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Great Lakes Fisheries Research Branch

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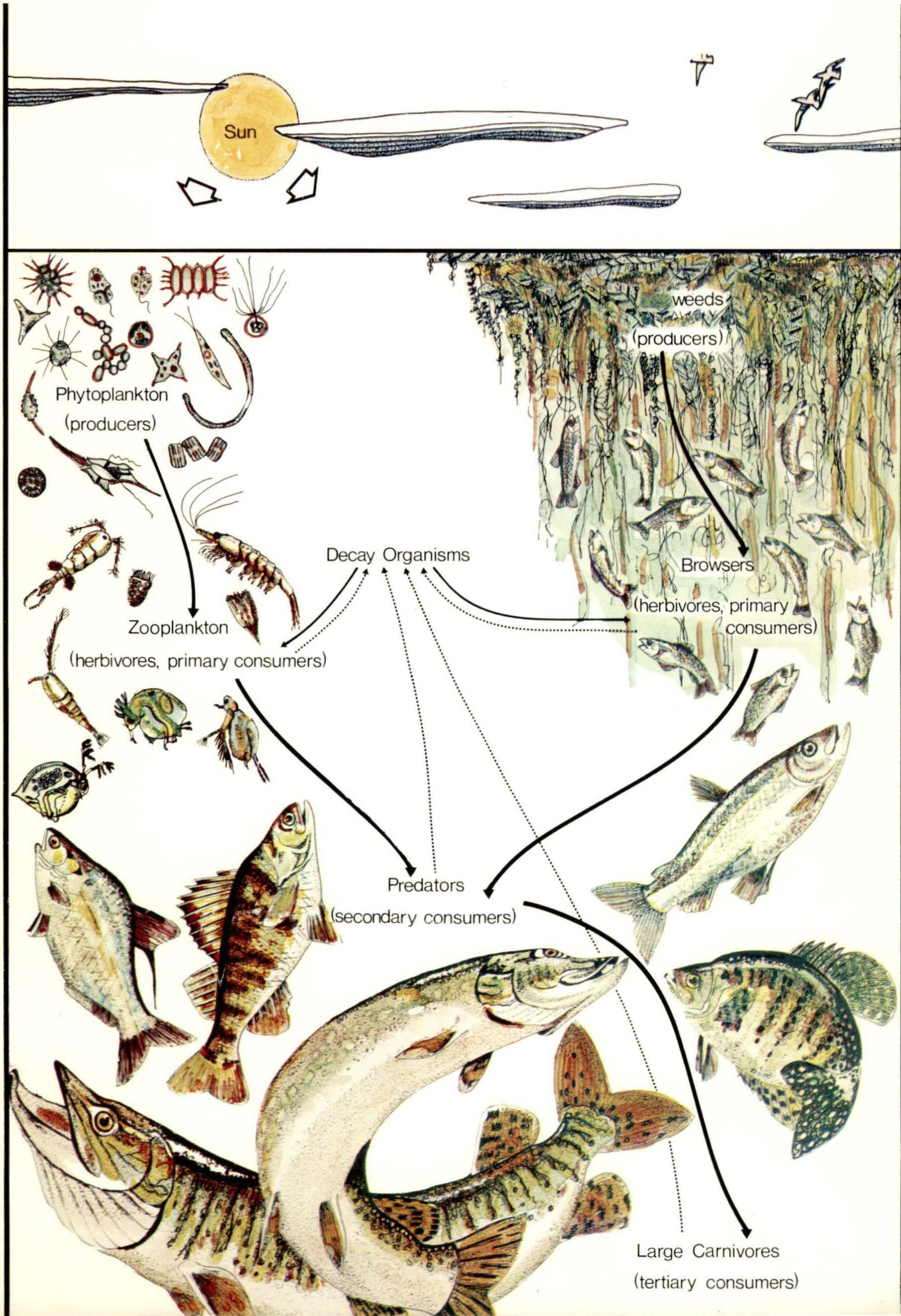

GREAT LAKES FISHERIES

RESEARCH BRANCH

ANNUAL REVIEW 1981

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DIRECTOR'S INTRODUCTION

The Great Lakes Fisheries Research Branch, until recently the Great Lakes Biolimnology Laboratory, is the research wing of the Ontario Region of the Pacific and Freshwater Fisheries of the Department of Fisheries and Oceans.

From its initiation in 1967 as a detachment of the Freshwater Institute at Winnipeg it has expanded over the years to an organization of 44 persons with a budget of approximately two million dollars.

The Laboratory's beginnings as a discrete entity in 1973 followed the signing of the Great Lakes Water Quality Agreement by Canada and the United States. The 1978 revision and re-signing of this bilateral Agreement resulted in an upgrading of the Laboratory's strength to meet increasing biological concerns in the Great Lakes. This Agreement remains the major mandate of the Branch though additional responsibilities are incurred under the Fisheries Act.

The GLFRB program is intimately involved with the other components of Great Lakes research conducted by a number of federal services of the Department of the Environment, e.g., National Water Research Institute, Ontario Region of the Inland Waters Directorate, Environmental Protection Service, Canadian Wildlife Service, National Health and Welfare, and provincial agencies such as Ontario Ministry of Natural Resources and Ministry of the Environment. Through further involvement with the International Joint Commission and the Great Lakes Fishery Commission, the Branch has direct dealings with U.S. federal and state agencies involved in Great Lakes research.

During 1980 the Branch incepted a regional research program on the effects of atmospheric loadings of contaminants on lake ecosystems, in particular the effects on fish populations. In 1981 this research became a component of the National Departmental Program on Acid Rain and the Branch has maintained a lead role in the description of effects based on a National Lake Inventory Survey being conducted by the regional groups in the Department.

GLFRB's major program on the Great Lakes is conducted under three program areas defined as Surveillance, Environmental Toxicology, and Ecosystems, with the conduct of the Acid Rain Program under Ecosystems.

The results of individual projects within these three program areas are given in the following descriptions of the Laboratory's activities, stressing the results of projects in the fiscal year 1981-1982.

R.L. Thomas
15 October, 1982

SURVEILLANCE

Program Leader - Dr. H. Shear.

INTRODUCTION

In response to specific requirements of the Great Lakes Water Quality Agreement (1972 and 1978), the surveillance program of GLFRB has evolved from the earlier descriptive biology program to one which now consists of four components:

(A) biological monitoring;

(B) contaminants surveillance in biota;

(C) fish health studies;

(D) phycological studies.

In addition to satisfying the very specific requirements of the Great Lakes Water Quality Agreement, the surveillance program has been developing a major input to the Great Lakes Fishery Commission through specific studies of the effects of environmental stress on fish health, and through reporting of levels of contaminants in biota (components (B) and (C) above).

The contaminants surveillance program has provided some very valuable data to the I.J.C. on contaminant levels in fish. There appears to be a downward trend in PCB and DDT concentrations in fish tissue over the years (1977-1981) in Lake Ontario, for example. This program has also produced data on levels of dioxins in fish and has been instrumental in developing the current guideline for dioxins considered safe for human consumption.

A new problem, that of toxaphene in Lake Superior, appears to be arising. Levels in whole fish range from 0.4 to 6.0 ppm in fish taken from Thunder Bay in 1980. Work on this compound is continuing.

Phycological studies on the Great Lakes have moved away from the routine identification and enumeration of phytoplankton to studies on the ecology of nannoplankton (very small algal species). Experiments are under way to determine the effects of trace metals on nannoplankton and the implications that this has on zooplankton grazing and contaminant dynamics.

New work initiated recently is looking at the development of an algal bioassay technique to assess the impact of dredge spoil disposal on natural phytoplankton communities.

The surveillance group consists of four biologists, one research scientist, and four technicians. Logistical support for surveillance activities is provided by the Bayfield Laboratory for Marine Sciences and Surveys (Canada Department of Fisheries and Oceans), the National Water Research Institute (Canada Department of the Environment), and the Ontario Ministry of Natural Resources.

General descriptions of the major projects in surveillance are given below.

A. Biological Monitoring

(1) Long-term biological index monitoring. Project Leader - Dr. H. Shear

It had been recognized for some time within the Department, that the present method of surveillance was outdated and costly, and was largely addressing water quality issues with little emphasis on fisheries issues. The practice of major surveys on the Great Lakes satisfied the needs of the International Joint Commission (IJC) and the research community in the early 1970's. However, the needs of the 1980's are quite different. We are in a phase of taking the pulses of the lakes, rather than giving them a major examination several times a year.

In an ideal situation, surveillance could be achieved with remote instrument platforms stationed at critical areas of the lake. These could measure chemical and biological parameters on a continuing basis, giving one a snapshot of the lake at any one time. This approach is clearly years away, but GLFRB has taken an initial step which goes part way towards this strategy. We sample a very few stations (in Lake Ontario initially) on a weekly basis. The routine chemistry is carried out similar to that on the major surveys. In addition, phytoplankton, zooplankton, and benthic samples are collected for identification, enumeration, and biomass estimation.

It is the intent that two major outputs result from this project:

(i) a major refinement of the time scale of processes in Lake Ontario, resulting in an optimum sampling strategy for the surveillance program;

(ii) information which will permit some modelling of productivity of the lake, with the goal of estimating potential fisheries production.

The project was initiated in March 1981 and the field season ended in mid-December. Most data are still undergoing analysis by GLFRB staff and colleagues in NWRI and will be available for study at a later date.

It is hoped that with a second year of data in Lake Ontario in 1982, the potential of the project will have been realized and the work will be extended into Lake Erie.

(2) Lake Superior study on factors affecting phytoplankton productivity. Project Leader - Dr. H. Shear

It has long been assumed that phosphorus was the factor limiting phytoplankton productivity in the Great Lakes. So strong was this belief, that an entire management program was developed and implemented around control of phosphorus inputs to the Great Lakes. For Lakes Ontario and Erie this assumption has proved to be correct; however, for Lake Superior there was some speculation that physical factors (e.g., light, temperature) may be more important in limiting the physiological responses of the phytoplankton community.

In August and September, 1979, GLFRB made use of a ship of opportunity (CSS Bayfield) to carry out some basic experiments measuring primary production and phosphorus kinetics at two nearshore (Rossport and Terrace Bay) and two offshore stations in Lake Superior. The results of this work suggest that the phosphorus turnover times were inconsistent with a severe phosphorus limitation in Lake Superior (Nalewajko et al., 1981). The results indicated that light intensity was probably the limiting factor for phytoplankton growth at these stations. Table 1 shows some of the parameters measured on these two cruises. In particular, the N:P ratios and phosphate turnover times are not consistent with published values for phosphorus-stressed communities. Parallel laboratory experiments confirmed that the phosphorus kinetics and primary production curves were indicative of a low-light adapted population.

During 1980 and 1981, extensive research was carried out in the Canadian Great Lakes to verify our hypotheses regarding light and temperature as factors limiting productivity. Preliminary analysis of the data indicates that there is a negative correlation between phosphorus turnover times and temperature up to about 10°C (Fig. 1). This would be highly significant in Lake Superior where

TABLE 1. Physical, chemical, and biological characteristics at four stations in Lake Superior in summer 1979

		Stn 1 Inshore	Stn 2 Offshore	Stn 3 Offshore	Stn 4 Inshore
		Rossport 48°45'36"N 87°31'30"W	48°15'54"N 87°13'54"W	47°59'12"N 87°14'00"W	Terrance Bay 48°42'36"N 87°06'36"W
Phytoplankton biomass $g\ m^{-3}$	Aug 6	0.46	0.19	0.12	0.30
	Sept 3-4	0.29	0.37	0.41	0.48
Chlorophyll a $\mu g\ l^{-1}$	Aug 6	1.74	1.02	0.8	1.38
	Sept 3-4	1.6	0.4	0.22	0.73
Total phosphorus $\mu g\ l^{-1}$	Aug 6	4	3	2	3
	Sept 3-4	2.1	5	5	4
Seston N:P atomic ratio	Aug 6	-	-	-	-
	Sept 3-4	13:1	8:1	10:1	12:1
TP:chl <u>a</u>	Aug 6	2.5:1	7.5:1	9.1:1	4.1:1
	Sept 3-4	1.2:1	4.9:1	5:1	3.6:1
Phosphate turnover time (min) from $^{32}PO_4$-P uptake kinetics (1/K) at 1 m	Aug 6	36.5	32.3	33.6	29.1
	Sept 3-4	18.9	14.4	18.9	14.8
Epilimnion: Depth			17 m	16 m	25 m
Temp.			12°C	12°C	12°C
Photic zone (1% light approx.)		25 m	29 m	29 m	25 m

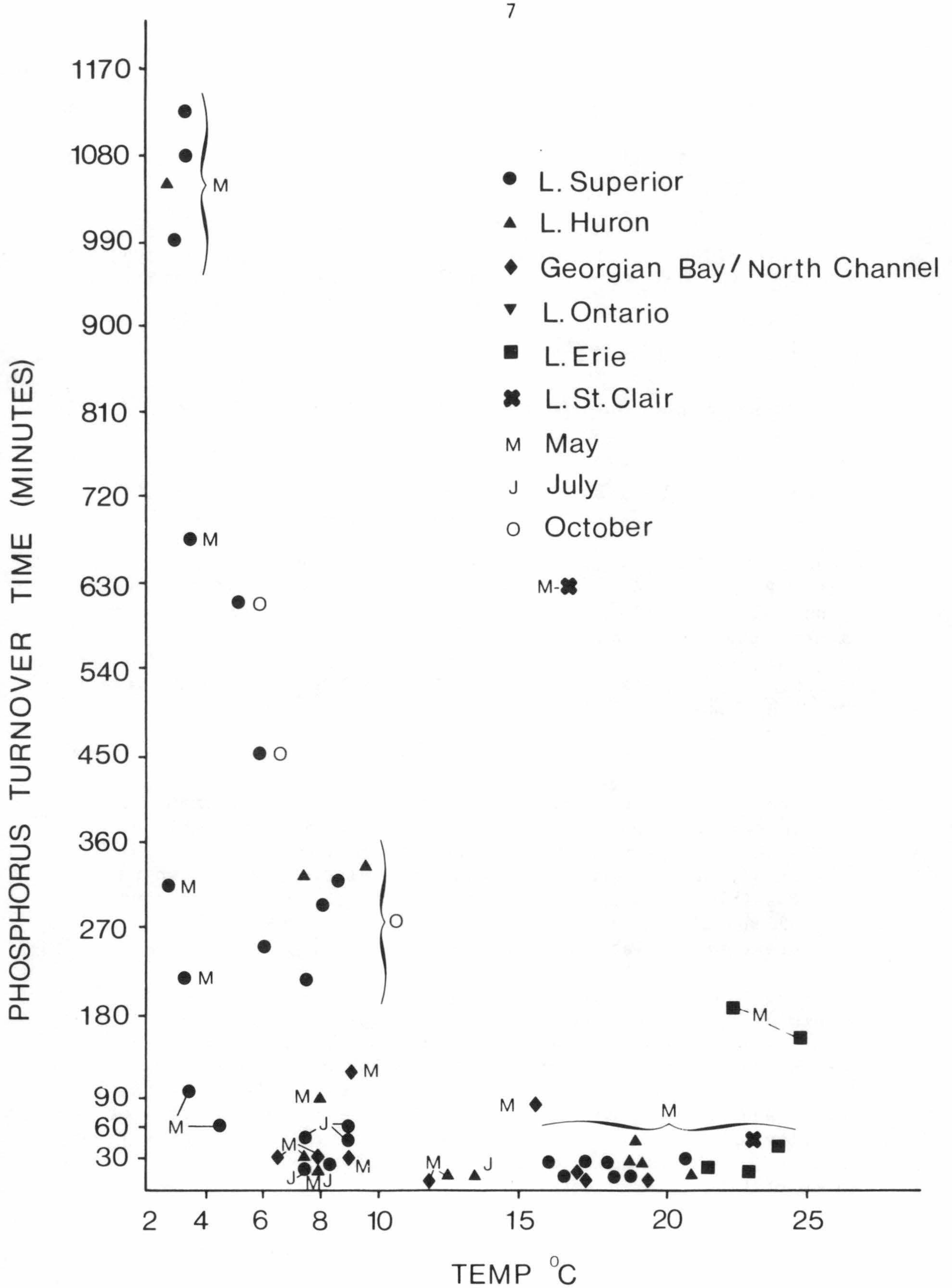

Fig. 1 Phosphorus turnover time (in minutes) as a function of water temperature.

the mean temperature in the photic zone (25 to 30 m) is below 10°C for most of the year (Bennett, 1978). Data for the 1980 cruises on Lake Superior are given in Table 2, and station locations in Fig. 2. The results of these cruises also indicate significant seasonal and spatial variabiity in phosphorus kinetics.

Data analysis on this project is continuing. It is planned to carry out additional research in this area in 1983 in conjunction with the intensive surveillance of Lake Superior in that year.

B. Contaminants Surveillance in Biota

(1) *Great Lakes international fish contaminants surveillance program. Project Leader - Mr. D.M. Whittle. Technician - J. Fitzsimons*

Introduction - The fish contaminants surveillance program is part of an International Joint Commission program on the Great Lakes, jointly carried out by the Canadian Department of Fisheries and Oceans, the U.S. Fish and Wildlife Service, and the U.S. Environmental Protection Agency. The Canadian portion of the program is conducted by GLFRB in cooperation with the Ontario Ministry of Natural Resources, and complements fish contaminants monitoring programs established by the Ontario Ministry of the Environment and various environmental agencies of the United States bordering on the Great Lakes.

The overall objective of the program can be stated as follows:

> 'to collectively survey the concentration of contaminants in selected species of Great Lakes fish and other biota, with the specific purpose of determining environmental trends in contaminant levels and relating these, where possible, to sources of such pollution, the effectiveness of remedial actions, and the potential implications to Great Lakes fish stocks and other biota'.

The Canadian portion of the program initially concentrated on determining baseline contaminant levels for several species of fish from Lakes Ontario and Erie, as well as plankton and benthic invertebrates from sites on the Lower Lakes. Subsequently, the program was expanded to cover several sites in Lake Superior, Lake Huron, and Georgian Bay. Further, with the recent concern for the security of toxic chemical disposal sites on the Niagara River, increased emphasis has been placed on the monitoring of the western basin of Lake Ontario (Fig. 3).

TABLE 2. Ptt, TP and C fixed at stations in the eastern half of Lake Superior, 1980 (see Fig. 2 for location of stations)

	Station								
	A	B	C	D	E	F	G	H	I
Phosphorus turnover time (min)									
May	672	-	-	1134	-	1081	-	1002	61.5
July	32	17	23.8	-	-	55.4	-	-	29.3
October	217	306	-	-	456	612	262	322	-
Total P $\mu g\ l^{-1}$									
May	4.0	-	-	4.0	-	4.0	-	4.0	4.0
July	5.0	4.0	4.0	-	-	4.0	-	-	5.0
October	3.0	7.0	-	-	3.0	3.0	3.0	5.0	-
C fixed $\mu g\ C\ l^{-1}\ h^{-1}$									
May	1.11	-	-	0.54	-	0.74	-	0.81	1.42
July	0.22	1.18	0.62	-	-	0.68	-	-	2.33
October	1.12	2.07	-	-	1.96	1.82	1.01	-	-

Fig. 2 Location of stations, eastern Lake Superior, 1980.

Fig. 3 Collection sites, fish contaminants surveillance program.

Lake trout and rainbow smelt were chosen as representative top predators and forage species, respectively. Where lake trout were not abundant, other locally available top predator species, such as rainbow trout, walleye, splake, or coho salmon, were substituted.

All top predator species were analyzed on an individual whole fish basis, while smelt samples were analyzed as five-fish composites. Table 3 indicates the range of routine and non-routine contaminants monitored. Non-routine contaminants were monitored at selected sites using the largest top predator samples available, while routine analyses were performed on all samples at every site monitored.

Trends - The trends in contaminant burdens for some of the routine compounds in top predator and forage fish species are described in Table 4. During the period of the program only DDT has shown a significant decline in both types of fish species. This continuing decline reflects the length of time DDT usage has been regulated in the Great Lakes basin. Table 4 also compares body burdens of organic and inorganic contaminants in fish collected from offshore sites in the Upper and Lower Great Lakes. Organic contaminant concentrations were consistently lower for both top predator and forage fish species from the Upper Lakes. Only mercury values from Lake Superior were greater than those values reported for Lower Lakes fish. This may result from the historical pollution associated with the pulp and paper industry concentrated along the north shore of Lake Superior.

As long-lived, high lipid content, and open lake integrators, lake trout are effective indicators of lake-wide contaminant levels. Within the Great Lakes they also provide an excellent means of both intra- and inter-lake comparisons of contaminant trends. Table 5 compares contaminant burdens in a single age-class (4+) of lake trout collected in 1980 from the primarily agricultural eastern basin of Lake Ontario, the industrialized western basin of Lake Ontario, a site in the northern portion of Lake Huron, and a site near Pie Island on the outer perimeter of Thunder Bay, Lake Superior. Levels of persistent organic compounds were significantly lower in the Lake Superior fish, while mercury values were only slightly higher, as compared with the other three areas. In order to provide a longer term perspective on trends in contaminant burdens, current data can be compared to similar data from historical surveys. Table 6 offers a comparison of the change in a range of various contaminants for Lake Superior lake trout monitored in 1974 and again in 1980. Over this period, levels of persistent organic compounds have decreased significantly while the decrease in trace metal levels is not as dramatic, and may only reflect analytical variability.

TABLE 3. Routine and non-routine contaminants monitored

Routine Contaminants Monitored	
PCB	Hg
Mirex	As
p,p'-DDE	Se
p,p'-DDD	Cu
p,p'-DDT	Zn
o,p'-DDT	Ni
Dieldrin	Cr
Heptachlor Epoxide	Cd
Chlordane	Pb

Non-Routine Contaminants Monitored
Octachlorostyrene
PCT
PBB
Chlorinated Benzenes
Chlorinated Phenols
Mirex Photodecomposition Products
Chlorinated Diphenyl Ethers
Organolead
Polychlorinated Dibenzodioxins
Polychlorinated Dibenzofurans
Toxaphene

TABLE 4. Open lake whole fish contaminants data ($\mu g\ g^{-1}$) 1977-80

		Lake Ontario				Lake Erie				Lake Huron				Lake Superior			
Species	Year	N	ΣDDT	PCB	Hg	N	ΣDDT	PCB	Hg	N	ΣDDT	PCB	Hg	N	ΣDDT	PCB	Hg
Lake Trout	1977	(42)	2.66	4.95	0.17												
	1978	(141)	1.16	7.10	0.19												
	1979	(176)	1.58	3.79	0.17					(49)[2]	0.20	0.78	0.16				
	1980	(110)	0.62	4.79	0.21					(47)	0.49	0.92	0.14	(50)	0.35	0.85	0.32
Coho Salmon	1977	(82)	1.43	3.03	0.16	(20)	0.55	0.91	0.14								
	1978	(99)	0.64	3.00	0.10	-	-	-	-								
	1979	(25)	0.81	1.21	0.11	(23)	0.19	1.07	0.09								
	1980	(26)	0.74	2.30	0.12	(33)	0.26	0.65	0.11								
Smelt	1977	(38)[1]	0.60	1.50	0.08	(85)[1]	0.06	0.18	0.05								
	1978	(70)[1]	0.44	1.82	0.05	(44)[1]	0.07	0.27	0.05								
	1979	(73)[1]	0.39	0.80	0.05	(32)[1]	0.09	0.25	0.04	(12)[1]	0.07	0.10	0.06				
	1980	(33)[1]	0.25	1.12	0.04	(39)[1]	0.14	0.27	0.04	(35)[1]	0.07	0.11	0.07	(12)[1]	0.07	0.11	
Walleye	1977					(9)	0.50	1.16	0.20								
	1978					(54)	0.26	1.40	0.17								
	1979					(30)	0.49	3.05	0.15								
	1980					(30)	0.47	1.41	0.12	(50)	0.17	0.23	0.20				

[1] - Five-fish composites.
[2] - Splake.

TABLE 5. Contaminant burdens in a single age-class (4^+) lake trout from four areas in the Great Lakes, 1980

	Lake Ontario		Lake Huron	Lake Superior
	Kingston Basin	Port Credit	Burnt Island	Thunder Bay
N	39	29	13	12
Total Length (cm)	55.7	55.5	41.0	46.2
Weight (g)	1906.8	1754.0	667.4	1104.8
% Lipid	18.94	18.37	11.13	14.06
PCB	3.98	5.52	0.94	0.90
ΣDDT	0.61	0.59	0.55	0.35
Dieldrin	0.12	0.05	0.08	0.04
Hg	0.19	0.22	0.15	0.29

Note: All results expressed as $\mu g\ g^{-1}$ wet weight otherwise unless noted.

TABLE 6. Lake Superior - lake trout. Whole fish contaminant data ($\mu g\ g^{-1}$)

	1974	1980
N	70(1)	50(2)
Weight (g)	1917.6	1832.4
Total Length (cm)	53.8	54.8
% Lipid	20.0	18.7
PCB	2.02	0.85
Dieldrin	0.15	0.05
ΣDDT	4.38	0.34
Hg	0.51	0.32
As	0.51	0.36
Cd	0.02	0.01
Cr	0.04	<0.02
Cu	0.82	0.70
Pb	0.04	< 0.10
Se	0.47	0.38
Zn	12.20	11.64

(1) Five fish composite samples.
(2) Individual fish.

Additional Studies - All samples for the open lake contaminants monitoring program are analyzed on a whole fish basis, while principal monitoring programs of provincial and state agencies analyze edible portions to produce consumption guidelines based on human health concerns. A program was initiated to investigate the relationship of contaminant levels in whole fish and in fillet samples. Representative aliquots of whole fish and edible portion were collected from the same individual fish, and submitted for organic and metal contaminant analyses. Lake trout and walleye were chosen as representative high and low lipid content fish, respectively. With the exception of mercury, all whole fish contaminant levels were greater than fillet levels for both species. For lake trout samples, with an average whole fish lipid content of 21.3 percent, mercury levels were 26 percent greater in fillet samples, while levels of persistent organic compounds such as PCB, DDT, dieldrin and chlordane averaged 51.7 percent greater in whole fish samples. For walleye, with an average lipid content of 11.0 percent, mercury levels were 40.3 percent greater in fillets, but major organic contaminants were 25.7 percent greater in whole fish samples. Therefore, in the case of ultra-trace organic contaminants at the parts per billion or even parts per trillion level, the analysis of whole fish samples is the preferred method for determining the occurrence of significant bioaccumulation of toxic materials. This method also serves as an early warning system for potential problems that may result in closure of a fishery for human health concerns.

Another aspect of the contaminants surveillance program is the investigation of the effect of contaminants on Great Lakes fish. Waterborne lead is toxic to fish, causing both haematological and neuropathological adverse effects. The most sensitive haematological effect is the inhibition of δ-amino levulinic dehydratase (ALA-D), an enzyme involved in haemoglobin catalase, and cytochrome syntheses. The activity of erythrocyte ALA-D is inversely related to the logarithm of both blood lead and waterborne lead concentrations, thus providing a good indication of both lead exposure and body burdens of lead. After eight to sixteen weeks, the enzyme is inhibited by exposure to waterborne lead concentrations as low as 10 to 13 μg^{-1}. Therefore, ALA-D inhibition provides an early warning capacity for adverse effects and is sensitive enough for the detection of waterborne lead concentrations equal to or lower than those causing chronic toxicity or those producing detectable body burdens. This data base was produced by controlled laboratory exposures of salmonids by the Aquatic Toxicology Section of GLFRB and it indicated that ALA-D activity could provide a means of surveying the exposure of feral fish to lead. Consequently, a survey was initiated to monitor ALA-D activities of lake trout - an open lake species, and carp and white suckers - principally inshore species.

Blood lead concentrations of lake trout increased from 19 μg^{-1} in eastern Lake Ontario to 92 μg^{-1} at a site in western Ontario, while ALA-D activities decreased correspondingly by about 33 percent (Fig. 4). Carp caught at inshore sites had blood lead concentrations five to ten times higher than lake trout. However, increases in blood lead concentrations did not produce corresponding decreases in ALA-D activities. Future research will be directed towards investigating the possible causes for this poor relationship and the development of alternative methods of ALA-D assay.

Future Programs -

1. Continued monitoring of representative fish species, plankton, and benthic invertebrates in order to determine trends in contaminant levels.

2. A study to determine the seasonal shift in contaminant burdens within the major organs, lipid deposits, and muscle tissue, of a single age-class of Lake Ontario lake trout. This study is being undertaken in cooperation with the Ontario Ministry of the Environment.

3. An investigation of the seasonal dynamics of a range of organic compounds associated with two distinct food chains and influenced by the Niagara River plume. This project will be developed in conjunction with the Environmental Contaminants Division of the National Water Research Institute, Canada Department of the Environment.

4. A continuing investigation of the utility of ALA-D activity as a tool for surveillance of lead exposure in feral fish.

5. Continued evaluation of the environmental levels of recently identified compounds such as polychlorinated dibenzofurans, 2,3,7,8,-tetrachloro dibenzo-p-dioxin and higher chlorinated dioxins, as well as photodecomposition products of some recently identified persistent organic compounds.

6. An investigation of the degree of fluctuating asymmetry in fin rays of fish as an indicator of environmental stress. This project will study the pectoral fin ray asymmetry of rainbow smelt, alewife, and slimy sculpin from both heavily contaminated and relatively clean areas of the Great Lakes. These observations may supply a potential early warning indicator of environmental stress on major diet items of Great Lakes fish.

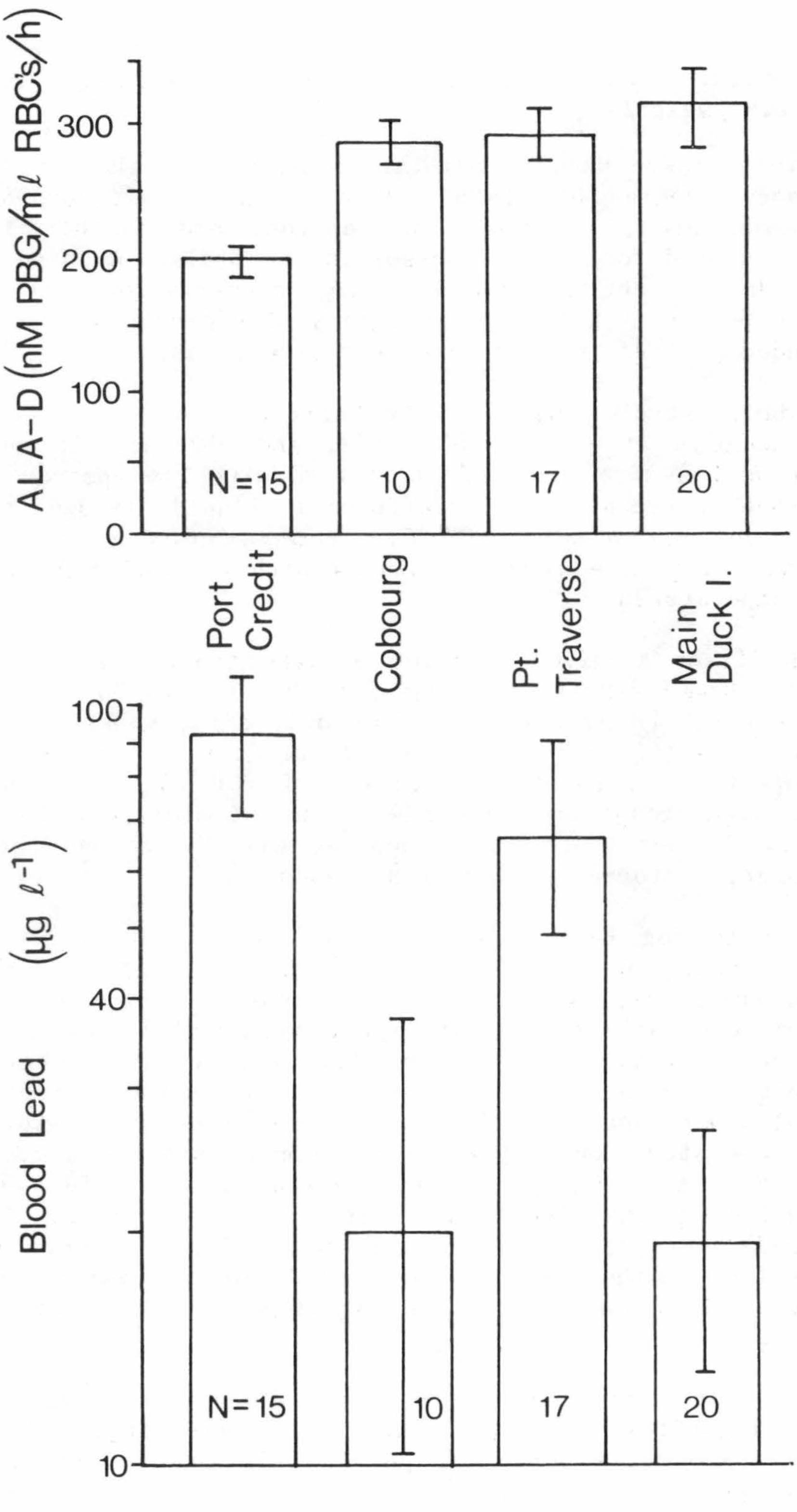

Fig. 4. ALA-D activities and blood lead concentrations of lake trout.

(2) ***Biological tissue archive studies.*** ***Project Leader - Mr. D.M. Whittle***

A biological tissue bank is maintained as part of the Contaminants Surveillance Program of GLFRB. Representative aliquots of fish tissue homogenates, plankton, zooplankton, and benthic invertebrates are stored for future contaminant analysis. Ongoing activities of the project involve defining preservation and storage conditions for maintaining the integrity of organochlorine residues for extended periods in a variety of tissue types.

To date, studies have involved storage of fish tissue and plankton samples at -20°, -40°, -80°, and -196°C. In addition, samples have been freeze-dried, preserved with five percent formalin and then frozen at -20°C, prefrozen in liquid nitrogen and held at -20°C, and air-dried at +60°C. Some samples of fish muscle tissue and liver have been inoculated with C^{14}-PCB and stored at various temperatures.

(a) **Fish Tissue Archive** - Samples of lake trout stored frozen at -20°C showed significant losses of HCB (23 to 25 percent) and pp'-DDE (59 to 62 percent) after only eight weeks of storage, with no significant decreases thereafter up to 49 weeks of cumulative storage time. Losses of PCB (30 to 33 percent) were significant only after 41 weeks of storage. The extent of total losses for all compounds will be assessed after a cumulative storage period of 96 weeks.

Data for lake trout indicate significant losses of HCB (70 percent), pp'-DDE (45 percent), and PCB (20 to 35 percent) upon freeze-drying. Losses subsequent to freeze-drying were significant only for PCB in lake trout samples stored 21 weeks at -20°C and brought the cumulative loss to 48 percent. As a result of these observed losses, no further freeze-dried samples were analyzed after 29 weeks of cumulative storage. A two-year study was initiated to compare storage temperatures of -20°C and -40°C. An evaluation of the effect of pre-freezing samples with liquid nitrogen was also made. This was intended to prevent the migration of lipid material to the exterior of the sample container before freezing was complete. Coho salmon from the Credit River were used for this study.

Significant losses were observed over one year of storage, regardless of temperature or pre-freezing, for pp'-DDD (four to sixteen percent), pp'-DDE (15 to 21 percent), oxychlordane (23 to 35 percent), dieldrin (18 to 39 percent), mirex (31 to 39 percent), and gamma-chlordane (71 percent).

Losses of PCB were significant only at -20°C (seven to ten percent) regardless of pretreatment. Significant losses of pp'-DDT occurred at both -20°C and -40°C regardless of pre-freezing, and were significantly higher at -20°C (17 to 19 percent) than at -40°C (six to nine percent). Neither HCB nor photo-mirex showed significant losses after one year of storage.

One more set of analyses is to be performed for this study, when two years of cumulative storage have elapsed.

(b) **Plankton Archive** - Bulk samples of oppossum shrimp (Mysis relicta) were used for this two-year study to assess the archiving potential of invertebrates. Thus far, samples stored one month at -20°C, or dried (+60°C) and stored at +20°C, show significant losses of HCB of 26 percent and 33 percent, respectively, compared to samples stored at -20°C.

In a further effort to evaluate the archiving potential of invertebrates, a two-year study using bulk net plankton samples was initiated. Results of analyses on samples stored for three weeks indicate significant losses of pp'-DDE when stored at either -20°C (26 percent), or dried (+60°C) and stored at +20°C (31 percent) compared to samples stored at -40°C. Also, significant losses of dieldrin (21 percent) were observed under the same conditions when compared to -40°C.

Two more sets of analyses are to be performed for this study, when one and two years of cumulative storage have elapsed.

(c) **Overview (Fish)** - Table 7 provides a summary of the storage conditions and individual compound losses. Initially, investigation of different archiving methodologies was undertaken to determine under what conditions losses of chlorinated hydrocarbons from fish homogenates could be prevented. This would eliminate the computation of rates of loss with their attendant correction factors, necessary if samples were stored at less than ideal conditions.

From the outset it was thought that -20°C would be sufficient to maintain the integrity of residues in fish homogenates for extended periods. This assumption has been proven false. Furthermore, it was felt that losses, if they occurred, would vary directly with the vapour pressure of the particular compound. This was not generally observed, since losses of pp'-DDE at -20°C were consistently higher than those of HCB. HCB is, however, over an order of magnitude more

TABLE 7. Biological tissue archive. Summary of storage conditions and subsequent specific compound losses

Treatment	Compound	Time Period Weeks	Percent Losses
Lake trout at -20°C	HCB	8	23-25
	pp'-DDE	8	59-62
	PCB	41	30-33
Lake trout, freeze-dried,	HCB	0	70
	pp'-DDE	0	45
	PCB	0	20-35
Lake trout, freeze-dried, followed by storage at -20°C	PCB	21	48
Lake trout at -40°C, prefrozen at -196°C	pp'-DDT	52	6-9
	pp'-DDD	52	4-16
	pp'-DDE	52	15-21
	Oxy-Chlordane	52	23-35
	Dieldrin	52	18-39
	Mirex	52	31-38
	γ-Chlordane	52	71
	HCB	52	N.S.D.
	Photo-Mirex	52	N.S.D.

N.S.D. = No significant difference.

volatile than pp'-DDE. The smaller losses generally observed for HCB over pp'-DDE may indicate that much of the HCB was already gone by the time of the initial analysis. The remainder, presumably more tightly bound, is lost at a considerably slower rate. This would suggest therefore, that, depending on when the first analysis is carried out on a sample after it is ground up, subsequent analysis of the same sample may or may not show a change. Analysis should be performed as soon after sample homogenization as possible if the archive is to reflect the environmental exposure to a compound.

Initial results indicate that a storage temperature of -40°C neither prevents the loss of most of the common chlorinated hydrocarbon pesticides nor is it better than -20°C in most cases. Therefore, colder storage temperatures need to be investigated. A radiolabelled PCB study will include temperatures of -80°C and -196°C, as well as -20°C and -40°C, and will hopefully provide the needed information for deciding whether or not a no-loss storage temperature is possible. Failing this, losses over the storage period of a tissue archive may have to be accepted, necessitating the determination of rates of loss. Whatever the case, the findings of the PCB study will only be applicable to Arochlor 1254 with its particular physical and chemical properties. It will, however, provide some insight into the behaviour of more labile compounds.

C. <u>Fish Health Studies</u>

Introduction - Environmental contaminants are monitored in Great Lakes fish to detect sites of discharge, geographical distribution, and temporal trends for existing chemicals, and to identify new and potentially hazardous substances. In most cases, concern for human health effects is limited to consumers, but the possibility exists that these chemicals may have adverse effects on the fish themselves. Laboratory toxicology suggests that contaminants may (a) alter physiological and biochemical functions, (b) influence migratory, social, and sensory behaviour, and (c) induce tumours, lesions, diseases, and other pathological conditions.

Great Lakes fish populations are rarely exposed to a single chemical under controlled conditions and the large number of interacting chemical and physical variables impacting on fish make it extremely difficult to develop clear cause and effect relationships. However, epidemiological studies in the Great Lakes indicate that some fish species show evidence of disease (Ryder, 1969), parasites (Nepszy, 1981), and tumours (Budd and Schroder, 1969;

Sonstegard, 1977). This data, supported by evidence that the prevalence of disease and pathological anomalies increase dramatically near polluted areas (McIntyre et al., 1978; Sindermann, 1979) suggests that some species of Great Lakes fish may be responding to environmental stress.

The International Council for the Exploration of the Sea (McIntyre et al., 1978) recognized the potential value of using fish condition as an indicator of environmental degradation and recommended that fisheries agencies routinely monitor sites and species at risk for evidence of disease, tumours, lesions, fin rot, and biochemical, physiological, and behavioural anomalies. Unfortunately, procedures for assessing the health and well-being of fish populations are in a developmental stage and have found more applicability in toxicology than applied fisheries research.

(1) Tumour monitoring in the Great Lakes. Project Leader - Mr. V.W. Cairns

The surveillance group initiated a program to assess the utility of pathological monitoring as a tool for identifying sites and species exposed to contaminant stress. The first step in this project was the production of a tumour identification manual which could be used to alert field biologists to the presence of fish tumours. The manual was prepared under contract to the Canada Department of Fisheries and Oceans and Canada Department of the Environment, and was followed by a tumour identification workshop.

Using the identification manual as a guide to commonly occurring tumours in Great Lakes fish, a preliminary survey began in 1980 at selected locations around the Lower Great Lakes (Fig.5) representing control sites and areas impacted by radioactive and industrial pollutants, eutrophication, and urban development. The three main objectives of the program were:

(a) to assess the practicality of routine pathological monitoring within surveillance;

(b) to identify a potentially useful monitoring species using the following criteria:

  (i) the species should be widely distributed throughout the Great Lakes;

  (ii) the species should be an indicator of nearshore conditions and spending most of its time directly or indirectly associated with bottom sediments;

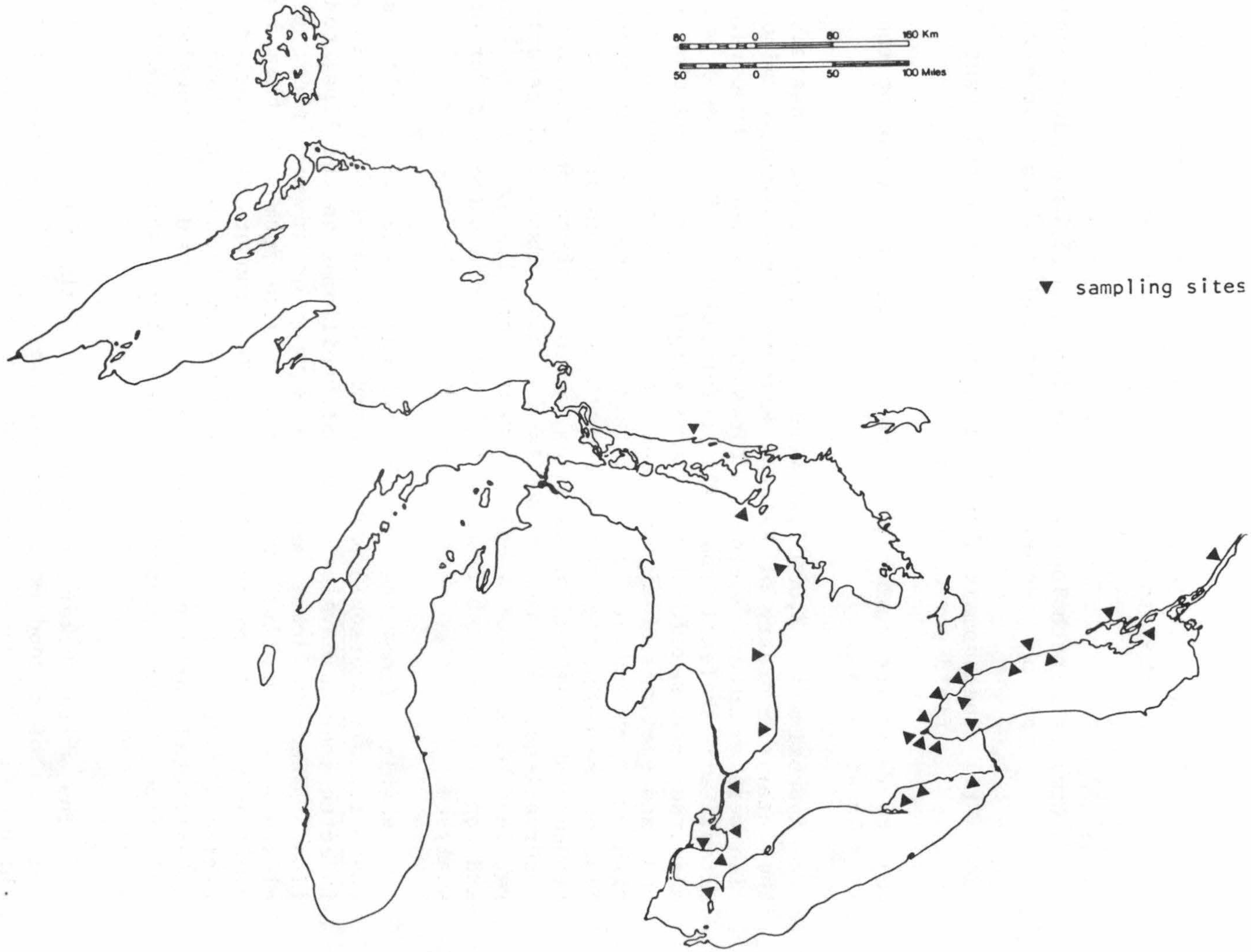

Fig. 5 Fish sampling sites on the Great Lakes.

(iii) the prevalence of the pathological condition should be related to specific contaminants or polluted environments;

(iv) the pathological condition should have adverse effects on the species or be an indicator of adverse effects;

(v) the anomaly should be easily observed and quantified by field personnel; and

(c) to determine tumour prevalence in selected areas of the Lower Great Lakes.

Approximately 8,000 fish were collected with the assistance of the Ontario Ministry of Natural Resources and Ontario Hydro. The fish were examined externally for signs of disease, tumours, parasites, and skeletal and gill deformities. Fish were weighed, measured, and sexed. Organs were weighed, gonad condition recorded, and sections of eight tissues from ten normal and ten affected fish of each species at each site were removed and preserved. Tissues representing abnormal pathological conditions were sectioned and examined histologically to confirm preliminary field observations. The remaining tissues were embedded in paraffin and retained as a tissue archive. Representative samples of tumoured and non-tumoured fish from several sites were submitted for organic analyses.

Results from the survey indicate that the white sucker (Catostomus commersoni) may be a promising bioeffects monitor. The infected species develop epidermal papillomas on the lips, body, or fins. The papillomas may occur singly or in multiples, usually clustered on the lips, and ranging in size from less than 5 mm to greater than 20 mm in diameter. The tumour is reported to be benign (Sonstegard, 1977) and efforts to induce the condition in non-affected white suckers by abrasive contact and inoculation of cell-free tumour preparations have been negative (Sonstegard, 1977).

The white sucker satisfied four of the five criteria for the selection of a good monitoring species. It is widely distributed throughout the Great Lakes, and occurred at 23 of the 28 sites sampled during the survey (Table 8). The papilloma is not confined to one geographical region and was observed at 17 of the 23 locations. In addition, the tumour can be observed and correctly diagnosed by inexperienced field personnel and data describing sex, age, and tumour prevalence can be obtained without sacrificing the fish. The white sucker feeds on bottom invertebrates, maintains a close association with bottom sediments, and is considered to be a

TABLE 8. Availability of fish at sampling locations and the frequency of pathological anomalies at these sites

Species	Pathological Condition	Number of Sites Species Captured	Number of Sites Condition Recorded
Brown Bullhead	Papilloma	14	8
Carp	Gonadal tumour	12	3
Carp X Goldfish Hybrid	Gonadal tumour	6	6
Channel Catfish	Papilloma	8	1
Coho	Thyroid hyperplasia	4	3
Drum	Epidermal hyperplasia	9	1
Gizzard Shad	Epidermal hyperplasia	8	0
Golden and Silver Redhorse	Papilloma	9	2
Longnose Sucker	Papilloma	2	1
Pike	Lymphosarcoma	9	0
Walleye	Lymphocystis, Dermal Fibroma	15	7
White Sucker	Papilloma	23	17
Yellow Perch	Gonadal tumour	16	8

Note: 28 sites visited in 1980.

good indicator of nearshore conditions. There is no direct evidence that epidermal papillomas are induced by environmental contaminants. However, the geographical distribution of tumour prevalence clearly indicates differences between sites and suggests increased prevalence in the nearshore western end of Lake Ontario, reaching a maximum of 41 percent in Hamilton Harbour (Fig. 6).

White suckers from Hamilton Harbour were studied extensively in 1981 to expand the data base on tumour prevalence and to determine the usefulness of the papilloma as an indicator of adverse effects at the individual and population levels. During the spring spawning migration 1200 white suckers were tagged of which 41 percent were affected by epidermal papillomas. Prevalence was found to be age-dependent, with only five percent occurrence on fish less than seven years old. Tumour frequency increased with age. Fifty percent of fish over 12 years of age (60 percent of the adult population) were affected by lip papillomas (Fig. 7).

Tumour prevalence was not influenced by sex (the ratio of effected males to affected females was 0.9 ± 0.2, $n = 3178$), and the presence of spent, tumour-bearing females in the downstream migration suggested that fish with papillomas participated in spawning activity. Fecundity measurements between papillomatous and non-papillomatous fish were not significantly different.

Eggs from tumoured and non-tumoured fish were fertilized and cultured in the laboratory. There was no difference in percent fertilization, percent hatch, swim-up survival, or growth. Fry from normal and papillomatous fish showed evidence of pericardial edema but this condition has been previously reported for Lake Huron white suckers (McElman and Balon, 1980), and is not considered unique to Hamilton Harbour.

The tumour surveillance program will continue to address the relevance of the papilloma to fish population health. The spawning migration will be monitored in 1982 for the purpose of recapturing tagged fish in order to estimate tumour incidence and to compare growth and mortality rates for tumour-bearing and normal fish. Several papillomas in the 1981 collection were large enough to almost occlude the mouth and in the more extreme cases would certainly have an effect on survival.

(2) Reproduction in Great Lakes trout. Project Leader - Mr. V.W. Cairns

Lake trout populations, plentiful during the first 30 years of the 20th century, dwindled and collapsed during the period from 1935 to

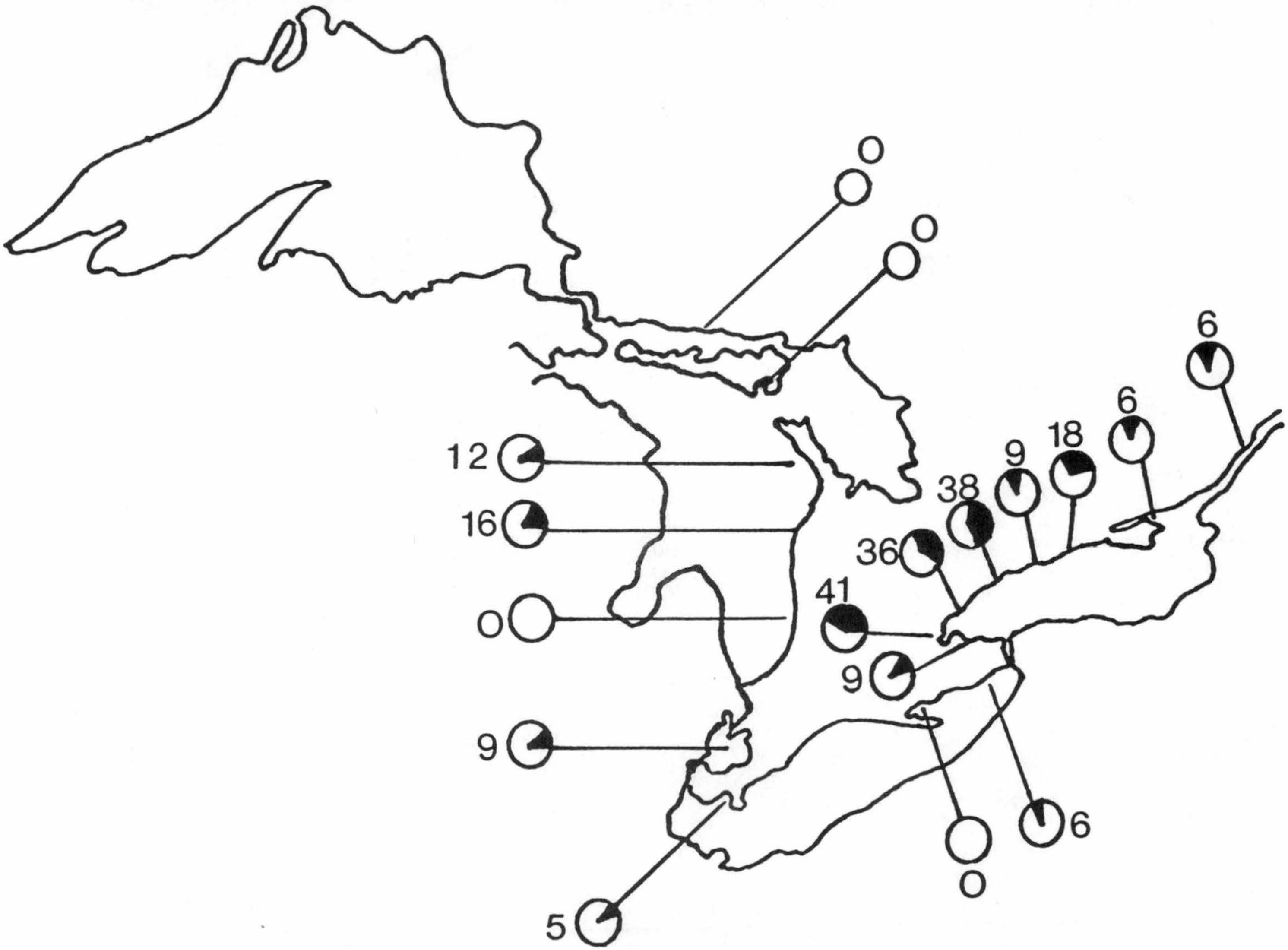

Fig.6 Prevalence (%) of epidermal papilloma on white suckers greater than 36 cm fork length.

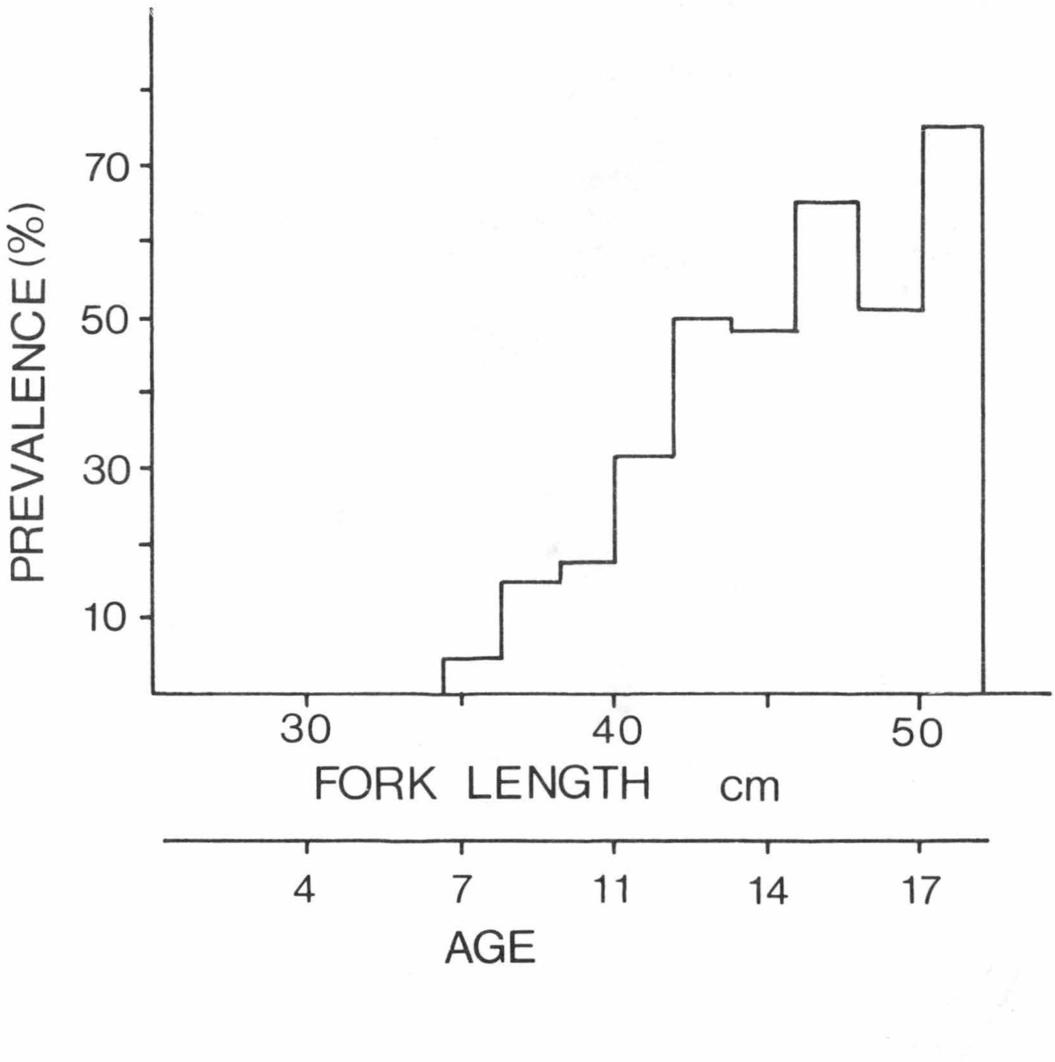

Fig. 7 Tumour prevalence and age distribution in a population of spawning white suckers in Grindstone Creek (Hamilton Harbour).

1950. The causes are numerous, but overfishing, lamprey predation, and changes in species composition are commonly believed to be the main factors responsible for the near extinction of lake trout in Lake Ontario.

Since the mid-1950's, restoration and rehabilitation of the lake trout population has been a major objective of both the provincial and state fisheries agencies. The Ontario Ministry of Natural Resources (OMNR) and the New York Department of Environmental Conservation stocked approximately 3.5 million lake trout into Lake Ontario between 1973 and 1978 in an effort to re-establish a viable, self-sustaining population. New York has recently achieved their objective of planting one million lake trout yearly into Lake Ontario.

The success of the stocking program depends, in part, on the ability of these animals to reproduce. In 1978 New York reported an anomaly in lake trout testes which appeared as a constriction at irregular intervals along the testis. The significance of the constriction to the reproductive potential of male lake trout and subsequent impacts on the restoration program are unknown.

A preliminary study was initiated in 1980 to assess the implication of gonadal constrictions on lake trout reproduction. A small sample of five normal and three constricted testes were collected from the eastern basin of Lake Ontario and submitted to Dr. Ruby at Concordia University for histopathological analyses. The report confirmed delayed cycles of spermatogenesis in the three constricted fish, premature release of developing germ cells, and a reduction of approximately 40 percent in sperm available for fertilization. Non-constricted lake trout were developing normally.

Although the number of samples submitted for analyses was too few to support definite conclusions, the available results clearly indicate a need to determine the geographical distribution of the constrictions, the percent occurrence, and possible adverse effects on reproductive success.

Samples of wild and hatchery-reared lake trout were collected from Lakes Superior, Michigan, Huron, and Ontario, with the assistance of the Ontario Ministry of Natural Resources (OMNR) and the U.S. Fish and Wildlife Service, Ann Arbor, Michigan. In addition, the OMNR also provided fish and observations from several inland lakes and three hatcheries.

The results indicate that the presence of testicular constrictions is widespread throughout the Great Lakes, occurring in hatchery-reared and wild fish (Table 9). Biologists with the OMNR

TABLE 9. Distribution of testicular constrictions in native and hatchery lake trout, splake and whitefish

Location	Fish	Percent Occurrence
Lake Ontario		
Eastern Basin	H.L.T.	37 (116)
Western Basin	H.L.T.	38 (349)
Lake Huron	H.L.T.	43 (21)
Lake Michigan	H.L.T.	33 (15)
Great Slave Lake	N.L.T.	+
Lake Opeongo	N.L.T.	5 (42)
Lake Simcoe	N.L.T.	10 (21)
Rideau Lakes	N.L.T.	40 (5)
Dorion Hatchery	H.L.T.	13 (30)
Hills Lake Hatchery	H.L.T.	27 (22)
Chatsworth Hatchery	Splake	13 (30)
Lake Nipissing	Whitefish	+
Rideau Lakes	Whitefish	+

H.L.T. = Hatchery reared lake trout.
N.L.T. = Native Lake trout.
\+ = Observed only.

have reported similar morphological conditions in splake from Georgian Bay, splake from the Chatsworth hatchery, and whitefish from Lake Ontario, Lake Nipissing, and the Rideau lakes.

Several projects were undertaken in 1981 to address issues raised in the histological :port. Samples of lake trout testes were collected monthly from Lake Ontario and Lake Opeongo to compare stages of spermatogenesis between wild and hatchery fish and between constricted and non-constricted Lake Ontario trout. In addition, correponding blood plasma samples were collected from constricted and non-constricted Lake Ontario fish from May through November to monitor androgen levels responsible for testicular maturation. Analyses for testosterone, 11-keto testosterone, and gonadotropin, will be completed under contract by May, 1982.

Scientists from the Canada Department of Fisheries and Oceans, Halifax, participated in a preliminary study to determine the ability of testicular and interrenal tissue, from constricted and non-constricted fish, to metabolize labelled progesterone and pregnenolone into labelled steroids. Four of the five non--constricted fish synthesized the precursors in a normal and predictable fashion. The constricted fish were also capable of steroid biosynthesis. However, care must be taken in interpreting these findings. Testicular histology suggested differences between constricted and non-constricted fish at the cellular level and steroid biosynthesis should be repeated with larger sample sizes on more severely affected fish.

Sperm counts for non-constricted and constricted Lake Ontario fish averaged 20.8 ± 5 and 16.8 ± 5 billion sperms per ml of semen, respectively. There was large variability between individuals and no significant differences between constricted and non-constricted fish.

Lake trout eggs from Lake Manitou were fertilized with sperm from two constricted and five non-constricted Lake Ontario males. The sperm was diluted in a chloride and carbonate extender and sperm concentrations from 10^8 sperms per egg to 10^2 sperms per egg were used to fertilize separate lots of 200 eggs. There was no apparent difference in fertilization rate between the two groups (Table 10).

Results of the hormone biosynthesis, sperm count, and egg fertilization tests do not support the initial observations that these fish may suffer reproductive impairment. Results from the blood androgen and comparative histology portions of the study are not yet available. In the meantime, steroid biosynthesis and egg fertilization tests will be repeated with larger sample sizes representing more severely affected males.

TABLE 10. Percent fertilization of Lake Manitou lake trout eggs with sperm from constricted Lake Ontario males

Number Spermatozoa/Egg	Constricted	Non Constricted
10^8	86	84
10^7	65	60
10^6	30	9
10^5	4	1
10^4	0	0

D. Phycological Studies

(1) Eutrophication - trophic status. Project Leader - Dr. M. Munawar. Technician - L. Michell

The trophic status of the St. Lawrence Great Lakes has changed considerably over the years due to increased urbanization and nutrient inputs from the Great Lakes basin. The recent awareness of the abundance of certain contaminants in these lakes has made it necessary to study and compare the past with the current biota. The determination of phytoplankton biomass and species composition have become established as methods to trace long-term changes in the lakes, because these organisms have short carbon turn-over rates and are sensitive to water quality conditions. Based on the past 12 years of work, the general distribution of phytoplankton biomass has been determined in all the Great Lakes except Lake Michigan. The mean distribution of biomass at various monitoring stations across the Great Lakes is given in Fig. 8. The lowest concentration of biomass was found in Lake Superior where most of the values were less than 0.2 g m^{-3}. However, the Western Arm, Thunder Bay, and Whitefish Bay had relatively the highest concentrations of all the Lake Superior stations. In Lake Huron, Georgian Bay, and North

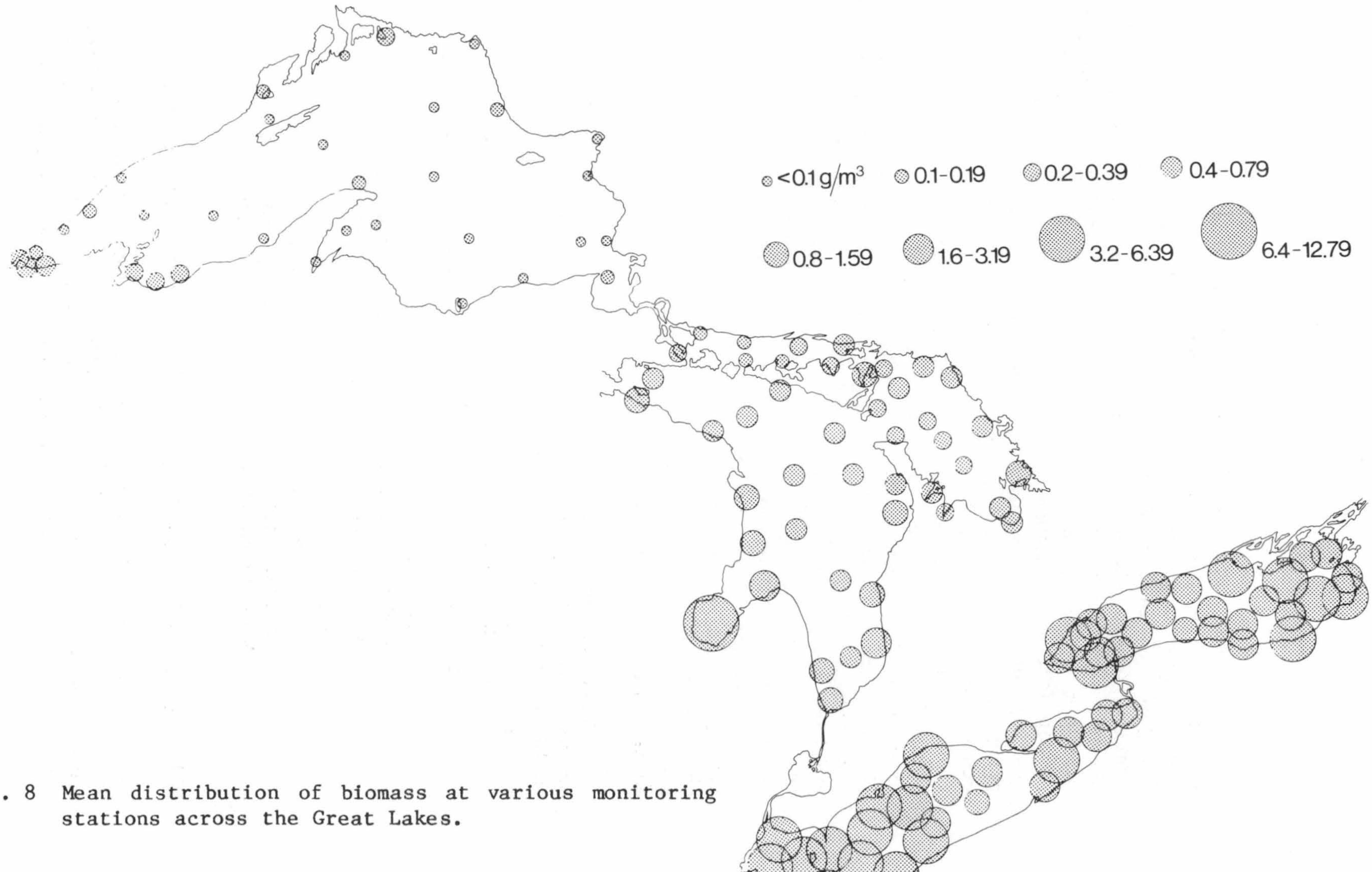

Fig. 8 Mean distribution of biomass at various monitoring stations across the Great Lakes.

Channel, most of the biomass values ranged between 0.4 and 0.79 g m^{-3}. On the other hand, the Saginaw Bay station exhibited the highest concentration of biomass found in the Great Lakes (>7 g m^{-3}). In Lake Erie, the eastern half showed a mean concentration ranging between 1.6 and 3.19 g m^{-3} and the western half showed an average biomass concentration ranging between 1.6 and 3.19 g m^{-3}. Figure 8 provides a simple but reliable picture of the phytoplankton abundance which more or less reflects the water quality conditions across the Great Lakes. Figure 9 shows the mean group composition which provides a general overview of the current ecological conditions. Diatoms were the main group in the composition of all the lakes except offshore Lake Ontario where green algae dominated. The dominant diatom population contained species from both oligotrophic and eutrophic environments. Surprisingly, the blue-green algae were the second most abundant after diatoms in Lake Huron. They were third and fourth most abundant in inshore/offshore Lake Ontario and western Lake Erie, respectively. Among the phytoflagellates, the cryptomonads demonstrate a remarkable pattern of occurrence since they were abundant in eutrophic as well as in oligotrophic environments. They were the second most important group in western Lake Erie as well as in Lake Superior. The chrysomonads, as expected, seemed to perform better in Lakes Huron and Superior. Dinoflagellates thrived best in the central and eastern basins of Lake Erie.

Based on the mean biomass classification proposed by Munawar and Munawar (1982), the St. Lawrence Great Lakes under discussion could be tentatively classified as follows:

Lake Superior .... Ultra-oligotrophic

Lake Huron .... Oligotrophic

Lake Ontario
- Inshore .... Meso-eutrophic
- Offshore .... Meso-eutrophic

Lake Erie
- Eastern basin .... Meso-eutrophic
- Central basin .... Meso-eutrophic
- Western basin .... Eutrophic

(2) <u>Nannoplankton dynamics</u>. Project Leader - Dr. M. Munawar

The qualitative and quantitative significance of nannoplankton has been a focus of attention for the past several years in GLFRB. The average size composition of phytoplankton biomass at selected stations across the Great Lakes, based on microscope counts, is

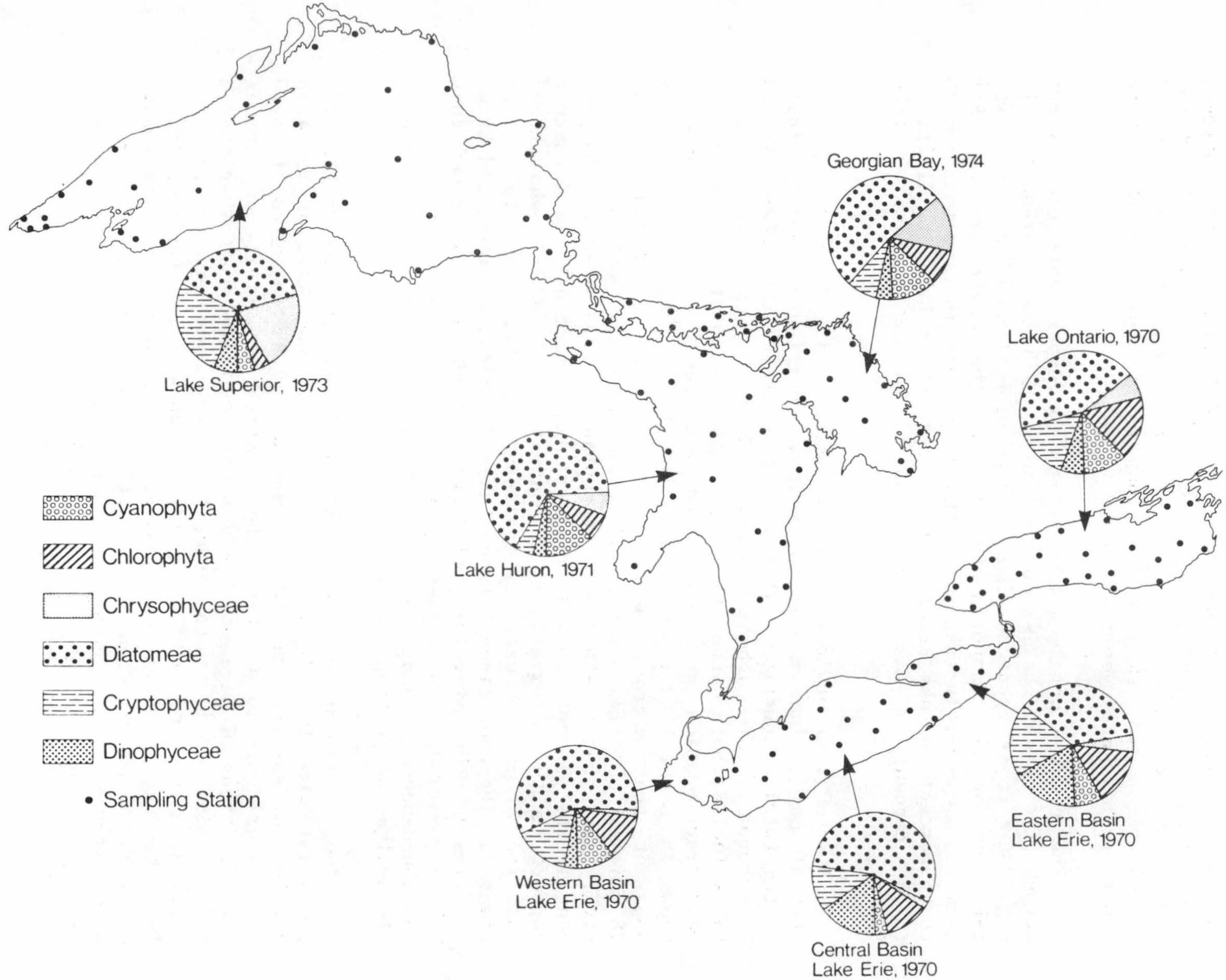

Fig. 9 Mean phytoplankton composition in the Great Lakes.

given in Fig. 10. On an average basis, 49 to 96 percent of the biomass was made up of nannoplankton (< 64 μm). Highest percent nannoplankton contribution was observed in Lake Superior and the lowest in Lake Huron. These data demonstrate the importance of nannoplankton and its size fractions which have been ignored in other Great Lakes investigations.

The results of the carbon-14 uptake experiments carried out across the Great Lakes during July, 1973, are presented in Fig. 11. It is apparent that a large proportion of carbon-14 was taken up by the nannoplankton in all the environments. For example, carbon-14 uptake was 87 to 95 percent in Lake Ontario; 70 to 98 percent in Lake Erie; 67 to 71 percent in Lake St. Clair; 74 to 90 percent in Lake Huron; and 67 to 100 percent in Lake Superior.

It was also obvious that the smaller size fraction of less than 10 μm (μ-algae and ultraplankton) contributed overwhelmingly to the total production. They were responsible for between 41 and 87 percent of the carbon-14 uptake. Current studies in the Great Lakes include both carbon-14 and pigment fractionation besides biomass fractionation up to < 5 μm and sometimes 1 μm. An example is shown in Table 11 for an offshore station in Lake Huron. It is apparent that micro-algae were responsible for 37 percent and 38 percent of total chlorophyll a and carbon-14 uptake, respectively, and that together with ultraplankton they comprised 50 percent of the pigment and carbon-14 uptake. These data lend further support to the observations of Munawar et al. (1978) who showed that the 10 μm size category possessed high P/B (activity coefficients). The comparison between Lakes Superior, Ontario, and Erie, in terms of P/B and chlorophyll/biomass quotients, indicated that Lake Superior had the highest quotients. This is attributable to the abundance of nannoplankton and the overwhelming contribution of micro-algae and ultraplankton.

The fractionation approach to algal toxicity was applied for the first time in 1977 as a follow-up of Lake Superior research carried out earlier (Munawar and Munawar, 1978). Results of toxicity experiments to determine the relative sensitivity of various size fractions of algae to heavy metals indicated that there was a major inhibition of photosynthesis in the nannoplankton, particularly in the ultraplankton (< 10 μm) (Munawar and Munawar, 1978). This observation was more or less applicable to all the experiments carried out in the Great Lakes with various metals. The results have far-reaching implications from an ecological point of view since the nannoplankton play a key role in the ecosystem dynamics and are vulnerable to grazing pressures.

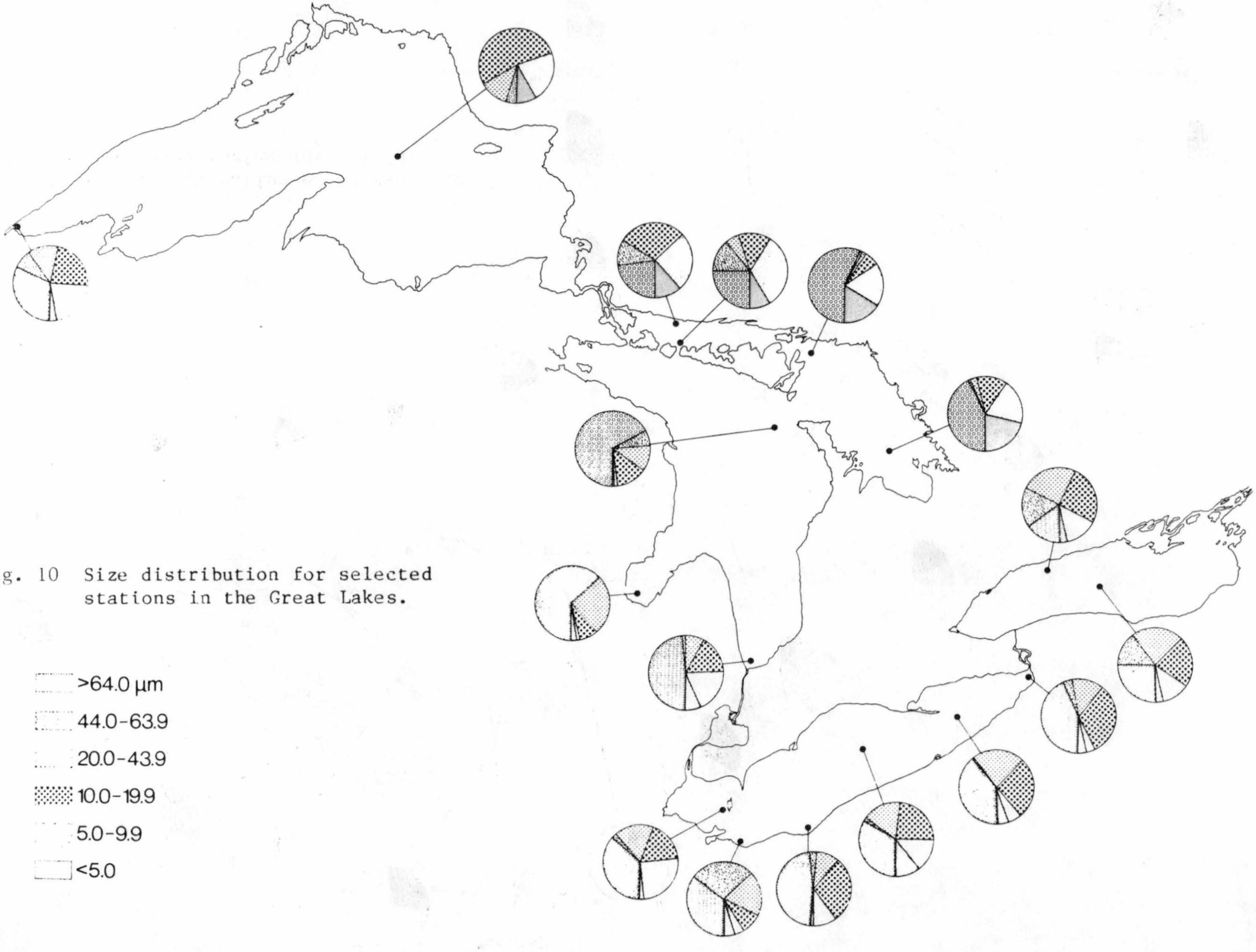

Fig. 10 Size distribution for selected stations in the Great Lakes.

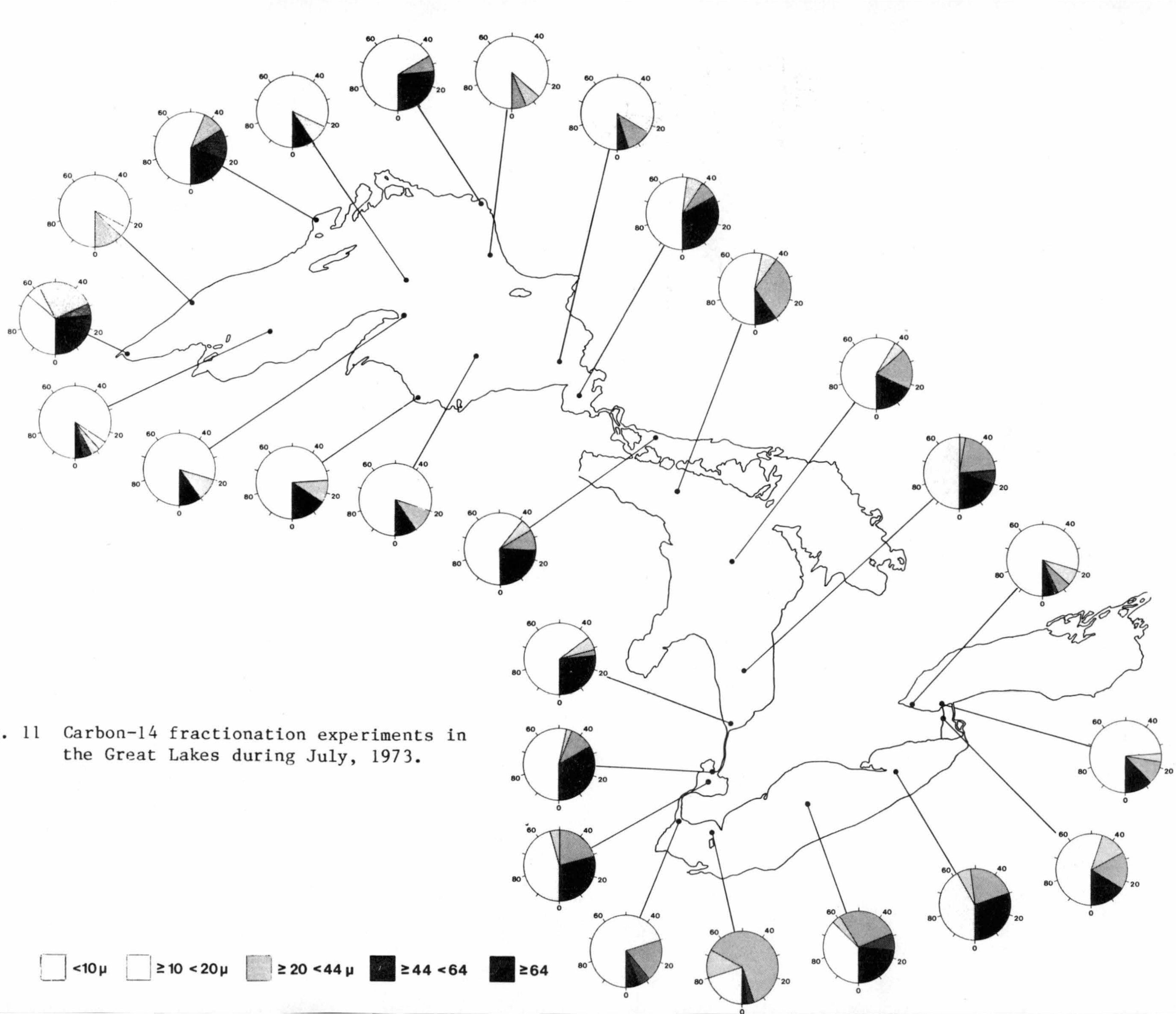

Fig. 11 Carbon-14 fractionation experiments in the Great Lakes during July, 1973.

TABLE 11. Chlorophyll a and ^{14}C uptake fractionation for an offshore station of Lake Huron, July, 1980

	<5 µm	5-10 µm	10-20 µm	20-44 µm	44-64 µm	>64 µm
Chlorophyll a	37	11.3	7.7	9.2	16.4	18.4
Carbon-14 uptake %	38	14.4	1.8	9.4	11.1	25.2

(3) Evaluation of chlorophyll a methodology in the Great Lakes. Project Leader - Dr. M. Munawar

A critical examination of filtration and separation procedures for the phytoplankton was undertaken. The particle-retaining efficiency of glass fibre filters used for filtration of Lake Ontario water samples was examined using the routine chlorophyll procedure. Preserved filtrates were analyzed by the Utermöhl technique for phytoplankton. A mean of 40 taxa were identified and enumerated in the filtrate. A comparison showed that 0.2 µm nuclepore and 0.45 µm cellulose membrane filters retained more particles than GF/C filters. The passage of cells through filters has been considered one of the reasons for variability observed in phosphorus-chlorophyll relationships and could lead to serious errors, particularly in oligotrophic waters. Scanning electron microscope studies on the ultrastructure of GF/C filters indicated 'window-like' spaces which permit the passage of nannoplankton (Fig. 12). Our studies, therefore, recommend the use of membrane filters for routine chlorophyll analysis (Munawar et al., in press).

(4) Bioaccumulation and contaminants surveillance - SEM/EDX. Project Leader - Dr. M. Munawar

A combination of scanning electron microscopy and energy dispersive X-ray spectroscopy (SEM/EDX) was found to be a very effective tool for characterizing the heavy metal load of Great Lakes phytoflagellates, diatoms, and green algae, and for the surveillance of heavy metal pollution. The sensitivity and short generation time of nannoplankton and the speed of the described technique make this procedure a useful aid in contaminants research. A commonly occurring green alga in eutrophic environments, Staurastrum paradoxum, is shown in Fig. 13. The elemental spectrum demonstrates the presence of metals in a cellular structure. Besides Mn

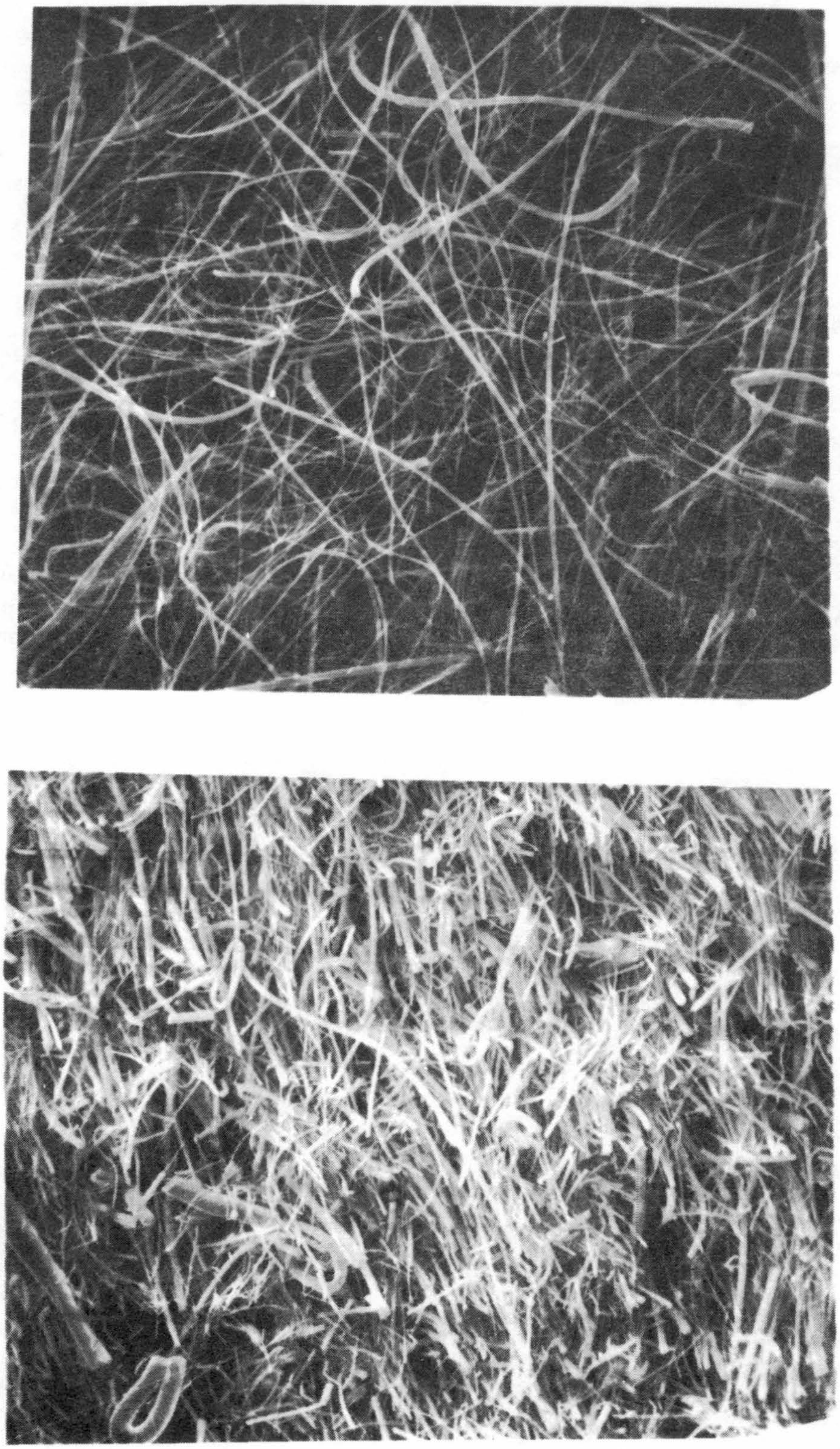

Fig. 12 Scanning electron microscope studies on the ultrastructure of GF/C filters.

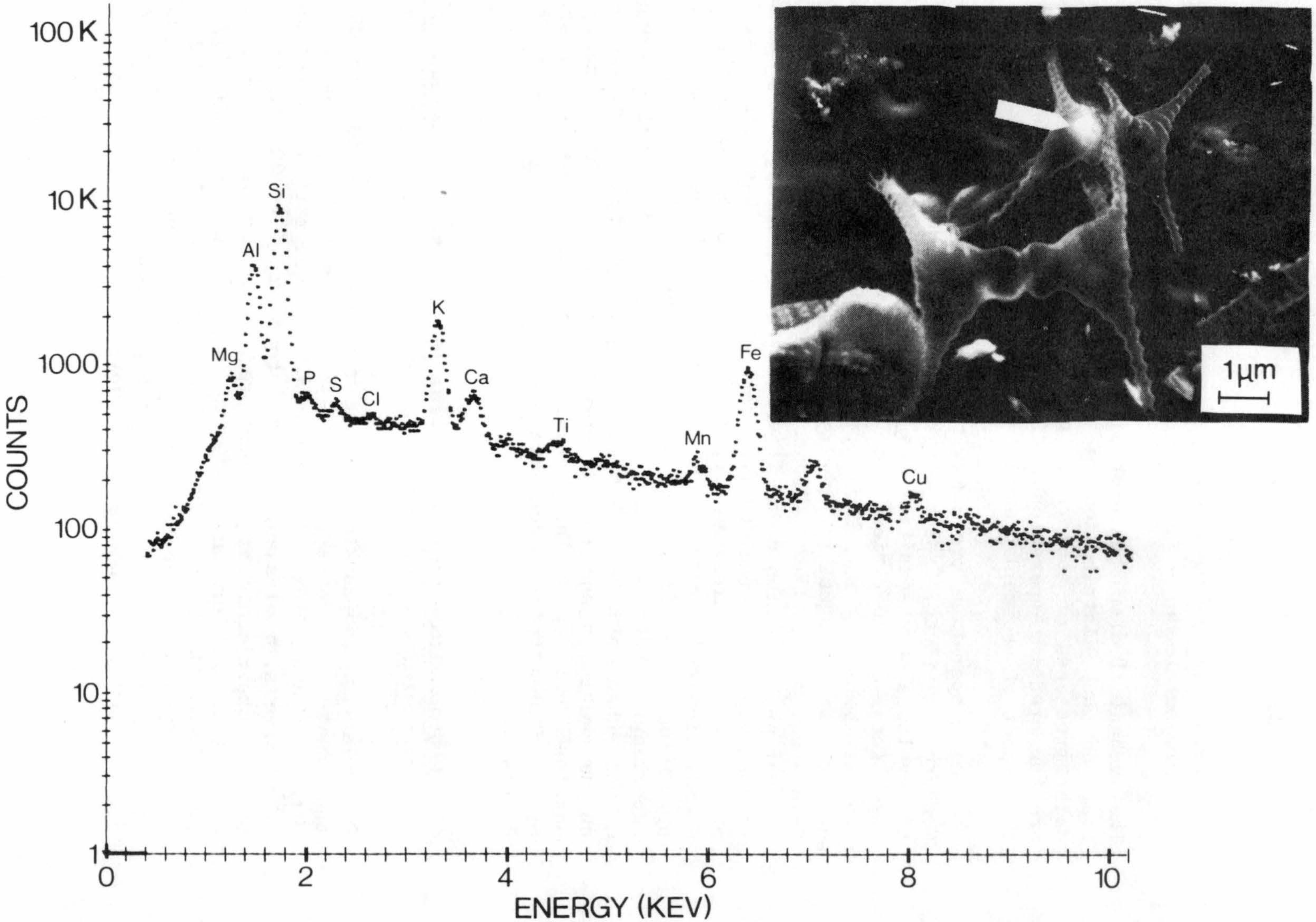

Fig. 13 Air-dried specimen of <u>Staurastrum</u> <u>paradoxum</u> (magnified 9000X) and an X-ray spectrum showing elemental composition at the location indicated by the arrow.

and Cu, elevated levels of Fe and Al were detected (Bistricki and Munawar, 1982).

(5) *Effect of sediment-associated contaminants on phytoplankton. Project Leader - Dr. M. Munawar*

The mechanical disturbance of aquatic sediments affects the concentrations and distribution of contaminants in the environment. Major processes of concern in the Great Lakes nearshore zone area are the dredging operations. Therefore it is essential to assess the impact of sediment-associated contaminants on biota.

A co-operative project with A. Mudroch of the National Water Research Institute, Canada Department of the Environment, attempted to develop a more sensitive and rapid bioassay technique which will take into consideration the differential response of various species belonging to different size fractions which constitute natural assemblages of phytoplankton. A bioassay has been developed using the radioactive primary productivity method, natural phytoplankton communities from Lake Ontario, and chemically treated elutriate obtained from various Great Lakes sediments. The phytoplankton species were further fractioned by their size with enumeration and identification of species and the carbon-14 uptake by various size fractions was determined. The results of the experiments indicated that the impact of dredge spoils could be either enhancement or inhibition of primary production, depending on the pollution and species present in the test assemblage. The developed bioassay is fast, sensitive, and useful in the assessment of availability of contaminants eluted during dredge spoil disposal.

(6) *Phytoplankton-zooplankton grazing as a transfer mechanism for contaminants. Project Leader - Dr. M. Munawar*

Phytoplankton-zooplankton grazing experiments were carried out in the Great Lakes by means of triple-tracer technique using an *in situ* grazing chamber. The phytoplankton food ration was fractioned into three size classes, namely 1 to 5 μm, 5 to 20 μm, and 20 to 64 μm. Experiments at a nearshore station in Lake Ontario indicated that smaller nannoplankton (1 to 20 μm) were greatly preferred over the larger (20 to 64 mm) fraction. The results imply that contaminant transfer pathway studies should focus on smaller algae as being crucial in phytoplankton-zooplankton links in trophic models (Munawar *et al.*, 1981).

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ENVIRONMENTAL TOXICOLOGY

Program Leader - Dr. P.V. Hodson.

INTRODUCTION AND HIGHLIGHTS

Research in 1981 continued on both contaminant dynamics and effects to:

(a) develop criteria suitable for water quality objectives for the protection of aquatic biota,

(b) develop principles of aquatic toxicology for assessing the hazards of contaminants to aquatic biota, and

(c) develop principles of contaminant dynamics for contaminants management in aquatic ecosystems.

Of particular importance in 1981 were studies demonstrating an interaction between acid rain and the rate of microbial methylation of metals. The enhanced methylation of mercury, lead, and arsenic by low pH may partially explain elevated mercury levels in fish from acid lakes and the disappearance of fish as pH declines. A study of the effect of exploitation pressure on mercury levels in walleye may influence fisheries management in contaminated ecosystems. Management of waterborne contaminants may be influenced by research results which demonstrate that measurements of variance are as important as measurements of concentrations in assessing hazards to biota.

The effects of contaminants on zooplankton are being studied using mixed populations of predators and prey. This work was significantly advanced by a new model of particle size conversion efficiency that simplifies and clarifies the quantification of contaminant effects. Research on quantitative structure-activity relationships between organic chemicals and their effects on fish has been facilitated by a new bioassay technique, i.e., intraperitoneal injections of contaminants into fish which has simplified data generation by avoiding aquatic exposures. Results to date demonstrate strong correlations to other measures of toxicity.

The work by Dr. A. Niimi on proposed extended winter navigation (reported below and in list of publications) is of special interest since it may be the first step in dealing with a very important fish habitat issue.

The effort devoted to specific contaminants is shifting from metals to organics. The activities in 1981 reflect this trend as will future publications. The outputs of the Toxicology program are primary publications but reports to the International Joint Commission and the Environmental Assessment and Review Process, lectures at local universities, advice to government, industries, and other scientists, and participation in expert committees, were also important results of research in 1981.

The following is a series of brief research reports under A. Contaminant Dynamics; B. Contaminant Effects; C. Other Studies.

A. Contaminant Dynamics

(1) Metal methylation in acidic environments. Project Leader - Dr. P.T.S. Wong. Technician - O. Kramar[1]

The methylation of lead, mercury, arsenic, and selenium was studied in sediment from an acidic lake (Plastic Lake, 46°11'N, 78°50'W) in Ontario (Table 12). The initial pH of the sediment was 5.8 and it was artificially adjusted to 6.5 and 7.5 with NaOH and to 5.5, 4.5, and 3.5 with H_2SO_4, HNO_3, or HCl. The results of these studies showed that pH affected the methylation of elements in various ways.

TABLE 12. Methylation of elements in the aquatic environment

Element	Maximum Percent of Methylation	pH Range	Reaction
Pb (IV)	0.01	3.5 - 7.5	Biological 50 - 76% Chemical 50 - 24%
Hg (II)	0.08	5.5 - 6.5	Biological
As (III) (V)	0.70	3.5 - 7.5	Biological
Se (IV) (VI)	0.02	3.5 - 7.5	Biological

Methylation of trimethyl lead acetate to tetramethyl lead increased with increasing pH and proceeded through both biological and chemical mechanisms. However, the methylation of organolead (II) compounds was biologically mediated and was enhanced at the lower pH range of 3.5 to 5.5. The formation of methyl mercury from mercuric chloride occurred only in the pH range of 5.5 to 6.5. Dimethyl mercury was not detected in these studies. Arsenic methylation occurred over the entire pH range studied, but levels of methylated compounds were enhanced below pH 5.5. Low levels of methylated selenium compounds were detected at pH 3.5 and increasing pH generally favoured the methylation of selenium compounds in sediment.

[1] *Other Participants: M. Baker (University of Waterloo); Y.K. Chau (National Water Research Institute)*

(2) Mercury levels in exploited fish populations. Project Leader - Dr. A.J. Niimi[1]

Mercury levels in white sucker, walleye, northern pike, and yellow perch, are being monitored in conjunction with a fisheries management project being conducted by the Freshwater Institute on a series of lakes near Winnipeg, Manitoba. Fish are being selectively harvested from four lakes whose populations have not been previously exploited. Zero, 10, 25 and 50 percent of the biomass has been removed. Initial estimates of mercury levels in the top predators range from 0.1 to 0.3 mg kg^{-1}, and concentrations are dependent on fish size. It is suggested that these concentrations represent a natural environment where mercury is present at slightly above background levels, but not sufficiently high to obscure any moderate changes. Mercury levels and the structure and biomass of the fish community will both be monitored in the future in order to ascertain if a correlation exists between these two parameters.

[1] *Other Participants: S. Campbell (Freshwater Institute, Winnipeg)*

(3) Lead accumulation by fish exposed to fluctuating concentrations of waterborne lead. Project Leader - Dr. P.V. Hodson. Technician - B.R. Blunt[1]

Lead accumulation by rainbow trout (*Salmo gairdneri*) under conditions of constant exposure was compared to accumulation under conditions of fluctuating exposure more typical of natural environments. The overall geometric means of exposure concentrations were equivalent between constant and fluctuating regimes. However, in the fluctuating regime the standard deviations of exposure concentrations were increased in a controlled, predetermined fashion. Lead accumulation in the blood of rainbow trout increased with the geometric mean exposure concentration, as expected (Fig. 14). As well, accumulation increased with the variance of the exposure, as expressed by the coefficient of variability (the standard deviation as a percentage of the mean). Therefore, the probability of fish accumulating a toxic dose of lead will increase as the variability of exposure increases, even if the average exposure remains constant. These results indicate that simple arithmetic or geometric means are not adequate for assessing the exposure of aquatic biota to waterborne contaminants.

[1] *Other Participants: S. McGaw*

(4) Survey of the lead contamination of Lake Ontario Fish. Project Leader - Dr. P.V. Hodson

Blood lead concentrations and the activity of an erythrocyte enzyme, δ-amino levulinic acid dehydratase (ALA-D), of Great Lakes fish were measured between 1979 and 1981, to describe lake-side patterns of lead contamination. These analyses showed that:

(a) Lead contamination of fish was widespread but rarely were concentrations high (Tables 13, 14, and 15).

(b) Fish in the vicinity of an industrial point source near Maitland, on the St. Lawrence River, were very heavily contaminated (Table 15).

(c) Offshore and/or predatory species (e.g., lake trout, pike, bass, salmon) generally had very low blood concentrations in contrast to benthic omnivores (e.g., carp, sucker) (Tables 13 and 14).

(d) Fish migrations may confound site to site comparisons of lead concentrations.

(e) The ALA-D technique appeared suitable for assessing the lead exposure of most of the species tested.

(f) Blood lead concentrations provided a very clear indication of the distribution of lead within Lake Ontario fish populations.

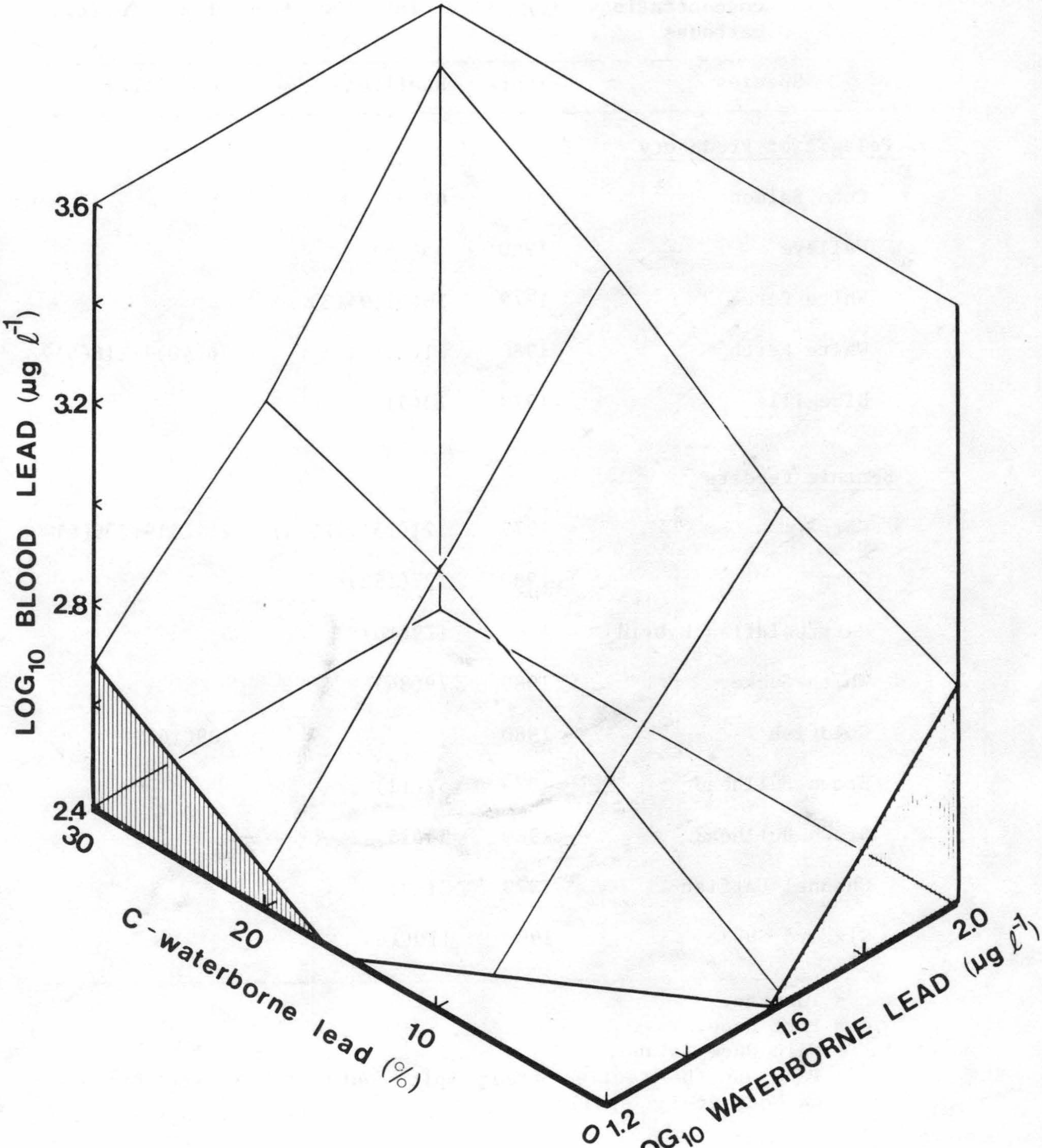

Fig. 14 The effect of increasing variability of lead exposure on the blood lead concentration of rainbow trout. Variability is expressed as the coefficient of variation $\left(C = \frac{\text{standard deviation}}{\text{mean}} \times 100\right)$

TABLE 13. Geometric means (and sample sizes) of blood lead concentrations ($\mu g\ l^{-1}$) in fish from Lake Ontario harbours

Species	Year	Hamilton	Other
Pelagic or Predatory			
Coho Salmon	1978	63(3)	
Walleye	1980	45(16)	
White Perch	1979	36(5);94(3)	
White Perch	1980	51(116)	76(40)[a]:116(5)[b]
Bluegills	1979	13(5)	
Benthic Feeders			
Carp	1979	121(15);125(4)	219(3)[c]:226(6)[d]
Carp	1980	127(152)	
Carp/Goldfish Hybrid	1980	179(10)	
White Sucker	1980	79(84)	
Goldfish	1980		289(16)[e]
Brown Bullhead	1979	52(11)	
Brown Bullhead	1980	53(35)	
Channel Catfish	1979	71(6)	
Gizzard Shad	1980	110(18)	

a = Toronto.
b,c = Port Hope.
d = Main Duck Island.
e = Pond on the Leslie Street Spit contaminated with Toronto Harbour dredge spoils.

TABLE 14. Geometric means (and sample sizes) of blood lead concentrations ($\mu g\ l^{-1}$) in fish from Lake Ontario

Species	Year	Hamilton	Port Credit	Port Hope	Cobourg	Other
Pelagic Feeders						
*Rainbow Trout	1980			28(21)		
Brown Trout	1980			47(7)		
Coho Salmon	1978	100(7)				
Coho Salmon	1979		55(20)			
Coho Salmon	1980		33(56)			
Lake Trout	1978	53(8)				
Lake Trout	1979		92(15)		20(10)	67(17)[a]:19(20)[b]
Lake Trout	1980	12(20)	18(34)		9(11)	19(19)[b]
Benthic Feeders						
White Sucker	1980		259(4)			60(15)[c]:235(30)[d]

* Blood lead concentrations of control rainbow trout in laboratory studies range from 10 to 300 $\mu g\ l^{-1}$.

a = Point Traverse

b = Main Duck Island.

c = Vineland.

d = Toronto.

TABLE 15. Geometric means (and sample sizes) of blood lead concentrations in fish from the St. Lawrence River

Species	Year	Brockville	Maitland	Johnstown
Pike	1980		399(17)	
	1981	291(1)	311(8)	10(1)
Carp	1980		5500(1)	
	1981	175(9)	4864(25)	1558(3)
White Sucker	1980		456(32)	
	1981	35(4)	694(18)	444(12)

The results demonstrate a need to monitor lead concentrations in benthic fish near point sources and the effects of chronic lead exposure on benthic fish at the most contaminated sites.

Difficulties were found in applying the ALA-D technique to some non-salmonid species due to migration (i.e., lead exposure may be quite variable within a sample of fish), biochemical characteristics unique to each species, and accumulation of different forms of lead. This enzyme responds to inorganic lead, and organic forms (e.g., alkyl leads) may cause high blood lead concentrations without corresponding enzyme inhibition. If this is true, then there would be three diagnostic patterns: (a) high ALA-D activity, low blood lead = unexposed fish; (b) low ALA-D activity, high blood lead = fish exposed to inorganic lead; (c) high ALA-D activity, high blood lead = fish exposed to organic lead. These possibilities will be evaluated in 1982.

(5) Contaminant levels in fish and eggs. Project Leader - Dr. A.J. Niimi

Fishery managers have long recognized that factors such as temperature and food supply can influence stock recruitment, but the presence of PCB's, DDT, mirex and HCB in biota may also affect survival rates. A study was initiated to examine the relationship between contaminant levels of fish and their eggs. The purpose is to estimate the probable toxicological effects of these contaminants on reproduction.

Rainbow trout and white sucker were collected from Lake Ontario, and white bass, smallmouth bass, and yellow perch were taken from Lake Erie during the spawning season. Up to 11 organic contaminants, including PCB, DDT, chlordane, dieldrin, HCB, and mercury, were measured in both fish and their eggs. Levels of PCB for rainbow trout, suckers, white bass, smallmouth bass, and yellow perch averaged 4.8, 3.4, 2.1, 2.4, and 0.6 mg kg^{-1}, respectively. DDT levels averaged 1.3, 0.5, 0.2, 0.3, and 0.2 mg kg^{-1} for the respective species. The results indicated that the percent of total residue transferred from adult to eggs was similar among the different contaminants within a species even though concentrations varied considerably. Between six and 26 percent of the organic contaminants and between 0.3 and 2.3 percent of the mercury monitored in the fish were deposited in the eggs among the five species examined. The percent transferred was dependent on the percent of total lipid in the fish that was deposited in the eggs. The levels of PCB monitored in the eggs of rainbow trout collected from Lake Ontario suggest that egg and fry survival could be affected based on other toxiciology studies. The other contaminants were not sufficiently concentrated to suggest adverse effects.

(6) <u>Pentachlorophenol uptake by fish</u>. Project Leader - Dr. A.J. Niimi. Technician - L. Luxon[1]

Pentachlorophenol (PCP) is a biocide widely used in North America by the wood products industry, and about 90 million kg is produced annually. PCP has a solubility of 14 ppm which is increased to 4,000 ppm when converted to sodium pentachlorophenate, its most common form. Water sampling programs of the Great Lakes indicate 78 of 85 bulk water samples from stream mouths and nearshore areas contain levels of 0.005 to 23 µg PCP l^{-1}. A study was conducted to determine the uptake of PCP by rainbow trout from water at levels that approached environmental concentrations.

Fish were exposed to waterborne PCP concentrations that averaged <10, 35, and 660 ng PCP l^{-1}. Residue analyses showed that fish exposed to <10 ng l^{-1} averaged 2 µg kg^{-1}, those exposed to 35 ng l^{-1} averaged 10 µg kg^{-1}, while those exposed to 660 ng l^{-1} averaged 160 µg kg^{-1} after 115 days exposure. It has been suggested that the liver is one of the principle organs associated with the metabolism of PCP. Analyses of the gall bladder and liver in the exposed fish demonstrated that two percent of the total PCP found in fish exposed at the <10 ng l^{-1} level occurred in these organs; this was increased to 8 and 14 percent of the total PCP at the two higher exposure levels. This suggests that uptake from water is an important pathway for PCP accumulation in fish. Further studies are now in progress to examine the importance of food as a pathway for PCP uptake.

[1] *Other Participants: C.Y. Cho (University of Guelph); C. McFadden.*

(7) Uptake of chlorobenzenes by rainbow trout. Project Leader - Dr. A.J. Niimi[1]

Subadult rainbow trout were exposed to ten chlorobenzenes in water at concentrations near environmental levels (ng/L) for up to 105 days. The di- and trichlorobenzenes attained equilibrium concentrations within eight days of exposure, tetrachlorobenzenes after 40 days, and pentachlorobenzene afer 70 days. Hexachlorobenzene continued to accumulate over the study period. The bioconcentration factor (BCF) was found to increase as the degree of chlorination on the aromatic ring increased. A high correlation ($r = 0.986$) was found between the BCF and published octanol-water partition coefficient for those substances that had attained equilibrium.

Ten adult rainbow trout were collected from Lake Ontario and analyzed for the same substances. The BCFs were then applied to field estimates of chlorobenzenes concentrations in Lake Ontario to estimate the accumulation of chlorobenzenes from water. The results suggested the di- to tetra-chlorobenzenes are accumulated primarily through the water, the pentachlorobenzene is accumulated from water more than food, and hexachlorobenzene is accumulated primarily through the food.

[1] *Other Participants: B.G. Oliver (national Water Research Institute)*

(8) Organic contaminants as indicators of energy conversion efficiency. Project Leader - Dr. U. Borgmann. Technician - K. Ralph[1]

The uptake of radiolabelled hexachlorobenzene (HCB) and hexachlorobiphenyl (PCP) by Daphnia from both food and water were studied. Uptake from water was rapid and equilibrium was reached after about two days. Addition of contaminated food (the alga Chlorella) resulted in a rapid loss of HCB or PCB from the food into the water, making it impossible to study contaminant uptake by Daphnia from food without simultaneous uptake from water. Uptake from food and water was not noticeably higher than from water alone, suggesting that the water uptake route predominates under laboratory conditions. This makes it impossible to use HCB or PCB uptake as a tool in studying energy conversion efficiency by Daphnia.

The uptake of radiolabelled aminoisobutyric acid (AIB), a relatively non-metabolizable amino acid, by Dapnia from food and water was also studied to develop a method for estimating energy conversion efficiency. AIB was taken up only from food, and once taken up was retained unless passed on to offspring. Unfortunately, efficiency of uptake from food was only about 50 percent, limiting its usefulness in efficiency studies.

1 *Other Participants: A.J. Niimi; M. Schneider*

(9) PCB dynamics in model ecosystems. Project Leader - Mr. S. Millard. Technician - C. Charlton

Research on PCB dynamics has been conducted in model plankton ecosystems (stainless steel columns, height 4.5 m, diameter 1 m, volume 3,400 litres) using ^{14}C-labelled Aroclor 1242. Sedimentation and volatilization are the most important pathways for PCB transport in our experiments. The main factors affecting the relative importance of sedimentation are zooplankton grazing and partitioning between the soluble and particulate phases. Partitioning is, in turn, affected by particle density, surface area, and adsorptive properties of the particles. Turbulence is probably the major factor determining the extent of volatilization.

Turbulence has increased in our experimental systems since our earlier experiments because of a changeover to pumps capable of higher pumping speeds. In a comparison between pumping speeds in two different experiments (low and high PCB loading), recovery of PCB (water column and sedimentation) was highest at the lower pumping speed, indicating lower volatilization losses (Table 16). Although seston levels were also lower at the higher pumping speeds, the relative size of the soluble pool was the same and therefore similar amounts of PCB were available for volatilization.

A model describing temporal changes in total PCB concentrations as a function of daily loadings and losses due to sedimentation, wall adsorption, and volatilization is in the early stages of development. Sedimentation coefficients for the model were derived from direct measurements using traps, while coefficients for wall adsorption were estimated by measuring adsorption to steel places suspended in the columns. Adsorption was relatively unimportant, usually accounting for less that five percent of the PCB added. Volatilization was predicted by determining the relationship between turbulence as quantified by the oxygen absorption coefficient (K_{O_2}) and the output of the pumps used to mix the epilimnion (Table 17). K_{O_2} was easily determined by stripping the mixed layer of oxygen with sodium sulphite and measuring the rate of re-oxygenation. Paris et al. (1978) found in beaker experiments that although volatilization coefficients (K_{PCB}) and K_{O_2} were both affected by turbulence, the ratio K_{PCB}:K_{O_2} was not, being 0.19 to 0.23 for Aroclor 1242. If this relationship were true for the columns, then K_{PCB} could be determined from pump speed and its relationship with K_{O_2}. K_{PCB} was measured by adding PCB's to columns containing water only, with varying levels of turbulence, and following the decline of the soluble pool. At the two highest turbulence levels similar values were obtained for this ratio, but this was not the case at the lowest pumping speed and for an unmixed column. Further research is planned.

TABLE 16. Comparison of PCB retained in epilimnion, sedimented, and recovered in columns with pumps for vertical mixing set at 17 and 32 l min^{-1}

	Low PCB Loading		High PCB Loading	
	17	32	17	32
Total PCB in epilimnion (dpm l^{-1})	3506	1902	28962	10940
Sedimentation (μCi)	0.40	0.79	2.62	6.97
Recovery (%)	56.4	41.4	50.6	29.4
Seston in epilimnion (mg l^{-1})	19.2	11.9	17.2	9.8
Soluble (% of total = soluble + particulate)	35.1	34.9	35.3	35.1

A contract on PCB dynamics in benthic food chains and sediments was issued to develop and apply a flow-through system for studying PCB flux from Lake Ontario sediments. At PCB concentrations varying from 0.3 to 2.75 ppm (dry wt) in the sediments, there was no significant difference between concentrations in the relative release rate. Rates declined exponentially at each concentration to an asymptote of 0.08 percent per week. This work is being continued to study the effect of organic content on the sediment on PCB release.

TABLE 17. Effects of a mixture of metals on Ankistrodesmus falcatus as shown by different bioassay techniques

Percent Metal Mixture	Percent Inhibition as Compared with Control			
	^{14}C-$NaHCO_3$ Uptake	Batch Culture	Chemostat Culture	Turbidostat Culture
10	0	3	0	ND
50	10	25	24	21
100	30	42	58	35
1000	ND	ND	ND	67

ND = not determined.

B. Contaminant Effects

(1) Comparison of algal bioassay techniques in toxicity studies. Project Leader - Dr. P.T.S. Wong[1]

Five techniques were used to study the effects of a metal mixture on freshwater green alga, Ankistrodesmus falcatus. Three techniques involved batch culture and the remaining two were continuous culture. The first was the conventional ^{14}C-$NaHCO_3$ technique in which algae were exposed to the metal mixture for various lengths of time and the effects determined by the amount of ^{14}C-$NaHCO_3$ taken up by the cells after a four-hour incubation. The second technique involved exposing the cells to a toxicant in a flask. At various intervals, small volumes of the medium were withdrawn and effects measured by cell counts under the microscope. In the third technique, a side-arm flask was used for the bioassay. The effect of metal mixtures on algal growth was conveniently monitored by inserting the side-arm flask into a Klett-Summerson colorimeter and recording the changes in optical density. The continuous culturing techniques involved a turbidostat and a chemostat. In the turbidostat (Fig. 15), a constant and predetermined number of cells were exposed to the metal mixture by an automated algal cultivation controller (Acc-5, Techtum Instrument). When cell numbers exceeded a predetermined value, their turbidity activated a photocell to open a valve and release fresh medium from a reservoir to a culture vessel to dilute the cells. The chemostat (Fig. 16) involved a constant supply of medium and metal mixture to a growth chamber. The effect of the toxicant on the growth kinetics of the alga was determined by cell counts.

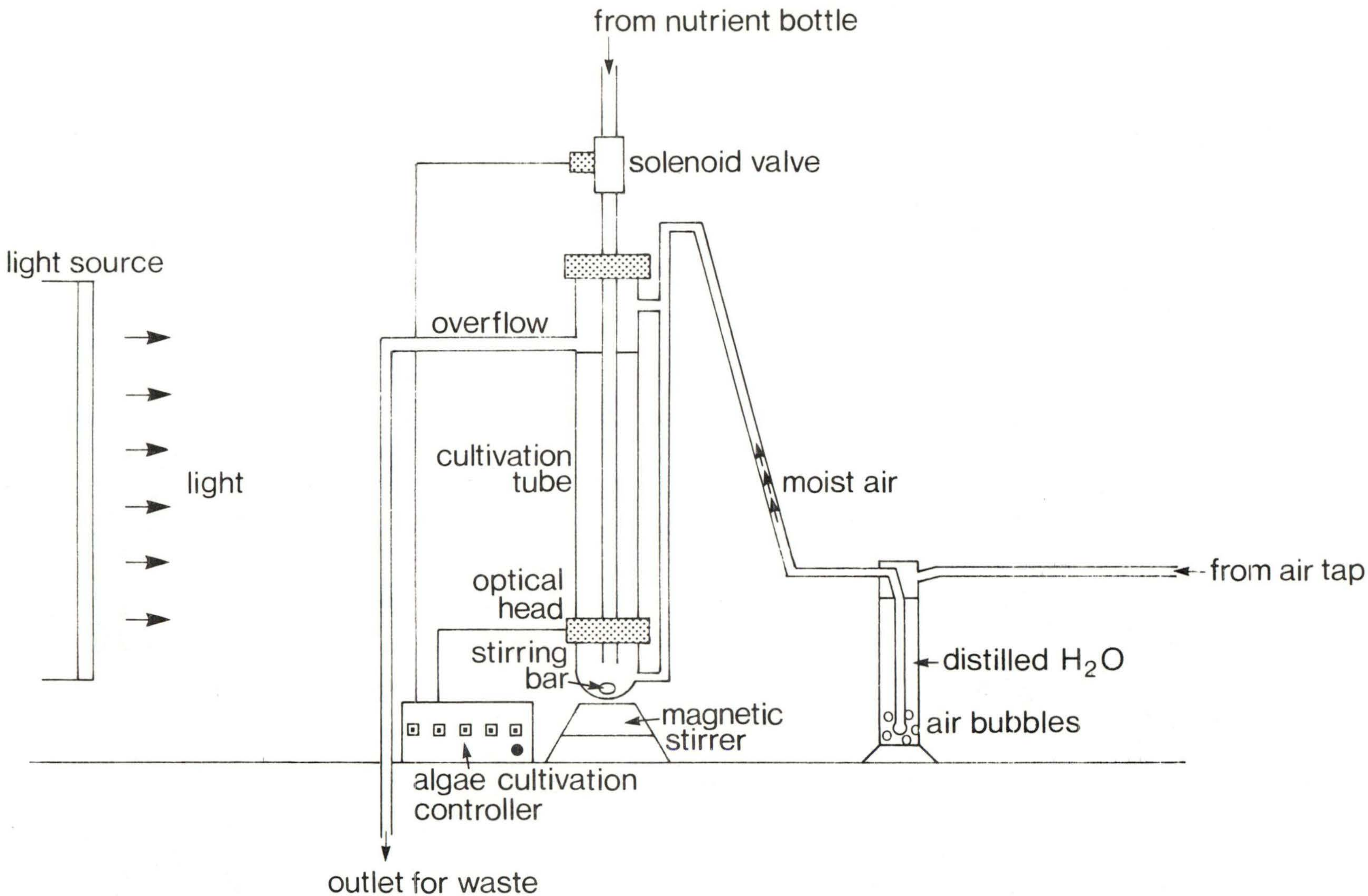

Fig. 15 Turbidostat.

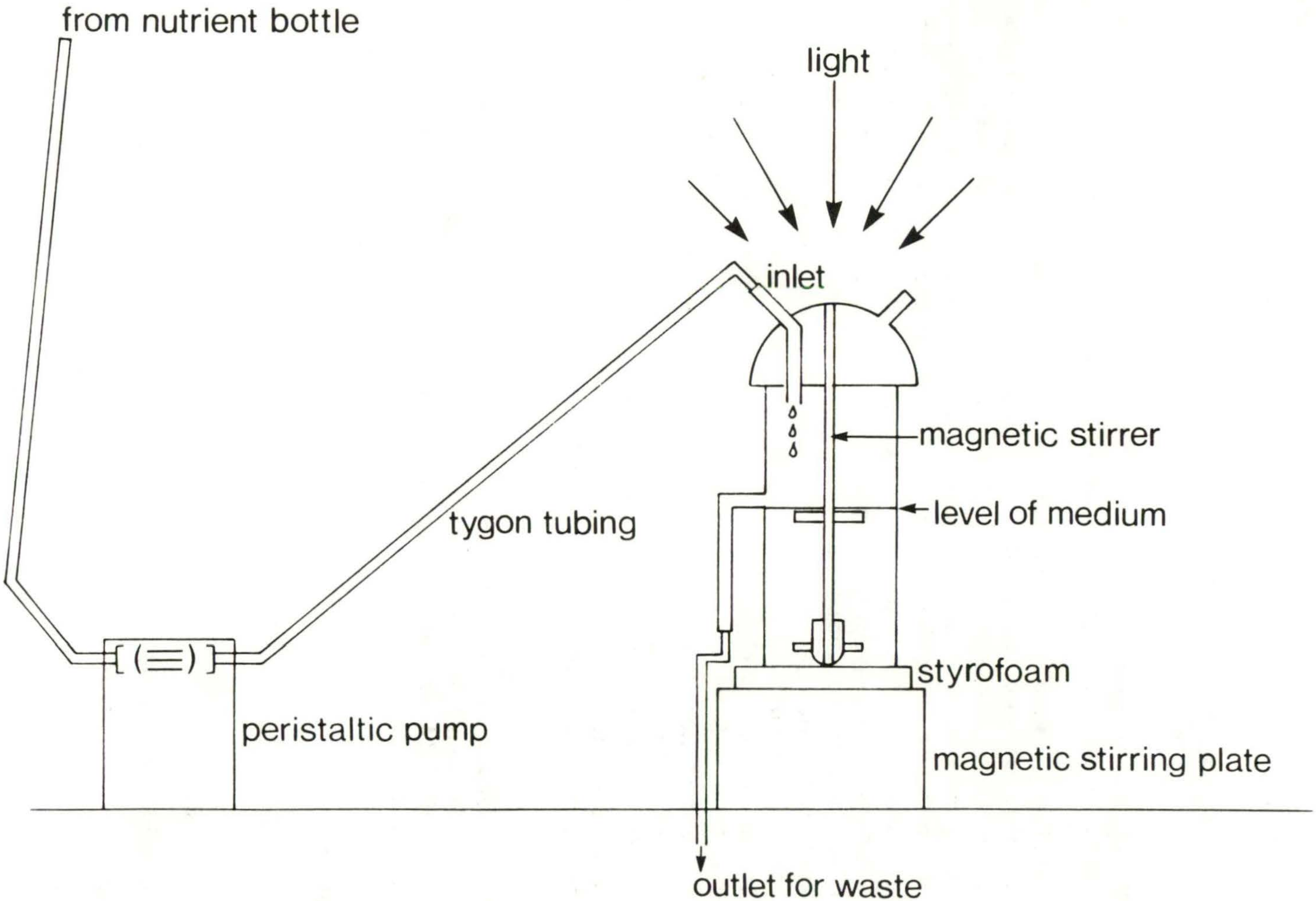

Fig. 16 Chemostat.

The results from these five techniques all indicated the toxic effects of the metal mixture on the green alga (Table 17).

[1] *Other Participants: D. Patel*

(2) Metal complexation and toxicity to invertebrates. Project Leader - Dr. U. Borgmann. Technician - K. Ralph

The toxicity of metals to aquatic biota is generally believed to be due largely, or entirely, to free metal ions. Metal-ligand complexes of both strong (e.g., EDTA) and weak (e.g., amino acid) complexing agents are usually non-toxic. Table 18 and Figure 17 show the effects of additions of EDTA and amino acids on the toxicity of copper to the rotifer Keratella cochlearis in Burlington Canal water. Strong complexing agents reduce metal toxicity in direct proportion to their concentration, since free metal ion concentrations do not approach toxic levels until total metal concentrations exceed total ligand concentrations. However, the concentration of weak complexing agents must exceed the total metal concentration before a significant proportion of the metal is complexed, and hence reduction in toxicity by weak ligands is a function of both the concentration and strength of the complexing agent. The α-amino acids are generally stronger complexing agents than the β-amino acids and this is reflected in their greater ability to reduce copper toxicity (Table 18).

TABLE 18. Copper concentration reducing rotifer numbers in 24 hours by 50 percent (EC_{50}), before and after addition of EDTA or amino acids to Burlington Canal water

Ligand Added	EC_{50} µg l^{-1}	Increase in EC_{50} µmol l^{-1}
None	85	-
EDTA (20 µmol l^{-1})	1320	19.4
Glycine (300 µmol l^{-1})	3640	55.9
Glutamic acid (300 µmol l^{-1})	4680	72.3
β-alanine (1000 µmol l^{-1})	346	4.1

Current research is on the development of techniques for determining free metal ion concentrations by addition of weak

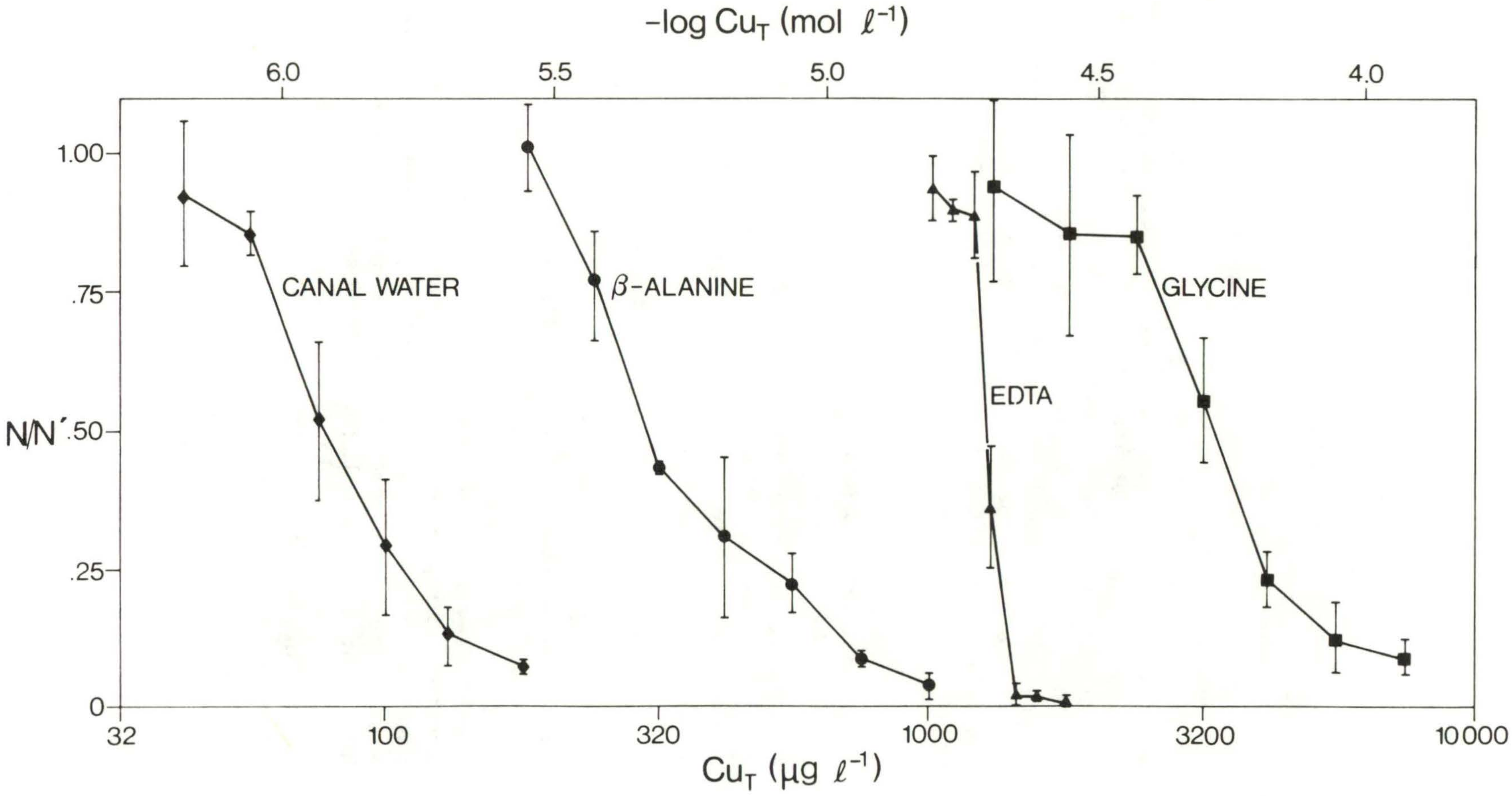

Fig. 17 Number of live Keratella (N) relative to control (N') after 24 hours exposure to various total copper concentrations without (canal water) and with added EDTA (20 μmol l^{-1}), glycine (300 μmol l^{-1}), or β-alanine (1000 μmol l^{-1}). Vertical bars indicate ±1 SD.

complexing agents in bioassays. For example, after addition of high concentrations of amino acids (e.g., Table 18), most of the copper is complexed to the amino acid, which acts as a metal ion buffer, analogous to the pH buffers used to control hydrogen ion concentration. If the stability constant for the metal-ligand complexes are known, it is possible to calculate free metal concentrations toxic to aquatic life and thereby 'calibrate' the bioassay. Free copper concentrations calculated from the data in Table 18, for example, are about $10^{-8.4}$ mol l^{-1} at 50 percent mortality. This equals approximately 0.3 percent of the total copper concentration in canal water causing 50 percent mortality before the addition of any complexing agents. Similar calculations have suggested that free copper concentrations below 10^{-9} mol l^{-1} inhibit growth of copepods in Burlington Canal water. Weak complexing agents (amino acids) acting as metal ion buffers are responsible for the lower slope of toxicity curves (Fig. 17) relative to the toxicity curve after addition of EDTA, which has a low buffering capacity.

(3) Zooplankton production model. Project Leader - Dr. U. Borgmann

A mathematical model has been developed for analyzing animal production in pelagic ecosystems. The model relies on a definition of conversion efficiency based on organism size rather than trophic level. Particle size conversion efficiency is defined as:

$$\varepsilon = \log(1/K_1)/\log(W_j/W_i)$$

where K_1 is the conventional conversion efficiency and W_j/W_i is the predator size divided by prey size. A review of the available literature suggests that the particle size conversion efficiency is at least as constant as conversion efficiency (i.e., K_1) from one trophic level to the next. This is probably partially due to the greater energy expended in collecting smaller prey items, as compared to larger prey. By assuming a constant particle size conversion efficiency, some of the mathematical problems encountered in modelling complex pelagic ecosystems can be avoided. Zooplankton production can then be related directly to potential fish production, for any given size of fish. The model has been used to examine microzooplankton production in the Burlington Canal. Because microzooplankton include both herbivores and carnivores, production of the entire microzooplankton community in our experiments could not have been analyzed in any other way.

(4) *Blood parameters in fish as an indicator of physiological stress. Project Leader - Dr. A.J. Niimi*[1]

The use of haematological measurements as a diagnostic procedure has been widely used in mammalian studies. The parameters most commonly monitored include haematocrit levels, haemoglobin content, red and white blood cell counts, or different cell ratios over the 20-minute period. The results suggest that measurements of haematocrit and possibly haemoglobin in fish collected from the field may not always be representative of the physiological status of the fish; these parameters may be influenced by capture and sampling stress.

The results indicated that haematocrit values of fish anesthetized with tricaine methanesulfonate (MS-222) and sampled after five to twenty minutes were significantly higher than those of fish sampled within one minute of capture and anesthesia. No differences were observed among haemoglobin content, red and white blood cell counts, or differential cell ratios over the 20-minute period. The results suggest that measurements of haematocrit and possibly haemoglobin in fish collected from the field may not always be representative of the physiological status of the fish; these parameters may be influenced by capture and sampling stress.

[1] *Other Participants: L. Lowe-Jinde (University of Guelph)*

(5) *Quantitative structure activity relationships (QSAR). Project Leader - Dr. P.V. Hodson. Technician - B. Blunt*

This project was undertaken to determine whether QSAR's can be used to predict chemical hazards to fish. The approach is to develop QSAR's based on short-term lethality and physiological responses of trout to contaminants. These QSAR's will be used to predict chronic toxicity as confirmed by trout embryo-larval tests. The success of these predictions will be the criterion for acceptance or rejection of QSAR as a useful tool. Work with chlorinated benzenes and para-substituted phenols in 1981 included:

(a) development of a fast technique for IP injections of trout with contaminants;

(b) correlations of lethality measured by IP injection, oral intubation and waterborne exposure;

(c) comparison of the uptake and distribution of selected radiolabelled compounds after oral intubation and IP injection;

(d) measurement of the physiological responses to injected para-substituted phenols; and

(e) initiation of two embryo-larval toxicity tests (phenol and 1,2,4-trichlorobenzene).

IP LD_{50}'s were linearly correlated to oral LD_{50}'s (correlation coefficient (r = 0.99), but the correlation to waterborne LC_{50}'s was non-linear (r = 0.98), probably due to variations in uptake kinetics during waterborne exposure. IP LD_{50}'s were not identical to oral LD_{50}'s because the uptake studies showed that blood concentrations of injected contaminants achieved a higher concentration in less time than ingested contaminants. The net result was a higher dose delivered to the site of toxic action, and an apparent greater toxicity of injected compared to ingested contaminant.

[1] *Other Participants: D.G. Dixon (University of Waterloo), K.L.E. Kaiser (National Water Research Institute); E.J. Kempe; S. Munger; M. Comba (National Water Research Institute)*

(6) <u>Other studies in fish toxicity</u>. Project Leader - Dr. P.V. Hodson. Technician - B. Blunt[1]

The chronic toxicity to fish of tetraethyllead was measured by an embryo-larval-fry bioassay with rainbow trout. No effect on eggs or newly hatched sac fry were observed at nominal concentrations of 1.0 $\mu g\ l^{-1}$ or less, but during four weeks of feeding, growth was significantly reduced at 0.45 and 1.0 $\mu g\ l^{-1}$.

A study with Dr. J. Hilton, University of Guelph, evaluated the toxicity to trout of dietary contaminants contained in Great Lakes fishes. Adult migrating coho salmon were collected in 1980 from Lake Ontario (gutted and whole), Lake Michigan (gutted), and the Pacific Ocean (whole) and rendered into fish meal that was used for diets equivalent in protein, fat, calories, moisture, and micro-nutrients. A standard equivalent laboratory diet was used as a control and all diets were analyzed for organochlorine contaminants. These diets were fed to juvenile rainbow trout starting at 1.0 g, at the University of Guelph. After 16 weeks, there was no obvious treatment effects on haematology, growth, and liver somatic index, but ascorbic acid levels were depressed in all fish meal diets.

A contract was issued to Dr. T. Chen, McMaster University, to:

(a) refine a technique for measuring vitellogenesis and gene expression in trout liver, and

(b) use this technique to evaluate the relative toxicity of compounds that induce mixed function oxidase activity (MFO), inhibit MFO activity, have no MFO effects, or are hepatotoxins.

[1] *Other Participants: J. Hilton (University of Guelph)*

C. Other Studies

(1) Extended winter navigation on the Great Lakes. Project Leader - Dr. A.J. Niimi

Canada and the United States must decide in the near future if shipping on the Great Lakes - St. Lawrence Seaway (GL-SLS) system is to be operated at capacity, or the system be upgraded to accommodate projected increases. Sections of the GL-SLS could approach operating capacity in the mid-1980's, and options to increase its capacity include extending the present 8½-month shipping season to 11 to 12 months, or upgrading facilities to accommodate larger vessels. The U.S. Army Corps of Engineers have examined this issue in depth, and have concluded that it is technically and economically feasible to extend the shipping season, and possibly increase the capacity.

The economic and environmental issues of the Corps analyses were examined from a Canadian perspective. Total cost of the proposed improvement was difficult to estimate because many of the positive and negative benefits of the economic and environmental issues were not clearly identified. It was established that most of the capital improvements on facilities that would be required are those located in Canada, and most of the environmentally sensitive areas, such as shorelines and wetlands, are located in Canadian waters. In view of this, it was suggested that the cost-sharing arrangement of the project proposed by the Corps may not be entirely suitable, but additional information would be required by both countries to make an equitable decision.

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ECOSYSTEMS

Program Leader - Dr. R.L. Thomas (Temporary)

INTRODUCTION

The Ecosystems program of GLFRB was originally implemented as a field orientated investigation to assess the interactions of freshwater ecosystems with those limnological conditions which are subject to varying degrees of anthropogenic perturbations. The original program was concentrated in oligotrophic Batchawana Bay in Lake Superior, and the hypereutrophic Bay of Quinte in Lake Ontario. The Bay of Quinte study is particularly interesting in that it is designed to evaluate and analyze shifts in community structure, at all trophic levels, which may occur in response to declining nutrient loadings resulting from the introduction of tertiary sewage treatment at the major towns situated on the Bay. Final analysis of a ten-year data base is currently under way and will shortly be produced as a composite publication on the limnology and ecology of the Bay.

A major shift in direction of the program was implemented in the 1980-1981 season when a program on the ecological effects of acid precipitation on sensitive lakes in Ontario was begun. In 1981/82 this program was formally incorporated into the National Long Range Transport of Atmospheric Contaminants Program (LRTAP) of the Federal Department of Fisheries and Oceans. Two major components of LRTAP are involved in the study of regional effects of sensitive headwater lakes and of a hydrologically calibrated watershed system, the Turkey Lakes, in the Algoma District north of Sault Ste. Marie. The lake inventory program has been extended into other eastern regions of Canada and GLFRB has been designated as the responsibility centre for the integration and analysis of the data acquired by DFO regional organizations. Under a Steering Committee, the Turkey Lakes program has been fully integrated with other agencies of government, both Provincial and Federal. Current reports of the results of these studies are being utilized in an assessment of effects on Canadian lakes as a component of the ongoing discussions with the U.S.A. concerning the establishment of a formal agreement between the two countries with respect to the transboundary movement of airborne contaminants.

A. <u>Studies on long range transport of atmospheric pollutants.</u> Project Leaders - Dr. J.R.M. Kelso (Sault Ste. Marie) and Dr. M.G. Johnson (Owen Sound). Technicians - R.H. Collins (S.S.M) and L.R. Culp (O.S.)

INTRODUCTION

The phenomenon of atmospheric deposition of contaminants in Canada, such as mineral acids, heavy metals, organics, is an environmental perturbation which urgently requires resolution (Johnson, 1981a). Although localized deposition near Sudbury first brought a Canadian focus to the problem in the 1950's and 1960's, recent studies indicated that aquatic systems which are remote from local influences, particularly in Ontario and Quebec, were adversely responding to greater atmospheric depositions than those which caused problems in Scandinavia.

GLFRB studies in Long Range Transport of Atmospheric Pollutants (LRTAP) are part of the Department of Fisheries and Oceans (DFO) National Program and as such are described in the National Program Plan for Studies on Acid Rain 1981/82. GLFRB was among the first few establishments in DFO to implement a program in LRTAP when, in 1979, it began a headwater lakes survey of habitat and biota in central Ontario, in order to provide data for the selection of a calibrated watershed. This headwater lakes survey served not only to aid in the selection of the Algoma calibrated watershed site (jointly operated by DFO, Department of the Environment (DOE) and the Ontario Ministry of Natural Resources (OMNR)), but also to provide the base protocol for DFO's National Inventory Survey, to direct research into indicators of fish well-being, and to identify those metals and organics causing concern.

Two levels of study are being carried out, (1) extensive studies of numerous lakes throughout Ontario, and (2) process studies undertaken predominantly in a single watershed in the Algoma region of Ontario.

(1) <u>Extensive Studies</u>

In Canada, a description has not yet been evolved of fisheries and/or habitat which would enable us to describe the status of the aquatic resource in relation to regional differences in sensitivity and deposition. A survey program was initiated in the Algoma area of Ontario in 1979 (Kelso <u>et al</u>., 1981) and was extended to all of central Ontario in 1980/81. To date, information has been collected from 185 lakes in six areas of Ontario - Atikokan, Nipigon, Sault Ste. Marie, Chapleau, Temagami, and Parry Sound. Data for each lake includes morphometric features, watershed descriptions, buffer-related chemistry, heavy metal concentrations in water and in surficial sediments, as well as phytoplankton and zooplankton community assemblages. Many of these lakes show a more extensive bicarbonate depletion than was expected (Fig. 18). The mean number of total benthic fauna is low in these lakes (Dermott, 1981), and there is only a slight reduction in total numbers of invertebrates in lakes with low buffering capacity. Poor correlations were found between pH and abundance, biomass, or diversity, as the variability within lakes of a given pH range was greater than between pH categories. Fisheries show symptoms of these conditions (Kelso, 1982) and levels of both mercury and lead are greater in fish from lakes of lower pH.

Although collection of samples was completed in 1980/81, data analysis of community structure has only begun for the phytoplankton, zooplankton, and benthos. Fish body burdens have been determined only for Algoma lakes. Cores of a set of five lakes (pH 4.5 to 6.8) have only begun to be analyzed.

Further to these collections of new data, the lake inventory data base of OMNR was used to develop an estimate of the number of lakes in Ontario which are already acid or which might become acid in the future. A methodology was developed whereby lakes were sorted by watershed and gamefish community type and their sensitivity assessed based on lake pH and conductivity (as a surrogate for alkalinity) and on precipitation pH. With appropriate adjustments, the inventory data were assumed to be representative of the total population of lakes in Ontario. Figures on counts and area of lakes by watershed were used to scale up the data.

A draft report was distributed for review and criticism by DFO and OMNR staff. The results (Minns, 1981) indicated that there probably are already 1,200 acid lakes in Ontario and approximately a further 15,000 might become acid in the future. Analysis by fish community indicated that lakes containing lake trout and brook trout are most sensitive and this is the fishery source most at risk.

In the fall of 1980, GLFRB initiated a contract to 'Assess the Effects of Acid Rain on Recreational Fisheries in Ontario Lakes'. The purpose of the work was to develop a model of the acidification process so that the acidification rate could be assessed, and also to develop a model of fish production and its response to acidification. An approach to scaling up the results was to follow from the work of Minns (1981).

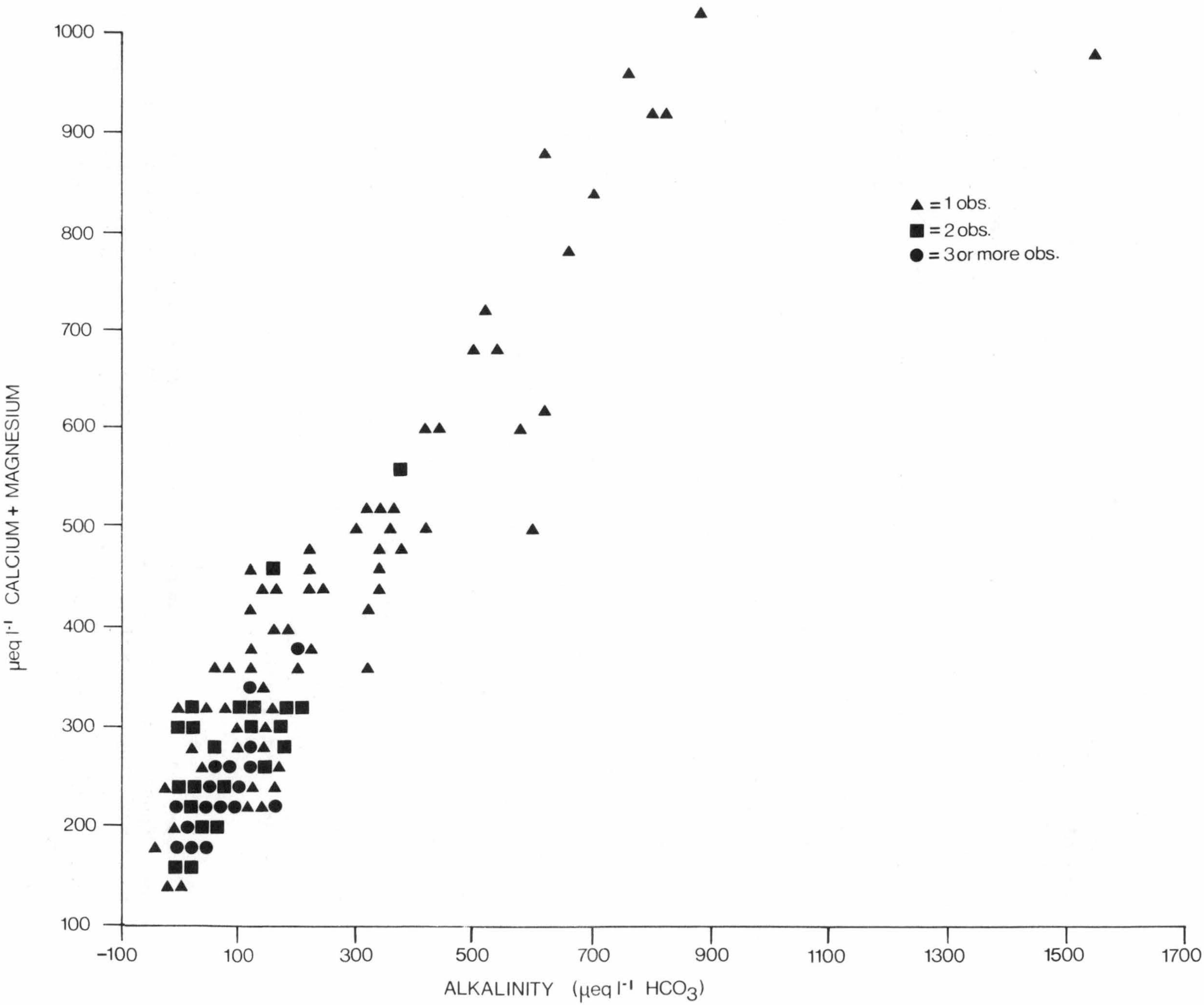

Fig. 18 Calcium + magnesium versus alkalinity for some Ontario lakes.

An acidification model was developed, based on the idea that alkalinity in a lake-watershed complex could be budgeted. Fish production was estimated using Ryder's Morphoedaphic Index, with a modification whereby alkalinity was used rather than total dissolved solids. As alkalinity declines, so does potential yield. Based on fish community types, a portion of potential yield was assumed to be gamefish and species proportions were also estimated. In addition, species pH extinction thresholds were specified.

The advisory committee for the contract reviewed the initial output and then, along with colleagues in DFO, OMNR, and OME, undertook a review and criticism process which led to model revisions.

The results indicate only modest losses of lakes in the future. However, as the consultants point out, there is considerable uncertainty regarding some parameter inputs to the model.

Since these modelling efforts (Minns, 1981, contract with consultants) were confined in area and data (an exception being Kelso and Minns, 1981), GLFRB instituted a workshop through Environmental and Social Systems Analysts to:

(a) estimate current status of lakes and rivers of eastern Canada;

(b) develop a model to predict the response of fish and their habitat to atmospheric deposition; and

(c) to evaluate the DFO's National Inventory Survey Program.

Presentation of the workshop results to a wide audience is scheduled for early 1982.

(2) Process Studies

Since extensive studies fail by their very nature to examine rates and mechanisms of response (Johnson, 1981b), whole ecosystem studies have been instituted by DFO at the Experimental Lakes Area (Freshwater Institute, Winnipeg), Algoma (joint DFO, DOE, OMNR), Westfield River (DFO), and Kejimkujik (DFO, Canadian Wildlife Service).

The Turkey Lakes Forested Watershed Study, an extensive program among governments and universities, is centred in a chain of lakes and streams in the Algoma District, Ontario. The area is one of sensitive geology and is presently exposed to moderate loading by LRTAP. The headwater lakes themselves have reduced pH's and support no fish. In flowing waters, the production of salmonids (brook trout and lake trout), increases downstream.

In the streams of the watershed, low standing stocks of fish exist and streams appear to be used seasonally by lake resident fish. In the stream macroinvertebrates, standing stocks range from low (headwater lake) to high (downstream lake) with apparently good species diversity.

The results of the benthos surveys in the Turkey Lakes, over a range of depths in each lake, indicated that, like the Sault Ste. Marie Lakes, there was poor correlation between diversity, or abundance, and pH or alkalinity. There was a slight shift in the percent composition of the fauna and an incease in Chironomus anthracinus at lower pH values. The littoral fauna showed no change in abundance but did show a significant increase in biomass with lower pH as a result of an increase in large species normally susceptible to fish predation. The anoxic conditions in the upper lake of the Turkey Lakes watershed interfaces with the separation of pH effects from that of other variables.

There is a considerable variation among heavy metal loads to these lakes (Johnson and Culp, 1982). Sediment Enrichment Factors (an index of anthropogenic inputs in relation to natural loads), varied from 0.3 to 30.9 for lead, 0.3 to 3.0 for zinc, 0.4 to 2.6 for mercury, and 0.7 to 2.2 for cadmium, while no significant enrichment was found for chromium, nickel, and copper.

Fish standing stocks increase with increasing downstream alkalinity, and salmonid production increases. No fish exist in the low pH headwater lake and experiments (1982/83) are designed to better define habitat and cause of this state. Since age class structure varies in the system, we are also trying to define these changes by variation in recruitment.

In addition to these response-oriented studies in the Turkey Lakes, organic contaminants of potential concern are being monitored and budgeted in two systems on the Bruce Peninsula. These contaminants are being partitioned within the ecosystem and monitored through time.

Recently, with OMNR, GLFRB began constructing case histories of lakes from historical data in Ontario. Problems have arisen in assessing the viability of the data and in sorting factors that appear to influence observed changes in lakes.

Other studies which are at present only in the data analysis stage include a spring sampling of lakes and streams draining from the Canadian Shield into Lakes Huron and Superior, and a spring sampling of a set of sensitive headwater lakes in the Sault Ste. Marie District. Although many streams (10 to 20 percent) show little buffering (negative to 20 μeq l^{-1}), the pH of all streams, except those arising near Sudbury, are generally greater than 5.5. On the other hand, first order lakes with buffering less than 25 μeq l^{-1} showed pH decreases of up to 2.5 units (down to pH 3.6) in the upper 5 m of the water column. Spring pH depressions decreased with increasing alkalinity. Duration of spring depressions were less than one month and occured while lakes were still ice-covered.

Since time for analysis of samples is long - up to one year - results of studies carried out even one to two years ago, are only now being received.

B. Other Studies

(1) Project Quinte. Project Leader - Mr. C.K. Minns. Technicians - W. Hyatt and C. Timmins

Ecosystems Group, in conjunction with the Ontario Ministry of Natural Resources and the Ontario Ministry of the Environment, have been conducting a study of the Bay of Quinte ecosystem since 1972. The purpose of the project is to study the response of various levels of biota to changes in the nutrient loading. Production and composition of phytoplankton, zooplankton, benthos, and fish, in addition to water quality, have been monitored regularly every year.

The Bay of Quinte can be divided into two sections, an upper shallow area with a mean depth of 3 m, and a lower area with a mean depth of 15 m. Four large rivers, the Trent, Moira, Salmon, and Napanee, drain into the upper Bay. The main point-sources of nutrients are at Trenton, Belleville, Napanee, and Picton. The Bay of Quinte has always been an important source of fish production, formerly supporting both a large commercial fishery and a healthy sport fishery. Nowadays the catches are still high but are dominated by less desirable species.

Measurements in the period 1972 to 1977 described the conditions in the Bay prior to the wide-scale implementation of phosphorus removal at the main point-sources. Since 1978, point-source phosphorus inputs have been approximately 30 percent of those in the previous period.

Analysis of data has shown the strong role of runoff in determining water quality in the Bay. The Bay has a large drainage area and there is considerable seasonal and secular variation in runoff. Whereas prior to 1978 the upper Bay was subject to prolonged algal blooms, the build-up now takes longer during the summer and peak values are reduced. Belleville water filtration plant has reported a marked decrease in the frequency of filter clogging since 1978. In the lower Bay, changes have been less obvious because of the domination of water quality by water flowing in from Lake Ontario proper.

Recent analyses of the zooplankton data indicates a reduction in productivity (corresponding to a reduced primary production), and changes in the relative importance of some species, suggesting a shift to larger individuals. To date there have been no major shifts in the benthos. In the earlier part of the study, it was found that the population of Pontoporeia affinis was declining in the depths of the lower Bay where oxygen levels are greatly reduced in the late summer, and it was first thought that this decline was leading to extinction. However, it now apears that the 'downtrend' was only evidence of variability since subsequent samples have shown higher densities.

The fish community has begun to show some significant changes, though it is thought unlikely that these are directly related to changes in the water quality. Since 1972, the alewive population has undergone large fluctuations, as they do elsewhere and yellow perch appear to show a steady increase. Some of the more important predators have begun to exhibit upward populations trends. Most notable is the occurrence of a strong walleye year class in 1978. This was the largest ever recorded in the Bay and the first of any note in many years. The upswing occurred when the white perch population underwent a dramatic decline in the spring of 1978, due most likely to a thermal kill, and no increase has been noted since then. Walleye will not be firmly re-established until there are three or more good year classes in the age-structure. Nineteen eighty-two is the first spawning year for the strong 1978 year class and hopes are high.

The project itself is beginning to wind down as the emphasis shifts to analysis and reporting the results of the study. A publication schedule has been established. When the analysis is at an advanced state there will be a critical review of future monitoring and research requirements for a fuller understanding of the Bay of Quinte ecosystem.

(2) Adaptive environmental assessment - simulation modelling. Project Leader - Dr. C.K. Minns. Biologist - J.E. Moore

During 1981, the Great Lakes Fish Commission (GLFC) invited the then Great Lakes Biolimnology Laboratory to participate in an evaluation of the application of the Adaptive Environmental Assessment (AEA) technique to fisheries management problems in the Great Lakes. AEA uses modelling workshops as a means of identifying key uncertainties and as a means of examining the concensus appreciation of the processes controlling systems such as fish communities. A group of scientists familiar with systems concepts, programming, and modelling attended a training course given jointly by the Institute of Resource Ecology and ESSA Ltd., on the University of British Columbia campus in Vancouver. Dr. C.K. Minns attended for GLBL. Subsequent to the course, a small group, including Dr. Minns, were invited to form a core modelling team for the GLFC to facilitate the holding of modelling workshops on Great Lakes problems. The team is drawn from the Ontario Ministry of Natural Resources, the Michigan Department of Natural Resources, Case Western University, and the Canadian Department of Fisheries and Oceans.

The Board of Technical Experts (of GLFC) decided to proceed with a demonstration/training workshop focussed on the interaction of lake trout rehabilitation, fishery regulations, and lamprey control In October, 1981, a workshop was held at Sault Ste. Marie, Michigan, and has proved successful. Subsequently, presentations describing the process of AEA and its use in the Great Lakes have been given to the Lake Committees of GLFC. The GLFC is on the verge of recommending further use of the methodology for identifying planning, management, and research requirements. The process will prove very useful in the examination of habitat-related problems, e.g., entrainment/impingement, toxicants and contaminants, etc.

(3) Larval fish ecology. Project Leader - Mr. J.K. Leslie.

Although the aquatic ecosystem of the Bay of Quinte has been extensively studied since 1972 when 'Project Quinte' was established, only one study (Lam, 1977) dealt with larval fish. Knowledge of the larval fish distribution and abundance would provide important data for the formulation of fisheries management policies on the important commercial and sport fisheries in the Bay. An abundance of species and habitat type (Hurley and Christie, 1977) and an extensive data base exists from a decade of continuous limnological research in the Bay of Quinte and a site in the area was selected in 1981 for a study of larval fish ecology. This provided an opportunity not only to fill gaps in the life history of many of the resident fish species but also to aid in the identification and description of certain Great Lakes larval fish.

Muscote Bay, at the upper end of the Bay of Quinte, was surveyed from late April until early October and approximately 200 shoreline samples were obtained from a fine-mesh larval fish seine, and 450 samples were taken in open water with paired conical nets. More than 45,000 larval and juvenile fish were caught at six fixed shore stations, and approximately half as many were also obtained from the open water, or transect, samples.

Preliminary results indicate that species and abundance were related to habitat type, and that movement of most shallow water species, such as larval white sucker (Catostomus commersoni) and Cyprinidae were confined to the nearshore areas.

At least 16 species were identified in samples obtained from late April to mid-June. The first species to appear were post-larvel lake whitefish (Coregonus clupeaformis), followed in early May by yellow perch (Perca flavescens), after which white suckers appeared. White perch (Morone americana), gizzard shad (Dorosoma cepedianum), and alewife (Alosa pseudoharengus) were also present in abundance.

Yellow perch was the most abundant species in Muscote Bay. Postlarval white suckers were notably transitory, as approximately 20,000 were caught in mid-May in two 10 m beach seine tows, while at the same site the previous week only 10 were caught, and none appeared in the samples taken the following week.

Shallow, warm water areas bordered by cattail marshes or with an abundance of submerged and emergent vegetation served as a nursery and refuge for many species.

(4) Benthic community structure, western Lake Erie. Project Leader - Mr. R. Dermott

This project was commenced to analyze the benthic samples collected congruently with a whole lake sediment survey carried out in 1979. The objective was to assess the response of the biota to the sediment parameters and to determine if the present status of the bottom fauna indicates any changes of water quality in western Lake Erie.

A total of 75 Shipek samples were analyzed under contract for identification to family level. Identifications of the oligochaetes and statistical analysis of the data will be completed in 1982.

The bottom fauna west of the island region was limited to nematodes, oligochaetes, Sphaerium, chironomids, and the leech Helobdella. The island area and eastward beyond Point Pelee possessed a more rich fauna including gastropods, isopods, and several ostracod genera, but limited in comparison to that in the other Great Lakes at similar depth (10 to 15 m). In the whole area examined, the chironomids were limited to Chironomus, the Tanypodinae Procladius and Coelotanypus and a few specimens of Cryptochironomus.

As in the recent study by Veal and Osmond (1981), Hexagenia was limited to one area to the east of the Detroit River. Lacking sufficient inshore samples, the present study can only conclude that Maumee Bay and the Raisin River area remain moderately polluted as outlined by Carr and Hiltunen (1965) with oligochaetes averaging greater than $1,000/m^2$. The Detroit River mouth, however, showed a slight improvement since 1961, with oligochaetes averaging only $850/m^2$ compared to $7,300/m^2$ in the same area sampled in 1961 by Carr and Hiltunen (1965).

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Baker, M.D., Wong, P.T.S., Inniss, W.E., and Mayfield, C.I. "Microbial activity in sediments from acidic Ontario lakes". 8th Ann. Aquat. Toxic. Workshop, Guelph, November 2-4.

Borgmann, U. "Metal complexation and toxicity to freshwater copepods". CCIW Chem./Biol. Seminar Ser., April 27.

Cairns, V.W. "Relationship between stream communities and Great Lakes fish". Pickering Naturalists, March.

Cairns, V.W. "Primary, secondary and tertiary stress in fish: an overview". Fish Health Workshop, Geneva Park, Ontario, November.

Cairns, V.W. "Recommendations from the Fish Health Workshop". Great Lakes Fishery Commission, Interim Meeting, December.

Chau, Y.K., and Wong. P.T.S. "Direct speciation analysis of molecular and ionic organometals". NATO Workshop on 'Trace element speciation in surface waters and its ecological implications', Nevri, Italy, November 2-4.

Dermott, R. "The benthic fauna of poorly buffered lakes displaying a gradient of pH". Acid Rain/Fish. Symp., Cornell Univ., Ithica, August 2-5.

Dixon, D.G., Hodson, P.V., and Kaiser, K.L.E. "The use of LD_{50} determination by intraperitoneal injection as a rapid method for initial estimates of pollutant toxicity to fish". 8th Aquat. Toxic. Workshop, Guelph, Ontario, November 2-4.

Hilton, J.W., and Dixon, D.G. "Effect of increased liver glycogen and liver weight on liver function in rainbow trout (<u>Salmo gairdneri</u>): recovery from anaesthesia and ^{35}S-sulphobromophthalein clearance". 24th Meet. Can. Fed. Biol. Soc., Montreal, June 15-19.

Hodson, P.V. "Use of blood lead and erythrocyte δ-amino levulinic acid dehydratase activity to detect lead exposure to fish populations". Proc. IAWPR Pre-Conf. Symp. Ecotoxicol., Toronto, May, 1980.

Hodson, P.V. "Effect of growth rate and size of fish on the rate of intoxication by waterborne lead". CCIW Chem./Biol. Seminar Ser., April 27, 1981.

Hodson, P.V. "Fish health surveillance". Univ. Waterloo, Ontario.

Hodson, P.V., and Hilton, J.W. "The nutritional requirements and toxicity to fish of dietary and waterborne selenium". Internat. Symp. Biogeochem., Stockholm, June 1-15.

Hodson, P.V., Blunt, B.R., and McGaw, S. "The effect of fluctuating lead exposures on lead uptake by rainbow trout (Salmo gairdneri)". 8th Ann. Aquat. Toxic. Workshop, Guelph, Ontario, November 2-4, 1981.

Hodson, P.V., Blunt, B.R., and Whittle, D.M. "The utility of a biochemical method for assessing the exposure and response to lead of feral fish". 6th Symp. Aquat. Toxicol., October 13-14, St. Louis, Missouri.

Johnson, M.G. "Pollution - 1980's style". Ont. Counc. Commerc. Fishermen, Toronto, January.

Johnson, M.G. "Contaminants as a stress on fish". Ont. Min. Ntrl. Resourc., Fish. Assessm. Unit Workshop, Geneva Park, March.

Johnson, M.G. "Pollution - 1980's style". Sydenham Sportsmen's Club, Owen Sound, September.

Johnson, M.G. "Environmental effects in urbanizing watersheds - international aspects". Toronto, October.

Kelso, J.R.M. "Chemical and biological status of headwater lakes of the Sault Ste. Marie District, Ontario". Michigan State Univ., April 1-4.

Kelso, J.R.M., and Minns, C.K. "Current status of lake acidification and its effect on the fishery resources of Canada". Acid Rain/Fish. Symp., Cornell, August, 1981.

Kelso, J.R.M. "Contaminants in the environment". Series of Seminars at Laurentian Univ.

Kelso, J.R.M. "Chemical and biological status of Ontario Lakes". DFO, St. John's, Nfld.

Munawar, M. "Diurnal rhythms in the Great Lakes: a proposal". Internat. Plankton Ecol. Workshop, Limnol. Inst., Univ. Konstanz, F.R.G., September.

Munawar, M. "An overview of research on the effects of dredge spoils on natural phytoplankton and the development of a bioassay". Environm. Protect. Serv. Comm., November.

Munawar, M., and Munawar, I.F. "Phycological studies in the North Channel". 24th Conf. Great Lakes Res., Ohio State Univ., Columbus, April.

Munawar, M., and Munawar, I.F. "Nannoplankton dynamics as a management tool in the Laurentian Great Lakes". Nannoplankton 'state-of-the-art' Symp., Can. Botan. Assoc., Univ. Guelph, June.

Munawar, M., Munawar, I.F., and Ross, P.E. "Microscopic evidence of phytoplankton passage through glass fibre filters and its implications for chlorophyll analysis". Ann. Meet. Amer. Soc. Limnol. Oceanogr., Univ. Wisconsin, June.

Munawar, M., Munawar, I.F.,and Ross, P.E. "Nannoplankton ecology and phytoplankton-zooplankton relationships in the North American Great Lakes". Internat. Plankton Ecol. Workshop, Limnol. Inst., Univ. Konstanz, F.R.G., September.

Shear, H., Lee, K., and Nalewajko, C. "A seasonal survey of phosphorus kinetics of Great Lakes phytoplankton". 44th Ann. Meet. Amer. Soc. Limnol. Oceanogr., Milwaukee, June.

Thomas, R.L. "Contaminants in the sediments of the Great Lakes". Ann. Meet. Amer. Assoc. Advancem. Sci., Toronto, January 6.

Thomas, R.L. "The Great Lakes - a scientist's perception". Can. Fed. Univ. Women, Kingston, January, 14.

Thomas, R.L. "The role of the scientist and government research in influencing environmental policy". Queen's Univ., January 19.

Thomas, R.L. "Contaminants in the sediments of Lake Ontario". New York Dep. Environm. Conserv., Albany, January, 27.

Thomas, R.L. "The current status of limnological research on Lake Ontario". Ann. Conf. Internat. Assoc. Great Lakes Res., Columbus, April, 28.

Thomas, R.L. "The Reagan cut-backs to the U.S. Great Lakes Research Program". Ann. Conf. Internat. Great Lakes Res., Columbus, April, April 28. (Presidential address).

Thomas, R.L. "Trace metals in Great Lakes sediments". Ann. Meet. Amer. Chem. Soc., Central and Great Lakes Div., Dayton, May, 21.

Thomas, R.L. "Acid rain". Burlington Rotary Club, Burlington, Ontario, June, 3.

Thomas, R.L. "Sediment studies in the Great Lakes". Inst. Sedimentol. Univ. Heidelberg, September, 29.

Thomas, R.L. "Sediment studies in the Great Lakes with particular reference to phosphorus availability". Dept. Geol. Mineral., Univ. Geneva, September, 30.

Thomas, R.L. "PCB's in sediment and fluvial suspended solids in the Great Lakes". Workshop on PCB's, Toronto, December, 11.

Wong, P.T.S. "Biochemistry of metals". Dept. Biochem., Univ. Toronto.

Wong, P.T.S. "Toxicity of metal mixture on algae". CCIW Chem./Biol. Seminar Ser., April, 27.

Wong, P.T.S. "Lead pathways in the aquatic environment". Dept. Biol., Univ. Waterloo, Ontario.

Wong, P.T.S., Chau, Y.K., and Patel, D. "Comparison of algal bioassy techniques in toxicity studies". 8th Ann. Aquat. Toxic. Workshop, Guelph, November, 2-4.

GREAT LAKES FISHERIES RESEARCH BRANCH

COMMITTEE REPRESENTATION

NAME OF COMMITTEE	NAME OF REPRESENTATIVE AND TYPE OF REPRESENTATION	COMMITTEE'S ROLE
1. INTERNATIONAL		
(a) International Association Great Lakes Research	R.L. Thomas - Past President	Administrative, elected by IAGLR Board of Directors.
(b) International Joint Commission Great Lakes Science Advisory Board	R.L. Thomas - Member	Research Advisory Board to the IJC.
(c) International Association Sediment Water Science	R.L. Thomas - President	New Association formed from the 1st and 2nd Conferences on the Interaction Between Sediment and Freshwater.
(d) International Association Great Lakes Research - Publication Committee	N. Watson - Member	Reviews publication policy and oversees publication of Journal of Great Lakes Research.
(e) IJC Lake Huron Work Group	M. Munawar - Member	Coordination of intensive studies on Lake Huron.
(f) IJC Lake Superior Task Force	H. Shear - Chairman	Coordinate and plan all surveillance and research in Lake Superior, 1983.
(g) Lake Erie/Lake St. Clair Fisheries Management Committee	V. Cairns - Member	To address fisheries issues on Lake Erie and to provide recommendations to GLFC and GLFRB on Lake Erie fisheries problems and programs.
(h) IJC Aquatic Ecosystems Objectives Commission	P.V. Hodson - Member	Writes rationales for and recommends water quality and ecosystems objectives.
(i) Society of Environmental Toxicology and Chemistry, Awards Committee	P.V. Hodson - Member	To develop and apply an awards program recognizing scientific excellence and achievement in environmental toxicology.

GREAT LAKES FISHERIES RESEARCH BRANCH - COMMITTEE REPRESENTATION

NAME OF COMMITTEE	NAME OF REPRESENTATIVE AND TYPE OF REPRESENTATION	COMMITTEE'S ROLE
(j) International Union of Biological Sciences, Canadian National Committee	J.R. Vallentyne - Senior Representative, Environmental Biology) (Also: IUBS, Paris, France, Member)	Nongovernmental, nonprofit organization, established in 1919. Its objectives are to promote the study of biological sciences, to initiate, facilitate and coordinate research and other scientific activities that require international cooperation, cooperative research, promote international Congresses and publication of reports.
(k) Steering Committee, Workshop for Implementing the Ecosystem Approach	J.R. Vallentyne - Chairman	Four organizations (IAGLR-IJC, SAB-GLT-GLFC BOTE), with interests and responsibilities in regard to the Great Lakes, established a Steering Committee to develop a proposal to facilitate implementation of the Ecosystem Approach in the Great Lakes Basin.
(l) International Association Water Pollution Research (Canadian National Committee)	H. Shear - Member	Coordinates policy for IAWPR. Coordinates input to biennial meetings. Develops editorial policy for Journal.
(m) IJC Surveillance Work Group	H. Shear - Member	Coordinates all Great Lakes surveillance activities. Prepares annual report to Water Quality Board.
(n) International Standards Organization Toxicity Working Group	V.W. Cairns - Member	To develop international toxicity test procedures.
(o) Great Lakes Fishery Commission	M.G. Johnson - Executive	Committee established by the Great Lakes Fisheries Convention.
(p) International Standardization Organization	P.T.S. Wong - Canadian Chairman	Algal toxicity assays standardization.
(q) International Plankton Ecology Group	M. Munawar - Executive	Chairman for North American input to an international monograph on plankton succession and ecology.

NAME OF COMMITTEE	NAME OF REPRESENTATIVE AND TYPE OF REPRESENTATION	COMMITTEE'S ROLE
2. NATIONAL		
(a) Great Lakes Working Group	R.L. Thomas - Member	Review, priorise, and allocate funding to the Federal Great Lakes Water Quality Program.
(b) National Advisory Group on Fish Habitat	R.L. Thomas - Member	Interchange and advisory group on fish habitat management and research.
(c) Fish Habitat Revitalization Project Advisory Committee	V.W. Cairns - Member	To develop and plan for management of fish habitat protection, mitigation, and development.
(d) Fisheries Management Review Committee on Research Scientists	R.L. Thomas - Member	Service review for performance enstatement and promotion of RES's in Fisheries Management.
(e) Fisheries Research Directors Committee	R.L. Thomas - Member	Interchange between all FM research directors.
(f) Departmental Policy Group on Acid Rain	R.L. Thomas - Member	To determine policy and funding for DFO National Acid Rain Program.
(g) DFO Advisory Board Scientific Information and Publications Branch	N. Watson - Member	Reviews policy and performance of Branch, especially papers for Can. J. Fish. Aquatic Sci.
	J.R. Vallentyne - Ontario Representative	Develop departmental policy for scientific information and publications. Liaison between SIPB and regions. Evaluate SIPB's scientific and technical information functions. Represent viewpoints on specific subjects regarding manuscripts, documentation publications, etc.
(h) DFO Science Subvention Program Review Committee	N. Watson - Member	Reviews grant applications and assists in allocating funding to successful applicants.

GREAT LAKES FISHERIES RESEARCH BRANCH - COMMITTEE REPRESENTATION

NAME OF COMMITTEE	NAME OF REPRESENTATIVE AND TYPE OF REPRESENTATION	COMMITTEE'S ROLE
(i) Interagency Committee on Toxic Chemicals - Dioxin Working Group	D.M. Whittle - Member	To produce a coordinated plan for the investivestigation and control of dioxins in the Canadian environment.
(j) Departmental Science Advisory Committee	P.V. Hodson - Member	Advise the DM on science issues.
(k) Aquatic Toxicology (Journal)	A.J. Niimi - on Editorial Board	Reviews papers submitted for publication.
(l) Canadian Society of Environmental Biologists	J.R. Vallentyne - President	To improve conservation of resources and ecosystem management.
(m) Rawson Academy of Aquatic Sciences	J.R. Vallentyne - Chairman	Study factors which affect the quality of Canadian waters; and to determine and predict the vulnerability of Canadian water resources. Study of any social, economic or legal matters which may relate to water resource management in Canada. Education re: Canadian water resources.
(n) Great Lakes Working Group, Subcommittee on Contaminants	V.W. Cairns - Member	Review and recommend contaminants-related projects to the Great Lakes Working Group for funding under the Great Lakes Water Quality Agreement.
(o) Scientific Advisory Committee	J.R.M. Kelso	Evaluate and plan future DFO's LRTAP program as a whole.
(p) DFO Management Review Committee Chemical Hazards Program and Policies	V.W. Cairns - Member	Review Environmental Contaminants Program and Activities.

GREAT LAKES FISHERIES RESEARCH BRANCH - COMMITTEE REPRESENTATION

NAME OF COMMITTEE	NAME OF REPRESENTATIVE AND TYPE OF REPRESENTATION	COMMITTEE'S ROLE
3. REGIONAL		
(a) CCIW Executive Committee	R.L. Thomas - Member and Rotating Chairmanship	Forum for management in CCIW at the inter--service, interdepartmental level.
(b) Great Lakes Fishery Commission Lake Ontario Committee	D.M. Whittle - Member	To provide a forum to coordinate fisheries activities on Lake Ontario among various federal, provincial and state environmental agencies bordering the lake.
(c) EPS, Toronto, Technical Review Committee	A.J. Niimi - on Editorial Board	Evaluate all submissions under federal EARP Ontario Region.
(d) Great Lakes Working Group Analytical Capabilities Committee	H. Shear - Member	Review and assess all matters relating to the analytical component of the GLWQA funded program.
(e) Great Lakes Working Group	H. Shear - Member	Review and assess all eutrophication--related projects under the GLWQA.
(f) Canada-Ontario Agreement Surveillance Committee	H. Shear - Member	As for IJC surveillance work group (1m above) , but coordination of Canada-Ontario programs only.
(g) Canadian Centre for Toxicology Advisory Committee	M.G. Johnson - Member	Advise Universities of Toronto and Guelph.
(h) Ontario Technical Committee on Acid Rain	J.R.M. Kelso - Member	Examine science, practicability and future Ontario studies on acid rain.

4. GRADUATE STUDENT COMMITTEES

	STUDENT NAME	DEGREE	UNIVERSITY
R.L. Thomas	J. Coakley	Ph.D	Waterloo
P.V. Hodson	D. Spry	Ph.D	McMaster
	L. Barker	Ph.D	McMaster
	D. Lauren	Ph.D	McMaster
	R. Lanno	M.Sc.	Guelph
P.T.S. Wong	M. Baker	Ph.D	Waterloo
	C. Hart	M.Sc.	Waterloo
	J. Trevor	Ph.D	Waterloo
	K. Lee	Ph.D	Toronto
M. Munawar	C. Hart	M.Sc.	Waterloo
	I. Jordan	M.Sc.	Montreal
	L. Martin	M.Sc.	Montreal

STAFF LIST

Director's Office

Dr. R.L. Thomas .... Director
Ms. J. Leatherdale .... Secretary
Dr. J.R. Vallentyne .... Senior Scientist
Ms. C. Fawcett .... Secretary

Administration

Ms. J. Crescuolo .... Admin. & Finance Officer
Ms. A. Vize .... Finance Clerk
Term Personnel: Ms. C. Reynolds

Surveillance - Program Leader, Dr. H. Shear

Dr. H. Shear .... Project Leader .... Long-term Biological Index Monitoring
Mr. H. Nicholson .... Technician
Dr. M. Munawar .... Project Leader .... Phytoplankton Ecology and Nannoplankton Dynamics
Ms. L. Michell .... Technician
Mr. V.W. Cairns .... Project Leader .... Bioeffects Monitoring
Mr. J. Fitzsimons .... Biologist
Mr. D.M. Whittle .... Project Leader .... Contaminants Surveillance
Mr. W. Hyatt .... Technician

Term Personnel: R. Campbell, M. Keir.
Students: V. Andrusiw, M. Heynen, G. Johnson, L. McCarthy, G. Munger.

Note: Dr. N. Watson on assignment to the Bayfield Laboratory for Marine and Science Surveys.

Environmental Toxicology - Program Leader, Dr. P.V. Hodson

Dr. P.V. Hodson .... Project Leader .... Fish Toxicology
Ms. B. Blunt .... Technician
Dr. P.T.S. Wong .... Project Leader .... Algal Toxicology and Metal Methylation
Ms. O. Kramar .... Technician

Continued.../

Environmental Toxicology - Program Leader, Dr. P.V. Hodson (Cont'd)

Dr. A.J. Niimi .... Project Leader .... Contaminants Dynamics in Fish
Ms. L. Luxon .... Technician
Dr. U. Borgmann .... Project Leader .... Invertebrate Toxicology
Ms. K. Ralph .... Technician
Mr. E.S. Millard .... Project Leader .... Contaminants Dynamics in Model Ecosystems
Ms. C. Charlton .... Technician

Term Personnel: S. Munger, M. Schneider.
Contract Personnel: M. Baker, G. Dixon, C. Hart, O. Johannsson.
Students: B. Dewit, J. Kempe, S. McGaw, D. Pike

Ecosystems Metabolism - Program Leader, Dr. R.L. Thomas (temporary)

Dr. C.K. Minns .... Project Leader .... Project Quinte
Mr. J. Moore .... Biologist
Mr. J. Leslie .... Project Leader .... Larval Fish Ecology
Mr. R. Dermott .... Project Leader .... Benthic Ecology
Mr. C. Timmins .... Technician

Sault Ste. Marie Laboratory

Dr. J.R.M. Kelso .... Project Leader .... Lake Superior Ecosystems, LRTAP
Mr. R. Collins .... Technician
Mr. J. Lipsett .... Technician

Owen Sound Laboratory

Dr. M.G. Johnson .... Project Leader .... Lake Huron Ecosystems, LRTAP
Mr. L. Culp .... Technician

Term Personnel: C. Baile, A. Douglas, S. George, J. Tost.
Students: P. Morrison, K. Richardson, G. Rieder, R. Sandre, C. Sierzputowski, S. Smith, K. Thomas.

Note: Dr. J. Cooley on assignment as Project Leader for DFO's LRTAP Program.

GREAT LAKES BIOLOMINOLOGY LABORATORY
PROGRAM ALLOCATIONS
1981-82

		Director's Office	Support Services: General Admin.	Support Services: Finance	Support Services: Assets Mangt.	Support Services: Information Services	Surveillance Program	Envir. Toxicology	Ecosystems Studies	TOTALS
"A" BASE	Salaries	141.0	22.0	17.5	-	-	167.5	225.0	362.0	935.0
	O&M	15.0	23.5	1.0	1.0	59.5	228.0	192.0	117.0	637.0
	Cap	-	-	1.0	-	-	33.5	27.5	15.0	76.0
	PY's	4.0	1.0	1.0	-	-	8.0	10.0	14.0	38.0
LRTAP	Salaries								83.5	83.5
	O&M								145.0	145.0
	Cap								15.0	15.0
	PY's								3.0	3.0
GLWQ EXTERNAL	O&M						74.0			74.0
	Cap	15.0						12.5		27.5