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NUTRIENTS IN LAKE HURON

by

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ABSTRACT

A digest is given of the nutrient data for Lake Huron, along with supplementary information about the temperature regime, the Secchi depth transparency, and dissolved oxygen in the hypolimnion.

Nitrate and reactive silicate did not fall to very low concentrations in surface waters during the summer of 1971, whereas soluble reactive phosphate was nearly undetectable, near 0.4 micrograms phosphorus per litre, throughout the year at all depths. ~~Possibly~~ Probably (HFHD) phosphorus is the growth-limiting element for phytoplankton in Lake Huron.

Two parameters have changed over the years. Secchi depth and reactive silicate concentrations have both declined, indirectly suggesting a slight increase in available phosphorus, perhaps coming in part from Lake Michigan.

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INTRODUCTION

A general introduction to the limnology of Lake Huron is to be found in the report "Fish and Wildlife as related to Water Quality of the Lake Huron Basin", published by the U.S . Department of the Interior in 1969 . That report contained negligible information about the major plant nutrients in the offshore part of the lake.

The scope of the present paper is limited to major plant nutrients, Secchi depth transparency, dissolved oxygen, and the temperature regime, all of which clearly have relationships with the phytoplankton. The subject of major ions is purposely avoided because it probably bears no relation to the phytoplankton or to eutrophication. Trace elements such as iron have not been discussed because of the difficulty of that subject.

The paper includes data from the main basin of Lake Huron and also a few stations in the North Channel. Georgian Bay has been omitted and also Saginaw Bay has been omitted . The distributions of total phosphorus in Saginaw Bay have been shown by Beeton et al, 1967.

For summarizing the data on Lake Huron, I have chosen to deal with lake-wide mean values of nutrients at a depth of 1 metre, representing data for the epilimnion, and mean values in the cold water-mass using the temperature criterion of colder than 5.0^{0}C. Such mean values were calculated for each cruise, and plotted against time of year to show the seasonal cycles. Horizontal distribution maps have been omitted. They would probably be instructive, showing for instance the mixing of Superior and Michigan waters at the northwest end of Lake Huron, and showing also the special condition of Saginaw Bay waters.

The mean values for each cruise are unweighted mean values calculated from all data from a depth of 1 metre, excluding Saginaw Bay data, or, for the hypolimnion, all data from samples colder than 5.0°C. The estimates of mean values could be improved if weighting factors were included to account for the uneven spacing of stations and sample-depths, but that has not been done. The weighting problem is most difficult in the case of some of the Secchi depth observations, because recent cruises have continued during each night when Secchi depth could not be observed, leaving large gaps in the spatial distribution of Secchi depth data.

Inventories of the data used in this paper are presented in Tables 1 and 2.

DESCRIPTION

Surface Temperature

Temperatures and temperature structure are characteristics related to the plant nutrient regime, and therefore it seems useful to include some information on surface temperatures. The data are presented in Table 3 and Figure 1 .

The occurrence of some 4°C temperatures at the lake surface indicates a "thermal bar" regime. In Lake Huron the spring thermal bar occurs in May and June, and the autumn thermal bar occurs in December.

After July 1 the prominent summer thermocline is found across the whole lake. However, in early summer there are large horizontal temperature gradients, with colder surface water over the deepest part of the basin in the northeast part.

Secchi Depth Transparency

Secchi depth transparency data for Lake Huron are summarized in Table 4 and illustrated in Figures 2, 3, and 4.

Only the lake-wide mean Secchi depth for each cruise has been considered. Hopefully, the unweighted mean value is valid. There was a considerable range of values on most cruises, and also there is the problem of patchy distribution of data, already mentioned.

Secchi depth transparency decreased in the period 1954 to 1971 (Figure 2). Mean values for July and August decreased from about 10 metres in 1954 to about 7 metres in 1971 (Figure 3).

Seasonal cycles in Secchi depth transparency for Lakes Ontario, Erie, and Huron are compared in Figure 4. In summer, Lake Ontario has the least transparency, near 2.8 metres.

Dissolved Oxygen in the Hypolimnion

Table 5 and Figures 5, 6 and 7 summarize the recent observations of dissolved oxygen in the cold water-mass of Lake Huron, together with the mean temperature of the same water-mass. The cold water-mass includes the samples having temperatures below 5.0°C. In summer this corresponds to the hypolimnion.

Oxygen percent saturation was calculated using recent determinations of oxygen solubility in water, as described in Dobson (1967).

On the cruise of the LIMNOS, November 22 to December 5, 1969, there was clearly an early-winter thermal bar regime, with a remnant of the cold hypolimnion offshore, underneath a thermocline, and oxygen-saturated cold surface water inshore. Here the oxygen values for the hypolimnetic remnant have been examined separately (and listed in Table 5).

The cold overturning water-mass in Lake Huron in spring was observed to have oxygen percent saturation values of 100% in April of 1971, rising to 105% in June before the onset of lake-wide stratification about July 1 (Figure 5). With rapid equilibration of oxygen between water and air, 100% saturation values throughout the period before July 1 would be expected. The explanation for the observed oxygen supersaturation lies with the temperature changes and a lag in equilibration of oxygen. Supporting evidence is contained in the temperature values (Figure 7) and the oxygen concentration values (Figure 6). Mean temperatures in the cold water-mass rose from 1.4 on April 24, 1971, to 4.1 on July 23. The mean oxygen concentrations were observed to be falling steadily during this period, and not rising to a peak in June in the manner of percent saturation.

Under summer stratification, the hypolimnion was depleted of oxygen to a slight but measureable degree. The depletion rate from July 23 to October 1, 1971, was 0.34 mg O_2/liter/30.5 days or 0.34 mg/liter/month. With such a small depletion rate for oxygen in the hypolimnion, very little regeneration of nutrients within the hypolimnion should be expected, when considered in terms of rate of change of concentration of nutrients. Observations of the major nutrients, considered below, support this conclusion.

Areal oxygen depletion rates in the hypolimnion of lakes, or the rate of loss of oxygen from a water column in the hypolimnion having unit surface area, may provide an indicator for the trophic state and allow approximate comparisons of bioactivity of the surface waters of lakes. The relation between ordinary depletion rate and areal depletion rate is:

Areal depletion rate (mg O_2/cm^2/month)
= 0.1 x hypolimnion thickness (metres)
x ordinary depletion rate (mg O_2/liter/month)

It is important to have a good estimate of hypolimnetic thickness, and the difficulty of such an estimate places a limitation on the accuracy of areal depletion rate values. Taking for Lake Huron a provisional and approximate hypolimnetic thickness of 60 metres, we get an areal depletion rate of 2.0 mg O_2/cm^2/month. C.H. Mortimer and G.E. Hutchinson place the middle of the mesotrophic range at 1.25 mg/cm^2/month (Hutchinson, 1957, page 644). Therefore, we get a trophic classification for Lake Huron of 2.0/1.25 = 1.6, on a scale with mesotrophy being indicated by 1.0. The reliability of such an indicator of trophic status of surface waters has not been clearly demonstrated, especially not for the case of deep lakes, and therefore the resulting trophic classification of 1.6, just derived, should probably not be given much weight. However, the concept of areal oxygen depletion rate helps to clarify why the oxygen concentration changes only slightly in the hypolimnion of a deep lake.

The main usefulness of these oxygen observations for the hypolimnion of Lake Huron will be to provide comparative data for depletion rates in future years, to indicate change or stability of the lake's metabolism.

Nitrate and Ammonia

The cold water-mass in Lake Huron (the water with temperatures less than 5.0°C) had a mean nitrate concentration of 247. micrograms nitrogen per liter (μg N/liter) from 920. observations from April to October 1971. There was no indication of measurable nitrate changes in the hypolimnion during summer (Table 6 and Figure 8).

At the 1-metre depth, nitrate depletion occurred from June to September. The mean depletion rate from June 22, 1971 to August 27, 1971 was 18. μg N/liter/month. On October 1 the mean nitrate concentration at a depth of 1 metre was 178. μg N/liter, or 72.% of 247. μg N/liter. Clearly nitrate does not approach very low levels during summer in the surface waters of Lake Huron, and nitrate is not at present a limiting nutrient for phytoplankton, but only an indicator of bioactivity.

The nitrate depletion rate for surface waters of Lake Huron during summer, approximately 18. μg N/liter/month, might be an indicator of the rate of change of standing stock of living material, if the living material remains in the epilimnion. On the other hand, if some sedimentation occurs, then nitrate depletion rates may be indicators of productivity without being indicators of standing stock in the epilimnion.

The nitrate depletion rate is reduced by mixing of epilimnial waters with colder waters as the thermocline deepens during the course of the summer. Therefore, 18. μg N/liter/month is somewhat of an underestimate of the biological rate of change.

In early summer, cooler surface waters are located over the deepest region of Lake Huron, in the east-central part. To show approximately the nitrate values of the warmer and cooler surface waters, the data of 1971 were divided into two sets on either side of the lake-wide mean surface temperature of each cruise, and the mean 1-metre nitrate values were computed for these warmer and cooler groups of stations (Table 7, Figure 9). Surface waters in the warmer and cooler regions were depleted of nitrate at the same rate in mid-summer, but the depletion began about one month earlier in the warmer region, i.e. near the shores. Apparently depletion occurs only when a distinct epilimnion is present. In June, July and August of 1971 the nitrate values of the warmer groups of stations averaged 29.μg N/ less than those of the cooler stations, while at the same time both groups were being depleted at a rate near 18.μg N/liter/month.

A second nitrogen fraction that was measured was ammonia (Table 8 and Figure 10). No seasonal trend was apparent, and there was no systematic difference between the cold water-mass and 1-metre samples. Results for 1969 and 1970 were somewhat higher than those of 1970, but this can perhaps be ascribed to analytical difficulties rather than a change in the lake. The mean value for ammonia from April 1971 to October 1971, for results for 1 metre and for the cold water-mass together, was 8. μg N/liter, from 1269 observations. These results were much lower than those for nitrate which averaged 247. μg N/liter in the cold water-mass.

Reactive Silicate

Reactive silicate concentrations in Lake Huron result from the mixture of Lake Superior waters with Lake Michigan waters and local Huron basin runoff, together with the effects of diatom activity within Lake Huron itself.

Silicate is the one nutrient for which historical data are available for Lake Huron (Table 9). Reactive silicate values for three cruises in June, July and August of 1954 can be compared with similar data for three cruises in the summer of 1971 (Table 10). Combining the results from the three cruises of 1954 we get: mean value in the cold water-mass ($T<5^{o}C$), 2580. μg SiO_2/liter, and mean value at the lake surface, 2060. μg SiO_2/liter. The corresponding results in 1971 were: cold water-mass, 1416. μg/ℓ, and lake surface, 967. μg/ℓ. The difference between the lake-surface value and that of the cold water-mass was 520. μg/ℓ in 1954 and 449. μg/ℓ in 1971. There was a similar uptake of silicate by diatoms before July in both of these years.

The silicate values in the cold water-mass may reflect approximately the mean silicate concentrations of waters entering Lake Huron, although the Lake Huron values can also be influenced by diatom growth, sedimentation and decay within Lake Huron itself. The reduction in the cold water-mass from 2580. μg/ℓ in 1954 down to 1416. μg/ℓ in 1971 suggests that there has been a change in the diatom production in Lake Michigan or Lake Huron or in both of these lakes. A rapid change in silicate concentrations in Lake Superior seems unlikely. Silicate depletion in Lake Michigan has been described already by Schelske and Stoermer (1971).

The silicate data for 1954 were reported by Ayers et al, 1956. In addition, Allen (1964) reported some silicate results for southern Lake Huron for summer 1956. The stations covered a small area, and therefore no attempt will be made to compare the data for surface waters. There were 31 observations of the cold water-mass ($T<5°C$), from June 5 to October 27, 1956, and their mean value was 2490. μg SiO_2/liter. The mean value for the cold water-mass was 2580. μg/liter in 1954 and 1416. μg/liter in 1971. Assuming a linear decline between these years, we get 2440. μg/liter for 1956, which nearly agrees with the observed 2490. μg/liter.

The observations of reactive silicate during 1971 are illustrated in Figure 11. The mean values for the cold water-mass suggest that there may have been a slight increase in the hypolimnion during the summer due to regeneration of reactive silicate from diatom remains. The mean values for a depth of 1 metre declined through the course of the summer, in a manner similar to nitrate. On October 1, 1971, the mean reactive silicate concentration at 1-metre depth was 831. μg SiO_2/liter, or 61% of 1367. μg/liter which was the mean value for surface waters on April 24, 1971. Thus silicate (as well as nitrate) does not approach very low levels during summer in the surface waters of Lake Huron, and silicate is not at present a limiting factor for diatoms. If the phosphorus fertilization of Lake Huron increases in future decades, silicate may become depleted in surface waters in summer, which will cause diatoms to be periodically replaced by other forms of algae (see Schelske and Stoermer, 1971).

To indicate the reactive silicate values of the warmer and cooler surface waters separately for the year 1971, the data were divided into two sets on either side of the mean surface temperature of each cruise, as already done for nitrate. As in the case of nitrate, the warmer nearshore waters began to be depleted of silicate earlier in the season, and at any one time during the summer the warmer waters had lower silicate values than the cooler surface waters (Table 11 and Figure 12). Silicate depletion due to diatom production began about early April in the warmer surface waters, whereas depletion began about early June in the cooler offshore waters.

The reactive-silicate changes in surface waters of Lake Huron result from the simultaneous mechanisms of diatom production, and vertical and horizontal mixing of waters. During August and September, the horizontal temperature distribution across the surface of Lake Huron become more uniform, and it is likely that horizontal mixing increased, tending to bring the silicate values of warmer and cooler regions closer together again.

Phosphorus in Various Forms

Recent measurements of phosphorus in Lake Huron have included three fractions: Soluble reactive phosphate, total filterable phosphorus, and total phosphorus. Samples analysed for total filterable phosphorus and for soluble reactive phosphate were filtered before analysis, through membrane filters having pore diameters of 0.45 microns (equals 0.45×10^{-3} millimeters). The mean phosphorus values for the cold water-mass and for a depth of 1 metre are listed in Tables 12, 13 and 14, and the mean values found during 1971 on the various cruises are illustrated in Figures 13, 14 and 15 .

No rational seasonal trends were observed. Some of the differences between cruises for total filterable phosphorus and for total phosphorus may perhaps be caused by analytical difficulties. All that can be done to summarize the data is to note the mean values for each measured fraction, and the mean values for some calculated fractions, for the entire period April 24 to October 1, 1971. Such mean values are as follows, based on about 1200 measurements of each fraction:

Soluble reactive phosphate	0.4 μg P/liter
Total filterable phosphorus	2.2 μg P/liter
Total phosphorus	4.6 μg P/liter
Particulate phosphorus (total minus total filterable)	2.4 μg P/liter
Dissolved organic phosphorus (total filterable minus soluble reactive)	1.8 μg P/liter

Vollenweider (1968) suggests that the phosphorus concentration of 10 micrograms phosphorus per liter is very significant, being the lower level for eutrophy. Perhaps particulate phosphorus corresponds to the standing stock of phosphorus in living matter and detritus, whereas perhaps particulate phosphorus plus soluble reactive phosphate indicates the potential standing stock of phosphorus. In the case of Lake Huron in 1971, particulate phosphorus was 2.4 μg P/liter and the sum of particulate and soluble reactive phosphorus was 2.8 μg P/liter. These values give a clue to the trophic status of the lake.

The decrease in nitrate at a depth of 1 metre during summer was 60. μg N/liter. From the known (??) nitrogen-to-phosphorus ratio of algae, approximately 7 nitrogen to 1 phosphorus by weight, we should expect a decrease of soluble reactive phosphate in the surface waters of Lake Huron during summer amounting to about 9. μg P/liter. The observed value for soluble reactive phosphate was 0.4 μg P/liter and it did not decrease significantly during the passage of summer. It seems difficult to reconcile the observed nitrate depletion with the steady low values of soluble reactive phosphate, if we assume the usual elemental ratios for the plankton.

DISCUSSION

Why Nutrient Depletion Occurs in Summer

Depletion of dissolved nutrients is related to the phenomenon of thermal stratification which isolates the surface waters from bottom waters during the summer. Due to the sinking of algal cells, the process of nutrient regeneration tends to occur mostly deep in the water column, below the thermocline where it cannot immediately affect the surface waters. Assimilation of nutrients, rather than regeneration, dominates in the epilimnion and hence nutrient depletion occurs. In winter, by contrast, the water column is well mixed vertically, and the regeneration of nutrients at any depth can affect the surface waters.

Another influential factor is the light regime. Incident light is greatest in June. Also, the effective amount of light in the mixed surface layer is controlled by the mixed-layer thickness, which is least in early summer and gradually increases as the thermocline deepens. A thermocline increases the effective light in the euphotic surface layer, because the mean depth in the lake of each algal cell is reduced.

In summary, the thermocline tends to isolate the assimilation of nutrients from their regeneration, and light is much increased in summer: both of these effects favor nutrient depletion from surface waters during summer.

A Provisional Working Hypothesis for Nutrients and Eutrophication

Dissolved nutrients tend to be exhausted by the phytoplankton during summer stratification . At other times of the year, light is probably the factor limiting production.

An increase in the phosphorus loading of a lake, and an increase in the winter and spring-overturn dissolved phosphate concentrations, result in an increased plant production in early summer. Whether this continues through the summer depends on whether phosphorus is entirely retained in the epilimnion, or whether it is lost to the hypolimnion by sedimentation of the cells.

The increase in plant production causes depletion of dissolved silicate and nitrate in the epilimnion in summer, and with enough permanent sedimentation of the elements the winter and spring-overturn values for silicate and nitrate may decrease over the years.

The effect of silicate and nitrate depletion in summer is the replacement of diatoms and green algae by the blue-green algae which can obtain their nitrogen from dissolved nitrogen gas . Thus, eutrophication with phosphorus causes a proportional increase in summertime standing crop and a change in the type of algae occurring during summer . Only phosphorus is the effective growth-limiting factor for blue-green algae.

An antidote for this simple hypothesis may be found in Lund (1965).

CONCLUSION

Phosphorus, nitrate, and silicate data for Lake Huron in 1971 have shown that the lake has not yet approached the phosphorus levels that will cause blue-green algae to occur in summer. Secchi-depth and nutrient data indicate that the lake is perhaps on the oligotrophic-mesotrophic boundary. Confirmation will come from future studies of the phytoplankton such as chlorophyll studies and species enumerations.

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Table 1. Inventory of historical data related to the nutrient conditions in Lake Huron.

Year of observations	relevant parameters measured	Data source
1954	Reactive silicate, Secchi depth transparency	Ayers et al, 1956
1956	Reactive Silicate	Allen, 1964
1960 to 1964	Secchi depth transparency, dissolved oxygen, temperature.	Rodgers, 1962 and 1963, and Great Lakes Institute, 1964, 1965 and 1971

Table 2. Inventory of data of the Canada Centre for Inland Waters on Lake Huron, related to the nutrient conditions.

Cruise dates	Vessel	Temperature	Secchi depth	Dissolved oxygen	Soluble reactive phosphate	Total filterable phosphorus	Total phosphorus	Nitrate	Ammonia	Reactive silicate
Aug. 6-13, 1968	THERON	x	x	x	x		x	x		x
Sept.23-29, 1969	MARTIN KARLSEN	x	x	x	x		x	x	x	x
Nov. 22-Dec. 5, 1969	LIMNOS	x	x	x						
May 11-18, 1970	MARTIN KARLSEN	x	x	x	x	x	x	x	x	x
Sept. 29-Oct 7, 1970	MARTIN KARLSEN	x	x	x	x			x	x	x
Apr. 19-28, 1971	MARTIN KARLSEN	x	x	x	x	x	x	x	x	x
May 17-25, 1971	MARTIN KARLSEN	x	x	x	x	x	x	x	x	x
June 15-28, 1971	MARTIN KARLSEN	x	x	x	x	x	x	x	x	x
July 19-27, 1971	MARTIN KARLSEN	x	x	x	x	x	x	x	x	x
Aug. 23-30, 1971	MARTIN KARLSEN	x	x	x	x	x	x	x	x	x
Sept. 28-Oct. 4, 1971	MARTIN KARLSEN	x	x	x	x	x	x	x	x	x

Table 3. Lake-wide mean and extreme surface temperatures of Lake Huron, from synoptic cruises.

Mean date of cruise	Vessel	Minimum temp. (^{o}C)	Mean temp. (^{o}C)	Maximum temp. (^{o}C)	Number of Stations
Apr. 14, 1962	PORTE DAUPHINE	0.5	1.1	3.4	59.
Apr. 24, 1971	MARTIN KARLSEN	0.1	1.6	7.3	93.
Apr. 30, 1964	PORTE DAUPHINE	1.8	2.7	7.3	61.
May 7, 1963	PORTE DAUPHINE	1.3	2.6	5.8	61.
May 15, 1970	MARTIN KARLSEN	1.7	3.8	10.4	100.
May 21, 1971	MARTIN KARLSEN	0.1	4.8	13.8	78.
May 24, 1962	PORTE DAUPHINE	2.5	4.8	12.4	60.
June 10, 1964	PORTE DAUPHINE	3.6	8.6	15.8	61
June 19, 1963	PORTE DAUPHINE	3.1	8.2	17.1	61.
June 22, 1971	MARTIN KARLSEN	3.0	11.9	21.3	83.
June 27, 1961	PORTE DAUPHINE	4.4	9.4	13.6	59.
June 28, 1960	PORTE DAUPHINE	3.8	10.3	14.8	59.
July 8, 1964	PORTE DAUPHINE	10.2	15.7	20.6	61.
July 17, 1963	PORTE DAUPHINE	9.7	14.9	20.3	61.
July 23, 1971	MARTIN KARLSEN	7.6	15.6	20.8	82.
July 25, 1962	PORTE DAUPHINE	13.5	16.6	18.8	57.
Aug. 2, 1961	PORTE DAUPHINE	15.5	19.6	22.2	59.
Aug. 9, 1968	THERON	9.0	17.2	22.6	100.
Aug. 17, 1963	PORTE DAUPHINE	12.3	15.5	19.1	61.
Aug. 18, 1964	PORTE DAUPHINE	11.4	15.8	18.9	61.

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Table 3. (continued)

Mean date of cruise	Vessel	Minimum temp (°C)	Mean temp. (°C)	Maximum temp. (°C)	Number of Stations
Aug. 27, 1962	PORTE DAUPHINE	15.4	17.8	21.5	58.
Aug. 27, 1971	MARTIN KARLSEN	14.2	17.1	20.4	78.
Sept. 7, 1961	PORTE DAUPHINE	18.2	20.1	21.8	59.
Sept.18, 1963	PORTE DAUPHINE	13.4	15.5	17.6	61.
Sept.26, 1962	PORTE DAUPHINE	7.6	13.6	16.8	51.
Sept.26, 1969	MARTIN KARLSEN	12.9	16.3	19.2	100.
Oct. 1, 1971	MARTIN KARLSEN	11.0	15.2	18.5	78.
Oct. 3, 1970	MARTIN KARLSEN	7.8	13.5	16.7	101.
Oct. 4, 1960	PORTE DAUPHINE	9.9	14.1	17.2	62.
Oct. 12, 1961	PORTE DAUPHINE	9.9	13.8	17.0	59.
Oct. 31, 1963	PORTE DAUPHINE	10.0	12.8	14.0	60
Nov. 25, 1964	PORTE DAUPHINE	5.1	7.4	9.0	58.
Nov. 28, 1969	LIMNOS	2.7	5.6	7.9	97.
Dec. 4, 1962	PORTE DAUPHINE	4.7	6.8	8.6	58.
Dec. 17, 1961	PORTE DAUPHINE	1.7	4.7	6.1	59.

Table 4. Lake-wide mean Secchi depth transparency values for Lake Huron, from synoptic cruises.

Mean date of cruise	Vessel	Lake-wide Mean Secchi depth (metres)	No. of Observations
June 28, 1954	many vessels	8.3	89.
July 27, 1954	many vessels	10.3	92.
August 25, 1954	many vessels	9.4	75.
June 28, 1960	PORTE DAUPHINE	6.6	39.
October 4, 1960	PORTE DAUPHINE	7.9	29.
June 27, 1961	PORTE DAUPHINE	6.3	37.
August 2, 1961	PORTE DAUPHINE	9.8	37.
September 7, 1961	PORTE DAUPHINE	8.5	31.
October 12, 1961	PORTE DAUPHINE	7.2	30.
December 17, 1961	PORTE DAUPHINE	5.3	14.
April 14, 1962	PORTE DAUPHINE	6.7	32.
May 24, 1962	PORTE DAUPHINE	6.8	38.
July 25, 1962	PORTE DAUPHINE	9.0	37.
August 27, 1962	PORTE DAUPHINE	9.3	32.
September 26, 1962	PORTE DAUPHINE	7.3	17.
December 4, 1962	PORTE DAUPHINE	8.1	20.
May 7, 1963	PORTE DAUPHINE	6.1	25.
June 19, 1963	PORTE DAUPHINE	6.2	29.
July 17, 1963	PORTE DAUPHINE	9.3	28.

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Table 4 (continued)

Mean date of cruise	Vessel	Lake-wide Mean Secchi depth (metres)	No. of Observations
August 17, 1963	PORTE DAUPHINE	8.5	24.
September 18, 1963	PORTE DAUPHINE	10.5	32.
October 31, 1963	PORTE DAUPHINE	7.9	18.
April 30, 1964	PORTE DAUPHINE	7.8	20.
June 10, 1964	PORTE DAUPHINE	7.2	23.
July 8, 1964	PORTE DAUPHINE	10.5	27.
August 18, 1964	PORTE DAUPHINE	9.8	29.
November 25, 1964	PORTE DAUPHINE	8.2	13.
August 9, 1968	THERON	7.2	58.
September 26, 1969	MARTIN KARLSEN	6.5	45.
November 28, 1969	LIMNOS	3.5	33.
May 15, 1970	MARTIN KARLSEN	5.6	56.
October 3, 1970	MARTIN KARLSEN	6.2	42.
April 24, 1971	MARTIN KARLSEN	5.9	51.
May 21, 1971	MARTIN KARLSEN	5.4	44.
June 22, 1971	MARTIN KARLSEN	5.6	50.
July 23, 1971	MARTIN KARLSEN	6.5	45.
August 27, 1971	MARTIN KARLSEN	6.9	42.
October 1, 1971	MARTIN KARLSEN	5.8	40.

Table 5. Recent observations of dissolved oxygen in the cold water-mass of Lake Huron. The "cold water-mass" includes samples having temperatures colder than 5.0°C. During summer stratification this corresponds to the hypolimnion.

Mean date of cruise	Vessel	Mean oxygen concentration mg/ℓ	Mean temp. (°C)	Mean oxygen percent saturation	Number of samples in the cold water-mass
Aug. 9, 1968	THERON	12.80	4.19	100.2%	163.
Sept. 26, 1969	MARTIN KARLSEN	12.01	4.28	94.1%	58.
Nov. 28, 1969	LIMNOS	12.19	4.51	96.1%	17.
May 15, 1970	MARTIN KARLSEN	13.69	2.62	102.5%	268.
Oct. 3, 1970	MARTIN KARLSEN	12.30	4.31	96.5%	82
Apr. 24, 1971	MARTIN KARLSEN	13.88	1.39	100.4%	431.
May 21, 1971	MARTIN KARLSEN	13.76	2.75	103.4%	270.
June 22, 1971	MARTIN KARLSEN	13.51	3.86	104.7%	150.
July 23, 1971	MARTIN KARLSEN	13.31	4.09	103.8%	105.
Aug. 27, 1971	MARTIN KARLSEN	12.83	4.13	100.2%	91.
Oct. 1, 1971	MARTIN KARLSEN	12.53	4.15	97.9%	81.

Table 6. Recent observations of nitrate in Lake Huron.

Data for the cold water-mass (temperature less than 5.0°C) and data for a depth of 1 meter are considered separately. Data for Saginaw Bay are omitted. Units are micrograms nitrogen per liter.

Mean date of Cruise	Vessel	Cold water-mass		Depth of 1 meter	
		Mean nitrate value (μgN/ℓ)	Number of observations	Mean nitrate value (μgN/ℓ)	Number of observation
Aug. 9, 1968	THERON	247.	53.	193.	96.
Sept. 26, 1969	MARTIN KARLSEN	267.	27.	190.	30.
May 15, 1970	MARTIN KARLSEN	250.	30.	243.	12.
Oct. 3, 1970	MARTIN KARLSEN	299.	5.	200.	12.
Apr. 24, 1971	MARTIN KARLSEN	250.	317.	252.	57.
May 21, 1971	MARTIN KARLSEN	242.	237.	244.	59.
June 22, 1971	MARTIN KARLSEN	249.	129.	224.	59.
July 23, 1971	MARTIN KARLSEN	240.	91.	204.	58.
Aug. 27, 1971	MARTIN KARLSEN	251.	75.	186.	59.
Oct. 1, 1971	MARTIN KARLSEN	253.	71.	178.	59.

Table 7. Nitrate at a depth of 1 meter in Lake Huron: mean values for the warmer stations and cooler stations separately. The data are divided into two sets on either side of the lake-wide mean surface temperature of each cruise. Units for nitrate are micrograms nitrogen per liter.

Mean date of Cruise	Vessel	Nitrate at a depth of 1 meter (μg N/ℓ)			
		Mean value for the warmer stations	Number of Observ-ations	Mean value for the cooler stations	Number of Observ-ations
Aug. 9, 1968	THERON	179.	52.	213.	40.
Apr. 24, 1971	MARTIN KARLSEN	247.	14.	256.	33.
May 21, 1971	MARTIN KARLSEN	248.	23.	241.	35.
June 22, 1971	MARTIN KARLSEN	213.	38.	244.	20.
July 23, 1971	MARTIN KARLSEN	191.	32.	220.	25.
Aug. 27, 1971	MARTIN KARLSEN	168.	18.	194.	38.
Oct. 1, 1971	MARTIN KARLSEN	165.	26.	187.	32.

Table 8. Recent observations of ammonia in Lake Huron. Data for the cold water-mass (temperature less than 5.0°C) and data for a depth of 1 meter are considered separately. Data for Saginaw Bay are omitted. Units are micrograms nitrogen per liter.

Mean date of Cruise	Vessel	Cold water-mass		Depth of 1 meter	
		Mean Ammonia Value (μgN/ℓ)	Number of Observ-ations	Mean Ammonia Value (μgN/ℓ)	Number of Observ-ations
Sept. 26, 1969	MARTIN KARLSEN	26.	27.	38.	30.
May 15, 1970	MARTIN KARLSEN	16.	30.	15.	12.
Oct. 3, 1970	MARTIN KARLSEN	10.	5.	17.	12.
Apr. 24, 1971	MARTIN KARLSEN	5.	316.	6.	57.
May 21, 1971	MARTIN KARLSEN	10.	237.	12.	59.
June 22, 1971	MARTIN KARLSEN	9.	127.	9.	59.
July 23, 1971	MARTIN KARLSEN	12.	91.	9.	59.
Aug. 27, 1971	MARTIN KARLSEN	10.	75.	6.	59.
Oct. 1, 1971	MARTIN KARLSEN	6.	71.	12.	59.

Table 9. Observations of reactive silicate in Lake Huron. Data for the cold water-mass (temperature less than 5.0°C) and data for a depth of 1 meter are considered separately. Data for Saginaw Bay are omitted. Units are micrograms SiO$_2$ per liter. Older data are from Ayers et al, 1956.

Mean data of Cruise	Vessel	Cold Water-mass		Depth of 1 meter	
		Mean Silicate value ($\mu g SiO_2/\ell$)	Number of Observations	Mean Silicate value ($\mu g SiO_2/\ell$)	Number of Observations
June 28, 1954	MANY VESSELS	2530.	41.	2150.	86.
July 27, 1954	MANY VESSELS	2690.	56.	2110.	94.
Aug. 25, 1954	MANY VESSELS	2520.	31.	1920.	76.
Aug. 9, 1968	THERON	1732.	54.	1032.	97.
Sept. 26, 1969	MARTIN KARLSEN	1402	27.	674.	30.
May 15, 1970	MARTIN KARLSEN	1054	30.	1032.	12.
Oct. 3, 1970	MARTIN KARLSEN	1792.	5.	867.	12.
Apr. 24, 1971	MARTIN KARLSEN	1384.	316.	1367.	57.
May 21, 1971	MARTIN KARLSEN	1395	237.	1262.	59.
June 22, 1971	MARTIN KARLSEN	1304.	129.	1034.	59.
July 23, 1971	MARTIN KARLSEN	1399	91.	999.	59.
Aug. 27, 1971	MARTIN KARLSEN	1546.	75.	868.	59.
Oct. 1, 1971	MARTIN KARLSEN	1556.	71.	831.	59.

Table 10. Comparison of reactive silicate values for Lake Huron, 1954 and 1971. Units are micrograms SiO_2 per liter.

		Mean value in cold water-mass		Mean value at lake surface	
June 28, 1954		2530.		2150.	
July 27, 1954		2690.		2110.	
Aug. 25, 1954		2520.		1920.	
Mean values, Summer of 1954		2580.		2060.	
Deficit at Surface, 1954.		2580. minus 2060. = 520			
June 22, 1971		1304.		1034.	
July 23, 1971		1399.		999.	
Aug. 27, 1971		1546.		868.	
Mean values, Summer of 1971.		1416.		967.	
Deficit at Surface, 1971.		1416. minus 967 = 449.			

Table 11. Reactive silicate at a depth of 1 meter in Lake Huron: mean values for the warmer stations and cooler stations separately. The data are divided into two sets on either side of the lake-wide mean surface temperature of each cruise. Units for silicate are micrograms SiO_2 per liter.

Mean date of Cruise	Vessel	Reactive silicate at 1 meter ($\mu g\ SiO_2/\ell$)			
		Mean value for the warmer stations	Number of Observ-ations	Mean value for the cooler stations	Number of Observ-ations
Aug. 9, 1968	THERON	896.	53.	1207.	40.
Apr. 24, 1971	MARTIN KARLSEN	1278.	14.	1400.	33.
May 21, 1971	MARTIN KARLSEN	1037.	23.	1407.	35.
June 22, 1971	MARTIN KARLSEN	936	38.	1217.	20.
July 23, 1971	MARTIN KARLSEN	830.	33.	1214.	25.
Aug. 27, 1971	MARTIN KARLSEN	782.	18.	906.	38.
Oct. 1, 1971	MARTIN KARLSEN	754.	26.	895.	32.

Table 12. Recent observations of soluble reactive phosphate in Lake Huron. Data for the cold water-mass (temperature less than 5.0°C) and data for a depth of 1 meter are considered separately. Data for Saginaw Bay are omitted. Units are micrograms phosphorus per liter.

Mean date of Cruise	Vessel	Cold water-mass		Depth of 1 meter	
		Mean SR-phosphate value (μg P/ℓ)	Number of Observations	Mean SR-Phosphate value (μg P/ℓ)	Number of Observations
Aug. 9, 1968	THERON	0.4	53.	0.5	97.
Sept. 26, 1969	MARTIN KARLSEN	0.6	27.	1.1	30.
May 15, 1970	MARTIN KARLSEN	1.7	28.	2.1	12.
Oct. 3, 1970	MARTIN KARLSEN	2.6	5.	1.6	12.
Apr. 24, 1971	MARTIN KARLSEN	0.4	316.	0.4	57.
May 21, 1971	MARTIN KARLSEN	0.4	237.	0.4	59.
June 22, 1971	MARTIN KARLSEN	0.3	129.	0.3	59.
July 23, 1971	MARTIN KARLSEN	0.4	91.	0.4	59.
Aug. 27, 1971	MARTIN KARLSEN	0.4	75.	0.3	59.
Oct. 1, 1971	MARTIN KARLSEN	0.5	71.	0.3	59.

Table 13. Recent observations of total filterable phosphorus in Lake Huron. Data for the cold water-mass (temperature less than 5.0°C) and data for a depth of 1 meter are considered separately. Data for Saginaw Bay are omitted. Units are micrograms phosphorus per liter.

Mean date of Cruise	Vessel	Cold water-mass		Depth of 1 meter	
		Mean TF-Phosphorus value (μg P/ℓ)	Number of Observations	Mean TF-Phosphorus value (μg P/ℓ)	Number of Observations
May 15, 1970	MARTIN KARLSEN	2.1	30.	2.4	11.
Apr. 24, 1971	MARTIN KARLSEN	1.0	23.	-	few.
May 21, 1971	MARTIN KARLSEN	2.0	227.	2.1	58.
June 22, 1971	MARTIN KARLSEN	3.7	121.	4.0	58.
July 23, 1971	MARTIN KARLSEN	1.4	86.	1.5	56.
Aug. 27, 1971	MARTIN KARLSEN	1.7	75.	1.9	58.
Oct. 1, 1971	MARTIN KARLSEN	2.0	69.	2.2	58.

Table 14. Recent observations of total phosphorus in Lake Huron. Data for the cold water-mass (temperature less than 5.0°C) and data for a depth of 1 meter are considered separately. Data for Saginaw Bay are omitted. Units are micrograms phosphorus per liter.

Mean date of Cruise	Vessel	Cold water-mass		Depth of 1 meter	
		Mean total phosphorus value (μg P/ℓ)	Number of Observations	Mean total phosphorus value (μg P/ℓ)	Number of Observations
Aug. 9, 1968	THERON	13.9	7.	5.5	12.
Sept. 26, 1969	MARTIN KARLSEN	6.1	14.	6.2	11.
May 15, 1970	MARTIN KARLSEN	5.3	29.	5.8	10.
Apr. 24, 1971	MARTIN KARLSEN	4.1	315.	4.0	56.
May 21, 1971	MARTIN KARLSEN	4.5	230.	4.9	56.
June 22, 1971	MARTIN KARLSEN	6.7	124.	6.7	59.
July 23, 1971	MARTIN KARLSEN	4.1	90.	3.4	59.
Aug. 27, 1971	MARTIN KARLSEN	4.4	75.	4.2	58.
Oct. 1, 1971	MARTIN KARLSEN	4.0	70.	4.4	59.

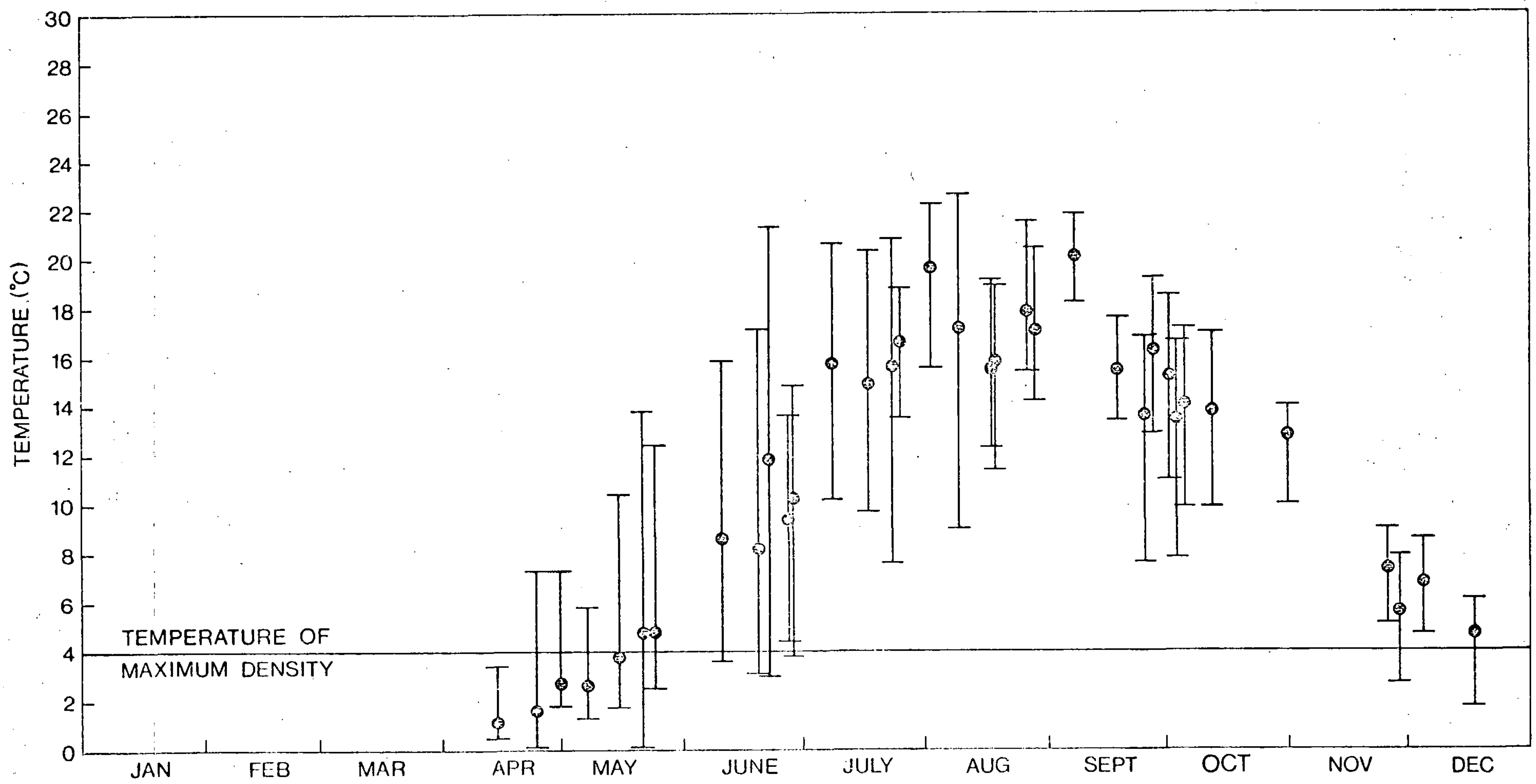


FIGURE 1. MEAN AND EXTREME TEMPERATURES AT A DEPTH OF 1 METRE IN LAKE HURON, FROM SYNOPTIC CRUISES, 1960 TO 1971.

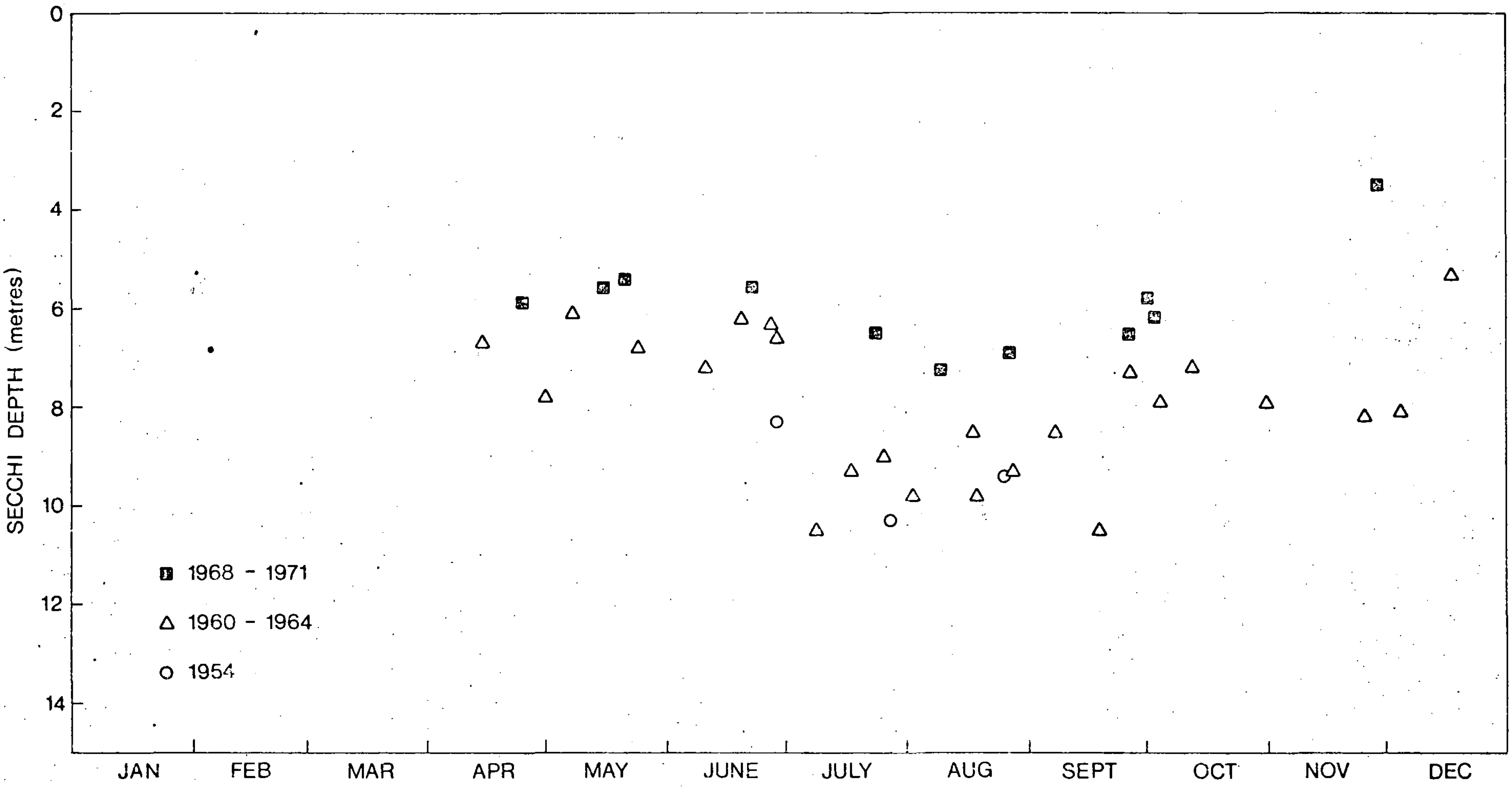
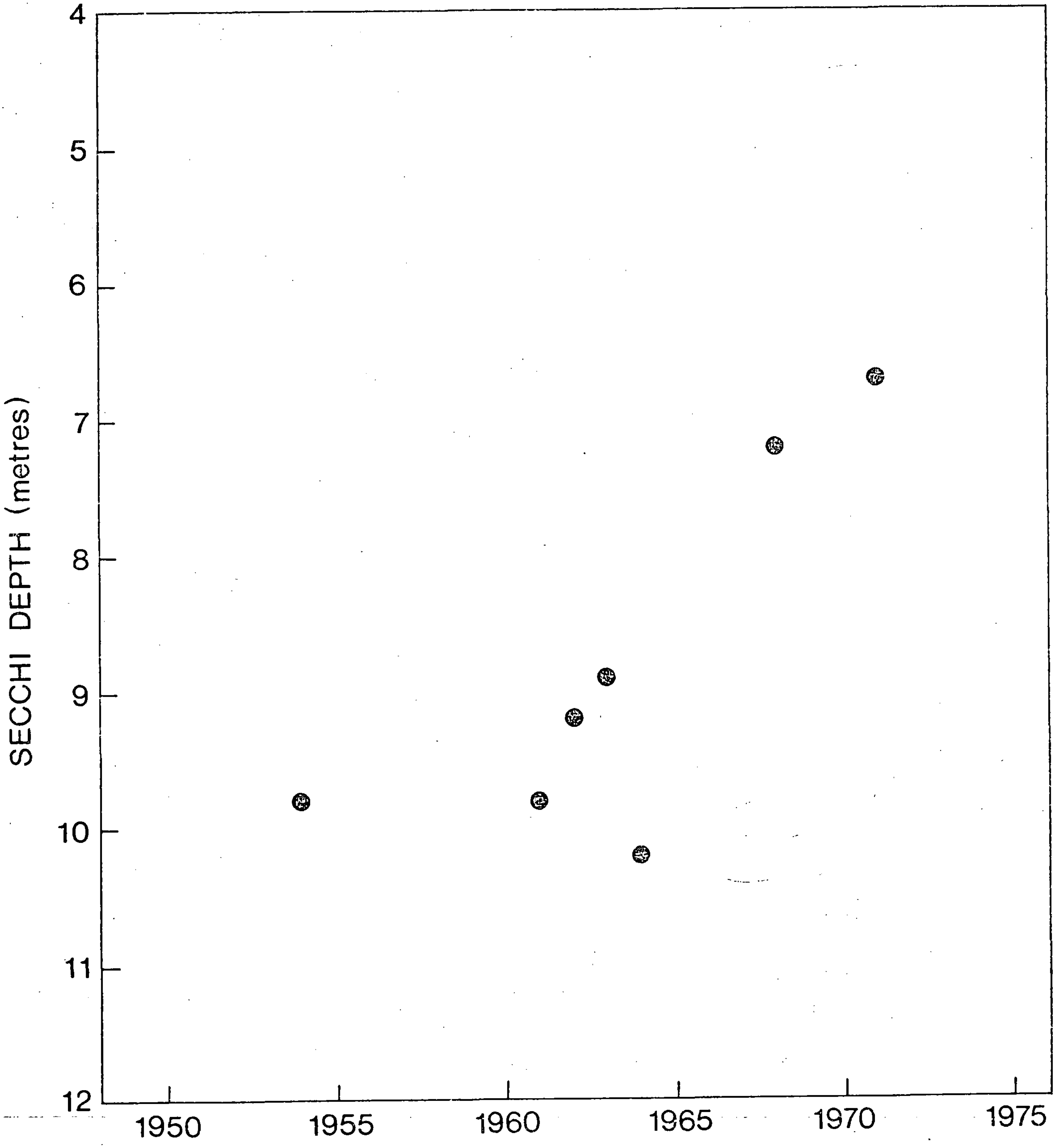


FIGURE 2. LAKE HURON SECCHI DEPTHS: LAKE-WIDE MEAN VALUES FROM SYNOPTIC CRUISES, 1954 TO 1971.

FIGURE 3. MEAN SECCHI DEPTH FOR LAKE HURON DURING JULY AND AUGUST OF EACH YEAR



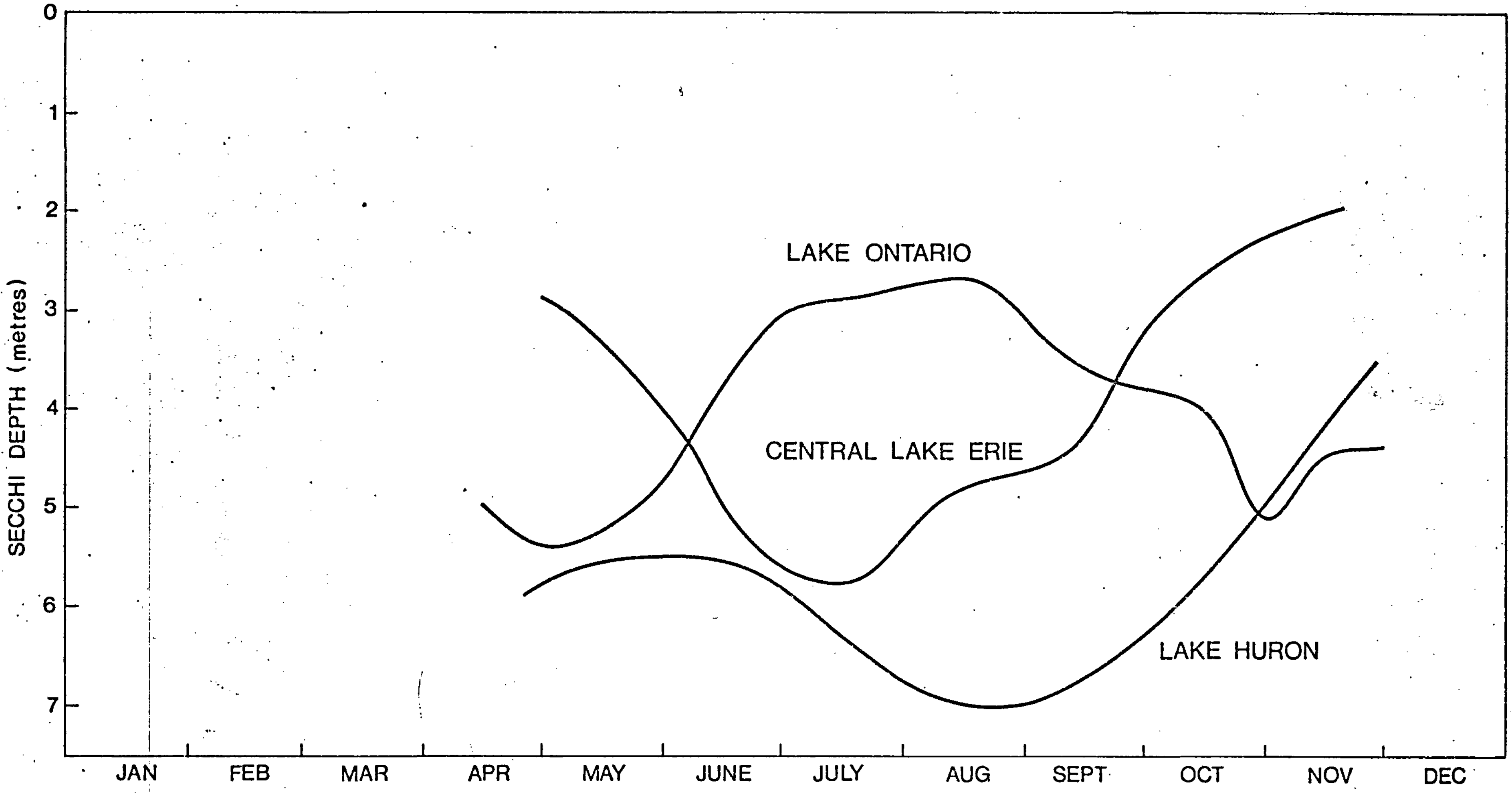


FIGURE 4. LAKE-WIDE MEAN SECCHI DEPTH VERSUS TIME OF YEAR, FOR LAKES HURON AND ONTARIO, AND FOR THE OFFSHORE PART OF CENTRAL LAKE ERIE. THE CURVES APPLY APPROXIMATELY TO THE YEARS 1967 TO 1971.

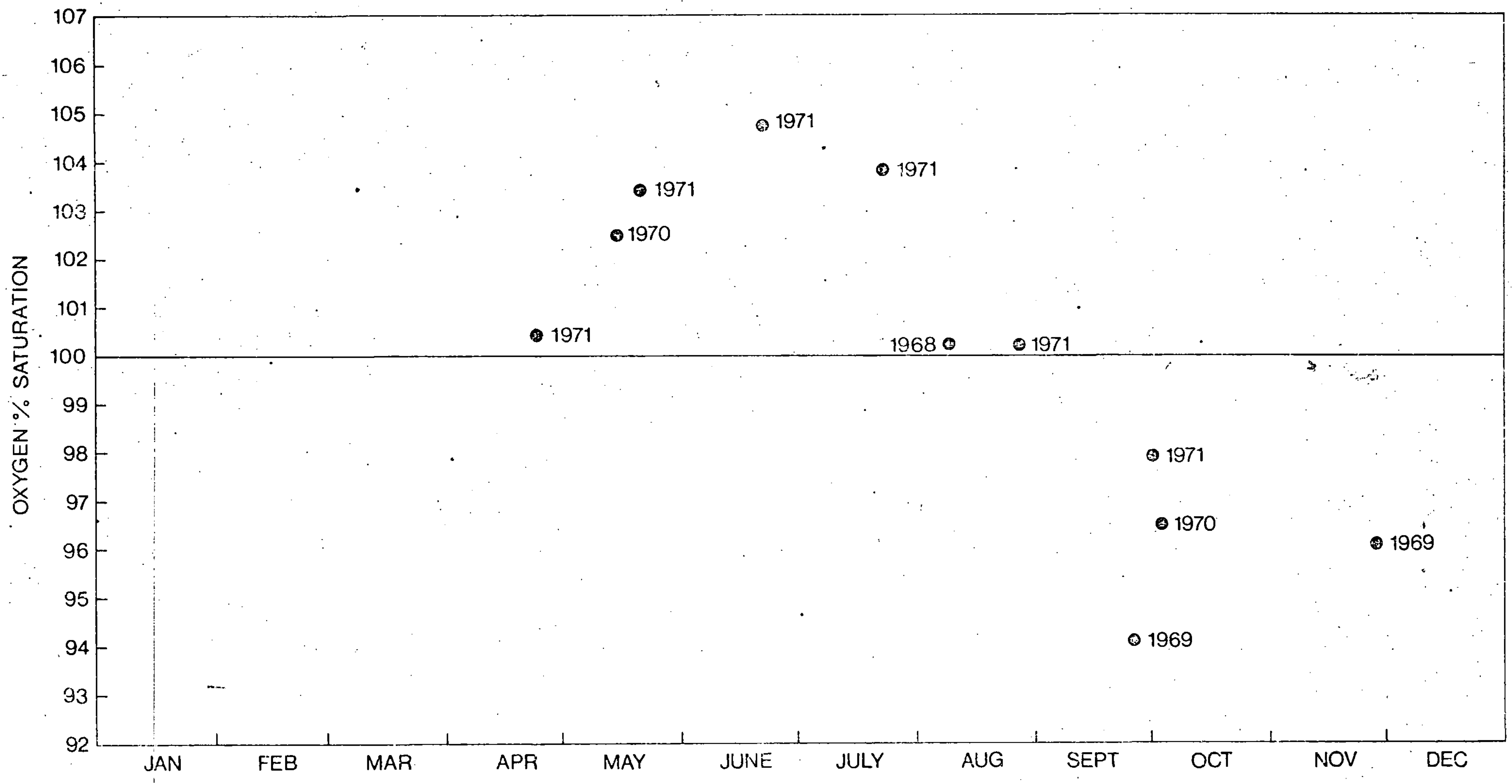


FIGURE 5. MEAN OXYGEN % SATURATION VALUES FOR THE COLD WATER-MASS ($T < 5^{\circ}C$) IN LAKE HURON, 1968 TO 1971.

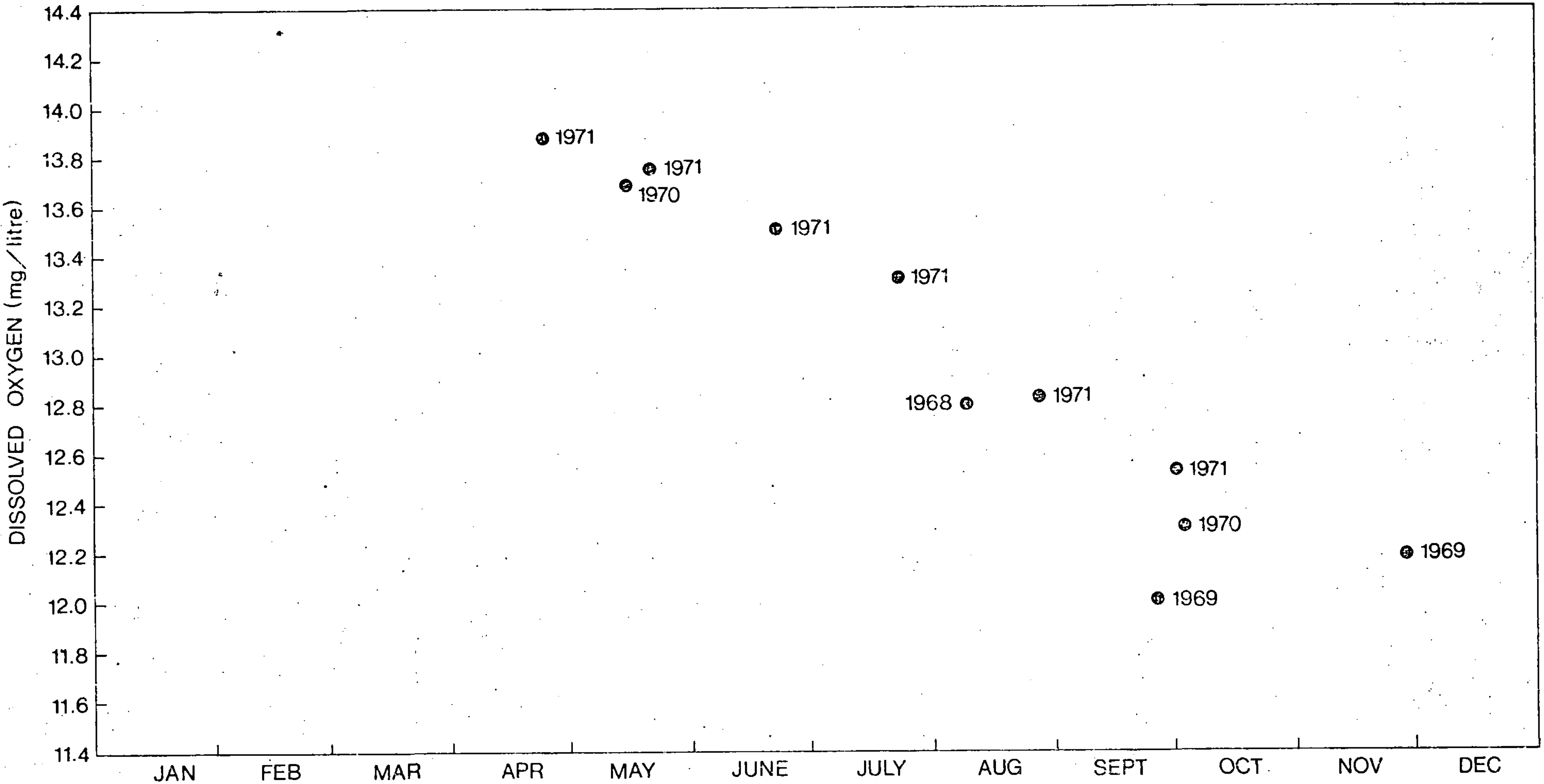


FIGURE 6. MEAN OXYGEN CONCENTRATIONS FOR THE COLD WATER-MASS ($T < 5^{\circ}C$) IN LAKE HURON, 1968 TO 1971.

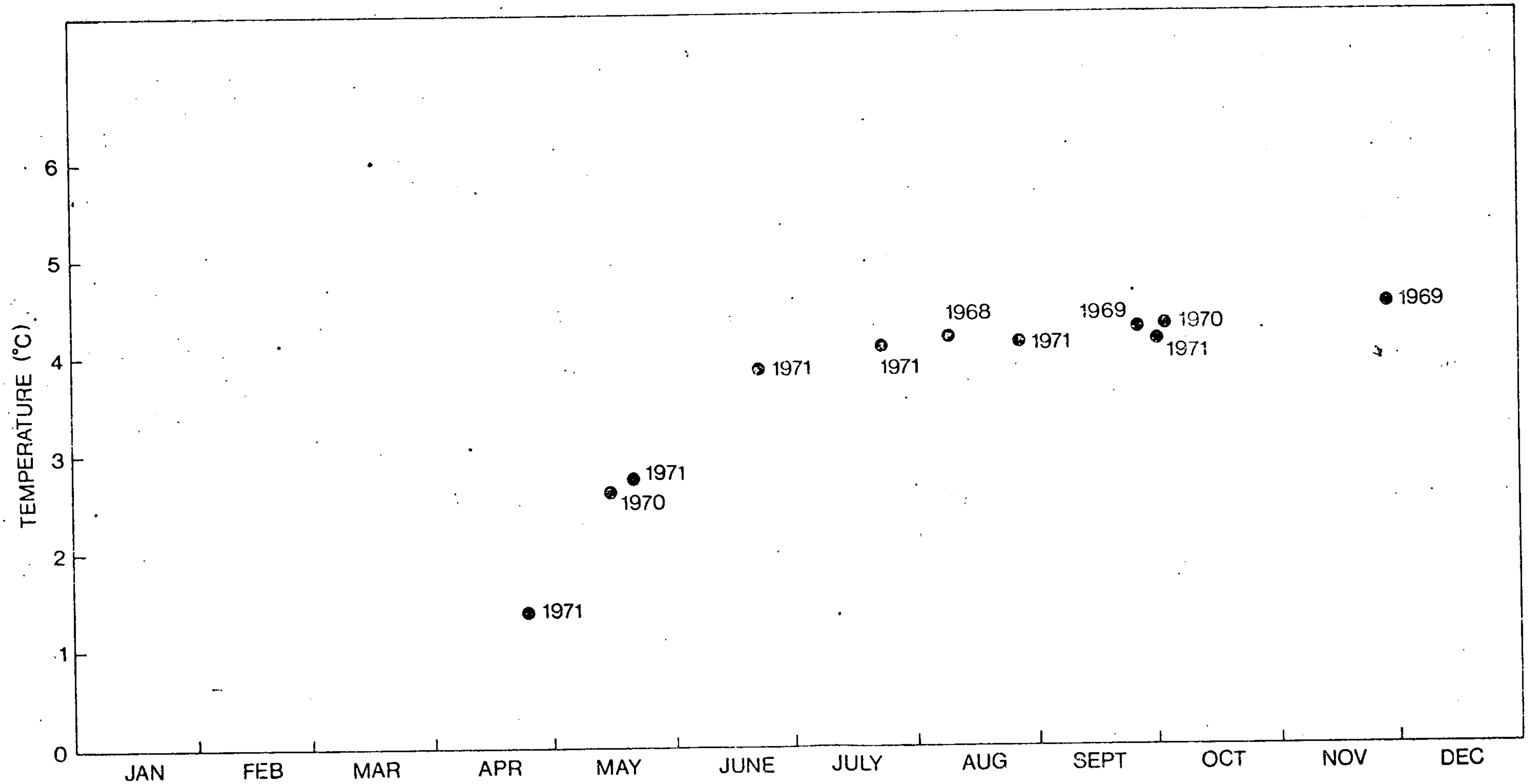


FIGURE 7. MEAN TEMPERATURES FOR THE COLD WATER-MASS (T < 5°C) IN LAKE HURON, 1968 TO 1971.

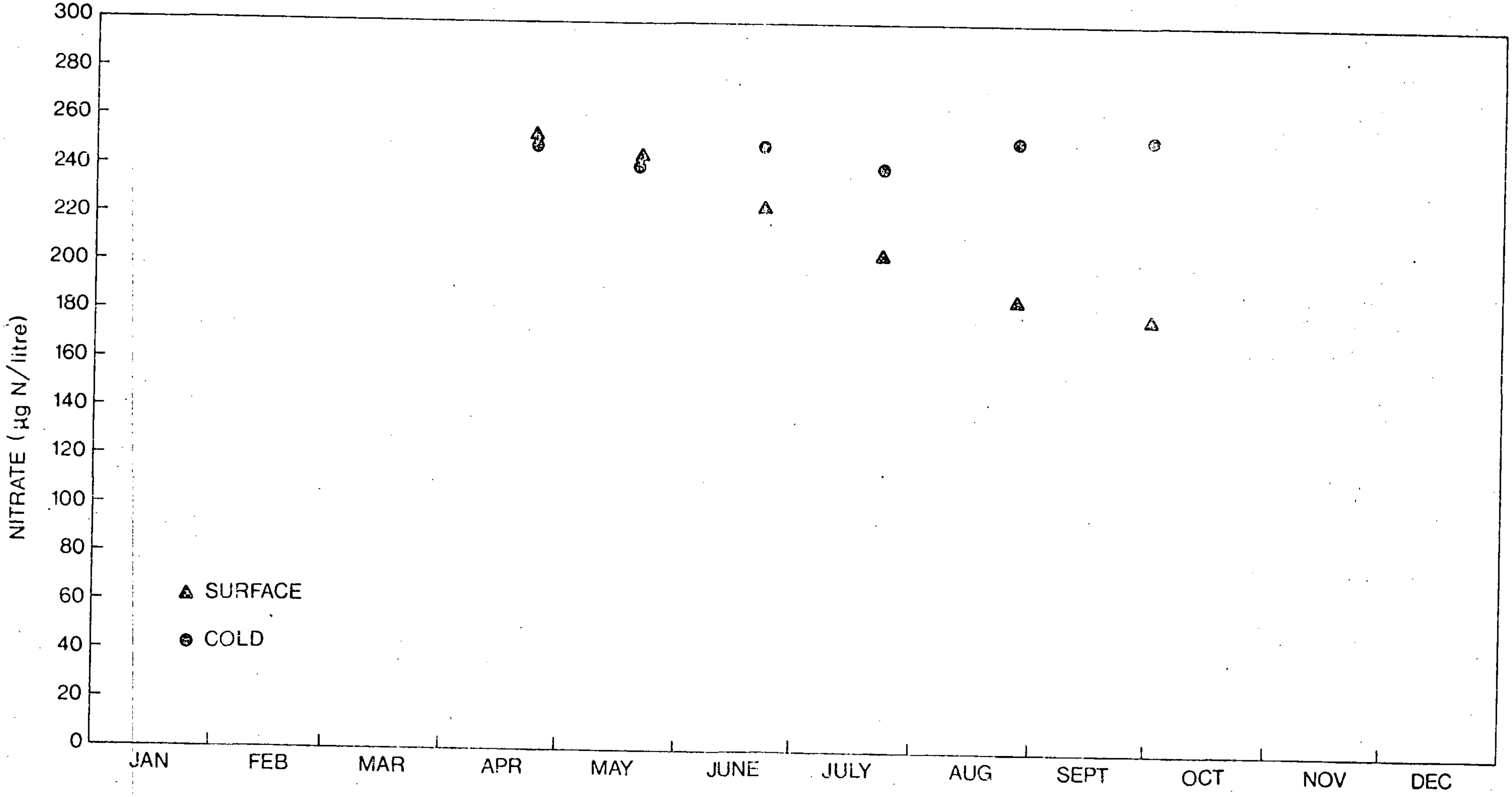


FIGURE 8: NITRATE IN LAKE HURON DURING 1971: MEAN VALUES IN THE COLD WATER-MASS ($T < 5^{\circ}C$), AND MEAN VALUES AT A DEPTH OF 1 METRE, FOR EACH CRUISE OF THE "MARTIN KARLSEN". UNITS ARE MICROGRAMS NITROGEN PER LITRE.

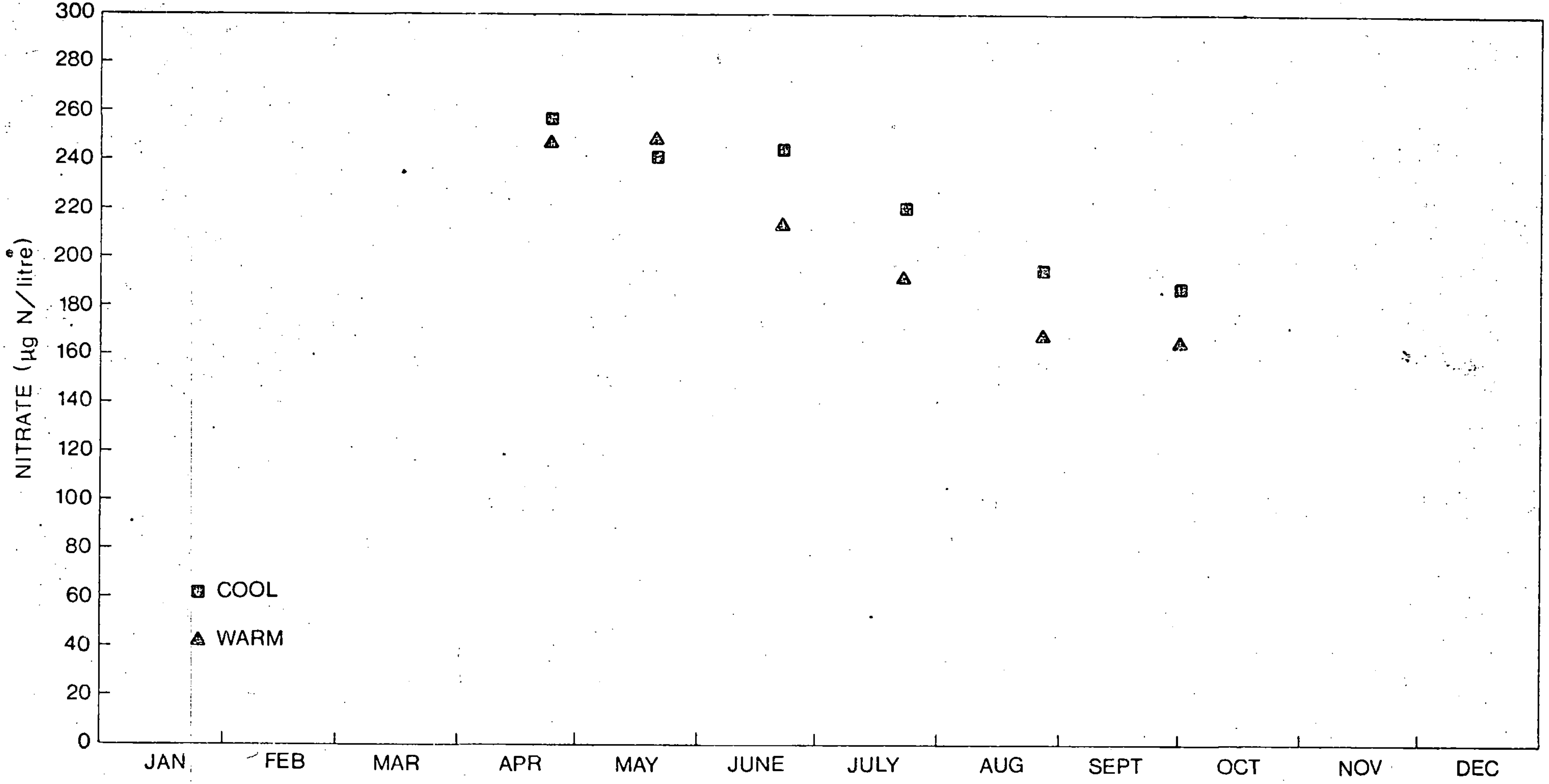


FIGURE 9. NITRATE IN LAKE HURON DURING 1971: MEAN VALUES FOR THE WARM 1-METRE SAMPLES AND MEAN VALUES FOR THE COOL 1-METRE SAMPLES, FOR EACH CRUISE OF THE "MARTIN KARLSEN". UNITS ARE MICROGRAMS NITROGEN PER LITRE.

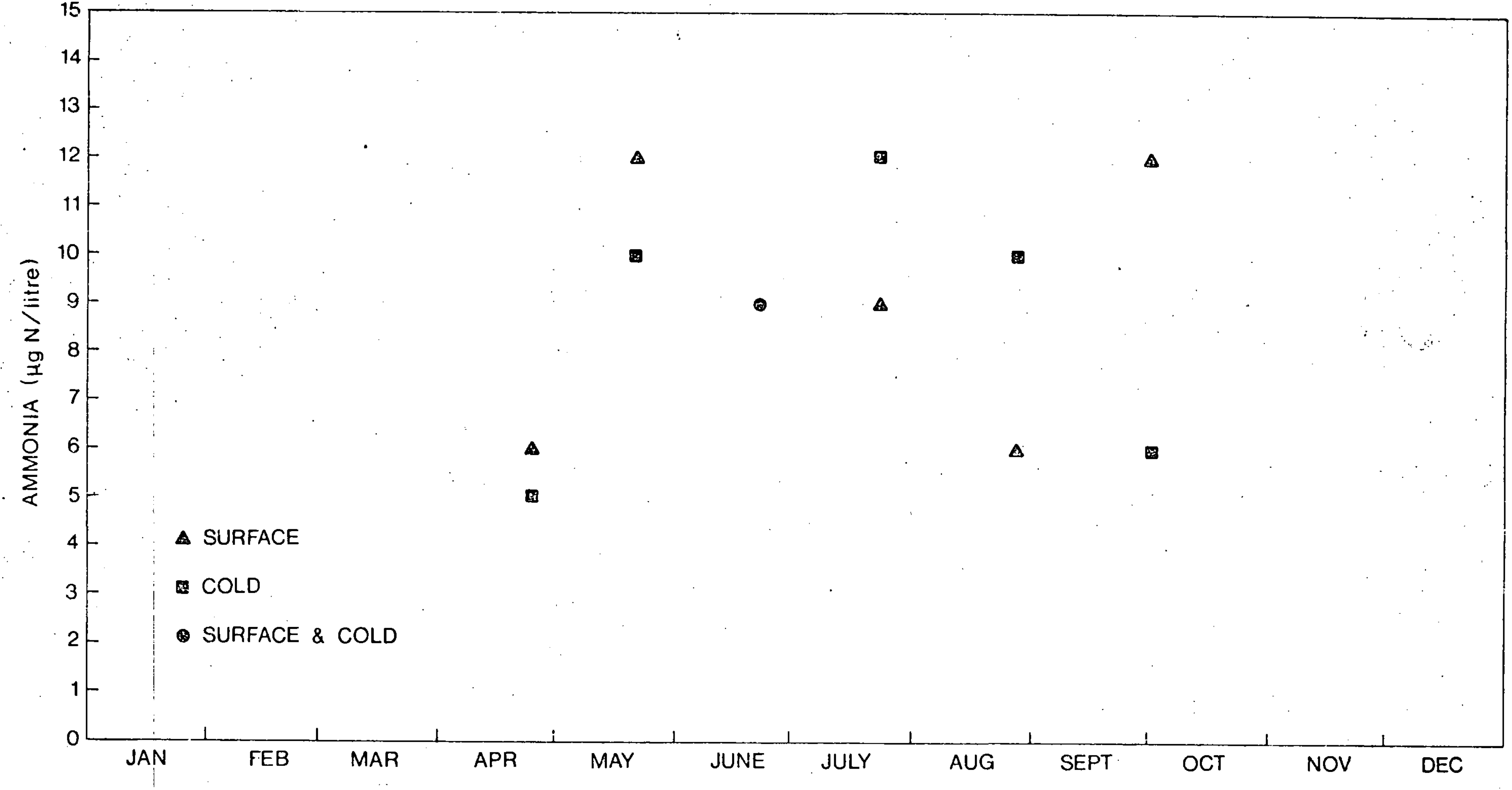


FIGURE 10. AMMONIA IN LAKE HURON DURING 1971: MEAN VALUES IN THE COLD WATER-MASS ($T < 5^{\circ}C$), AND MEAN VALUES AT A DEPTH OF 1 METRE, FOR EACH CRUISE OF THE "MARTIN KARLSEN". UNITS ARE MICROGRAMS NITROGEN PER LITRE.

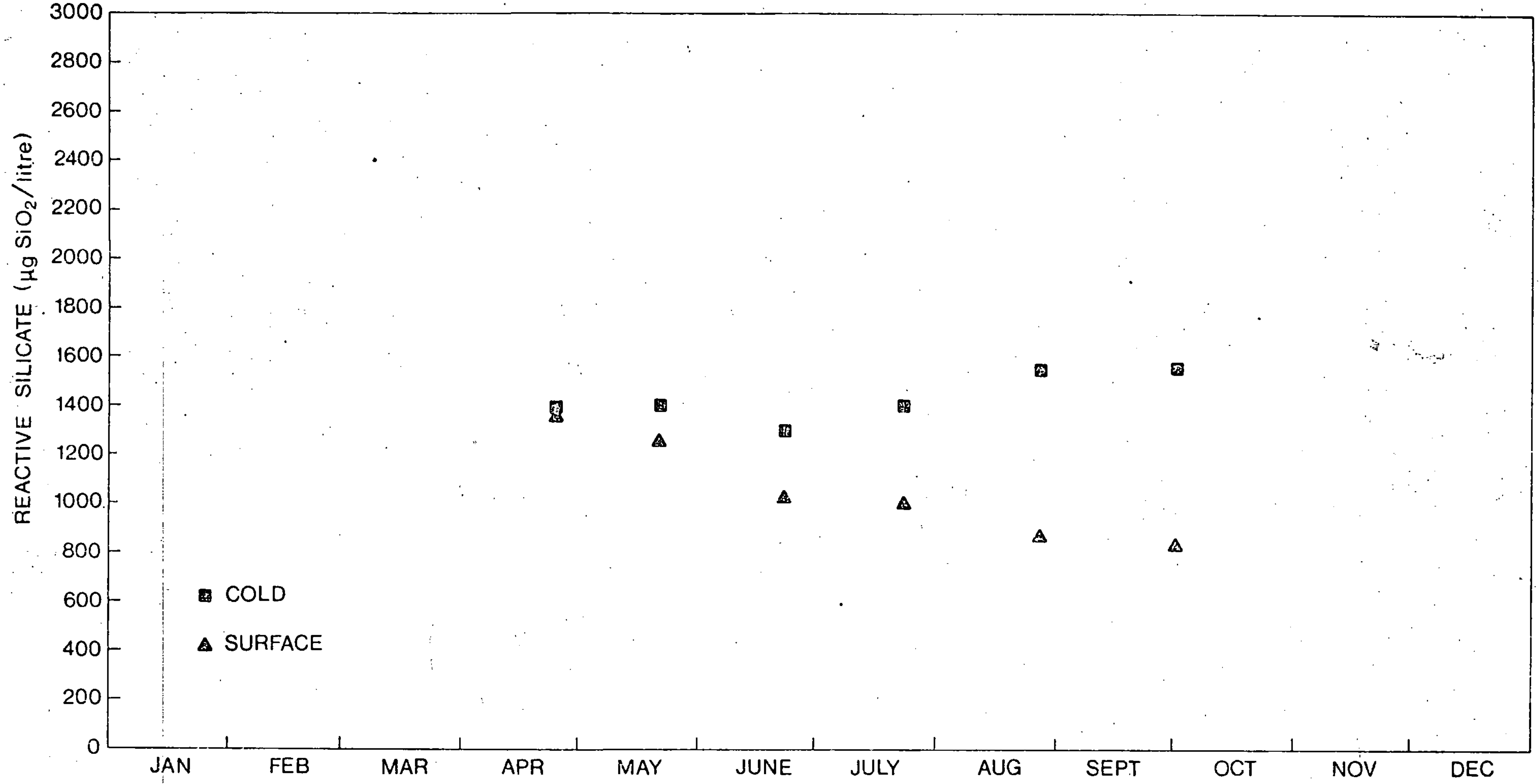


FIGURE 11. REACTIVE SILICATE IN LAKE HURON DURING 1971: MEAN VALUES IN THE COLD WATER-MASS (T < 5°C), AND MEAN VALUES AT A DEPTH OF 1 METRE, FOR EACH CRUISE OF THE "MARTIN KARLSEN". UNITS ARE MICROGRAMS SiO_2 PER LITRE.

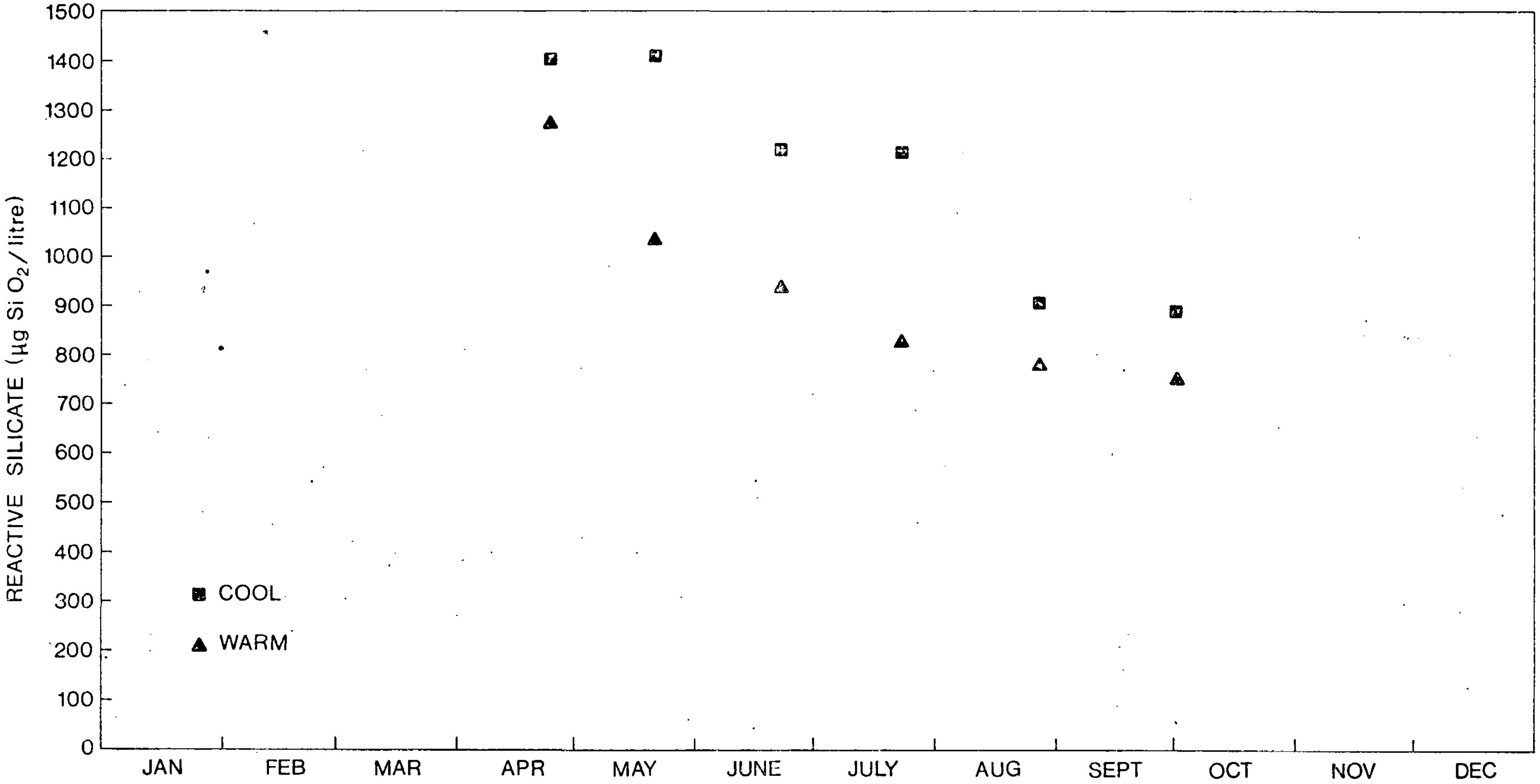


FIGURE 12. REACTIVE SILICATE IN LAKE HURON DURING 1971: MEAN VALUES FOR THE WARM 1-METRE SAMPLES AND MEAN VALUES FOR THE COOL 1-METRE SAMPLES, FOR EACH CRUISE OF THE "MARTIN KARLSEN". UNITS ARE MICROGRAMS SiO_2 PER LITRE.

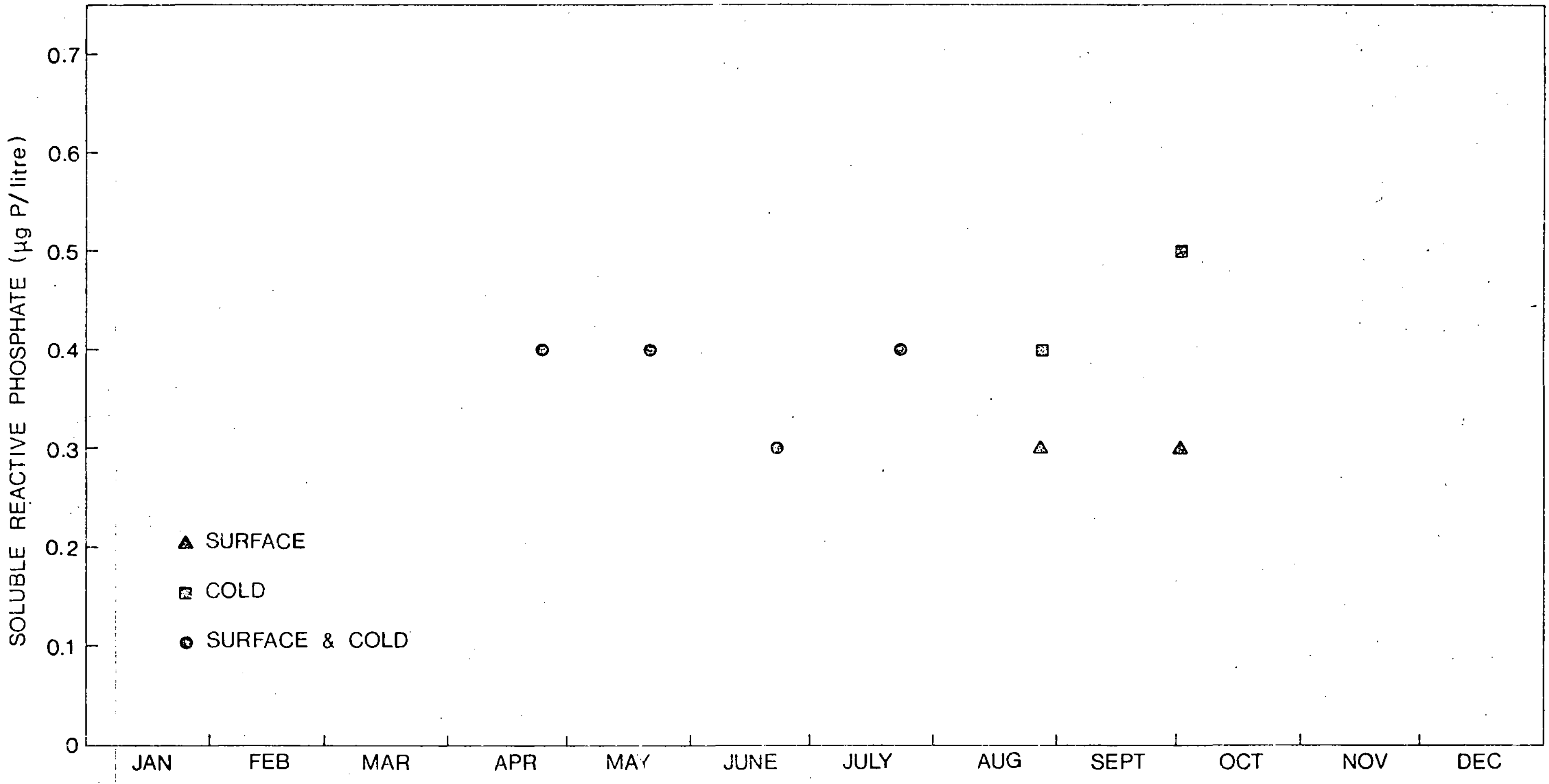


FIGURE 13. SOLUBLE REACTIVE PHOSPHATE IN LAKE HURON DURING 1971: MEAN VALUES IN THE COLD WATER-MASS ($T < 5^{\circ}C$), AND MEAN VALUES AT A DEPTH OF 1 METRE, FOR EACH CRUISE OF THE "MARTIN KARLSEN". UNITS ARE MICROGRAMS PHOSPHORUS PER LITRE.

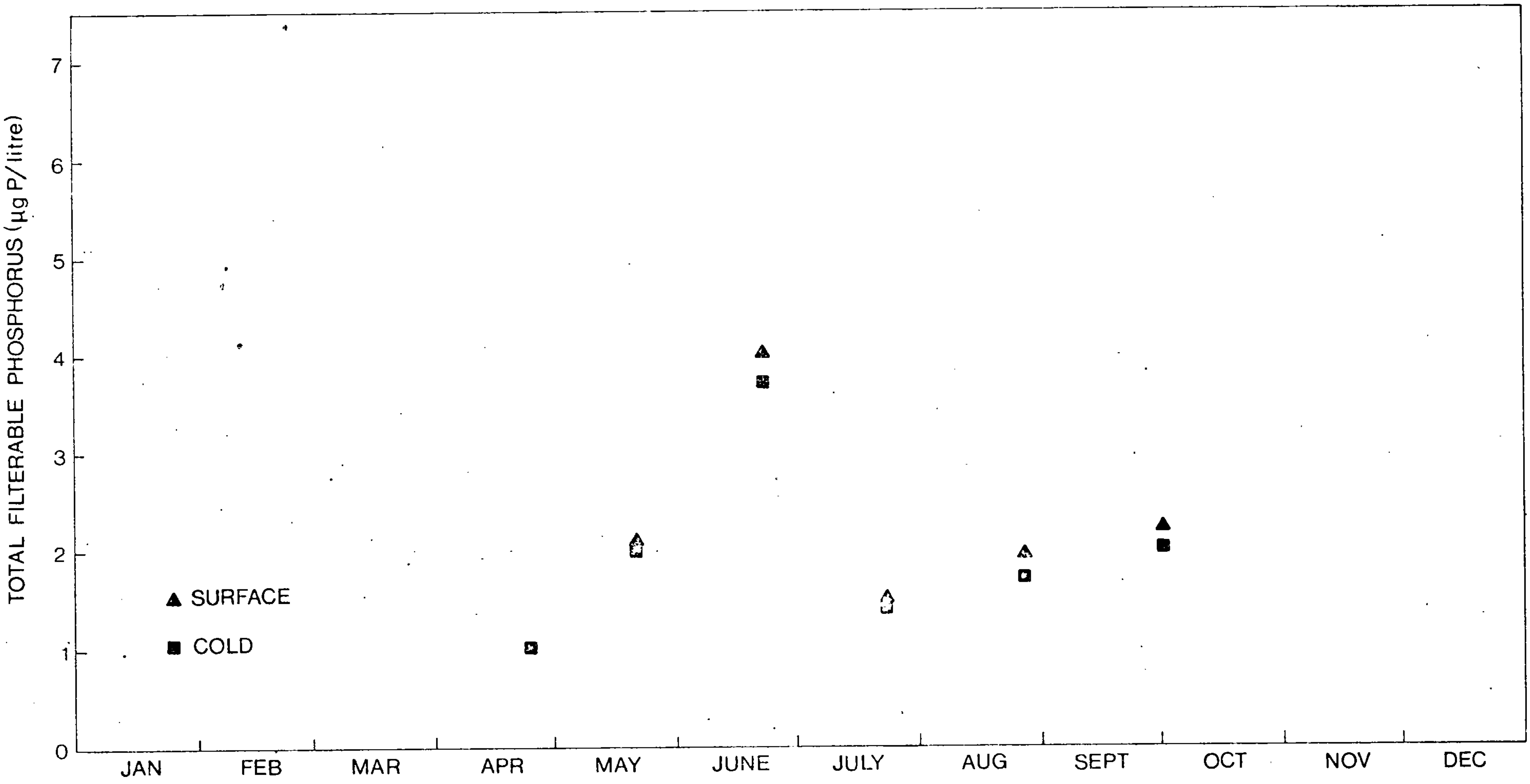


FIGURE 14. TOTAL FILTERABLE PHOSPHORUS IN LAKE HURON DURING 1971: MEAN VALUES IN THE COLD WATER-MASS ($T < 5^{\circ}C$), AND MEAN VALUES AT A DEPTH OF 1 METRE, FOR EACH CRUISE OF THE "MARTIN KARLSEN". UNITS ARE MICROGRAMS PHOSPHORUS PER LITRE.

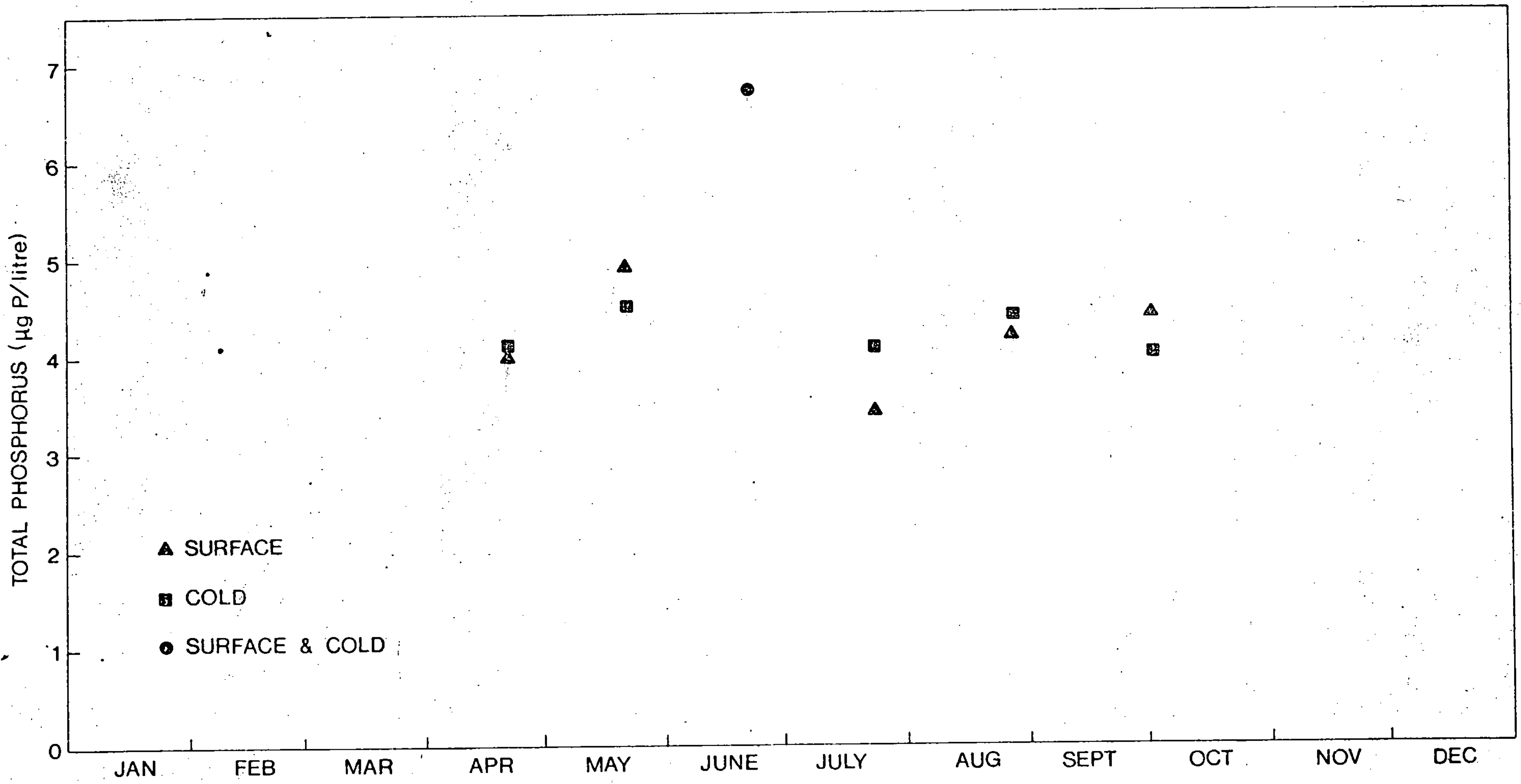


FIGURE 15. TOTAL PHOSPHORUS IN LAKE HURON DURING 1971: MEAN VALUES IN THE COLD WATER-MASS ($T < 5^{\circ}C$), AND MEAN VALUES AT A DEPTH OF 1 METRE, FOR EACH CRUISE OF THE "MARTIN KARLSEN". UNITS ARE MICROGRAMS PHOSPHORUS PER LITRE.