**Canadian Technical Report of Fisheries and Aquatic Sciences 1709**

October 1989

# EVALUATION OF THE MICROBIAL LOOP IN THE NORTH AMERICAN GREAT LAKES

by

Thomas Weisse[t] and Mohiuddin Munawar[a]

[t]Limnological Institute, University of Konstanz
P.O. Box 5560, D-7750
Konstanz, West Germany

[a]Great Lakes Laboratory for Fisheries and Aquatic Sciences,
Department of Fisheries and Oceans, Bayfield Institute,
Canada Centre for Inland Waters,
Burlington, Ontario, Canada
L7R 4A6

Cat. No. Fs 97-6/1709 ISSN 0706-6457

Correct citation for this report

Weisse, T. and M. Munawar, 1989 Evaluation of the microbial loop in North American Great Lakes. Can. Tech. Rep. Fish. Aquat. Sci. 1709. pp.i-v, 1-30.

## ABSTRACT

Weisse, T. and M. Munawar, 1989 Evaluation of the microbial loop in North American Great Lakes. Can. Tech. Rep. Fish. Aquat. Sci. 1709. pp.i-v, 1-30.

The significance of the "microbial loop" in relation to the trophic status of the North American Great Lakes was assessed for the first time during the summers of 1988 and 1989. The abundance of bacteria (BACT), autotrophic picoplankton (APP), and heterotrophic nanoflagellates (HNF) was analyzed at 78 stations distributed across Lakes Michigan, Huron, Erie, and Ontario. In addition, $^{14}$C-primary production was measured in three different size fractions. The BACT abundance was low at offshore stations in the oligotrophic North Channel, Georgian Bay, and main Lake Huron (0.39-1.33 x $10^6$ BACT $ml^{-1}$). Considerably higher values were recorded in meso-eutrophic to eutrophic Lakes Michigan, Erie, and Ontario (0.73-3.35 x $10^6$ BACT $ml^{-1}$). The HNF showed similar trends ranging from 0.44 x $10^3$ HNF $ml^{-1}$ (North Channel) to 3.13 x $10^3$ HNF $ml^{-1}$ (L. Michigan). The APP showed the most pronounced distributional patterns. The lowest concentrations were found in Georgian Bay (12.7 x $10^3$ APP $ml^{-1}$), while the highest concentrations occurred in eastern Lake Erie (286.0 x $10^3$ APP $ml^{-1}$). APP was also high in the eutrophic Saginaw Bay but dramatically low in contaminated areas of Lakes Erie and Ontario. Primary production revealed similar trends. The response of BACT and HNF to eutrophication and contamination was less clear.

The "microbial loop" evaluation appears to have a great potential in probing the complexities of food web dynamics and trophic interactions which are ultimately controlled by the sensitivity of micro-organisms to nutrients and contaminants.

## RÉSUMÉ

Weisse, T. and M. Munawar, 1989 Evaluation of the microbial loop in North American Great Lakes. Can. Tech. Rep. Fish. Aquat. Sci. 1709. pp.i-v, 1-30.

La signification du "cycle microbien" dans les Grands Lacs Laurentiens a été étudée pour la première fois selon les différents niveaux trophiques durant les étés 1988 et 1989. Les abondances de bactéries (BACT), picoplanctons autotrophes (PPA) et nanoflagellés hétérotrophes (NFH) ont été analysés à 78 stations réparties à travers les lacs Michigan, Huron, Érie et Ontario. La productivité primaire ($^{14}C$) a été également mesurée pour trois classes de tailles différentes.

Aux stations situées au large dans trois zones oligotrophes (le chenal du Nord, la baie Georgienne, et le bassin principal du lac Huron) l'abondance bactérienne était faible (0.39-1.33 X $10^6$ BACT $ml^{-1}$). Des valeurs considérablement plus élevées (0.73-3.35 X $10^6$ BACT $ml^{-1}$) ont été enregistrées dans les eaux méso-eutrophes à eutrophes des lacs Michigan, Érie et Ontario. Les nanoflagellés hétérotrophes ont démontré des tendances semblables, variant de 0.44 X 103 NFH $ml^{-1}$ (chenal du Nord) jusqu'à 3.13 X $10^3$ NFH $ml^{-1}$ (lac Michigan). Les variations spatiales les plus prononcées ont été observées chez le PPA, dont la gamme des abondances s'étend de 12.7 X $10^3$ PPA $ml^{-1}$ (la baie Georgienne) jusqu'à 286.0 X $10^3$ PPA $ml^{-1}$ (bassin est du lac Érie). Les abondances du PPA étaient aussi très élévées à la baie de Saginaw (zone eutrophe), mais très faibles aux endroits contaminés des lacs Érie et Ontario. La productivité primaire révèle des tendances similaires. Les réponses des bactéries et des NFH à l'eutrophication et à la pollution toxique sont moins claires.

L'évaluation du "cycle microbien" semble prometteuse pour l'analyse des complexités de la maille alimentaire et des interactions trophiques, qui sont controlées par la sensibilité des microorganismes aux substances nutritifs et aux produits toxiques.

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

## INTRODUCTION

Although the significance of pelagic micro-organisms composing the "microbial loop" (Azam et al., 1983) in marine and freshwater ecosystems has now been generally accepted, very little is known about the abundance, biomass, and population dynamics of bacteria and protozoa in the North American Great Lakes. However, studies on the distribution and primary production of the autotrophic picoplankton (0.2-2.0 $\mu$m) have been made (Munawar & Fahnenstiel, 1982; Munawar & Munawar, 1986; Munawar et al., 1987; Leppard et al., 1987). Other studies showed the autotrophic picoplankton to be sensitive to heavy-metal contamination (Munawar & Munawar, 1982; Munawar et al., 1987; Munawar & Weisse, 1989; Severn et al., 1989) and its use as an early-warning indicator of pollution has been proposed.

The present report provides, for the first time, detailed data on the abundance of bacteria, autotrophic picoplankton, and heterotrophic nanoflagellates in Lakes Michigan, Huron, Erie, and Ontario. Additionally, size-fractionated primary production was measured simultaneously.

## METHODS

Water samples from across the Great Lakes (Figs. 1 & 2) were

collected by an integrating water sampler from the euphotic zone during the months of August to October, 1988 and 1989. The free-living bacteria (BACT), autotrophic picoplankton (APP), and heterotrophic nanoflagellates (HNF) were preserved in formalin (1.5 % vol/vol final concentration) and enumerated by means of epifluorescence microscopy. Depending on the abundance of micro-organisms, between two and five ml of the samples were filtered onto 0.2 $\mu$m black Nuclepore filters and counted at 1250X magnification. A NIKON LABOPHOT microscope equipped with a HBO-100W mercury lamp and filter block V (excitation wavelength 405 $\mu$m) was used for the enumeration. BACT and HNF were stained with DAPI (Porter & Feig, 1980), while APP were identified by their orange autofluorescence.

The samples were separated into three size-fractions (< 2 $\mu$m, 2-20 $\mu$m, > 20 $\mu$m) and primary production was estimated by the $^{14}$C-technique according to Vollenweider et al., (1974) and Munawar et al., (1987)

## RESULTS AND DISCUSSION

The abundance of the microbial loop components at 78 stations in Lakes Michigan, Huron, Erie, and Ontario is given in Tables 1 to 11. At offshore stations, cell numbers of BACT and HNF in each lake varied little during August and September, 1988 (Tables 1 to 6). The average abundance was highest in Lake Michigan and lowest

in Lake Huron (Figs. 3 and 4). The BACT abundance found in L. Michigan was higher than values reported by Scavia & Laird (1987). Our estimates of the microbial loop components measured in L. Ontario during late summer 1988 are similar to results obtained in 1982 (Pick & Caron, 1987).

The APP showed the most pronounced distributional patterns (Fig. 5). In the Great Lakes, they consisted predominantly of chroococcoid cyanobacteria. Eucaryotic picoplankton occurred only sporadically and in low abundance. The relatively large standard error of the mean APP abundance in Lake Erie is caused by the extremely high numbers ($286 \times 10^3$ APP $ml^{-1}$) recorded at station 55 in eastern Lake Erie (Table 2), the highest value found during this study. Regarding the trophic status, the APP abundance in Lake Michigan appears to be low compared to the other lakes. However, it must be considered that samples from L. Michigan were collected later (October) than samples from the other lakes (August/September). Previous investigations revealed that in L. Ontario APP peaked in late August at the time of maximum water temperature (Caron et al., 1985; Pick & Caron, 1987). At one station in L. Superior, however, seasonal variation of APP production was small (Munawar & Fahnenstiel, 1982; Fahnenstiel et al., 1986). Therefore, it is not known whether the low APP abundance in L. Michigan was due to seasonal variation or was caused by other factors.

Total primary production (TPP) in Lakes Huron and Ontario was distinctly lower than in L. Erie (Fig. 6). APP production (<2 $\mu$m)

varied much less than that of nanoplankton (2-20 μm) and netplankton (>20 μm). Similar to the microbial abundance, the variation of TPP at offshore locations in the oligotrophic North Channel, Georgian Bay, and main L. Huron was less than one order of magnitude (Table 10). In contrast, nutrient- and contaminant-rich Saginaw Bay, station to station variation was large and TPP increased dramatically compared to main L. Huron. In L. Erie, TPP increased along a nutrient and contaminant gradient from the east to the west. It is interesting to note that APP production did not show this trend. Only at station 357, was higher APP production found (Table 10). APP abundance decreased along the transect both in August, 1988 and August, 1989 (Fig. 10), although the 1989 values were lower and the differences between the eastern and western part of L. Erie less pronounced than in 1988.

We observed a similar decrease of APP cell numbers in the contaminated areas of L. Ontario, Ashbridges Bay (Toronto), and Hamilton Harbour (Fig. 9). This scenario is different from the Lake Huron-Saginaw Bay transect where APP abundance was higher inshore than at the offshore reference stations. Obviously, the APP responded sensitively to different sources of nutrient and contaminant enrichment. These findings confirm results from earlier studies which had demonstrated that APP is particularly sensitive to heavy-metal contamination (Munawar & Munawar, 1982; Munawar et al., 1987; Severn et al., 1989). A more detailed account on the response of APP abundance and production to anthropogenic stress is given by Munawar & Weisse (1989).

We found no unequivocal pattern of changing BACT and HNF cell numbers in relation to nutrient and contaminant enrichment (Figs. 7 & 8). The exceptionally high HNF concentrations recorded in Hamilton Harbour during September 1988, were not measured on other occasions (Weisse & Munawar, unpubl. data). No obvious changes in the community structure of BACT or HNF along the transects were found. However, since HNF and larger protozoa are the major consumers of both autotrophic and heterotrophic picoplankton production in lakes (Weisse, 1988, 1990; Bloem & Bar-Gilissen, 1989), predator-prey interactions will strongly affect the observed community standing stocks.

The results presented in this report point to great structural and functional changes within the "microbial loop" depending on the trophic status and the impact of contaminants. Although cell numbers are only a rough indicator of the ecological significance, the apparent differences, namely in the APP abundance, between the various areas of the Great Lakes imply distinct changes in the relative importance of the "microbial loop" in relation to the classic planktonic food web. A more detailed analysis, taking into account growth dynamics and trophic relations among the microbial loop organisms, will be presented elsewhere (Weisse & Munawar, in prep.). Finally, although our data are preliminary, they demonstrate the great potential of the "microbial loop" evaluation in probing the complexities of food web dynamics which appear to be ultimately controlled by the sensitivity of micro-organisms to substrate and contaminant supply.

ACKNOWLEDGEMENTS

We would like to thank L. McCarthy, P. Desroches, C. Franchisca, L. Keeler, J. Nawrocki, and D. Miller for their assistance in various aspects of the project. We also thank I.F. Munawar and H.F. Nicholson for the review of the report and editorial assistance respectively. Assistance of the captain and crew of the C.S.S. Limnos and Advent is acknowledged for sampling. We would like to thank P. Ross and L. Beauregard for the french translation of the abstract.

REFERENCES

Azam, F., T. Fenchel, J.G. Field, J.S. Gray, L.A. Meyer-Reil & F. Thingstad. 1983. The ecological role of water-column microbes in the sea. Mar. Ecol. Prog. Ser. 10: 257-263.

Bloem, J. & M.-J. Bar-Gilissen. 1989. Bacterial activity and protozoan grazing potential in a stratified lake. Limnol. Oceanogr. 34: 297-309.

Caron, D.A., F.R. Pick & D.R.S. Lean. 1985. Chroococcoid cyanobacteria in Lake Ontario: vertical and seasonal distributions during 1982. J. Phycol. 21: 171-175.

Fahnenstiel, G.L., L. Sicko-Goad, D. Scavia & E.F. Stoermer. 1986. Importance of picoplankton in Lake Superior. Can. J. Fish. Aquat. Sci. 43: 235-240.

Leppard, G.G., D. Urcioli & F.R. Pick. 1987. Characterization of cyanobacterial picoplankton in Lake Ontario by transmission electron microscopy. Can. J. Fish. Aquat. Sci. 44: 2173-2177.

Munawar, M. & G.L. Fahnenstiel. 1982. The abundance and significance of ultraplankton and micro-algae at an offshore station in central Lake Superior. Can. Tech. Rep. Fish. Aquat. Sci. 1153 (I-IV):1-13.

Munawar, M. & I.F. Munawar, 1982. Phycological Studies in Lakes Ontario, Erie, Huron and Superior. Can. J. Bot. 60(9):1837-1858.

Munawar, M. & I.F. Munawar. 1986. The seasonality of phytoplankton in the North American Great Lakes: A comparative synthesis. In: M. Munawar & J.F. Talling (Eds.), Seasonality of Freshwater Phytoplankton: A Global Perspective. Hydrobiologia 138: 85-115.

Munawar, M. & T. Weisse. 1989. Is the "microbial loop" an early warning indicator of anthropogenic stress? In: M. Munawar, G. Dixon, C.I. Mayfield, T. Reynoldson & M.B. Sadar (Eds.), Environmental Bioassay Techniques and their Application. Hydrobiologia: 188/189:163-174.

Munawar, M., I.F. Munawar, W.P. Norwood & C.I. Mayfield. 1987. Significance of autotrophic picoplankton in the Great Lakes and their use as early indicators of contaminant stress. In: M. Munawar (Ed.), proc. Internat. Symp. on phycolcogy of Large Lakes of the world. Arch. Hydrobiol. Beih. Ergebn. Limnol. 25: 141-155.

Pick, F.R. & D.A. Caron. 1987. Picoplankton and nanoplankton biomass in Lake Ontario: relative contributions of phototrophic and heterotrophic communities. Can. J. Fish. Aquat. Sci. 44: 2164-2174.

Scavia, D & G. A. Laird. 1987. Bacterioplankton in Lake Michigan: Dynamics, controls and significance to carbon flux. Limnol.Oceanogr. 32: 1017-1033.

Porter, K.G. & Y.S. Feig. 1980. The use of Dapi for identifying and counting aquatic microflora. Limnol. Oceanogr. 25: 943-948.

Severn, S.R.T., M. Munawar & C.I. Mayfield. 1989. Measurements of sediment toxicity of autotrophic and heterotrophic picoplankton by epifluorescence microscopy. In: P.G. Sly & B.J. Hart (Eds.), Sediment/Water Interaction. Hydrobiologia 176/177: 525-530.

Vollenweider, R.A., M. Munawar & P. Stadelmann. 1974. A comparative review of phytoplankton and primary production in the Laurentian Great Lakes. J. Fish. Res. Bd. Can. 31: 739-762.

Weisse, T. 1988. Dynamics of autotrophic picoplankton in Lake Constance. J. Plankton Res. 10: 1179-1188.

Weisse, T. 1990. Trophic interactions among heterotrophic microplankton, nanoplankton, and bacteria in Lake Constance. In: P. Biró & J.F. Talling (Eds.), Trophic Relationships in Inland Waters. Hydrobiologia 191: (in press).


N
71
79
89
69
77
82
42
27
65
61
29
12
11
55
48
35
31
17
15
9
41
6
10
45
43
30
33
23
8
7
13
14
97
95
32
20
98
5
4
3
99
94
100
96
14
12
101
16
15
101A
8
5
1
2
1
55
23
9
358
25
29
84
357
1
2
3
10

Fig. 1.

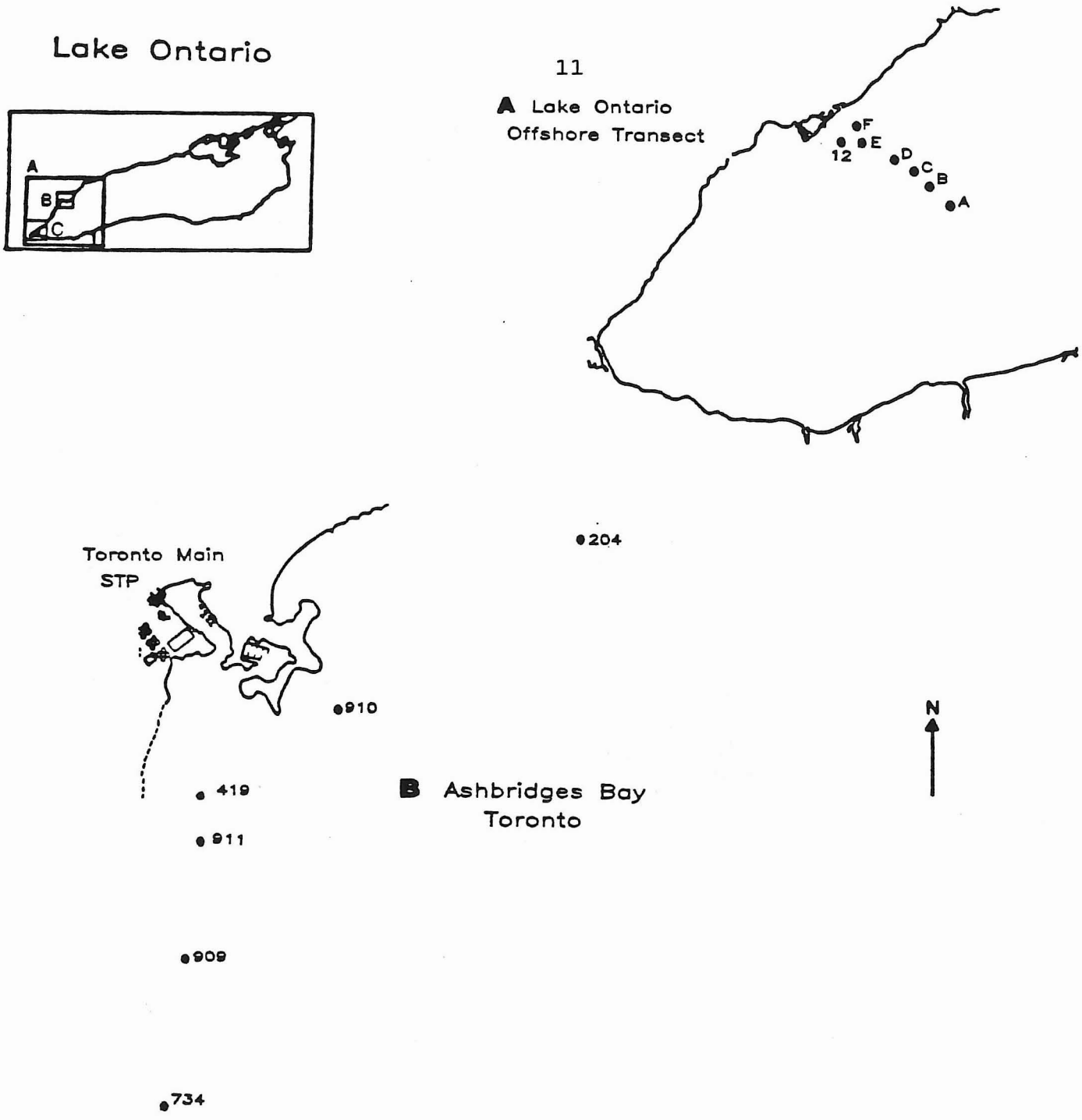
Lake Ontario
A
B
C
A Lake Ontario
Offshore Transect
F
E
12
D
C
B
A
204
Toronto Main
STP
910
N
419
B Ashbridges Bay
Toronto
911
909
734
C Hamilton Harbour
6
2
3
5
1
4

Fig. 2.

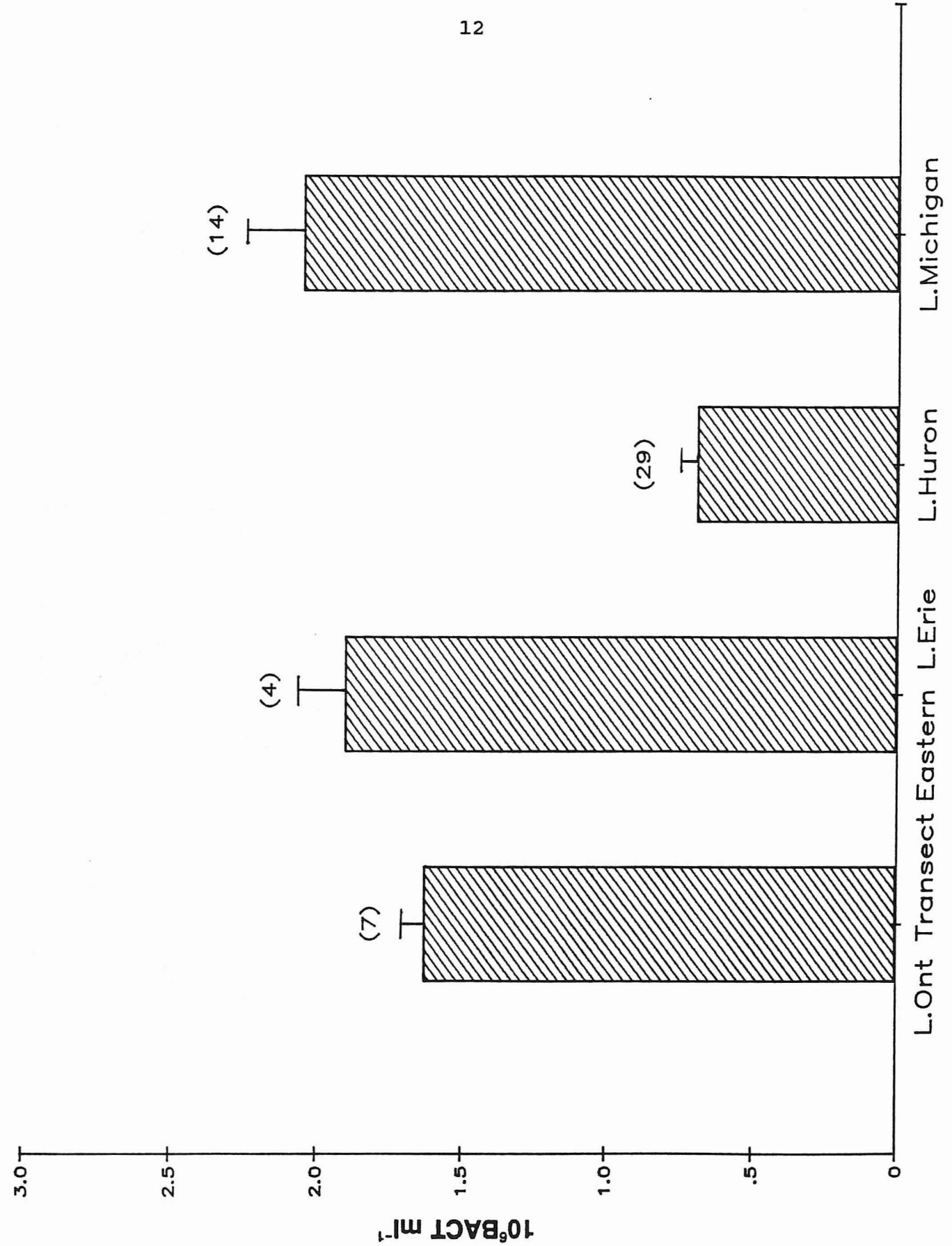
3.0
2.5
2.0
1.5
1.0
.5
0
$10^6$BACT $ml^{-1}$
(7)
(4)
(29)
(14)
L.Ont Transect Eastern
L.Erie
L.Huron
L.Michigan

Fig. 3.

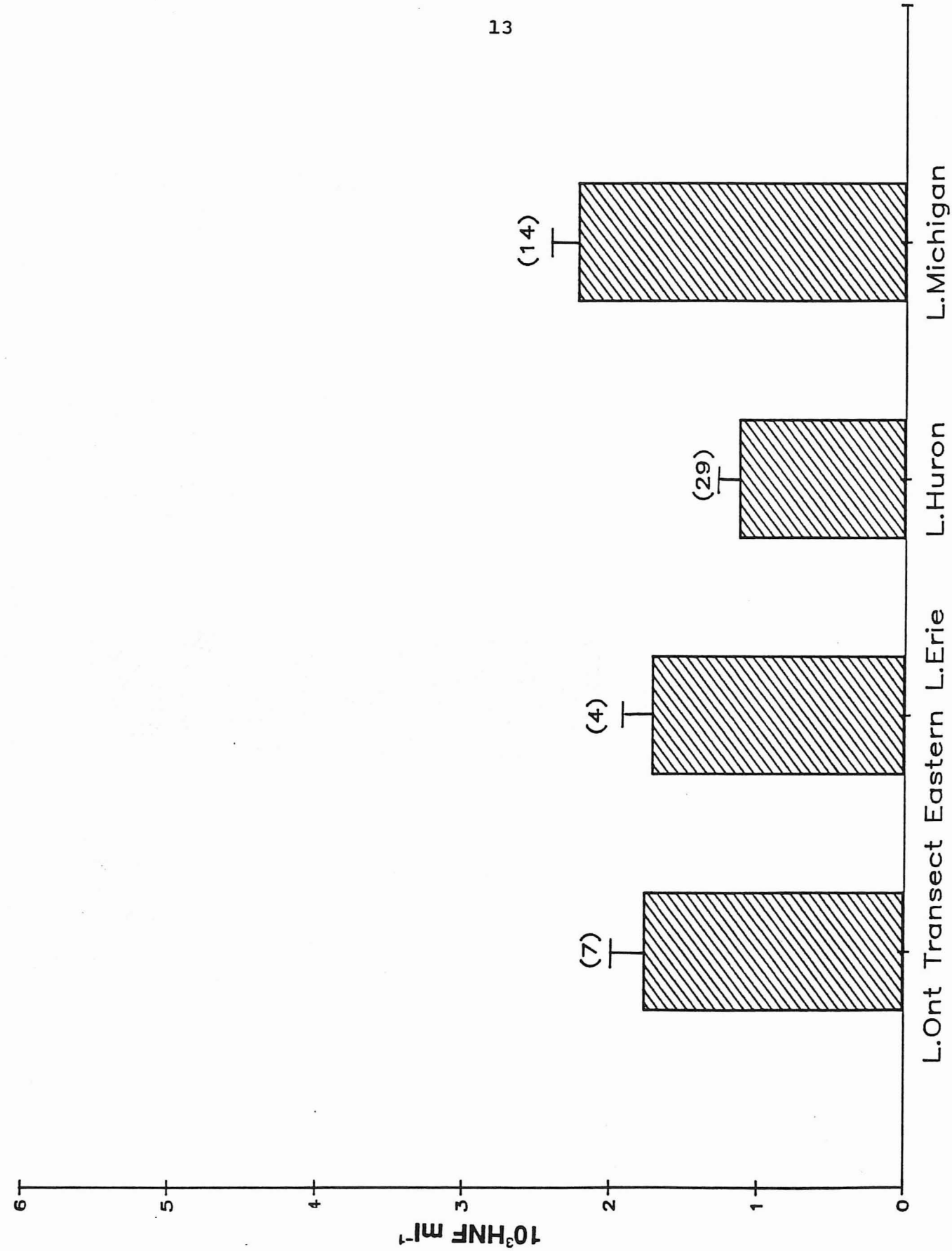
$10^3$HNF $ml^{-1}$
0
1
2
3
4
5
6
(7)
(4)
(29)
(14)
L.Ont
Transect Eastern L.Erie
L.Huron
L.Michigan

Fig. 4.

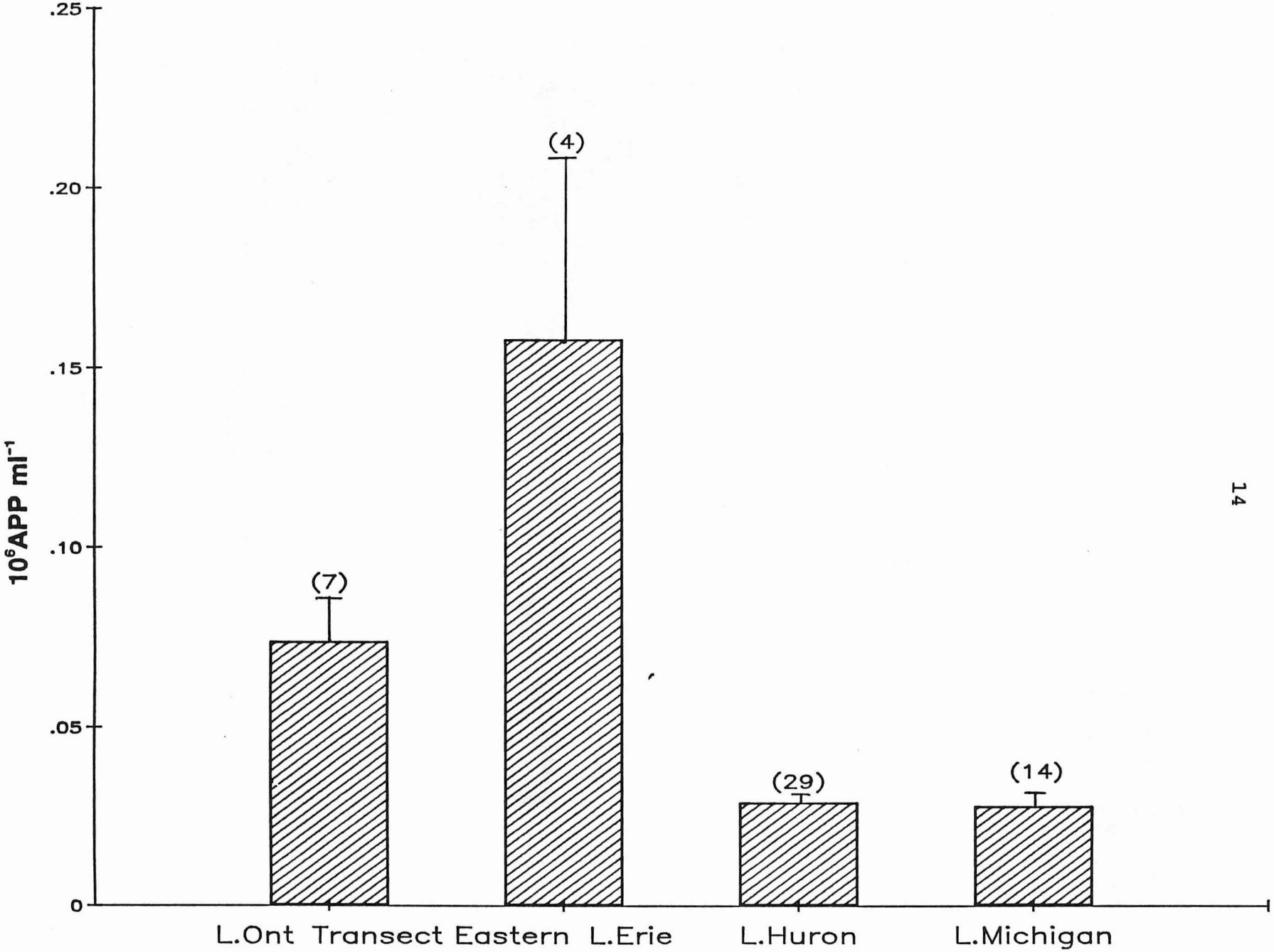
.25
.20
.15
.10
.05
0
$10^6$APP $ml^{-1}$
(7)
(4)
(29)
(14)
L.Ont Transect Eastern
L.Erie
L.Huron
L.Michigan



Fig. 5.

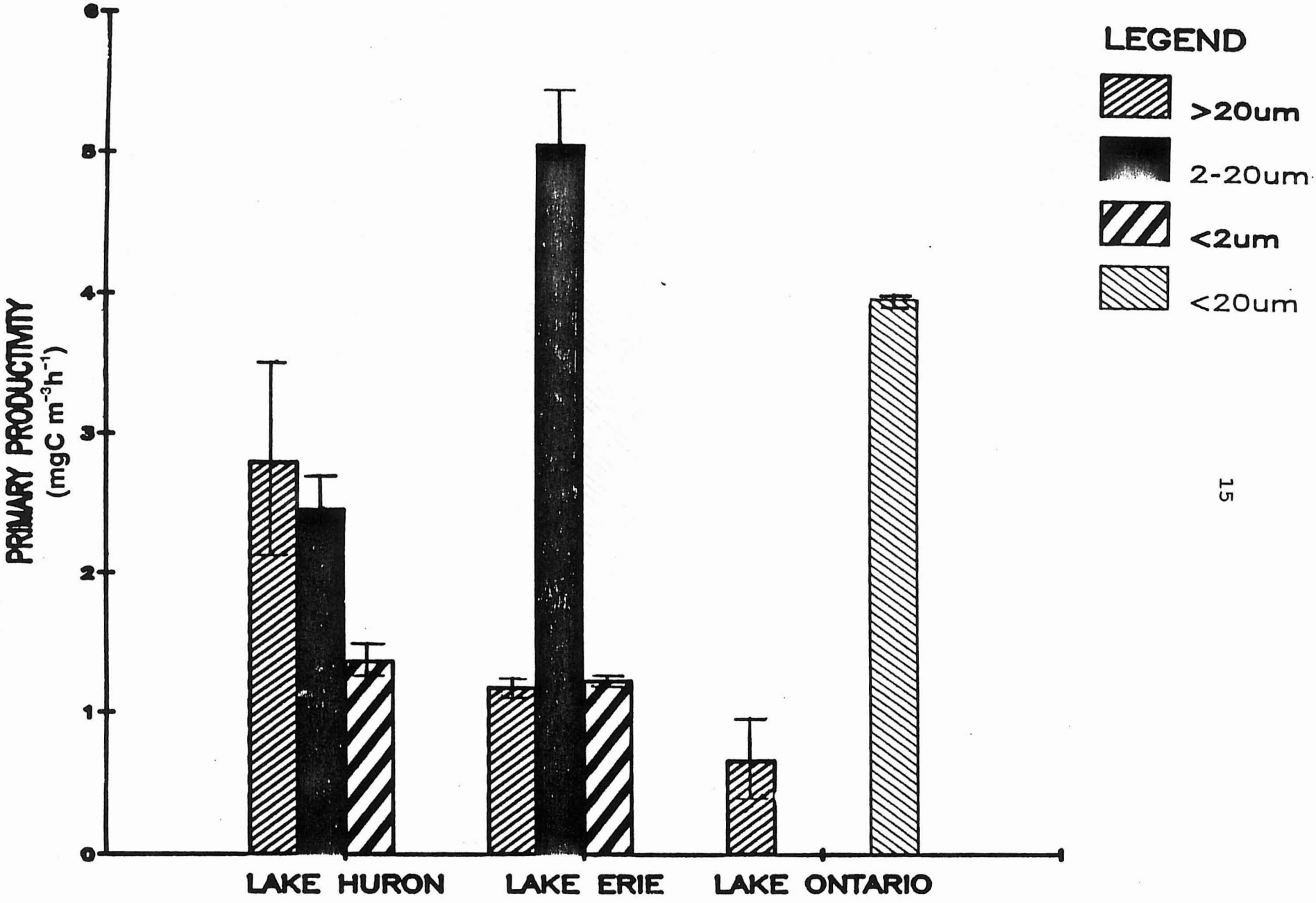
LEGEND
>20um
2-20um
<2um
<20um
PRIMARY PRODUCTIVITY
(mgC m-3h-1)
0
1
2
3
4
5
6
LAKE HURON
LAKE ERIE
LAKE ONTARIO



Fig. 6.

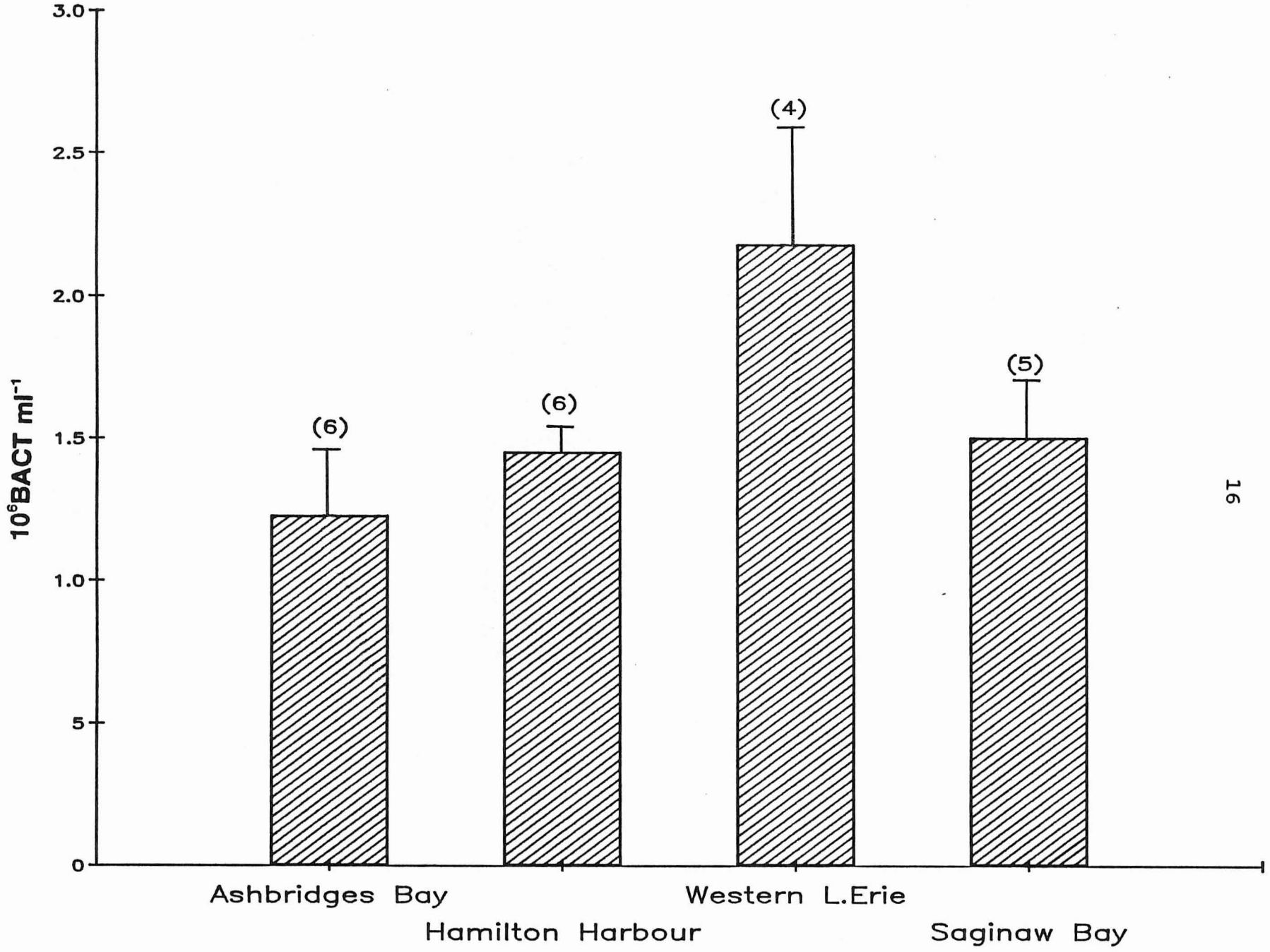
3.0
2.5
2.0
1.5
1.0
5
0
$10^6$BACT $ml^{-1}$
(6)
(6)
(4)
(5)
Ashbridges Bay
Hamilton Harbour
Western L.Erie
Saginaw Bay



Fig. 7.

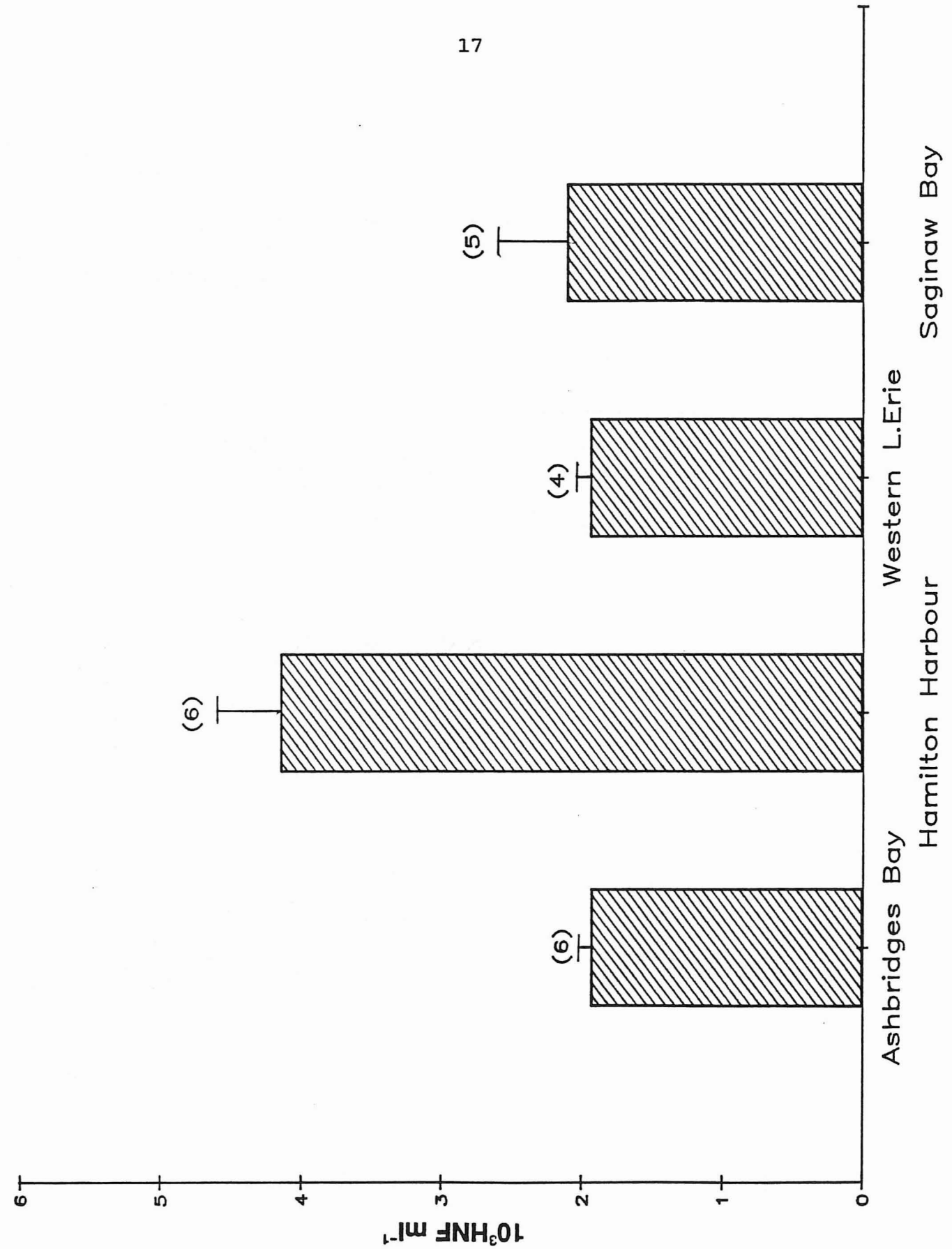
$10^3$HNF ml$^{-1}$
0
1
2
3
4
5
6
(6)
(6)
(4)
(5)
Ashbridges Bay
Hamilton Harbour
Western L.Erie
Saginaw Bay

Fig. 8.

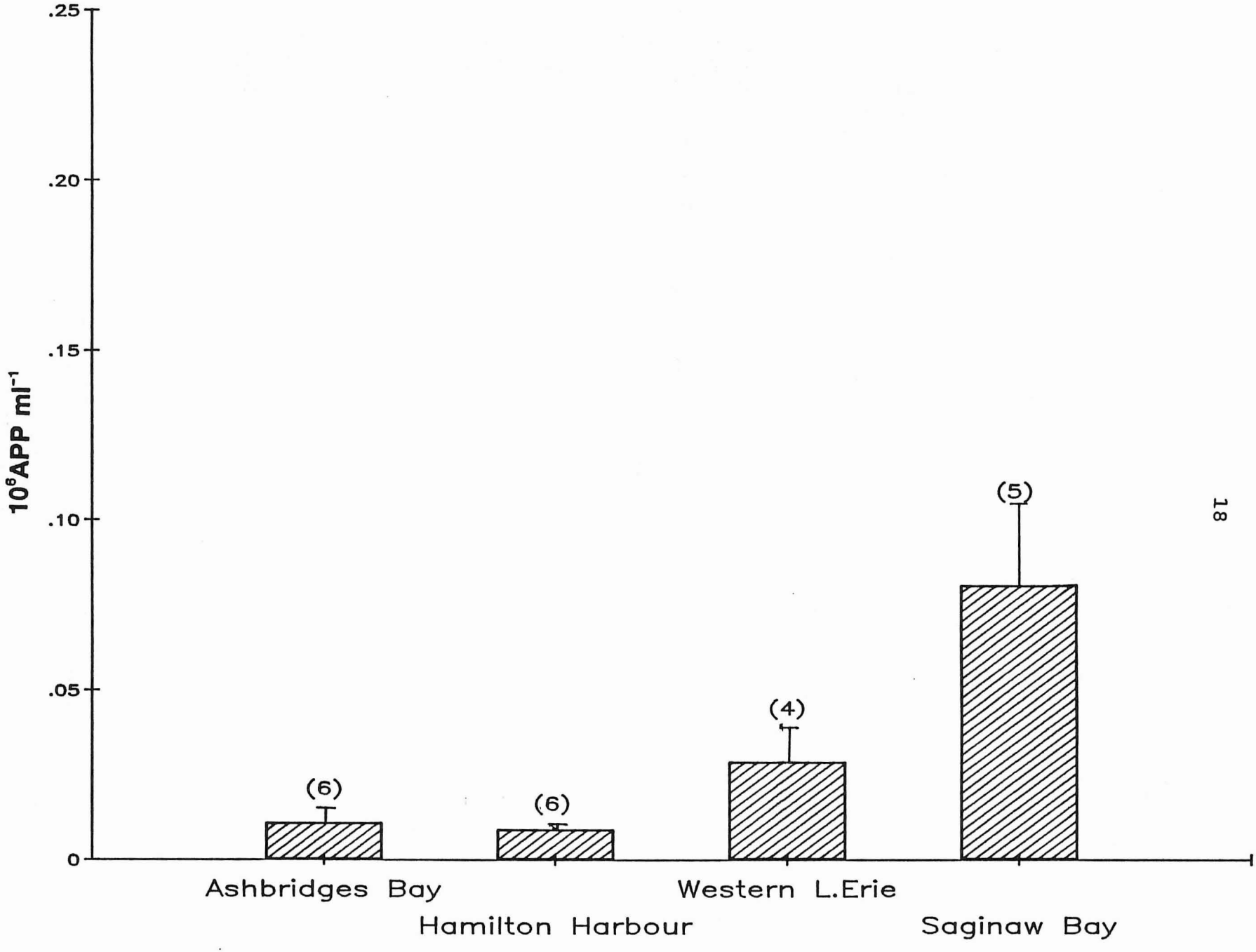
.25
.20
.15
.10
.05
0
$10^6$APP ml$^{-1}$
(6)
(6)
(4)
(5)
Ashbridges Bay
Hamilton Harbour
Western L.Erie
Saginaw Bay



Fig. 9.

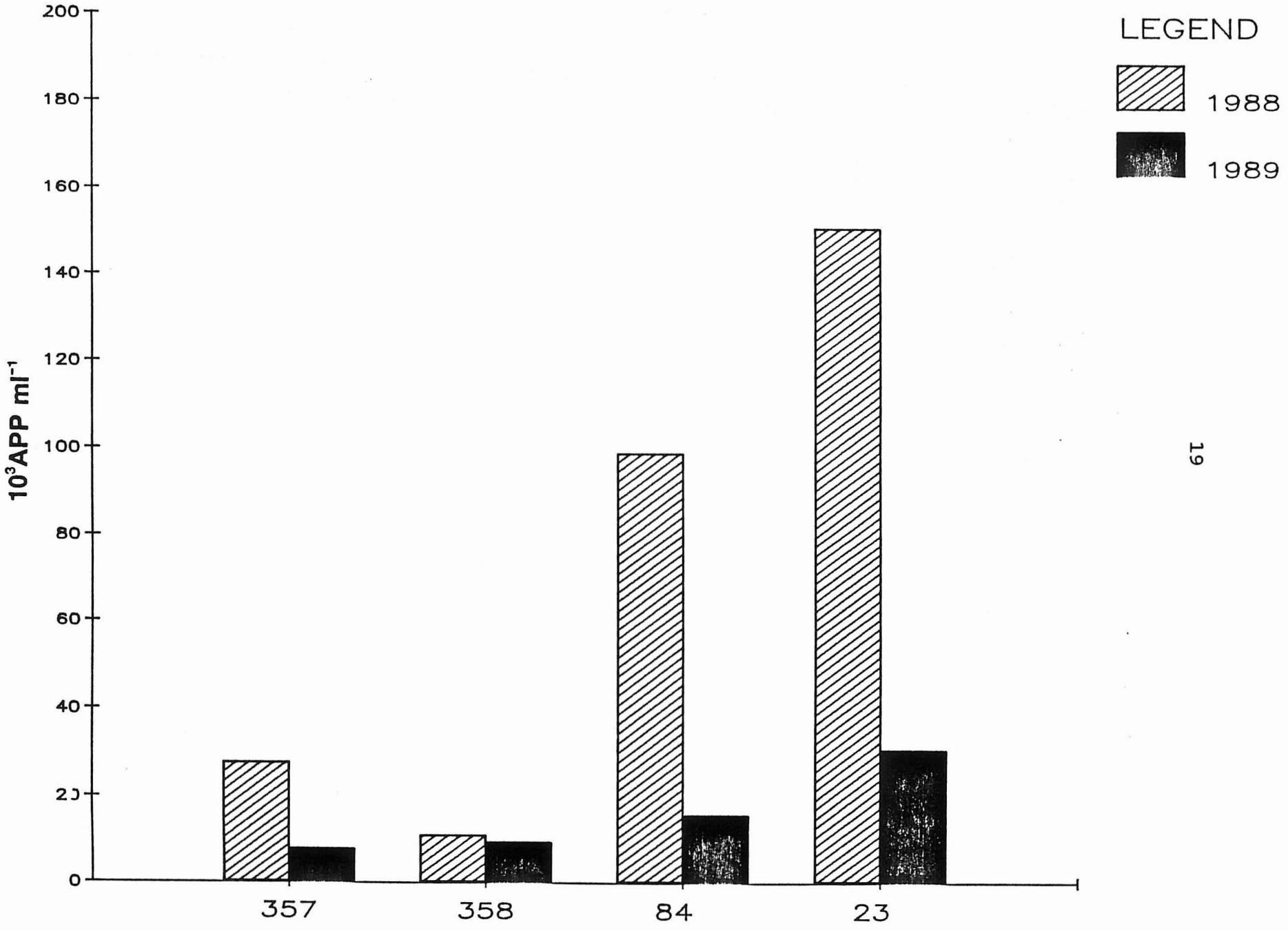
LEGEND
1988
1989
$10^3$APP $ml^{-1}$
200
180
160
140
120
100
80
60
40
20
0
357
358
84
23

Fig. 10.

Table 1. **Abundance of microbial loop components in Lake Ontario during August and September, 1988.**

| STATION | | BACT* | HNF† | APP‡ |
|---|---|---|---|---|
| | | ($10^6$ ml$^{-1}$) | ($10^3$ ml$^{-1}$) | ($10^3$ ml$^{-1}$) |
| **Lake Ontario Offshore** | A | 1.48 | 1.11 | 102.20 |
| | B | 1.71 | 1.30 | 65.40 |
| | C | 1.34 | 2.02 | 83.80 |
| | D | 1.67 | 1.89 | 110.40 |
| | E | 1.60 | 1.24 | 108.30 |
| | F | 1.74 | 2.10 | 30.80 |
| | 1 | 3.35 | 1.93 | 129.10 |
| | 2 | 2.08 | 2.80 | 109.20 |
| | 3 | 2.26 | 2.34 | 75.70 |
| | 12 | 1.90 | 2.78 | 53.10 |
| **Ashbridges Bay, Toronto** | 734 | 0.83 | 1.63 | 6.90 |
| | 909 | 0.80 | 1.76 | 7.70 |
| | 911 | 0.85 | 2.09 | 6.10 |
| | 419 | 1.22 | 1.88 | 6.40 |
| | 910 | 2.25 | 2.17 | 7.00 |
| | 204 | 1.43 | 2.09 | 29.40 |
| **Hamilton Harbour** | 1 | 1.20 | 3.86 | 7.97 |
| | 2 | 1.56 | 5.79 | 11.15 |
| | 3 | 1.22 | 4.88 | 13.55 |
| | 4 | 1.72 | 4.42 | 7.17 |
| | 5 | 1.44 | 2.95 | 7.97 |
| | 6 | 1.58 | 3.00 | 6.37 |

*Bacteria; †Heterotrophic nanoflagellates; ‡Autotrophic picoplankton

Table 2. **Abundance of microbial loop components in Lake Erie during August and September, 1988.**

| STATION | BACT ($10^6$ $ml^{-1}$) | HNF ($10^3$ $ml^{-1}$) | APP ($10^3$ $ml^{-1}$) |
|---|---|---|---|
| 55 | 2.44 | 2.29 | 286.00 |
| 23 | 1.76 | 1.65 | 150.60 |
| 9 | 1.63 | 1.63 | 96.40 |
| 84 | 1.79 | 1.32 | 98.80 |
| 29 | 1.61 | 2.19 | 19.90 |
| 357 | 3.08 | 1.98 | 27.90 |
| 358 | 2.65 | 1.73 | 11.20 |
| 25 | 1.39 | 1.88 | 57.40 |

Table 3. **Abundance of microbial loop components in Lake Huron and Saginaw Bay during August and September, 1988.**

| | STATION | BACT ($10^6$ ml$^{-1}$) | HNF ($10^3$ ml$^{-1}$) | APP ($10^3$ ml$^{-1}$) |
|---|---|---|---|---|
| Lake Huron | 1 | 1.33 | 0.97 | 17.00 |
| | 5 | 0.89 | 0.76 | 16.20 |
| | 8 | 0.90 | 1.56 | 37.80 |
| | 14 | 1.00 | 1.93 | 22.30 |
| | 12 | 1.13 | 3.56 | 22.30 |
| | 32 | 0.94 | 1.05 | 32.70 |
| | 30 | 1.07 | 1.17 | 29.50 |
| | 41 | 0.64 | 1.03 | 22.30 |
| | 48 | 0.75 | 1.56 | 42.70 |
| | 55 | 0.54 | 1.08 | 49.40 |
| | 61 | 0.39 | 0.99 | 42.70 |
| | 65 | 0.51 | 1.12 | 37.00 |
| Saginaw Bay | 101 | 1.63 | 3.19 | 98.80 |
| | 101A | 1.86 | 3.30 | 160.20 |
| | 100 | 1.04 | 1.63 | 47.80 |
| | 98 | 1.97 | 1.58 | 54.20 |
| | 95 | 1.03 | 0.86 | 42.20 |

Table 4. **Abundance of microbial loop components in the North Channel during August and September, 1988.**

| STATION | BACT ($10^6$ ml$^{-1}$) | HNF ($10^3$ ml$^{-1}$) | APP ($10^3$ ml$^{-1}$) |
|---|---|---|---|
| 77 | 0.64 | 1.32 | 40.20 |
| 69 | 0.40 | 0.65 | 20.70 |
| 71 | 0.40 | 0.44 | 30.40 |
| 79 | 0.48 | 0.95 | 27.80 |
| 82 | 0.71 | 0.68 | 26.60 |
| 89 | 0.81 | 0.91 | 54.70 |

Table 5. **Abundance of microbial loop components in Georgian Bay during August and September, 1988.**

| STATION | BACT ($10^6$ ml$^{-1}$) | HNF ($10^3$ ml$^{-1}$) | APP ($10^3$ ml$^{-1}$) |
|---|---|---|---|
| 42 | 0.72 | 0.54 | 55.20 |
| 27 | 0.68 | 0.81 | 18.10 |
| 29 | 0.53 | 1.25 | 26.30 |
| 35 | 0.54 | 0.81 | 33.50 |
| 31 | 0.88 | 0.61 | 19.70 |
| 17 | 0.43 | 0.71 | 14.30 |
| 15 | 0.55 | 1.59 | 12.70 |
| 9 | 0.64 | 1.29 | 12.70 |
| 43 | 0.61 | 0.54 | 15.90 |
| 6 | 0.56 | 1.32 | 19.70 |
| 45 | 0.46 | 1.69 | 31.30 |

Table 6. **Abundance of microbial loop components in Lake Michigan during October, 1988.**

| STATION | BACT ($10^6$ $ml^{-1}$) | HNF ($10^3$ $ml^{-1}$) | APP ($10^3$ $ml^{-1}$) |
|---|---|---|---|
| 1 | 2.12 | 2.26 | 25.47 |
| 2 | 1.97 | 1.81 | 31.71 |
| 3 | 2.66 | 2.68 | 59.74 |
| 5 | 2.55 | 3.13 | 34.37 |
| 7 | 2.88 | 1.39 | 25.42 |
| 8 | 1.96 | 2.88 | 33.89 |
| 9 | 0.7 | 2.75 | 0.97 |
| 10 | 2.12 | 2.95 | 29.05 |
| 11 | 1.92 | 1.56 | 8.96 |
| 12 | 2.60 | 2.71 | 23.96 |
| 13 | 1.73 | 2.19 | 17.43 |
| 14 | 1.07 | 1.91 | 28.08 |
| 15 | 1.42 | 3.09 | 25.66 |
| 16 | 2.97 | 1.67 | 53.93 |

Table 7. **Abundance of microbial loop components in Lake Ontario during August, 1989.**

| | STATION | BACT ($10^6$ $m^{-1}$) | HNF ($10^3$ $m^{-1}$) | APP ($10^3$ $ml^{-1}$) |
|---|---|---|---|---|
| **Lake Ontario Offshore** | A | 1.30 | 1.69 | 93.0 |
| | C | 1.53 | 1.25 | 122.7 |
| | F | 1.75 | 2.68 | 108.9 |
| **Ashbridges Bay, Toronto** | 734 | 1.40 | 1.80 | 34.0 |
| | 909 | 1.45 | 0.92 | 35.8 |
| | 419 | 1.87 | 2.98 | 66.6 |
| | 431 | 2.09 | 2.10 | 77.6 |
| | 910 | 1.49 | 1.25 | 60.8 |
| | 204 | 1.15 | 0.92 | 47.5 |

Table 8. **Abundance of microbial loop components in Lake Erie during August, 1989.**

| STATION | BACT ($10^6$ ml$^{-1}$) | HNF ($10^3$ ml$^{-1}$) | APP ($10^3$ ml$^{-1}$) |
|---|---|---|---|
| 23 | 1.19 | 0.81 | 30.81 |
| 84 | 1.04 | 0.68 | 15.94 |
| 357 | 0.89 | 0.44 | 7.97 |
| 358 | 1.23 | 0.68 | 9.56 |

Table 9. **Abundance of microbial loop components in Lake Huron and Saginaw Bay during August, 1989.**

| | STATION | BACT ($10^6$ ml$^{-1}$) | HNF ($10^3$ ml$^{-1}$) | APP ($10^3$ ml$^{-1}$) |
|---|---|---|---|---|
| **Lake Huron** | 33 | 0.52 | 0.78 | 8.76 |
| | 23 | 0.45 | 1.73 | 5.49 |
| | 20 | 0.51 | 2.18 | 4.89 |
| **Saginaw Bay** | 94 | 0.57 | 1.32 | 12.62 |
| | 95 | 0.87 | 0.51 | 5.44 |
| | 96 | 0.44 | 1.25 | 6.16 |
| | 97 | 0.67 | 1.97 | 9.16 |
| | 98 | 0.63 | 0.54 | 4.25 |
| | 99 | 0.89 | 0.81 | 15.05 |
| | 100 | 1.16 | 1.19 | 33.78 |
| | 101 | 0.85 | 0.64 | 20.85 |

Table 10. **Size-fractionated primary productivity ($mgC \cdot m^{-3}h^{-1}$) at offshore stations of Lake Huron during August and September, 1988.**

| Station | >20μm | 20-20μm | <2.0μm |
|---|---|---|---|
| 1 | 3.1 | 2.7 | 1.82 |
| 5 | 1.16 | 2.2 | 0.98 |
| 8 | 2.5 | 2.4 | 1.14 |
| 14 | 2.95 | 3.4 | 2.8 |
| 12 | 1.3 | 2.1 | 1.9 |
| 94 | 3.16 | 3.7 | 3.5 |
| 41 | 16.4 | 4.5 | 1.5 |
| 55 | 1.9 | 2.8 | 0.9 |
| 61 | 2.4 | 2.1 | 1.4 |
| 65 | 0.8 | 1.1 | 3.1 |
| 69 | 0.9 | 3.1 | 0.9 |
| 71 | 3.0 | 0.8 | 2.7 |
| 77 | 6.9 | 2.0 | 1.7 |
| 79 | 0.9 | 2.7 | 0.76 |
| 82 | 1.7 | 0.8 | 2.5 |
| 89 | 1.9 | 5.4 | 0.15 |
| 42 | 4.5 | 2.9 | 1.6 |
| 27 | 1.8 | 1.4 | 0.75 |
| 29 | 1.9 | 1.9 | 0.61 |
| 35 | 1.5 | 2.3 | 1.15 |
| 31 | 1.8 | 2.0 | 1.27 |
| 17 | 1.16 | 1.9 | 0.81 |
| 15 | 1.6 | 2.3 | 0.42 |
| 9 | 6.9 | 4.5 | 0.7 |
| 43 | 0.96 | 2.08 | 0.9 |
| 6 | 1.8 | 1.9 | 0.8 |
| 45 | 0.92 | 1.7 | 0.6 |

Table 11. **Size-fractionated primary productivity ($mgC \cdot m^{-3}h^{-1}$) at offshore stations of Lakes Erie and Ontario during August and September, 1988.**

| Lake/Station | >20μm | 2-20μm | <2μm |
|---|---|---|---|
| **Lake Erie** | | | |
| 55 | 0.73 | 4.7 | 1.5 |
| 23 | 0.84 | 5.0 | 1.04 |
| 9 | 1.23 | 6.84 | 1.31 |
| 84 | 1.96 | 3.85 | 1.14 |
| **Lake Ontario** | | | |
| 1 | 0.98 | 4.65 | 1.43 |
| 2 | 0.74 | 3.38 | 0.95 |
| 3 | 1.02 | 3.54 | 0.97 |

| | >20μm | <20μm |
|---|---|---|
| 12 | 0.7 | 3.7 |
| A | 0.6 | 3.9 |
| B | 0.7 | 4.6 |
| C | 0.7 | 4.6 |
| D | 0.7 | 4.2 |
| E | 0.7 | 4.4 |
| F | 0.6 | 2.7 |