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Twenty-five years of research on the Great Lakes: 1967-1991

by

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ABSTRACT

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This manuscript summarizes the evolution and contributions of the research program of the Great Lakes Laboratory for Fisheries and Aquatic Sciences over the period 1967 - 1991. In that 25-year time span the program has changed dramatically to reflect issues, new knowledge, and changing priorities. The program continues to be closely linked to the Canada/United States Great Lakes Water Quality Agreement. Frustrations and aspirations for future research are discussed.

RESUME

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Ce manuscrit résume l'évolution et les contributions, lors des années 1967-1991, du programme de recherche par le Laboratoire des Grands Lacs pour les pêches et les sciences aquatiques. Depuis ces dernières 25 années, le programme a changé radicalement afin d'addresser les nouvelles connaissances et les priorités variantes. Le programme continue à renforcer l'Accord du Canada et des États-Unis relatif à la qualité des eaux des Grands Lacs. Les frustrations et les aspirations de recherches futures sont examinées.

<u>CONTENTS</u>

PREFACE

This overview of 25 years of research by the Great Lakes Laboratory for Fisheries and Aquatic Sciences at CCIW was prepared primarily for staff members of DFO and the many other groups and agencies which operate in the Great Lakes region. This is an extraordinarily complex environment in terms of institutions as well as ecology and socio-economics. Consequently, at any time there are undoubtedly many people, even in our own department, who will want to know more about GLLFAS. Hopefully, there are also many people who would like to know more about the Great Lakes cleanup and the research of GLLFAS that has assisted the whole process. We hope this report will provide what they need.

The report is also dedicated to the staff of GLLFAS, including those who have gone to other pursuits. Much credit should go to the biologists and technicians who supported the scientists and sometimes carried individual projects. Secretarial staffs over the years have made an enormous yet often invisible contribution to the GLLFAS program. The large number of students, of generally excellent quality, who helped out over the years deserve a special vote of thanks. Colleagues of GLLFAS staff members in sister agencies and in universities in Canada and the United States deserve their fair share of the credit for accomplishments of the laboratory. Similarly the many people in support services, in workshops, in laboratories, and in boats are to be thanked for their ideas and help.

We have tried to avoid giving a shopping list of projects, lists of publications, or any information on budgets. These are available elsewhere. Publications lists with each section are very limited cross-sections representative of the work of the laboratory plus some of the significant Great Lakes reports of the period published elsewhere. We have provided a list of staff members currently and formerly occupying continuing and term positions (Appendix 1). Otherwise this is a review of the approaches and main areas of research adopted by the laboratory, or prescribed for it, as was the case in the early years of the IJC references and tasks of the 1972 Water Quality Agreement. The story shows the maturity attained by GLLFAS over the years. It may reveal some of the frustrations of the group, and aspirations for future research are discussed in one specific section of the overview.

Omissions and errors are the responsibility of the author, Murray Johnson, and the Director of GLLFAS, John Cooley. The main research accomplishments, given in 'Summary and Highlights', are in the judgement of the present staff of GLLFAS and not reflective of DFO policy or opinion.

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Scientist Emeritus

John Cooley
Director, GLLFAS

Burlington, Ontario
January, 1992

LIST OF INITIALIZED TITLES

CCIW - Canada Centre for Inland Waters
CODE -Centre of Disciplinary Expertise
DFO - Department of Fisheries and Oceans
ELA - Experimental Lakes Area
FHM - Fisheries and Habitat Management
FRB - Fisheries Research Board (of Canada)
FWI - Freshwater Institute (Winnipeg)
GIS - Geographic Information System
GLBL - Great Lakes Biolimnology Laboratory
GLFC - Great Lakes Fishery Commission
GLFRB - Great Lakes Fisheries Research Branch
GLLFAS - Great Lakes Laboratory for Fisheries and Aquatic Sciences
IFYGL - International Field Year on the Great Lakes
IJC - International Joint Commission
LAMPS - Lakewide Management Plans
LRTAP - Long Range Transport of Acid Precipitation
NIS - National Inventory Survey
NWRI - National Water Research Institute
OME - Ontario Ministry of the Environment
OMNR - Ontario Ministry of Natural Resources
OWRC - Ontario Water Resources Commission
PLUARG - Pollution from Land Use Activities Reference Group
QSAR - Qualitative Structure-Activity Relationships
RAP - Remedial Action Plan
SPOF - Strategic Plan for Ontario Fisheries

1. SUMMARY AND HIGHLIGHTS

"In the past, choices were often made without adequate knowledge or understanding of the ways in which economic development affects the environment. Therefore, the Government believes that strengthening the foundations of decision-making should be a priority. Through better science, technology, education and dissemination of information, and through the appropriate use of regulation and economic incentives, improved decision-making will result. In turn, this will mean more effective solutions to the environmental concerns of Canadians."

From: Government of Canada. 1990. A Framework for Discussion on the Environment. (The Green Plan - A National Challenge). Ottawa

Jurisdiction over fisheries and fish habitat in Ontario is shared between federal and provincial governments. Canada has legislative authority under the Constitution Act and Ontario has property rights. Consequently, administrative arrangements are necessary to divide and share responsibilities. In 1967 the federal government maintained responsibility for habitat research as well as sea lamprey control and fish inspection. International obligations were assumed by the federal government with the signing of the Great Lakes Fisheries Convention in 1955 (which created the Great Lakes Fishery Commission, (GLFC), the Great Lakes Water Quality Agreement in 1972, and a series of reference studies for the International Joint Commission (IJC) over many years.

Surveys and research on the Great Lakes were accelerated to meet the needs of the 1964 Reference on Pollution of Lake Erie, Lake Ontario, and the International Section of the St. Lawrence River, and numerous emerging environmental issues. The federal government established the Canada Centre for Inland Waters at Burlington (CCIW), in a trailer complex in 1967, and in the present laboratories by 1972. A small detachment from the Fisheries Research Board's Freshwater Institute (FWI) in Winnipeg began lower lakes surveys in 1967 at CCIW. With the large increase in staff and budget for new assignments, especially research tasks in the Water Quality Agreement, the Fisheries Research Board (FRB) established the Great Lakes Biolimnology Laboratory (GLBL) in 1972. It occupied office and laboratory space in the Main Laboratory Building at CCIW, which was expanded subsequently, with the development of an excellent aquatic toxicology facility in the adjoining Hydraulics Laboratory.

The CCIW housed survey and research units from several federal agencies - Inland Waters Directorate and the Canadian Hydrographic Service (of the Department of Energy, Mines and Resources), Department of Health and Welfare, FRB, and Canadian Wildlife Service. Support services such as ships, library, electronic and mechanical shops, drafting and shipboard technical expertise were provided to all units, according to program needs and with guidance of the CCIW Management Committee, of which FRB was a member. University participation in Great Lakes studies was actively encouraged and supported, not only by these many services, but also by various departmental grant programs.

As government reorganized, first with Environment Canada, then Fisheries and Oceans separating from Environment, and inter-departmental restructuring, GLBL was renamed Great Lakes Fisheries Research Branch (GLFRB) in 1982 and Great Lakes Laboratory of Fisheries and Aquatic Sciences (GLLFAS) in 1987. The laboratory reported to Winnipeg from 1967 to 1972, then to Ottawa directly from 1972 to 1976, to the Burlington headquarters for the Department of Fisheries and Oceans (DFO) Ontario Region until 1986, when it reported once more to Winnipeg, the headquarters of the DFO Central and Arctic Region. In 1976 GLBL established a detachment of its own in Sault Ste. Marie to facilitate research on Lake Superior in collaboration with fisheries staff of the Ontario Ministry of Natural Resources (OMNR). This was repeated in 1980 with a detachment established at Owen Sound on Georgian Bay. These detachments helped to balance activities throughout the Great Lakes and to carry out the acid rain program on inland lakes and rivers. The Owen Sound laboratory was closed in 1989, while the Sault Ste. Marie group moved to the Sea Lamprey Control Laboratory. Also, the Fish Disease Certification Laboratory in Toronto was added to GLLFAS in 1987, as a result of DFO reorganization. This laboratory is responsible for monitoring the distribution of infectious diseases of importance to fish stocks, especially salmonids raised for commercial aquaculture in Ontario.

The GLLFAS carries out research on fish habitat in the Great Lakes and some inland lakes, with emphasis on both 'structural' (or traditional) and water quality aspects of habitat. Its objectives are as follows: to provide the understanding and knowledge necessary to ensure the long-term protection and enhancement of the fishery resource of the Great Lakes and the habitat which sustains it, and
to meet the research commitments contained in the bilateral agreements on the Great Lakes, both with the United States and the Province of Ontario.

The earliest research was entirely in support of the IJC reference on pollution of the lower Great Lakes. The program expanded to include two new references, one on the upper lakes and a second on pollution from land-use activities, plus work on waste heat, dredged spoils, toxic substances and a new surveillance program. These studies were prescribed by the 1972 Great Lakes Water Quality Agreement, which was refocused in 1978 to include considerably more work on contaminants, and to adopt an 'Ecosystem Approach' to environmental problems. The Water Quality Agreement research program in GLLFAS matured in many ways, with stronger programs in toxicology, habitat studies and surveillance. At the same time, a strong initiative on the effects of acidification on inshore waters of the Great Lakes and inland lakes gave GLLFAS new dimensions to its work as well as its first major departmental responsibility. Also, as the GLFC began to develop an ecosystem based strategy, GLLFAS (with other Great Lakes fishery agencies) helped GLFC develop collaborative programs and evaluate new approaches to old (sea lamprey control) and new (fish community health) problems.

Over these 25 years, 1967 - 1991, the main clients of GLLFAS have been the IJC and Great Lakes Water Quality Board, or more accurately, the array of Great Lakes Water Quality agencies which were hungry for good information on effects of pollution on aquatic systems and fish communities of the Great Lakes. A second important client group, the GLFC and associated fisheries agencies, was gradually engulfed with environmental problems which eroded the value and stability of commercial and growing recreational fisheries. These agencies had problems of their own in limiting exploitation, allocating harvests, and controlling the sea lamprey, all of which also affect fish community health and ultimately ecosystem well-being. They too needed help with diagnosis of environmental problems and determination of the effects of habitat deterioration on aquatic communities. Over these 25 years GLLFAS has helped to bridge the gap between the fisheries sector and environmental protection/water management sectors. This gap was formidable in the 1960s and 1970s, and 'bridge-building' was a frustrating, but never dull, task. Considerable progress was made in the 1980s, as both sectors adopted broader views of the issues and worked together in synergistically productive ways. The gap will be reduced further through the 1990s, particularly where effective remedial measures provide incentive, through encouragement, as results are achieved.

Although the issues are usually extensive and many laboratories have joined in studies at various times and from many angles, GLLFAS staff made significant contributions to science and management particularly in the following areas:

- Identification of critical phosphorus loads to the Great Lakes and a prescription for phosphorus reductions was led by Richard Vollenweider. Opposition from the detergent lobby was met head-on by Jack Vallentyne, then at the Freshwater Institute. Vallentyne's 'Algal Bowl' later put the issue in a scientific context for the public.

- The issue of waste heat from thermal power plants was a minor problem compared to the losses of fish by impingement at intakes and by entrainment through the heating-cooling process in condensers as observed at several plants by John Kelso and his team.

- Surveillance of contaminants in biota was rationalized in a well-designed and co-ordinated international program by Don Williams, Mike Whittle and their colleagues in OMNR and the US Fish and Wildlife Service.

- GLLFAS was the first laboratory to verify lead methylation in nature, these and other limnological studies on organo-metals (arsenic, selenium, tin) were carried out by Paul Wong and Y.K. Chau/DOE (Lakes Research Division). Toxicological studies of lead and alkyl lead on algae (by Paul Wong) and fish (by Peter Hodson) were important in obtaining a re-definition of the Specific Water Quality Objective for lead in the Water Quality Agreement. Peter Hodson's work on the enzyme ALA-D in fish, as a 'signal' of lead pollution, was of value in reducing alkyl lead inputs to the St. Lawrence River.

- Simple experiments on the effects of combined metals on algae, and the serious effects of combinations of metals at their 'safe' objective levels, by Paul Wong and his team, were important in qualifying the application of Specific Water Quality Objectives to Great Lakes problems. Subsequently, studies by Uwe Borgmann showed that toxicity of metals to crustaceans was not necessarily related to free metal concentrations, that some chelated metals were absorbed and toxic, and that body burden of metals in animals was directly related to chronic toxicity while concentration in water was not related.

- Studies by Paul Wong, again with Y.K. Chau (and others in Lakes Research Division), on limnology, occurrence, and toxicity of organotin compounds, especially tributyl tin, supported the replacement of TBT with safer anti-fouling paints for boats.

- As part of the Upper Lakes Reference study, John Kelso's waste heat group collaborated with Lakes Research Division to examine the effects of paper-mill effluent plumes on water quality and biota in Nipigon Bay. This was the start of research on the complex organics at pulp-mill wastes and fish health, an interest which currently has been revived in GLLFAS through the work of Kelly Munkittrick and Mark Servos.

- Better techniques allowed the identification of increasingly smaller algae in Great Lakes waters, and size-fractionation experiments carried out by Mohi Munawar showed the very large contribution made by 'ultraplankton' (and, later, 'picoplankton') to primary production and their greater sensitivity to toxic chemicals.

- The Bay of Quinte (Lake Ontario), one of the most eutrophic bays in the Great Lakes, has been continuously studied since 1972. The limnological data base is one of the longest in the Great Lakes. Working closely, GLLFAS, Ontario Ministry of Environment (OME) and OMNR have documented the changes in biota and water quality attributable to nutrient reductions and natural factors. Ken Minns, Scott Millard and their many colleagues continue to examine many processes and relationships as this 'experiment' evolves, such as the potential for recycling of sediment phosphorus into current production and the food-chain relationships that influence algal abundance, especially the alewife-zooplankton link.

- The incidence of tumours, of certain kinds, present on fish was related to contamination of waters and sediments near industrial complexes. Vic Cairns and co-workers were able to induce some tumours by laboratory exposure to contaminated sediments. A short course and tumour identification manual (GLFC) were prepared to assist fishery workers and provide more epidemiological data. Similar work on constricted gonads in lake trout lead to some interesting physiological studies but the phenomenon was not traced to any toxicological cause. Recent work has focused on lake trout spawning, egg and larval ecology by John Fitzsimons.

- Two strong data bases on the Lake Ontario open-water community, one from the 'Bioindex' biological monitoring program, and the other from the contaminant surveillance program, have had increasing use beyond state-of-the lake reporting. Contaminant concentrations in biota, together with particle-size theory (in food chains), were used by Uwe Borgmann to estimate trophic level efficiencies. The results were useful in making estimates of total fish production and predicting results of perturbations. The effects of trophic-level relationships on the abundance of algae, especially between alewife and zooplankton, have been studied by Ora Johannsson, Scott Millard, Ron Dermott and colleagues. These findings are of critical importance to those responsible for either fisheries or nutrient control programs.

- The Ecotoxicology Division of GLLFAS was designated as a regional Centre of Disciplinary Expertise (CODE) for freshwater fisheries contaminants and toxicology as part of a national program to assign specific responsibilities of strategic importance to regional science programs.

- In January 1988 Greenpeace issued a press release urging Canadians to refrain from eating fish taken from near pulp mills in Canada because of the possibility of dioxin contamination arising from the use of chlorine during the bleaching sequence. An ongoing federal program to sample fish and sediments near kraft mills in British Columbia was accelerated to cover all 46 kraft pulp mills across Canada. GLLFAS, and particularly various members of the Ecotoxicology Division, were delegated the national responsibility for overseeing all the sampling and analytical aspects of a 4-year DFO survey program. Their early accomplishments were recognized by a Deputy Minister's Commendation in 1989 for the excellence demonstrated in responding to a national priority for DFO.

- Information on quantitative structure-activity relationships (chemical-physical properties versus potential for mode and extent of uptake, biomagnification and toxicity to biota) was produced by Art Niimi in many extensive experiments. The data were then employed in interpretation of field observations on contaminant partitioning in biota and environment. Art Niimi's work on contaminants in Lake Ontario with Barry Oliver (National Water Research Institute/(NWRI)(DOE) was of considerable interest to the scientific community.

- GLLFAS took on a national responsibility in the acid rain program with the compilation of the National Inventory Survey of representative sensitive lake areas from Ontario east. From this Ken Minns further developed a regional risk assessment model which overlaid acid deposition rates on lake sensitivity features. A number of abatement scenarios were compared using this model, information which was very important as Environment Canada developed the Canadian position on remediation and exerted pressure on the US for control programs. GLLFAS also played an important part in research on a system of calibrated watersheds with its studies on aquatic biota in the Turkey Lakes Calibrated Watershed. During the period 1980-84, John Cooley was seconded to a headquarters position to be the DFO Acid Rain Program manager.

- GLLFAS provided considerable input to the development of Remedial Action Plans (RAP) at several Areas of Concern designated in the revised Water Quality Agreement. In some areas, such as the Bay of Quinte, GLLFAS provided almost 20 years of primary and secondary production data and phosphorus modelling to assist the RAP team. At other sites, such as Hamilton Harbour, Toronto Harbour, the Spanish River, Jackfish Bay and Severn Sound, GLLFAS staff initiated projects relating to benthos, larval fish production, fish health, contaminants, and fish habitat. Staff helped with the combined RAPs in Lake Superior and was involved in the first remedial projects under DOE's Clean-Up Fund to rehabilitate fish habitat in Thunder Bay, Nipigon Bay and Hamilton Harbour.

- The Ecosystem Approach, adopted in the 1978 Great Lakes Water Quality Agreement, was promoted by DFO in various ways. The Pollution from Land Use Activities Reference Group, of which Murray Johnson was Canadian chairperson, recommended ecosystem management and carried out some preliminary basin-wide nutrient management modelling. The Research Advisory Board of IJC, of which Jack Vallentyne was a member, recommended the Ecosystem Approach. DFO Headquarters provided strong support on this issue.

- The announcement of DFO's Fish habitat Policy in 1986 stimulated research to define productive capacity and to quantify the effects of various habitat types on fish production, biomass, species richness, and community composition. The project provided fisheries and habitat data to RAP writing teams in Hamilton, Quinte, and Severn Sound, but the most practical results were the development of fish community targets for RAP sites, and cooperative work with the OMNR and Fish Habitat Management to develop a Fish Habitat

Management Plan for Severn Sound. The application of Geographic Information System (GIS) technology was advanced rapidly by Jim Moore and Ken Minns who were able to document fish habitat changes at RAP sites and predict the impact of habitat enhancement on fish production.

- GLLFAS was the federal coordinating agency for zebra mussels on the Great Lakes. Ron Dermott provided valuable data on the distribution and abundance of zebra mussels in the lower Great Lakes and predicted the rate of mussel colonization in Lake Ontario and the St. Lawrence River. Impact studies showed that zebra mussels altered the benthic community by eliminating sensitive native species, particularly other bivalves, and enhancing the production of others such as the amphipod *Gammarus*. John Fitzsimons and Joe Leach (OMNR) cooperated in a study to show that Lake Erie walleye continued to use spawning shoals that were almost completely covered by zebra mussels. They found live walleye eggs among the mussels and no indication that zebra mussels adversely affected either spawning success, egg survival, or water quality. Cooperative studies with the University of Toronto and Canada Coast Guard were undertaken to monitor the effectiveness of the new ballast water guidelines in preventing further introductions of exotic species to the Great Lakes. Although compliance with the guidelines was high, the study showed that some organisms survived mid-ocean ballast water exchange.

2. GETTING TO KNOW THE GREAT LAKES

> "In general, the opportunities to use Lake Erie will increase when the opportunism of those who have abused the lake in the past is effectively constrained, and when all agencies involved in protection, wise use and enhancement of the fishery and associated aquatic resources move forward together in the task with far greater resolve and cooperation than ever before."
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> From Regier, H.A. and W.L. Hartman 1973. Lake Erie's Fish Community: 150 Years of Cultural Stress. Science 180: 1248-1255, (22 June 1973).

Beginning in the mid 1800s, Great Lakes fish communities were depreciated by intensive, selective fisheries, invasion of marine species (sea lamprey, alewife, smelt, white perch), destruction and modification of habitat in lakes, marshes and rivers and accelerating physical-chemical pollution. Lake Ontario was affected first - it was the first lake to be settled, industrialized and connected to mid-Atlantic waters via canals[1]. Atlantic salmon were gone by 1900. By 1970 lake trout, deep water chubs, burbot, and whitefish were rare and only the invaders - alewife, smelt, and white perch - were abundant. Scientists propose that overfishing and some losses of spawning habitat reduced numbers of piscivores (trout, burbot and some other large species) making the survivors more vulnerable to sea lamprey and releasing the smelt, which preyed on and caused the collapse of deepwater chubs and other small species[2].

In Lake Erie commercial fisheries for lake trout, whitefish, and lake herring ended by 1940, blue pike and walleye stocks collapsed by 1960, and yellow perch production became erratic[3]. In addition to long-term losses of spawning areas as a result of siltation on shoals and marsh drainage, over-enrichment by nutrients led to severe oxygen depletion in bottom waters and resultant adverse changes in biota. By 1961 mayflies were essentially replaced by species much less useful to fish.

In Lake Huron, including Georgian Bay and the North Channel, commercial fisheries declined sharply in the 1940s, mainly as a result of the combined effect of two predators - sea lamprey and man[4]. Pollution was implicated in Saginaw Bay, which was heavily loaded with industrial and municipal wastes, and locally in some harbours and estuaries. Lake Superior fish stocks were gradually and individually depleted as the commercial fisheries expanded, even before sea lamprey entered the lake. By the 1960s catches fell sharply, and sea lamprey and people were again the main cause. Pollution was locally severe, particularly near pulp and paper mills. The walleye stock of Nipigon Bay likely was lost because of such pollution[5].

There were many problems in addition to gross depreciation of fish stocks, especially in the lower Great Lakes. Fouling of the lakeshore with rotting windrows of the filamentous green alga *Cladophora*, beach closures, tastes and odours in water supplies and oil spills were the demonstrable penalties of rapid post-war development. Public pressure for government action mounted and on October 7, 1964, the government of Canada and the United States requested the IJC to investigate the 'extent...causes...and localities of pollution in waters of Lake Erie, Lake

Ontario, and the International Section of the St. Lawrence River'. Article IV of the Boundary Waters Treaty of 1909 requires that 'boundary waters and waters flowing across the boundary shall not be polluted on either side to the injury of health or property on the other side.' The first reference to IJC in 1912 included all boundary waters. The concern was waterborne diseases such as typhoid fever, the study was a microbiological study, the results were incriminating, a 'water quality agreement' was developed but not concluded because of the introduction of chlorination of municipal water supplies. In 1946 the IJC was asked to examine industrial and municipal pollution problems in the St. Marys, St. Clair, Detroit and Niagara Rivers. IJC's 1950 report led to water Quality Objectives and some cleanup of 'conventional' pollutants. By 1964 the governments recognized the need for a more extensive examination of the problem, beginning with the lower Great Lakes.

Traditionally IJC uses the services of engineers and scientists of the technical agencies of Canada and the United States in carrying out each reference. The demand accelerated through the 1960s. By 1967 the Department of Energy, Mines and Resources had formed its Great Lakes Division, developed a large (2500 sq. ft.) trailer laboratory at Burlington and launched the C.S.S. Limnos at the Port Weller Shipyards. The FRB of Canada had left London, Ontario in 1967 for a new home on the campus of the University of Manitoba. It left behind its Sea Lamprey Control Laboratory, relocated to the waterfront in Sault Ste. Marie. FRB was asked to participate in Great Lakes studies. The Eutrophication Section (under J.R. Vallentyne) joined in the effort, and by 1967 had begun to staff a detachment at the Canada Centre for Inland Waters. H.F. Nicholson was the first FRB recruit at CCIW. He joined some of the first cruises on Lake Erie and Lake Ontario, continuing his work on fluorometric measurement of chlorophyll in water initiated at the Lowestoft laboratory in England.

The federal government had never operated a laboratory for limnological research on the Great Lakes until CCIW was established in 1967. Early research was carried out by the University of Toronto (Ontario Fisheries Research Laboratory) and the University of Western Ontario (Fisheries Research Laboratory at Erieau, Ontario). The provincial Department of Lands and Forest operated four fisheries research stations on the Great Lakes (Glenora on Lake Ontario, Wheatly on Erie, South Baymouth on Lake Huron and Maple north of Toronto) and a physical limnology program (at Maple). The latter was part of the inter-agency Great Lakes Geophysical Research Group and, by 1960, with the Ontario Fisheries Research Laboratory, formed the Great Lakes Institute of the University of Toronto. Synoptic cruises began in 1958 using C.M.S. <u>Porte Dauphine</u> on loan from the Royal Canadian Navy. The FRB supported individual researchers in the Universities and financially assisted the Great Lakes Institute at the University of Toronto. Strangely enough, the FRB was responsible for research only on Lake Superior until the early 1970s but it did not operate a laboratory there. In contrast, the US federal government operated several stations on the Great Lakes. The Fish and Wildlife Service carried out extensive programs of fisheries and limnological research from 1950 on at several laboratories (in Ann Arbor, Hammond Bay on Lake Huron, Marquette and Ashland on Lake Superior, Ludington on Lake Michigan, Sandusky on Lake Erie). The US Public Health Service established a research laboratory in Chicago in the early 1960s (later EPA).

Inclusion of FRB in the CCIW program was necessary to ensure that vital research on phytoplankton, zooplankton, and benthos would be made. The Department of Lands and Forests and FRB signed an agreement in 1967 which formalized this Great Lakes activity as well as the establishment of the Experimental Lakes Area (ELA) near Kenora where experimental limnology by ELA scientists would answer some of the questions on eutrophication of lakes.

In 1968 the FRB detachment acquired its first leader, Richard Vollenweider. He had a support staff of three persons, but, at that time, some FWI scientists, particularly Andrew Hamilton, Kazimir Patalas and Jack Vallentyne were deeply involved in Great Lakes research. In 1968 FRB staff participated in six CCIW cruises on each of lakes Erie and Ontario and one cruise on each of lakes Huron and Superior aboard the M.V. Theron and two Great Lakes Institute cruises on the CCGS Porte Dauphine. Andrew Hamilton collaborated with Ralph Brinkhurst (University of Toronto) and Harry Herrington on an overview of Great Lakes Institute benthos data[6]. New surveys emphasized plankton, obtaining continuous records of chlorophyll and phytoplankton and zooplankton collections at monitor stations. A special late-summer cruise on Lake Ontario was designed to determine abundance of deepwater zooplankton (e.g. *Limnocalanus macrurus*). In cooperation with Great Lakes Division staff, sediment collectors were evaluated in three types of substrate. The results guided future studies. FRB staff at CCIW participated in three cruises on the Great Slave Lake and one cruise on Lake Winnipeg; C^{14} primary production rates, algal abundance, and nutrient concentrations were measured.

During 1969 the FRB detachment participated in many cruises (15 Lake Ontario, 5 Lake Erie, 2 Georgian Bay, 1 Lake Huron and 2 Lake Superior cruises), aboard M.V. Martin Karlsen, CCGS Porte Dauphine and CSS Limnos. Emphasis continued on plankton distribution and abundance in time and space (because of the requirements of IJC studies and the emphasis in the Great Lakes Institute (University of Toronto) on benthos, Department of Lands and Forests on fish, and Ontario Water Resources Commission (OWRC) on the *Cladophora* issue). Most of the findings were immediately useful in the diagnosis of water quality for IJC. Many findings were of considerable scientific interest. The abundance of very small algal species (the nanoplankton) revealed that earlier studies were biased to larger species. Correlations among nutrient load, heat content, seasonal cycles of crustacean zooplankton species, and standing stocks were found. Equipment development to accomplish many tasks, such as shipboard measurement of primary production, was important work at that stage. Experimental demonstration of the effects of phosphorus removal from municipal wastes on natural waters from Erie and Ontario was shown by Jack Vallentyne in collaboration with OWRC staff[7]. Results were very influential in the argument for phosphorus removal, initially in detergents and then in municipal wastes. Together with the participation by Richard Vollenweider in the preparation of recommendations to IJC on allowable phosphorus loading rates for the lakes, these efforts may be among the most influential on water management, in the face of heavy opposition by industry, through the history of the laboratory.

By 1970 the staff had grown to 11, and the detachment operated as a section of the Lakes Division (of Inland Waters), to which Richard Vollenweider had been seconded as leader. Arnold Nauwerck headed the detachment in 1970 and 1971. The first permanent buildings of CCIW were completed, although the main laboratory building would not be completed until early 1972. In 1970 FRB joined 13 cruises on Lake Ontario, 10 on Lake Erie and 2 on Lake Huron, including Georgian Bay, and 2 on Lake Superior. New work was begun on primary production and related bioassays to examine responses to nutrient and trace metal additions, and to PCBs, DDT, and dieldrin in the laboratory. However, most effort continued in descriptive studies of the plankton throughout the Great Lakes. This was a huge task - for example, by 1970 350 algae species had been found by Mohi Munawar in Lake Ontario, only 70 of which had been recorded earlier. The first report published by a detachment member was H.F. Nicholson's 'The Chlorophyll a content of the surface waters of Lake Ontario, June to November, 1967' (Fish. Res. Board Can. Tech. Rep. 186.)

In late 1970 the Government of Canada announced the formation of Environment Canada (Department of Fisheries and Forestry, the water sector of Energy, Mines and Resources, the Meteorological Service of Transport, units from Health and Welfare and others). All components of CCIW would be in the new department. Managers looked forward to more effective administration and support services and a higher level of program coordination.

Activities in 1971 focused on three areas: the first benthos survey (carried out on Lake Huron), the monitoring of Great Lakes plankton (chlorophyll, primary production, algae, and zooplankton) and examination of the effects on algae of selected nutrients, toxic substances, and chelating compounds (potential replacements in detergents). Morphological variability in algae in lake water appeared to have some diagnostic value. The different seasonal dynamics of algae in inshore and offshore regions of Lake Ontario were quantified. New understanding of life histories and population dynamics, relationships between phytoplankton and zooplankton, differences among the lakes, diurnal vertical migration of zooplankton, as well as species composition and abundance, provided a basis for a better understanding of the tropho-dynamics of these systems. Unfortunately, a dozen or more years would pass before scientists would pursue a tropho-dynamic approach to the study of these pelagic systems, with a potential reward of much better understanding of the dynamics of eutrophic systems (especially the significance of balanced fish communities on the 'food chain') as well as the dynamics of fish production.

Unquestionably, inter-agency politics affected science on the Great Lakes at that time. In spite of the need for convergence of science in the traditional fields of sanitary engineering (pollution), limnology, and fisheries, the artificial division of nearshore versus offshore responsibilities, fish versus other biota, and perhaps other barriers, slowed the development of stronger, more fundamental, approaches to resources management in the Great Lakes. Regardless of this issue, the descriptive work carried out by FRB during 'the early years' was essential, not only to address the needs of IJC and governments, but also as a foundation for future research.

Clearly, the main product of research in this 1967-1971 period was for the inquiry by IJC, which found that the waters of Lake Erie, Lake Ontario and the St. Lawrence River 'are being seriously polluted on both sides of the boundary to the detriment of both countries and to an extent which is causing injury to health and property on the other side of the boundary.' The IJC recommended adherence to General and Specific Objectives (proposed by IJC), immediate reduction of phosphorus in detergents, improved waste-treatment facilities including phosphorus reductions, continued monitoring, better contingency plans for spills of oil and hazardous materials[8]. The main contribution of FRB was the rationale for phosphorus limitation. Important products of the research were the development of the expertise and knowledge of the lakes for the problems which would inevitably occur. In 1970 the dangers of PCBs in the environment were suspected, and mercury was discovered in Lake St. Clair fish at levels above the action guideline. The IJC, in its report, expressed concern about heat inputs, pesticides, dredging and disposal of contaminated bottom sediments, methylation of mercury and accumulation in the food chain, and toxics generally.

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3. RESEARCH AND THE WATER QUALITY AGREEMENT

"The Great Lakes basin has been a laboratory for testing new approaches to protecting and enhancing environmental quality. Because it is the joint responsibility of two nations, the basin provides a model for managing other shared resources around the globe. Environmental problems do not respect national boundaries; those who care about shared resources elsewhere have much to learn from programs tested in the Great Lakes"

From: T.E. Colborn et. al. 1990. Great Lakes, Great Legacy? The Conservation Foundation, Washington, D.C. and Institute for Research on Public Policy, Ottawa.

A major turning point in the research at CCIW occurred with the signing of the 'Canada - US Agreement on Great Lakes Water Quality' by Prime Minister Trudeau and President Nixon on April 15, 1972. The Agreement called for two new references to IJC, one on water quality in the upper Great Lakes and a second reference on pollution from land use activities (agriculture, forestry, urban runoff, landfills, and other non-point sources of pollutants). Commitments were made to refine nutrient budgets, to develop criteria for waste heat, radioactivity and many toxic substances and for characterizing polluted dredged materials, to develop a surveillance program and other tasks. CCIW got off to a good start - the official opening of the Main Laboratory Building (and Wastewater Technology Centre) took place on May 5.

The IJC, in its role of auditing progress under the Agreement, established a Water Quality Board and Research Advisory Board (both of which spawned a variety of committees) as well as the two new Reference Groups. Scientific management suddenly became very complicated (and international in scope) and very rapidly moving. The FRB detachment doubled in size in 1972-73, and took on new studies on waste heat, toxic substances, dredged-spoils disposal, as well as continuation of main lake studies and surveillance. New collaborative projects developed, for example, Project Quinte which involved the OMNR and Environment OME, University of Guelph, Queen's University and Environment Canada. In recognition of the increased scope of the program and the need to operate more effectively in a complex, dynamic infrastructure at CCIW and in the Great Lakes, the detachment became a full-fledged laboratory of the Fisheries Research Board of Canada. It was established on December 1, 1972, as the 'Great Lakes Biolimnology Laboratory.' Murray Johnson moved from Lakes Research Division to lead GLBL. (As it turned out, this was the last FRB laboratory created - by 1973 the laboratories of FRB became part of the Fisheries and Marine Service.)

With a new building, a new Water Quality Agreement, a new responsibility centre and a growing number of new staff, 1972 was a hectic, yet stimulating year. The major scientific project was part of the International Field Year for the Great Lakes (IFYGL) program on Lake Ontario; primary production was measured through nine cruises and at two fixed stations where diurnal cycles were studied. Much effort went into analysis of plankton data from earlier cruises. Several publications came out in 1971 and 1972 on Great Lakes plankton by Walter Glooschenko, Mohi Munawar, Richard Vollenweider, Jim Moore and Kaz Patalas (at FWI). The first toxicological study in new growth chambers at CCIW was the examination of effects of PCBs at 1 to 50 ppb on cell division by two species of green algae. Project Quinte was initiated to lead into an assessment of the effects of phosphorus removal on the limnology and fisheries of the Bay of Quinte in eastern Lake Ontario. This was an important breakthrough in establishing a better working relationship between research units of federal and Ontario fisheries agencies.

In 1973 GLBL had three main programs,(1). Descriptive biolimnology and surveillance, (2). Environmental toxicology, and (3). Ecosystem metabolism studies, with most new staff joining the latter two programs. This structure served the laboratory quite well for the next dozen years; consequently a closer look at terms of reference of each program is informative.

Descriptive biolimnology and surveillance: - 'based on the examination of communities of algae, zooplankton, zoobenthos, and fish, to determine damage to aquatic resources... and causes, to establish baseline descriptions... and to develop and apply surveillance techniques on a sound statistical and economical basis'.

Environmental toxicology: - 'development of criteria for aquatic life for toxic materials of concern... and in relation to accumulation in aquatic food chains. A more fundamental emphasis is on the sublethal effects of toxic substances, singly and in combinations, on individual organisms as well as the biomagnification of pollutants in food chains and the physiological and ecological significance of tissue levels of contaminants.'

Ecosystem metabolism studies: - 'determine the extent of relationships among production at primary, secondary, and decomposer levels and the manner and degree that these relations are disrupted by environmental stresses over space and through time... including pollution by toxic and oxygen-consuming wastes, waste heat, nutrient inputs, dredged spoil disposal.'

These goals continue to be useful. Even now the significance of tissue levels of toxics in biota is still being studied, with the potential to be more informative in protecting aquatic life than concentrations in water or loadings. The relationship between primary and secondary levels of production is still a critical area of research. As scientists learned in the 1980s, there is much more to eutrophication than phosphorus loadings, and balance among algae, zooplankton, and fish (at different trophic levels) is a critical factor.

As part of the Upper Lakes Reference Study, GLBL examined plankton and benthos on six cruises on Lake Superior. As well, the paper-mill effluent plume at Marathon on Lake Superior was tracked with drogues and chemical measurements to study the response by entrained plankton. Participants learned enough there to carry out a very successful study on the paper-mill plume at Red Rock in 1974.[1] The Pollution from Land Use Activities Reference Group (PLUARG), of which Murray Johnson was the Canadian chairperson, developed an early-action report to IJC and governments and a detailed study plan in 1973.

The so-called 'tasks' of the Water Quality Agreement in which GLBL participated were on toxic substances, waste heat, dredged spoils disposal, and surveillance. Metals were selected for initial studies because they were more economically analyzed and, so it was thought, their limnology and toxicology were less complex than organics. The first studies on lead dispelled that idea! Di-methyl and tri-methyl lead were more toxic than inorganic lead to algae and bacteria. Microorganisms in lake muds could methylate these forms of lead to tetra-methly lead[2]. This study, by Paul Wong, Lynne Luxon and Y.K. Chau (of Lakes Research Division), was the beginning of several years of important work on lead, and eventually some other organo-metals. The waste-heat studies were initiated at the 2160-Mw Pickering Nuclear Generating Station where a towed thermistor array and a digital, echo-counting system provided a simultaneous picture of the thermal plume and distribution of fish. Ultrasonic tags were placed on brown bullheads, which were released in the plume to track their movements. Dredged spoils, released offshore from Port Stanley in Lake Erie were found to attract fish (a free meal, literally). Electro-acoustic fish census equipment showed not only the fish but also the drifting, sedimenting solids in three dimensions. A pilot-scale artificial island in Lake St. Clair was constructed by Public Works. As it progressed the benthos community in the vicinity was examined (with little if any impact observed).

Work continued on analysis of the IFYGL data base, Project Quinte, and the inevitable backlog of samples and data from earlier cruises. The staff of GLBL, counting students, was 40 persons in 1973 and several university researchers and their students joined in several projects.

Field studies for the Upper Lakes Reference were completed in 1974 on Georgian Bay and the North Channel of Lake Huron, as well as the paper-mill plume at Red Rock. Staffs of GLBL and Lakes Research Division worked together closely and competently in the intensive study of the Red Rock plume. Analysis of Lake Superior data continued. One important finding was the high proportion of flagellates in an algae community that had been considered diatom dominated. A new species of oligochaete was found in Lake Superior and subsequently described and named by David Cook. A pilot surveillance program was carried out on Lake Ontario with other CCIW units. One objective was to optimize the number of cruises versus number of stations to make ongoing surveillance both effective and economical.

By 1974 toxicological studies cut across all trophic levels and some limnological processes. Work continued on lead: its methylation in sediments, and toxicity of various forms to algae, invertebrates, and fish. Studies on cadmium were initiated. In a contract with James F. MacLaren Ltd., a large number of hazardous substances was categorized by toxicity to aquatic life, magnitude of uses, and modes of storage and transport. Information on potential danger of hazardous chemicals was required in the Water Quality Agreement (Task 11).

GLBL staff lost an esteemed colleague on October 26, 1974, when David Wright died in a traffic accident; he had developed invertebrate cultures and light bench equipment and was conducting studies on the effects of lead on photo responses by invertebrates.

Through the period 1975 to 1979 most reports from Environmental Toxicology were on metals and organo-metals, especially lead. However, recommendations were made to the Great Lakes Water Quality Board on many toxic substances. The Annual Aquatic Toxicity Workshops, begun in 1974, served an extremely useful function in coordination of research among Environment Canada, and some provincial and university laboratories in this rapidly expanding field. Many of the questions regarding metals toxicity were about speciation and completion of metal forms, their effects on biota when combined, the early-warning symptoms of chronic exposure, routes of uptake, and effects of ancillary environmental and physiological factors on uptake. Methylation of selenium and arsenic was examined, particularly how to analyze these forms and their effects on biota. A limited effort was started on organic toxicants, like PCP, HCB, and PCBs. Some of the first laboratory experiments on multi-trophic level systems were carried out in so-called 'Lake Column Simulators' (1-meter diameter columns with thermal and light-regime controls). These were used to look at dredged-spoils disposal and later at biomagnification and kinetics of ^{14}C-labelled PCBs. Through this period (to 1979) approximately 50 papers were published by Paul Wong, Peter Hodson, and Uwe Borgmann (and their colleagues), almost all on metals and organometals.

One of these papers, which attracted considerable attention, was 'Toxicity of a mixture of metals on freshwater algae' by Paul Wong, Lynne Luxon, and Y.K. Chau.[3] Water quality objectives were set for toxic substances individually, and they tend to be considered singly by environmental protection agencies. Effects may be at least additive, and sometimes synergistic, when biota receive exposure to mixtures. Borgmann also examined the interactive effects of metals in mixtures on copepod populations.[4] This and other precautions on the use of specific water quality objectives were given to the IJC in a brief from the Fisheries and Marine Service in 1978.

By 1976 waste heat studies had been carried out at four thermal generating stations - Pickering, Nanticoke, Douglas Point, and Lennox. For fish, at least, discharge (plume) related effects were minimal and local. However, mortality from impingement (on screens) and entrainment (through condensers) was severe for fish, and likely insignificant for algae and zooplankton. Although temperature and temperature change objectives had been requested in the Water Quality Agreement, the effect on fish of impingement and entrainment was the real problem. Careful plant location away from fish spawning and nursery areas was the obvious solution. John Kelso, with Gary Milburn of the US Environmental Protection Agency, proposed that mortality of young fish at 89 Great Lakes power plants probably would affect recruitment.[5] Unfortunately, support ended from Water Quality Agreement allocations, and field studies to attempt to quantify this mortality on selected stocks of Great Lakes fish could not be carried out.

The Bay of Quinte effort was intensified in 1978, concurrent with the reduction of phosphorus in wastewater effluents. Project Quinte continued subsequently at a lower level of effort (and continues at a modest level today) to describe and interpret the response of the system to nutrient management. During 1977 and 1978 similar studies were initiated on Batchawana Bay of Lake Superior to assess the inputs, food-chain transfer, and effects of contaminants (PCBs to begin) on biota. Work on PCBs at Batchawana and Quinte was designed to compare contaminant behaviour and impacts in oligotrophic and eutrophic bays. GLBL scientists believed that contaminant behaviour would be adequately understood only in a tropho-dynamic framework. Unfortunately the chemical analytical needs of the project far exceeded the capacity and interest of other units at CCIW. The Batchawana Bay program floundered, but the GLBL staff at Sault Ste. Marie quickly provided the foundation for the new program on acid rain. In 1979 visits were made to over 40 potential sites for intensive studies on acidifying Precambrian Shield lakes before a final choice was made of the Turkey Lakes study area.

The two reference studies were completed - the Upper Lakes Reference Group reported[6] in 1977 and the Pollution from Land Use Activities Reference Group reported[7] in 1978. Research requested in the 1972 Water Quality Agreement consumed most of the time of GLBL staff. Waste heat studies were wound down when resources were cut. Work on toxic substances came close to the same fate, when Treasury Board declined to provide support for its continuation. In some circles, administrators believed that all of the required work had been done when specific water quality objectives had been specified in Annex 1 of the Water Quality Agreement. Fortunately, Fisheries and Marine Service headquarters realized the importance of the research in Environmental Toxicology and saved the program. Ironically, when the 1978 Water Quality Agreement was ratified, toxic substances comprised one of the main issues and considerable research was requested.

By 1977 the Great Lakes program on contaminants in biota was rationalized and GLBL had a large role. Previously, fish inspection information on contaminants had been used by environmental agencies, ignorant of the biased nature of the data (because fish inspectors sampled suspect stocks). GLBL with the OMNR, in collaboration with the US Fish and Wildlife Service, established an unbiased sampling program to ensure good trend-in-time results, which would be related to management of contaminants at source. Key species, including some fish food organisms, were selected and times, locations, and methods were standardized. Studies were carried out to determine the best methods for storage, preparation and analysis. This marked the beginning of the Great Lakes fish tissue archive which is now one of the largest running studies of its kind in the Great Lakes basin. Research projects grew from the surveillance program, for example, and work was initiated to find factors responsible for tumours in fish and malformed gonads in lake trout.

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4. TOXICOLOGY IN THE 1980s

"The presentations at IAGLR [Symposium on Fish Community Health Assessment] were reminiscent of seven blind men describing an elephant by touch, each having access to only part of the body. Seven different pictures emerged, none related to the others. It is clear that the concept of fish community health and its assessment are not well defined. Its purposes, boundaries, and assumptions have never been defined."

From: Hodson, P.V. 1990. Fish Community Health Assessment: A Useful Concept? Journal Great Lakes Research 16 (4): 628-630

The Environmental Toxicology program in GLBL, and toxicology generally, made considerable progress in the 1980s. There was a heightened awareness of the issues, evident in the 1978 Water Quality Agreement, and less naivety among environmental agencies (and even fisheries agencies) about the kind of research that was needed. Through the 1980s toxicology became much more sophisticated, yet at the same time, more practical and applied. Even so, toxicology is a young science and much effort went into learning how to approach it.

Although work on metals continued through the 1980s (particularly on lead, tin, copper, cadmium, zinc, and mercury, and to a lesser extent on the metaloids arsenic and selenium), several new dimensions were added. Almost all projects led to field studies, to confirm the occurrence and significance of cause-effect observations first demonstrated in the laboratory, to test 'early-warning' responses, to evaluate bioassay methods and, when called on, to assist in defining the extent and severity of real-world pollution problems.

Toxicology was more closely tied to ecological features of populations and communities, particularly the tropho-dynamic parameters. Uwe Borgmann measured the effect of metals on growth efficiency in zooplankton, and extended this approach to modelling the effects of toxic substances on pelagic ecosystems. Information on contaminant levels across trophic levels yielded estimates of biomass 'transfer' across trophic levels (food-chain efficiencies), while trophic level models (such as particle-size distributions) could be used to make predictions about food-chain dynamics of contaminants[1]. This approach was rapidly applied to interpretation of contaminant levels in biota, for example, the important paper by Art Niimi of GLBL and Barry Oliver of NWRI on organic contaminants in the Lake Ontario system (which was one of GLBL's papers most frequently cited by other researchers)[2]. The application to modelling fisheries production appears to be feasible, while the value of tropho-dynamic analysis (and management of the food chain) is recognized as a new dimension in dealing with eutrophication. By the end of the 1980s, major international projects on the Great Lakes used this approach and profited from the earlier research and strong data bases which had been acquired, to a large extent, from surveillance programs.

Emphasis also shifted to the significance of tissue residues in biota. Stress on organisms was correlated more with body burdens than ambient water concentration or loading. Body burden integrates the exposure, effects of ancillary environmental factors, and the physiological state or stage of the organism. Tissue (or cell) concentrations indicate danger levels, particularly if critical organs are examined. In the 1980s new data across taxonomic levels allowed GLBL scientists to begin to develop a comparative toxicology. Differences in mode of action of acute and chronic responses were suggested, in part, by differences in distribution of toxic substances among organs and tissues.

A major redirection of approach was necessary with the shift of concern to toxic organics, simply because of the astronomical number of potential toxicants. Methods were needed to allow prediction of effects from chemical characteristics, (the QSAR - quantitative structure- activity relationships approach). Screening of organics also required more use of rapid methods and surrogate responses than earlier work on traditional pollutants. The relationship between acute responses (in quick and dirty methods) and effects of chronic exposure had to be examined to be on safe ground. In some studies, a nutrition-based approach added an important dimension, for example, in work on selenium (which is a nutrient at low and toxicant at high concentrations). This perspective was also useful in other studies, in that nutrition and pathology are obviously linked.

Three major forces shaped this redirection of effort in the 1980s. The DFO was separated from Environment Canada; consequently the main concerns shifted to resource and habitat protection, away from the emphasis in Environment Canada on monitoring and regulation of chemicals in water. Secondly, the IJC adopted an 'Ecosystem Approach' which promoted comprehensive, more fundamental approaches to issues. Narrow water-quality based approaches were considered less likely to lead to improvements in the Great Lakes. Thirdly, for the first time, the Great Lakes Fishery Commission was interested in the mechanisms and significance of contaminants in fish, (formerly an annoyance) and developed a keener interest in fish health.

During the 1980s staff became involved in more operational activities than was the case in the 1970s, when IJC and Water Quality Board committee work was the main activity. The Environmental Assessment and Review Process (EARP), special interdepartmental actions to control lead and tin-based anti-fouling preparations, and to review the implications of extended navigation in the Great Lakes called on GLBL expertise. In addition, there were increased demands on GLBL staff for IJC assignments, including committees on ecosystem objectives, surveillance and toxic substances, as well as the Science Advisory Board.

The research on lead was taken to the field; the feasibility of using levels of blood lead and an enzyme extremely sensitive to lead (ALA-D) was demonstrated at several sites. Examination of a problem due to alkyl lead contamination in the St. Lawrence River eventually led to elimination of the discharge. These physiological tests also allowed the rapid testing of a variety of factors mediating lead toxicity[3]. The lead studies at CCIW formed the basis for a new water quality objective for lead for the Great Lakes, including an adjustment for alkalinity. As well, the information was summarized for a Royal Society of Canada report on 'Lead in the Environment', and supported the recommendation and adoption of limits on lead levels in gasoline.

The search for other 'early warning' measurements, usually easily performed physiological tests, was continued. Field studies on mixed-function oxidases (the MFO enzyme group) showed that higher concentrations in lake trout and white sucker were correlated with higher pollutant concentrations. Adenine nucleotides and metallothioneins in clams provided a record of heavy metal pollution. Analytical methods were developed at CCIW to detect a variety of organo-tins in environmental samples from several Ontario sites and structure-toxicity relationships were examined[4]. Toxicity to algae was higher as the length of the carbon chain increased. Effects on rainbow trout, distribution among organs, and elimination rates of tri-butyltin were measured. TBT was detected in fish from selected harbours.

Selenium affected fish in the laboratory almost exclusively by dietary uptake. Although some harbours in the Great Lakes, and even Georgian Bay, have elevated selenium levels, there are no documented cases indicating adverse effects of selenium on biota.

Attention turned to some of the variety of factors which may mediate toxicity. Organic chelators affected metal toxicity to copepods, cladocerans, and fish in the laboratory, as did natural complexing agents in field samples. However, in some cases the toxicity of copper actually increased when complexing agents were added. This meant that free copper (and other metals) was not the only form taken up by organisms; consequently toxicity inferred from free ion measurements could be misleading. In fact, it is not possible to predict metal toxicity accurately from chemical data alone. Low pH enhanced methylation of mercury, lead, and arsenic (but not selenium), which likely is one of the factors contributing to usually high mercury levels in acidified lakes. The toxicity of metals in relation to pH (hydrogen ions being a toxicant) was examined in support of GLBL work on the acid-rain problem. Fluctuating and constant lead levels in water produced different exposures at the same average concentrations.

QSARs were employed in studies of organic contaminant dynamics, acute and chronic toxicity. Interesting results included the demonstration by Art Niimi of a one-to-one relationship of measured bioconcentration factors for PCBs in fish with chlorine content and octanol-water partition coefficients. An analysis by Peter Hodson showed that the toxicity of chemicals to trout was very similar to their toxicity to mammals (when partitioning processes were accounted for), thus permitting the interchange of data for first-order estimations of toxicity. The toxicity of 12 chlorobenzenes to algae was related to their water solubility and partition coefficients between water and octanol. Responses in egg-development biochemistry to selected organics were related to physical-chemical properties. All of this kind of information was essential to rationalize the regulation of organic chemicals and to carry out the detective work in the field to try to relate cause with effect.

Considerable laboratory work was carried out on kinetics of toxic substances. Art Niimi generated uptake and depuration rate constants for a number of contaminants that were far more accurate than any previously available. Compounds studied included HCB (hexachlorobenzene), PCBs, PCP (pentachlorophenol) furans, dioxins, PAHs (polycyclic aromatic hydrocarbons) and others, including chlorinated phenol derivatives which are a component of pulp-mill wastes. Most of this work was carried out with fish, but some uptake studies by Borgmann were made with invertebrates, for example cadmium uptake from sediments. The work on contaminant dynamics in fish led to a review paper by Niimi on biological half-lives of chemicals in fishes[5].

Methodology was upgraded and evaluated. For example, *in situ* algal bioassays were developed to test whether laboratory results could be applied to field situations. These helped to highlight the factors that affect toxicity and those that could bias estimates of toxicity. Tests were developed using the amphipod *Hyalella azteca* to evaluate toxic characteristics of sediments. The response to handling, shown by altered blood characteristics of fish, raised some precautions in the use of such tests. Demonstration of the toxicity of metals to algae, exposed to ten metals at their water quality objective levels, was a reminder of the risk in using single-substance objectives in waters which typically have many substances at chronically toxic levels.

Other important review articles were published, for example, on occurrence of biological methylation of elements in the environment, biotransformation and toxicity of lead, organometallics in the environment, metal speciation and toxicity of free metal ions in aquatic biota, the nutritional requirements and toxicity to fish of dietary and waterborne selenium, the use of quantitative structure-activity relationships to predict the acute and chronic toxicity of organic chemicals to fish, the role of biochemical indicators in the assessment of ecosystem health, physiological effects of contaminant dynamics on fish, a review of methods for prediction of potential fish production with application to the Great Lakes and Lake Winnipeg, and several others on these topics. The large number of review papers published over this period indicates not only the expertise developed in GLBL but also recognition of the responsibility to assess the state of the science for application by IJC and many other agencies to the Great Lakes clean-up.

The Water Quality Agreement (of 1978) was revised (in various annexes) in the so-called 1987 Protocol. The revision would have some impact on the types of pollution issues addressed by the Ecotoxicology Division. There would be some changes in approach to these issues, probably more a result of the evolution of thinking in the group and the acquisition of new staff.

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5. FISH HABITAT RESEARCH IN THE 1980s

> "The loss of river habitats, marshes, reefs, beaches and natural shorelines is perhaps the most important stressor affecting the fisheries in the lower lakes. The most productive habitats in sheltered embayments and estuaries are often the most affected. The effects extend beyond the nearshore and influence the entire lake community. Not surprisingly, the effects of habitat loss on fish communities are difficult to distinguish from the adverse effects of toxic chemicals."
>
> From: Environment Canada, Department of Fisheries & Oceans, Health & Welfare Canada. 1991. Toxic chemicals in the Great Lakes and Associated Effects. Vol. II. Effects.

Research on waste heat (and entrainment/impingement effects) and dredged spoils and spoil disposal had ended. The work on production dynamics and contaminants was phased out at Batchewana Bay by 1979. Acid rain was the latest issue to receive support, and the Sault Ste. Marie detachment was in place and ready. Collaboration with OMNR was steadily increasing, on Lake Superior with the Fisheries Assessment Unit, at the Bay of Quinte with FRB, and on the acid-rain issue. Therefore, a new GLBL detachment was established in Owen Sound in 1980; its objective was to collaborate with OMNR research and assessment units on Lake Huron and Georgian Bay on problems of common concern such as fish habitat loss and acid-rain effects in northern and eastern Georgian Bay. Project Quinte was continued following the major reductions in phosphorus inputs in 1978 and later refinements. More emphasis was placed on fish habitat studies as the DFO habitat policy was implemented. The Ecosystem Approach turned everyone's attention to aquatic communities and their critical habitats. Project Quinte and the Long Range Transport of Acid Precipitation (LRTAP) program were ecosystem oriented but these two projects took much of the effort of the Fish Habitat Studies group (formerly Ecosystem Studies). Nontheless several smaller investigations of fish habitat were carried out through the 1980s. By 1988 DFO had installed a Fisheries and Habitat Management Branch in Burlington which together with the RAP process and the Fish Habitat Policy of DFO comprised the elements to provide momentum to a much broader and more intensive examination of fish habitat.

During the late 1960s and early 1970s the production rates and biomass of phytoplankton and zooplankton in the Bay of Quinte were among the highest recorded in natural freshwater. Macrophytes nearly disappeared, benthos was characteristic of severely eutrophic waters and the fish community consisted mainly of alewife, gizzard shad, white perch, yellow perch, and other coarse fish. Point-source phosphorus loads decreased by 50 percent after 1978, and phosphorus concentrations declined by 35 percent. Phytoplankton production declined but dominant taxa remained the same. Zooplankton communities did not change. Benthos production declined, except that of *Pontoporeia affinis* which rebounded from heavy predation by white perch after heavy mortality apparently caused by water temperature changes. Changes in the fish community, with a decline in white perch, and increases in walleye and yellow perch, appeared to be most closely related to climatic anomaly and predator-prey interactions than to changes in nutrient inputs. However, reduced eutrophic state may have maintained conditions suitable for walleye and yellow perch. This information and a great deal more was synthesized and appeared in a supplementary number of the Journal of Fisheries and Aquatic Sciences in 1986.[1]

Monitoring continues at the Bay of Quinte at a relatively low level and most of the recent research has focused on food-chain interactions (particularly relationships among alewife and dominant phytoplankton and zooplankton species) and light versus phosphorus limitation of primary production. There is some evidence of a cause-effect relationship between alewife population size and algal abundance, but the expected role of zooplankton in mediating this response has not been observed. Gradually Project Quinte became the research arm of the Quinte Remedial Action Plan. The problem has been documented (the Stage 1 RAP) and plans for rehabilitation are now being prepared (the Stage 2 RAP). There is a close working relationship between Project Quinte and the Lake Ontario Bioindex project because of considerable overlap in participants and scientific issues, such as the top-down (predation driven) versus bottom-up (nutrient driven) models of eutrophication.

A variety of field projects was carried out in collaboration with OMNR field staff. In Lake Superior John Kelso worked with OMNR staff on movements of rainbow trout, following spawning in Batchawana Bay and on electro-acoustic census of the herring (ciscoe) stock in Black Bay. In Lake Huron, Murray Johnson collaborated with the South Baymouth research laboratory on production characteristics of the South Bay community and with the Lake Huron Fisheries Assessment Unit on whitefish fry habitat and food in the coastal zone along the Bruce Peninsula. The South Bay project was curtailed when OMNR reduced its program there and withdrew key staff to the Maple office.

Research projects on lake trout spawning shoals, their microlimnology, health of spawners, fate of deposited eggs and related questions have been carried out in Lake Ontario by John Fitzsimons, and in Lake Superior, and Megasin Lake by John Kelso. These were coordinated with other fishery agency projects on lake trout stocks with the help of the GLFC. The data from western Lake Ontario indicate that several strains of lake trout congregate on the spawning shoals but only a few strains successfully reproduce, suggesting that strain selection is an important part of the lake trout restoration program. Inappropriate strains and poor embryo survival are the two most important factors affecting successful lake trout reproduction in western Lake Ontario. Occasional studies on the geographic distribution of the pink salmon and time and strength of its spawning runs were carried out in several locations in the Great Lakes.

Throughout the 1970s and 1980s, GLLFAS has been involved with issues requiring an understanding of larval fish taxonomy and habitat requirements. In the 1970s, fishery agencies were concerned that power plant intakes were entraining large numbers of larval walleye. John Leslie determined that the deepwater sculpin not larval walleye were the most abundant species entrained in hydroelectric intakes. Since then, larval fish research has been an important part of GLLFAS.[2] Studies have been conducted to determine the effects of the St. Clair River 'blob' on larval fish in Lake St. Clair, to document the impact of zebra mussels on larval fish production, and to determine the larval fish community in Bay of Quinte, Hamilton Harbour, Lake St. Clair, and Severn Sound.

Until the 1970s the issue of acid rain and acidified lakes was considered a regional, Sudbury area problem. That is, until Scandinavian data on acid deposition rates and lake impacts were compared with Canadian information. Higher deposition rates here, on many aquatic systems of similar sensitivity, indicated that many areas from Ontario to Nova Scotia were vulnerable. GLBL began work on acid rain in 1979 with a survey of lake areas, mostly in Algoma, to rationalize the selection of a system for intensive studies on possible impacts. The Turkey Lakes Study Area was selected by a research team from GLBL, Lakes Research Division, Great Lakes Forest Research Centre, and the Atmospheric Environment Service. Understanding the relationship between sulphate emissions from Canada and the US and effects on forest and aquatic systems would require careful integration of studies. By 1981/82 the Turkey Lakes study was built into the inter-departmental national plan which included similar work at ELA, Lac Laflamme and Kejimkujik study areas. Participation by universities and other research agencies was obtained.

Over the next few years GLBL staff studied production of phytoplankton, zooplankton, benthos, and fish in the five lakes at the Turkey Lakes Study Area. Sediment cores were examined to calculate historical trends in metal loading rates and chironomid/chaoborid communities. The gradient from low pH and alkalinity in the upper lakes to moderate pH and alkalinity in the lower lake were correlated with changes in the biota. No fish were present in the upper lake, while fish stocks increased downstream, as did production of salmonids. The major change in benthos was the abundance of larger, littoral downstream species in the fishless lake. Paleoecological data indicated that the headwater lake probably always was fishless. By 1986 sufficient information had been obtained on the Turkey Lakes system to hold a workshop; the results were published as a supplementary number of the Journal of Fisheries and Aquatic Sciences in 1988.[3] By the end of the decade research on processes declined, but monitoring in this and the other study areas continued, as part of the LRTAP inter-departmental program. Most of GLBL's work at the Turkey Lakes Study Area was carried out by its Sault Ste. Marie detachment. Having this laboratory on the spot at the right time probably saved two years in response to a critical issue. In 1980, partly in response to the needs of the LRTAP program, GLBL established a second detachment in Owen Sound on Georgian Bay. This group also joined in the Turkey Lakes studies as well as in other acid-rain research.

Several surveys of Ontario lakes were undertaken and data mainly from earlier provincial surveys were reviewed to attempt to detect changes over time. This was not particularly rewarding, mainly because of the quality of data for this new purpose. New surveys were carried out on headwater lakes in several regions of Ontario with different sulphate deposition rates. These were near Atikokan, Nipigon, Sault Ste. Marie, Chapleau, Temagami and Parry Sound. By 1981 data were obtained on 185 Ontario lakes, which became part of the DFO's National Inventory Survey (NIS). The objectives of this survey were to determine the effects of acid rain on freshwater fish communities and their habitat, to establish a baseline, to define regional differences resulting from variations in atmospheric deposition, geological sensitivity, and susceptibility of fish communities. Close to two-thirds of the 700,000 lakes receiving acid deposition above background levels in eastern Canada (south of 54°N) have low alkalinity (<100 $\mu eq\ l^{-1}$) and must be considered highly susceptible to impacts of acid rain. Higher metals were often associated with low pH, especially aluminium, copper, and nickel. Damage may have occurred already in more than 150,000 lakes with low pH (<6.0).

To be useful for management purposes and in critical negotiations with the United States, large data bases, such as the OMNR and NIS data, had to be interpreted using models. These were used to look at cause-effect relationships, to scale-up results on subsets of lakes, and to predict probable impacts of various pollution abatement strategies. Several modelling workshops provided the means for model development, testing and peer review. The first published analysis of the NIS data[4] and subsequent work by Ken Minns and John Kelso on the probable damages to fisheries resources with various abatement scenarios, was GLBL's first assignment to co-ordinate and carry out a national DFO project.

A widespread misconception about the Great Lakes was that they were not vulnerable to acid rain and associated effects. However, parts of Georgian Bay were affected. Perhaps one of the problems in large ship research is to forget the bays, inlets and river mouths, where fish often spawn or congregate in nursery or feeding areas. The Owen Sound detachment sampled rivers, bays, and open waters during the spring freshet for several years, collected sediment cores to reveal the temporal increases in several heavy metals, and examined benthos to discover local areas of seasonal acidification. GLBL attempted, without much success, to interest resource managers in carefully documenting likely damage to fish communities from seasonal acidification of these critical habitats. This task was never completed because the Owen Sound laboratory was closed in 1989.

Organic contaminants in precipitation were of concern to Great Lakes workers, but they were of much less interest to acid-rain researchers. The Sault Ste. Marie and Owen Sound detachments examined organics in precipitation and biota in the Turkey Lakes and two small, Bruce Peninsula lakes. They provided some of the earliest data on this issue, which heated up by the late 1980s.

One of the largest projects in GLBL's LRTAP program was the examination of water chemistry and fish communities in 255 lakes in four watersheds in central Ontario (Seguin, Shawanaga, Mahzenazing and Little Rapid). Most surveys had examined lakes as separate units; this project was based on connected and cascading units. The data on water chemistry was used to estimated pre-acidification lake chemistry and rate of change by acidification.[5] The fish data indicated that, prior to acidification, introduction of centrarchids (smallmouth bass, largemouth bass particularly) caused changes to fish communities similar to effects of acid rain, that is, loss of many minnow species. Some minnows are less exposed to acidification because they frequent larger lakes, which tend toward average, moderate pH and alkalinity, while headwater lakes have more variable chemistry and minnows are often eliminated. Yellow perch and pumpkinseed sunfish were the most tolerant species. A subset of 19 of these lakes was examined intensively. Fish production was measured to examine acidification effects on fish standing stocks and production. No such data were available on any headwater shield lakes, (except in an experimentally acidified lake at ELA). At lower ANC (acid-neutralizing capacity) and pH, fish weight and population growth rates were often lower. Fish community production was related to ANC (as well as to biomass and average fish weight).[6]

In the late 1980s the GLBL LRTAP program centred on the biomonitoring component of the national program at the Turkey Lakes watershed and a subset of Parry Sound lakes, as well as risk assessment modelling. Some new inputs to the effects model filled in geographic gaps. Output to Environment Canada and the Royal Society of Canada related effects to control scenarios. For example, in 1989 the US considered SO_2 emission reductions of 5 to 10 million tons, but 15 to 20 million ton reductions would be necessary to minimize projected damage in Canada. Canadian controls would have to be better than the 50 percent reduction scheduled in the federal-provincial agreement. In addition, the risk assessment data base was suitable for new models which addressed climate change scenarios.

The development of Canada's Fish Habitat Policy in 1986, followed by the creation of the Fish Habitat Management (FHM) section in Burlington, stimulated research on fish and habitat relationships. A cooperative study with Fish Habitat Management was initiated to determine how fish production and biomass varied between habitat types and to develop a model for predicting the productive capacity of habitats using the GIS. Early studies focused on RAP sites, particularly Hamilton, Quinte, and Severn Sound where extensive habitat and biological databases already existed. Jim Moore and Ken Minns took the lead role developing the GIS. Bob Randall and Vic Cairns provided nearshore electrofishing data and detailed habitat inventories from the three sites. The electrofishing data were used to describe community indicators of stress based on biomass, species richness, community composition, and the ratio of native and exotic species, and to establish fisheries targets for Hamilton Harbour. The detailed habitat surveys combined with the fisheries data encouraged a cooperative project with OMNR and FHM to develop a Fish Habitat Management Plan for Severn Sound. The fish and habitat associations study is in the very early stages of development.

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6. STATE-OF-THE-LAKES SURVEILLANCE

"Properly co-ordinated, these surveillance programs will also permit continuous monitoring of compliance with agreements between Canada and the United States regarding water quality objectives and standards and the programs to achieve them. They will also permit a continuous review of the adequacy of the agreed objectives and programs so that necessary changes may be recommended to the two Governments as appropriate and the international agreements amended accordingly."

From: International Joint Commission. 1970. Pollution of Lake Erie, Lake Ontario and the International Section of the St. Lawrence River. IJC, Ottawa.

Most of the major pollution studies through the 1960s and 1970s created the need for ongoing monitoring to audit the effectiveness of remedial measures. These included the Erie/Ontario/St. Lawrence Reference, the Upper Lakes Reference and further studies on the interconnecting channels. High concentrations of mercury had been discovered in sediments in Lake Huron and Lake Ontario in 1968, and in fish from Lake St. Clair to the St. Lawrence River in 1970. Chlorinated hydrocarbons (DDT, PCBs etc.) were found in Lake Michigan fish in 1971, and in common terns at Hamilton, which were correlated with death of embryos and deformed chicks. Advances in analytical chemistry and toxicology were the key to a Pandora's box of new issues. PLUARG's work on industrial landfills raised the alarm on potential problems from continuing dispersal of contaminants. The 1978 Water Quality Agreement called for improved surveillance, and the federal Environmental Contaminants Act of 1976, if it was to accomplish controls at source, would have to be supported by field data - carefully collected, well analyzed, and properly interpreted.

By 1978 the Water Quality Board had developed a Great Lakes International Surveillance Program for all lakes and connecting channels. GLBL worked with many other agencies on this plan. Its operational responsibilities included surveillance of metal and organic contaminant residues in fish and other biota, and monitoring phytoplankton, zooplankton, and benthos communities, particularly in Lake Ontario (with US agencies monitoring Lake Erie). Two main GLBL projects encompassed these responsibilities, the Contaminants Surveillance project and the Lake Ontario Bioindex project. The Tissue Archive study was an offshoot of the contaminants monitoring because the future demand for reputable samples for analysis of 'new' contaminants was inevitable. Tumour monitoring was initiated in 1980, as a logical extension of the contaminants program. Some of the results of toxicological research provided surveillance tools which might be useful but would have to be rigorously evaluated (like high ALA-D enzyme levels indicating lead toxicity, high MFO enzyme levels as a sign of exposure to chlorinated hydrocarbons and petroleum wastes). Work on anomalies in reproductive systems of lake trout appeared to be a useful surveillance measure initially, but the cause-effect mechanism was not adequately understood. Consequently, this work evolved into an ongoing research program, which continues now in a multi-agency effort under the wing of the Great Lakes Fishery Commission. The Lake Ontario Bioindex project provides both trend-in-time data for surveillance purposes and an increasingly valuable source of data for trophic level studies, which are improving the understanding of eutrophication processes and contaminant fate and pathways. The Contaminants Surveillance project also provides data for surveillance and data of excellent quality for research purposes. The two main projects have grown together on Lake Ontario into what is now (along with Project Quinte) one of the most extensive useful time series of environmental data on the Great Lakes.

The GLBL open-lake contaminants surveillance project is one of four related Canadian activities, the others being OME's nearshore spottail shiner (young-of-year) monitoring, OMNR's sport fish monitoring, and commercial fish monitoring by the DFO Fish Inspection staff. The latter two activities are biased towards problem stocks and sizes, while the OME project is aimed at local, probably recent, contamination. GLBL collects data on selected metals and organics generally in lake trout, rainbow smelt, the benthic amphipod *Pontoporeia affinis*, and plankton. All of the Great Lakes are examined each year. The data go directly into the Surveillance Subcommittee and the Water Quality Board's annual report to IJC.

Associated studies have included those on the seasonal dynamics of organic contaminants, evaluation of levels of toxaphene and various furans and dioxins, and photodegradation products of some persistent organic compounds, use of ALA-D levels in fish blood to determine lead intoxication, and fin ray asymmetry in fish as an indicator of stress. Levels of PAHs in benthic macroinvertebrates also were examined.

In the Tissue Archive project, various methods of freezing specimens have been evaluated, and extraction methods have been assessed. ^{14}C-labelled PCBs provided a reliable way to determine losses in immediate field handling, subsequent storage, extraction, and analysis. Freezing at very low temperatures now takes place within minutes of retrieval from sampling gear. The archive is one of the top three in North America. The US agencies plan to collaborate on a single US archive for Great Lakes biota, and they may receive support from the Great Lakes Protection Fund.

GLBL was given the responsibility by DFO to develop an ultra-trace analytical laboratory to satisfy departmental requirements for analysis of dioxin and other difficult and highly toxic materials. Concerned by the detection of the highly toxic and potentially carcinogenic compound dioxin in fish from Lake Ontario in 1981, the Department generated a Treasury Board Submission to build an ultra-trace contaminant analytical laboratory in Burlington. The Department requested these funds in order to fulfil its mandate under the Fish Inspection Act, the Great Lakes Fisheries Convention Act and the Fisheries Act. The concern that an estimated 1.3 billion dollar annual fisheries operation was in jeopardy was a convincing enough argument to persuade the Treasury Board analysts on the need for such a federal government facility on the Great Lakes. The two major proponents of the effort for the Ontario Region were Pat Chamut and John Davis who currently find themselves in an identical position in the Pacific Region. Since its inception the ultra-trace laboratory has provided a far wider range of analytical support than dioxins and has played a major role under the regional CODE for Freshwater Fisheries Contaminants and Toxicology.

Great Lake fish populations are exposed to many contaminants at varying levels. Cause - effect relationships are elusive; consequently, this calls for an epidemiological approach. By the late 1970s patterns were evident in prevalence of disease and pathological anomalies in fish and pollution hot spots. GLBL, therefore, began monitoring tumours in fish in April, 1980, to determine if tumour incidence could be used successfully as a surveillance tool. Three fish species (and 8000 fish) were examined at 27 sites on the lower lakes. White sucker lip papilloma was the first potentially useful index. On a variety of tumours an identification manual was prepared to alert fisheries biologists and generate more information. Hamilton Harbour white suckers, which showed the highest incidence, were studied more intensively to evaluate the technique.

Concurrently constricted gonads in eastern Lake Ontario lake trout were examined histologically and a survey throughout the Great Lakes (with OMNR and US Fish and Wildlife Service) showed that the anomaly was widespread in hatchery-reared and wild fish. Work intensified, especially to evaluate dysfunction by comparison with normal fish. Lake Opeongo and Lake Ontario trout were compared. Results of hormone biosynthesis, sperm count, and egg fertilization tests did not support the initial hypothesis that the fish had reproductive impairment. Work on androgens continued but this study subsequently took on a broader ecological approach with the work on spawning stocks and spawning shoals.

Further work on white sucker lip papillomas showed that papillomas were present on the lips of white suckers from all sites. Background levels varied between zero and nine percent. Fish from northern Lake Huron were the least affected with levels varying from zero to 10 percent. High levels of papillomas occurred in western Lake Ontario and prevalences of greater than 40 percent occurred in Sixteen Mile Creek and the Humber River. The Hamilton Harbour Grindstone Creek stock was intensively studied. There were no differences detected in growth of suckers with or without papillomas and the population had a normal distribution of year classes in spite of high incidence, especially in older fish. Recaptures from earlier years had more and larger tumours.

This work was expanded with the observation of liver tumours in white suckers. Fish from western Lake Ontario were affected with bile duct and liver cell tumours. Fish from eastern Lake Ontario were affected only with bile duct tumours. Surprisingly, liver tumour frequency was highest at the sites with elevated lip papillomas. These observations led to more tumour surveys on the upper lakes by the OME and to detailed analysis of liver lesions and liver parasites by the Ontario Veterinary College.

Work on tumours was generally completed by 1987. Circumstantial evidence that tumours are related to chemical stress is found in patterns of incidence, induction by chemicals, and sediment extracts in other laboratories, and metabolism by fish of environmental contaminants into carcinogens. However, it is unlikely that tumours in Great Lakes fish will be linked to individual pollutants.

The Lake Ontario Bioindex project was based on earlier data which showed that frequent samples had to be collected but a large number of stations was not required in order to understand the condition of the lake. The project was initiated in 1980 with sampling at four stations in support of the Great Lakes International Surveillance Plan. Currently two stations, one at 130 m deep in the centre of the lake and the other at 34 m in the eastern basin are sampled weekly through April to October. Sufficient information now exists to examine trends in nutrients and biological variables through the 1980s.[2] Reduction in phosphorus loads to Lake Ontario apparently are effective in reducing biomass of algae and higher trophic levels in shallower waters. In the midlake, algal biomass did not decrease but reductions at higher trophic levels occurred during summer stratification, suggesting some effect of food-chain interactions.

Several agencies have monitored benthos communities in the Great Lakes including work by GLLFAS on Lakes Superior and Huron as part of the Upper Lakes Reference Study. Earlier collections by the Great Lakes Institute at the University of Toronto have been examined to strengthen data bases, and re-surveys have been carried out in selected areas in the Great Lakes. Similarly, phytoplankton surveys have been repeated to build a data base to examine trends through time. Recent issues, like the invasion of the Great Lakes by the zebra mussel, have placed further demands on the laboratory for information on the state of the lakes. The long-term data bases developed originally to detect trends in water quality, benthos, and plankton in Quinte and Lake Ontario are providing useful data for modelling the impacts of zebra mussels on trophic interactions. The phosphorus model developed for Quinte was used to predict the effects of zebra mussels on the water quality and community composition of the Bay of Quinte.

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7. INTERNATIONAL FISHERIES ISSUES

> "Stresses affecting fishery resources rarely act singly, have complex interactions and often impact several levels of the aquatic ecosystems, so that remedial management must address problems on a comprehensive whole-system basis. A natural focus of the fisheries agencies, therefore, is the maintenance and development of entire fish communities which can provide improved contributions to society."
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> From: A Joint Strategic Plan for Management of Great Lakes Fisheries. Great Lakes Fishery Commission, Ann Arbor, Michigan, December, 1980.

Issues of international importance to Great Lakes fisheries have been addressed by the GLFC since 1955, and was assigned responsibilities for formulating and coordinating fishery research and management programs, advising governments on measures to improve the fisheries, and implementing a program to control the sea lamprey. Because fisheries agencies and GLFC were preoccupied with control of lamprey and problems of allocation of fish stocks, GLFC acted rather slowly to develop a position on environmental issues and to intervene actively. Finally, in 1976 GLFC consolidated the accumulated concerns of its lake committees and forwarded a brief to IJC titled 'Environmental Quality and Fishery Resources of the Great Lakes'. This brief addressed the problems of eutrophication, power plants and waste heat discharges, dredging and spoils disposal, shoreline and nearshore habitat losses, contaminants and other toxic substances, water levels and flow regulation in the Great Lakes. The two full commissions met in Fort Erie in February 1976 for the first time. The staff of GLBL assumed an important role in developing links between the worlds of fisheries and water quality.

The research community (in fisheries and limnology) continued to develop an ecosystem science and attempted to transfer the knowledge to management of aquatic systems. The first of a series of important symposia was on salmonid communities in oligotrophic lakes (SCOL in 1971), followed by one on perciids (PERCIS in 1976), the sea lamprey (SLIS 1979) on the determination, characteristics and management of fish stocks (STOCS in 1981), fish habitat (CIGLAH in 1988), stock assessment and yield prediction (ASPY in 1985) and other workshops. GLBL staff were involved in all of these initiatives.

In 1978, spurred on by Lake Committees, GLFC asked its Scientific Advisory Committee to determine 'if current research on contaminants was adequate to assess effects on Great Lakes fish'. A total of 25 experts were interviewed. Vic Cairns (of GLBL) summarized their considered opinions. There were few field examples of the effects of contaminants, mainly because we had not learned how to look for appropriate evidence. They cautioned GLFC, that even if measurement of fish community health was made, adverse effects would be cumulative in response to many stresses and after the fact. By focusing on contaminants (that biomagnify) many equally harmful but fugitive chemicals would be unevaluated. This work culminated in a workshop on contaminant effects on fisheries which provided significant leadership in a relatively new field.[2]

In 1981 GLFC began an examination of 'Adaptive Environmental Assessment', which was a workshop approach to analyze technical problems, identify uncertainties, search for consensus on cause-effect relationships and attempt to model various management options. A core modelling team was established (including Ken Minns of GLBL) to explore the application of this approach to lake trout management, control of sea lamprey, and regulation of fisheries. Two workshops followed, one on lake trout research needs and one on assessment of sea lamprey populations. GLFC's Board of Technical Experts (with Ken Minns and John Cooley) advised GLFC on the advantages of using modelling in planning and research. A similar initiative commenced under the IJC, where some proponents wanted to see a super-model to deal with most issues. Fortunately, common sense prevailed and specific models were recommended as most suitable for various purposes.

Because of concern about possible effects of the lampricide TFM on stream fauna, GLBL monitored invertebrate communities in two streams being treated with TFM. Surber net and drift samples of invertebrates taken from Soper Creek (near Bowmanville) indicated few adverse effects; only some oligochaetes and leeches were killed. Similar work in the Goulais-Achigan system (near Sault Ste. Marie) showed increased drift of some groups, but only small losses in invertebrates.[3]

In 1988-89 the Sault Ste. Marie detachment carried out research on the relationship between stream habitat characteristics and sea lamprey production in spawning and nursery areas.[4] This work was designed to improve assessment methodology, one of the research needs identified in GLFC's examination of an IPM approach (integrated pest management) to lamprey control. A proposal was prepared in 1990 by GLBL to study the relationship between a sea lamprey stock and a lake trout stock in Stuart Lake, using a controlled experimental approach. This proposal failed to obtain support in the Board of Technical Experts, although this type of experimental work on the sea lamprey-lake trout interaction was perceived to be an important research need for integrated sea lamprey management. At the same time, other studies on the health of lake trout stocks and limnology of spawning shoals have been carried by GLBL and other laboratories, coordinated to a limited extent by GLFC.

GLBL has participated in many of the strategic planning activities of GLFC, in particular the Strategic Great Lakes Fisheries Management Plan[5] and subsequent workshops on guidelines for habitat planning and management. GLBL has supported the Board of Technical Experts and Habitat Advisory Board, as well as Lake Committees (concerned with issues and solutions on each of the lakes) and Fish Diseases Committee (DFO headquarters staff). Most recently the laboratory has assisted GLFC and IJC in efforts to achieve regulatory control over vessel ballast water disposal. The zebra mussel, exotic river ruffe (a fish species) and many other exotics have been released into the Great Lakes. The only way to prevent further introductions is the replacement of potentially dangerous ballast water, and cleaning if necessary before entry into the Great Lakes system.

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8. RESEARCH IN THE 1990s

"Laboratory studies have the manipulative capability of observing cause-effect relationships although application of the results to the field is often limited by the number of experimental variables examined. Field studies are crucial in identifying existing issues but often lack the resolution to identify underlying causes. These observations clearly indicate the need for collaborative studies so fish health can be evaluated at the ecosystem level with a reasonable degree of confidence."

From: A.J. Niimi. 1990. Review of biochemical methods and other indicators to assess fish health in aquatic ecosystems containing toxic substances. Journal Great Lakes Research 16(4): 529-541

GLLFAS will continue its work on the many environmental issues that confront fisheries agencies in the Great Lakes region. In the face of growing demands, on top of ongoing commitments, it must be particularly aware of the need to maintain continuity and quality of research, strength of purpose, and cohesion among its members. It will continue to strive for more effective partnerships among fisheries and environmental research groups, and greater impact on management policies and programs in the Great Lakes.

In the 1990s more time should be spent in planning research, transferring information and evaluating the results achieved. The entire function of research should be evaluated, from setting objectives, developing projects, synthesizing information, transferring it and evaluating effectiveness. More effort should be spent on assessing the success of managers, committees and agencies in effectively using the results from science programs. More effort will be required to maintain working relations with US agencies, in response to the reduced role of IJC in coordination of programs. The scientific community will have more and more dialogue with stakeholders. Relevant, issue-oriented, proactive discussion of environmental issues will be demanding of, but rewarding for, research agencies.

Potential new projects should be subject to criteria, such as: central to the DFO mandate; appropriate for a research approach; good fit with GLLFAS resources and expertise; reasonable expectation of affecting policy or program; availability of funds. The laboratory should identify, define and strengthen its core program, that is, the main approaches and topics which are in many ways independent of today's and yesterday's issues (see definitions of programs in 1972 - page 14). Success in so-called 'crisis research', with soft funding, short term and quick turnaround, will depend on how perceptive and strong the core program is. Synthesis has been done effectively by GLLFAS. Transfer of information will need more attention in GLLFAS and more help from the federal-provincial and international boards and committees which have these responsibilities. Through the 1990s the main clients will still be IJC, GLFC, and the many fisheries and environmental agencies involved in restoration and management of the Great Lakes. The main overall strategy of the laboratory will be to contribute information on the physical and chemical habitat which will strengthen fisheries plans and lakewide management plans (LAMPs) and their RAPs. The cohesion between physical and chemical habitat and between habitat and fisheries will be ensured by strong core research which relates stresses on aquatic systems to their productivity and stability.

Quite likely experimental management will become one of the most informative research approaches through the 1990s. Project Quinte was experimental management, and nutrient management was the main remedial measure. New habitat restoration in Hamilton Bay and Cootes Paradise, Nipigon Bay and Thunder Bay will provide valuable information on physical habitat needs of aquatic communities. The Lake Superior initiative ('zero discharge' policy) will be an experiment on a huge scale. In transferring information, GLLFAS should provide an improved working definition of the Ecosystem Approach. Also, more research is required on relatively unperturbed ecosystems in order to understand the defects in sick ecosystems.

Work on tropho-dynamic models will continue through the decade. This research typifies the needed linkages between limnological science on one hand and fisheries and environmental management on the other. By this approach, cultural eutrophication will become better understood as the role of aquatic community balance is described. Contaminant pathways and dynamics will be modelled in new ways that will allow predictions for management purposes, and of course, tropho-dynamic models have considerable value to managers of fisheries if precision can be increased and species-partitioning is introduced. Habitat assessment and inventory studies also should be closely keyed to system productivity and fish production.

The value of time series, such as Project Quinte, Lake Ontario Bioindex, Contaminants Surveillance and the Acid Rain Biomonitoring programs is now well recognized. The Quinte data base is one of the longest time series in the Great Lakes. The Bioindex program certainly should be expanded, as budgets permit, into the other three Canadian lakes. This would give the laboratory a state of preparedness which would be invaluable in addressing future issues. The payoff to core research is bound to be high, based on those from the current time-series.

The ecological basis for habitat protection will be strengthened through the 1990s. DFO is the main client and it needs improved knowledge to implement the 'no net loss' principle to evaluate mitigative measures, to develop habitat inventory and assessment procedures, such as determining effects of incremental losses. The RAPs on the Great Lakes continue to provide DFO with an outstanding opportunity to enhance its scientific basis for habitat protection and restoration. The Strategic Great Lakes Fisheries Management Plan requires that lake fisheries and habitat plans be prepared, which should be harmonized with planning in LAMPs and RAPs under terms of the Water Quality Agreement. The main goal of GLLFAS should be to advance beyond the descriptive stage and into experimental management (in amelioration and restoration projects).

GLLFAS will further develop a 'comparative toxicology' as studies proceed at several trophic levels with similar approaches. Field studies will attempt further to translate physiological responses to effects on field populations, especially in measured correlations with reproduction and demographic characteristics of fish communities (and other biota). The Green Plan needs this kind of information on toxic pollutants so that new remedial programs are relevant and effective.

9. RESEARCH PLANNING AND MANAGEMENT

> "The research community has a unique opportunity and responsibility to be much more active participants in designing a future that will inevitably be very different from the past. Research managers, for their part, will have to decide whether they are to be staunch defenders of the status quo or if they are to find creative ways to foster and manage active and unfettered discussion, debate and research on alternate futures."
>
> From: Hamilton, A.L. 1989. Getting there from here: future directions in Great Lakes research. In: Great lakes 2000: Building a Vision. International Joint Commission, Ottawa.

GLLFAS has operated across sectors in resources management, primarily fisheries, water and, to some extent, air. It has operated within a federal mandate, at the federal-provincial level and on many Canada-US programs. Planning and management of research is extraordinarily complicated, not simply because of the large variety of participating agencies and programs, but because of the differences in policies, priorities, and approaches to research. These are generally a larger hurdle for the research manager than the implementation of programs. GLLFAS has been involved in research strategies developed by DFO, interdepartmentally (especially at CCIW), under the umbrella of IJC references and the Water Quality Board, in collaboration with many groups under the Fishery Commission and jointly with the OMNR. These 'mechanisms' are described here, together with some of the associated problems and, of course, benefits to Great Lakes research generally.

DFO, like most large government agencies today, has to spend more effort managing input to research than output. Because most GLLFAS research programs are developed 'outside' normal DFO channels (through the Canada Ontario Agreement on Great Lakes Water Quality, or Interdepartmental Committee on Water, for example) DFO has not had a 'hands on' understanding of the Great Lakes Program. For these reasons DFO allowed GLLFAS to carry out departmental responsibilities on the Great Lakes, especially in the early years, with minimal headquarters participation. GLLFAS performed some key national tasks during the 1980s, such as the analysis and interpretation of dioxin concentrations in fish and the synthesis of information from several DFO regions on lake characteristics and fish communities in areas sensitive to acid rain loadings. Apparently DFO is increasingly aware that GLLFAS has matured into a laboratory with considerable and extensive experience in fish health and production, environmental stress, and habitat quality. GLLFAS has been in the front lines against a formidable array of habitat issues, many of which eventually confront other DFO regional laboratories. Consequently, the scientific output from GLLFAS has been of increasing importance to the department and the program is now better understood by staff officers than it was earlier.

The main problems for GLLFAS research managers arose mainly from differences in conceptual approaches with environmental protection managers. The latter usually dealt with issues one by one, while fisheries researchers preferred to study populations and communities of fish (and biota generally) in relation to the most important man-made and natural stresses. This problem still exists. Problems were often too narrowly prescribed, for example, for most issues addressed by the 1972 Water Quality Agreement. Funding priorities began to change faster than scientists could complete essential studies. Consequently, the laboratory developed the longer term, core research activities (described in earlier sections) which could be supported by shorter term funds earmarked for agreement tasks. Unfortunately, impacts on fish habitat of the more traditional type (structural, often inshore, at estuaries and wetlands) were neglected because issues, like eutrophication, were narrowly defined and because of limited understanding. Today there is substantial stakeholder interest in fish habitat and GLLFAS is expected to have the answers. There is considerable pressure on GLLFAS to catch up. Much of this research is being carried out within RAP studies, while other habitat studies are part of investigations on sea lamprey, lake trout and other species. Regrettably, DFOs Fish Habitat Policy had not provided the necessary research support to prepare the laboratory for the important work which had to be done in Areas of Concern and elsewhere in the Great Lakes.

There were many important advances in fisheries and limnological research, that were the direct result of the Great Lakes Water Quality Agreement and the funds provided by Canada, the US, provincial and state governments.[1] Collaboration was rewarding for the individual scientist in government and universities, to the managers of support services, to the administrators of environmental and resource programs and to the IJC. Accountability was an important element in IJC's strategy to oversee the Water Quality Agreement, and extensive peer review of research findings promoted good work. A regional loyalty to the Great Lakes developed among professionals. The International Association of Great Lakes Research was a large 'invisible college' whose concerns transcended jurisdictional boundaries. The Water Quality Agreement was important for the Association and the reverse was equally true. Many GLLFAS scientists served on Association boards and committees.

The GLFC was a second focal point for significant scientific advances, primarily as a forum for information exchange and generation of sound approaches to science.[2] Many GLLFAS staff served with GLFC, from the Board of Technical Experts, Habitat Advisory Board to the Commission executive itself. The GLFC operated much differently than did IJC, because it was more like a forum for managers to do inter-agency business than a third party to oversee fisheries management and its benefits. However, the Strategic Great Lakes Fisheries Management Plan defines a role for GLFC more like that of IJC. GLLFAS tried on a few occasions to obtain GLFC research funds (obtained from Canada and US as a 50:50 contribution) to carry out important work on side-effects of TFM and experimental sea lamprey-lake trout interactions. These funds have traditionally been used solely by US agencies to study sea lamprey biology, alternative control methods, registration studies for lampricides and other activities. Nonetheless GLLFAS has been an ardent supporter of the GLFC program and has benefitted in return through many productive associations with staff in many agencies.

The most important relationship for GLLFAS, but not adequately developed even yet, is with the OMNR, which owns the fishery resource and shares the management under the federal Fisheries Act. In 1973-1976 the Strategic Plan for Ontario Fisheries (SPOF) was developed by federal and provincial staffs. A series of reports was prepared[3] to guide future management and restoration of the resource throughout Ontario. The 1967 federal-provincial agreement was basically an allocation of discrete duties. In SPOF a shared effort was proposed, making best use of the strengths of the agencies and the rest of the fisheries community. By 1988 the agencies were prepared to co-sign an agreement, but progress on the subsidiary agreements, which address the practical problems, has been slow. Stronger collaboration between DFO and OMNR is important in achieving progress in RAPs and Lakewide Management Plans (under the Water Quality Agreement). Collaboration is required to strengthen the lake management planning process which both agencies were committed to when they signed the Great Lakes Strategic Fisheries Management Plan. Clearly, there is a need for stronger collaboration in research, especially in studies on fish habitat, restoration, and enhancement. Collaboration in some areas has been good over the years, for example on Project Quinte and on the Great Lakes Contaminant Surveillance Program. At present there is no linkage between OMNR and DFO for research planning except in the few joint projects and the Canada-Ontario Great Lakes Water Quality Agreement Committee to which OMNR was added in 1984. There is explicit provision for this, however, in the Canada-Ontario Fisheries Agreement and in the terms of reference of the supervisory committee (Canada-Ontario Fisheries Agreement Board). This is one of the few serious flaws in existing research planning mechanisms, although the overall complexity of research planning, as described here, is always a challenge for the scientific staff.

In the late 1980s research managers were brought together by the Science Advisory Board of IJC as a Council of Great Lakes Research Managers. They examined research needs to ensure success of the Great Lakes cleanup, especially of RAPs. Modelling was reviewed as a potentially valuable tool in carrying out the cleanup. The Council wisely rejected the idea of a super model, in preference to the most useful individual models for certain purposes, among which linkages could be created.

Research management encompasses many difficult tasks in GLLFAS, as in most research laboratories. Research managers must incorporate 'crisis budgets', and work requirements, into a rational program which is more stable, useful and fundamental in its objectives. For example, the Bay of Quinte limnological database of the last 20 years and the expertise and knowledge acquired there, will be more useful in examining the impact of the zebra mussel than any large and fast crash program. At the same time program managers must resist promoting crises simply to sustain ongoing programs. Research managers have to appreciate the longer term, core interests of scientists and match these appropriately with the shorter term project needs of the laboratory. Research approaches and concepts come from the scientists, information requirements are usually made available by management, and the research manager must attempt to match approaches with these needs over time. Research laboratories may be heavily committed to longer term projects, making it appear to be difficult to respond to crisis programs. However, good long term projects that anticipate the need for sound understanding of natural systems, should put the laboratory in a better position to respond quickly and knowledgeably to crisis information needs. At the same time research managers have to strike an effective balance between excessive fragmentation of projects and staff, and diversification which seems to be essential for survival of laboratory and scientist when funding sources and priorities are rather fluid. The manager has to balance the proportions of staff time spent on research and in assisting with operational programs. This balance seems to have been achieved in GLLFAS and the extramural responsibilities have been shared rather fairly.

The challenge facing GLLFAS is to develop and use a planning process, or cycle, that manages research output. As in most groups the focus is mainly on input - How much will this project cost? When will it end? How can we get support services? In house or buy? How much can we cut the budget without having project withdrawn? If we were managing output, the questions would be very different. How does project fit into GLLFAS goals? What questions will be answered? Is scientific approach sound? How will we apply results? Any presuppositions What effort will go into synthesis and how will we transfer information to management? It is important to use a planning cycle which examines programs from goals and commitments, through research objectives, selection of an appropriate research strategy, followed by synthesis of findings and transfer of information, concluding with an evaluation of the overall program and fine-tuning of objectives as the cycle is repeated.

Research managers and scientists alike must commit significant proportions of their time to synthesis of information and its transfer. The GLLFAS staff has prepared a large number of review articles in the primary literature and many reports to various committees of IJC, Water Quality Board, GLFC and other agencies. Although it is a relatively small laboratory, it has nonetheless provided a significant part of the membership of these committees. It has contributed to the Environmental Assessment and Review Process and actions under the Canadian Environmental Protection Act. The end users of information and the effectiveness of information transfer and subsequent use should be identified and evaluated, respectively, as a regular phase of research planning and management.

References

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(2) Fetterolf, C.M. Jr. 1980. Why a Great Lakes Fishery Commission and why a Sea Lamprey International Symposium. Can. J. Fish. Aquat. Sci. 37: 1588-1593.

(3) Loftus, K.H., M.G. Johnson & H.A. Regier. 1978. Federal-provincial strategic planning for Ontario fisheries: management strategy for the 1980s. J. Fish. Res. Board Can. 35: 916-927

10. INFORMATION AND EDUCATION

> "The best way to protect the uses of the resources of the Great Lakes Basin ecosystem is to instill and enhance an ecosystem ethic with an accent on environmental responsibility in the public, industry, and government agencies. The concept of protecting the ecosystem as an end in itself is fundamental to the maintenance of valued uses."
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> From: R.L. Thomas, J.R. Vallentyne, K. Ogilvie and J.D. Kingham. 1988. The Ecosystems Approach: A Strategy for the Management of Renewable Resources in the Great Lakes Basin. (etc.)

The public has become more interested in resources management and therefore more involved in decision-making. Public participation itself is on the plus side in quality of life. Consequently public organizations and individuals need information, and researchers have a responsibility to provide it. Students also need more direct contact with researchers and managers. Value systems continue to evolve, and, of course, our youth is more open-minded and more likely to place a high value on a healthy state of natural resources.

Participation by GLLFAS staff in information events and programs changed considerably over 25 years. Initially, talks of a general nature to students and service clubs were the usual activity, but, by the 1980s, site-specific information was being provided to stakeholder groups which were formed as part of the RAP process. Talks to public groups and schools continued to increase, and, in 1976, Jack Vallentyne transferred from Ottawa to Burlington to develop a science-oriented information program for the Ontario Region, DFO. He located his office at CCIW and later went on GLLFAS complement. The information program has occupied more than half of his time.

Jack Vallentyne has talked to more than 100,000 students, to 2000 teachers, often in their professional development programs, and at workshops to science teachers. Much of his information, tailored to his audience, comes from research in GLLFAS, like the acid rain sensitivity maps and contaminant trends in Great Lakes fish. In general, the Great Lakes cleanup story is good news, except for some toxics, some closed beaches, and the zebra mussel invasion. While Vallentyne has talked to several thousand adults in various groups, he believes that students are his most important audience. For most presentations he dresses in a brown safari suit and boots, and carries an illuminated globe of the world. He began to dress as 'Johnny Biosphere' in 1980 to grab the attention of students - which he surely did! Some of these appearances produce opportunities to reach wider audiences via TV appearances and newspaper articles. He has found that attitudes of young people have changed rapidly in the last few years and they are influencing their parents and even the political system. Much of the balance of his time has been spent in professional workshops on Great Lakes issues, co-chairperson of IJC's Science Advisory Board and laboratory activities.

GLLFAS staff have had a variety of opportunities to increase ecosystem awareness in the Great Lakes basin. These range from help with Science Fairs and Career Days to participation in local municipal 'sustainable development' committees. The greatest involvement has been in talks at schools and to adult groups, and visits to CCIW by many groups and individuals of all walks of life. Open House at CCIW has been held on several occasions (1979, 1982, 1985, 1988); these were attended by in excess of 100,000 people. Each event required considerable preparation to convert CCIW into a 'Science Centre'. Yet these events give positive feedback to staff for their work.

During the late 1980s some GLLFAS staff, particularly in Fish Habitat Studies, were heavily involved in RAP activities. Much of this effort was in providing information to Stakeholders Groups. The Bay of Quinte, Hamilton Harbour, Severn Sound, and Lake Superior (Thunder Bay, Nipigon and Jackfish) RAPs required most input from GLLFAS.

11. REFLECTIONS

> "We cannot afford to waste time in the impasse among jurisdictions and among approaches at the expense of developing workable strategies. Strong political leadership is required. It will be important for IJC and GLFC to help in identification of issues and root causes, to encourage strategic planning and public participation to seek solutions, and to take a broad overview of whether public policy is consistent with the finite capacity of the Great Lakes ecosystem to maintain quality of life."
>
> From: M.G. Johnson. 1980. Great Lakes Environmental Protection Policies from a Fisheries Perspective. Canadian Journal Fisheries and Aquatic Science. 37: 1196-1204.

The primary concerns of the staff of GLLFAS are whether good progress has been made over 25 years, and the direction the laboratory will take over the next decade or more. There are several reasonable ways to measure progress, such as the publication record, growth in budget and staff, representation on important boards and committees, but the only satisfactory and comprehensive way is to assess change in fisheries, aquatic communities and fish stocks, fish habitat, and the policies and values held by governments and their agencies, and changing public attitudes.

Fisheries and fish communities have shown considerable improvement through the 1980s. As a result of nutrient controls and pollution abatement generally, lamprey control, fish stocking and, most important, habitat restoration in key areas, the Great Lakes support a flourishing recreational fishery. It is the largest in North America, with one million anglers and 11 thousand worker years, worth four billion dollars annually. The total economic benefit of the food fishery to the Great Lakes economy was about 270 million dollars and nine thousand jobs. However, the news is not all good. There are areas in the Great Lakes where the incidence of tumours in fish is circumstantially related to industrial areas and validated by laboratory studies in some cases. Unfortunately, some native fish species (such as lake trout) still do not reproduce successfully in many areas. Plankton and benthos communities still show environmental degradation in many areas, although improvements are reported continually. There are still substantial numbers of fish consumption advisories and restricted fisheries because of chemical contamination, particularly for lake trout, Pacific salmon, and walleye. Levels of many toxic chemicals in biota decreased since 1975 but they have now levelled off, presumably because of continued lower inputs, diffuse sources, contaminated sediments, and the extremely persistent nature of some chemicals. Further load reductions and cleanup are needed. The policy objective for Lake Superior - zero discharge - will require watching; previous loadings and ongoing atmospheric inputs may make this cleanup a slow process.

Structural habitat in wetlands and inshore zones of the lakes was so badly depreciated in many areas, especially in the lower lakes, that full restoration is impossible and rehabilitation will be slow and costly. Fisheries agencies, and hopefully the public also, cannot gauge progress in terms of pollution abatement only. Restoration of habitat must be carried out at the same time. Unfortunately research on structural habitat issues was, in effect postponed, with the exception of some useful work on lake trout, sea lamprey and other fish communities, for example the Bay of Quinte warmwater community. Only now a very few researchers are beginning to examine habitat in ways that will quantitatively link habitat features with fish community production, diversity and balance. It is unfortunate that GLLFAS did not initiate habitat studies earlier but most funds were earmarked for other studies and federal agencies had responsibilities to carry out mostly offshore work. Recent initiatives by the federal government to rehabilitate Areas of Concern in Quinte, Severn Sound, Hamilton Harbour, and Thunder Bay have catalyzed renewed interest in nearshore habitats. Approximately 25 percent of laboratory resources are focused on understanding fish and habitat relationships, particularly in Areas of Concern. New technologies, such as the GIS, facilitate multi-trophic analyses and are quickly merging the historic open lake data with nearshore processes.

Through these 25 years fisheries scientists on the Great Lakes progressed from writing 'obituaries' of stocks, through a period of analysis of cause-effect relationships into, finally, rehabilitation studies. They are advocates of adaptive management, where results of real - world management programs are studied closely and fine-tuned based on new information. This approach puts the researcher into an influential position and precludes arguments that more research is needed before remedial programs can begin.

Surprisingly, some fisheries agency personnel in the Great Lakes have been slow in supporting RAPs at Areas of Concern. The reasons likely are varied - perhaps the lack of special budgets, lower priority fish stocks or inadequate expertise. However, they cannot afford not to support RAPs, for the following reasons. Fisheries agencies have applied pressure for rehabilitation for years. Also, as trophodynamic studies on aquatic communities have shown, fisheries management (manipulation of food chains) is an integral part of the solution. Furthermore, if we lose the constituency for fisheries in any area by neglecting rehabilitation efforts, public pressure for better fisheries and healthier aquatic communities likely would decrease.

It is important, therefore, that fisheries management plans become a strong component of LAMPs under the Water Quality Agreement. Furthermore, RAPs must be modified if necessary to meet the needs of lakewide plans. Near-field and far-field effects of abatement programs should be examined together. This means that work on LAMPs must catch up quickly to programs in the Areas of Concern. Fisheries agencies should show some leadership here.

GLLFAS has spent 25 years attempting to bridge the gap between fisheries management and water management. Talking to environmental protection staff about fish was no less challenging than talking to fisheries staff about environmental issues, but GLLFAS staff continued to describe the many relationships. Even lamprey control could be related to regulating the abundance of algae. The habitat protection provisions of the Fisheries Act can be used in restoration of the Great Lakes. Habitat inventory and descriptors eventually will plug directly into models which are used to determine quantitative and qualitative features of fish production. At the same time, studies in ecosystem epidemiology provide some of the most compelling arguments for the Great Lakes cleanup by an increasingly knowledgeable public which knows that 'sick' ecosystems mean trouble for people. And so on! Consequently, it is important for GLLFAS to continue to strengthen bridges across resource sectors and to promote collaboration in resources planning.

The IJC and GLFC have played a vital role in resources planning. Third-party objectivity, rooted in independent thought, has been and will continue to be, critical to the Great Lakes cleanup and rational policy-making in the future. GLLFAS looks on the two commissions as key clients for the kinds of research it does. Increased collaboration between IJC and GLFC would be desirable, for example, in State-of-the Ecosystem reports on the lakes, acting together to ensure that public agencies set good examples in environmental protection and resources management, and other areas.

The GLLFAS research program could have been better. There were unfinished projects - the demographic effect of impingement and entrainment mortalities of fish on fish population has not been examined. There was the occasional, apparently unavoidable, ventures. Sometimes GLLFAS programs (with appropriate CCIW help) went overboard on technology - measurements of oxygen, temperature, and wave height were sent from a buoy at a Quinte station to a satellite in space and never returned to earth. We learned from these mistakes and still believe that science will progress faster if innovative and perhaps unconventional approacheds are tried.

A strong linkage with the OMNR fisheries research program has not evolved over these 25 years, in part because of re-organizational disruptions at several times and levels within agencies and perhaps because of differences in program priorities. Nonetheless many professional linkages have been formed and perhaps these can be more extensive and stronger. Hopefully the fisheries research programs of the two agencies (and US agencies also) will make better use of fish populations as the basis for environmental studies (in relation to the array of important natural and man-made stressors as opposed to single-stress studies), and understanding over-stressed systems requires knowledge of more normal systems.

Of course, there were inevitable frustrations! Why was it easier to get funds to measure contaminant residues in fish, than to assess effects that those body burdens had on fish health? Why must the onus of proof of environmental damage be on the public, rather than proof of safety be required of manufacturer and user? Why is cost-benefit analysis applied to Great Lakes cleanup projects if the destruction of habitat was illegal in the first place? GLLFAS will simply have to work away on these and many other issues beyond its control.

GLLFAS matured through the 25 years, 1967 to 1991. The earliest work was almost entirely descriptive because knowledge of Great Lakes limnology was so limited. Toxicological research was initiated in the laboratory, mainly because of prescribed needs of the Water Quality Agreement. After several years, the foundations for stronger field programs had been built, allowing the laboratory to examine some of the complex scientific questions. At the same time GLLFAS broadened its concerns and, working hard with other groups, helped to redirect the Water Quality Agreement and programs of the IJC and GLFC into a stronger ecosystem approach. Exchange of people and information, generally on an international level, increased as the work of the laboratory was recognized. Significant advances occurred in data handling, with much less dependence on a 'computer elite' and much more scope for analysis and modelling. More synthesis and transfer of information was accomplished in the 1980s especially. In general, GLLFAS staff feel that they have come a long way scientifically in 25 years, affected the course of action in the Great Lakes cleanup, and are well prepared to meet new issues and difficult challenges.

Appendix 1. Laboratory staff, 1967-1991. (The year periods only indicate when personnel joined the staff of the Laboratory. Tenure of employment is not given).

1967

Nicholson, H., Technician

1968-1972

Management

Vollenweider, R., Director 1968-1970
Nauwerck, A., Director 1971-1972
Sully, L., Secretary

Scientists

Carpenter, G.
Glooschenko, W.
Leslie, J.
Moore, J.
Munawar, M.
Watson, N.

Technicians

Collins, R.
Mansey, L.
Shrivastava, H.

1973-1982

Management

Johnson, M., Director 1972-1976

Thomas, R., Director 1976-1984

Bouverat, L., Secretary
Leatherdale, J., Secretary
Marshall, B., Secretary
Moore, D., Secretary
German, N., Typist

Administration

Crescuolo, J.
Davis, B.
O'Connor, J.
Vize, A.

Scientists

Borgmann, U.
Cairns, V.
Cook, D.
Cooley, J.
Dermott, R.
MacKinnon, M. (PDF)
Millard, S.
Minns, K.
Niimi, A.
Shear, M.

Appendix 1 (continued)

1973-1982 (cont.)

Gächter, R. (PDF)
Hodson, P.
Johanssonn, O.
Kelso, J.
Kwiatkowski, R.
Love, R.
Stadelmann, P. (PDF)
Whittle, M.
Williams, D.
Wilson, B.
Wong, P.
Wright, D.

Technicians

Blunt, B.
Brooksbank, M.
Burnison, B.
Charlton, C.
Culp, L.
Dupuis, G.
Fitzsimons, J.
French, A.
Gorny, D.
Hall-Armstrong, J.
Hyatt, W.
Keir, M.
Kramar, O.
Loveridge, C.
Luxon, L.
Ralph, K.
Spry, D.
Timmins, C.

Non-continuing positions

Anderson, J., Archer, M., Celeste, K., Comeau, J., Cove, R., Devet, L., Dunlop, G., Fencott, P., Fox, D., Glooschenko, D., Hall, T., Johnson, G., Kay, E.S., Mahaffy, D., Malecki, M., McGee, S., Moyles, B., Mulvaney, G., Psutka, M., Reynolds, C., Rockwood, J., Roslyn, K., Simpson, D., Titley, B.

1983-1987

Management

Cooley, J., Director 1984-present

Administration

Fawcett, G.
Heiman, J.

Scientists

Sergeant, G.
Vallentyne, J. (SE)

Appendix 1 (continued)

Technicians

Bennie, D.	Lipsit, J.
Bonnell, R.	Michell, L.
George, S.	Palazzo, V.
Haras, W.	Rhamey, S.
Heiman, T.	Thibodeau, M.

Yaromich, J.

Non-continuing Positions

Gray, B., McCarthy, L., McNeill, I., Smith, S.

1988-1991

Management

Hoyt, A., Secretary	Lyon, C., Secretary

Scientists

DeBruyn, R.	Randall, R.
Huestis, S.	Servos, M.
Myles, D.	Shaw, M.
Munkittrick, K.	Valere, B.

Technicians

Hope, D.	Kissoon, G.

Norwood, W.

Non-continuing Positions

Ali, N., Beauregard, L., Burley, M., Chisholm, E., Gardiner, B., Geiling, D., Heuval, E., Leggett, M., McKenna, D., Young, R.

Note: PDR = Post Doctorate Fellowship
SE = Scientist Emeritus