GREAT LAKES FISHERY COMMISSION

1994 Project Completion Report[1]

Great Lakes Fishery Commission Ecosystem Partnership Coordination

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Final Report

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Summary

This report is an account of activity and findings of the Ecosystem Partnership Coordination (EPC) position funded by the Great Lakes Fishery Commission, U. S. Environmental Protection Agency, and the U.S. Fish and Wildlife Service. The purpose of creating this temporary position was to explore the basis for developing stronger partnerships in setting and implementing common objectives for ecosystem management of the Great Lakes. As originally conceived, the position was to focus on the integration of Lakewide Management Plans (LaMPs) and Fish Management Plans (FMPs) for Lake Michigan and Lake Ontario. Approaches to these two planning activities, however, proved to be too disparate and unconsolidated for integration. The Lake Michigan LaMP for Critical Pollutants had a narrow focus on pollution, and neither the U.S. EPA or Environment Canada had an active strategy to implement a systematic and comprehensive ecosystem approach to restoration of the chemical, physical, and biological integrity of the Great Lakes. Although committed to an ecosystem approach, the highest priority concern of water quality managers is to reduce pollution of the Great Lakes by critical pollutants. The most pressing, environmental concerns of fish managers, in contrast, are related to habitat and conventional pollutants. Nevertheless, fish managers had yet to develop integrated FMPs that linked Fish Community Objectives and the Environmental Objectives required to achieve the goals of fishery management. In view of these differences in approach, the primary function of the EPC position, therefore, became analysis of the impediments to ecosystem management in the Great Lakes and preliminary work to assist the development of institutional coordination.

Despite these differences, water quality and fish managers share a broad complementarity in approach to ecosystem management. Water quality managers focus primarily on external stresses that cause various impairments of beneficial uses of the Great Lakes, and fish managers are concerned primarily with restoration and maintenance of fish populations of the open waters of

the Great Lakes. In attempting to identify the environmental objectives necessary to achieve their stated fish community objectives, fish managers are providing criteria for restoration of beneficial uses. Water quality managers need such criteria to bound levels of stress reduction (i.e. pollution loading restrictions and levels of required habitat remediation) in order to achieve operational guidelines for restoring the integrity of the ecosystems of the Great Lakes. This complementarity of approach provides an opportunity to explore more iterative or evolutionary approaches to establishing end points for the ecosystem objectives necessary to implement a more strategic plan for ecosystem management. To move toward a more strategic integration of ecosystem management, will require: 1) a broad commitment to joint management by water quality and fish managers, 2) an explicit attempt to derive an operational set of interim environmental objectives, and 3) the design of joint management activities.

To pursue this opportunity to build on the complementarity of management approaches, water quality and fish managers must overcome substantial challenges. Differences in mandate, perception of priorities, and style of management create major institutional impediments to systematic and comprehensive coordination of ecosystem management. Many of the current problems are, in fact, the unintended consequences of uncoordinated management of water quality, fisheries, shipping, and human developments in the Great Lakes Basin. Solution of this problem will require the governments of Canada and the United States (in cooperation with local, Provincial, State, and Tribal agencies) to set up more explicit institutional arrangements. At a minimum, this will require creation of a mechanism to promote strategic planning, monitoring, and coordination of management activity on a lake-by-lake basis.

To pursue ecosystem management in a strategic way will also require reconsideration of the central role of objective setting. Various agreements mandate the development of Ecosystem Objectives, Fish Community Objectives, and Environmental Objectives for the Great Lakes. The ambiguities of these objectives, however, has made derivation of indicators and end points nearly impossible and has forced managers to make policy choices. Ideally, objective setting represents social preference for trade-offs of user interests as balanced by responsible stewardship for the natural resources of the Great Lakes. A more strategic approach requires: 1) viewing the development of ecosystem objectives as a progressive, vision clarifying process, 2) developing end points from objectives, and 3) including explicit milestones to gauge progress toward the objectives as part of the objective setting process.

Although coordination of water quality and fish management is necessary for progress in implementing ecosystem management, it is not sufficient. Water quality and fish management issues are themselves imbedded in a hierarchy of other management decision-making and social and economic developments. It is important to recognize that a systematic and comprehensive approach to the restoration of the ecosystems of the Great Lakes requires joining ecological restoration and human development at spatial and temporal scales that are beyond human experience. The integrity of the Great Lakes ecosystems is affected by activities far outside the basin. Long-term, restoration of Great Lakes ecosystems must at least include explicit consideration of hydrology (water quantity management issues) and potential effects of global climate change.

Introduction

From July 1, 1992, to December 31, 1993, Dr. Joseph Koonce[1] assumed an 18 month position with the Secretariat of the Great Lakes Fishery Commission as the Ecosystem Partnership Coordinator (EPC). The position was funded by the Environmental Protection Agency (Great Lakes National Program Office), the U.S. Fish and Wildlife Service (Great Lakes Initiative), and the Great Lakes Fishery Commission. Following the report of a Round Table on an ecosystem approach to the management of Lake Michigan[2], the purpose of establishing an ecosystem partnership coordination position was to develop a stronger partnership in setting and implementing common objectives for ecosystem management of the Great Lakes and to develop the foundations for future cooperation and integration of management. This report is a summary of the activities of this 18 month period and an analysis of the challenges and opportunities confronting ecosystem management of the Great Lakes.

Goals

The original proposal had three specific objectives: coordination of the interdependence of Lake-wide Management Plans (LaMPs) and Fishery Management Plans (FMPs) for the Great Lakes, facilitation of use of ecosystem objectives by fishery management agencies, and development of linkages among efforts necessary to quantify the consequences of management policies. Under the direction of a steering committee, the primary duties of the EPC were to include: 1) representation of fishery input to the LaMP process and 2) provision of staff support to Lake Committees of the GLFC to incorporate ecosystem objectives and indicators into the FMP

[1] Dr. Koonce took this secondment as a leave-of-absence from the Department of Biology, Case Western Reserve University.

[2] In 1990, a Round Table, sponsored by the Great Lakes Fishery Commission, the Science Advisory Board of the International Joint Commission, and the Lake Michigan Federation, reviewed possibilities for coordination of a LaMP for Critical Pollutants and a Fish Management Plan for Lake Michigan (Eshenroder *et al.*, 1990). Recommendation 5 called for a temporary appointment to support fishery collaboration in the development of a Lake Michigan LaMP.

process. By representing the GLFC in the US. Policy Committee for the Great Lakes 5-Year Strategy and the LaMP policy committees for Lake Michigan and Lake Ontario, the EPC position would further contribute to joining environmental and fishery programs. A steering committee was to play a central role in obtaining access to these committees. Also, by serving as staff support to the Lake Committee Chairperson, this position would promote the incorporation of broader ecosystem objectives into the Fishery Management Plans for each of the Great Lakes.

A secondary duty of the EPC was to analyze linkages among end points, indicators, and management actions. These linkages ultimately would determine the success of ecosystem management. Two areas were to receive most attention. First, because habitat suitability was the primary issue linking water quality and fish community restoration, the EPC was to work with the Habitat Advisory Board of the GLFC to determine information and monitoring needs necessary to implement ecosystem objectives. Second, the EPC was to work with US. Fish and Wildlife Service to bring issues arising from the Restoration Act and related initiatives into an ecosystem management context. These secondary duties were to concentrate on two primary tasks: 1) to initiate a workshop for the Habitat Advisory Board on habitat protection and rehabilitation policies, 2) and to review research issues arising from introduction of non-indigenous species and to incorporate these issues into an ecosystem management perspective.

Revised Goals and Work Plan

By mutual agreement of the funding agencies, Mr. Bob Beecher, Executive Secretary of the Great Lakes Fishery Commission, assumed a supervisory role for the EPC. Each agency, in turn provided an individual to serve on a steering committee:

- Ms. Margaret Dochoda, Great Lakes Fishery Commission,
- Mr. Paul Horvatin, Environmental Protection Agency, and
- Mr. Charlie Wooley, U. S. Fish and Wildlife Service.

The steering committee members provided access and briefings for ongoing initiatives, and Dr. Koonce attended a number of meetings necessary to launch and to maintain partnership activities (see Appendix I). Coordination of LaMPs and FMPs was the primary focus of much of the initial work, but the early stage of integration of these activities precluded any direct coordination work. The impediments to direct coordination seem to originate with disparate approaches to organization of partnership activities within the water quality and fish management agencies.

In response to these impediments, the steering committee considered a more limited set of tasks than originally proposed. By the end of the first six months of the position, the challenge for the EPC became one of balancing the delivery of short-term products that would be of value with maintaining progress on development of institutional coordination for ecosystem management. The steering committee suggested a compromise set of two primary tasks:

- to use reporting for the State of the Lakes Ecosystem Conference (SOLEC) to illustrate the necessary modification of LaMP and FMP processes to support a more strategic approach to coordinated ecosystem management; and
- to assist the Habitat Advisory Board's efforts to link fish community objectives to broader environmental objectives for each of the Great Lakes.

Implicit in these tasks was a commitment to continue exploring possible foundations for a more formal coordination of ecosystem management of the Great Lakes.

Findings

Principles governing the protection and restoration of the natural resources of the Great Lakes emphasize an ecosystem approach. Because governments distribute responsibility for implementation of these principles among many agencies and jurisdictions, formation of partnerships is a natural prelude to coordinated planning and management. Supplementing their binational agreements, for example, Canada and the U.S. have initiated internal coordinating programs. The Canada-Ontario Agreement provides a mechanism for sharing fiscal and regulatory responsibility for resources of the Great Lakes. In the U.S., a multi-agency strategy[3] provides a statement of goals and partitions responsibility for achievement among various agencies (Federal, State, and Tribes). Despite these auspicious institutional arrangements and the sympathy of agency personnel for an ecosystem approach, the actual possibilities for program coordination were much less promising than envisioned in 1990. Details of the nature of these challenges to ecosystem management are given in the next section.

From the beginning, the EPC project assumed that LaMPs and FMPs were to be the primary vehicles for implementation of ecosystem management. However, water quality management and fish management in the Great Lakes take different approaches to common problems, and they have quite different perceptions of problem priorities and of responsibilities for management initiatives. Within the first six months of EPC activity, two central assumptions proved to be unreliable:

1) LaMPs for Critical Pollutants were not suitable as organizing frameworks for program coordination, and
2) The process for development of FMPs was not sufficiently developed for active exploration of the interdependence of fish community objectives and environmental objectives for each of the Great Lakes.

Pollution control is obviously the highest priority for water quality managers. The general principles of Annex 2 of the 1987 Protocol begin with "Remedial Action Plans and Lakewide Management Plans shall embody a systematic and comprehensive ecosystem approach to restoring and protecting beneficial uses in Areas of Concern or in open lake waters." However, in specifying the focus of Lakewide Management Plans on critical pollutants, Annex 2 clearly implies that reduction in pollution loading is required to restore beneficial uses:

[3] Protecting the Great Lakes. A Joint Federal/State 5-year Strategy (1992-1997). April 1992 Draft. U.S. Environmental Protection Agency, Great Lakes National Program Office.

> "6. (a) The Parties, in consultation with State and Provincial Governments, shall develop and implement Lakewide Management Plans for open lake waters, except for Lake Michigan where the Government of the United States of America shall have that responsibility. Such Plans shall be designed to reduce loadings of Critical Pollutants in order to restore beneficial uses. Lakewide Management Plans shall not allow increases in pollutant loadings in areas where Specific Objectives are not exceeded."

As a consequence of this priority, LaMPs for Critical Pollutants can not serve as organizing frameworks for program coordination.

For the U.S. EPA, the commitment to LaMPs for Critical Pollutants hinders the development of more systematic, ecosystem approaches to restoration of beneficial uses. In this context, in fact, the development of Ecosystem Objectives languishes. Ecosystem Objectives, as mandated under Annex 1 of the 1987 Protocol, call for the development of specific, lake-ecosystem objectives, which by their content define goals for restoration of beneficial uses. Because pollution is only one of the causes of impairment of beneficial uses, LaMPs for Critical Pollution tend to become ends to themselves rather than vehicles for more comprehensive planning. Operationally, therefore, emphasis on LaMPs for Critical Pollutants seem to have led to the following:

- EPA seems committed to a primary emphasis on LaMPs as management plans for toxic contaminants for Lake Michigan. Many seem to believe that this is a necessary first step and other activity will follow from it. Even successful completion of this step, however, does not address many difficult issues of coordination of management plans for restoration and maintenance of the Lake Michigan ecosystem.
- Overall coordination of LaMPs does not seem to be a major activity of the US Policy Committee for the Great Lakes 5-year Strategy. The Lake Superior LaMP appears to be following a different pattern than the Lake Michigan LaMP, and there is substantial disagreement among U.S. EPA, Environment Canada, and State and Provincial Agencies about the scope of the Lake Erie LaMP.

- The US Policy Committee does not seem particularly active. Apart from the April 1992 strategy document, there does not seem to be an "institutional" plan to move forward. Furthermore, bi-national coordination will be required for LaMP implementation throughout the Great Lakes. Some type of international coordination is required and the 5-yr strategy does not provide any implementation framework for ecosystem management.

At the present time, therefore, it is not clear to whom fishery input to LaMP process should be directed.

Fish managers are also facing problems in the formulation of Fish Management Plans. FMPs represent the coordination of development of Fish Community Objectives and Environmental Objectives as mandated by The Joint Strategic Plan for Management of Great Lakes Fisheries (SGLFMP). The main difficulty with development of FMPs is that they are only giving superficial treatment to environmental objectives. SGLFMP was signed in 1980 by the federal, state, provincial, and tribal authorities. Among other issues, SGLFMP charged lake committees with identifying environmental issues, which may impede achievement of fish community objectives and created a Habitat Advisory Board to assist lake committees in developing environmental objectives essential to achieving fishery objectives. With the more recent explicit statement of a strategic vision for healthy Great Lakes ecosystems, the GLFC has established specific milestones and coordinating framework for ecosystem based management initiatives, but progress in implementing fishery management plans is extremely slow and uneven. In reality, FMPs have not been proposed by any lake committee. Fish community objectives that are available for Lake Ontario and Lake Superior do not address specific environmental problems or establish linkage between fishery objectives and environmental remediation. Other lake committees are delayed in delivery of Fish Community Objectives. Furthermore, the Lake

Committees and the Habitat Advisory Board have not established an effective mechanism to promote incorporation of broader ecosystem objectives into fishery management plans.

Although these differences in approach and priorities have hindered active coordination of water quality management and fish management, there remains substantial complementarity of effort and opportunities for future coordination. The Habitat Advisory Board held a Workshop on Environmental Objectives in an attempt to assist Lake Committees in drafting more specific environmental objectives and to communicate these objectives to water quality managers. The report of the workshop is included in Appendix 2. Participants recognized that the broad complementarity of water quality and fish management approaches to ecosystem management. Explicit recognition of this complementarity could, in fact, provide an impetus to link derivation of Ecosystem Objectives and Fish Community Objectives, plan for reduction in Critical Pollutants, and restore habitat.

The complementarity reflects differences in approach to the resources of the Great Lakes. With their dominant concern for pollution loading, water quality managers focus on external stresses of a lake. They detect impaired uses, identify the external stress causing the impaired use (pollution or habitat degradation), and find regulatory or other ways of eliminating the stress. Cooperative fish management, in contrast, focuses on fish stocks of common concern. This approach is concerned mainly with the open water of a lake.

In setting Fish Community Objectives, fish managers are providing an end point for restoration, that is setting conditions for acceptable restoration of beneficial use. Fish Community Objectives, however, are components of Ecosystem Objectives, and themselves must be reconciled with broader concerns for other beneficial uses. Fish Community Objectives are not necessarily in conflict with Ecosystem Objectives, but setting them independently may create conflicting goals. Fish Management Plans represent integrated sets of Fish Community Objectives and

Environmental Objectives, which are physical, chemical, or biophysical characteristics of a lake ecosystem necessary to achieve stated Fish Community Objectives.

Environmental Objectives so derived are important for water quality managers because they provide end points for restoration in that they provide bounds for allowable levels of external stresses. Without such end points, water quality managers have little basis for justifying the levels of external stresses that are allowable. Beneficial use impairment, while a useful concept to detect sources of external stress on a lake ecosystem, is difficult to translate into restoration goals because of the hidden trade-offs implicit in any beneficial use context. After all, acceptable end points for beneficial uses depend upon management goals, and conflicts over end point specification inevitably involve conflicts over use priorities.

Fish managers also benefit from the needs of water quality managers for specific environmental objectives. In trying to derive Environmental Objectives from Fish Community Objectives for Lake Superior and for Lake Erie, participants in the HAB workshop found that the Fish Community Objectives were not linked to explicit environmental requirements. Derivation of Environmental Objectives that would be of use to water quality managers thus will require fish managers to develop more specific Fish Community Objectives, which would also provide end points for Ecosystem Objectives. This complementarity suggests a process of iterative approximation of end points for ecosystem management. Although there appears to be little institutional flexibility to implement such a process at this time, future steps should include at least the following three stages:

1. Establish a broad commitment to joint management by water quality and fish managers. The more formal the arrangement the better it will be.
2. Attempt to derive an *interim* set of environmental objectives. By using objective setting on an interim basis, managers have a way of exploring consequences of various

policy choices (Ecosystem Objectives, Fish Community Objectives, or pollution loading).

3. Design joint management activity (shared monitoring and linkage of management actions to state of system) through iterative reconsideration of objectives.

Challenges to Ecosystem Management

For ecosystem management, the two most important legal agreements between Canada and the US are the 1955 Convention on Great Lakes Fisheries and the 1978 Great Lakes Water Quality Agreement. Historically, attempts to implement effective, complementary regulations for the fisheries of the Great Lakes failed repeatedly from 1893 to 1952. An important impediment was the reluctance of state agencies to surrender any management authority to federal or international governmental entities. The invasion of sea lamprey into the upper Great Lakes and the subsequent demise of their fisheries, however, created an urgency for more cooperative management initiatives. With the signing of the Convention on Great Lakes Fisheries, Canada and the US formed the Great Lakes Fishery Commission (GLFC) to manage sea lamprey and to assist in the resolution of impediments to restoration of productive fisheries. Fishery management agencies found that the GLFC provided a useful umbrella under which to address inter-jurisdictional issues. In 1980, fishery management agencies formally organized their inter-jurisdictional activities by signing "A Joint Strategic Plan for the Management of Great Lakes Fisheries" (SGLFMP). The GLFC, in turn, committed its support for research, assessment, coordinated management, and issue resolution.

The 1978 Great Lakes Water Quality Agreement (GLWQA) committed the governments of Canada and the U.S. to an ecosystem approach for the management of the Great Lakes. This approach contrasted with the then prevailing "pollutant-by-pollutant" approach to the control of chemical pollution of the lower Great Lakes that characterized the 1972 GLWQA. This call for an ecosystem approach resonated with a long-term interest of the GLFC and its cooperators in an ecosystem approach to fishery management, conservation of genetic diversity of fish stocks, and rehabilitation of lake trout. SGLFMP required fishery management agencies to develop a set of fish community objectives and associated environmental objectives for each of the Great Lakes. The authors of SGLFMP requested that the GLFC establish a Habitat Advisory Board (HAB) to assist the lake committees in specifying these environmental objectives and to link them to management agencies charged with water quality regulations. Concern with an ecosystem approach to management issues resulted in a confluence of interests among fishery and water quality managers, and the IJC and GLFC initiated a series of collaborative efforts on implementation of the ecosystem approach, development of ecosystem objectives, control and prevention of the spread of non-indigenous species, and identification of habitat impairment.

The 1987 Protocol amended the Great Lakes Water Quality Agreement by calling for more specific measures to address impairment of beneficial uses. The Protocol reemphasized the need to deal with persistent toxic substances and endorsed the continued efforts of Canada and the US to implement programs and other measures, in cooperation with State and Provincial Governments, that would fulfill the objectives of the Agreement. A new feature of the Protocol was its formal endorsement of Remedial Action Plans (RAPs) and Lakewide Management Plans (LaMPs) as embodying "...a systematic and comprehensive ecosystem approach to restoring and protecting beneficial uses in Areas of Concern or in open lake waters." By accepting the management responsibility for implementing a systematic and comprehensive ecosystem approach, the Parties have thus taken an important step toward truly integrated management of the Great Lakes ecosystem.

Great Lakes Fisheries Issues

The Great Lakes are the world's most valuable freshwater resource. Their fisheries have constituted a major component of this value. From the 1890s to 1910s, annual yields of mostly high-valued species ranged from 116 to 147 millions pounds (Smith 1972). By the 1950s, yield had declined by 50% and consisted mainly of lower valued species. Many native species have either become extinct or have lost significant subpopulations. Non-indigenous fish species such as sea lamprey, alewife, rainbow smelt, and white perch have invaded the Great Lakes and have fundamentally altered fish communities. Beginning with the control of sea lamprey populations in the mid 1950s, fisheries began a gradual recovery aided by intensive stocking programs for Pacific salmon and lake trout. Aggressive fishery management has led to remarkable recoveries of native stocks as well as large standing stocks of hatchery fish, which persisted until the past few years. The recreational fisheries in Lakes Michigan, Erie, and Ontario are world-class, and contributions of the fisheries of the Great Lakes to regional economies are in the billions of dollars annually. Recent trends, however, may indicate that the levels of recovery may not be sustainable, and the persistence of contaminant problems and habitat degradation continue to make restoration an elusive goal.

Underlying recent changes in Great Lakes fisheries are some rather simple fishery issues. The 1971 GLFC-sponsored international symposium on salmonid communities in oligotrophic lakes (Journal of the Fisheries Research Board of Canada, Volume 29, No.6, June 1972) suggested three categories of challenges for wise management:

(1) balancing predator and prey;

(2) preventing unplanned or ill-considered introductions; and

(3) maximizing available habitat.

Many of the problems we now face originate with our inability to meet these challenges. Like the decline of Chinook salmon in Lake Michigan, the imminent decline of alewife in Lake Ontario will have a cascade effect on sustainability of sports fisheries for salmon and trout. A large part of the problem is due to stocking levels that are no longer commensurate with the productive capacity of the lakes.

Because of the continuing introduction of exotic organisms, the past is no longer a guide to the future of the Great Lakes fisheries, and we must find new ways to re-address these "old" issues. Although now the best protected ecosystem in the world from ballast invaders, the risk for the Great Lakes has only been reduced and not eliminated. The Great Lakes continue to be at risk for introduction of serious new fish diseases from the West Coast (IHNV and VHS), and for re-establishment of the Great Lakes disease EEDV in the region's hatchery and wild lake trout. Intentional introductions undertaken for non-fishery reasons seem to be occurring without the scrutiny and consultation accorded those undertaken for fishery purposes. Grass carp have been introduced for plant control, Arctic charr have been introduced (and then recalled) for pen aquaculture, striped bass raised for other purposes have accessed the Great Lakes, rudd have been introduced as a side effect of the bait fish industry, and black carp are contemplated as a means of zebra mussel control.

Habitat remediation is the most complex issue of these three challenges. Habitat factors can be grouped into two broad categories: physical characteristics of a lake and its tributaries and chemical characteristics associated with loading of substances and their residence time in various parts of a lake ecosystem. Spawning habitat and wetland nursery areas are examples of the former and eutrophication and pollution due to toxic substances the latter.

Eutrophication of the lower lakes was one of the main concerns of the 1972 Great Lakes Water Quality Agreement. Efforts of Government were directed toward reduction of phosphorus loading for Lakes Erie and Ontario, and the Parties selected specific target loading rates to restore beneficial uses. Given the recent trends of declining alewife populations in Lakes Michigan and Ontario, it would seem that fishery managers have not considered the implications of reduced nutrient loading to the stocking levels for predators in both lakes. Furthermore, the invasion of zebra mussel has fundamentally altered the nutrient dynamics of Lake Erie; resulting in even lower levels of productivity than anticipated for the desired phosphorus loading levels. Chlorophyll a levels in Lake Erie are now nearly the same as in Lake Superior (Leach, personal communication). Clearly, fishery agencies need the assistance of environmental agencies to understand and predict implications and outcomes of strategies to reduce nutrient loading.

Physical habitat remediation is another area in which fishery and environmental agencies will need to cooperate. To a major extent, many of the habitat factors important to fisheries have already been discounted. River spawning stocks of many open water species, for example, have been extirpated. The recent gains in fishery restoration have come about through extensive use of stocking, which relies on hatcheries to overcome habitat limitations, or shifts in the composition of fish communities to species less sensitive to the types of habitat degradation that has occurred in the Great Lakes. Shoreline development and future modifications of tributaries provide both opportunities and hazards to future remediation of the fish communities of the Great Lakes. To understand and predict impacts of these changes and to recommend appropriate measures (e.g. in remedial action plans) will require a level of coordination that may exceed that provided in the Protocol.

The issues of predator-prey balance, control of exotics, and habitat improvement are only part of the current dilemma. In a larger sense, the recent declines in the quality of the fisheries of the Great Lakes is an issue of the failure of collective stewardship. Although binational agreements have called for management in an ecosystem context, no management agency has the mandate for such a broad management approach. Each management agency, therefore, seeks to implement best management practices within its own sphere of interest. Many of the current problems are unintended consequences of uncoordinated management of water quality, fisheries, shipping, and human developments in the Great Lakes basin.

Contaminants and Fisheries

Of all the issues addressed by the 1978 Great Lakes Water Quality Agreement and the 1987 Protocol, toxic substances are clearly the most important problem. Contaminants affect fisheries either through impacts on fish health and productivity and/or through real and perceived effects of fish consumption on human health. The GLFC's strategic vision recognizes this impact and sets a specific milestone: "Reduction of toxic substances to levels that do not impair the health of aquatic organisms nor the wholesomeness of fish for consumption by humans and wildlife" (GLFC 1992). Fish managers can influence contaminant availability through manipulation of the fish community (e.g. stocking, fishing intensity, sea lamprey control). However they must rely on environmental agencies to manage the release of toxic contaminants and on public health agencies to identify human health objectives for environmental and fishery agencies.

Gaps in Approaches to Ecosystem Based Problems

Less than ten years ago, the fisheries of the Great Lakes represented an unprecedented success of fisheries management. This pinnacle resulted from a slow recovery of the fisheries resources of the Great Lakes over the past thirty to forty years through the collective partnership of federal, state, and provincial agencies. Sustaining this miraculous recovery has, however, proven to be difficult. Beginning in the late 1980s, the Chinook salmon fishery in Lake Michigan experienced a dramatic reversal with the appearance of an epizootic of bacterial kidney disease (BKD). Other fish diseases have curtailed or limited hatchery production of salmon and trout that is needed to maintain rehabilitation efforts. Alewife populations, which had reached nuisance levels in the 1960s, have begun alarming declines in Lakes Michigan and Ontario. Although there is evidence of recovery of native planktivores in both lakes, maintaining the current fishery depends upon stable population levels of alewife, and their future does not appear promising. The salmon fishery in these two lakes is thus in jeopardy. Almost paradoxically, sea lamprey populations are increasing throughout the Great Lakes. Especially in northern Lake Huron, pollution reduction in the St. Marys River has increased habitat for larval sea lamprey to such an extent that the abundance of the parasitic phase of sea lamprey is so high that prudent management may require substantial reductions in fishery harvests. Throughout the Great Lakes, however, the demand for fishing is rising and many populations have reached exploitation levels that may be excessive. Finally, a new set of invading species threaten to alter the ecosystems of the Great Lakes. Zebra mussel invasion in Lake Erie has now begun to have dramatic effects on nutrient and contaminant recycling as well as food chain dynamics. This invasion along with lowered nutrient loading rates due to improvements in pollution control may mean that the futures of Lake Erie and eventually Lake Ontario will be quite likely different from their historical conditions. In short, the state of Great Lakes fisheries has become precarious and sustaining the miracle of the Great Lakes sport fisheries has become a major challenge.

Limitations of Current Approaches

The Great Lakes Water Quality Agreement has committed the United States and Canada to an ecosystem based management of the Great Lakes. Existing programs and institutional arrangements, however, are falling short of the integration of management planning required to implement ecosystem based management. The major planning initiatives (Remedial Action Plans for the Areas of Concern, Lakewide Management Plans for Critical Pollutants, and Fish Management Plans) are progressing. Each has a separate focus, but overlapping concerns with habitat are not being effectively addressed. The main coordinating mechanism in the 1987 Protocol is the formulation of Lakewide Management Plans for Critical Pollutants. The LaMPs, which are under development, however are concerned primarily with toxic contaminants. The Remedial Action Plans (RAPs) and developing RAP networks thus have no vehicle for basin-wide coordination. From a fisheries point of view, the development of fish community objectives for each of the lakes has focused primarily on goals for open water fish community structure and little on the requirements for near shore habitat conditions required to achieve these objectives. The evolving problem for integration of management is thus threefold. First RAPs are limited to specific sites and propose remediation of tributaries and near shore habitat. FMPs are concerned primarily with open water fish communities, and the LaMPs are focused only on toxic contaminants.

Continuation of this independence is no longer productive. Many of the RAPs have explicit fish community objectives, but they are often not coordinated with lake-wide fish management objectives. Similarly, the developing fish community objectives do not incorporate habitat remediation that will be obtained with implementation of the RAPs. Although the Habitat Advisory Board of the Great Lakes Fishery Commission is beginning a process to define environmental objectives necessary to achieve fish community objectives in each of the Great Lakes, the environmental objectives that will emerge have only piecemeal receptors in water quality management initiatives. More holistic ecosystem objectives, which are being developed by federal water quality agencies also encounter institutional voids. Ecosystem objectives emerging from the

Bi-national Objectives Development Committee, for example, have been derived for Lake Ontario and have been tentatively adopted by the Lake Michigan LaMP. Yet these objectives have not been thoroughly vetted for consistency with Fish Community Objectives, which are under consideration by fishery managers for each of the Great Lakes. If this independence of initiatives continues, important opportunities for cooperation will be missed, and conflicting goals may become established in policies of federal, state, and provincial agencies.

Solution of this problem will require the Parties to set up more explicit institutional arrangements to facilitate integrated management of Great Lake ecosystems. New institutional arrangements should include steps to:

- Create a mechanism to promote consistent planning coordination on an inter-lake basis;
- Establish lake specific mechanisms to assure integration of planning and to arrange for institutional responsibilities to implement lake-wide plans;
- Develop common ecosystem objectives with quantitative end points and obtain agreement on key indicators with which to measure state of the ecosystem; and
- Coordinate monitoring and commitment to management responses based on indicator levels through regular, comprehensive, and integrated state of the lake reports.

These recommendations could be adopted within the framework of the Great Lakes Water Quality Agreement by expanding the scope of LaMPs. This expansion of the scope of LaMPs is certainly consistent with the intent for the creation of LaMPs in the 1987 Protocol and would thus facilitate management based on a common strategic plan for the integrated management of Great Lake ecosystems.

Linkage of Objectives, End Points, and Indicators

Objectives are implicit in the purpose or goals of the major agreements for management of the Great Lakes. The purpose of the 1978 Great Lakes Water Quality Agreement (GLWQA) is "...to restore and maintain the chemical, physical, and biological integrity of the waters of the

Great Lakes Basin Ecosystem. In the 1987 Protocol, completion of the third stage of RAP review an comment occurs "when monitoring indicates that identified beneficial uses have been restored." Similarly, the fourth stage of LaMPs will be completed "When monitoring indicates that the contribution of the Critical Pollutants to impairment of identified beneficial uses have been eliminated." In fish management, the goal of SGLFMP (GLFC 1980) is

> *"To secure fish communities, based on foundations of stable self-sustaining stocks, supplemented by judicious plantings of hatchery-reared fish, and provide from these communities an optimum contribution of fish, fishing opportunities and associated benefits to meet needs identified by society for: wholesome food, recreation, employment and income, and a healthy human environment."*

In both the GLWQA and SGLFMP, the agreements set forth a requirement to develop objectives, which provide an operational basis for defining conditions for judging attainment of the agreement. The 1987 Protocol requires the Parties to develop Ecosystem Objectives, and SLGFMP requires fish managers to develop Fish Community Objectives and companion Environmental Objectives. Development of such objectives, however, has proven to be extremely difficult. Development of Ecosystem Objectives requires an interpretation of purpose (e.g. chemical, physical, and biological integrity), identification of indicators with which to monitor progress toward the objective, and specification of end points for these indicators that represent quantitative interpretations of attainment of the objective.

Two work products of the EPC task directly addressed this issue. For the State of the Lakes Ecosystem Conference, Dr. Koonce has prepared a report, *The State of Aquatic Community Health of the Great Lakes*, which is included in Appendix 3. Secondly, Dr. Koonce presented a paper, which is included as Appendix 4, at EPA's Midwest Environmental Indicators and Biocriteria Conference in May 1993: *Problems in the Specification of End Points and Indicators* *for the Pelagic Zone of Lake Ontario*. These papers present an argument that part of the difficulty in deriving Ecosystem Objectives and linking them to indicators and end points is the lack of more explicit context for use of the linkage.

These papers point to a generic problem in all efforts to develop objectives and define indicators and end points with which to monitor the state of the ecosystem. In attempting to assess the state of aquatic community health of the Great Lakes, Koonce (Appendix 3) found that specification of benchmarks (end points) for ecosystem integrity of the Great Lakes was only partially a scientific or technical task. The reasons for this difficulty in establishing criteria for ecosystem integrity relate to five fundamental issues:

- Great Lakes ecosystems are unique. Their size and unique geological history makes selection of "undisturbed" controls for benchmarks nearly impossible.
- Historical ecosystem functions are incompletely known. Thus making derivation of historical benchmarks uncertain.
- Ecosystem function depends upon biological diversity, and biological diversity of the Great Lakes has changed with introduction of non-indigenous species and rarefication of native species and stocks.
- No unique relations between ecosystem function and community structure exist. Different community structures may have quite similar ecosystem function, and management decisions are more often based on community structure that on ecosystem function.
- No use context is specified in notions for restoration of ecological integrity. Sustainable use implies acceptable levels of degradation of ecosystem function and community structure.

Given these problems with establishing criteria for desired state of ecosystems of the Great Lakes, Koonce concluded:

"At best, scientific analysis will allow specification of alternative configurations of the structure of aquatic communities in the Great Lakes that are consistent with fundamental ecological principles. The ultimate selection of a restored state is thus a matter of social preference. Because social preference for state of the Great Lakes ecosystems embodies an implicit set of uses, the specification of quantitative end points for the indicators is embroiled in the determination of acceptable ways of using the resources of the Great Lakes. Ecosystem objectives do not address the issue of how to balance the various uses of these resources, and managers may find future progress toward attaining the goals of the GLWQA impeded by the lack of consensus on the desired state of aquatic ecosystems (Appendix 3, p. 23)."

By analyzing the attempts to develop indicators for the Ecosystem Objectives for Lake Ontario, Koonce (Appendix 4) further argued that lack of a unifying context for use of information also complicates the linkage among objectives, indicators, and end points. Broad statements of Ecosystem Objectives do not provide much guidance for management of Great Lakes resources. Operationally, acceptable end points from a management perspective depend upon the goals of the managers, and conflicts over these end points are often conflicts over use of resources. To escape this problem, Koonce argues that the context for formulation of objectives, end points, and indicators must be more strategic.

"Formulation of strategic ecosystem objectives, therefore, must involve an iterative, process that serves to clarify the "vision" of a restored ecosystem as well as developing an understanding of the trade-offs required to achieve it. Science has an important role

to play in helping identify the potential consequences of future management choices, to offer criticism concerning the validity of endpoints, and to help design programs to monitor state of the ecosystem. Social preference, ultimately, determines policy directions. Social preference, however, can be only as rational as the planning process that generates choices. In the context of ecosystem management of the Great Lakes, such a rational approach will require a new way of formulating ecosystem objectives. Investing in a strategic planning approach appears to be one way to try. Guidelines for strategic ecosystem objectives are thus: 1) view the development of ecosystem objectives as a progressive, "vision" clarification process; 2) develop endpoints from the objectives; and 3) include explicit milestones to gauge progress. Because of the range of conflicting interests in the Great Lakes region, such a strategic planning process will require a neutral forum within which common ground can be established. The framers of the Joint Plan for the Strategic Management of Great Lakes Fisheries used the Great Lakes Fishery Commission for this purpose. The challenge will be to find a comparable arena for ecosystem management in context of the Great Lakes Water Quality Agreement (Appendix 4, p. 12)".

Unresolved Issues

The purpose of creating the EPC position was to assist development of cooperation between water quality and fish managers. This axis of interests, however, may be too narrow. These management activities themselves are imbedded in more general concerns with human development and use of water in the Great Lakes basin. Joining ecological restoration and human development, however, requires grappling with interactions at spatial and temporal scales that are beyond human experience.

The integrity of Great Lakes ecosystems is no longer an exclusive function of human activities in the basin. Atmospheric deposition is a major source of toxic contaminants entering the lakes, often with origins far outside the basin. On a global scale, atmospheric accumulation of CO_2 and other "greenhouse" gases threatens to alter climate, which could have substantial effects on the health of Great Lakes ecosystems. Within the basin, consumptive use of water, demands for recreational opportunities, demands for fishing, and demands for coastal development are tied to the global economy through local effects on social and economic factors. Government institutions charged with management of Great Lakes resources also face challenges that often originate outside their mandates for management action. No agency of government is responsible for restoring and maintaining the health of the Great Lakes, rather responsibility is distributed among a plethora of agencies and jurisdictions. In considering the impacts of global climate change on the health of the Great Lakes, therefore, evaluation of the status of research and impact assessment and of the needs for new initiatives must start with recognizing that we begin on uncharted ground. More than new research initiatives will be required to proceed. We may also need better ways of linking research, management, and formulation of public policy to adapt to impending changes on a global scale.

Despite the difficulties in developing common objectives for the restoration of health of the Great Lakes, management agencies share concern about some habitat issues. These issues are also important linkages to understanding the possible effects of global climate change on ecosystem health. The issues concern suitability of four habitat types:

- Tributaries,
- Near-shore (wetlands and littoral zone),
- Offshore hypolimnetic zone, and
- St. Lawrence and Gulf of St. Lawrence system.

Much of the deterioration of the health of the Great Lakes has been caused by destruction of the physical and chemical integrity of these zones. The Areas of Concern referenced in the 1987 Protocol, for example, are largely degraded tributary and embayment systems.

A major component of the loss of biodiversity in the Great Lakes is associated with the extinction of adfluvial species, i.e. species that require river environments for spawning and nursery areas. Dam construction, channelization, sedimentation, alteration of hydraulic and temperature regimes, and contamination with toxic substances have eliminated important habitat for historically important species such as lake sturgeon, brook trout, Atlantic salmon, walleye, and sauger. Restoration of tributary habitat, including possible dam removal and installation of fish-passage devices are under active consideration throughout the Great Lakes basin. Suitability of tributary habitat, however, is very sensitive to hydraulic and temperature regimes. Climate change is likely to have significant impact on precisely these attributes.

The near-shore environment of the lower Great Lakes has also been extensively modified by coastal development. Near-shore wetlands and macrophyte beds in embayments are also important habitat for fish and wildlife. The most serious impacts have followed wetland destruction through drainage and diking. Efforts to preserve remaining wetlands are underway, but the patchwork pattern of preserved areas may not be sufficient for wetland adaptation to changing regimes of water levels and fluctuations in water level. Similarly, hardening of the near-shore environment with jetties, armor stone, and bulkheads decreases its capacity to serve as spawning and nursery areas for some species. This coastal development also limits capacity of natural shorelines to adapt to changing flow and water level regimes in a way that minimizes adverse effects on fish and wildlife populations.

On the whole, offshore areas are likely to be less sensitive to climate change. The exception will be the Central Basin of Lake Erie. El-Shaarawi (1987) has shown that water level, water temperature, and phosphorus loading are the controlling factors for oxygen depletion in the Central Basin of Lake Erie. Before their extirpation, blue pike occupied the cool waters of the Central Basin. Their production was a mainstay of the commercial fishery for many years prior to 1955. This habitat is now being re-colonized by walleye, and it is possible that a deep water percid could become reestablished. The risk of hypolimnetic anoxia, however, is sensitive to climate factors (water level and rate of warming in the spring). Phosphorus loading targets accepted under the GLWQA agreement may not be appropriate for all climate change scenarios.

Of all the stresses that have led to impairments of Great Lakes health, invasion of exotic species have led to the most damage. Of the 139 non-indigenous species documented by Mills *et al.* (1993), nearly a third entered via the St. Lawrence River. Most of these were associated with shipping (e.g. ruffe and zebra mussels), but many of the non-indigenous fish species such as alewife, white perch, and possible sea lamprey invaded the Great Lakes from the Atlantic drainage of the St. Lawrence. The location of the Gulf of St. Lawrence is northern enough to isolate the Great Lakes from other anadromous species such as striped bass. Global climate change could, however, affect ocean circulation patterns and lead to more invading species. The population explosions of alewife and white perch have been associated with depressed predator populations. Although a "healthy" Great Lakes ecosystem is no guarantee of resistance to invasion, the effects of new invasions is likely to be less severe.

These potential linkages between climate change and ecosystem health suggest five critical issues for further examination:

- Invasions of exotic organisms through the St. Lawrence;
- Alteration of hydraulic regimes of tributaries;
- Alteration of thermal regimes of tributaries;
- Alteration of flows, water levels, and water level fluctuations; and
- Adaptive potential of near-shore environments.

The last four issues have analogies in restoration of terrestrial ecosystems such as the Oak Savannah. Ideas emerging from landscape ecology are emphasizing the importance of understanding not only amount of land in conservation and restoration areas, but also the spatial pattern of the areas.

The previous five issues are important to understanding the potential effects of climate change on ecosystem health, or more properly, on plans to restore ecosystem health. In addressing these uncertainties, a number of other issues are likely to emerge. Table 1 lists some candidates for further consideration.

Table 1. Uncertainties, management needs, and research needs that are likely to emerge from a more explicit consideration of the effects of climate change on the health of Great Lakes ecosystems.

Key Uncertainties
• How much restored tributary habitat is enough? • What are the effects of community structure on success of invading species? • What is the role of water level fluctuations in the maintenance of wetland and near-shore macrophyte assemblages? • Are there effects of wetland and submerged aquatic vegetation patch size and connectedness that determine the resilience of near-shore environments to variation in water level and fluctuations in water level?
Management Needs
• Need for cooperative management (water quality, quantity, and biological management authorities are currently vested in separate agencies) • Need common visions for future state of Great Lakes--a public consensus forged with explicit consideration of trade-offs • Need for explicit consideration of uncertainty of global change • Need for a method to evaluate worth of information in the development of policy.
Research Needs
• Effective presentation of climate change information to managers • Evaluation of flexibility of management policies and worth of information • Evaluation of public participation and education initiatives to assist the development of common vision for the long-term health of the Great Lakes

Recommendations

Fisheries-related issues faced by the Great Lakes and their managers are of such complexity that they can only be effectively addressed within institutional arrangements that are binational and science-based. For fisheries managers to engage environmental managers more effectively on issues of common concern, it will be necessary to evaluate available mechanisms such as LaMPs and RAPs, as well as SGLFMP, in order to ensure that institutional arrangements are up to the 1990s challenge of ecosystem management. Based on the experience with SGLFMP (Dochoda and Koonce, 1994) and experience of the EPC project, critical elements of a new approach must include:

- Explicit statement of vision--What do we want the ecosystems of the Great Lakes to be? Answering this question will require a public participation process more like that employed in Remedial Action Plans than traditional public consultation process such as currently used in the Lake Michigan LaMP.
- Coordination of management authority including reporting requirements and responsibility for specific management actions; and
- Development of a strategic planning framework to pursue and clarify the vision.

Further, the strategic planning framework should have the following properties:

1. Binational scope,
2. Separate vision from management, do not require managers to set policy,
3. Focus on long term objectives,
4. Focus on use,
5. Link science to management,
6. Provide regular opportunities for reporting,
7. Provide a mechanism for handling disputes,
8. Provide incentives, and
9. Ensure commitment

Recommendation 1: **Parties to the Great Lakes Water Quality Agreement and Fish Management Agencies (Provincial, State, and Tribes) should initiate discussion for the establishment of a formal arrangement for ecosystem management of the Great Lakes. This agreement should be strategic and evolutionary in that it must provide for clarification of the vision for the future of the Great Lakes region and Great Lakes ecosystems.**

Establishing a new framework for ecosystem management should be an ultimate goal of water quality and fish managers, but intermediate steps should be taken that anticipate more formal agreements and prepare for their successful formulation and implementation. Water quality and fish managers, therefore, should find opportunities to build partnerships through cooperative activities. At the present time, water quality management is so focused on regulation of pollution stresses that holistic evaluation of the relative risks of various stresses to overall integrity of ecosystems of the Great Lakes is quite difficult to consider. Contaminants are not the only important problems or even the most important stress in the Great Lakes. Three steps would help water quality managers and fish managers focus more clearly on issues of common concern: 1) Organize water quality management on a lake-by-lake basis similar to the Lake Committee structure adopted under SGLFMP, 2) Identify clearly the role LaMPs for Critical Pollutants will fill as more systematic and comprehensive ecosystem management plans emerge, and 3) Launch a program to establish priorities for addressing pollution, habitat, and biological stresses on ecosystems of the Great Lakes. Three recommendations that would assist development of partnerships through cooperative activity are, therefore:

Recommendation 2: **The Parties should create a system of Lake Committees parallel to the lake committee structure of the Great Lakes Fishery Commission under the terms of the Joint Strategic Plan for Management of Great Lakes Fisheries. These water quality management**

committees should hold annual meetings in conjunction with the fish management committees and convene joint technical meetings to coordinate management activities.

<u>Recommendation 3:</u> The Parties should establish a consistent structure for Lakewide Management Plans. LaMP management committees should be formed for each lake and include fish management and water quality management agencies. The goal of these committees should be to insure that parallel, but coordinated planning may occur for Critical Pollutants, Habitat Restoration and Protection, Regulation of Exotic Species, and Fish Management.

<u>Recommendation 4:</u> The Parties in conjunction with Provincial and State Governments, Tribes, and Non-Governmental Organizations should begin a Priorities Project for analysis of physical, chemical, and biological stresses on Great Lakes Ecosystems. The goal of this project would be to rank the impairments to beneficial uses of the Great Lakes according to the degree of risk to the restoration and maintenance of the integrity of Great Lakes Ecosystems.

Experience with the EPC project has confirmed the value of the Habitat Advisory Board of the Great Lakes Fishery Commission as a common meeting ground for joining water quality and fish management issues. The Environmental Objectives Workshop (Appendix 2) showed substantial opportunity for refining Environmental Objectives in joint work by water quality and fish managers. With substantial concerns about compromises of management mandates and personnel resources, fish managers will continue to rely on the Habitat Advisory Board for transitional leadership in linking water quality and fish management issues. The broad representation of management agencies on the Habitat Advisory Board makes it ideally suited to press ahead on derivation of operational environmental objectives. Results of the Environmental Objectives Workshop indicate that fish managers will require further assistance on at least three matters: 1) Form of Fish Community Objectives, 2) Technical assistance in characterizing habitat use and restoration potential by various fish species, and 3) continued championing of new institutional arrangements that recognizes the mandate of fish managers for the fishery resources of the Great Lakes as well as their obligations to stewardship of the entire ecosystem of the Great Lakes Basin.

<u>Recommendation 5:</u> The Habitat Advisory Board should continue the efforts begun with the Environmental Objectives Workshop in November, 1993. Follow-up assistance to Lake Committees should focus both on technical assistance and promotion of discussion of alternative institutional arrangements for ecosystem management. Technical assistance should assist with at least two specific issues:

- **Provide guidance about the characteristics of Fish Community Objectives that promote linkages to environmental objectives; and**
- **Provide technical assistance in the identification of habitat requirements of fish species and inventory of status of that habitat.**

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Appendix 1. Activity Summary of Ecosystem Partnership Coordinator

Summary of primary meetings attended by Dr. Joseph F. Koonce from July 1, 1992 to December 31, 1993.

Date	Activity	Comments
June 23-24	HAB Meeting	Introduced the idea of partnership coordination and began planning for habitat workshop
July 29	Habitat Coordination Meeting	Attended as GLFC representative for partnership activities in habitat remediation. Also, met with Lou Blume to discuss ways of assisting EPA reporting of status and trends of health of the Great Lakes
Sept. 8	Steering Committee Meeting	Met with partnership steering committee to review terms of reference and to endorse work plan for the next year.
Sept. 9-10	SOLEC Steering Committee Meeting	Joined steering committee as representative of GLFC and began to assist in the linkage of fishery and water quality issues in the State of the Lakes Conference.
Sept. 12	LOPCHIC Meeting	Continued previous activity on developing ecosystem health indicators for the pelagic community of Lake Ontario, but began linking the indicators discussion to SOLEC and to future LaMP activity.
Nov. 9-10	HAB Meeting	Facilitated a session between HAB members and fishery managers to explore ways that HAB could assist lake committees in the incorporation of broad ecological objectives into fish community management plans.
Nov. 12-13	SOLEC Steering Committee Meeting	Attended the second steering committee meeting. Was assigned the responsibility of coordinating a "cluster" paper on ecosystem health and reported on a draft outline of the paper and potential contributors. This work assisted linkage of fishery and water quality issues as the relate to broader understanding of indicators and end points for ecosystem management of the Great Lakes.
Jan 22, 1993	SOLEC Steering Committee Meeting	Continued SOLEC responsibilities
Jan 26	HAB subcommittee Mtg	Drafted proposal for EOW
Feb. 3-5	HAB meeting	Participated in workshop and planning for coordination of RAPs, LaMPs, and FCOs
Feb. 9-12	Attend Climate Change Workshop	Explored linkages among water quality, water quantity, and fish management concerns
Mar 2-4	Attend EPA's Symposium on	Participated in symposium and reviewed the idea for EOW with EPA

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	Ecological Restoration	
Mar 8-11	Attend RAP workshop and plan for EOW	Participated in Hartig's RAP workshop and work on EOW proposal
Mar 22-25	Attend Lower Lakes Meetings	Presented EOW proposal to Lake Erie and Lake Ontario Committees
Mar 29-31	Attend Upper Lakes Meetings	Presented EOW proposal to Lake Committees: Superior, Huron, Michigan
April 13	Attend CLC Meeting	Presented EOW proposal for approval by CLC
Apr. 28-29	Attend EOWG Meeting	Discussed coordination of EOW and Ecosystem Objectives Development
May 5	Attend EPA Biocriteria Conference	Gave presentation on End Points and Indicators Problem
May 24-27	Attend Annual GLFC Meeting	Gave presentation on Partnership Activity
June 4-11	Attend IAGLR and SOLEC Meetings	Participated in partnership networking and SOLEC reporting
July 21	Attend SOLEC Meeting	Attended Steering Committee Meeting
Sept. 7-8	Attend SOLEC Meeting	Attended Steering Committee Meeting
Sept. 16-17	Attend Env. Canada LaMP Meeting	Discussed coordination of LaMPs and FCOs
Sept. 30-Oct 1	Attend Conf on GLWQI	Gave presentation on Fish Perspectives on GLWQI
Sept. 22-24	Attend IJC Meeting and RAP forum	Networking for partnerships
Nov. 3-5	Attend HAB Env Obj Workshop	Facilitated Workshop
Dec. 1	Attend GLFC Interim Meeting	Reported on Partnership Activity
Dec. 6-8	Attend Climate Change Workshop	Gave presentation on Habitat and Climate Change Implications
Dec. 8-9	Attend SOLEC Meeting	Participated in SOLEC Steering Committee Meeting

Appendix 2. Environmental Objectives Workshop Report

Habitat Advisory Board
Great Lakes Fishery Commission

Workshop on Environmental Objectives

Clarion Inn
Romulus, Michigan
November 3 to 5, 1993

Summary of Proceedings

by
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February 28, 1994

Appendix 2. Report of Workshop on Environmental Objectives

Appendix 2. Report of Workshop on Environmental Objectives

Workshop Goals

The Habitat Advisory Board of the Great Lakes Fishery Commission has been charged with developing a strategy for incorporating environmental objectives into the Fish Community Objectives that have been or are being prepared for each of the Lake Committees. The goal of this workshop was to examine a framework for identifying environmental objectives that are necessary to achieve fish community objectives. Environmental objectives, in this context, are specific targets for physical and chemical attributes (e.g. nutrient loadings, contaminant loadings, habitat availability, and habitat quality). The responsibility for helping Lake Committees identify environmental objectives[4] comes from the Joint Strategic Plan for the Management of Great Lakes Fisheries (SGLFMP). The 1980 agreement indicates:

> *Fishery agencies shall endeavor to obtain full consideration by the Great Lakes environmental agencies of the potential impacts of their activities and decisions on fishery needs and objectives. The Great Lakes Fishery Commission will ... charge the (Habitat Advisory Board) to assist each lake committee to develop environmental objectives essential to achieving its fishery objectives. Unresolved environmental issues may be referred by lake committees to the Great Lakes Fishery Commission which shall represent fishery interests in these issues to the most appropriate body* (e.g. IJC, U.S. EPA, Environment Canada, State Department, External Affairs).

From a water quality perspective, the workshop also drew support from the Great Lakes Water Quality Agreement, 1987 Protocol, Supplement to Annex 1, #3:

> "...Consistent with the purpose of this Agreement to maintain the chemical, physical and biological integrity of the waters of the Great lakes Basin Ecosystem, the Parties, in consultation with State and Provincial Governments, agree to develop the following ecosystem objectives for the boundary waters of the Great Lakes System, or portions thereof, and for Lake Michigan: (a) Lake Superior The Lake should be maintained as a balanced and stable oligotrophic ecosystem with lake trout as the top aquatic predator of a cold-water community and the *Pontoporeia hoya* as a key organism in the food chain; and (b) Other Great Lakes Ecosystem Objectives shall be developed as the state of knowledge permits for the rest of the boundary of the Great Lakes System, or portions thereof, and for Lake Michigan."

Workshop Organization

The workshop involved about 40 participants (Appendix 1) for two and a half days. Delivery of four specific objectives motivated workshop organization. These objectives were

[4] Environmental objectives are not ecosystem objectives. Ecosystem objectives should, however, be compatible with fish community and related environmental objectives. Environmental objectives should likewise be articulated in language actionable by environmental agencies. End points are the quantifiable condition that signals success. Indicators are factors that should be monitored in determining the effectiveness of a particular measure or suite of measures.

(1) To recommend environmental objectives for Lakes Superior and Erie, where possible, including end points and indicators;
(2) To identify of information gaps restricting specification of environmental objectives, end points, and indicators for (areas of) Lakes Superior and Erie;
(3) To recommend action plans for finalizing Environmental Objectives for Fish Community Objectives in Lakes Superior and Erie; and
(4) To recommend a process for derivation of Environmental Objectives for Lakes Huron, Michigan, and Ontario.

Through a series of plenary and break-out sessions, participants first attempted to derive implied environmental objectives from the fish community objectives, which were available for Lake Erie in draft form and for Lake Superior in approved form[5]. Attention next shifted to analysis of the water quality objectives that emerge from the Great Lakes Water Quality Agreement. Annex 2 of the Agreement lists fourteen use impairments of the physical, chemical, or biological integrity of the Great Lakes. By reviewing water quality stresses that lead to these impairments, participants came to an understanding of the water quality objectives of regulatory agencies charged with enforcing pollution abatement in the Great Lakes basin. Following this review, participants attempted to synthesize draft environmental objectives for Lake Erie and Lake Superior by joining water quality and implied environmental objectives. Finally, participants reviewed information gaps or other impediments to finalizing these environmental objectives, and they concluded by developing a set of recommendations to the Habitat Advisory Board for next steps in this process.

Implied Environmental Objectives

Lake Superior

The fish community objectives for Lake Superior addressed four components of the fish community structure: forage, predators, other species (including minor, but non-depleted stocks of selected species, and depleted stocks of several native species), and sea lamprey. The Lake Superior Fish Community Objectives also include three broad environmental objectives: no net loss of habitat, restore damaged habitat, and reduce contaminant levels in fish below consumption advisory levels.

Discussions produced a consensus that the Fish Community Objectives could lead to a series of general environmental objectives, but also exposed some conflicting goals of restoration between water quality and fish management agencies. Candidate environmental objectives included:

- spawning habitat,
- nursery habitat for juvenile fish,
- contaminant levels, zero is the end point, but pursuit would involve a wide range of indicators of contaminant levels and their effects, and
- other physical and chemical attributes related to these objectives (such as oxygen concentration, temperature, and flow regime in critical habitat).

Participants agreed that these environmental objectives could become more explicit by unifying spawning and nursery habitat through analysis of life-cycle requirements of the fish species identified in the Fish Community Objectives. One suggestion was to focus habitat restoration on

[5] Busiahn, Thomas R [ed.]. 1990. Fish Community Objectives for Lake Superior. Great Lakes Fish. Comm., Spec. Publ. 90-1, 23 p.

the requirements of featured species such as sturgeon or coaster brook-trout, which would lead to satisfaction of habitat requirements of most other impaired species. Environmental objectives so specified would provide a basis for more explicit classification of habitat on the basis of function in an ecosystem context. Spawning and nursery habitat requirements vary among offshore, nearshore, and tributary spawning species. Due to the linkage of spawning and nursery habitat in a life-cycle approach, the specification of indicators and end points for environmental objectives must deal with these habitat complexes as intact, functioning systems.

Discussions of indicators and end points for environmental objectives raised a series of potential conflicts. Within the Fish Community Objectives, the main conflict concerns the trade-offs between the sea lamprey objective and the objective for restoration of degraded populations of tributary spawning species. Improving habitat for native species will also benefit sea lamprey. The need for increased levels of sea lamprey control in response runs contrary to the ecosystem goals of the Binational Lake Superior Program. The Fish Community Objectives are not explicit enough to rationalize this trade-off in purely technical terms. The acknowledgment of joint role of values and technical information in definition of end points for the indicators of environmental objectives revealed even more potential conflicts between water quality and fish community approaches to setting environmental objectives. An example of these conflicts is the fundamental issue of the productive capacity of Lake Superior and the effects of habitat restoration on the fish community. Will restoration of tributary-spawning species erode the production of the whitefish fishery? If so, fishery managers may want to limit the extent of tributary restoration, but such a policy might not be acceptable from an ecosystem perspective, which seeks to restore depleted stocks to their historic levels.

Given this set of possible objectives with the attendant difficulties in specifying end points, participants agreed that some process considerations are in order. The interaction of limited technical information and conflicting values implies that the process must be iterative and self-correcting. End point specification is necessary to expose conflicts, but the actual specifications should be viewed as interim.

Lake Erie

Visualizing the future of Lake Erie is difficult. The Lake Erie ecosystem is changing rapidly due to a combination of factors. Invasion of exotic species, steadily declining nutrient loading with improved regulation of pollution sources, and success of fisheries have led to difficulties in developing Fish Community Objectives. The draft nature of the Fish Community Objectives, which were available to participants, thus raised substantial impediments to derivation of implied environmental objectives. Discussions revolved around four major issues:

- Contaminants. Toxic substances affect fish health in the Areas of Concern in Lake Erie. The lake-wide effects of contaminants is more difficult to predict with the alteration of food webs now occurring with the invasion of zebra mussels. The objective is to eliminate contamination due to toxic substances.
- Trophic condition. The Great Lakes Water Quality Agreement has set targets for phosphorus loading. With the invasion of zebra mussels, however, water quality improvements have the potential to lower the productive capacity of the fisheries of Lake Erie. Phosphorus loading target is thus an area of conflict between fish managers and water quality managers.
- Habitat. Lake Erie has lost large areas of wetland, shoreline, and tributary habitat. Life cycle use of habitat by fish is a way of linking "styles" of use with flow regime, spawning substrate use, and nursery area requirements. Specification of end points, however, is confounded by the uncertainties of limits

to the productive capacity of Lake Erie. The central question is whether the production of fish is limited by reproductive habitat or by nutrient loading.

- Structure of fish community. Major questions concerned role of naturalized-exotic species, diversity (both genetic and community), yield of offshore species, state of nearshore species complexes, and the fate of rare and endangered species. Difficulty in answering these questions frustrated resolution of environmental objectives. There is a fundamental question about whether long-term objectives for fish community structure are worth doing in the face of so much uncertainty.

Environmental objectives for Lake Erie will involve toxic contaminants, spawning and nursery habitat, and nutrient loading. A wide array of indicators is available for toxic substances, and the discussions focused on integrative-indicators based on life cycle requirements for reproductive habitat. Indicators for trophic condition and end point, however, were incompletely specified. The main impediments to further resolution of environmental objectives were the fundamental uncertainties about the extent and scope of changes now occurring in Lake Erie, ambiguity of the Fish Community Objectives, and fundamental conflicts goals of fish and water quality managers.

Conclusions

Participants seemed to agree on the fundamental set of environmental objectives for the two lakes. Toxic contaminant, reproductive habitat, and nutrient loading were the main subjects of implied environmental objectives. The indicators of chemical integrity are less controversial than for physical and biological integrity. Physical habitat indicators must focus on reproductive use requirements including the spatial and temporal integration of spawning and nursery areas. Both groups have suggested a life cycle approach to accomplish this unification. Some form of integrated, habitat-suitability index appears to be a candidate, but it will need more careful analysis. Environmental objectives for biological integrity are much more problematical. In part, biological factors determine the habitat suitability for nursery areas in wetlands and nearshore environments. Manipulation of the fish community through exploitation and introductions (both planting of hatchery stocks or planned introductions) have the capacity to modify habitat. Specification of environmental objectives, therefore, requires iteration with Fish Community Objectives.

End point specification for environmental objectives involves trade-offs. Participants were less able to find ways of approaching this problem. The trade-offs have some technical basis (i.e. objective analysis of the consequences of various policy options), but they are largely determined by the resolution of conflicting values and uses of various stakeholders. The Fish Community objectives for both lakes are not specific enough to indicate that these value conflicts have been resolved. Without end points, environmental objectives will only indicate direction of remedial action relative to current condition.

Other key findings emerged concerning specification of indicators and end points of implied environmental objectives. Although indicators and end points for toxic chemical-contaminants are straight forward, causality linkages may require more thoughtful analysis to establish the basis of risk evaluation as action plans are developed. Environmental objectives for physical habitat should proceed from a systems perspective of functional habitat units. Indicators and end points must focus on early life history habitat requirements for spawning and nursery areas. Finally, the productive capacity from a tropho-dynamic perspective must be established for both lakes. Without understanding the relative contributions of reproductive habitat and nutrient loading to productive capacity of either lake, the Fish Community Objectives may perpetuate conflicting goals.

Water Quality Objectives

Lake Superior

Use impairments and associated stresses have been well documented for Lake Superior[6]. Table 1 lists the impairments and the main stresses responsible by chemical, physical, and biological categories. For physical and chemical stresses, derivation of environmental objectives was straight forward. Indicators of stresses from toxic chemicals include a broad array of biochemical measurements (e.g. mixed function oxidase levels, hepatic porphyrians, and retinol levels), physiological characteristics (e.g. tumor incidence, thyroid abnormalities, and congenital malformations), consumption advisories, and population effects (reproductive impairment, disease incidence, and parasite incidence). The end points for these indicators are all no effect. The goal of water quality management is thus elimination of discharge of toxic substances and remediation of areas of concern to uncontaminated levels. Nutrient loading is not a concern for Lake Superior on a lake-wide basis, but some areas of concern also exist here as well. In these cases, however, water quality standards continue to press for reduction in loadings to the maximum extent possible.

Table 1. Summary of stresses and use impairments for Lake Superior

Stress	Use Impairment
Physical Dams Wetland loss/alteration Dredging Siltation Alteration of flow regime Alteration of thermal regime Coastal development	• Fish and Wildlife Populations • Fish and Wildlife Reproduction • Benthos • Aquatic Vegetation
Chemical Toxic Substances	• Wildlife Health • Fish Health • Benthos Health • Human Health
Nutrients	• Fish and Wildlife Populations • Benthos Populations
Biological Exploitation Introduction of Exotic Species Disease Food Supply	• Fish and Wildlife Populations

Indicators of physical habitat quality are also clear, but end point specification is more problematical. Tributary systems, for example, have a variety of indicators for flow and

[6] Lake Superior Binational Program. 1993. State of the Lake Superior Basin Reporting Series. Vol. II: Draft Stage 1 Lakewide Management Plan.

temperature regimes. Classification and inventory methods are widely available for tributary substrates as well as near-shore habitat and wetland zones. The end point targets for these indicators depend upon historical analysis of the changes induced by human activities such as dam construction, wetland filling and draining, and shoreline hardening. Although "no net loss" of habitat is a guiding principle for future regulation of habitat alteration in the Great Lakes region, restoration of habitat does not have a workable end point in the sense of chemical contaminants. Because other factors act jointly with physical habitat degradation to impair fish and wildlife health, it is difficult to relate levels of habitat restoration to reversal of these use impairments.

The challenge of setting objectives for remediation of biological stresses is much more complex. Fish and wildlife impairments include a number of alterations of community and population structures. Establishment of non-native species and substantial loss of genetic diversity, however, precludes a simplistic use of historical conditions to establish end points. Pest control of unwanted exotics, such as ruffe, sea lamprey, and purple loosestrife raise a series of questions about use of toxic materials or further introduction of exotic species for control purposes. Exploitation of fish and wildlife is both a stress and a beneficial use, but the trade-off decisions in this balance may have profound consequences for the attainment of other restoration goals.

The implied environmental objectives and the water quality objectives overlap. For biological stresses and some physical habitat stresses, implied environmental objectives provide a way to establish end points for water quality objectives. Restoring the biological integrity from an impaired use perspective requires fixing things, but the amount of "fixing" is not necessarily tied to restoring a particular level of biological integrity. Fish community objectives help establish levels of expectation of the biota of Lake Superior and thus represent targets for remediation. The end points of implied environmental objectives are the linkages that provide a basis for specifying necessary and sufficient conditions for restoration efforts. Participants identified the following linking concepts:

- Life cycle approach to setting habitat objectives. Where reproduction and juvenile survival are limiting, life cycle approach provides an integrated basis for establishing restoration targets.
- Deriving end points for environmental objectives is not exclusively a technical exercise. Target setting requires trade-offs, and many of the trade-offs involve differing value perspectives.
- An iterative process is needed to get agreement on environmental objectives. Not all trade-offs are well understood. Initial environmental objectives should be interim. Revisions should follow from experience with remediation process and clarification of the factors causing impairments.

Lake Erie

Participants agreed that five groups of stresses have led to most use impairments of Lake Erie:

- Sedimentation (burial of substrate, increased turbidity, contaminated sediments, and resuspension of sediment),
- Stream modification (dams, channels, logging, and other land use changes),
- Wetland loss (diking, draining, reduction, and modification of connectivity and interchange)
- Toxic substance pollution (particularly of bioaccumulating micro-contaminants), and
- Invasion of exotic species (e.g. zebra mussels, white perch, etc.).

The magnitude of the impairments vary by the severity of the stress, its geographical scope (lake-wide or limited to specific areas of concern), and reversibility (in the sense of permanence of the change). Of the five major stresses, only sedimentation appeared to be reversible in the near-term. All were judged to have high severity and lake-wide effects as well as intense effects in areas of concern. Other stresses of concern were related to ongoing management actions. Overexploitation seems to be a problem for some Lake Erie fish stocks, and nutrient loading reductions raise concerns about the sustainable productive capacity of Lake Erie.

To varying degrees, all 14 use impairments listed in Annex 2 of the Great Lakes Water Quality Agreement afflict Lake Erie. What is not clear is how remediation of these impairments will benefit the fish community. The Lake Erie ecosystem is currently undergoing dramatic changes with the combined effects of invasion of exotic species (particularly the recent zebra mussel invasion), lowered nutrient loading rates, and growing expectations of major recreational and commercial fisheries. Although developing fish community objectives for such a dynamic system is equally problematical, the fish community objectives do provide a context for setting targets for environmental objectives that would be otherwise difficult to obtain.

Objectives for toxic substances were the most easily established. A reasonable objective appears to be reduction and eventual elimination of persistent bioaccumulative toxic substances. The end point is, of course, functional "zero," which would require additional research to identify. Indicators would include a broad range of measurements, including: loadings, concentrations in water, concentrations in sediment, concentrations if fish and wildlife, and various biological measurements (e.g. pathological abnormalities or reproductive impairments).

Participants found that other environmental objectives required interpretation through analysis of the life cycle requirements of various species. Examples include:

- Restore natural flow regimes by reducing hydraulic extremes to improve walleye spawning and nursery activities as measured by improved hatching growth and survival rates;
- Allow walleye access to historic tributary spawning sites resulting in higher productivity and more stable recruitment from river stocks with increased genetic diversity and decreased fluctuation of year class strengths.
- Increase in total area and shoreline length of fish accessible coastal and tributary wetlands. End point is restoration to 50% of historical level, distributed throughout the basin with a minimum patch size, which needs to be determined. Wetlands to be restored to provide spawning, nursery, feeding, and refuge habitat for species identified in the fish community objectives, as well as rare, threatened and endangered species. Indicators would include: improved larval walleye and perch survival and growth, evenness of year-class strength, and improvement in status of spotted gar.
- Sediment environmental objective. Settleable solids should not exceed X mg/l over the spawning beds during spawning and incubation periods (where X is a value to be determined with further research). Turbidity shall not exceed Y units during critical periods of exogenous feeding (where Y will be determined in future analysis). Known existing turbidity ranges for adults shall not be exceeded. Indicators of condition would include hatching success, growth and survival of fry, and biomass and distribution of adults.
- Exotics. Environmental objectives identified by participants were: Prevention of introductions of new non-indigenous species, minimize impact of sea lamprey, and maintain fish community structure under threat of new introduced exotics.

Recommendations

These attempts to develop environmental objectives for Lake Superior and Lake Erie had some remarkable parallels. First, the efforts to develop fish community objectives, under the SGLFMP mandate, and to establish water quality objectives for the Great Lakes, in the mandate of the GLWQA, are complementary. The chief difference is a matter of approach. The fish community objectives arise from a concern with managing the open-water fish stocks (i.e. stocks of common concern), and the water quality management regulations deal with human activity along tributaries and near-shore areas. Only by unifying these approaches will either achieve ultimate success. Fish community objectives can provide targets for environmental objectives; providing that they are sufficiently precise. If they are, implied environmental objectives can be established and used to establish minimal levels of habitat restoration required to attain the fish community objectives. Without, an explicit identification of stresses contributing to impairments of fish and wildlife health, however, fish community objectives will never be attained.

These discussions also point to substantial institutional impediments that will block cooperation among water quality managers and fish managers. These two approaches often originate with quite different value perceptions. Because of their mandate and demands of their resource users, fish managers have a commitment to provide sustainable fisheries in the Great Lakes. Their objective is to provide as much harvest for recreational and commercial fisheries as is possible under prudent management. Water quality management, in contrast, orients to a goal of restoring the physical, chemical, and biological integrity of the Great Lakes. In this context, fishing could be considered just another stress and not a beneficial use to be maintained. No where is this conflict clearer than in the disagreement about the wisdom of further reductions in phosphorus loading to Lake Erie. Fish managers are worried that further reductions will lower productive capacity of the fisheries unnecessarily, and water quality managers a committed to attain a level of phosphorus loading to minimize the risks of anoxia in the Central Basin hypolimnion.

Because trade-offs are central to any target setting activity, water quality managers and fish managers may need an extension of the process tried in this workshop. For environmental objectives to emerge from such a process, three steps would seem to be necessary:

1) Commitment to joint management, which means an explicit recognition of management mandate and authority. No one agency is in charge.
2) Recognition that environmental objectives will be interim, that is they do not have to be final in their first draft. Rather, interim objectives should be viewed as devices to generate consideration of consequences of policy choices.
3) Design of joint management activity through agreement on iterative reconsideration and adjustment of targets through mutually agreed management actions and monitoring activities and reporting.

Analysis of Information Gaps and Impediments

Lake Superior

As participants reviewed the complex challenges to formulating environmental objectives for Lake Superior, they identified a number of deficiencies in knowledge, in availability of information, and in the usage of such information. Repeatedly, participants found specification of restoration goals or end points for environmental objectives impeded by various information gaps. Specific information needs included:

- Evaluation and inventory of the historical occurrences of now depleted stocks (e.g. sturgeon and coaster brook trout); and
- Knowledge of the regulation of the productive capacity of the lake, particularly with regard to the trade-offs in lake tropho-dynamics as habitat is restored to increase the abundance of depressed native populations;

Inadequacy of current assessment of habitat also emerged as an information gap. Participants found a lack of techniques for classification and inventory of habitat on a lake-wide basis. In seeking future technological innovations, participants expressed preference for techniques that are measurable with available resources, appropriate to habitat use by fish species, and responsive to the types of habitat stresses (shoreline hardening, wet land loss, siltation, etc.), which require management planning. Although they anticipate major contribution from Geographical Information Systems and remote-sensing imagery, participants concluded that techniques should be developed that will utilize the volunteer efforts of cottage owners and other interested parties.

As necessary as additional information is to establishing environmental objectives, participants raised substantial concerns regarding the current usage of available information. Given that SGLFMP was signed in 1980, the question arose, "Why has it taken so long to attempt to derive environmental objectives from fish community objectives?" Participants questioned whether an adequate institutional framework existed to develop a comprehensive, team approach to solving this problem. Recognizing that new ways of thinking about these subjects may be necessary, participants itemized several issues for better use of information:

- Need more organized approach to utilizing the information, including establishing a framework of information needs and an assessment of the status of the information;
- Recognizing importance of existing information and actively pursuing access to it (some what accomplished);
- Improve the perspective of how we think about habitat, moving from a "no net loss" to a "net gain" approach and improving a system of tracking losses to track gain;
- How to apply the information in the management world in a broad forum. Need a more comprehensive approach so that different agencies may start using that perspective in the day-to-day processes.

Lake Erie

The rapid changes in the Lake Erie ecosystem create substantial challenges to establishing fish community objectives as well as environmental objectives. Information gaps merge with uncertainties about trends and status of Lake Erie to impede progress in setting either set of objectives. Participants itemized five broad categories of issues that characterize these impediments: habitat issues, contaminant issues, diversity issues, issues concerning non-indigenous species, and finally issues of ecosystem management. Table 2 lists these issues.

Table 2. Issues impeding definition of environmental objectives and fish community objectives for Lake Erie.

Habitat	• Need to understand how a species' habitat or trophic level is limited or is likely to change, and how habitat availability affects fish community structure. • Need to quantify amount of wetland required to support a given population of walleye. • Need to relate habitat type to hatching success. • Need for better understanding of the relation of nutrient levels to fish production (i.e. What does removing phosphorus limitation on production mean for Fish Community Objectives and fish management?). • Need to know species by species whether they are limited by habitat or lake trophic condition?
Contaminant	• How do contaminants affect ecosystem structure and function? • How will contaminants recycle and concentrate in presence of zebra mussels?
Diversity	• Are there unique strains that would utilize headwaters if dams were removed--would diversity increase? -Were they ever used? -Would productivity increase? (e.g. Grand River, Ohio) -Would year classes be stabilized? • What are genetic and behavioral contributions to spawning site selection by Walleye? Are there unique river run stocks? • Do we know enough about genetic diversity of Erie stocks?
Exotic Species	• How will Erie fish community respond to zebra mussels and other exotics? (e.g. shift to benthic pathways?) • Are white perch suppressing yellow perch populations?
Ecosystem Management	• How do we integrate single species management into "fish community" concept? • Need to understand indicators of community/ecosystem health. • Need models to integrate information about species and habitat interactions for decision-making.

Recommendations for Finalizing Environmental Objectives

Lake Superior

From a Lake Committee perspective, the basic challenge is to complete the delivery of linked environmental objectives and fish community objectives as specified by SGLFMP. The Lake Superior Committee, however, confronts difficulties in balancing the delivery for existing management responsibilities and the acceptance of new initiatives involving coordination of water quality and fish management. Participants recognized the opportunity to engage institutional building through joining the efforts of the Lake Committee and the Binational Lake Superior Program, but agencies must commit staff time to completing environmental objectives.

Nevertheless, there was a consensus that scarce personnel resources should not be allowed to limit an opportunity to move forward.

Participants concluded that some type of joint exercise between the Binational Program and the Lake Superior Committee is needed. HAB could play a role in assisting the linkage of these two programs. The central issue in this linkage is the use of habitat modifications and water quality regulation to help with the delivery of fish community objectives. To pursue this issue will involve resolving the roles of habitat restoration, the role of a contaminant strategy, and the role of stocking and exploitation in the improvement of the Lake Superior ecosystem. Engaging in such a joint activity, however, requires the Lake Superior Committee and the Binational Program to surrender some autonomy. Without an explicit agreement for joint work, therefore, initial progress must come from encouraging informal linkages. Some possible steps include:

- Development of a pragmatic habitat atlas for Lake Superior,
- Support the upcoming HabCARES workshop,
- Encourage the start-up of committees to plan sturgeon and brook trout restoration,
- Identify research needs and emerging research opportunities, and
- Contribute to a research plan for the new research vessel funded by the National Biological Survey.

Lake Erie

Managers confront too many unresolved issues to address a process for finalizing environmental objectives for Lake Erie. The discussions at the workshop revealed substantial opportunities for progress, but the first step requires completion of a set of fish community objectives. Participants generally recognized that the Lake Erie Committee has a responsibility for producing environmental objectives necessary to achieve management goals for fish communities and fisheries, which depend upon them. Fish community objectives, however, must be consistent with broader ecosystem objectives. SGLFMP provided a vehicle for fish managers to enter the dialog about ecosystem objectives, and the opportunity now exists to incorporate the fishery issues into lake-wide management planning efforts. Some elements of a more integrated approach would include:

- Fish community objectives should recognize other parts of food web,
- Fish community objectives should be broader, i.e. restoring fish communities as near as possible to a historical condition (benefits will come),
- Recognize the utility of producing environmental objectives from user perspective, but remain sensitive to need for reconciliation of conflicting objectives of various user groups,
- Recognize the need for fish managers to articulate their expectations for environmental objectives and the need for dialog with water quality managers for review and evolution of acceptable fish community objectives and environmental objectives, and
- Use of nutrient/food chain bioenergetic models to communicate the basis for preference for environmental objectives and management actions.

Conclusions and Recommendations for HAB Assistance to Lake Committees

Lake Committee Concerns

Although the Lake Committees recognized opportunities for better delivery of environmental objectives, fish managers repeatedly expressed reservations regarding compromises of their mandate for fish management and of their personnel resources. Three outcomes of this workshop are possible. First, fish managers could elect to do nothing special at the present time. Under available resources, they could continue working to deliver fish community objectives and environmental objectives by the best means. Alternatively, they could seek to capture additional resources to expand the personnel base for more extensive collaboration and information gathering necessary to accelerate derivation of environmental objectives. Finally, there was some discussion of institutional adjustments (joint LaMP and Lake Committee meetings, formation of joint LaMP management committees, etc.) to use existing resources more effectively. A significant impediment is the continuing absence of a formal process for integrating environmental and fishery concerns. Environmental initiative must recognize the mandate and authority of fishery managers. If LaMP type processes are to serve as a unifying framework, then fishery managers must come to the table as more that just another group of stake holders. They must be part of the LaMP management team.

Requests of HAB

HAB has a continuing role in providing technical assistance to the Lake Committees for the development of environmental objectives. Participants generally agreed that the workshop had been useful, and recommended some next steps for HAB to consider. First, participants expressed a need for a report on the workshop that would allow for reflection on results and opportunities for future activity. HAB should consolidate this report and then review the range of future actions. From a Lake Committee perspective, this review and any recommendations for next steps should be on the agenda of the March Lake Committee meetings. The report should also be delivered to the Lake Superior Binational Program for their February meeting. Specific requests of HAB by participants included:

- Recommendations on a process for the development of plans to bring back depleted species;
- Recommendations on a process for the development of plans to restore tributary systems;
- Assistance in revising the three environmental objectives in the Lake Superior Committee's statement of Fish Community Objectives to make them operational.

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Appendix 2. Report of Workshop on Environmental Objectives

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Appendix 3. SOLEC Manuscript

THE STATE OF AQUATIC COMMUNITY HEALTH OF THE GREAT LAKES

STATE OF THE LAKES ECOSYSTEM CONFERENCE

by

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Appendix 3 SOLEC Manuscript

Introduction

This paper attempts to summarize current understanding of the health of the aquatic communities of the Great Lakes. The focus of this summary is the set of aquatic communities that interact with the lakes of the Great Lakes basin. By necessity, this range of communities includes terrestrial species (fish eating birds, mammals, and reptiles) that rely on food webs of the lakes or habitat of associated wetlands and other near-shore environments. The emphasis on health of these communities is a response to the adoption of an ecosystem approach to management of natural resources. More holistic than a pollutant-by-pollutant approach to improvement of water quality associated with earlier laws and agreements, the Great Lakes Water Quality Agreement of 1978 committed Canada and the U.S. to a long-term recovery goal of "...restoring and maintaining the chemical, physical, and biological integrity of the waters of the Great Lakes basin ecosystem." Relying on an analogy to human health, the restoration of ecosystem integrity has become synonymous with returning the ecosystems of the Great Lakes to a healthy state. Good health is a desirable system property, and wellness has become a symbolic goal of an integrated, ecologically grounded approach to restoration of the ecosystems of the Great Lakes. Recognizing the abuses of the past 200 years of human activity in the Great Lakes basin, the challenge is to balance ecosystem restoration and maintenance with human development. The necessity of this balance is the fundamental premise of "ecologically sustainable, economic development" advocated by the Brundtland Commission (World Commission on Economic Development, 1987).

Concepts of Ecosystem Health

In reality, the concept of ecosystem health is often more symbolic than functional. As with human health, maintenance and restoration of ecosystem health admits both curative and preventative approaches. The curative approach finds what is wrong and fixes it while the preventative approach takes a more holistic view and attempts to minimize the risk of illness. Considering human health, the dichotomy of the two approaches yields the current dilemma with technological approaches to medicine--elimination of illness does not necessarily produce wellness. For humans, wellness is a harmony of mind and body, and extensions of the health analogy to ecosystems falters because we lack a definition of wellness (cf. Minns, in press). In the context of ecosystem management, not only do we face the causality problem (i.e. finding what is wrong and fixing it), but we also lack clear guidance about the nature of a healthy ecosystem.

One approach to this resolving this uncertainty is to consider the adaptive potential of ecological communities. Holling (1992) argues that a small set of processes structure ecosystems. Within constraints of habitat characteristics and climate variability, ecological communities tend toward nominal cycles that are characteristic of various ecosystem types. The structure of climax communities of terrestrial ecosystems, as with their analogs in the aquatic communities of the Great Lakes (cf. Loftus and Regier 1972), exists in balance with patterns of disturbance. The result is a predictable set of patterns of ecosystem dynamics in which community composition changes through a series of recognizable transient states before returning to the nominal or climax state. Nominal states and succession transients are thus common elements to all "healthy" ecosystems, and a concept of community health must include reference to the persistence of the nominal state as mediated by functioning feedback mechanisms. The adaptive properties of ecological communities are manifestations of this ecosystem homeostasis. As Rapport (1990) states, ecosystem health depends upon the integrity of the homeostatic mechanisms, and "integrity refers to the capability of the system to remain intact, to self regulate in the face of internal or external stresses, and to evolve toward increasing complexity and integration."

Unfortunately, specification of the nominal state of an ecological community is somewhat arbitrary. Although Ryder and Kerr (1990) argue that natural ecological communities do tend to evolve toward co-adapted or "harmonic" assemblages, chronological colonization and invasion patterns are accidental, and multiple nominal states could evolve given slightly different composition of colonizing species. This issue becomes especially important when ecosystem restoration is the main challenge as in the Great Lakes. The original ecological communities no longer exist, and many exotic species have established viable and at times dominant populations. Justification of preference for specific nominal states may be aided by historical analysis (e.g. Ryder 1990), yet alternate states are certainly possible. At some level, the decision about which nominal state to pursue in restoration becomes a social preference. Scientific notions may contribute to the decision, but ultimately people must decide what their objectives are for ecosystem restoration and maintenance. Hence, what constitutes "ecosystem health" is, in part, a value judgment.

The notion of ecosystem health is also hierarchical. The integrity of an ecosystem is a complex function of the health of its constituent populations, the biological diversity of its ecological communities, and the balance between ecological energetics and nutrient cycling. At some levels in such a hierarchy, illness is much easier to detect. Evaluation of the health of fish and wildlife populations, for example, admits a direct extension of notions of human health in which incidence, morbidity, and mortality statistics are accepted measures of healthiness. The health of an individual organisms, in turn, is judged relative to nominal biochemical and physiological functions. Indications of impaired health derive from biochemical, cellular, physiological, or behavioral characteristics, which can be observed and, to some degree, be associated with known causes. Impaired health of an individual may subsequently manifest itself in its population through effects on reproduction or mortality, and the proportion of unhealthy individuals in a population influences the entire ecological community by altering the balance of competition and predator-prey relations that provide its dynamic structure.

Great Lakes Aquatic Ecosystem Objectives

The ecosystem approach, which was advocated with the 1978 Great Lakes Water Quality Agreement, requires ecosystem objectives. With the adoption of the 1987 Protocols, specific objectives were set forth in the Supplement to Annex 1:

> *"Lake Ecosystem Objectives. Consistent with the purpose of this Agreement to maintain the chemical, physical and biological integrity of the [waters] of the Great Lakes Basin Ecosystem, the Parties, in consultation with State and Provincial Governments, agree to develop the following ecosystem objectives for the boundary waters of the Great Lakes System, or portions thereof, and for Lake Michigan:"*
>
> *"(a) Lake Superior*
>
> > *The Lake should be maintained as a balanced and stable oligotrophic ecosystem with lake trout as the top aquatic predator of a cold-water community and the Pontoporeia hoyi as a key organism in the food chain; and"*
>
> *"(b) Other Great Lakes*

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Ecosystem Objectives shall be developed as the state of knowledge permits for the rest of the boundary waters of the Great Lakes System, or portions thereof, and for Lake Michigan."

The first effort of the Parties to draft ecosystem objectives for the other Great Lakes grew out of the activities of the Ecosystem Objectives Working Group (EOWG) for Lake Ontario (Bertram and Reynoldson 1992). Five ecosystem objectives have emerged from this effort:

"The waters of Lake Ontario shall support diverse healthy, reproducing and self-sustaining communities in dynamic equilibrium, with an emphasis on native species."

"The perpetuation of a healthy, diverse and self-sustaining wildlife community that utilizes the lake for habitat and/or food shall be ensured by attaining and sustaining the waters, coastal wetlands and upland habitats of the Lake Ontario basin in sufficient quality and quantity."

"The waters, plants and animals of Lake Ontario shall be free from contaminants and organisms resulting from human activities at levels that affect human health or aesthetic factors such as tainting, odor and turbidity."

"Lake Ontario offshore and nearshore zones and surrounding tributary, wetland and upland habitats shall be sufficient quality and quantity to support ecosystem objectives for health, productivity and distribution of plants and animals in and adjacent to Lake Ontario".

"Human activities and decisions shall embrace environmental ethics and a commitment to responsible stewardship."

These objectives have been incorporated into the draft Lakewide Management Plan for Lake Michigan. The Lake Superior Binational Program, which was created by the parties for a demonstration of the zero discharge objective for toxic contaminants, has also used the framework of these objectives to propose extensions of the ecosystem objectives adopted for Lake Superior in the 1987 Protocols.

Indicators

Fish and Wildlife Health Indicators

Indicators of fish and wildlife health have developed from concern with disease and abnormalities in physiology and behavior. Living organisms respond to environmental stresses through a variety of physiological and behavioral mechanisms. Beitinger and McCauley (1990) review the notion of a general adaptation syndrome at a physiological level that includes a primary response in the endocrine system and a secondary response involving blood and tissue alterations. Impaired health occurs when these adaptations are not sufficient to permit normal function. Assessments of fish and wildlife health in the Great Lakes have employed a range of specific indicators of these physiological responses to stress. A partial list would include:

Indicator	Associated Stress
Induction of Mixed Function Oxidase Enzymes (MFO)	Induction indicates exposure to toxic chemicals
Inhibition of Amino Levulinic Acid Dehydratase (ALA-D)	Inhibition indicates exposure to inorganic lead compounds
Hepatic Porphryia	Elevated levels of highly carboxylated porphyrins (HCPs) is indicative of induced toxicity by organochlorines (PCBs, HCB, and TCDD)
Hepatic Vitamin A (Retinol)	Reduction in levels indicates unsaticfactory nutritional status and/or effects of exposure to toxic chemicals
Thyroid Related Abnormalities	Changes indicate altered metabolic status and/or exposure to toxic chemicals
Tumor Incidence	Indicates toxic exposure to toxic chemicals, particularly PAHs
Fin Ray Asymmetry	Indicates poor environmental quality
Congenital Malformations	Increased incidence indicates excessive exposure to developmental toxins
Disease Incidence	Increased incidence bacterial Kidney Disease (BKD) and other bacterial and viral diseases in fish indicate nutritional or chemical stress
Parasite Incidence	Increased incidence indicates pollution or stress condition

These indicators represent a hierarchy of the response of fish and wildlife to various stresses in the environment, but their diagnostic specificity varies as effects move from biochemical to population levels. Some biochemical indicators, such as induction of MFOs, are non-specific and indicate only exposure to some types of organochlorines, which may come from pollution sources or from natural sources. These exposures may or may not result in illness. In general, translation of the exposure indicators to health assessment is also not always straight forward (cf. Munkittrick 1993). Nevertheless, these indicators together give general indications of the quality of the environment with respect to factors causing stress on biochemical and physiological processes.

Community Health Indicators

Like fish and wildlife health indicators, the purpose of developing community health indicators is to detect and diagnose pathology. Indicators of the health of an ecological community, however, are imbedded in a hierarchical set of ecological interactions and in a poorly coordinated hierarchy of ecosystem management jurisdictions and initiatives (cf. Evans, Warren, and Cairns, 1990). Without an integrating framework, indicators of community health tend focus on those parts of an ecosystem most valued by their proponents. As Koonce (1990) has argued, this lack of an integrating framework creates obstacles for the use of indicators to characterize trends for the entire Great Lakes basin or to guide management actions to correct the pathologies. A pathology from one perspective, after all, may be a beneficial condition to another. Gilbertson (1993), for example, argues that the requirement for supplemental stocking of salmonids to work around the failure of lake trout reproduction in Lake Ontario is symptomatic of a pathology, but many recreational fishers prefer to catch non-native Chinook salmon and view emphasis on lake trout rehabilitation as undesirable if in doing so the Chinook fishery declines. Ideally, indicators should follow from the objectives for ecosystem management, but as discussed below, ecosystem objectives are often not specific enough to provide a basis either for deriving quantitative end points consistent with the objective or for guiding the selection of an appropriate set of indicators with which to monitor trends in ecosystem health and to specify corrective action.

Attempts to develop sets of indicators have arisen in parallel with government mandates for ecosystem management. The 1978 Great Lakes Water Quality Agreement committed Canada and the U.S. to move beyond control of chemical pollutants to a goal of restoring and maintaining the chemical, physical, and biological integrity of the waters of the Great Lakes basin ecosystem. Within the International Joint Commission (IJC), the Science Advisory Board created an Aquatic Ecosystem Objectives Committee (AEOC) to develop ecosystem objectives and indicators for the Great Lakes. These efforts led to proposed indicators based on indicator species for oligotrophic portions of the Great Lakes (Ryder and Edwards 1985) and for mesotrophic areas (Edwards and Ryder 1990). Following the 1987 revisions to the Great Lakes Water Quality Agreement, Canada and the U.S. established a Binational

Objectives Development Committee, which subsequently formed the Ecosystem Objective Work Group (EOWG) to continue development of ecosystem objectives and indicators. Various national initiatives have also complemented the binational efforts. Noteworthy is the Environmental Monitoring and Assessment Program (EMAP) of the Environmental Protection Agency. The primary goal of the Great Lakes EMAP strategy under development (Hedtke *et al.*, 1992) is to estimate current status and trends of indicators for the ecological condition of each of the Great Lakes. As a result of these various initiatives,

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Table 1. Indicators proposed by the Lake Ontario Pelagic Community Health Indicator Committee for ecosystem structure and functional energy flow (after Christie 1993).

Indicator	Historical Data	Methodology for Collection	Status of Assessment	Interpretive Status
Biomass or production size spectrum	None - some current data in Sprules group	Traditional net sampling, various techniques for each organism targeted little calibration.	Currently developing new sampling methodologies	Has utility in displaying the entire structure of the ecosystem.
Yield of piscivores	Long-term commercial statistics. Some recent creel census data.	Requisite reports from commercial fishermen, spot surveys of anglers and charter boats.	Inadequate bridging between old and new data series. Need better institutional assessment data and more comprehensive creel, and charter data.	Presently used to measure fisherman satisfaction. Convergence on predicted yield estimate can measure ecosystem health.
Ratio of Piscivore to prey biomass	Comparable to above; more data available for the predator species than for the prey, especially nearshore.	Traditional fishery tools; gillnets, trawls, trapnets, seines.	Inadequate assessment of small nearshore species especially. No bridging between inshore, offshore programs. Biased estimates of relative biomass. Currently developing new sampling methodologies based on sonar.	Should measure approach to steady state conditions, and deviations therefrom. Rigorous attention to sampling routine should allow early-warning use of variance, and trend data.
Fraction of yield as native fish.	Lake trout, rainbow trout data back to the 1950s. Chinook salmon more recent.	Fin clips used in past, nasal insert tags currently used in all larger fish released. Otolith, scale, and fin ray abnormalities used for fish smaller at release, and for F_2 and later recoveries.	Methods of differentiating genetic origins of naturally produced fish still developmental.	Data presently analyzed in the form needed.
Zooplankton size distribution.	Some data available from 1972. Continuous at the CCIW Bioindex stations.	Standard techniques used. Recently extended by new computerized count-measure procedures.	Currently applied in part-spectrum applications. All collections extant for series comparisons. Inshore data not consistently collected.	Not expressly used in present lake reporting, and especially useful when compared with nearshore data, and placed in the context of other indicators.
Total P levels <= 10 mg/l	Monthly surveillance (1976-1981); biannual survey (1982-present)	Discreet depth samples at 1 meter	Adequate methods currently being used. Consistent comparisons with nearshore conditions desirable.	Analysis ongoing and reliable. Good when used in conjunction with other indicators; provides information on the baseline productivity of the lake, and linkage to future biological problems related to return to excess P loads.
Fish species diversity.	Standard gillnet, trawl, trapnet, seine collections. Gillnet data continuous since 1957 and 1958 in Bay of Quinte and Kingston Basin. Trawl data continuous since 1972 in all areas. Broken series for the others.	Conventional net sampling. Programs need broadening to include shoreline and small species, integration to allow comparison within and between series.	Analysis needs to focus on evenness component of diversity. Statistical analysis of variance in each zone should measure improving health, and the reverse.	Conservative property. Is robust when developed from comparable collection techniques.

standardization of indicators of aquatic community health of the Great Lakes is only just beginning, and the indicators summarized here are thus far less robust than those for fish and wildlife health.

Indicators considered in these various initiatives fall into three categories: Indicator or integrator species, ecosystem function indicators, and composite indices of ecosystem integrity. An example of the first category is the use of lake trout (*Salvelinus namaycush*) and *Pontoporeia* for oligotrophic ecosystems (Ryder and Edwards 1985) and walleye (*Stizostedion vitreum*) and burrowing mayfly (*Hexagenia limbata*) for mesotrophic waters (Edwards and Ryder 1990). These species satisfy fundamental criteria for surrogate species (Edwards and Ryder 1990): a strong integrator of the biological food web at one or more trophic levels; abundant and widely distributed within the system; and perceived to have value for human use to make sampling easier. An example of indicators of ecosystem function is the proposed use of biomass size spectra (Sheldon *et al.* 1972) as measures of ecosystem health (Kerr and Dickie 1984). Table 1 lists this and other candidate indictors of ecosystem function that have been evaluated by the Lake Ontario Pelagic Community Health Indicator Committee. Finally, there are a wide variety of examples of composite indices (Karr 1981; Steedman 1988; Rankin 1989; Yoder 1991; and Minns *et al.* in press). As Rapport (1990) notes, these indices are based on a number of variables, but usually cover biotic diversity, indicator species, community composition, productivity, and health of organisms. The Dichotomous Key, designed to assess the health of the oligotrophic aquatic ecosystems (Marshall *et al.* 1987), is in fact an example of an aggregate index using lake trout as a surrogate for the biological integrity of oligotrophic portions of the Great Lakes.

Status and Trends for Fish and Wildlife Health

Toxic contamination of the Great Lakes is widely-perceived threat to fish and wildlife health. A recent compilation by the Government of Canada of scientific literature on the effects of persistent toxic chemicals (Anon. 1991b) concluded that persistent chemicals have had a significant impact on fish and wildlife species in the Great Lakes basin. Observed effects include alteration of biochemical function, pathological abnormalities, tumors, and developmental and reproductive abnormalities. A possible consequence of these effects is a decrease in fitness of populations. Contaminant body burdens in fish and wildlife also have led to alerting the public through consumption advisories to a potential human health threat. On the whole, however, the effects of toxic contamination on wildlife is much clearer than for fish populations.

Fish populations in the Great Lakes do show evidence of exposure to toxic contaminants. Induction of some MFOs (i.e. those which result in elevation of EROD or AHH activity) signals AHH receptor activation, which may result in unfavorable biological responses. Surveys of mixed function oxidase (MFO) activity in lake trout (*Salvelinus namaycush*) clearly indicate elevated levels in southern Lake Michigan and western Lake Ontario (Figure 1). Because mixed function oxidase enzymes are induced by a variety of toxic chemicals, elevated MFO activity can not be associated with specific toxic chemicals, nor is it possible to attribute specific health effects to these elevated enzyme activities. Nevertheless, the patterns of lake trout MFO activity coincide with geographic variation in contaminant loading. White sucker (*Catostomus commersoni*) also showed similar patterns of higher MFO activity in Lake Michigan and Lake Ontario, but also showed patterns of higher activity in the nearshore than in animals sampled in off shore environments (Figure 2). Impairment of lake trout reproduction in Lake Michigan seems to reflect this chemical contamination (Mac 1988), and, by similarity of circumstances, chemical contaminants are possibly responsible for reproductive failure of lake trout in Lake Ontario. Further clarification of the effects of chemical contaminants on population health of fish may rest on resolution of methodological issues (Gilbertson *et al.* 1990, Gilbertson 1992).

Circumstantial evidence is also strong for chemically induced carcinogenesis in Great Lakes fish. Summary of observations (Anon. 1991b) indicate that proof of causation of incidence patterns of tumors is lacking. Nevertheless, the overwhelming evidence leads to the conclusion (Anon 1991b):

> *There is strong circumstantial evidence that environmental carcinogens are responsible for the occurrence of liver tumours in brown bullheads from the Black, the Buffalo and the Fox Rivers, and possibly in bullheads from several other Areas of Concern. There is no "proof" that chemical carcinogens are responsible for liver tumours in walleye and sauger from the Keweenaw Peninsula, or in white suckers from western Lake Ontario. However, the limited geographic distribution of the effects and the association with contaminated environments indicates a chemical etiology.*

Not all fish diseases, however, have a chemically dominant etiology. Recent observation of outbreaks of bacterial kidney disease (BKD) among Chinook salmon (*Oncorhynchus tshawytscha*) in Lake Michigan and dramatic increase in their mortality in the late 1980's (Figure 3) has not been linked to contaminants. The Great Lakes Fish Disease Control Committee concluded that "...*the chinook mortality problem should be considered the result of an ecosystem imbalance rather than the "fault" of any one pathogen.*" Although *Renibacterium salmoninarum* is the causative agent of BKD, they believe that the disease is stress mediated and not a simple epizootic. However, they advise implementing hatchery practices to reduce the prevalence of *Renibacterium salmoninarum*. To that end, the committee has proposed a set of guidelines for the control of disease agent import into the Great Lakes basin (Hnath 1993 and Horner and Eshenroder 1993). Other "diseases" have been observed to wax and wane in various fish populations. Smelt populations in Lake Erie, for example, experienced an epizootic of parasitism by the microsporidian, *Glugea hertwigi*, in the 1960s (Nepszy *et al.* 1978).

Relative to fish, effects of toxic contaminants on wildlife species are more extensively documented. By 1991, various studies had identified contaminant-associated effects on 11 species of wildlife in the Great Lakes (Anon. 1991b). Affected species include shoreline mink (*Mustela vison*), otter (*Lutra canadensis*), double-crested cormorant (*Phalocrocorax auritus*), black-crowned night-heron (*Nycticorax nycticorax*), bald eagle (*Haliaeetus leucocephalus*), herring gull (*Larus argentatus*), ring-billed gull (*Larus delawarensis*), Caspian tern (*Sterna caspia*), common tern (*Sterna hirundo*), Forster's tern (*Sterna forsteri*), and snapping turtle (*Chelydra serpentina*). Of these, 9 species showed historical evidence of reproductive impairment due to contaminants (see Table 1, Anon. 1991b, p. 563). Temporal and spatial trends in samples of cormorants, bald eagles, and herring gulls provide important evidence for the magnitude of the effects of contaminants on wildlife health and recent improvements.

Cormorants began to nest in the Great Lakes earlier in this century. Estimates of abundance in the 1940s and 1950s indicated about 1000 pairs, but that these numbers declined substantially through the 1970s (Anon. 1991b). Productivity studies clearly implicated reproductive failure, which resulted from DDE-induced egg shell thinning, as the cause of these declines (Figure 4). Since 1979 cormorant populations have increased substantially throughout the Great Lakes (Gilbertson *et al.* 1991), but prevalence of bill defects and other developmental anomalies throughout the 1980s suggest that sufficient amounts of PCBs and other toxic contaminants occurred in fish to influence the embryo development of these and other colonial, fish-eating bird species, particularly in Green Bay (Fox *et al.* 1991).

Bald eagles have shown drastic declines throughout their North American range. Wiemeyer *et al.* (1984) suggested that toxic contaminants have contributed to these declines with DDT causing eggshell thinning and reproductive impairment. Restrictions on the manufacture and use of DDT, PCB, and other organic compounds seemed to reverse these trends, and within the conterminous U.S. the Fish and Wildlife Service reported that bald eagles had recovered from a low of 400 pairs nationwide in 1964 to 2700 pairs in 1989 (Anon. 1991b). Great Lakes populations have followed this recovery trend, but reproductive success of breeding pairs nesting on shorelines of the Great Lakes or on tributaries with adfluvial fish populations from the Great Lakes are lower than those nesting inland (Best *et al.* in press). Between 1966

Table 2. Temporal and geographic variations of productivity of Great Lakes Herring Gulls, 1972-1985 (after Table 10, Anon. 1991b, p. 601), expressed as 21 day-old chicks per pair.

Location	1972	1973	1974	1975	1976	1977	1978	1979	1980	1981	1982	1983	1984	1985
Lake Ontario														
Snake I.	0.21					1.01	0.86	1.60	1.49	1.73		1.34		
Scotch Bonnet I.	0.12	0.06		0.15		1.10	1.01			2.13				
Brother's I.	0.10													
Presq'ile Pk.	0.06													
Black Ant I.	0.08													
Mugg's I.						1.52	1.47	1.56		1.40			1.17	
Lake Erie														
Big Chicken I.	0.45													
Port Colborne			0.48	0.65	0.79		1.45			1.60				
Middle I.							1.70	1.63	1.62	2.10		2.17	0.95	1.00
Lake Huron														
Chantry I.				1.48		1.12	1.40	2.17	2.17	2.16		1.84		
Double I.							1.57	2.17	2.25	2.23		1.25	2.33	
Lake Superior														
Agawa Rk.				1.32	1.55		1.66	0.88	0.40	0.37	0.14	0.37	0.85	1.30
Granite I.							1.12	1.70	1.40	0.46	1.39		1.39	

and 1992, seven bald eaglets were found with abnormal bills, 16 per 10,000 banded (Bowerman *et al.* in press), and four eaglets with deformities were found on Great Lakes shorelines in 1993 (Fox, personal communication).

More than any other wildlife species, the herring gull has become an indicator of contaminant trends in the Great Lakes (Mineau *et al.* 1984). As year-round residents, adult herring gulls offer a monitoring opportunity to detect regional variability in contaminant stress that is not complicated by migratory patterns characteristic of other fish-eating bird species (Weseloh *et al.* 1990). Since 1974, the Canadian Wildlife Service has maintained a long-term monitoring program for toxic chemicals through a network of 13 sites throughout the Great Lakes. In general, organochlorine residues in herring gull eggs have declined from higher levels in the early 1970s (Anon. 1991b, p. 332). As is the case with cormorants, temporal and geographic variation of productivity reflect these trends (Table 2). Reproductive success was low in the early 1970s and has improved since. Although the etiology of these changes has not been rigorously determined, egg exchanges suggest both intrinsic and extrinsic factors were involved and biochemical markers provide substantial indication that biochemical abnormalities are strongly associated with diets contaminated by polyhalogenated aromatic hydrocarbons (Fox *et al.* 1988). Gilbertson *et al.* (1991) have proposed mechanisms to account for these reproductive effects, and despite recent declines in contaminant levels, according to Fox (1993) "...data confirm the continued presence of sufficient amounts of PCBs and related persistent halogenated aromatic hydrocarbons in forage fish to influence the physiology of these birds over much of the Great Lakes basin." Contaminant-associated problems appear to be most severe in hot spots such as Saginaw Bay, Lake Ontario, and Green Bay.

Status and Trends for Community Health

Objectives for restoration of the physical, chemical, and biological integrity of the ecosystems of the Great Lakes have not defined explicit interim goals. Realizing that pre-Columbian states of the Great Lakes ecosystems represented one definition of a "healthy" ecosystem, one interim goal for restoration could be re-establishment, to the maximum possible extent, of natural communities. Alternatively, an interim goal could be the restoration of a functional equivalent of historical communities. Although this issue (i.e. development of indicators and end points for ecosystem objectives) is under active consideration, the historical benchmark remains an important reference point with which to judge the extent of degradation of Great Lakes ecosystems and the prospects for various levels of restoration.

Any assessment of the status and trends of ecosystem health must begin with the catastrophic loss of biological diversity and subsequent establishment of non-indigenous populations. Fish play a major role in structuring aquatic ecosystems as do trees in many terrestrial ecosystems (Steele 1985). Summaries of the changes in the fish species composition of the Great Lakes (Lawrie and Rahrer 1973, Wells and McLain 1973, Berst and Spangler 1973, Hartman 1973, and Christie 1973) reveal substantial alteration of the fish communities. Table 3 lists the species that have either disappeared from the lakes or have been severely depleted, but these losses belie a much more fundamental loss of genetic diversity among surviving indigenous species. Goodier (1981), for example, showed evidence that Lake Superior supported about 200 spawning stocks, including 20 river spawning stocks, of lake trout prior to 1950.

Table 3. Summary of fish species lost or severely diminished by lake in the Great Lakes. An asterisk (*) indicates stocking programs exist to attempt re-introduction.

Common Name	Species Name	Status
Lake Ontario		
Atlantic salmon	*Salmo solar*	Extinct*
Lake sturgeon	*Acipenser fluvescens*	Depleted
Blackfin cisco	*Coregonus nigripinnis*	Extinct
Lake trout	*Salvelilnus namaycush*	Extinct*
Shortnose cisco	*Coregonus reighardi*	Depleted
Bloater	*C. hoyi*	Extinct (?)
Kiyi	*C. kiki*	Extinct
Burbot	*Lota lota*	Depleted
Blue pike	*Stizostedion vitreum glaucum*	Extinct
Fourhorn sculpin	*Myoxocephalus quadricornis*	Extinct
Lake Erie		
Blue pike	*Stizostedion vitreum glaucum*	Extinct
Lake trout	*Salvelilnus namaycush*	Extinct*
Longjaw cisco	*Coregonus alpenae*	Extinct
Lake Sturgeon	*Acipenser fluvescens*	Depleted
Lake herring	*Coregonus artedii*	Extinct
Lake whitefish	*C. clupeaformis*	Depleted
Sauger	*Stizostedion canadense*	Extinct
Lake Huron		
Lake trout	*Salvelilnus namaycush*	Extinct*
Lake sturgeon	*Acipenser fluvescens*	Depleted
Blackfin cisco	*Coregonus nigripinnis*	Extinct
Deepwater cisco	*C. johannae*	Extinct
Longjaw cicso	*C. alpenae*	Extinct
Shortnose cisco	*C. reighardi*	Extinct
Kiyi	*C. kiyi*	Extinct
Lake Michigan		
Lake trout	*Salvelinus namaycush*	Extinct*
Blackfin cisco	*Coregonus nigripinnis*	Extinct
Deepwater cisco	*C. johannae*	Extinct
Shortjaw cisco	*C. zenithicus*	Extinct
Longjaw cisco	*C. alpenae*	Extinct
Shortnose cisco	*C. reighardi*	Extinct
Kiyi	*C. kiyi*	Extinct
Lake herring	*C. artedii*	Depleted
Lake sturgeon	*Acipenser fluvescens*	Depleted
Emerald shiner	*Notropis atherinoides*	Extinct
Lake Superior		
Blackfin cisco	*Coregonus nigripinnis*	Extinct
Shortjaw cisco	*C. zenithicus*	Extinct
Shortnose cisco	*C. reighardi*	Extinct
Kiyi	*C. kiyi*	Extinct
Lake herring	*C. artedii*	Depleted
Lake sturgeon	*Acipenser fluvescens*	Depleted

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Accompanying these changes in diversity of Great Lakes fishes was a succession of invasions and intentional introduction of non-indigenous fish species. Species that have established substantial

Sea lamprey	*Petromyzon marinus*
Alewife	*Alosa pseudoharengus*
Smelt	*Osmerus mordax*
Gizzard shad	*Dorosoma cepedianum*
White perch	*Morone americana*
Carp	*Cyprinus carpio*
Brown trout	*Salmo trutta*
Chinook salmon	*Oncorhynchus tshawytscha*
Coho salmon	*O. kisutch*
Pink salmon	*O.gorbuscha*
Rainbow trout	*O. mykiss*

populations include:

Since 1985, other species such as the ruffe (*Gymnocephalus cernuus*), the rudd (*Scardinius erythrophthalmus*), fourspine stickleback (*Apeltes quadracus*), and two species of goby (*Neogobius melanostomus* and *Proterorhinus marmoratus*) have also invaded the Great Lakes (Mills *et al.* 1993). Including these introductions, Mills *et al.* (1993) have documented 139 non-indigenous aquatic organisms (plants, invertebrates, and fish) that have become established in Great Lakes ecosystems.

The pre-Columbian species assemblages of the Great Lakes represented an adaptive complex that was an essential determinant of the wellness of Great Lakes ecosystems. The loss of so much diversity diminished the health of the Great Lakes, but recent trends to restore fish communities raises the question of whether it is possible to establish standard of functional equivalency to these historical fish communities. By launching an aggressive, bi-national program to control sea lamprey, which with overexploitation caused the extirpation of lake trout in Lake Michigan and Lake Huron as well as a substantial reduction in the lake trout diversity of Lake Superior, the Canadian and U.S. governments prepared the way for an intensive stocking program to reintroduce lake trout and non-indigenous salmonid predators to all of the Great Lakes. These efforts have certainly resulted in development of highly successful sports fisheries in the Great Lakes that surpass historical communities in the range of species available to anglers. The stability of these fisheries, however, is not clear. Except for Lake Superior, the salmonid stocking programs are not complimented by natural reproduction. The fisheries, in fact, are dependent upon the continuation of artificial propagation. Furthermore, the prey species complex that support these predators is also dominated by unstable populations of invading species like alewife and smelt. The loss of the highly adaptive coregonid complex and diversity of native lake trout stocks has thus left a void that introductions have so far failed to fill.

Although indicators of ecosystem function have been applied systematically to the Great Lakes, some studies hint at these continuing problems. Biomass size spectrum studies of Lake Michigan (Sprules *et al.* 1991) have shown promising results for the use of particle-size spectra in analyzing food web structure. Through this analysis, Sprules *et al.* (1991) found that picivore biomass was lower than expected. The imbalance in the food web appears to be limited availability of prey fish production to the mix of stocked piscivore species. Zooplankton size distribution, as a component of the biomass size spectrum, also indicates imbalance between planktivory and piscivory. According to the Lake Ontario Pelagic Health Indicator Committee (Christie 1993), a mean zooplankton size of 0.8 to 1.2 mm would indicate a healthy balance in the fish community. Over the period 1981 to 1986, the observed range of mean size of zooplankton was 0.28 to 0.67 mm (Johannsson and O'Gorman 1991), indicating excess planktivory. Emerging evidence for 1993, however, suggests that Lake Ontario may be undergoing an abrupt shift in zooplankton size with a collapse of the dominant prey fish population (E. L. Mills, Cornell University, personal communication). The recent trends in Lake Michigan and Lake Ontario may suggest that declines in productivity of both lakes associated with reduced phosphorus loading make these systems less able to sustain predator stocking levels that were successful earlier. Recent modeling studies of Lake Michigan and Lake Ontario (Stewart and Ibarra 1991; and Jones *et al.* in press) indicate a strong possibility that excessive stocking of predators is de-stabilizing the food webs in these ecosystems.

The recent history of Lake Erie further illustrates how tenuous is the continuing effort to restore the health of the Great Lakes. As reviewed by Hartman (1973), the ecosystem integrity of Lake Erie reached its lowest point in the decade of the 1960s. The combined effects of eutrophication, over exploitation of fishery resources, extensive habitat modification, and pollution with toxic substances had severely degraded the entire ecosystem of Lake Erie. Once thriving commercial fisheries had all but disappeared and the populations of the last remaining native predator, the walleye, had fallen to a record-low level. Beginning in the 1970s, new fishery management strategies and pollution abatement programs contributed to a dramatic reversal. Lake Erie walleye fisheries rebounded to world-class status (Hatch *et* *al.* 1987), and point-source phosphorus loading has declined to target levels in the 1972 Great Lake Water Quality Agreement (Dolan 1993). These reductions were accompanied by a dramatic decrease in the abundance of nuisance and eutrophic species of phytoplankton (Makarewicz 1993a) and an associated decline in zooplankton biomass (Makarewicz 1993b). Surveys of the benthic macroinvertebrate communities further illustrate the improvement in the most degraded sediment areas of Western Lake Erie. Compared with surveys conducted in 1969 and 1979, Farara and Burt (1993) found that there was a marked decline in the abundance of pollution tolerant oligochaetes and that overall the macroinvertebrate community of Western Lake Erie has shifted to more pollution intolerant and facultative taxa.

The invasion of zebra mussels into Lake Erie has affected these recovery transients. Leach (1993) reported that associated with zebra mussel increases was a 77% increase in transparency between 1988 and 1991, a 60% decrease in chlorophyll a, and a 65% decline in number of zooplankters. Although Leach (1993) has observed an increase in the amphipod *Gammarus* in nearshore benthic communities dominated by zebra mussels, Dermott (1993) has observed an inverse relation to abundance of *Diporeia* and the "Quagga" mussel, which appears to be a second *Dreissena species.* These abrupt changes in water quality and associated plankton and benthic communities make predictions about future status of the Lake Erie ecosystem highly uncertain. Despite the recovery of walleye, however, the causes current trends of change in the structure and function of the Lake Erie ecosystem are dominated by effects of non-indigenous species. The extent of the changes in community structure of the Western and Central basins is so great that the historical species composition is unlikely to serve as a workable benchmark with which to assess ecosystem health.

The offshore, oligotrophic portions of the Great Lakes also seem to show variable recovery of health. The lake trout surrogate indicator (Edwards and Ryder 1985) is the only indicator of aquatic community health that has been systematically applied to the oligotrophic areas of the Great Lakes. As documented in Edwards *et al.* (1990), this indicator is a composite index, which is derived from a wide range of conditions necessary to sustain healthy lake trout stocks. The rationale for the use of lake trout as a surrogate for ecosystem health is based on the notion that lake trout niche characteristics and historical dominance in the Great Lakes provide the best basis to detect changes in overall ecosystem health. The index is based on scores from a Dichotomous Key of questions about lake trout or their habitat (Marshall *et al.* 1987). A score of 100 indicates pristine conditions. For the period 1982-85, Edwards *et al.* (1990) indicate that Lake Superior had the highest score (i.e. was the least degraded) followed by Lake Huron , Lake Ontario, Lake Michigan, and Lake Erie (Figure 5). The Dichotomous Key further allows dissection of the indicator score into components associated with various stress categories. In all cases except Lake Erie, contaminants are an important cause of lower indicator values (Figure 6).

Marshall *et al.* (1992) reported on historical and expected future trends in the lake trout indicator for the period 1950 to 1995. The overall value of the indicator showed a decline through the mid-1960s with a projected recovery by 1995 approaching 1950 levels (Figure 7). Ryder (1990) argues that this recovery pattern indicates that recovery to near pristine conditions is a reasonable goal. Dissection of the score into stress categories, however, indicates that contaminant problems are not improving as rapidly as other stresses (Figure 8). In an independent effort, Powers (1989) applied the Dichotomous Key to explore trends in the ecosystem health of Lake Superior and Lake Ontario. Her conclusions were similar to the findings of Marshall *et al.* (1992) for Lake Superior, but she found that Lake Ontario's trends indicated substantial and continuing imbalance.

Powers (1989) explored the possible effects of various fishery management schemes on the future health of the Lake Ontario. In 1973, the indicator showed a degraded state, and ecosystem health appeared to decline through 1983 in spite of a rather substantial recovery of recreational fishing (Figure 9). Future projections showed a recovery to the 1973 level as rehabilitation of lake trout approached the goals set in the Lake Trout Rehabilitation Plan for Lake Ontario (Schneider et al., 1985). Other aspects of the Lake Ontario system health profile (Figure 9), however, are more troubling. In spite of achieving some of the interim goals for lake trout rehabilitation by 1988, the system health of Lake Ontario resists exceeding the degraded condition in 1973. Over the period 1973 to 1988, the lake trout population and other salmonid populations have increased markedly due to intensive stocking efforts. The indicator implies that this rehabilitation effort did not increase system health. Closer analysis of the stress categories (Figure 10) reveals that toxic contamination increase bears a large responsibility for the decrease in system health. Lake trout restoration provided an indication of just how degraded the Lake Ontario ecosystem really was. Further recovery of system health in Lake Ontario seems to be hindered by fundamental shifts in the fish community (Environmental Biotic stresses), future levels of exploitation (Exploitation stress), and continuing toxic contamination. Whether the indicator is sensitive enough to improvements in these stresses is not clear, but it certainly does not show any indication of improvement of system health despite a massive investment of resources in the rehabilitation of Lake Ontario.

Composite indices other than the Dichotomous Key of Marshall *et al.* (1987) have also been applied to portions of the Great Lakes. Ohio EPA, for example, has attempted to characterize the state of the estuarine fish communities in Ohio waters of Lake Erie (Thoma, unpublished report, Ohio EPA). Using an Index of Biotic Integrity (IBI), Ohio EPA found that only one of fourteen estuaries sampled met minimal integrity and health criteria (Figure 11). Factors responsible for the degraded state of the estuarine communities include extensive habitat modification, point source discharges, and diffuse, non-point sources effects preclude most sampled sites from attaining minimal goals. However, the most serious degradation is the modification of wetlands in the estuaries (Thoma, unpublished report).

Management Implications

The Great Lakes today do not meet stated ecosystem objectives. In recent years, various indicators show improving conditions in all lakes. All of the lakes have some extremely degraded areas associated with local pollution sources. These areas of concern are subject to individual Remedial Action Plans, which vary greatly in scale and time to implementation. Apart from its areas of concern, Lake Superior is clearly in the best state of recovery, and even considering continuing concern about levels of toxic contaminants in fish and wildlife, ultimate achievement of the objectives seems a reasonable goal. The governments of Canada and the U.S., in fact, have selected Lake Superior for a demonstration program for zero discharge of toxic contaminants as part of their responsibilities under the Great Lakes Water Quality Agreement. All of the other Great Lakes, however, have some significant problems that will impede future recovery. These include: contaminant levels in fish and wildlife that are sufficient to continue producing effects on health of humans, fish, and fish-eating wildlife; large-scale degradation of tributary and nearshore habitat for fish and wildlife; inadequate reproduction of native predatory fish; imbalance of aquatic communities associated with population explosions of invading species like sea lamprey, white perch, and zebra mussels; and expectations of production from fish communities through stocking and exploitation levels that are not consistent with the productive capacity of the ecosystems.

Appendix 3 SOLEC Manuscript

Chemical pollution of the Great Lakes has decreased. Phosphorus loading targets have been attained for Lake Erie and Lake Ontario, and there is continuing improvement in the regulation of non-point sources of nutrient and sediment loading throughout the Great Lakes basin. Although trends are also encouraging, declining levels of toxic contaminants in fish and wildlife have leveled off (cf. companion paper on the state of toxic contaminants in the Great Lakes). Concern with this continuing contamination led the National Wildlife Federation and the Canadian Institute for Environmental Law and Policy to call for more active efforts of governments to adopt a uniform system of consumption advisories for fish and to move more aggressively to promote a program for zero discharge of toxic contaminants (Anon. 1991c). The 1987 Protocols to the GLWQA created an initiative for Lake Wide Management Plans (LaMPs) to address the need for a more coordinated approach to management of critical pollutants. Management plans for toxic chemicals have been the first focus of these efforts in Lake Ontario and Lake Michigan. These efforts promise continued downward trends in chemical pollution, and future progress in restoration of the ecosystems of the Great Lakes will depend upon reducing physical and biological stresses.

The physical integrity of the ecosystems in the Great Lakes basin has been degraded by a wide range of historical human activities. The assessment of Ohio's estuarine fish communities (Thoma, unpublished report) is typical of other areas in the Great Lakes. Thoma lists several types of habitat modifications that contribute to degradation: wetland filling, marina construction, shipping channel construction and maintenance, and bank alterations with either rip rap or vertical bulkheads. Throughout the Great Lakes, natural shorelines, wetlands, and tributaries have disappeared or have been altered. Impoundments and siltation have eliminated spawning habitat for adfluvial fish species, and nearshore fish communities as well as nursery areas for off shore fish species have been seriously impaired. The magnitude of these effects have been well documented for some Areas of Concern (e.g. Ohio EPA, 1992). However, the overall effects of these habitat modifications on the health of open water fish communities is not readily documented. In Lakes Ontario and Michigan and to lesser extents in Huron and Superior, stocking of top predators obscures the effects of degraded habitat. In Lake Erie, Lake St. Clair, and mesotrophic portions of the other Great Lakes (e.g. Green Bay, Bay of Quinte, and Saginaw Bay) the fish communities may have already compensated for these effects by restructuring and elimination of tributary dependent stocks. A major challenge to aquatic resource managers will be the inventory and classification of this habitat (cf. Busch and Sly 1992) to support planning for preservation and remediation of critical habitat.

Although physical and chemical stresses have contributed to the decline in the integrity of Great Lakes' ecosystems, stresses associated with biological factors have, in fact, caused much more severe degradation, particularly in lake ecosystems. The primary stresses are over-exploitation of biological resources and introduction of exotic organisms. Sustainable exploitation of renewable, natural resources is a challenge to managers. Ludwig *et al.* (1993) argue that technical and social factors combine in such a way that the challenge may never be fully met. Certainly, the history of the Great Lakes offers dramatic examples of the effects of over fishing and mismanagement. Christie (1972) documents the major role of over fishing in destabilizing the fish community of Lake Ontario, and similar findings are available for Lake Erie (Nepszy 1977), Lake Michigan (Wells and McLain 1973), Lake Huron (Berst and Spangler 1973), and Lake Superior (Lawrie and Rahrer 1973). The interaction of exploitation and the deliberate and accidental introduction of non-indigenous species has proven to be extremely disruptive. The invasion of sea lamprey into the upper Great Lakes resulted in the demise of lake trout in Lake Michigan and Lake Huron and the loss of a number of lake trout stocks in Lake Superior before an international program for the control of sea lamprey was begun in the 1950's (Smith and Tibbles 1980). The extent of the disruption of the food web by sea lamprey and more recently by zebra mussels and the spiny water flea have led to recommendations for more stringent controls on introductions (IJC and GLFC 1990). Mills *et al.* (1993) document 139 non-indigenous species that have become established since the 1880s. Although few of these species have had the disruptive impact of purple loosestrife, sea lamprey or zebra mussels, they have a cumulative effect on the structure of aquatic communities of the Great Lakes, and their persistence raises substantial problems for the rehabilitation and maintenance of native species associations.

Various indicators clearly show that the state of the health of aquatic communities of the Great Lakes do not satisfy the ecosystem objectives adopted by Canada and the United States. Although some of these indicators show signs of improvement, managers will find an emerging problem in obtaining agreement on quantitative specification of endpoints for the indicators that will specify attainment of ecosystem objectives. The goal of the GLWQA is to restore and maintain the integrity of the ecosystems of the Great Lakes. Until now, there has been an assumption that specification of ecosystem integrity is largely a scientific or technical issue. The extent of historical disruption of aquatic communities and the establishment of large numbers of non-indigenous species, however, may preclude the use of native associations (i.e. pre-settlement ecosystems) as benchmarks for ecosystem integrity. At best, scientific analysis will allow specification alternative configurations of the structure of aquatic communities in the Great Lakes that are consistent with fundamental ecological principles. The ultimate selection of a restored state is thus a matter of social preference. Because social preference for state of the Great Lakes ecosystems embodies an implicit set of uses, the specification of quantitative end points for the indicators is embroiled in the determination of acceptable ways of using the resources of the Great Lakes. Ecosystem objectives do not address the issue of how to balance the various uses of these resources, and managers may find future progress toward attaining the goals of the GLWQA impeded by the lack of consensus on the desired state of aquatic ecosystems.

The role of State-of-the-Lakes reporting is to define the condition of the ecosystems of the Great Lakes relative to the desired state and to identify and prioritize management initiatives necessary to improve and/or to maintain it. As such, the State of the Lakes Report is a vital part of a strategic management process. However, the current state of management of the Great Lakes is deficient as a strategic planning process. As Naisbitt (1980) stated, strategic planning requires a strategic vision with explicit milestones. As discussed above, the goals and specific objectives in the GLWQA do not serve as a strategic vision nor does it provide milestones. The challenge of ecosystem management in the Great Lakes, therefore, is as much a challenge to institutional structure as to individual management agencies.

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Figure Legends

Figure 1. Patterns in observations of mixed function oxidase (MFO) activity in lake trout of the Great Lakes basin (after Anon. 1991b, Fig. 2, p 521)

Figure 2. Patterns in observations of mixed function oxidase (MFO) activity in white sucker of the Great Lakes basin (after Anon. 1991b, Fig. 3, p 522)

Figure 3. Harvest and BKD incidence trends for Chinook salmon in Lake Michigan. Data provided by Kelly Smith, Michigan Department of Natural Resources.

Figure 4. Trends in productivity of couble-crestested cormorants in Lake Ontario (after Table 6, Anon. 1991b, p. 589).

Figure 5. Scores for each Great Lake for the interval 1982-1985 from the Dichotomous Key. The vertical line in each bar is the percent uncertainty associated with the score. Data are from Edwards *et al.* (1990, p. 601).

Figure 6. Contribution by stress category to Dichotomous Key scores for each Great Lake for the interval 1982-1985. Vertical lines in each box represent percent uncertainty. Data are from Edwards *et al.* (1990, p. 602).

Figure 7. Comparison of annual harvest of all salmonines in Lake Superior with the score from the Dichotomous Key. Data are from Marshall *et al.* (1992, p. 65).

Figure 8. Contribution by stress category to Dichotomous Key scores for trends in Lake Superior Data are from Marshall *et al.* (1992, p. 64).

Figure 9. Estimated ecosystem health index for Lake Ontario in the period 1973 to 2002. Ecosystem health index values were derived from the ecosystem health index of Ryder and Edwards (1985) by a recursive procedure (Powers, 1989).

Figure 10. Contribution of various stress categories to the degradation of ecosystem health in Lake Ontario, after Powers (1989).

Figure 11. Minimum, maximum, and mean Index of Biotic Integrity (IBI) for 14 estuaries. For comparison the Warm Water Habitat aquatic life use criterion value of 32 is plotted as a solid line. Figure is from Thoma (unpublished report, Ohio EPA).

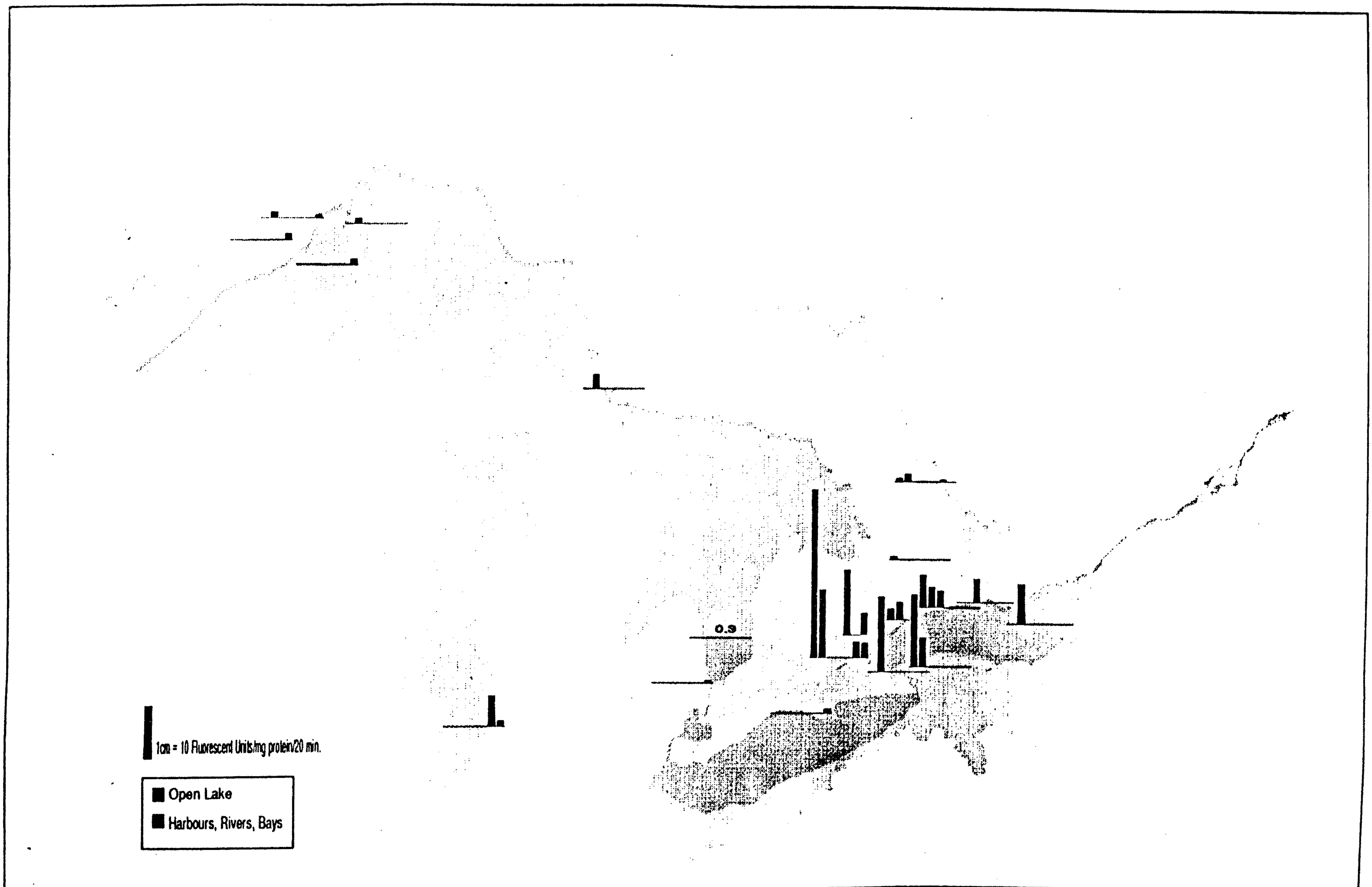
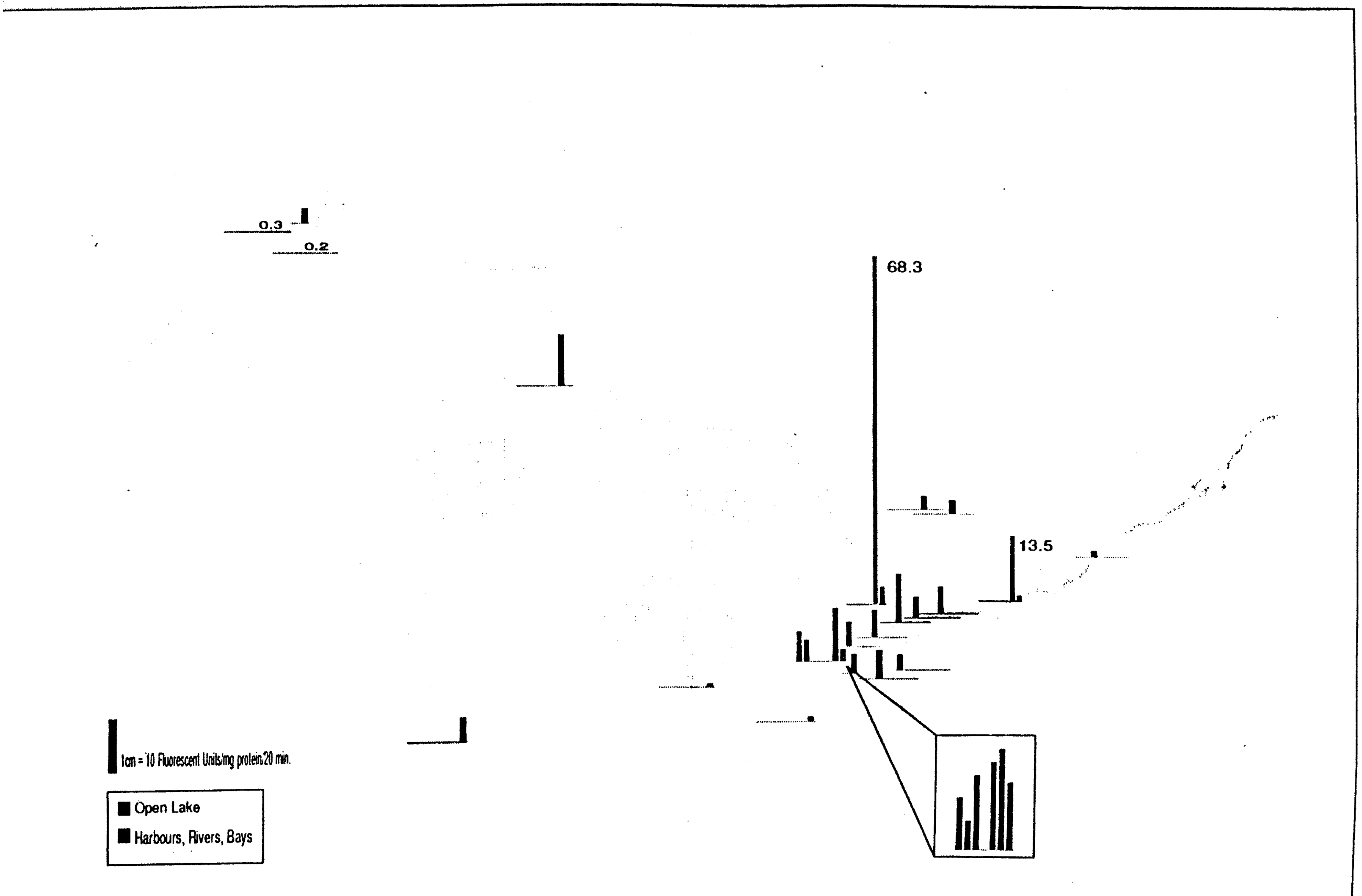


Figure 1. Mixed function oxidase (aryl hydrocarbon hydoxylase) activity in lake trout *(Salvelinus namaycush)* from the Great Lakes, 1982-1988.

(From P. Hodson, National Water Research Institute Canada, Burlington, Ontario. Personal communication.)



;ure 2. Mixed function oxidase (aryl hydrocarbon hydoxylase) activity in white suckers *(Catostomus commersoni)* from the Great Lakes, 1982-1988.

om P. Hodson, National Water Research Institute Canada, Burlington, Ontario. Personal communication.)

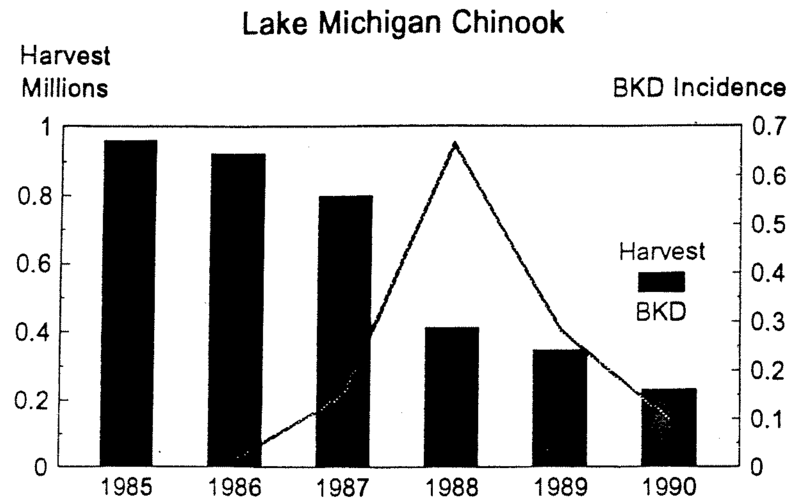

Lake Michigan Chinook
Harvest
Millions
BKD Incidence
1
0.8
0.6
0.4
0.2
0
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
Harvest
BKD
1985
1986
1987
1988
1989
1990

Figure 3.

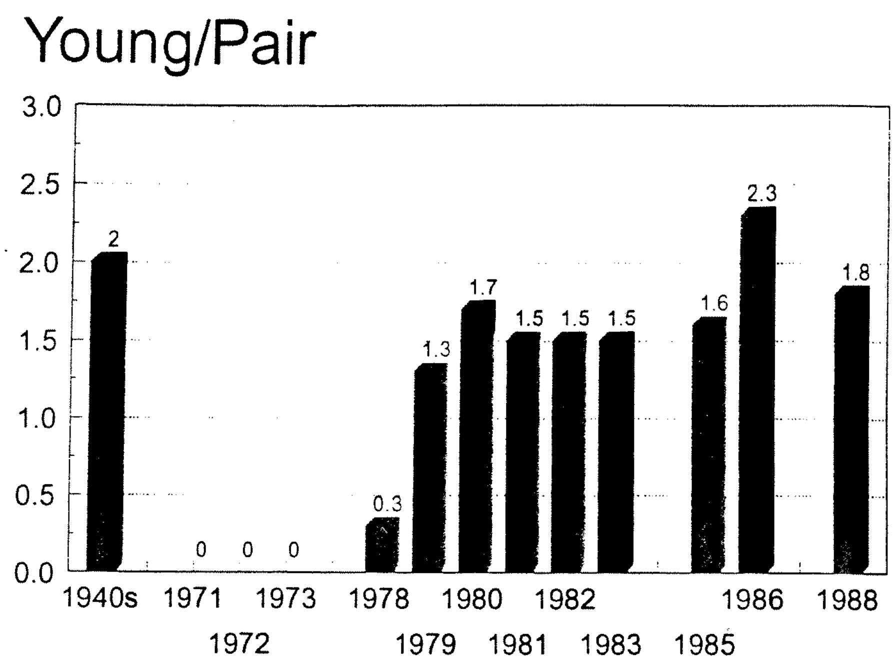
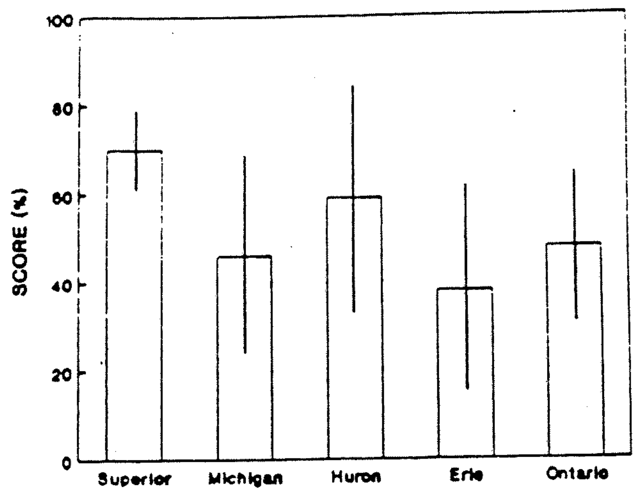

Young/Pair
3.0
2.5
2.0
1.5
1.0
0.5
0.0
2
0
0
0
0.3
1.3
1.7
1.5
1.5
1.5
1.6
2.3
1.8
1940s
1971
1972
1973
1978
1979
1980
1981
1982
1983
1985
1986
1988

Figure 4.

Figure 5.



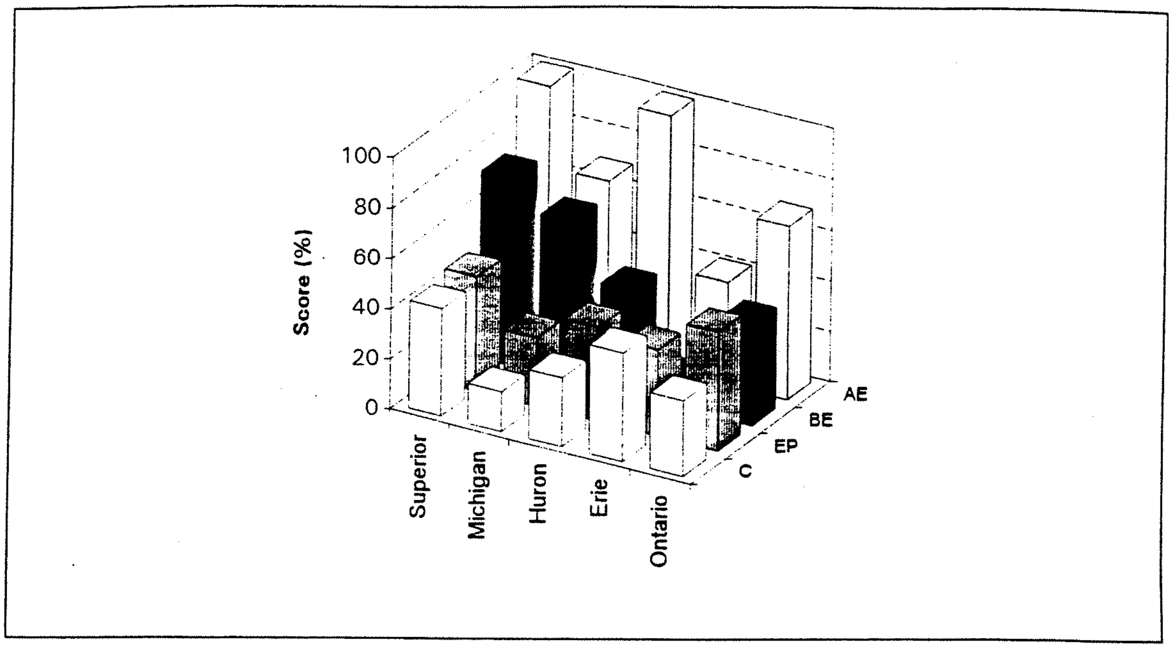

Score (%)
100
80
60
40
20
0
Superior
Michigan
Huron
Erie
Ontario
AE
BE
EP
C

Figure 6.

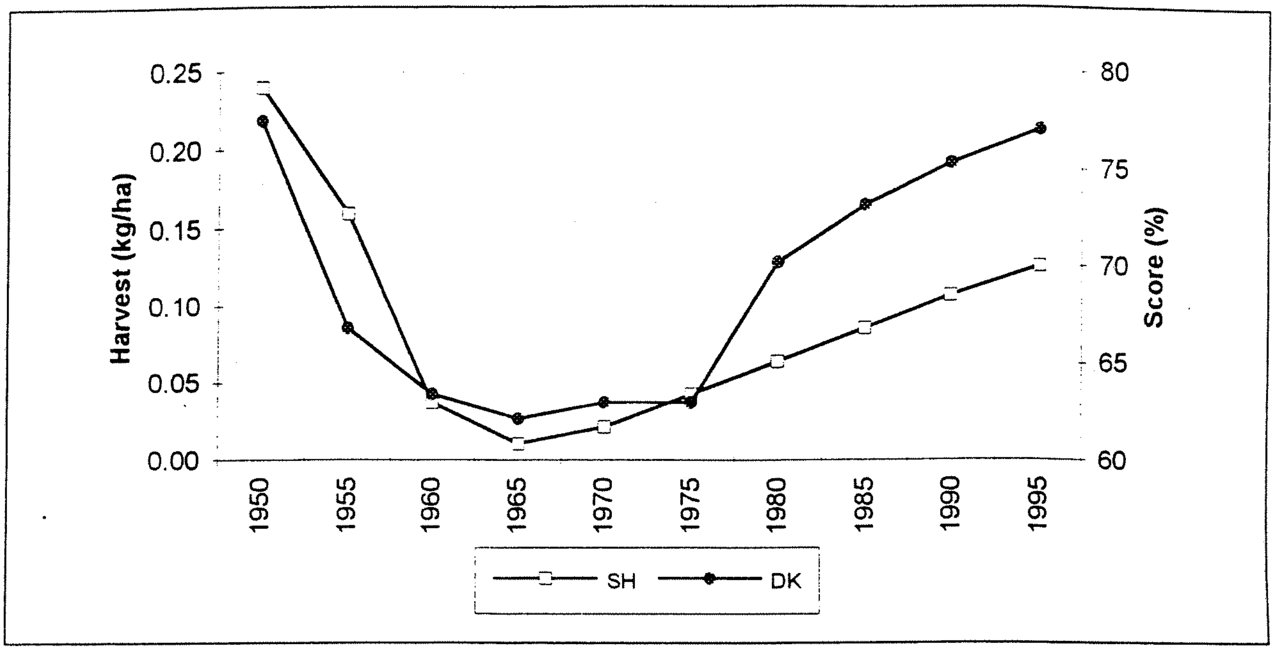
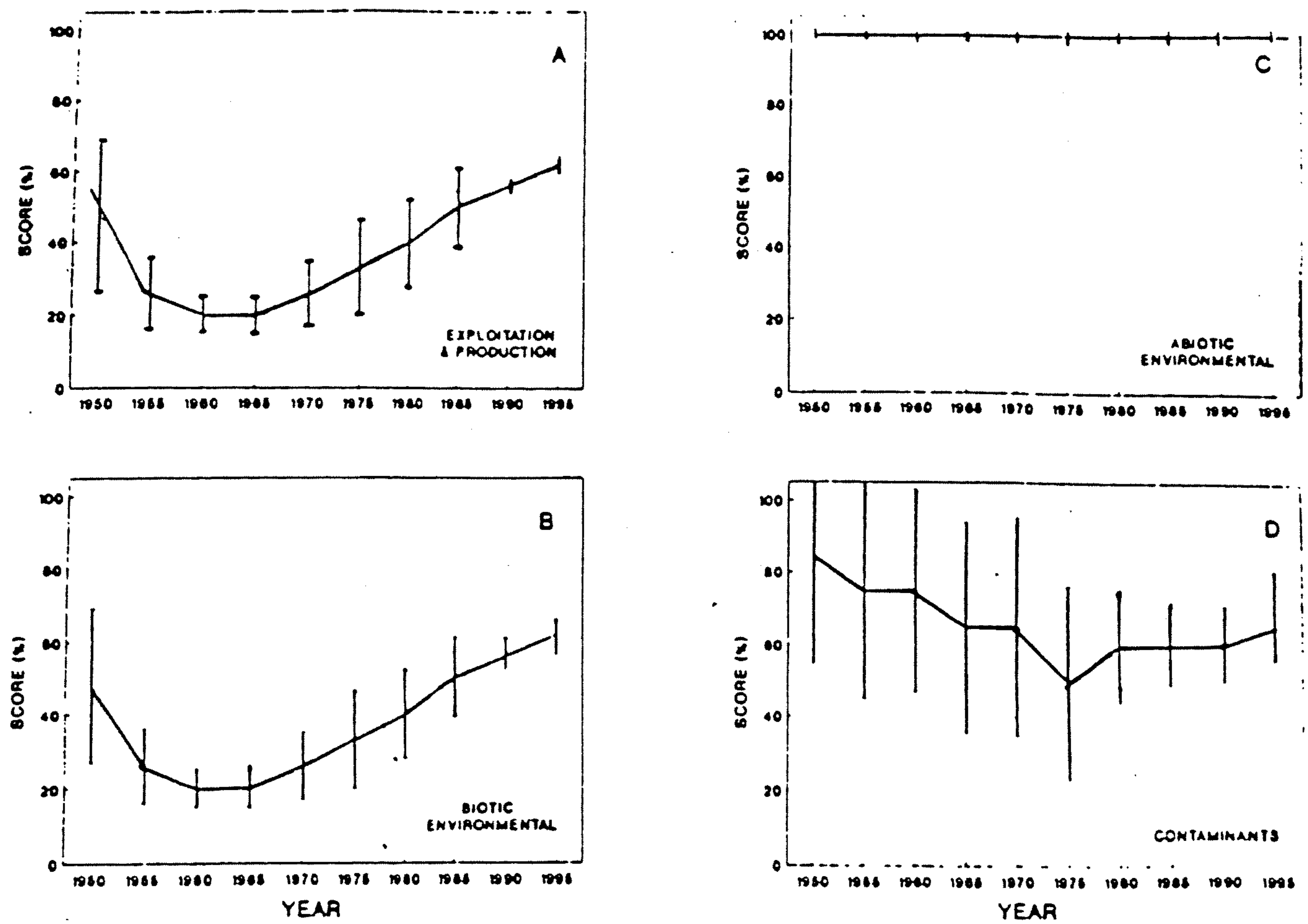

0.25
0.20
0.15
0.10
0.05
0.00
Harvest (kg/ha)
80
75
70
65
60
Score (%)
1950
1955
1960
1965
1970
1975
1980
1985
1990
1995
SH
DK

Figure 7.

Figure 8.



A
EXPLOITATION & PRODUCTION
B
BIOTIC ENVIRONMENTAL
C
ABIOTIC ENVIRONMENTAL
D
CONTAMINANTS
SCORE (%)
YEAR

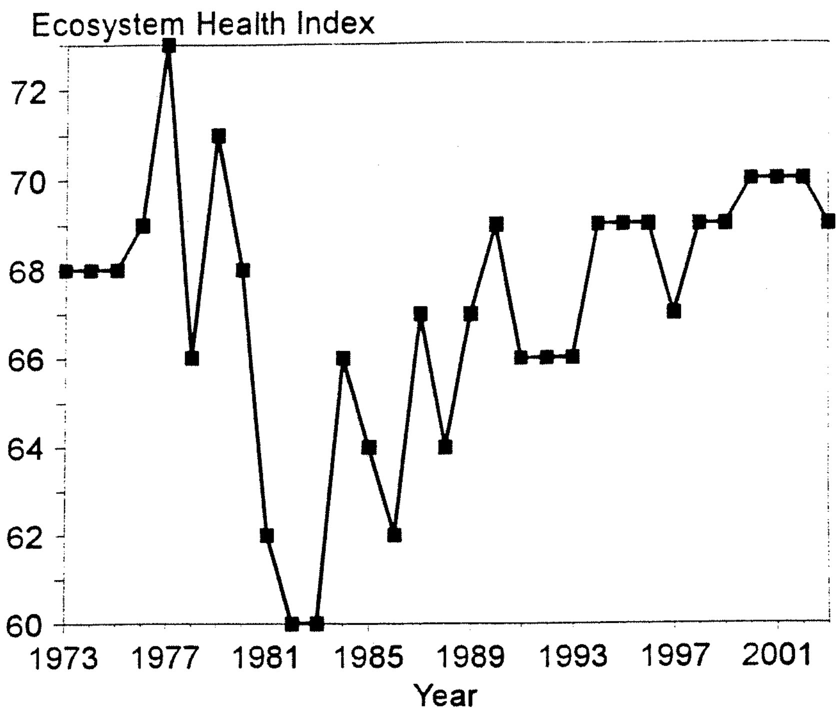

Ecosystem Health Index
72
70
68
66
64
62
60
1973
1977
1981
1985
1989
1993
1997
2001
Year

Figure 9.

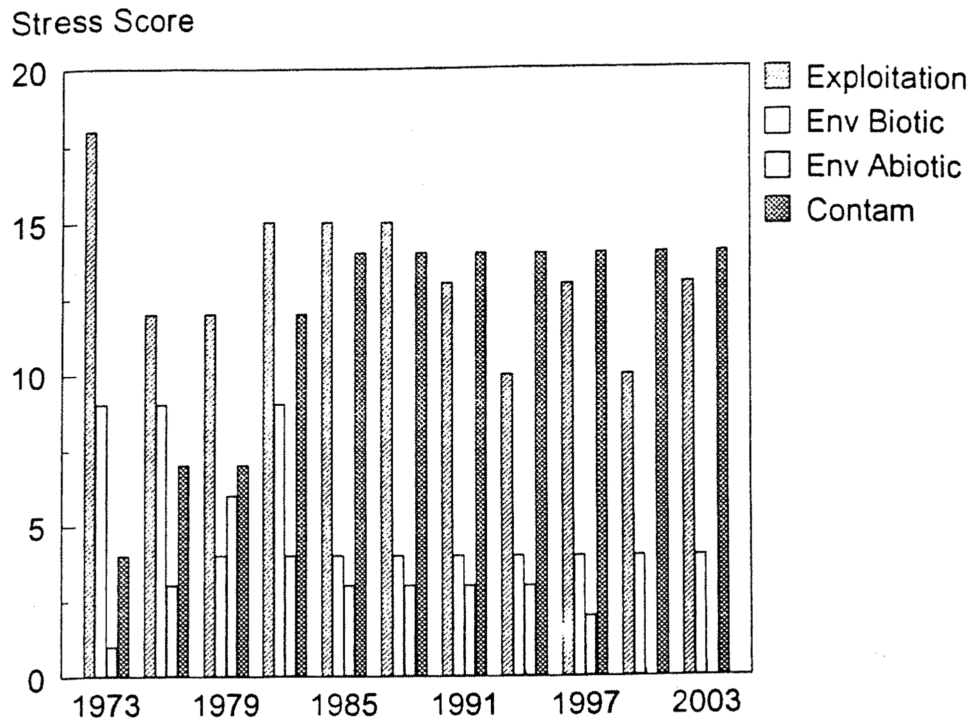

Stress Score
20
15
10
5
0
1973
1979
1985
1991
1997
2003
Exploitation
Env Biotic
Env Abiotic
Contam

Figure 10.

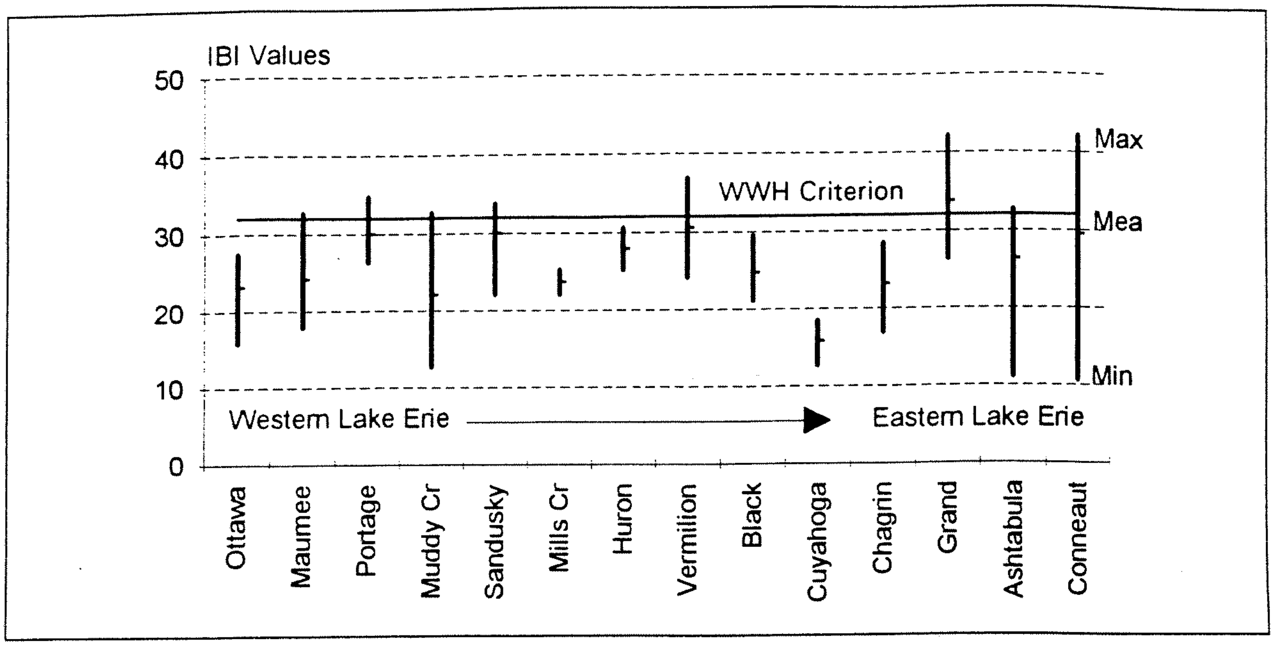

IBI Values
50
40
30
20
10
0
Max
Mea
Min
WWH Criterion
Western Lake Erie
Eastern Lake Erie
Ottawa
Maumee
Portage
Muddy Cr
Sandusky
Mills Cr
Huron
Vermilion
Black
Cuyahoga
Chagrin
Grand
Ashtabula
Conneaut

Figure 11

Appendix 4. Biocriteria Conference Manuscript

Appendix 4. Biocriteria Conference Manuscript

Problems in the Specification of End Points and Indicators for the Pelagic Zone of Lake Ontario

Presented at Midwest Environmental Indicators and Biocriteria Conference
Chicago, Illinois
May 3, 1993

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DRAFT 5/12/93

Appendix 4. Biocriteria Conference Manuscript

Abstract

Attempts to develop quantitative indicators and end points for the pelagic zone of Lake Ontario have raised a number of difficult issues that may be common to all efforts to develop environmental indicators for the Great Lakes. The objective of this paper is 1) to illustrate some of the problems in specifying end points and indicators that were encountered by a task group charged with implementing an ecosystem objective for the pelagic zone of Lake Ontario, and 2) to present evidence that solution of these problems will require new context and greater clarity in the statement of ecosystem objectives. Drawing on a case study of the Lake Ontario Pelagic Community Health Indicator Committee (LOPCHIC), the paper begins with the problem of establishing a unique set of quantitative end points from the stated ecosystem objective for the pelagic zone of Lake Ontario. The paper continues by showing that lack of a unifying context to use information from indicators of the state of the pelagic community further complicates linkage of indicators and end points to more fundamental ecosystem objectives. Solution of these problems may require reexamination of the process of developing ecosystem objectives. Because social preference plays such a large role in constraining choices and ecological theory provides incomplete guidance, the process of defining ecosystem objectives must not obscure the existence of trade-offs, which are needed, to restore and maintain Great Lakes ecosystems in desired states.

Keywords: ecosystem indicators, Lake Ontario, pelagic zone

Introduction

The 1978 Great Lakes Water Quality Agreement (GLWQA) committed the governments of Canada and the U.S. to an ecosystem approach for the management of the Great Lakes. This approach contrasted with the then prevailing "pollutant-by-pollutant" approach to the control of chemical pollution of the lower Great Lakes that characterized the 1972 GLWQA. To implement the 1978 GLWQA, the governments required the development of ecosystem objectives, and the International Joint Commission initiated a systematic exploration of the scientific basis for ecosystem objectives through its Science Advisory Board. The efforts of the Aquatic Ecosystems Objectives Committee, which was created by the Science Advisory Board to develop ecosystem objectives and indicators for the Great Lakes, led to proposed indicators based on surrogate organisms for oligotrophic waters (Ryder and Edwards 1985) and mesotrophic waters (Edwards and Ryder 1990). With the adoption of the 1987 Protocols to the GLWQA, the governments adopted a lake trout and *Pontoporeia hoyi* ecosystem objective for Lake Superior (Anon. 1987) and appointed a Binational Objectives Development Committee, which subsequently formed the Ecosystem Objectives Working Group (EOWG), to continue development of ecosystem objectives and indicators for the other Great Lakes.

This paper is a perspective on the problems in developing indicators and endpoints from the ecosystem objectives developed for Lake Ontario by the EOWG. Bertram and Reynoldson (1992) have summarized the approach taken by the EOWG and the goals and ecosystem objectives that the EOWG proposed for Lake Ontario in 1990. Subsequent to the statement of five broad ecosystem objectives for Lake Ontario, the EOWG created five technical committees to define indicators and endpoints for each of the ecosystem objectives. The subject of this paper is the work of the Lake Ontario Pelagic Community Health Indicators Committee (LOPCHIC) that the EOWG charged with identifying quantifiable indicators for the open water ecosystem objective.

Goals of Ecosystem Management and Ecosystem Objectives

The EOWG proposed three broad goals for the Lake Ontario ecosystem. As summarized by Bertram and Reynoldson (1992), these included:

- *The Lake Ontario ecosystem should be maintained and as necessary restored or enhanced to support self-reproducing diverse biological communities.*
- *The presence of contaminants shall not limit the use of fish, wildlife and waters of the Lake Ontario basin by humans and shall not cause adverse health effects in plants and animals.*
- *We as a society shall recognize our capacity to cause great changes in the ecosystem and we shall conduct our activities with responsible stewardship for the Lake Ontario basin.*

To clarify these goals, the EOWG proposed the following ecosystem objectives:

- *The waters of Lake Ontario shall support diverse healthy, reproducing and self-sustaining communities in dynamic equilibrium, with an emphasis on native species.*
- *The perpetuation of a healthy, diverse and self-sustaining wildlife community that utilizes the lake for habitat and/or food shall be ensured by attaining and sustaining the waters, coastal wetlands and upland habitats of the Lake Ontario basin in sufficient quality and quantity.*
- *The waters, plants and animals of Lake Ontario shall be free from contaminants and organisms resulting from human activities at levels that affect human health or aesthetic factors such as tainting, odor and turbidity.*

- *Lake Ontario offshore and nearshore zones and surrounding tributary, wetland and upland habitats shall be sufficient quality and quantity to support ecosystem objectives for health, productivity and distribution of plants and animals in and adjacent to Lake Ontario.*
- *Human activities and decisions shall embrace environmental ethics and a commitment to responsible stewardship.*

The first of these ecosystem objectives was assigned to the LOPCHIC. The charge to the committee was to evaluate published literature and identify appropriate, measurable indicators that could be used to monitor progress toward meeting the objectives. Implicitly, this charge also required the committee to establish endpoints for the indicators that would provide a basis for judgment of attainment of ecosystem objectives.

Developing Indicators and Endpoints for Lake Ontario

European colonization of North America subjected the Lake Ontario ecosystem to extreme degradation (Christie 1972). As a consequence of the degraded state of the ecosystem, restoration of Lake Ontario has not been guided by consistent visions of the future (Christie 1993). Therefore, one of the first acts of the LOPCHIC was to attempt a more explicit statement of the open water ecosystem objective:

> *Lake Ontario should be maintained as a steady-state ecosystem with self-sustaining stocks of lake trout and other native species as major, but not necessarily the only, top aquatic predators, and with appropriate lower trophic level composition and abundance to sustain ecosystem production.*

The need for this restatement was the first hint that identification of indicators for ecosystem objectives was not exclusively a scientific problem. The original and restated ecosystem objectives certainly rely on valid scientific principles. The key concepts in both objectives are the value of native species over exotic species, the importance of natural reproduction to restoration of self-sustaining populations, the need for preservation and restoration of biological diversity, and the tendency of a self-regulating community to exist in a dynamic equilibrium with its environment. Although these concepts are consistent with well-established principles of ecological energetics, they are not sufficient to describe a preferred or nominal structure of a biological community. All ecosystems whether degraded or pristine are adaptive. Within constraints of biological diversity, habitat structure, climate variability, variability of human interventions, ecosystems will tend toward characteristic nominal states. In a cybernetic context, the nominal state is the "target" and the return trajectory to the target following disturbance is a function of the strength of the adaptive feedback mechanisms or resilience and stability of the system. Judgment about the health of an ecosystem is always based on the integrity of the homeostatic mechanisms that maintain the nominal state, and as Rapport (1990) states, "...integrity refers to the capability of the system to remain intact, to self regulate in the face of internal or external stresses, and to evolve toward increasing complexity and integration." To identify indicators and appropriate endpoints, therefore, requires an explicit description of the nominal state of the ecosystem. The EOWG's first objective for the open waters of Lake Ontario was simply too general for the derivation of a description of nominal state, and the LOPCHIC preferred to adopt a more explicit objective.

In the revised ecosystem objective for the pelagic zone of Lake Ontario, the LOPCHIC invoked the historical biological community with lake trout as the major top predator. In part, preference for this nominal state is justifiable in scientific terms. Ryder (1990) argues that "...the only aquatic ecosystem that has persisted sufficiently long to exhibit the appropriate attributes of consistent integrity, enduring resilience, and tolerable levels of stability under a vast regimen of natural stresses is the moderately pristine condition as exemplified by the Great Lakes ecosystem of about 200 years ago." Ryder and Kerr (1990) reinforce this preference by noting that natural ecological communities tend to evolve toward co-adapted or harmonic assemblages. However, the history of colonization and invasion patterns of ecosystems are accidental, and multiple nominal states could evolve given slightly different composition of colonizing species. Many of the native species of Lake Ontario and their genetic diversity have been lost, and with the presence of various exotic species (e.g. alewife, smelt, and rainbow trout) that are self-sustaining, the scientific basis of preference for a particular nominal state loses force and is replaced by mix of pragmatism and social preferences, which are rooted in human value systems. In the end, the restated objective itself reflects this ambivalence. From it, no clear vision of a nominal state emerges. Rather, it functions more as a statement of bounds for acceptable nominal states.

Subsequent efforts of the LOPCHIC to identify appropriate indicators for its ecosystem objective for the pelagic zone of Lake Ontario did not absolutely require a clear vision of endpoint. The basic assumption was that, once identified, the characteristics of the appropriate indicators would provide the necessary context for more explicit consideration of the endpoint problem. Through its review and workshop discussions, the LOPCHIC proposed a set of six indicators of ecosystem function and a composite index based on a lake trout as a surrogate for ecosystem health (Christie 1993). The indicators of ecosystem function included: biomass particle size spectrum, total phosphorus concentration, mean size of zooplankton, biomass ratio of piscivore to prey fish, piscivore production or yield, proportion of salmonid recruitment due to wild fish, and diversity of fish species. The composite index was an extension of the Dichotomous Key (Ryder and Edwards 1985) as applied to Lake Ontario (Powers 1989, and Edwards *et al.* 1990).

The LOPCHIC preferred these indicators for a variety of reasons. The indicators of ecosystem function are primary indicators, being measurable with accepted methodology for data collection and feasible to monitor. Interpretative status of these indicators is also attractive. For the most part, theory of ecological energetics and a wealth of empirical data provide a basis from which to derive expectations for nominal values. Table 1 lists proposed nominal values and rationale for five of these indicators of ecosystem function. The weakness of these indicators is that the implied nominal values do not describe a unique set of endpoints corresponding to the ecosystem objectives or to the stated goals of ecosystem restoration.

Of the five indicators in Table 1, three depend upon theory of ecosystem energetics. Sheldon *et al.* (1972) provided a basis to relate size structure of a pelagic ecosystem to the energy flow up a spectrum of body sizes. Applications of this theory to the Great Lakes (Borgmann 1987; Minns *et al.* 1987; and Sprules *et al.* 1991) have shown the utility of the approach, and the LOPCHIC (Christie 1993) relied on it to rationalize endpoints summarized in Table 1. Boudreau and Dickie (1992), however, show that biomass spectra may have internal structure that depends upon the relative importance of zooplankton and benthos in the flow of energy to fish. Furthermore, Boudreau and Dickie (1992) argue that the primary level of the biomass spectrum is determined jointly by nutrient availability and the energy transfers within the system. Application of the theory, therefore, requires observations of the system in its nominal state, and these are only potentially available from historical states. However, historical states were not adequately monitored to obtain the proper data, and future nominal states must accommodate sustainable fisheries that in themselves alter the structure of the community.

The endpoint conundrum, therefore, persists. Ecosystem function is based on biological diversity. Evolutionary theory predicts that biological diversity will adapt to physical, chemical, and biological characteristics of an ecosystem, but chance and history act with this adaptive potential to prevent accurate prediction of the community structure (species composition, age composition, abundance, and distribution of individuals) that will be obtained in any ecosystem (cf. Mac Arthur 1972). The current mix of theory and empirical data underlying these indicators may have some important scale limitations. The Great Lakes are unique ecosystems. Their geological history and use by human populations makes a scientific determination of acceptable endpoints for the indicators virtually impossible. Scientific knowledge does provide a way of screening proposed endpoints for consistency with nominal standards of healthy ecosystems, but science is unable to indicate *a priori* which particular community structure is best or what constitutes acceptable types and levels of human activity in the ecosystem.

The LOPCHIC use of a surrogate organism to assess state of the ecosystem offers a possible solution to the problem of specifying meaningful endpoints for ecosystem objectives, but here again the solution is far from exclusively scientific. The surrogate organism approach to establishing indicators for ecosystem objectives has a longer history than the ecosystem function indicators. Under the auspices of the IJC, indicators based on surrogate organisms rose to prominence (Ryder and Edwards 1985, and Edwards and Ryder 1990). The Dichotomous Key implemented by Edwards *et al.* (1990) represents a composite index, which is referred to as an Indicator of Ecosystem Health (IEH) by LOPCHIC (Christie 1993), that combines a variety of information about the state of lake trout and their environment into a metric of ecosystem health. The endpoint for this metric is a score of 100, which represents an intact lake trout community in Lake Superior that existed about 200 years ago. Edwards *et al.* (1990) could apply this indicator to all of the Great Lakes because lake trout communities in the Great Lakes, perhaps in all of the Boreal region, showed similar evolutionary trends (cf. Loftus and Regier 1972). Powers (1989) applied this indicator to Lake Superior and Lake Ontario. Like Marshall *et al.* (1992), Powers (1989) found that Lake Superior showed a monotonic tendency to return toward the pristine endpoint. In Lake Ontario simulations, however, the IEH does not show this behavior. Figure 1 contrasts the trends that Powers (1989) obtained for the IEH with observed and predicted lake trout abundance. From the perspective of fishery management, sea lamprey control and stocking programs have generated an very important recreational fishery in Lake Ontario, but from an ecosystem perspective the system remains in an unhealthy state. This assessment of system state follows directly from the implicit reference of system health to a "natural" Lake Ontario ecosystem, which was dominated by native predator and prey fish species as called for in the ecosystem objectives. Because these remnants are still available in Lake Superior, the pristine system health appears to be a reachable goal for the endpoint of Lake Superior rehabilitation. However, no operational endpoint emerges for the Lake Ontario application of the IEH. This apparent lack of utility for Lake Ontario may be as much a policy problem as a technical problem of applying this measure of system health to severely degraded ecosystems. Alternatively (Ryder, personal communication), the recovery time for Lake Ontario may be much longer than for Lake Superior because of its more degraded condition.

Discussion

Bertram and Reynoldson (1992) maintain that indicators are needed to measure progress toward meeting ecosystem objectives. For some purposes this is indeed an important function of indicators. In a more general context of ecosystem management, however, indicators have a much more important role. Any set of ecosystem indicators are imbedded in a hierarchical set of ecological interactions and also a poorly coordinated hierarchy of ecosystem management jurisdictions and initiatives (cf. Evans *et al.* 1990). Koonce (1990) has argued that this lack of an integrating framework for ecosystem management creates serious obstacles for the use of indicators to characterize trends for the Great Lakes or to guide management actions to correct unacceptable stresses. I believe that the lack of this strategic planning context of ecosystem objectives, indicators, and endpoints is a fundamental omission in the approach adopted by the EOWG.

The main difficulty with the approach of EOWG is the lack of an explicit relation between ecosystem objectives and endpoints. I have argued above that choice of endpoints is not exclusively a scientific problem, but that scientific information could contribute to a rational approach to choosing endpoints. Three possible criteria to guide these choices are consistency of objectives and endpoints, satisfaction of objectives and goals with attainment of endpoints, and validity of endpoints. The role of scientific analysis is fairly clear only in the application of the first and last criteria. Judgments of validity, for example, depend upon scientific understanding of constraints on permissible states of an ecosystem. An endpoint that requires violation of fundamental principles of conservation of matter and energy is not valid. Consistency between objectives and endpoints is a factual issue, but effective screening of endpoints for consistency requires that some be inconsistent. The more general an objective is the smaller becomes the set of inconsistent endpoints. The ecosystem objective for open waters of Lake Ontario as originally stated by the EOWG admits a wide range of self-sustaining communities as candidate endpoints, many of which are mutually exclusive. Science alone can not determine which is better. On satisfaction of objective with attainment of endpoints, science is nearly silent. With generally stated ecosystem objectives, managers and members of the public may have quite different visions of a recovered ecosystem. Not all of these implicit visions will be satisfied by a particular endpoint, and the implicit visions may, in fact, have inherently conflicting demands of an endpoint community structure.

The ecosystem objectives for the open water of Lake Ontario, as proposed by the EOWG or as modified by the LOPCHIC, obscure some conflicting goals of management. Lake Ontario is an exploited ecosystem. It is used by industries, municipalities, fishers, boaters, and other user groups for a variety of purposes, which have varying degrees of compatibility. Fundamentally, ecosystem management must balance these multiple uses, but without explicit agreement on the endpoints, common ground is difficult to achieve. Even considering fisheries management alone, the stated ecosystem objectives hide a range of conflicting positions. The mix of top predators, for example, is an extremely important issue to recreational fisheries interests, but this decision has top-down effects on the rest of the ecosystem structure. Other issues such as the level of control of sea lamprey, role of stocking to supplement natural reproduction, and harvest levels and species mix affect various fisheries interests differently, but the stated ecosystem objectives do not have a context to place limits on acceptable human use of the ecosystems. Managers are thus forced to resolve conflicts that are really issues of policy, but resolution of policy conflicts in the creation of more specific ecosystem objectives raises the prospect of endless deliberations to balance opposing voices.

From the management perspective of an agency, endpoint specification is troublesome. In a multi-jurisdictional milieu, it is nearly chaotic. Linking endpoints and indicators, however, is required for coordination of management initiatives. One way of linking objectives, indicators, and endpoints is to employ a strategic planning process to coordinate management. Strategic planning begins with a clear statement of objectives, which include explicit endpoints and milestones, an ongoing assessment of the state of the system with reporting, and the specification of management initiatives according to the state of the system. The Joint Strategic Plan for Management of Great Lakes Fisheries (Anon. 1980) is an example of such a multi-agency strategic planning process. Ultimately, conflicts over endpoints are conflicts of use. Agreement on endpoints thus requires explicit consideration of conflicts in management goals. The fishery management agencies in the Great Lakes basin established a mechanism to resolve such conflicts in the management of fish stocks of common concern and required managers to develop fish community objectives for each of the Great Lakes. Although the implementation of this strategic planning framework is not complete, some important implications have emerged. The most important of these is that formulation of objectives is an open, iterative process. Agreement on strategic objectives is an evolutionary process. Much of the concern with formulating more explicit ecosystem objectives is the difficulty in obtaining agreement for the final draft of goals and endpoints. Rarely, is this possible. Agreement comes with a process of examining the consequences of various objectives and their inherent conflicting effects on various user groups. Formulation of strategic ecosystem objectives, therefore, must involve an iterative, process that serves to clarify the "vision" of a restored ecosystem as well as developing an understanding of the trade-offs required to achieve it. Science has an important role to play in helping identify the potential consequences of future management choices, to offer criticism concerning the validity of endpoints, and to help design programs to monitor state of the ecosystem. Social preference, ultimately, determines policy directions. Social preference, however, can be only as rational as the planning process that generates choices. In the context of ecosystem management of the Great Lakes, such a rational approach will require a new way of formulating ecosystem objectives. Investing in a strategic planning approach appears to be one way to try. Guidelines for strategic ecosystem objectives are thus: 1) view the development of ecosystem objectives as a progressive, "vision" clarification process; 2) develop endpoints from the objectives; and 3) include explicit milestones to gauge progress. Because of the range of conflicting interests in the Great Lakes region, such a strategic planning process will require a neutral forum within which common ground can be established. The framers of the Joint Plan for the Strategic Management of Great Lakes Fisheries used the Great Lakes Fishery Commission for this purpose. The challenge will be to find a comparable arena for ecosystem management in context of the Great Lakes Water Quality Agreement.

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Tables

Table 1. Ecosystem function indicators by the Lake Ontario Pelagic Community Health Indicator Committee and proposed endpoints.

Indicator	Endpoint
Biomass Size Spectrum	Even distribution of log-log allometry of biomass density on body size
Total Phosphorus	10 μg/l
Mean Zooplankton Size	0.8 to 1.2 mm
Piscivore production	1.25 to 2.5 kg $ha^{-1}yr^{-1}$
% wild salmonid recruitment	100%

Figures

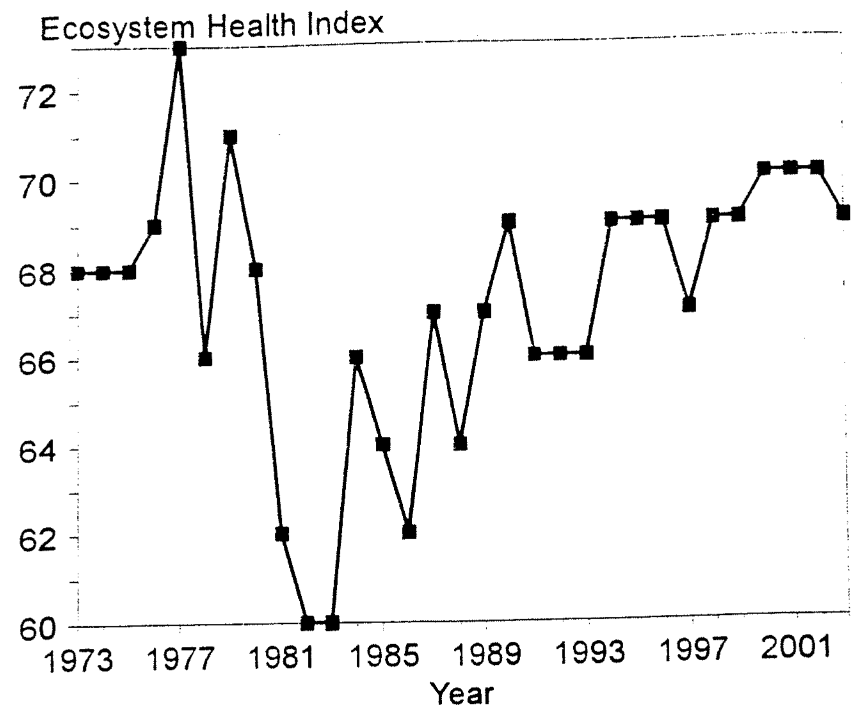

Figure 1.