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LAKE ERIE - AN ATLAS DISPLAYING SOME OLDER WATER QUALITY DATA FOR COMPARISONS WITH RECENT DATA

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NATIONAL WATER RESEARCH INSTITUTE
INSTITUT NATIONAL DE RECHERCHE SUR LES EAUX

LAKE ERIE

AN ATLAS DISPLAYING SOME OLDER WATER QUALITY DATA FOR COMPARISONS WITH RECENT DATA

By

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NWRI Contribution Number 01-040

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MANAGEMENT PERSPECTIVE

This Atlas is a compilation of graphs constructed by the author since 1966, and the Atlas portrays Lake Erie water quality parameters related to the eutrophication control problem, mostly in the period 1966 to 1986. This evidence indicates a gradual, decreasing response of conditions in the lake to society's remedial measure of reducing the external loading to Lake Erie of the nutrient element phosphorus.

The Atlas is a reference for comparisons with more recent data. The latter should be examined to find out if Lake Erie is now (2001) too 'oligotrophic' and maybe requiring 'mesotrophication' by careful, active management of the phosphorus loading from the lake-basin's sewage treatment plants.

SOMMAIRE À L'INTENTION DE LA DIRECTION

Cet atlas est une compilation de graphiques exécutés par l'auteur depuis 1966. L'atlas renferme des paramètres de qualité de l'eau ayant trait à la lutte contre l'eutrophisation; la plupart de ces paramètres ont été mesurés au cours de la période de 1966 à 1986. Ces données indiquent une diminution graduelle des réactions observées dans le lac face aux mesures prises pour réduire la charge externe en phosphore.

L'atlas constitue une référence permettant de comparer des données plus récentes. Il faudra examiner ces dernières pour déterminer si le lac Érié est maintenant (en 2001) trop « oligotrophe » ou s'il pourrait profiter d'une « mésotrophisation » grâce à une gestion active et vigilante de la charge en phosphore provenant des stations de traitement des eaux usées qui se trouvent dans le bassin du lac.

ABSTRACT

This Atlas portrays the 'trophic status' of Lake Erie, mostly for the early years of monthly monitoring from 1966 to 1986 by ships and staff of Canada's Environment and Fisheries Departments from their Burlington laboratory called the Canada Centre for Inland Waters.

The structure or distribution of water temperature is thoroughly displayed, because of its importance in relation to water quality and especially the water-masses of well-mixed character.

Secchi transparency was quite variable and had a broad minimum, that is, maximum turbidity, in the 1970's decade.

Data for chlorophyll a in the Central Basin during July and August indicated declining values to 1986, the last year considered. That trend is probably a response to reduced external loading of phosphorus from urban and agricultural areas, which was the goal of the 1972 Great Lakes Water Quality Agreement between the United States and Canada.

The author's diagrams of distributions of dissolved oxygen show trends in the vulnerable Central and Eastern hypolimnions. A recovery of dissolved oxygen by 1984 is not revealed.

Particulate organic carbon, particulate nitrogen, and particulate phosphorus all declined (up to 1984), confirming the observed changes in the chlorophyll a data.

The measurements of 'total phosphorus' in water samples showed no change in the mid-summer values up to 1984. The early work by Dr. Julian Williams of the National Water Research Institute, on apatite and related minerals in Lake Erie sediments, could perhaps be extended to the water column. Mineral equilibria could be stabilizing the phosphorus concentrations in some fractions.

RÉSUMÉ

Cet atlas présente un tableau de l'état trophique du lac Érié, surtout pendant les premières années de surveillance mensuelle, de 1966 à 1986, effectuée par des navires et le personnel d'Environnement Canada et de Pêches et Océans Canada, à partir de leur laboratoire appelé le Centre canadien des eaux intérieures, situé à Burlington.

La structure ou la distribution de la température de l'eau est fidèlement présentée à cause de son importance en rapport avec la qualité de l'eau et surtout avec les masses d'eau homogènes.

La transparence mesurée au disque de Secchi était assez variable et présentait un large minimum, qui correspond à la turbidité maximale observée au cours des années 1970.

Les données relatives à la teneur en chlorophylle a dans le bassin central durant juillet et août indiquent une diminution constante jusqu'en 1986, la dernière année considérée. Cette tendance est probablement le résultat de la réduction des charges en phosphore externe à partir des zones urbaines et agricoles; c'était d'ailleurs l'objectif de l'Accord relatif à la qualité de l'eau dans les Grands Lacs qui a été conclu entre le Canada et les États-Unis en 1972.

Les diagrammes de l'auteur concernant la distribution de l'oxygène dissous montrent certaines tendances dans les hypolimnions du centre et de l'est du bassin. On n'a pas observé de rétablissement de l'oxygène dissous jusqu'en 1984.

Le carbone organique particulaire, l'azote particulaire et le phosphore particulaire ont tous diminué (jusqu'en 1984), ce qui confirme les changements observés dans les concentrations de chlorophylle a.

Les mesures du « phosphore total » dans les échantillons d'eau n'ont révélé aucun changement au cours de l'été jusqu'en 1984. Les travaux de pionnier de Julian Williams de l'Institut national de recherche sur les eaux, qui portaient sur l'apatite et des minéraux apparentés dans les sédiment du Lac Érié, pourraient probablement être appliqués à la colonne d'eau. Les minéraux en équilibre pourraient peut-être stabiliser les concentrations de phosphore dans certaines fractions.

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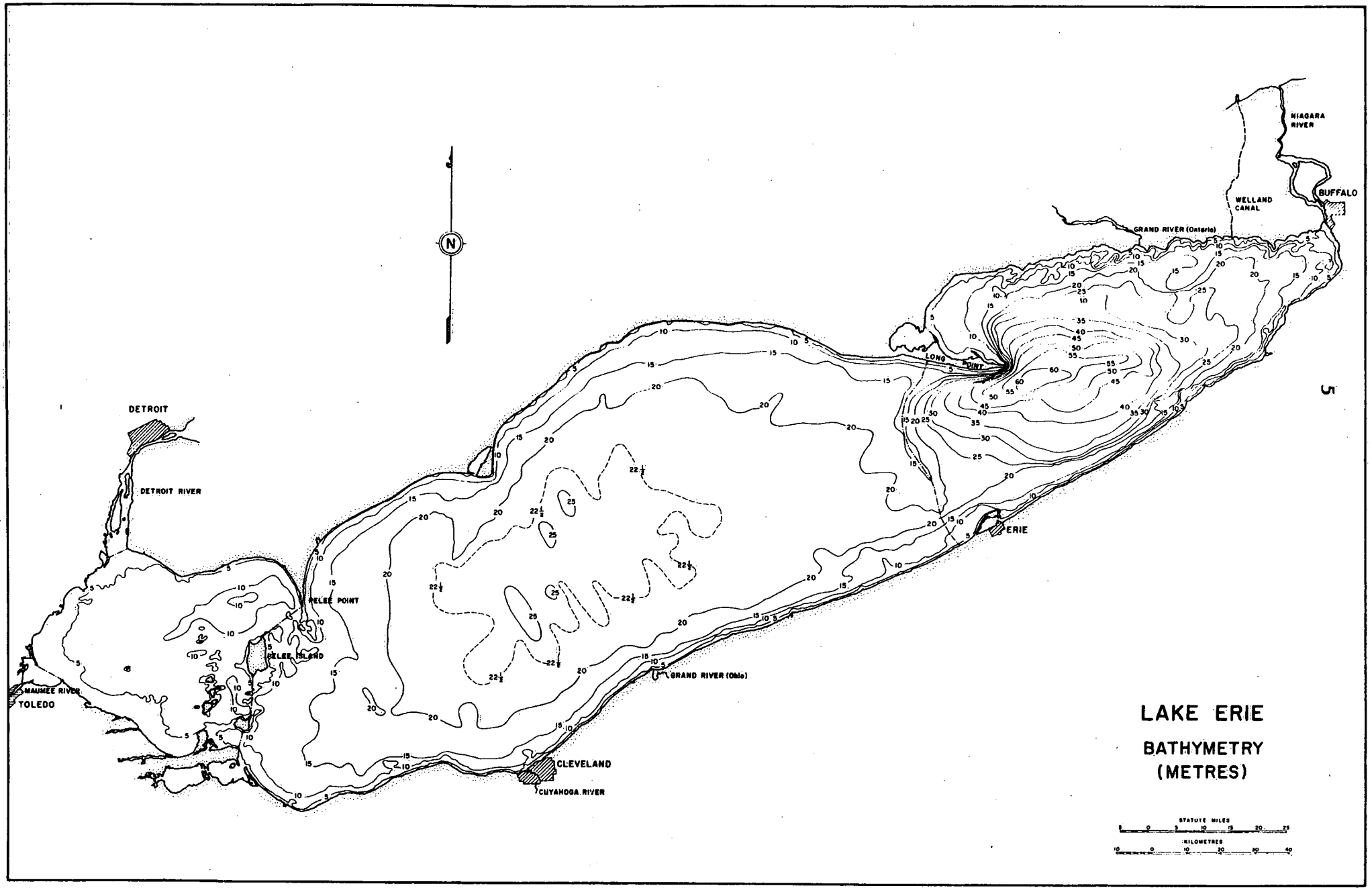
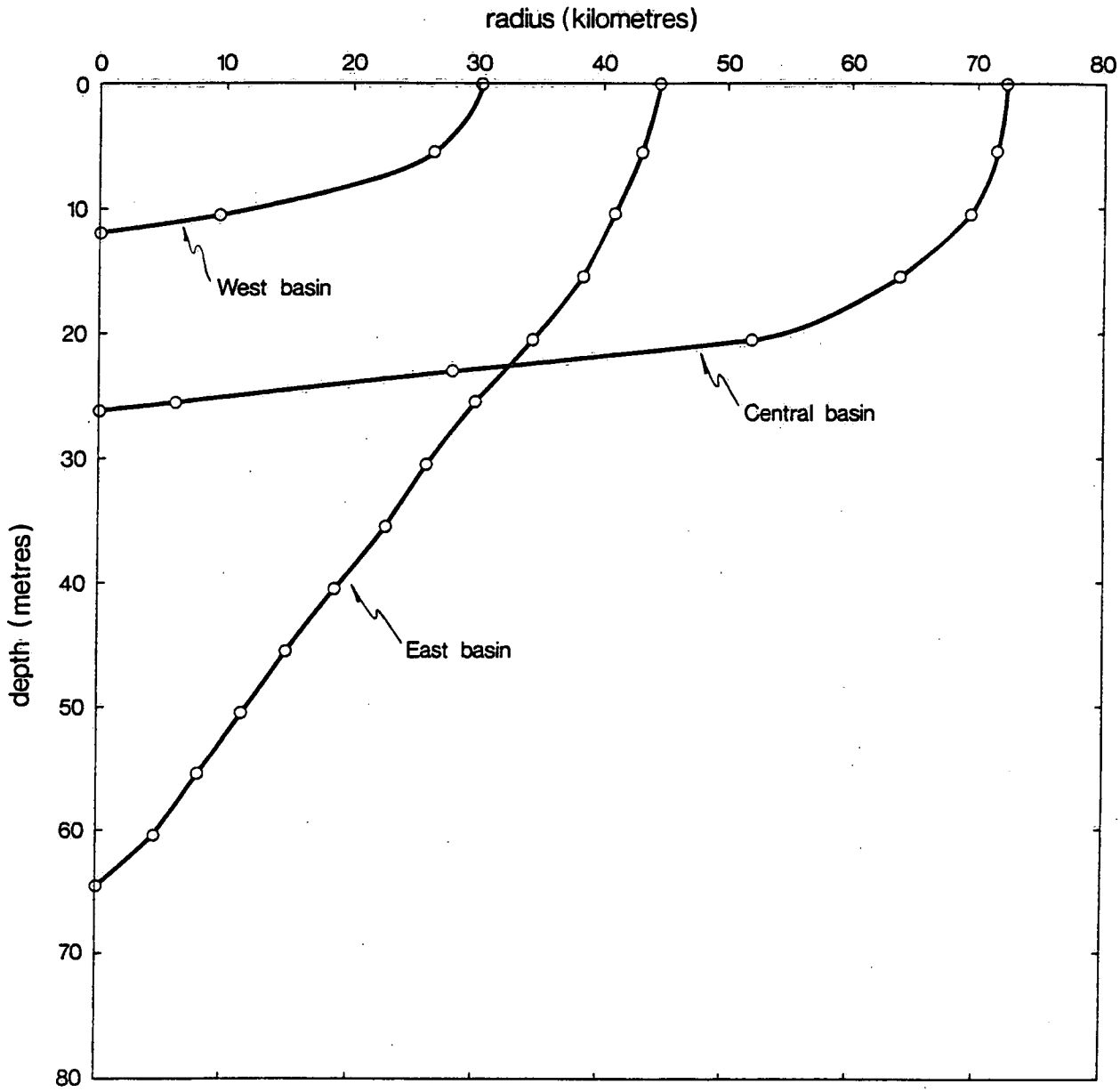
INTRODUCTION

I constructed these diagrams over the years 1966 to 1996 while I was employed at the Canada Centre for Inland Waters, whose research ships have continued to monitor Great Lakes waters, and whose laboratories have diligently measured key constituents of the water samples.

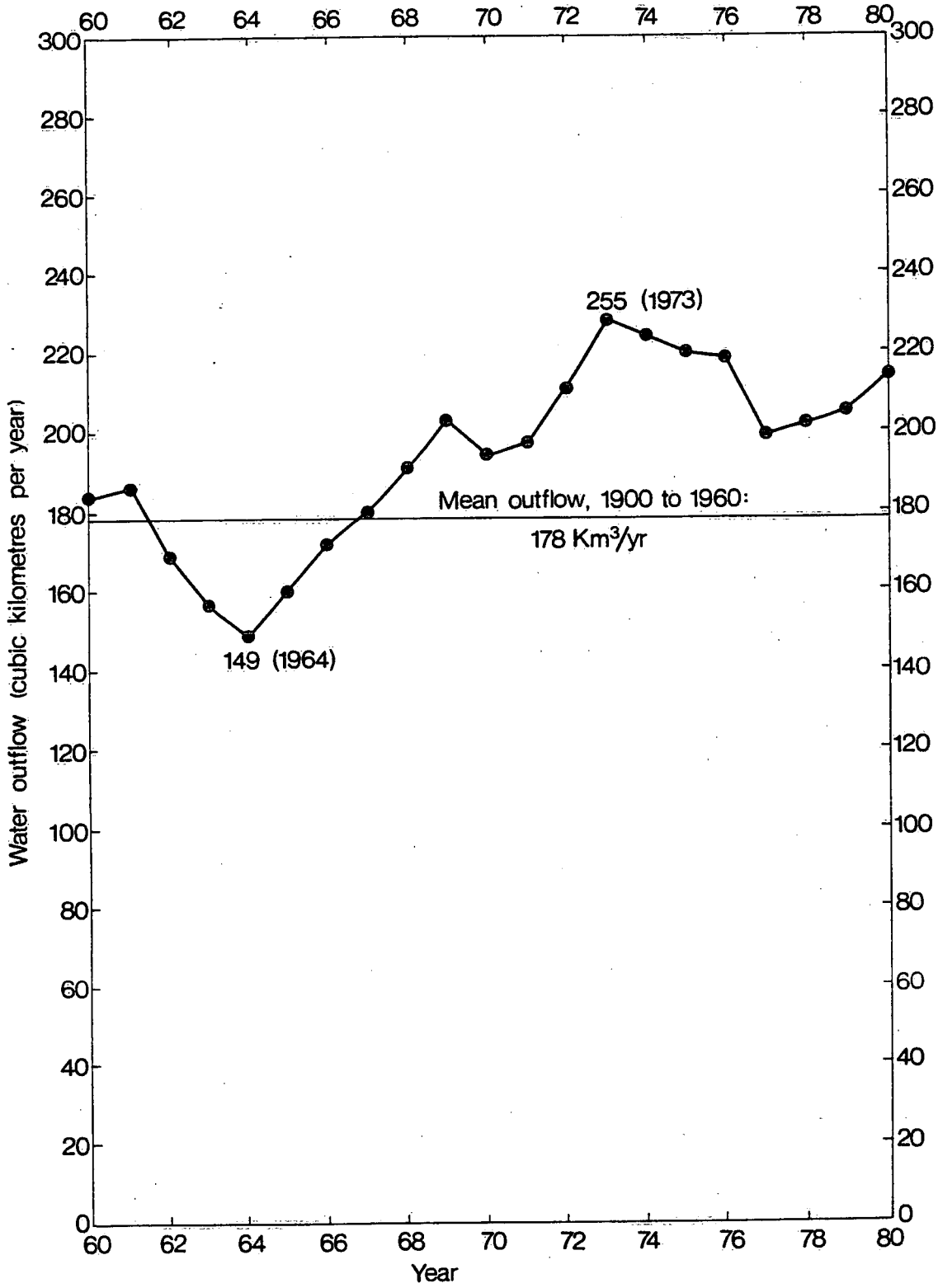
The Great Lakes data-bank of the National Water Research Institute is known as the STAR file — it continues to be a vast data set relatively untapped by interpreters. Here I offer the viewer my own contributions toward the Lake Erie data display.

BATHYMETRY, ETC.

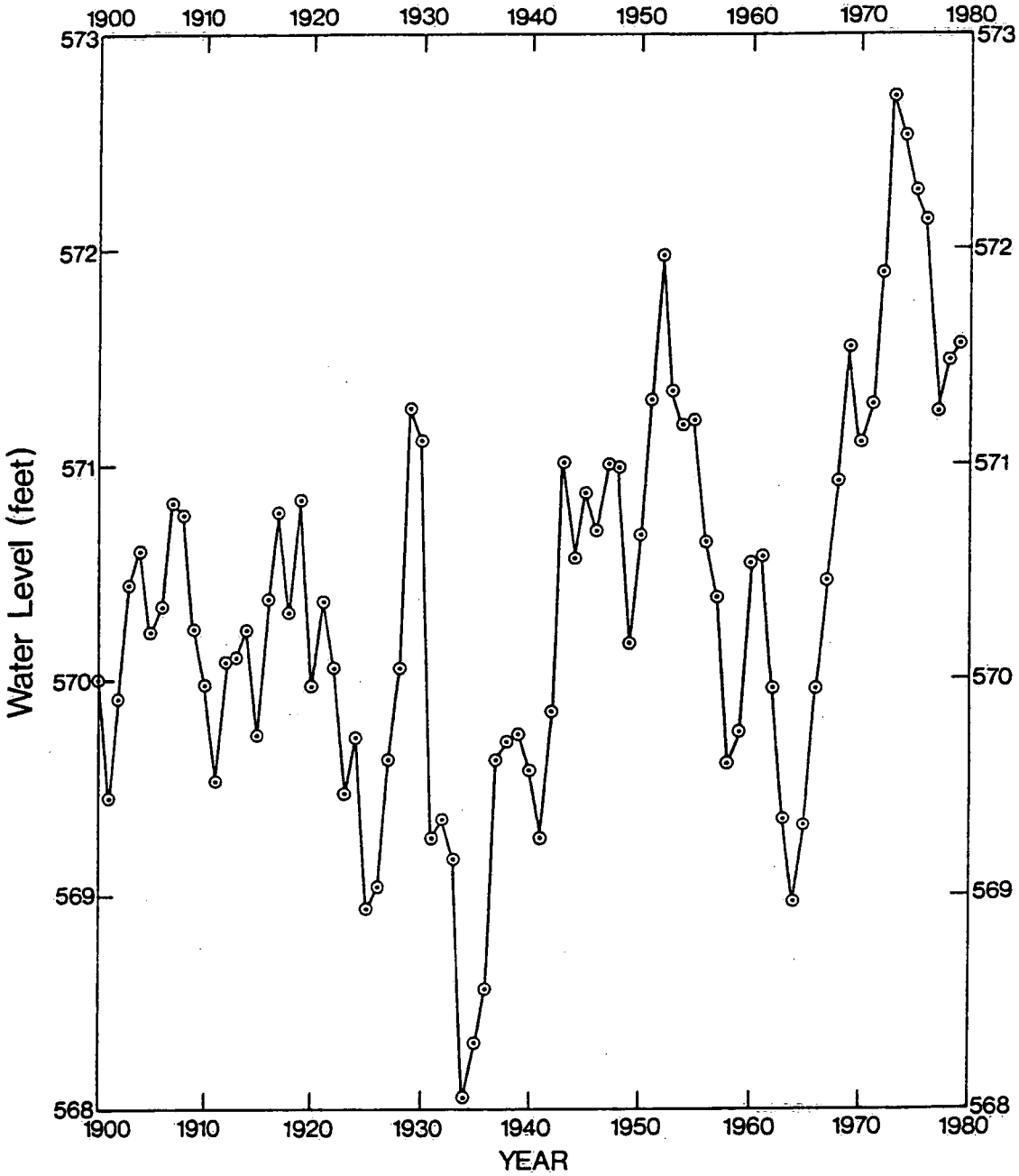

LAKE ERIE
BATHYMETRY
(METRES)
N
DETROIT
DETROIT RIVER
PELEE POINT
PELEE ISLAND
MAUMEE RIVER
TOLEDO
CLEVELAND
CUYAHOGA RIVER
GRAND RIVER (Ohio)
ERIE
LONG POINT
GRAND RIVER (Ontario)
WELLAND CANAL
NIAGARA RIVER
BUFFALO
STATUTE MILES
KILOMETRES



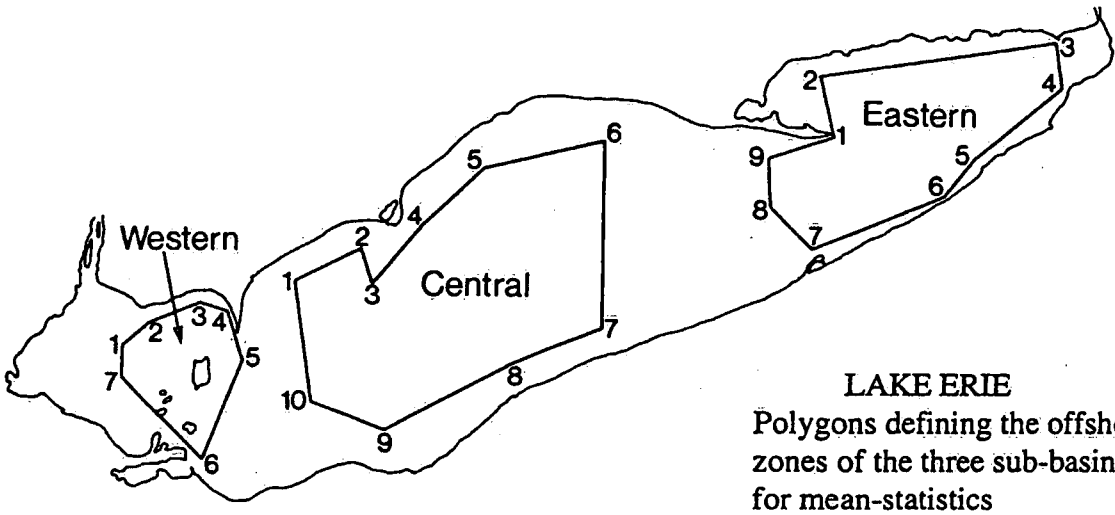
GENERALIZED PROFILES OF THE LAKE BOTTOM FOR THE THREE BASINS OF LAKE ERIE.



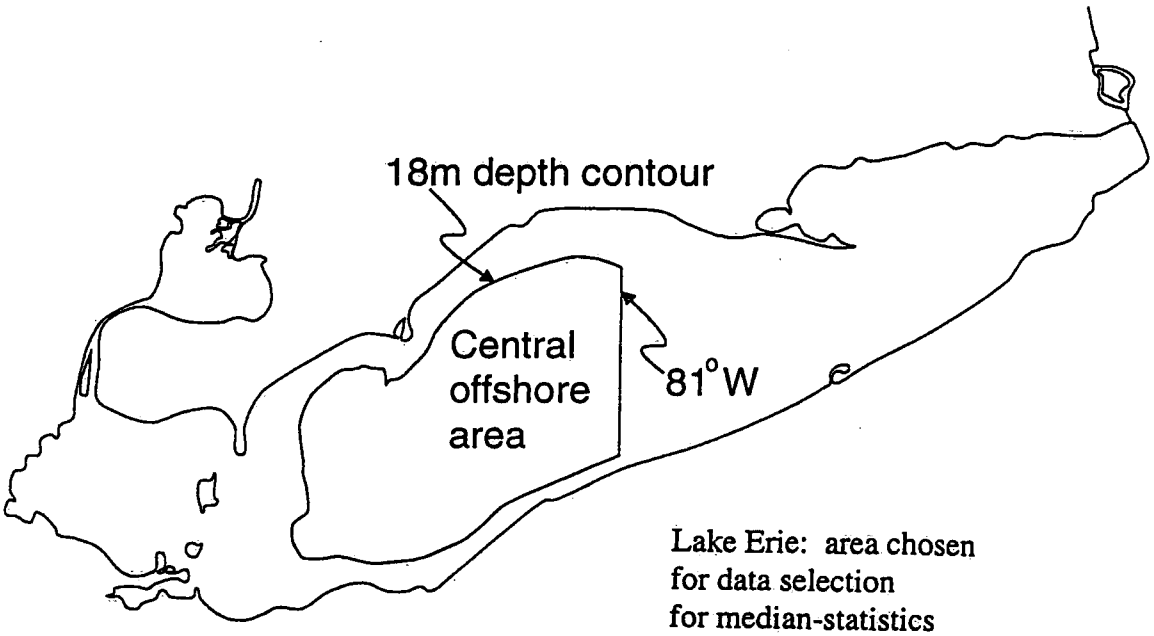
Lake Erie, water outflows (Km^3/yr), 1960 - 1980.



Lake Erie: Annual average water levels (in feet, International Great Lakes Datum, 1955; measured at Cleveland)

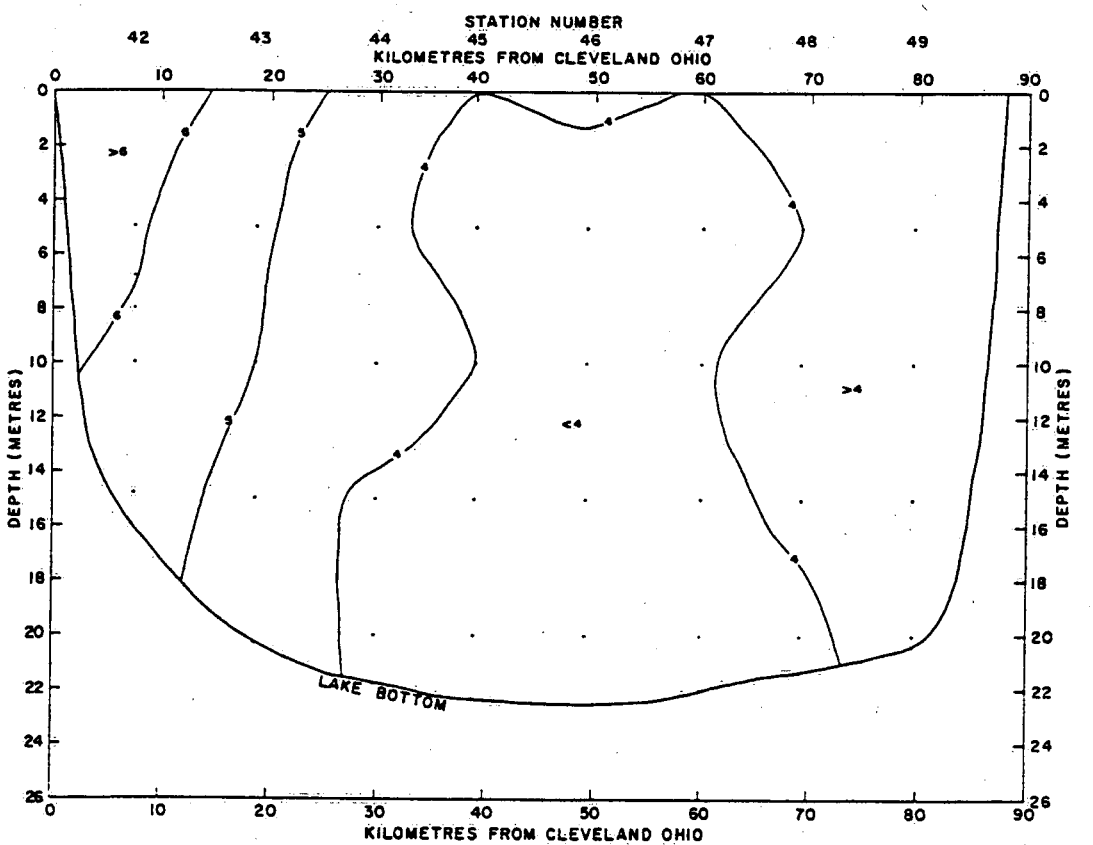


LAKE ERIE
Polygons defining the offshore zones of the three sub-basins for mean-statistics

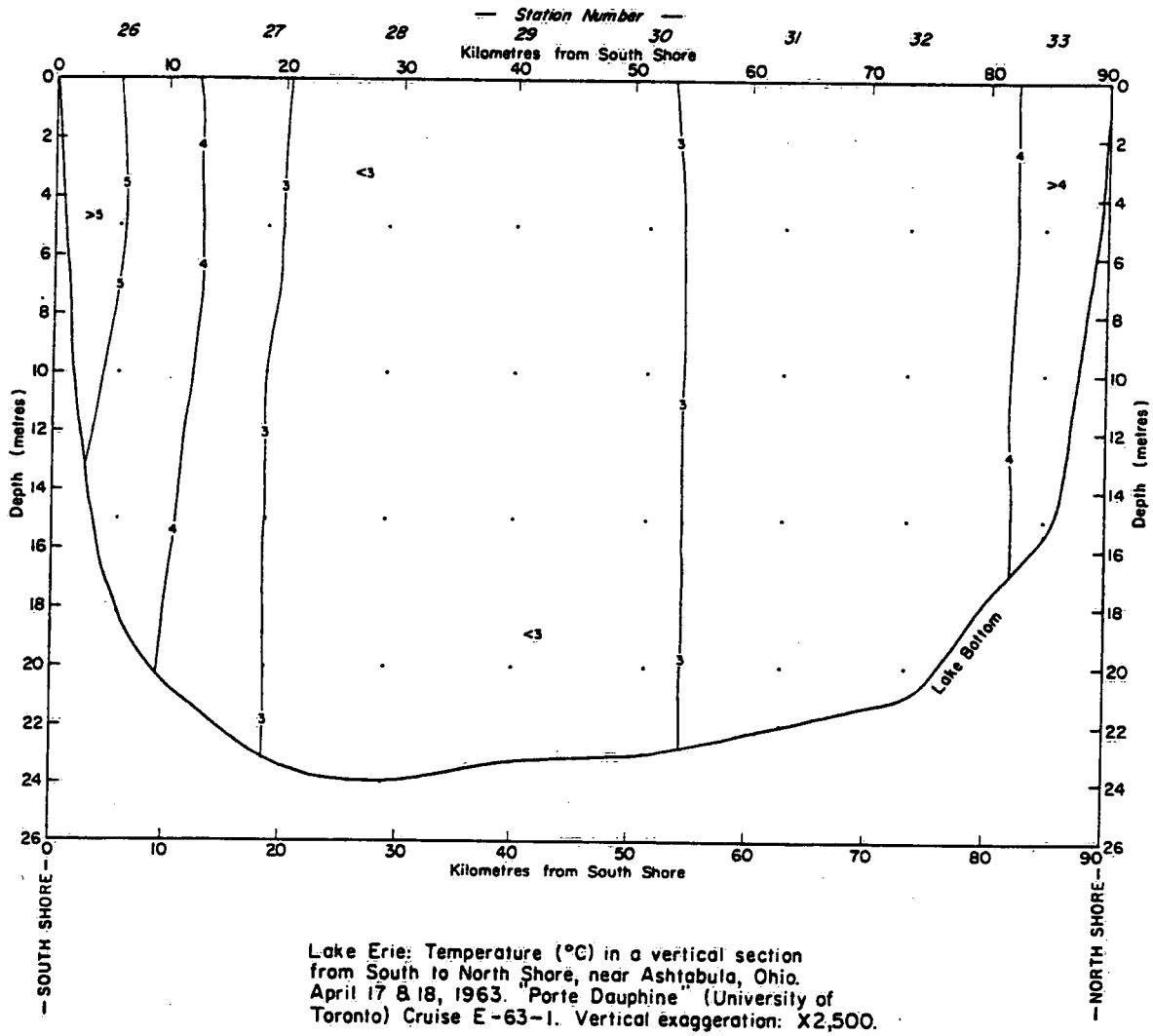


Lake Erie: area chosen
for data selection
for median-statistics

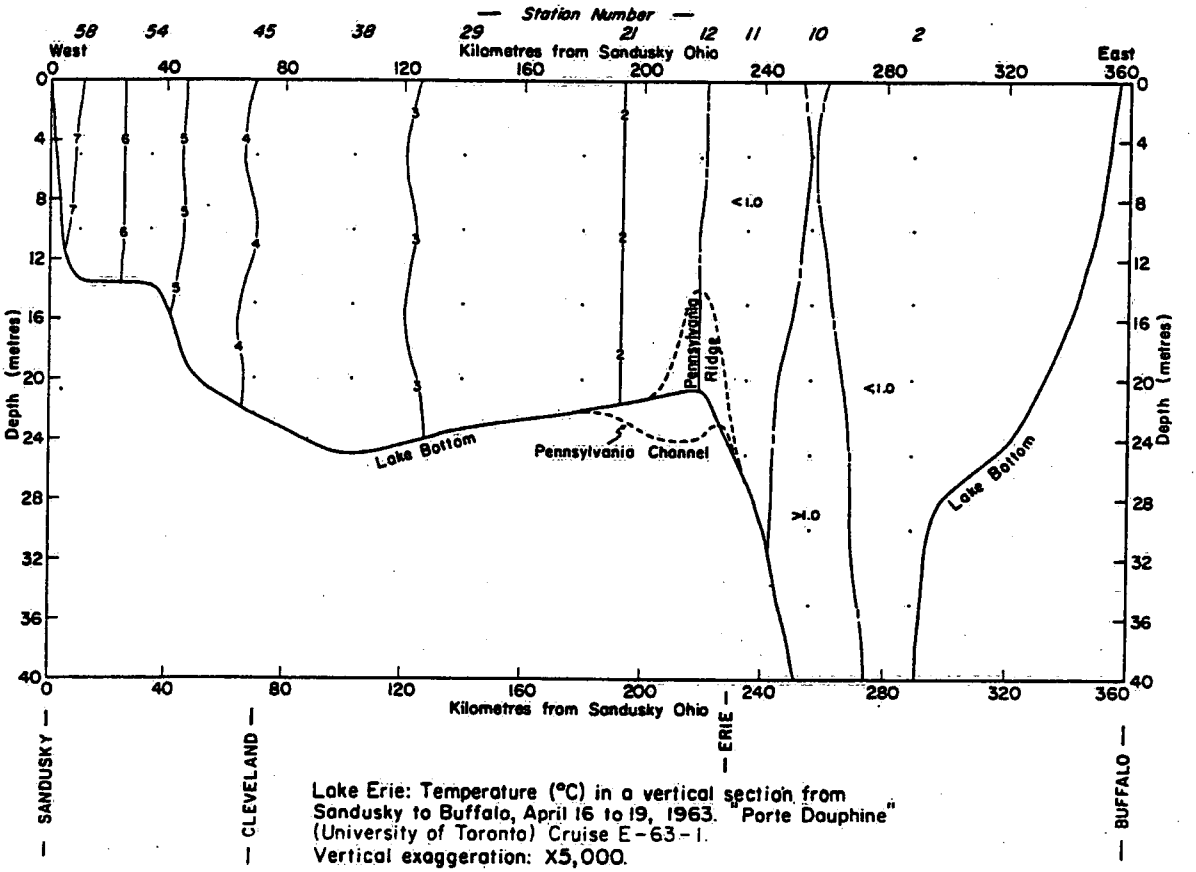
TEMPERATURE



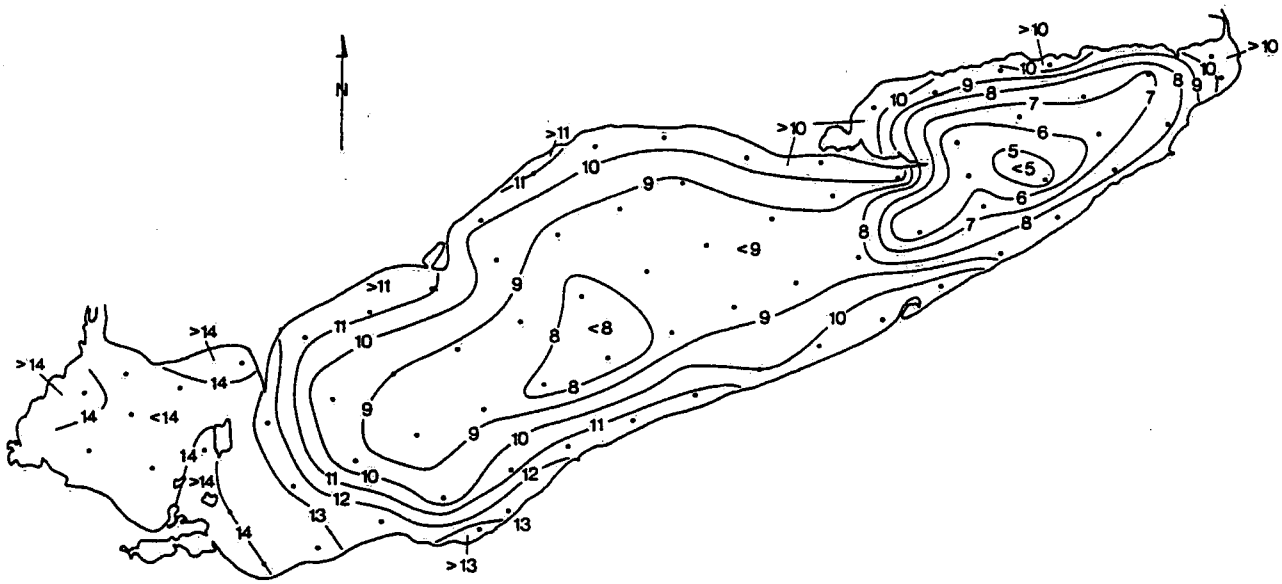
LAKE ERIE TEMPERATURE (°C) IN A VERTICAL SECTION
FROM CLEVELAND TO ERIEAU, APRIL 18 & 19, 1963.
"PORTE DAUPHINE" (UNIVERSITY OF TORONTO) CRUISE E-63-1
VERTICAL EXAGGERATION X 2,500.



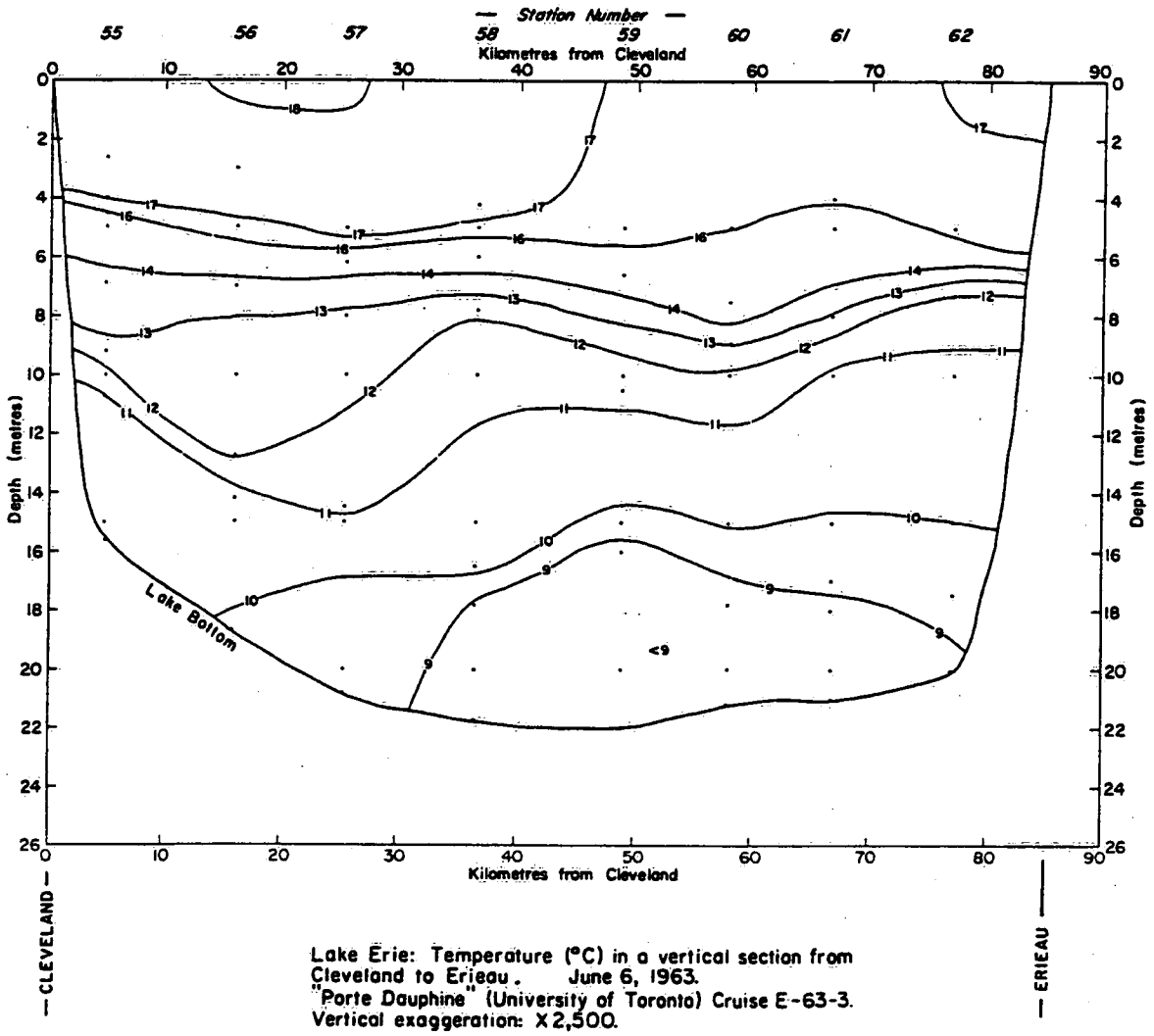
Lake Erie: Temperature (°C) in a vertical section from South to North Shore, near Ashtabula, Ohio. April 17 & 18, 1963. "Porte Dauphine" (University of Toronto) Cruise E-63-1. Vertical exaggeration: X2,500.



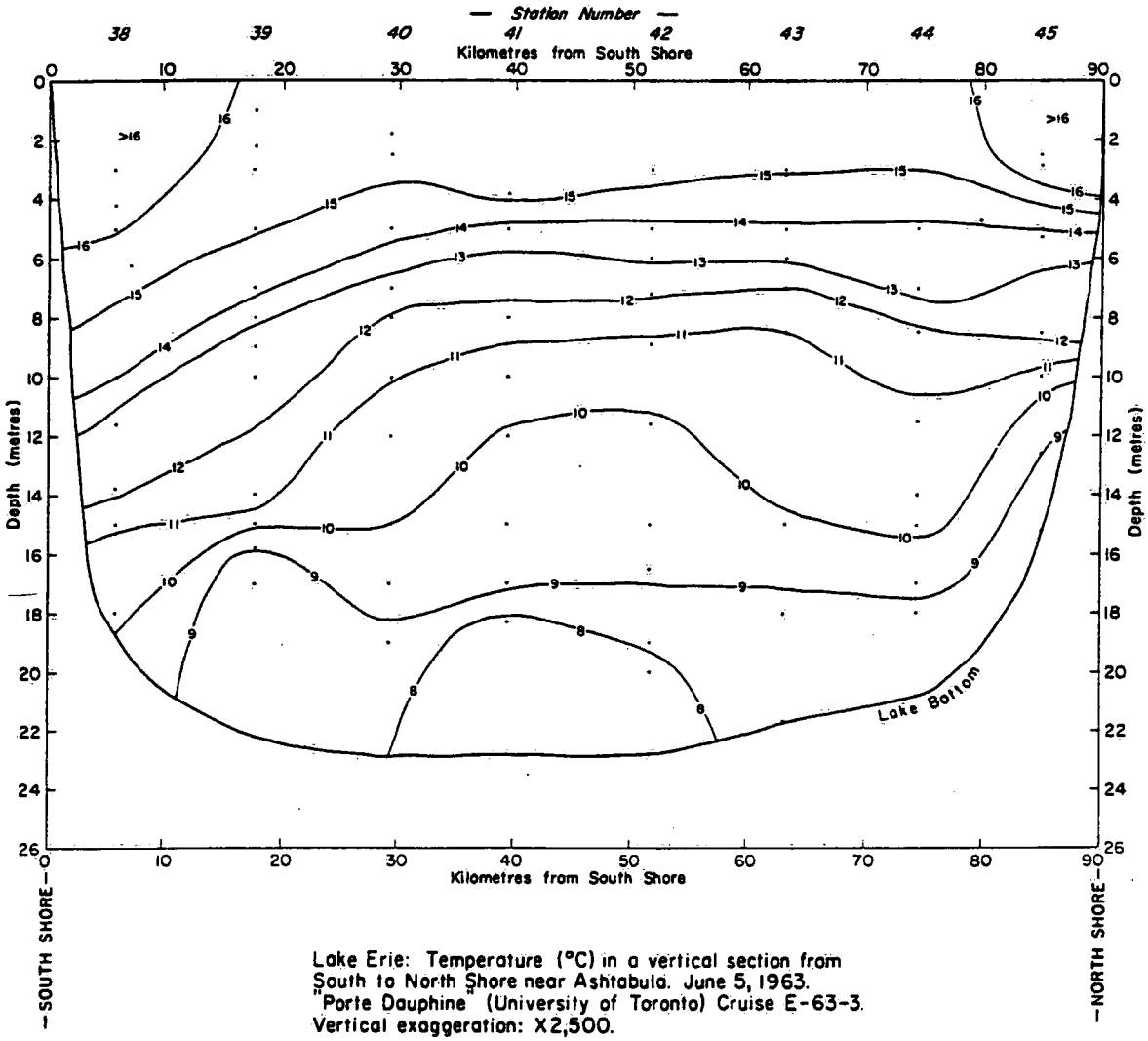
Lake Erie: Temperature (°C) in a vertical section from Sandusky to Buffalo, April 16 to 19, 1963. "Porte Dauphine" (University of Toronto) Cruise E-63-1. Vertical exaggeration: X5,000.



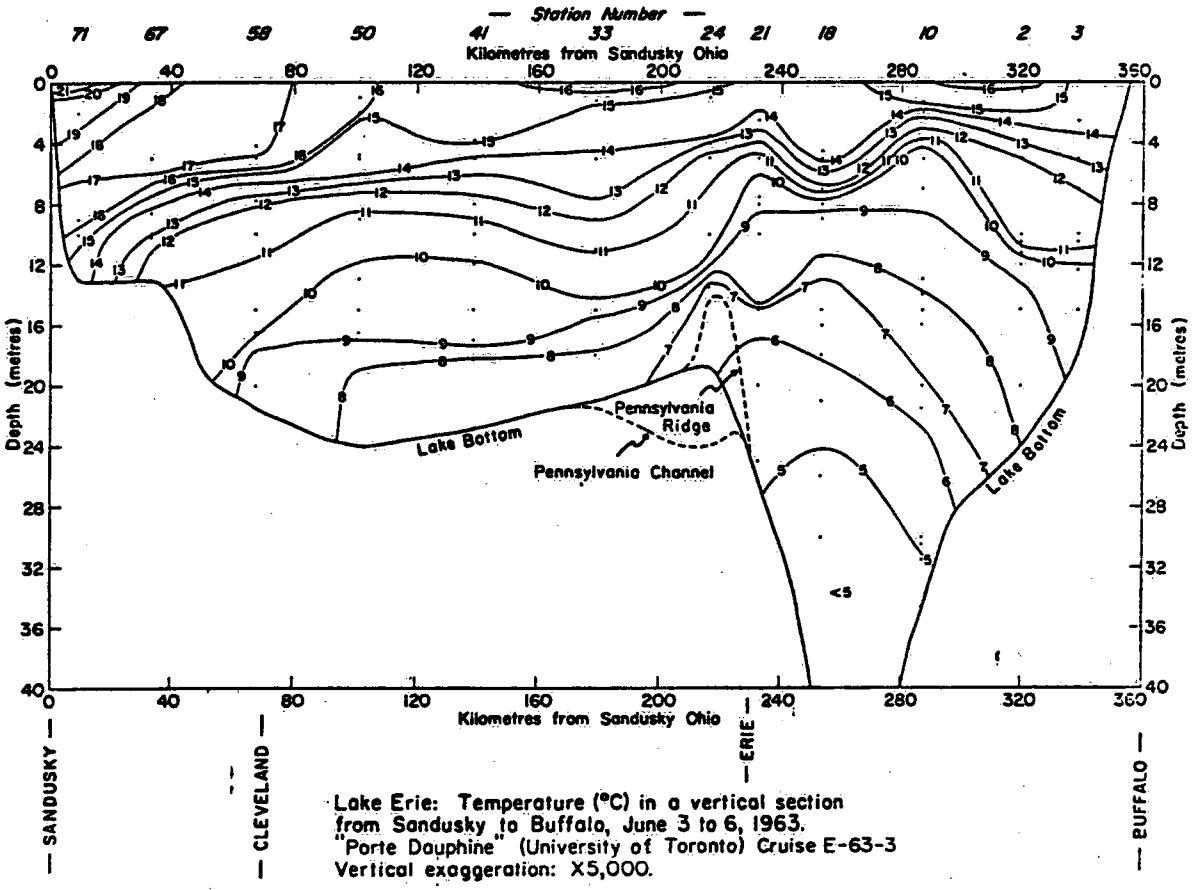
Temperatures of Lake Erie, 1 metre depth,
May 17 to 22, 1968, CCIW vessel "Theron".



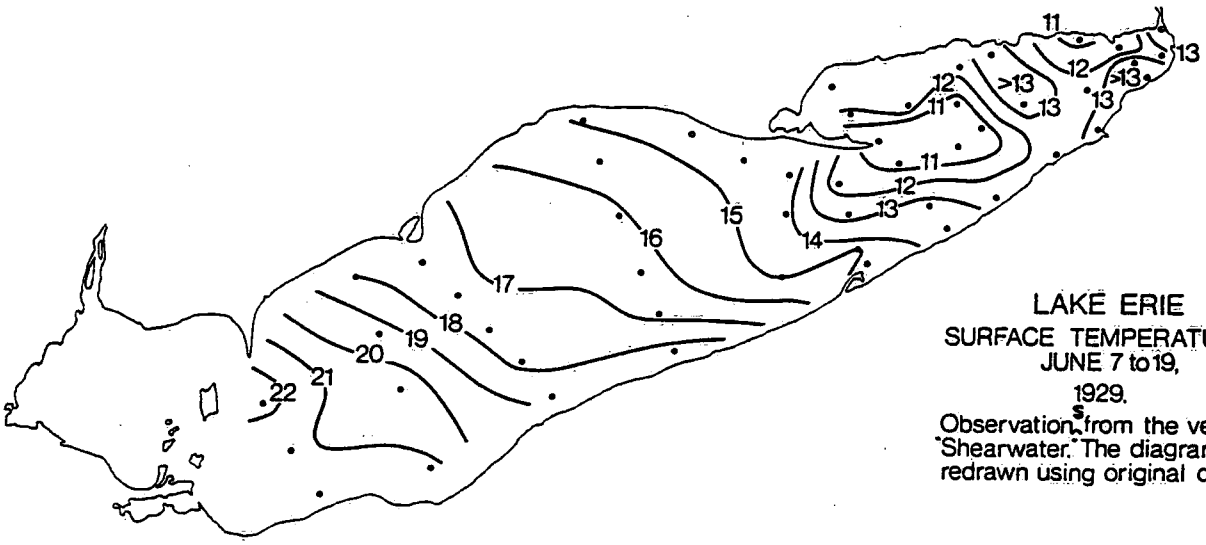
Lake Erie: Temperature (°C) in a vertical section from Cleveland to Erieau. June 6, 1963.
"Porte Dauphine" (University of Toronto) Cruise E-63-3.
Vertical exaggeration: X 2,500.



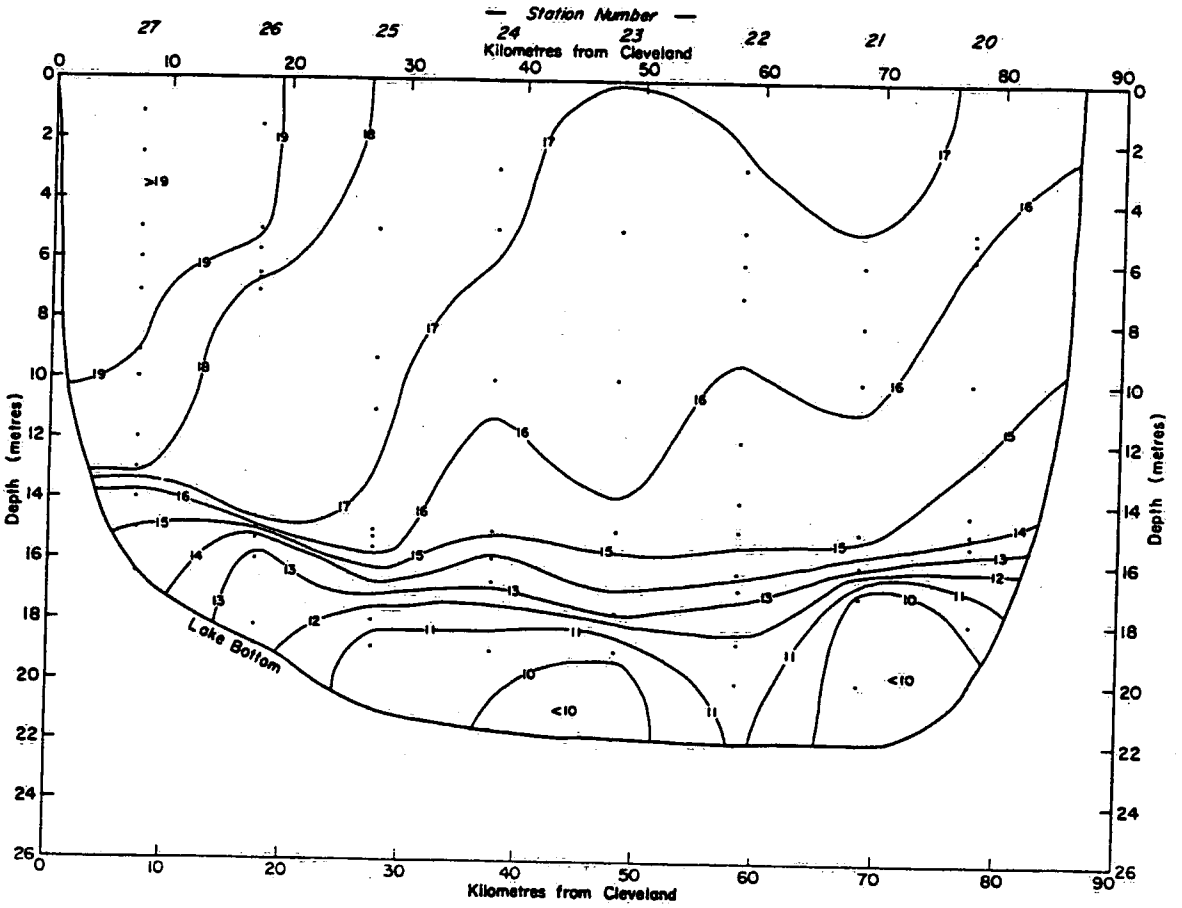
Lake Erie: Temperature (°C) in a vertical section from South to North Shore near Ashtabula. June 5, 1963. "Porte Dauphine" (University of Toronto) Cruise E-63-3. Vertical exaggeration: X2,500.



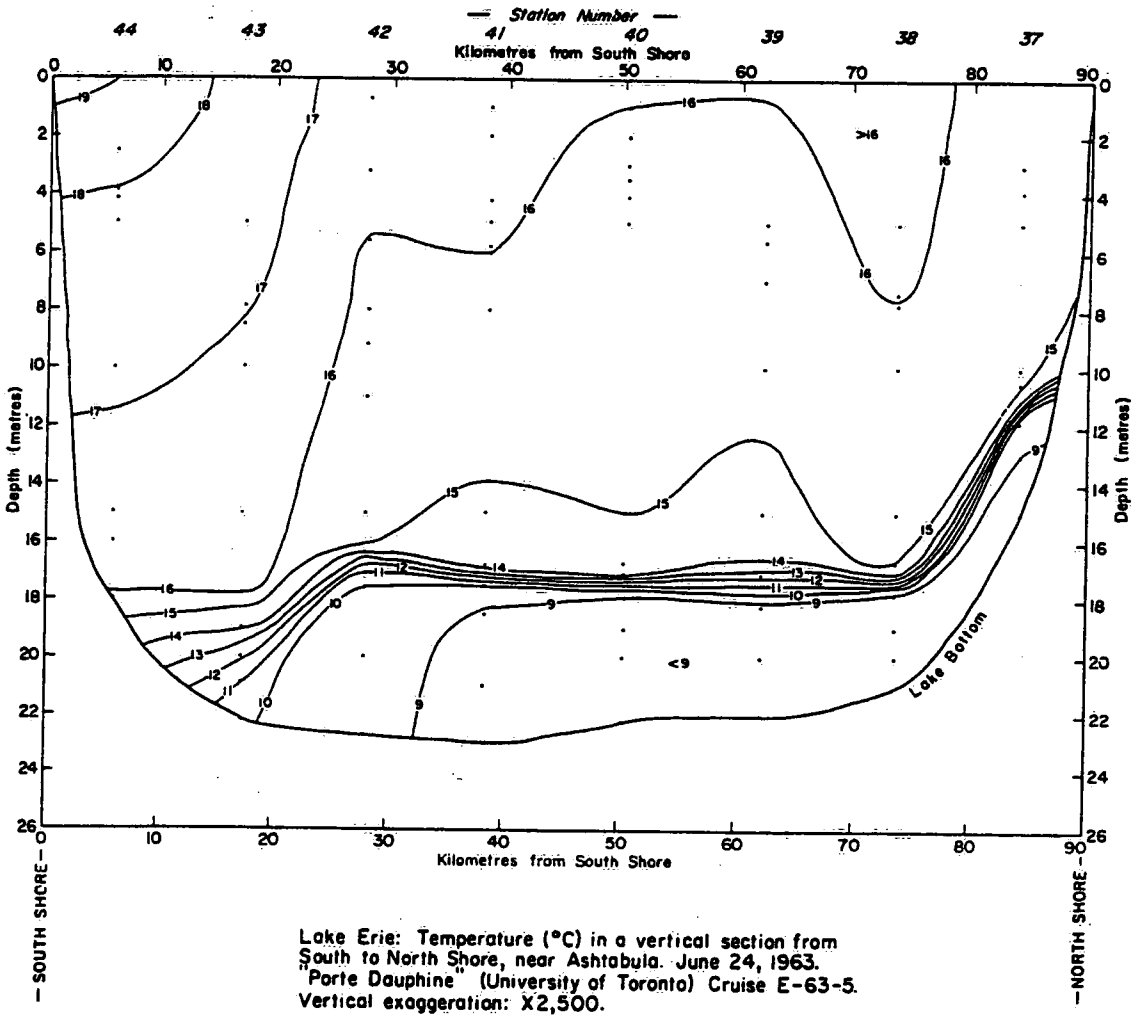
Lake Erie: Temperature (°C) in a vertical section from Sandusky to Buffalo, June 3 to 6, 1963. "Porte Dauphine" (University of Toronto) Cruise E-63-3 Vertical exaggeration: X5,000.



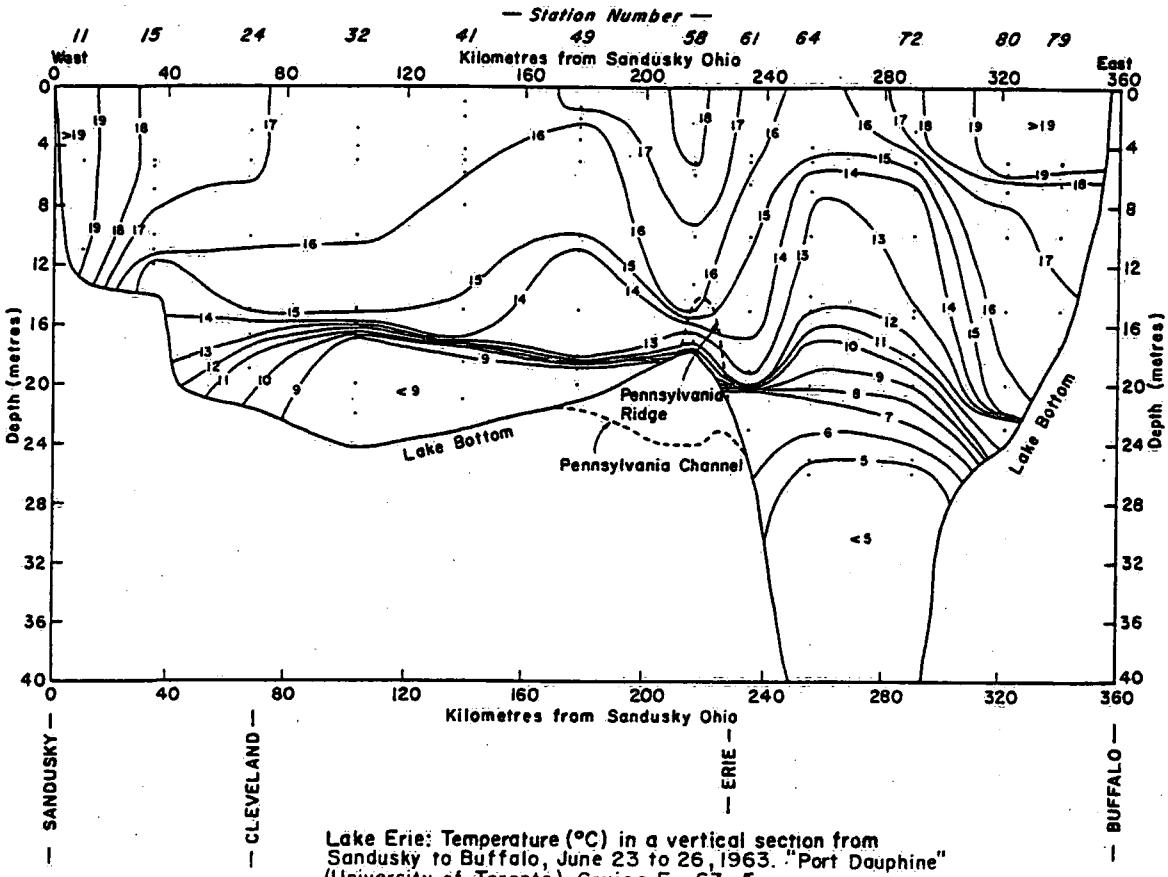
LAKE ERIE
SURFACE TEMPERATURES
JUNE 7 to 19,
1929.
Observations from the vessel "Shearwater." The diagram is redrawn using original data.



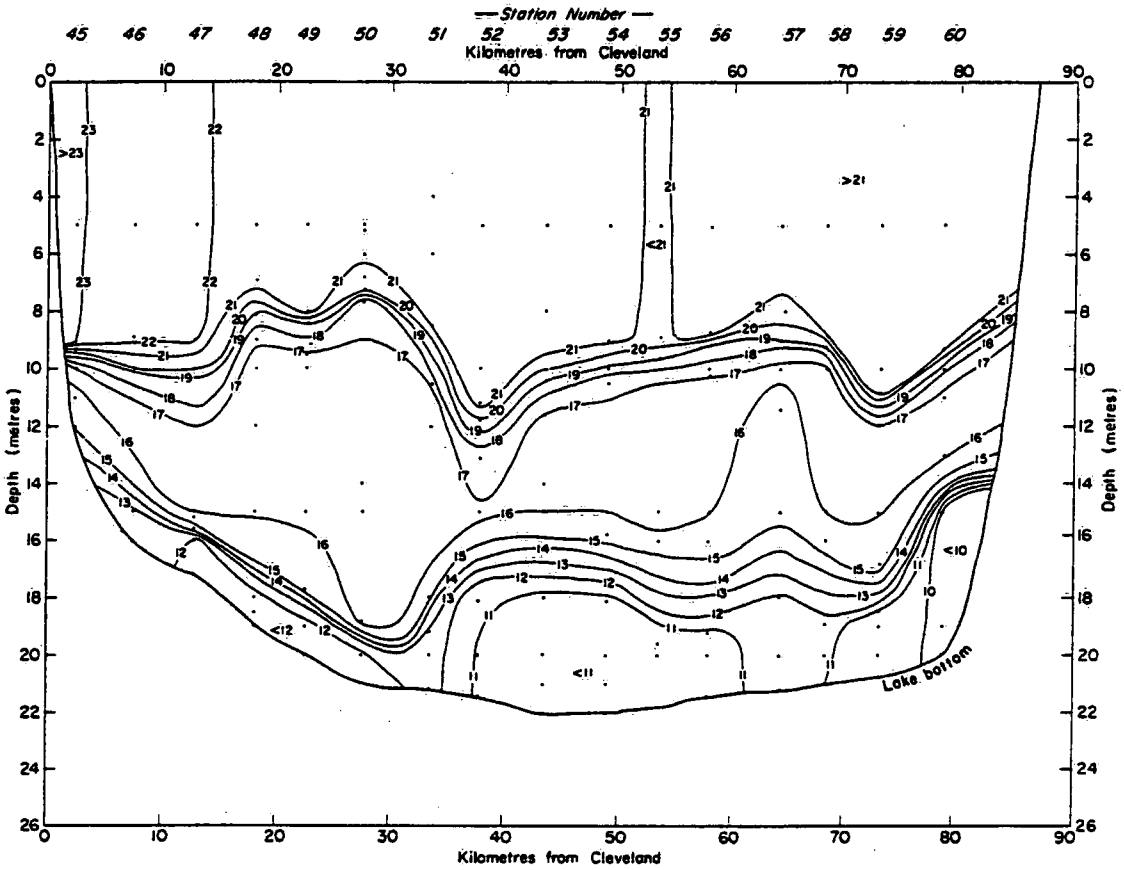
Lake Erie: Temperature (°C) in a vertical section from Cleveland to Erieau. June 23, 1963.
"Porte Dauphine" (University of Toronto). Cruise E-63-5.
Vertical exaggeration: X2,500.



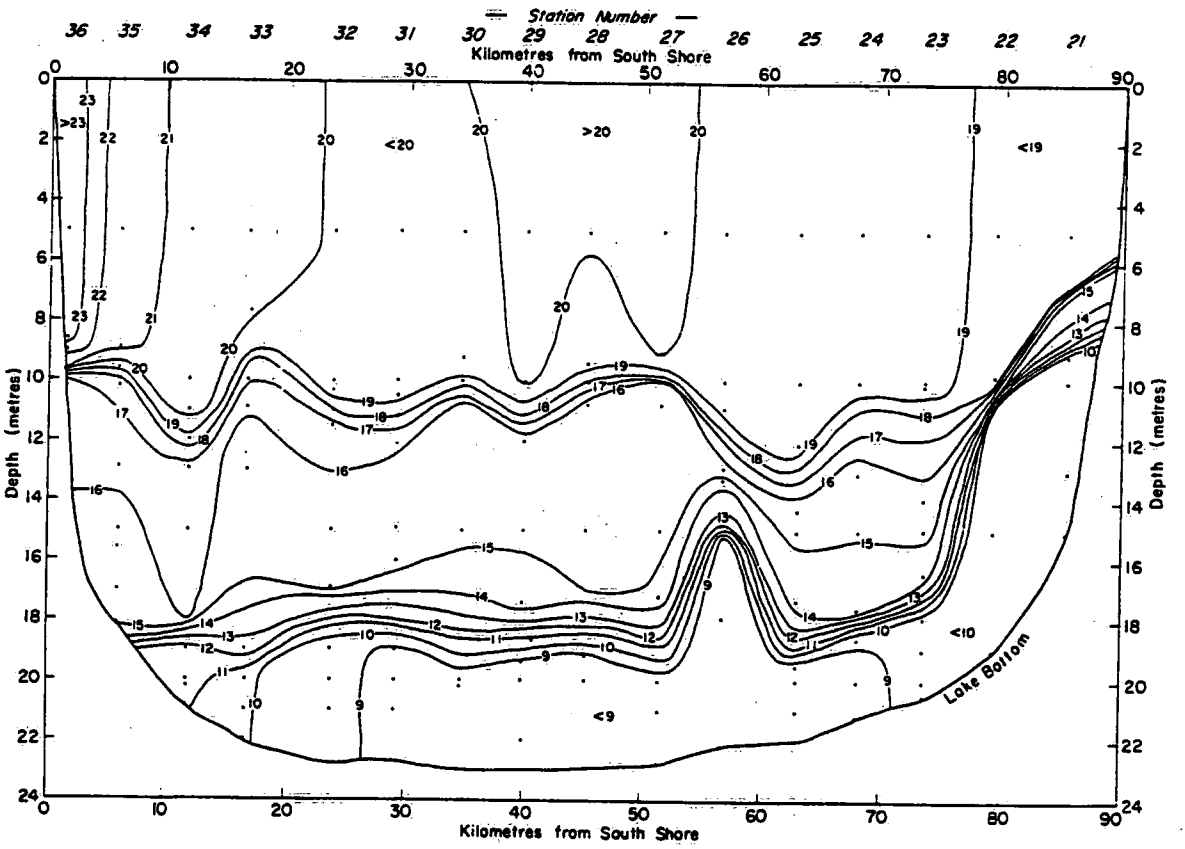
Lake Erie: Temperature (°C) in a vertical section from South to North Shore, near Ashtabula. June 24, 1963. "Porte Dauphine" (University of Toronto) Cruise E-63-5. Vertical exaggeration: X2,500.



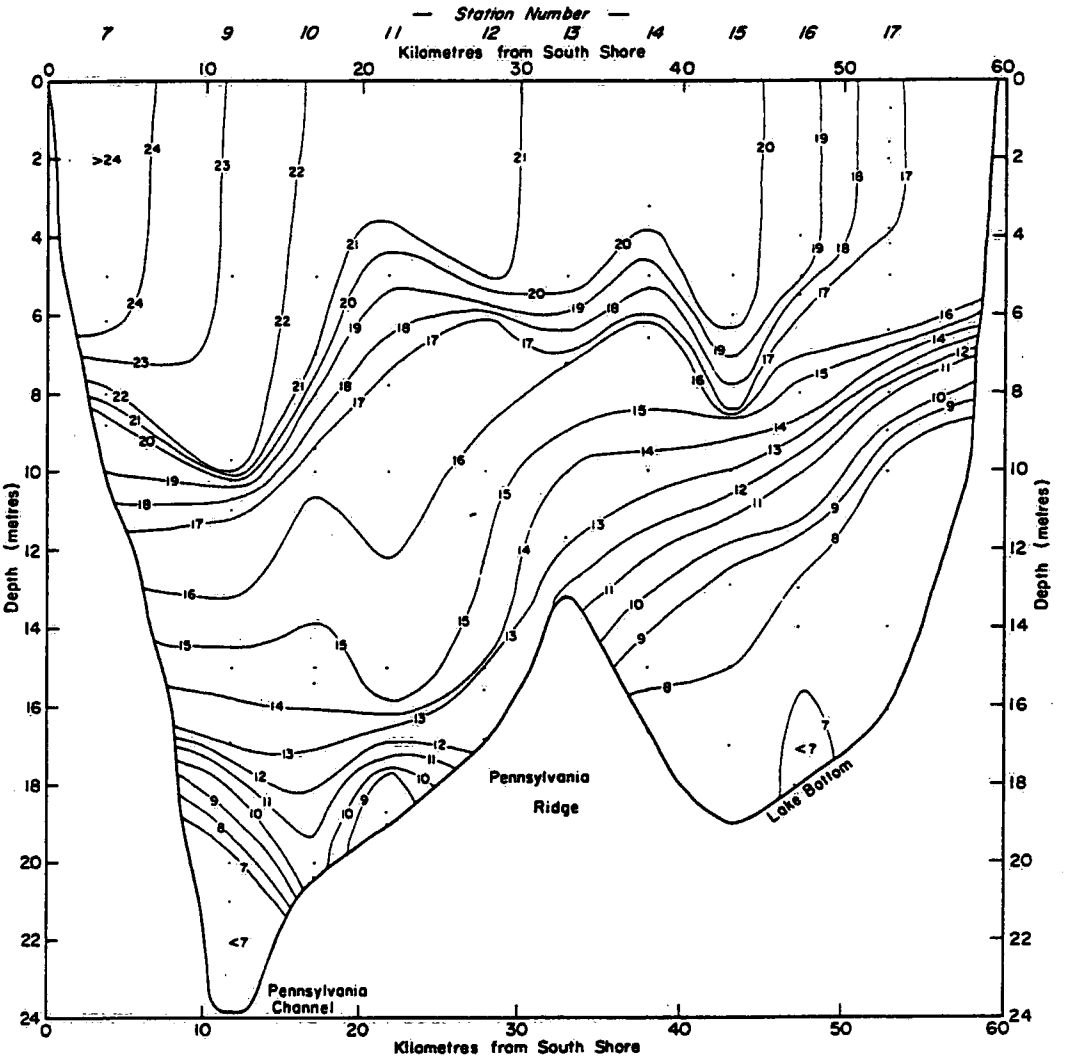
Lake Erie: Temperature (°C) in a vertical section from Sandusky to Buffalo, June 23 to 26, 1963. "Port Dauphine" (University of Toronto) Cruise E-63-5
Vertical Exaggeration X5,000.



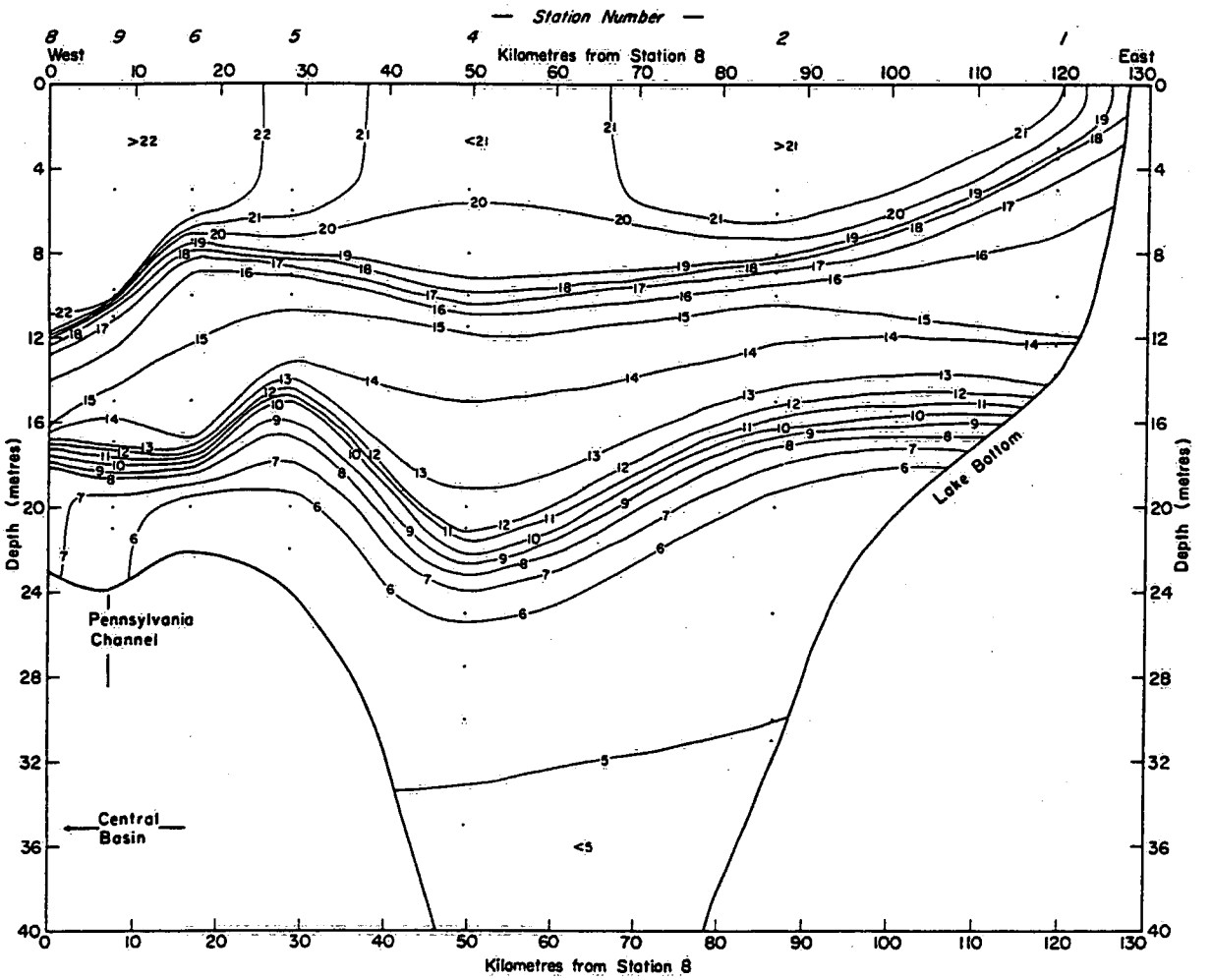
Lake Erie: Temperature (°C) in a vertical section from Cleveland to Erieau. July 4, 1963. "Porte Dauphine" (University of Toronto) Cruise E-63-6. Vertical exaggeration: X 2,500.



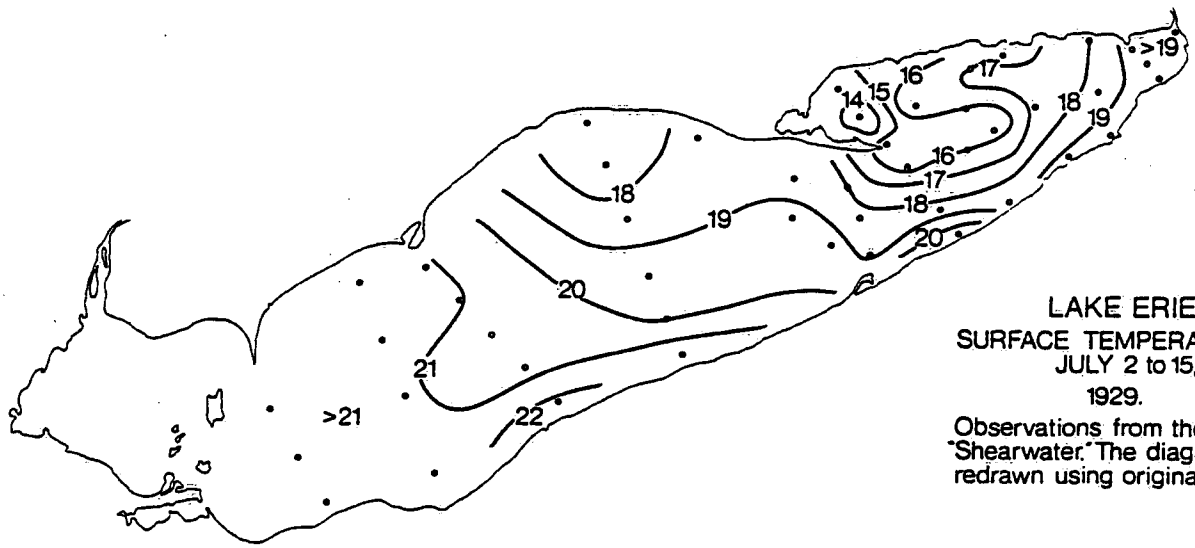
Lake Erie: Temperature (°C) in a vertical section from South to North Shore, near Ashtabula. July 3, 1963. "Porte Dauphine" (University of Toronto) Cruise E-63-6. Vertical exaggeration: X 2,500.



Lake Erie: Temperature (°C) in a vertical section from South to North Shore near the city of Erie. July 3, 1963. "Porte Dauphine" (University of Toronto) Cruise E-63-6. Vertical exaggeration: X2,500.

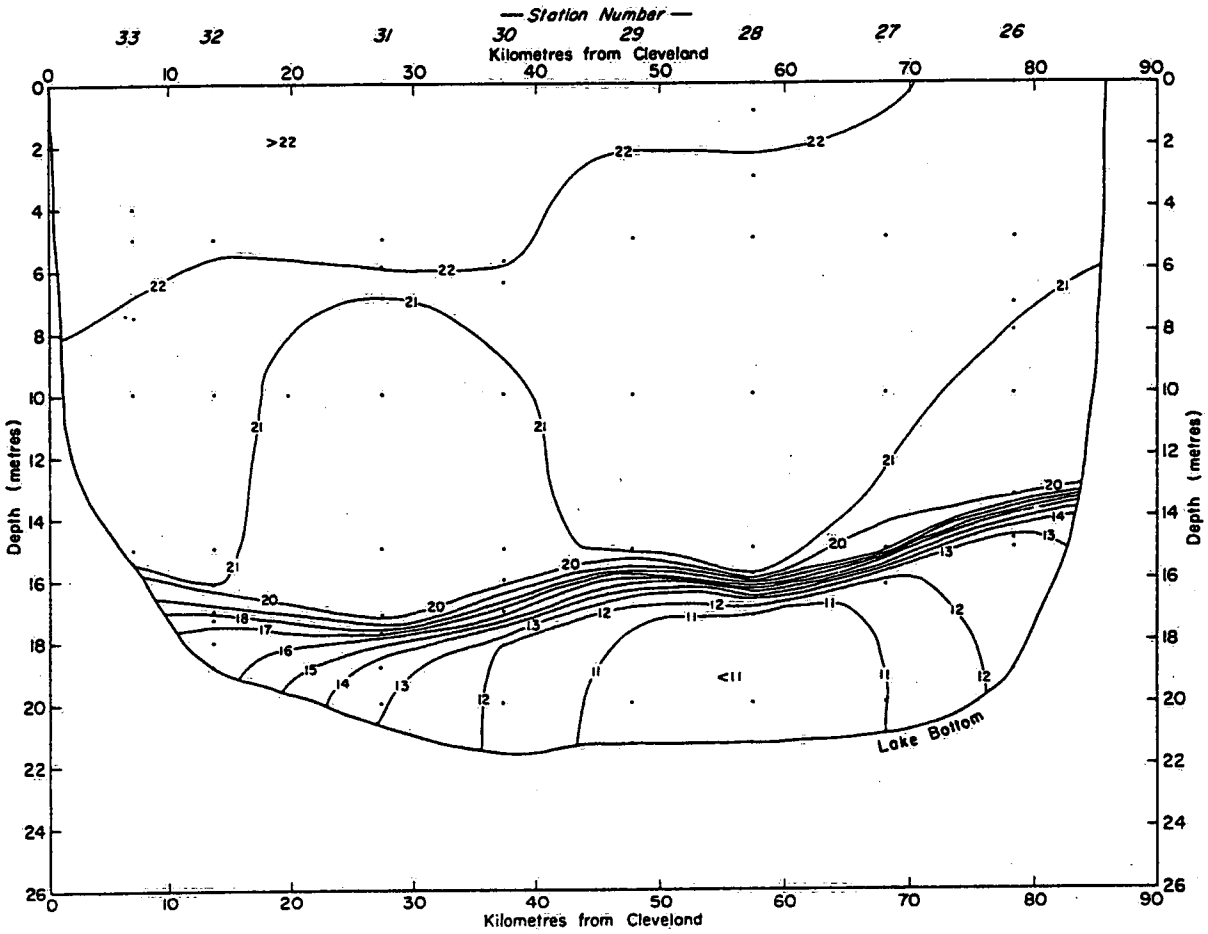


Lake Erie: Temperature (°C) in a vertical section.
from Pennsylvania Channel to Port Colborne, July 2, 1963.
Porte Dauphine (University of Toronto) Cruise E-63-6.

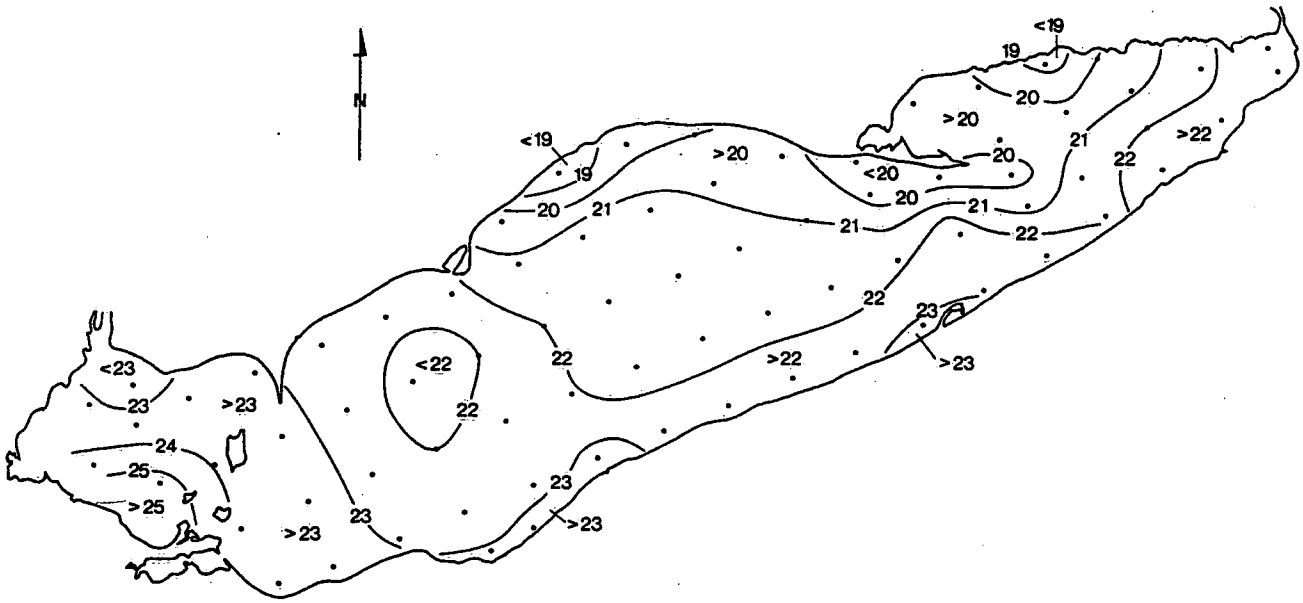


LAKE ERIE
SURFACE TEMPERATURES
JULY 2 to 15,
1929.

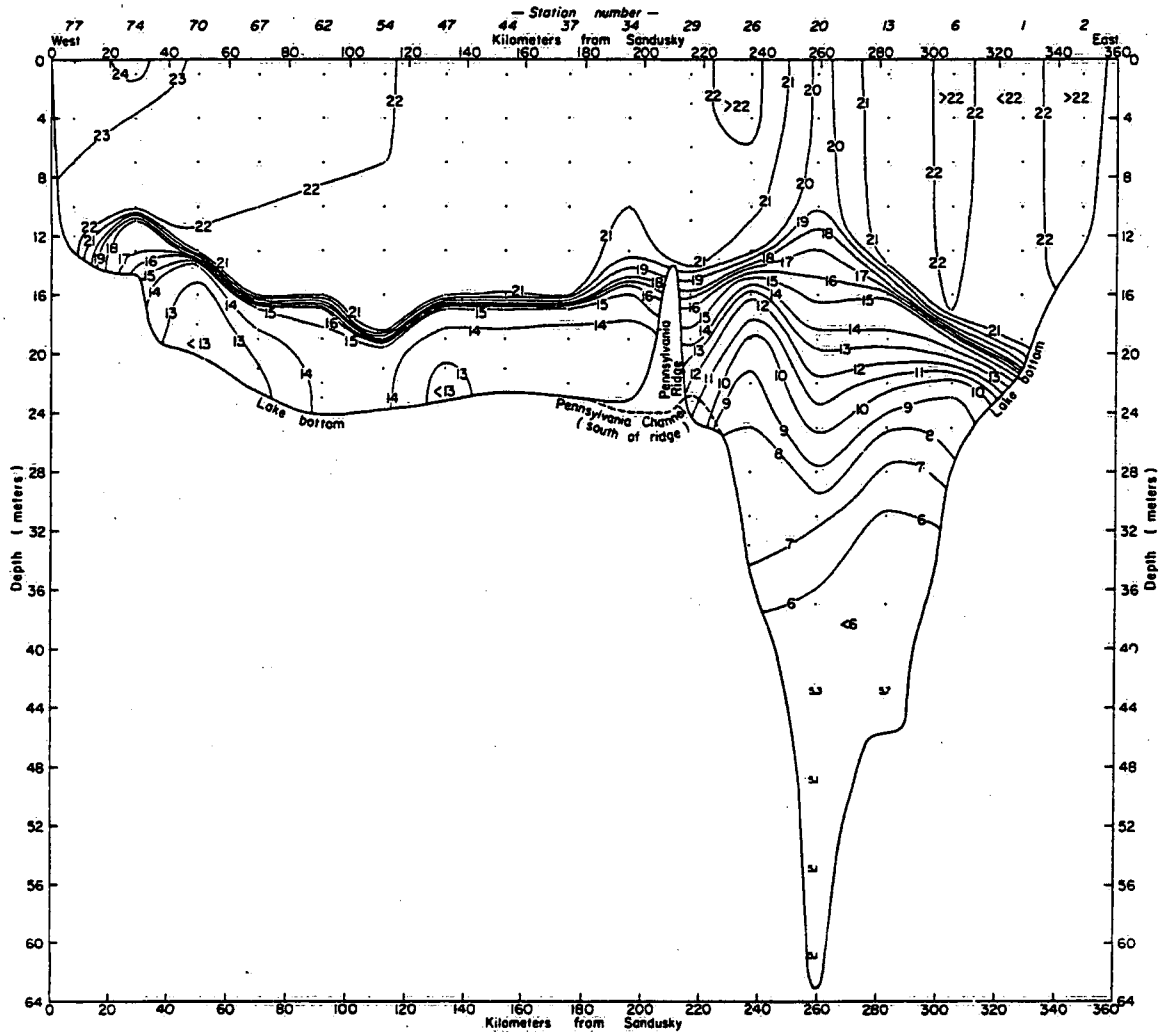
Observations from the vessel "Shearwater." The diagram is redrawn using original data.



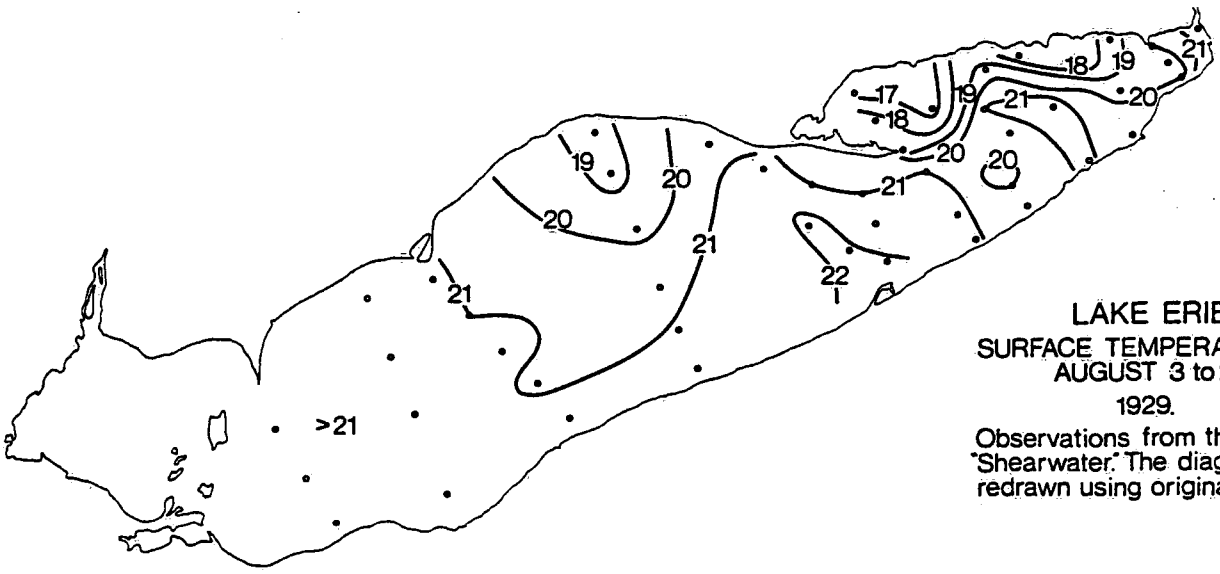
Lake Erie: Temperature (°C) in a vertical section
from Cleveland to Erieau . July 23, 1963.
Porte Dauphine (University of Toronto) Cruise E-63-7.
Vertical exaggeration: X2,500.



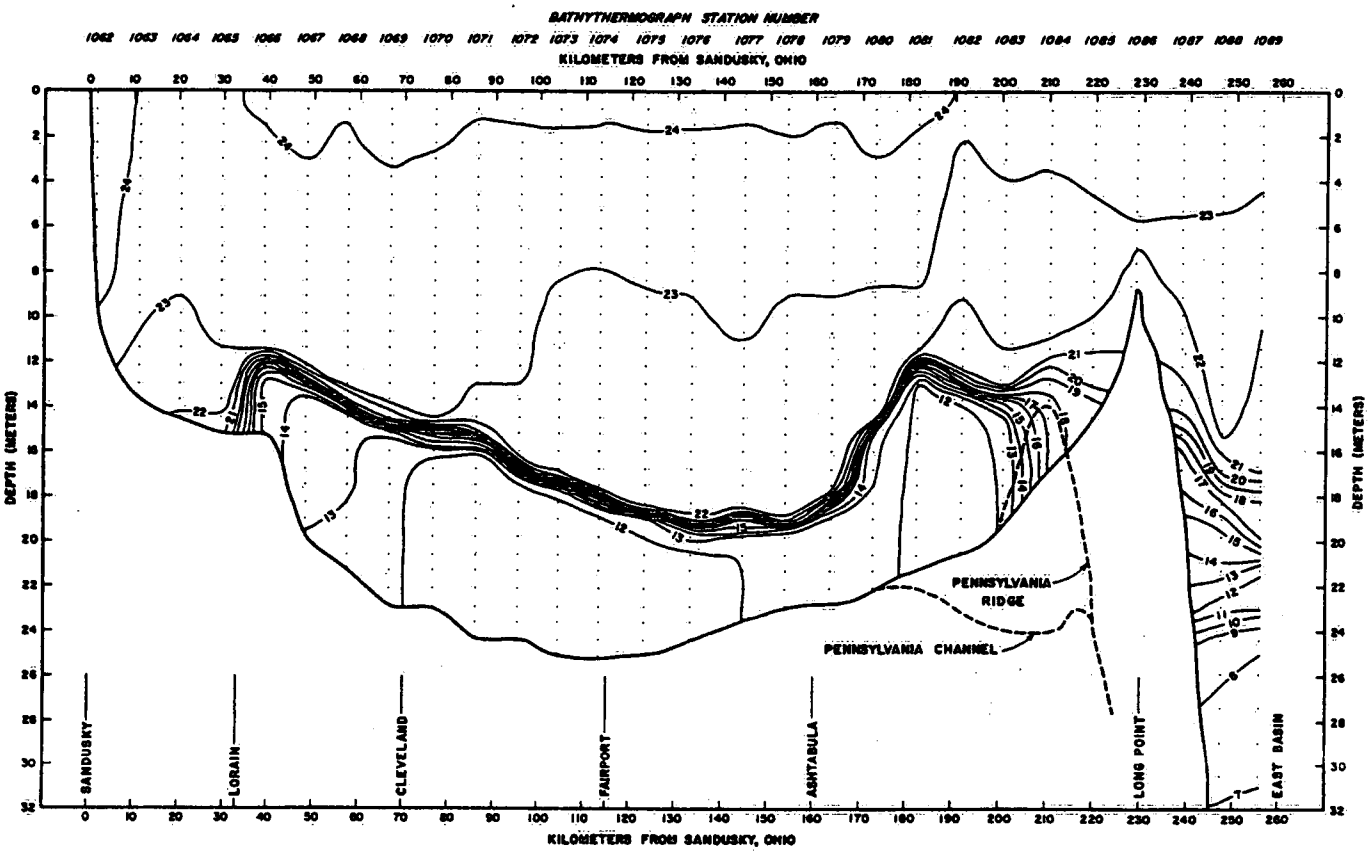
Temperatures of Lake Erie, 1 metre depth,
July 29 to August 3, 1968, CCIW vessel "Theron".



Lake Erie: Temperature (°C) in a vertical section from Sandusky to Buffalo, July 29 to August 2, 1968. Vessel 'Theron' (Canada Centre for Inland Waters), Cruise 68-1-08. Vertical exaggeration: X 5,000.



LAKE ERIE
SURFACE TEMPERATURES
AUGUST 3 to 20,
1929.
Observations from the vessel "Shearwater." The diagram is redrawn using original data.

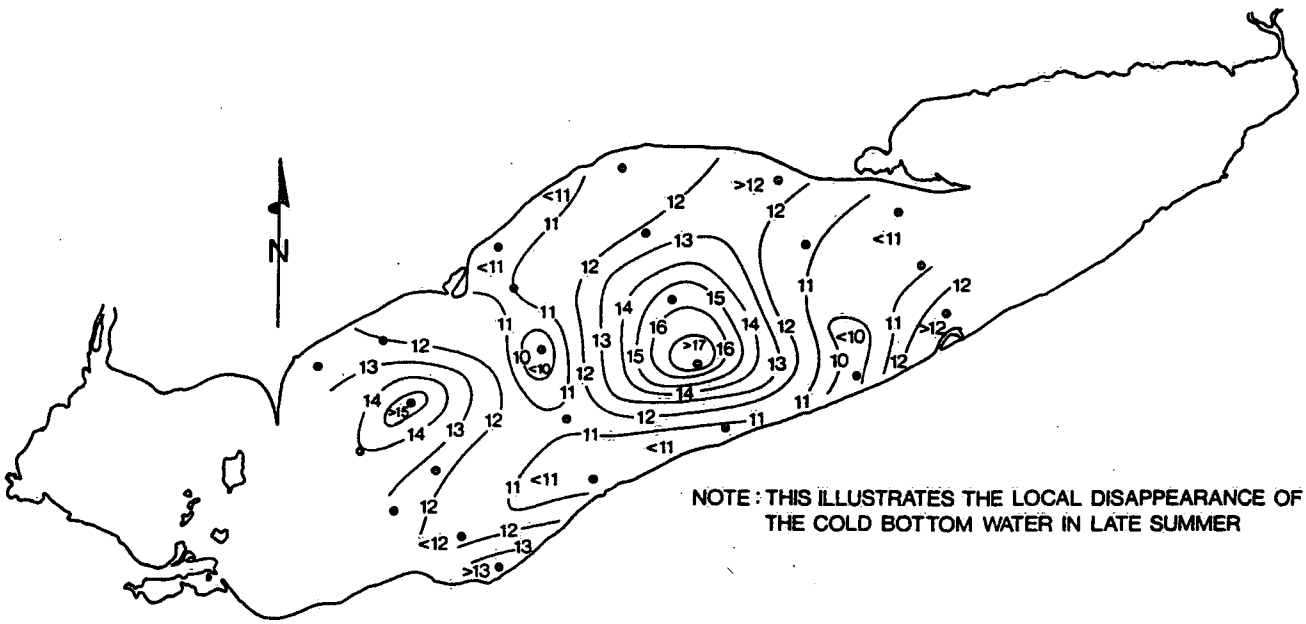


LAKE ERIE

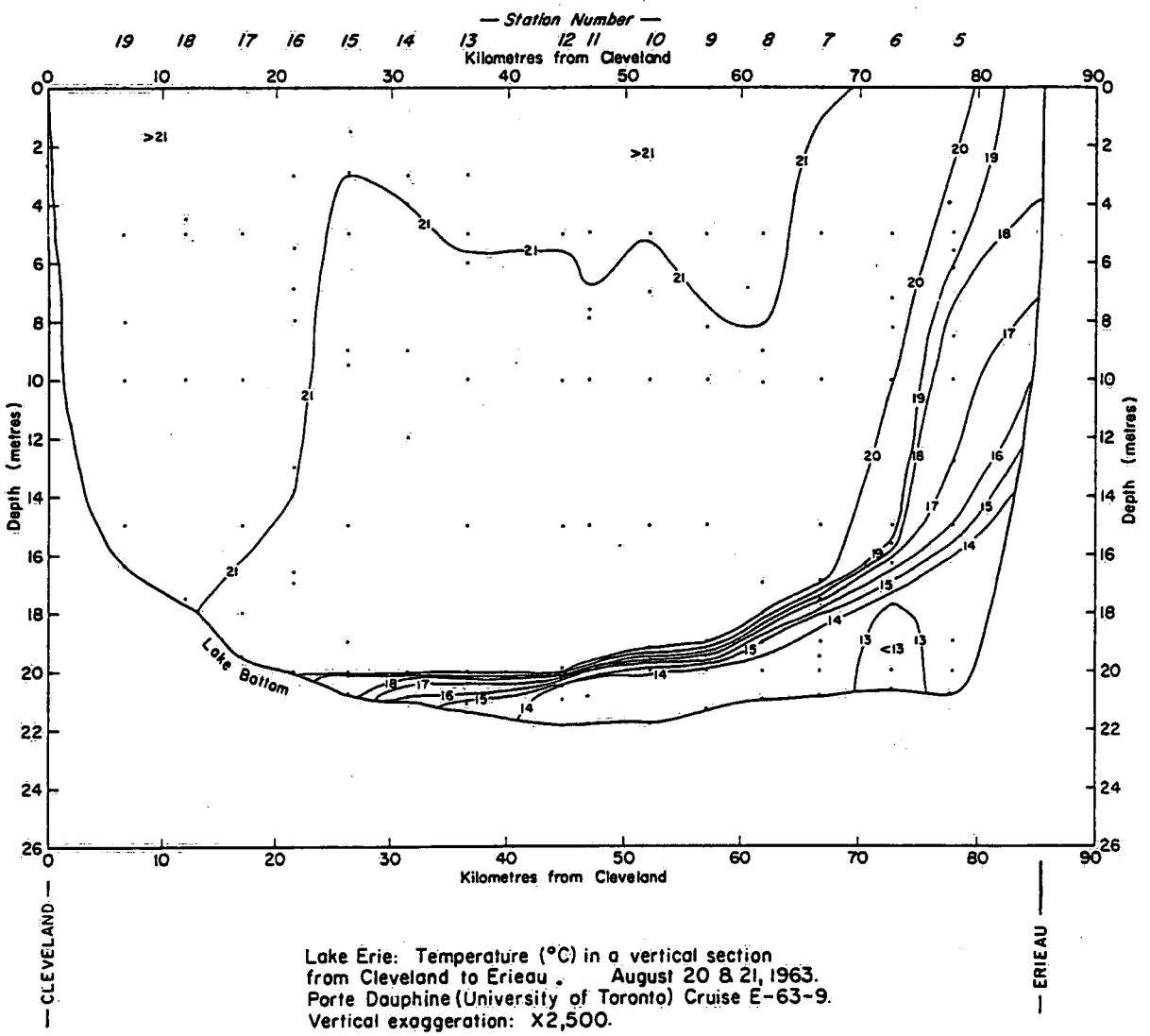
TEMPERATURE (°C) IN A VERTICAL SECTION
FROM
SANDUSKY–LONG POINT–THE EASTERN BASIN

AUGUST 13 & 14, 1953

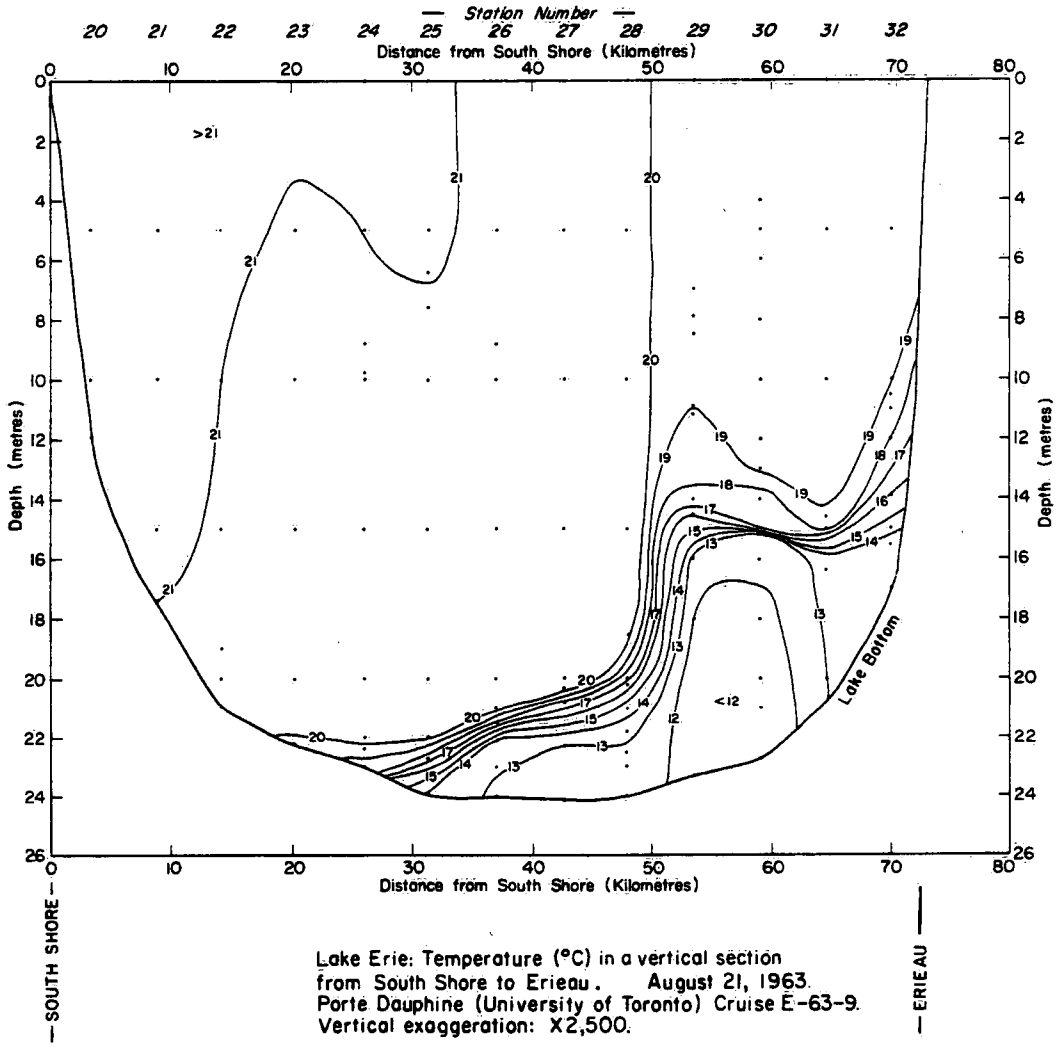
VERTICAL EXAGGERATION X 5,000
(DATA FROM HERDENDORF 1967)



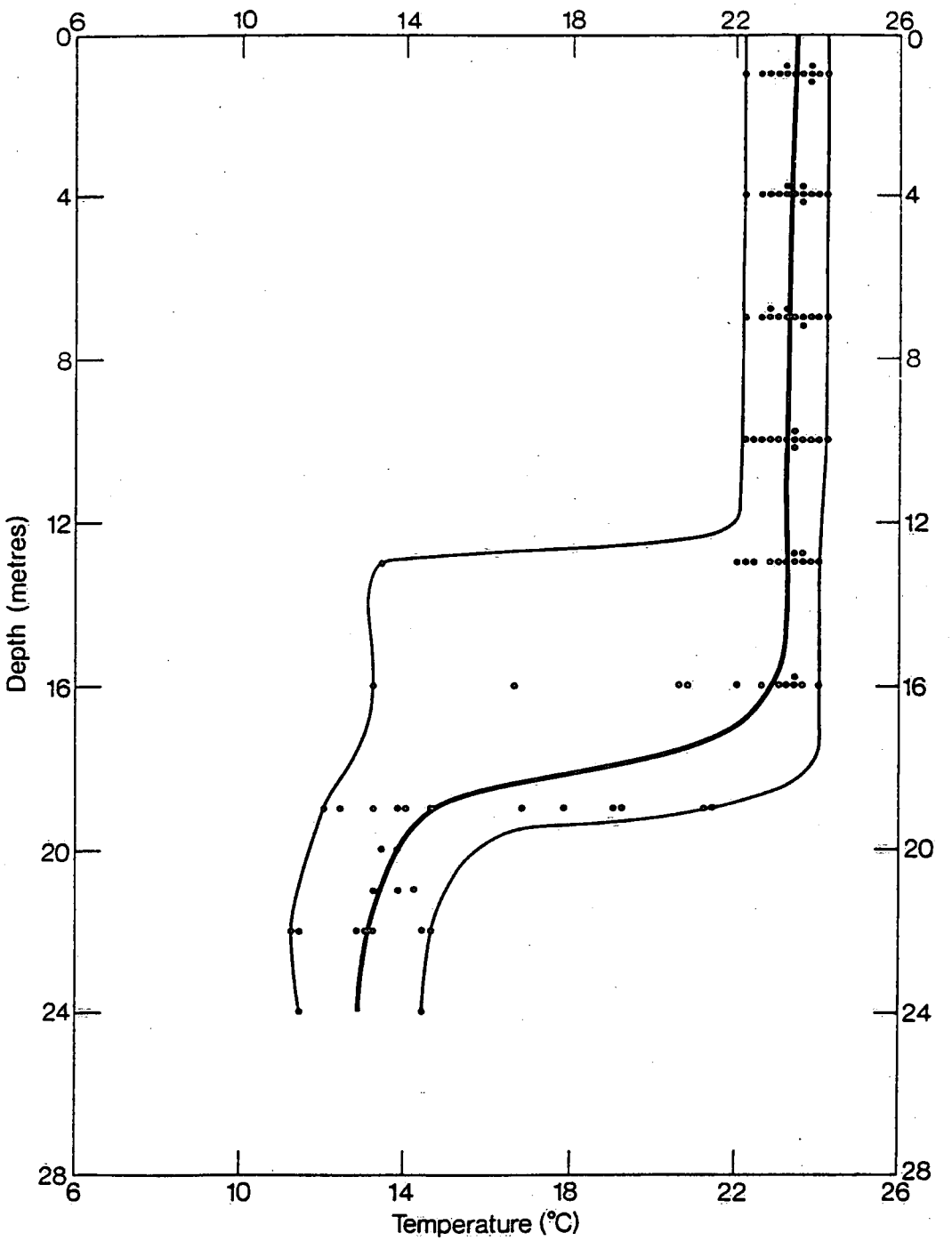
Lake Erie
Central Basin: temperature (°C) of the water sample having the lowest oxygen value at each station, August 18 to 20, 1971, "Martin Karlsen"



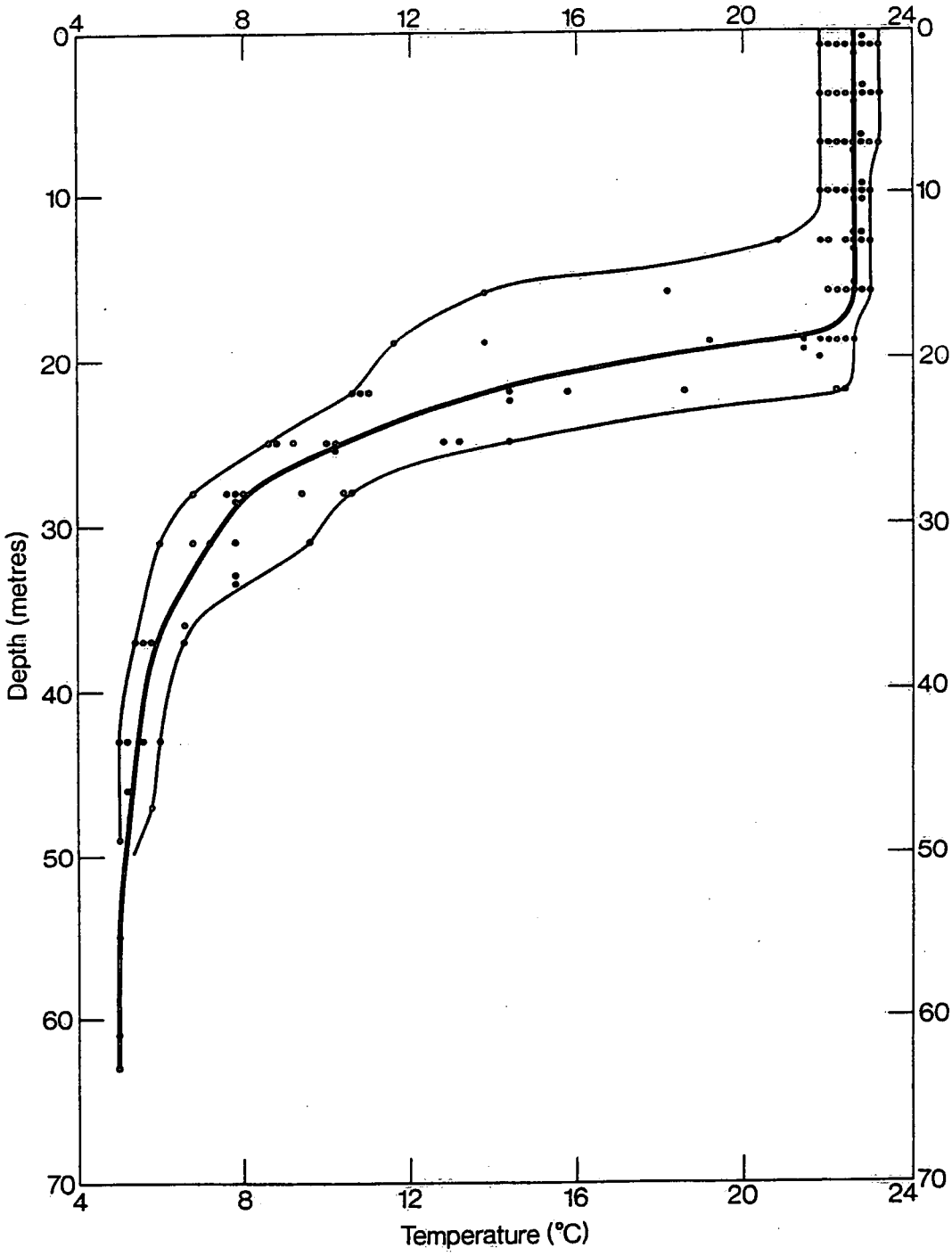
Lake Erie: Temperature (°C) in a vertical section from Cleveland to Erieau. August 20 & 21, 1963. Porte Dauphine (University of Toronto) Cruise E-63-9. Vertical exaggeration: X2,500.



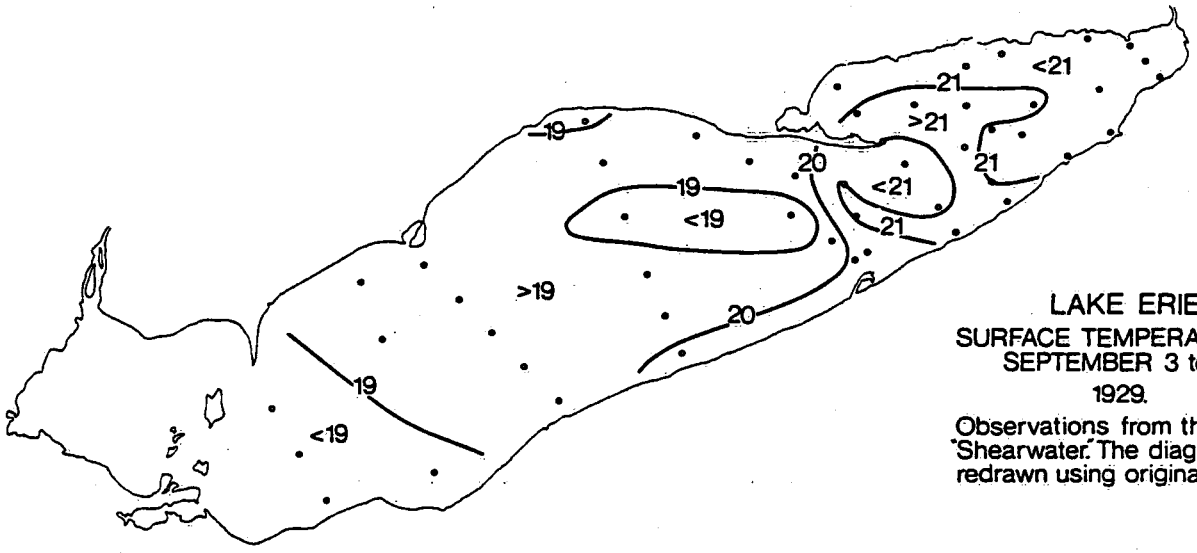
Lake Erie: Temperature (°C) in a vertical section from South Shore to Erieau. August 21, 1963. Porte Dauphine (University of Toronto) Cruise E-63-9. Vertical exaggeration: X2,500.



Central Lake Erie, "Martin Karlsen", August 27 & 28, 1969: Temperatures vs. depth.

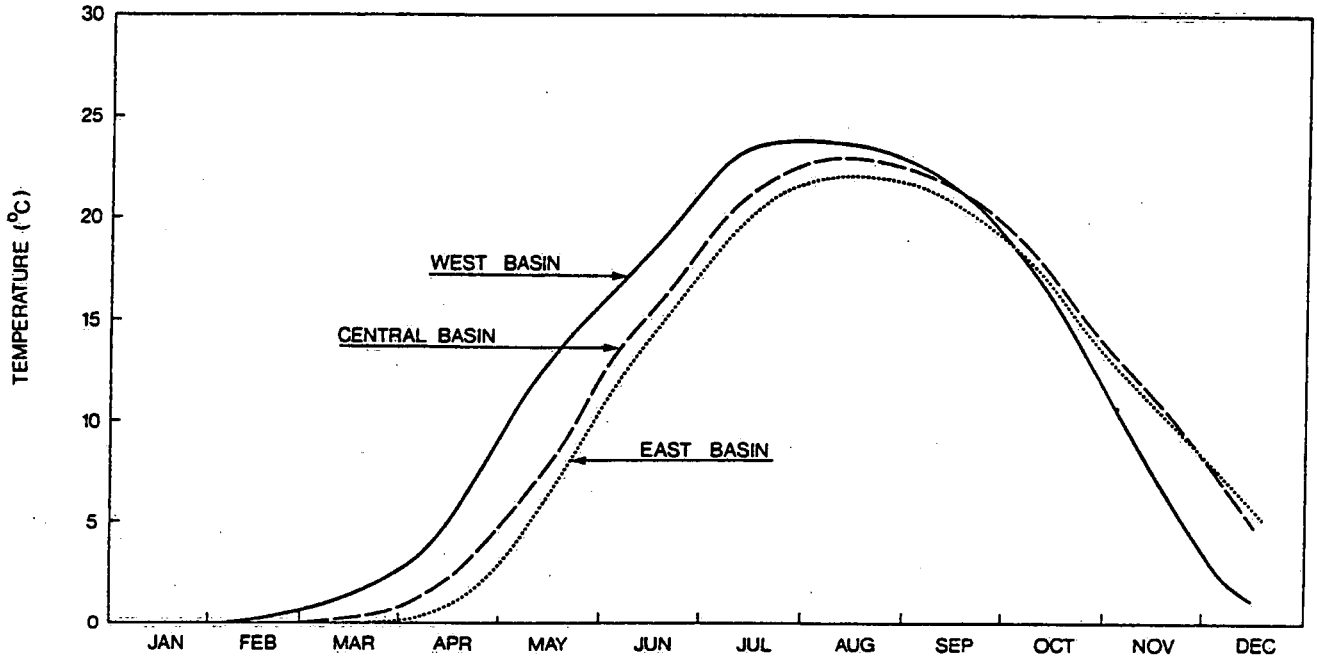


Eastern Lake Erie, "Martin Karlsen", August 29, 1969: Temperatures vs. depth.

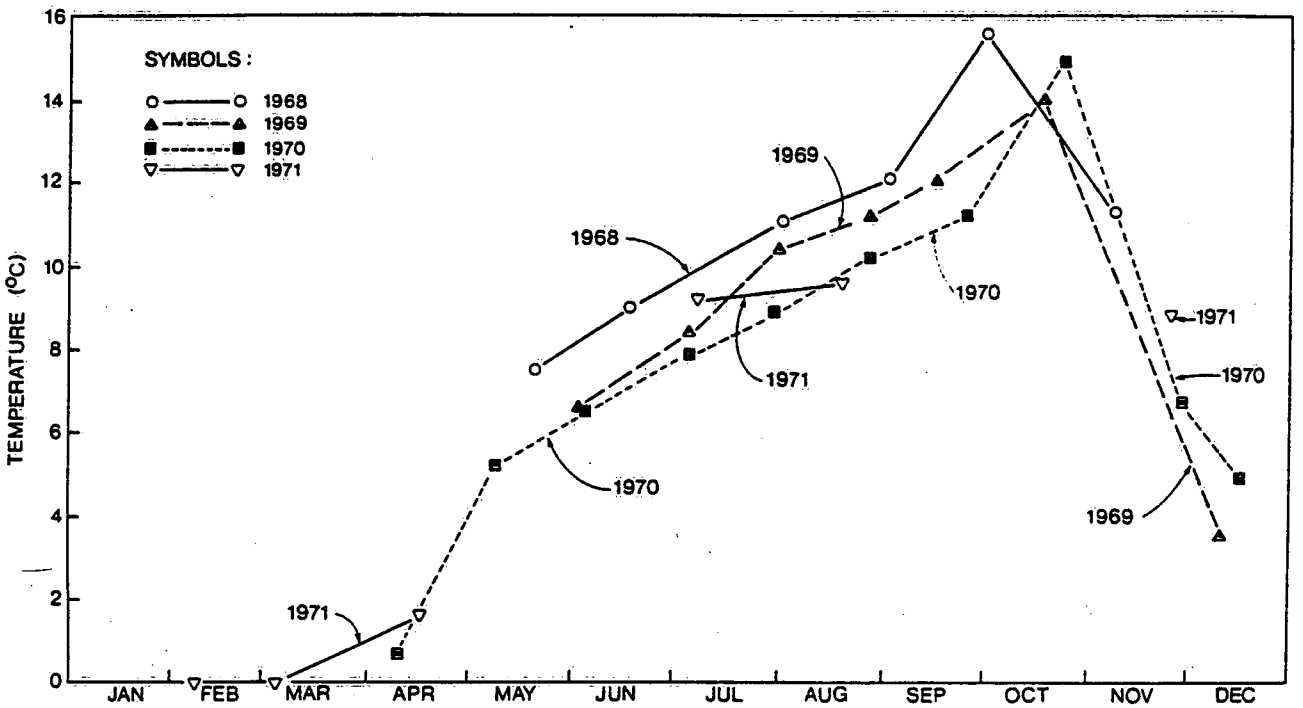


LAKE ERIE
SURFACE TEMPERATURES
SEPTEMBER 3 to 19,
1929.

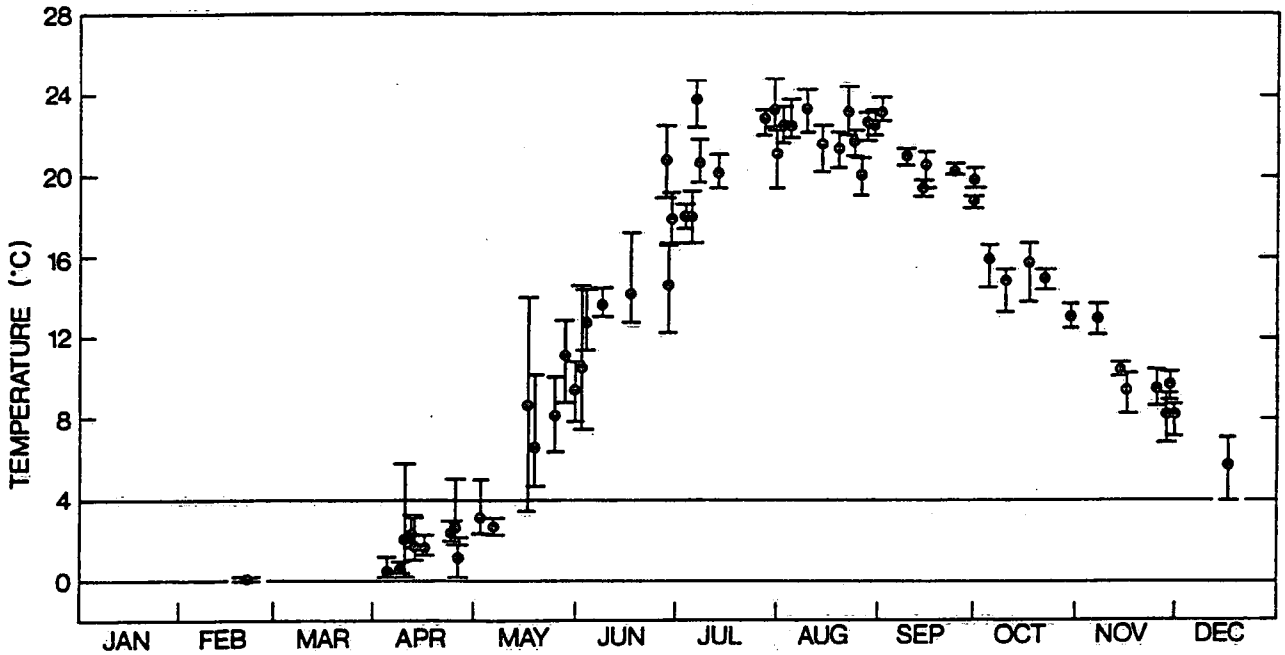
Observations from the vessel "Shearwater." The diagram is redrawn using original data.



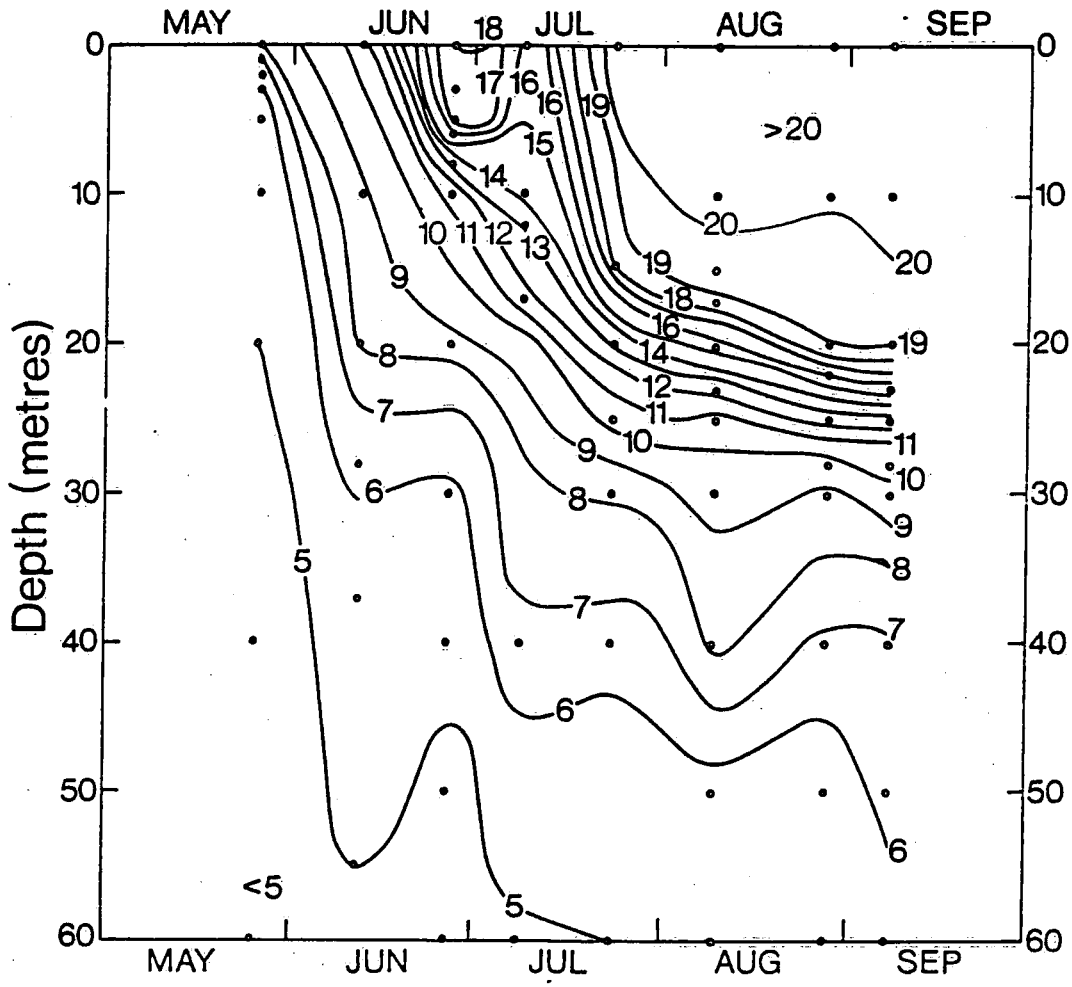
SMOOTHED SEASONAL TEMPERATURE CYCLES FOR 1-METRE DEPTH IN THE THREE BASINS OF LAKE ERIE. BASED ON CCIW DATA IN THE YEARS 1968 TO 1971



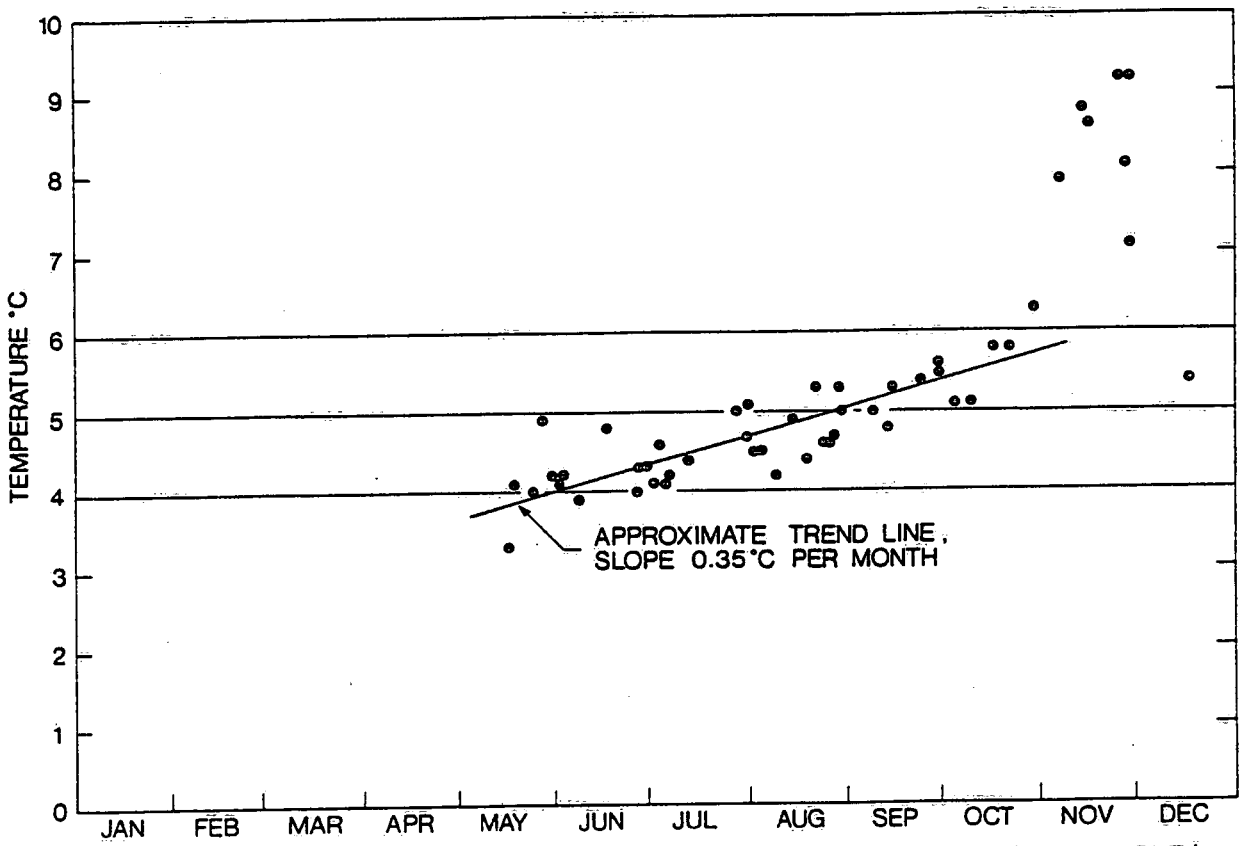
THE MINIMUM TEMPERATURE IN CENTRAL LAKE ERIE ON EACH CRUISE OF CCIW IN THE YEARS 1968 TO 1971.



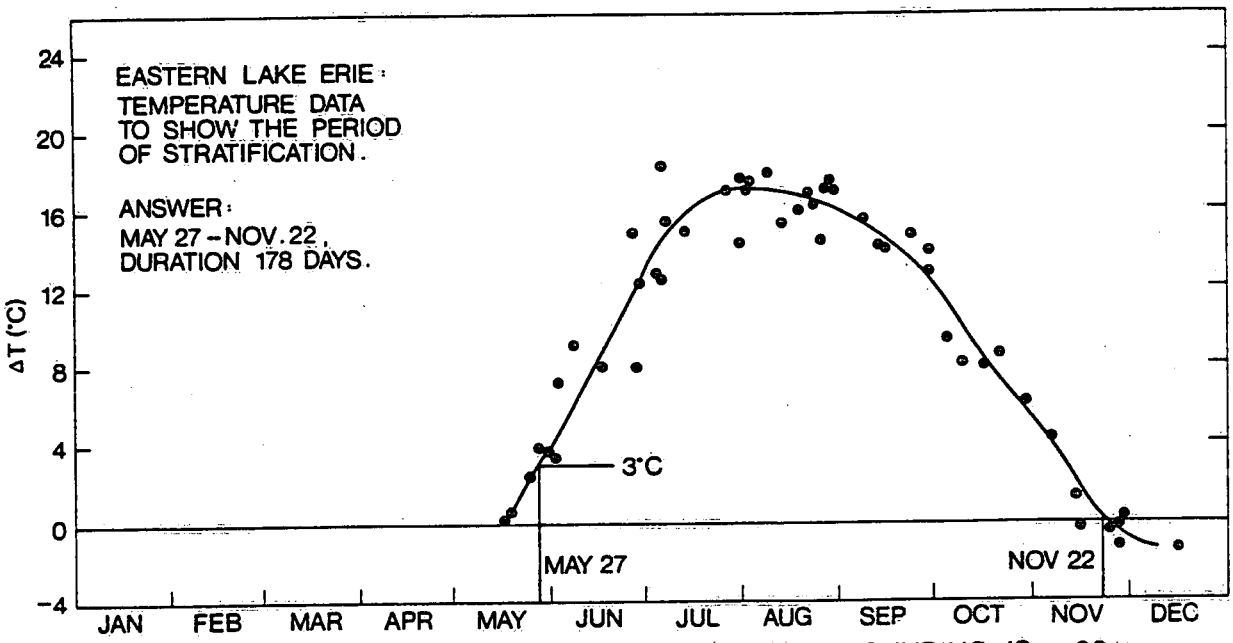
EASTERN LAKE ERIE, OFFSHORE PART WHERE THE SOUNDING IS >20 m: SURFACE TEMPERATURES (MAXIMUM, MEAN, AND MINIMUM ON EACH CRUISE, °C) ON 62 CRUISES IN THE YEARS 1966 – 1976.



A time-depth diagram of temperatures in the east basin of Lake Erie during 1929, observed from the vessel "Shearwater" at station 15.

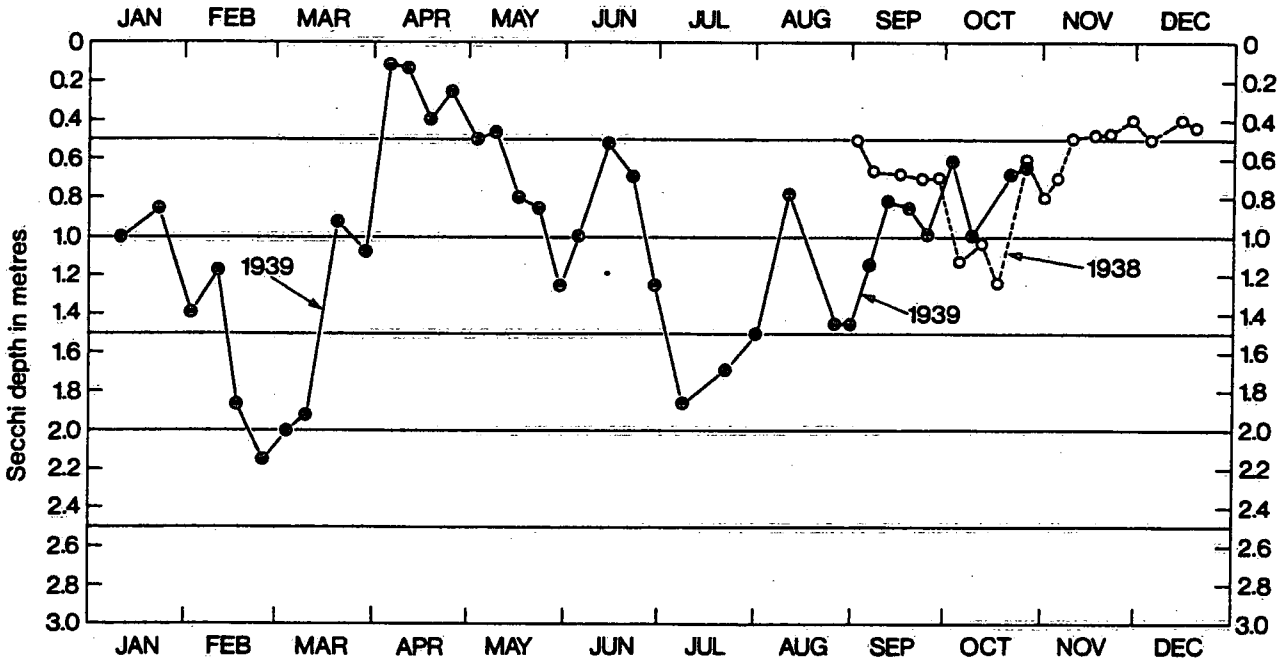


EASTERN LAKE ERIE: TEMPERATURES AT THE BOTTOM OF THE 'DEEP HOLE', ON 50 CRUISES IN THE YEARS 1966–1976.

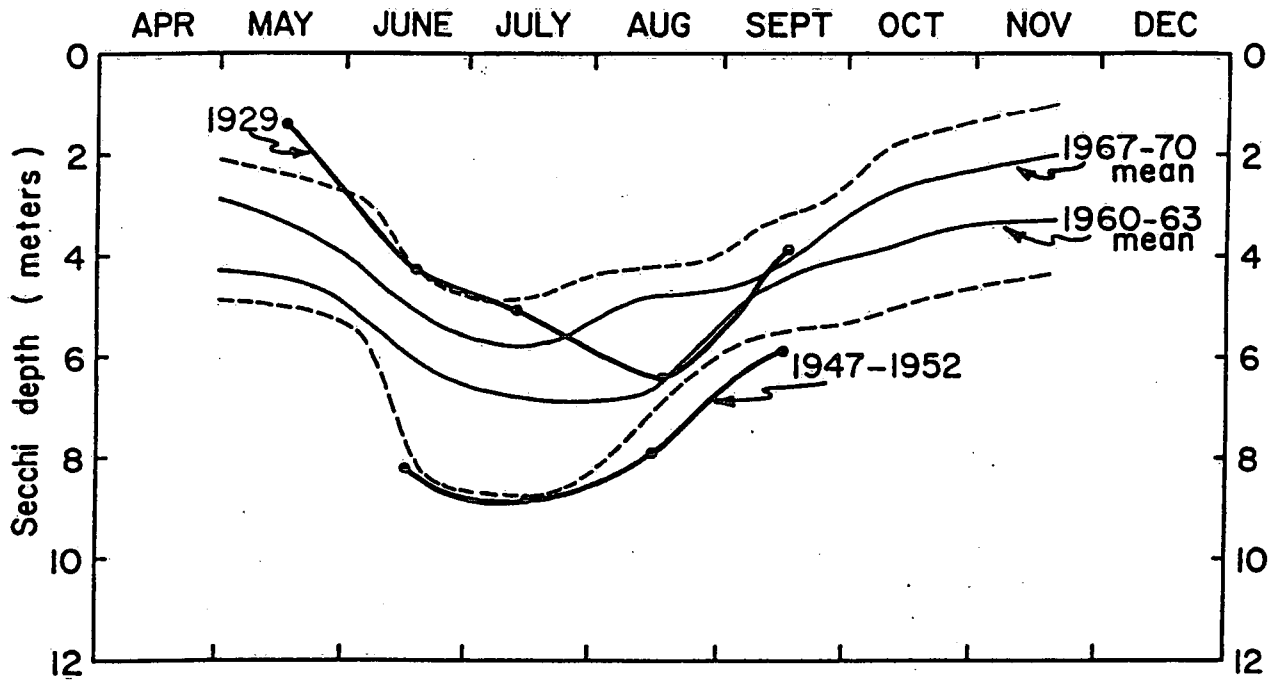


EASTERN LAKE ERIE, OFFSHORE PART WHERE THE SOUNDING IS >20 m: MINIMUM SURFACE TEMPERATURE MINUS MINIMUM BOTTOM TEMPERATURE (ΔT, °C) ON 50 CRUISES IN THE YEARS 1966 – 1976.

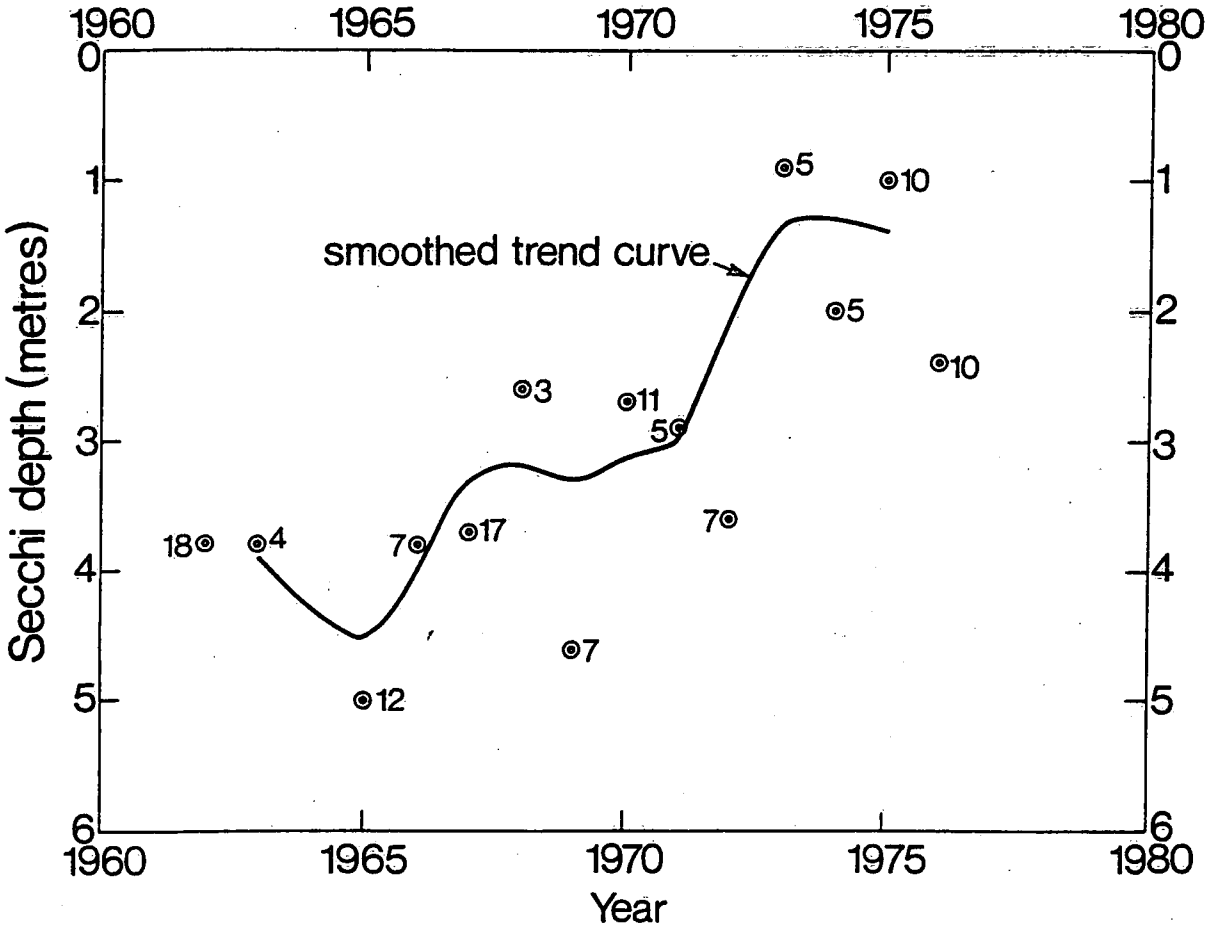
SECCHI TRANSPARENCY



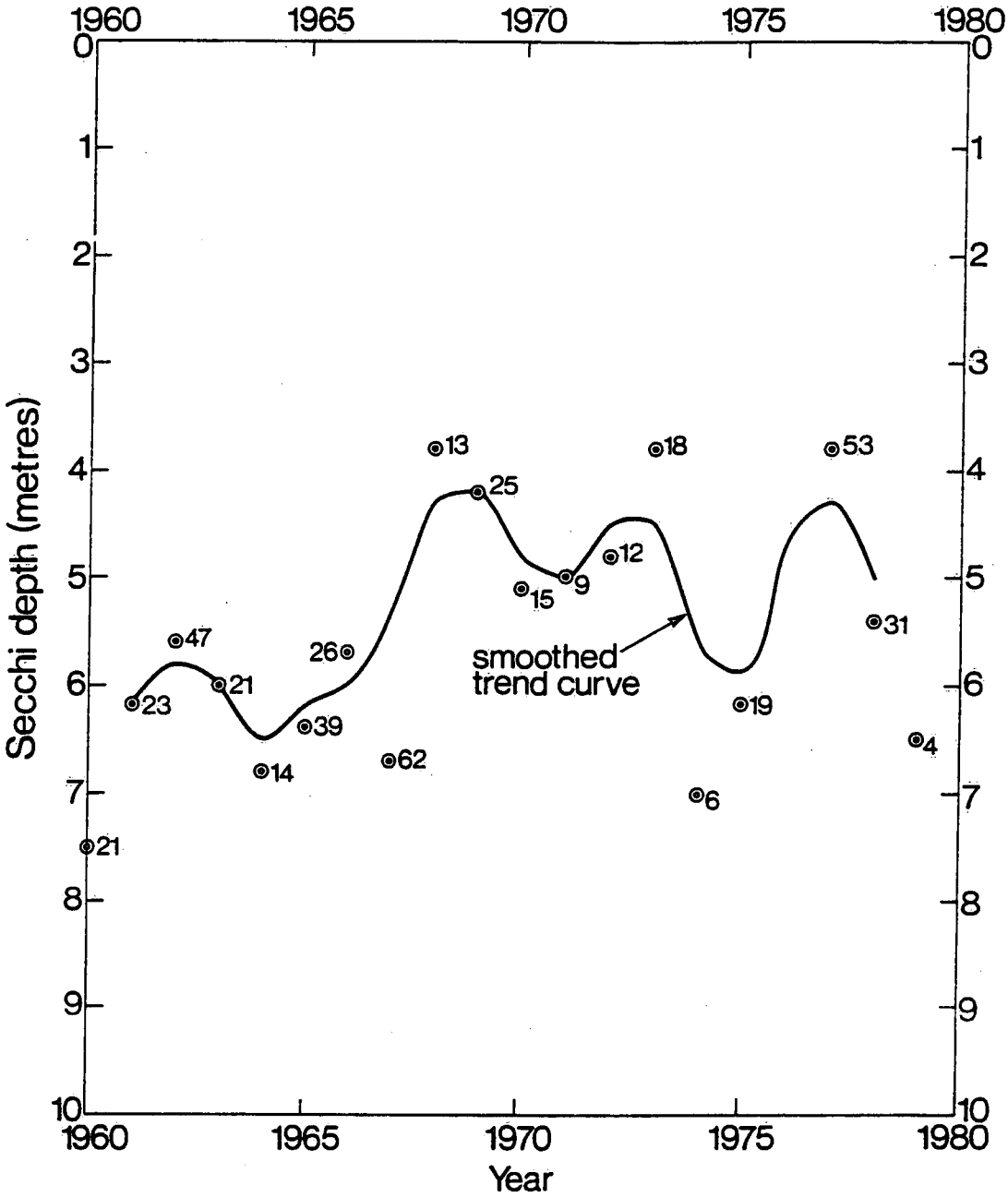
Lake Erie, western part, near the Bass Islands: Secchi transparencies from September 2, 1938 to October 26, 1939. Data from: D.C. Chandler, 1940, Ohio Journal of Science.



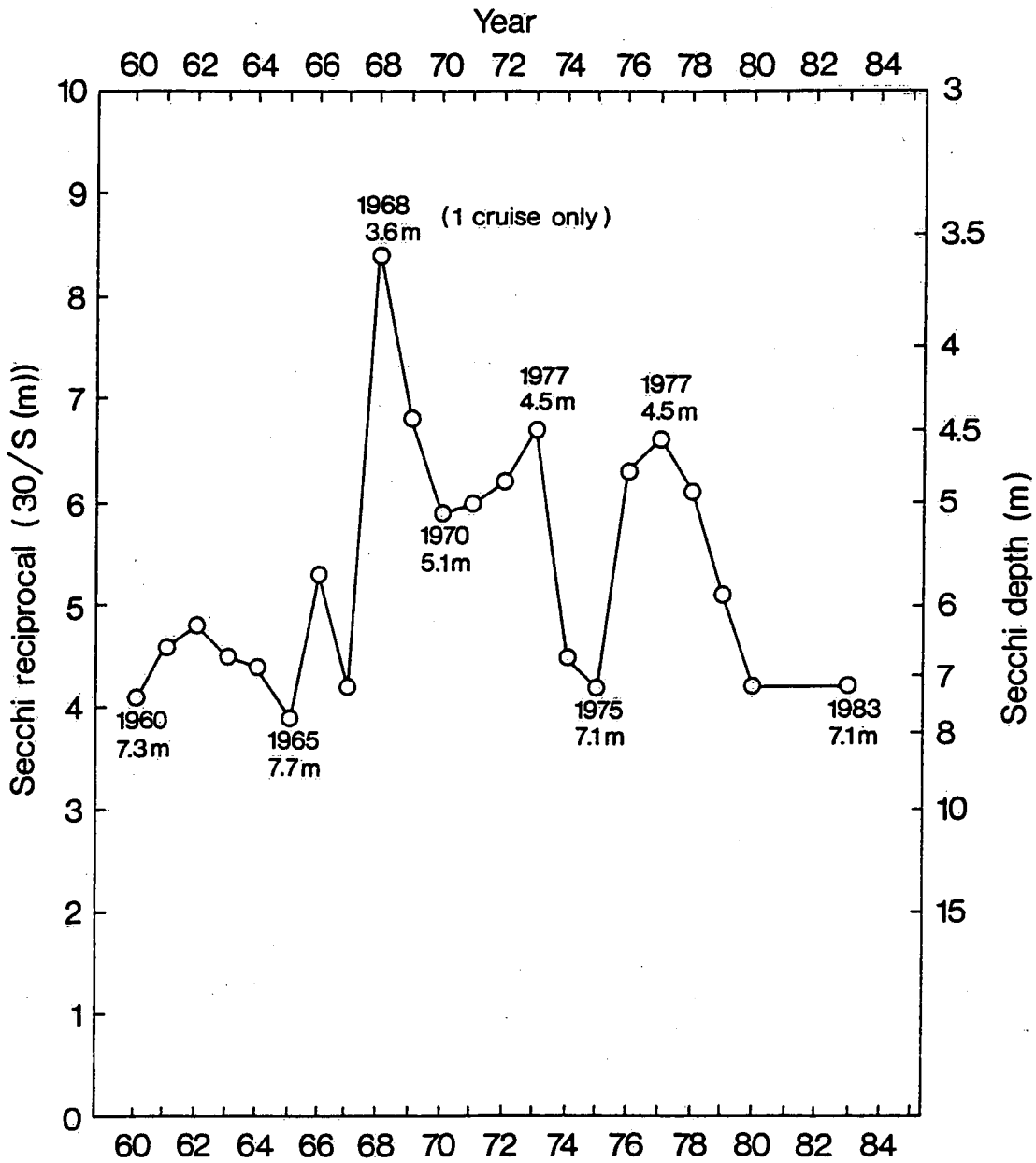
Secchi depths in Central Lake Erie (offshore part where the sounding is greater than 20 meters). The two dashed lines enclose all mean values for cruises of 1960-63 and 1967-70.



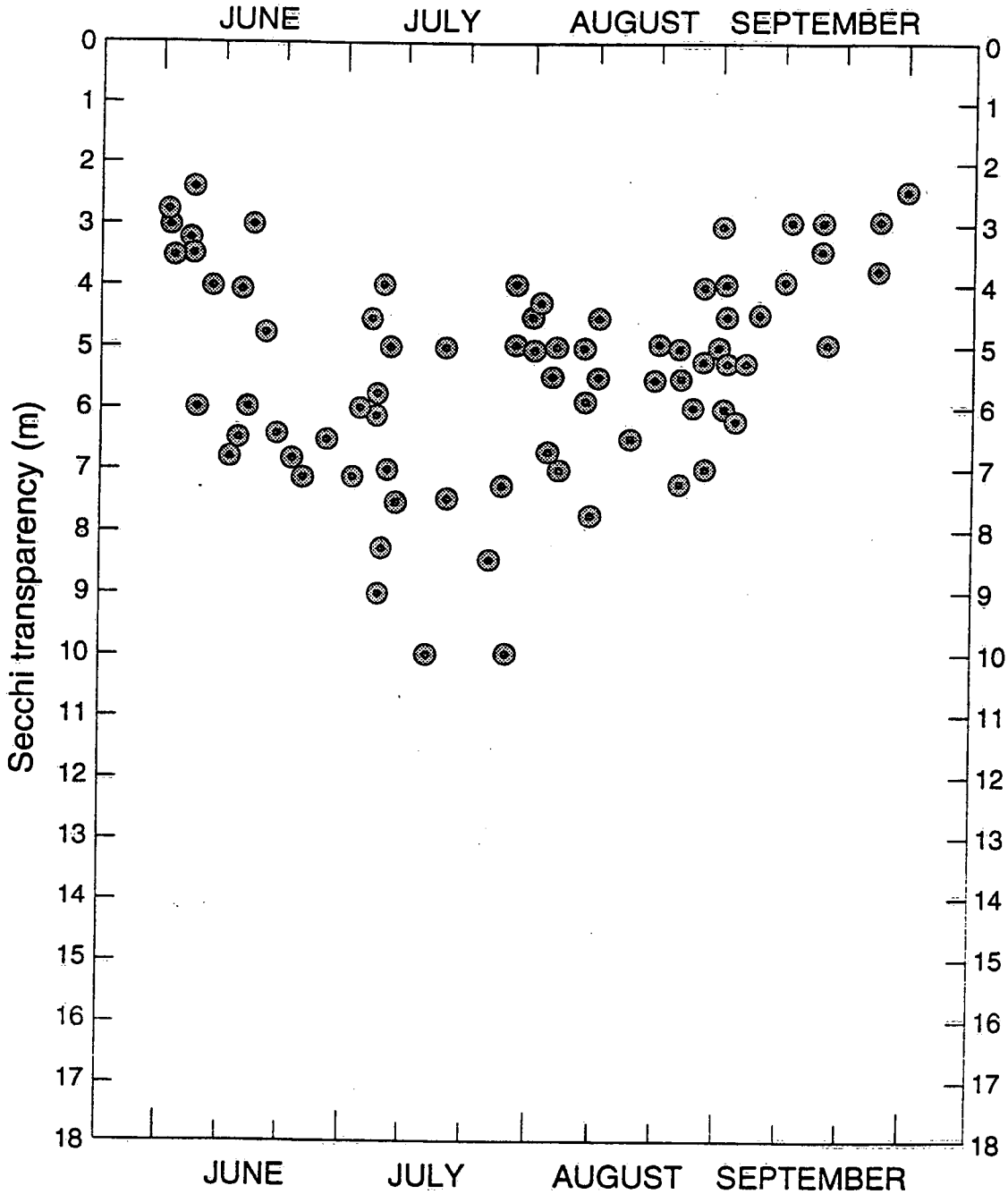
Central Lake Erie, Secchi transparency in spring (April 1 to May 15), 1962 to 1976. The number of observations each spring is indicated.



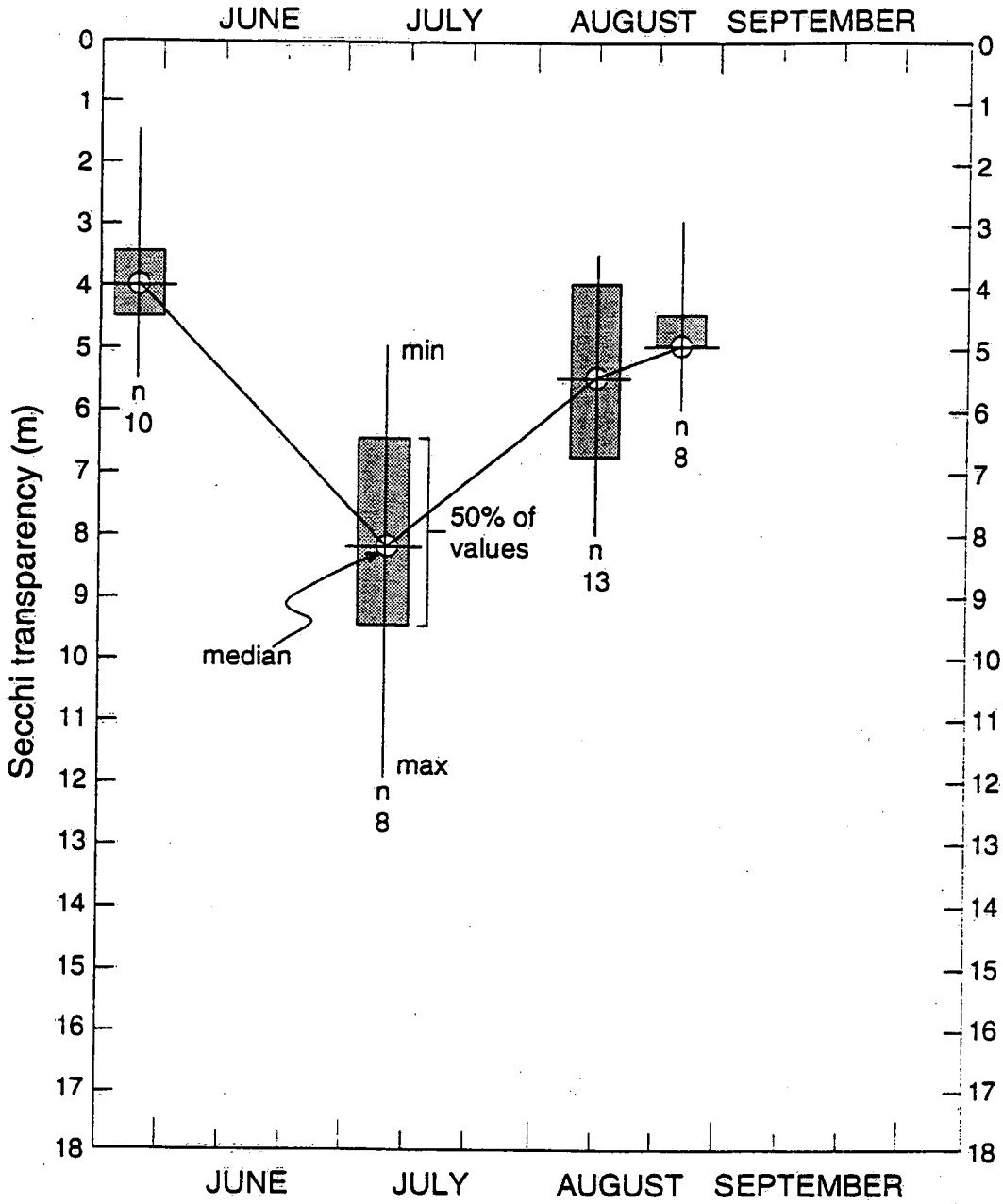
Central Lake Erie, Secchi transparency in summer (June 15 to September 15), 1960 to 1979. The number of observations each summer is indicated.



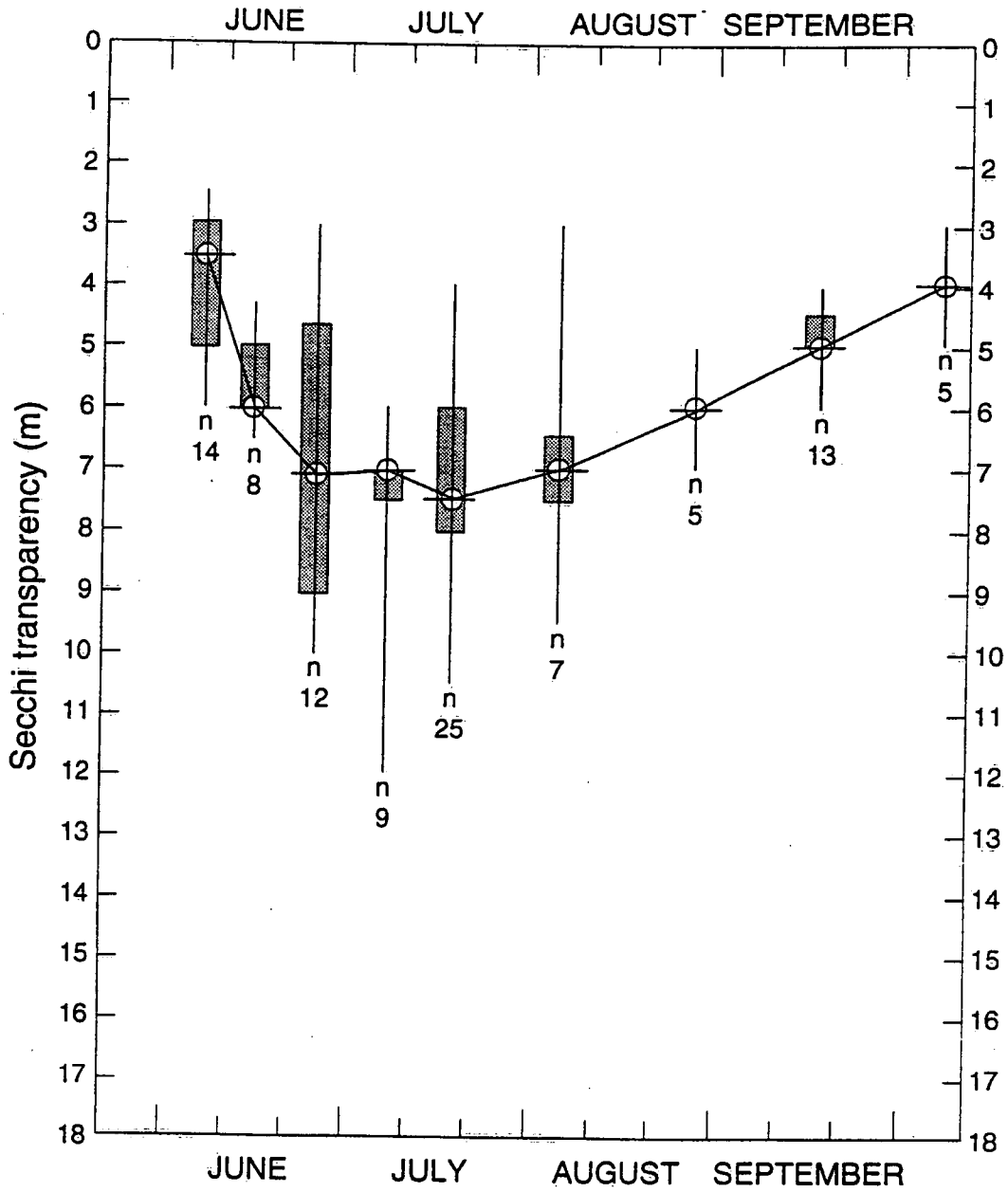
Secchi transparency in Central Lake Erie, offshore zone, July & August (mean values), 1960 to 1983.



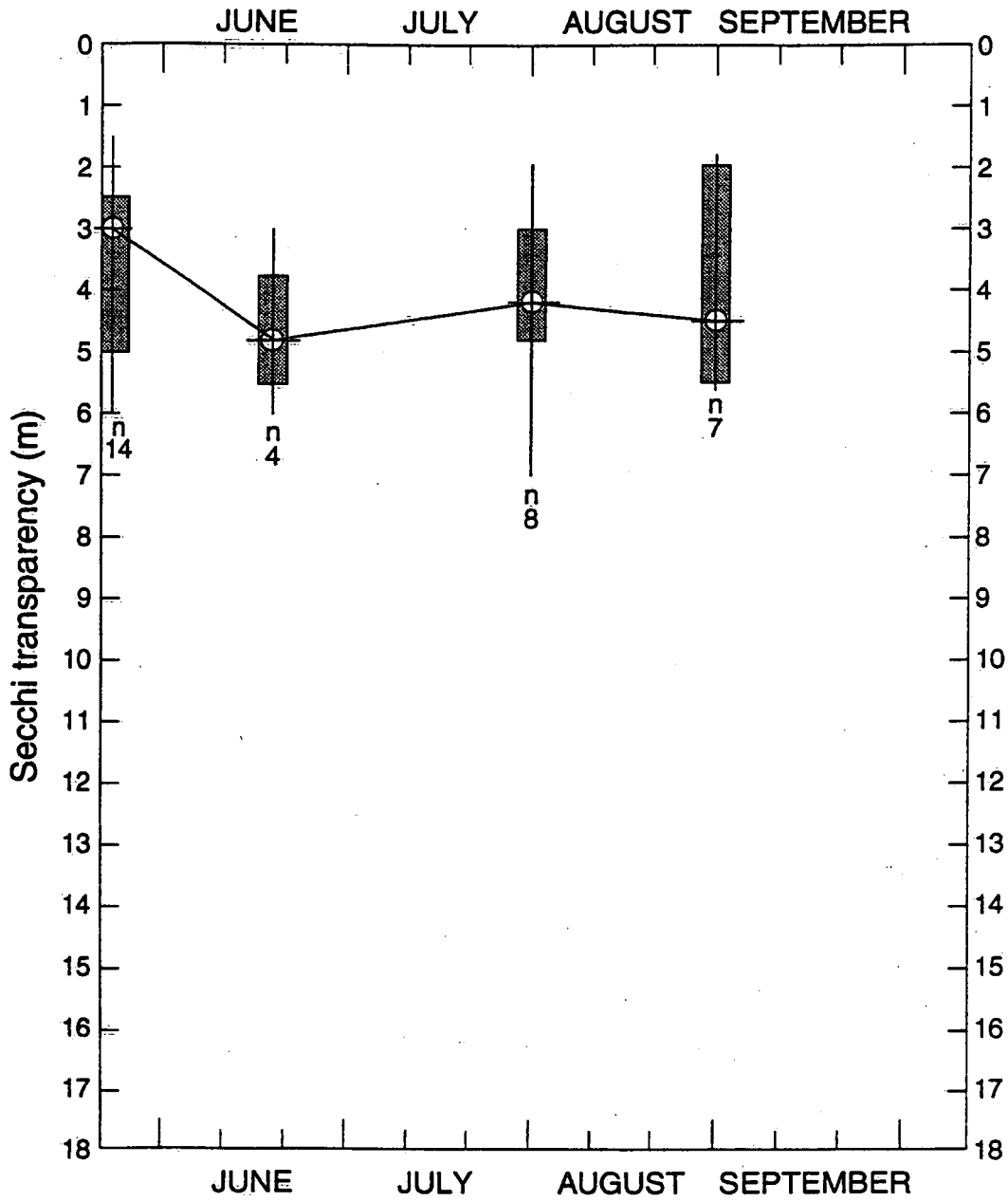
Central Lake Erie, offshore, Secchi transparency, cruise-medians in four summer months,vs. time of year, data for the years 1966 to 1993, Canadian data.



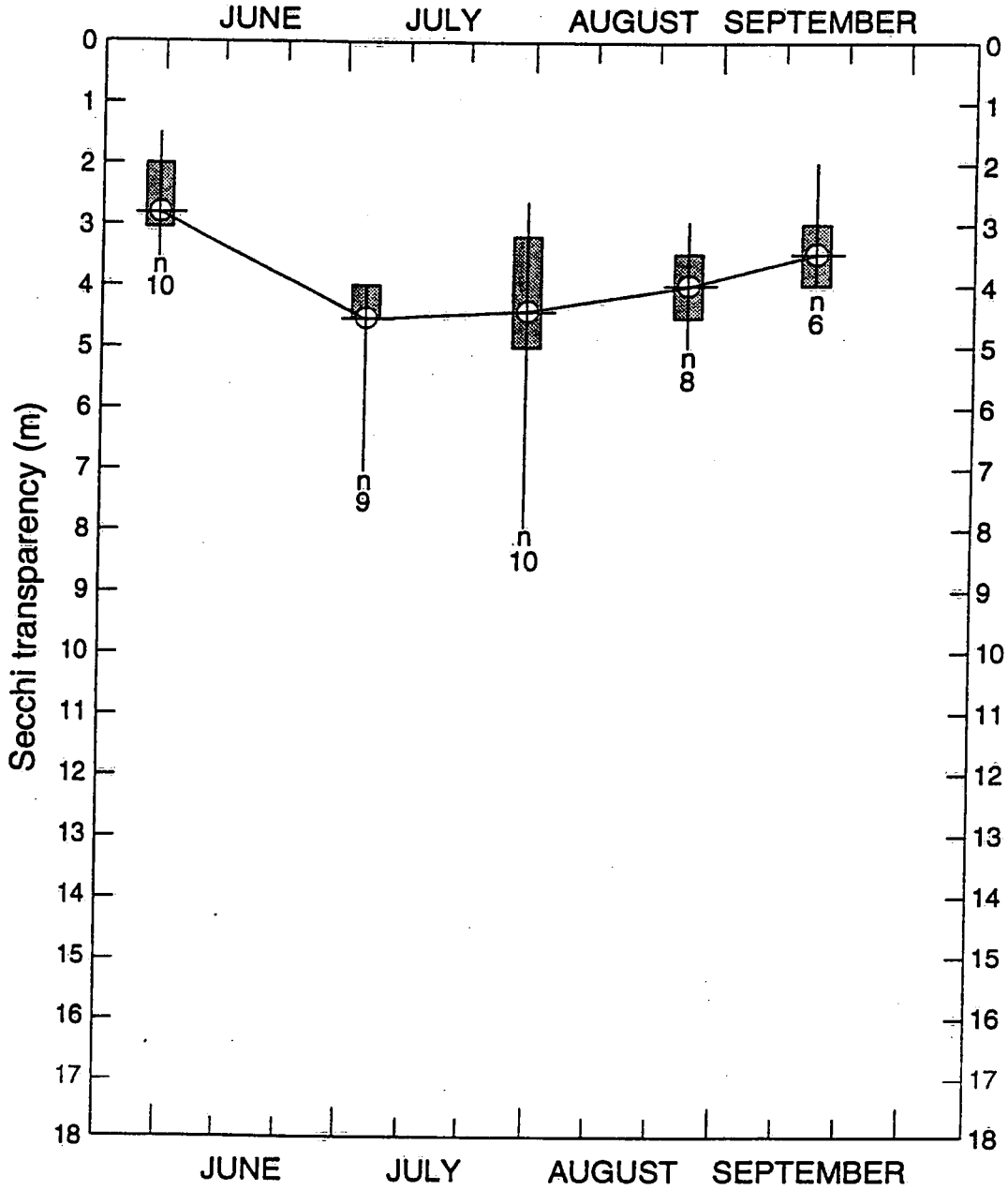
Secchi transparency, Central Lake Erie, offshore, median statistics on each cruise in summer 1966, Canadian vessels Brandal and Porte Dauphine.



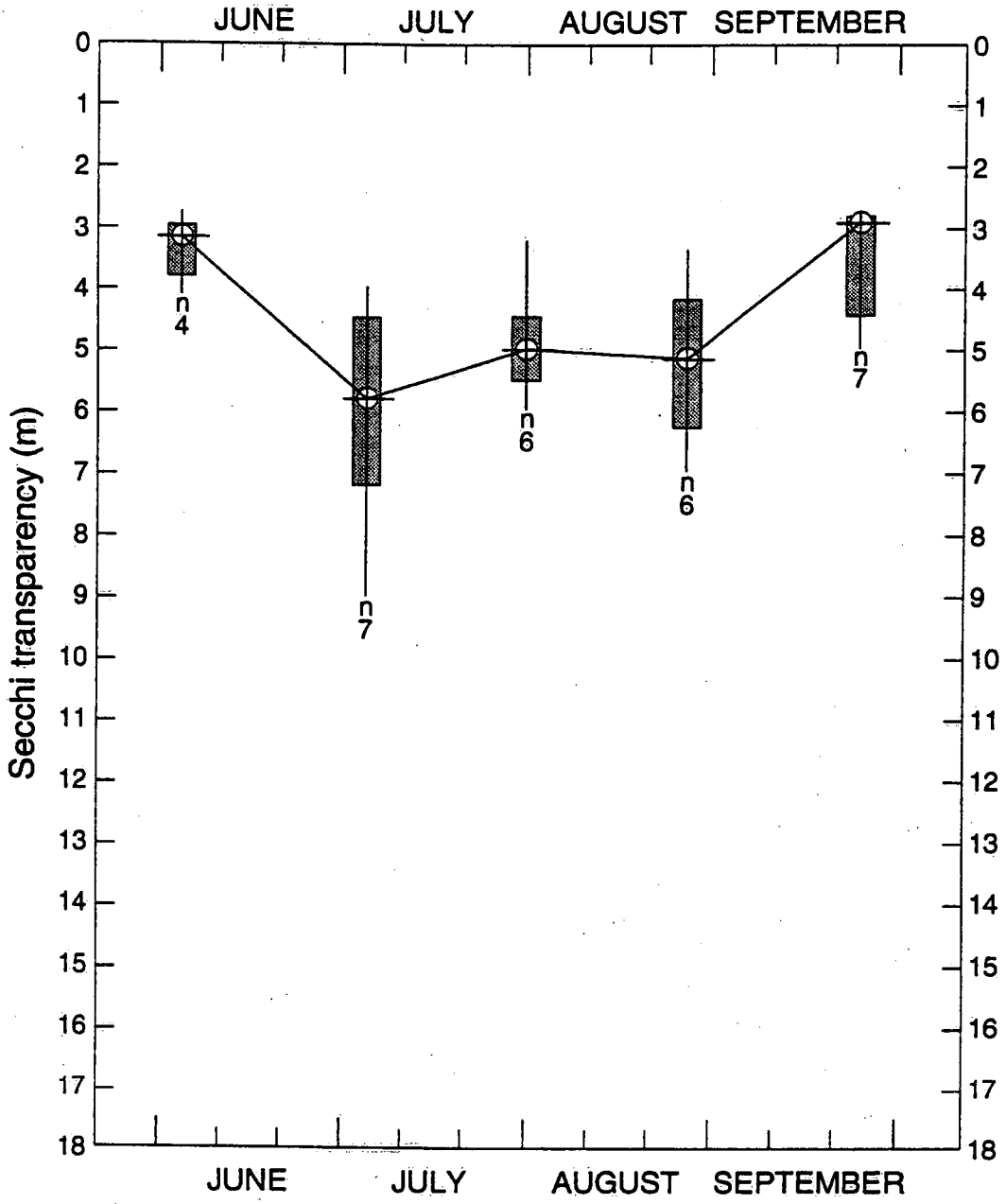
Secchi transparency, Central Lake Erie, offshore, median statistics on each cruise in summer 1967, Canadian vessel Brandal.



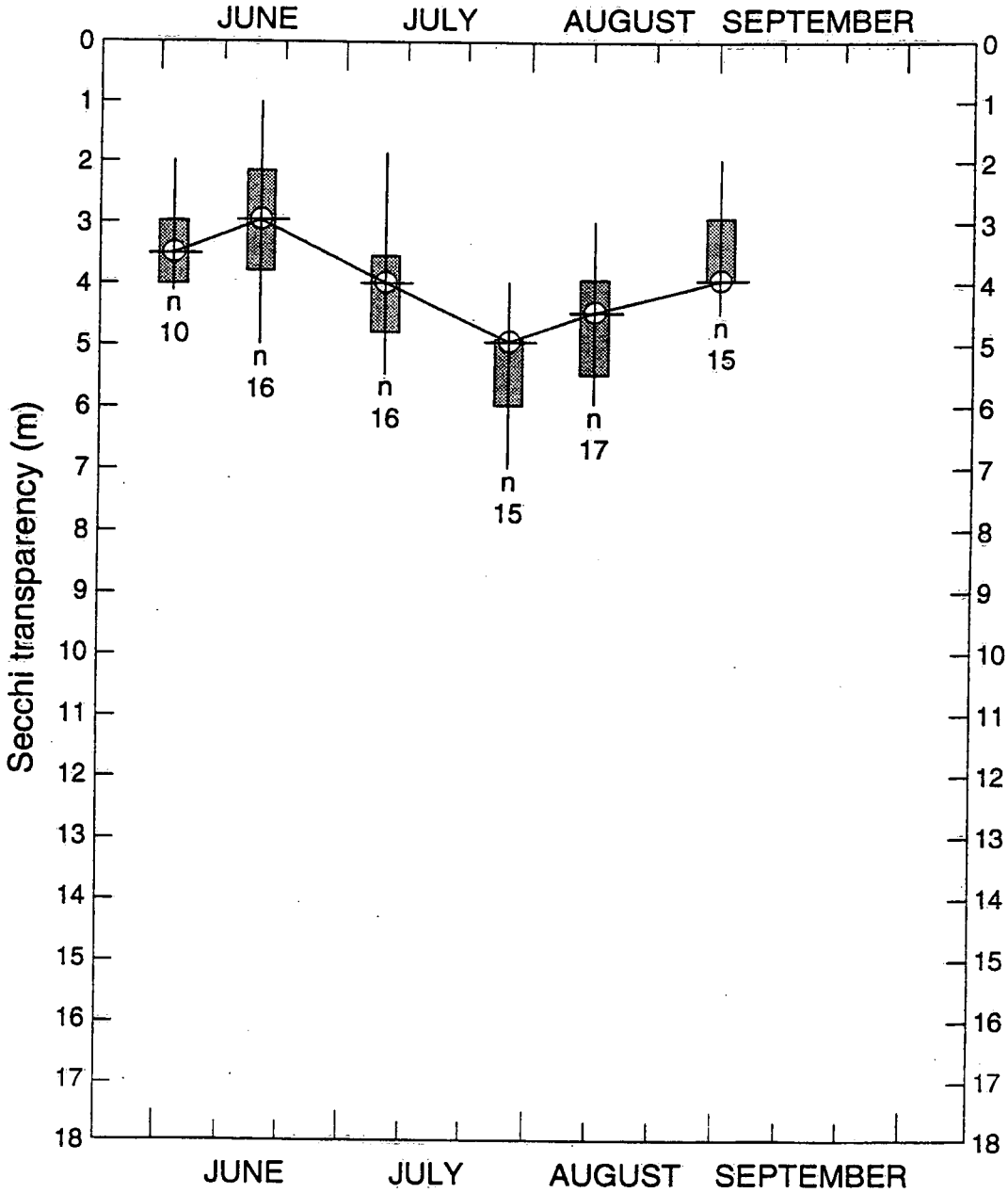
Secchi transparency, Central Lake Erie, offshore, median statistics on each cruise in summer 1968, Canadian vessel Theron.



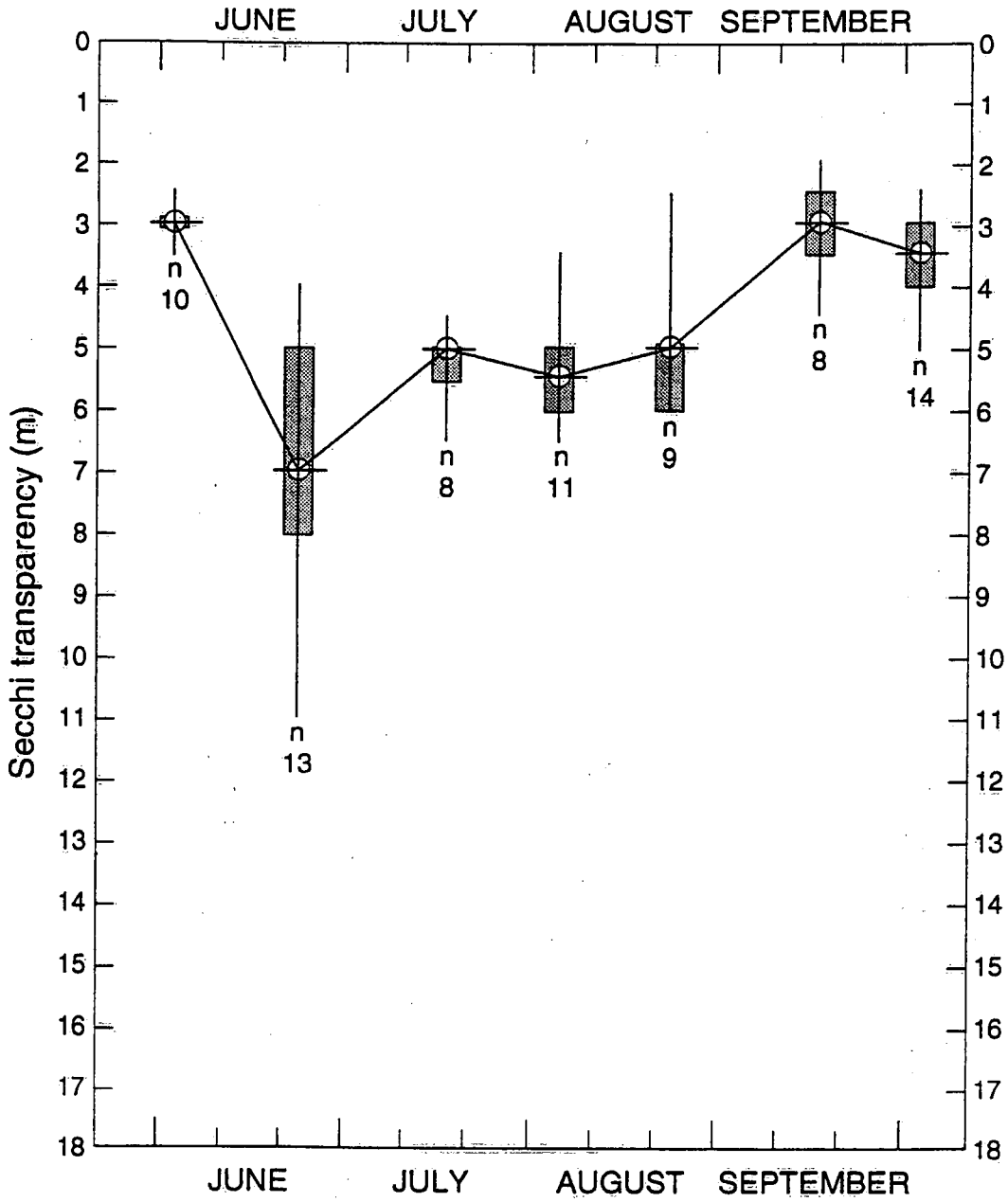
Secchi transparency, Central Lake Erie, offshore, median statistics on each cruise in summer 1969, Canadian vessel Martin Karlsen.



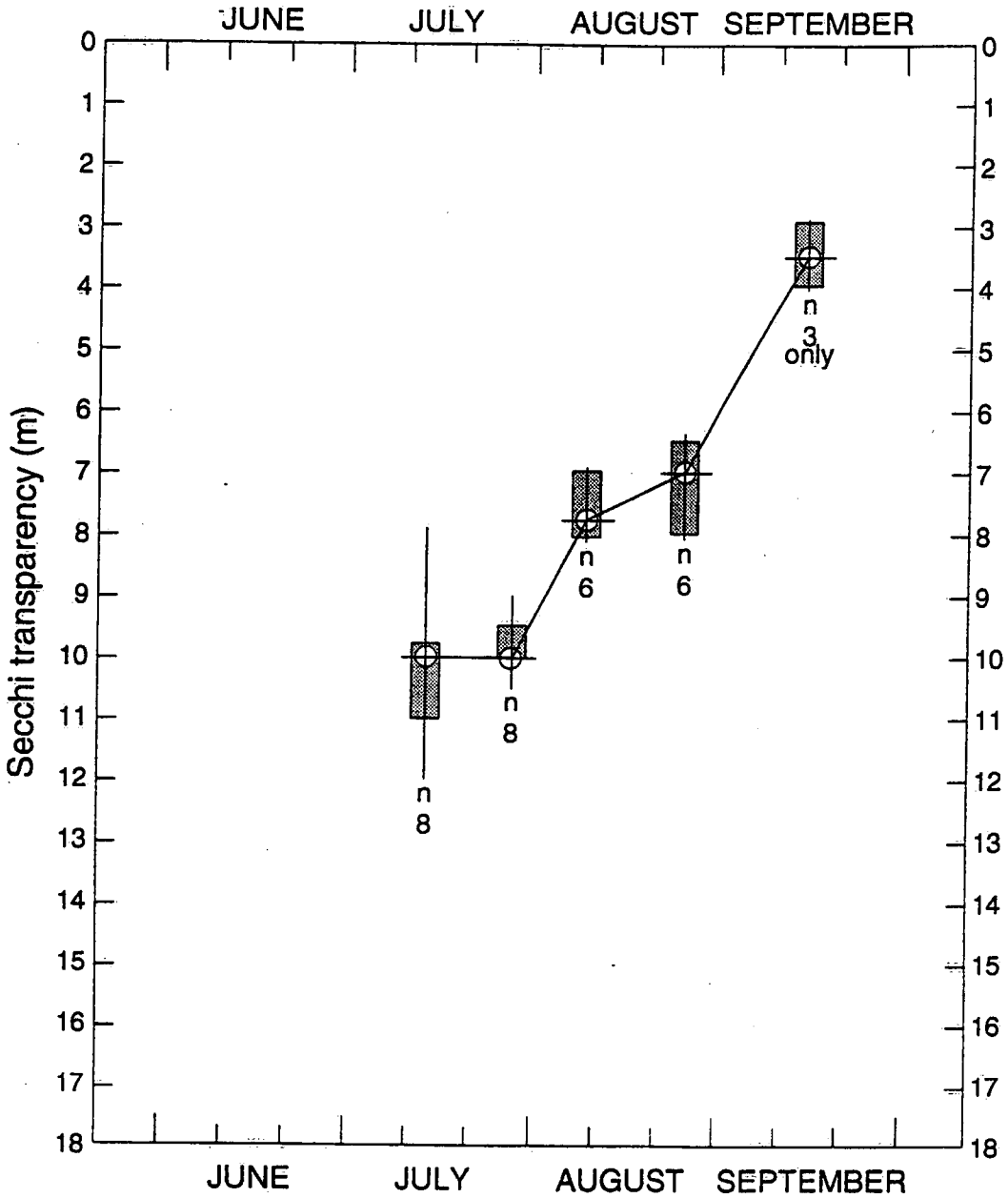
Secchi transparency, Central Lake Erie, offshore, median statistics on each cruise in summer 1970, Canadian vessel Martin Karlsen.



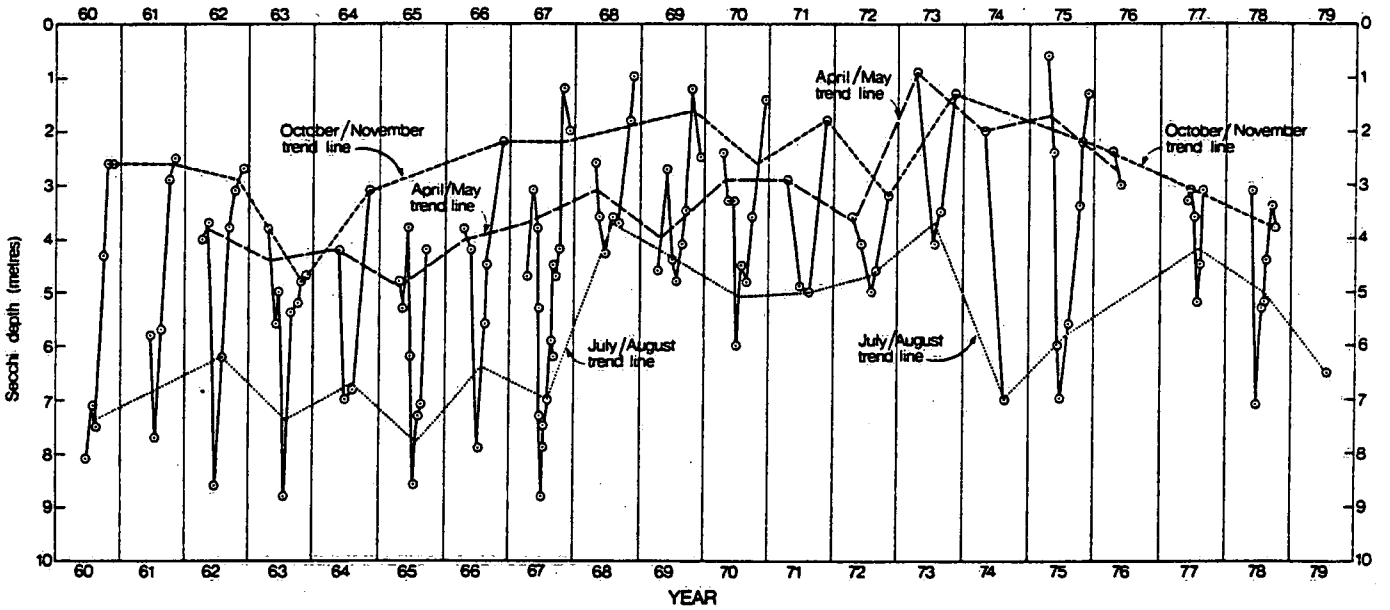
Secchi transparency, Central Lake Erie, offshore, median statistics on each cruise in summer 1977, Canadian vessels Petrel and Limnos.



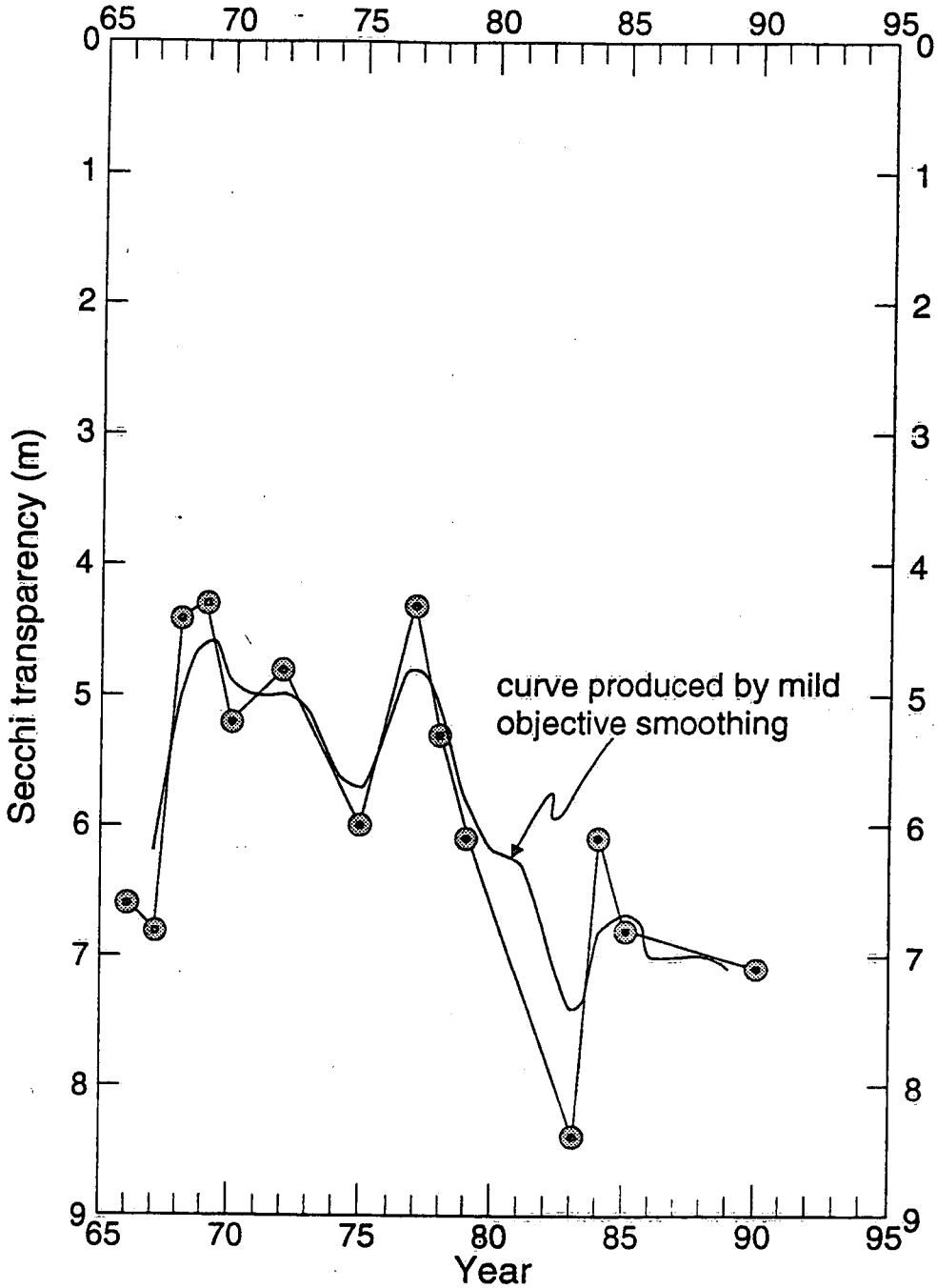
Secchi transparency, Central Lake Erie, offshore, median statistics on each cruise in summer 1978, Canadian vessel Limnos.



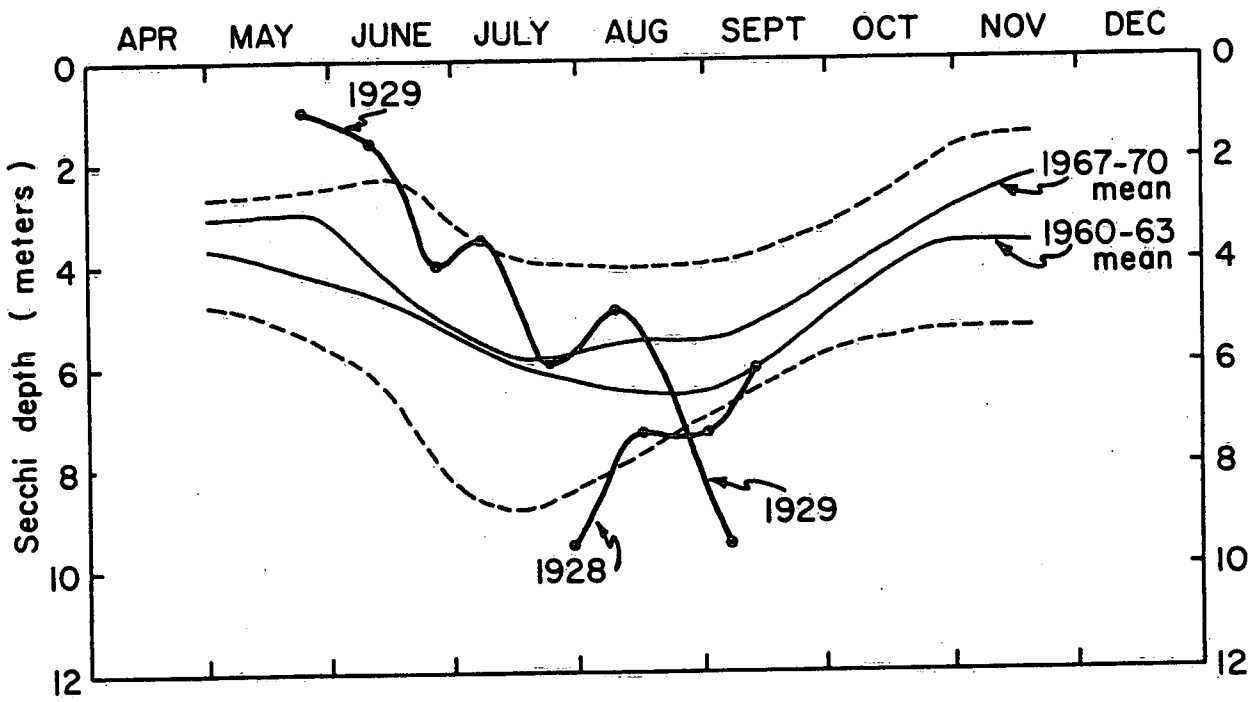
Secchi transparency, Central Lake Erie, offshore, median statistics on each cruise in summer 1983, Canadian vessels Advent and Limnos.



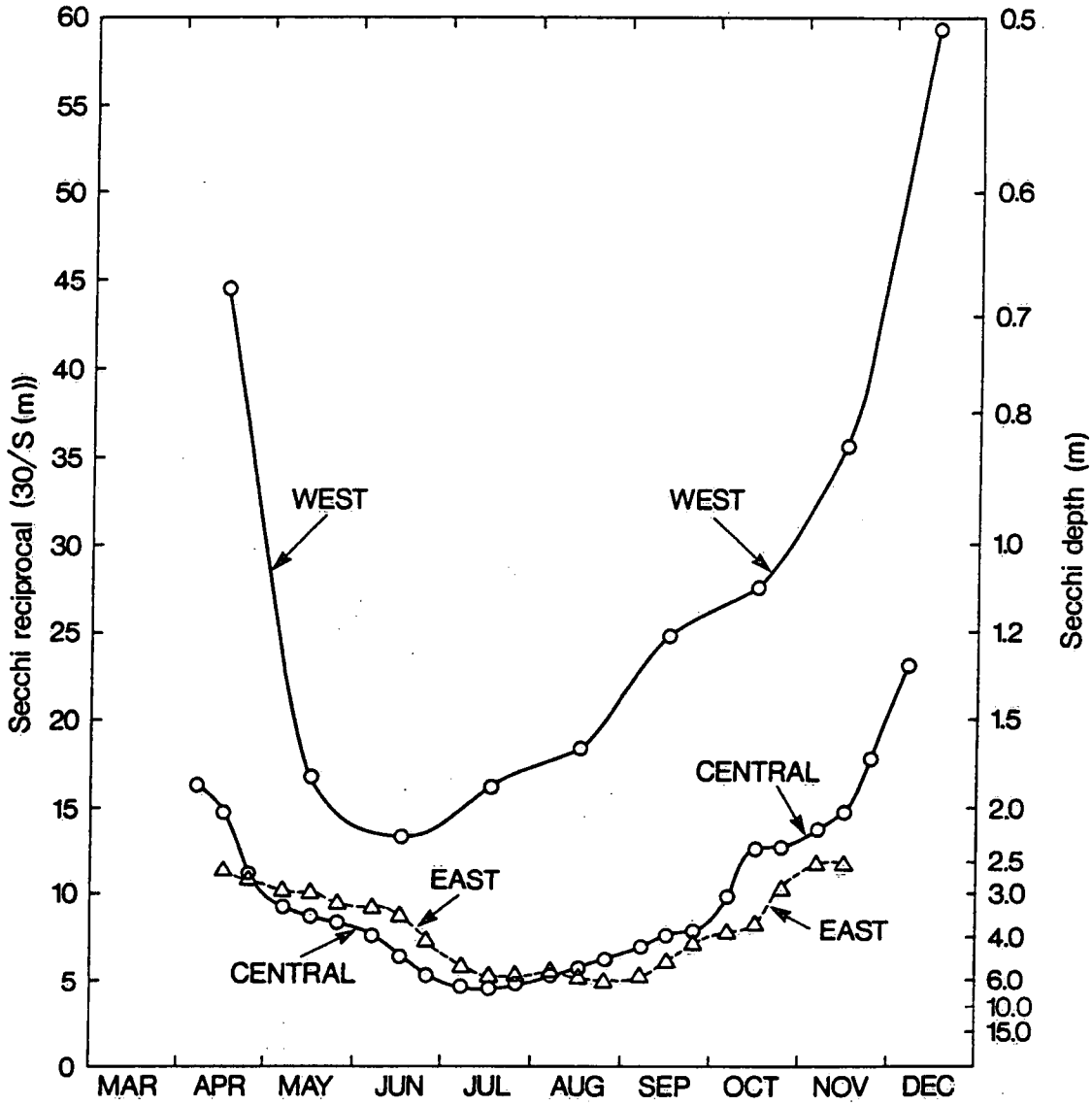
Central Lake Erie, Secchi transparency in an offshore polygon: data for the years 1960 to 1979. Each dot is the mean value from about 10 observations on a single cruise. Lines joining the dots within each year indicate the seasonal cycle. Long-term trend curves also shown, for three seasons: spring (April & May), summer (July & August), and autumn (October & November)



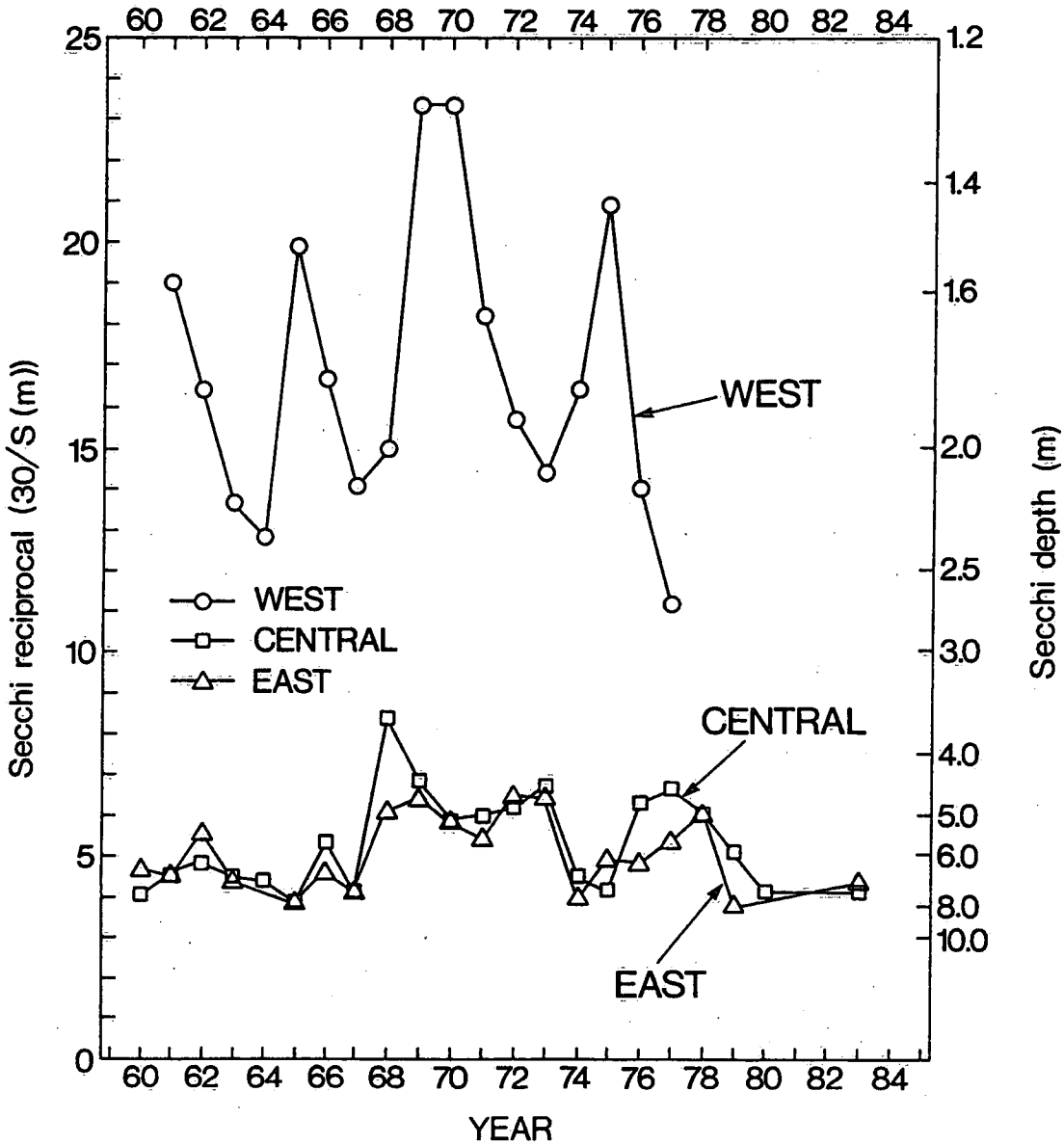
Secchi transparency in Central Lake Erie, offshore, 1966 to 1990, July/August averages each year, and a smoothed curve. Canadian data from the CCIW STAR file.



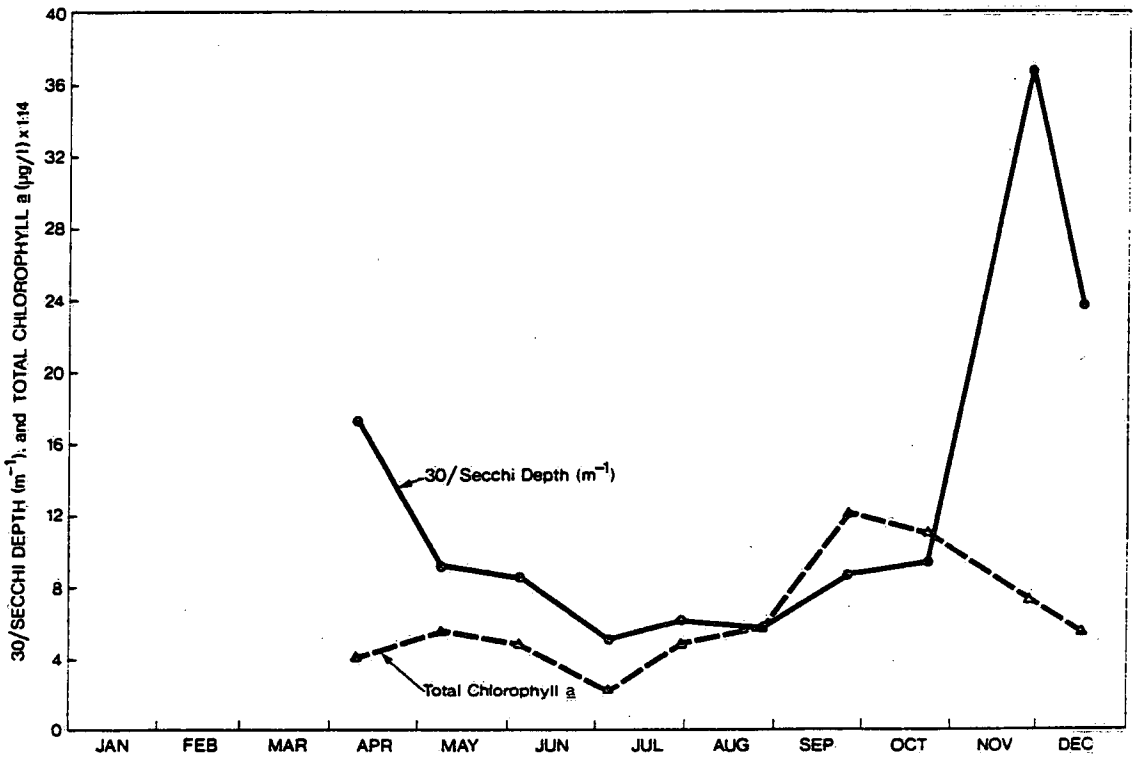
Secchi depths in Eastern Lake Erie (offshore part where the sounding is greater than 20 meters). The two dashed lines enclose all mean values for cruises of 1960-63 and 1967-70.



Secchi transparency in three offshore areas of Lake Erie: the mean seasonal cycles (1960 to 1980).

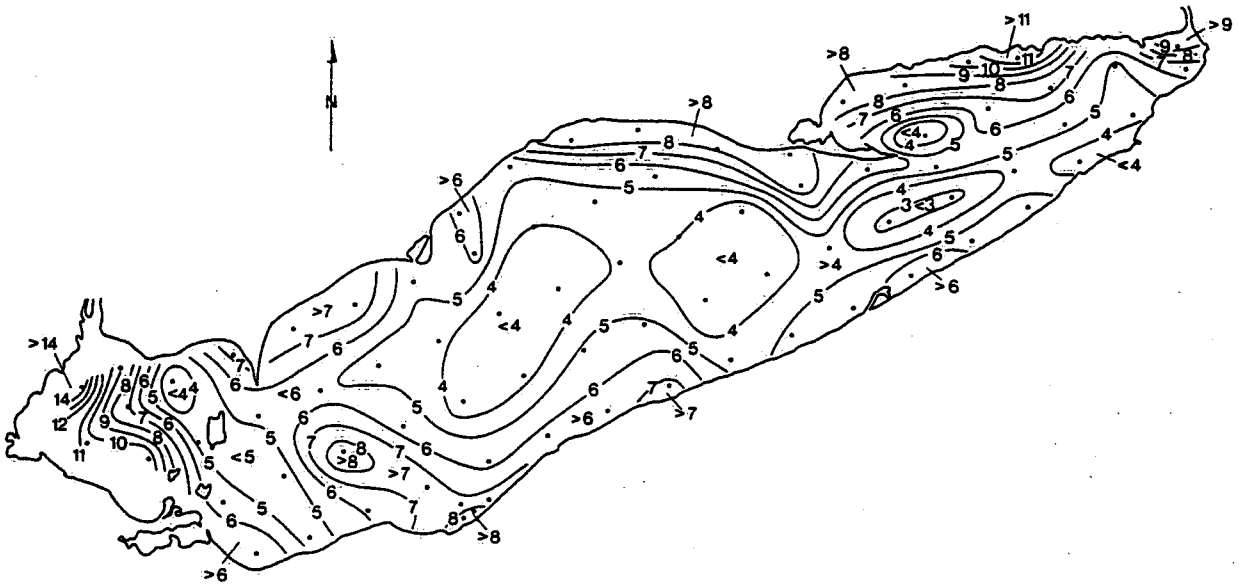


Secchi transparency in three offshore regions of Lake Erie in summer, mean values, 1960 to 1983.

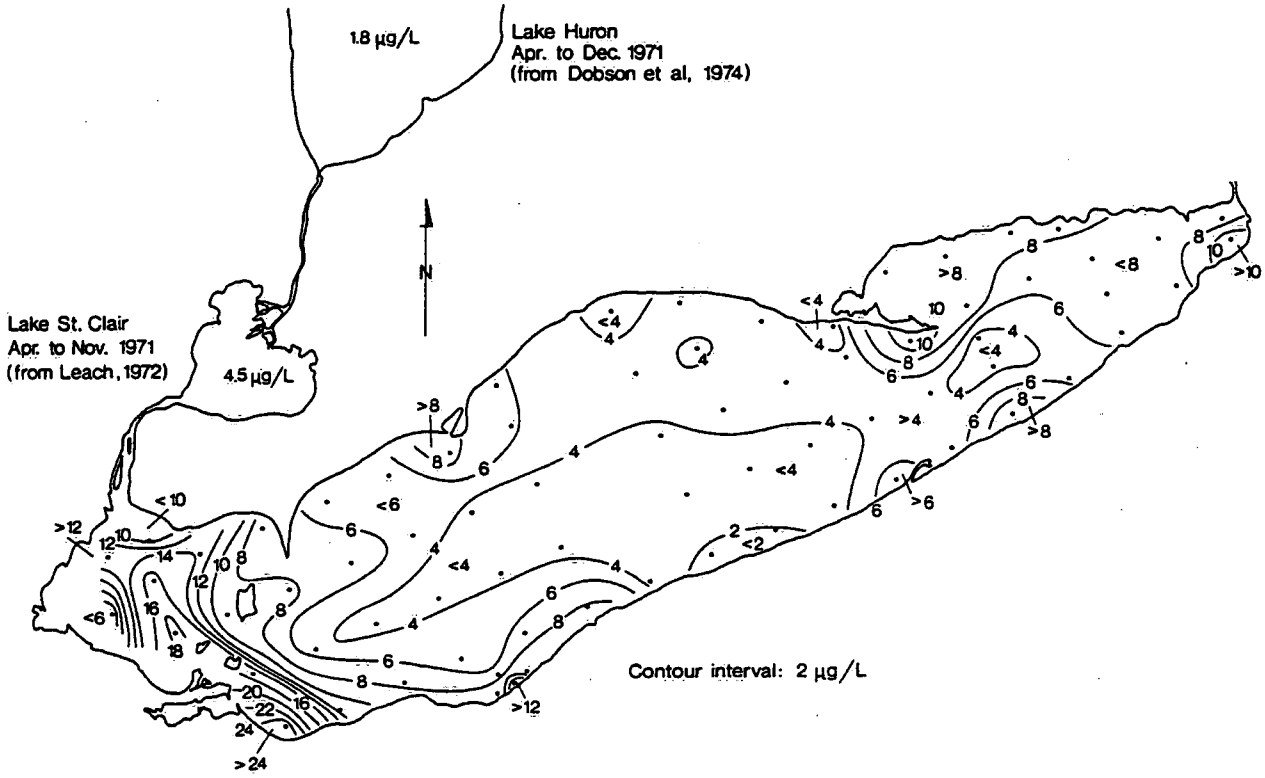


COMPARISON OF THE SEASONAL CYCLES OF 30/SECCHI DEPTH (m^{-1}) AND TOTAL CHLOROPHYLL a IN CENTRAL LAKE ERIE DURING 1970, SHOWING THAT TURBIDITY IS LARGELY NOT ASSOCIATED WITH PHYTOPLANKTON IN SPRING AND AUTUMN.

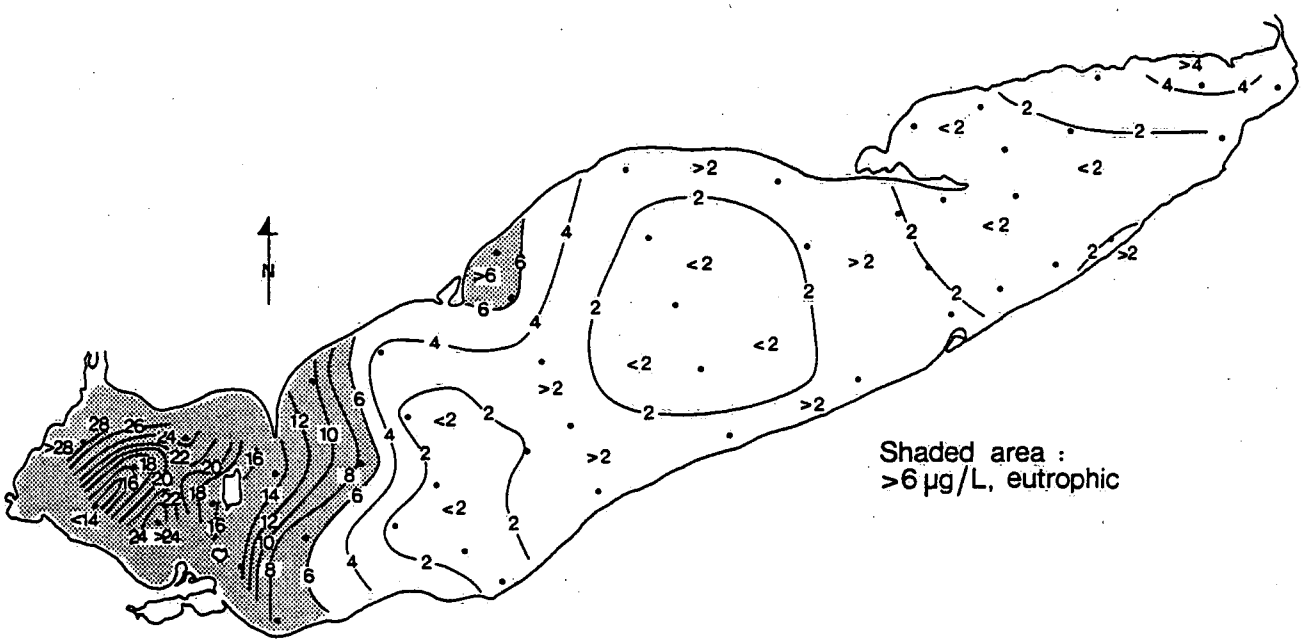
CHLOROPHYLL



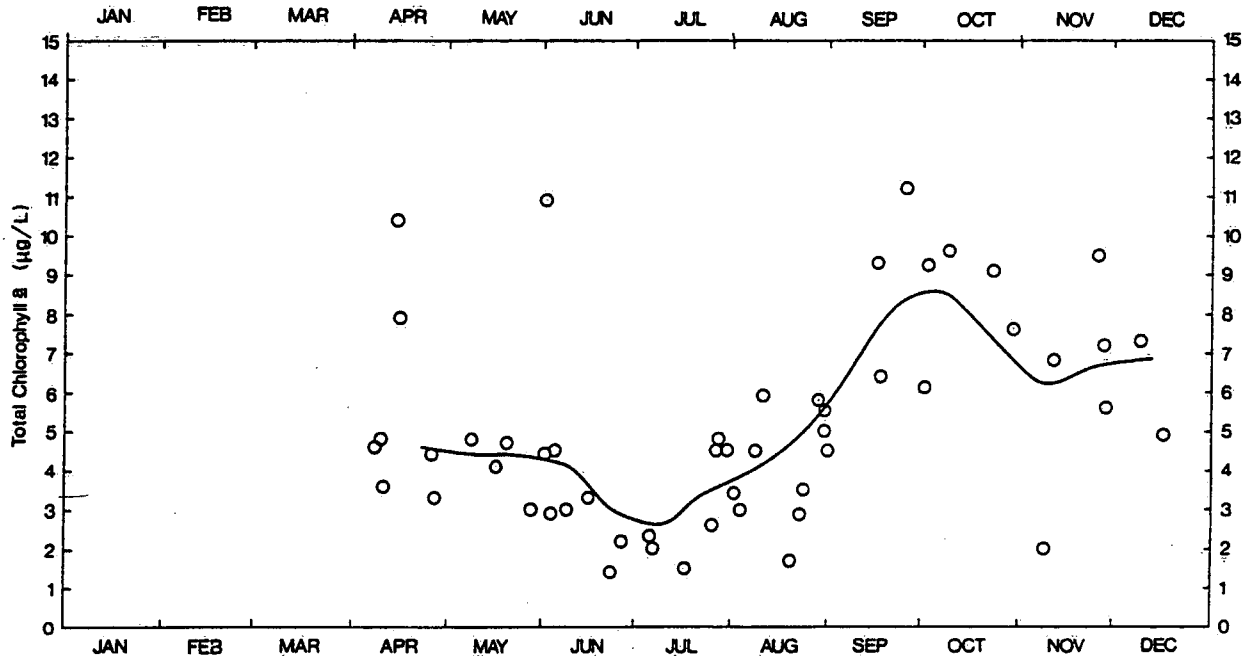
Total chlorophyll a (µg/L) in Lake Erie, surface distribution map (samples from 1 metre depth) May 17 to 22, 1968, CCIW vessel "Theron".



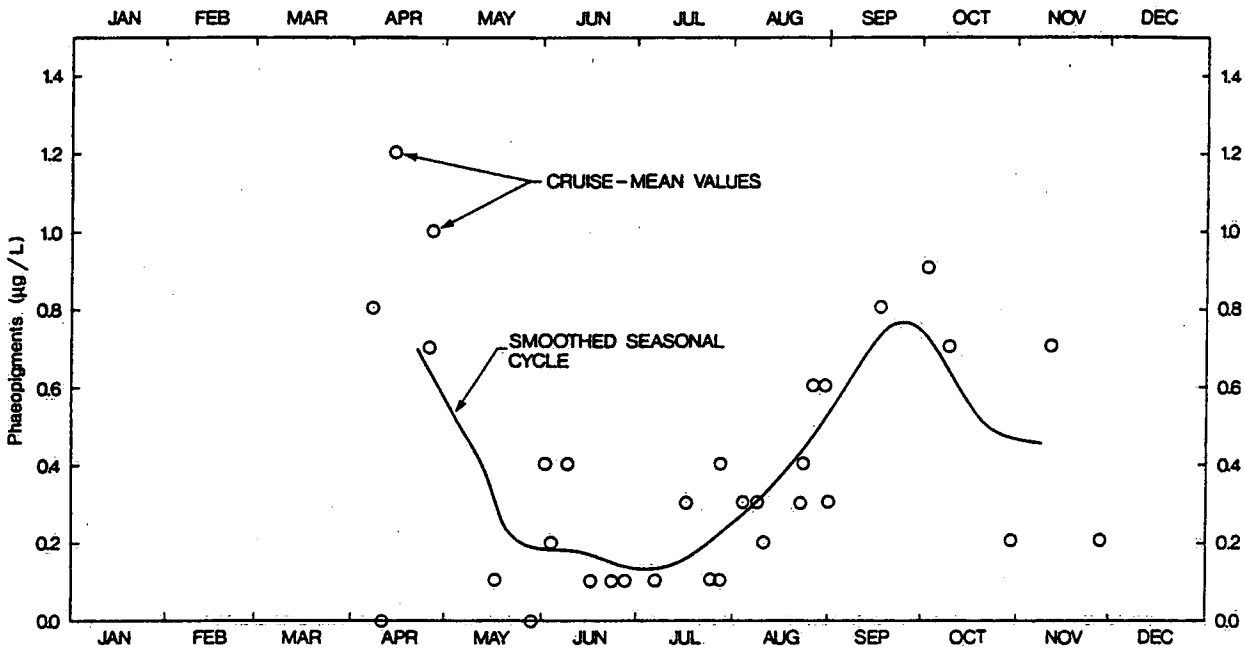
Total chlorophyll a (µg/L) in Lake Erie, surface distribution map (samples from 1 metre depth) July 29 to August 3, 1968, CCIW vessel "Theron".



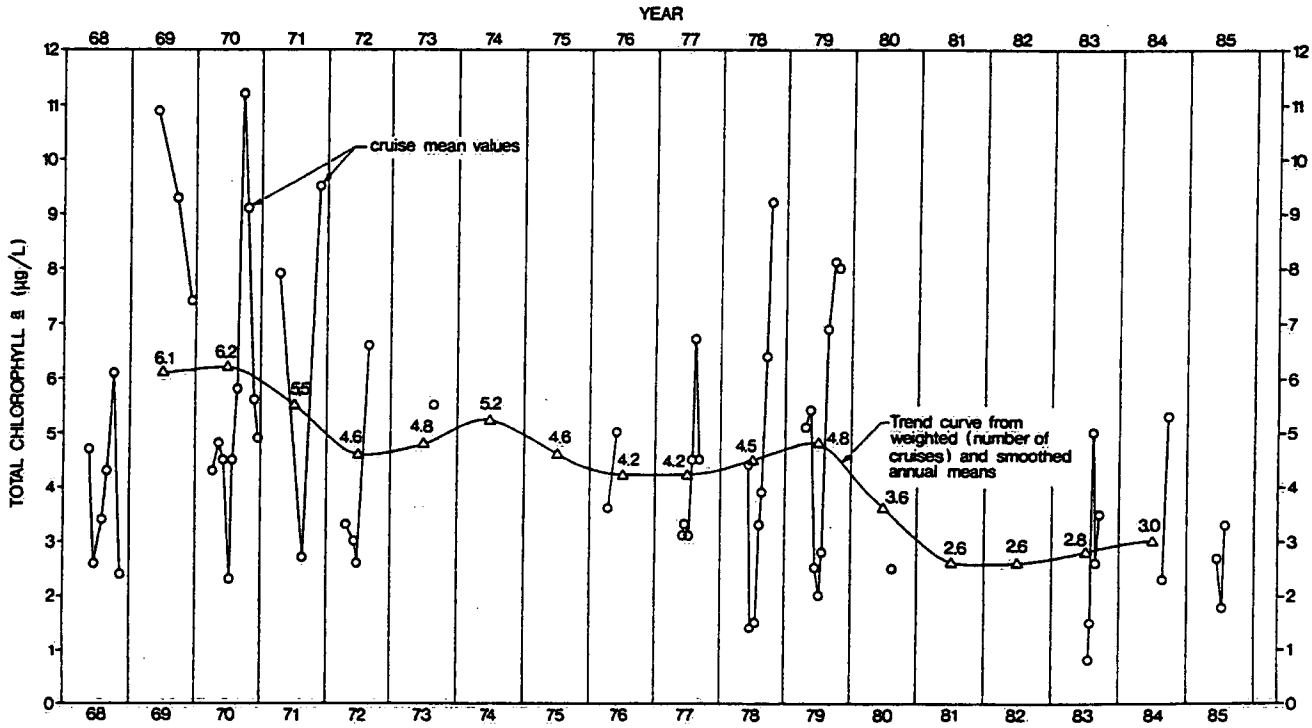
Lake Erie, total chlorophyll a at 1 m depth, August 17 to 21, 1971, "Martin Karlsen".



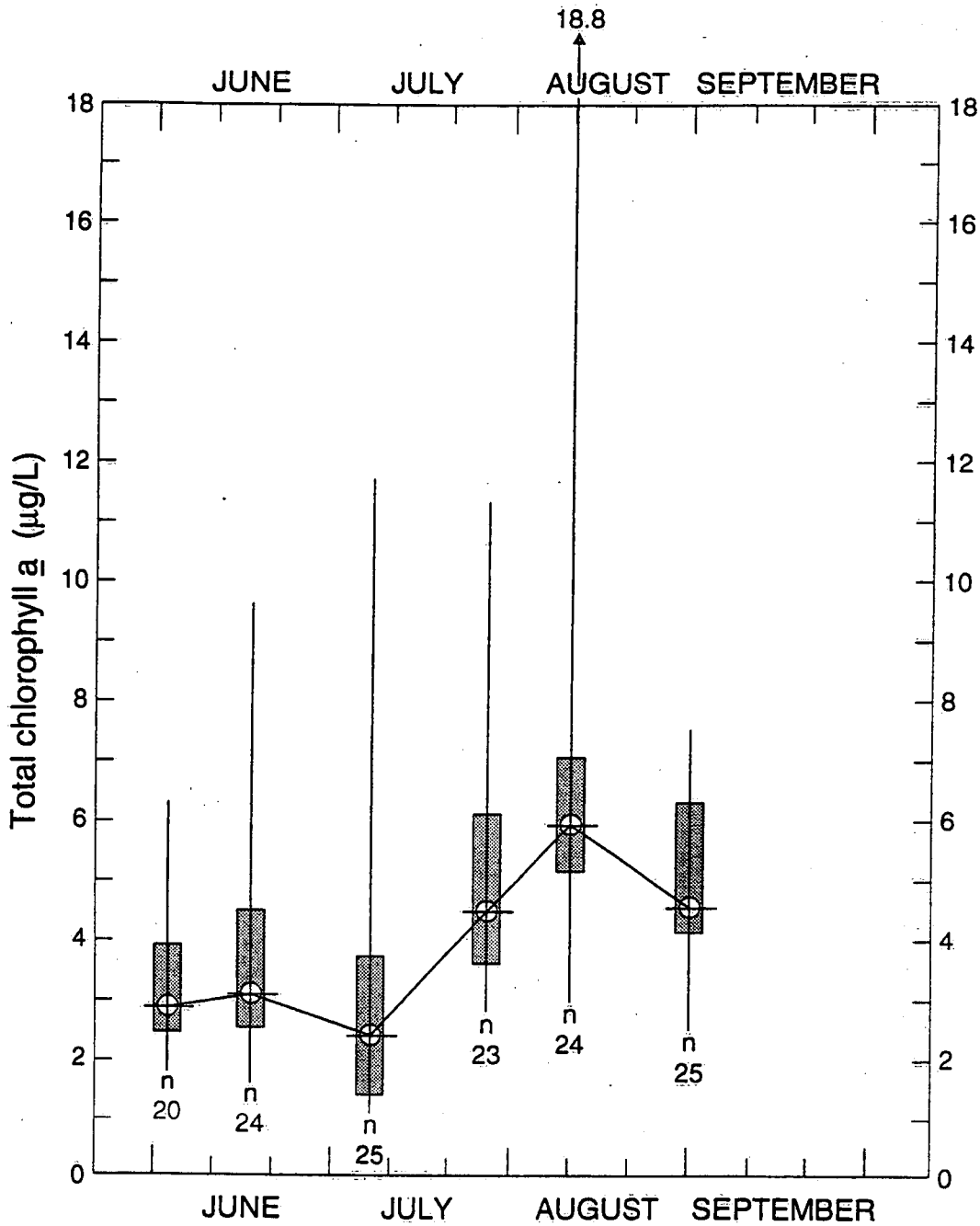
Total chlorophyll a in offshore surface waters of Central Lake Erie: 52 cruise-mean values and a smoothed seasonal cycle curve (CCIW data in the years 1968 to 1979).



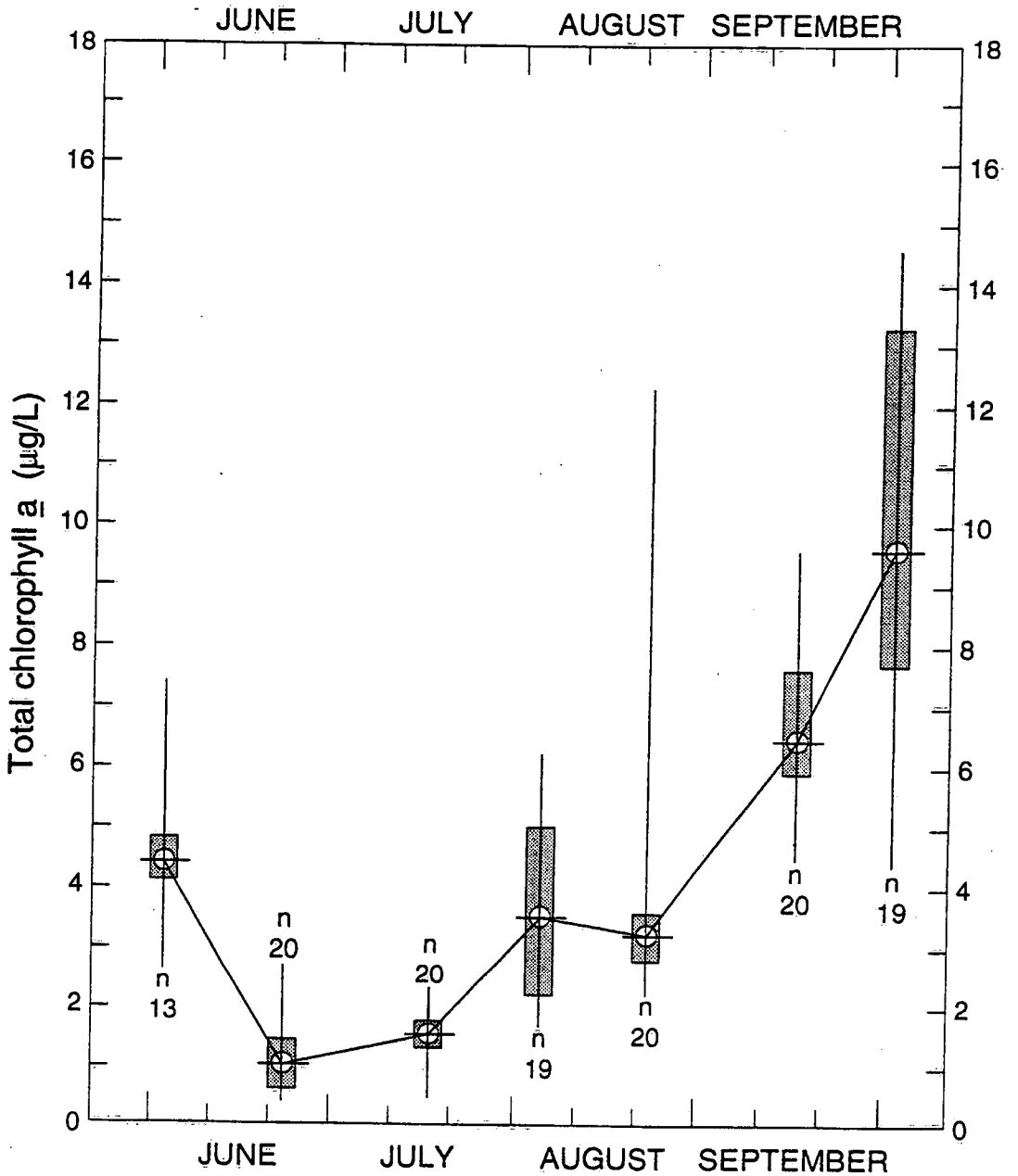
Phaeopigments (degraded chlorophyll a) in Central Lake Erie offshore near-surface waters: cruise-mean values on 32 cruises of CCIW vessels in the years 1972 to 1979, and the smoothed seasonal cycle.



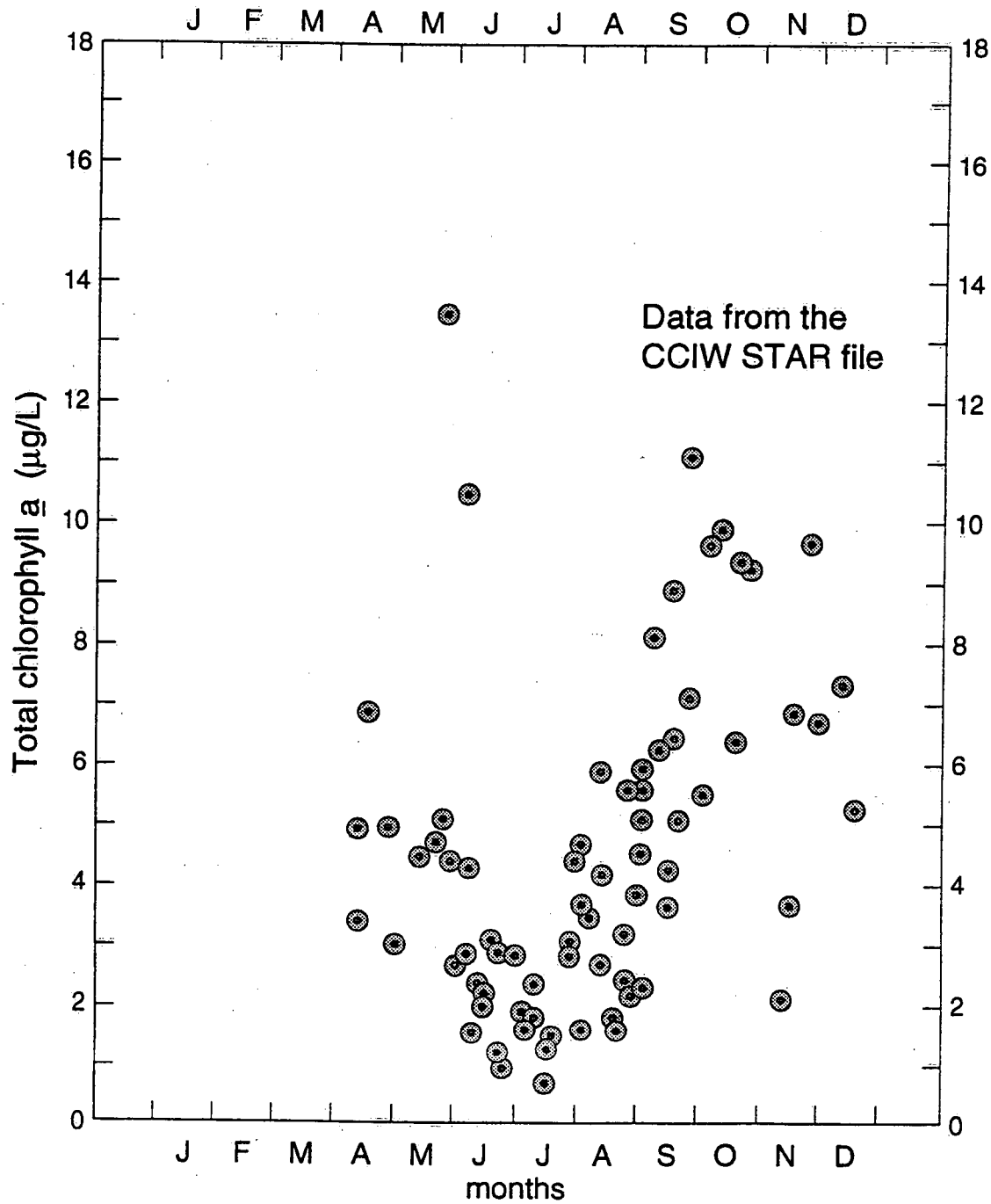
Total chlorophyll a in Central Lake Erie, offshore surface waters: CCIW data cruise mean values, 1968 to 1985



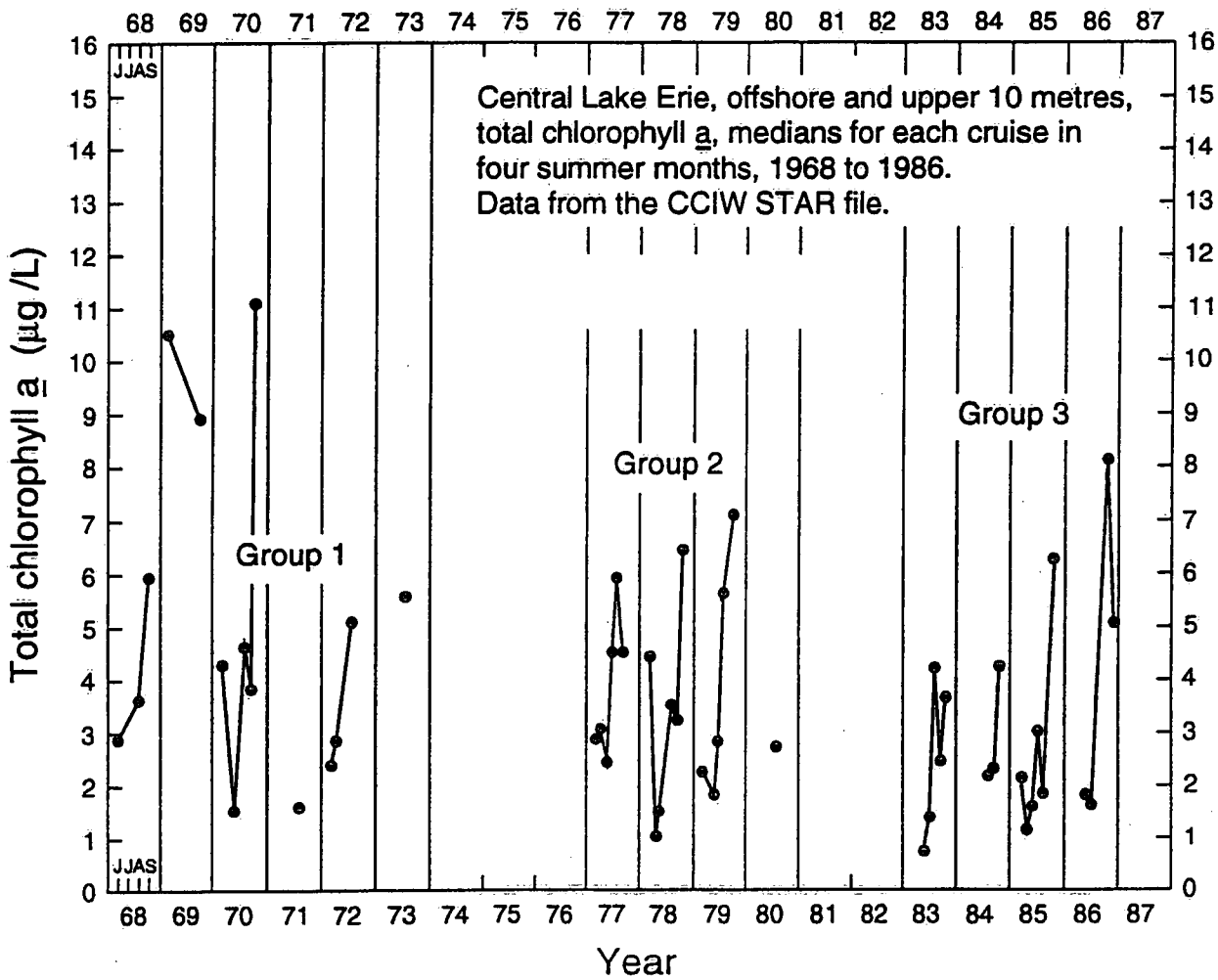
Total chlorophyll a, Central Lake Erie, offshore and upper 10m, median statistics on each cruise in summer 1977, Canadian vessels Petrel and Limnos.

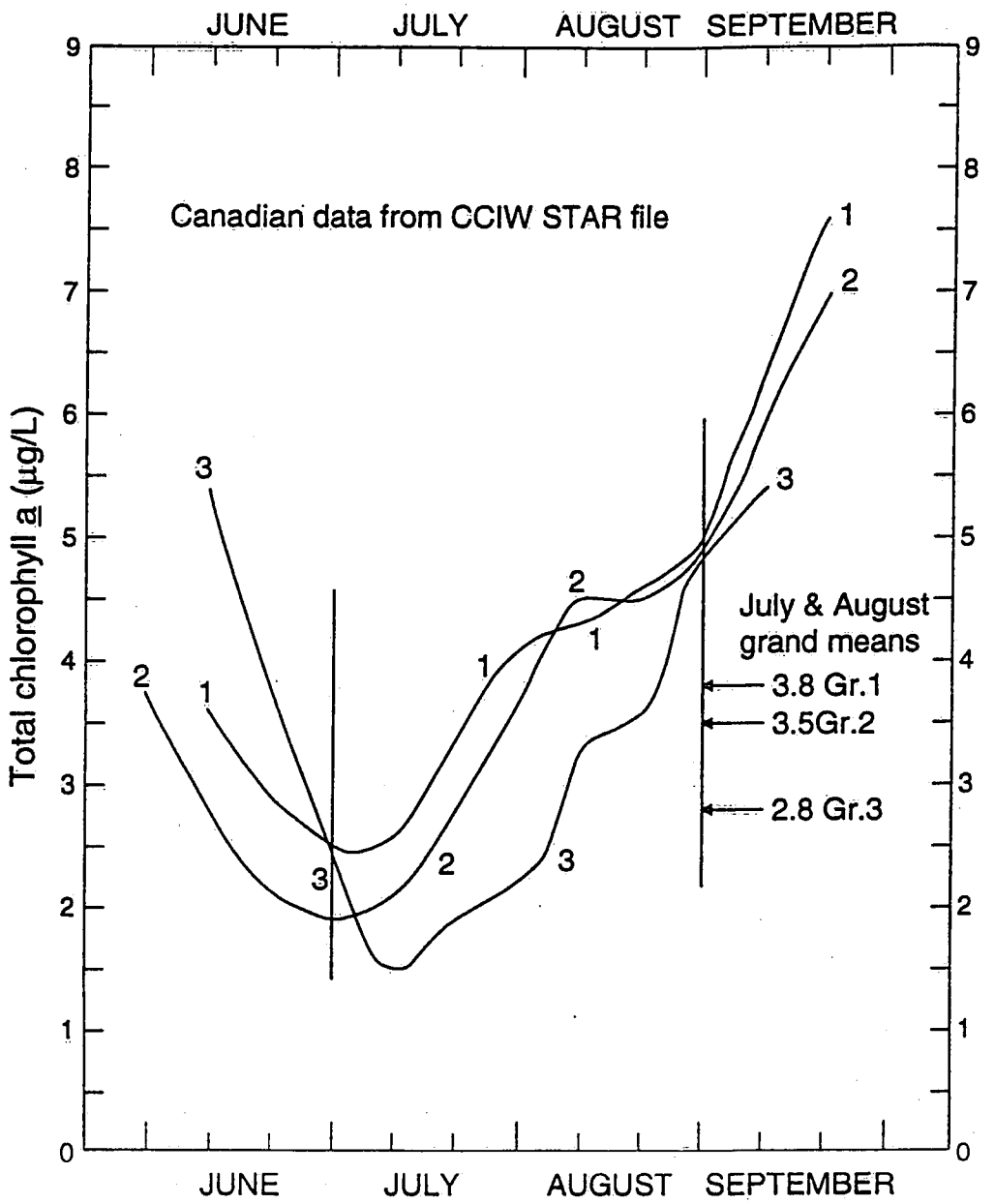


Total chlorophyll a, Central Lake Erie, offshore and upper 10m, median statistics on each cruise in summer 1978, Canadian vessel Limnos.

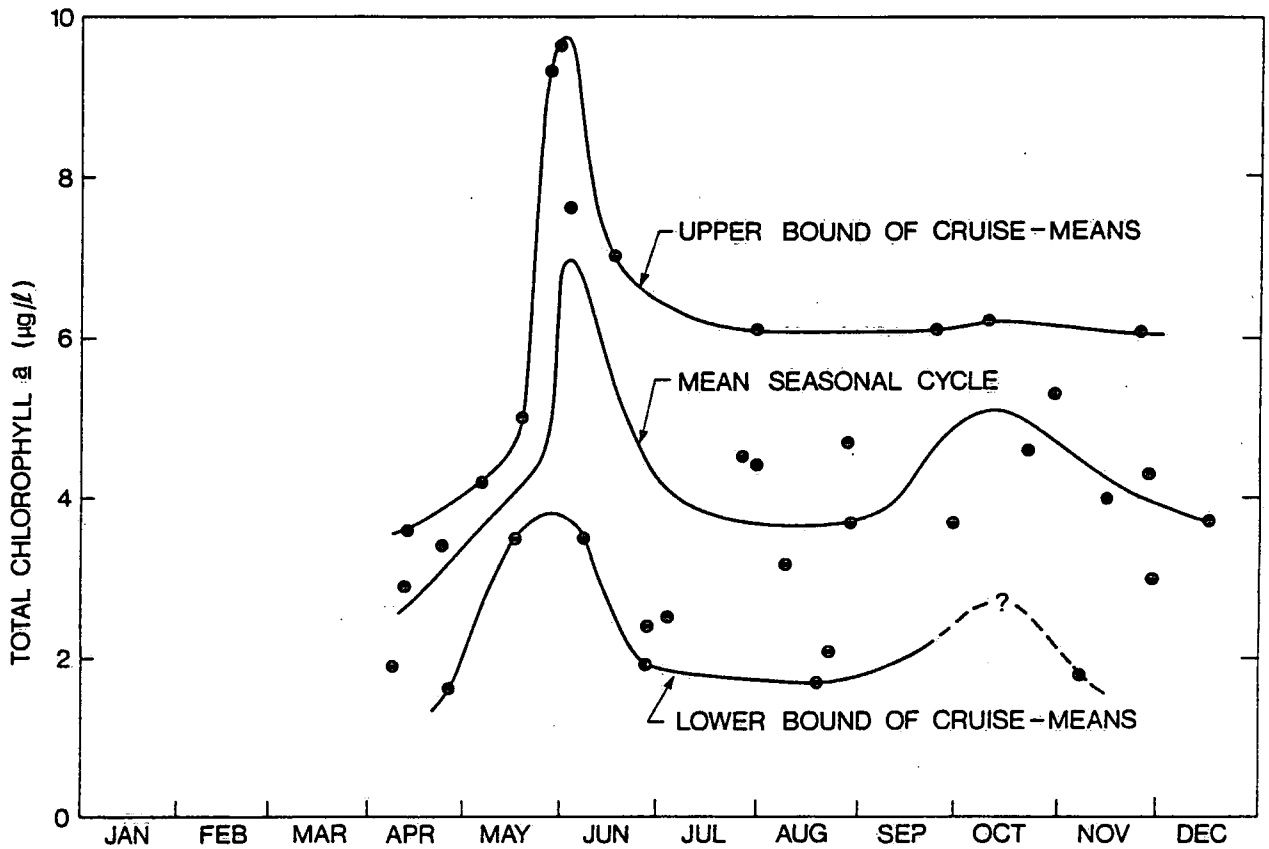


Central Lake Erie, offshore and upper 10m, total chlorophyll a, medians each cruise, 1968 to 1986, plotted vs. time-of-year.


Central Lake Erie, offshore and upper 10 metres,
total chlorophyll a, medians for each cruise in
four summer months, 1968 to 1986.
Data from the CCIW STAR file.
Group 1
Group 2
Group 3
JJAS
JJAS
Total chlorophyll a (µg /L)
Year
68 69 70 71 72 73 74 75 76 77 78 79 80 81 82 83 84 85 86 87
0 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16



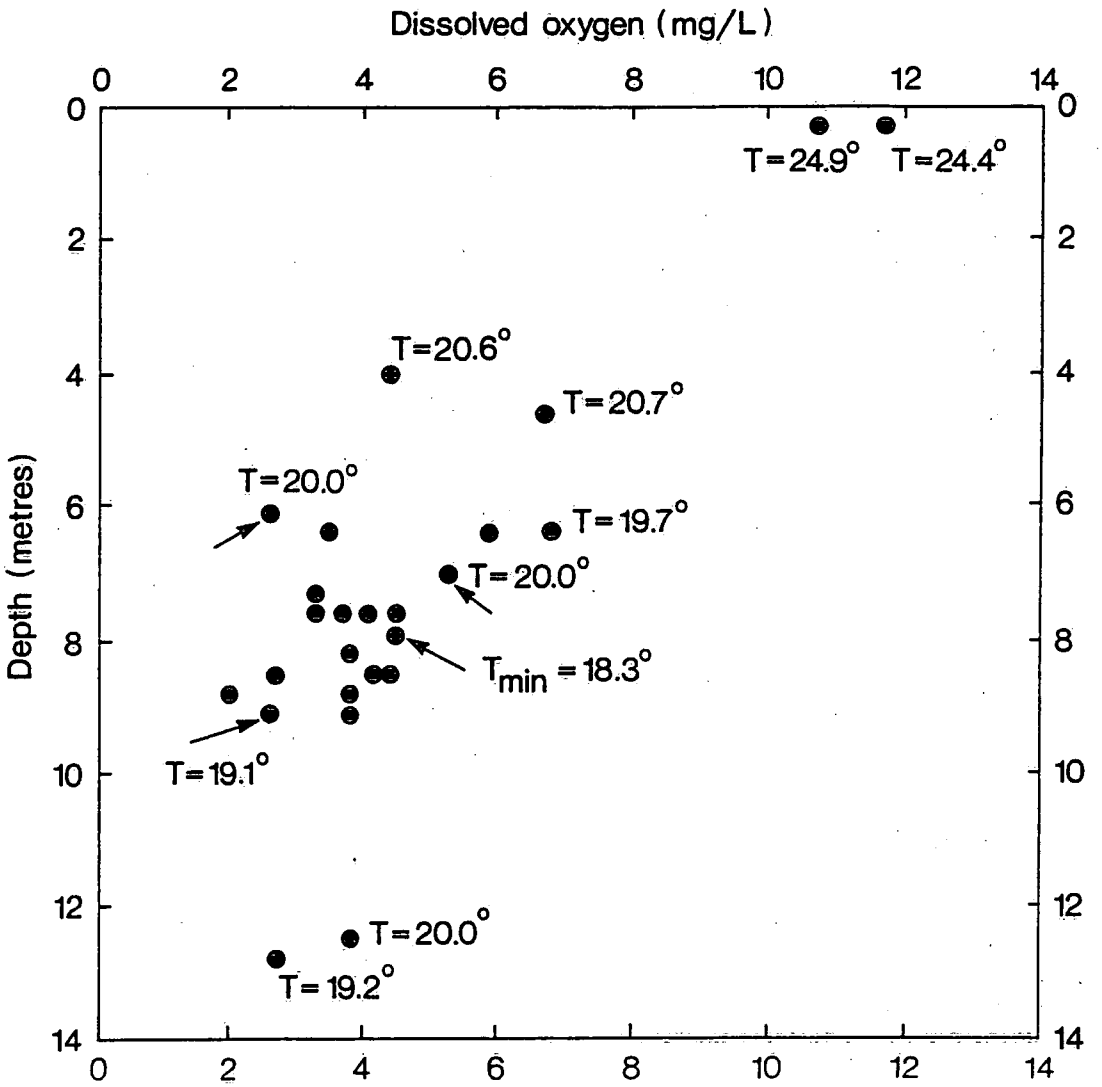
Central Lake Erie, offshore and upper 10m, total chlorophyll a, smoothed seasonal curves from three groups of data:
① 1968, 70 ② 1977, 78, 79 ③ 1983, 85, 86.
(There were no other years with adequate data)



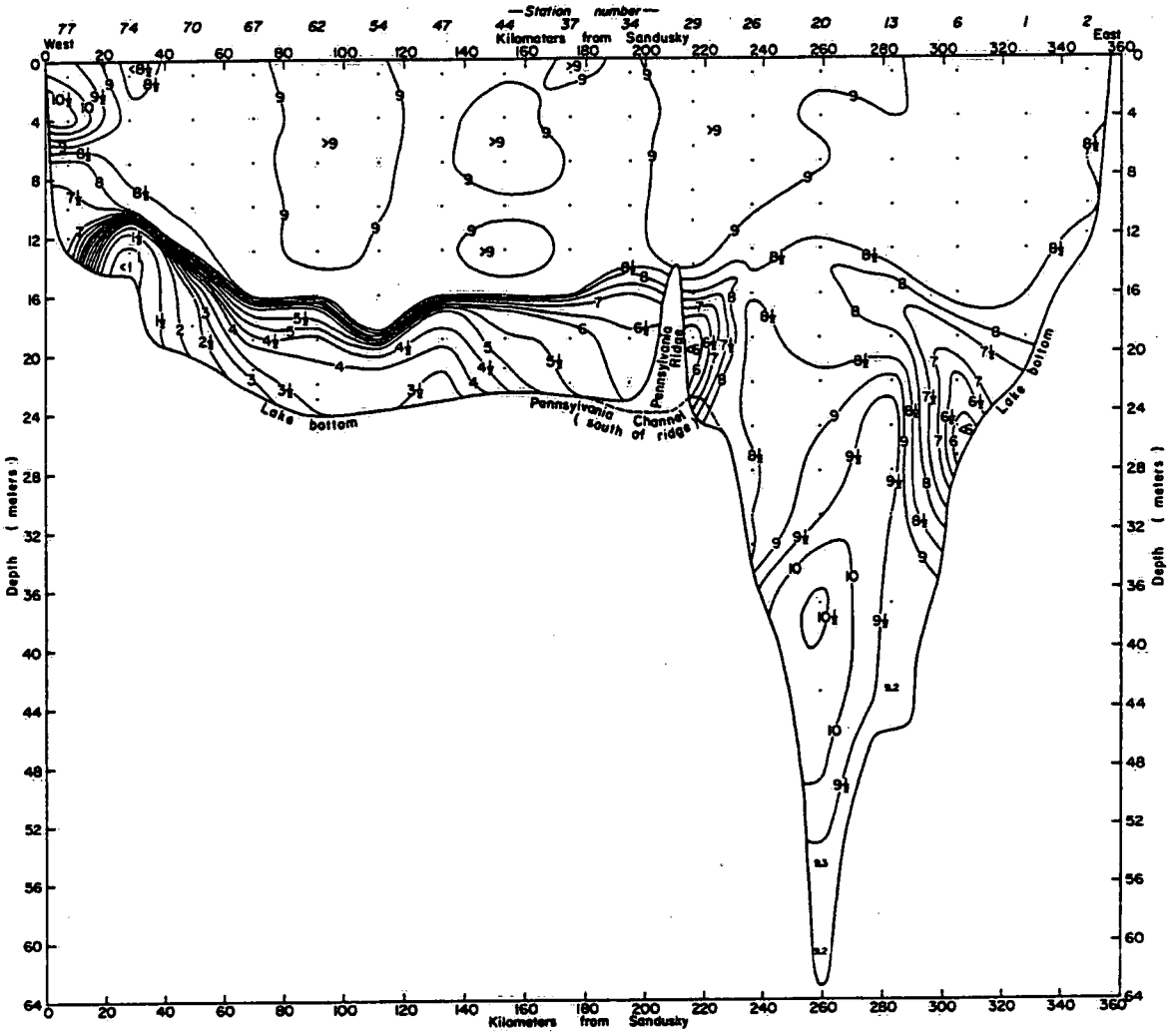
EASTERN LAKE ERIE, OFFSHORE PART WHERE THE SOUNDING IS >20 m: TOTAL CHLOROPHYLL a IN SURFACE WATERS (THE MEAN VALUES ON EACH CRUISE, µg/ℓ) ON 35 CRUISES IN THE YEARS 1968 - 1976.

(The Curves are Speculative.)

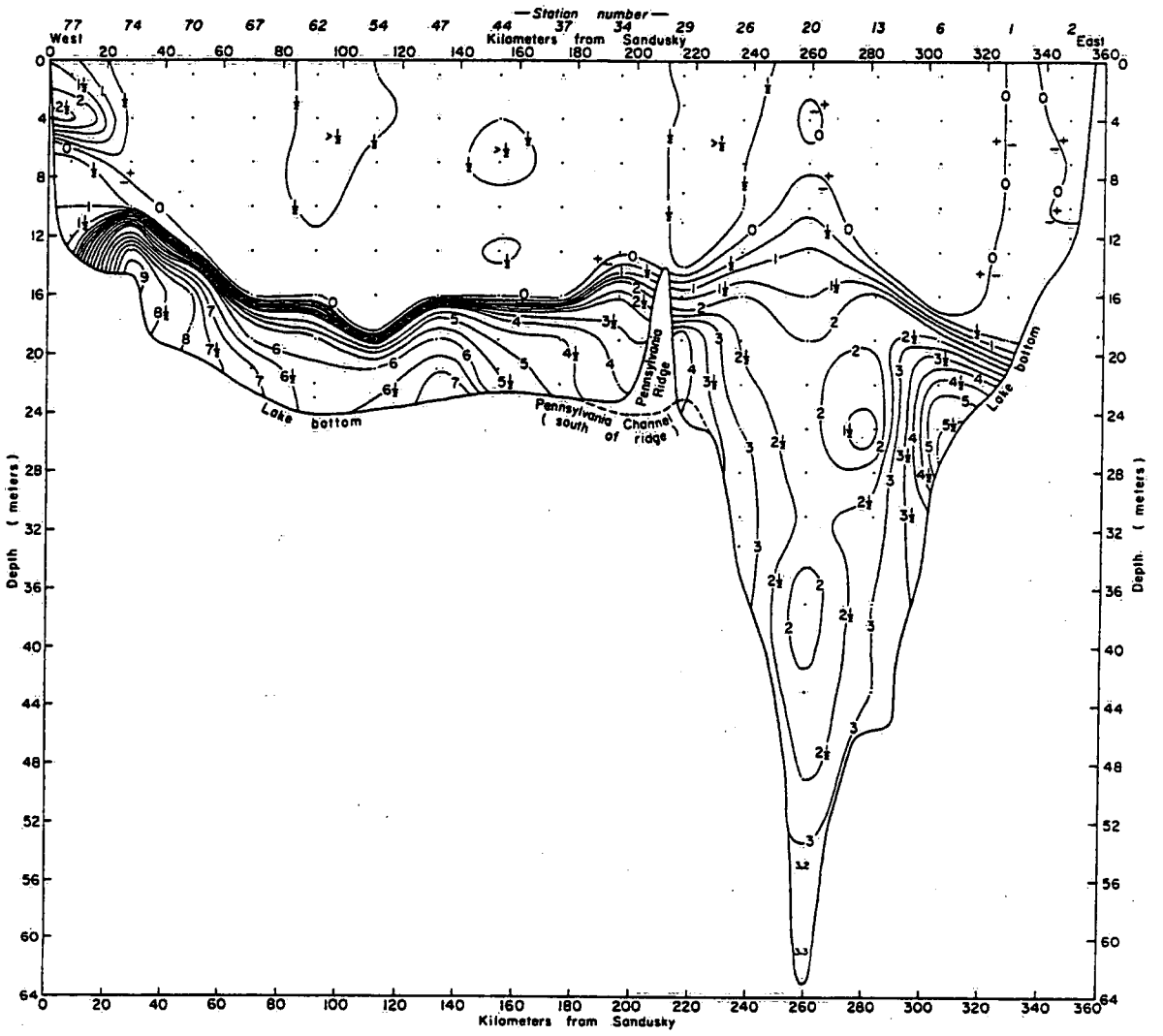
DISSOLVED OXYGEN



Dissolved oxygen (mg/L) in Western Lake Erie, June 28 & 29, 1963 (data from Carr, Applegate and Keller, 1965).

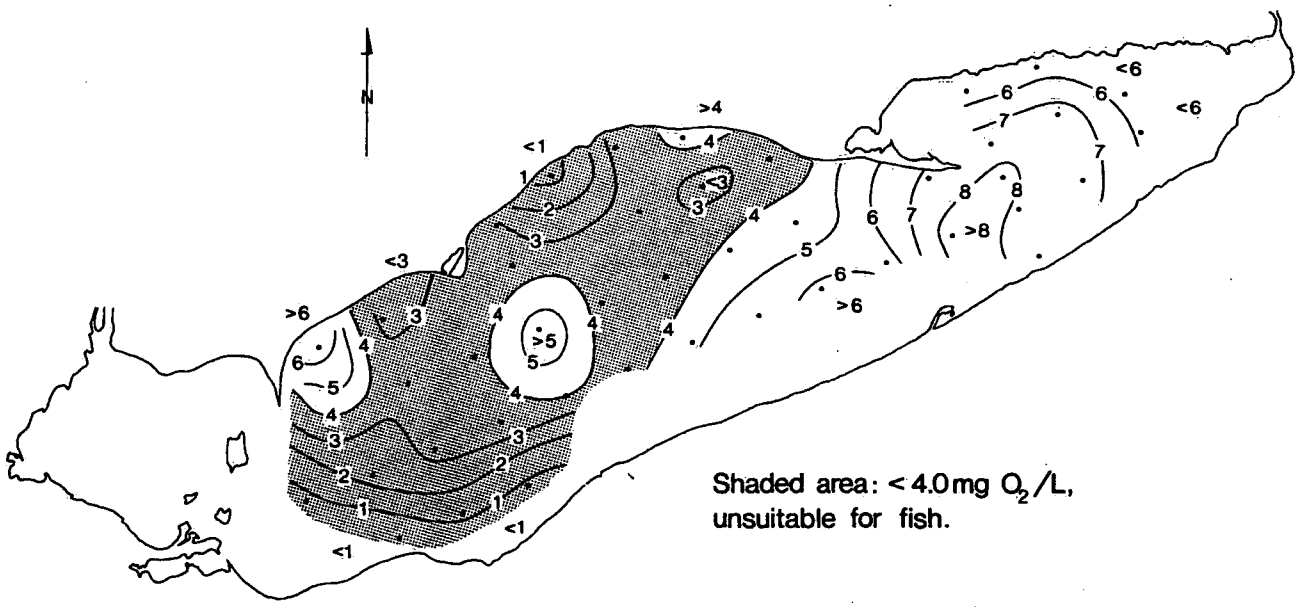


Lake Erie: Dissolved oxygen (mg/l) in a vertical section from Sandusky to Buffalo, July 29 to August 2, 1968. Vessel 'Theron' (Canada Centre for Inland Waters). Cruise 68-1-08. Vertical exaggeration: X 5,000.

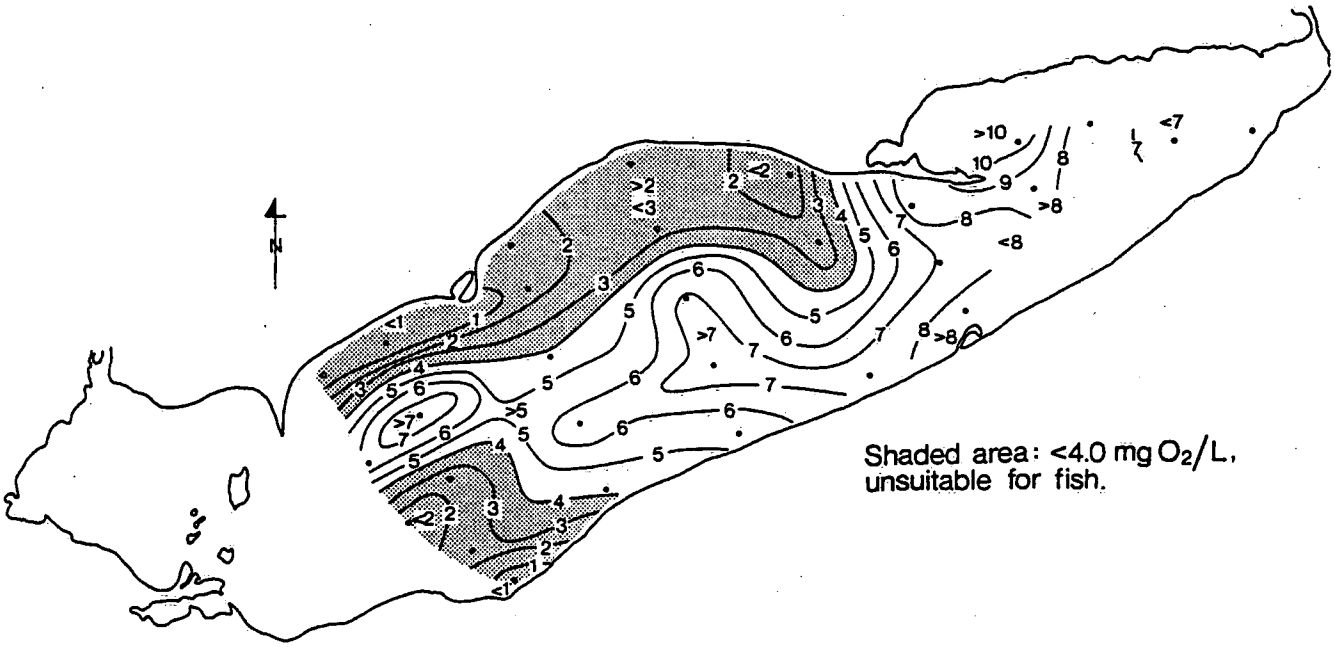


Lake Erie: Oxygen anomaly (mg/l) in a vertical section from Sandusky to Buffalo, July 29 to August 2, 1968. Vessel 'Theron' (Canada Centre for Inland Waters). Cruise 68-1-08. Vertical exaggeration: X 5,000.

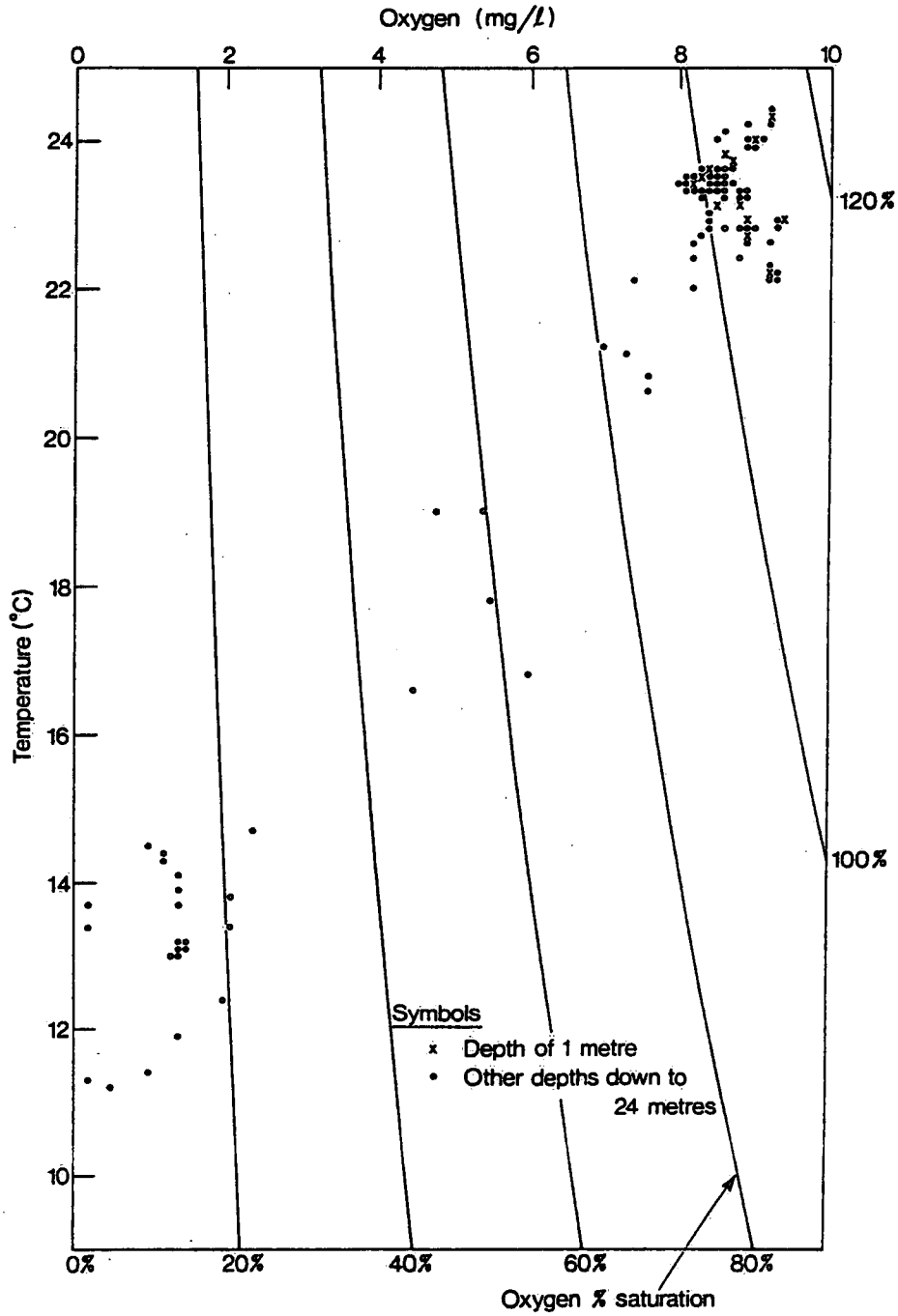
Oxygen anomaly =
observed $[O_2]$ mg/l
minus the solubility-value $[O_2]$ mg/l



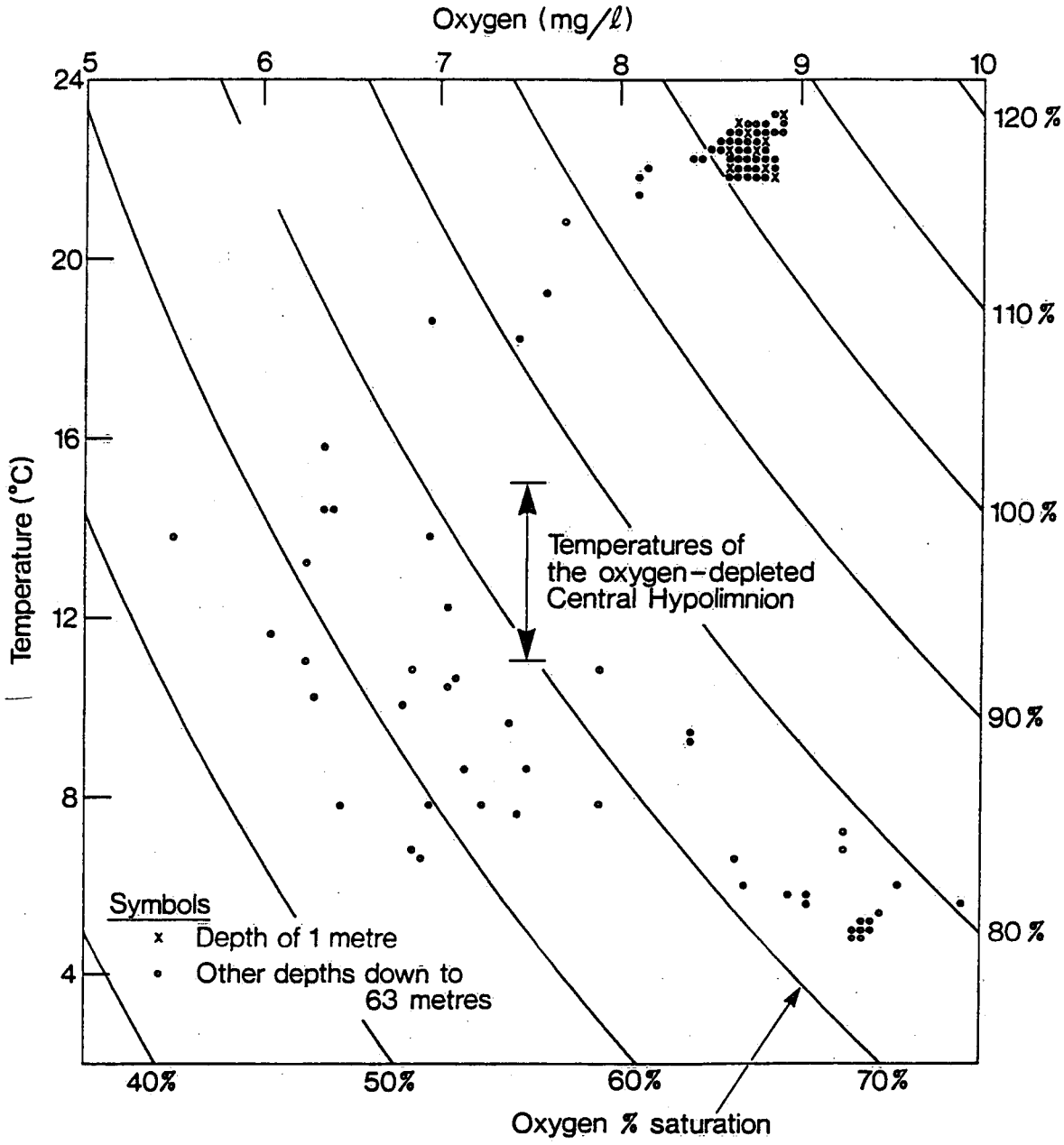
Dissolved oxygen (mg/L) in Lake Erie: the lowest value at each station having hypolimnion and/or thermocline, July 30 to August 2, 1968, CCIW vessel "Theron".



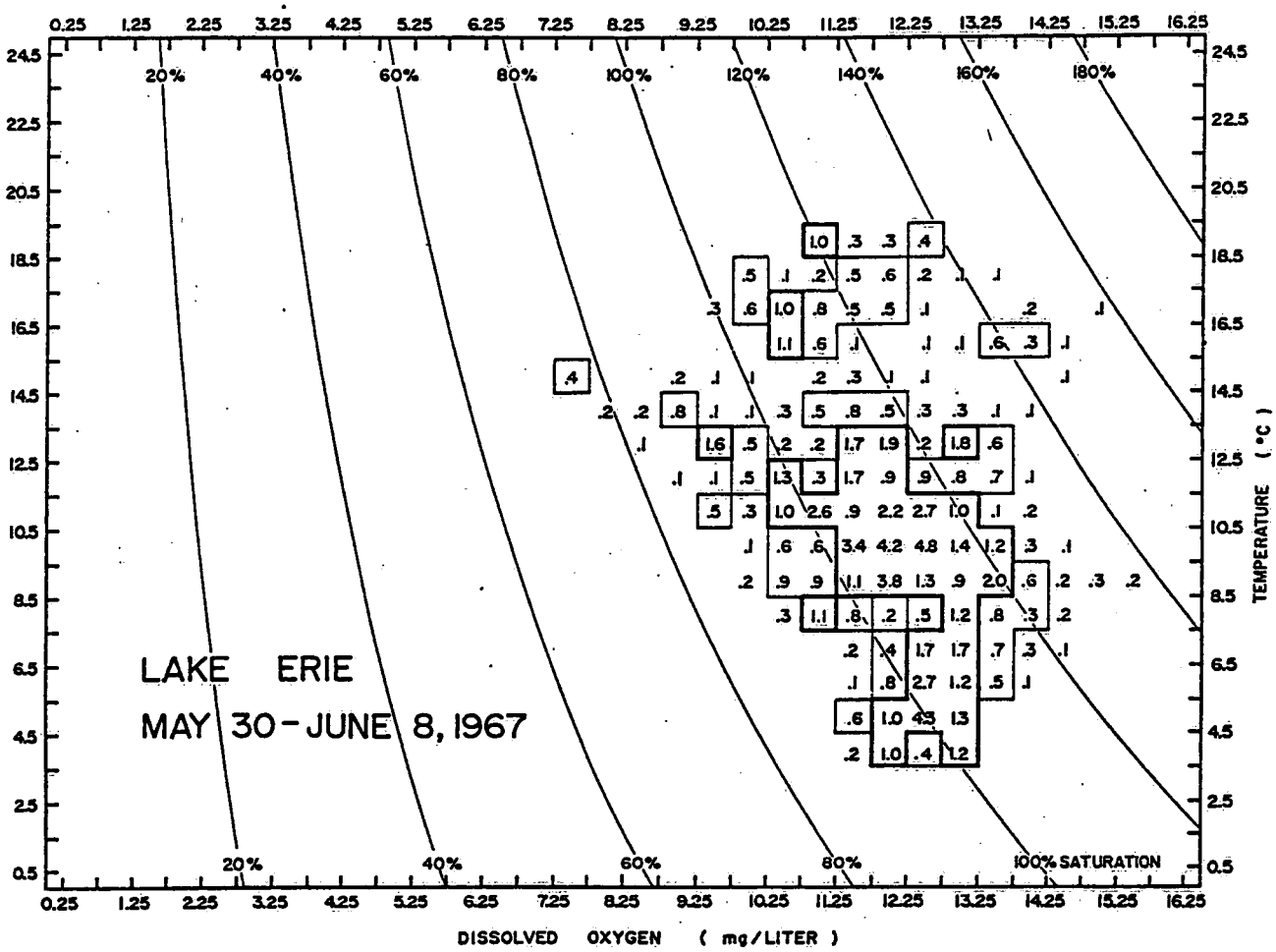
Lake Erie, dissolved oxygen (mg/L) near the bottom in the Central Basin, and at similar depths in the Eastern Basin, August 17 to 21, 1971, "Martin Karlsen".



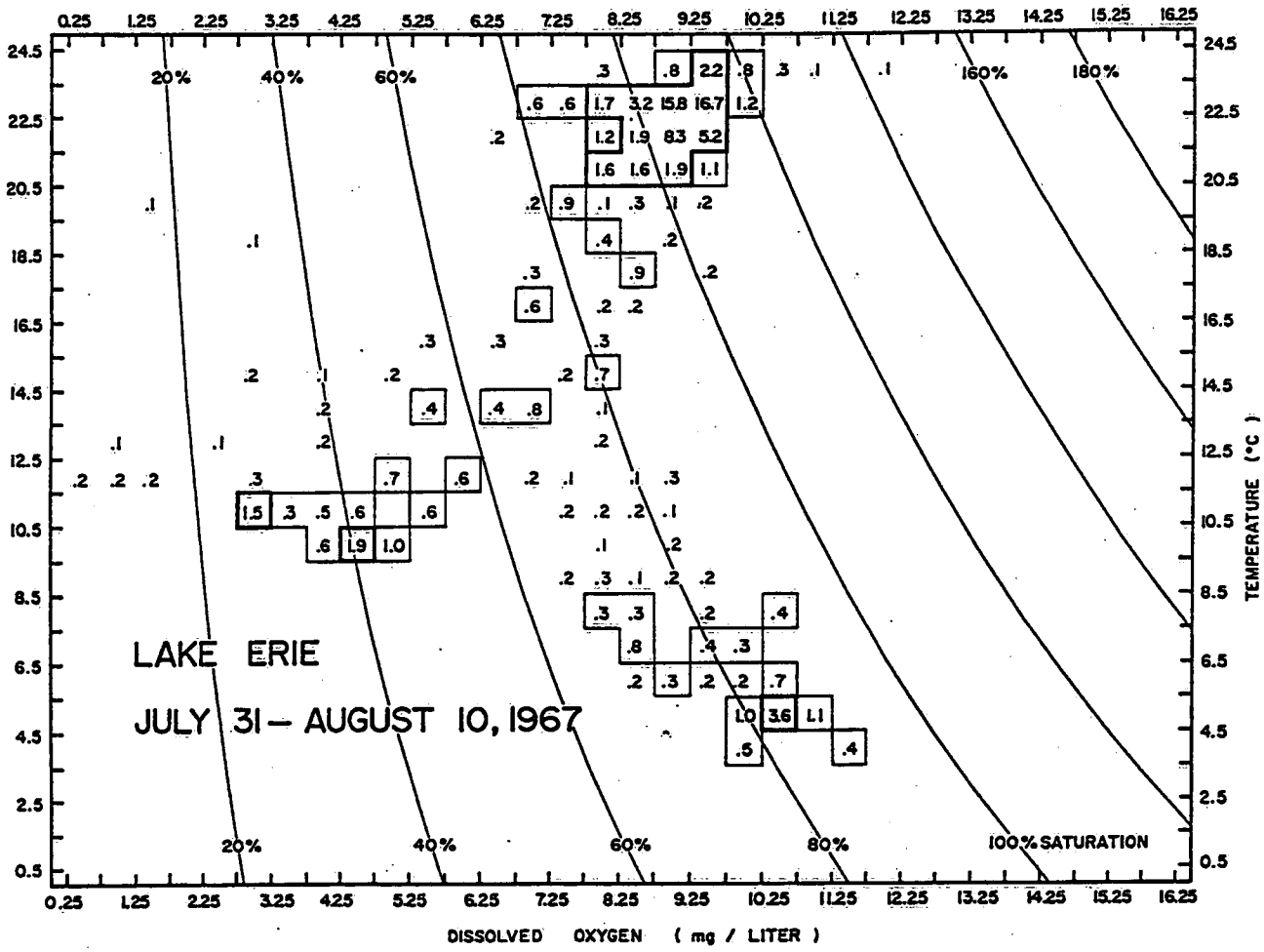
Central Lake Erie, "Martin Karlsen", August 27 & 28, 1969: Oxygen/temperature relations.

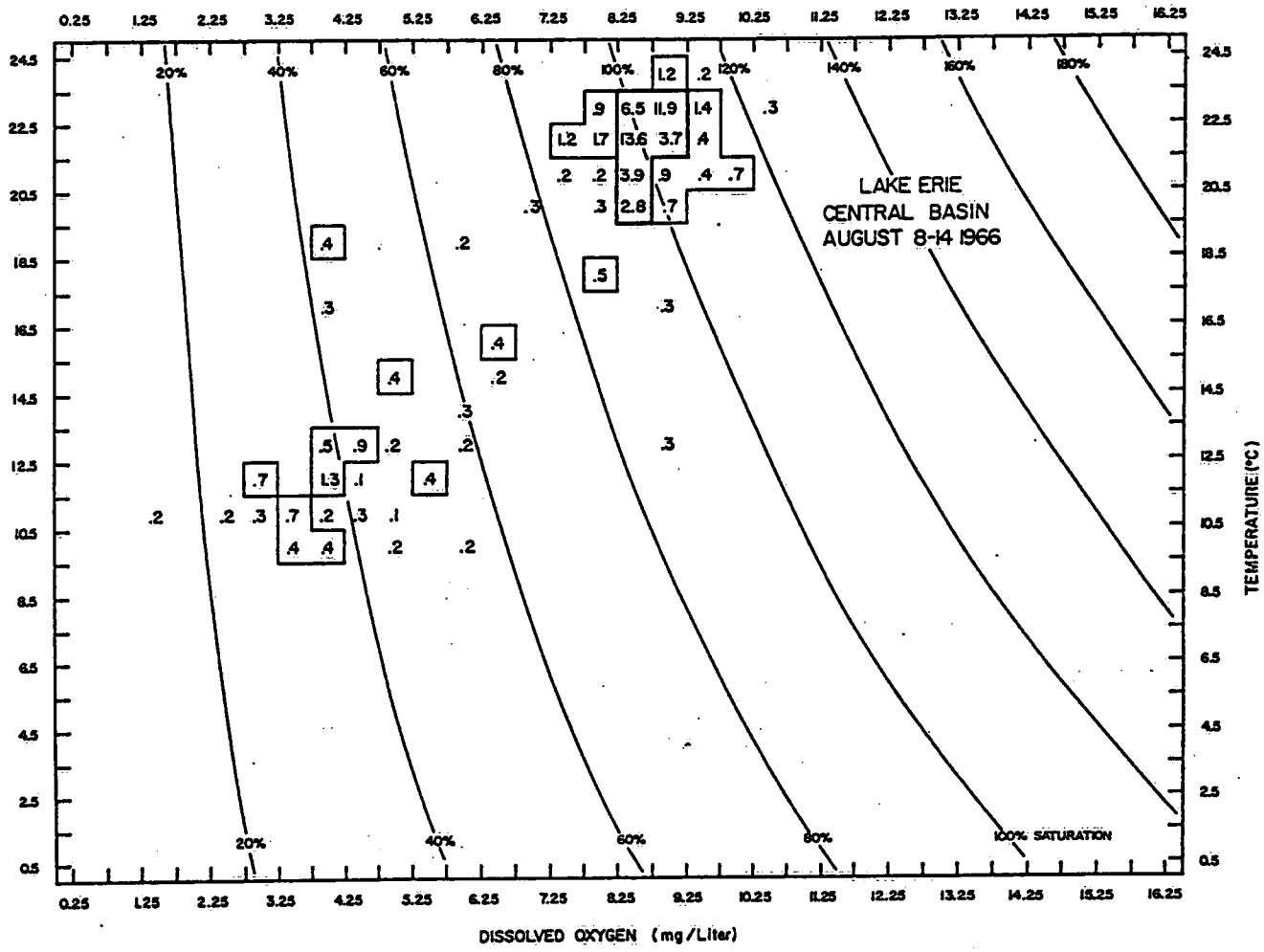


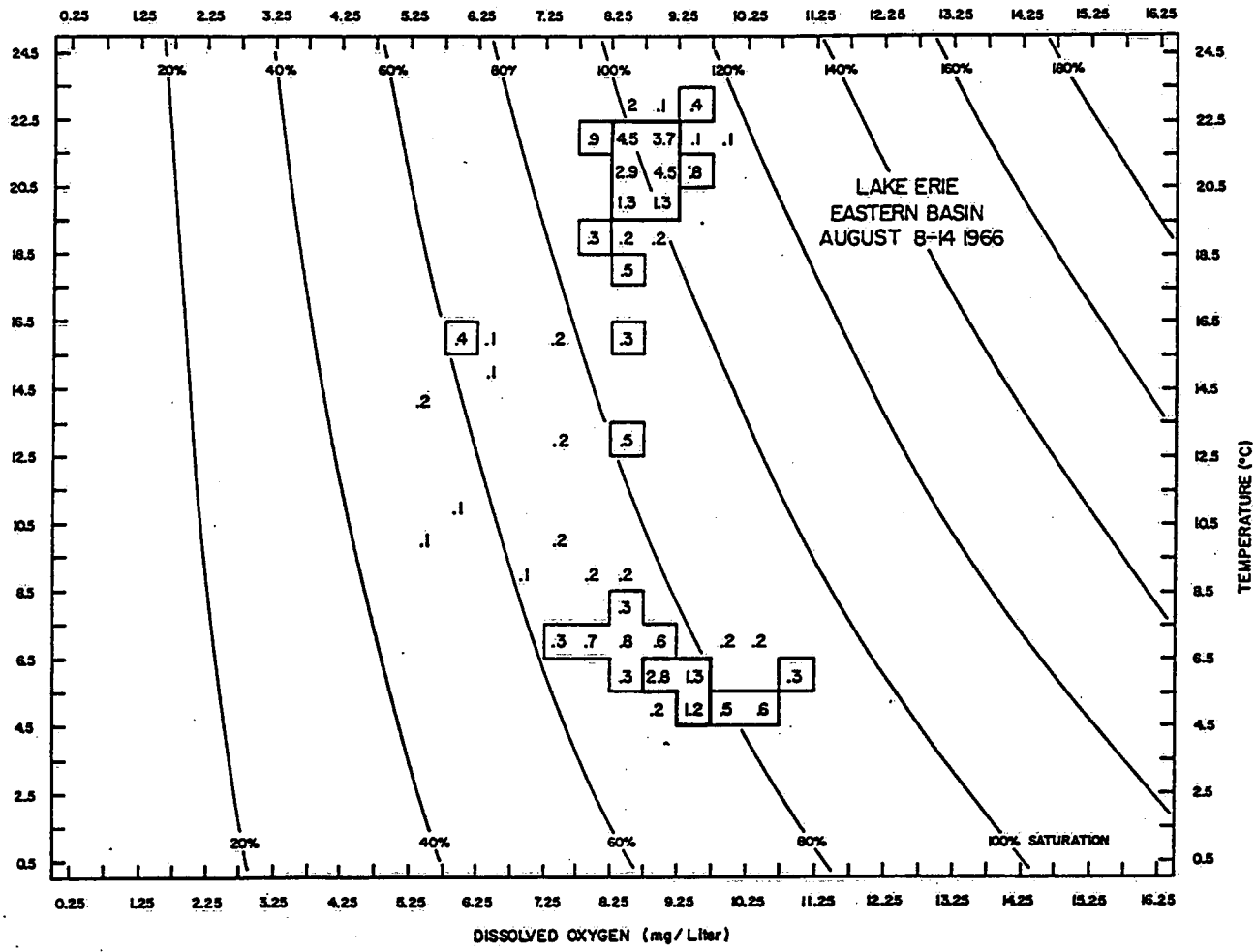
Eastern Lake Erie, "Martin Karlsen", August 29, 1969: Oxygen/temperature relations.

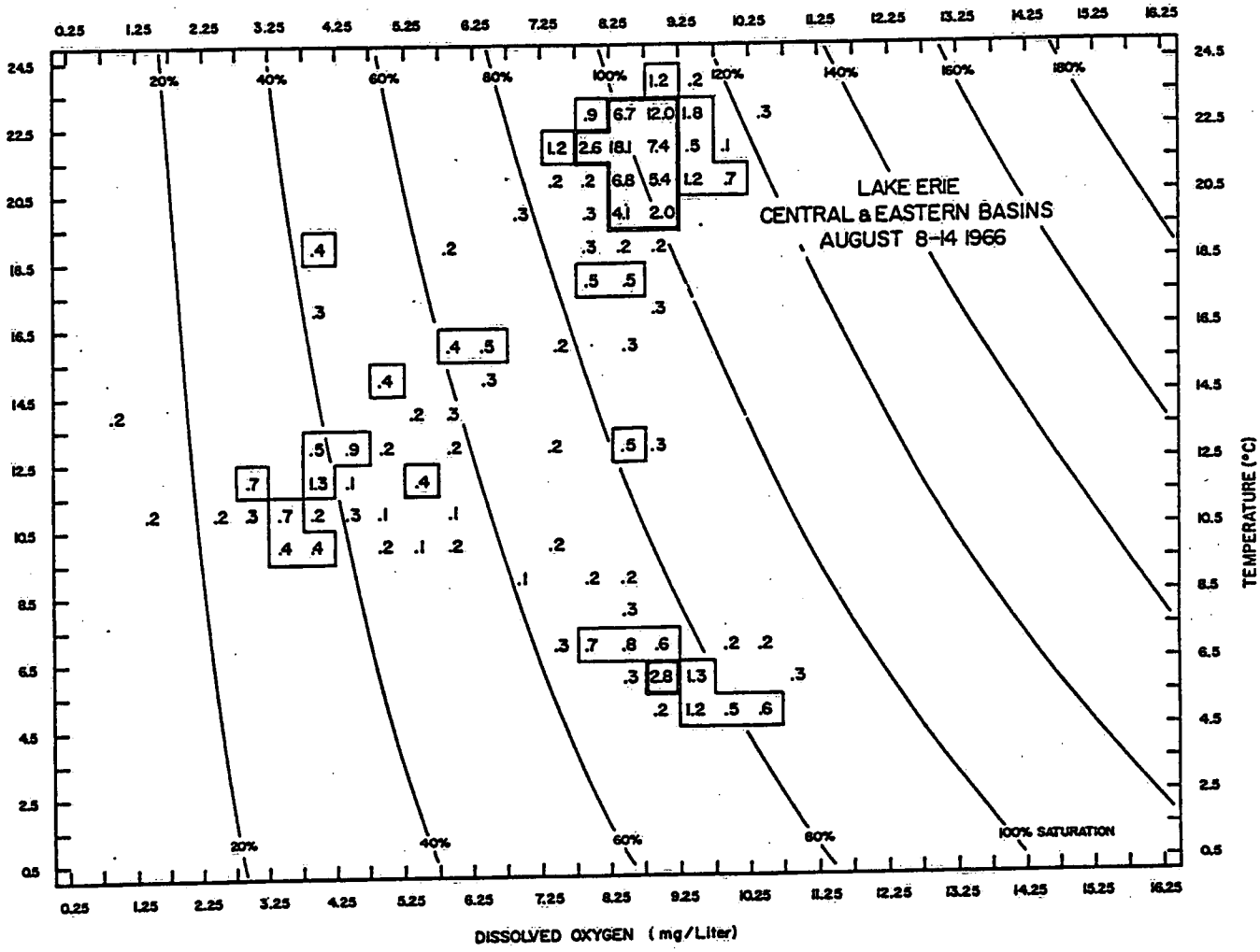


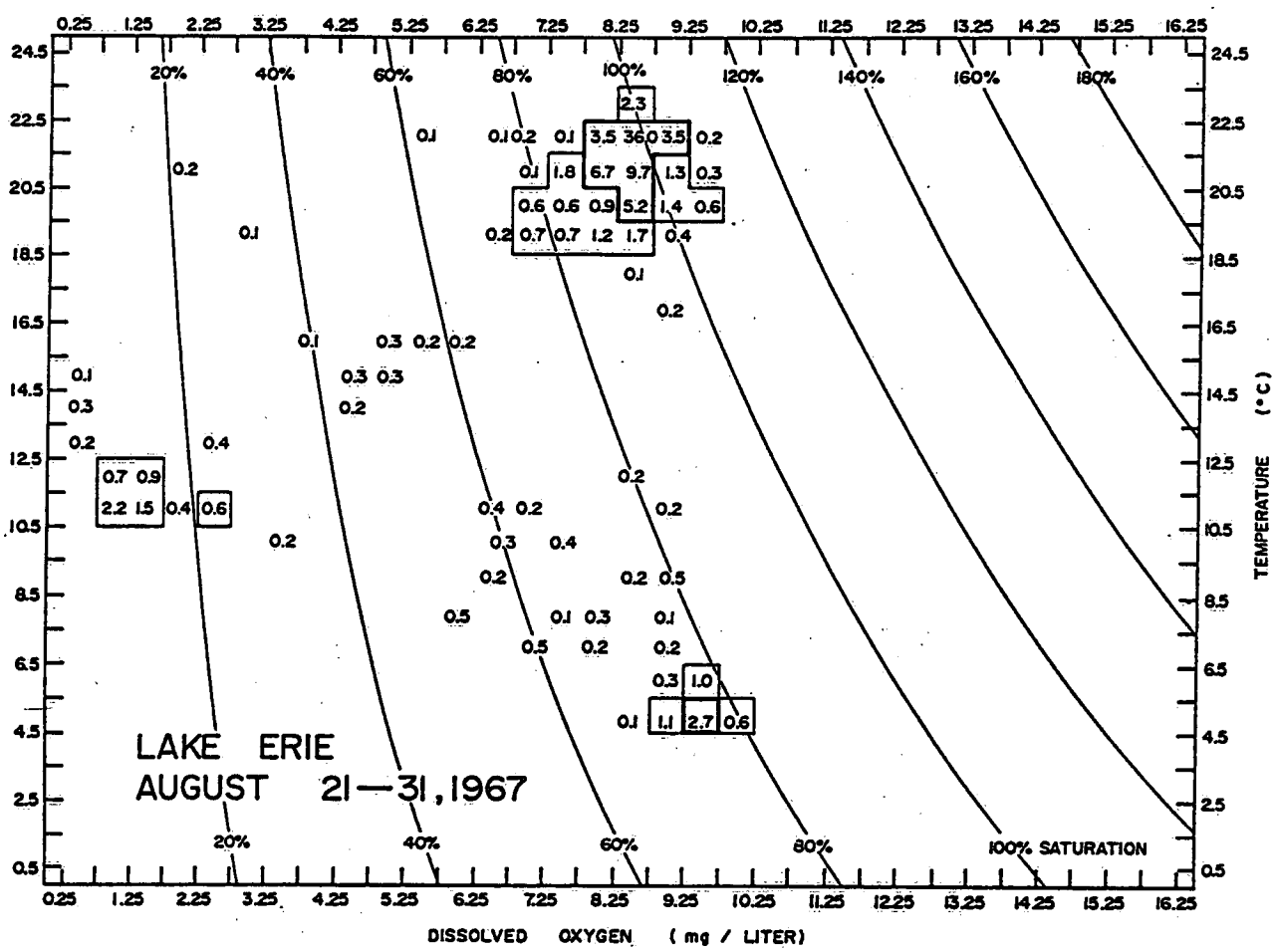
This is a bi-variate histogram for dissolved oxygen and temperature.
The numbers indicate the volume (%) of the lakewater in each bi-variate class of oxygen and temperature.
Thus the entire lake is described in a single diagram.


LAKE ERIE
JULY 31 – AUGUST 10, 1967
20%
40%
60%
80%
100% SATURATION
160%
180%
DISSOLVED OXYGEN (mg / LITER)
TEMPERATURE (°C)

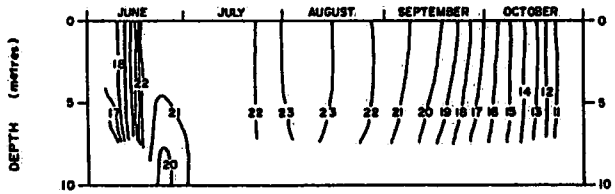

LAKE ERIE
CENTRAL BASIN
AUGUST 8-14 1966
20%
40%
60%
80%
100%
120%
140%
160%
180%
100% SATURATION
DISSOLVED OXYGEN (mg/Liter)
TEMPERATURE (°C)


LAKE ERIE
EASTERN BASIN
AUGUST 8-14 1966
20%
40%
60%
80%
100%
120%
140%
160%
180%
100% SATURATION
DISSOLVED OXYGEN (mg/Liter)
TEMPERATURE (°C)


LAKE ERIE
CENTRAL & EASTERN BASINS
AUGUST 8-14 1966
20%
40%
60%
80%
100%
120%
140%
160%
180%
100% SATURATION
DISSOLVED OXYGEN (mg/Liter)
TEMPERATURE (°C)

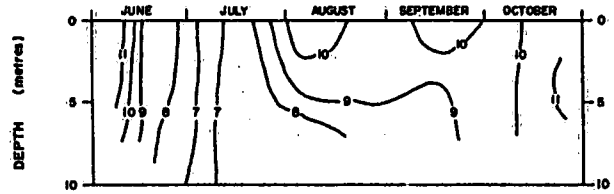

LAKE ERIE
AUGUST 21—31, 1967
20%
40%
60%
80%
100%
120%
140%
160%
180%
100% SATURATION
DISSOLVED OXYGEN (mg / LITER)
TEMPERATURE (°C)

LAKE ERIE 1967
WEST BASIN
STATION 168



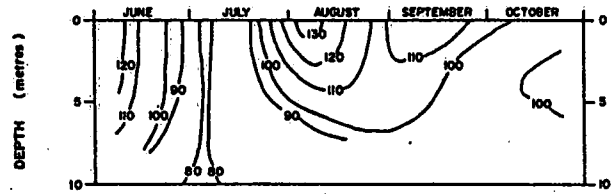
TEMPERATURE (°C)

LAKE ERIE 1967
WEST BASIN
STATION 168



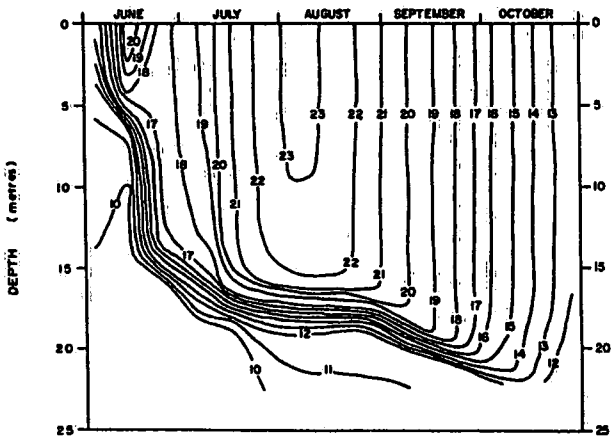
OXYGEN (mg./liter)

LAKE ERIE 1967
WEST BASIN
STATION 168



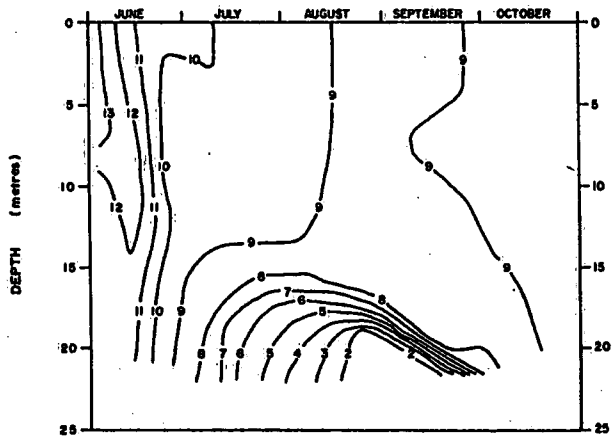
OXYGEN PERCENT SATURATION

LAKE ERIE 1967
CENTRAL BASIN
STATION 88



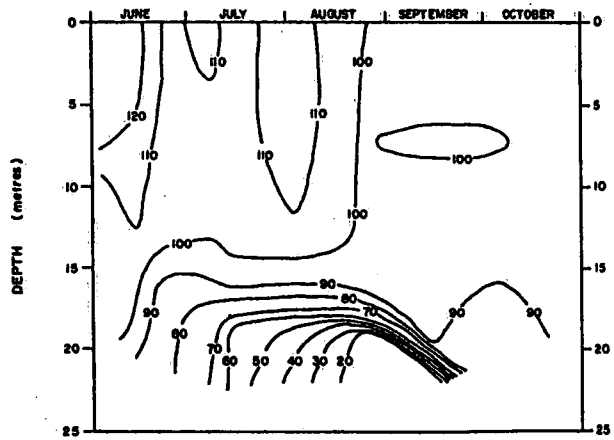
TEMPERATURE (°C)

LAKE ERIE 1967
CENTRAL BASIN
STATION 88

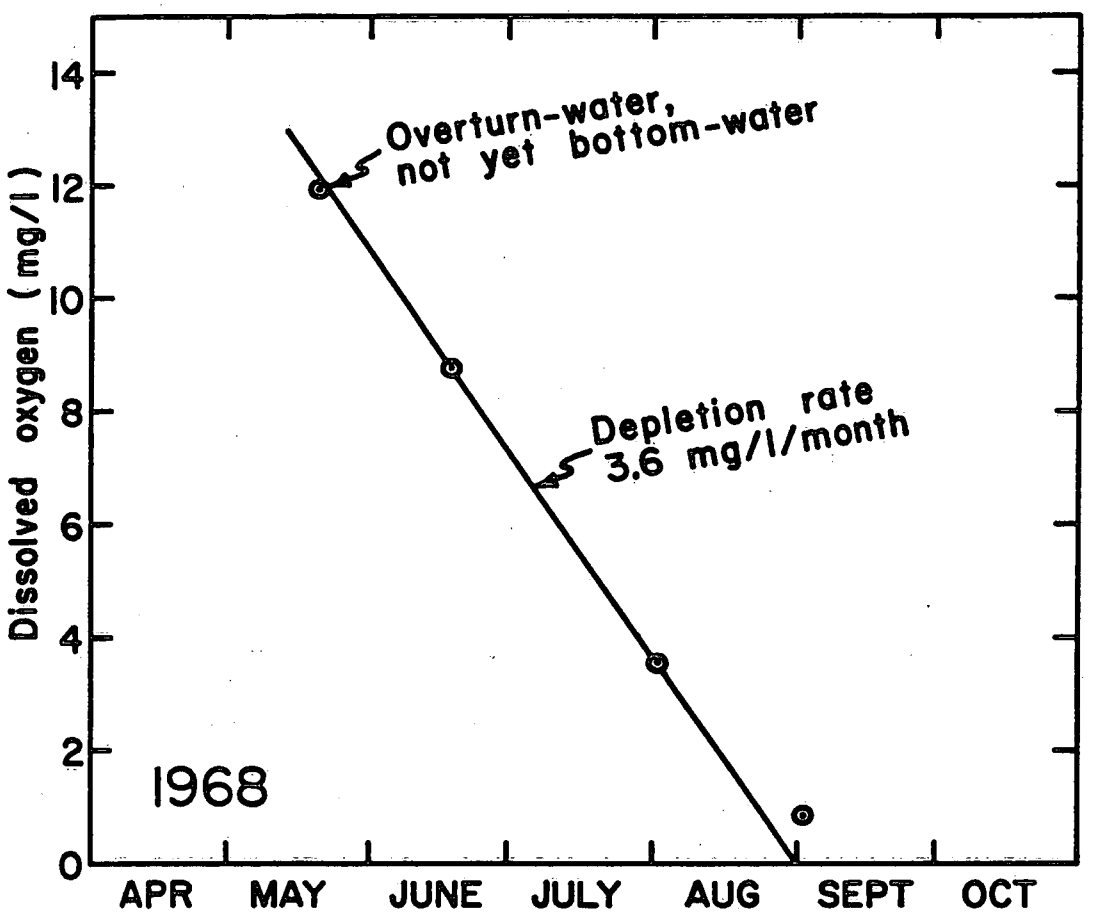


OXYGEN (mg./liter)

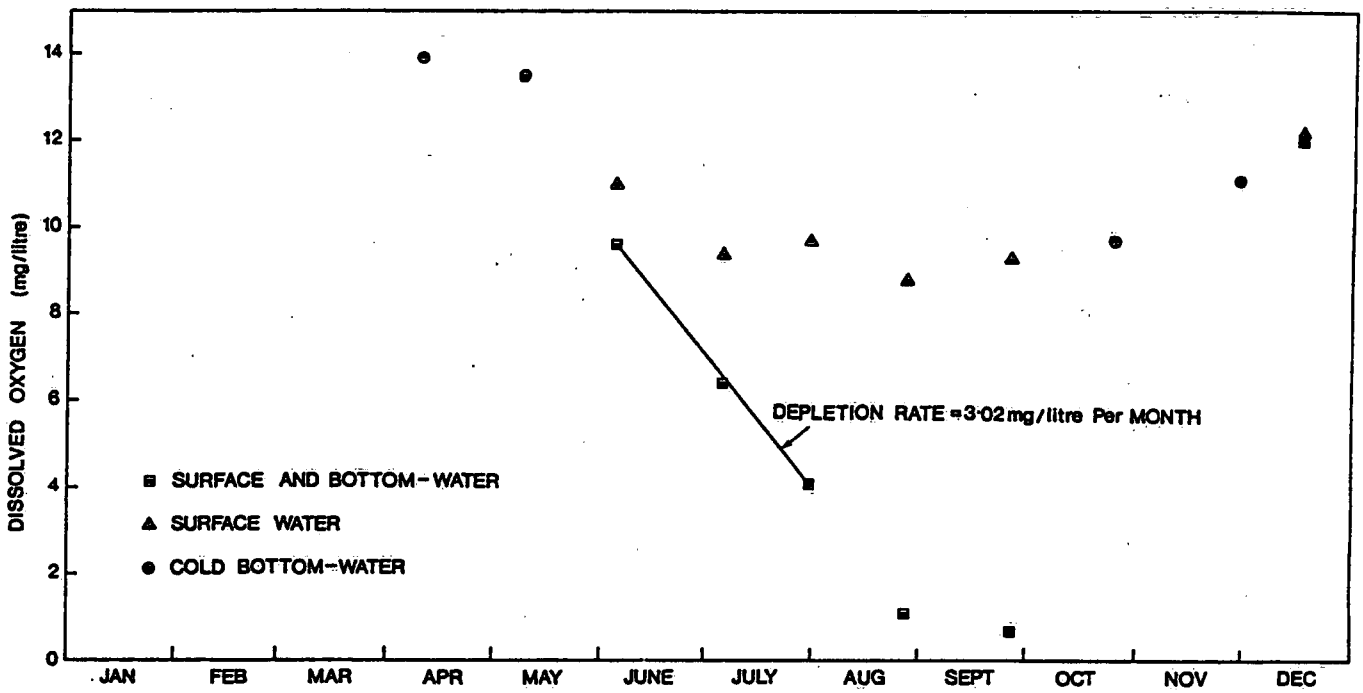
LAKE ERIE 1967
CENTRAL BASIN
STATION 88



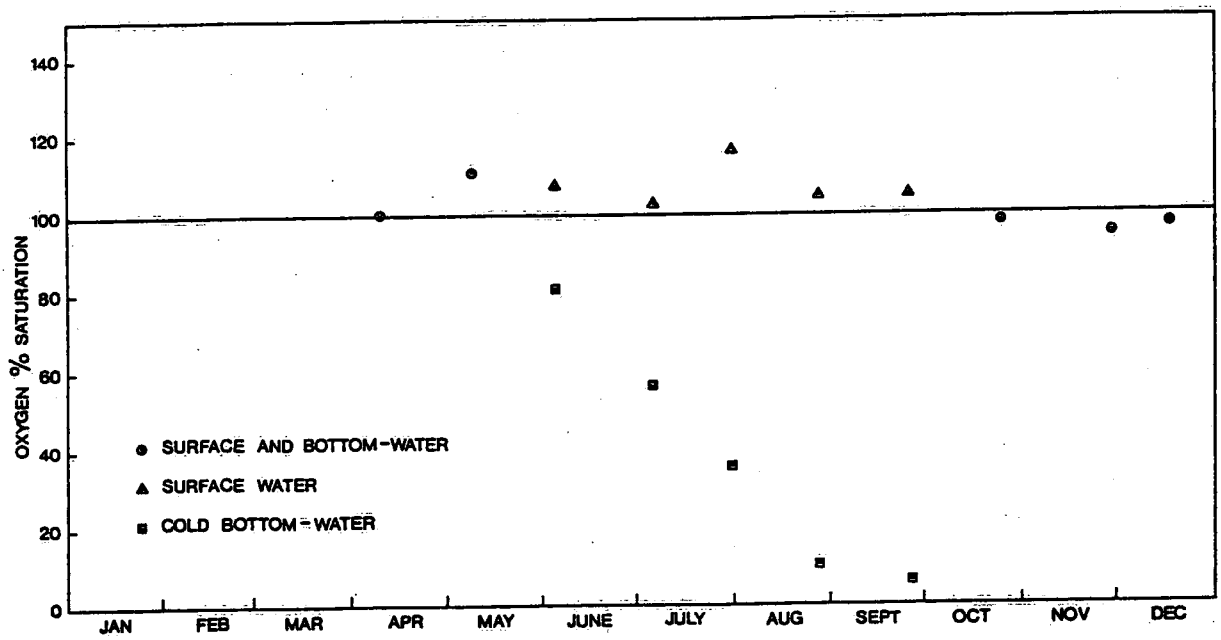
OXYGEN PERCENT SATURATION



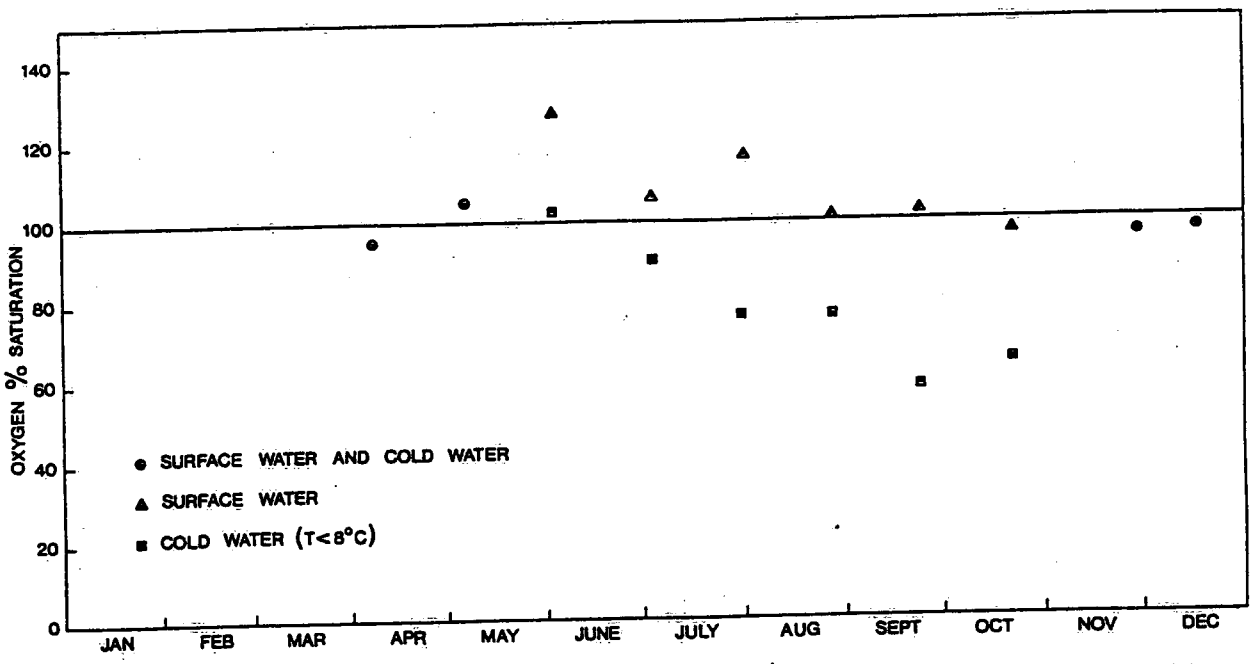
Lake Erie, central bottom-water: mean oxygen values for each cruise in 1968. Vessel "Theron" (Canada Centre for Inland Waters).



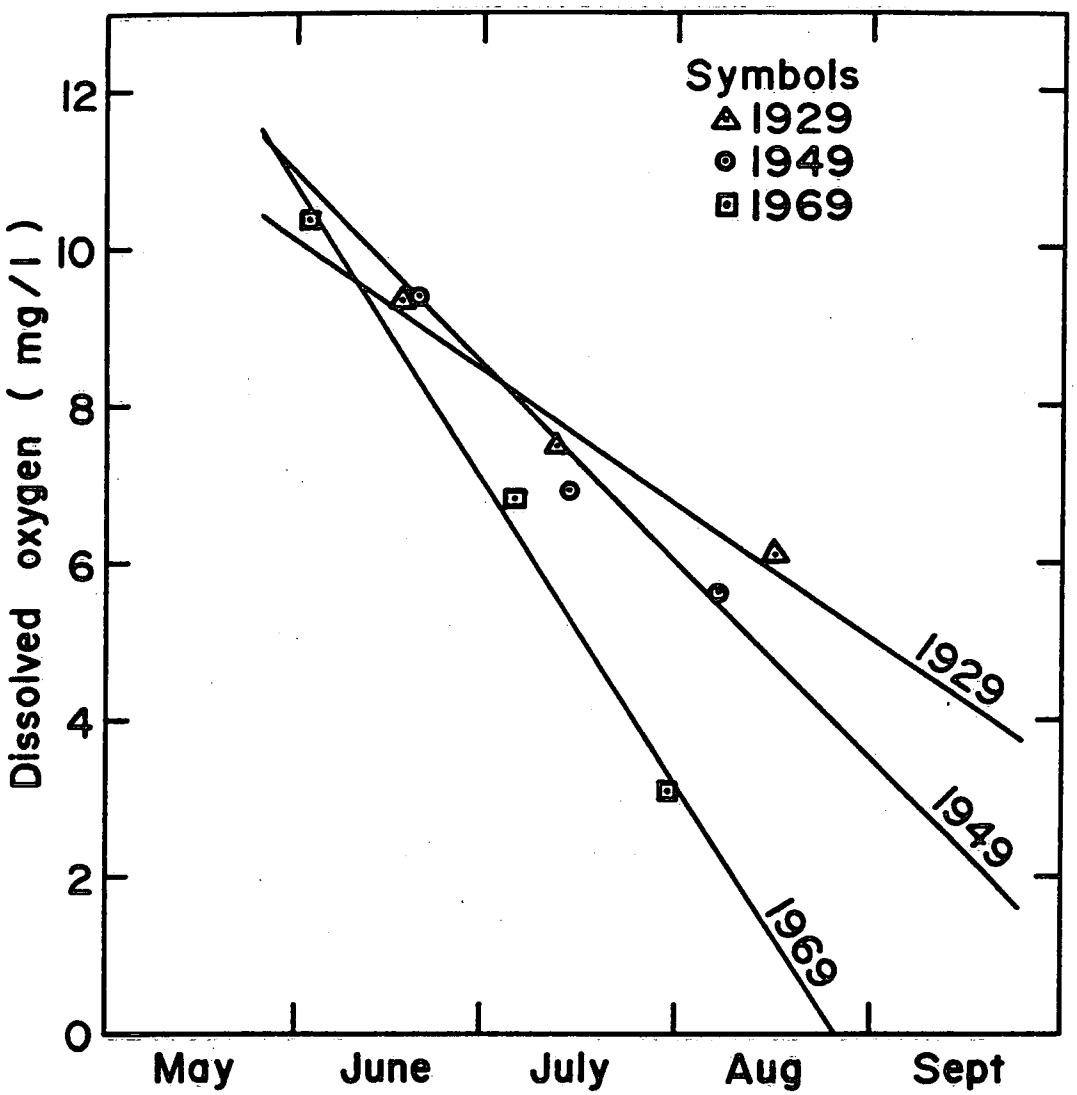
CENTRAL LAKE ERIE, OFFSHORE PART WHERE THE SOUNDING IS >18 METRES: UNWEIGHTED MEAN OXYGEN CONCENTRATIONS AT A DEPTH OF 1 METRE, AND ALSO IN THE COLD BOTTOM-WATER, FROM CRUISES OF THE MARTIN KARLSEN DURING 1970.



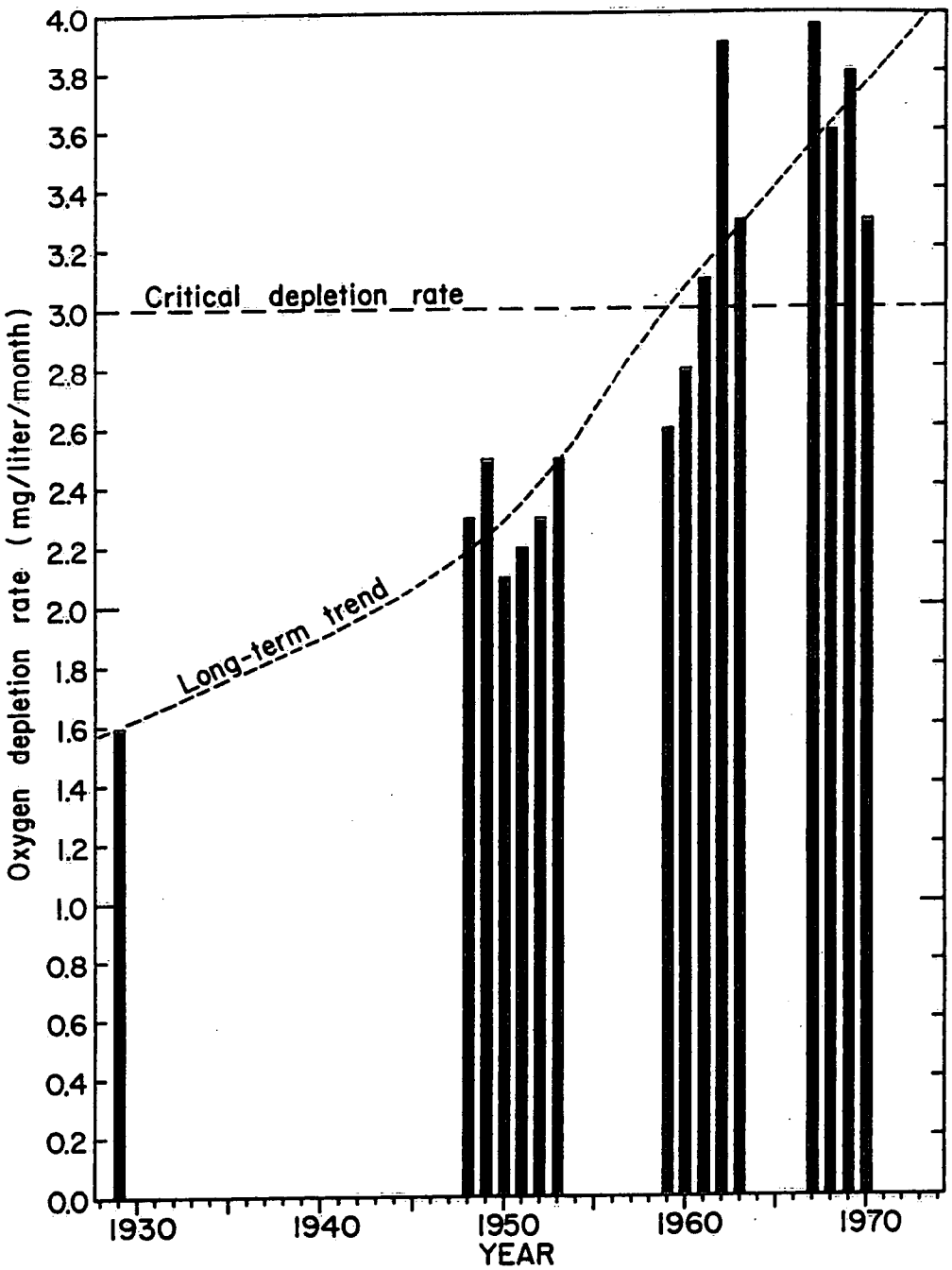
CENTRAL LAKE ERIE, OFFSHORE PART WHERE THE SOUNDING IS >18 METRES: UNWEIGHTED MEAN OXYGEN % SATURATION VALUES AT A DEPTH OF 1 METRE, AND ALSO IN THE COLD BOTTOM-WATER, FROM CRUISES OF THE MARTIN KARLSEN DURING 1970.



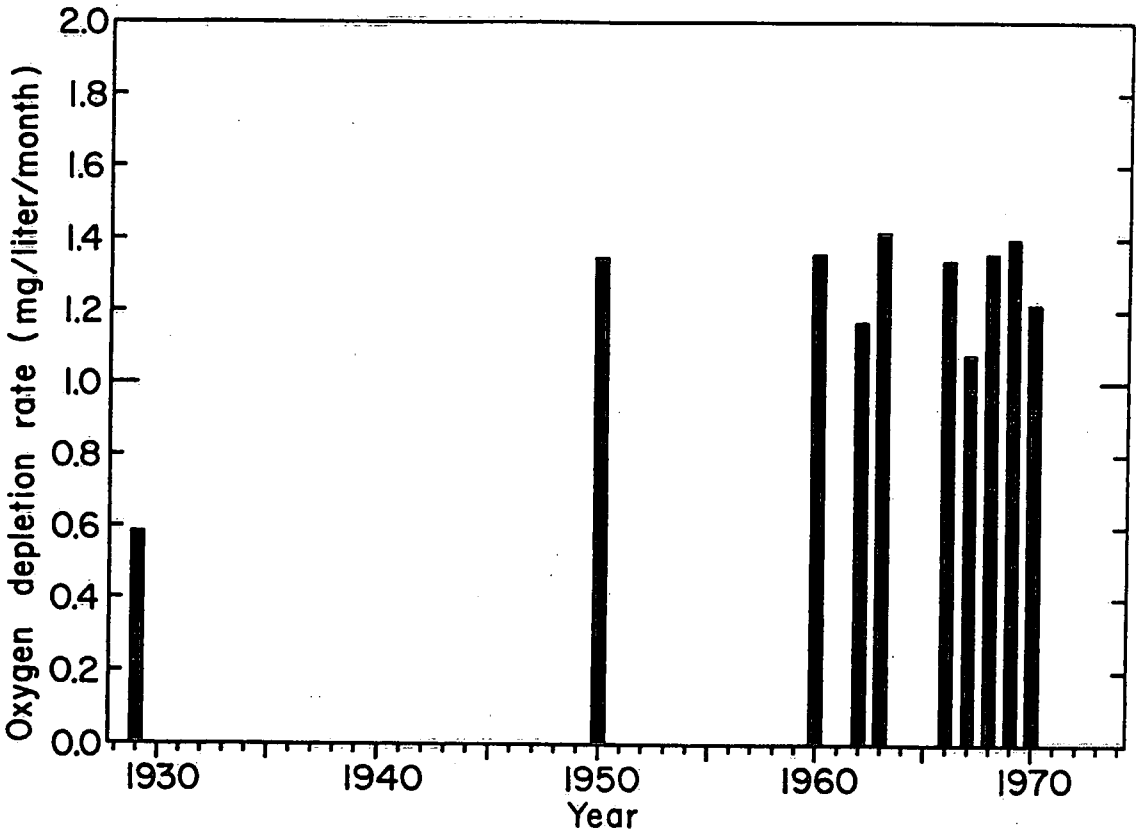
EASTERN LAKE ERIE, OFFSHORE PART WHERE THE SOUNDING IS >18 METRES; UNWEIGHTED MEAN OXYGEN % SATURATION VALUES AT A DEPTH OF 1 METRE, AND ALSO IN THE COLD WATER-MASS (T < 8°C), FROM CRUISES OF THE MARTIN KARLSEN DURING 1970.



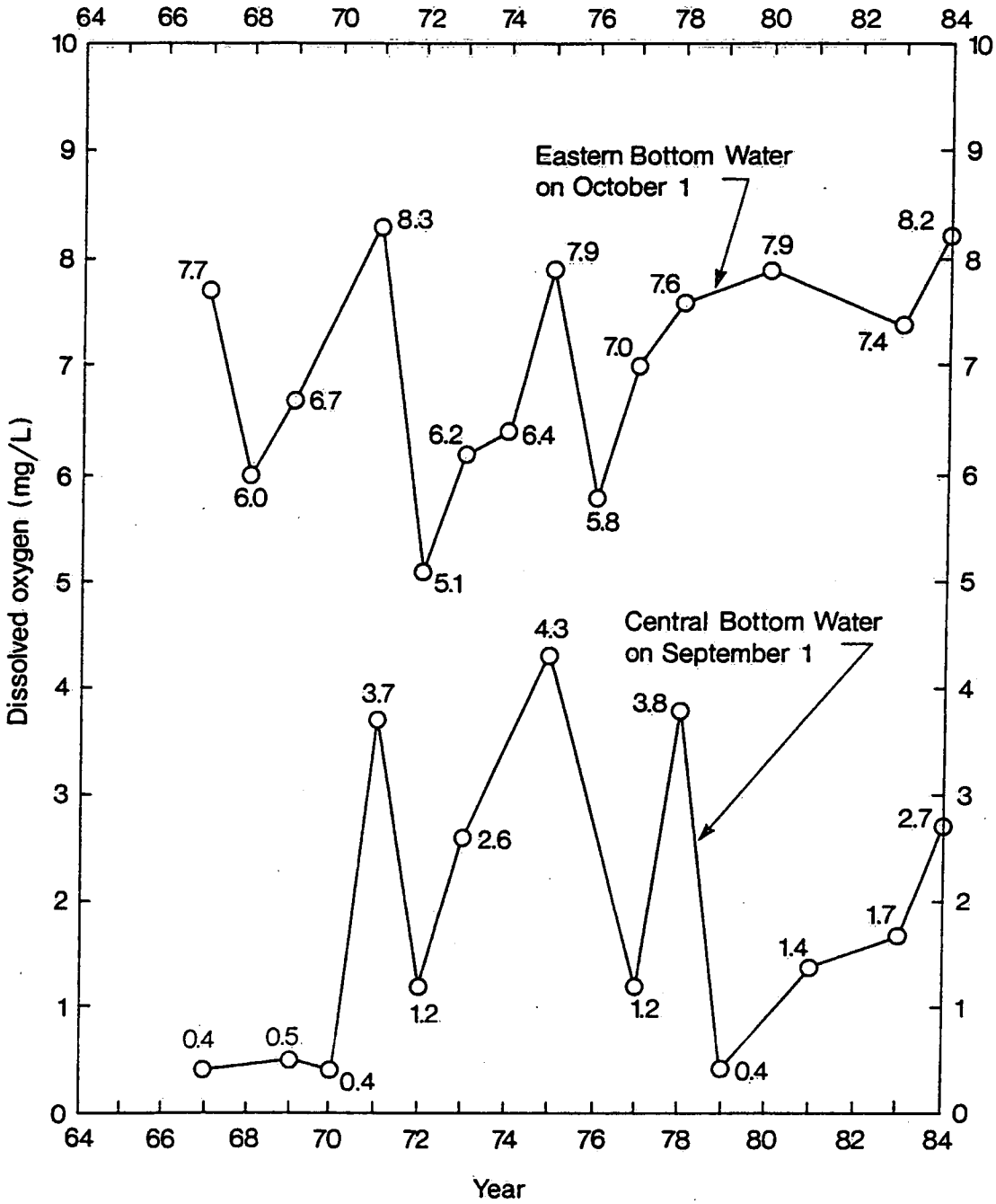
Dissolved oxygen in the bottom-water of central Lake Erie during 1929, 1949, and 1969: mean values for each cruise, and the inferred straight-line trends for each year.



Mean depletion rates for dissolved oxygen during summer in the bottom-water of central Lake Erie. Note that the critical rate of 3.0 mg/liter/month, reached in 1961, produces zero oxygen levels before the end of summer stratification.

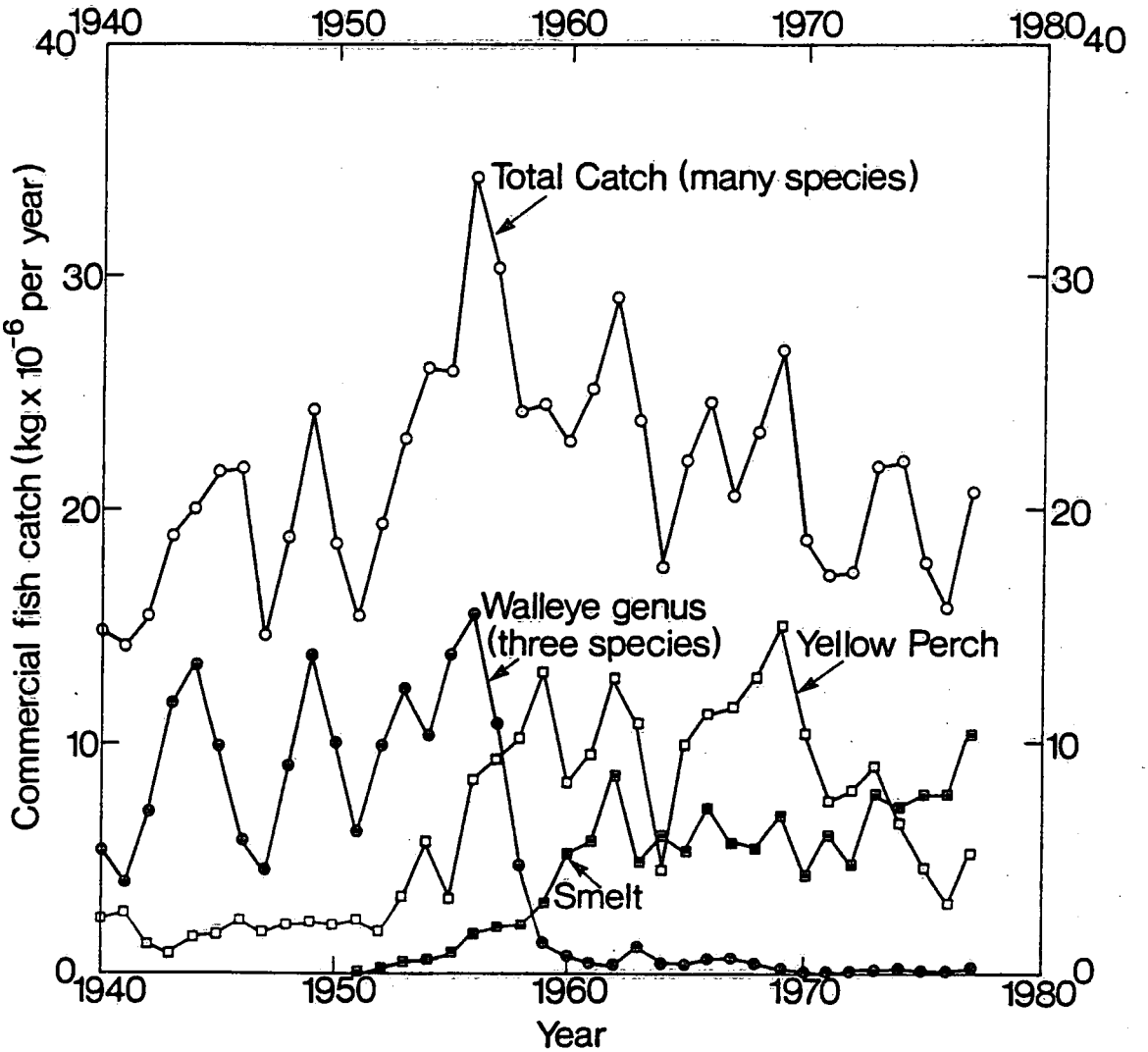


Oxygen depletion rates during summer in the hypolimnion of Eastern Lake Erie.

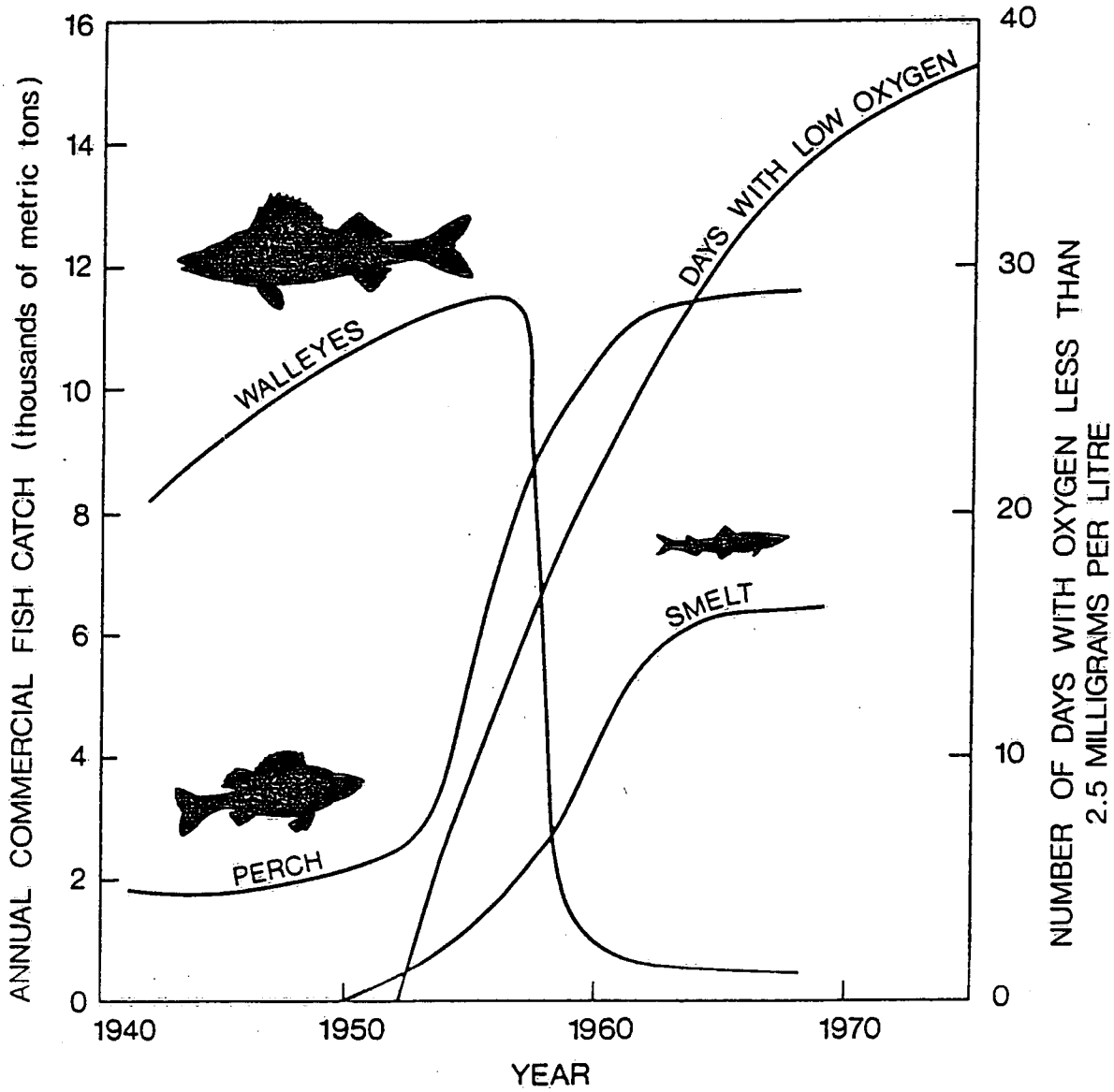


Dissolved oxygen in Central and Eastern Lake Erie: mean values in the Bottom Waters in late summer of each year.

FISH



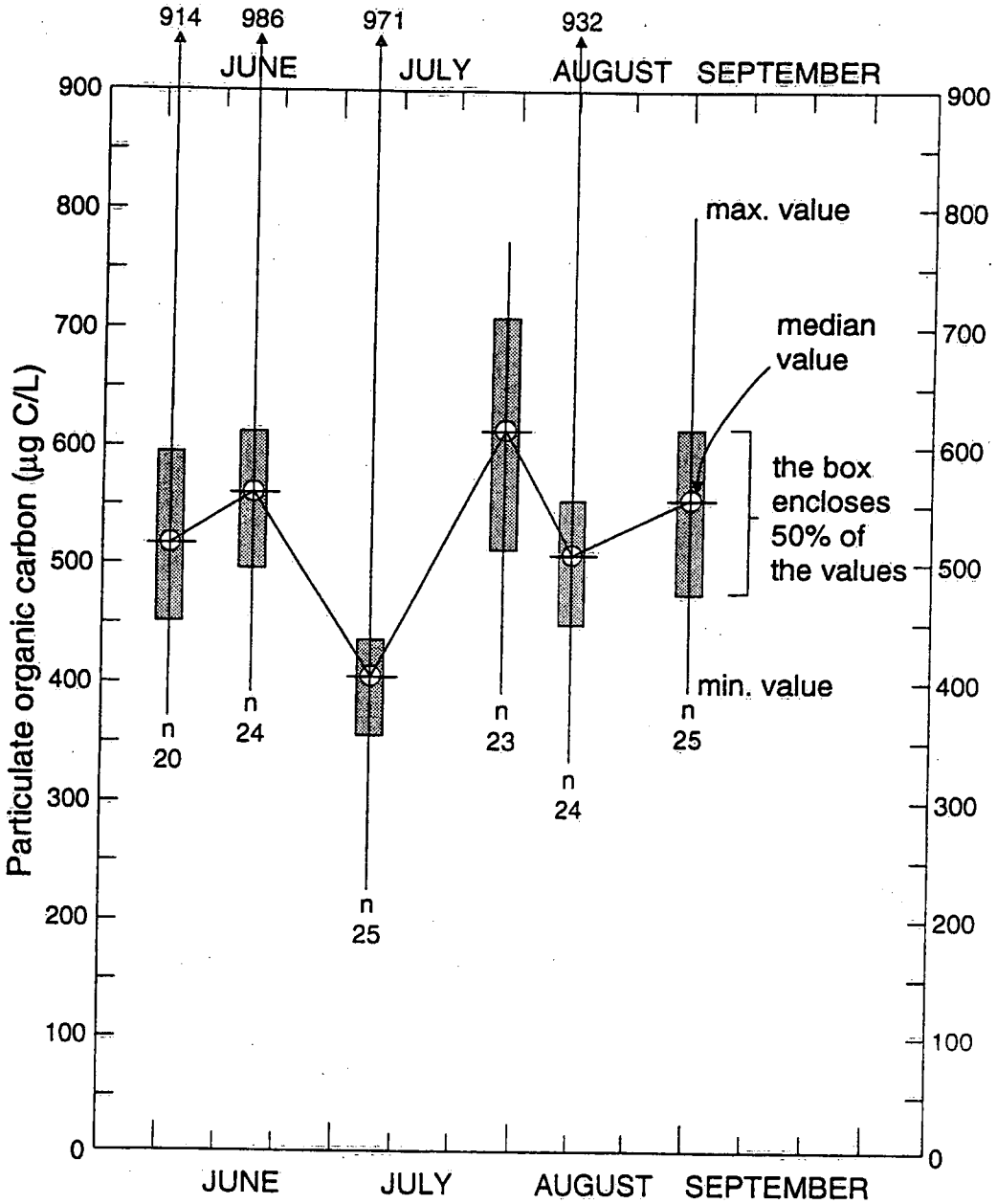
Lake Erie, annual commercial fish catch, 1940 to 1977: total catch and catch within major groups excluding whitefish.



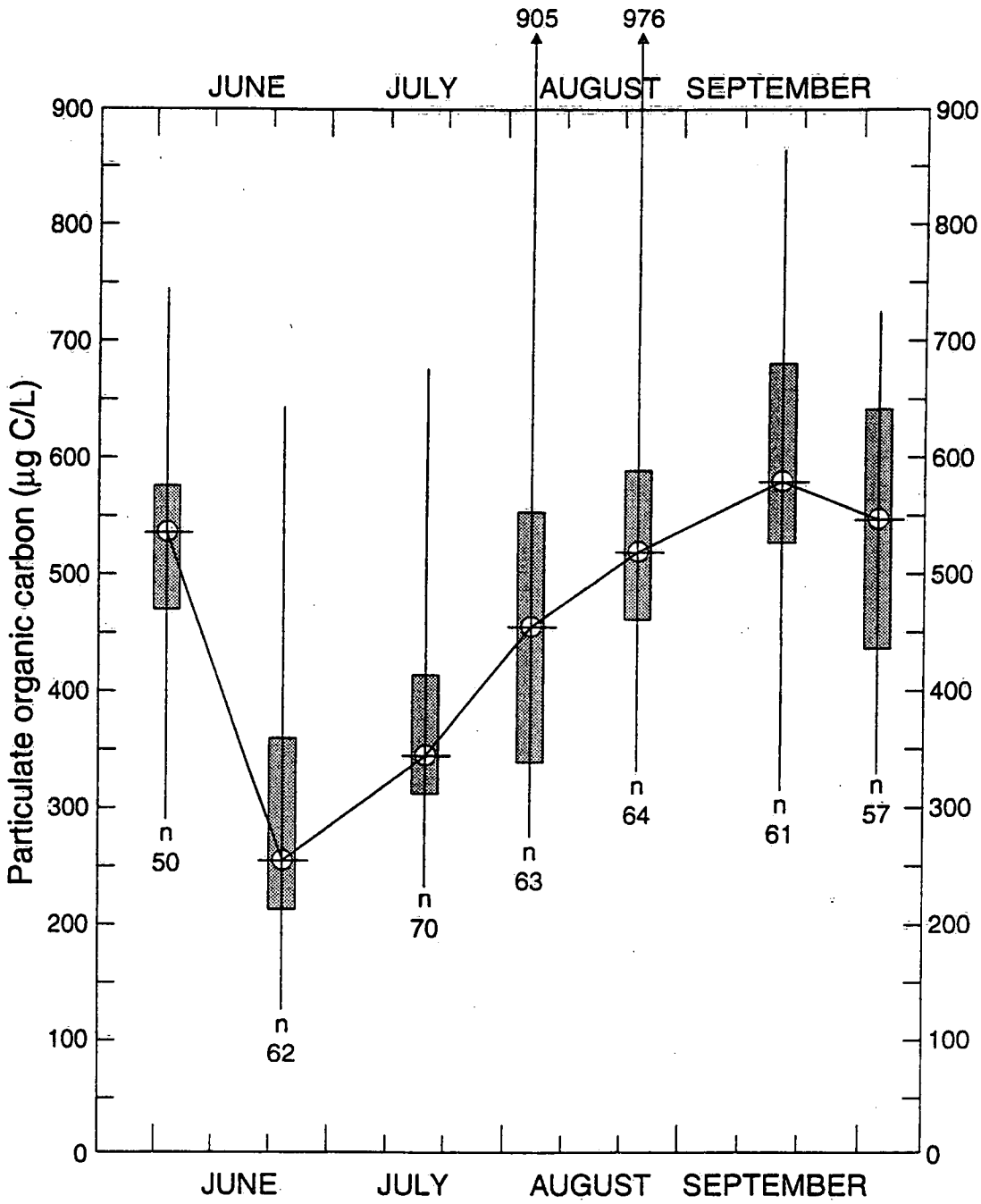
LAKE ERIE: HISTORY OF COMMERCIAL FISH CATCHES IN MAJOR GENERA, AND HISTORY OF DISSOLVED OXYGEN IN THE CENTRAL HYPOLIMNION, SHOWING COINCIDENCE IN THE LATE 50'S.

THE CURVES ARE SMOOTHED THROUGH ACTUAL DATA.

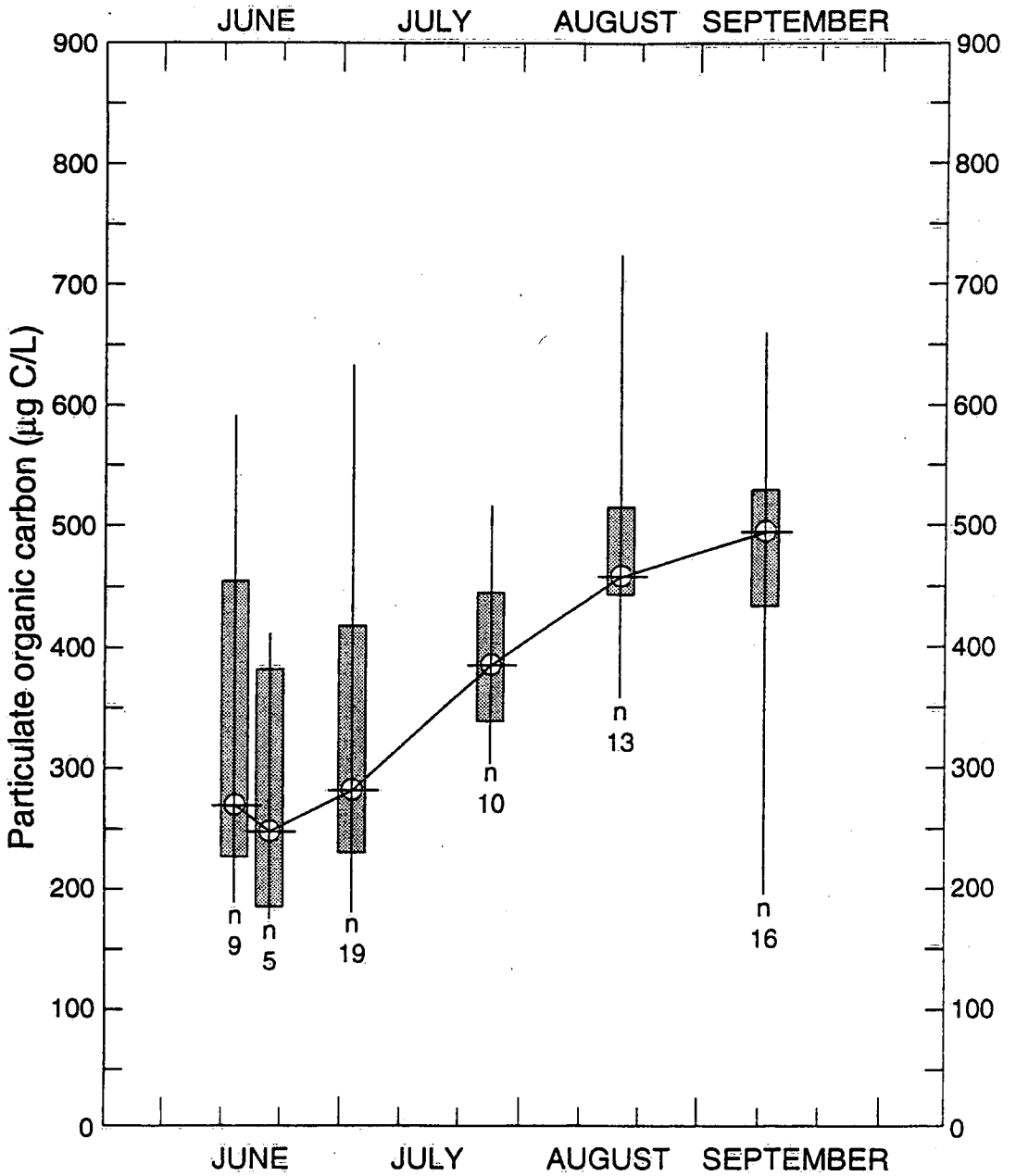
CARBON



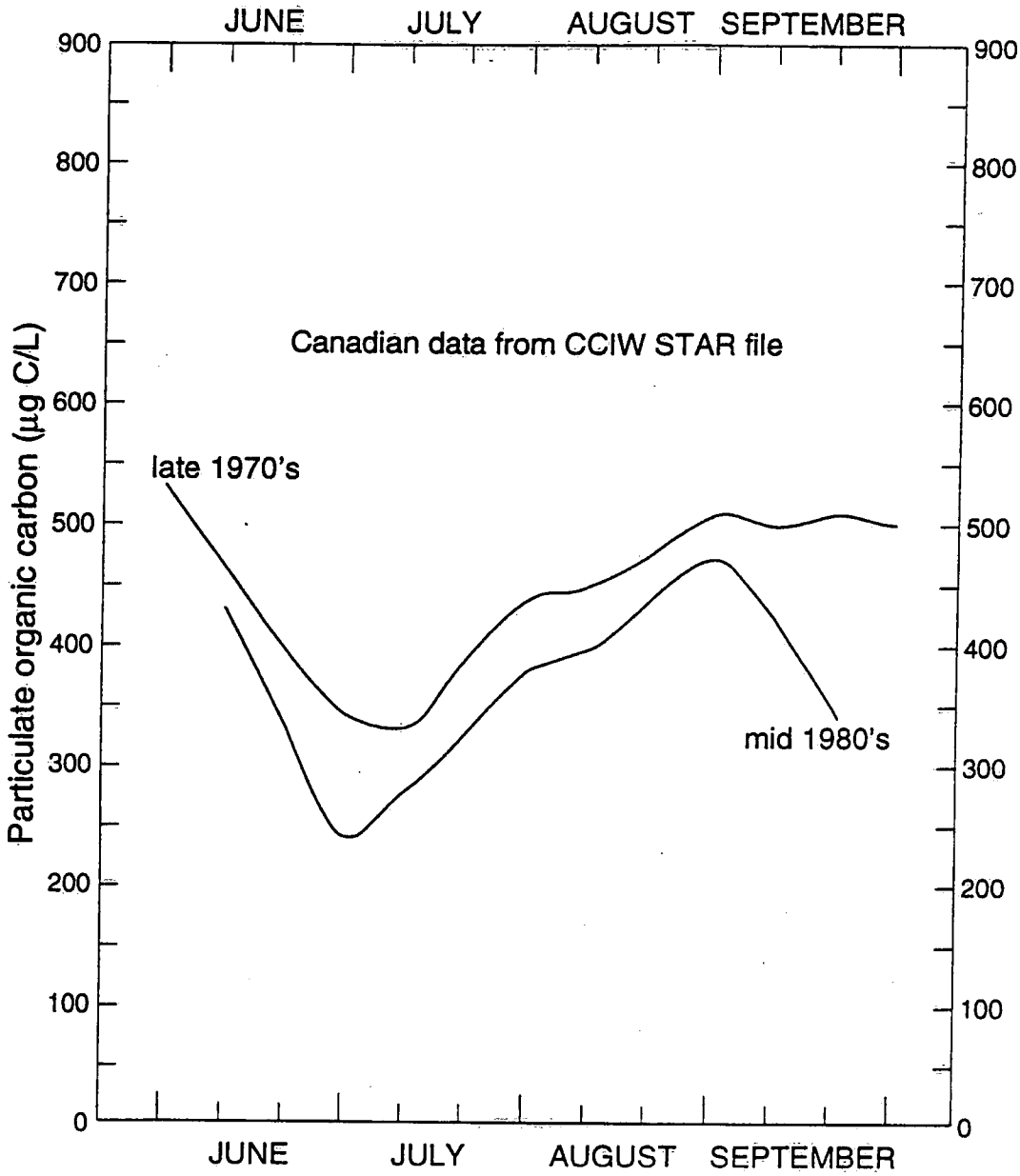
Particulate organic carbon, Central Lake Erie, offshore and upper 10m, median statistics on each cruise in summer 1977, Canadian vessels Petrel and Limnos.



Particulate organic carbon, Central Lake Erie, offshore and upper 10m, median statistics on each cruise in summer 1978, Canadian vessel Limnos.



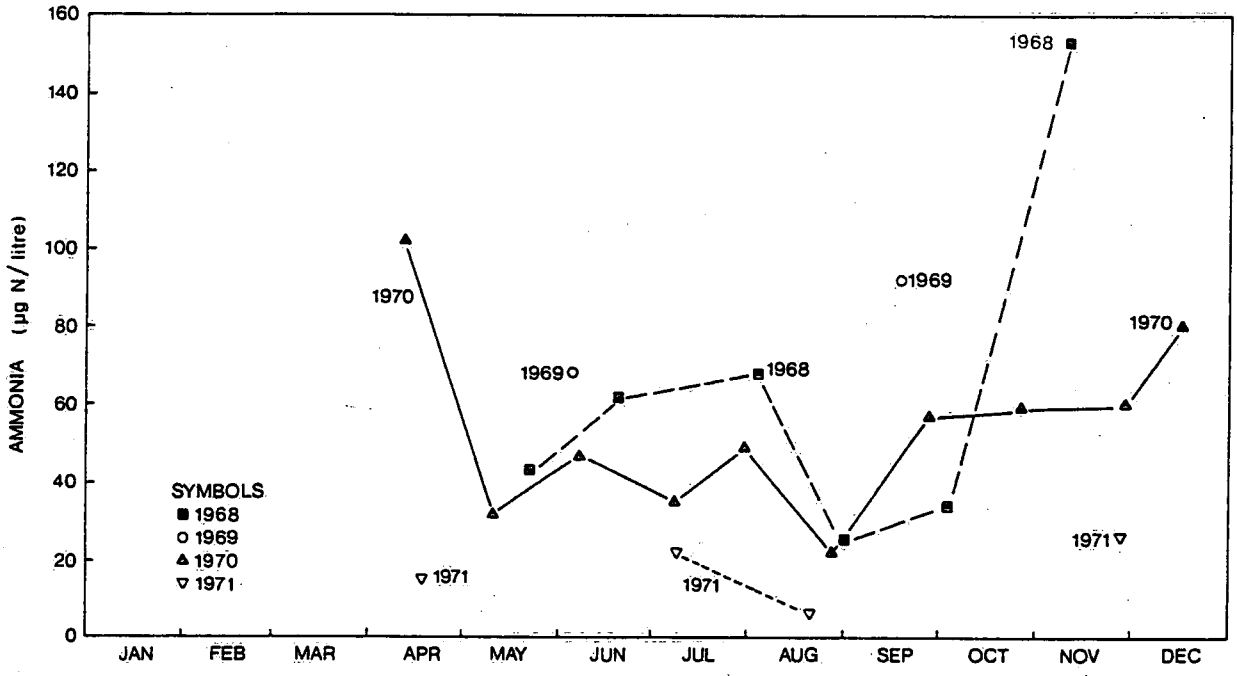
Particulate organic carbon, Central Lake Erie, offshore and upper 10m, median statistics on each cruise in summer 1985, Canadian vessels Advent and Limnos.



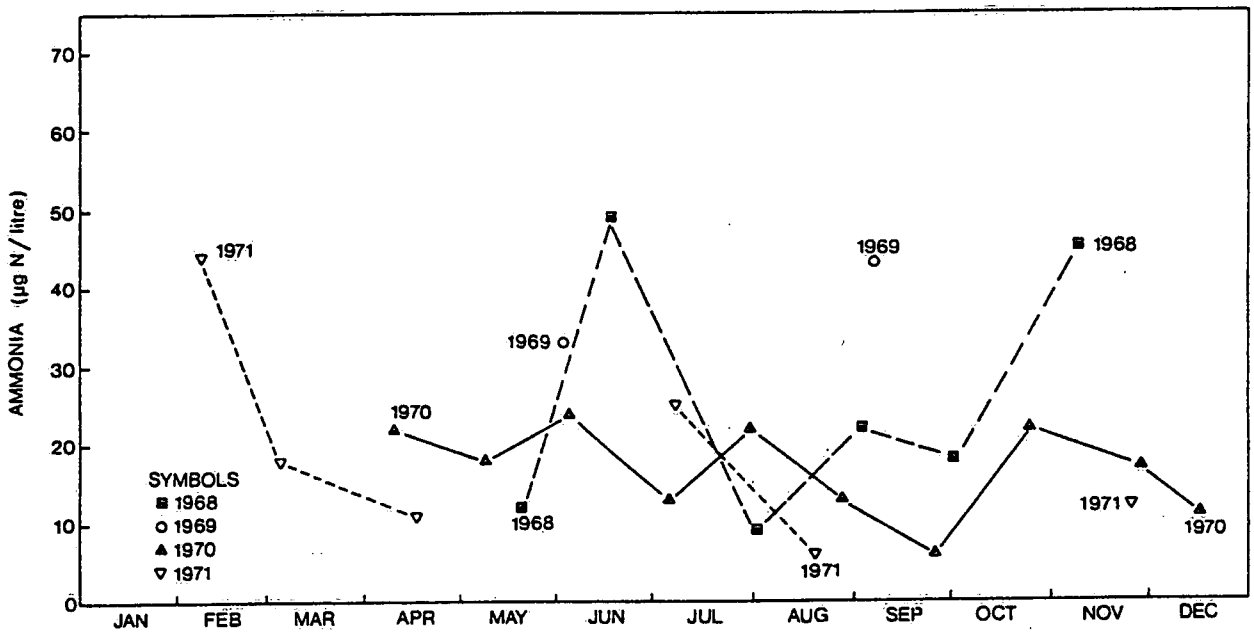
Central Lake Erie, offshore and upper 10m, particulate organic carbon, smoothed seasonal curves for two groups of data:
① 1977, 78, 79 ② 1983, 84, 85, 86.

All other years 1966 to 1993 have inadequate data for this approach to discerning changes of POC.

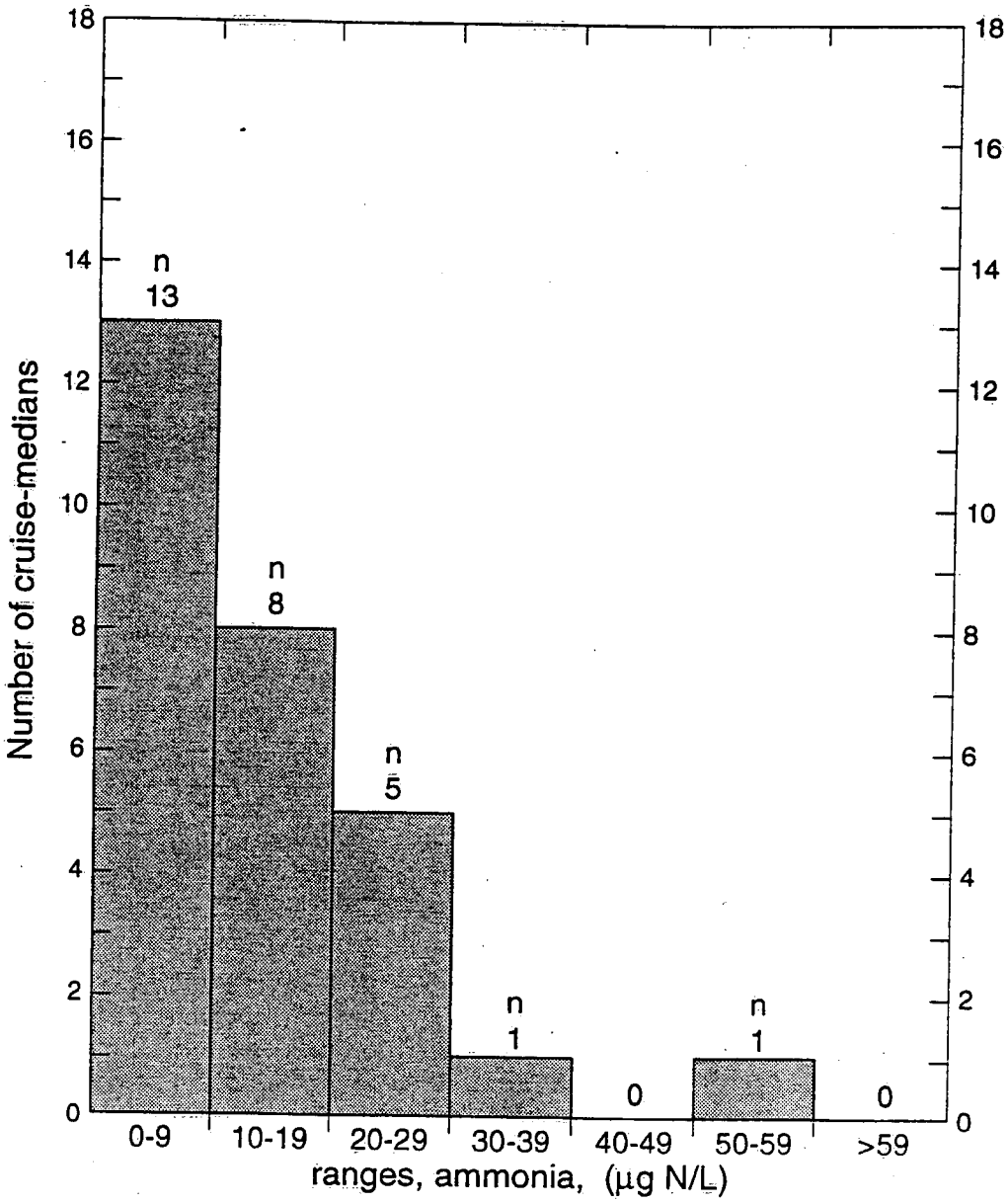
NITROGEN



WESTERN LAKE ERIE: UNWEIGHTED MEAN AMMONIA CONCENTRATIONS AT A DEPTH OF 1 METRE, FROM CRUISES OF THE CANADA CENTRE FOR INLAND WATERS IN THE YEARS 1968 TO 1971. UNITS ARE MICROGRAMS NITROGEN PER LITRE.

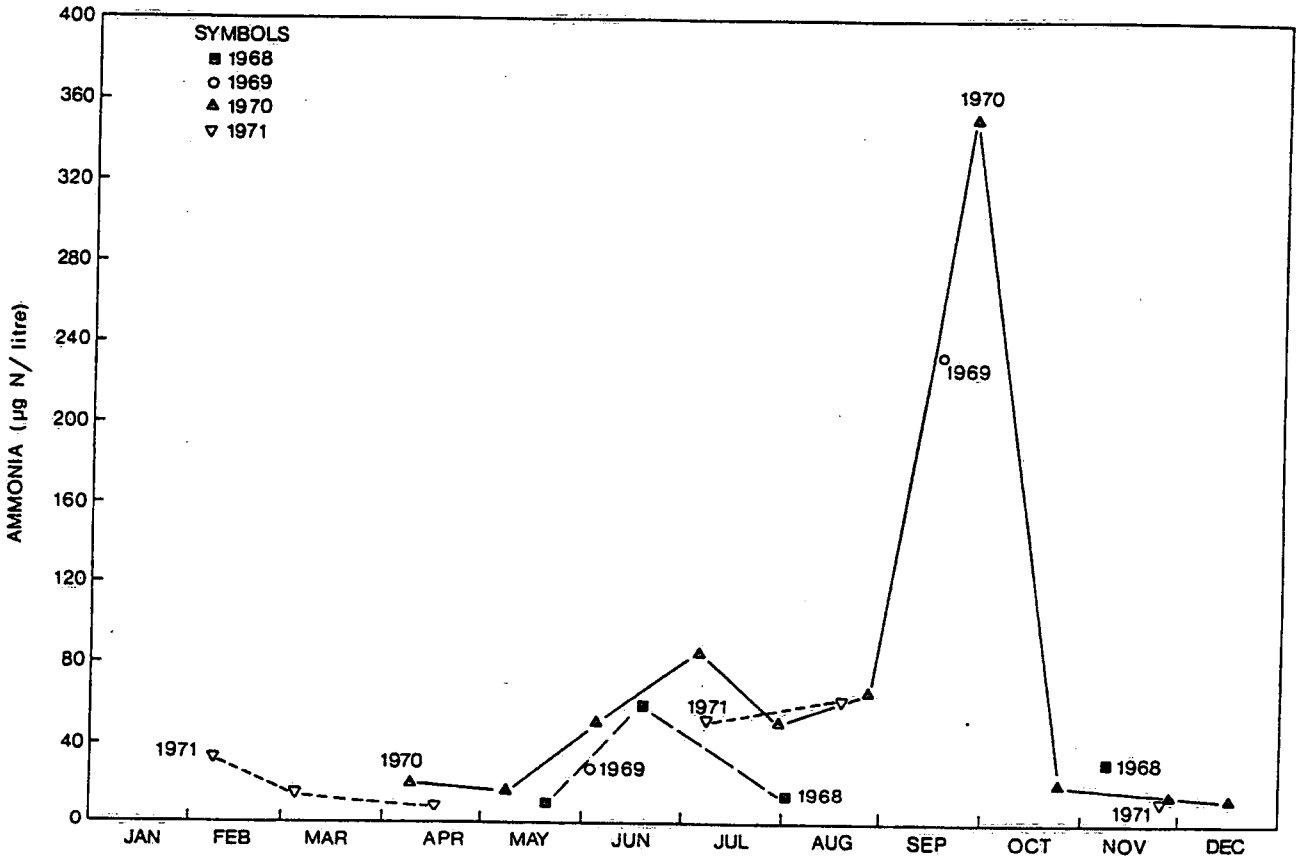


CENTRAL LAKE ERIE: UNWEIGHTED MEAN AMMONIA CONCENTRATIONS AT A DEPTH OF 1 METRE, FROM CRUISES OF THE CANADA CENTRE FOR INLAND WATERS IN THE YEARS 1968 TO 1971. UNITS ARE MICROGRAMS NITROGEN PER LITRE.

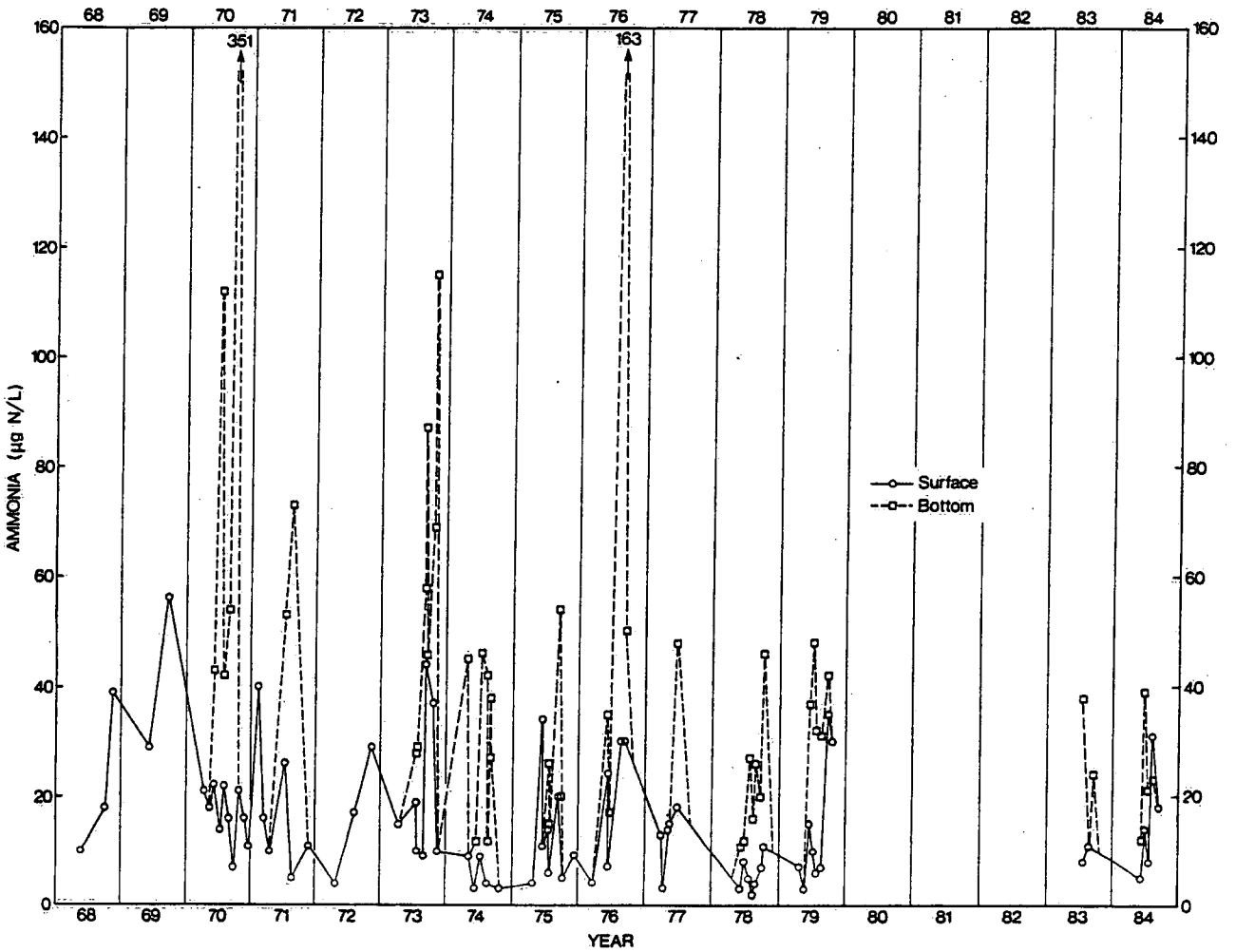


Central Lake Erie, offshore and upper 10m, ammonia (µg N/L), histogram of cruise-medians, June to September, 1969 to 1984, Canadian data from the CCIW STAR file.

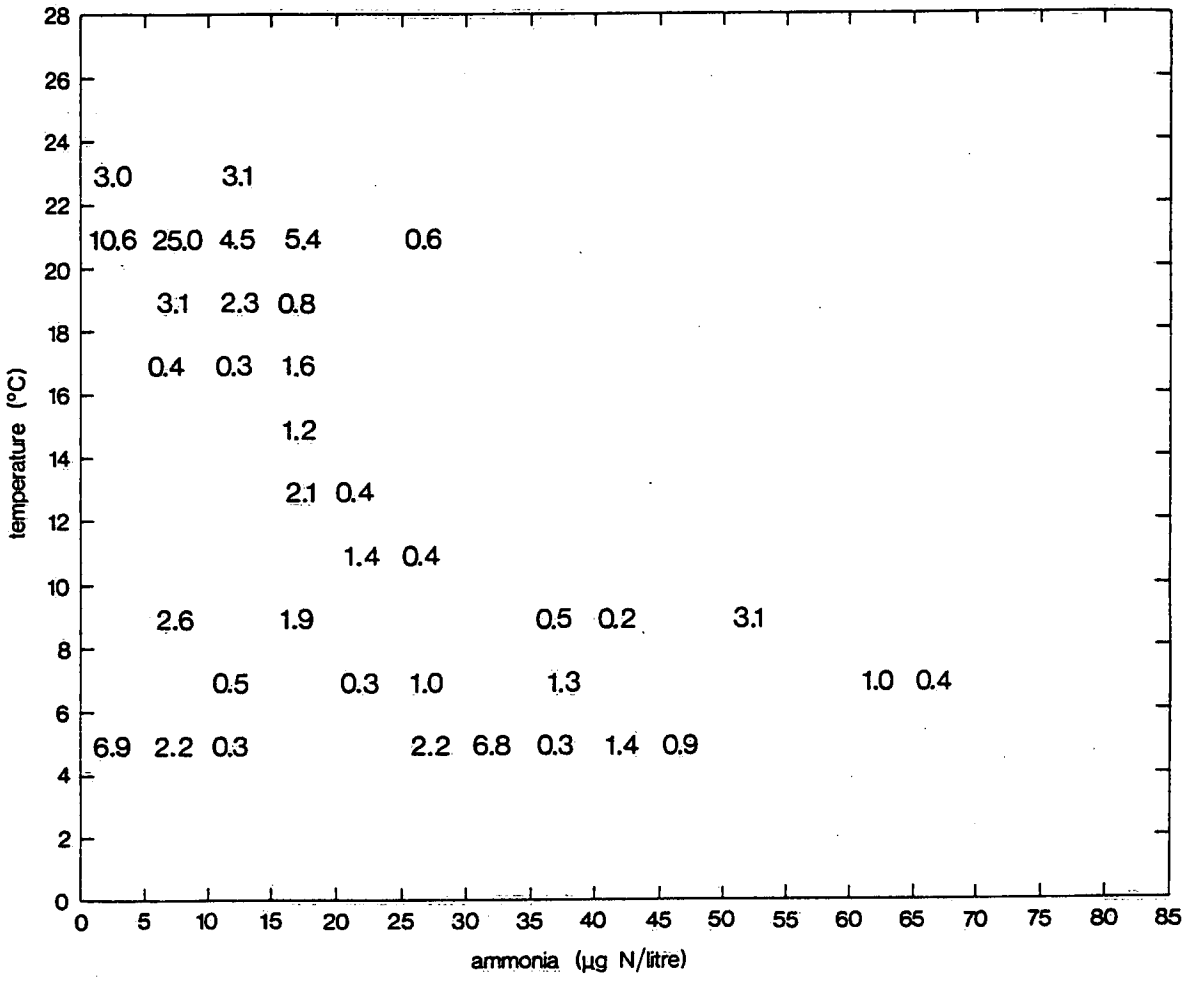
Conclusion: ammonia cruise-medians were usually <30. µg N/L and often ~10. µg N/L.



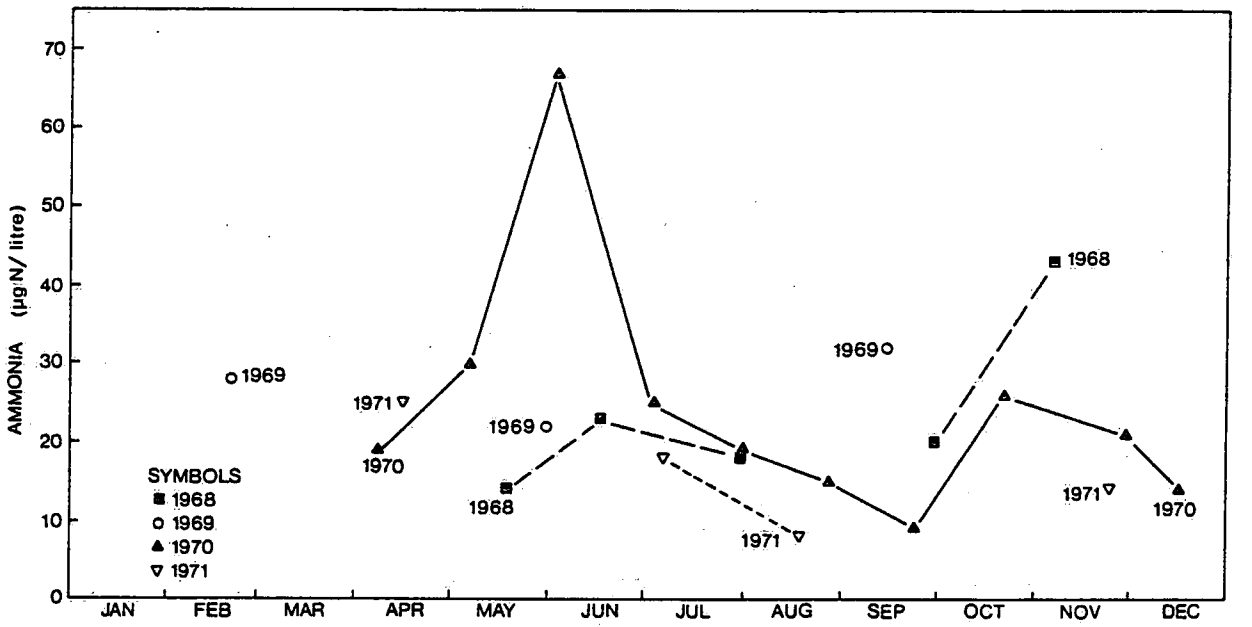
CENTRAL LAKE ERIE: UNWEIGHTED MEAN AMMONIA CONCENTRATIONS IN THE COLD BOTTOM-WATERS, FROM CRUISES OF THE CANADA CENTRE FOR INLAND WATERS IN THE YEARS 1968 TO 1971. UNITS ARE MICROGRAMS NITROGEN PER LITRE.



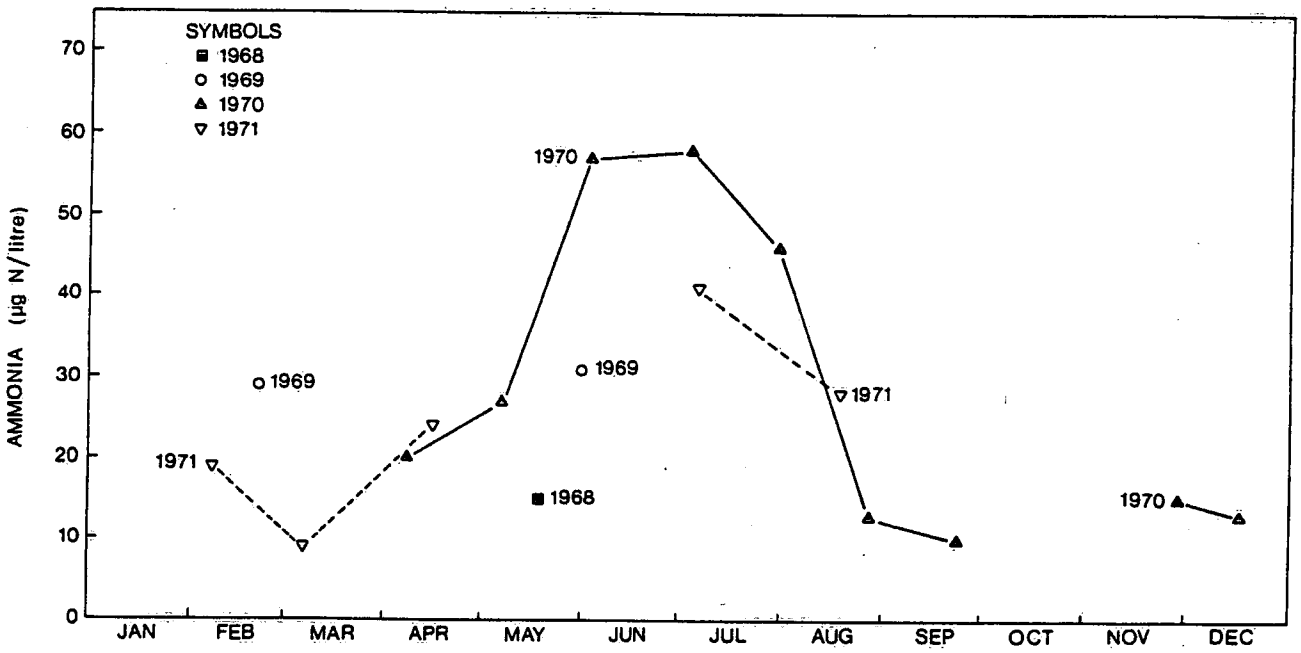
Ammonia in Central Lake Erie: mean values for surface waters and bottom waters in the offshore part, on cruises of CCIW and U.S. vessels, 1968 to 1984.



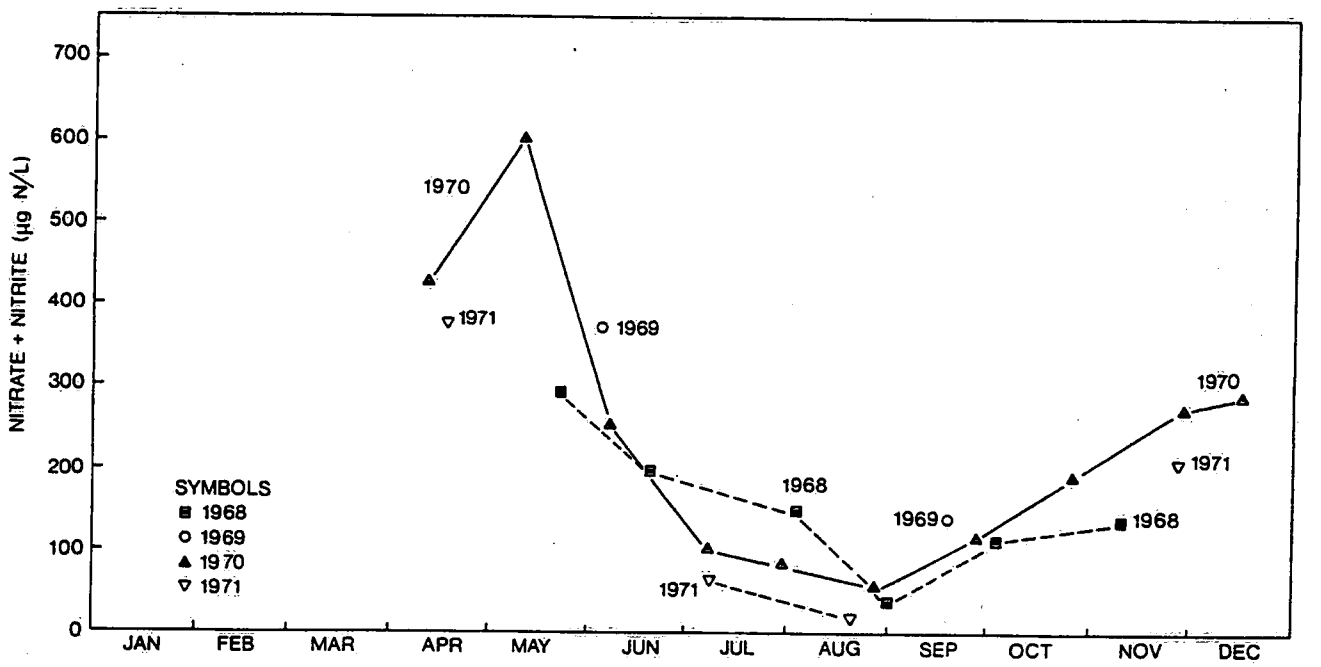
Eastern Basin of Lake Erie, August 17 and 18, 1971. Cruise of the "Martin Karlsen".
Ammonia - temperature histogram (percentage of the eastern basin's volume in each class).
The mean ammonia concentration for the entire eastern basin was 15 micrograms nitrogen per litre.



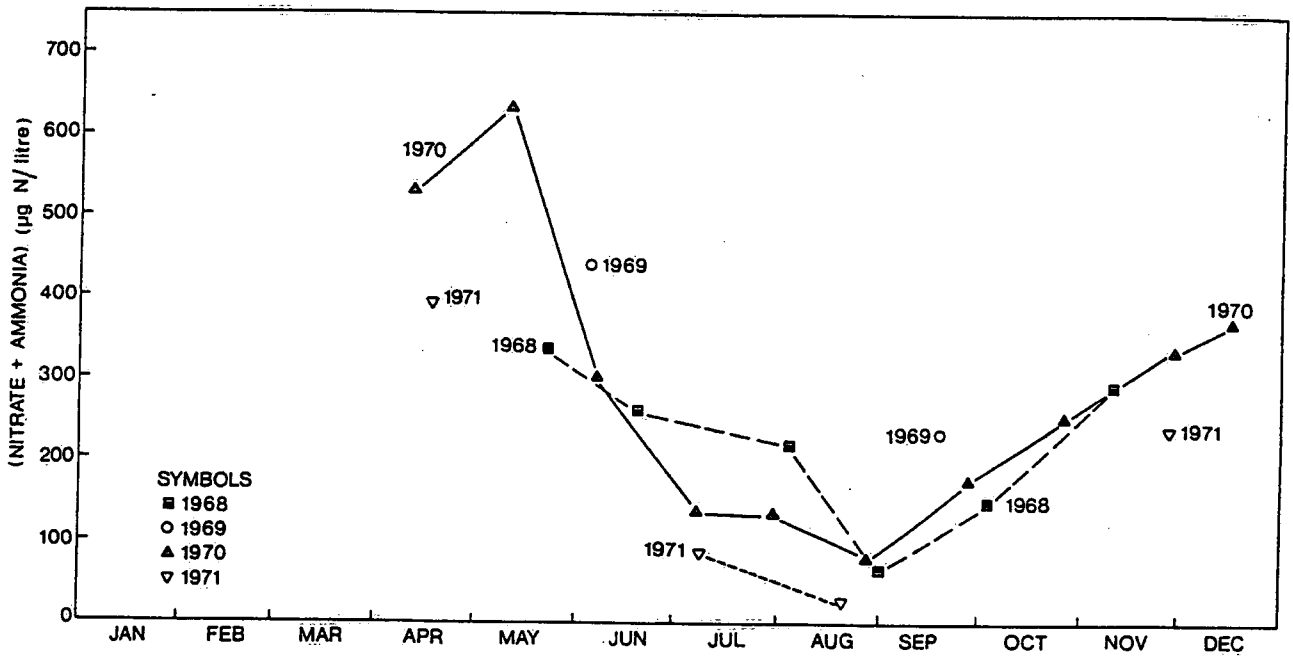
EASTERN LAKE ERIE: UNWEIGHTED MEAN AMMONIA CONCENTRATIONS AT A DEPTH OF 1 METRE, FROM CRUISES OF THE CANADA CENTRE FOR INLAND WATERS IN THE YEARS 1968 TO 1971. UNITS ARE MICROGRAMS NITROGEN PER LITRE.



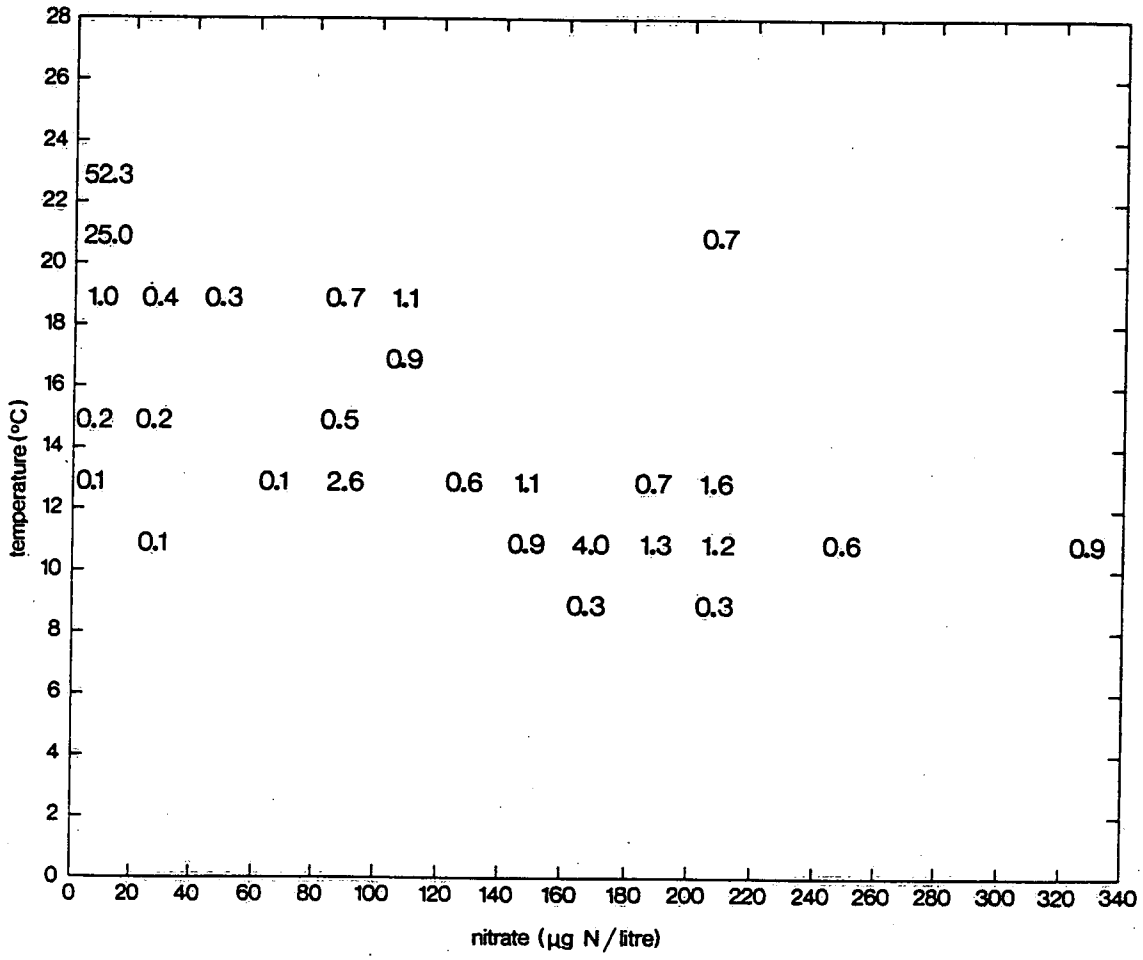
EASTERN LAKE ERIE: UNWEIGHTED MEAN AMMONIA CONCENTRATIONS IN THE COLD BOTTOM-WATERS (TEMPERATURE LESS THAN 8°C), FROM CRUISES OF THE CANADA CENTRE FOR INLAND WATERS IN THE YEARS 1968 TO 1971. UNITS ARE MICROGRAMS NITROGEN PER LITRE.



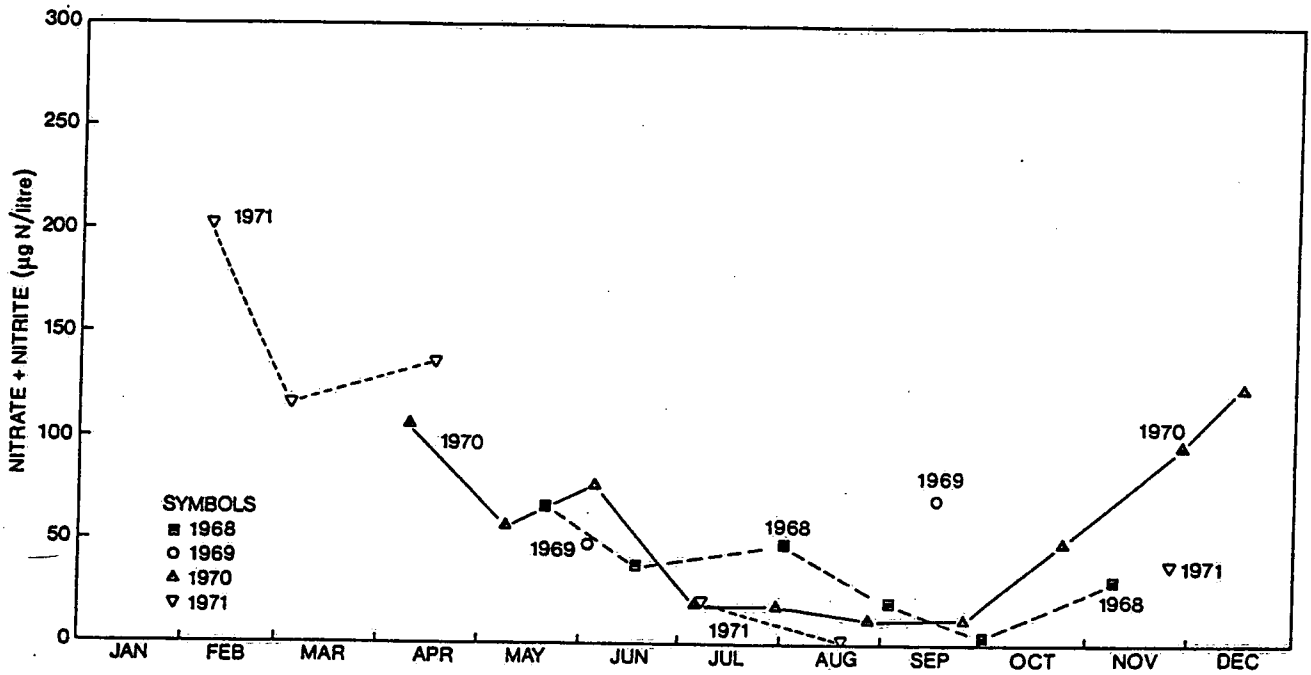
WESTERN LAKE ERIE: UNWEIGHTED MEAN NITRATE + NITRITE CONCENTRATIONS AT A DEPTH OF 1 METRE, FROM CRUISES OF CCIW IN THE YEARS 1968 to 1971.



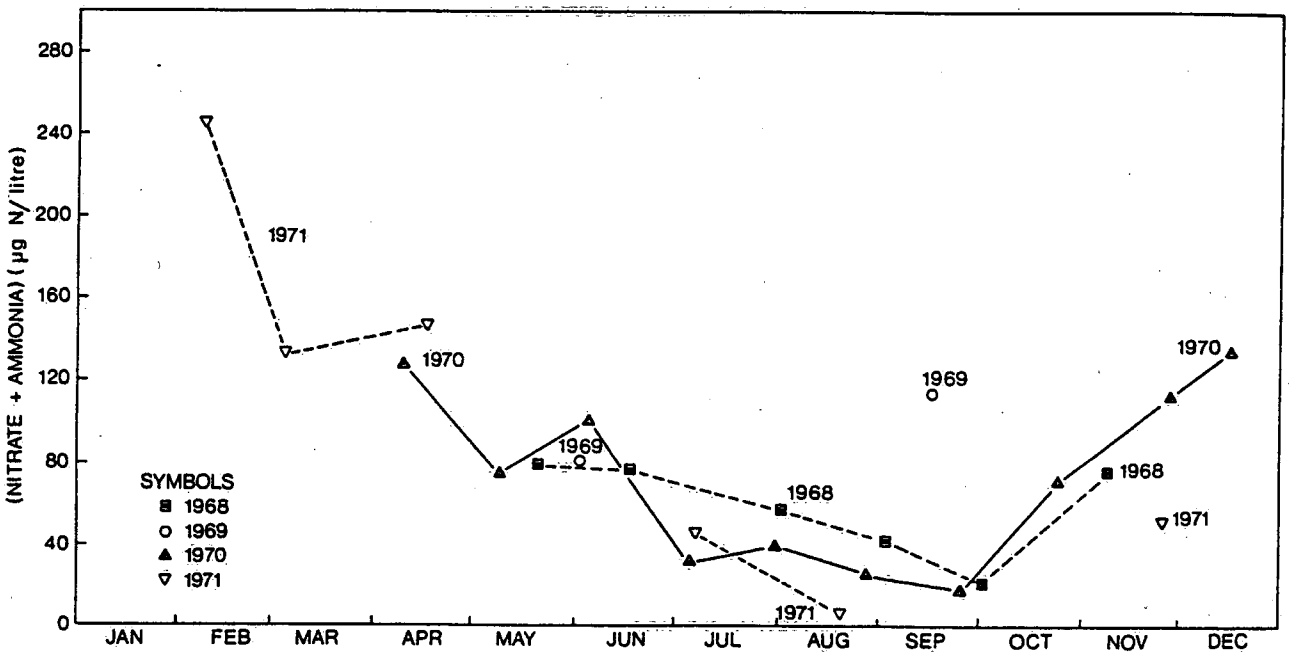
WESTERN LAKE ERIE: UNWEIGHTED MEAN (NITRATE + AMMONIA) CONCENTRATIONS AT A DEPTH OF 1 METRE, FROM CRUISES OF THE CANADA CENTRE FOR INLAND WATERS IN THE YEARS 1968 TO 1971. UNITS ARE MICROGRAMS NITROGEN PER LITRE



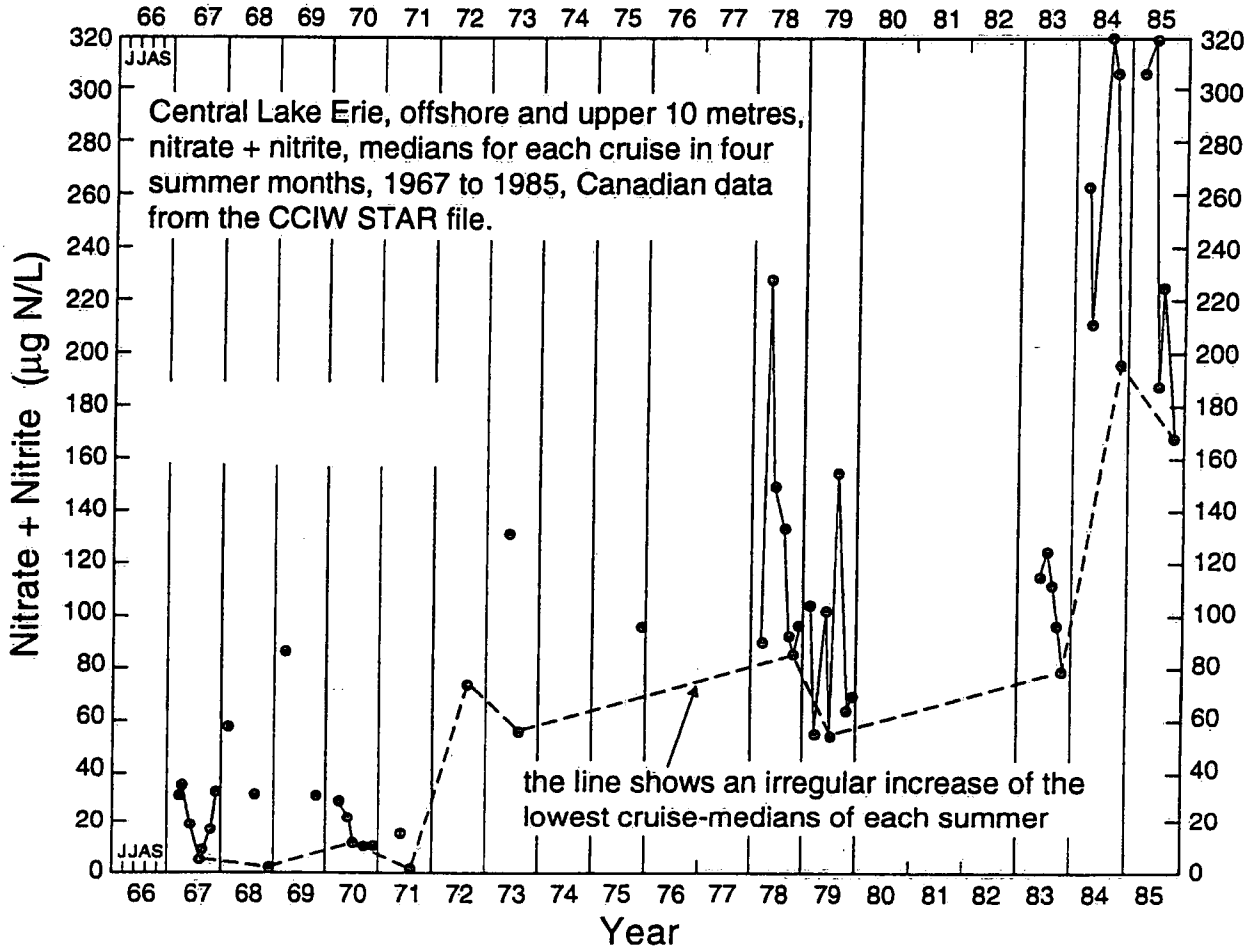
Central basin of Lake Erie, August 18 - 20, 1971. Cruise of the "Martin Karlsen".
Nitrate - temperature histogram (percentage of the central basin's volume in each class).
The mean nitrate concentration for the entire central basin was 41 micrograms nitrogen per litre.

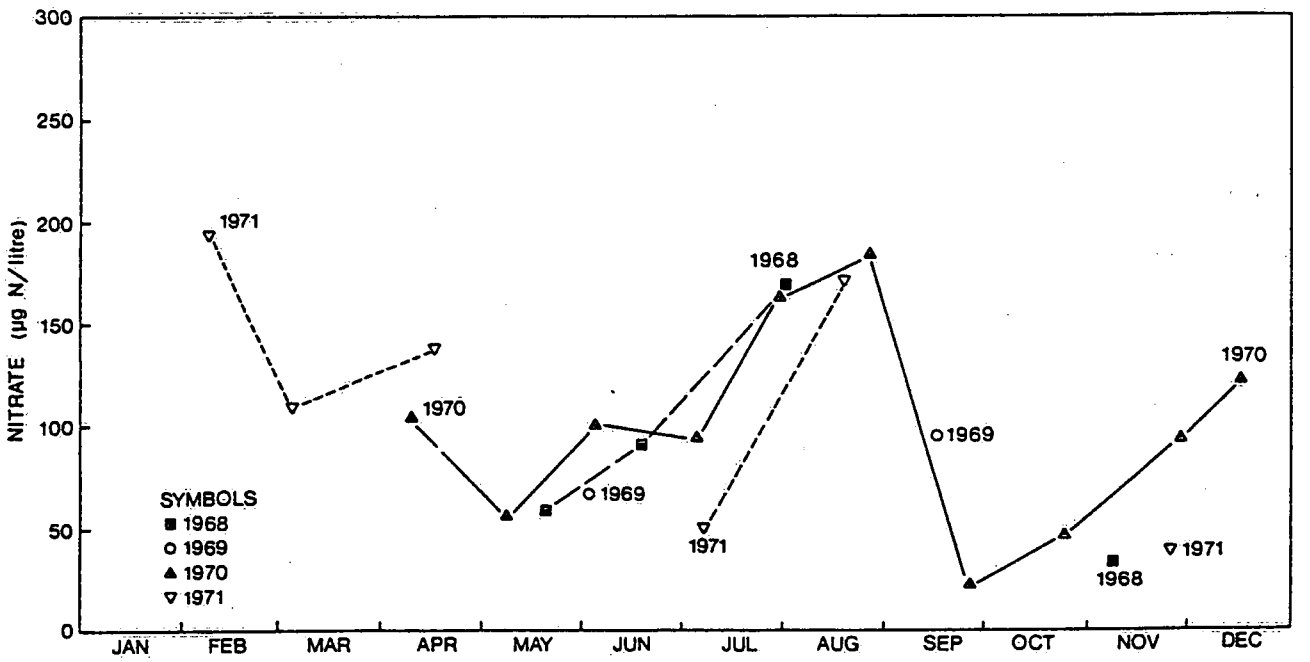


CENTRAL LAKE ERIE: UNWEIGHTED MEAN NITRATE + NITRITE CONCENTRATIONS AT A DEPTH OF 1 METRE, FROM CCIW CRUISES, 1968 TO 1971.

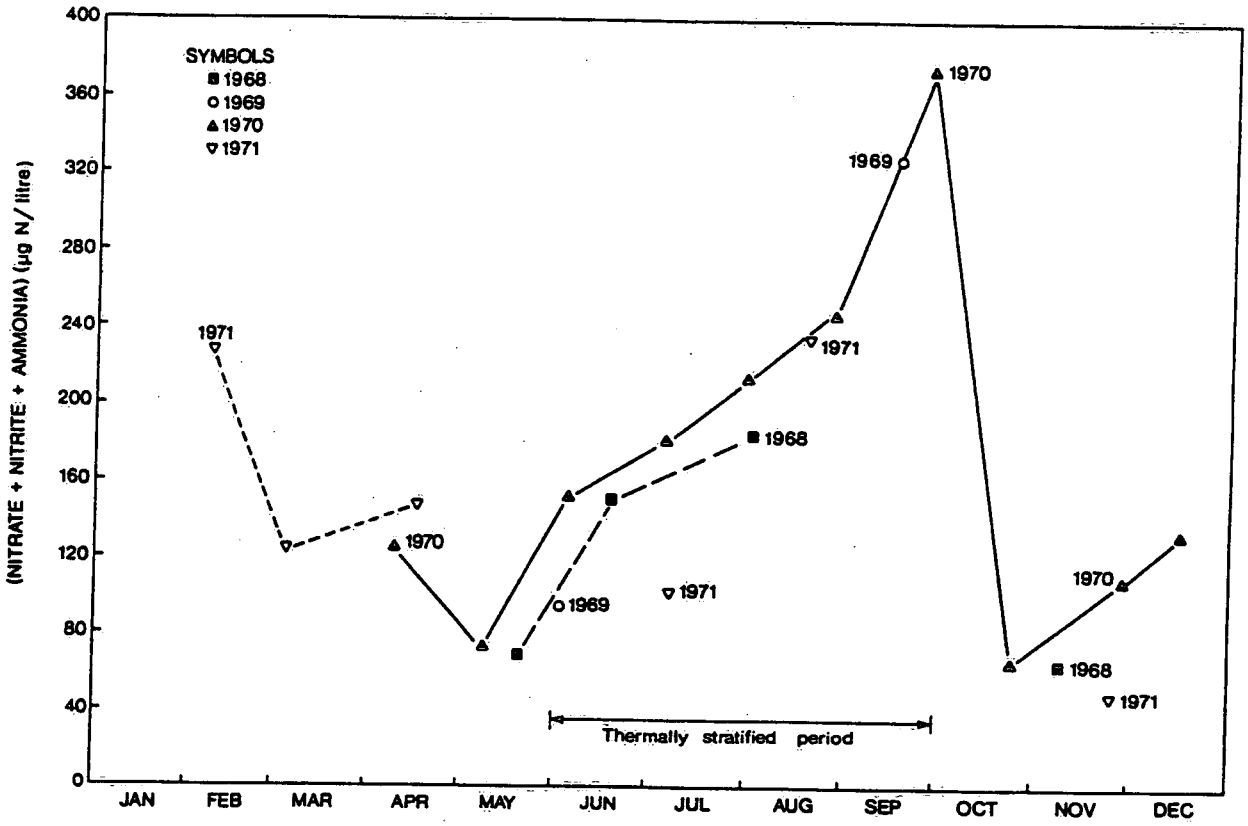


CENTRAL LAKE ERIE: UNWEIGHTED MEAN (NITRATE + AMMONIA) CONCENTRATIONS AT A DEPTH OF 1 METRE, FROM CRUISES OF THE CANADA CENTRE FOR INLAND WATERS IN THE YEARS 1968 TO 1971. UNITS ARE MICROGRAMS NITROGEN PER LITRE.

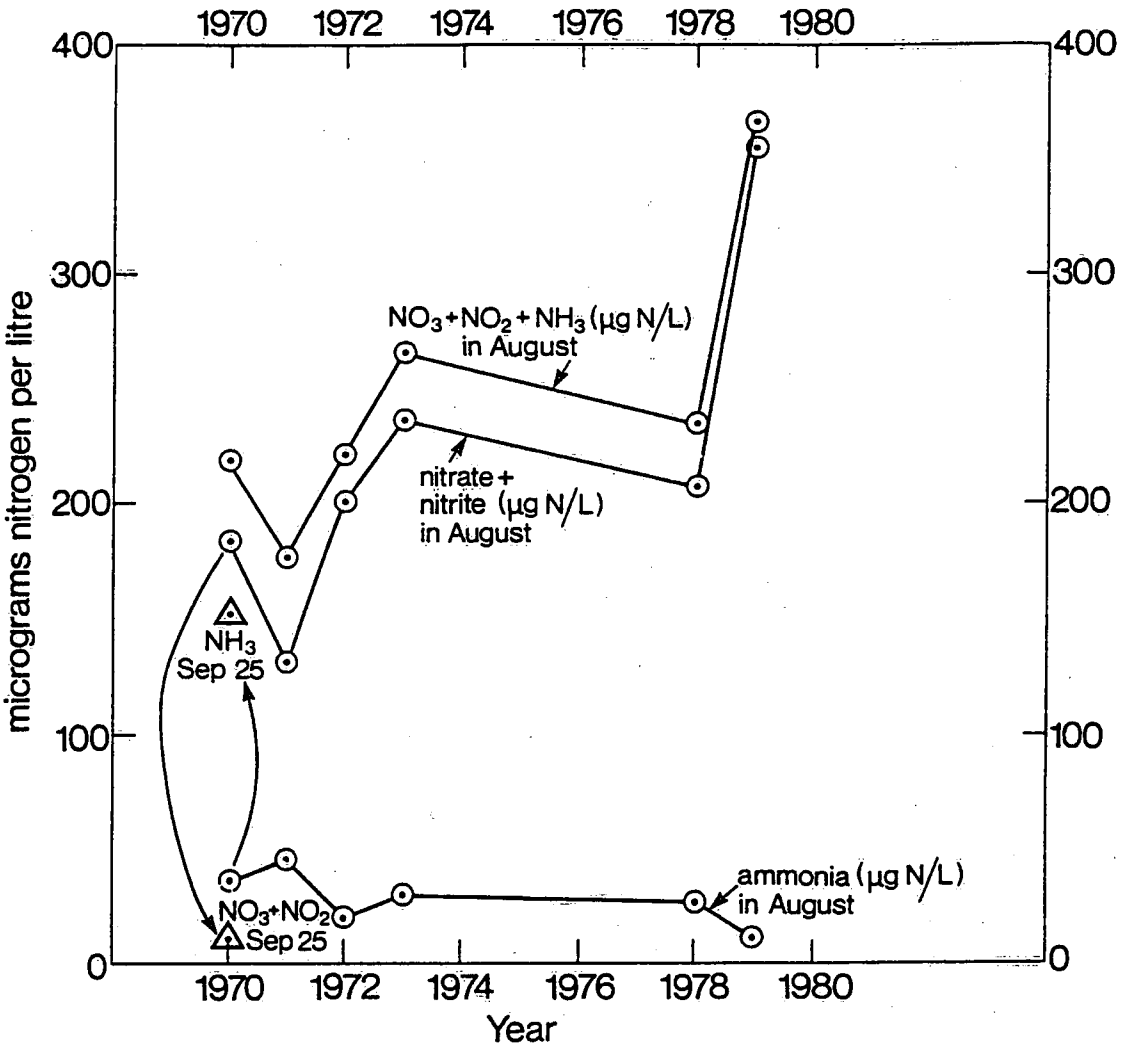

Central Lake Erie, offshore and upper 10 metres, nitrate + nitrite, medians for each cruise in four summer months, 1967 to 1985, Canadian data from the CCIW STAR file.
the line shows an irregular increase of the lowest cruise-medians of each summer
JJAS
Nitrate + Nitrite (µg N/L)
Year
66 67 68 69 70 71 72 73 74 75 76 77 78 79 80 81 82 83 84 85
0 20 40 60 80 100 120 140 160 180 200 220 240 260 280 300 320



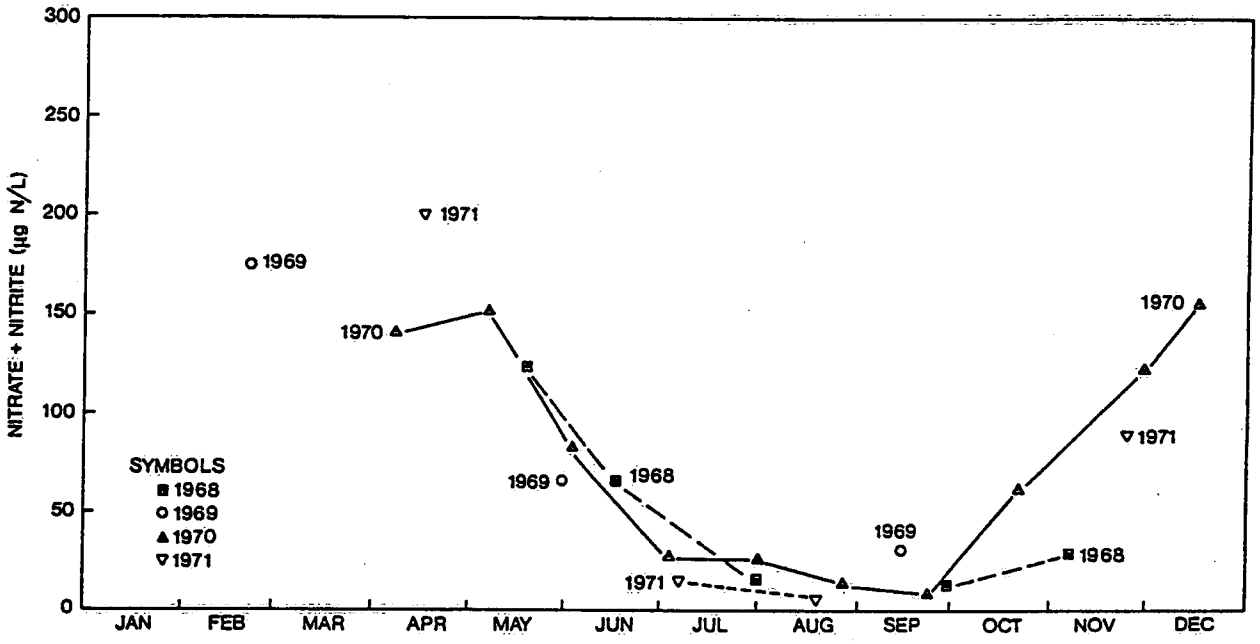
CENTRAL LAKE ERIE: UNWEIGHTED MEAN NITRATE CONCENTRATIONS IN THE COLD BOTTOM-WATERS, FROM CRUISES OF THE CANADA CENTRE FOR INLAND WATERS, IN THE YEARS 1968 TO 1971. UNITS ARE MICROGRAMS NITROGEN PER LITRE.



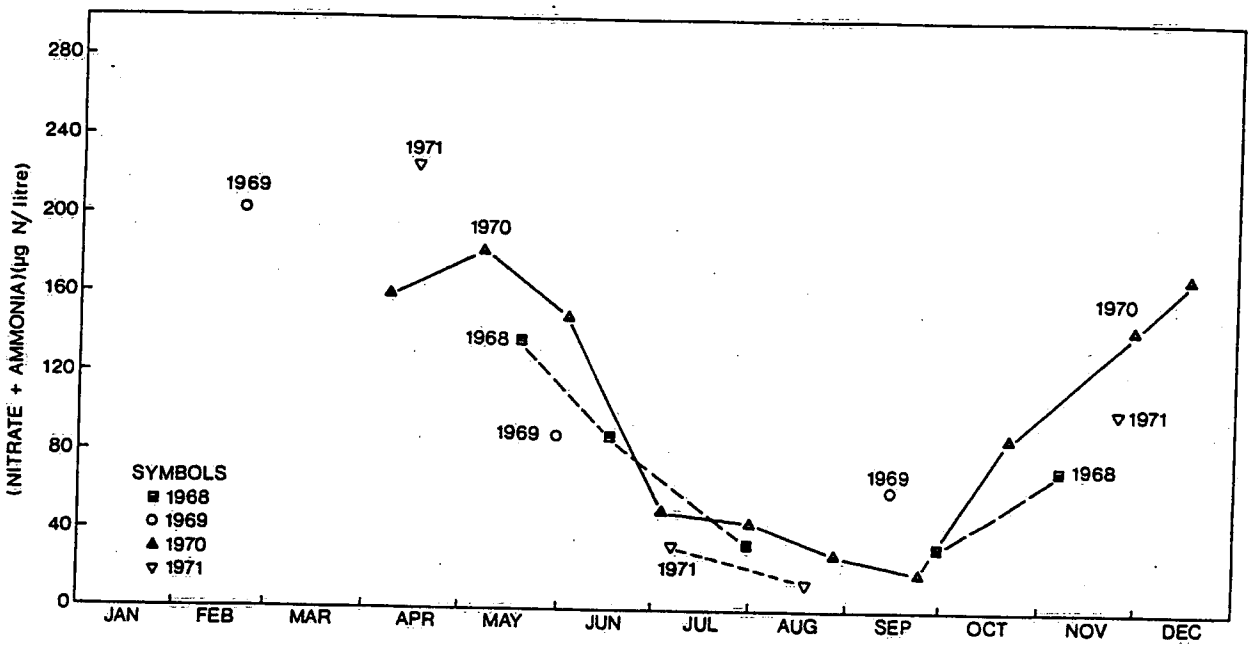
CENTRAL LAKE ERIE: UNWEIGHTED MEAN (NITRATE + NITRITE + AMMONIA) CONCENTRATIONS IN THE COLD BOTTOM-WATERS, FROM CRUISES OF CCIW VESSELS 1968 TO 1971.



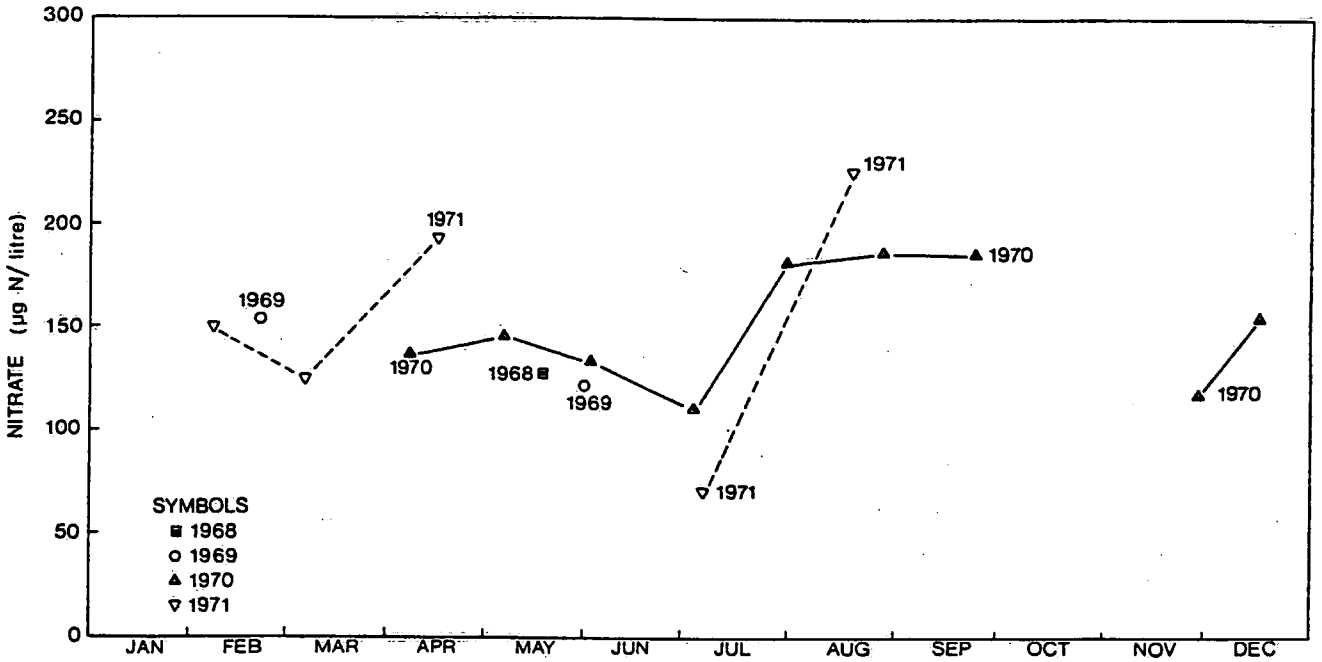
Central Erie Bottom Water, nitrate + nitrite, and ammonia and their sum, in August of a series of years in the 1970's (CCIW data). Also a shift to more ammonia was observed in late September of the year 1970 only.



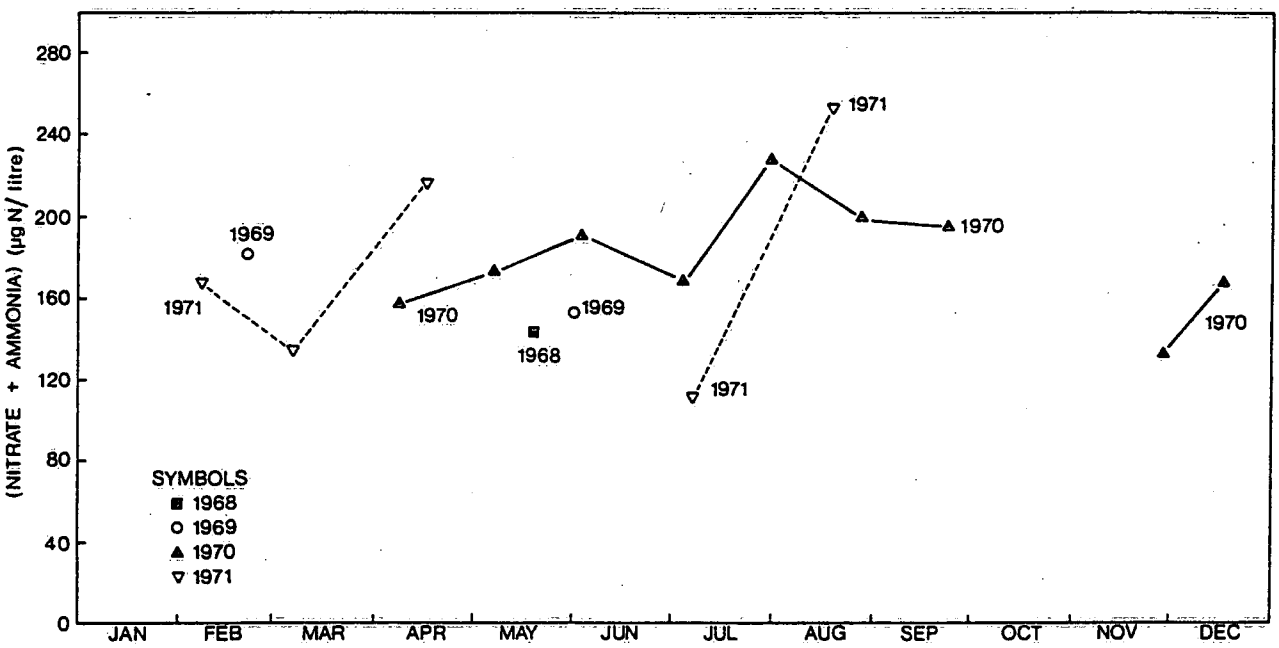
EASTERN LAKE ERIE: UNWEIGHTED MEAN NITRATE+NITRITE CONCENTRATIONS AT A DEPTH OF 1 METRE, FROM CRUISES OF CCIW IN THE YEARS 1968 to 1971.



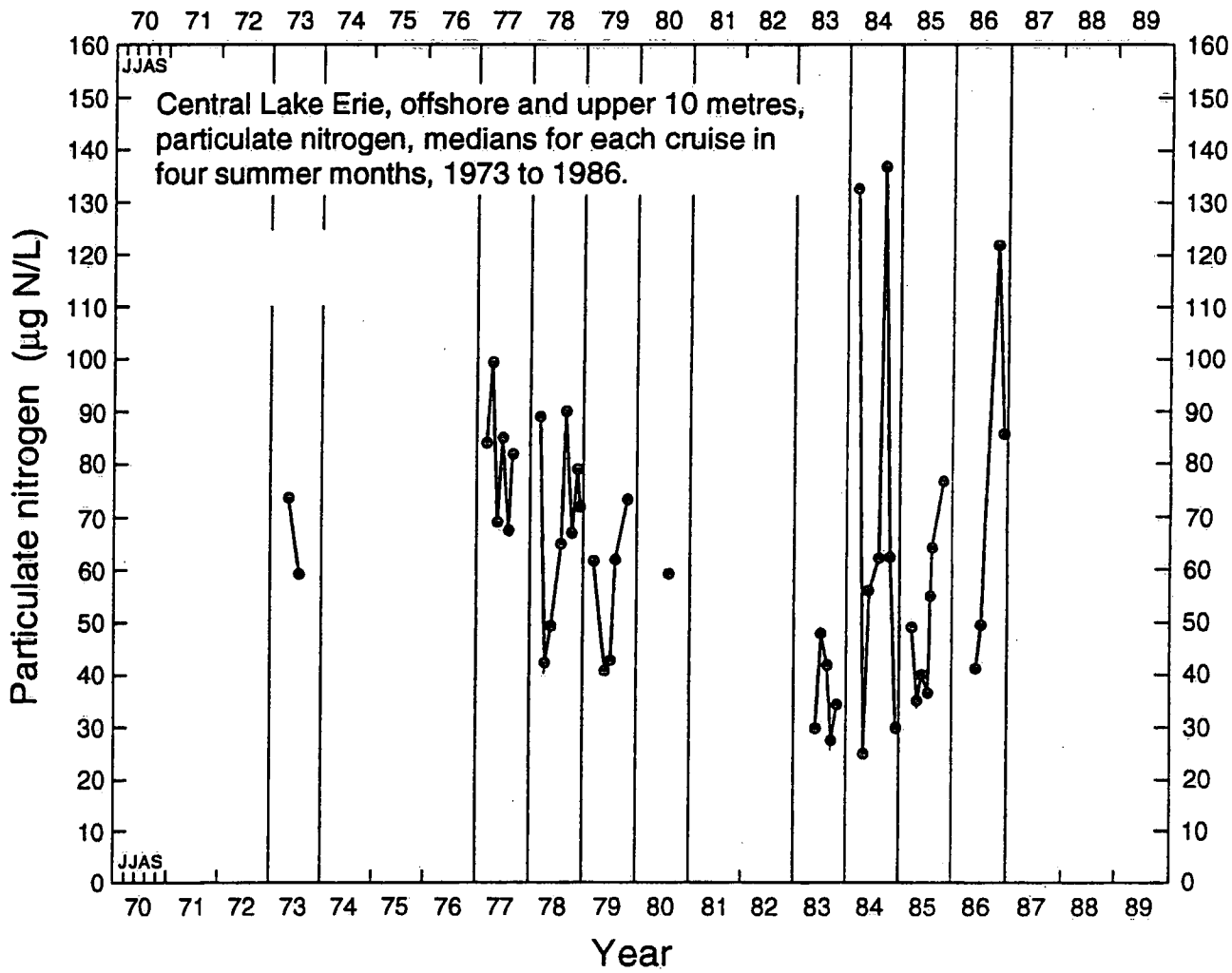
EASTERN LAKE ERIE: UNWEIGHTED MEAN (NITRATE + AMMONIA) CONCENTRATIONS AT A DEPTH OF 1 METRE, FROM CRUISES OF THE CANADA CENTRE FOR INLAND WATERS IN THE YEARS 1968 TO 1971. UNITS ARE MICROGRAMS NITROGEN PER LITRE.

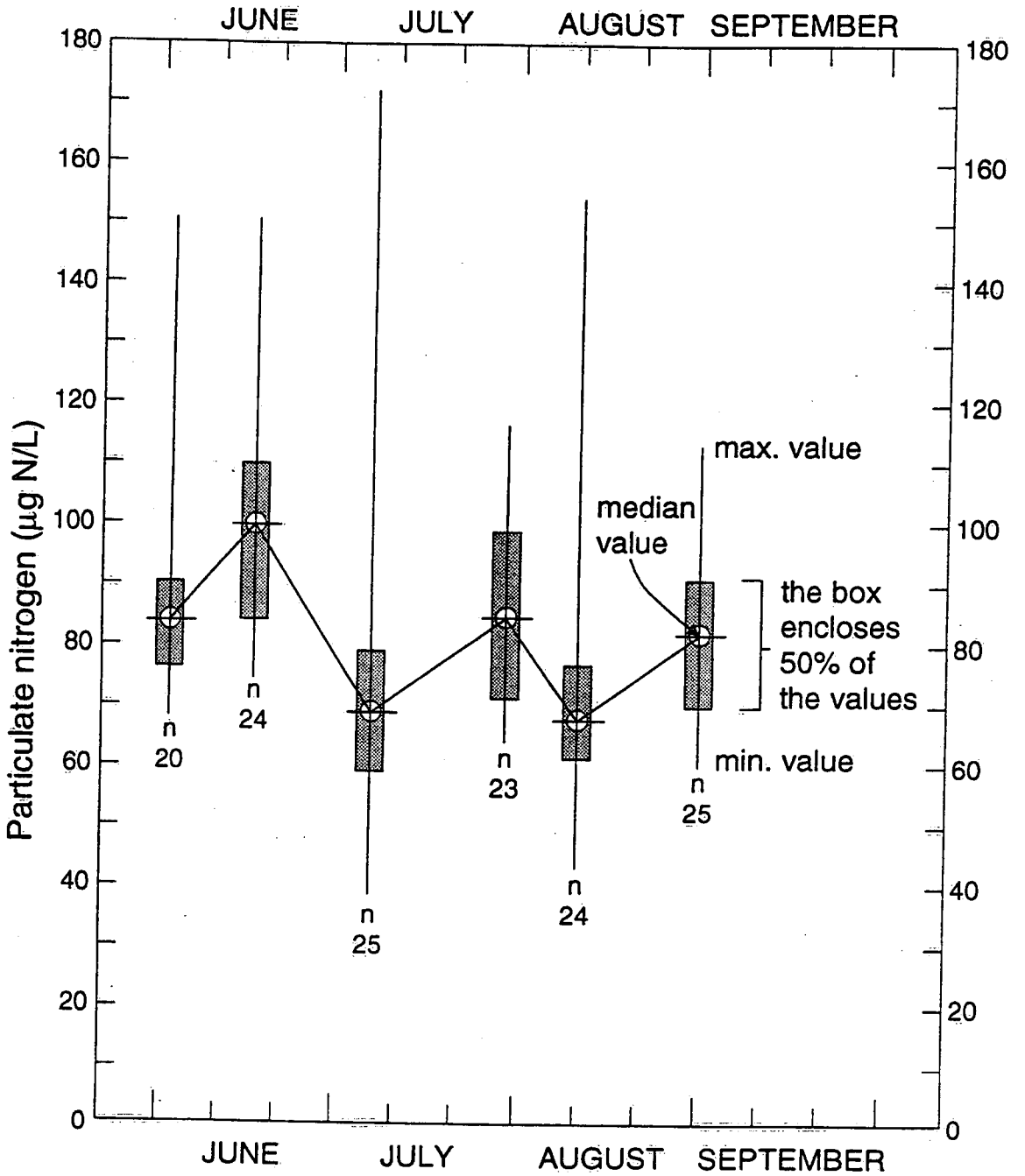


EASTERN LAKE ERIE: UNWEIGHTED MEAN NITRATE CONCENTRATIONS IN THE COLD BOTTOM - WATERS (TEMPERATURE LESS THAN 8°C), FROM CRUISES OF THE CANADA CENTRE FOR INLAND WATERS IN THE YEARS 1968 TO 1971. UNITS ARE MICROGRAMS NITROGEN PER LITRE.

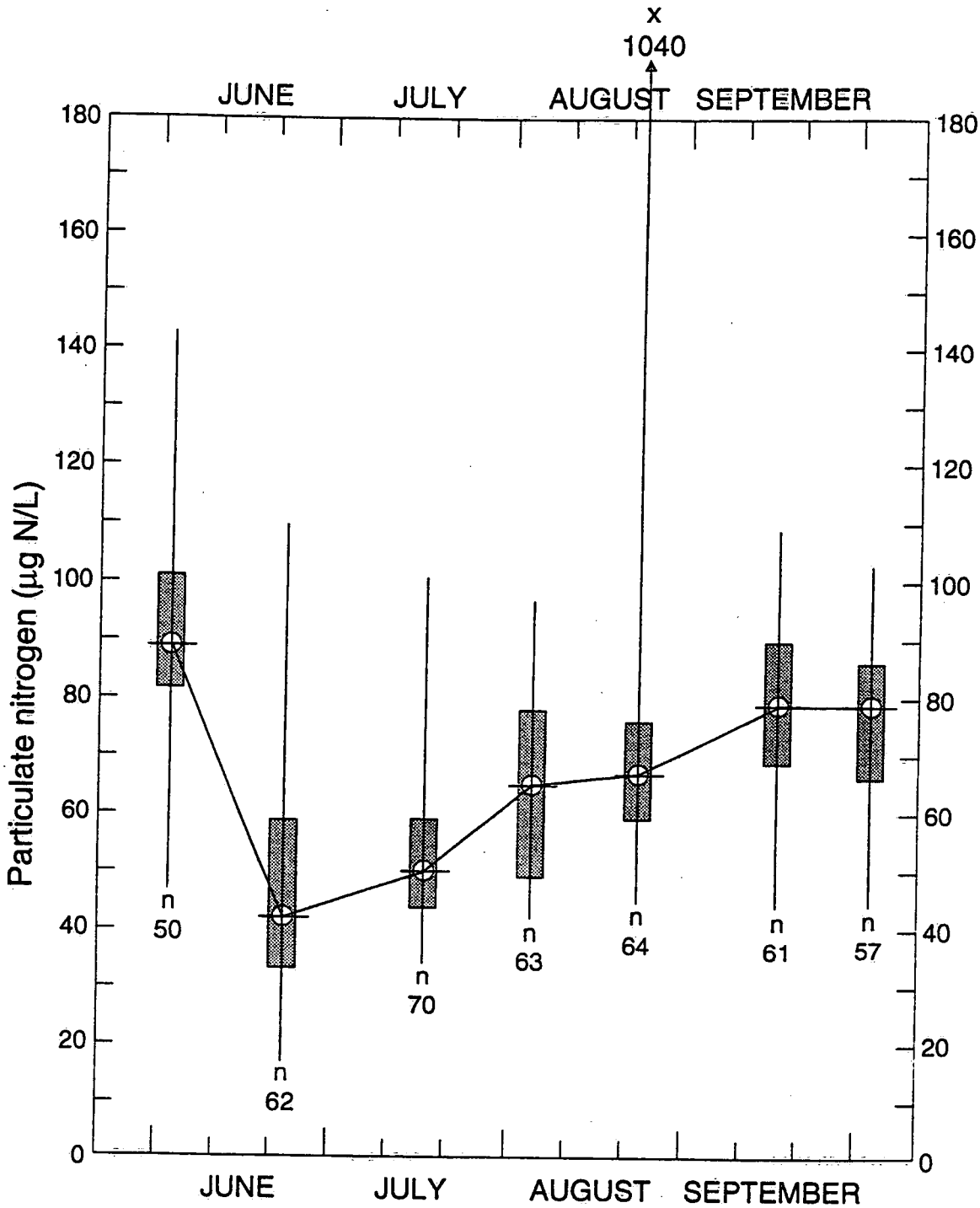


EASTERN LAKE ERIE: UNWEIGHTED MEAN (NITRATE + AMMONIA) CONCENTRATIONS IN THE COLD BOTTOM-WATERS (TEMPERATURE LESS THAN 8°C) FROM CRUISES OF THE CANADA CENTRE FOR INLAND WATERS IN YEARS 1968 TO 1971. UNITS ARE MICROGRAMS NITROGEN PER LITRE.

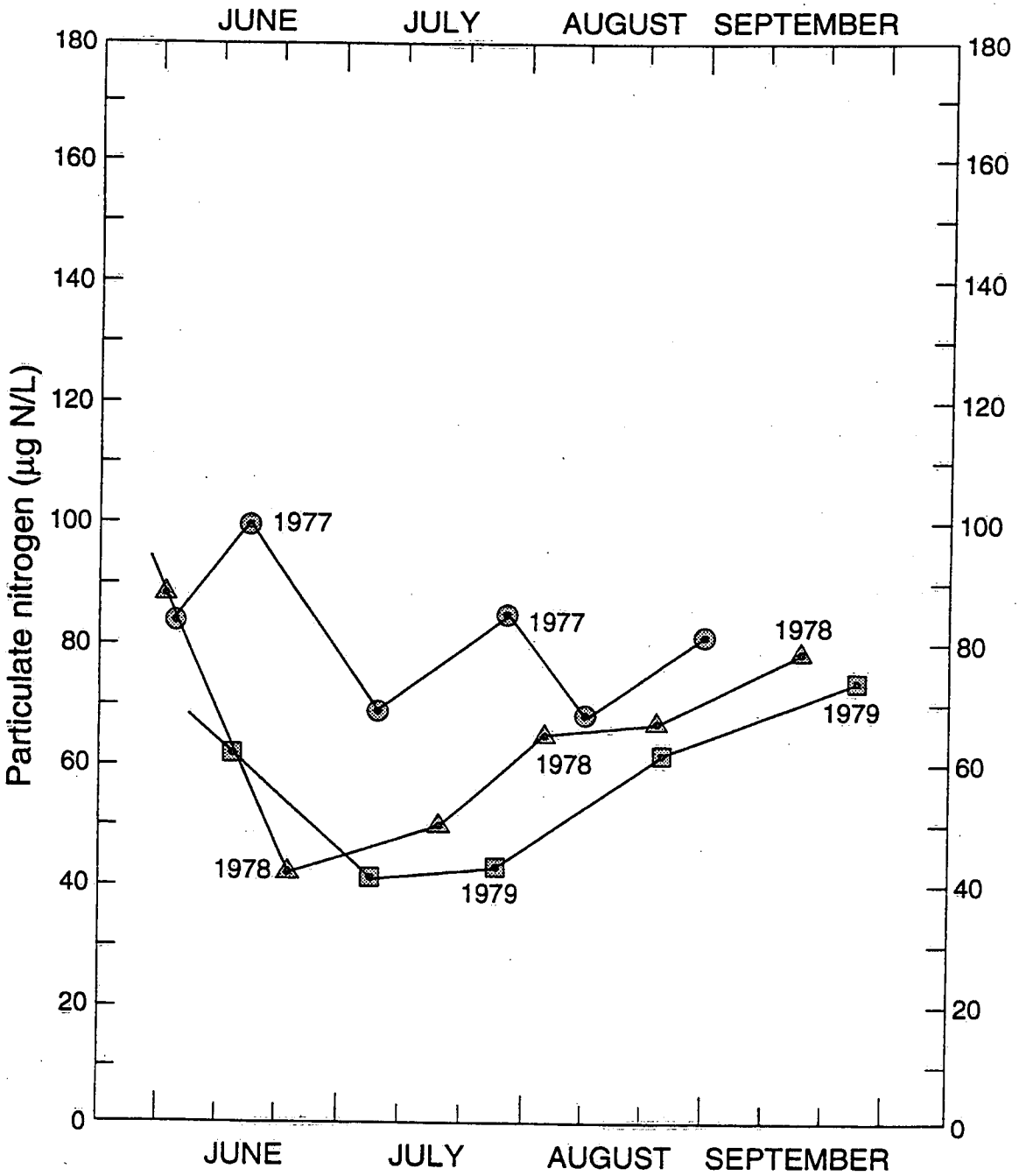

Central Lake Erie, offshore and upper 10 metres, particulate nitrogen, medians for each cruise in four summer months, 1973 to 1986.
Particulate nitrogen (µg N/L)
Year
JJAS
70 71 72 73 74 75 76 77 78 79 80 81 82 83 84 85 86 87 88 89
0 10 20 30 40 50 60 70 80 90 100 110 120 130 140 150 160



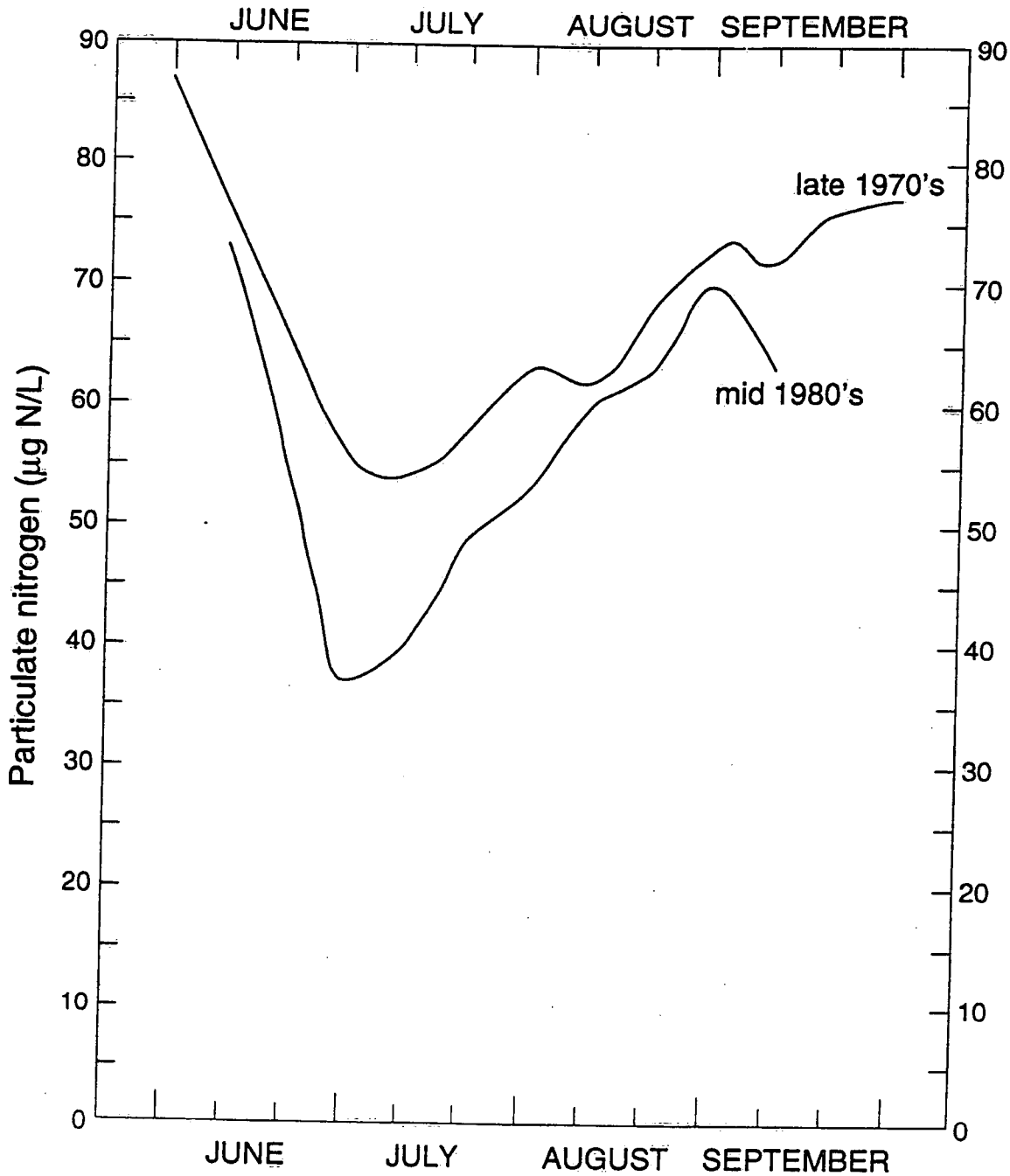
Particulate nitrogen, Central Lake Erie, offshore and upper 10m, median statistics on each cruise in summer 1977, Canadian vessels Petrel and Limnos.



Particulate nitrogen, Central Lake Erie, offshore and upper 10m, median statistics on each cruise in summer 1978, Canadian vessel Limnos.

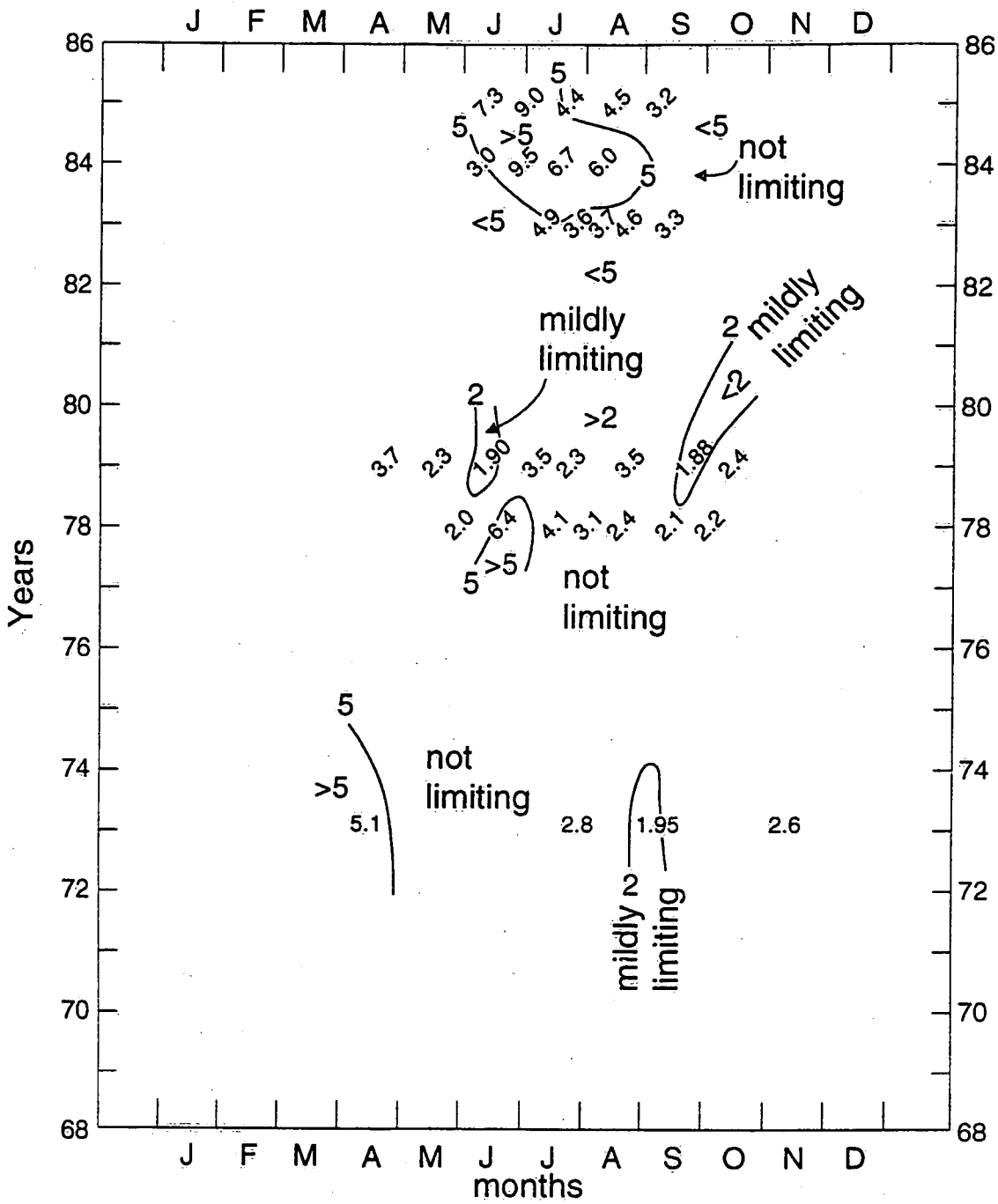


Central Lake Erie, offshore and upper 10m, particulate nitrogen, medians on each cruise, in 4 summer months in the years 1977 to 1979.



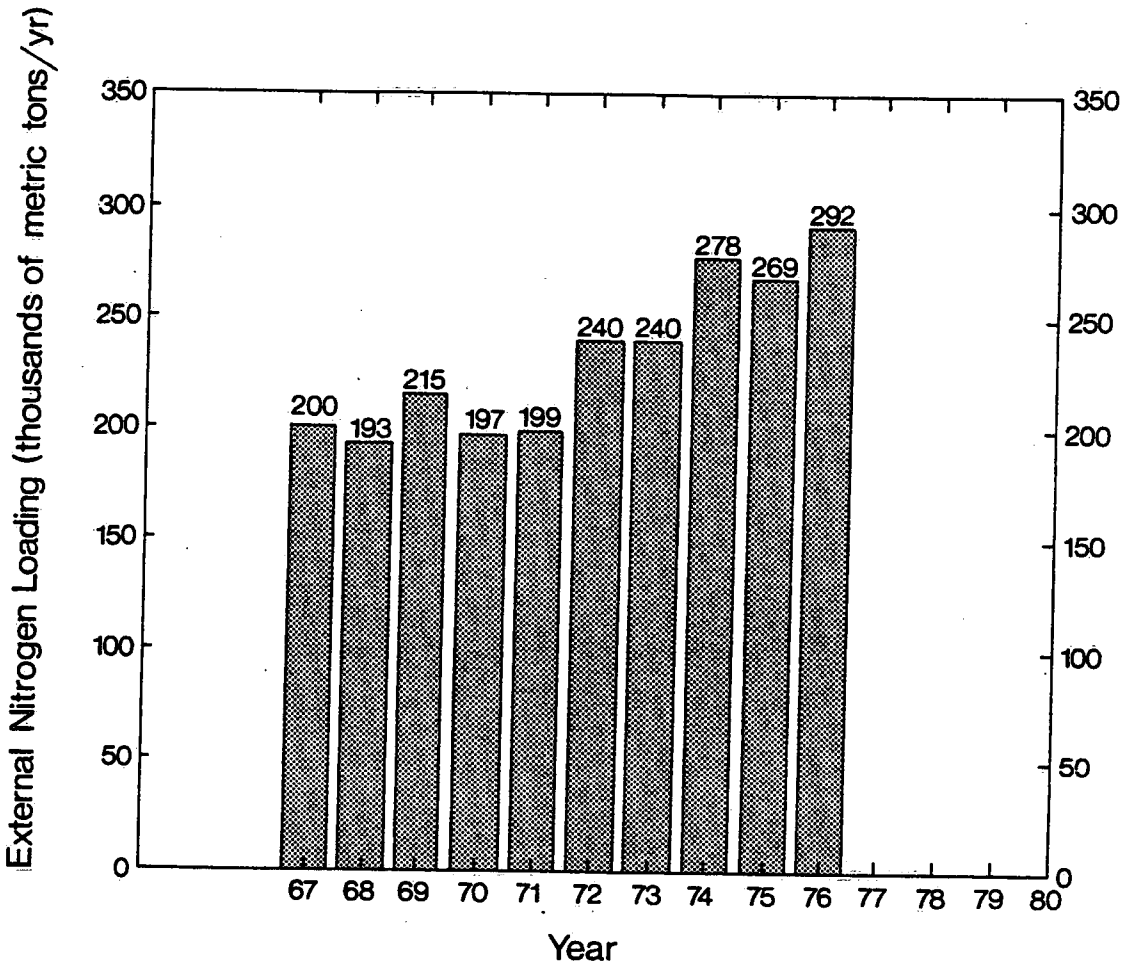
Central Lake Erie, offshore and upper 10m, particulate nitrogen, smoothed seasonal curves for two groups of data: ① 1977, 78, 79 ② 1983, 84, 85, 86.

(Canadian data. All other years 1966 to 1993 had too few data.)



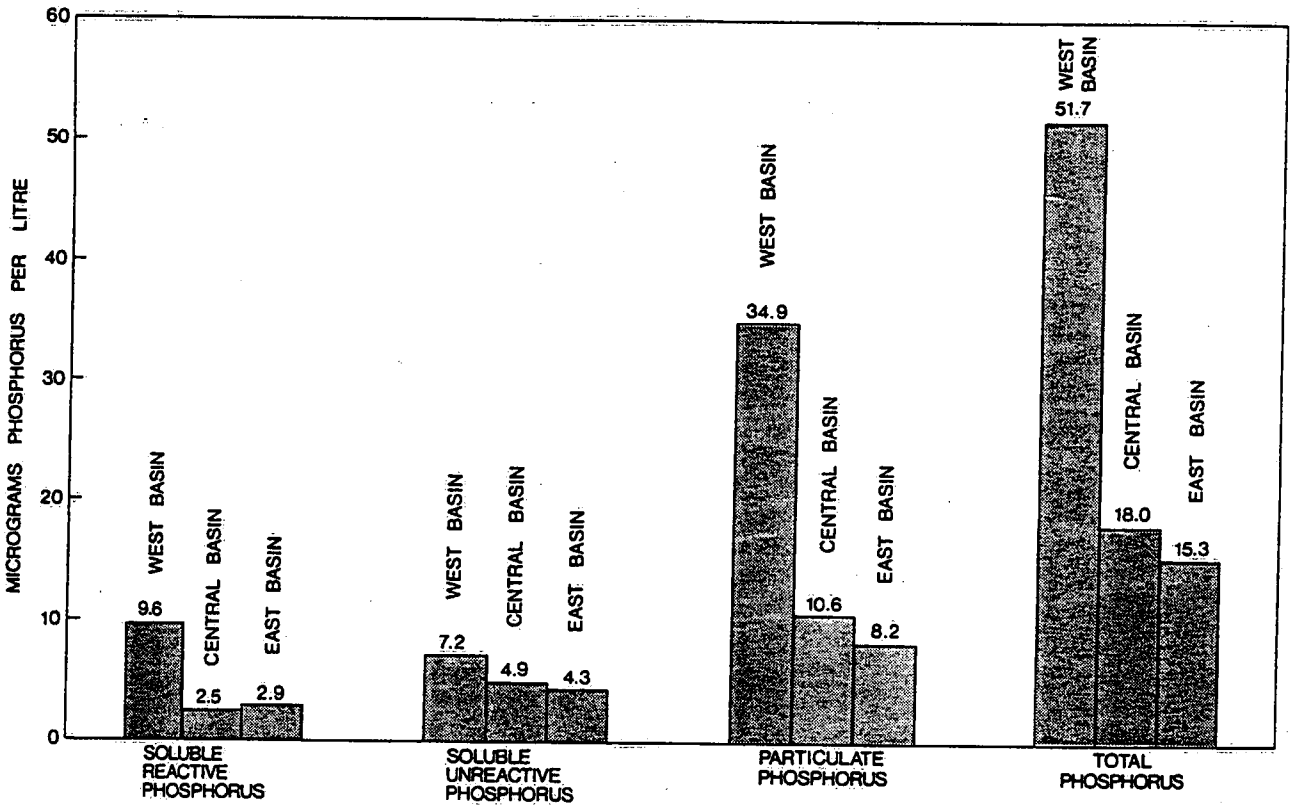
Central Lake Erie, PGF_N by cruise, 1973 to 1985.

$$PGF_N = \textit{potential growth factor for nitrogen (surface waters)} = \frac{\textit{particulate N + soluble reactive N}}{\textit{particulate N}}$$

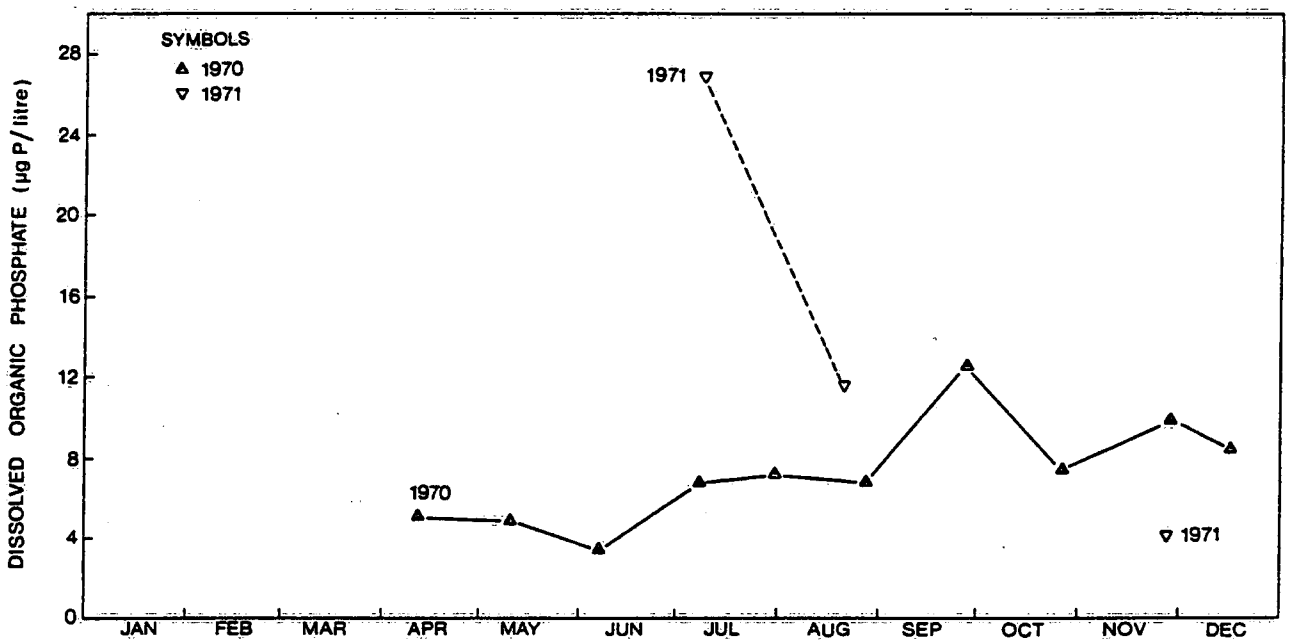


Lake Erie: external loading of total nitrogen, 1967 to 1976 (data from Fraser and Willson, 1981)

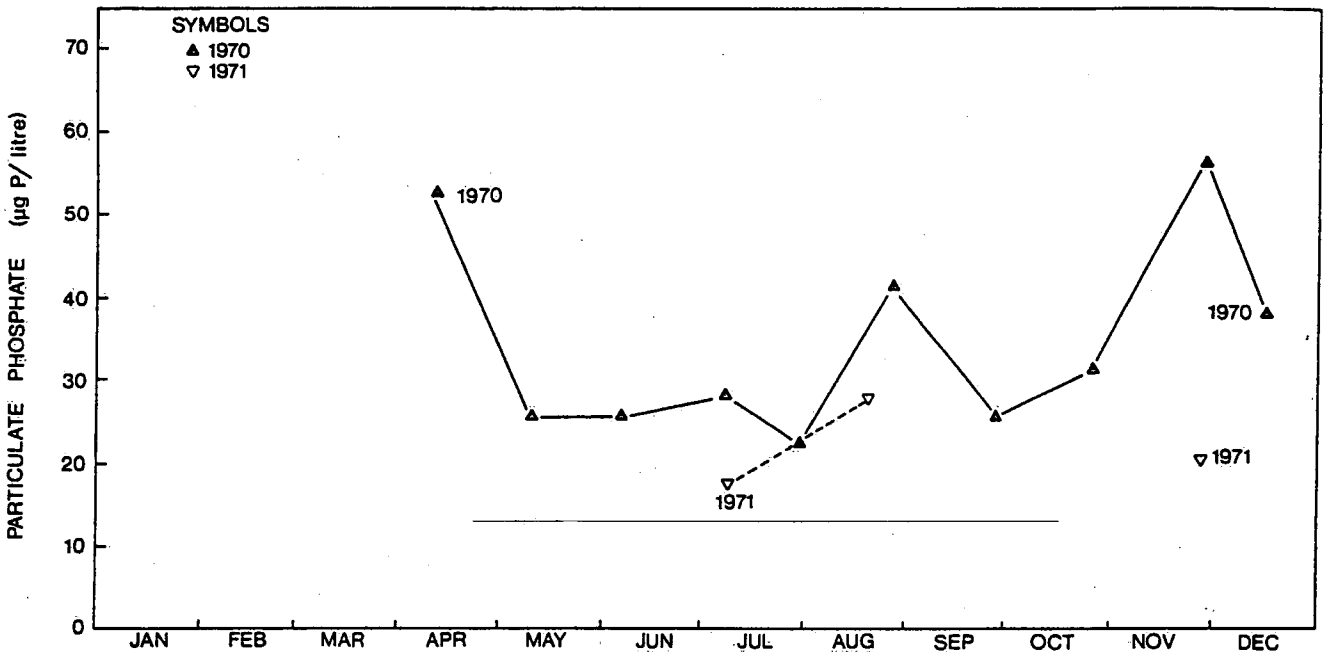
PHOSPHORUS



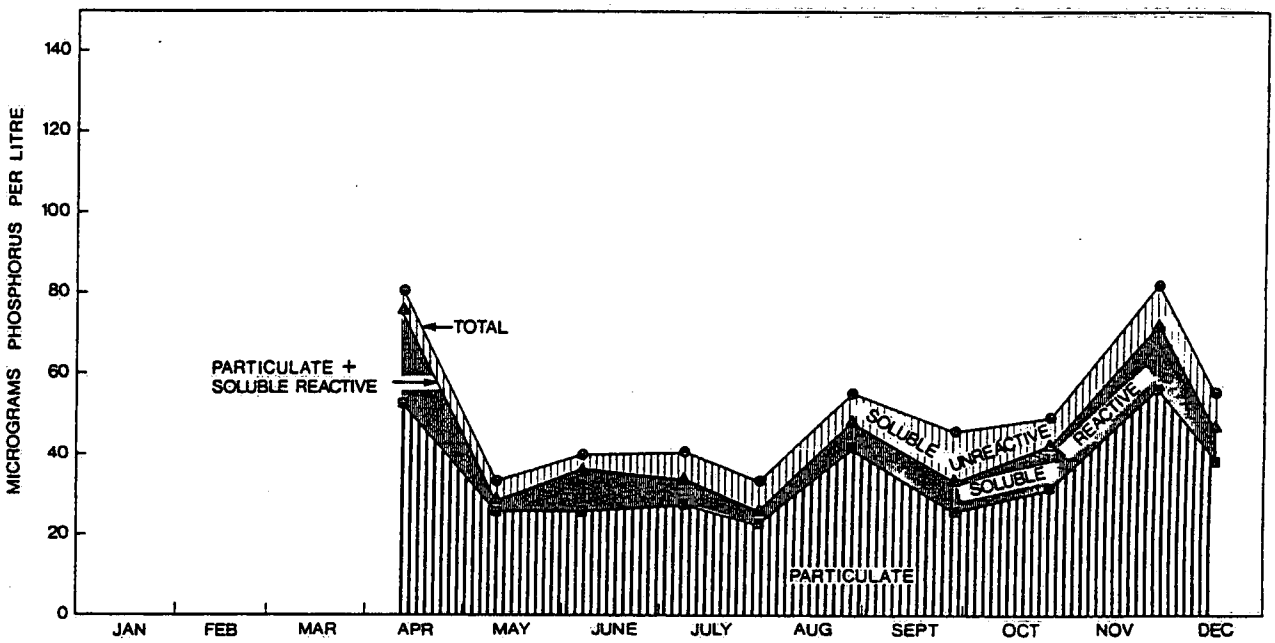
LAKE ERIE: MEAN VALUES OF PHOSPHORUS FRACTIONS FOR SURFACE WATERS IN THE THREE BASINS DURING THE ICE-FREE PERIOD APRIL TO DECEMBER 1970.



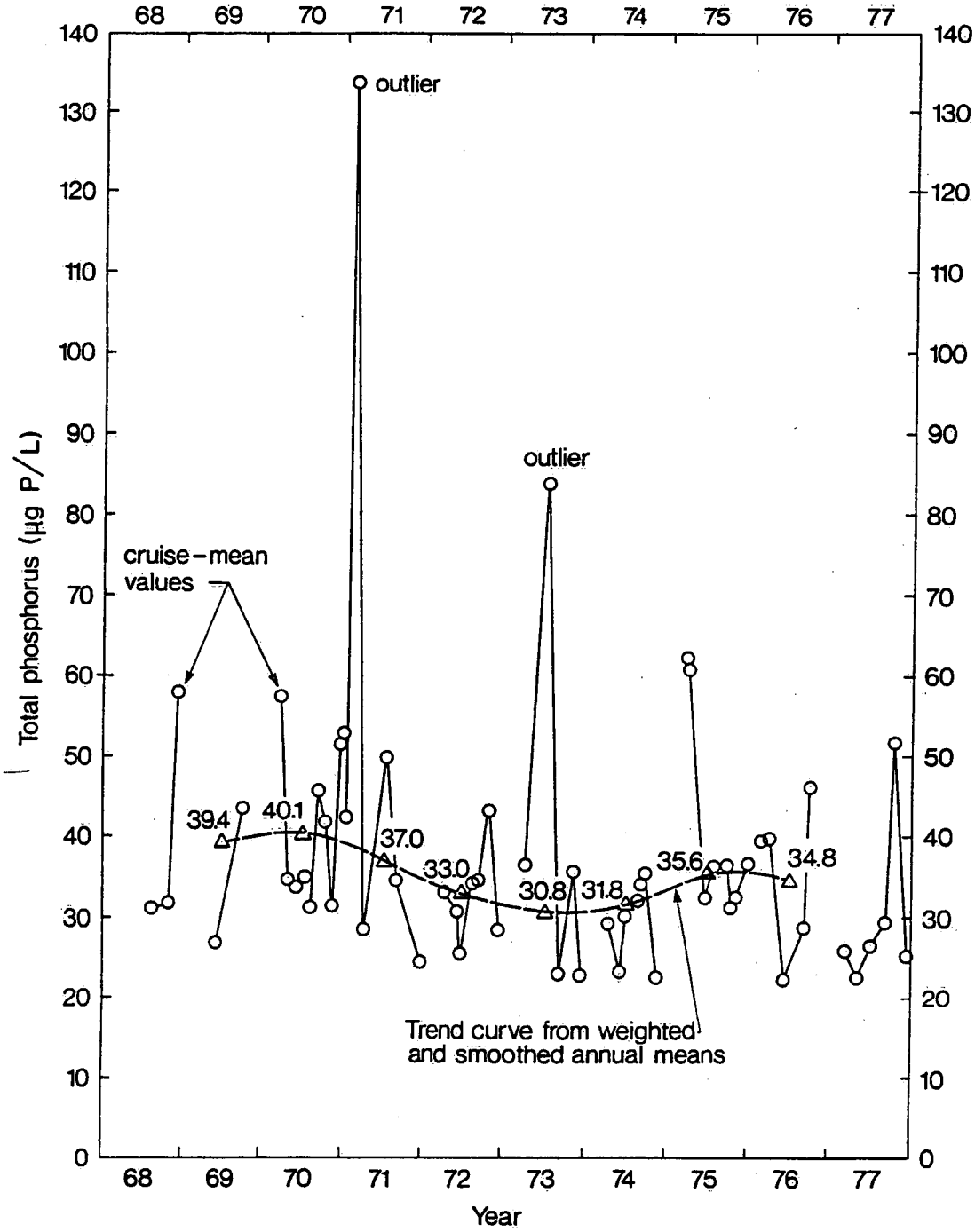
WESTERN LAKE ERIE: UNWEIGHTED MEAN DISSOLVED ORGANIC PHOSPHATE CONCENTRATIONS AT A DEPTH OF 1 METRE, FROM CRUISES OF THE CANADA CENTRE FOR INLAND WATERS IN THE YEARS 1970 AND 1971. UNITS ARE MICROGRAMS PHOSPHORUS PER LITRE.



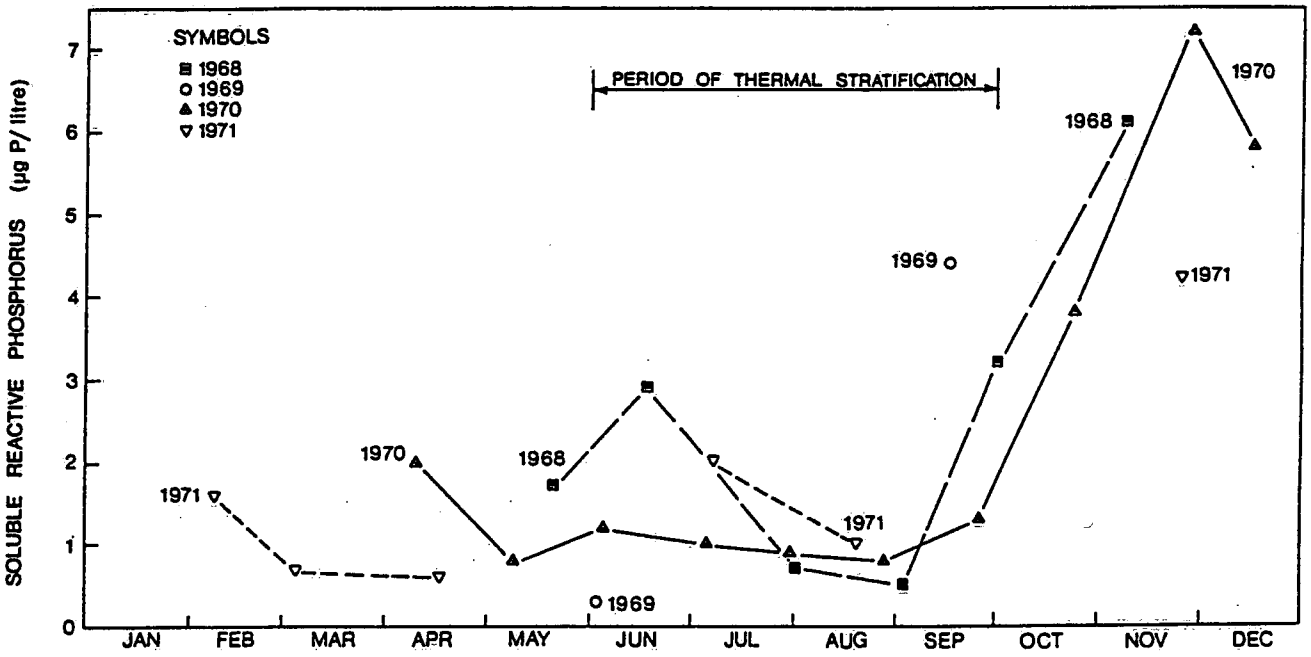
WESTERN LAKE ERIE: UNWEIGHTED MEAN PARTICULATE PHOSPHATE CONCENTRATIONS AT A DEPTH OF 1 METRE, FROM CRUISES OF THE CANADA CENTRE FOR INLAND WATERS IN THE YEARS 1970 AND 1971. UNITS ARE MICROGRAMS PHOSPHORUS PER LITRE.



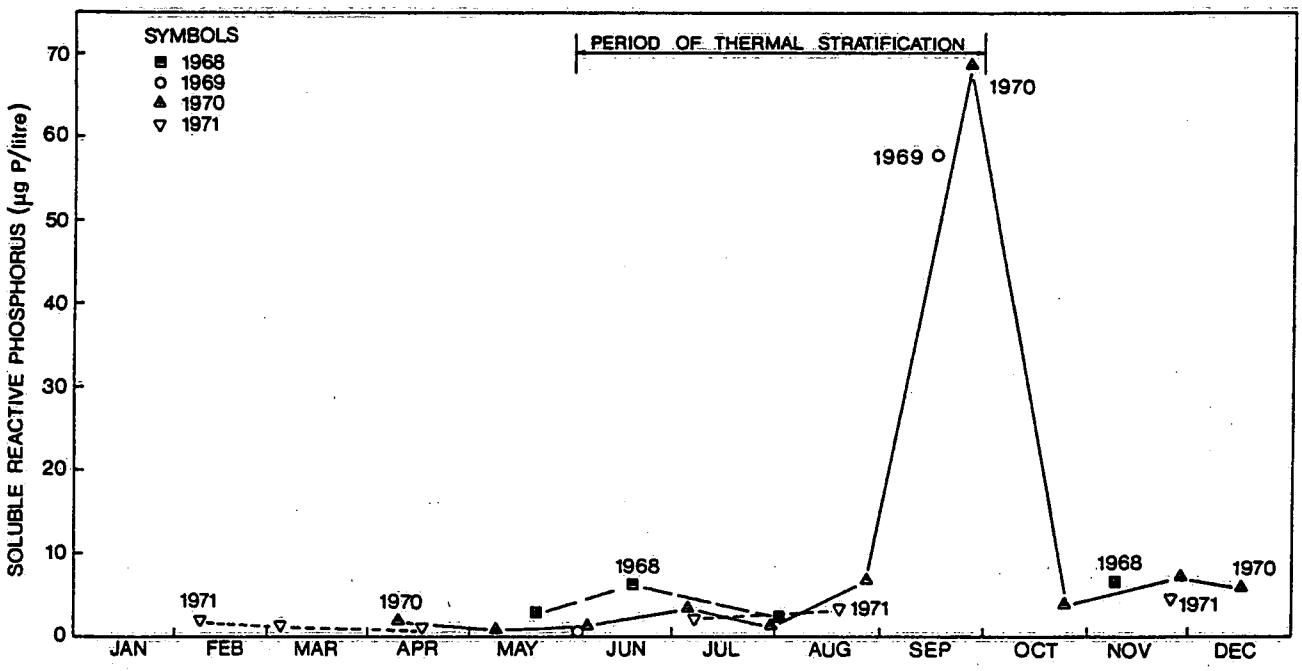
WESTERN LAKE ERIE: UNWEIGHTED MEAN VALUES FOR THE VARIOUS PHOSPHORUS FRACTIONS AT A DEPTH OF 1 METRE, FROM CRUISES OF THE MARTIN KARLSEN DURING 1970.



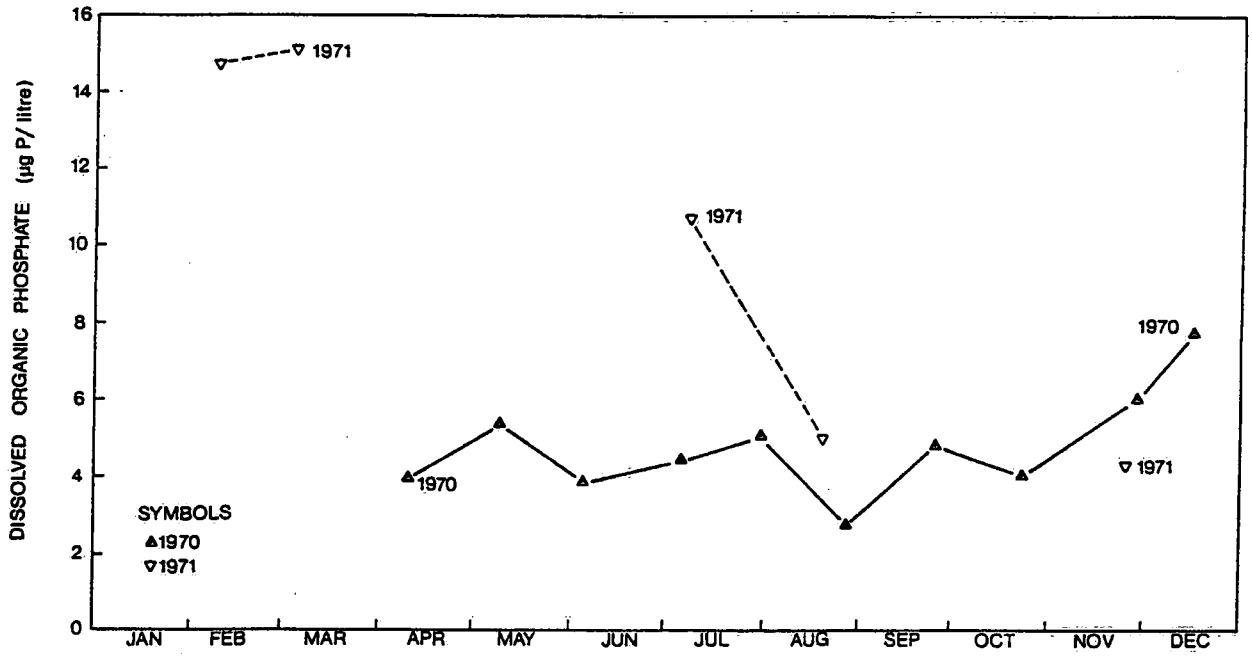
Total phosphorus in Western Lake Erie, offshore surface waters, CCIW & US data, cruise-mean values 1968 to 1977, and smoothed annual mean values 1969 to 1976



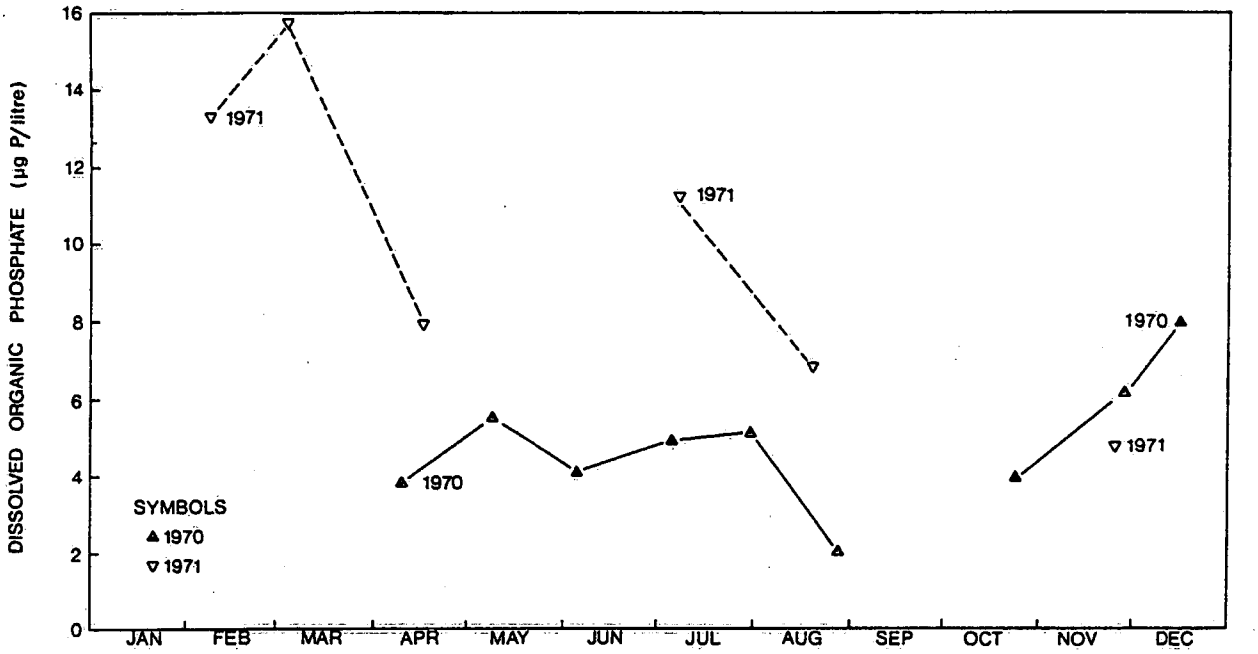
CENTRAL LAKE ERIE: UNWEIGHTED MEAN SOLUBLE REACTIVE PHOSPHORUS CONCENTRATIONS AT A DEPTH OF 1 METRE, FROM CRUISES OF THE CANADA CENTRE FOR INLAND WATERS IN THE YEARS 1968 TO 1971.



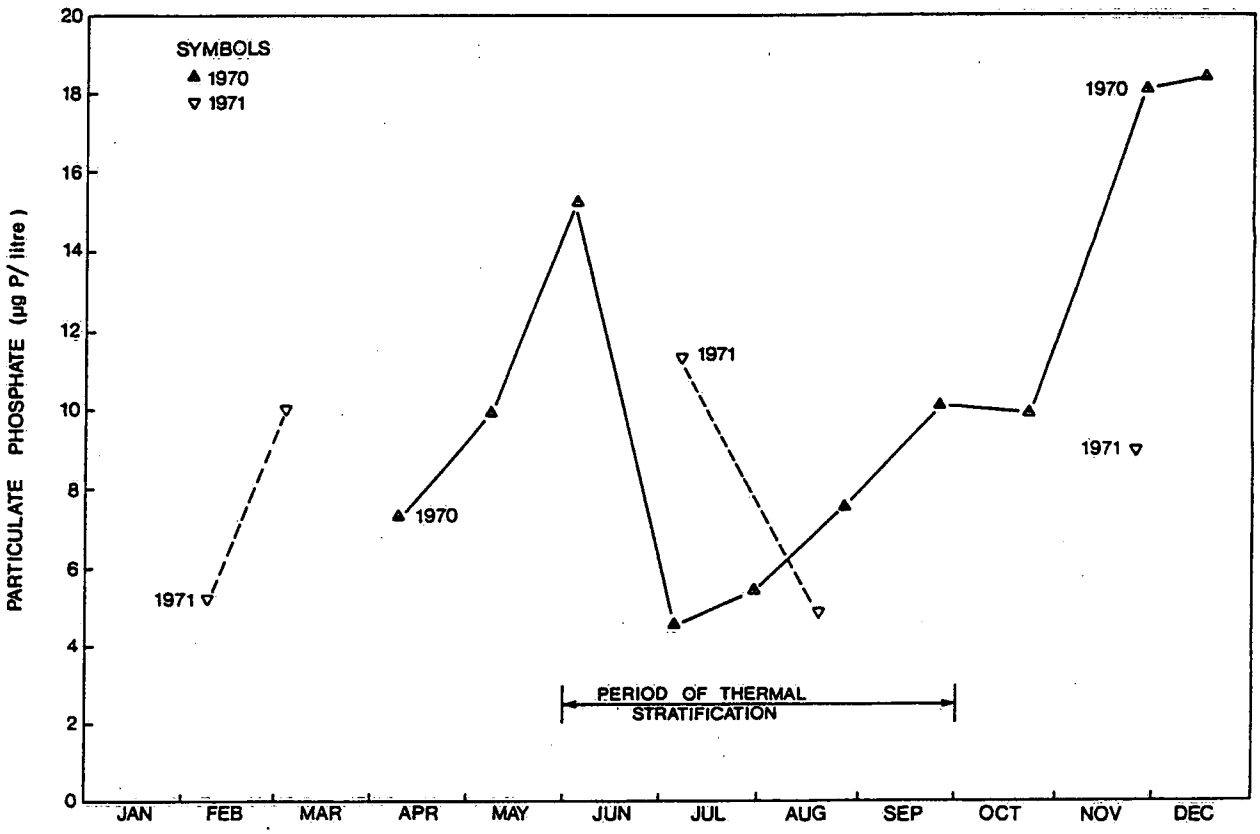
CENTRAL LAKE ERIE: UNWEIGHTED MEAN SOLUBLE REACTIVE PHOSPHORUS CONCENTRATIONS IN THE COLD BOTTOM-WATERS, FROM CCIW CRUISES, 1968 TO 1971.



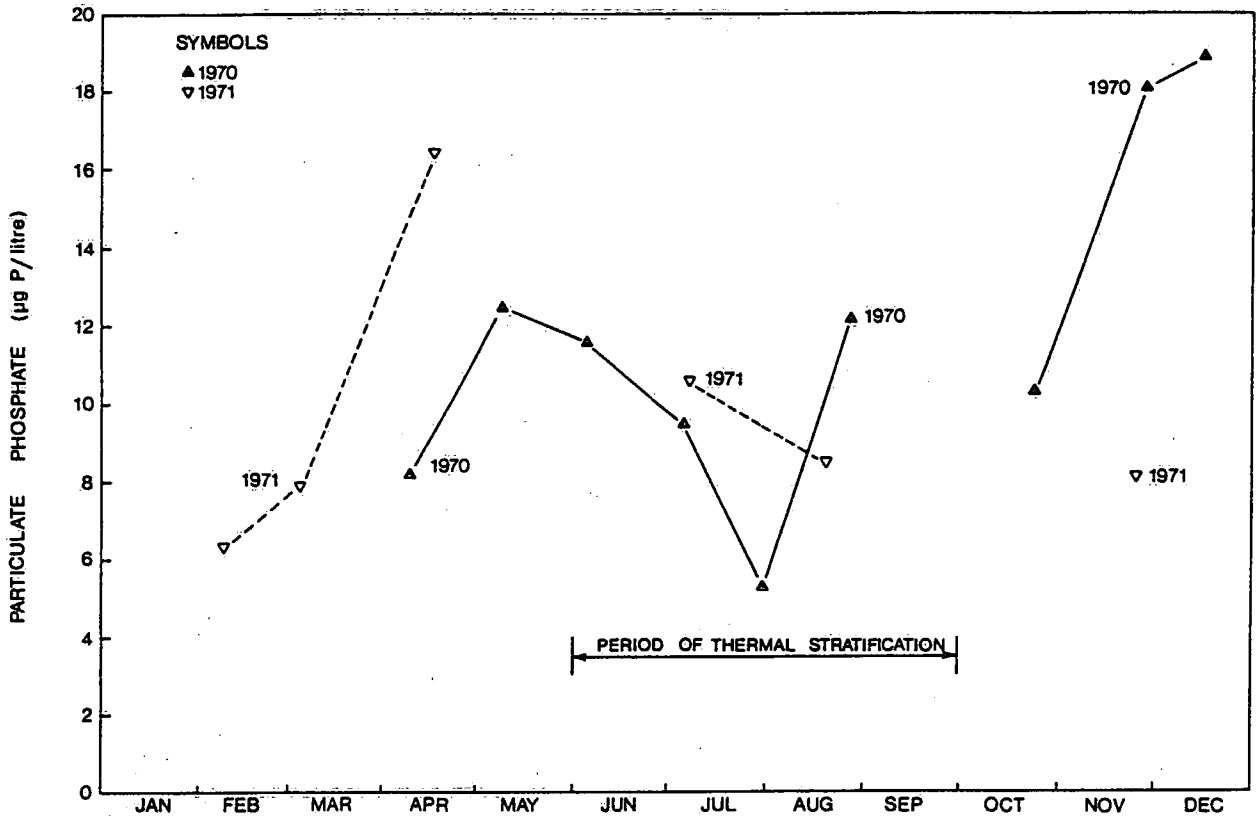
CENTRAL LAKE ERIE: UNWEIGHTED MEAN DISSOLVED ORGANIC PHOSPHATE CONCENTRATIONS AT A DEPTH OF 1 METRE, FROM CRUISES OF THE CANADA CENTRE FOR INLAND WATERS IN THE YEARS 1970 AND 1971. UNITS ARE MICROGRAMS PHOSPHORUS PER LITRE.



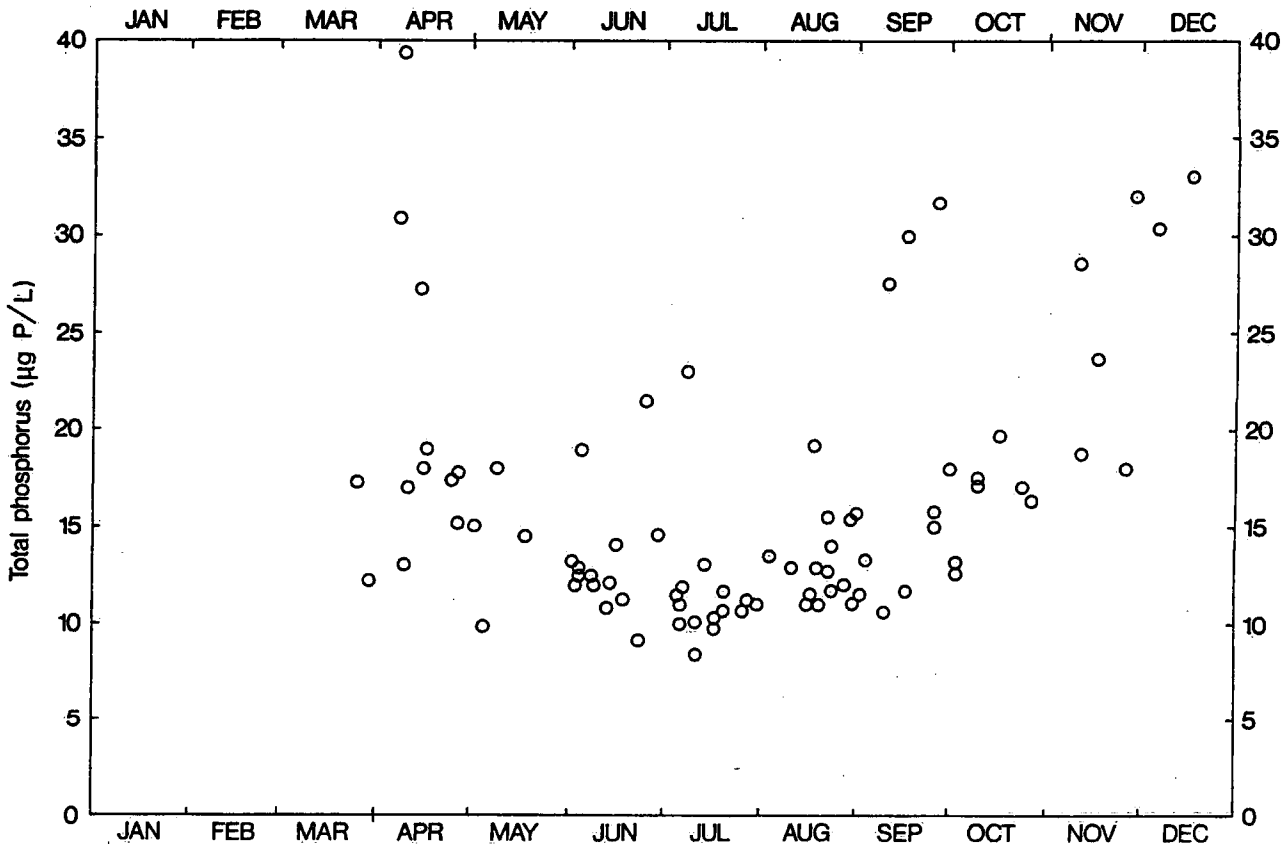
CENTRAL LAKE ERIE: UNWEIGHTED MEAN DISSOLVED ORGANIC PHOSPHATE CONCENTRATIONS IN THE COLD BOTTOM-WATERS, FROM CRUISES OF THE CANADA CENTRE FOR INLAND WATERS IN THE YEARS 1970 AND 1971. UNITS ARE MICROGRAMS PHOSPHORUS PER LITRE.



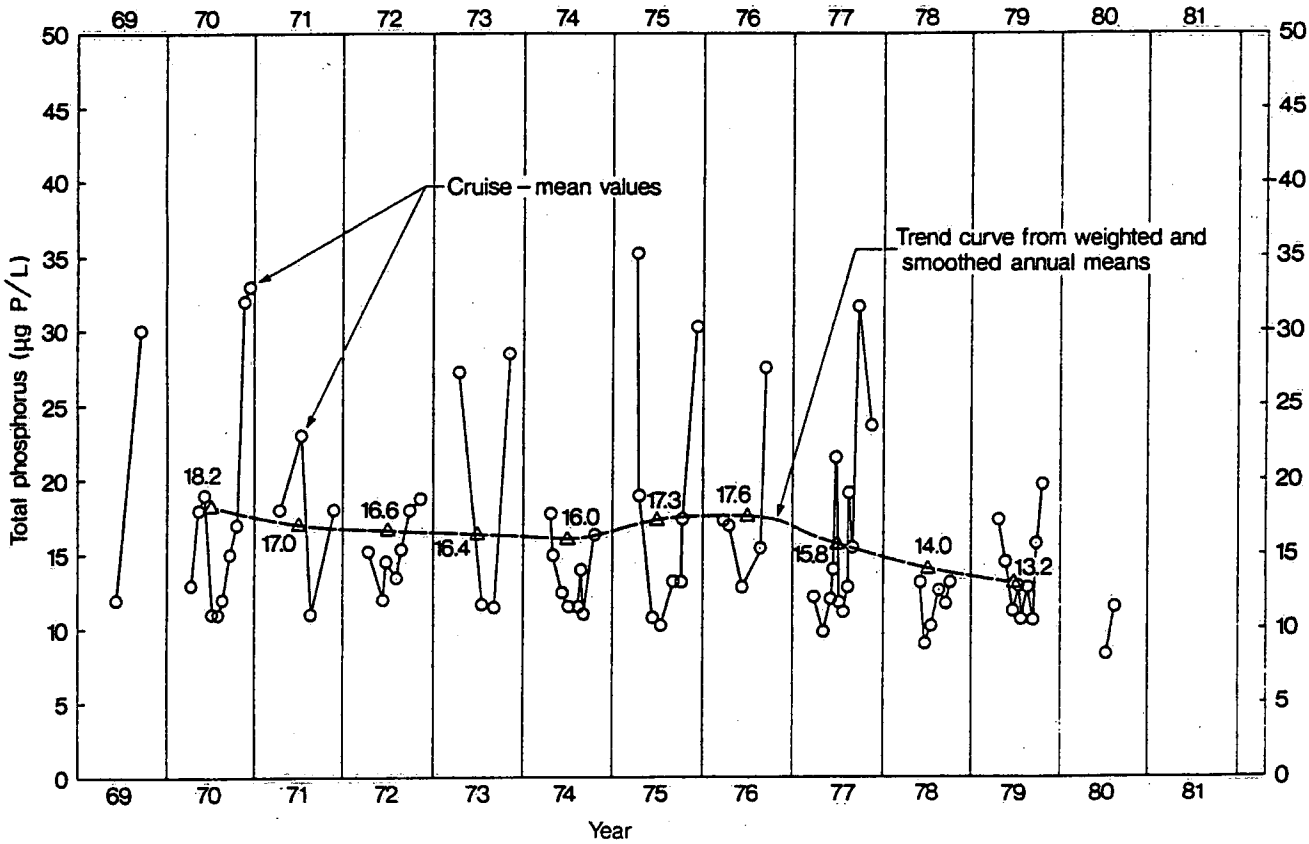
CENTRAL LAKE ERIE: UNWEIGHTED MEAN PARTICULATE PHOSPHATE CONCENTRATIONS AT A DEPTH OF 1 METRE, FROM CRUISES OF THE CANADA CENTRE FOR INLAND WATERS IN THE YEARS 1970 AND 1971. UNITS ARE MICROGRAMS PHOSPHORUS PER LITRE.



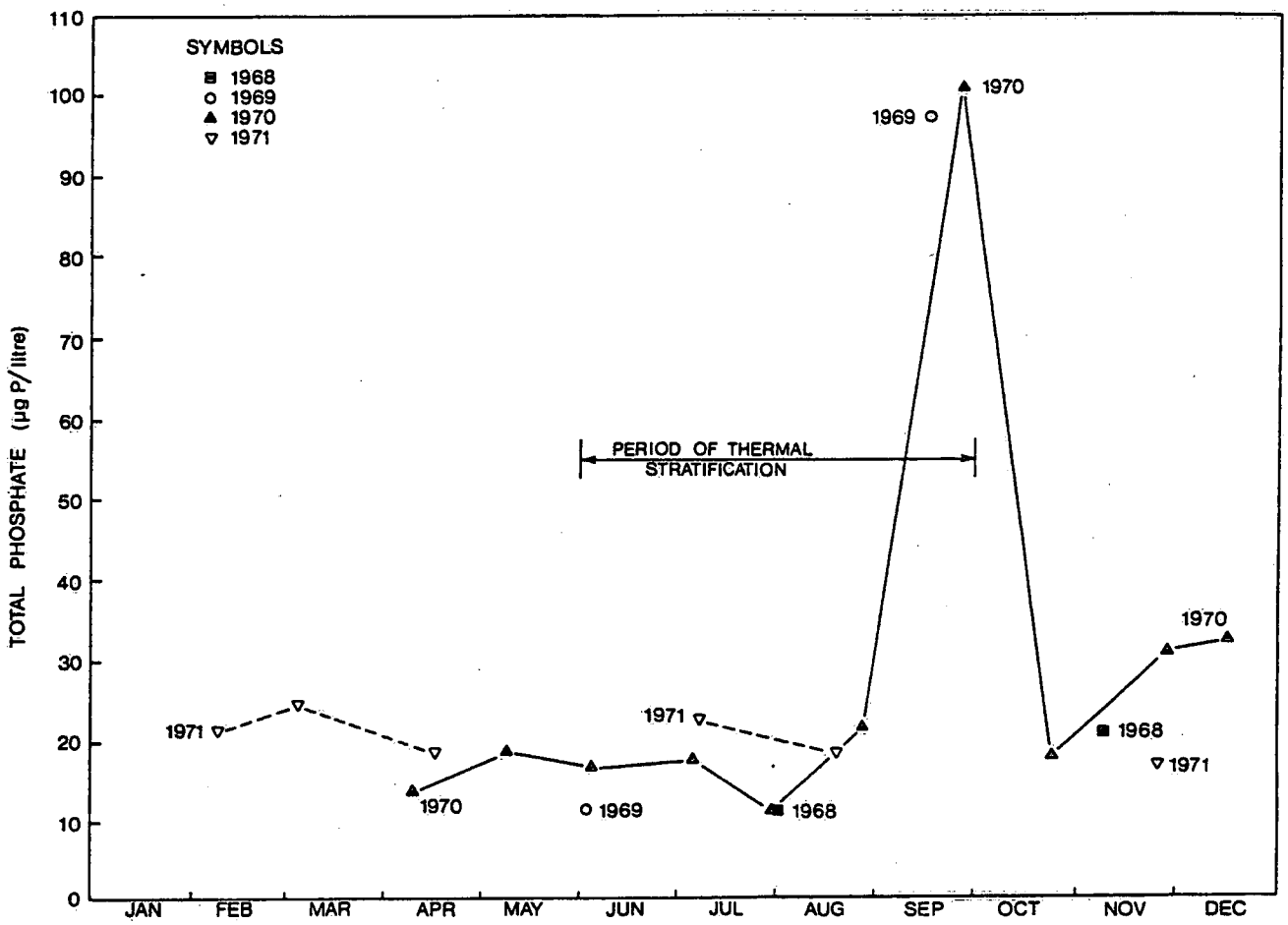
CENTRAL LAKE ERIE: UNWEIGHTED MEAN PARTICULATE PHOSPHATE CONCENTRATIONS IN THE COLD BOTTOM-WATERS, FROM CRUISES OF THE CANADA CENTRE FOR INLAND WATERS IN THE YEARS 1970 AND 1971. UNITS ARE MICROGRAMS PHOSPHORUS PER LITRE.



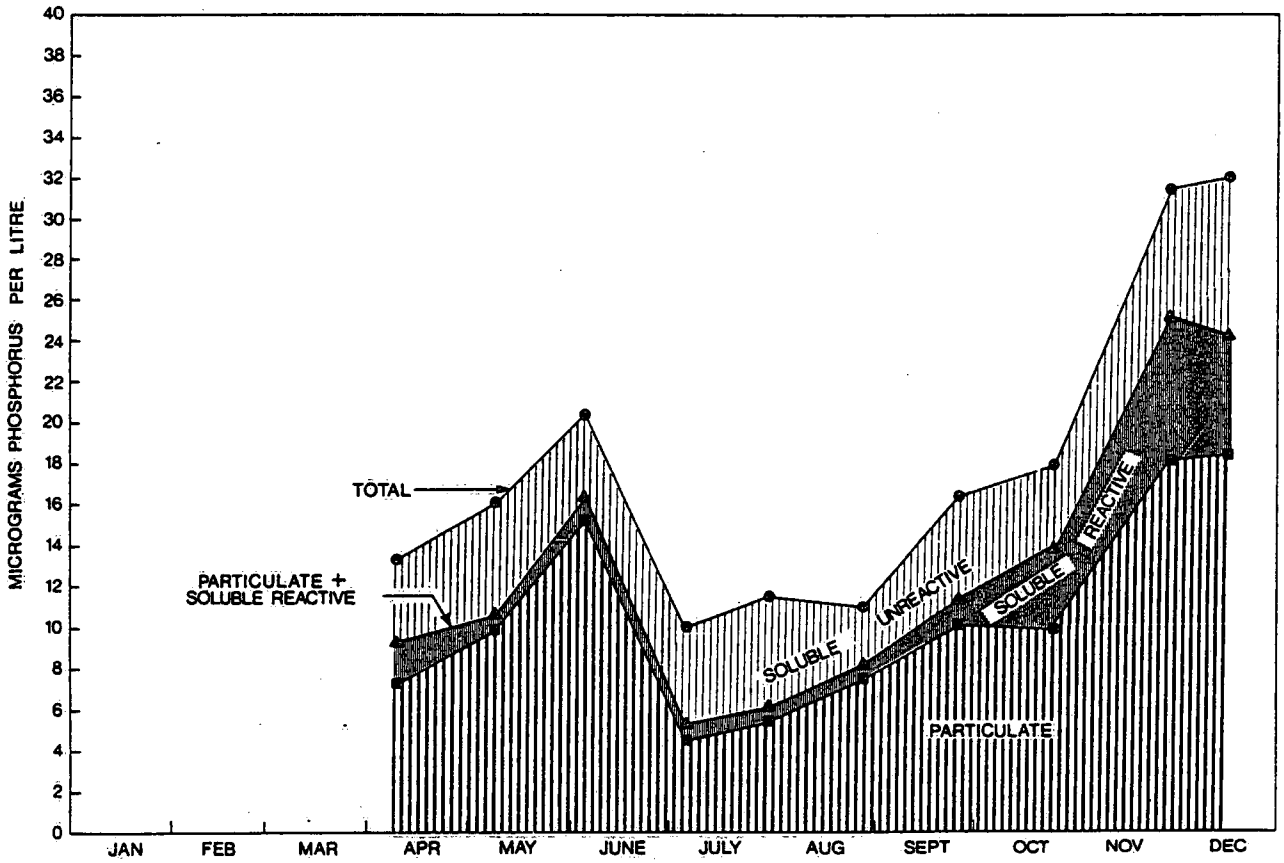
Total phosphorus in Central Lake Erie: cruise-mean values in the offshore surface waters, versus time of year, 1969 to 1980, Canadian and U.S. data.



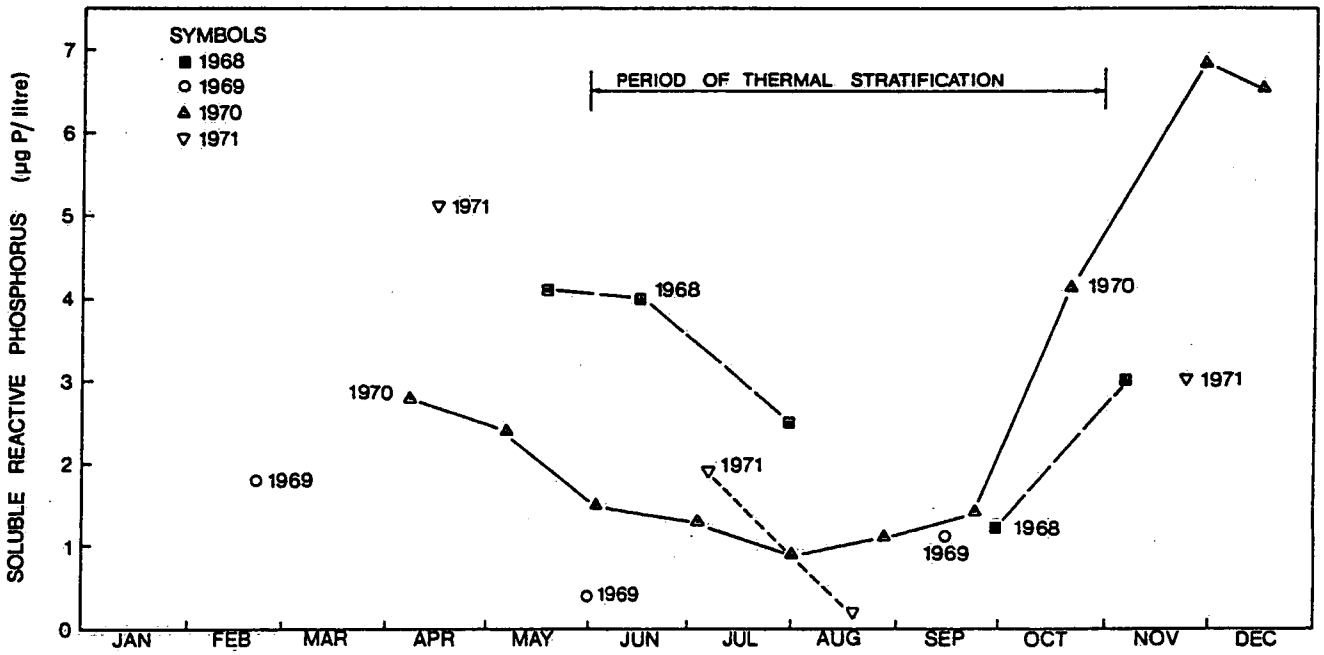
Total phosphorus in Central Lake Erie, offshore surface waters, CCIW & U.S. data, cruise–mean values 1969 to 1980, and smoothed annual mean values 1970 to 1979



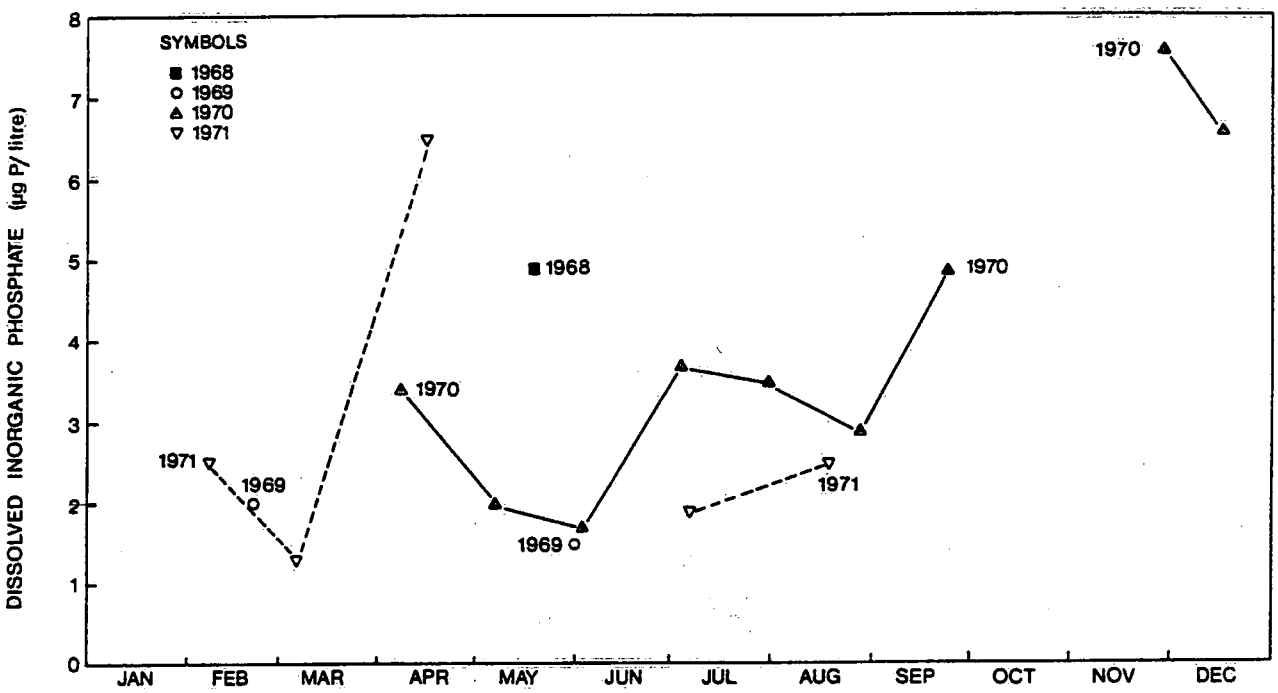
CENTRAL LAKE ERIE: UNWEIGHTED MEAN TOTAL PHOSPHATE CONCENTRATIONS IN THE COLD BOTTOM-WATERS, FROM CRUISES OF THE CANADA CENTRE FOR INLAND WATERS IN THE YEARS 1968 TO 1971. UNITS ARE MICROGRAMS PHOSPHORUS PER LITRE.



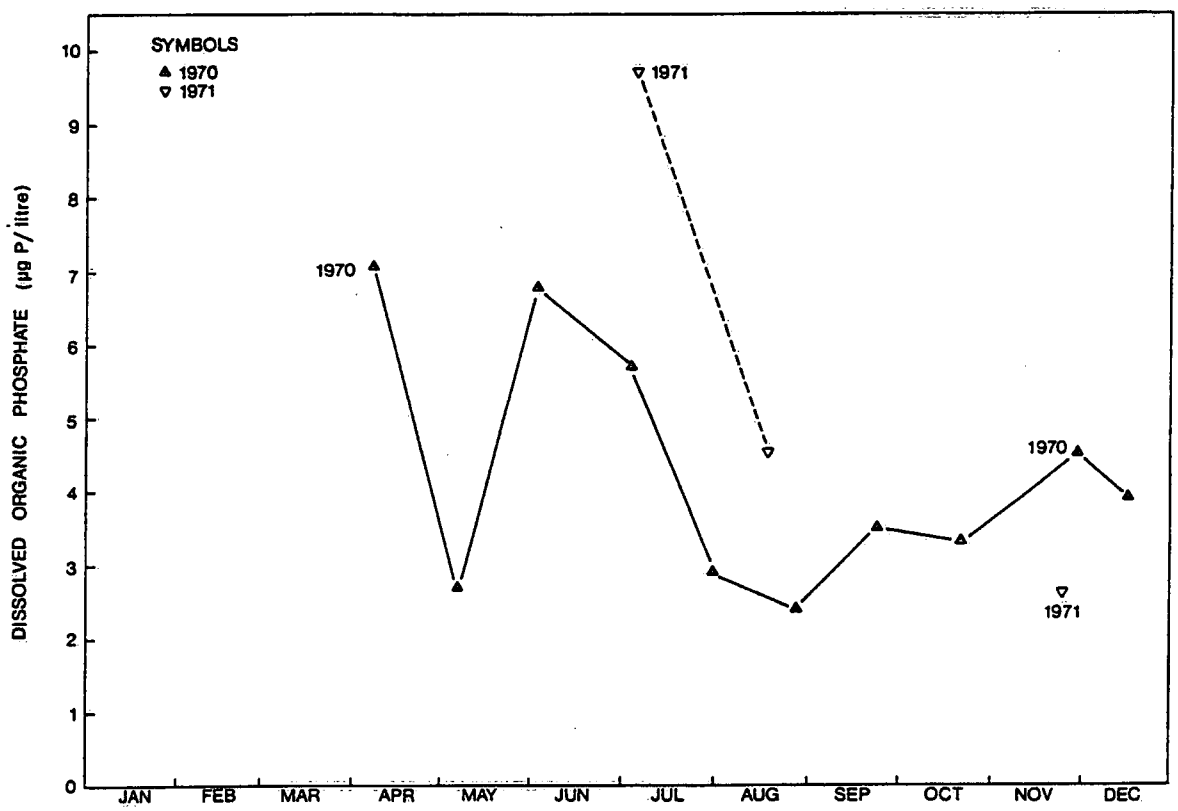
CENTRAL LAKE ERIE, OFFSHORE PART WHERE THE SOUNDING IS >18 METRES: UNWEIGHTED MEAN VALUES FOR THE VARIOUS PHOSPHORUS FRACTIONS AT A DEPTH OF 1 METRE, FROM CRUISES OF THE MARTIN KARLSEN DURING 1970.



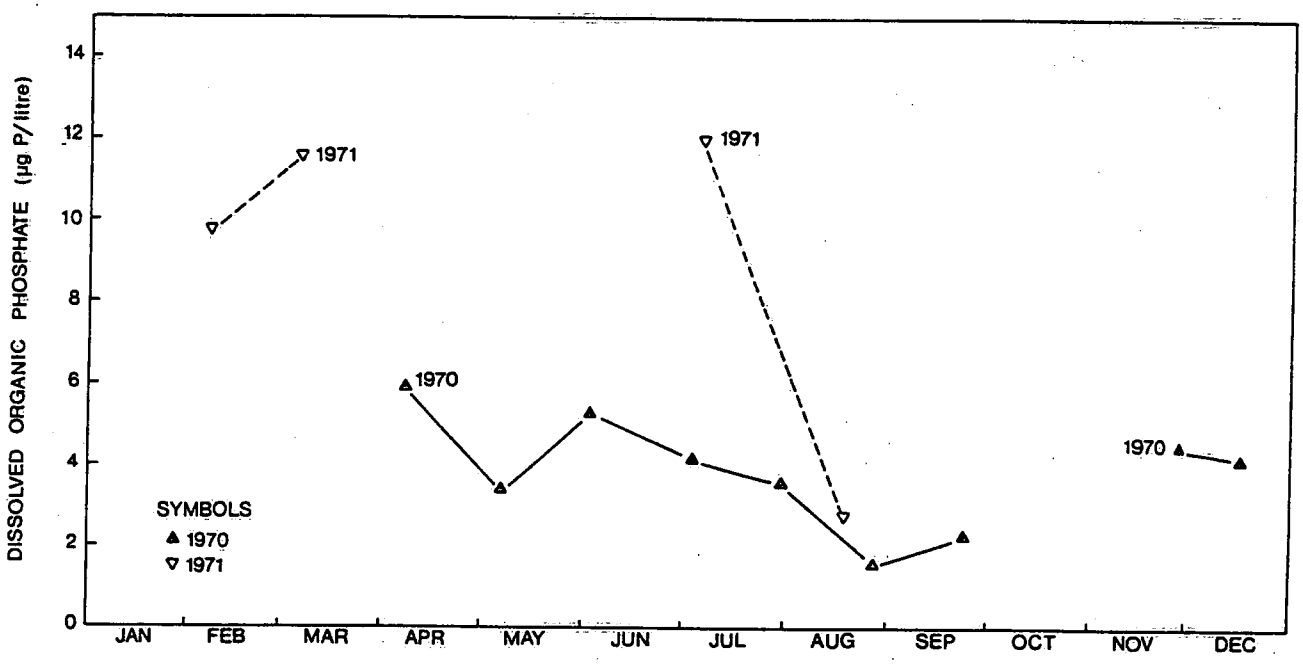
EASTERN LAKE ERIE: UNWEIGHTED MEAN SOLUBLE REACTIVE PHOSPHORUS CONCENTRATIONS AT A DEPTH OF 1 METRE, FROM CRUISES OF THE CANADA CENTRE FOR INLAND WATERS IN THE YEARS 1968 TO 1971.



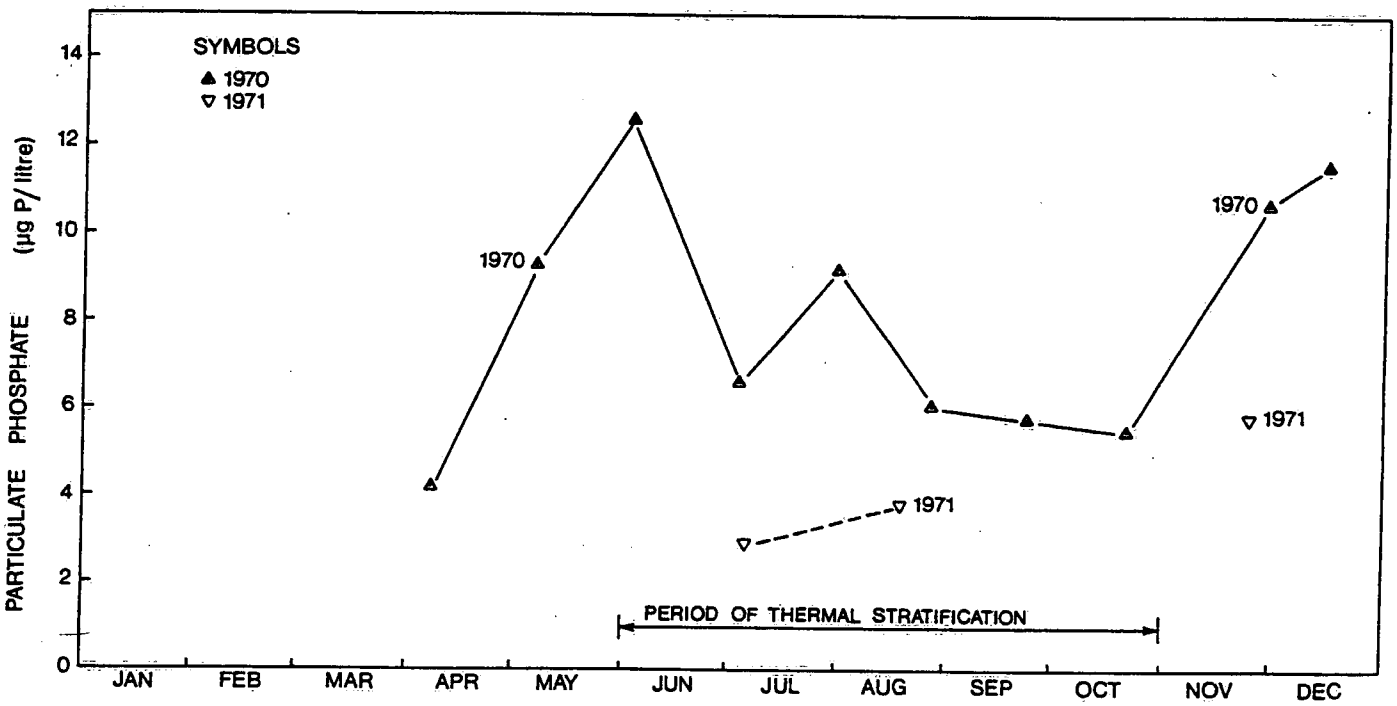
EASTERN LAKE ERIE: UNWEIGHTED MEAN DISSOLVED INORGANIC PHOSPHATE CONCENTRATIONS IN THE COLD BOTTOM - WATERS (TEMPERATURE LESS THAN 8°C) FROM CRUISES OF THE CANADA CENTRE FOR INLAND WATERS IN THE YEARS 1968 TO 1971. UNITS ARE MICROGRAMS PHOSPHORUS PER LITRE.



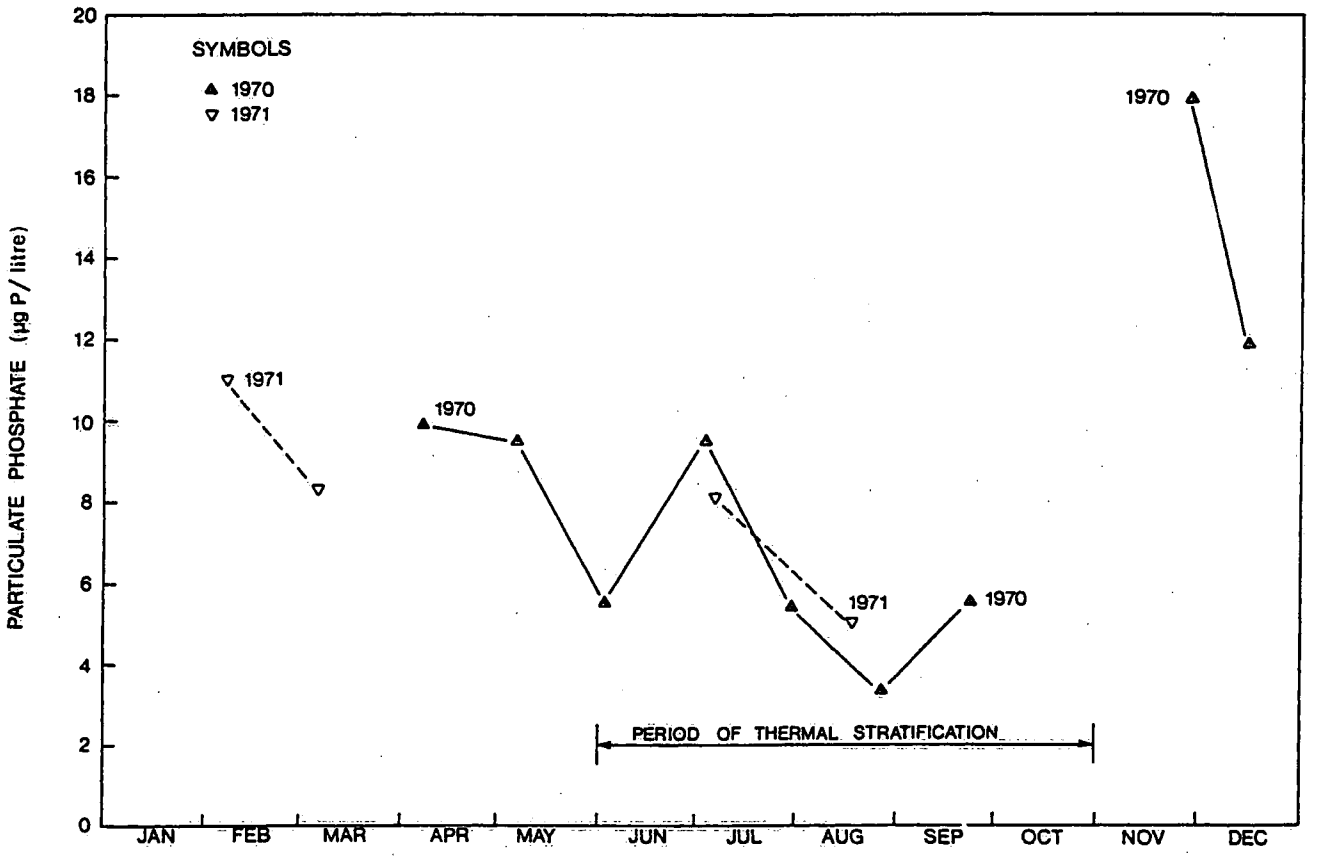
EASTERN LAKE ERIE: UNWEIGHTED MEAN DISSOLVED ORGANIC PHOSPHATE CONCENTRATIONS AT A DEPTH OF 1 METRE, FROM CRUISES OF THE CANADA CENTRE FOR INLAND WATERS IN THE YEARS 1970 AND 1971. UNITS ARE MICROGRAMS PHOSPHORUS PER LITRE.



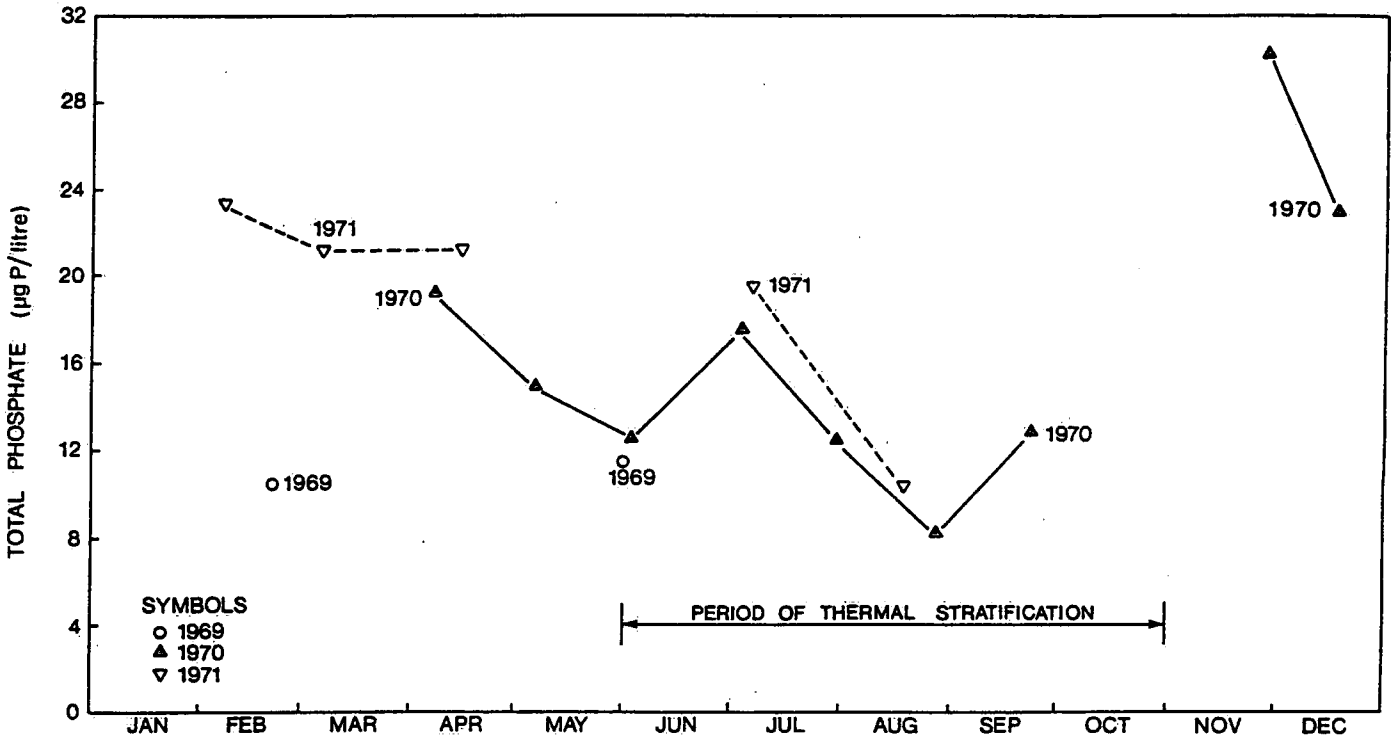
EASTERN LAKE ERIE: UNWEIGHTED MEAN DISSOLVED ORGANIC PHOSPHATE CONCENTRATIONS IN THE COLD BOTTOM - WATERS (TEMPERATURE LESS THAN 8°C), FROM CRUISES OF THE CANADA CENTRE FOR INLAND WATERS IN THE YEARS 1970 AND 1971. UNITS ARE MICROGRAMS PHOSPHORUS PER LITRE.



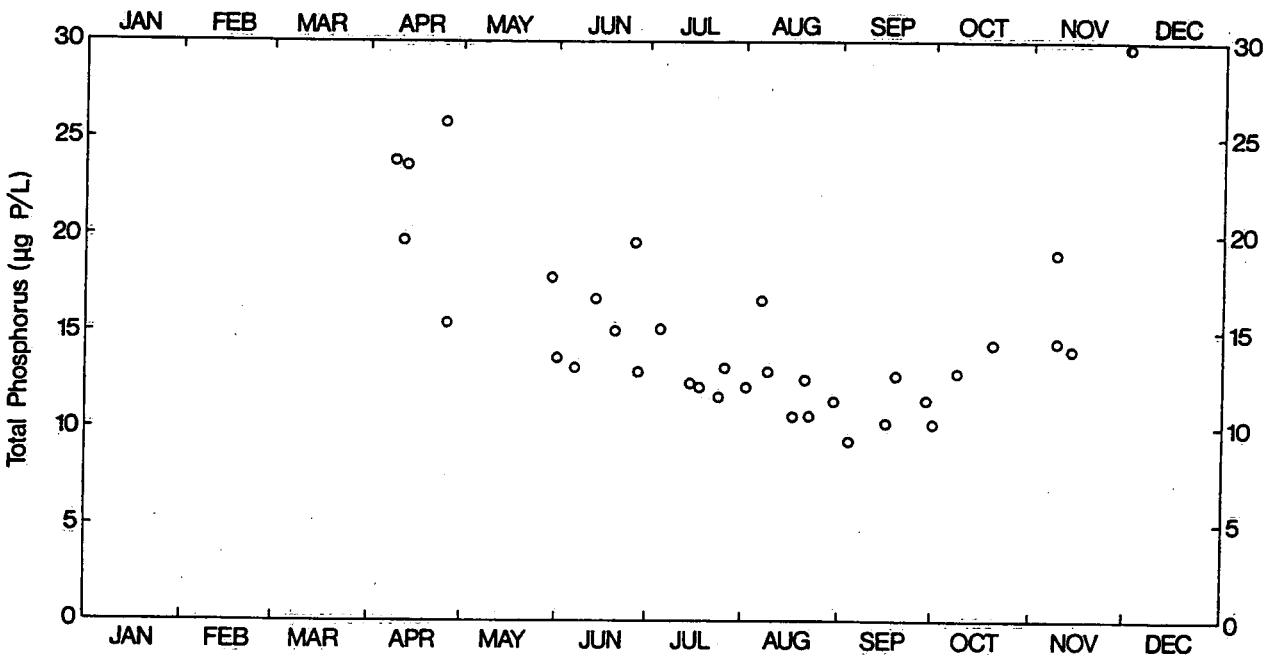
EASTERN LAKE ERIE: UNWEIGHTED MEAN PARTICULATE PHOSPHATE CONCENTRATIONS AT A DEPTH OF 1 METRE, FROM CRUISES OF THE CANADA CENTRE FOR INLAND WATERS IN THE YEARS 1970 AND 1971. UNITS ARE MICROGRAMS PHOSPHORUS PER LITRE.



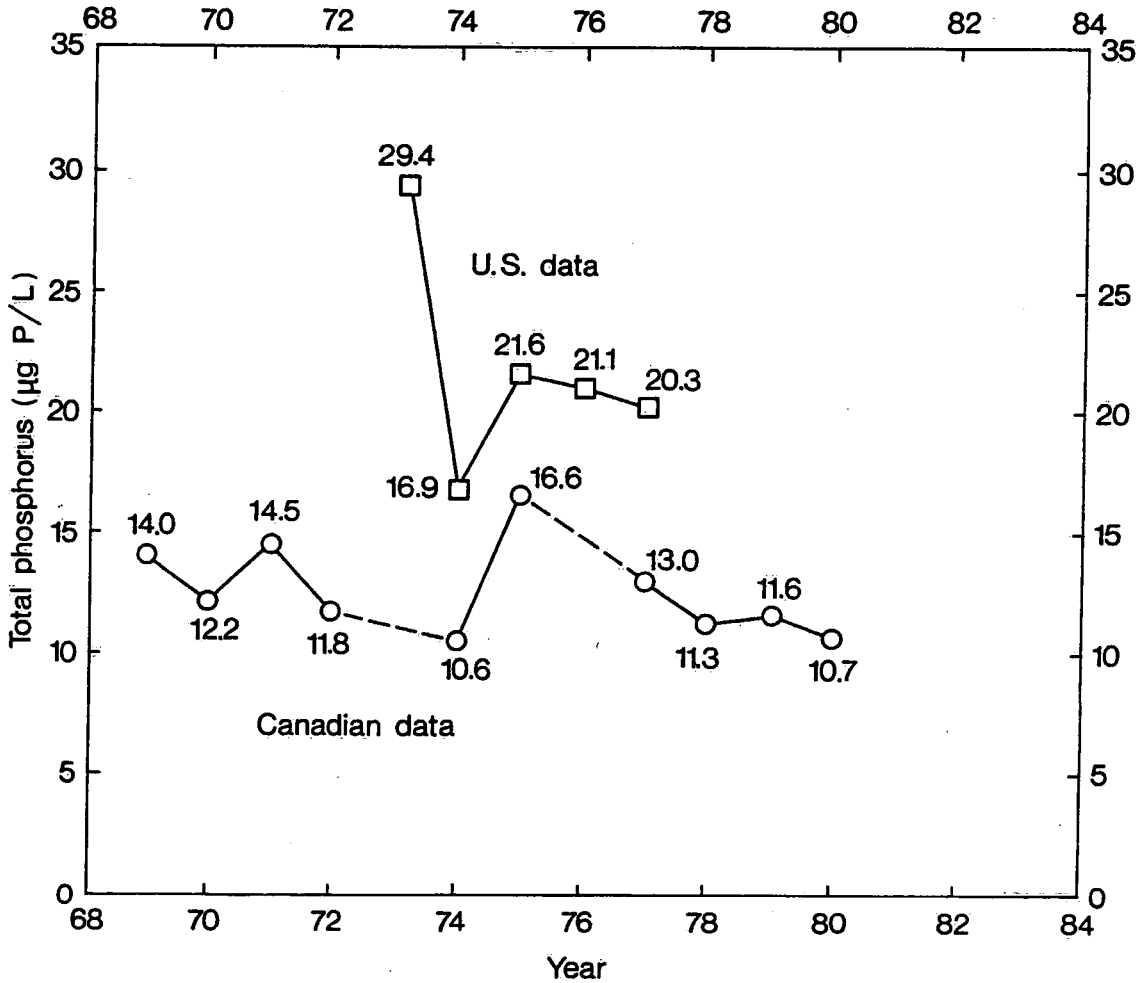
EASTERN LAKE ERIE: UNWEIGHTED MEAN PARTICULATE PHOSPHATE CONCENTRATIONS IN THE COLD BOTTOM-WATERS (TEMPERATURE LESS THAN 8°C) FROM CRUISES OF THE CANADA CENTRE FOR INLAND WATERS IN THE YEARS 1970 AND 1971. UNITS ARE MICROGRAMS PHOSPHORUS PER LITRE.



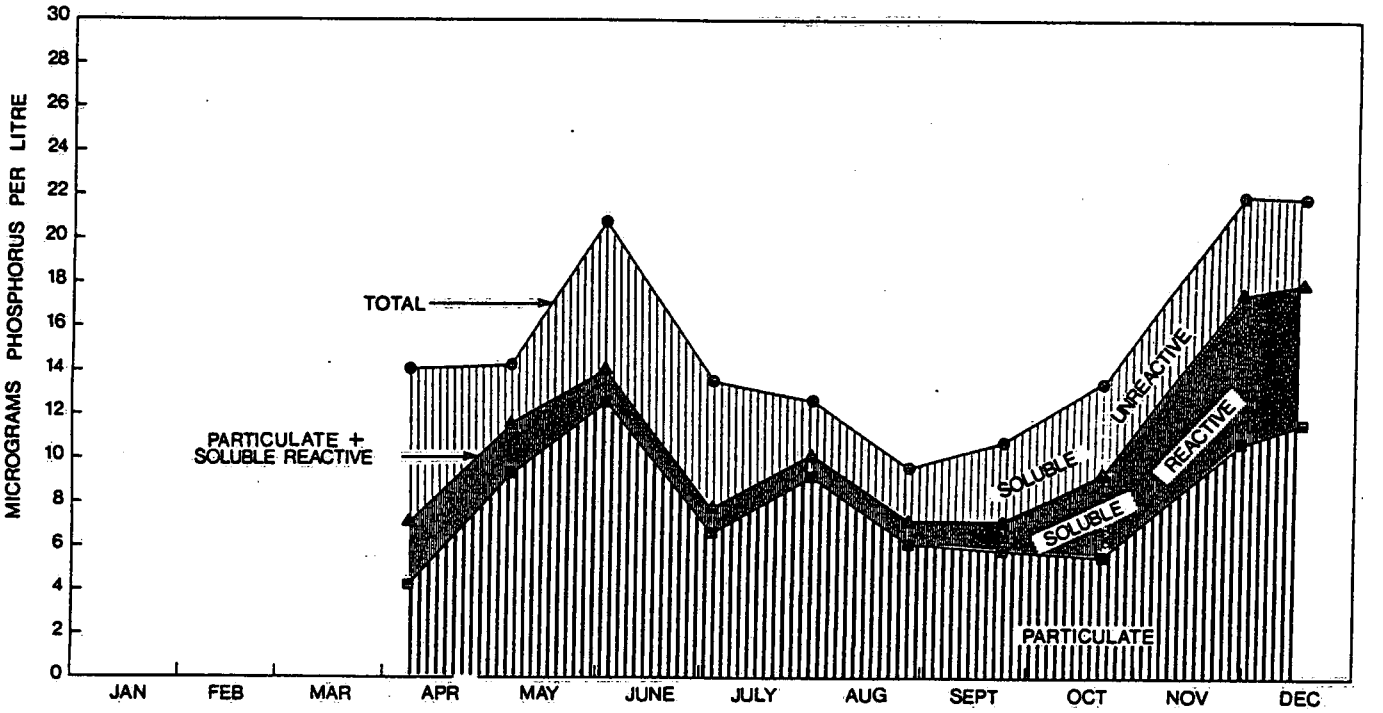
EASTERN LAKE ERIE: UNWEIGHTED MEAN TOTAL PHOSPHATE CONCENTRATIONS IN THE COLD BOTTOM-WATERS (TEMPERATURE LESS THAN 8°C), FROM CRUISES OF THE CANADA CENTRE FOR INLAND WATERS IN THE YEARS 1969 TO 1971. UNITS ARE MICROGRAMS PHOSPHORUS PER LITRE.



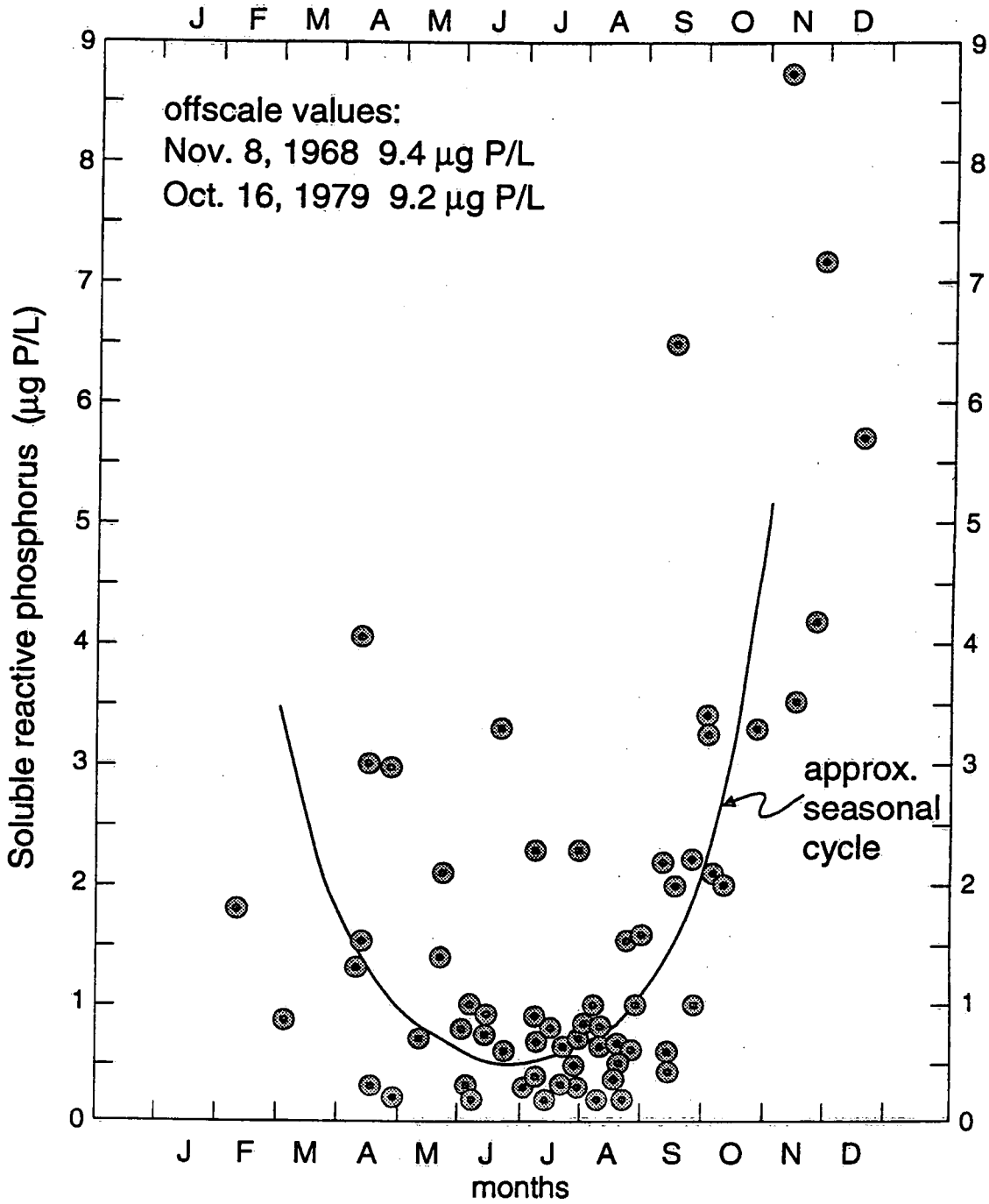
Seasonal cycle of total phosphorus in Eastern Lake Erie: mean values on 35 cruises of CCIW vessels, offshore zone, upper 10 metres, 1972 to 1980.



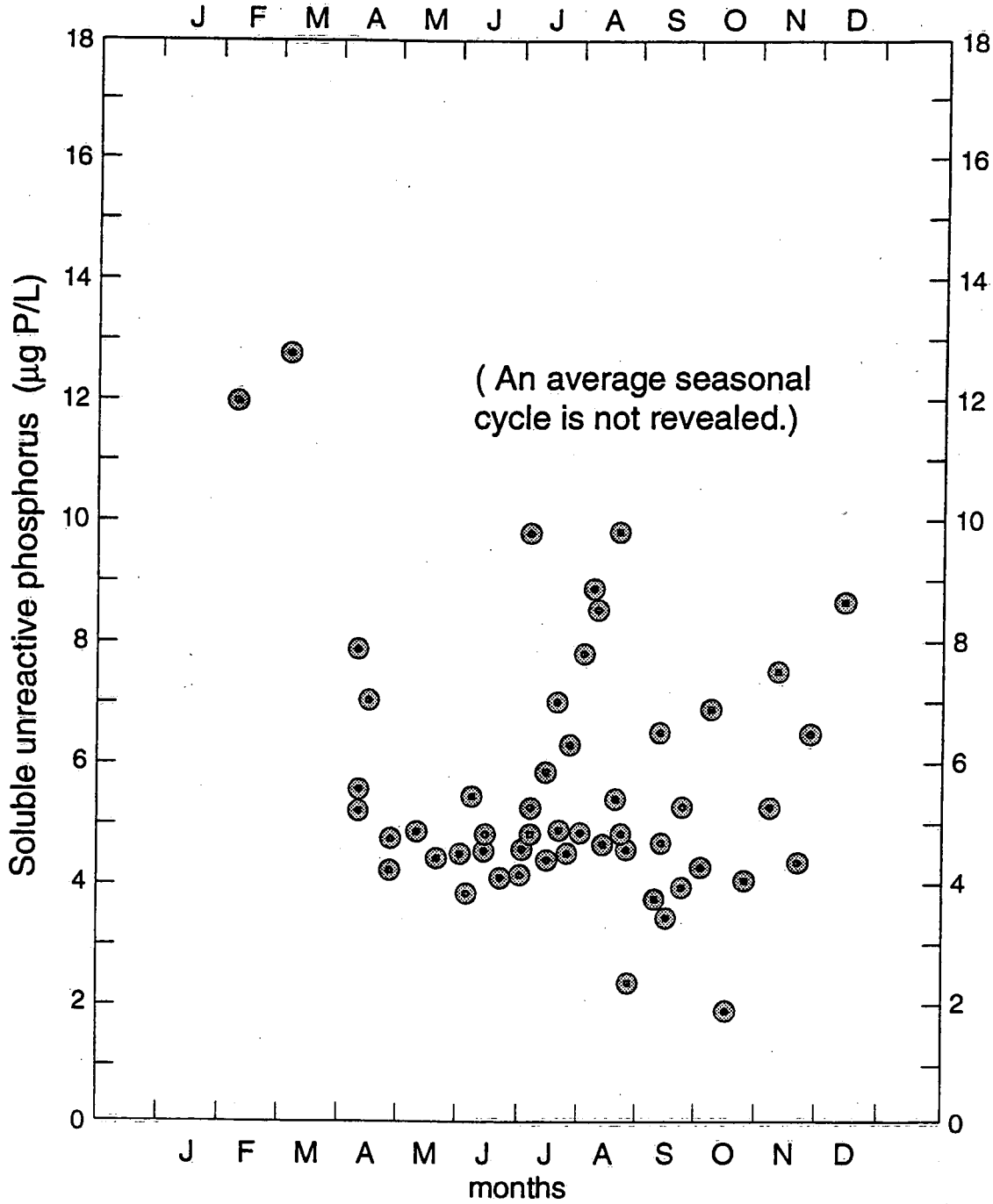
Total phosphorus in Eastern Lake Erie, upper 10 metres, offshore zone, mean values of (July, August, September) 1969 to 1980. Canadian & U.S. data shown separately.



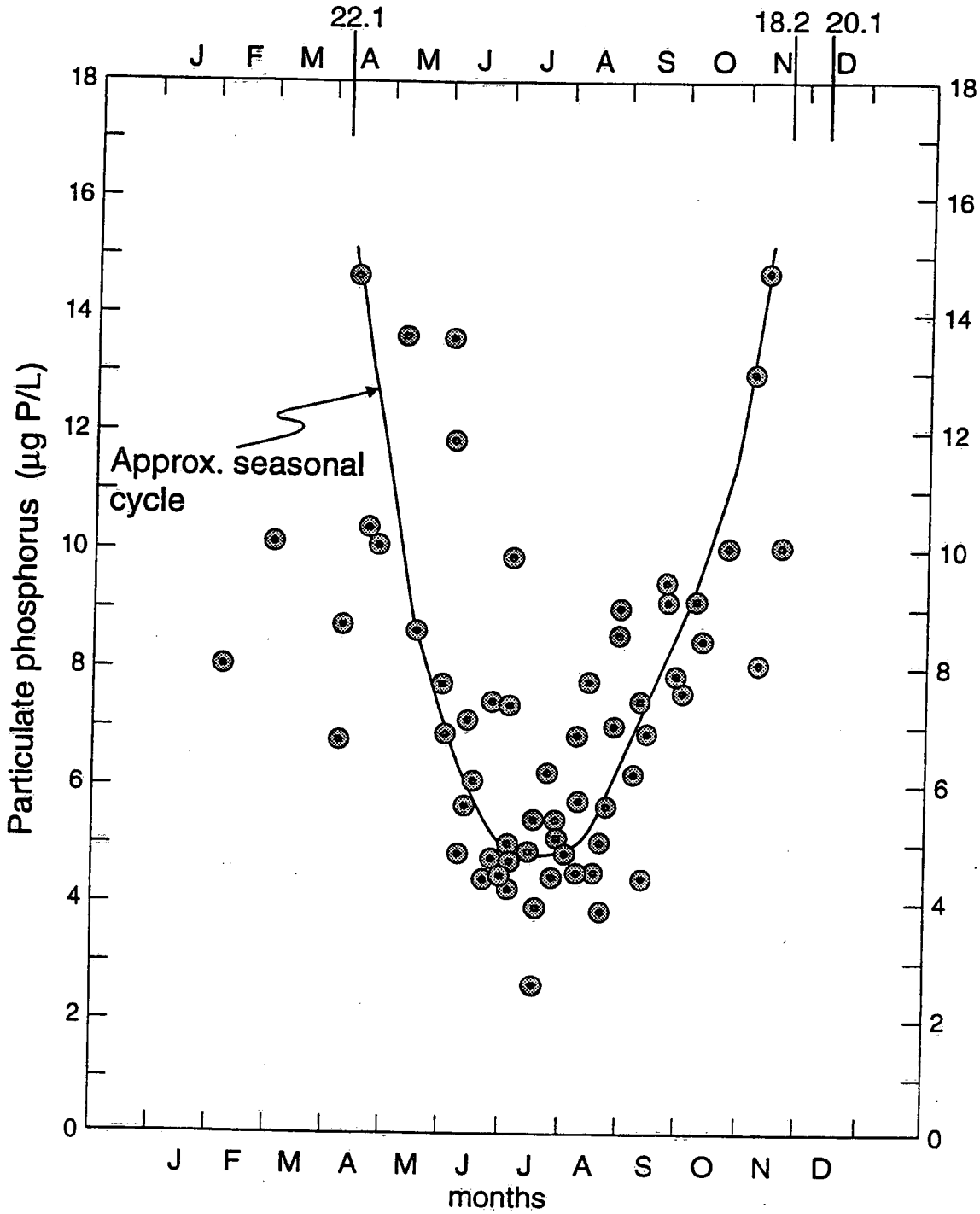
EASTERN LAKE ERIE, OFFSHORE PART WHERE THE SOUNDING IS >18 METRES: UNWEIGHTED MEAN VALUES FOR THE VARIOUS PHOSPHORUS FRACTIONS AT A DEPTH OF 1 METRE, FROM CRUISES OF THE MARTIN KARLSEN DURING 1970.



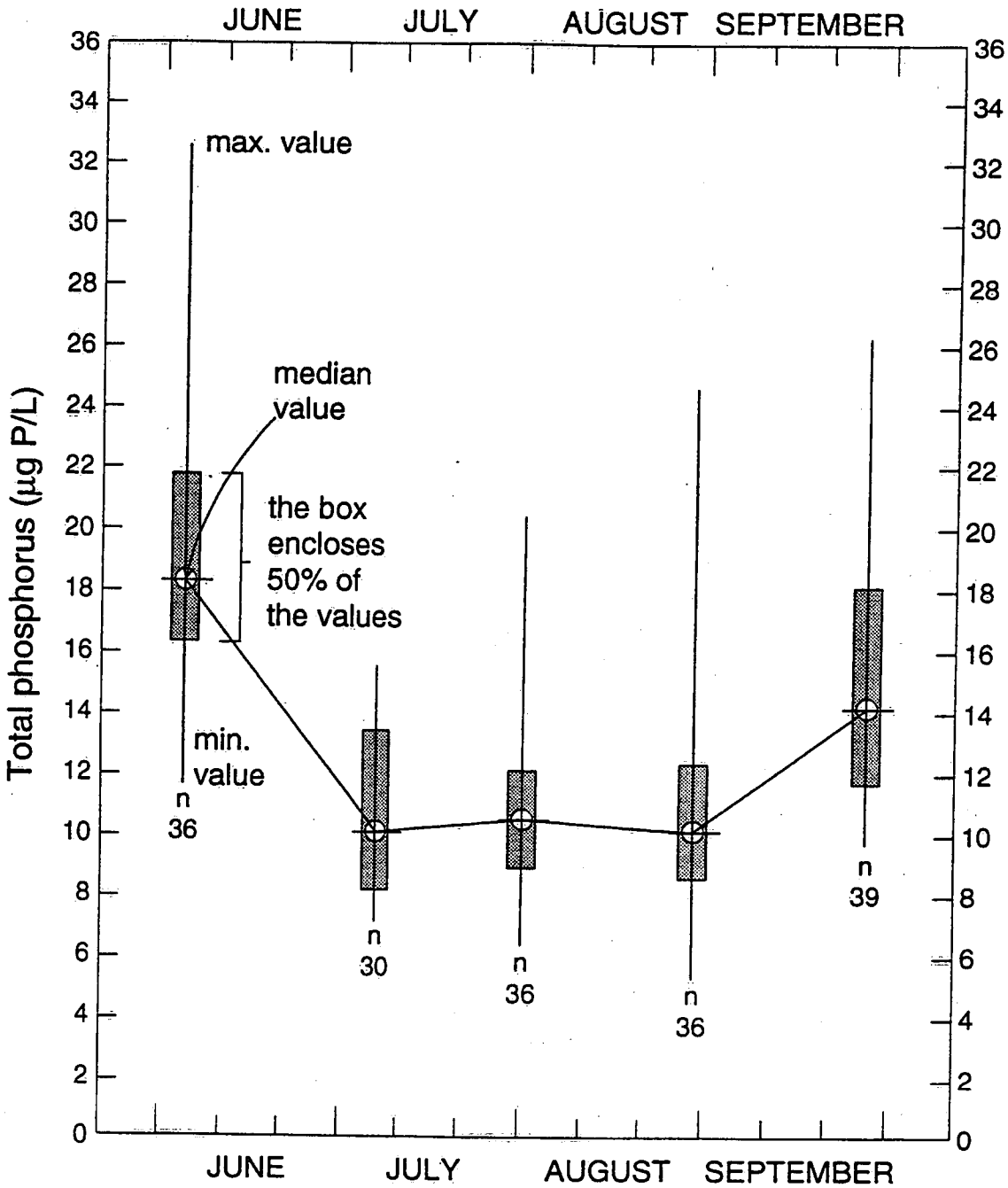
Central Lake Erie, offshore and upper 10m, soluble reactive phosphorus, medians each cruise, 1968 to 1993, plotted vs. time-of-year, Canadian data.



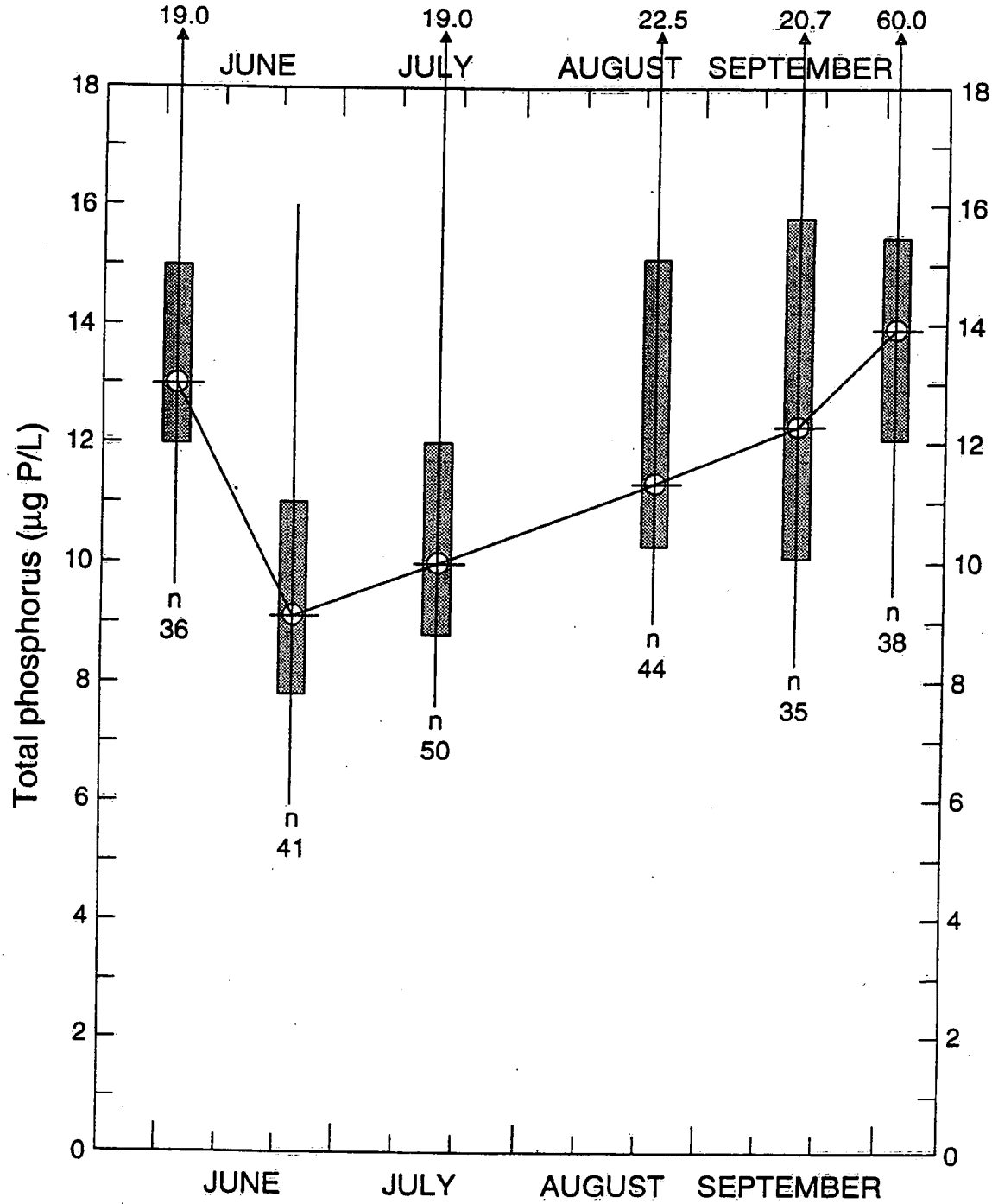
Central Lake Erie, offshore and upper 10m, soluble unreactive phosphorus, 'average' on each cruise, 1970 to 1985, plotted vs. time-of-year, Canadian data.



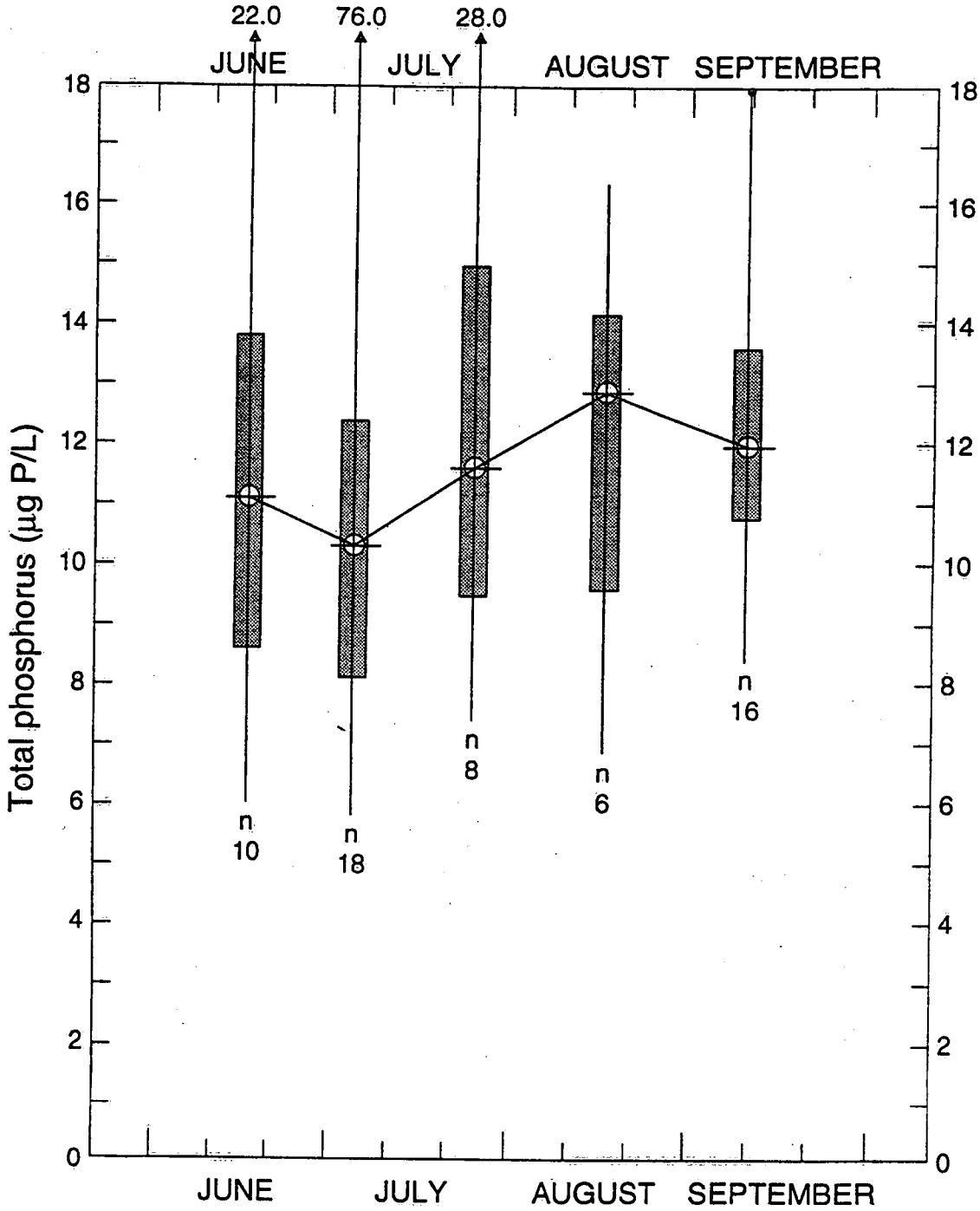
Central Lake Erie, offshore and upper 10m, particulate phosphorus, 'average' on each cruise, 1970 to 1985, plotted vs. time-of-year, Canadian data.



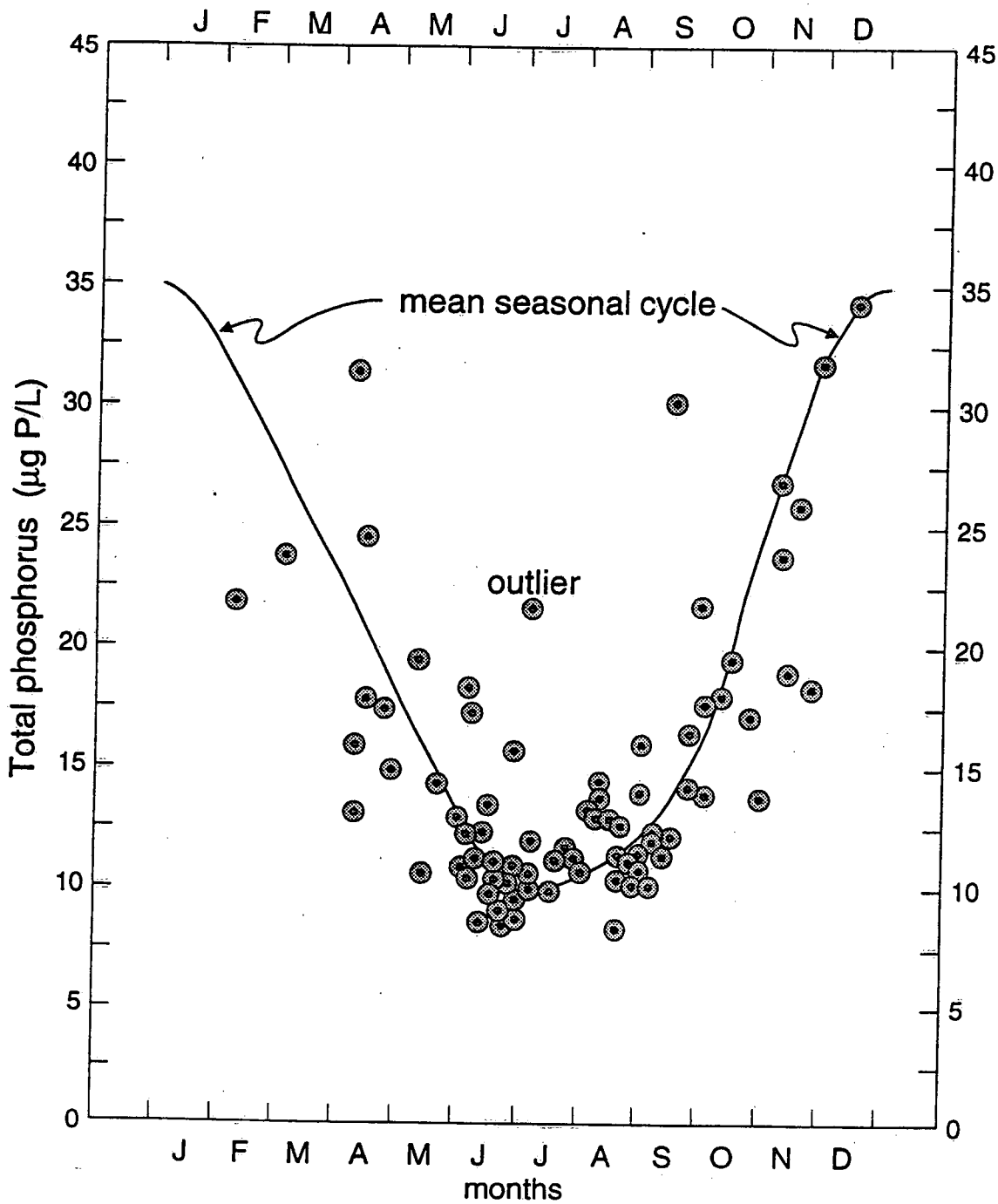
Total phosphorus, Central Lake Erie, offshore and upper 10m, median statistics on each cruise in summer 1970, Canadian vessel Martin Karlsen.



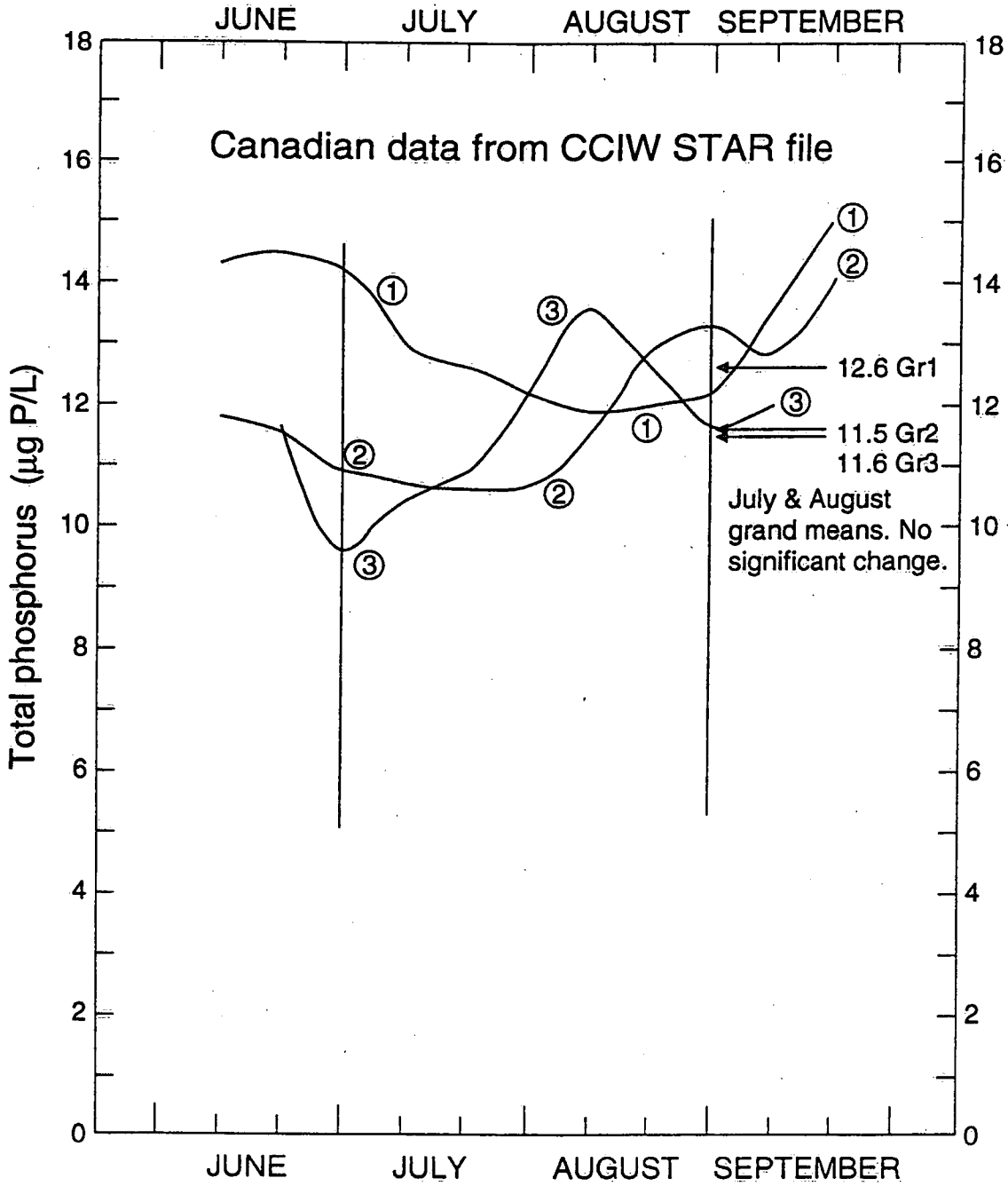
Total phosphorus, Central Lake Erie, offshore and upper 10m, median statistics on each cruise in summer 1978, Canadian vessel Limnos.



Total phosphorus, Central Lake Erie, offshore and upper 10m, median statistics on each cruise in summer 1985, Canadian vessels Advent and Limnos.

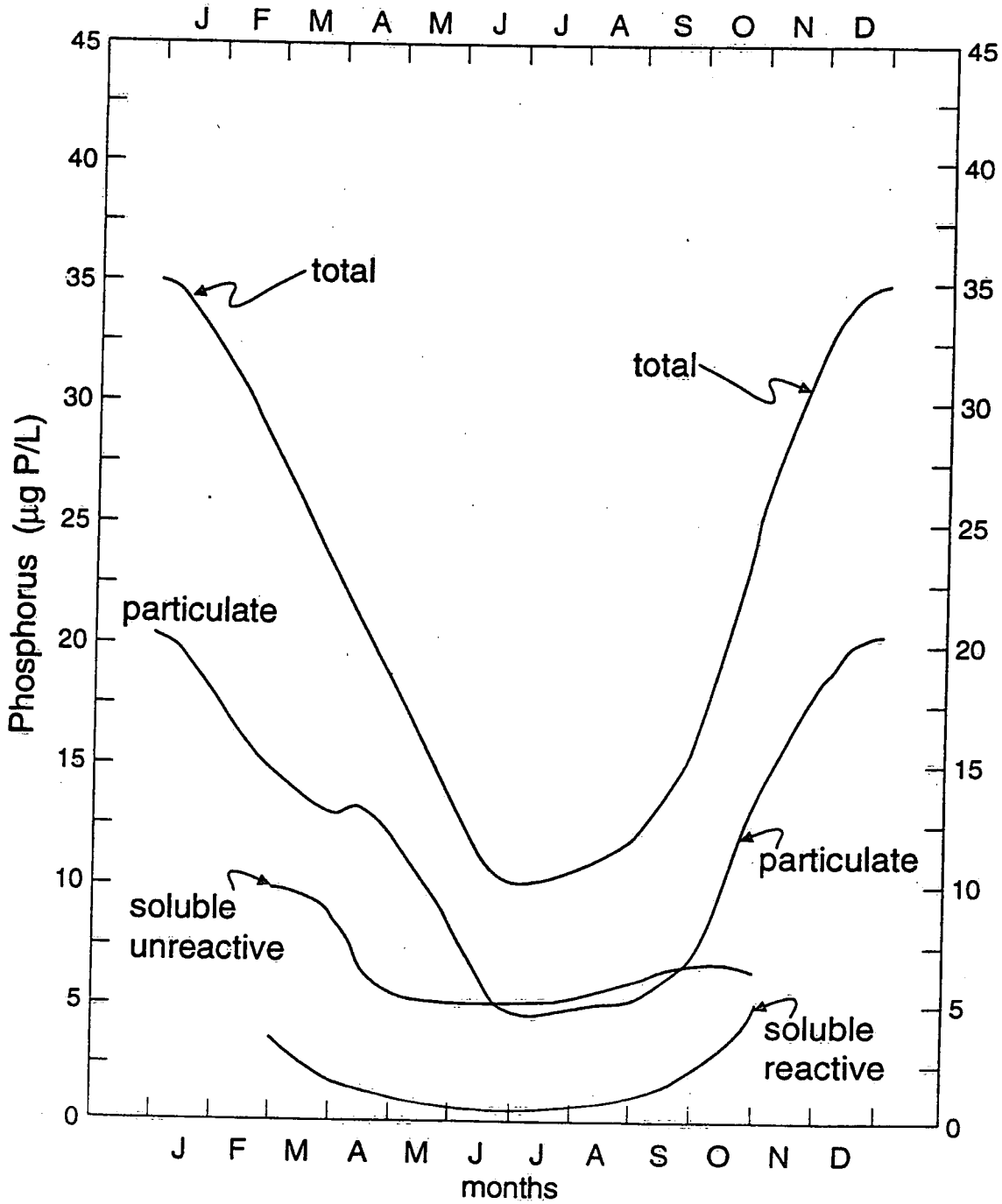


Central Lake Erie, offshore and upper 10m, total phosphorus, medians each cruise 1968 to 1993, plotted vs. time of year, Canadian data.

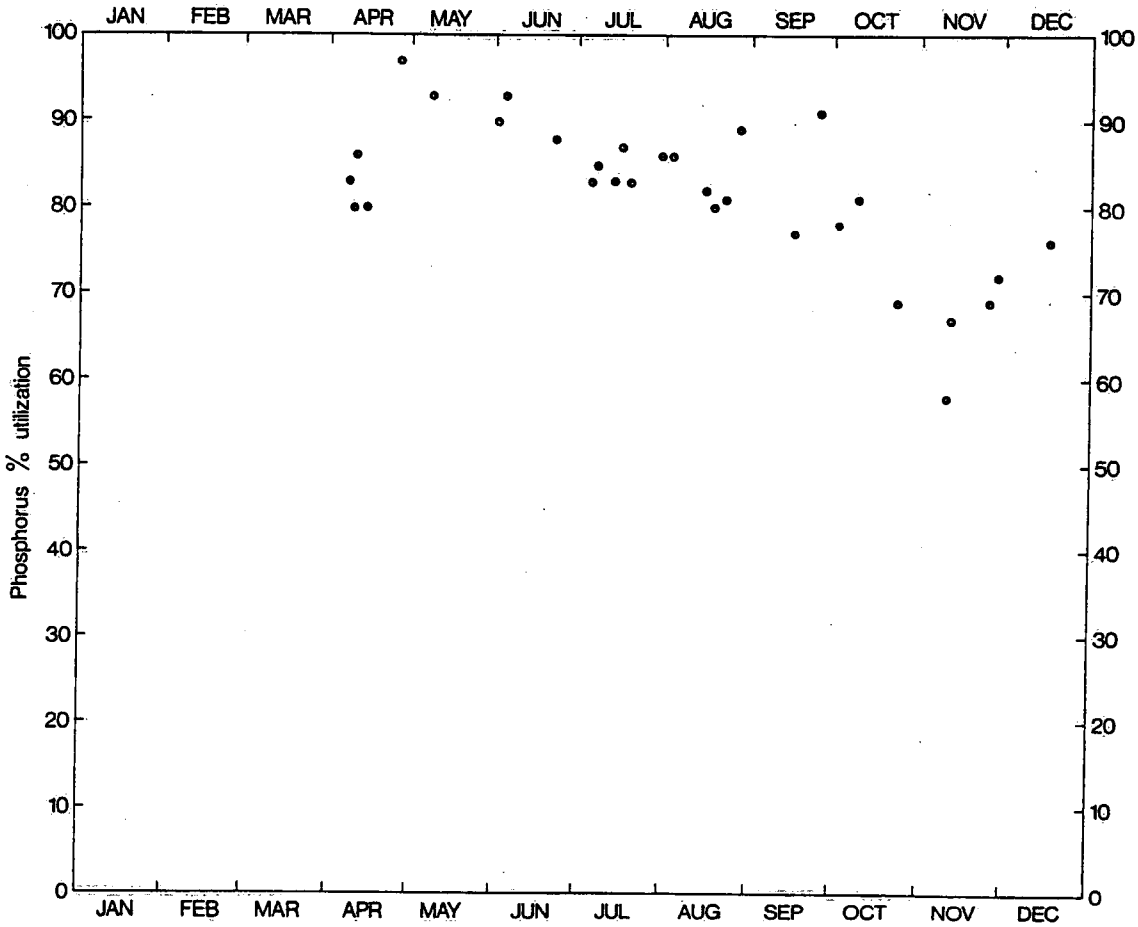


Central Lake Erie, offshore and upper 10m, total phosphorus, smoothed curves from three groups of data: ① 1970 & 1972
② 1977 1978 1979
③ 1983 1984 1985

(There were no other years with adequate data.)

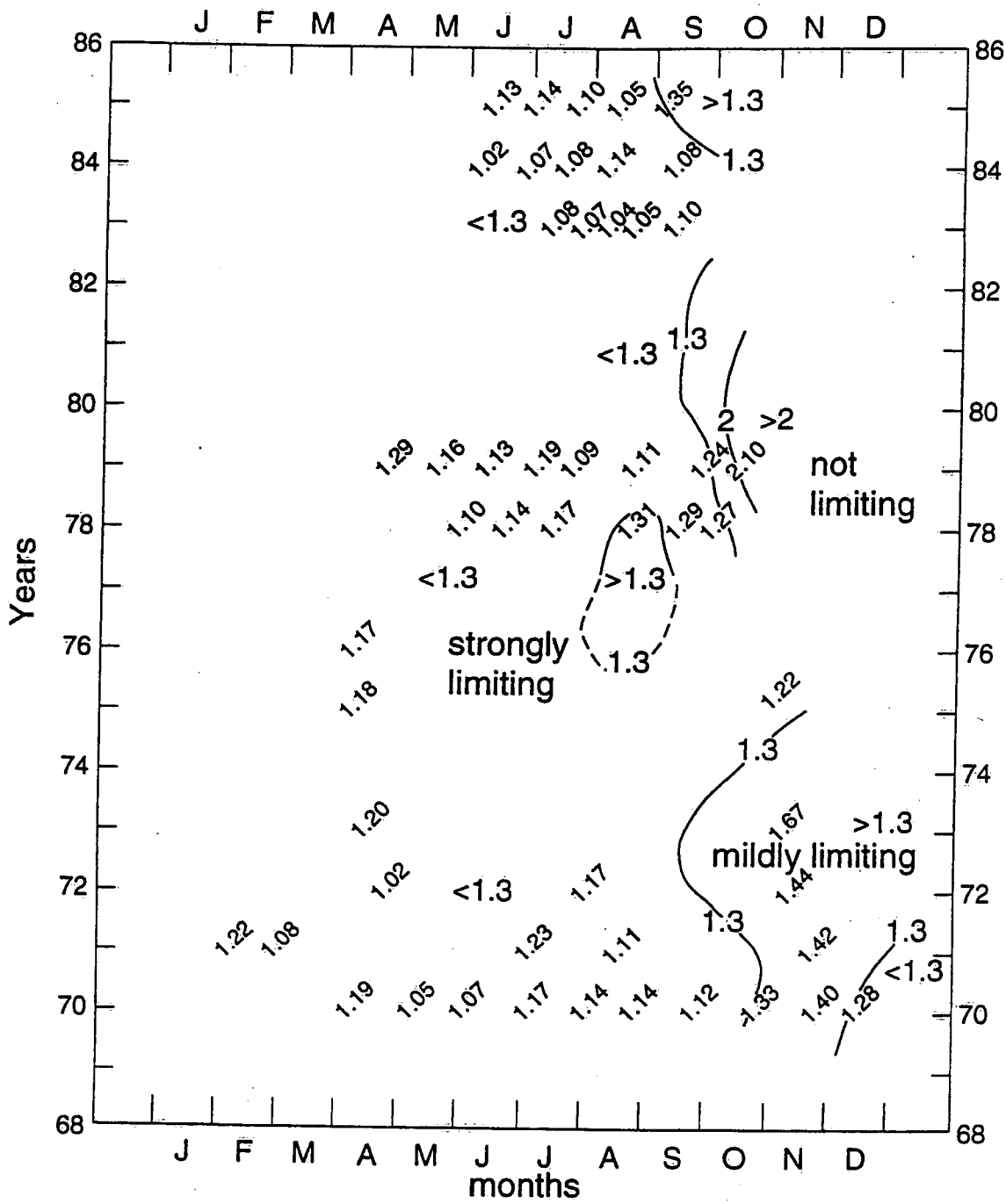


Phosphorus forms in Central Lake Erie, offshore and upper 10m, seasonal cycles, average from cruise medians, Canadian data, mostly 1970's and 1980's.



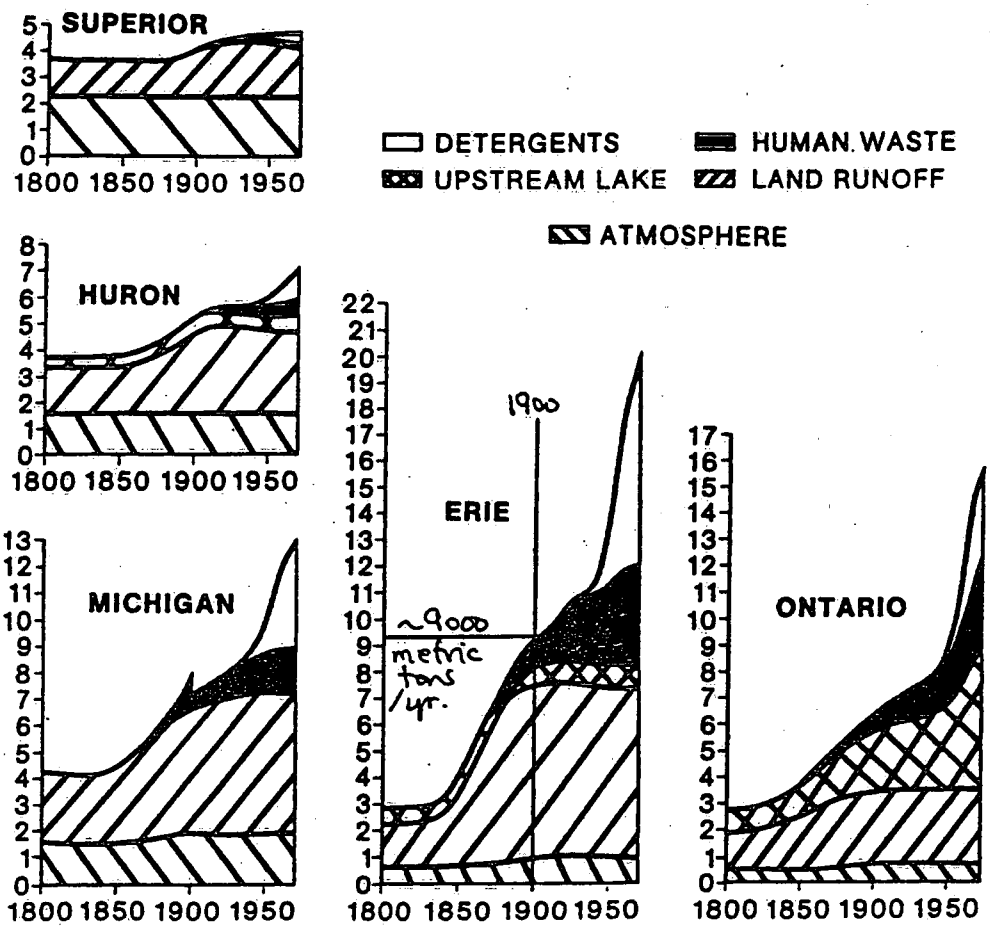
Central Lake Erie, offshore near-surface waters: Phosphorus % utilization* versus time of year, mean values on cruises in the years 1970 to 1979.

(*) Definition: $\left(\frac{\text{Particulate P}}{\text{Particulate + Sol. reactive}}\right) \times 100\,\%$

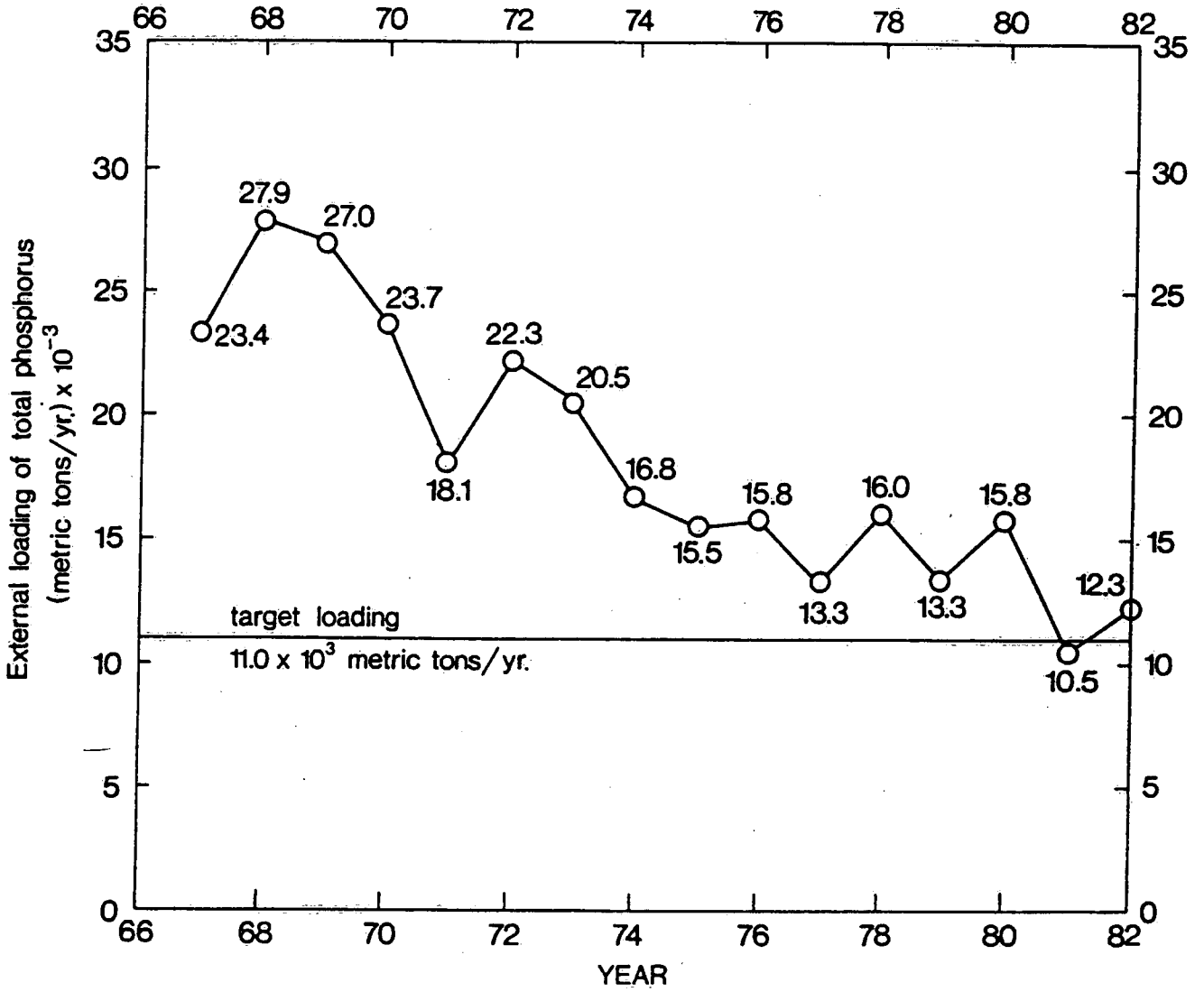


Central Lake Erie, PGF_P by cruise, 1970 to 1985.

$$PGF_P = \textit{potential growth factor for phosphorus in near-surface waters.} = \frac{\textit{particulate P + soluble reactive P}}{\textit{particulate P}}$$



HISTORICAL LOADINGS OF TOTAL PHOSPHORUS, IN THOUSANDS OF TONS PER YEAR, AS CALCULATED BY MODEL (CHAPRA, 1977)



Annual external loadings of total phosphorus to Lake Erie, 1967 to 1982, (data from Fraser, 1984).

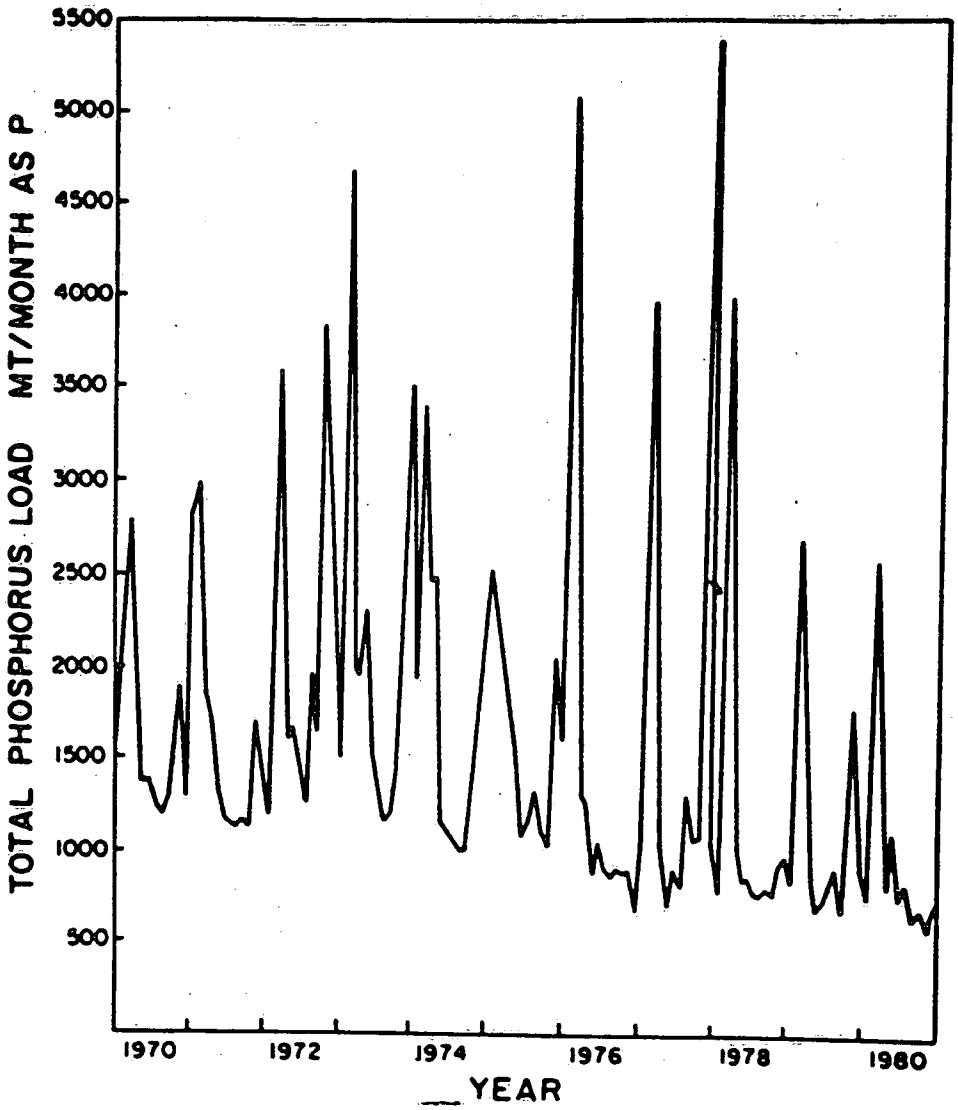
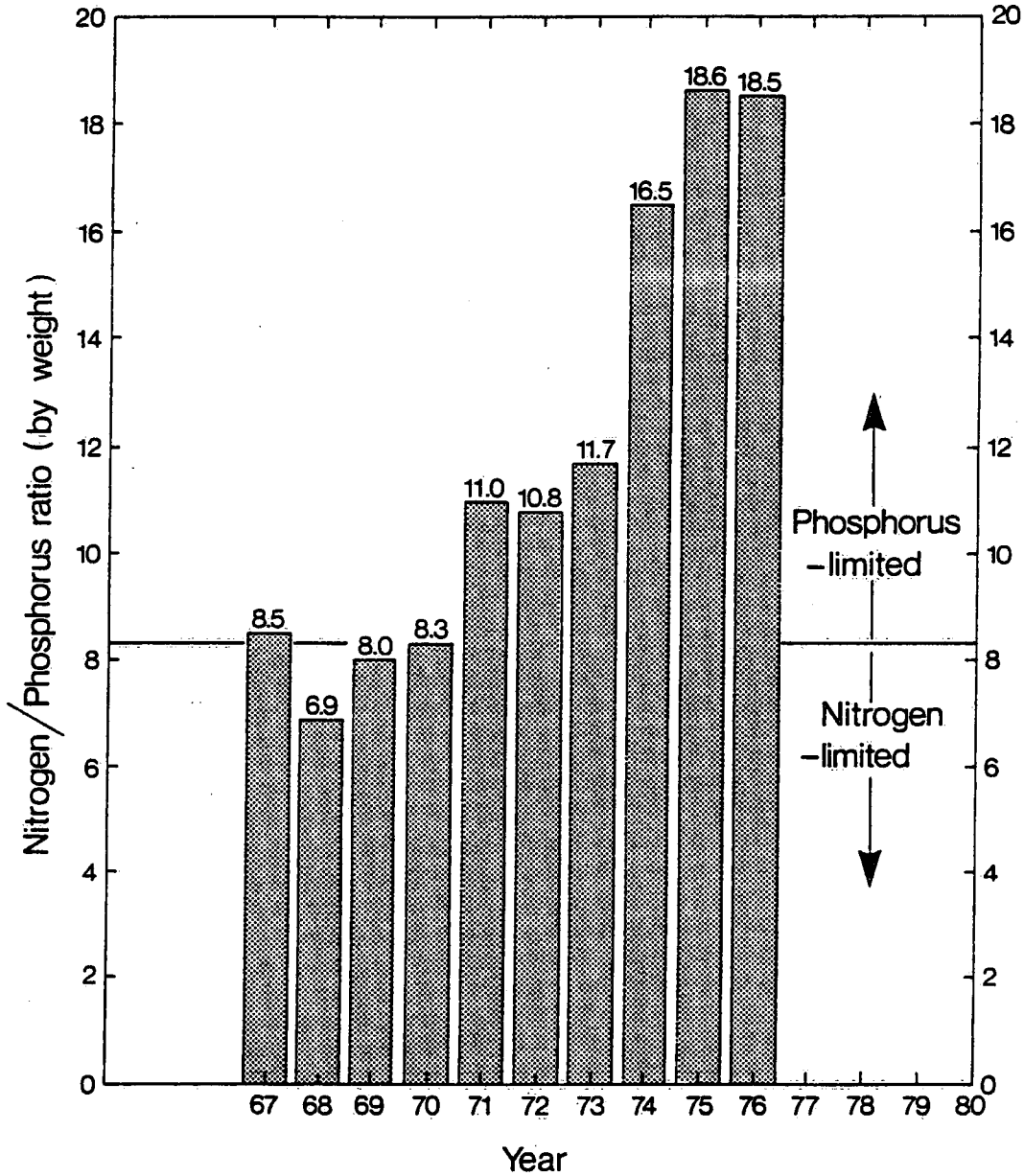


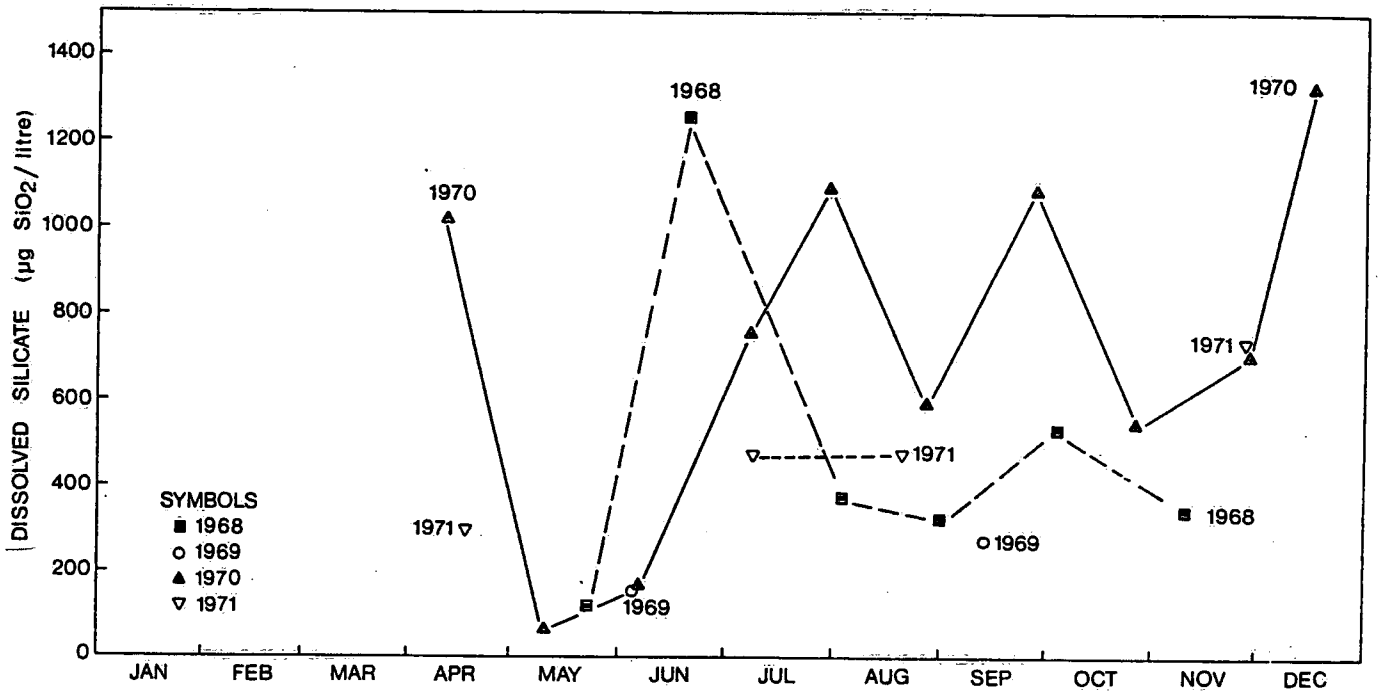
FIG. 5. Monthly total phosphorus loads to Lake Erie, 1970–1980.

From Yaksich et al., 1985, Jour. Of Gr.L.Res., 11(2): p.125

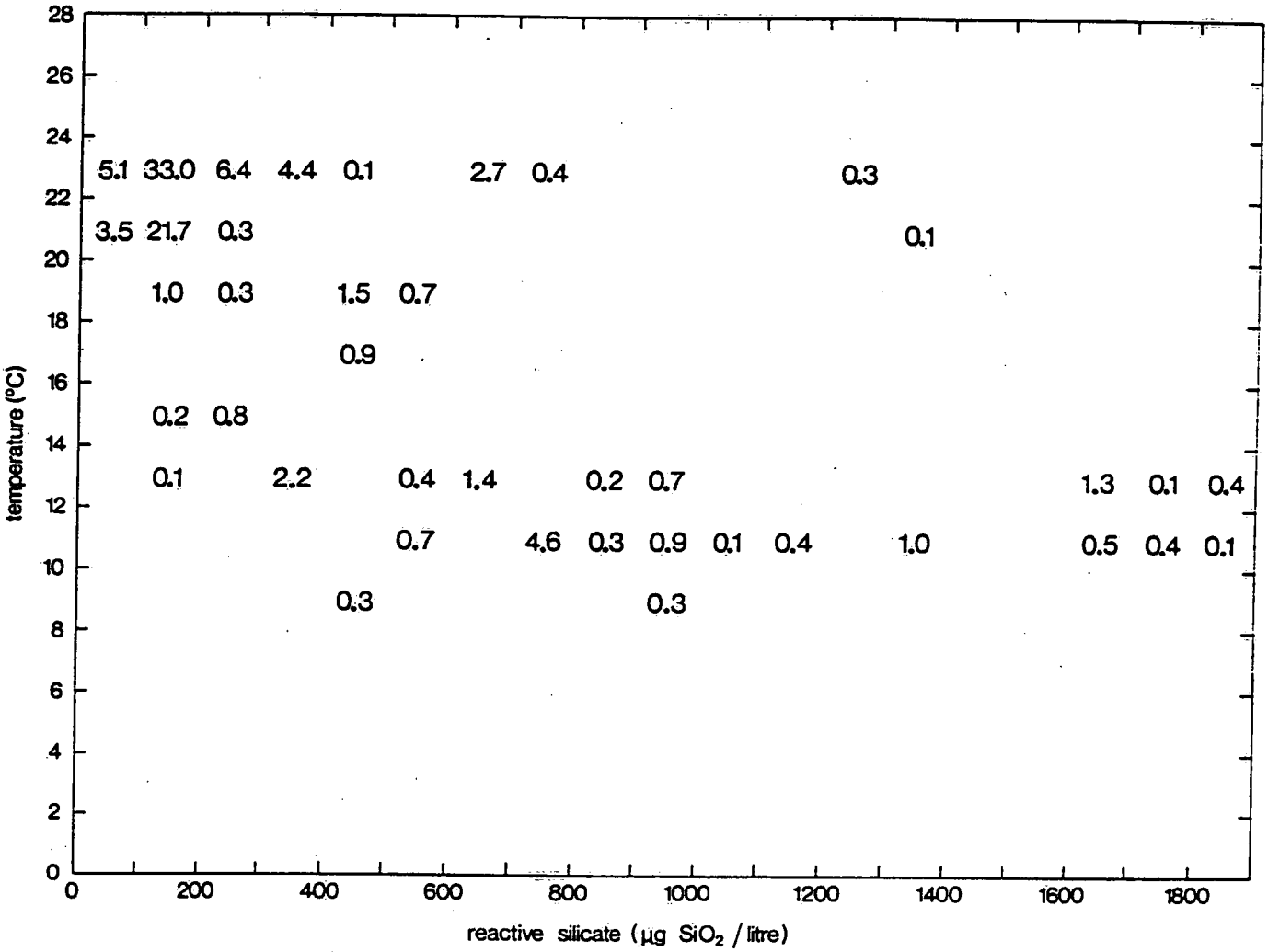


Lake Erie: the nitrogen/phosphorus ratio (by weight) in the external loading to the lake of total nitrogen and total phosphorus, 1967 to 1976 (data from Fraser and Willson, 1981).

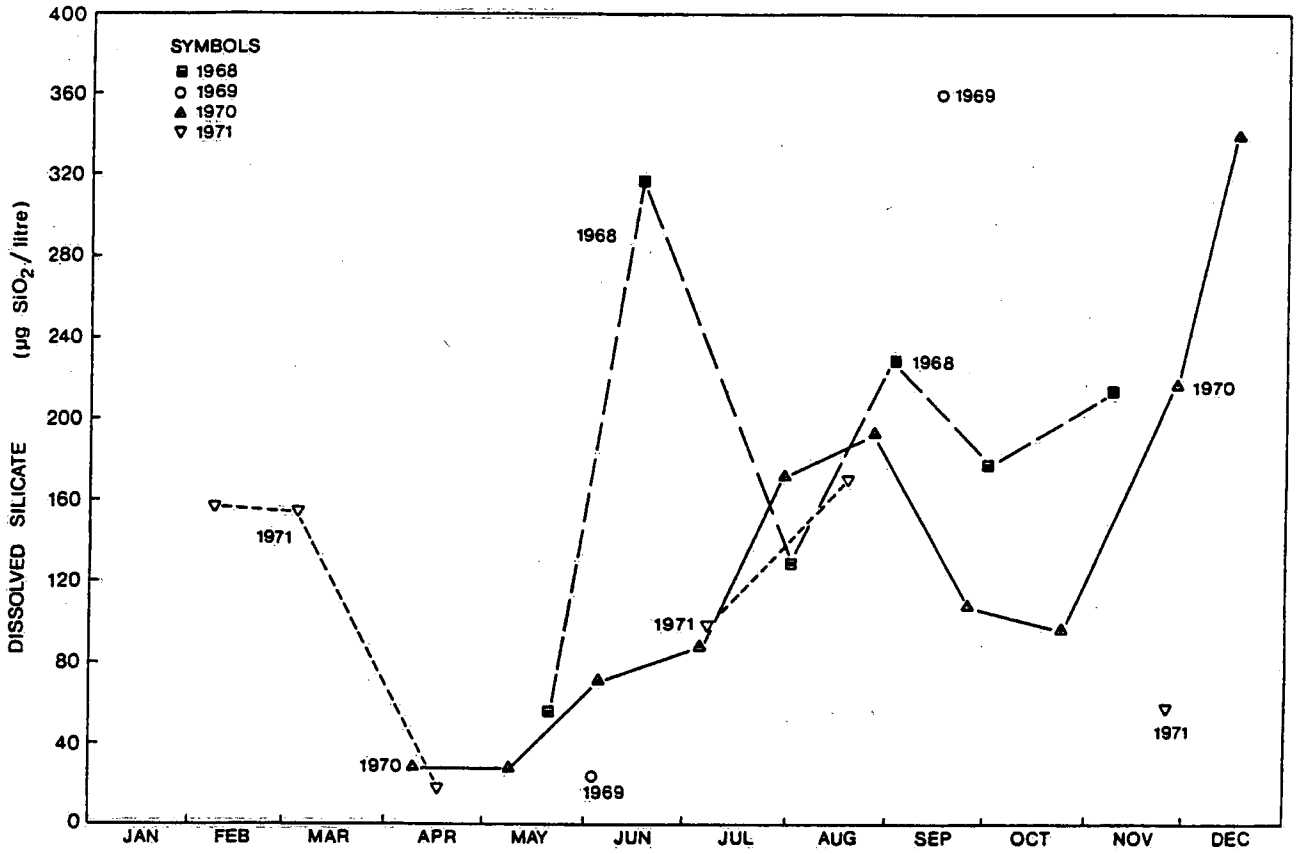
SILICON



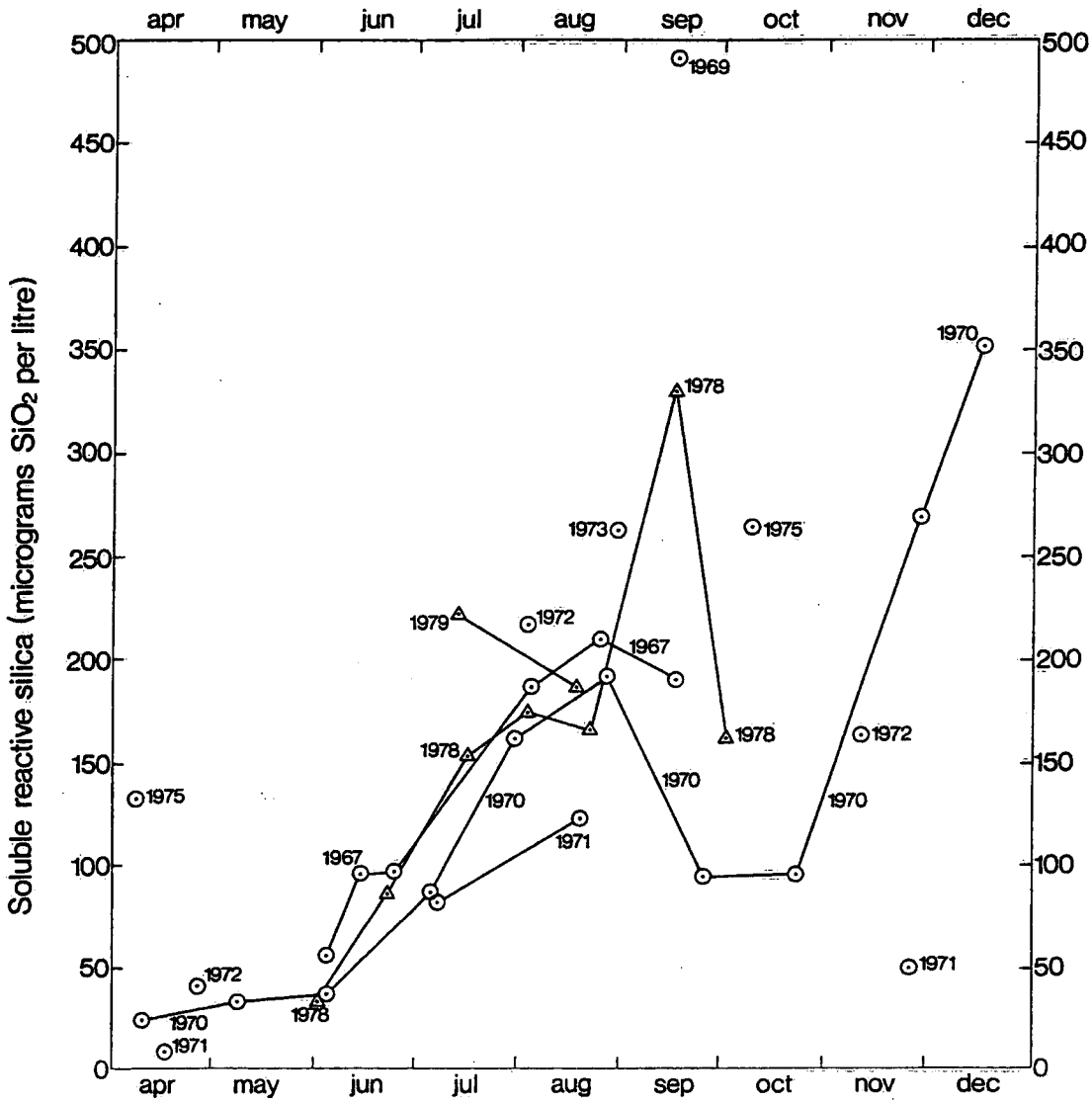
WESTERN LAKE ERIE: UNWEIGHTED MEAN DISSOLVED SILICATE CONCENTRATIONS AT A DEPTH OF 1 METRE, FROM CRUISES OF THE CANADA CENTRE FOR INLAND WATERS IN THE YEARS 1968 TO 1971. UNITS ARE MICROGRAMS SiO_2 PER LITRE.



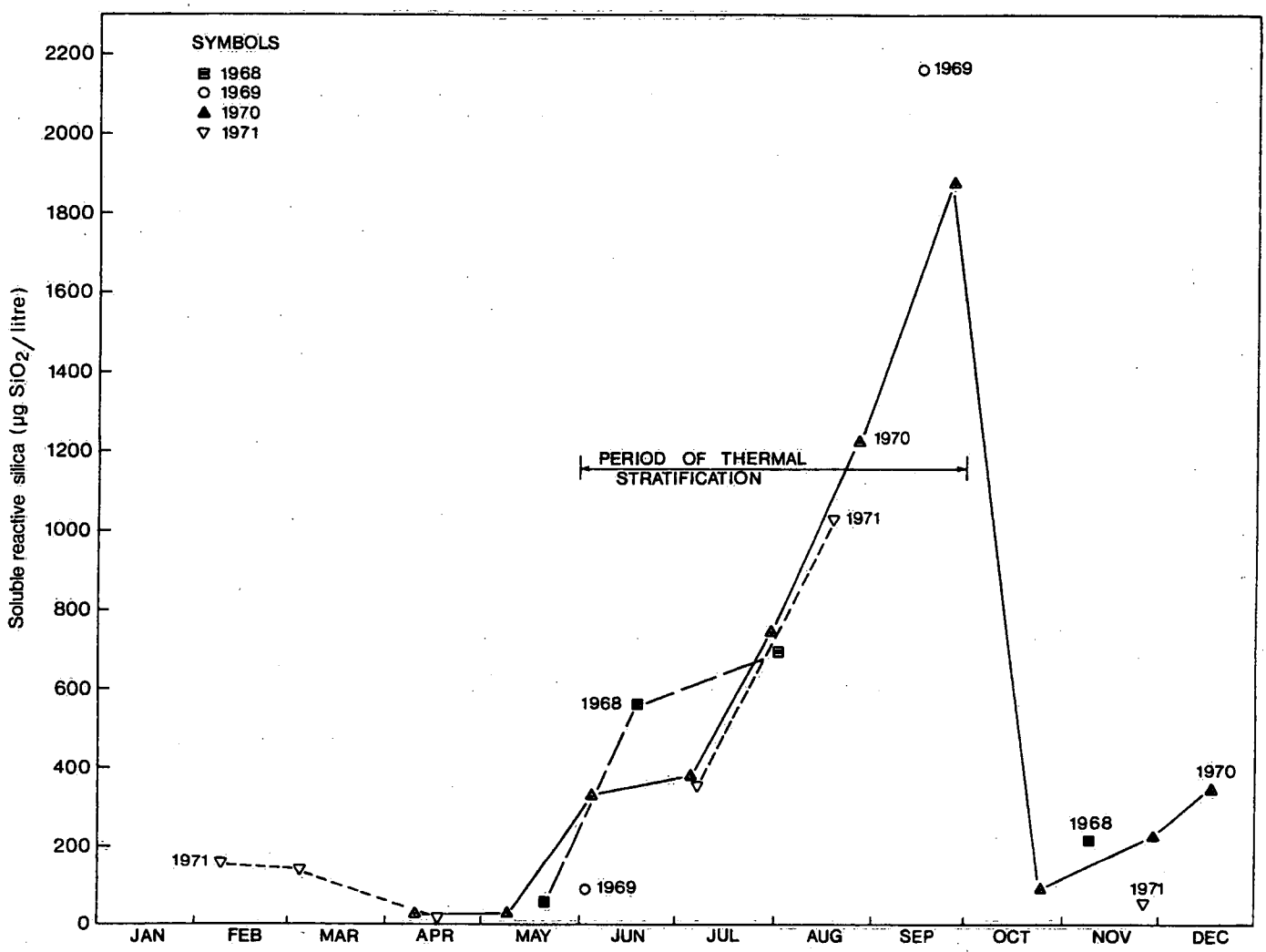
Central Basin of Lake Erie, August 18 - 20, 1971. Cruise of the "Martin Karlsen".
Silicate - temperature histogram (percentage of the central basin's volume in each class).
The mean silicate concentration for the entire central basin was 310 micrograms per litre.



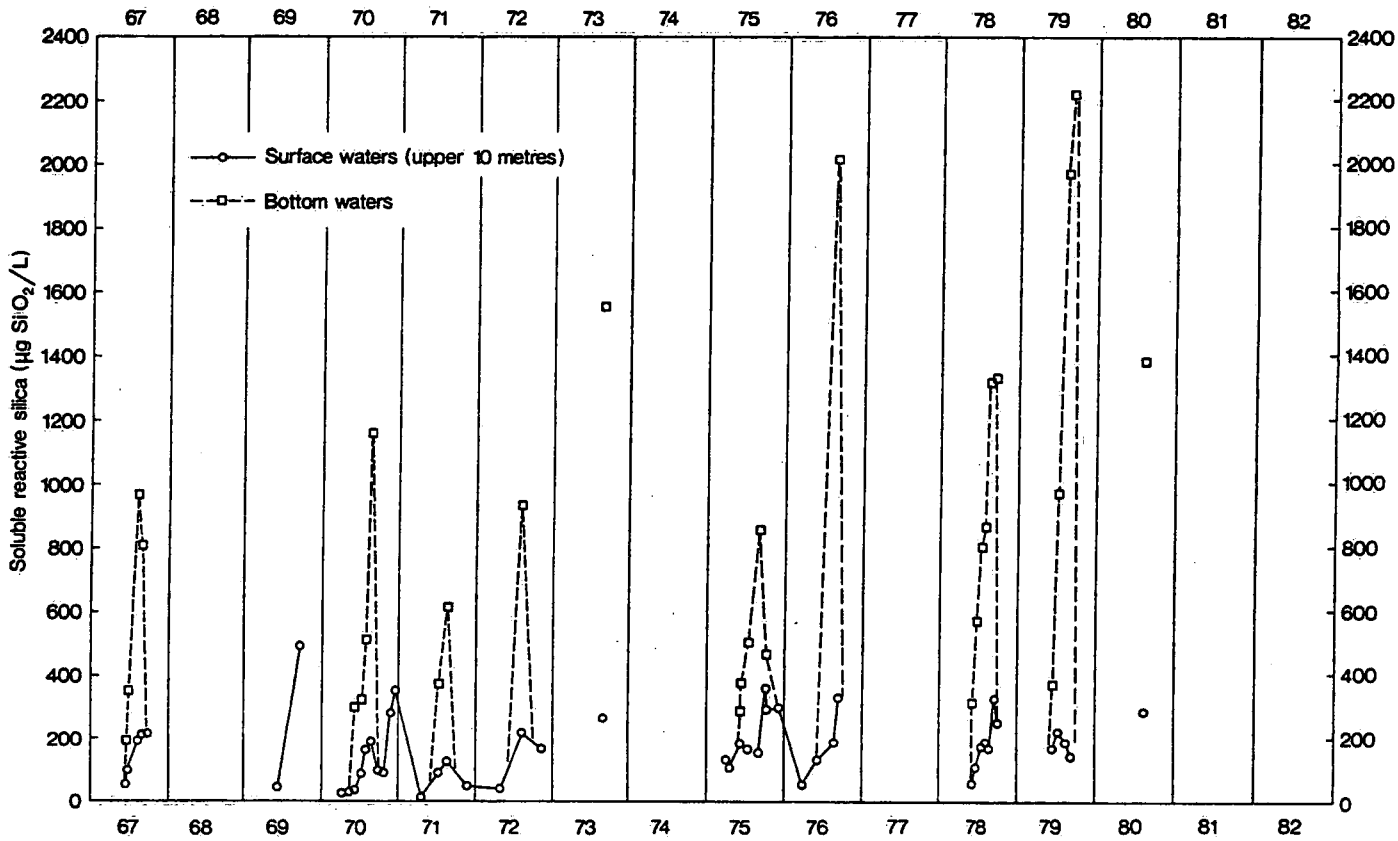
CENTRAL LAKE ERIE: UNWEIGHTED MEAN DISSOLVED SILICATE CONCENTRATIONS AT A DEPTH OF 1 METRE, FROM CRUISES OF THE CANADA CENTRE FOR INLAND WATERS IN THE YEARS 1968 TO 1971. UNITS ARE MICROGRAMS SiO_2 PER LITRE.



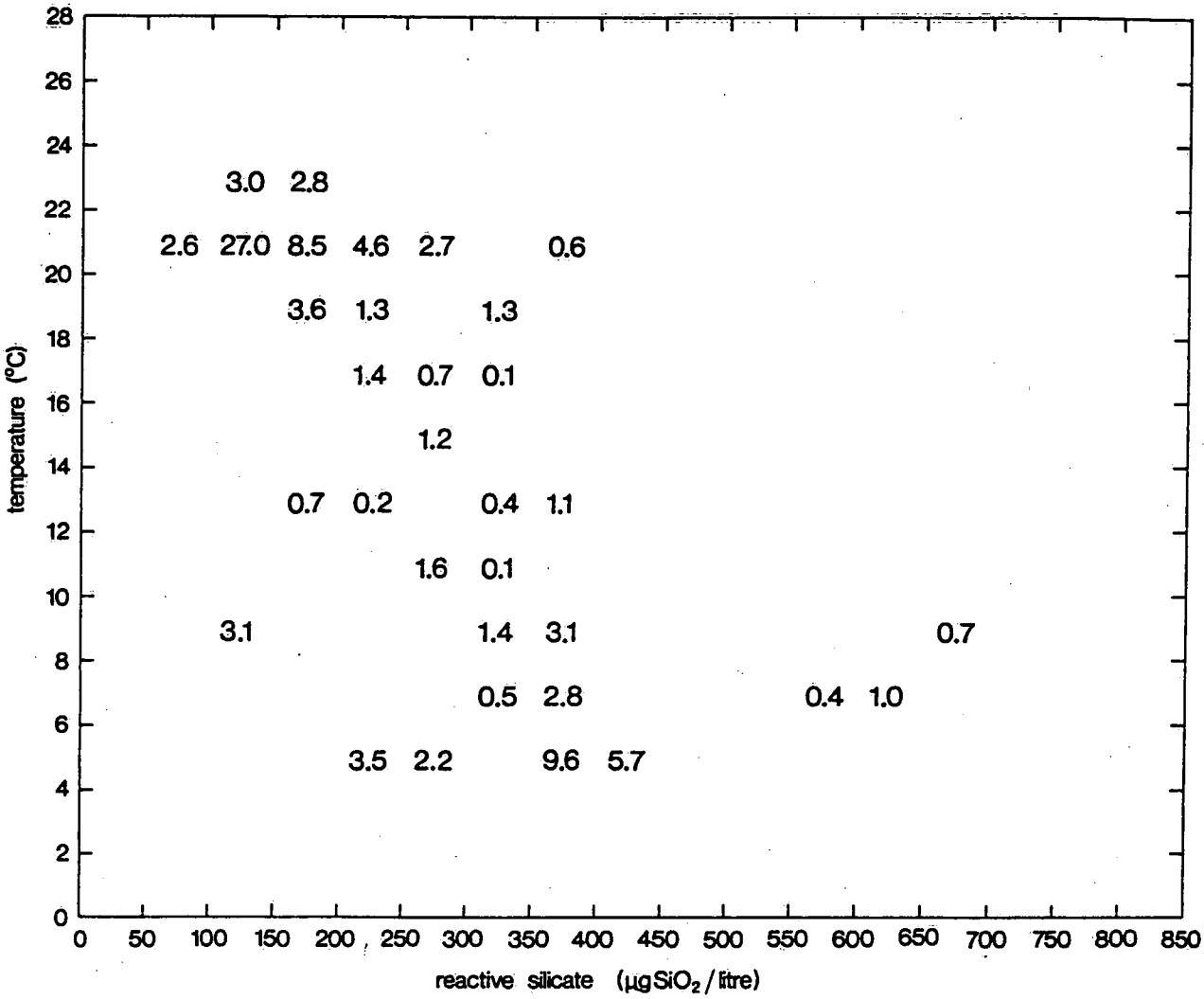
Central Lake Erie, the offshore polygon: seasonal cycles of soluble reactive silica in near-surface waters; mean values on each cruise, samples whose depths are ≤10 metres; CCIW data for the years 1967 to 1979.



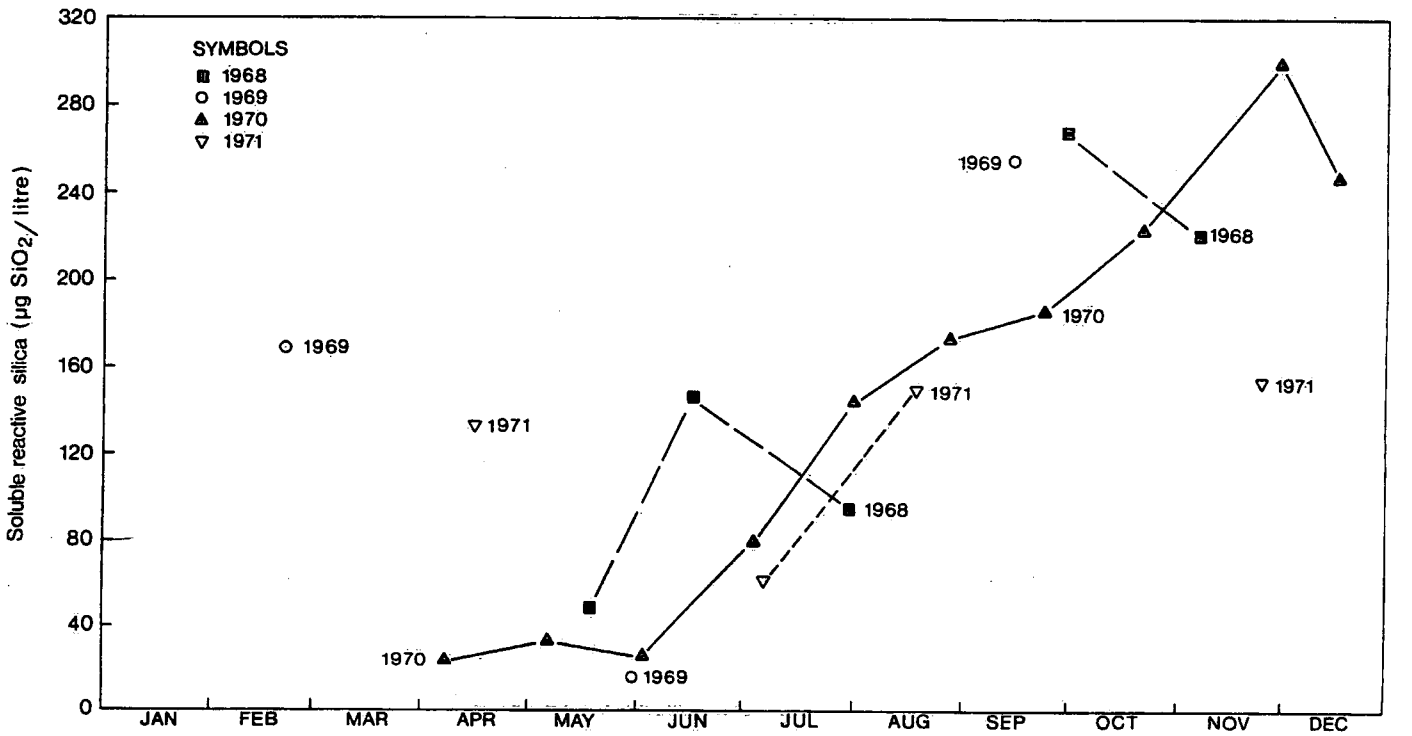
CENTRAL LAKE ERIE: UNWEIGHTED MEAN SOLUBLE REACTIVE SILICA CONCENTRATIONS IN THE COLD BOTTOM - WATERS, FROM CRUISES OF CCIW VESSELS, 1968 to 1971.



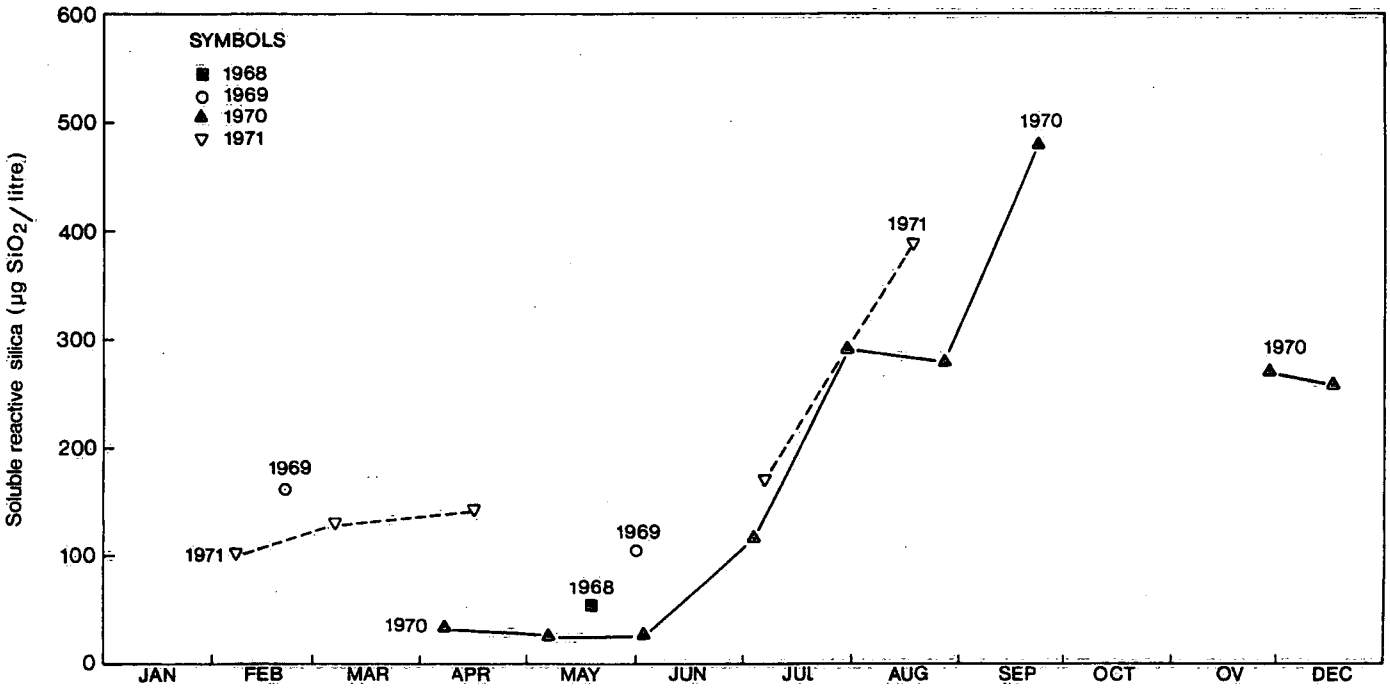
Central Lake Erie: soluble reactive silica, cruise – mean values of surface and bottom waters in the offshore part, 1967 to 1980, Canadian and U.S. data.



Eastern Basin of Lake Erie, August 17 and 18, 1971. Cruise of the "Martin Karlsen".
Reactive silicate - temperature histogram (percentage of the eastern basin's volume in each class).
The mean reactive silicate concentration for the entire basin was 234 micrograms SiO_2 per litre.



EASTERN LAKE ERIE: UNWEIGHTED MEAN SOLUBLE REACTIVE SILICA CONCENTRATIONS AT A DEPTH OF 1 METRE, FROM CRUISES OF CCIW VESSELS, 1968 to 1971.



EASTERN LAKE ERIE: UNWEIGHTED MEAN SOLUBLE REACTIVE SILICA CONCENTRATIONS IN THE COLD BOTTOM-WATERS (Temperatures <8 °C), FROM CRUISES OF CCIW VESSELS, 1968 to 1971.

EVIDENCE OF CHANGE, SUMMARIZED

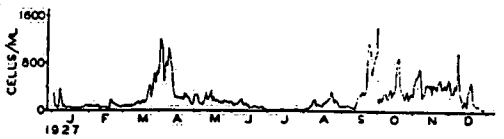


FIG. 2. The record of phytoplankton abundance for the year 1927. Typical vernal and autumnal maxima are depicted, separated by winter and summer minima.

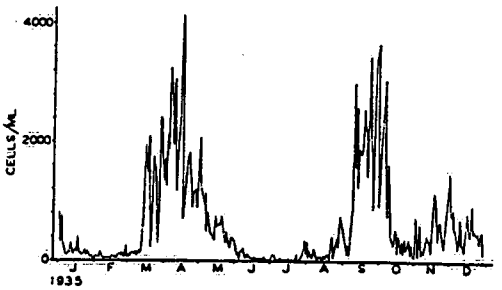


FIG. 3. The record of phytoplankton abundance for 1935.

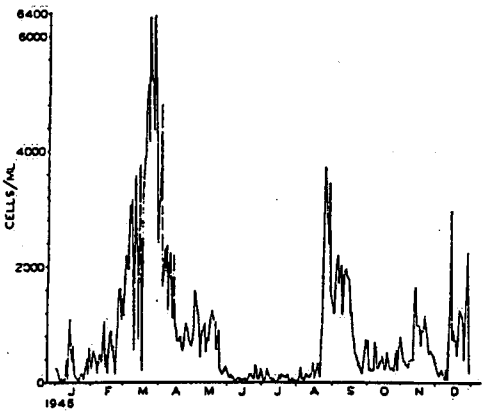


FIG. 4. The record of phytoplankton abundance for 1946.

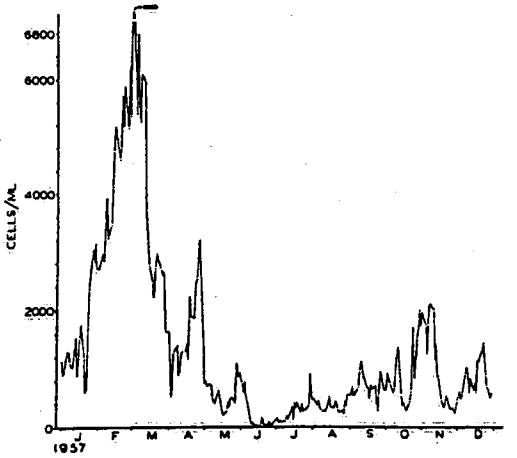


FIG. 5. The record of phytoplankton abundance for 1957.

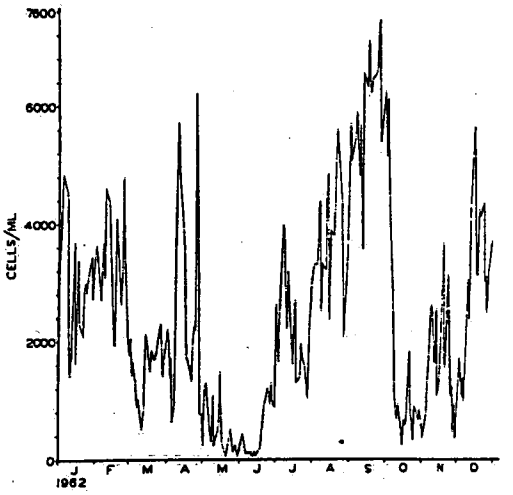


FIG. 6. The record of phytoplankton abundance for 1962.

EVIDENCE FOR THE EUTROPHICATION OF LAKE ERIE FROM PHYTOPLANKTON RECORDS

Charles C. Davis

Reprinted from LIMNOLOGY AND OCEANOGRAPHY
Vol. 9, No. 3, July 1964
pp. 275–283

ABSTRACT

The Division Avenue Filtration Plant of the Cleveland Division of Water and Heat has undertaken almost daily phytoplankton counts of water samples from Lake Erie since 1919. Data exist for 25 full years and for 7 additional partial years between 1919 and 1963. There has been a consistent increase in the average quantity of phytoplankton. The vernal and autumnal phytoplankton maxima have consistently become more intense and have lasted longer. The periods of minimum phytoplankton development in winter and summer have become shorter and less well marked, until the winter minimum failed to develop at all in some of the latest years. Certain marked qualitative changes also have occurred. These effects are thought to have been caused by an increasingly rapid eutrophication of the water in Lake Erie.

Summary of changes of measured trophic indicators, Central Lake Erie, offshore and upper 10.m, July and August in three groups of years, based on CCIW data. (The central year of each group is identified here.)

Parameter Name and Units	(1) 1970	(2) 1978	(3) 1984	% change, groups (2)&(3)
Secchi transparency (m)	~5.	~5.	~7.	-
Secchi reciprocal (1/S(m))	-	0.20	0.14	-30.%
Total phosphorus (μg P/L)	12.6	11.5	11.6	+1.%
Total chlorophyll a (μg /L)	3.8	3.5	2.8	-20.%
Particulate phosphorus (μg P/L)	6.3	5.9	4.8	-19.%
Particulate nitrogen (μg N/L)	no data	62.	53.	-15.%
Part. organic carbon (μg C/L)	no data	420.	360.	-14.%
	average change, 1978 to 1984, omitting Total P:			-20.%

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REFERENCES

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SUPPLEMENT 1:

SUGGESTIONS FOR FUTURE MONITORING

1. The effective volume of each water sample should be known and controlled (1 litre) because of the presence of scattered larger particles, especially zooplankton.

2. The practice of vertically-~~interpreted~~ integrated sampling, producing samples of unknown temperature and unknown internal variability, should be revisited. A better approach may be to return to 'point', 'discrete' samples.

3. Monitoring with lake-wide monthly cruises of a major vessel is informative, and should be continued every year in the ice-free months.

4. Ideally, a manned platform in the middle of the Central Basin, for sampling the water column every two hours throughout the ice-free seasons, would help to learn about variability of the water properties as influenced by winds and currents, especially outside the thermally-stratified summer season. A time-series platform would, of course, be a major commitment of engineering, seamanship, and long-term staffing and expense. However, the present atlas shows that Central Erie offshore upper waters pass through a mid-summer minimum of nutrients and plankton. Thus the other seasons are very important for biological production and sediment resuspension, with weather-driven fluctuations. A habitable platform designed like a small offshore oil drilling platform could be a way of advancing significantly our knowledge of Lake Erie.

5. New parameters for monitoring should include urea, particulate biogenic silica, and iron.

SUPPLEMENT 2:

STUDY OUTLINE FOR A LAKE

- bathymetry, morphometry, basic geology.
- water levels, water budget, rivers, outflow, rainwater, groundwater.
- temperatures, currents, winds-records, ice.
- salinity, conductance, major ions.
- alkalinity, pH, CO_2 system.
- dissolved oxygen, methane, H_2S.
- light, Secchi, turbidity, color.
- major nutrients, nutrient limitation.
- phytoplankton, chlorophyll a.
- zooplankton.
- particulate matter, bacteria.
- fish, fisheries.
- metals, organic contaminants, sediments, benthos.
- beach conditions, harbors, plumes, outfalls, intakes, macrophytes.
- humans
  - population, towns, cities, growth-control.
  - drinking water.
  - sewage disposal, nutrient loading control.
  - agriculture, farm animals, feedlots, sustainability.
  - industries, industrial wastes, power-stations.
  - transportation, recreation, air-quality.
- special topics: colloids, polysaccharides, iron, manganese, health of lake-biota, human health, filtration and the word "dissolved", sedimentation and resuspension, frequency of sampling, methods of analysis.

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