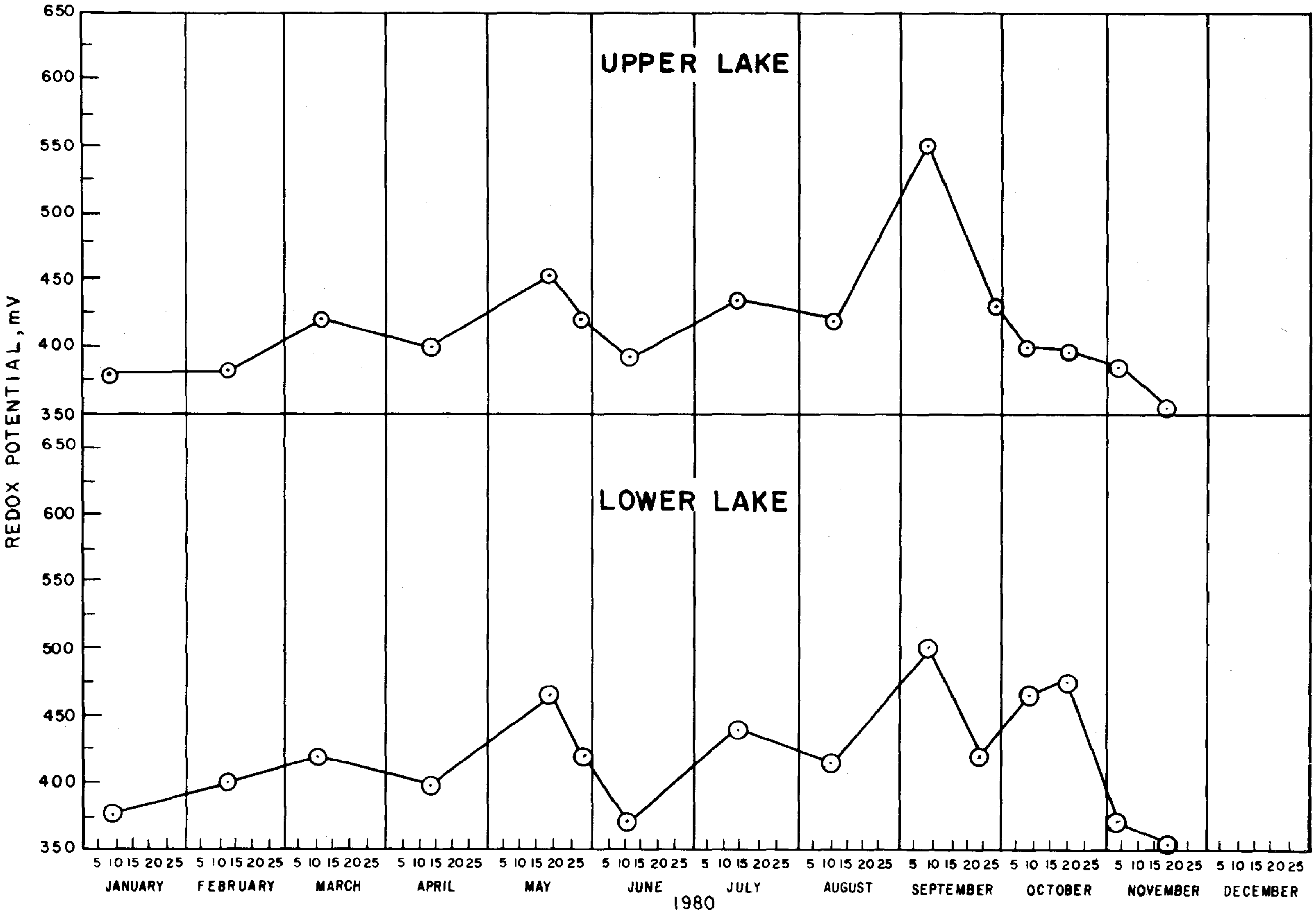


Figure 15.—Bottom oxidation-reduction potential of Twin Lakes during 1980.

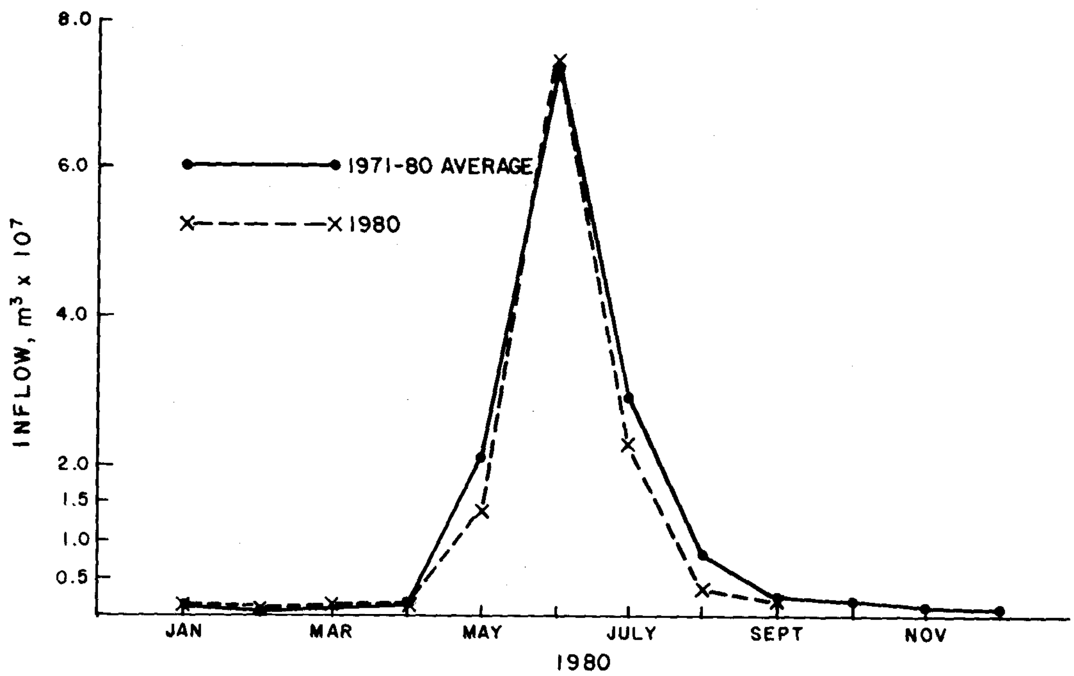


Figure 16.—Monthly inflow volume to Twin Lakes by way of Lake Creek.

and magnitude of this runoff pattern heavily influence the ecology of Twin Lakes and, therefore, reference to inflow patterns will often be made in this report.

Light Extinction Coefficients

Figure 17 shows light extinction coefficients for 1980 (dashed line), and the average coefficients for 1974-79 (solid line). The value of the light extinction coefficient (η) is inversely proportional to the clarity of the water, so the minimum values indicate clearer conditions while the maximum values reflect more turbid conditions. As with inflow data, the pattern for both lakes was generally typical during 1980; however, there were some minor variations from the normal. Some exceptions were that the lower lake was somewhat more turbid during the winter (ice-on) season than normal and was somewhat less turbid during the ice-free season. Although these differences are not significant, some speculative explanations for them are presented. The greater light extinction coefficients in early 1980 (or reduced water clarity) are due to a heavier snow cover during winter and the increased concentrations of phytoplankton that occur in late summer. Both of these conditions occurred in 1980. The somewhat greater clarity of the lower lake during the ice-free season may be due to a combination of a more sudden peaking of runoff in June and a greater degree of stratification, which resulted in an increase of layering of plankton near the bottom of the thermocline. However, the main point is that the pattern was similar to that normally found at Twin Lakes.

The bottom graph on figure 17 for the upper lake shows a much different pattern than the lower lake. First, it must be noted that the 1980 data and the 1974-79 average data are fairly close except for July and August. This difference is reflected in the runoff data (fig. 16) where the volume of runoff was lower than normal in July and August. Decreased runoff results in decreased turbidity. The main effect of the annual runoff pattern on turbidity is twofold. First, the upper lake acts as a settling basin, especially during high or average runoff years, allowing greater nutrient input but less sediment loading to the lower lake. Typically, this results in greater production in the lower lake. Second, the upper lake, especially during high or average runoff years, tends to be severely flushed of its plankton population. The increased turbidity, at least for a time, may limit biological production. Thus, there is a good association

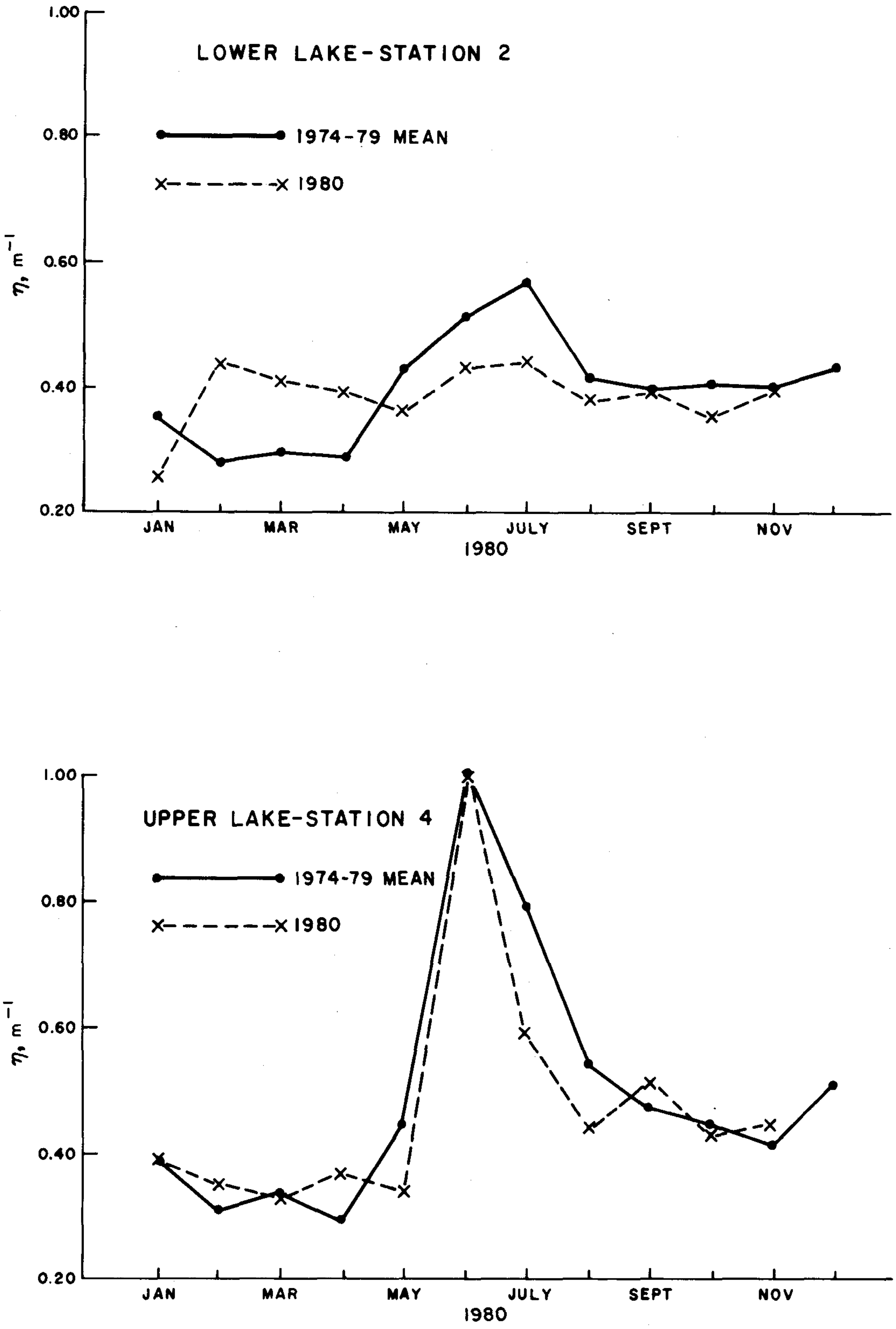


Figure 17.—Light extinction coefficients for Twin Lakes.

involving the volume of runoff, light extinction coefficient, and aquatic production in Twin Lakes.

Water Chemistry

Waters of Twin Lakes and its tributaries can be characterized as calcium bicarbonate and/or calcium sulfate water. Sartoris et al., (1977) [10], discuss in greater detail the anions and cations in Twin Lakes. Generally, the waters in Twin Lakes can be referred to as extremely soft. Table 2 shows the 1980 maximum and minimum water chemistry data for Twin Lakes and Lake Creek. Figures 18 through 30 graphically show some of the chemical trends.

Figure 18 presents data on TDS (total dissolved solids) in water samples collected during 1980 from both lakes and the inflow and outflow of Lake Creek. These data are arranged chronologically from left to right, and upstream to downstream from top to bottom. The TDS ranged from 24 to 130 mg/L. Two major trends in the data are notable. First, during the peak inflow period (June-August), the TDS concentrations were lowest. Conversely, when flows were lowest (fall and winter), TDS concentrations were highest. The second notable trend is that TDS concentrations generally decrease downstream, indicating that solids settle out in the lakes. Likens (1975) [25] categorizes lakes with total inorganic solids concentrations between 10 and 200 mg/L as oligomesotrophic. Twin Lakes has always been in the lower or middle range of these limits.

Field measurements of alkalinity were averaged for each collection date and plotted on figure 19. These alkalinity values are for the bicarbonate

Table 2. — *Minimum and maximum water chemistry values for Twin Lakes and Lake Creek during 1980*

Element	Lake Creek inflow		Twin Lakes: Upper Lake		Twin Lakes: Lower Lake		Lake Creek outflow	
	max.	min.	max.	min.	max.	min.	max.	min.
	(mg/L)							
Total dissolved solids	130	34	76	24	64	32	104	24
Calcium	18.4	9.6	9.6	7.2	10.4	9.6	11.2	10.4
Magnesium	2.44	2.44	1.46	0.98	3.05	0.98	1.46	0.49
Sodium	2.30	0.69	0.92	0.69	1.15	0.69	1.38	0.69
Potassium	1.17	0.78	1.17	0.39	1.17	0.39	1.17	0.78
Carbonate	0	0	0	0	0	0	0	0
Bicarbonate	29.3	22.6	21.3	20.1	25.0	22.6	24.4	22.6
Sulfate	34.1	16.3	13.0	8.16	13.9	11.0	13.0	16.8
Chloride	0.72	0	0.71	0.71	4.97	0.71	0.71	0
Iron	3.540	ND[1]	1.220	ND	0.186	ND	1.340	ND
Lead	0.006	ND	0.002	ND	0.006	ND	0.001	ND
Copper	0.031	ND	0.011	ND	0.014	ND	0.007	ND
Manganese	0.053	ND	0.610	ND	0.320	ND	0.020	ND
Zinc	0.020	ND	0.010	ND	0.020	ND	0.010	ND
Orthophosphate P	0.003	ND	0.005	ND	0.006	ND	0.004	ND
Total P	0.030	ND	0.030	ND	0.045	ND	0.045	ND
Total Kjeldahl N	0.180	ND	0.240	0.070	0.367	0.060	0.150	ND
Nitrite N	0.004	ND	0.002	ND	0.003	ND	0.005	ND
Nitrate N	0.180	0.045	0.074	0.021	0.102	ND	0.040	ND
Ammonia N	0.09	ND	0.05	ND	0.06	ND	0.05	ND

[1] ND = not detectable.

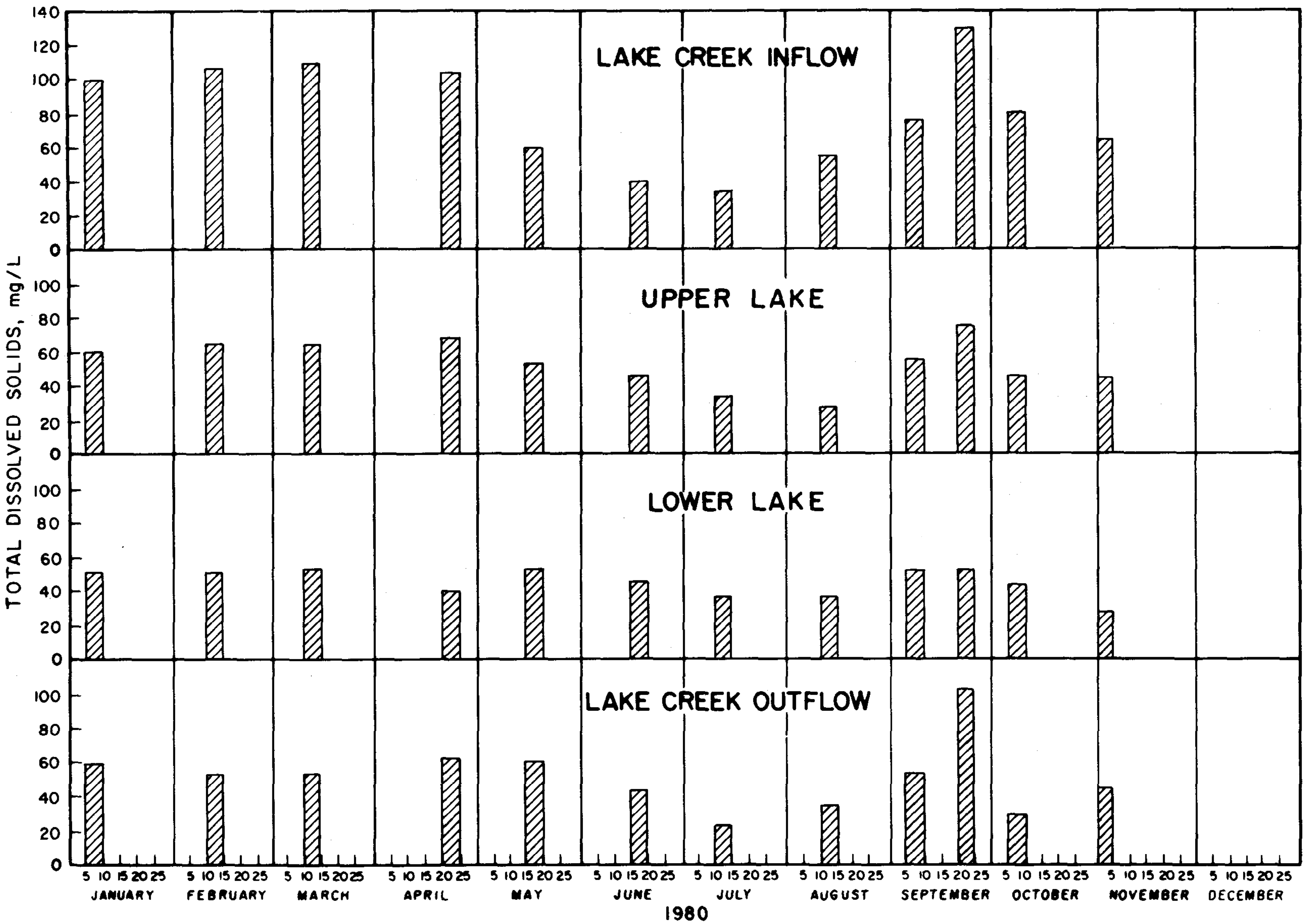


Figure 18.—Total dissolved solid concentrations for Twin Lakes and Lake Creek inflow and outflow during 1980.

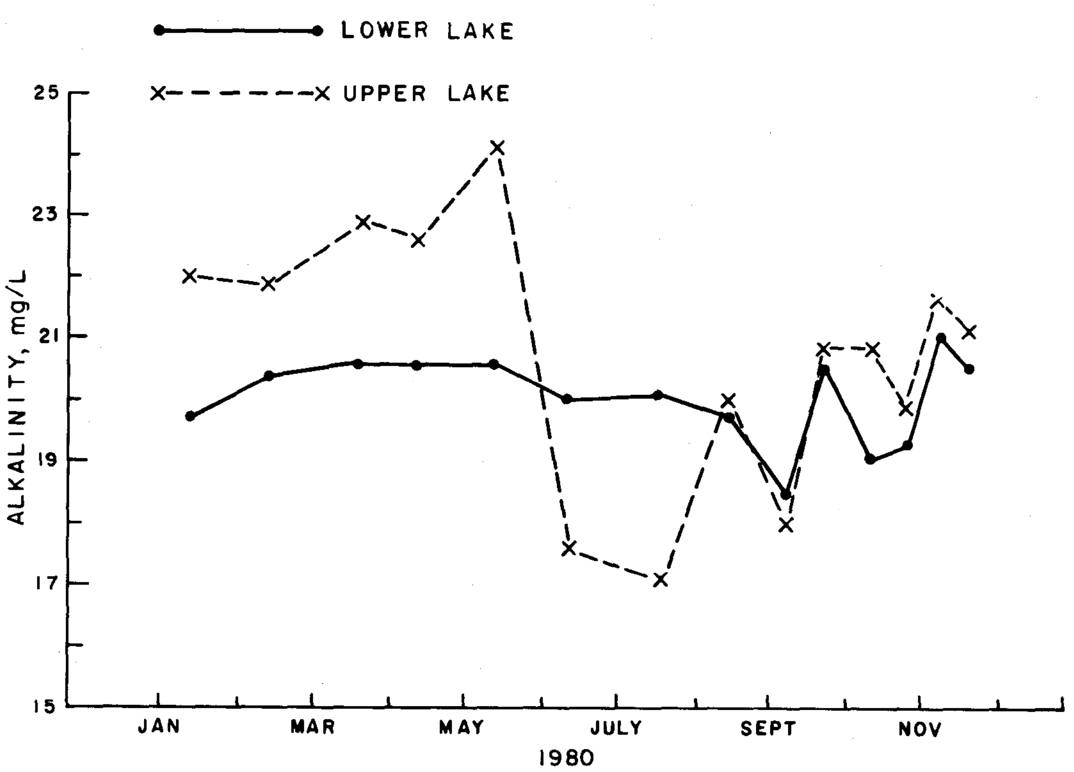


Figure 19.—Bicarbonate alkalinity for Twin Lakes during 1980.

(HCO_3^-) form because the field pH measurements were always lower than 8.3, the point above which the carbonate form begins to exist. The range of bicarbonate alkalinity values for the upper lake was 17 to 24 mg/L. Alkalinity was highest in this lake during the low runoff periods and lowest during high runoff. The high alkalinity values correspond with times when the TDS concentrations were also high (fig. 18). This relationship does not hold for data from the lower lake, which indicates a chemical shift in the lower lake or the influence of the upper lake as a settling basin. Alkalinity concentrations in the lower lake tend to remain relatively constant between 19 and 21 mg/L. Alkalinity of Twin Lakes water is always quite low, about half the average concentration for the world's rivers and lakes (Livingstone, 1963 [26]).

Observed concentrations of five trace metals (iron, manganese, lead, zinc, and copper) in Twin Lakes water are plotted on figures 20 through 24. The data are arranged chronologically from left to right, and from upstream at top to downstream at bottom. The lakes are located in the mineralized belt that runs through Colorado, and are heavily influenced by a heavy metals input by way of Lake Creek. This influence and the ecological implications on the input of heavy metals are discussed in detail elsewhere (Sartoris et al., 1977 [10]). Large amounts of heavy metals are brought into Twin Lakes during runoff, the major source of this input is from the South Fork of Lake Creek. Apparently, the metals come from natural sources found above an elevation of 3600 meters. This is not to say that human influence in the area, such as mining activities, roadbuilding, and forest harvesting, has not been a factor, especially by increasing erosion in the Lake Creek watershed. These metals, which include large concentrations of iron, enter the lakes mostly in the particulate state. Settling then occurs, resulting in a large buildup of heavy metals in the sediments. Bergersen (1976) [6] presented an analysis of metals at various depths in the sediments of Twin Lakes. During times when stratification and oxygen depletion occur in the hypolimnion of either lake, metals can be converted to their ionic forms. Metals in their ionic form can be toxic to aquatic life in very low concentrations. This phenomenon occurred during late winter 1975, and the lower end of the food chain was reduced significantly. The food chain took almost 3 years

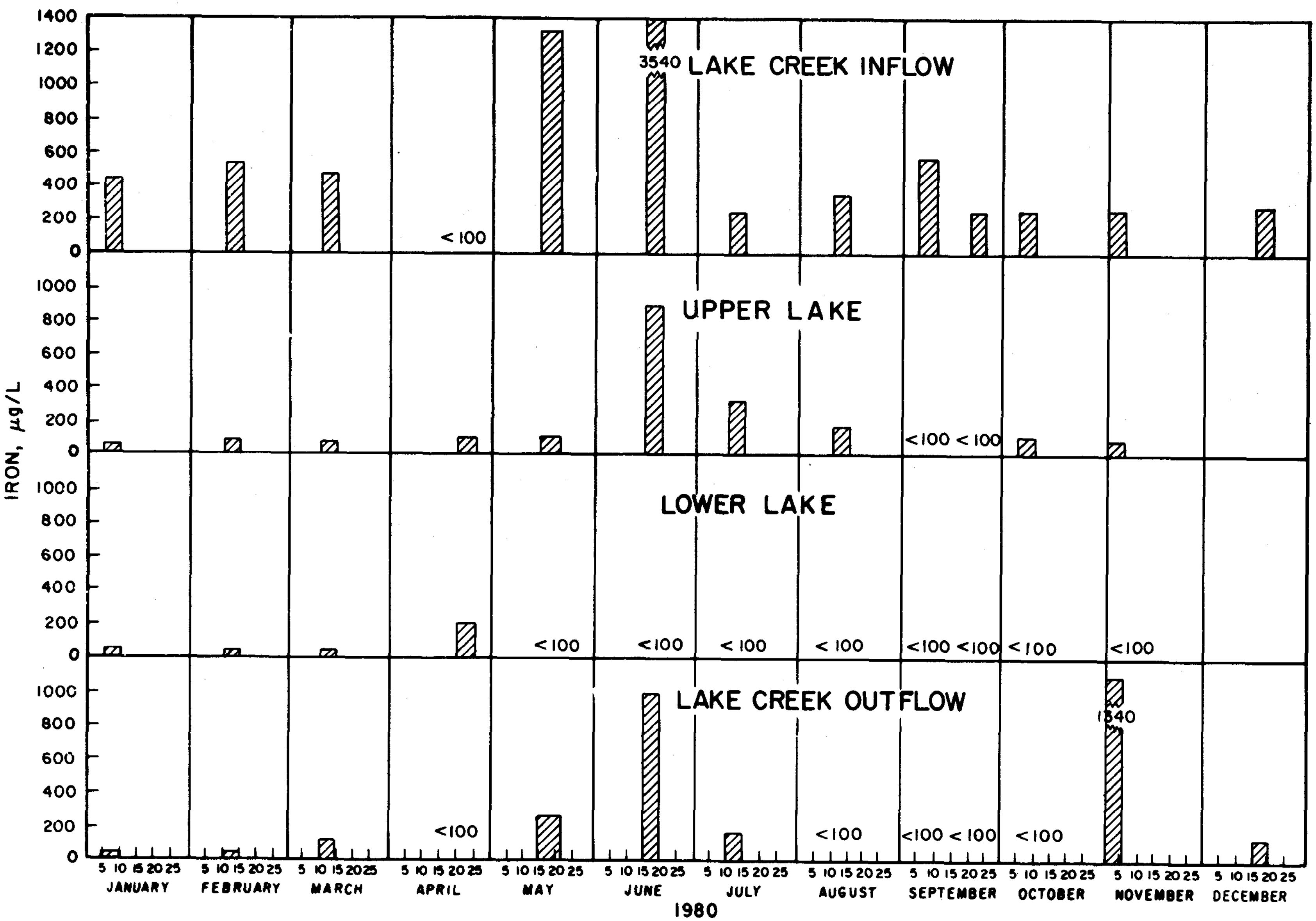


Figure 20.—Iron concentrations for Twin Lakes and Lake Creek inflow and outflow during 1980.

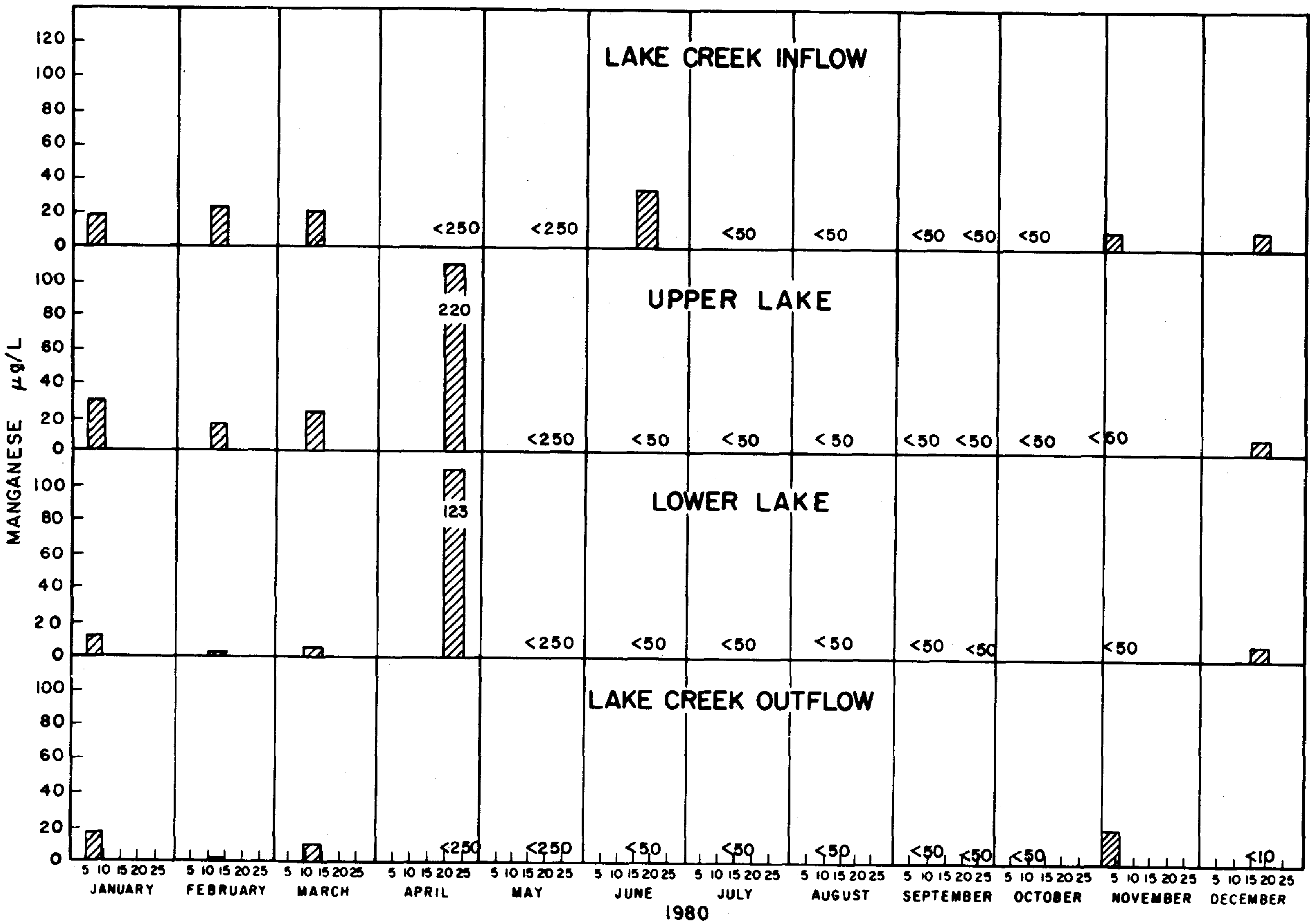


Figure 21.—Manganese concentrations for Twin Lakes and Lake Creek inflow and outflow during 1980.

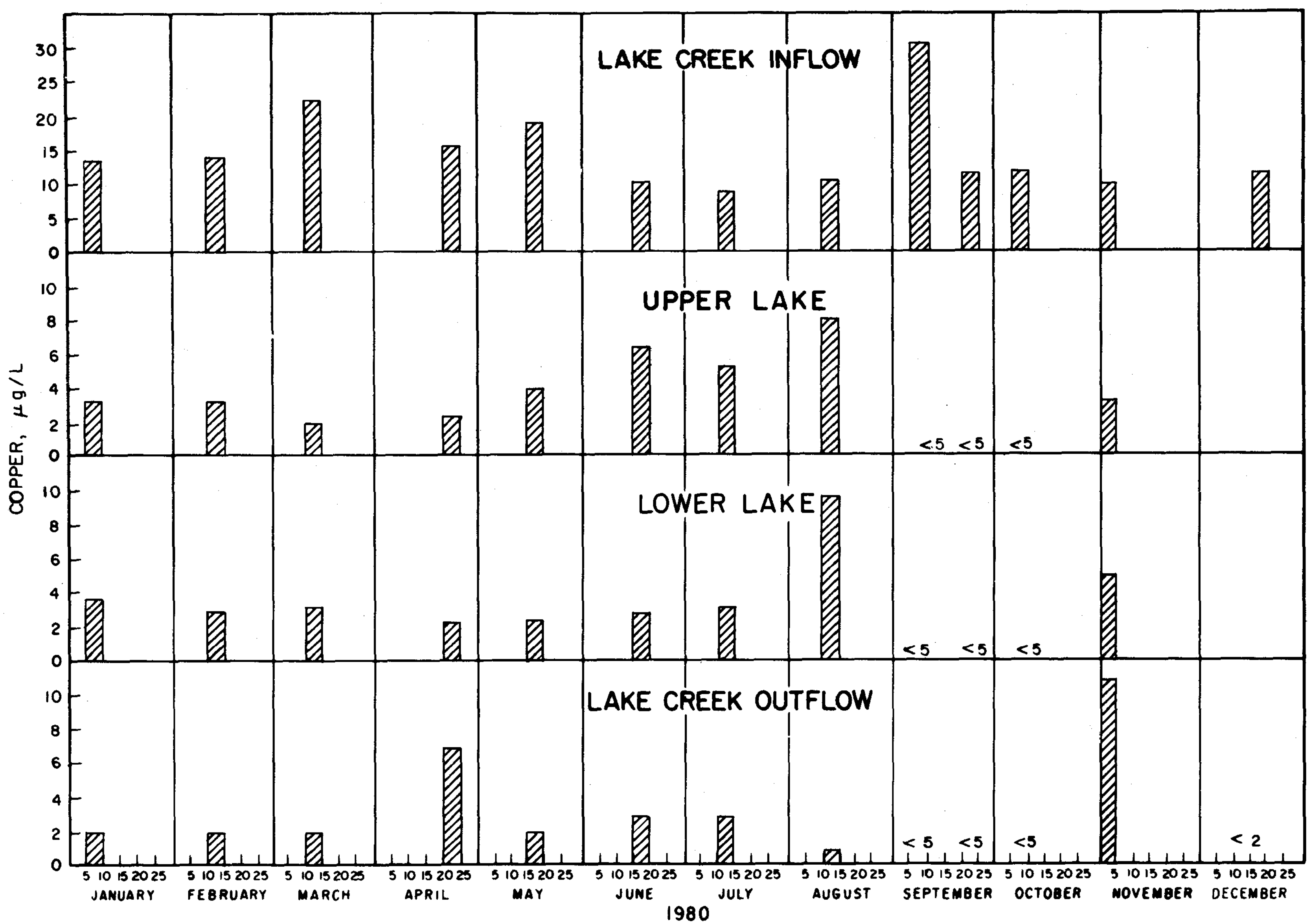


Figure 22.—Copper concentrations for Twin Lakes and Lake Creek inflow and outflow during 1980.

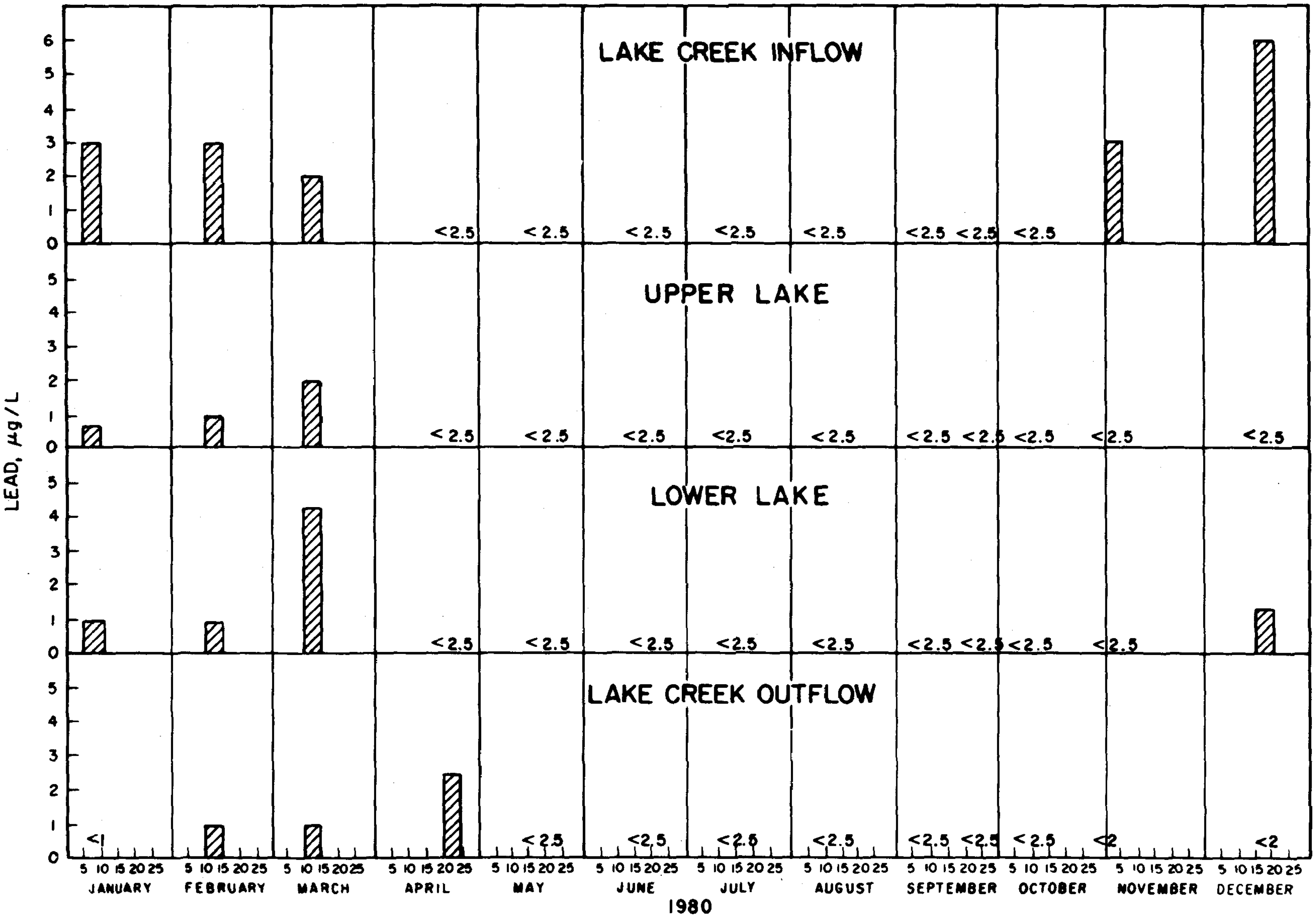


Figure 23.—Lead concentrations for Twin Lakes and Lake Creek inflow and outflow during 1980.

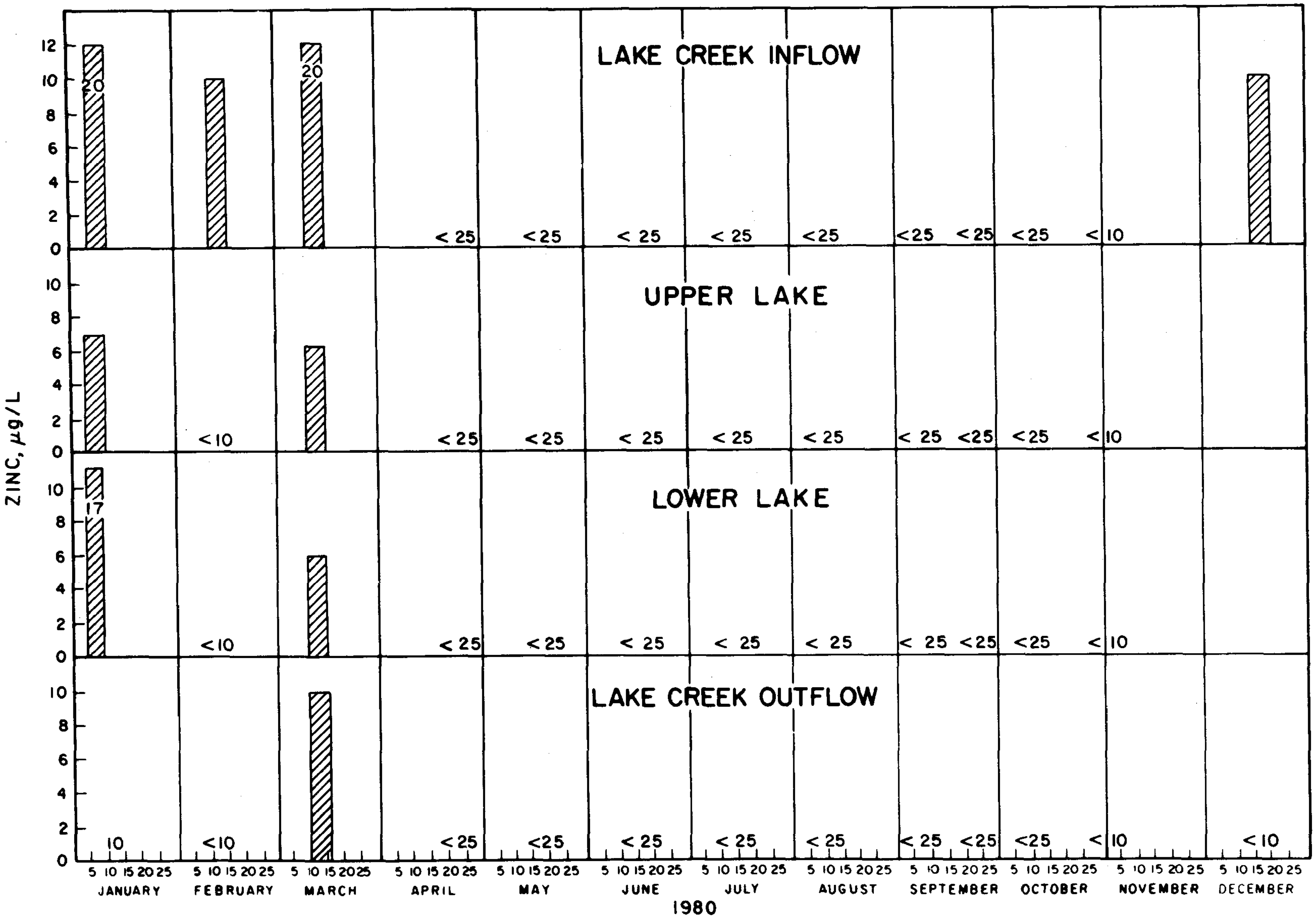


Figure 24.—Zinc concentrations for Twin Lakes and Lake Creek inflow and outflow during 1980.

to fully recover to previous levels. No indication of this phenomenon has been observed since; however, if certain conditions were present, it could happen again. The presence of relatively high concentrations of metals and relatively low concentrations of TDS could result in a poisoning of the biota within the hypolimnion of the lakes if anoxic conditions occur in the future. This condition is very natural and probably has occurred many times in the past; however, certain changes in the aquatic ecology of the lakes, such as an increase in eutrophication, could result in an increase in the frequency of this phenomenon due to decomposition of organic material.

Two important aspects of the data plotted on figures 20 through 24 are: (1) iron concentrations were greatest in the inflow, especially just prior to peak runoff; however, in five of the nine months from March through November, concentrations in the outflow were greater than they were in the lower lake due to construction activities of the new Twin Lakes Dam; and (2) copper concentrations were greatest in the inflow and increased in the lakes when they were stratified for a time, such as in April and August. Since the analytical detection limits for metals changed frequently (4 times for manganese) and radically (1 to 250 mg/L for manganese), little else can be said about these data.

Figures 25 through 30 are bar graphs of some of the nitrogen, phosphorus, and silica nutrients data collected from Twin Lakes during 1980. The same chronological, upstream to downstream, arrangement of data previously mentioned is also used on these figures. Figure 25 is for TKN (total Kjeldahl nitrogen). Generally, concentrations of this chemical element were greater in the lakes than in the inflow or outflow, reaching a maximum of 367 mg/L in the lower lake during February. LaBounty et al., (1980) [16] reported the average TKN concentrations during 1979 as 106 mg/L in the lakes and 96 mg/L for the inflow. Average concentrations for 1980 were 135 mg/L in the lakes and 65 mg/L for the inflow. The average concentration for the outflow was 78 mg/L. The estimated mass of TKN imported to Twin Lakes during 1980 was 8.2×10^6 kg while 9.9×10^6 kg was exported. Data in figure 26 indicate clearly that nitrate-nitrogen concentrations in the inflow were significantly greater than in either lake or in the outflow. Also notable is the fact that nitrate concentrations decreased progressively downstream. The estimated mass of nitrate-nitrogen imported to Twin Lakes by way of Lake Creek during 1980 was 15.5×10^6 kg. The total amount exported was 1.8×10^6 kg, or a net decrease of 13.7×10^6 kg. The TKN data indicate the fate of this unexported nitrogen. The average TKN, or organic plus ammonia nitrogen, increased from 65 to 135 μg/L from inflow to Twin Lakes. The inorganic nitrate that is used in primary production remains tied up in biomass, which is reflected in the TKN data. The final fate of this nitrogen is in the fish. They may be caught and removed from the lake, or they may die and, along with much of the other biota, end up in the sediments. This same kind of transformation of various components of the nitrogen budget is described by Ashton (1981) [27] for an impoundment in South Africa.

The ammonia-nitrogen component of the nitrogen budget for Twin Lakes is shown on figure 27. Data on this figure indicate ammonia to be most abundant in late spring and late fall when the lakes are turning over. Most of the ammonia-nitrogen, one end product of decomposition of organic matter, is generated by heterotrophic bacteria at the sediment-water interface. At the same time, many generations of the bacteria are completed by turnover. Thus, higher levels of ammonia-nitrogen would be expected at these times and complete mixing of the lakes would distribute it throughout the water column.

Figures 28 and 29 contain data on the orthophosphate-phosphorus and total phosphorus concentrations of water samples collected from Twin Lakes during 1980. As in previous years, phosphorus continues to be extremely limiting. Concentrations of either orthophosphate or total phosphorus were always less than 5 μg/L during 1980, with the greatest concentrations occurring after spring turnover. According to the classification of lakes based on total phosphorus concentrations presented by Likens (1975) [25], Twin Lakes is an ultraoligotrophic lake. However, orthophosphate-phosphorus concentrations during 1980 were detectable (>1 μg/L) much more frequently than during 1979, 42 percent of the time as compared to less than 1 percent in 1979. Conversely, total phosphorus was detectable only half as often during 1980 (15 percent of the time) as it was during 1979 (30 percent). The cause and significance of these observations are

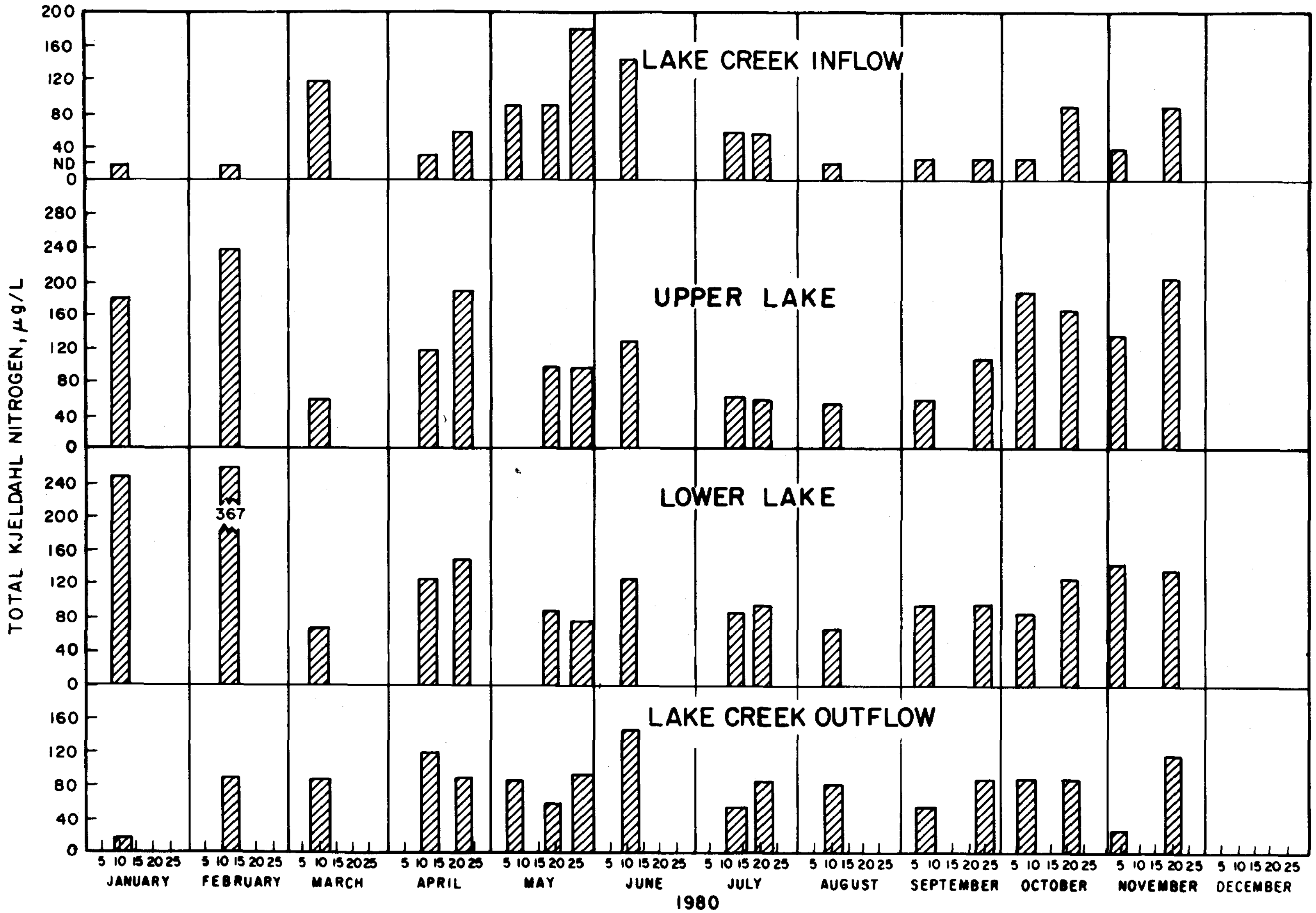


Figure 25.—Total Kjeldahl nitrogen concentrations for Twin Lakes and Lake Creek inflow and outflow during 1980.

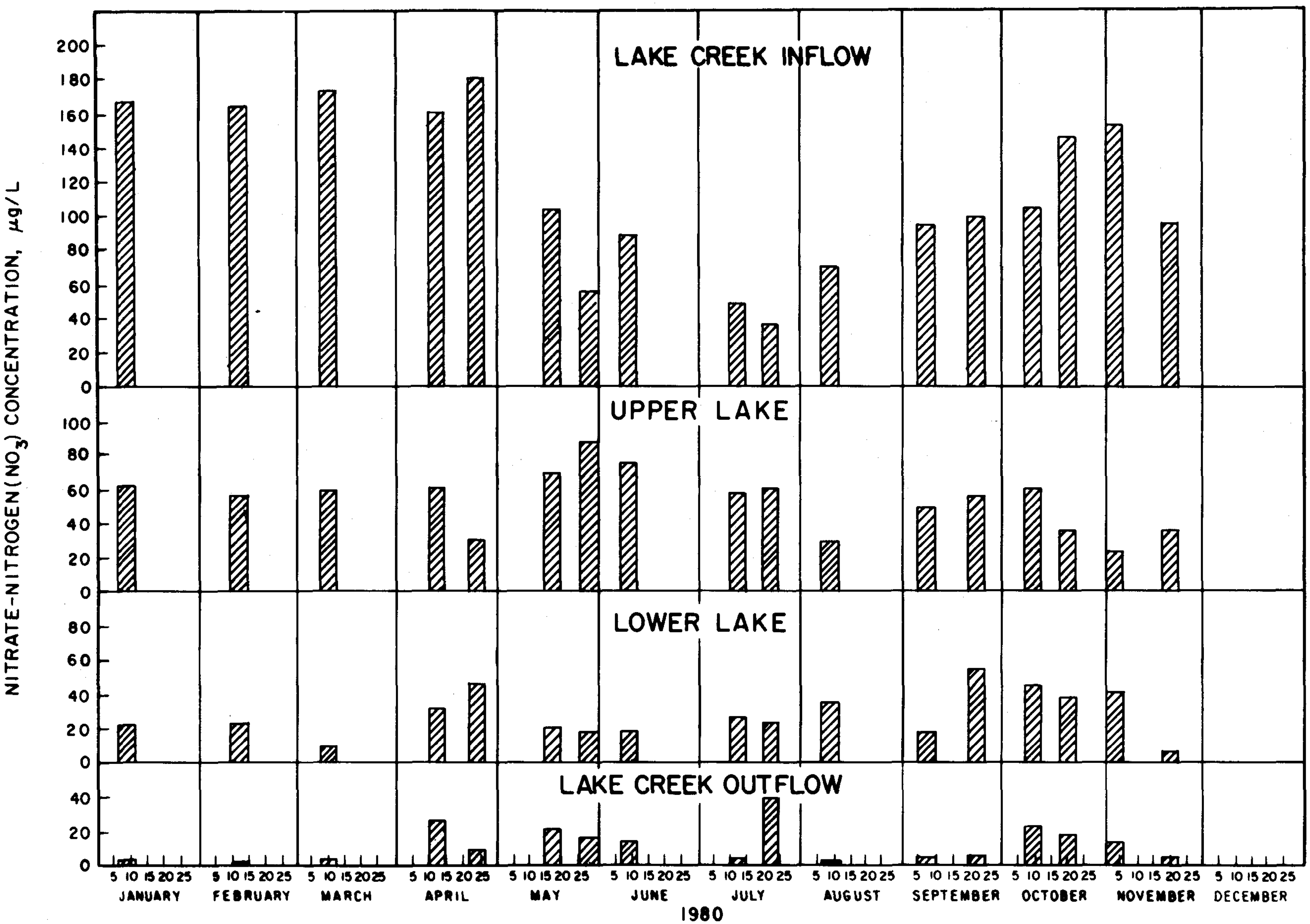


Figure 26.—Nitrate-nitrogen concentrations for Twin Lakes and Lake Creek inflow and outflow during 1980.

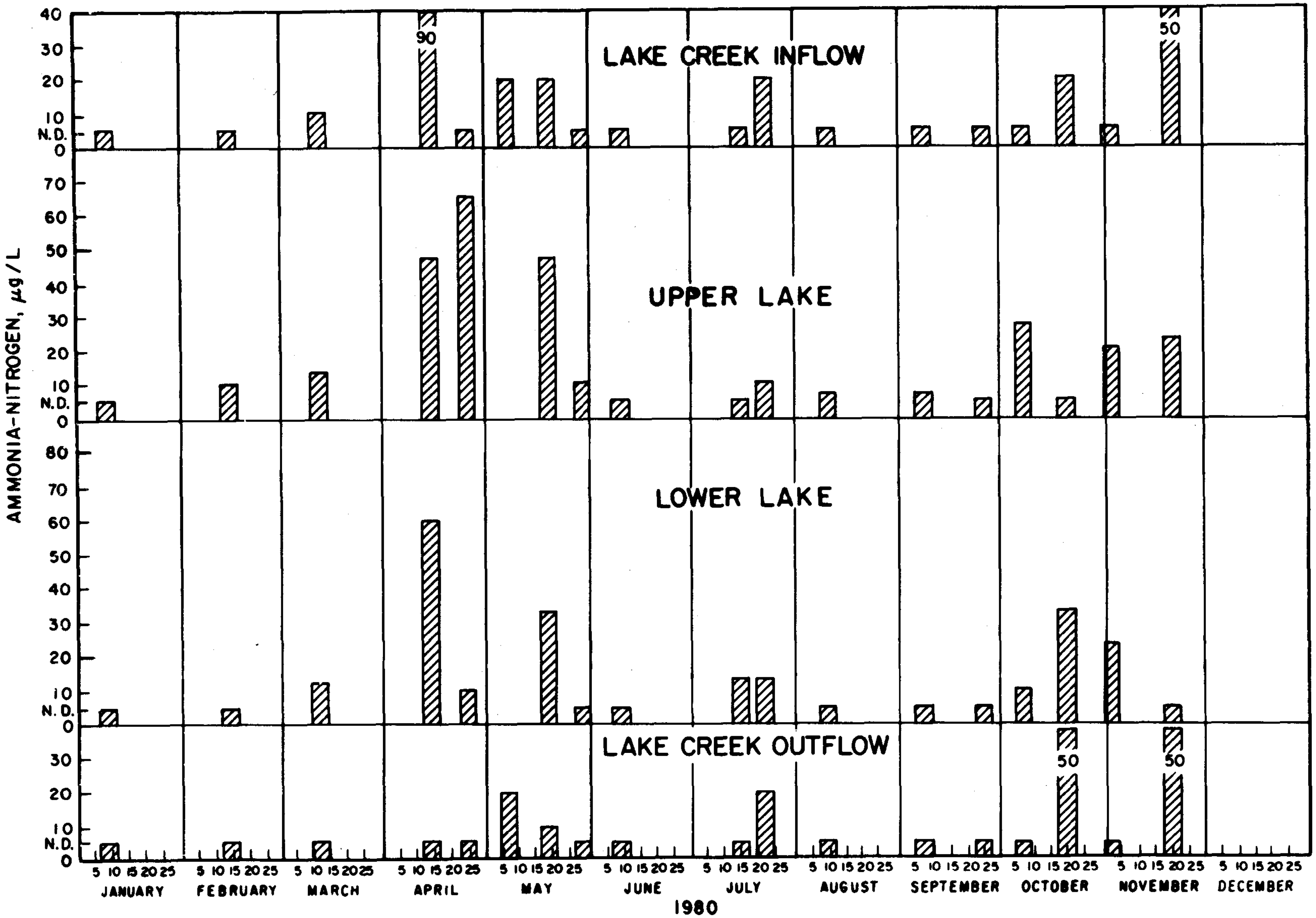


Figure 27.—Ammonia-nitrogen concentrations for Twin Lakes and Lake Creek inflow and outflow during 1980.

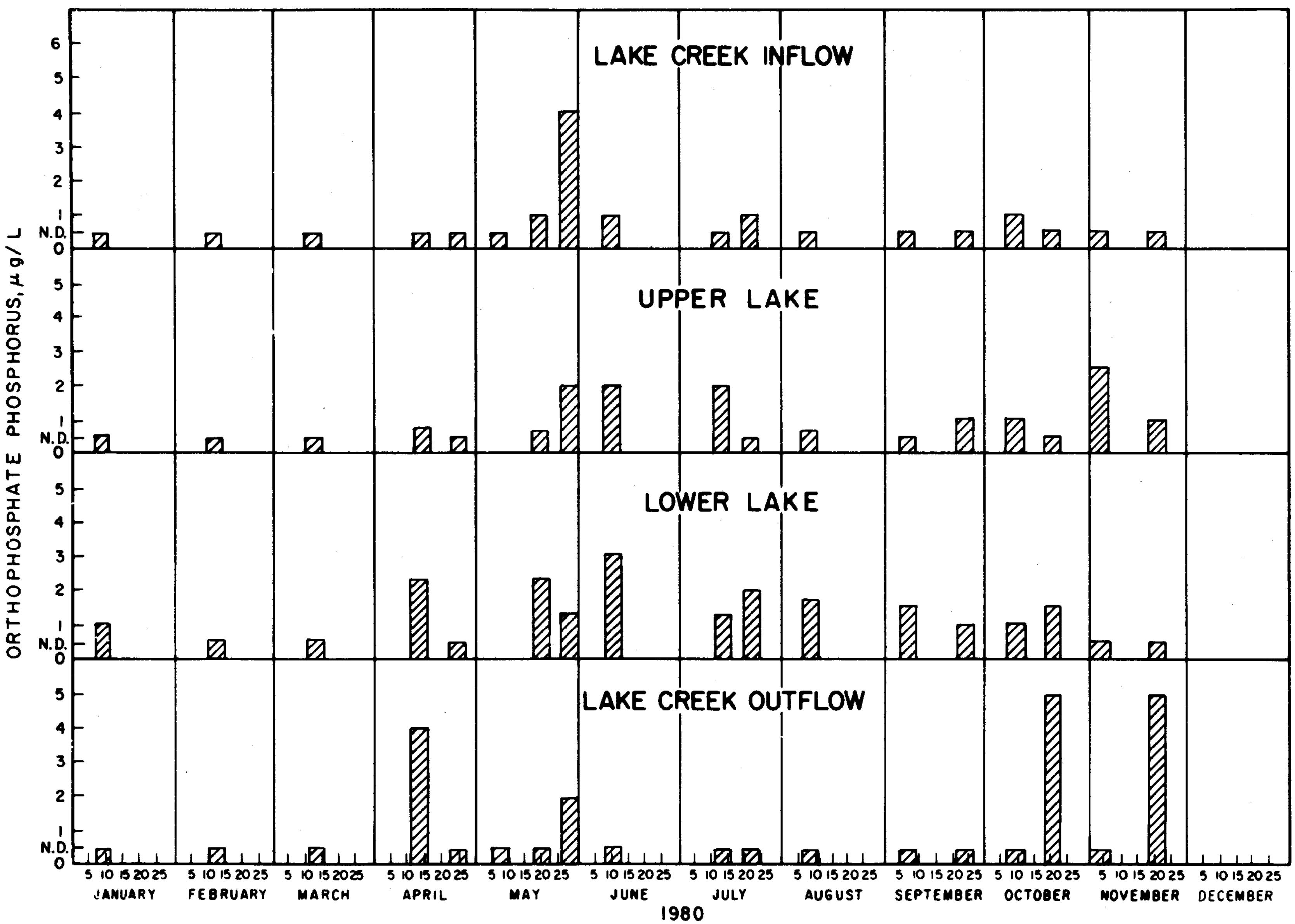


Figure 28.—Orthophosphate-phosphorus concentrations for Twin Lakes and Lake Creek inflow and outflow during 1980.

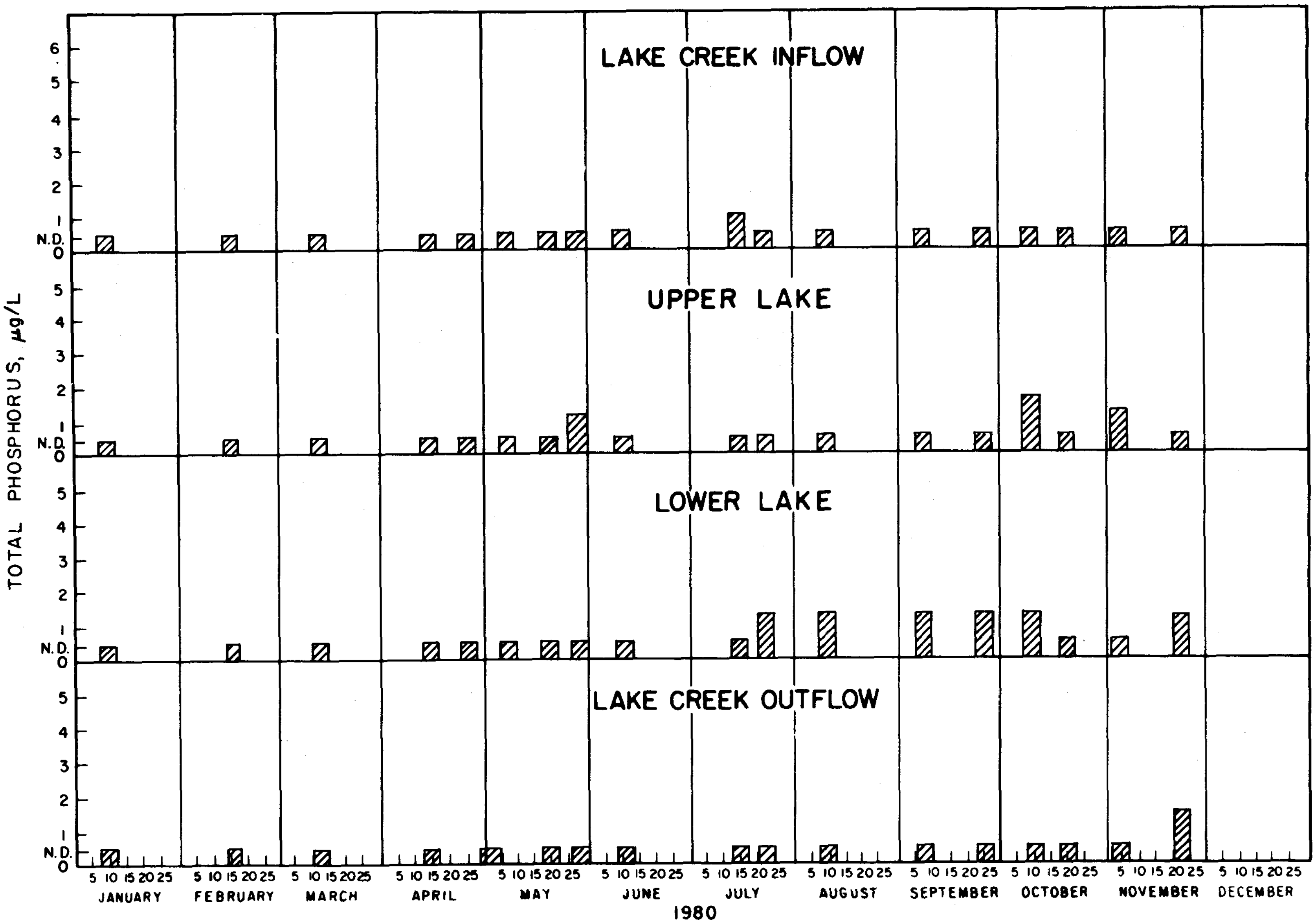


Figure 29.—Total phosphorus concentrations for Twin Lakes and Lake Creek inflow and outflow during 1980.

not totally clear; however, as discussed later in this report, there was a shift in dominant species of phytoplankton during 1980.

Figure 30 shows silica concentrations ranging between 4.1 and 6.7 mg/L in water samples collected during 1980. Occurrences of maximum and minimum concentrations were similar to those of the total dissolved solids. However, the silica content has been found to be less variable than other inorganic constituents (Wetzel, 1975 [28]). Cole (1979) [29] noted that concentrations of silica commonly range between 2 and 25 mg/L in rivers and lakes, and Livingstone (1963) [26] showed 13 mg/L for the world's freshwater average. While the range of 4.5 to 6.7 mg/L of silica found in Twin Lakes may seem somewhat low, there is still sufficient silica to not limit phytoplankton growth. Further evidence for this is the fact that silica concentrations do not fluctuate during the most productive period of the year. If silica were in fact limiting, concentrations at Twin Lakes should drop to less than 1 mg/L during the most productive times of the year. This phenomenon is found to occur often in more eutrophic habitats, as silica depletion has been reported to reflect eutrophication in some lakes (Schelske, 1975 [30]).

Summarizing the physical-chemical data collected during 1980, the lakes continue to be oligotrophic and highly phosphorous limited. Biological data from the several years of this study seem to indicate that temperature, light notwithstanding, is the physical factor which most limits production qualitatively and quantitatively. When light is sufficient and water temperatures near the surface remain above 16 to 17 °C for at least 2 to 3 weeks, many species of phytoplankton normally found in very low numbers in Twin Lakes begin appearing. Likewise, the abundance of other algae increases. This results in an increase in zooplankton, especially rotifers. This subject is discussed in more detail in the next section.

Biological Parameters

Primary Productivity. — Primary productivity determination using the ^{14}C technique is a method for measuring the instantaneous rate at which algae are fixing carbon in cellular development. This method was used on each of the Twin Lakes 15 different times during 1980. Data from these surveys are plotted on figures 31 and 32. Figure 31 contains the calculated areal production in mg C/(m^2·d) (milligrams of carbon fixed per square meter of lake per day). Per day means the time between sunrise and sunset. The points plotted represent values obtained from the surveys accomplished during each month. The following paragraph is a general description of annual events at Twin Lakes.

Rates of production are generally lower in the upper lake than in the lower lake, and both lakes decrease in production during the winter when they are covered with snow and ice. Production rates are generally highest in the lower lake just after spring or fall turnover, while the rates drop off during midsummer when stratification is strongest and runoff has subsided. Three peaks in productivity data collected from the upper lake are indicative of different events that occurred during 1980. The first peak followed ice-off and spring turnover, which occur 3 to 4 weeks before runoff begins. Data in figure 16 indicate the intensity and abruptness of runoff, which severely depresses primary phytoplankton production. Both flushing and reduced light penetration due to turbidity generally occur for a 3- to 4-week period in late June and early July. The magnitude of these effects is highly dependent on the runoff volume. For example, during 1976 and 1978, runoff was relatively low and early season productivity was not depressed to any significant degree. The second peak in primary productivity data occurred in July after the runoff had subsided, thus allowing increased light penetration to the point where nutrients could be used in production. Low values found during August, corresponding to a similar reduction in the lower lake, indicate that the lakes were stratified and nutrient limited. That is, runoff was low and stratification sealed the autochthonous nutrients in the hypolimnion. The third peak occurred as rates began to increase during the fall as the lakes turned over and nutrients were mixed into the lighted upper zone of the water column. The pattern just described is similar to that observed at Twin Lakes during most years since 1973.

Data plotted in figure 32 show more graphically the seasonality of production, and some other points are illustrated. First, the influence of snow and ice cover is particularly obvious. Not only does ice cover decrease the dispersal of plant nutrients in the water column, it also severely limits light penetration. Both are essential for

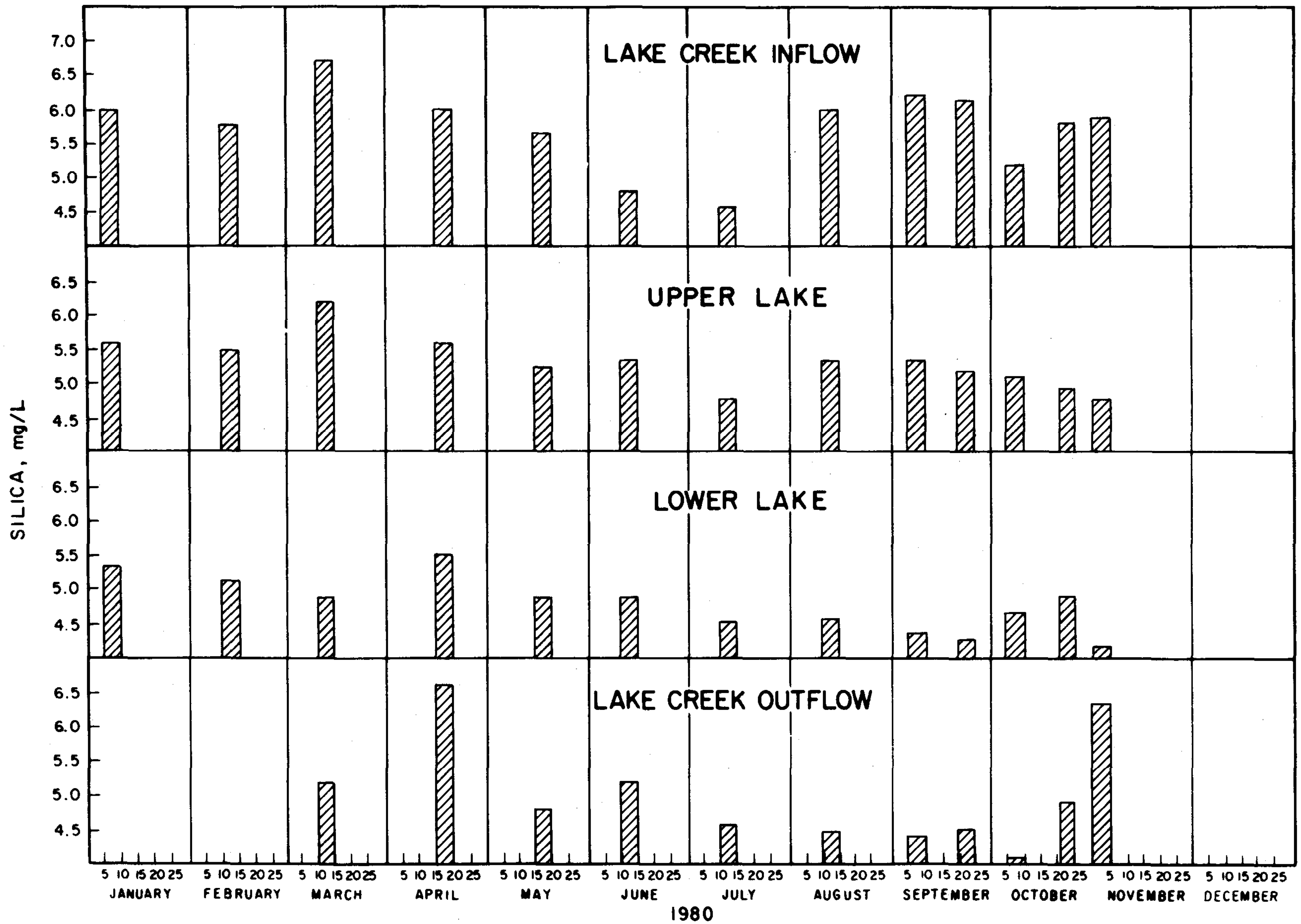


Figure 30.—Silica concentrations for Twin Lakes and Lake Creek inflow and outflow during 1980.

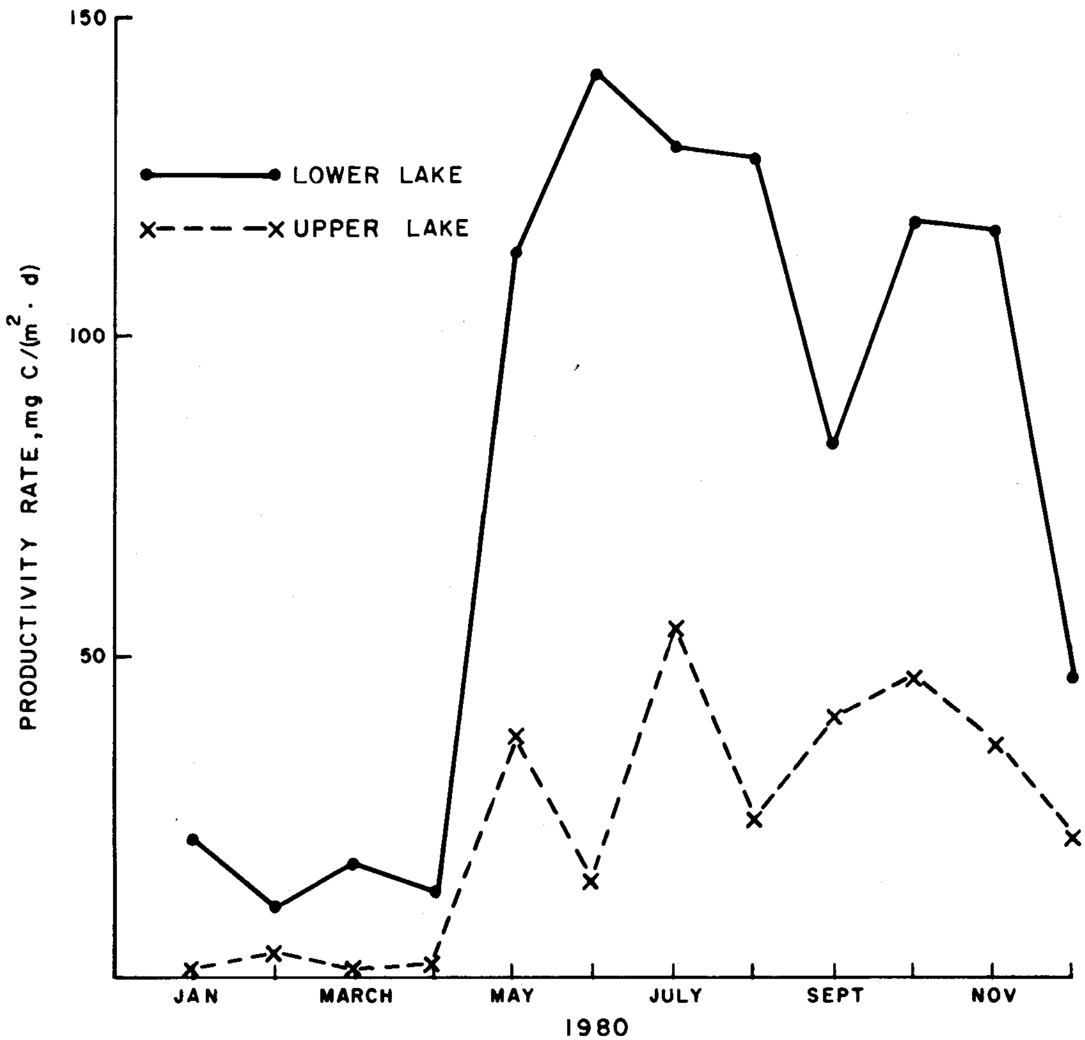


Figure 31.—Areal primary productivity rates for Twin Lakes during 1980.

primary production. However, it is suspected that light is the major limiting factor of phytoplankton production during winter, since in past years, when snow cover has been slight or nonexistent, primary productivity under the ice has been substantial. Following ice-off in May 1980, production increased throughout the water column. As stated earlier, silt-laden inflow and its flushing effect limit upper lake productivity until mid-July. On the other hand, since the upper lake acts as a sediment catch basin, the lower lake benefits from a substantial input of nutrients (without turbidity), especially nitrate and phosphorous. This is reflected in the relatively high rates of primary production in the lower lake during May through mid-July. From late July to late September, primary productivity remained relatively low. From mid-September until the day that ice formed on the lakes, primary productivity rates increased. It especially increases during mid-October when fall turnover occurs.

LaBounty et al., (1980), reported that the highest rate of primary production measured at Twin Lakes was 21.7 mg C/($m^2 \cdot h$). This value was obtained on May 19, 1979, only 1 day after ice-off and spring turnover. During most years, the maximum rates are obtained in October and November. The second highest rate measured was 14.4 mg C/($m^2 \cdot h$) on October 5, 1978. The highest rate measured during 1980 was 13.8 mg C/($m^2 \cdot h$) on November 4. Not uncommon to oligotrophic lakes is the phenomenon where the rate of primary production is greatest

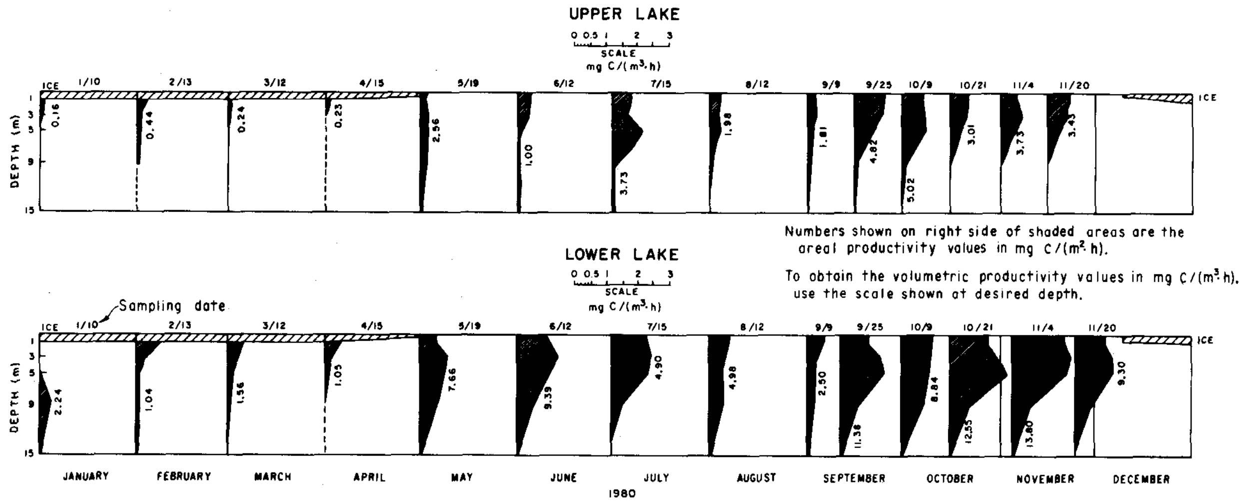


Figure 32.—Profiles of primary productivity rates for Twin Lakes during 1980.

at some depth below the surface. This commonly occurs at Twin Lakes, especially in or near the thermocline. This is due, in part, to light inhibition of photosynthesis at the water surface and the increased availability of nutrients at the top of the thermocline.

Table 3 shows a comparison of primary production rates at Twin Lakes with those from other localities selected from table 14-10 in Wetzel (1975) [28]. The mean daily and annual productivity are displayed along with the observed ranges for each locality. On an annual basis, both of the Twin Lakes fall in the oligotrophic category. The low annual productivity of the upper lake reflects the influence of runoff. The annual values for the lower lake compare favorably with those from other oligotrophic alpine lakes. A publication now in preparation will discuss in more detail primary productivity data collected in Twin Lakes since 1973.

Chlorophyll-a Concentration. — Chlorophyll *a* is an estimate of the phytoplankton biomass. Figure 33 displays the trends for chlorophyll *a* concentrations during 1980. Data in this figure are presented in profile; that is, abundance of chlorophyll *a* is presented from the surface to a

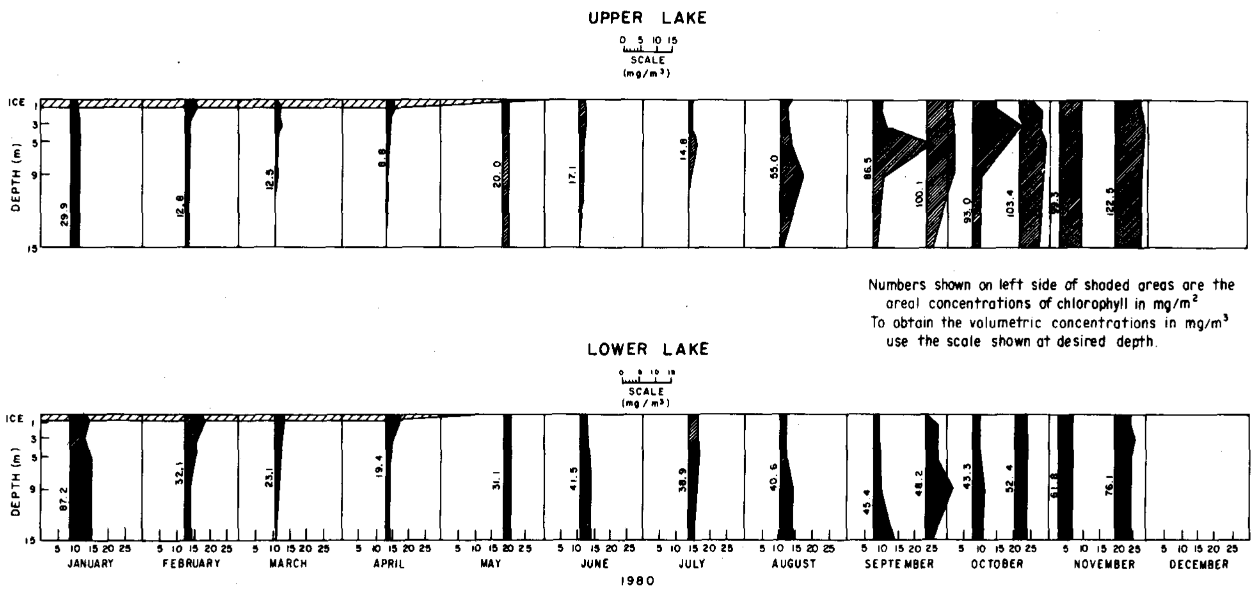


Figure 33.—Profiles of chlorophyll *a* biomass concentrations in Twin Lakes during 1980.

Table 3. — *Comparison of primary production rates for phytoplankton in Twin Lakes with other selected lakes*

Lake	Remarks	Mean daily productivity for entire year, mg C/(m²·d)	Range observed, mg C/(m²·d)	Annual productivity, g C/(m²·yr)
Twin Lakes (upper, N[1] = 13)	1979 — influenced by heavy spring runoff	20	1-65	8
Twin Lakes (upper, N = 15)	1980 — influenced by heavy spring runoff	27	2-60	9
Twin Lakes (lower, N = 13)	1979	86	5-308	30
Twin Lakes (lower, N = 15)	1980	76	11-141	22
Castle (Calif.) [28]	Deep, alpine	98	6-317	36
Lawrence (Mich.) [28]	Small, hard water; 7-year average	112.6	5-497	41.1
Char (Canada) [31][2]	80 percent of total production by benthic flora	1.1	0-35	4.1
Meretta (Canada) [31][2]	Polluted by sewage	3.1	0-170	11
Clear (Calif.) [32][2]	Very large, shallow	438	2-2440	160
Erken (Sweden) [33][2]	Large, deep, naturally productive	285	40-2205	104
Minnetonka (Minn.) [34][2]	Extremely complex basin, large, deep	[3]820		[3]300

[1] N = Number of samples taken.
[2] Data extracted from table 14-10, Wetzel (1975) [28].
[3] Estimated.

depth of 15 m from 14 sampling dates for each lake. Three conclusions are apparent from these data. First, there is a seasonal trend for chlorophyll in both lakes, with low concentrations occurring during late winter through early summer. Maximum values occurred during September-November when the thermocline was sinking, which exposed more and more of the bottom to turnover.

The second conclusion is the effect that thermal stratification has on chlorophyll *a* concentrations. When the lakes are isothermal, April-June and late October-December, the concentrations are nearly equal at all depths. This is due to circulation by turbulence from the inflow, wind action, and clarity of the lake water (later in the season). During periods of stratification, phytoplankton are concentrated somewhere in or around the thermocline, at least during part of the year. Some years, this layer of phytoplankton persists until turnover and actually sinks as the thermocline sinks. In other years, the concentration of phytoplankton somehow mysteriously breaks up, disappears, or disperses. The absence or presence of nutrients needed for phytoplankton reproduction is probably the cause of this phenomenon. In 1980, the pattern of phytoplankton stratification existed near the thermocline for short intervals. Since the life of some of these species of algae may be just a few days, we are probably seeing the constant dying and replacement of the population. The magnitude of this replacement undoubtedly depends on nutrient availability.

The third conclusion is that there were greater concentrations of chlorophyll *a* in the upper lake than in the lower lake during late 1980. However, primary productivity rates and algae cell counts from the upper lake were less. The average concentrations for the upper and lower lakes during 1980 were 3.6 and 3.0 mg/m^3, respectively, or 17 percent higher in the upper lake. The opposite has been true during previous years. For example during 1979, the average values were 1.5 and 3.8 mg/m^3 for the upper and lower lakes, respectively.

Likens (1975) [25] categorized lakes with chlorophyll *a* concentrations between 0.3 and 3.0 mg/m^3 as oligotrophic and those with concentrations between 2 and 15 mg/m^3 as mesotrophic. Based on this classification, both of the Twin Lakes are on the border between oligotrophic and mesotrophic. However, this is only one category. When other categories are considered such as rate of primary production and phosphorous concentration, the Twin Lakes are classified as oligotrophic, or relatively low in production. This is discussed later in this report in more detail.

Plankton Abundance. — Figures 34, 35, and 36 present data on the trends and composition of the phytoplankton and zooplankton populations of Twin Lakes during 1980. Figure 34 shows plots of the average concentrations on each of the 16 sampling dates. Populations in both lakes follow the now familiar abundance pattern of late winter low, midsummer high, a slight late summer drop, and late fall resurgence.

Phytoplankton concentrations ranged between about 1 cell per liter to just under 1000 cells per liter in the upper lake and from 28 to just over 13 000 cells per liter in the lower lake. The 1980 averages were 314 and 2717 cells per liter for the upper and lower lakes, respectively, almost nine times more in the lower lake. During 1979, the average densities were 1000 and 4000 cells per liter for the upper and lower lakes, respectively (LaBounty et al., 1980 [16]), four times greater in the lower lake.

Average zooplankton concentrations (fig. 34) ranged between 1.4 and 65.9 individuals per liter in the upper lake and between 8.6 and 125.8 individuals per liter in the lower lake. Overall concentrations during 1980 were 23 and 46 individuals per liter for the upper and lower lakes, respectively. These values compare to 13 and 47 individuals per liter for the upper and lower lakes, respectively, during 1979 (LaBounty et al., 1980 [16]). Concentrations in the lower lake during 1980 were similar to those in 1979; however, zooplankton were, on the average, almost twice as abundant in the upper lake during 1980 than during 1979.

Species composition of the phytoplankton population during 1980 are displayed in figure 35, when *Synedra* and *Asterionella* dominated both lakes most of the year. *Synedra* was especially abundant in the lower lake during 1980, unlike other years of this study when this species has been far less common. *Synedra* seems to have displaced both *Asterionella,* which has very similar nutrient requirements, and *Dinobryon,* which has an upper tolerance for phosphorus less than that of either *Asterionella* or *Synedra.* This species switch is not easy to explain, especially since Twin Lakes is such a phosphorus-poor system. It is probably the result of many factors, including temperature, which was higher in the epilimnion during 1980 than during other recent years. Temperature seems to be the likely factor because both *Synedra* and *Asterionella* were far more abundant in the upper lake during 1980 than during recent years. At the same time, water temperatures in the epilimnion of the upper lake were much higher. These relatively higher water temperatures in the epilimnia of both lakes seem to have resulted in an increased abundance of several species of phytoplankton other than the three previously mentioned. These include the green algal species *Dictyosphaerium* and *Spherocystis* and the golden-brown species *Mallomonas.* During February, April, and September, these three species made up about 50 percent of the phytoplankton population in the

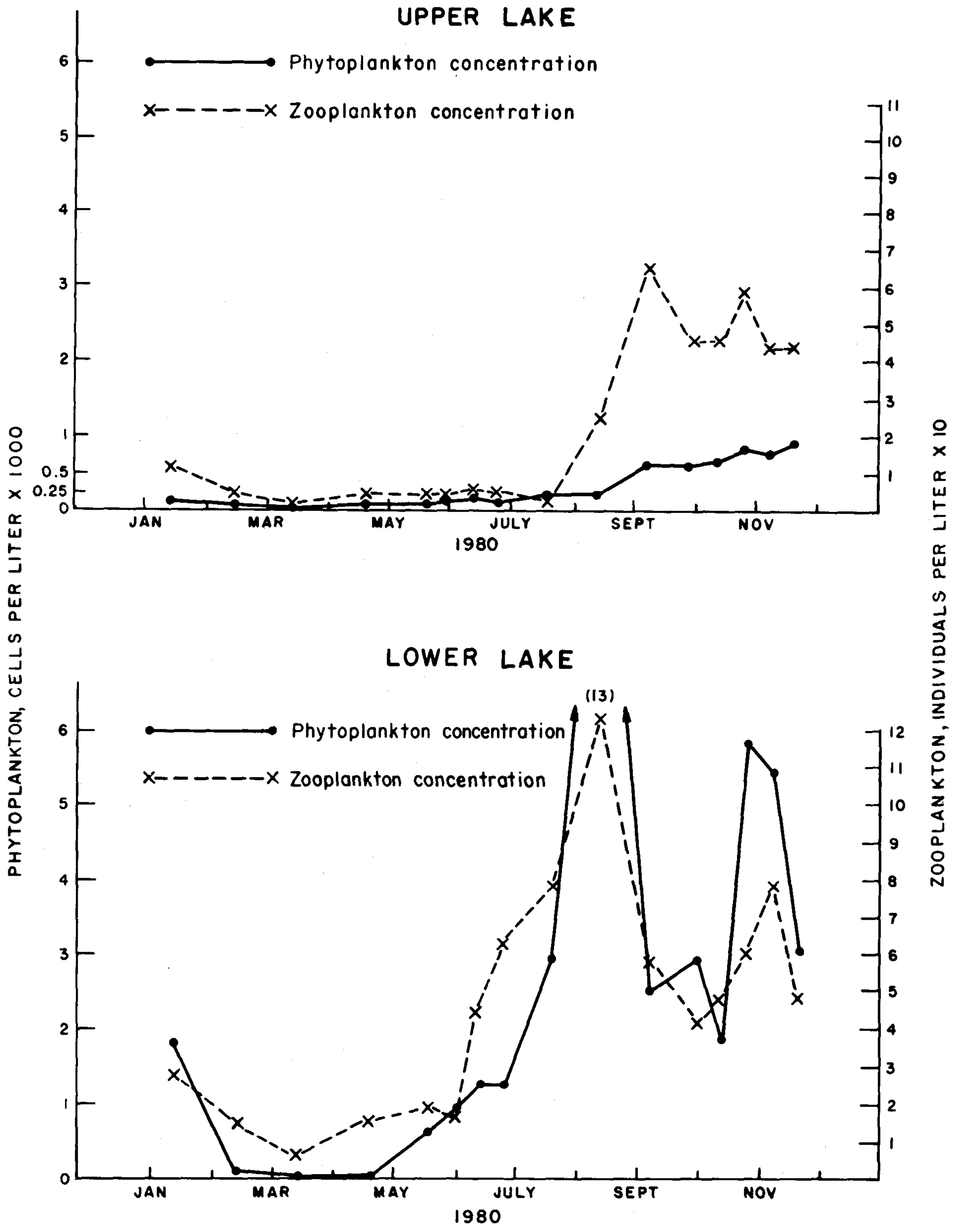


Figure 34.—Average plankton concentrations for Twin Lakes during 1980.

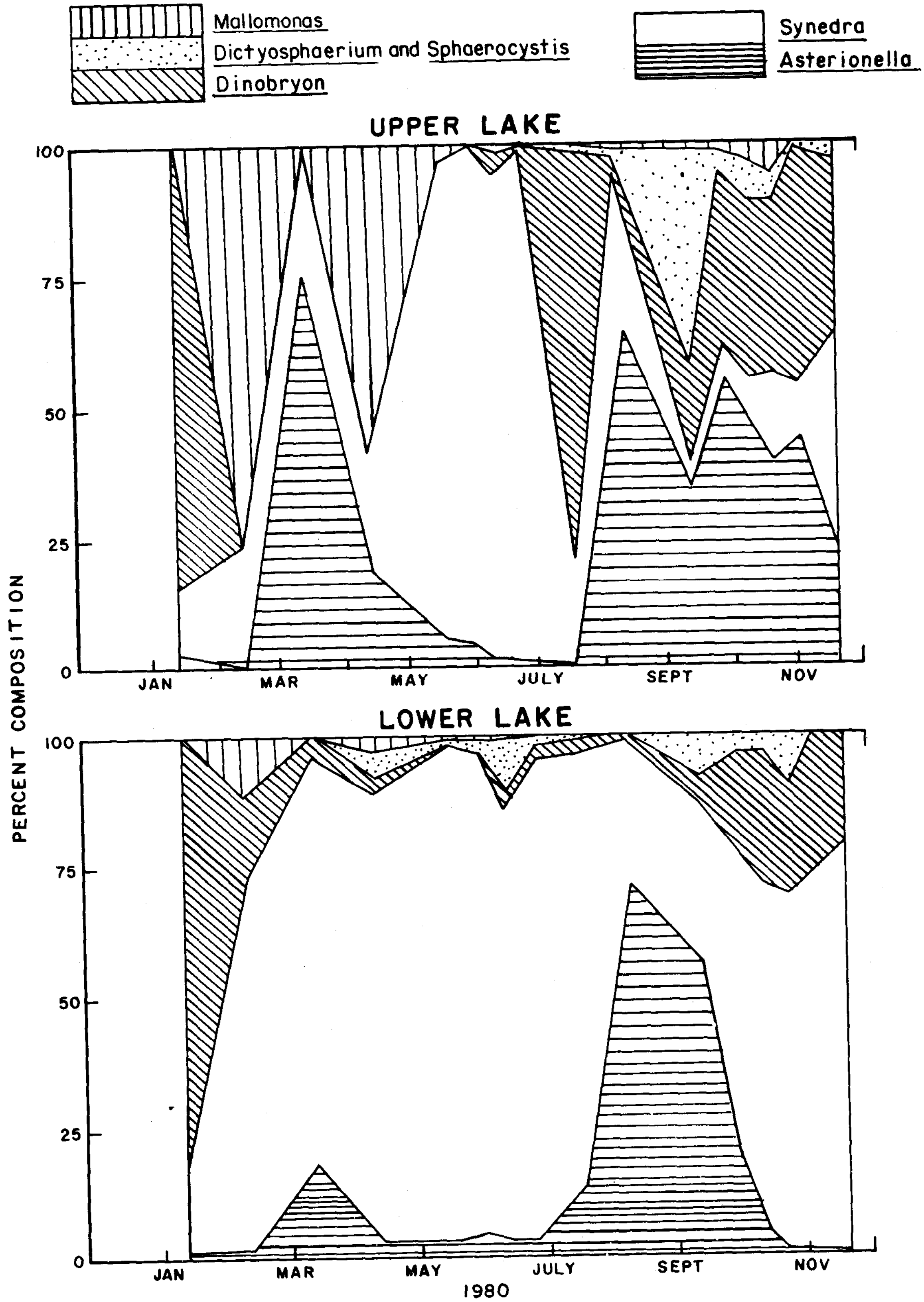


Figure 35.—Species composition of phytoplankton population in Twin Lakes during 1980.

upper lake. The diatom *Tabellaria* was found during late June and into November in both lakes, but not in concentrations large enough to be plotted. The blue-green species, *Oscillatoria,* which has been found in Twin Lakes during previous years in small concentrations, was not detected during 1980. Since its presence indicates enrichment, its absence is a positive indication that Twin Lakes is in normal condition ecologically for a high mountain oligotrophic lake.

As in previous years, the lakes were dominated by *Dinobryon, Asterionella,* and *Synedra,* with the latter two being most abundant during winter to midsummer and *Dinobryon* most abundant from midsummer to early winter. *Dinobryon* was most abundant when phosphorous was most limiting. Wetzel (1975) [28] suggested that *Dinobryon* tolerates phosphorous levels lower than *Asterionella,* and the data from Twin Lakes support this suggestion. However, total and orthophosphate phosphorus are always found in concentrations less than 5 μg/L, which indicate Twin Lakes to be extremely phosphorus-poor. It is difficult to state that any one of these species is favored by a lower concentration of phosphorus than the other since all three are known to both tolerate and have optimum growth in lakes with phosphorus concentrations below 20 μg/L (Hutchinson, 1957 [35]; Wetzel, 1975 [28]; and Cole, 1979 [29]).

Four kinds of zooplankton are commonly found at Twin Lakes: mysis shrimp, cladocerans or water fleas, copepods, and rotifers. Mysis is a nocturnal species and will occur in samples of plankton collected during the night hours in the littoral zone. Mysis are also considered along with the benthos since they dwell on the bottom during the day. Mysids, copepods, and rotifers are by far the most abundant kinds found, with cladocerans occurring only occasionally and in the form of the relatively small-bodied species *Bosmina* sp. Juday (1906) [36] reported that cladocerans, including *Daphnia* spp., made up from 20 to 45 percent of the adult zooplankton population of Twin Lakes during 1902-03. From 1974 through 1979, cladocerans (exclusively *Bosmina)* never made up more than 1 percent of the zooplankton population (LaBounty et al., 1980 [16]). On August 11, 1980, *Bosmina* made up 5 percent of the zooplankton population of the upper lake. On several other occasions, after late July, *Bosmina* made up 1 percent or less of the population of each lake. Mysis shrimp were introduced in 1957. They are extremely predaceous to species of zooplankton that are smaller-bodied than they are. The newly constructed forebay, which is connected to the lower lake, was filled with water for a year during 1978-79. Cladocerans, especially *Daphnia,* were very abundant in this forebay. Cladocerans are also abundant in all reservoirs, lakes and ponds in the vicinity of Twin Lakes where sampling has been done. Therefore, the paucity of cladoceran species in Twin Lakes is presently directly attributable to predation by mysis shrimp. Goldman et al., (1979) [37] described a similar alteration in the zooplankton fauna following the introduction of mysis in Lake Tahoe. Rotifers included predominantly three species: *Kellicotia* sp., *Keratella* sp., and *Polyarthra* sp. However, *Branchionus* sp. and *Asplanchna* sp. were also found later in the year. Rotifers began to dominate the lower lake in June and the upper lake in August (fig. 36). This situation followed the dominance of the zooplankton fauna by copepod nauplii, which occurred from March to July in the lower lake and from May through August in the upper lake. Some species of rotifers (e.g. *Polyarthra)* are reported to feed on copepods (Buikema, Jr., A. L. et al., 1978 [38]). Some rotifers in Twin Lakes could be using copepod nauplii as a food source. If true, this would result in both a "bloom" in the rotifer population and a decline in the copepod population. Evidence to support this observation is seen in the relative stability of the *Cyclops* and *Diaptomus* population (in numbers, not percent composition) after nauplii dwindle in abundance. That is, recruitment of nauplii to adult copepods seems extremely low. Therefore, the nauplii either just die off or are consumed by predators. Also, the mysis shrimp may be preying on copepods. This is especially likely in Twin Lakes since other sources of food are uncommon. In addition, rotifers must especially crop the nauplii in order to support the rather large expansion that their populations experience just after nauplii are most abundant. *Cyclops* is the most abundant of the two copepods. This situation does not change much from year to year; however, overall abundance does change. Data on this subject will be presented in a later comprehensive report on the zooplankton of Twin Lakes.

The data shown on figure 36 provides further illustration of an important aspect about the ecology of Twin Lakes. That is, the upper lake not only contains significantly smaller zooplankton populations than the lower lake, but the

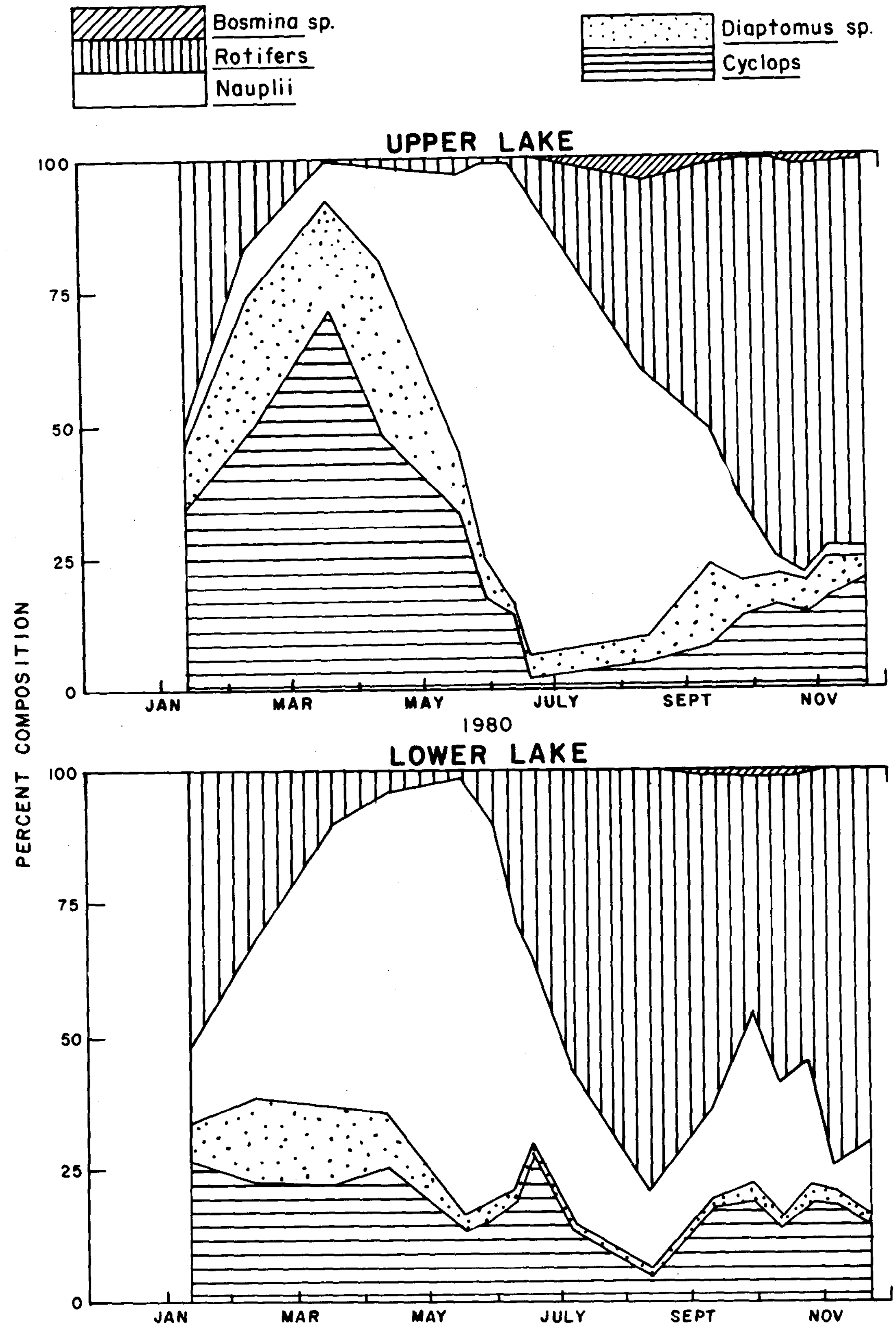


Figure 36.—Species composition of zooplankton population in Twin Lakes during 1980.

zooplankton is also 1 to 2 months behind in biological succession following spring turnover. The copepod nauplii and rotifer population illustrate this best. Just as the nauplii population of the lower lake peaks, it is just developing in the upper lake. Later in the summer, just as the rotifer population peaks in the lower lake, the upper lake's nauplii population is finally reaching a maximum, and its rotifer population is beginning to develop. Thus, there is a delay in the annual cycle of the upper lake. The obvious reason for this is that the upper lake acts as a "cushion" for the lower lake as it catches the cold, silty spring runoff from Lake Creek. This means that temperatures are cooler, and light is more limiting. Both of these physical factors limit biological production. This condition in the upper lake does not subside significantly until mid-to-late July. The upper lake continues to receive the relatively cold Lake Creek inflow while the lower lake is receiving the relatively warmer epilimnetic water from the upper lake by way of the channel. Even though this appears to be the most obvious and plausible answer, it is not the only reason why the biological cycle of the lower lake is 1 to 2 months ahead of the cycle in the upper lake. Consideration must also be given to the fact that as biota (nauplii, rotifers, *Astinonella, Dinobryon,* etc.) develop in the upper lake, some of it is flushed into the lower lake. This is especially true early in the year when, under certain flows, nearly all of the plankton can be flushed into the lower lake in just a few days. At the same time, during the early part of the year, flows out of the lower lake are kept minimal as both lakes are allowed to fill. This means that plankton is concentrated in the lower lake even though some of it is produced in the upper lake. Good quantitative evidence for this observation is not yet available from Twin Lakes.

Benthos. — Four types of benthic animals are collected in dredge samples from Twin Lakes. Chironomids, or the nonbiting midges (family Chironomidae-Tendipedae), are representatives of the order of flies (Diptera) and are best known as the predominant insect of lake sediments (Mundie, 1957 [39]). They are sometimes present in great numbers and may be detritus, animal, or plant feeders participating in the exchange of material within the sediments and between them and the outside water. The second type is the oligochaetes (family Oligochaeta). These are aquatic earthworms that, like chironomids, burrow in the bottom sediments and take part in the exchange of substances within the sediments and between them and the outside water. The third type are the fingernail clams (family Sphaeriidae) who are part of a group of very small bivalved freshwater organisms with marine ancestry (Cole, 1979 [29]). Clams found at Twin Lakes belong to the genus *Pisidium,* the tiny pea clam. The clams are represented by two species: the nearly worldwide *Pisidium casertanum* (Poli), found in a wide range of habitats, and the North American *P. pauperculum* Sterki, limited to lakes and larger streams (personal communication, Dr. Dwight W. Taylor, Pacific Marine Station, Dillon Beach, Calif.). The fourth type of benthos are the mysids or opposum shrimps (order Mysidacea) which, as previously mentioned, are considered both plankton and benthos. They stay on the bottom during daylight hours where they are collected in dredge samples taken during the day. At night, they migrate to the surface and are collected with other zooplankton. Mysis shrimp resemble transparent crayfish and reach maximum lengths of about 30 mm. *Mysis relicta* Loven was introduced into Twin Lakes in 1957 as a potential food source for the introduced lake trout *Salvelinus namaycush* Walbaum [40, 41]. This introduction was extremely successful. Nesler (1981) [41] reported densities of *Mysis* in Twin Lakes up to 510 per square meter using a benthic, sled-type trawl.

Table 4 summarizes the benthos data collected during 1980 from Twin Lakes, and figures 37 and 38 contain graphic presentations of the benthos data from 1979 and 1980. Mean, standard deviaton, and range for each of the four kinds of benthos are plotted. Chironomids and fingernail clams were both more abundant in the lower lake, chironomids by one-third and clams by 16 times. Based on preliminary data, mysis shrimp were about twice as abundant in the lower lake; however, discussion of mysis abundance is somewhat provisional since successful phototrawl methods of estimating mysis density are just now being developed. Oligochaetes were about three times more abundant in the upper lake where sediments contained much more debris in the form of wood and bark chips and leaf litter. Biomass data indicate similar trends; however, chironomid biomass in the lower lake was about 3.5 times greater than in the upper lake. This indicates that chironomids in the lower lake are larger, perhaps more mature, or even consist of different species typically larger than those found in the upper

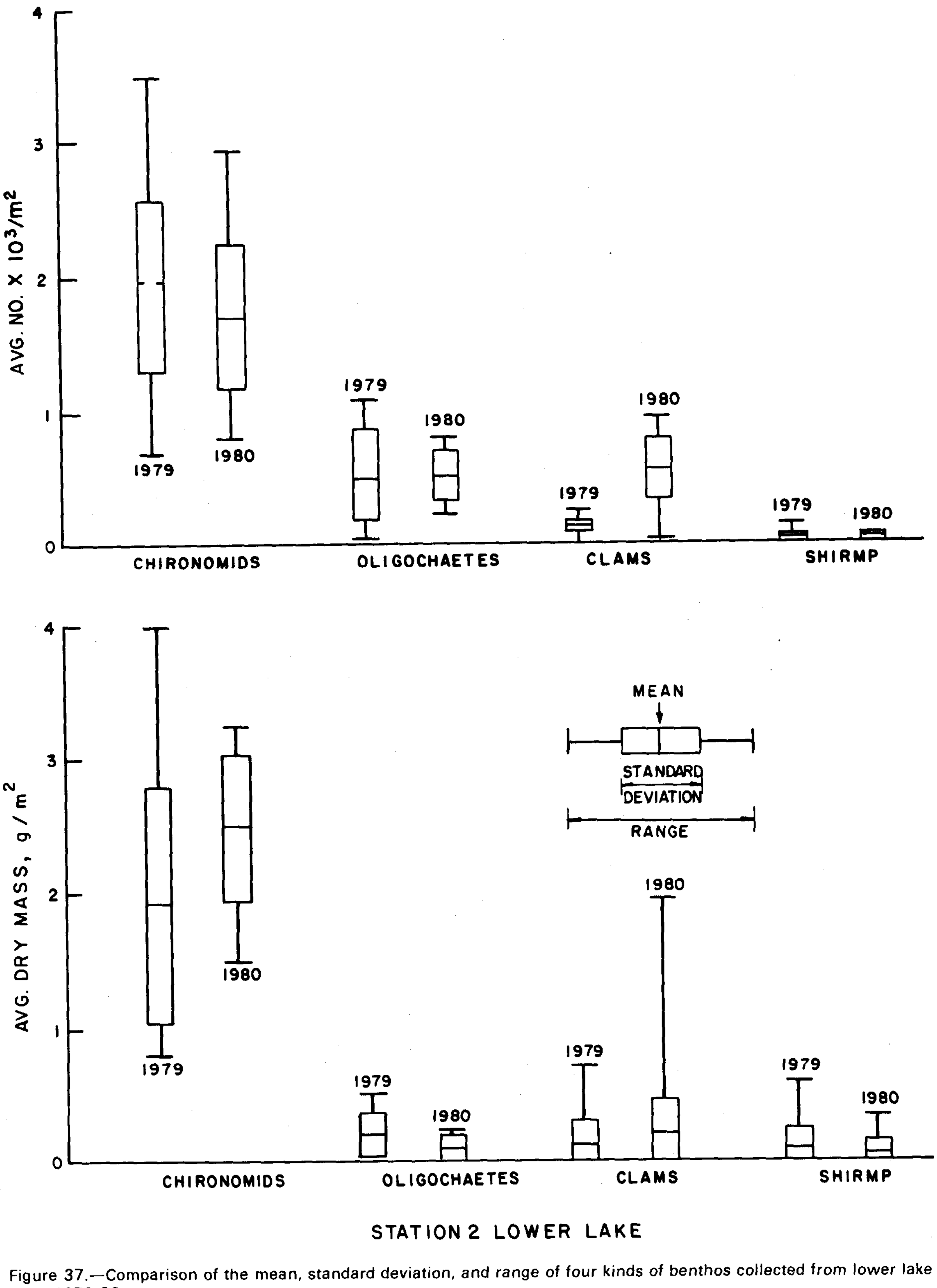


Figure 37.—Comparison of the mean, standard deviation, and range of four kinds of benthos collected from lower lake in 1979-80.

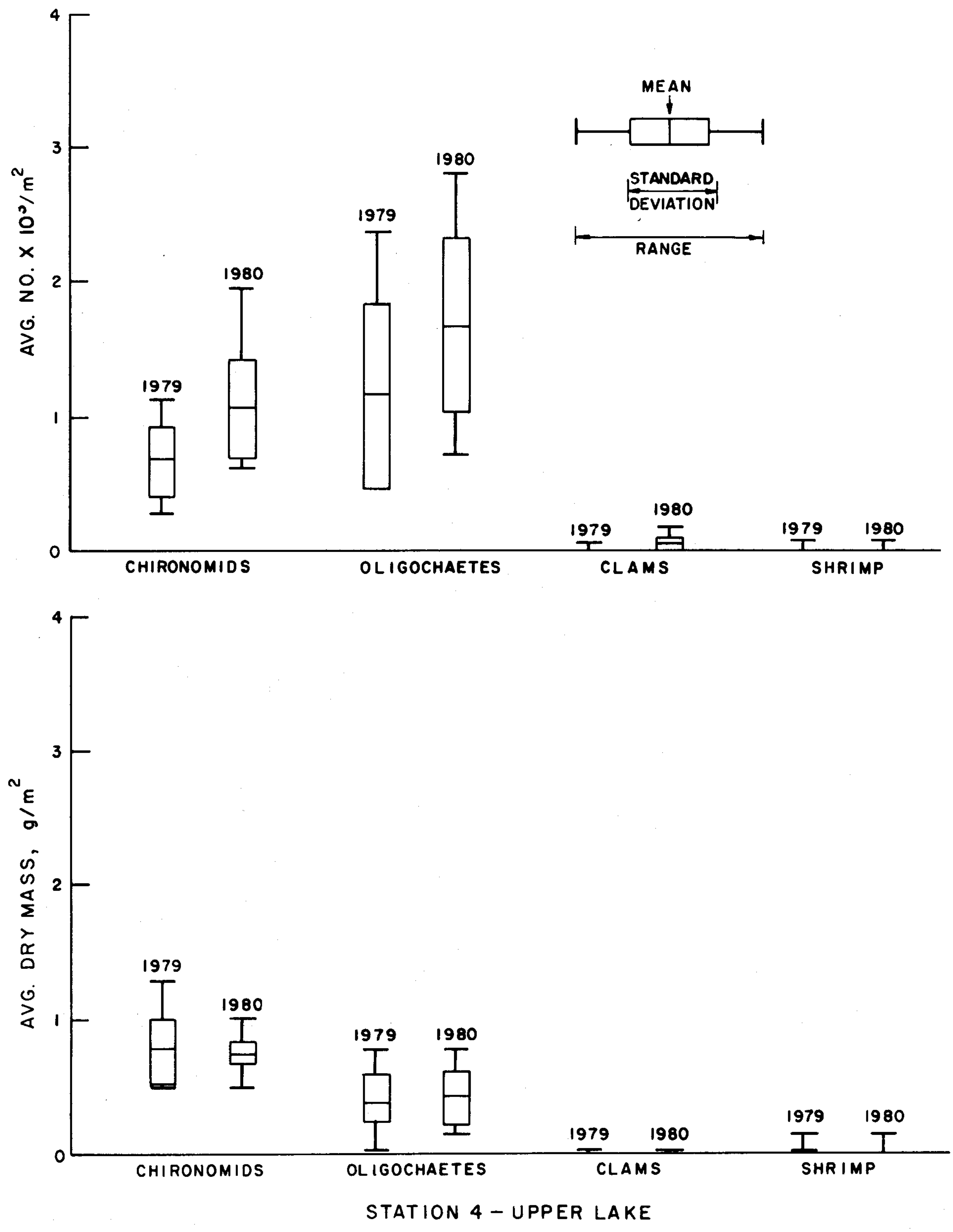


Figure 38.—Comparison of the mean, standard deviation, and range of four kinds of benthos collected from upper lake in 1979-80.

Table 4. — *Summary of benthos data from Twin Lakes during 1980*

Station	Organism	Avg. no. per square meter (28 samples)	Avg. dry mass, g/m² (28 samples)
2	Chironomids	1700	2.48
	Oligochaetes	503	0.12
	Pisidium spp.	558	.20
	Mysis relicta	22	.04
4	Chironomids	1063	.73
	Oligochaetes	1677	.43
	Pisidium spp.	34	.01
	Mysis relicta	9	.01

lake. Data on figures 37 and 38 show the similarity between benthos data collected in 1979 and 1980, except for clams in the lower lake where their abundance was significantly greater in 1980. However, this difference was not apparent in the clam biomass data from Twin Lakes, which indicates that there must have been a recent large recruitment of small individuals into the benthic clam population. Two summary observations from the data shown on figures 37 and 38 are: (1) there is proportionally greater abundance and biomass of chironomids compared to other benthos in the lower lake, and (2) there is somewhat greater abundance but slightly lesser biomass of oligochaetes relative to chironomids in the upper lake. The abundance of chironomids, oligochaetes, and fingernail clams at stations 2 and 4 during 1980 are plotted on figures 39, 40, and 41, respectively. Scatter of the data, especially in September and December, represents slight differences in collecting techniques used by different individuals; however, the trends are apparent. Chironomids became less abundant during the year, especially in May just after ice-off. This trend indicates maturity and metamorphosis to terrestrial adult midge flies, and the subsequent recruitment of small immature larvae into a size class large enough to be retained in our sieves. This is best shown in the biomass data between May and September (fig. 39). Abundance and biomass of chironomids were always greater at station 2. The opposite is true for oligochaetes; that is, the abundance (with one exception) and biomass were greater at station 4 (fig. 40). This difference between the benthos of the two lakes may be due to a number of factors. First, the bottom of the upper lake collects a lot of leaf and wood litter as well as heavy metal-laden sediment, especially during June and July when runoff is greatest. This could result in smothering of chironomid larvae just when they are beginning to develop into small larvae and grow. Also, components of the silt, such as some heavy metals, could preclude chironomid larvae development and growth. Second, conditions at the lake bottom, such as dissolved oxygen concentrations, temperature, particle size of stratum, and organic content, could be more conducive for chironomids and less conducive for oligochaetes in the lower lake, and less conducive for oligochaetes and more conducive for chironomids in the upper lake. Cole (1979) [29] notes that oligochaetes feed mainly on bacteria, while chironomids feed mainly on organic material settling out of the water column. Production is higher in the lower lake, which provides a more abundant food source for chironomids, while the bacteria in a llochthonous organic debris in the upper lake may be a food source for oligochaetes. For whatever reason, oligochaetes have always been more abundant in the upper lake and chironomids more abundant in the lower lake.

Abundance and biomass data for pea (fingernail) clams *(Pisidium* spp.) during 1980 are displayed in figure 41. Again, there is some scatter in the data, particularly in September and October. This may be a result of different individuals using different collecting techniques. This seems particularly true for benthos collections. Nevertheless, the evidence is unmistakable that the lower lake has a far greater abundance of pea clams than the upper lake. This fact has been

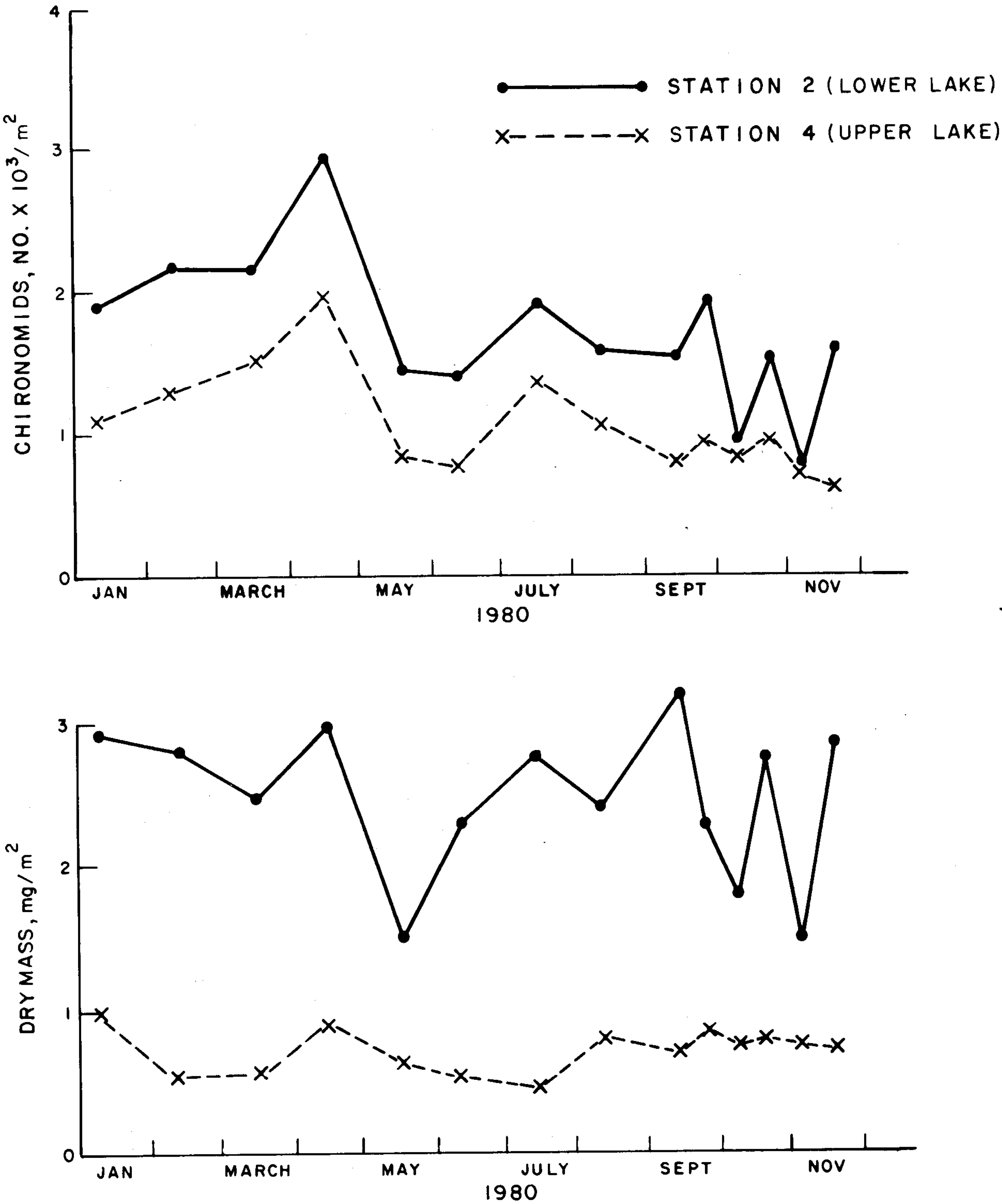


Figure 39.—Density and biomass of chironomid larvae in Twin Lakes during 1980.

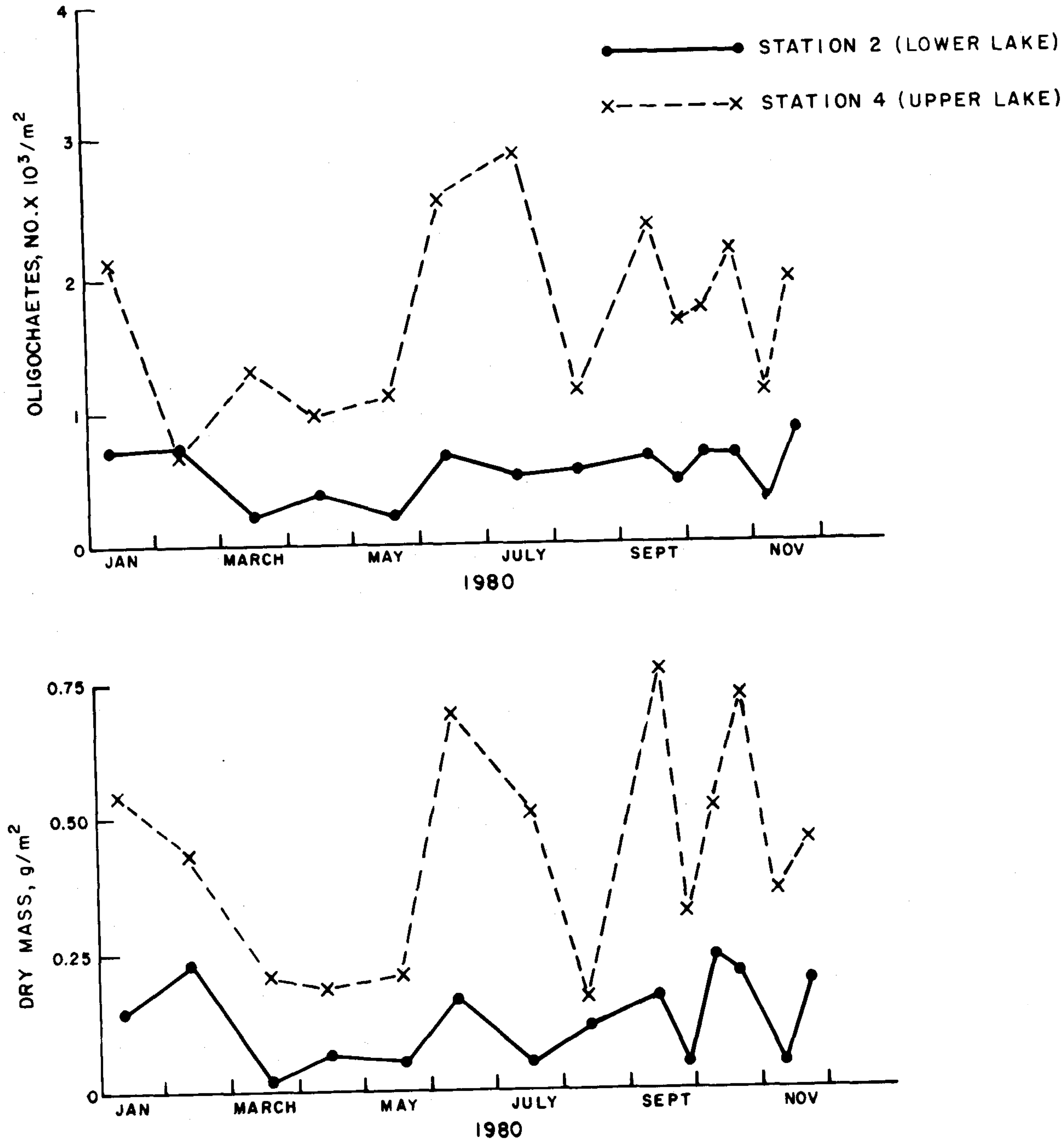


Figure 40.—Density and biomass of oligochaetes in Twin Lakes during 1980.

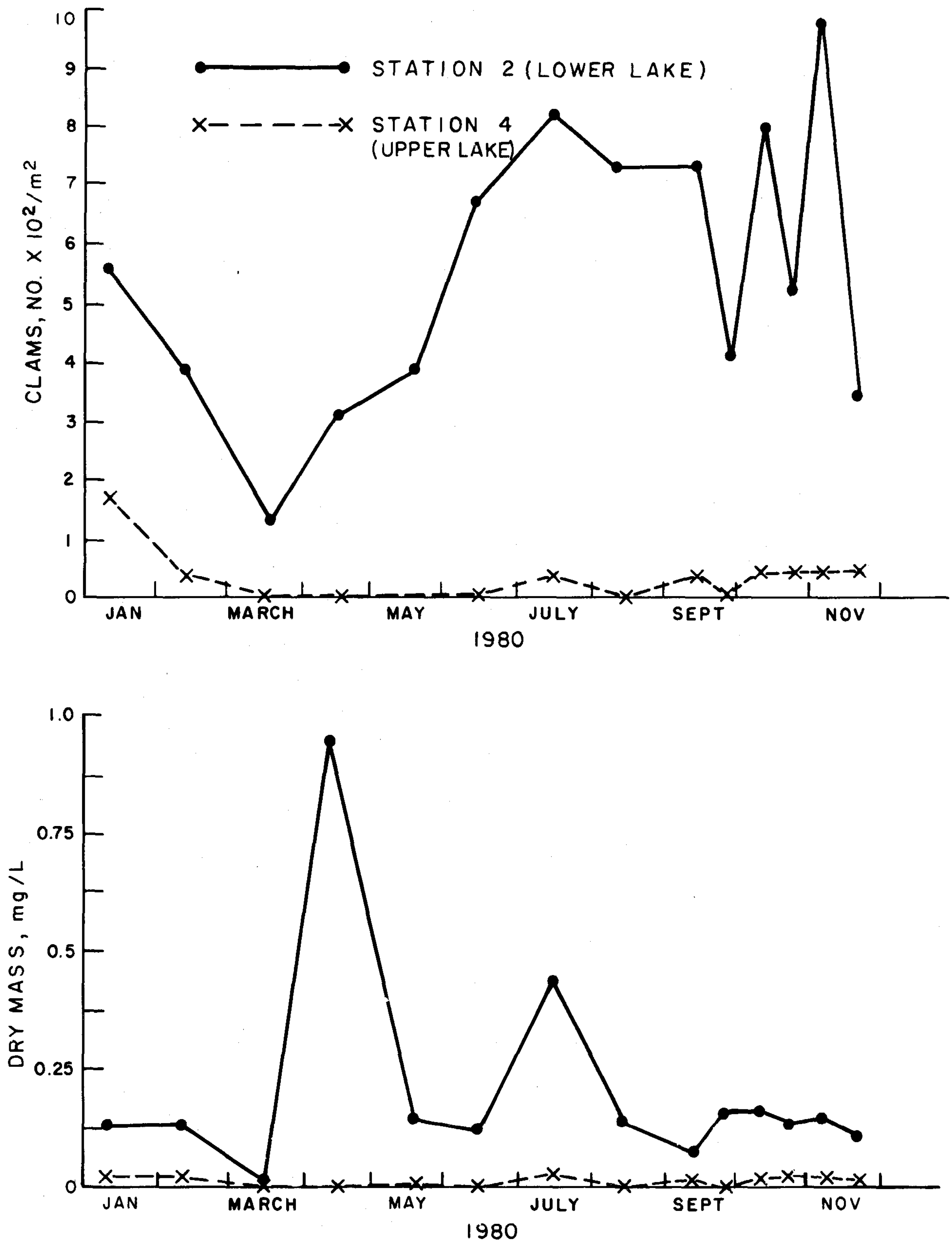


Figure 41.—Density and biomass of pea clams in Twin Lakes during 1980.

true since the study began in 1971. There have been years (1973-76) when no clams were collected from the upper lake. One reason may be that physical and chemical conditions in the upper lake do not favor development of this kind of benthos. In addition, recolonization by clams would be extremely slow since they are limited in their movement to the upper lake. Abundance data (fig. 41) indicate that at station 2 there is a significant drop in abundance by March and then recovery over the next 4 months. Recovery late in the year from a nearly nonexistent clam fauna is also indicated for the upper lake. Since this benthic animal seems to be quite sensitive to environmental stress, as evidenced by the paucity of clams in the upper lake, any increase in abundance is positive evidence of favorable conditions for aquatic biota that thrive in oligotrophic lakes. In summary, the Twin Lakes seem to be ecologically healthy at the end of 1980.

Abundance and biomass data for samples of *Mysis relicta* collected from Twin Lakes with the benthic dredge during 1980 were not plotted. There is a limited value to these data since our methods of collection are not conducive to accurate estimation of mysid densities. Nesler (1981) [41] presents the most accurate analysis of the relative abundance of mysis in Twin Lakes based on data obtained using a benthic trawl. Densities of mysis, varying considerably for the 204 samples collected in 1977-79, ranged from 0 to 355 per square meter. Mysis densities were greatest at the deep lower lake sampling locations. The abundance of mysis seems to reflect that of the zooplankton population as a whole (Nesler, 1981 [41]).

Other forms of benthos are present in Twin Lakes which have not been mentioned. These include a benthic cladoceran (*Alona* sp.), gastropods, trichoptera, hemiptera, ephemeroptera, and amphipods (Krieger, 1980 [12]). These forms were all found in the stomachs of benthic feeding suckers collected from Twin Lakes. The conventional methods of collecting samples of benthic muds with dredges and straining them through sieves are not conducive to successful collection of these forms because many forms of benthos live among macrophytes, rocks, and other substrates making collection difficult. Samples were taken at the deepest points in the lakes, and are therefore representative of the deep lake environment.

Table 5 compares the average abundance of benthos in Twin Lakes, excluding mollusks, with those of other locations selected from the literature. This comparison indicates that the benthic fauna of Twin Lakes represents that of a healthy and moderately productive oligotrophic lake, at least during the past 2 years. This observation is not only substantiated by comparisons made with other lakes but also by the kinds of animals that make up the benthic fauna: chironomids, oligochaetes, pea clams, mysis shrimp, and the other forms found in the stomachs of suckers.

SUMMARY

Tables 6 and 7 summarize the extreme values of some of the limnological data collected from Twin Lakes during 1980. The extremes of most limnological parameters fall within the normal range of all data collected since 1973. In 1980 however, both lakes were somewhat warmer near the surface and cooler at the bottom than average. This means that stratification was stronger than normal; this was especially true for the upper lake. The upper lake continues to be far less productive than the lower lake. The upper lake is subject to the influence of turbid runoff laden with heavy metals, especially during maximum runoff. Tables 6 and 7, besides presenting the extremes for each parameter, also present the month when each extreme was observed. Analysis of these data indicates that about 70 percent of the minimums for both lakes occurred during the late fall and early winter while about 70 percent of the maximums occurred during the summer through early fall. The obvious conclusion is that the season influences the lake's ecology, and the grouping of parameters in different ways reveals the degree to which this is true. For example, in the lower lake, primary productivity, chlorophyll *a* concentration, phyto- and zooplankton concentrations, and oligochaete and clam densities were all at a minimum in January, February, or March. Note that these are all biological parameters. At the same time, runoff, total Kjeldahl nitrogen, total phosphorus, and orthophosphate phosphorus were also at their lowest. These are all factors that have direct influence on the biological parameters. Runoff is one of the most influential parameters in biological production since it brings in the necessary nutrients. There is also the combined influence of temperature, ice and snow cover, and light. All of the various physical factors, as well as the timing of their extremes, can influence the ecology of Twin Lakes for years to come. Documentation of the effects of a severe winter is presented by Sartoris et al., (1977) [10], and discussed by LaBounty et al., (1980) [16]. Further detailed discussion of all ecological events at Twin Lakes will be presented in separate reports on various aspects of the biological limnology of Twin Lakes.

Table 8 summarizes the general trophic parameters of Twin Lakes based on data collected during 1980. In addition, a portion of table 9-4 from Likens (1975) [25] is included in table 8 to show his trophic classifications based on the various parameters. Table 9 is a qualitative summary based on the data presented in table 8. Based on data collected during 1980, the Twin Lakes are categorized as oligotrophic in seven of seven parameters.

Table 5. — *Comparison of abundances of benthic fauna (excluding mollusks) at Twin Lakes and other selected locations.*

Location	Number per square meter	Bibliography Reference
Twin Lakes (upper, 1979, N[1] = 34)	1814	LaBounty et al., 1980 [16]
Twin Lakes (upper, 1980, N = 28)	2740	—
Twin Lakes (lower, 1979, N = 34)	2453	LaBounty et al., 1980 [16]
Twin Lakes (lower, 1980, N = 28)	2203	—
Great Slave Lake (Canada)	1603	Rawson, 1953 [41]
Seminoe Reservoir (Wyo.) (4-year average)	1518	Sartoris et al., 1981 [43]
Alcova Reservoir (Wyo.) (3-year average)	4175	Sartoris et al., 1981 [43]
Waterton Lake (Canada)	370	Rawson, 1942 [43]
Loch Levan (Scotland)	2027	Maitland et al., 1970 [45]
Lake Pocasse (S. Dak.)	0 to 5220	Roline and LaBounty, 1980 [46]
Candlewood Lake (Conn.)	5500	Deevey, 1941 [47]
Lake Cayuga (N.Y.)	6000	Henson, 1954 [48]

[1] N = Number of samples taken.

Table 6. — *Extremes of some of the limnological data collected from the lower lake during 1980*

Parameter	Units	Maximum	Month measured	Minimum	Month measured
Ambient light[1]	g-cal/(cm^2·h)	44	July	22.5	Sept.
Wind[1]	km/h	9.5	Sept.	5	Oct.
Air temp.[1]	°C	15.5	July	-6	Oct.
Water surface temp.[1]	°C	16	Aug.	4	Oct.
Water temp.[1]	°C	18	Aug.	0	Dec.-Apr.
Stratification temp. difference	°C	10	Aug.	0	Oct., Nov., and May
Water temp. (monthly mean)	°C	11	Aug.	2.2	Dec.
Dissolved oxygen	mg/L	9	June	1.3	Oct.
pH		8.3	Sept.	6.3	Oct.
Conductivity	µS/cm	89	May	65	Feb.
Redox potential	mV	500	Sept.	350	Nov.
Light extinction coefficient	m^{-1}	0.26	Jan.	0.44	July
Secchi depth	m	6.3	Oct.	3.0	July
Alkalinity	mg/L	21	Nov.	18.5	Sept.
TKN	µg/L	367	Feb.	60	Mar.
Nitrate - N	µg/L	60	Sept.	<10	Nov.
Ammonia - N	µg/L	60	Apr.	<5	Jan.-Feb., June-Sept.
Ortho-P	µg/L	3	June	<1	Feb.-Apr.; Nov.
Total P	µg/L	2	July-Oct.	<1	Jan.-June; Nov.
Silica	mg/L	5.5	Apr.	4.2	Nov.

Table 6. — *Extremes of some of the limnological data collected from the lower lake during 1980 — Continued*

Parameter	Units	Maximum	Month measured	Minimum	Month measured
Primary productivity (areal)	mg C/(m²·d)	143.5	Nov.	10.6	Jan.
Primary productivity	mg C/(m²·h)	2.0	Nov.	0	Apr. (below 9 m)
Chlorophyll *a* concentration	mg/m³	7.7	Sept.	0.6	Apr. (below 15 m)
Avg. phytoplankton concentration	No./L	13 007	Aug.	28	Mar.
Avg. zooplankton concentration	No./L	125.8	Aug.	8.6	Mar.
Density of chironomid larvae	No./m²	2 922	Apr.	800	Nov.
Density of oligiochaetes	No./m²	800	Nov.	216	May
Density of pea clams	No./m²	974	Nov.	129	Mar.

[1] 5-day average

Table 7. — *Extremes of some of the limnological data collected from the upper lake during 1980*

Parameter	Units	Maximum	Month measured	Minimum	Month measured
Water temp.	°C	17	Aug.	0	Dec.-Apr.
Stratification temp. difference	°C	12	Aug.	0	Oct., Nov., and May
Water temp. (monthly mean)	°C	11	Aug.	2	Dec.
Dissolved oxygen	mg/L	10	June	3.6	Mar.
pH		8.3	Oct.	6.5	Oct.
Conductivity	µS/cm	90	Apr.-May	64	July

Table 7. — *Extremes of some of the limnological data collected from the upper lake during 1980 — Continued*

Parameter	Units	Maximum	Month measured	Minimum	Month measured
Redox potential	mV	550	Sept.	350	Nov.
Inflow volume	$m^3 \times 10^7$	7.5	June	0.07	Feb.
Light extinction coefficient	m^{-1}	0.33	Mar.	1.01	June
Secchi depth	m	6.2	May	2.0	June
Alkalinity	mg/L	24	May	17	July
TKN	µg/L	240	Feb.	50	Aug.
Nitrate - N	µg/L	90	May	20	Nov.
Ammonia - N	µg/L	65	Apr.	<5	Jan.; June-Sept.
Ortho-P	µg/L	2	May-July; Nov.	<1	Jan.-Apr.; Aug.-Oct.
Total P	µg/L	2	Oct.	<1	Jan.-Sept.; Nov.
Silica	mg/L	6.2	Mar.	4.6	July
Primary productivity (areal)	$mg\ C/(m^2 \cdot d)$	57.9	Oct.	1.6	Jan.
Primary productivity	$mg\ C/(m^3 \cdot h)$	0.9	Oct.	0	Apr. (below 3 m)
Chlorophyll *a* concentration	mg/m^3	18.0	Sept.	0.3	July (below 15 m)
Avg. phytoplankton concentration	No./L	997	Nov.	1	Mar.
Avg. zooplankton concentration	No./L	65.9	Aug.	1.4	Mar.
Density of chironomid larvae	$No./m^2$	1969	Apr.	627	Nov.
Density of oligiochaetes	$No./m^2$	2813	July	714	Feb.
Density of pea clams	$No./m^2$	173	Jan.	0	Mar.-June; Aug.-Sept.

Table 8. — *Some general limnological characteristics of Twin Lakes compared to parameters by Likens (1975)* [25] *to categorize trophic status*

Lake	Mean primary productivity, mg C/(m²·d)	Total organic carbon, mg/L	Chlorophyll *a*, mg/m³	Dominant phytoplankton	Light extinction, m⁻¹	Total P, µg/L	Total N, µg/L
Twin Lakes (lower, 1980)	76.4	[1]1.6-2.1	0.6-5.3	Chrysophyceae	0.26-0.44	<1-2	60-367
Twin Lakes (upper, 1980)	19.6	[1]1.4-1.7	0.3-7.9	Bacillariophyceae	0.33-1.01	<1-2	50-240
Ultra-oligotrophic	<50		0.01-0.5	Chrysophyceae, Cryptophyceae	0.03-0.8	<1-5	<1-250
Oligotrophic	50-300	<1-3	0.03-3	Dinophyceae, Bacillariophyceae	0.05-1.0		
Oligo-mesotrophic						5-10	250-600
Mesotrophic	250-1000	<1-5	2-15		0.1-2.0		
Mesoeutrophic						10-30	500-1100
Eutrophic	>1000	5-30	10-500		0.5-4.0		

[1] As measured in 1975

Table 9. — *Categorization of trophic status of Twin Lakes based on data in table 8*

Parameter	Upper Lake	Lower Lake
Primary productivity	Ultraoligotrophic	Oligotrophic
Chlorophyll *a*	Oligotrophic	Oligotrophic
Dominant phytoplankton	Oligotrophic	Oligotrophic
Light extinction coefficient	Oligotrophic	Oligotrophic
Total organic carbon	Oligotrophic	Oligotrophic
Total P	Ultraoligotrophic	Ultraoligotrophic
Total N	Ultraoligotrophic	Ultraoligotrophic

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