Report to Congress

Great Lakes Fishery Resources Restoration Study

Report

U.S. Fish and Wildlife Service
Department of Interior

Prepared by

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Acknowledgements

The Service gratefully acknowledges our Bad River Tribal Council, Bay Mills Indian, Community of Michigan, Chippewa-Ottawa Treaty Fishery Management Authority, Grand Portage Reservation, Grand Traverse Band of Ottawa and Chippewa Indians, Great Lakes Fishery Commission, Great Lakes Commission, Great Lakes Indian Fish and Wildlife Commission, Illinois Department of Natural Resources, Indiana Department of Natural Resources, Keweenaw Bay Indian Community, Michigan Department of Natural Resources, Minnesota Department of Natural Resources, New York State Department of Environmental Conservation, Ohio Department of Natural Resources, Pennsylvania Fish and Boat Commission, Red Cliff Band of Lake Superior Chippewa Indians, Sault Ste. Marie Band of Chippewa Indians, U.S. Army Corps of Engineers, U.S. Environmental Protection Agency-Great Lakes National Program Office, U.S. National Biological Service-Great Lakes Science Center, and Wisconsin Department of Natural Resources partners for assistance in contributing information to and reviewing drafts of this document and for their many helpful comments and suggestions.

Without the tireless, selfless, and dedicated efforts of Service staff in the Great Lakes Coordination Office and the Lower Great Lakes, Alpena, Green Bay, and Ashland Fishery Resources Offices, this report could not have been completed.

United States Department of the Interior

FISH AND WILDLIFE SERVICE
Washington, D.C. 20240

IN REPLY REFER TO:

FWS/MA

SEP 13 1995

The Honorable Albert Gore, Jr.
President of the Senate
Washington, D.C. 20510

Dear Mr. President:

We are pleased to submit the Great Lakes Fishery Resources Study that was undertaken pursuant to Section 2005(a) of the Great Lakes Fish and Wildlife Restoration Act, P.L. 101-537. This report focuses on the status of fishery resources and habitat in the Great Lakes Basin including the effectiveness of present management plans, and analysis of the impacts and management control alternatives for recently introduced nonindigenous species. Recommendations have been developed regarding those actions necessary to restore the fishery resources of the Great Lakes Basin to sustainable levels. Please do not hesitate to contact our office if you have any questions or comments.

Sincerely,

Director

Enclosure

United States Department of the Interior

FISH AND WILDLIFE SERVICE
Washington, D.C. 20240

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The Honorable Newt Gingrich
Speaker of the House of Representatives
Washington, D.C. 20510

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Sincerely,

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Executive Summary

The *Great Lakes Fish and Wildlife Restoration Act* (1990), hereafter called the Act, outlines activities that the U.S. Fish and Wildlife Service (Service) and the Corps of Engineers will undertake to assist the management, protection, and restoration of the natural resources of the interjurisdictional, bi-national basin of the Great Lakes. The Great Lakes Fishery Resources Restoration Study (Study) presented in this report is one of the required activities of the Act. The Act includes recognition that the system is addressed by many institutions, is large, and is ecologically complex.

Management, protection, and restoration of Great Lakes resources provides unique challenges. One of the challenges involves the size, more comparable to oceans than lakes, resulting in the need to use research tools such as "ocean type" vessels. Scientific challenges include questions concerning the applicability of site specific data to understand natural resource problems at the sub-basin, basin, or whole lake level, since jurisdictional field investigations are often limited to their home area and natural resources are not limited by political boundaries. Other challenges are the maintenance of costly, long-term, data collection programs and the use and compatibility of data from various sources and time periods to understand ecosystem health trend analyses.

The U.S. Federal, Native American Tribal, and State governments have collaborated to jointly initiate projects to better understand and rehabilitate the ecosystem. The States have primary jurisdiction over resident fish and wildlife in the Great Lakes Basin and human activities affecting these species. The Service conducts activities under numerous Federal authorities that generally relate to migratory and interjurisdictional species and habitat. Such laws include, but are not limited to the *Fish and Wildlife Act of 1956*, *Endangered Species Act*, *Migratory Bird Treaty Act*, and the *Nonindigenous Aquatic Nuisance Prevention and Control Act* (see Appendix III). The U.S. Federal government has negotiated bi-national treaties concerning the Great Lakes. These treaties provide for international cooperation between the U.S. and Canadian Federal governments. Protection of bi-national ecosystem health is a Federal role in the *Boundary Waters Treaty* (1909).

Several Native American tribal governments have treaties with the United States, through which they retained rights to harvest fish and, in some cases wild game and other natural resources, in ceded territories. These Native American Tribes have implemented management programs to regulate their harvest, restore, and enhance natural resources, and coordinate with State and U.S. and Canadian Federal governments. Native American Tribes, as active partners in management of the Great Lakes, bring a unique and valuable perspective that is based on their long history, pre-dating that of the U.S. and Canada, and their strong ethic for conserving resources for the "Seventh Generation".

The Act provides the basis for agencies of the U.S. Federal government to work in partnership with Great Lakes States and Native American Tribes and to address resource management problems of the bi-national basin. The Act also provides for coordination of U.S. Federal activities. The Act became law in November, 1990, and limited funds have been appropriated since Fiscal Year 1992 (Figure 1). Efforts were made to use these funds to address completion of the Study, conduct specific restoration projects, provide additional scientific information upon which to conduct management actions, provide fiscal/partnership support, and enhance coordination activities between State, Native American Tribal, and Federal agencies.

This report details the results of the Study and makes specific Findings and Recommendations which immediately follow the Executive Summary for the convenience of the reader. These Findings and Recommendations are based upon information contained in the body of the Study report and the Recommendations are summarized in tabular format in Appendix I.

Great Lakes fish species status and trends are subjectively summarized in Appendix II, providing a current overview of the status of knowledge, or lack thereof, of fish communities of the Great Lakes Basin. This information will be updated in future biennial reports to Congress on progress made with respect to the Act.

Implementation of Study recommendations will enable careful management of the living resources of the Great Lakes, ensuring maximum public benefit and guaranteeing perpetuation of these resources. Agreed-upon goals and objectives of international cooperative efforts in the Great Lakes Basin between the U.S. and Canada will be realized as the health of fish and wildlife resources improves. When viable and productive stocks of native and other desired fish species are available, bald eagles successfully reproduce and inhabit shorelines, mink and otter once again claim their habitat, chemical and other stress-induced deformities in fish and wildlife are eliminated, and fish and wildlife can be consumed with little or no risk to human health, then restoration goals for the Great Lakes Basin will have been met.

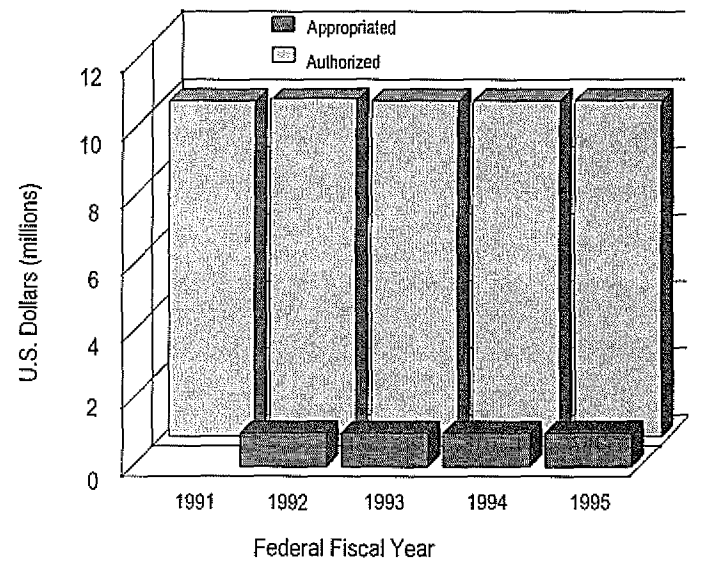


Figure 1. Appropriations and authorized funding levels for the Great Lakes Fish and Wildlife Restoration Act of 1990.

Findings and Recommendations

Findings

Basin-wide findings

Restoring the Great Lakes ecosystem, home for 10 percent of the U.S., and 25 percent of the Canadian populations, to a condition that meets the needs identified by society, will require that increased efforts be undertaken, both to quantify these needs and to address them. Working under the cooperatively developed guidance of the *Strategic Plan for Management of Great Lakes Fisheries* (Great Lakes Fishery Commission 1980) and the *Great Lakes Water Quality Agreement*, State, Provincial, Native American Tribal, and Federal agencies bordering the Great Lakes have made significant progress toward the goal of restoring a healthy fish community to the lakes. These resource agencies are working under budget constraints and only the highest priority activities are undertaken. Much of what has been gained could be lost without adequate support. The Act authorizes increased funding for resource agencies to address the most pressing needs in the Great Lakes.

Restoration of the Great Lakes is a complex process requiring the cooperation of local, City, County, State, Provincial, Native American Tribal and Federal agencies in addition to many conservation and public interest groups. Within a governmental agency, there can often be dramatic differences in how the resource management and environmental sections of the agency approach Great Lakes issues. In the future, environmental 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. Concepts of responsible resource use and management and biological conservation should not be at odds, but should be integrated via partnerships to meet future needs. Information exchange and cross program forums should be established to encourage management and environmental policies to be endorsed as one.

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.

Lake Ontario findings

The Lake Ontario ecosystem has undergone significant declines in productivity during the 1980s that parallel reductions in phosphorous concentrations; resulting in a return to an oligotrophic lake trophic level. Prey fish (alewife and rainbow smelt) production and biomass levels are declining. This predator/prey imbalance is leading to reductions in predator survival and growth, which have caused managers to change their stocking strategies by reducing stocking levels in 1993 and 1994. However, water quality improvements, reduced exploitation and recent reductions in alewife and rainbow smelt have increased the feasibility of restoring ciscoes and sculpins, the once major components of the prey fish community in Lake Ontario. The restoration of these species is a significant element of current and future restoration plans for indigenous top predators, such as lake trout and Atlantic salmon.

Lake Ontario's lake trout population disappeared due to habitat degradation and overexploitation. Lake trout restoration is currently progressing; however, numerous information gaps remain, limiting further advancement. According to the existing *Draft Lake Ontario Lake Trout Rehabilitation Plan - 1990 Revision*, by the Lake Trout Technical Committee of the Lake Ontario Committee, Great Lakes Fishery Commission, issues expected to affect lake trout rehabilitation in Lake Ontario within the next decade fall into three groups: (1) spawning dynamics and early life history; (2) spawning and nursery habitat; and (3) population maintenance and fish community interactions.

Atlantic salmon were extirpated from Lake Ontario in the late 1800s. As interest and involvement in Atlantic salmon restoration increases, it is necessary to assess and prioritize historic spawning tributaries, potential habitat, and current impairments to Atlantic salmon restoration. A total of 200,000 Atlantic salmon fry are allocated for annual stocking in Lake Ontario, but this target has not been met due to the lack of availability of fish. This target could be met, if feasibility studies relating to the establishment of Atlantic salmon populations in Lake Ontario tributaries were incorporated with restoration efforts. Limited feasibility studies are currently addressing survival, reproduction, and recruitment. Other issues limiting restoration include: development of a large scale Atlantic salmon broodstock and production program; and addressing genetics, fish health, product evaluation, and rearing and instream flow requirements.

An abundance of data have been collected, are available and continue to be compiled to describe past changes and current conditions in Lake Ontario. However, research addressing other critical components within the system is not being conducted. Habitat concerns in Lake Ontario encompass the physical, chemical and biological environment required to support the aquatic community. Limited abundance, distribution and productivity of species, and poor habitat quality and quantity are obstacles to restoring and maintaining the aquatic community. Protection and restoration of sensitive habitats such as spawning and nursery grounds, and improved upstream and downstream passage are critical issues requiring action.

The recent recognition of the need to revise the *Fish Community Goals and Objectives for Lake Ontario* by the agencies charged with management of the lake is an important step in designing the future direction of restoration of a healthy ecosystem in Lake Ontario. Beyond the scope of the individual species involved, the *Fish Community Goals and Objectives for Lake Ontario* address concurrently important issues such as habitat and genetic integrity. Many of the identified fishery management needs are already ongoing such as lake trout restoration recovery plans; others, such as lake sturgeon recovery plans and an Atlantic salmon broodstock program, are currently being initiated.

The Lake Ontario basin and its aquatic resources provide great opportunities. Long-term maintenance should focus on an ecosystem approach in order to preserve and enhance the current habitat resources in the basin.

Lake Erie findings

Lake Erie is highly susceptible to environmental changes because of its shallowness, low water volume, and its location among the Great Lakes. Changes are rapid and involve the majority of the lake since the shallow nearshore area comprises over 80% of the total surface area. Implementation of phosphorus abatement programs over the past two decades has been a success in reducing the overall productivity of the system and eliminating algal blooms and fish kills. However, continuing improvement in water quality may result in a less productive system. Fish community structure is expected to change and productivity is expected to decline as system productivity declines. These less productive conditions may favor a return of indigenous fish species indicative of oligotrophy, such as lake herring and lake whitefish.

A general lack of information exists on the nearshore fish community. Information exists for the economically and recreationally important walleye, smallmouth bass, and yellow perch which have been monitored regularly by the

States since the 1970s. While these three species have generally been targets for monitoring programs, some information on other species has been collected. Monitoring assessments employ different gear throughout the lake making it difficult to compare or combine information. Attempts have been made to combine data for walleye and yellow perch to estimate population size using the CAGEAN model, but results are questionable. Causes of many of the current trends are unknown.

An ecosystem approach to monitoring of the aquatic community is required. Such an approach would include monitoring nutrient levels and lower trophic levels such as phytoplankton and zooplankton populations. A monitoring program for zooplankton has been initiated, but needs to be made current. Monitoring programs need to be expanded to other trophic levels.

Improvements in the water quality of Areas of Concern, such as in the Buffalo River, have allowed fish and wildlife to return. However, impairments to complete restoration still exist. Beneficial use impairments include: restrictions on fish and wildlife consumption; dissolved oxygen depletion; existence of fish tumors and other deformities; contaminated sediments; degradation of the benthos; and loss of fish and wildlife habitat.

Human activities have destroyed many important habitats within the basin. Remaining habitats important to fish and wildlife as feeding, breeding, nesting, spawning and nursery areas may still be in danger of destruction.

The recent development of draft Fish Community Goals and Objectives for Lake Erie by the agencies charged with management of the lake is an important step in designing the future direction of restoration of a healthy ecosystem in Lake Erie. Beyond the scope of the individual species involved, the *Fish Community Goals and Objectives* for Lake Erie address concurrently important issues such as habitat and genetic integrity. Many of the identified fishery management needs are already ongoing, such as lake trout restoration recovery plans, and others including Lake sturgeon recovery plans are currently being initiated.

Lake Huron findings

With the exception of regions near population centers such as inner Saginaw Bay and Georgian Bay, the limnological condition of Lake Huron has changed very little since the 1800s. It remains a deep oligotrophic lake.

The fish community of the lake, however, has undergone dramatic change due to a number of factors. Over-exploitation, habitat loss and degradation and introduction of nonindigenous fish species have combined to cause alterations that, in many cases, are irreversible.

Historically, Lake Huron ranks third among the Great Lakes in commercial fish production. Lake trout and lake herring ranked one and two in total catch through 1940. Although excessive harvest coupled with degraded water quality and habitat alteration depressed lake trout stocks in many locations, the introduction of sea lamprey led to the final collapse of lake trout in Lake Huron. Eutrophication of Saginaw Bay, a primary production area for lake herring in the main basin, was a major contributor to the collapse of lake herring populations. Innovations in commercial fishing gear added further pressures to a declining Lake Huron fish community. The introduction and use of the deep-water trap net is thought to be a major contributor to the collapse of the lake whitefish fishery in Lake Huron.

The introduction of nonindigenous species such as alewife and rainbow smelt further aggravated the increasing instability of the Lake Huron fish community. In some cases the nonindigenous players simply filled voids created by lost stocks, and flourished. In other cases they directly competed with indigenous species and assisted in declines of those stocks.

In all, the present day fish community and the food web that drives the system only vaguely resembles that of the early 1800s. This is not to say, however, that all changes have been negative. Active fishery management, necessitated by the declining health of the system, has led to a far better understanding of the interaction between individual components of the ecosystem, and, in many cases, to recovery of some species. Much work remains, however, before stability can be returned to the system.

The recent development of *Fish Community Goals and Objectives for Lake Huron* by the agencies charged with management of the lake is an important first step in describing a healthy ecosystem in Lake Huron. Beyond the scope of the individual species involved, the *Fish Community Goals and Objectives for Lake Huron* address important issues such as habitat and genetic integrity. Many of the identified fishery management needs are ongoing, such as lake trout rehabilitation, whereas others, including lake sturgeon recovery plans, are currently being initiated. Unfortunately, the needs far outweigh existing capabilities.

Lake Michigan findings

Historically, Lake Michigan was the most productive of the oligotrophic Great Lakes in terms of yield to the commercial fishery. The indigenous fish community that supported that yield was drastically altered by the invasion of nonindigenous species such as sea lamprey and alewife, heavy fishing pressure, and habitat degradation. Indigenous species such as lake sturgeon stocks were drastically reduced in the early 1920s from over exploitation and habitat degradation; lake trout stocks were extirpated in the 1950s with the dramatic increase in sea lamprey abundance; and yellow perch, lake herring, burbot and bloater, declined precipitously in the 1960s following the explosion of alewife. By the 1960s, alewife comprised up to 80 percent of the total fish biomass in Lake Michigan. They died and washed up in great numbers, leaving a smelly rotten odor along shorelines and beaches, because the lake could not support that level of alewife biomass. Chinook and coho salmon, brown trout and rainbow trout were introduced in the late 1960s to reduce the burgeoning alewife population and create an enhanced sport fishery.

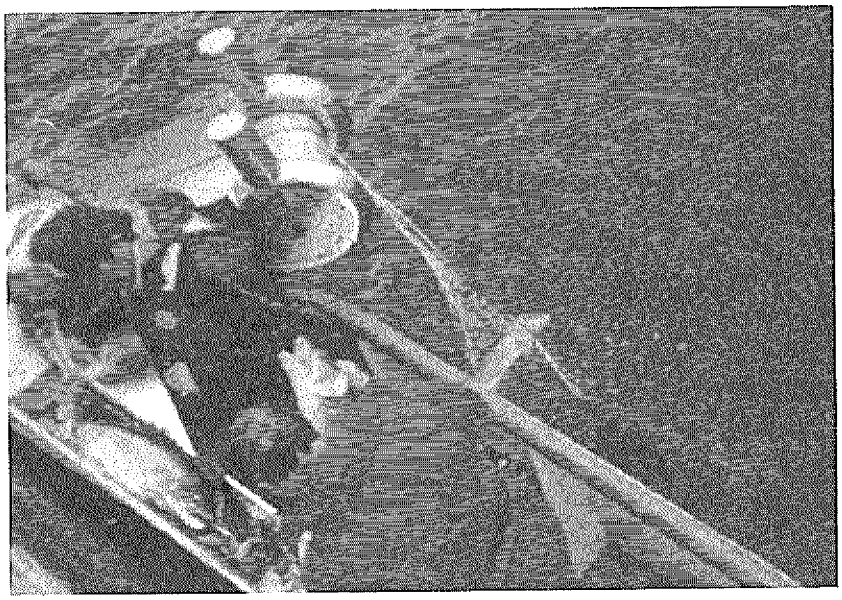
Significant progress has been made in the rehabilitation of fish communities in Lake Michigan in the last 30-35 years. Reduced sea lamprey numbers, as a result of annual chemical treatments in spawning streams, has reduced lamprey-induced mortality to the point that efforts to reestablish stocks of lake trout could proceed. The intensive hatchery program that developed to stock Pacific salmon and other stream trout created a trout and salmon sport fishery second to none. Increased salmonine predation on alewives, coupled with environmental variation, substantially reduced the alewife population to the point where indigenous fish species had an opportunity to rebound. In the 1980s, bloater rebounded to abundance levels that exceeded those of alewives at their earlier peak; and yellow perch rebounded to levels that produced near record total harvest. Lack of sustained natural reproduction of lake trout and recent declines in chinook and coho stocks, continue to highlight the need for further rehabilitation of Lake Michigan. Single species management, the focus of rehabilitation efforts thus far, will have to evolve to managing the fish community as a whole following guidelines now being developed for ecosystem management.

Fishery agencies who cooperatively manage Lake Michigan, have recently developed draft *Fish Community Goals and Objectives* to guide fisheries rehabilitation. Though it focuses on the fisheries portion of the Lake Michigan ecosystem, it recognizes that the *Great Lakes Water Quality Agreement* also needs to be pursued aggressively. Community analyses need to be applied to all trophic levels to meet future information needs.

Lake Superior findings

Lake Superior is the least altered of the Great Lakes, yet the lake, its fishery and its watershed have been significantly degraded. Lake herring, which made up the bulk of the historical commercial catch, have begun to recover following severe depletion. Lake trout, the most economically valuable species in the historical catch, have largely recovered offshore. The status of inshore lake trout stocks is mixed. Some have largely recovered due to stocking and sea lamprey control. Recovery of others is in early stages, or has been slowed by fishery harvest. Some nearshore fishes, especially lake sturgeon and coaster brook trout, are far below historical levels due to overfishing, habitat changes, and effects of introduced species. Two tributary fishes are extirpated from the watershed, and one deepwater species is a candidate for threatened status.

Aquatic habitat is generally of good quality, though toxic contaminants are widespread at low levels in the water and sediments. Tributary streams are important for the spawning of some fishes, but some streams are significantly degraded by activities in the watershed, including logging, agriculture, mining and hydropower dams. Nonindigenous species have had perhaps the greatest irreversible effect on Lake Superior: sea lamprey continue to kill thousands of lake trout, rainbow smelt have largely replaced indigenous species as inshore forage, and ruffe threaten the nearshore coolwater fish community. Nevertheless, the agencies that cooperatively manage Lake Superior have made much progress in the past 25-35 years. They have described their vision for the future in the *Fish Community Goals and Objectives for Lake Superior*, and have reported their progress in achieving that vision in "State of the Lake" reports.



Alpena Fishery Resources Office photo

Recommendations

The following recommendations, except where specifically indicated, address issues common to all five of the Great Lakes and their watersheds. These recommendations (see Appendix I for a tabular representation of these recommendations including title and period) identify priorities not currently funded through any of the agencies, but considered essential to meet the *Fish Community Goals and Objectives* for each of the Great Lakes. Funding necessary to accomplish some of these tasks would be provided to the partners on an equal cost-share basis by the Service, as funds become available. Funding of projects would be accomplished based upon priorities established via a multi-agency committee project approval process to be developed by the Service, the Great Lakes Fishery Commission, and the State and Native American Tribal partners and other interested parties.

All recommendations included in this report assume the effective establishment of the aforementioned project approval process, are not limited to funding through or implementation by the Service, and rely heavily on input, funding, and future cooperation among Great Lakes Basin partners. It is expected that future projects addressing these recommendations will focus first on implementation where information is sufficient and on data collection where information is lacking. The Service and Great Lakes Basin partners will work with Congress to further develop these recommendations, some of which could be carried out within existing resources.

1 Develop and Adopt Aquatic Community and Habitat Goals and Objectives to Support Ecosystem Management

Create a mechanism to promote strategic planning, monitoring, and coordination of management activity on a lake-by-lake basis. This will require reconsideration of the central role of objective setting. Various agreements mandate the development of *Ecosystem Objectives*, *Fish Community Goals and Objectives*, and *Environmental Objectives* for the Great Lakes. Ambiguities associated with these objectives, however, have made derivation of indicators and end points nearly impossible and 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. In cooperation with the International Joint Commission, Great Lakes Commission, Great Lakes Fishery Commission, other interjurisdictional agencies, the States' resource agencies and Native American Tribal partners, Aquatic Community and Habitat Goals and Objectives should be developed and adopted.

2 Fully Implement the *Strategic Plan for Management of Great Lakes Fisheries*

The *Great Lakes Fishery Convention* and the *Strategic Plan for Management of Great Lakes Fisheries* provide institutional frameworks for coordination of fishery management on the Great Lakes, and linkages to environmental management of the Great Lakes. However, the parties signatory to these agreements need to increase their commitment to implementing these frameworks if the agreements are to be successful. In addition, the Great Lakes Fishery Commission and U.S. and Canadian Federal Governments should quickly propose and provide arbitration procedures acceptable to all signatories of the plan including an evaluation process. If funded at authorized levels, the Act could support the efforts of the signatory parties.

3 Conduct Comprehensive and Standardized Ecological Monitoring

Lack of sufficient ecological information exists to make well advised decisions. Limited ecological monitoring at different trophic levels is occurring, however, this needs to be broadened among States, Provinces and agencies, and in time and space. Using improved methods and techniques that are currently being developed, monitor all offshore, nearshore and tributary areas and trophic levels of the ecosystem. Efforts should include density and diversity measurements of the aquatic community, especially phytoplankton, zooplankton, and benthic organisms.

4 Standardize Fish Community Assessment Data and Establish Comprehensive Fishery Databases

Compatibility of assessment data between management agencies is required to meet future needs of the Great Lakes fish community. Usefulness of collected assessment data could be enhanced by establishing database systems that enable maintenance of data integrity among all agencies. The Service should work with other Federal and non-Federal agencies, as appropriate, to develop a uniform, comprehensive lake-wide database containing all available information on: commercial and recreational catch in U.S. waters; fish stocking; stock assessment; coded-wire tagging; and mark-recapture statistics. These databases should be updated on a timely basis in concert with the Lake Technical Committees and individual jurisdictions to achieve data quality and uniformity, as well as continuity with historic data. Programs that will benefit from data standardization include lake-wide creel census programs, lake-wide assessment surveys, stocking programs and recovery of externally and internally marked fish including those with binary coded-wire tags. Protocols for data collection, storage and analyses will be developed along with a database management system that will make information accessible to all agencies.

5 Develop Offshore Capabilities

One or more capable offshore research vessels should be deployed on Lake Superior to gather information on offshore and pelagic fish stocks. Construction of the vessel already funded by the U.S. Congress should be completed without further delay. Midwater trawling and hydroacoustics should be incorporated with bottom trawling to better estimate total species biomass and distribution in all areas of the lake.

6 Fish Community Assessment Program

The need to move to fish community management will require fish community research and monitoring. Many current monitoring programs target a single species, often in limited areas. New methods of sampling need to be developed to assess fish communities and their use of available habitat. Understanding fish recruitment mechanisms and the interaction between species before recruitment, will enable managers to develop strategies that will promote self-sustaining fish populations. Ongoing assessment of forage species with hydroacoustic and trawling gear needs to be expanded to include assessments of predator and inshore species. Due to limited vessels to conduct lake-wide assessments, the testing and development of new techniques would require a multi-agency effort. Incorporating existing monitoring programs, such as those using binary coded-wire tags, into a lake-wide fish community assessment also needs to be evaluated. Development and testing of new sampling gear and subsequent protocols will likely take a minimum of five years, after which a specific annual assessment program could be initiated.

7 Fish Community Modelling

Population models combining ecological theory and population dynamics information from assessment programs are useful tools for testing our knowledge of Great Lakes fish community functions and predicting responses to management actions. Recent modelling exercises such as SIMPLE (Sustainability of Intensively Managed Populations in Lake Ecosystems) and IMSL (Integrated Management of Sea Lamprey) have provided valuable insight on species interactions in Lake Michigan, but these models need to be adapted for use in the other Lakes. Further development of population modelling coupled with an enhanced lake-wide assessment program will provide a powerful and necessary tool for the rehabilitation and management of Great Lakes fisheries.

8 Coordinate State and Native American Tribal Harvest Monitoring and Management: Measure Commercial and Recreational Fish Catches

The Service should assist State and Native American Tribal governments in coordination of harvest monitoring and management to ensure that the fishery resource is protected, consistent with the sovereignty and rights of the respective governments. Standardized commercial catch and effort databases need to be developed and historical catch and effort data needs to be integrated with these standardized databases. In addition, fishery agencies should fund and conduct a basin-wide survey to estimate commercial catch and effort, and repeat the survey annually. Currently some agencies conduct recreational fishery surveys while others lack resources to do so. Standard basin-wide creel surveys provide biological, social and economic information for planning and evaluating management actions. A basin-wide creel survey should be conducted to estimate recreational angler catch and effort, the survey should be repeated at intervals sufficient to detect trends in the recreational fishery. The Service should work with the States and Canadian agencies to promote complete creel survey coverage of a uniform quality throughout the Great Lakes.

9 Evaluate Ecological Effects of Stocking and Revise Stocking Strategies, as Necessary, to be Consistent with Proposed Aquatic Community and Habitat Goals and Objectives

Stocking is used throughout the Great Lakes, however the effects of stocking large numbers of fish on the ecosystem and its ability to sustain those fish is not clearly understood. One technique contributing to the evaluation of the ecological effect of stocking is marking all stocked fish. Marking provides an indirect means of measuring natural reproduction by comparing the contribution of marked and unmarked fish in the fisheries, and a means of evaluating the effectiveness of stocking programs. Where stocking is deemed necessary for restoration or to support local fisheries, stocked fish should be distinctively marked to distinguish them from wild fish of the same species.

10 Ecological Information Clearinghouse/Geographic Information System

To evaluate net loss or gain of fish and wildlife habitat, establish a uniform, comprehensive basin-wide ecological database containing all available information linked to physical location in the each of the Great Lakes. In consultation with the International Joint Commission, Great Lakes Commission, Great Lakes Fishery Commission, other interjurisdictional agencies, the States' resource agencies and Native American Tribal partners, provide, for each Lake, a single clearinghouse for compiled ecological information to meet research and management needs. It is envisioned that this effort would consist of a distributed network, with each agency maintaining its own data in-house and shipping updated files to the ecological information clearinghouse as necessary in read-only format (this process could be made automatic and transparent). For each of the Great Lakes, a comprehensive Geographic Information System

would house the ecological information. Several initiatives have made progress in the development of Geographic Information System databases, but more effort is required. This effort would focus on determining lake-wide Geographic Information System needs for each Lake and consolidating/interfacing existing Geographic Information System efforts to ensure comparability.

11 Identify, Inventory, Protect and Rehabilitate Significant Habitats

Significant habitats necessary for self-sustaining populations of fish and wildlife are threatened or impaired. Actions should include: identifying and protecting habitats used by fish and wildlife for spawning, breeding, nesting, rearing and feeding; and rehabilitating degraded habitats to be utilized by a diverse community. Service Coastal Refuges present an opportunity to contribute significantly to this effort.

12 Develop and Implement Action, Restoration and/or Enhancement Plans for Exploited, and/or Declining Indigenous Aquatic Species

Action, restoration and/or enhancement plans are important tools for maintaining integrity and biodiversity of the ecosystem. The Service should support appropriate Lake Committees and stakeholders in the development of action, restoration and/or enhancement plans for declining indigenous species (including unionid mussels, American eel, Atlantic salmon, lake trout, brook trout, coaster brook trout, shortjaw cisco, lake whitefish, walleye, yellow perch, arctic grayling, lake sturgeon, northern pike, muskellunge, smallmouth bass, largemouth bass, common loon, mink and river otter) and exploited species (including steelhead, chinook and coho salmon). These plans should be developed to be consistent with the proposed Aquatic Community and Habitat Goals and Objectives. Strategies might include, but not be limited to: continuing and expanding monitoring of populations and/or harvest; standardizing assessment procedures; setting harvest limits to protect exploited populations; and identifying and protecting sensitive habitats.

13 Develop and Implement Action/Restoration Plans for Forage Fish

Action plans are an important tool for maintaining integrity and biodiversity of the ecosystem. The Service should support appropriate Lake Committees and stakeholders in the development of an action plan for forage fish consistent with the proposed Aquatic Community and Habitat Goals and Objectives.

14 "Close the Door" on Nonindigenous Species Introductions

Public agencies and non-governmental organizations must cooperate to prevent transport and release of viable organisms into the Great Lakes. Pathways of introduction include ballast water transport, bait bucket transfer, releases from aquaculture or stocking practices and boating. Solutions must be biologically effective, as well as practical, and be based on engineering, operational, regulatory, economic and safety factors. For example, research and development is needed on potential ballast water management options that have already been identified in collaboration with the maritime industry. The studies must be inter-disciplinary, involving biologists and engineers, business operators and government personnel. To support research and monitoring of management options, it will be necessary to develop techniques for bio-sampling of ballast tanks on Great Lakes and ocean-going ships.

15 Implement and Expand Effective Sea Lamprey Control

The U.S. State Department and Fisheries and Oceans Canada, parties to the *Great Lakes Fisheries Convention*, should meet obligations according to agreed upon funding formulas and fund the Great Lakes Fishery Commission's mandated program. In its *Strategic Vision for the Decade of the 1990s*, the Great Lakes Fishery Commission has pledged to support fishery management goals by providing "an integrated sea lamprey management program that supports the *Fish Community Objectives* for each of the Great Lakes and that is ecologically and economically sound and socially acceptable". Fundamental to meeting the vision is an accelerated research program to develop alternative controls to reduce dependence on chemicals, implementation of a control program on the St Mary's River, evaluation of the sterile male release program, and an increase in assessment activities to meet program objectives.

16 Great Lakes Fishery Commission Line Item Funding for Sea Lamprey Control Efforts in the St. Mary's River

The sea lamprey population in the St. Mary's River has been identified as the most serious impediment to sea lamprey control in the Great Lakes. It is also considered one of, if not the most significant, impediments to restoring a healthy fish community in Lake Huron. The size of the river precludes conventional treatment methods and requires the development of specific control strategies. Funding for sea lamprey control has been marginal, at best, over the last several years and has allowed only routine treatments of major lamprey producing tributaries in the upper Great Lakes, excluding the St. Mary's. To ensure proper attention to the most serious problem area, additional funding specifically identified for the St. Mary's River is needed.

17 Fund Implementation of the Great Lakes Fishery Commission's Basin-wide Sea Lamprey Barrier Plan

Construction of low-head dams and electrical barriers to block migrations of spawning adults can reduce lampricide use and provide more effective control by limiting habitat available to lamprey and removing spawning adults at traps. Of the U.S. Great Lakes tributaries regularly treated with lampricide, many have sites where barriers could be constructed. These U.S. projects have the potential to reduce basin-wide lampricide use, cut treated stream mileage, and significantly reduce populations of parasitic lampreys.

18 Prevent or Delay the Spread of Ruffe

The *Ruffe Control Program*, the first such program to be prepared under the *Nonindigenous Aquatic Nuisance Prevention and Control Act*, should be implemented by appropriate government and private entities. The program is an integrated plan that addresses each of the ways by which ruffe may spread. Range reduction by chemical treatments, prevention of ballast water transport and education to prevent movement via anglers and bait dealers are all essential to containing the ruffe and must be supported by vigilant monitoring and surveillance. Portions of a control program have been implemented.

19 Determine the Impacts of Hydroelectric Facilities and Dam Operations on Fishery Resources

Fishery resources are impacted by dams inhibiting upstream and downstream passage, creating unstable habitat and causing entrainment-related mortalities. The extent of these impacts on the aquatic community is unknown. Specifically, the following impacts need to be determined: dewatered areas and minimum flow requirements; water-level fluctuations on fish spawning, fecundity and condition, aquatic vegetation and invertebrates; and entrainment on fish communities.

20 Increase Involvement in the Binational Program to Restore and Protect Lake Superior and Expand this Mechanism to Lakes Huron, Erie, and Ontario

Fishery managers should increase their involvement with the Binational Program.

21 Establish Uniform Tissue and Sediment Contaminant Levels Used by Various Agencies for Ecosystem Health

Contaminant levels for tissue and sediment are inconsistent or absent among agencies. Uniform levels are needed to prevent reproductive, aesthetic, and consumptive impairments. Specific strategies should include evaluation of agency programs that established the current contaminant levels and conducting additional studies to address information gaps.

22 Broaden the Scope of Current State Antidegradation Policies, Regulations, and Strategies

Current State water quality antidegradation policies, regulations, and strategies do not specifically address biological integrity. These policies should be reviewed and revised, if necessary, to clearly state their goal of biological integrity as the *Clean Water Act* and *Great Lakes Water Quality Agreement* intend.

23 Develop and Implement an Action Plan to Analyze Contaminant Level Effects on Aquatic Resources

Monitoring of contaminants and analysis of their effects occurs on a limited basis throughout the basin. A plan should be developed to include the following: establishment of regular monitoring at standard locations; identification of effects on fish reproduction, egg development, fry emergence and larval survival; identification of effects on plants, plankton, macroinvertebrates and piscivorous wildlife; and determination of rates of bioaccumulation within the food web.

24 Participate in Remedial Action Plans, Lake-wide Management Plans, and the Environmental Monitoring and Assessment Program

As remedial action projects are implemented, their effects on the fish and wildlife community need to be assessed. Fishery managers should increase their involvement with Remedial Action Plans and contribute to the Monitoring and Assessment Program planning process in the Great Lakes.

25 Salmonine Egg Viability

The viability of lake trout eggs and Pacific salmon eggs from Lake Michigan, has been a point of concern. Cause and effect relationships need to be explored through research efforts. In addition, the effect of poor egg survival needs to be monitored from a rehabilitation and management perspective, to determine the overall effect on Lake Michigan fish communities. The viability and hatching success of lake trout or salmon that mature in Lake Michigan will provide an indicator of the health of the Lake Michigan ecosystem. A monitoring program needs to be designed to provide a systematic measure of the egg viability of key fish species in Lake Michigan.

26 Establish an Isolation or Quarantine Facility

Management agencies are concerned about maintaining wild genetic traits in hatchery broodstocks of lake trout and possible coaster brook trout. To accomplish this, wild gametes must pass disease clearance in an isolation facility prior to introduction to hatchery systems. Such a facility should also be designed to support imported adult salmon and other fish from outside the Great Lakes Basin for broodstock development and should be capable of isolating six lots of fish.

27 Develop an Epizootic Epitheliotrophic Disease (EEDV) Diagnostic Test

A diagnostic test for EEVD is needed to expedite determination of disease in lake trout eggs and young fish for the purpose of establishing lake trout broodstocks from wild Great Lakes stocks.

28 Fish Health

Low egg viability and diseased salmonids are examples of the problems that develop when recruitment of these predators is dependent on intensive aquaculture. Maintenance of fish health within the hatchery has been well researched. Wild fish health and its potential to be an indicator of ecosystem health is a field of study that is not as well developed. Appropriate indicators of fish health should be developed for key fish species in the wild. An example is the recent decline of chinook salmon in Lake Michigan where a lack of knowledge concerning fish health in the wild exists.

29 Fish Genetics

Since the collapse of indigenous Great Lakes fish and fisheries in recent decades, the rehabilitation of indigenous fishes is an attempt to recolonize the Lakes, a phenomenon that occurred historically following periods of glaciation. The extinction of gene pools adapted to the Lakes for species like lake trout and possibly lake herring, raises concern over the ability of available genetic strains to effectively recolonize all of the available habitat. Analyses of available genetic strains and their survival in the Lakes are crucial for indigenous species restoration efforts.

30 Lethality of Sea Lamprey Attacks

Research is needed to evaluate the effects of sea lamprey wounding on mortality of fish species other than lake trout. For example, attacks on chinook salmon are extensive, but the timing of these attacks and their contribution to

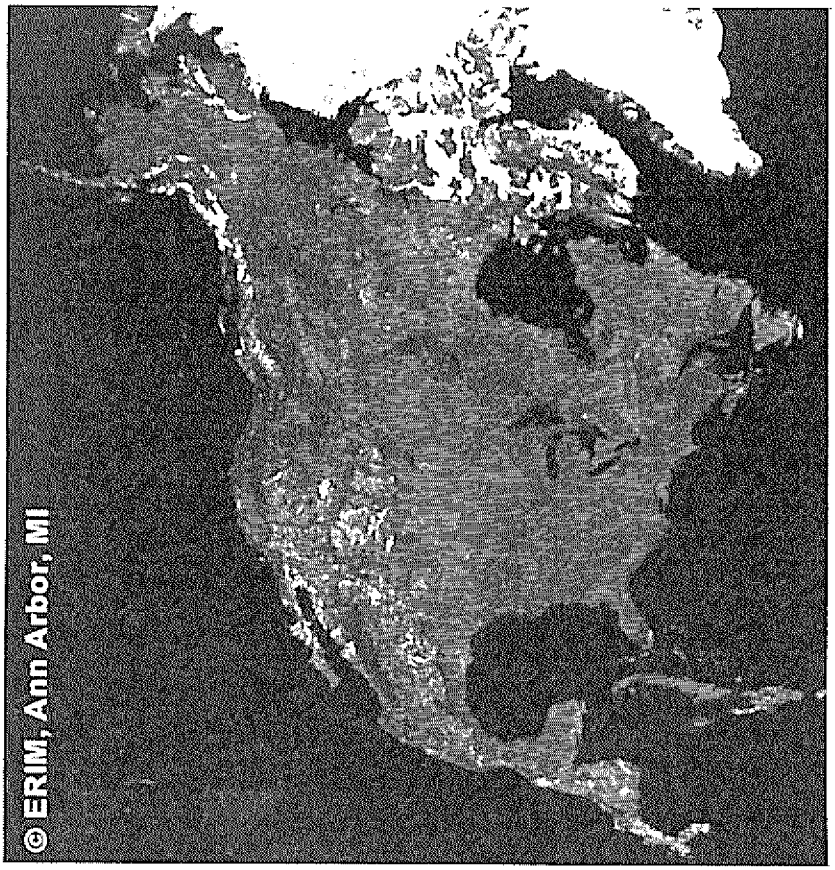
overall mortality is not known. Research has been conducted with lake trout to quantify mortality resulting from sea lamprey attacks but similar work is needed with other species, especially in light of burgeoning lamprey populations in northern Lake Huron.

31 Develop Aquatic Resource Education Programs

Education programs focusing on the values, functions and dynamics of ecosystems are needed so that society understands their role in the system and makes informed decisions. Education programs should focus on issues such as the prevention and control of nonindigenous nuisance species introductions, the role of deliberately introduced nonindigenous self-sustaining and supplementally-stocked species, indigenous species restoration (e.g. lake trout, lake sturgeon), habitat restoration, and endangered species.

32 Conduct a Cormorant Fishery Predation Study

A fishery predation study to determine the diet of the Great Lakes cormorant population, similar to that started in 1992 by the Fish and Wildlife Service, Canadian Wildlife Service and New York State Department of Environmental Conservation should be conducted for each of the Great Lakes to quantify fishery predation and generate recommendations to decrease predatory impacts on newly-stocked fish, if necessary.



Courtesy of Environmental Research Institute of Michigan, Ann Arbor, MI

Introduction

Purpose of the Document

In response to the Congressional request for information on the Great Lakes and progress in implementing the Great Lakes Fishery Resources Restoration Study(Study)required in the *Great Lakes Fish and Wildlife Restoration Act* (1990) 16 U.S.C.@ 941 *et seq.*, this report herewith provides results obtained.

Due to the limited appropriation of funds the Study was, by necessity, limited in focus. However, progress was made on all five major Study components throughout the Great Lakes Basin.

Great Lakes Fish and Wildlife Restoration Act

Historic perspective

"For thousands of years, indigenous populations have been relying, to some extent, on the Great Lakes for their livelihood. ...These waters provided an abundant fishery for the peoples of the emerging peninsula, and the large lakes were viewed with wonder and awe. Cultures rose and were supplanted by other indigenous cultures. Eventually, the Anishnabeg (Ojibway, Ottawa, and Potawatomi) took possession of the land after a series of migrations which originated on the Eastern Seaboard. They moved from one aquatic environment to another and possessed the technology to effectively harvest large numbers of fish from the waters of Mi-chi-gum, Mi-chi-ganing, or Mi-chi-go-nong, as the lakes were called. The name translated to "big or large lake/water" and was used to collectively refer to the very large bodies of water that surrounded the region's peninsulas. ...an important part of a tradition and legacy that has been bestowed on the region by Native peoples.

...In the post Civil War period,...the Great Lakes fishery was "harvested" with a vengeance. Na-me, the Sturgeon, an important fish to the Anishnabeg, became a rarity as a result of targeted commercial fishing. The large Sturgeons wreaked havoc with commercial nets and therefore were marked for extermination. The average size of Lake Trout declined precipitously. Fifty and sixty pound fish became rarer and rarer and the end was not in sight. On land, the same things were happening. The enormous White Pine forests were being cut at an astronomical rate while market hunting was taking an enormous toll on wildlife. Unfortunately these trends continued into the 20th century and in many instances were responsible for irreparable harm to the fishery, flora and fauna. ..." (Cornell 1993).

Background information

The Great Lakes provide an immense natural resource for the people of the United States and Canada. The five Great Lakes contain 20 percent of the world's fresh surface water and cover approximately 246,049 square kilometers (95,000 square miles). Approximately 25 percent of the total population of Canada and 10 percent of the U.S. population live within the Great Lakes Basin and about 25 million people use it as a water supply. The water-related resources are an integral part of activities such as outdoor recreation and tourism valued at $15 billion annually, $6.89 billion of which is related to the fishing industry. Additionally, the Great Lakes Basin contains over 728 square kilometers (281 square miles) of coastal wetlands which provide habitat for endangered species and breeding areas for waterfowl, other migratory birds, and fish.

The demand for harvestable fishery resources offers an increasingly difficult challenge. Historically, large numbers of lake trout, lake whitefish, lake herring, walleye, blue pike, lake sturgeon, yellow perch and other fish populated the Great Lakes and supported a major commercial fishing industry. In Lake Ontario, Atlantic salmon were gone by 1900 and sturgeon were severely depleted. Populations of commercially valuable fish further declined precipitously during the 1950s and 1960s due to a combination of factors, including over-fishing, sea lamprey predation, competition with nonindigenous nuisance species, and pollution. Resource management agencies throughout the Great Lakes region responded by implementing aggressive long-term programs designed to restore the fisheries, including the introduction of nonindigenous hatchery-reared salmon, lake trout stocking and sea lamprey control.

To varying degrees these programs have succeeded and the Great Lakes are once again vital to the recreation and economy of the region. Participants in the fishing industry in the U.S. generate about $2.22 billion in sales to local businesses and the industry represents $4.4 billion in annual economic activity. About 75,000 jobs are supported by sport fisheries, and commercial fisheries provide an additional 9,000 jobs and $270 million annually. A small portion of the commercial harvest is taken by tribal fisheries that operate pursuant to treaties dating from 1836 and 1842.

These public values and benefits are confirmed by an extensive body of Federal legislation and international treaty conventions that pertain to the Great Lakes. The U.S. Fish and Wildlife Service (Service) has been granted a number of these authorities (see Appendix III). The roles and responsibilities of the Service for Great Lakes resources pertain primarily to protection of anadromous, migratory, endangered, inter-jurisdictional (or international) species and management of federal lands.

Nonindigenous nuisance species such as the sea lamprey, zebra mussel, ruffe, spiny water flea, purple loosestrife, and *Phragmites* continue to threaten the indigenous living resources in the Great Lakes. In addition to the threats that nonindigenous nuisance species impose, water level regulations, channelization, hydropower dams, shoreline structures, and filled wetlands challenge indigenous species at various stages in their life cycles.

The living resources in the Great Lakes must be carefully managed to ensure maximum public benefit while guaranteeing their perpetuation. The goals and objectives of the international cooperative efforts between the United States and Canada will be realized as the health of fish and wildlife resources improves. Restoration goals for the Great Lakes Basin will be met when viable and productive stocks of indigenous and other desired fish species are available, bald eagles successfully reproduce and inhabit shorelines, mink and otter re-inhabit suitable shorelines throughout the Basin, chemical and other stress-induced deformities in fish and wildlife are reduced or eliminated and fish and wildlife can be consumed with little or no risk to human health.

The complexity of the Great Lakes ecosystem is matched by the complexity of the institutional framework in place for Great Lakes management. The Great Lakes system is managed at many levels from municipalities to national governments: two Federal governments, eight States, Native American Tribes, and two Provinces share responsibility in the system along with municipalities, county boards, and regional and international bodies such as the Great Lakes Fishery Commission, Great Lakes Commission and International Joint Commission. Adding to this management complexity is the diversity of interests represented by research institutes, universities, citizen groups, businesses, and private individuals within the Great Lakes Basin.

Adoption of an ecosystem perspective in the stewardship and rehabilitation of Great Lakes resources is widely recognized as crucial for the future of the system. Current resource assessments, and research and management tools alone are inadequate to evaluate changes in large complex ecosystems. New tools must be developed as an outgrowth of partnership efforts to identify ecosystem impairments, focus rehabilitation efforts, adaptively manage resources and monitor results.

The Service has the capability to act as a catalyst in the development of an ecosystem based approach to resource conservation in the Great Lakes. The size and complexity of the Great Lakes and the objectives of the Great Lakes Fish and Wildlife Restoration Act (Appendix IV) require partnerships to guarantee success in resource conservation. The Service's approach to insure that cooperation and partnerships flourish in Great Lakes activities is simple: 1) coordinate internally and externally with all identified partners constantly, and 2) remind ourselves on a daily basis that in some Great Lakes activities, the Service will provide leadership; in others, the Service may aid or simply provide the technical assistance, as requested, to our partners, necessary to achieve shared goals.

Based upon the progress being made by Great Lakes ecosystem partners, the future outlook for rehabilitation is bright.

Purposes of the Act

The Act (Appendix IV) directs the Service: to provide technical assistance to the Great Lakes Fishery Commission, States, Native American Tribes and other interested entities to encourage cooperative conservation, restoration and management of the fish and wildlife resources and their habitats in the Great Lakes Basin; to carry out a comprehensive study of the status, and the assessment, management and restoration needs, of the fishery resources of the Great Lakes Basin; and to develop proposals to implement recommendations resulting from that study.

The Act also provided for the establishment of offices. A centrally located Great Lakes Coordination Office was established in East Lansing, Michigan for intra- and interagency coordination, information distribution and to promote public awareness of all Service activities in the Great Lakes Basin. The Lower Great Lakes Fishery Resources Office was established in Amherst, New York, to carry out all Service operational activities related to fishery resource protection, restoration, maintenance and enhancement in the Lower Great Lakes. Additionally, the Ashland, Wisconsin Fishery Resources Office was expanded and Fisheries Resources Offices were established in Green Bay, Wisconsin and Alpena, Michigan to perform similar activities in the Upper Great Lakes.

Great Lakes Fishery Resources Restoration Study

The Act requires the Director of the Service to conduct a study of the status of the fishery resources of the Great Lakes Basin, hereafter called the Study, in collaboration with State and Native American Tribal partners and the Great Lakes Fishery Commission. The Study is to focus on the assessment, management, and restoration needs of Great Lakes fishery resources.

The Service invited State and Native American Tribal entities to enter into a memorandum of understanding regarding the Study (Appendix V) and coordination of Great Lakes activities.

During fiscal years 1992, 1993, and 1994, the Service met with all of the States and Native American Tribes bordering the Great Lakes to develop a better understanding of unmet fishery resource needs. The meetings also provided an opportunity to discuss the Service's role within the Great Lakes Basin. Cooperative projects and planning between the States, Native American Tribes and other partners are currently underway. The Fishery Resources Offices are assisting Lake Committees of the Great Lakes Fishery Commission with implementation of the *1980 Joint Strategic Plan for Management of Great Lakes Fishery Resources* (hereinafter referred to as *Strategic Plan for Management of Great Lakes Fisheries*).

Study Objectives

The Act outlined five Study objectives to be addressed by the Service and its partners.

Study Objective I:

Identify and describe the component drainages of the Great Lakes Basin by including the drainage for each of the Great Lakes and analyzing how the characteristics and current or expected land and water uses of those drainages have affected, and can be expected to affect in the future, the fishery resources and fish habitats of the Great Lakes Basin.

Study Objective II:

Analyze historical fishery resource data for the Great Lakes Basin to identify the causes of past and continuing declines of the fishery resources and the impediments to restoring those resources.

Study Objective III:

Evaluate the adequacy, effectiveness, and consistency of current Great Lakes interagency fisheries management plans and Federal and State water quality programs, with respect to their effects on Great Lakes fishery resources.

Study Objective IV:

Analyze the impacts of, and management control alternatives for, recently introduced nonindigenous species, including the zebra mussel, the ruffe, and the spiny water flea in accordance with the *Aquatic Nuisance Prevention and Control Act of 1990.*

Study Objective V:

Develop recommendations and action plans including:

"(A) an action plan to analyze the effects of contaminant levels on fishery resources;

"(B) an action plan for the cooperative restoration and enhancement of depleted, nationally significant fish

stocks, including lake trout, yellow perch, lake sturgeon, walleye, forage fish and Atlantic salmon;

"(C) planning and technical assistance that should be provided to the Great Lakes Fisheries Commission, States and Indian Tribes to assist their fishery resource restoration efforts;

"(D) mitigation measures to restore and enhance fishery resources adversely affected by past Federal (including federally assisted or approved) water resource development projects and other activities;

"(E) increasing the involvement of the International Joint Commission, the Great Lakes Commission, the Great Lakes Fishery Commission, and other interjurisdictional entities regarding fishery resources protection, restoration and enhancement;

"(F) research projects and data gathering initiatives regarding population trends of fish stocks, including population abundance and structure, interspecific competition, survival rates and behavioral patterns;

"(G) identifying important fishery resource habitat and other areas that should be protected, restored, or enhanced for the benefit of Great Lakes fishery resources;

"(H) identifying how private conservation organizations, recreational and commercial fishing interests, the aquaculture industry, and the general public could contribute to the implementation of the fishery resource restoration and enhancement recommendations developed pursuant to this Act; and

"(I) identifying appropriate contributions that should be made by States and other non-Federal entities to the cost of activities undertaken to implement the recommendations, including a description of -

"(i) the activities that shall be cost-shared;

"(ii) the entities or individuals which shall share the costs of those activities;

"(iii) the proportion of appropriate project and activity costs that shall be borne by non-Federal interests; and

"(iv) how the entities or individuals who share costs should finance their contribution.

Limited progress has been made on all five of the Study objectives throughout the Great Lakes. Based upon availability of information from work initiated prior to the Act and ongoing work related to the Study, Lakes Ontario and Erie were addressed using a trophic guild approach. Lakes Huron, Michigan and Superior were addressed using a habitat-based fish community approach.

Development of proposals

The Service, in collaboration with partners participating in forums such as the Lake Committee structure of the Great Lakes Fishery Commission and the Service's Great Lakes Basin Ecosystem Team, will aid in the development of proposals to implement the recommendations of the Study. Some of these proposals are contained in this report, but most will be developed subsequent to further work. Based upon available funding, proposals will be prioritized via a multi-agency committee project approval process developed by the Service, the Great Lakes Fishery Commission, and the State and Native American Tribal partners. The proposals will use an ecosystem approach to incorporate the goals of the *Great Lakes Water Quality Agreement*, as revised in 1987, the 1954 *Great Lakes Fisheries Convention*, State and Native American Tribal natural resource management agencies, and the *Strategic Plan for the Management of Great Lakes Fisheries*.

Great Lakes Basin Description

Great Lakes climate

The Great Lakes (Figure 2) are located in the northern temperate zone and have been characterized as having a humid microthermal climate consisting of rain and snow with cold winters. The Great Lakes climate is modified by the lakes themselves, resulting in a partial maritime with southwesterly winds in the summer and southeasterly winds in the winter (Berst and Spangler 1973; Ryder 1972).

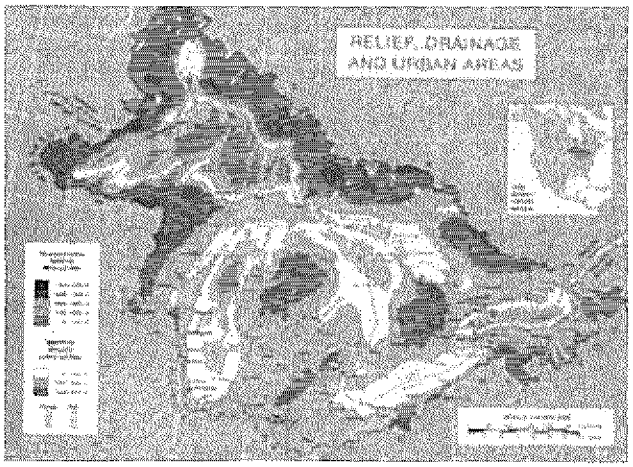


Figure 2. Map illustrating the Great Lakes watershed (U.S. Environmental Protection Agency and Environment Canada 1988).

Physiographics, hydrographics, and trophic state

The Great Lakes-St. Lawrence system contains the St. Lawrence and St. Mary's Rivers and Lakes Ontario, Erie, Huron, Michigan, and Superior and connecting channels. Each of the five Great Lakes is among the fifteen largest freshwater lakes in the world and the system contains 65 trillion gallons of fresh water; a full 20 percent of the world's supply and 90 percent of the U.S. supply (Donahue 1991). A discussion of physiographics, hydrographics, and trophic state of each of the Great Lakes follows.

Lake Ontario

Physiographics and hydrographics

Lake Ontario (Figure 2) is the smallest of the Laurentian Great Lakes in surface area, but it is the twelfth largest lake in the world by volume (Table 1).

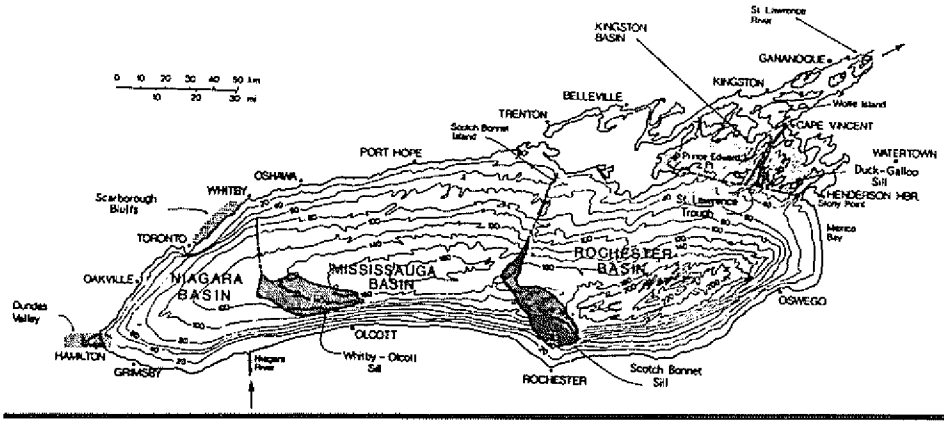


Figure 3. Map illustrating the four basins of Lake Ontario.

Lake Ontario is divided into four basins (Figure 3). The three major basins - the Niagara, Mississauga, and Rochester basins, from west to east, are separated by the Whitby-Olcott and Scotch Bonnet sills, respectively. The eastern most, Kingston basin, is separated from the Rochester basin by the Duck-Galoo sill.

The sediments follow a gradient of sands and gravels in the nearshore areas to silts and clays in the deeper portion of the basins. The Niagara basin has a maximum depth of 128 meters (420 feet), while the Mississauga basin maximum is

Table 1. Great Lakes physiographic and hydrographic features.

			Ontario	Erie	Huron	Michigan	Superior	Total	
Length		*kilometers*	311	338	330	494	563	2,081	
		miles	193	210	205	307	350	1,293	
Breadth		*kilometers*	85	92	293	190	257	n/a	
		miles	53	57	182	118	160	n/a	
Elevation		*meters*	75	174	177	177	183	n/a	
		feet	246	571	581	581	601	n/a	
Maximum depth		*meters*	244	64	229	281	406	n/a	
		feet	801	210	751	923	1,333	n/a	
Mean depth		*meters*	84	19	55	85	148	n/a	
		feet	276	62	180	279	487	n/a	
Volume		*cu.km.*	1,640	484	3,540	4,920	12,200	22,784	
		cu.mi.	393	116	850	1,180	2,927	5,466	
Discharge		*cu.m./sec.*	6,877	5,730	5,297	1,588	2,126	n/a	
		cu.ft./sec.	243,000	202,269	186,970	55,000	75,051	n/a	
Retention time		*years*	6.0	2.5	23.0	99.0	182.0	n/a	
Area:									
Water		*sq.km.*	18,960	25,700	59,600	57,800	82,100	244,160	
		sq.mi	7,340	9,910	23,000	22,300	31,700	94,250	
Land drainage area	a	*sq.km.*	64,030	78,000	134,100	118,000	127,700	521,830	
		sq.mi.	24,720	30,140	51,700	45,600	49,300	201,460	
Total		*sq.km.*	82,990	103,700	193,700	175,800	209,800	765,990	
		sq.mi.	32,060	40,050	74,700	67,900	81,000	295,710	
Shoreline Length	b	*kilometers*	1,146	1,402	6,157	2,633	4,385	17,017	c
		miles	712	871	3,827	1,638	2,726	10,210	c

a
Land drainage area for Lake Huron includes the St. Marys River, Lake Erie includes the St. Clair-Detroit, system and Lake Ontario includes the Niagara River.

b
Including islands.

c
These totals are greater than the sum of the shoreline length for the lakes because they include the connecting channels (excluding the St. Lawrence River).

(adapted from Erdevig, 1991)

about 201 meters (659 feet). The Rochester basin drops to approximately 245 meters (803 feet). The Kingston basin has a maximum depth of 30 meters (98 feet), although the average depth is much less. Islands and extensive littoral area are common in the Kingston basin. (Eckert 1984; Martini and Bowlby 1991; Sly 1991).

Natural shoreline structure is quite variable around the lake, ranging from bluffs of varying composition to low lying sandy beaches. Coastal marshes are commonly found in embayments and creek mouths. In addition to agriculture, extensive urbanization, particularly in the vicinities of Toronto, Hamilton, and Rochester, has significantly impacted the shoreline and associated wetlands (Living with the Lakes 1989) resulting in a loss of 50 percent due to urbanization

of greater than 80 percent of the shoreline in these areas (Whillans *et al.* 1992). The Lake Ontario shoreline is more complex in the east (Kingston basin) than it is in the western and central portions. Contributing to the complexity in the eastern section is the Bay of Quinte, which has numerous small embayments and a highly convoluted shoreline. The eastern portion of the Bay is dominated by bedrock outcroppings.

Lake Ontario receives all of the outflow from the upper four Great Lakes via the Niagara River, at the average annual rate of 5,520 cubic meters per second (194,856 cubic feet per second). Direct inflow from all other major tributaries adds an additional 540 cubic meters per second (19,062 cubic feet per second) (Sly 1991). Theoretical water retention time is about six years because of the great inflow from the Niagara River (Living with the Lakes 1989). Modern fluctuations in the water level of Lake Ontario are less than 2 meters per year, far less than historical fluctuations (Great Lakes-St. Lawrence River Regulation 1990; Sly 1991), largely as a result of artificial water-level regulation coupled with a relatively small surface area, which limits evaporation effects.

Lake Ontario stratifies thermally in summer and winter, and mixes in spring and fall. Summer stratification is well pronounced, resulting in classical zonation, while winter stratification is rather weak. Due to its large heat capacity, Lake Ontario usually remains free of ice in the winter, with the exception of inshore shallows and sheltered embayments. Hypolimnetic upwellings of cold water from the deep are common, even during maximum summer stratification. Vertical thermal bars are a feature of the warming and cooling processes of the lake and serve to temporarily segregate inshore and offshore waters, particularly at the onset of summer stratification. The isolation of inshore waters serves to restrict dispersion of nearshore pollutants, nutrients and other loadings (Eckert 1984). Circulation is typically wind driven, and frequently characterized by several cells, corresponding generally with the sub-basins.

Trophic State

The trophic status of Lake Ontario has recently been regarded as mesotrophic, based on average phosphorus concentrations (Living with the Lakes 1989; Leach and Herron 1992) although many inshore areas and embayments are decidedly eutrophic. Lake Ontario has had a productive sport fishery that is changing quickly. Very high, artificial levels of nutrients and primary productivity in the open waters are down significantly (Smith and Lange 1994)tending towards oligotrophic.

The phytoplankton community of Lake Ontario is dominated by diatoms, green algae, dinoflagellates, and flagellates, which together comprise 90 percent of phytoplankton. *Cladophora sp.* are the predominant attached alga. The zooplankton community is largely composed of *Bosmina longirostris* and *Daphnia retrocurva* (Johannsson and O'Gorman 1991). The deepwater benthos is populated by *Disporia hoyi* and *Mysis relicta*, while the more eutrophic, nearshore regions are characterized by a predominance of oligochaetes, particularly *Potamothrix* species and *Aulodrilus* species.

The current trophic status is approaching oligotrophic in most of the open water with changes in nutrients impacting primary and secondary productivity.

Lake Erie

Physiographics and hydrographics

Lake Erie is the shallowest, most southern, and warmest of the Great Lakes and lies at the boundary of the humid microthermal and humid mesothermal climates. It is the fourth largest of the Laurentian Great Lakes in surface area and the smallest by volume (Table 1).

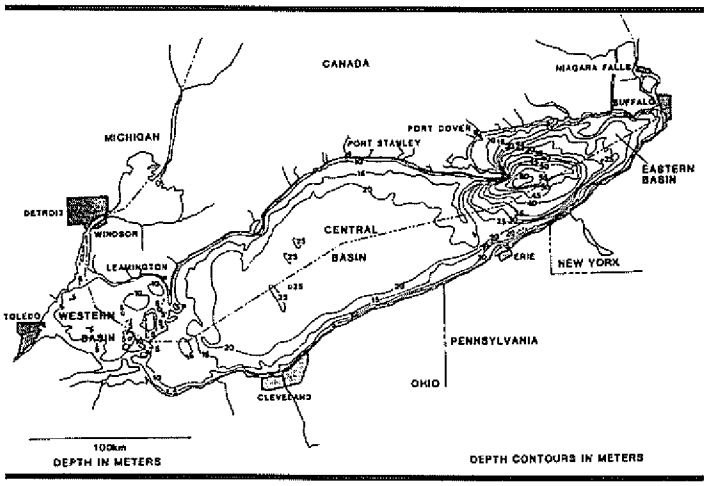


Figure 4. Map illustrating the three basins of Lake Erie.

Lake Erie is divided into three basins (Figure 4). The western and central basins are separated by the Pelee-Lorraine Sill, and the central and eastern basins are separated by the Long Point-Erie Sill. The western basin is the shallowest, with a maximum depth of 20 meters (67 feet), and an average depth of 7 meters (24 feet). The central basin is the largest in surface area (63 percent of the total), and has a maximum depth of 26 meters (84 feet), and an average depth of 19 meters (61 feet). The eastern basin is the deepest, with a maximum depth of 64 meters (210 feet) and an average depth of 24 meters (80 feet).

Lake Erie is a typical dimictic lake, undergoing spring and fall mixing. Summer stratification occurs in the central and eastern basins. Most of the lake is covered with ice in the winter.

The substrate is a combination of bedrock (composed of marine sedimentary rock including limestone, dolomite, shale, and sandstone), sand and gravel in the nearshore, and mud in deeper areas. The shoreline includes bluffs, sandy beaches, and coastal wetlands. Islands are present in the western basin and along the Pelee-Lorraine Sill. Most of the natural reefs also occur in the western basin.

The Lake Erie basin features several types of coastal wetlands, including estuarine wetlands, coastal lagoons, and managed marshes. The highest concentration of coastal wetlands occurs in western Lake Erie. Severe northeast and northwest storms create rapid fluctuations of water levels and waves that erode the shoreline; these events inhibit the development of coastal wetlands in many other areas.

Estuarine wetlands are drowned river mouths, where the major water input is from one or two tributaries. Most of the tributaries along the southwestern shore create estuarine wetlands. The more important estuarine wetlands include: Old Woman Creek Estuarine Sanctuary, the lower Maumee River, the lower Sandusky River and Sandusky Bay, and Big Creek Marsh.

Coastal lagoons derive their water from the lake and are separated from it by a sand spit or barrier beach. Coastal lagoons around Lake Erie include Sheldon Marsh, just east of the mouth of Sandusky Bay, and Point Pelee, Ontario.

Managed marshes are areas that have been diked and have gates to maintain desired water levels. Examples of these marshes around Lake Erie include Winous Point Marsh and Moxley Marsh in Sandusky Bay, and Ottawa National Wildlife Refuge, Metzger Marsh, and Magee Marsh located between the Maumee and the Portage Rivers.

More than 90 percent of the total inflow to Lake Erie comes from the Detroit River. The average annual inflow at the head of the Detroit River is 5,140 cubic meters per second (181,442 cubic feet per second). Average annual inflow from tributaries and surface runoff is estimated at 580 cubic meters per second (20,474 cubic feet per second). Water residence time in Lake Erie is a short 2.5 years due to the small volume. Outflow from Lake Erie is through the Niagara River and the Welland Canal. The Combined outflow averages approximately 5,730 cubic meters per second (202,269 cubic feet per second).

Trophic State

Lake Erie historically had the highest productivity of all the Great Lakes, and is still as productive a fishery as the other four Great Lakes combined. The trophic status or productivity of the lake has changed dramatically in this century due to increased nutrient input, especially phosphorous. Nutrient loadings increased dramatically through the 1950s and 1960s, increasing phytoplankton three-fold from 1927 to 1962, and twenty-fold by 1973. As a result, the trophic status was classified in the 1970s as mesoeutrophic in the eastern and central basins, and eutrophic in the western basin. Phosphorous abatement programs started in the 1970s have reduced the nutrient loading significantly over the last two decades, decreasing productivity to the more oligotrophic historical conditions in the eastern and central basins and mesoeutrophic in the western basin.

Lake Huron

Physiographics and hydrographics

Lake Huron (Figure 2) is the fifth largest lake in the world and the second largest of the Laurentian Great Lakes. It has the longest shoreline and the third largest water volume (Table 1). Descriptions of lake morphometry have been reviewed by Berst and Spangler (1973), Ristic (1989) and Michigan Sea Grant (1992).

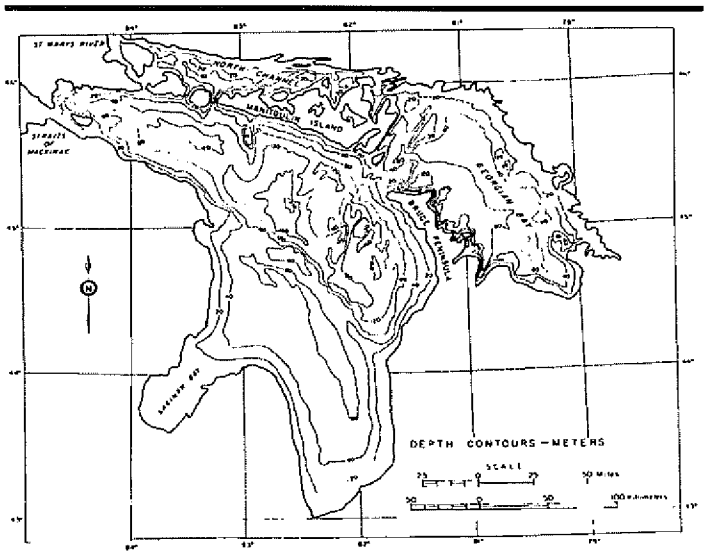


Figure 4a. Lake Huron contour map.

Formed approximately 10,000 years ago following the Wisconsin glaciation (Ryder 1972), Lake Huron has a drainage basin of 193,700 square kilometers (74,000 square miles), one-third of which is the lake surface (Berst and Spangler 1973). The north shore is mainly Precambrian in origin while the remainder of the lake bed is Paleozoic (Hough 1958). A portion of the Niagran Escarpment, a Devonian rock formation, extends from the northern to the southeastern part of the lake and is present as a chain of islands and a peninsula.

Lake Huron is comprised of three basins; the main basin, the North Channel, and Georgian Bay. The main basin is the largest and has a surface area of 41,659 square kilometers (16,085 square miles) and an average depth of 61 meters (200 feet) (Berst and Spangler 1973). The North Channel is located on the northeastern coast of the lake and is separated from the main lake by a chain of islands. Its surface area is 4,550 square kilometers (1,757 square miles) with an average depth of 22 meters (72 feet) (Berst and Spangler 1973). Georgian Bay, located on the eastern coast of the lake and defined from the main basin by the Bruce Peninsula, is the largest bay in the Great Lakes system. Its surface area is 13,752 square kilometers (5,310 square miles) with an average depth of 51 meters (167 feet) (Berst and Spangler 1973).

There are two major bays, Georgian Bay and Saginaw Bay. Georgian Bay, described above, is a prominent feature and the largest bay in the lake. Saginaw Bay on the western shore of Lake Huron is the second largest bay in the Great Lakes system. It is 42 kilometers (26 miles) wide and projects 82 kilometers (51 miles) into the land mass (Beeton *et al.* 1967). Its surface area covers 2,960 square kilometers (1,143 square miles) and is divided equally into a shallow inner bay, 5 meters (15 feet) average depth, and a deeper outer bay, of 16 meters (51 feet) average depth (Beeton *et al.* 1967).

Two main subsurface ridges are located in Lake Huron, the Six Fathom Scarp, and the Ipperwash Scarp. The Six Fathom Scarp extends across Lake Huron from Alpena, Michigan to Kincardine, Ontario and divides the lake proper

into two distinct basins. Southwest of the ridge the lake is uniform, having a maximum depth of 91 meters (299 feet); and north of the ridge a deep trough exists, having a maximum depth of 229 meters (751 feet) (Berst and Spangler 1973). The deepest waters of Lake Huron and many concentric shoals are located north of this ridge (Berst and Spangler 1973). The Ipperwash Scarp is located south of the Six Fathom Scarp.

There are over 30,000 islands in Lake Huron, the majority in Georgian Bay. A prominent chain of islands in the northern part of the Lake separates the main basin from the North Channel and Georgian Bay. Manitoulin Island, the main island of this chain, is the largest in Lake Huron and the largest freshwater island in the world. Drummond and Cockburn Islands are also part of this chain.

Major waters which enter Lake Huron include outflows from Lakes Superior and Michigan, and stream flow from tributaries. With an elevation equivalent to that of Lake Michigan (Table 1), Lake Huron and Lake Michigan form a hydrological unit and continuous water body at the straits of Mackinac (Berst and Spangler 1973). Lake Huron receives the outflows from Lake Superior of approximately 2,126 cubic meters per second (75,051 cubic feet per second) and from Lake Michigan of approximately 1,558 cubic meters per second (55,000 cubic feet per second), which enter the lake in the north by way of the St. Mary's River and the Straits of Mackinac respectively (Table 1). Major U.S. tributaries enter the lake to the west and include, from north to south: the Cheboygan River, Thunder Bay River, Au Sable River, and the Saginaw River. Major Canadian tributaries enter the lake to the north and east and include, from north to south: the Mississagi River, Spanish River, French River, Magnetawan River, Muskoka River, Severn River, and the Saugeen River. The St. Clair River, at approximately 5,297 cubic meters per second (186,970 cubic feet per second), drains the lake to the south and leads to Lake Erie by way of the Lake St.Clair/ Detroit River system (Bolsenga and Herdendorf 1993). The residence time of water in Lake Huron is 23 years (Berst and Spangler 1973).

Water circulation is anticyclonic and flows from north to south. In the main basin, currents follow the western shore south into Saginaw Bay and along the submersed ridge, circling north again off the coast of the Bruce Peninsula and into Georgian Bay. Currents also flow out of the St. Mary's River, along the northeastern shore through the North Channel into Georgian Bay.

A humid continental climate consisting of a cool summer but no dry season is prevalent in the region with an annual average precipitation of 873 millimeters (34 inches). There is a dimictic thermal regime in the Lake, generally yielding a spring turnover in May and a fall turnover in November (Rockwell *et al.* 1989). The component basins and water bodies have different physical, thermal and chemical characteristics (Berst and Spangler 1973). For example, thermoclines form at different times and depths in the main basin and in Georgian Bay due to differences in their physical and chemical properties.

Trophic State

Lake Huron waters are oligotrophic, except in eutrophic areas of Saginaw Bay (Berst and Spangler 1973). Lake nutrient concentrations were low compared to the other Great Lakes due to low loading, and the annual concentration ranges were small (Moll *et al.* 1987). The surface waters have low concentrations of chlorophyll a ranging from 0.3 to 1.3 micrograms per liter (Rockwell *et al.* 1989). Oxygen saturation levels were generally in excess of 90 percent (Dolan *et al.* 1986) and at all depths throughout the year (Berst and Spangler 1973).

Lake Michigan

Physiographics and hydrographics

Lake Michigan (Figure 5) is the third largest of the Laurentian Great Lakes (Table 1) and the sixth largest lake in the world (Beeton 1984). It is the only Great Lake wholly within the U.S., bordered by the states of Illinois, Indiana, Michigan, and Wisconsin. However, because of movement of fish between Lake Michigan and Lake Huron and of its discharge to Huron 1,588 cubic meters per second (55,000 cubic feet per second), the lake is important internationally. The Lake Michigan watershed is slightly more than twice the surface area of the lake (Table 1), and is near equally split between the east and west side of the lake. Most of the watershed lies in the upper and lower peninsulas of Michigan and northeastern Wisconsin with very little in Illinois and Indiana. The northern part of the Lake Michigan watershed is covered with forests, sparsely populated and economically dependent on natural resources and tourism. The southern portion of the watershed is heavily populated with intense industrial development and rich agricultural areas along the shore.

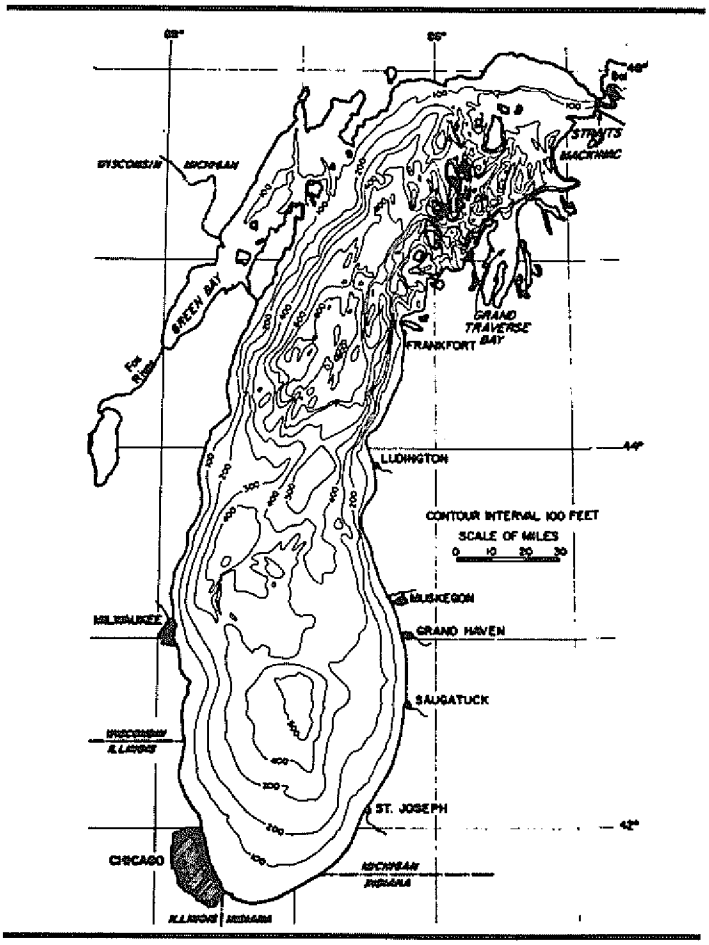


Figure 5. Lake Michigan contours.

Elongated in shape, Lake Michigan is divided into a southern basin that is relatively smooth in contour, sloping to a maximum depth of 170 meters (558 feet), and an irregularly shaped northern basin with a maximum depth of 281 meters (923 feet). Wells and McLain (1973) provide an excellent summary of the limnology of Lake Michigan, and the brief description provided here is excerpted from their paper.

The world's largest freshwater dunes line the lake shore. Millions of people annually visit the dunes/beaches at State and National parks and lake shores. Major tributaries to Lake Michigan are the Fox-Wolf River system in Wisconsin and the St. Joseph, Grand, Muskegon, Manistee, Pere Marquette, Menominee, and Kalamazoo Rivers in Michigan. There is an out-of-basin diversion through the Illinois Waterway at the Chicago River.

Trophic State

The waters of Lake Michigan have been enriched with loadings of municipal and industrial waste and agricultural runoff. However, the bottom waters remain well oxygenated and, with the implementation of the *1972 Great Lakes Water Quality Agreement*, estimated loadings of phosphorus appear to be low enough to preserve its oligotrophic state (International Joint Commission 1989). Enrichment is mainly a problem in specific localities such as southern Green Bay where excessive loadings have degraded the sediments.

Green Bay, a major embayment connected to the northern basin, is 190 kilometers (118 miles) long, relatively shallow and more productive on a surface-area basis than is Lake Michigan proper. Lake Michigan is classified as oligotrophic with features characteristic of deep, cold lakes. Biological production in oligotrophic lakes is low compared to shallow and nutrient-richer lakes such as Lake Erie. Lake Michigan has been a major producer of valuable fishery products

more because of its great size than its fertility. The lake has also been subjected to a plethora of toxic contaminants, most notably a complex mixture of PCBs.

Although Lake Michigan proper has not been severely impacted physicochemically by human settlement of the basin, the alteration of streams by deforestation, damming, draining of swamps and pollution has seriously impaired their usefulness for fish reproduction. Many native species of fish such as lake whitefish spawned in the lake and in streams, but the river-spawning forms are now greatly depleted or extinct (Smith 1972). Despite these impairments, Lake Michigan remains a magnificent resource, and can produce high sustainable yields of valuable fishery products.

Lake Superior

Physiographics and hydrographics

Lake Superior (Figure 6) is one of the world's great inland seas -- the biggest, deepest, coldest and clearest of the five Laurentian Great Lakes (Table 1); a habitat so unique that it developed races of fish found nowhere else; a volume of water so massive, representing more than half of the total volume of all the Great Lakes (Matheson and Munawar 1978), that the seasons only begin to cool or to warm it; a sea whose depths are little known, because humans frequent only its fringes. Lake Superior lies at the head of the St. Lawrence River drainage, its surface 183 meters (600 feet above mean sea level, but its deepest point is more than 213 meters (700 feet below sea level. Due to the constant isostatic uplift of the Sault St. Marie outlet for the past 4,000 years, western Lake Superior has experienced a continued rise in mean lake level, upon which has been superimposed both higher and lower lake level episodes related to climate changes (Larsen 1994). From its location in the middle of the continent, its waters flow 2,081 kilometers (1,293 miles) to the east before mixing with salt water in the Gulf of St. Lawrence. The shoreline is almost evenly divided area lies in the United States.

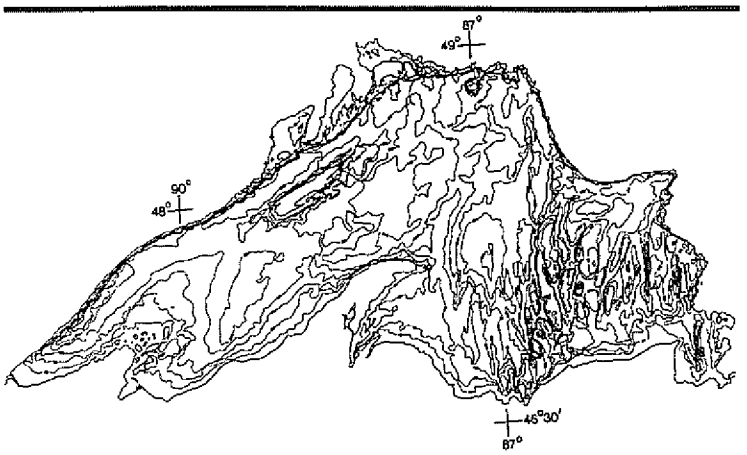


Figure 6. Lake Superior contours.

The drainage basin of lake Superior encompasses 127,700 square kilometers (49,300 square miles). About 39 percent of the total drainage basin is made up of the lake itself (Upper Lakes Reference Group 1976).

The lake lies along the southern edge of the Canadian Shield, a region of complex geological history dominated by granite and sandstone overlain by glacial till (Lawrie and Rahrer 1973). The eastern portion of the north shore is within the Superior Province of the Shield, characterized by irregular tumbled hills, the roots of ancient mountains, with local relief of 61-152 meters (200-500 feet). The north and south shores of western Lake Superior are within the Southern Province of the Shield. Topography is hilly, of somewhat lesser elevation than the Superior Province, with some local relief as great as 213 meters (700 feet).

The Lake Superior basin emerged from glacier cover between 13,000 and 9,000 years ago. During that time ice-melt formed pro-glacial lakes of changing configuration and drainage patterns. The native fish community of Lake Superior is a product of this complex post-glacial history.

The topography around the lake is variable, and, in many cases, dictates the productivity and fish species in a specific area. For example, the slope of the Minnesota north shore is very abrupt, both above and below the water line. The thin soils are underlain by hard igneous bedrock. The littoral zone is quite narrow, and most streams entering the lake are blocked by barrier falls short distances upstream. Spawning habitat for anadromous fishes is very limited.

Prevailing westerly winds on this shore push surface waters offshore, resulting in a strong upwelling of cold water from the deep. As a result, the fishery in Minnesota waters has always depended on pelagic coldwater species, with few coolwater or bottom dwelling fishes in the harvest. In contrast, the south shore in Wisconsin has a more gradual slope and a variety of depths, including extensive shallow areas. Soils are formed atop thick layers of clay and sand underlain by sandstone. Streams have extensive estuaries, and many have miles of anadromous fish spawning habitat. This area receives the relatively warm surface waters pushed by the prevailing westerlies. The fish community in this area is much more varied, including species that prefer warmer waters. Other portions of Lake Superior show similar variation in topography and temperature.

About 3 percent of the U.S. shoreline of Lake Superior consists of wetlands (PLUARG 1976). Wetlands are important as spawning and nursery areas for some fish populations in Lake Superior, but detailed information on the status and trends has not been collated. The Service has inventoried the wetlands of Minnesota and Michigan, and the Wisconsin Department of Natural Resources inventoried Wisconsin wetlands. However, at this writing, the Lake Superior basin information has not been digitized in GIS format and cannot be readily extracted from the statewide databases.

The mean annual air temperature of the Lake Superior basin is low, about 1.7-2.2 °C (35-36 °F), with a short growing season of 60-140 days. Annual precipitation averaged 75.2 centimeters (29.6 inches)/year from 1900 to 1972 (Upper Lakes Reference Group 1976). West winds (southwest to northwest) blow about 40 percent of the time with mean velocities of 7.9-14.9 (26-49 feet)/second. Wind speeds are generally higher over the lake than on land. Large waves form where wind passes over long distances of open water (Phillips 1978).

The mean lake temperature does not exceed 6.1 °C (43 °F), the coldest of the Great Lakes (Bennett 1978). However, the amount of heat energy stored in Lake Superior in each annual cycle is the largest of any of the Great Lakes. Because of its large heat storage, Lake Superior affects the climate within the basin and beyond. Local effects include precipitation, fog, wind speed changes, and moderation of temperature variations over the land (Matheson and Munawar 1978). Effects extend beyond the basin as the lake contributes moisture and heat to intensify storms (Phillips 1978).

The native plant communities of the basin were almost entirely forest. North of the lake were extensive tracts of boreal spruce-fir forests, characterized by balsam fir, black spruce, and white spruce, with scattered thickets of deciduous species such as trembling aspen, white birch, and alders. South of the lake, the original forest cover was deciduous, dominated by sugar maple and yellow birch, with white and red pine, white and black spruce, white birch, and balsam fir as secondary species. Between the boreal and southern deciduous forests was an intermediate area dominated by white and red pines.

Lake Superior has a highly irregular shoreline and lake basin. It is shaped like a wolf's head, with the snout at the mouth of the St. Louis River on the extreme western end; the eye at Isle Royale, a 97 kilometer (60-mile) long island in the northwestern portion of the lake; and the mouth at the Keweenaw Peninsula, a 145 kilometer (90-mile) long protrusion from the south-central shore.

Lake Superior has a relatively small littoral zone, especially on its northwestern and northeastern shores, where the bottom drops steeply to depths of 183-244 meters (600-800 feet). About 80 percent of the lake is deeper than 73 meters (240 feet), roughly the depth at which "deepwater" fish species begin to dominate the community. The Canadian shore has three large, relatively shallow bays (Thunder Bay, Black Bay, and Nipigon Bay) that provide more diverse and productive fish habitat than the open lake. On the south shore, relatively shallow, productive areas include the extreme west end, Chequamegon Bay, the east side of the Keweenaw Peninsula, and Whitefish Bay on the extreme east end.

The large central basin is relatively regular in configuration, with depths of 183-274 meters (600-900 feet). The eastern basin, where the greatest depth of 406 meters (1,333 feet) occurs, is highly irregular, with a series of shoals and trenches oriented in a north-south direction. Several of the trenches exceed 274 meters (900 feet) in depth.

Summer thermal stratification occurs only temporarily in open waters, and is more persistent in sheltered inshore waters. Currents and upwellings are prominent features of the thermal habitat, induced by uneven heating and the prevailing westerly winds. Currents distribute summer heat gain so that maximum heat content of the water occurs near October 1, well after maximum summer air temperatures (Bennett 1978). Lake Superior rarely freezes over during the winter, so deep mixing of waters can lead to the development of homothermous water of about 2.2 °C (36 °F) to a depth of 183 meters (600 feet). Deeper waters are at the temperature of maximum density 3.9 °C (39 °F) throughout the year (Lawrie and Rahrer 1973). Maximum ice cover occurs around late March. Ice covers 60 percent of the lake in normal winters, 40 percent in mild winters, and more than 95 percent in severe winters (Matheson and Munawar 1978).

Currents induced by temperature structure establish a persistent pattern of circulation (Matheson and Munawar 1978). Surface currents exhibit a general counter-clockwise circulation. Currents flowing from west to east are strongest along the south shore and obtain maximum strength along the northern side of the Keweenaw Peninsula. Coastal upwelling occurs along the northwest shore caused by the return flow as the prevailing westerly winds drive surface water towards the east. Upwelling also occurs in a large area in the middle of the lake. Due to upwellings along the northern shore, water temperature is consistently lower during the summer, but ice formation is delayed.

The mean annual discharge to the St. Marys River was 2,100 cubic meters per second (74,130 cubic feet per second) from 1900 to 1972 (Upper Lakes Reference Group 1976), with a low of 1,773 cubic meters per second (62,576 cubic feet per second) in 1963 and a high of 2,625 cubic meters per second (92,655 cubic feet per second)in 1952 (Lawrie and Rahrer 1973). The level of Lake Superior has been held relatively stable since 1922 by a compensation dam on the St. Mary's River, the lake's only outlet. The amplitude of seasonal variation rarely exceeds 0.5 meter (1.5 feet).

About 200 rivers flow into Lake Superior (Matheson and Munawar 1978). The largest is the Nipigon River in Ontario, which drains a sub-watershed of 4,856 square kilometers (1,875 square miles). The second largest tributary is the St. Louis River on the U.S. side. Altogether, there are about 28,968 kilometers (18,000 miles) of streams within the Lake Superior basin (PLUARG 1976).

Trophic state

The waters of Lake Superior are remarkably low in total dissolved solids (Matheson and Munawar 1978). Most of the water input to the lake is derived from precipitation falling on a watershed composed of hard, impervious, and chemically resistant rocks. The drainage is by way of many short tributaries, which minimize the contact time during which mineral matter may be dissolved. Because nearly 40 percent of the basin area is occupied by the lake surface, precipitation falling directly onto the lake dilutes drainage water so that Lake Superior water is commonly said to resemble rain water (Matheson and Munawar 1978). With respect to the major ions, there is no evidence that any change in water chemistry has occurred within historical times (Upper Lakes Reference Group 1977).

Primary productivity by phytoplankton is very low, about 1009 kilograms/hectare/year (900 pounds/acre/year) dry weight (Upper Lakes Reference Group 1977), near the low end of the range for freshwater ecosystems. By comparison, the open waters of the other Great Lakes are 2-5 times as productive as Superior (Vollenweider *et al.* 1974). Water clarity is high, with visibility typically 10 meters (33 feet) or more, indicative of the sparse phytoplankton populations.

The low productivity of Lake Superior is indicated by documented fish yields. During 1916-1940, a period of high and stable yields, Lake Superior produced annual yield of 0.9 kilograms/hectare (0.8 pounds/acre), probably near the maximum sustainable level (Ontario Ministry of Natural Resources 1987). During the period 1879-1969, annual commercial yields averaged 0.8 kilograms/hectare (0.7 pounds/acre) (Smith 1972). Current annual yield is about 0.5 kilograms/hectare (0.4 pounds/acre), reflecting low catches of lake herring, which dominated historical yields.

Socioeconomics

The rich tapestry of mineral, fossil fuel, water, land, and living resources of the Great Lakes Basin create economic opportunity for its human inhabitants resulting in demands upon these resources. Water resource demands include electric power generation, transportation, drinking water, agriculture, industrial processes, sanitation, and recreation. The purpose of this section is to give a broad overview of the dynamic interactions between the region's human population and its natural resources, and to describe the complexity of issues facing aquatic resource managers in the Great Lakes Basin.

Great Lakes economic structure

The book *Great Lakes Economy: Looking North and South* presents a thorough analysis of the economy of the Great Lakes region (Testa 1991). The following material is largely drawn from this publication.

Demographics and sources of personal income

Almost one-third of the U.S. population resides in the eight Great Lakes States. Of these States, New York, Pennsylvania, Illinois, Michigan, and Ohio have an above average percentage of their populations living in metropolitan areas (Erdevig 1991).

Average personal income in the Great Lakes States is slightly higher than the U.S. average with sources of personal income being quite similar to those in the rest of the country (Erdevig 1991).

Energy issues

Bournakis and Hartnett (1991) reported that regional energy consumption in 1988 was distributed as follows: petroleum, 36.7 percent; coal, 30.1 percent; natural gas, 22.8 percent; nuclear fuel, 8.6 percent; and renewable resources including hydropower, 1.8 percent. Energy consumption for 1988 was distributed as follows: transportation, 23.1 percent; industrial 25.1 percent; commercial, 9.9 percent; residential, 16.4 percent; reject heat, 24.8 percent; and exports, 0.7 percent. The industrial sector was the largest consumer of energy, with the commercial and residential sectors together equalling industrial sector consumption.

The largest fossil-fueled electrical generating plant in the world is located on Lake Erie at Monroe, Michigan, however the Great Lakes region's coal resources have a high sulfur content rendering them inadequate in meeting the region's demand for clean energy. Consequently, the region imports large quantities of natural gas, oil, and low sulfur coal, making energy production vulnerable to price fluctuations. The energy statistics of the late 1980s indicate that the region is becoming more dependent on imported oil and therefore, is vulnerable to the negative effects of potential oil embargoes.

Oil and gas development in lower Michigan, and potentially in northern Wisconsin, heightens the potential for pollution of ground and surface water during exploration, extraction, and transmission. Effects may include groundwater contamination by lost drilling mud, brine, and hydrocarbon seepage from leaky delivery systems. Surface water may be impaired by sediment from disturbed production sites (Michigan Chapter, American Fisheries Society, Spring 1992 Newsletter).

Electrical generation-related impacts on aquatic organisms include impingement on screens, thermal enrichment of habitat, entrainment in water intake and circulation/cooling systems, extreme fluctuations in stream flow, and prevention from access to habitat by barriers such as low-head dams. Increasing demand for electricity in the Great

Lakes region is expected to give rise to increased energy demand, resulting in increased generating capacity and impacts on aquatic organisms. Aquatic resource professionals and electrical generation professionals need to work together to minimize impacts upon aquatic organisms.

Role of waterborne transportation

Economic activity during settlement of the Great Lakes region consisted mostly of resource exploitation including fishing, trapping, mining, and timber harvest aided by water-based transport (Donahue 1991).

In the mid-1900s, regional and national U.S. and Canadian economies were built on the Great Lakes-St. Lawrence Seaway transportation system. Navigation system improvements ranging from channel and lock construction to innovative vessel designs and loading-unloading equipment resulted in increased cargo carrying capacity and lower transportation costs. This same system that supports deep draft transportation from the Atlantic Ocean to Lake Superior (Thorp and Ballert 1991) also allows invasion of the Great Lakes by nonindigenous aquatic species, such as ruffe, spiny water flea, alewife, zebra mussel, quagga mussel, and sea lamprey resulting in wholesale changes in the ecosystem of the Great Lakes. These species threaten indigenous populations and are detrimental to the integrity of the ecosystem.

Transportation continues to be a major factor in the modern economic infrastructure of the Great Lakes region. Waterborne commerce has served as an important means of integrating of the economies of Great Lakes States. The largest volume of shipments are of iron ore, coal, and limestone supporting the steel industry and its customers, but the ports of Duluth, Chicago, and Toledo are important for farm product shipments to other lake ports and overseas (Eldevig 1991). To protect the integrity of the Great Lakes Basin ecosystem, aquatic resource professionals and transportation industry officials need to work together to prevent further invasions by nonindigenous species.

Non-fuel mineral resources

Four non-fuel minerals dominate production in the Great Lakes States: crushed stone, sand and gravel, iron ore, and portland cement. With the exclusion of iron ore, three of these products are mined in close proportion to the economic size of the region. Minnesota and Michigan iron ore, however, accounts for 98 percent of the U.S. production value of the mineral. Of the 173 million tons of all cargo shipped on the Great Lakes in 1989, 66.7 million tons were iron ore, and 35 million tons were stone related to the iron ore and steel industry. Other industrial minerals, especially sand and gravel and crushed stone, are tied to construction activities in close proximity to the deposits. Abrasive, bromine, calcium chloride, copper, fluorite, gold, peat, salt, silver, talc, wollastonite, and zinc are also produced in the Great Lakes region and extremely important to the U.S. economy (Whaley 1991). One copper mine is operating in the U.S. portion of the Lake Superior basin. The White Pine mine in Ontonagon County, Michigan produced 44,000 tons of copper in 1990, and employed about 1,000 workers. Unexploited deposits of copper and iron in the Lake Superior basin are being considered for mining raising concerns for aquatic habitat impacts resulting from acid mine drainage, heavy metal deposition from smelters, and disposal of tailings.

Manufacturing and agricultural industries

Manufacturing and agriculture are critical components of the Great Lakes regional economy. Production of motor vehicles is one of the more important industries in the Great Lakes area. In 1989, about 58 percent of all autos produced in the U.S. were assembled in five of the Great Lakes States with Michigan alone producing a full one-third. Similarly, about 56 percent of all trucks and busses were manufactured in the Great Lakes area, mostly in Michigan and Ohio (Erdevig 1991).

Just over one-fifth of U.S. cash receipts from farm marketings comes from Great Lakes States with major commodities including corn, soybeans, milk, and hogs. Almost one-half of the corn, soybeans, and milk and two-fifths of the hogs produced in the U.S. come from these eight States (Erdevig 1991). The Lake Erie basin leads the Great Lakes region in the number of farms, and in the production of hogs and pigs, sheep, chickens, corn, soybeans, and wheat.

Manufacturing and agricultural industries have contributed to contamination of the Great Lakes with toxic chemicals, persistent pesticides, and sedimentation. Aquatic resource professionals need to work together with industry to minimize negative impacts upon aquatic ecosystems and to rehabilitate those areas where degradation has occurred.

Forest resources

Forests cover 54 percent of the Great Lakes region's land area below Hudson Bay, supporting wood products industries, essential habitat for plant and animal species and providing desirable locations for recreation and tourism activities (Leffers 1991).

The forest products industry includes 5 pulp and paper mills in the U.S. portion of the Lake Superior watershed, with a combined capacity of 2,100 tons/day. About a dozen wood products mills employ more than 100 workers each in the U.S. portion of the watershed, but there are many smaller wood products enterprises.
Forests are critical to the regional ecosystem, helping to stabilize soils, clean air, and circulate water. Stewardship of forest resources to maintain these important functions while supporting the wood products industries so important in Ontario, Minnesota, Wisconsin, and Michigan, is a common goal across the region. Aquatic resource professionals and foresters need to work together to minimize aquatic habitat destruction and pollution resulting from the forest products industry.

National, State and Provincial parks

Many natural and cultural assets of the region that are preserved and managed through separate State and Provincial and National Parks systems and form the basic elements of an outdoor recreational infrastructure (Thorp and Smith 1991). The U.S. Department of Interior's National Park Service has jurisdiction over 5,119 square kilometers (1,969 square miles) in the Great Lakes States including: two national parks; four national lakeshores; one national seashore; seventeen national historic sites; five national historical parks; five national monuments; one national battlefield; one national military park; four scenic rivers; and four national scenic trails. Environment Canada oversees five national parks in Ontario and three in Quebec with a combined area of 3,106 square kilometers (1,211 square miles). Great Lakes States have more than 625 State parks and Ontario has the largest absolute area of any Canadian Province reserved in Provincial parks.

Outdoor Recreation and Tourism

Residents of the Great Lakes region and visitors to the area view outdoor recreation as not just a quality-of-life issue, but as a way of life. The attractiveness of the Great Lakes for outdoor recreation activities is directly connected to diversity and health of the entire Great Lakes Basin ecosystem. Outdoor recreation is of concern to both the public and private sectors, with competitive or complementary linkages between the two. For example, the private sector provides lodging for publicly administered parks, whereas, both may compete for hikers or campers. The dynamic nature of this relationship raises policy issues, especially when questions of funding or program development arise at the community level.

Nearly $69 billion dollars of travel-related expenditures were attributed to the eight Great Lakes States in 1987 (Thorp and Smith 1991). This amounted to 25 percent of the U.S. total. Ontario and Quebec received approximately $13 billion or 54 percent of Canada's $24 billion total. These expenditures supported a wide range of enterprises and

activities covering both the private and public establishments and facilities and including such functions as transportation, lodging, food, amusements, recreation, retail trade, and the provision of information services. Of course, all of these activities and enterprises depend upon the diversity and health of the Great Lakes Basin ecosystem which provides the infrastructure supporting the travel-related industry.

Fishing

Great Lakes fish provide a valuable food supply for numerous Native American Tribes who continue to fish for subsistence under court affirmed treaty rights. Subsistence fishing is most prevalent in Lake Superior and northern Lakes Michigan and Huron, especially in areas adjacent to tribal reservations. The St. Mary's River, fished intensively for centuries by Native American Tribes, continues to be used by these subsistence fishers.

The Great Lakes region supports angling year-round (Thorp and Smith 1991). These anglers exert tremendous fishing pressure on indigenous and nonindigenous fish populations in the Great Lakes and their connecting waters.

According to the Service's *1991 National Survey of Fishing, Hunting, and Wildlife-Associated Recreation*, 2.6 million Great Lakes anglers spent 25 million days in 20 million trips fishing. They spent $1.3 billion on these trips and equipment. Trip-related expenses totaled $870 million. Of these expenditures, almost $331 million (38 percent of trip cost) was spent on food and lodging; $173 million (20 percent of trip cost) was spent on transportation; and $366 million (42 percent of trip cost) was spent on other items such as guide fees, equipment rental and bait. Great Lakes anglers spent $467 million on equipment. They bought $190 million worth of fishing equipment such as rods and reels; spent $29 million on auxiliary equipment such as camping equipment and binoculars; and $247 million on the purchase of such special equipment as boats and vans.

Great Lakes fishing includes not only the Great Lakes, but also their tributaries, bodies of water connecting the Great Lakes, and the St. Lawrence River south of the bridge at Cornwall. Lake Erie continues to be the most popular of the lakes among anglers with 35 percent of Great Lakes anglers fishing it in 1991, an average of 8 days per angler. Lake Michigan ranked a close second with 34 percent averaging 6 days per angler. Lake Ontario was fished by 12 percent of all Great Lakes anglers in 1991, an average of 8 days per angler.

The connecting waters (St. Mary's river system, St. Clair, Niagara and Detroit Rivers) attracted 10 percent of the total Great Lakes anglers averaging 12 days of fishing per angler in 1991. While Lake St. Clair was fished by only 5 percent of all Great Lakes anglers, they fished an average of 14 days per year, more than on any other Great Lake or connecting water.

An excellent synopsis of Great Lakes commercial fishing activities is provided by Thorp and Smith (1991). At first, the Great Lakes supported large, stable populations of fish including lake trout, lake herring, and lake whitefish. Fishing, whether by Native Americans or settlers and their commercial enterprises, was productive. But when large scale lumbering and shoreland development impaired water quality and flow conditions in tributaries and coastal marshes, spawning success declined. By 1885, exploitation by 10,000 commercial fishers began to take its toll. The U.S. Great Lakes commercial fish harvest peaked in 1899 at 119 million pounds. Invasion of the parasitic sea lamprey and other nonindigenous species, combined with impaired water quality and excessive harvest, destroyed the commercial fishery. The Great Lakes States, Native American Tribes, Service and the binational Great Lakes Fishery Commission have all played major roles in fishery rehabilitation. Effective sea lamprey control using chemical treatment provided opportunities for successful hatchery-supported planting programs. Stocking has contributed huge numbers of lake trout and Pacific salmon, in all of the Great Lakes.

The Great Lakes commercial fishery is of major economic significance to the Native American Tribes and minor economic significance to the States. As an example, in 1986 the majority of the Lake Erie commercial fishery harvest included yellow perch, walleye, rainbow smelt, and white bass with the value of the U.S. harvest at $1,050,800 (U.S. $) and Canadian harvest at $36,472,948 (Canadian $). Great Lakes commercial fishers also play a critical role in providing the non-angling population of the Great Lakes Basin with edible fish, available at restaurants, hotels, and markets.

Recreational boating

In 1988, more than one-third of all watercraft in the U.S. were registered in the Great Lakes States as recreational boats (Thorp and Smith 1991). Approximately 3,527,000 recreational boats were registered in the region, but due to jurisdictional differences in registration requirements and data veracity questions, exact recreational boat activity on the Great Lakes remains unavailable. One Michigan State University/Department of Park and Recreation Resources study indicated that "boat days" on the Great Lakes grew 63 percent from 1974 - 1980 and 41 percent from 1980 - 1986. The study also estimated that approximately 700,000 U.S. recreational boats are used on the Great Lakes each year.

Boat manufacturers, retailers, marina operators and marine business suppliers all represent the diverse recreational boating industry in the Great Lakes. According to the U.S. Bureau of Labor Statistics, the eight Great Lakes States account for 6,000 private sector, marina-related jobs and 10,000 boat dealer and supplier jobs. The *Detroit Boat and Fishing Show* has doubled its attendance since 1981, with sales volume growing much more rapidly. In 1989, the Detroit show generated $61.5 million in sales. The *Cleveland Mid-America Boat Show*, held each January, is the largest U.S. show.

The Laventhol and Horvath accounting firm has predicted that the area around southern Lake Michigan (Kenosha, Wisconsin to Muskegon, Michigan) will generate 850 new shoreside dwelling units and 1,000 boat slips at marinas and residential developments each year. A 1986 Ohio Sea Grant study indicated that the "typical" Lake Erie marina had been in operation for 18 years, grossed $894,000 in annual sales and employed 5.5 people on a full-time annual basis with a similar number of additional full time equivalents during the average 6.6 month season. The mean annual payroll for the marinas was $100,000.

Other activities

The President's Commission on Americans Outdoors (1987) acknowledged that recreation is big business with a total of $262 billion of related expenditures made in 1984, $100 billion of which was categorized as outdoor recreation. Bicycle sales have been increasing in recent years, surpassing car sales. Most U.S. bicycle manufacturers are based in the Great Lakes region, mainly Illinois and Ohio. Thousands of miles of trails in the region are used by bicyclists, cross-country skiers, snowmobilers, and hikers. Great Lakes States had 54 percent of the 1991 U.S. total of trails developed from abandoned rail lines amounting to 2,775 kilometers (1,724 miles). Ontario has also developed trails along rail corridors no longer in use.

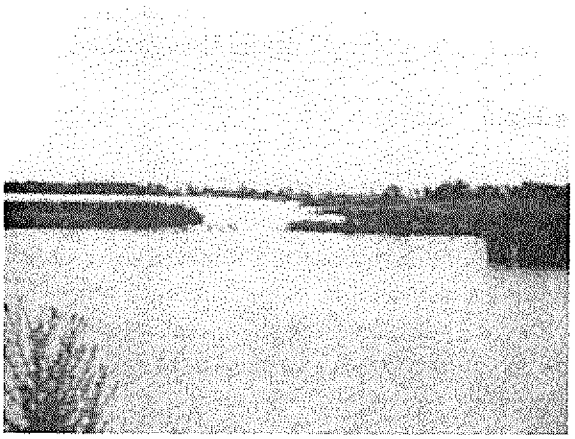
One third of U.S. downhill ski revenues are generated in Great Lakes States and more than half of the alpine ski areas in Canada are in Ontario and Quebec. Snowmobiling also accounts for large expenditures amounting to about $1.3 billion annually. In 1987, the Great Lakes States had 742,868 registered snowmobiles; 70 percent of the U.S. national total with Michigan, Minnesota, Wisconsin, and Illinois among the top five States. These activities impact cover vegetation.

Destruction of cover vegetation varies depending upon the nature of trail-related recreational activities and the responsibility of individual recreationists. Off-road vehicles are capable of generating conditions facilitating soil erosion, if not responsibly operated. Soil erosion degrades aquatic habitat, destroying spawning, rearing, and cover areas and eventually resulting in diminished populations of species including sport fish.

Ecosystem Approach

Ecosystem Health Concepts

Natural resource agencies are going through major adjustments in their approaches to resource management, restoration, and enhancement. The terms "ecosystem" and "holistic," although not new, are now codified in international agreements and laws. The application of these concepts to resource management has been challenging and has invited the use of the analogy of human health, to explain ecosystem health issues. Although this analogy is useful for some communications, it has limits for scientific application since, for example, descriptors and definitions for ecosystem "wellness" have not been developed.



Alpena Fishery Resources Office photo

Other terms used to describe ecosystem health include integrity, complexity, and diversity. Rapport (1990) stated that "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." "Integrity", as defined by Rapport, is not a static condition.

Loftus and Regier (1972) related the terrestrial ecologist's concept for climax communities to the aquatic realm and the rejuvenation achieved by disturbances. Ryder and Kerr (1990) suggested that ecological communities evolve and that integrity of an ecosystem is indicated by the status of indigenous species in species assemblages. Since a variety of evolutionary changes, such as changes in species and increased complexity and diversity may be indicators of an ecosystem's "wellness," ecosystem health might be described as "ecosystem vitality in support of natural biological functions." A focus on ability to support biological functions allows for natural and/or anthropogenic changes in species assemblages within an ecosystem that could still be described as "functionally healthy" even though stressed by harvest or habitat modification.

Historic conditions or natural, undisturbed ecosystems are often suggested as targets or examples of ecosystem wellness. This would appear applicable when humans are not a major component of the landscape. However, in ecosystems where permanent human development is a major factor, humans must be considered part of the landscape. Use of undisturbed systems or pre-development time frames as descriptors of wellness or benchmarks for today's anthropogenically stressed systems undermines the ecosystem approach by excluding avoidable and unavoidable effects of humans within that landscape.

The current challenge for natural resource managers is to understand the ecosystem's functional vitality and the interactions between various trophic levels. Identification of obstructions to energy flow is fundamental to assessment of ecosystem vitality and functional impairments caused by anthropogenic stresses.

Implementation of the ecosystem management concept requires an understanding of natural resource goals. Society within the Great Lakes basin is now debating natural resource goals for each lake in the system. Considerations range from "a return to pristine conditions" to "intensive aquaculture." Both extremes will be compromised since these extremes can neither be reached nor sustained.

Society's impacts on the ecosystems of Lakes Ontario, Erie, and Michigan have been severe. Some historical effects, such as toxic contaminant loading, excessive nutrient enrichment and overharvest are reversible. Others, such as introductions of nonindigenous species, drainage basin changes, and lost indigenous species are not. Lake Superior is the least altered of the Great Lakes, but even its ecosystem has been permanently changed via drainage basin changes and introductions of nonindigenous species and, therefore, can not be returned to its historically pristine condition.

While "intensive aquaculture" provides some options for resource managers, challenges, such as: maintenance of genetic diversity; maintenance of fish health within hatcheries; facilitation of stocked fish recruitment; and fish production costs ensure that this method alone will not suffice to ensure a healthy, productive, and diverse aquatic Great Lakes ecosystem.

Support for the Ecosystem Approach

The *Strategic Plan for Management of Great Lakes Fisheries*, directed the preparation of fish community objectives for each of the Great Lakes. Within this plan, the following common goal was established for all Great Lakes:

> *"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.*

The *Strategic Plan for Management of Great Lakes Fisheries* document, approved by the eight Great Lakes states, the Chippewa-Ottawa Fishery Treaty Management Authority, the Great Lakes Indian Fish and Wildlife Commission, the Province of Ontario, the Canadian Department of Fisheries and Oceans, and the Service reflects the *Boundary Waters Treaty* (1909). The *Canada-U.S. Great Lakes Water Quality Agreement*, signed in 1972 and amended in 1978 and 1987, requires an ***ecosystem approach*** to solve water quality related problems using a coordinated, binational approach. Although numerous definitions for ecosystem management have been written, the following one is applicable (USBLM 1993):

> *"Ecosystem management is a process that considers the total environment. It requires the skillful use of ecological, economic, social, and managerial principals in managing ecosystems to produce, restore, or sustain ecosystem integrity, and desired conditions, uses, products, values and services over the long term."*

The *Great Lakes Water Quality Agreement*, Annex 2 (1987) states that "Impairment of beneficial use(s) means a change in the chemical, physical or biological integrity of the Great Lakes System sufficient to cause any of the following:

(iii) *Degradation of fish and wildlife populations*;
(iv) *Fish tumors or other deformities*;
(v) *Bird or animal deformities or reproduction problems*;
(vi) *Degradation of benthos*;
(viii) *Eutrophication or undesirable algae*;
(xiii) *Degradation of phytoplankton and zooplankton populations.*
(xiv) *Loss of fish and wildlife habitat.*"

Some of these criteria may be used as stand-alone measurements. However, when applying the ecosystem approach, these criteria are also sub-sets or symptoms of (XIV) *Loss of fish and wildlife habitat.* Loss should be defined as actual destruction and/or functional impairments (Sly and Busch 1992a). Habitat should be defined as the biological, chemical, and physical setting needed to support all life functions of the organisms (Sly and Busch 1992a).

Various agreements and regulations require restoration of the Great Lakes. The *Great Lakes Water Quality Agreement* (1987) and the *Great Lakes Critical Program Act* (1990) each identify "restoring and maintaining the chemical, physical, and biological integrity of the waters of the Great Lakes ecosystem or Basin," as the goal. The *Great Lakes Fish and Wildlife Restoration Act* (1990) identifies a scientific approach to restoring the fishery resources and the *Great Lakes Critical Program Act* (1990) requires "a systematic and comprehensive ecosystem approach to restoring and protecting the beneficial uses" through implementation of *Lakewide Management Plans* and *Remedial Action Plans* for designated areas within the Great Lakes basin.

Setting Ecosystem Goals and Objectives

Restoration and rehabilitation require identification of target goals. Such goals and objectives have generally been available from a number of sources for specific water quality measurements. They have also been developed for some specific fish species and one habitat type (wetlands), but with the exception of the published Lake Superior and Ontario *Fish Community Objectives* and the soon to be published Lake Michigan and Lake Huron *Fish Community Objectives*, goals and objectives have not been available for fish communities and other aquatic habitat units. Very little work has been done in identifying goals and objectives at the landscape level, although development of *Lakewide Management Plans* using the ecosystem approach would be a big step forward.

In setting fish species goals or attempting to develop fish community or aquatic habitat goals, biologists and managers are usually forced to use only such readily available information as historic production from commercial landings. This source usually provides the best available information, however, it contains major biases. As already discussed, historic conditions have changed and, with society included in the ecosystem, those conditions can not now be completely restored. Fish species have also been added and lost; many of these changes are permanent. Therefore, predicting future population sizes or fish production from species that have been lost or replaced with new species that have been added to the fish community, requires a different approach. Suggestions are provided in the following sections.

Lake Ontario: an Ecosystem Approach Case Example

To more effectively improve and maintain the Great Lakes ecosystem, present ecosystem status must be determined to focus our efforts and allow us to measure our progress. Understanding the status of available habitat is mandatory to make decisions on the need for and viability of restoration efforts intended to improve Great Lakes ecosystem integrity. Lake Ontario habitat availability, with associated levels of impairment, were determined by Busch *et al.* (1993).

The aquatic resources of Lake Ontario are impaired according to the International Joint Commission. This means that the Commission, its agents (Environment Canada and the U.S. Environmental Protection Agency) and partners (States, Provinces, and private and public agencies) have reached the conclusion that anthropogenic stresses are having a significant negative impact on the ecosystem.

Efforts were made to evaluate the status of the Lake Ontario ecosystem. The general problem is presented in Figure 7. This report focuses on the assessment of functional impairments to the habitats of the Lake Ontario ecosystem. Physical changes to the basin were inventoried. Chemically-caused stresses were reviewed. General impacts on the ecosystem's health caused by nonindigenous species were also evaluated.

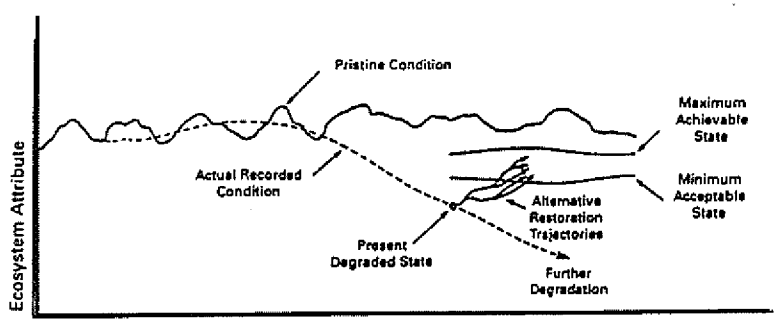


Figure 7. Conceptual representation of the degradation of an ecosystem and the recovery due to restoration initiatives (from Council of Great Lakes Research Managers 1991).

Habitat classification methodology

Table 2. The hierarchy of aquatic habitat classification (modified from Sly and Busch 1992b).

SYSTEM	SUB-SYSTEM	DIVISION	SUB-DIVISION	CLASS[1]
Lake Ontario				
|----------	Open water----------	Circulatory basin----------	|	[Water column=Wc,
|			*(Open Water)*	Substrate = S,
|			|	Plant material =Pm]
|			Deep water reef,	
|			>25 meters	Wc, S
|			Fluvial deposition zone	Wc, S, Pm
|			Major embayment,	
|			<25 meters deep	Wc,S, Pm
|			Major embayment	
|			>25 meters deep	Wc, S
|			Relict trench	Wc, S, Pm
|			Sub-basin, <25 meters	Wc, S, Pm
|			Sub-basin, >25 meters	Wc, S
Nearshore----------		Shoreline----------	|	[Wc, Water quantity
		|	|	= Wq, S, Pm, Plant
		|	|	cover = Pc]
		|	*(Shoreline for 100 m, developed*	
		|	*littoral zone <3 m])*	
		|	Active sand dune	Wc, S, Pc
		|	Erodible bluff	Wc, S, Pc
		|	Erodible plain	Wc, S, Pc
		|	Non-erodible bluff	Wc, S, Pc
		|	Non-erodible plain	Wc, S, Pc
		|	Relict sand dune	Wc, S, Pc
		|	Upland	S, Pc
		|	*(Wetlands)*	
		|	Open water connected,	Wc, S, Pm, Pc
		|	Not connected	Wc, S, Pm, Pc
		|	*(Tributary and embayments)*	
		|	Embayment, restricted	Wc, S, Pm, Pc
		|	Embayment, tributary	
		|	dominated	Wc, S, Pm, Pc
		|	Embayment,unrestricted	Wc, S, Pm, Pc
		|	Tributary reach	Wc, Wq, S,
		|		Pm, Pc
		|	*(Special features)*	
		|	Artificial fill/breakwall	S, Pc
		|	Artificial island S, Pc	
		|	Artificial shoal <25 meters	Wc, S, Pm
		|	Artificial spit/jetty	S, Pc
		|	Barrier structures	S, Pc
		|	Offshore bar/Lagoons	Wc, S, Pm, Pc
		|	Pond	Wc, S, Pm, Pc
		|	Rocky outcrop	Wc, S, Pc
		|	Shoal/Reef, <25 meters	Wc, S, Pm

[1]Each Class level descriptor had three modifiers - biological, chemical, and physical.

The Aquatic Habitat Classification System was used to inventory and assess the Lake Ontario ecosystem. The complete methodology is described in Busch and Sly (1992) and details of its application to Lake Ontario are provided in Busch *et al.* (1993).

A classification scheme should be based upon geographic and geological parameters and provide a means for defining and assessing individual and lakewide aquatic habitat units from a functional perspective. The "condition" of a habitat unit was judged relative to its ability to support fish and wildlife populations. The Aquatic Habitat Classification System is a hierarchical method that allows for systematic splitting of an aquatic ecosystem from its largest, most general component, to smaller, more discrete subunits of habitat at the class level (Table 2). It allows for use of

modifiers, or descriptors selected to fulfill the needs of specific applications. The current project defines habitat units, and assigns appropriate physical, chemical, and biological descriptors to provide means for habitat evaluation.

Definition of aquatic habitat(s)

In classical biological usage, habitat is generally described as a geographical entity, such as a coastal marsh or the littoral zone of a lake, with little emphasis on biota. This approach lacks the focus needed for a detailed analysis and evaluation of a complex, multiple habitat ecosystem. The need for a more functional ecosystem-based approach to habitat evaluation, especially from a management viewpoint, has long been recognized (Platts 1980; Ryder and Edwards 1985) and was recently addressed by Sly and Busch (1992a).

Consistent with an ecosystem-based approach, habitat is defined as the sum total of the physical, chemical, and biological attributes of a specific location, which constitutes a distinct fish or wildlife refuge, feeding site or breeding location. For the current project, habitat units were described and assigned physical, chemical, and biological descriptors to provide the means for evaluation of the availability and functional health of these habitats (Busch *et al.* 1993). A list of impairments, with descriptors, was also developed (Busch *et al.* 1993). These are stresses (chemical, physical or biological) which interfere with the normal functions of the habitat unit and, therefore, affect life processes of organisms living within that habitat unit.

Lake Ontario is a diverse ecosystem consisting of many interconnected habitats. Each of these is influenced by **natural** and **anthropogenic** physical, chemical, and biological factors which determine the health of the habitat unit.

Habitat classification methodology-identification and justification

The Aquatic Habitat Classification System was used to inventory and assess the Lake Ontario ecosystem. The complete methodology is described in Busch and Sly (1992) and details of its application to Lake Ontario are provided in Busch *et al.* (1993).

In selecting the classification scheme, it was imperative that the scheme allow identification and input of data on habitat units based upon geographic and geological parameters and to provide a means for defining and assessing individual and lakewide aquatic habitat units from a functional perspective. The selection of potential habitat units was based on well defined physical factors, such as topography, stratigraphy, and other classical landform descriptors. These habitats were then considered from the perspective of biological interactions and community structure, whether actual or potential. From these considerations, a listing of functionally distinct habitat units, sufficient to define all lakewide habitats, was developed by Busch *et al.* (1993).

Using the Aquatic Habitat Classification System hierarchy as a model (Table 2), all lake habitats fall under two major categories, or Sub-Systems. The Open Water sub-system, includes the circulatory basins and extends shoreward, to either the sand/silt sediment boundary or the attached plant boundary, whichever reaches the greater depth. Shoreward of this boundary is the Nearshore sub-system, that includes all coastal features, as well as islands and shallow water features such as reefs and shoals. These are included here since they, like the shore, are dominated by edge or interface effects.

Circulatory basins are further divided into sub-basins and major embayments. In the case of Lake Ontario, four morphometric sub-basins are described (Martini and Bowlby 1991). Major embayments are those whose bathymetric profiles and substrate composition include both nearshore and open water features. Also, these embayments are more influenced by lake waters than by shore contributions. Smaller embayments, or those which do not meet the above criteria, are treated separately under the coastline division.

The open water sub-system is further divided into two depth classes - less than 25 meters and greater than 25 meters. This is based on the following criteria: 1) wave activity exerts its influence to a maximum depth of approximately 25 meters (Martini 1992), and 2) thermocline development in Lake Ontario is restricted to the top 25 meters (Sly 1991). Thus, the major physical forces defining this habitat exert their effects within the 25 meter contour. Therefore, the area from the nearshore boundary to the 25 meter contour constitutes a separate zone from deeper waters.

The nearshore sub-system is described from a classical geological basis. Since subsequent definitions of habitat units rely on an understanding of coastal morphology, the following definitions were adopted: The shore is that zone, from the low water mark landward to the base of the cliff, large or small, which marks the landward limit of effective wave action (Johnson 1965). A cliff, is defined as the abrupt change in gradient, no matter how small, indicating where wave erosional forces cease, and is usually demarcated by a change in vegetation and substrate. The coast is the zone landward of the base of the cliff, with the line of demarcation known as the coastline. The beach is the zone of unconsolidated material, or debris, between the low water mark and the bottom of the cliff.

Findings

The habitat information inventory by Busch *et al.* (1993) provided the habitat information base for Lake Ontario. Information and supportive literature were identified, obtained, and organized according to biological, chemical and/ or physical application. Ideally, the information should be loaded into a computerized data base and used with a Geographic Information System. This was not done for lack of funds and time. Instead, an "expert system" or Delphi technique (Zuboy 1981; Crance 1987) was used to evaluate the anthropogenic stresses on the 29 habitat units identified at the Sub-division level (Table 2) and further clarified by the Class-level descriptors.

Table 3. Estimated anthropogenic impairments (stresses) affecting habitat functions in Lake Ontario (Habitats combined into five general categories. Estimated impact was multiplied by its estimated percent of total surface area for watershed effect).

Habitats combined by general categories and @ % of basin surface area	Biological stresses	Chemical stresses	Physical stresses	Total stress impact by habitats
Open water (67 percent)	0.11	0.03	0.02	0.16
Shoreline (100m inland and littoral area 3 m) (15 percent)	0.03	0.03	0.03	0.09
Wetlands (4 percent)		0.01	0.02	0.05
Tributary and embayments (12%)	0.04	0.09	0.12	0.25
Special features (2 percent)	0.01	0.01	0.01	0.03
Total stress impact by type	0.21	0.17	0.20	0.58

Functional impairments of 88 habitat categories (Class level) were evaluated for biological, chemical or physical stresses. The criteria were the severity of the ecological impact and the expected permanence of the stress. The assessment used a scale of 0.1 to 1.0 to estimate the degree of disturbance for each of the habitat categories. This was repeated for biological, chemical, and physical stress factors. The results, by stress factors for each of the 88 habitat categories, were combined and averaged for five habitat groups (Tables 2 and 3). The results were multiplied by an approximation of the size of the habitat's area (percent of the surface area of the system) to relate the impairment to the health of the ecosystem.

The results (Table 3) indicate that the Lake Ontario ecosystem, during the 1960-90 period, was functionally impaired by 58 percent. The stresses were caused almost equally by biological (.21), chemical (.17), and physical (.20) stressors. Most of the impacts were found in the "open water" caused by biological concerns and "tributary/embayments caused by physical changes and obstructions (dams) and chemical loadings.

The functional performance of the "open water" habitats was very stressed by exotic species. This was partly due to the dramatic change in the open-water species with the loss of native species, the invasion of nuisance exotics, and the need to rely on the stocking of exotic species to make use of this habitat niche. The wide distribution and the permanence of nuisance exotics resulted in the high stress indicator.

Physical changes in the tributaries due to hydro-power development, construction of harbor facilities, and the maintenance dredging for harbors result in significant impairments. Chemical stress were also most significant in the tributaries, many of which are used as harbors with associated high concentrations of people and high levels of point and non-point contributions of chemicals.

Surprisingly, shoreline/littoral and wetland habitats were not heavily stressed habitats due partially to the effect of governmental regulations for protection of "lake-connected wetlands" and the "shoreline and littoral zone". These strengthened regulations resulted in protection of the physical area of these habitat units which have not recently significantly decreased. Biological stresses by exotics such as purple loosestrife and zebra mussel invasion were identified.

Prior to government restrictions these habitats were greatly altered. In addition to agriculture, extensive urbanization, particularly in the vicinities of Toronto, Hamilton, and Rochester, has significantly impacted the shoreline and associated wetlands (Living with the Lakes 1989) resulting in an overall loss of 50 percent in local loss due to urbanization of greater than 80 percent (Whillans *et al.* 1992).

The estimated overall impairment reported in Table 3, is very similar to the health condition of 50 percent reported for Lake Ontario by Edwards *et al.* (1990). Their results described the conditions in the mid 1980s using the Dichotomous Key (Ryder and Edwards 1985), with lake trout as the index species. Edwards *et al.* (1990) include "exploitation and production" as a significant stressor since their assessment focused on the performance of lake trout (Figure 8). Conversely, in our aquatic habitat assessment the focus was on impairments to the functional performance of habitats, therefore, numerical abundance of top predators was not critical. However, in our evaluation, native top predators like burbot had to be self-sustaining, species under rehabilitation like lake trout had to have multi-year class broodstocks and stocked exotic predators had to be able to survive and grow.

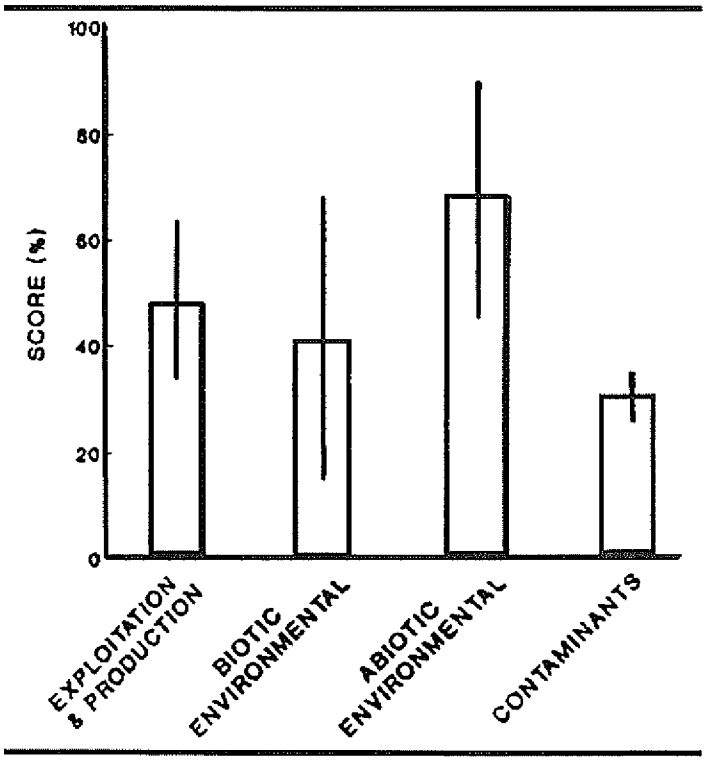


Figure 8. Dichotomous Key scores by stress category for Lake Ontario (vertical line extending from each bar indicates percent uncertainty (from Edwards *et al.* 1990).

Both this and the Edwards *et al.* (1990) ecosystem "health" assessments indicate that chemical stresses in Lake Ontario, although still of concern, are less important than physical and biological impairments, which are the most significant problems.

Information obtained from the ecosystem health assessment provides a focus for action in restoring the health of the lake. The focus needs to be on: (1) protecting the system from unintentional introductions or invasions of nuisance exotic species, (2) restoring the health of the tributaries by reestablishing natural up and down fish passage and (3) cleaning-up and preventing chemical contaminants.

Lake Ontario tributary habitats

As stated previously, the Lake Ontario evaluation identified physical stressors as affecting the functional health of Lake Ontario tributaries to the greatest degree, followed by chemical and biological. This can be described by analyzing the change in hydrologic characteristics in five Lake Ontario tributaries; Genesee, Oswego, Salmon, Black, and Raquette. The first four rivers are the largest U.S. tributaries to Lake Ontario, excluding the Niagara River. The Raquette River is one of four significant tributaries to the St. Lawrence River near Massena, New York. With the construction of dams, habitat has shifted from a free-flowing, riverine system to a series of fluctuating impoundments and low-flow sections. Some river segments exhibit more drastic fluctuations due to the storage and release of water (cycling), creating an unstable habitat and limiting shoreline production, while other segments operate on a run-of-the-river basis. Theoretically, run-of-the-river operation means that the same amount of flow entering the impoundment is leaving the impoundment, resulting in a more stable environment, including stable wetlands, and leading toward more natural conditions.

This analysis is used in two approaches: 1) river kilometers displaying characteristics similar to historic conditions [e.g. free-flowing habitat]; and 2) total river kilometers affected by dams. Qualifiers and assumptions associated with this analysis, include:

- Only the mainstem of river systems was used; therefore, habitat loss and habitat potential are underestimated because of available habitat in tributary streams;
- Due to absence of historic hydrologic data, historic conditions = total river kilometers expressed as free-flowing, riverine habitat (without dams);
- Current habitat available = total river kilometers (miles) displaying characteristics similar to historic condi tions (e.g. free-flowing habitat). Although this existing habitat is a riverine habitat, quantity and quality is reduced due to lower and/or fluctuating water levels;
- Total river kilometers affected by dams leaves the few river kilometers which remain in a more natural state of free-flowing habitat; and
- River kilometers are approximate ($\pm$ 1.6-3.2 kilometers or $\pm$ 1-2 miles).

Overall riverine habitat

A decrease in the river kilometers of free-flowing habitat has occurred in all five rivers; some more than others, due to the construction of dams.

Eleven out of 37 kilometers (23 miles) of free-flowing habitat on the Oswego River was the most drastic loss (52 percent), while only eight kilometers (five miles) were lost (3 percent) on the Genesee River. The Black and Raquette Rivers both lost 92 kilometers (57 miles) or 51 percent of their free-flowing habitat, and the Salmon River lost 18 kilometers (11 miles) or 25 percent. In terms of total river kilometers affected, Figure 9 presents the remaining kilometers that are not impacted by dams. These waters support a fairly stable community because of reduced water-level fluctuations and/or no dewatered areas. Again, the Oswego River is most impacted, with only 1.6 kilometers (1 mile) remaining unaltered (96 percent loss), followed by a mere 31 kilometers (19 miles) remaining on the Raquette River.

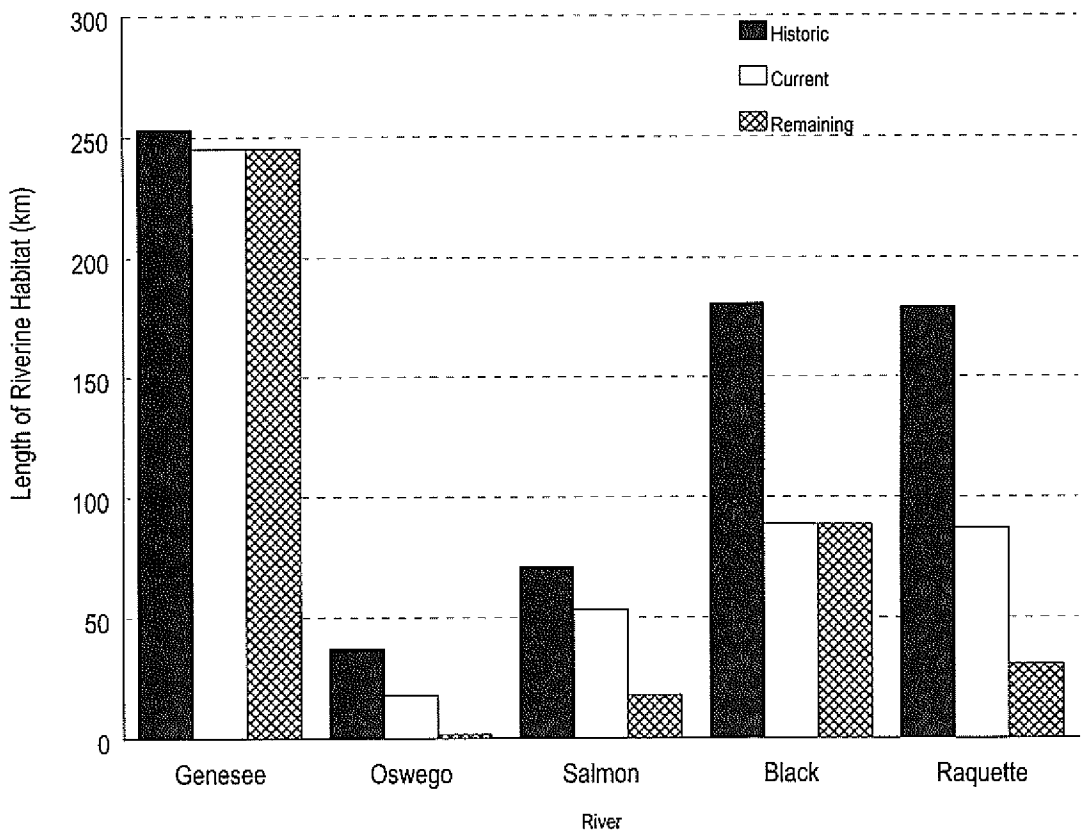


Figure 9. Total riverine habitat(km) in five U.S. Lake Ontario tributaries impacted by the construction of dams. Bars represent historic free flowing habitat (black), current habitat which displays characteristics similar to historic conditions (white), and remaining not impacted by dams (hatched).

The reduction in free-flowing conditions for the five rivers combined, due to damming and hydropower operation is 46 percent, leaving 54 percent unaffected (Figure 10). This is consistent with data presented in Table 3, where physical changes are a significant impairment to river/tributary systems contributing to the ecosystem "health" assessment previously described.

Due to this reduction in free-flowing habitat, there has been an ecological shift in habitat type on these rivers. River habitats (expressed as river kilometers) in the five rivers combined consisted of 54 percent free-flowing habitat, 20 percent run-of-the-river, and 26 percent storage and release (Figure 10).

Rehabilitation of these habitats focuses on the objective of healthy, productive, and as "natural as possible" tributary ecosystems. These concepts are addressed through the Federal Energy Regulatory Commission regulatory process that includes economic costs and benefits.

Consistent with the physical, chemical, and biological definition of habitat, we need to focus efforts toward improving tributary habitats to allow for increased productivity of a diverse community. After years of neglect, tributaries are again becoming an extremely important component and contributor to the Lake Ontario nearshore community. Mitigative measures at dams, such as upstream and downstream passage, established or enhanced minimum flow releases, and/or reduced water-level fluctuations can increase the potential for available habitat and productivity (Figure 10). By working toward changing hydropower projects from cycle to run-of-the-river operations, habitat stability may be increased and available free-flowing habitat enhanced. The small percentage of non-riverine storage and release, cycling habitat in Figure 10 is due to flood control dams seasonally ponding water when river flows are higher than normal.

By adding downstream passage, entrainment-related mortality of fish would be reduced, enhancing population size, and age-class structure. Upstream passage needs to be provided around or through man-made barriers which impede migrations. Access and use of natural habitat is crucial to restoring native species, such as Atlantic salmon and lake sturgeon, so they can re-inhabit historic, suitable spawning grounds.

Migratory fish habitats

Tributaries are often analyzed in terms of their role as spawning and nursery areas for migratory fishes. One of the crucial needs of migrating fishes is the ability to access suitable habitat for spawning. Historically, natural barriers such as waterfalls formed the upstream limit of fish migrations. Today, some migrations are impeded by the presence of dams below this historic, natural barrier.

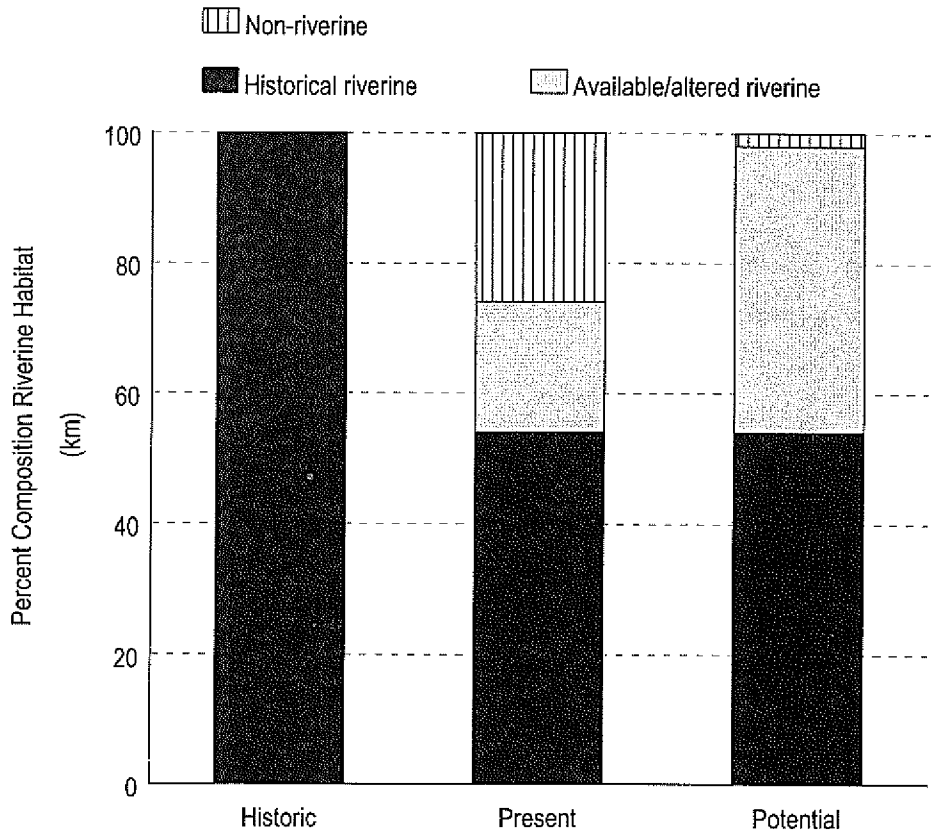


Figure 10. Percent composition of habitat available to fishes in five U.S. Lake Ontario tributaries up to the first impassible barrier. Bars represent before the construction of dams (black), after the construction of dams (white), and if mitigative measures to enhance habitat was performed at hydropower facilities (hatched). (See text for explanation of mitigative measures.)

Figure 11 shows the total river kilometers, historically and currently available to migrating fishes, as well as the potential free-flowing habitat mileage available if upstream passage were provided to the historic barrier. In general, most rivers provide much less free-flowing habitat than was available in the past; however, by providing upstream passage, little migratory fish habitat is gained above what currently exists (Figure 11). This is because: 1) the natural barrier is below all dams (e.g. Genesee); or 2) no riverine habitat will be gained due to numerous dams below the natural barrier (e.g. Salmon, Black, Raquette). The exception is the Oswego River where there was no historic barrier

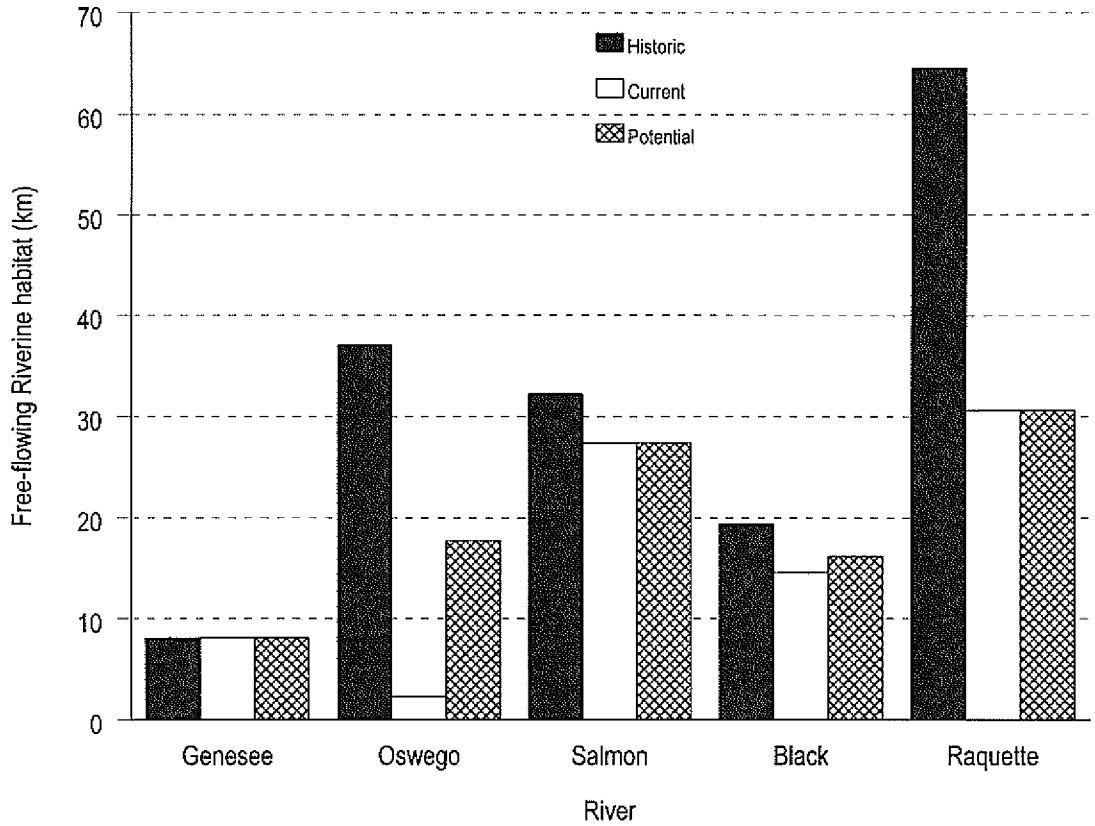


Figure 11. Free-flowing riverine habitat (km) available to migrating fishes in five Lake Ontario tributaries before hydropower development (historic), after hydropower development (current), and if upstream and downstream passage were provided to the historic, natural barrier (potential).

to fish migrations; hence, fish were documented migrating over 161 kilometers (100 miles) into the Finger Lakes and their tributaries (Parsons 1973). If passage were provided, the Oswego River would supply nearly 50 percent of historical free-flowing habitat, and reopen the entire area of the Finger Lakes and their tributaries.

Potential available habitat provided by upstream passage (Figure 11) may be species specific and may not allow full utilization of the river by all indigenous species. Passage needs to accommodate as many indigenous species and movement strategies of fish as possible. For example, American eel can overcome more difficult obstacles than salmon or trout, and these species can overcome obstacles that lake sturgeon cannot. In contrast, passage of undesirable species such as sea lamprey must be limited to the greatest extent possible.

Other tributary habitats

The above analysis was performed for five large rivers where data were available and compiled. Numerous smaller tributaries, with and without large dams, provide habitat for nearshore/tributary fishes. These smaller tributaries should be examined for the potential to enhance productivity of Lake Ontario's nearshore community. These streams are rarely as developed as larger river harbors, leaving an estuary-like confluence with Lake Ontario that can serve as fish and wildlife breeding and nursery areas. Also, most of these streams do not have an impassable barrier, the primary concern of accessibility is lacking. Habitat modification can address enhancement for a diverse fishery community.

Lake Ontario

Trophic Guild Analyses

It has been recognized, since the 1950s, that industrial and agricultural runoff pollution have been intense environmental stressors. Since the 1970s, major efforts have been successful in decreasing the input of such stressors to the ecosystem. Presently, most of the water quality goals set forth in the 1970s are being reached, and with the exception of certain persistent substances like organo-chlorine compounds and heavy metals, the Great Lakes are returning to their pre-industrial and agricultural pollution levels. Because of these improvements, it is thought that more recent changes in Great Lakes fish communities may be more attributable to biotic factors such as predation, competition, and reduced abundance of alewife and rainbow smelt.

In line with this concept, we have chosen to present fishery trends in Lake Ontario and Lake Erie in terms of a trophic guild approach; examining changes in fish communities, with regards to species composition and energy transfer interactions. Fish species were grouped into trophic guilds according to their adult, non-spawning, feeding habits. Five trophic guilds were established: herbivore, omnivore, planktivore, piscivore, and macroinvertivore as defined below. In Lake Ontario and Lake Erie, species of interest within each guild, located either in the offshore or nearshore/tributary areas, are discussed.

Trophic guild definitions and assumptions being used in the Great Lakes Fishery Resources Restoration Study

Herbivore: Greater than 75 percent of the diet consists of plants from substrate (diatoms and blue-green algae associated with substrate) and vascular plants.

Omnivore: Diet consists of at least 25 percent plant and equal to or greater than 25 percent animal material.

Planktivore: Greater than 75 percent of the diet consists of zooplankton <u>and/or</u> phytoplankton.

Carnivore:

- **Piscivore:** Greater than 75 percent of the diet consists of fish.
- **Macroinvertivore:** Greater than 75 percent of the diet consists of macroinvertebrates (insects, crustaceans, annelids, etc.)

Assumptions:

1) Summer, adult, non-spawning life stage.
2) Feeding preferences (i.e., greater than 75 percent of the diet), not the incidental material in the diets.
3) Two areas are considered within the lake proper (for the most part, to the first impassable barrier): Offshore and Nearshore/Tributary.

Species selected to be discussed in the study:

1) Species identified in the Act (lake trout, yellow perch, lake sturgeon, walleye, forage fish, and Atlantic salmon).
2) Species for which long term data are available and that represent the guild they occupy.
3) Species of special interest. Certain species will be discussed in the study because of changes in abundance but may not necessarily fit into the guild assumptions. They may have limited or no data or their range/habitat is not considered nearshore or offshore. Populations of these special interest species will have increased or decreased due to habitat changes (e.g. dace decline in many of the upper watershed tributaries caused by habitat degradation).

Offshore: The area including those waters that become thermally stratified in summer; and, for the most part, containing the coldwater fish community.

Nearshore: The area including all coastal features, as well as islands and shallow water features such as reefs and shoals; and, for the most part, containing the cool/warmwater fish communities.

Limitations to using commercial catch data for guild analyses

Fish trophic guild trends were analyzed using combined commercial harvest from the U.S. and Canada for Lake Ontario and Lake Erie, starting in 1867, and recent agency stock assessment data from each State and the Province of Ontario. While commercial harvest is the only long-term information available for the fisheries, there are limitations with the data. Changes in harvest may not be a reflection of population changes, but may be the result of: changes in target species by the commercial fishery; technological improvements in gear, gear efficiency, and type; regulation changes; and/or changes in location of catch. For example, changes or improvements of fishing gear may have allowed increased harvest of fish without increased effort, which could be interpreted as an increase in population size when it is really the result of increased exploitation. An additional inherent problem resides in replacement of commercial fishing by the recreational fishery. Today, limited commercial fishing is allowed in the waters of New York, mostly in Chaumont Bay at the east end of Lake Ontario and trap net-only commercial fishing is allowed in Lake Erie. Pennsylvania has incorporated more restrictive regulations pending final buy-out of a gill net fishery in 1996. Ohio has eliminated gill net commercial fishing and Michigan has limited gill net commercial fishing.

To remove biases associated with data, natural resource agencies have started stock assessment programs to provide more accurate pictures of the fish community and species abundance. Where possible, agency stock assessment data collected by Michigan, Ohio, Pennsylvania, New York, and Ontario have been used in analyses. However, these data generally only go back to the mid-1970s. Also, sampling procedures and fishing gear differ between agencies, and therefore, cannot easily be combined into one index of abundance for a species of concern. Cooperative whole lake assessments by natural resource agencies are needed to evaluate the integrity and stability of the Great Lakes ecosystem.

Historic and Current Status of Fishery Resource and Trends

Offshore fish community

Lake Ontario at one time supported 140 species of fish. Appendix II lists species composing the Lake Ontario fish community (past and present), and current status of stocks being monitored. The Lake's offshore fish community has contained 29 different species of fish which occupy three major trophic guilds during their adult, non-spawning stage of life. The species composition and diversity within each of the guilds have changed drastically over time (Table 4), and, based on the historical commercial catch data, the overall yield of the lake has declined (Figure 12). The planktivorous guild, historically dominated by lake herring, is currently dominated by the nonindigenous alewife and rainbow smelt. The macroinvertivorous guild, consisting of lake whitefish and sculpin species has declined or disappeared entirely with no significant species replacement. Atlantic salmon, lake trout, burbot, and blue pike dominated the piscivorous guild, but today the guild is primarily occupied by stocked nonindigenous salmonine species: coho and chinook salmon, and brown and rainbow trout, in addition to reintroduced lake trout.

Historically, there was a substantial commercial fishery for lake trout, lake herring, cisco, and lake whitefish as well as blue pike, lake sturgeon, and burbot. The impacts of habitat destruction and overfishing, combined with the intro-

duction of the nonindigenous rainbow smelt and alewife, resulted in the decline or extinction of most of the indigenous offshore fish species. For stream spawners such as Atlantic salmon, clearing of land and damming of rivers, prevented reproduction resulting in their disappearance by the early 1900s. Later, high levels of nutrients discharged into the lake resulted in low oxygen levels and eutrophic conditions. These conditions continued to negatively impact indigenous stocks already at record low levels.

Rehabilitation measures have been taken to restore fish species. Nutrient abatement target levels established by the International Joint Commission have been reached. The loss, degradation or alteration of physical habitat, and biological impacts have yet to be adequately addressed. Biological information presented here relies heavily on commercial catch data, which can often be interpreted as reflecting several different and sometimes conflicting trends. Also, only species of direct economic importance are included in commercial data, while many other species that are important components of the ecosystem are not included. This fact only reinforces the need for improved knowledge and stock assessment techniques of the fauna and interrelationships within the community, in order for management agencies to have sufficient data to effectively restore and manage the productivity of the Lake Ontario ecosystem (Christie 1973).

Table 4. List of select fish species from Lake Ontario offshore habitats according to trophic guild. Total number of species per guild is in parenthesis. Origin and current status is designated; I=Indigenous; N=Nonindigenous; C=Increasing; D=Decreasing; S=Stable; X=Extinct; U=Unknown.

GUILD COMMON NAME	ORIGIN	STATUS
HERBIVORE (0)		
OMNIVORE (0)		
PLANKTIVORE (5)		
Alewife	N	D
American shad	N	X
Rainbow Smelt	N	D
Lake Herring	I	S
Shortjaw Cisco	I	X
MACROINVERTIVORE (11)		
Lake Whitefish	I	C
Bloater	I	X
Kiyi	I	X
Blackfin Cisco	I	X
Shortnose Cisco	I	X
Rainbow Trout	N	S
Round Whitefish	I	U
Trout-perch	I	C
Slimy Sculpin	I	D
Spoonhead Sculpin	I	X
Deepwater Sculpin	I	X
Fourhorn Sculpin	I	X
White Bass	N	U
PISCIVORE (8)		
Sea Lamprey	N	D
Coho Salmon	N	S
Kokanee Salmon	N	X
Chinook Salmon	N	D
Atlantic Salmon	I	S
Brown Trout	N	S
Lake Trout	I	S
Striped Bass	N	X
Blue Pike	I	X
Burbot	I	U

Offshore planktivorous guild

The five fish species which, at one time or another, have contributed to the planktivorous guild are: lake herring, shortjaw cisco, alewife, rainbow smelt, and American shad. An attempt was made to introduce American shad between 1870 and 1873 (Christie 1973), and the last American shad reported was in 1931 (Smith 1985). Lake herring and shortjaw cisco are two of the six species of coregonines that were found in abundance in Lake Ontario. The commercial fishery for shortjaw cisco started in 1875 and by 1900 they were extinct in Lake Ontario. The remaining four cisco species were in the macroinvertivorous guild, all of which became extinct in Lake Ontario.

Historically, lake herring were the dominant planktivorous species and a large contributor to the early commercial fishery (Figure 13). Lake herring commercial harvest was relatively low in the late 1800s, until it peaked between 1900 and 1920. At this point, the fishing effort shifted toward lake trout, lake whitefish and burbot. A final resurgence of lake herring occurred from the 1930s through the mid-1940s. From then on, the population continued to steadily decline until its collapse between 1950-55, when rainbow smelt had become well-established. Predation on lake herring juveniles by rainbow smelt, and competition for food with rainbow smelt may have contributed to the demise of the lake herring population (Christie 1973). Lake herring abundance remains depressed (Luckey 1994), but recent indications are that they may be increasing.

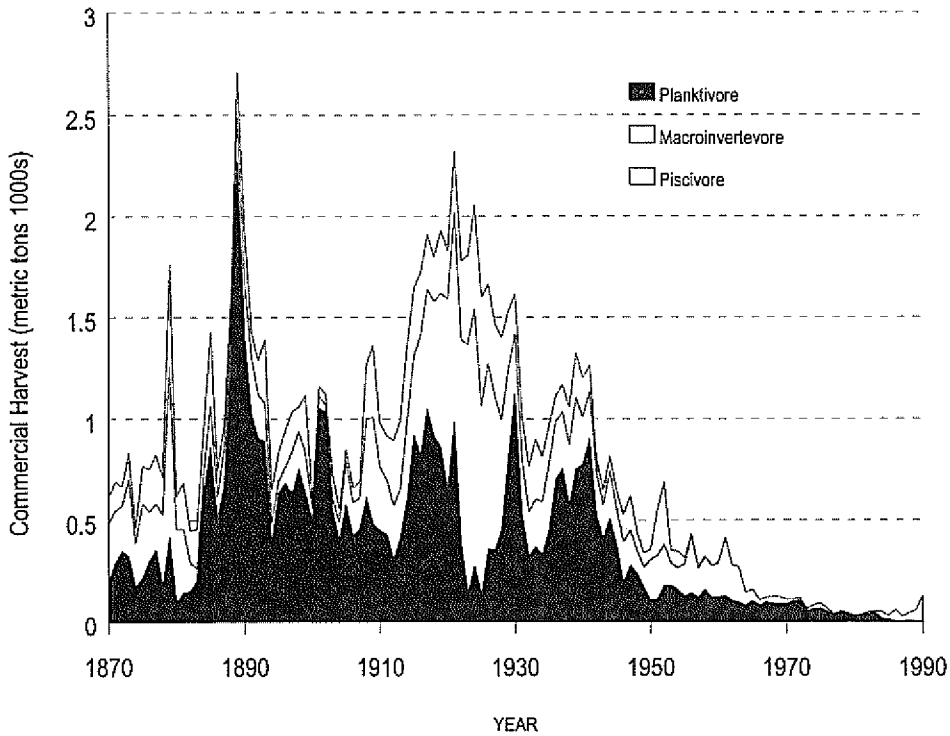


Figure 12. Offshore trophic fish communities (guilds) for Lake Ontario as represented by commercial harvest records (1870-1990). Guilds were defined by the primary diet item. Communities include planktivore, macroinvertivore, and piscivores (data from Great Lakes Fishery Commission).

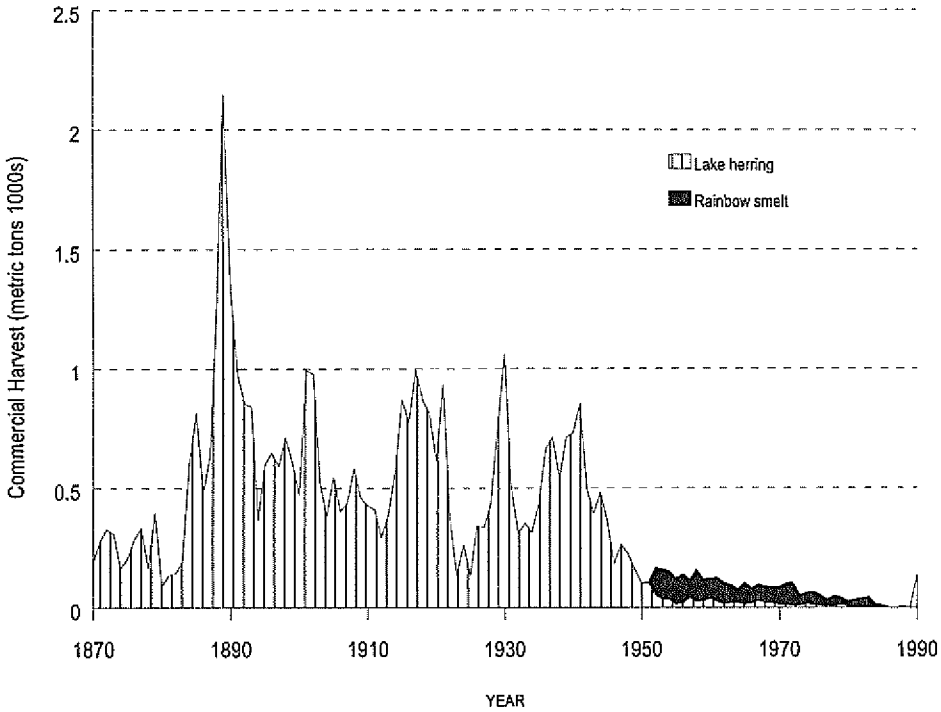


Figure 13. Trends in the Lake Ontario offshore planktivorous guild, as represented by commercial harvest records(1870-1990). Rainbow smelt have replaced lake herring as the major planktivorous species (data from Great Lakes Fishery Commission).

Rainbow smelt are believed to have been introduced during the late 1920s or early 1930s, and the rainbow smelt fishery began around 1945 (Christie 1973). Alewife became established in Lake Ontario in the 1860s, entering through the Erie Barge Canal (Christie 1973). The collapse of lake trout and burbot stocks in the 1940s reduced predation on rainbow smelt, and possibly served to assist an increase in the rainbow smelt population (Christie 1973). Commercial harvest of rainbow smelt remained high until the 1960s and then began to decline (Figure 14). The commercial fishery was principally Canadian, with only one New York fisherman participating.

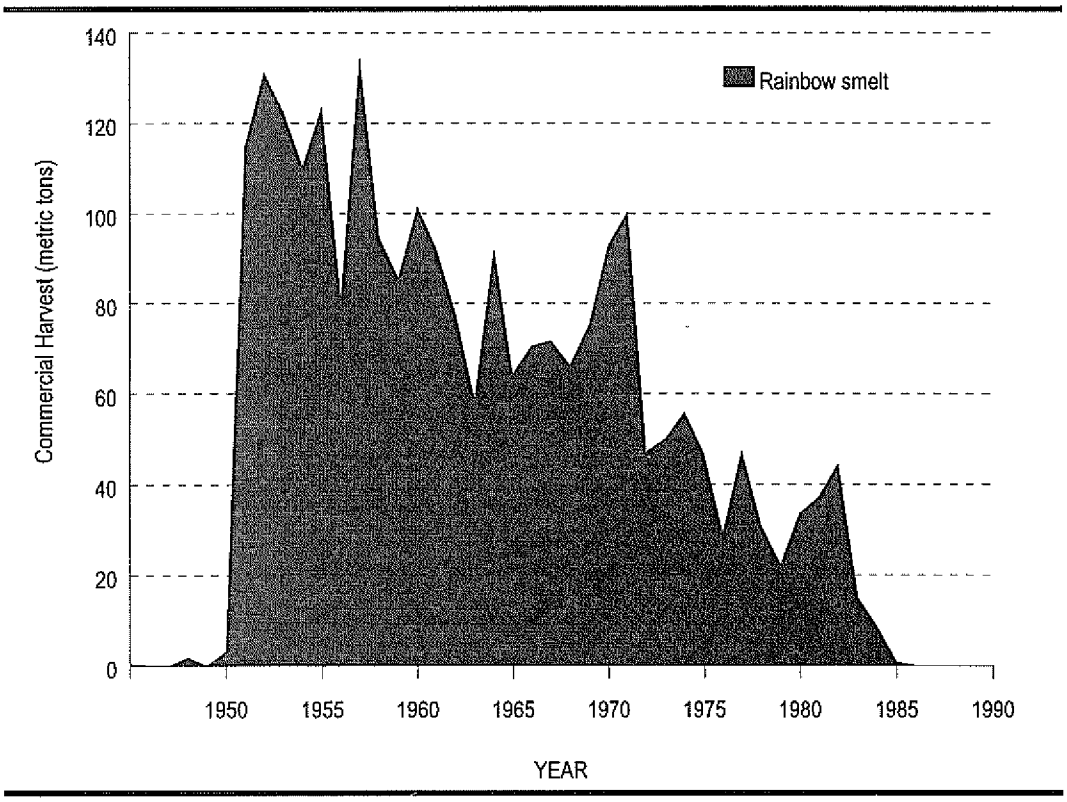


Figure 14. Annual commercial harvest of rainbow smelt from Lake Ontario (1945-1985) (data from Great Lakes Fishery Commission).

Pollution from municipal and industrial sources had degraded water quality by the 1950s. Effects of waste, containing high levels of phosphorous discharged into the lake, peaked during the 1960s and 1970s, resulting in an increase in plankton production levels. Combined with the loss of the large predators, alewife and rainbow smelt populations drastically increased in abundance (Lange and Smith 1993). Initiatives were undertaken to control the large nonindigenous prey fish populations and to create sportfishing opportunities by stocking nonindigenous salmon and trout species. Other initiatives were taken to improve water quality, such as the *1972 Great Lakes Water Quality Agreement*, and phosphorous levels in the lake began to decline. Since the early 1980s, total phosphorous levels have declined by 25 percent and zooplankton production has been reduced by 50 percent (Figure 15) (Lange and Smith 1993). The reduction in plankton levels has resulted in a decline in alewife and rainbow smelt biomass indices since the early 1980s (Figure 16) (Lange and Smith 1993). An abundance of primarily Pacific salmon and trout stocked in the lake resulted in fewer large alewife and rainbow smelt. The surviving alewife and rainbow smelt are in poor condition, most likely as a result of reduced plankton production (Figure 17) (Lange and Smith 1993). Indigenous species that could potentially be enhanced and restored as a result of the reduction in competition and predation from alewife and rainbow smelt are: lake trout, lake whitefish, cisco, sculpin, yellow perch and emerald shiner (Krueger *et al.* 1994).

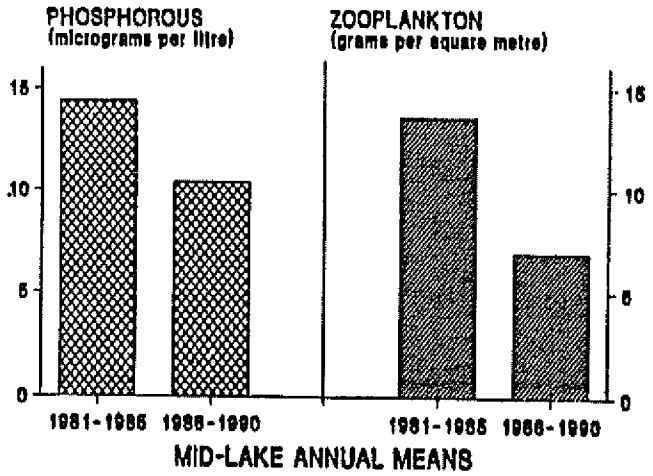


Figure 15. Changes in total phosphorous and zooplankton production in Lake Ontario (Lange and Smith 1993).

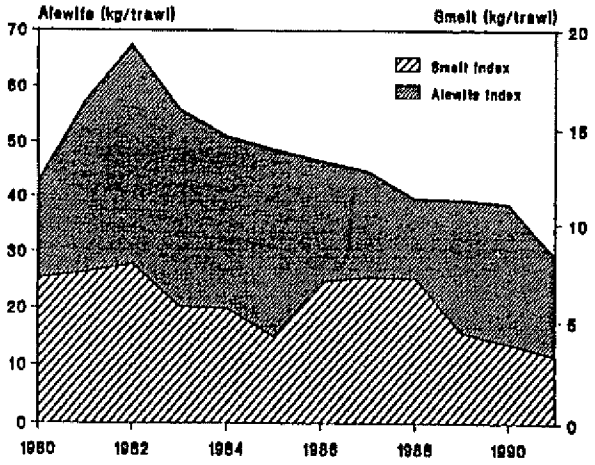


Figure 16. Biomass index of alewife and smelt in Lake Ontario. Results are based on three year averages of standard bottom trawl catches from U.S. waters (Lange and Smith 1993).

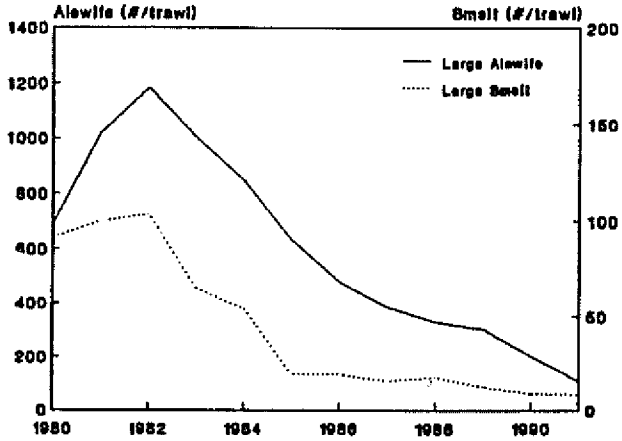


Figure 17. Trawl indices of abundance for the largest alewife and smelt in Lake Ontario (Lange and Smith 1993).

Offshore Macroinvertivorous Guild

Eleven fish species have occupied the macroinvertivore guild. They are lake whitefish, round whitefish, trout-perch, four species of sculpin (slimy, spoonhead, mottled, and deepwater sculpin), and four species of cisco (bloater, kiyi, blackfin, and shortnose). Most of these species are currently extinct in Lake Ontario and others have greatly reduced stocks (Figure 18). In 1993, trout-perch were found to be at record low levels in northeastern Lake Ontario (O'Gorman 1994), however, they remain abundant overall.

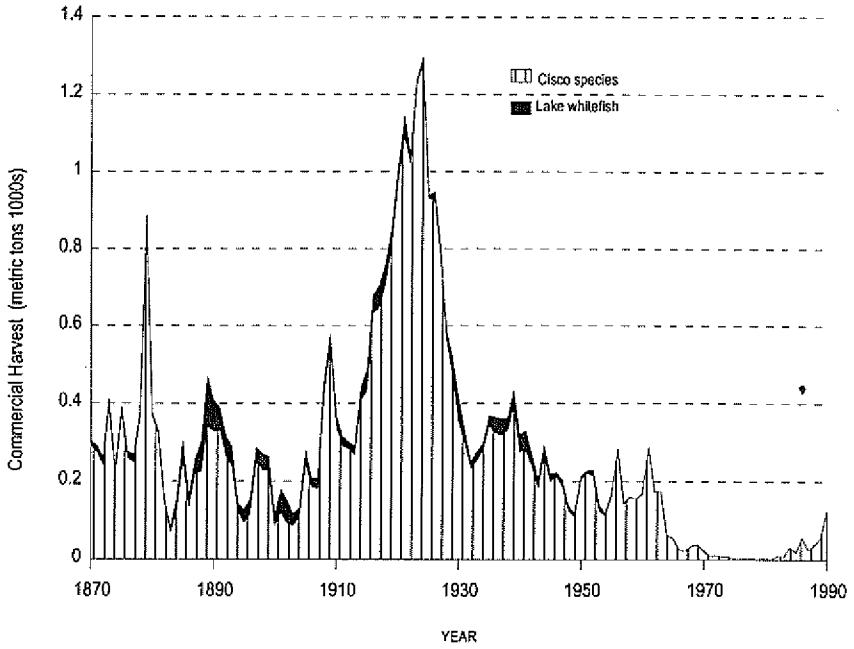


Figure 18. Trends in the Lake Ontario offshore macroinvertivorous guild, as represented by commercial harvest records (1870-1990). Lake Ontario macroinvertivores include lake whitefish and cisco species (data from Great Lakes Fishery Commission).

Lake whitefish was the main species for the Lake's commercial fishery, and remained so until the 1960s, after lake trout and cisco stocks had declined (Christie 1973). The commercial harvest indicated that lake whitefish population levels were extremely low between 1880-1900, peaked during the 1920s, were greatly reduced by the 1940s, and continued to decline to near collapse in the 1970s and 1980s (Figure 19). A recovery is now occurring.

Despite endurance of the stocks, several factors identified by Christie (1973) made the collapse of lake whitefish inevitable: 1) when the commercial fishery for lake trout and burbot declined, all of the effort was directed toward lake whitefish; 2) despite drops in the populations, gillnets were introduced in 1950, increasing fishing efficiency and harvest rates; and 3) reproducing fish were being harvested at a much faster rate than they could be replaced, and most failed to replace themselves.

In addition to overexploitation, the stresses from nonindigenous species increased in importance. As top predators disappeared from the open lake, sea lamprey attacks on lake whitefish increased during the 1950s (Christie 1973). Pelagic larval lake whitefish are vulnerable to alewife and rainbow smelt predation (Krueger *et al.* 1994). White perch

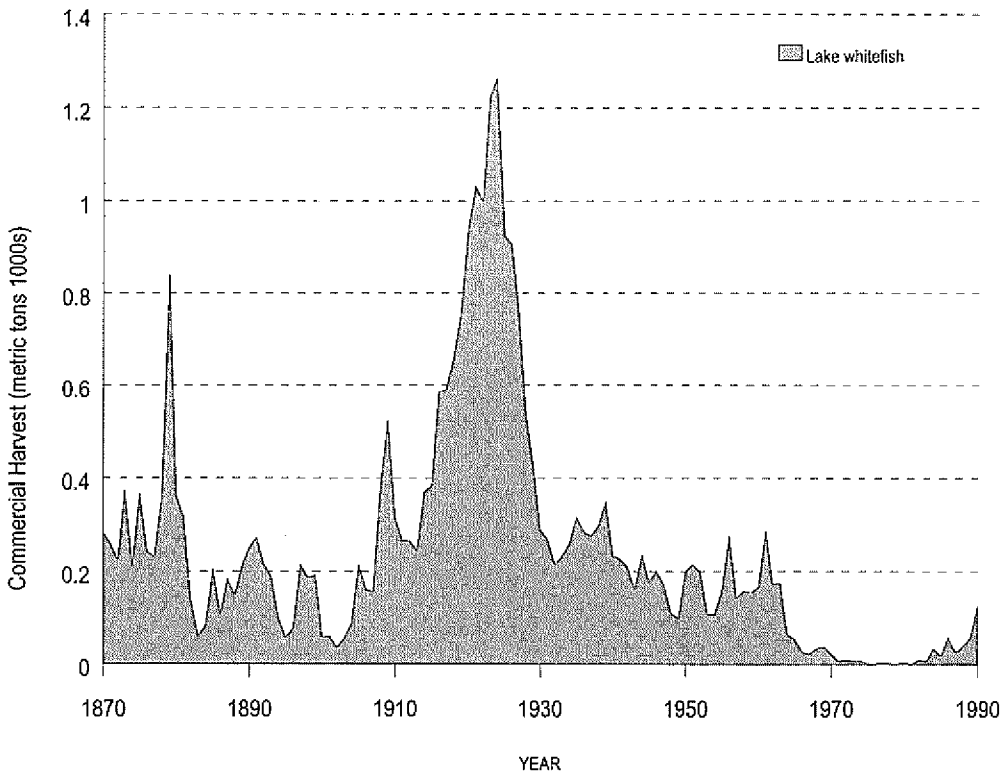


Figure 19. Commercial catch of Lake Ontario lake whitefish (1867-1990) (data from Great Lakes Fishery Commission).

actively feed during the spring in important lake whitefish spawning areas. Since the white perch diet consists of small fish, lake whitefish larvae are potentially an important component of their diet, and therefore negatively impacted. Indicative of this, the white perch population increased substantially during the 1950s, just prior to the lake whitefish collapse (Christie 1973).

Lake whitefish abundance has dramatically increased since the early 1980s (Figure 20) with eastern basin whitefish now more common than alewives and lake trout (New York State Department of Environmental Conservation - personal communication). This is believed to be a result of stricter fishing regulations, decreasing harvest, reduction in eutrophication, declining alewife, rainbow smelt, and white perch populations which feed on lake whitefish larvae, and sea lamprey control (Hoyle 1993b). Since 1973, an inverse relationship exists between the catch of lake whitefish and the catch of rainbow smelt (Casselman and Scott 1992).

A potential threat to lake whitefish populations in the eastern basin is the zebra mussel. In 1992, zebra mussels were recorded for the first time on lake whitefish spawning shoals in Lake Ontario. Zebra mussels are filter feeders, feeding primarily on phytoplankton, impacting the zooplankton community, the main food of lake whitefish larvae (Hoyle 1933a).

The Great Lakes once contained the greatest diversity of deepwater coregonids found anywhere in the world, totalling six species. Lake herring and shortjaw cisco were the only species found outside the Great Lakes. Blackfin cisco, shortnose cisco, kiyi and bloater were species found only in the Great Lakes (Todd and Smith 1992).

The commercial fisheries for deepwater ciscoes and lake herring were intertwined, and were combined in the catch reports until 1951. As a whole, the commercial catch of ciscoes declined between the 1880s and 1920s (Figure 18). It is believed that each of the species individually collapsed at different times between 1920 and 1969 (Christie 1973).

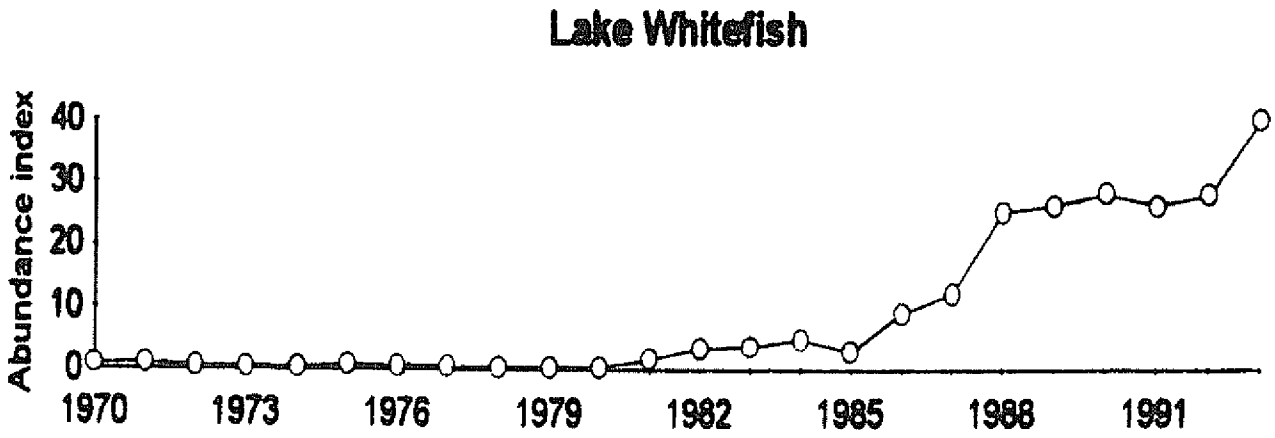


Figure 20. Standard gillnet indices of abundance for lake whitefish in Lake Ontario, 1970-1991 (Lange and Smith 1994).

Blackfin was the largest of the ciscoes and was the first to disappear. Shortnose and kiyi were last reported in Lake Ontario in 1964 (Smith 1985) and the bloater was the last of the deepwater coregonids to be commercially overexploited. Since bloater was the smallest of the ciscoes, the legal minimum mesh size was reduced in the 1940s in order to better target them (Christie 1973).

Species with pelagic larval forms, such as cisco and sculpin, are vulnerable to nonindigenous alewife and rainbow smelt predation (Christie 1973; Krueger *et al.* 1994). Collapse of bloater and expansion of rainbow smelt occurred simultaneously. Bloater decline has been attributed to competition for food with rainbow smelt and predation on bloater juveniles by rainbow smelt (Christie 1973). By 1960, there was no commercial fishery for any deepwater coregonids and bloater are now considered extinct in Lake Ontario.

Four sculpin species historically inhabited the offshore macroinvertivorous guild (Appendix II), feeding on bottom-dwelling insects, mysids, and copepods. The spoonhead sculpin is an extinct species. While the deepwater and fourhorn sculpins are extinct in Lake Ontario, they are still present in Lakes Superior, Michigan, and Huron. Although it is unknown when the deepwater and fourhorn sculpin disappeared, significant numbers were caught in commercial gillnets intended for cisco until the 1950s (Christie 1973). The abundance of slimy sculpin in Lake Ontario varies from year to year.

Slimy sculpin were considered to be abundant during the 1960s and 1970s. Lake trout restoration efforts began in Lake Ontario in the 1970s, and presently slimy sculpin are a large part of the diet of lake trout, particularly juveniles (39-52 percent wet weight) (Elrod and O'Gorman 1991). Between 1983-85, reductions in slimy sculpin abundance were found to be linked to predation by increased numbers of juvenile lake trout in southern Lake Ontario (Owens and Bergstedt 1994). Sculpins having pelagic larval forms, are also vulnerable to predation by alewife, rainbow smelt, and burbot (Owens and Bergstedt 1994; Krueger *et al.* 1994). Historically, all sculpins and ciscoes were available to

lake trout and burbot. Lake trout restoration in Lake Ontario is contingent upon the success of the juveniles. The primary food of juvenile lake trout has been reduced from a diverse and abundant prey fish community to one species, the slimy sculpin (Elrod and O'Gorman 1991).

With the exception of blackfin cisco, the persistence of these deepwater coregonids in the Upper Great Lakes (Todd and Smith 1992) provides an opportunity for their restoration in Lake Ontario. Water quality improvements, decreased harvest, and recent reductions in alewife and rainbow smelt abundance have increased the feasibility of restoring once major components of the prey fish community in Lake Ontario. Restoration of these species may be a significant element of restoration plans of indigenous top predators, such as lake trout and Atlantic salmon.

In March, 1994, the Lake Ontario Committee (Great Lakes Fishery Commission) charged the Lake Ontario Technical Committee to review and outline program requirements to re-establish indigenous prey species. The review is to include: 1) identification of policy and regulatory requirements; 2) technical feasibility; 3) disease considerations; and 4) a potential time frame. In August, 1994, the Service held a meeting to address this charge. As a result of this meeting: 1) a letter of request was submitted to National Biological Service-Wellsboro by the Lake Ontario Committee for assistance in researching technical restoration questions regarding stress physiology associated with culture conditions and transportation of larval fish, as well as any additional questions that arise; 2) a proposal will be submitted to the Great Lakes Disease Control Committee describing the purpose and research in restoring indigenous prey species; and 3) plans are being developed for a steering committee and task groups to address the four components of this charge.

Offshore piscivorous guild

Eleven fish species have occupied the piscivorous guild. They are lake trout, Atlantic salmon, burbot, blue pike, sea lamprey, striped bass, brown trout, and four Pacific salmonines (rainbow trout and coho, kokanee, and chinook salmon). The Lake Ontario Atlantic salmon was extinct by the late 1800s. Lake trout and burbot were the major deepwater piscivores in Lake Ontario until they became rare in the early 1950s. Blue pike was extinct by the early

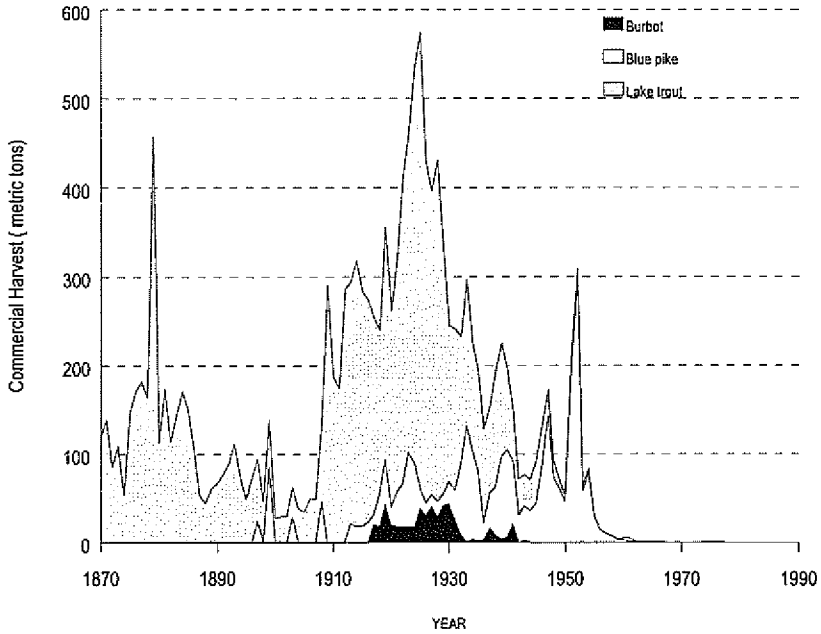


Figure 21. Trends in the Lake Ontario offshore indigenous piscivorous guild, as represented by commercial harvest records (1870-1990). Lake Ontario piscivores include the burbot, blue pike and lake trout. After the 1960s, the blue pike was extinct (data from Great Lakes Fishery Commission).

1960s (Figure 21). In 1878, one-hundred and forty striped bass fingerlings were introduced into the lower Genesee River, with only three known recaptures (Crossman and Van Meter 1979).

Lake Ontario formerly supported a valuable and abundant commercial lake trout fishery, primarily in Canadian waters, which peaked during the 1920s. Lake trout harvest rates steadily declined, collapsed in the early 1950s, and the fish disappeared from the lake by 1960. In addition to overexploitation, sea lamprey and habitat degradation played important roles in furthering the decline of the significantly weakened population (Christie 1973). Other contributing factors included extinction of indigenous prey cisco and sculpin species, and introductions of nonindigenous species.

A lake trout restoration effort initiated in 1953 was abandoned in 1965, due to high mortality caused by incidental commercial harvest and sea lamprey. Rehabilitation efforts resumed in 1973, following increased commercial fishing regulations and initiation of lampricide treatments in 1972. The primary goal identified in the *1983 Joint Plan for the Rehabilitation of Lake Trout in Lake Ontario* is to rehabilitate the lake trout population of Lake Ontario such that the adult spawning stock(s) encompass several year classes, sustains itself at a relatively stable level by natural reproduction, and produces a useable annual surplus (Schneider *et al.* 1983). Implementing the plan has resulted in: increased abundance of mature lake trout; survival of stocked young adult lake trout; survival of older fish; and older lake trout frequency in creel and assessment surveys (Schneider *et al.* 1983).

Current concerns regarding the rehabilitation of lake trout are the low survival rate of naturally produced lake trout fry to the yearling life stage. Although egg deposition and fry emergence have been documented, capture of naturally produced yearlings has been limited (presumptive wild yearling and young-of-the-year lake trout were captured in 1994). This may be due to a number of impacts such as contaminants and lack of protective nursery habitat. Most likely, it is due to predation on lake trout eggs and fry, particularly by alewife (Krueger *et al.* 1994), and reduced availability of indigenous prey species.

Alewife predation on lake trout fry is the suspected cause of nearly 100 percent mortality of emergent fry in near-shore spawning areas where alewife were abundant over the past decade (Krueger *et al.* 1994). Lake trout restoration may not be achieved unless alewife abundance continues to decline and remain low. Survival of naturally-reproduced lake trout fry is not expected to occur if alewife abundance increases (Krueger *et al.* 1994). Lake trout survival and restoration could be enhanced by stocking predatory salmonines as a means of managing alewife populations. However, a complete crash in the alewife population could be the result if piscivores are overstocked. Also, predation by adult salmon and trout and cormorants may be decreasing juvenile lake trout survival and investigations are necessary to assess the impact.

A lake trout project under a Cooperative Agreement between the Service and The Research Foundation of State University of New York and the National Fish and Wildlife Foundation was initiated October 1, 1994. At the western end of Lake Ontario an artificial reef was constructed in 1990 by Niagara County Department of Planning and Industrial Development to improve fishing opportunities. This project, *Ecosystem Management and Evaluation of a Multi-Purpose Reef in Lake Ontario*, takes an ecosystem approach toward understanding community ecology of the artificial reef. Spawning activity, egg deposition and fertilization rates, and genetic strain of lake trout will be examined, as well as the seasonal coolwater fish community and effects of zebra mussels on indigenous benthic macroinvertebrates. The scheduled completion date of the project is September 30, 1995.

Burbot is the only truly freshwater cod species, and they occupy the deepwater piscivorous guild. At the turn of the century, their numbers were scarce, but during the 1920s they became abundant in the commercial harvest. Burbot composed a large portion of the incidental catch in the valuable lake trout fishery (Christie 1973). The burbot and lake trout harvest rates steadily declined until both species were nearly decimated in the early 1950s (Figure 21). Like lake trout, overexploitation by commercial fishing has been reported as the primary cause of the collapse of burbot. Sea lamprey played an important role in furthering the decline of the significantly weakened population (Christie

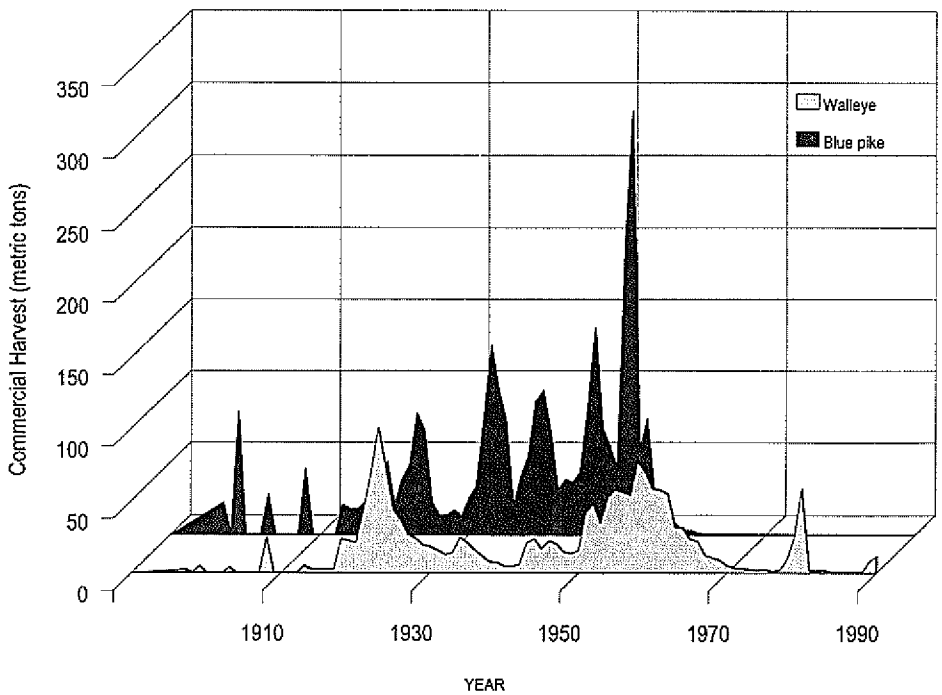


Figure 22. Annual commercial harvest of blue pike and walleye from Lake Ontario. As blue pike began to decline harvest efforts for walleye increased (data from Great Lakes Fishery Commission).

1973). Currently, burbot are still rare in Lake Ontario (Owens and Bergstedt 1994), but are beginning to increase. Historically, burbot also used sculpins and ciscoes as prey. Protection and enhancement of the slimy sculpin population, as well as restoration of other indigenous prey species may be necessary in order to ensure that the recovery of indigenous burbot is not hindered.

The Lake Ontario commercial harvest of blue pike was substantial through the 1930s-1940s, until it collapsed in 1953 and commercial fishing ended in 1961 (Figure 22). No blue pike were observed during fishery investigations in 1960, 1964 or 1972. After the demise of Atlantic salmon, lake trout and lake whitefish, the loss of the last commercially valuable deepwater species in Lake Ontario, caused serious economic consequences (Trandahl *et al.* 1975).

The Service informally recognized the endangered status of blue pike in the early 1960s. Despite endangered status, attempts to preserve blue pike were lacking. The *Endangered Species Protection Act of 1966* (80 Stat. 926) and the *Endangered Species Conservation Act of 1969* did not provide Federal prohibition against taking or possession of indigenous endangered fish and wildlife. Under provisions of these Acts, it was only recognized as an endangered species in the Federal Register (Trandahl *et al.* 1975).

In the Great Lakes, the last confirmed blue pike was taken from Lake Erie in 1965 (Billington 1994). The *Endangered Species Act of 1973* (87 Stat. 884) resulted in appointment of a Blue Pike Recovery Team in 1975 and in October, 1975 a *Blue Pike Recovery Plan* was prepared. At the time, it was believed that remaining stocks may have existed in the Lake Huron drainage and Lake Nipissing (Trandahl *et al.* 1975).

Over the years, the New York State Department of Environmental Conservation has conducted numerous evaluations of potential "blue pike" specimens compared with preserved blue pike specimens at New York State Museum, but none have been determined to be blue pike.

Introduced, nonindigenous salmon species which have been or currently are introduced to the Lake Ontario ecosystem include rainbow and brown trout, kokanee, coho, pink, and chinook salmon. The kokanee salmon introductions from 1950-1970 did not become established. Brown trout have been stocked annually since 1973, and currently return to numerous tributaries to spawn. Coho salmon introductions between 1873-1933 did not become established. They have been stocked annually since 1968, and coho currently return to numerous tributaries to spawn. Chinook salmon were stocked between 1874-1925 without becoming established. They have been stocked annually since 1968, and chinook currently return to numerous tributaries to spawn (Crossman and Van Meter 1979). Pacific salmonines have been stocked to reduce overabundant alewife and rainbow smelt, which exhibited massive die-offs (Lange and Smith 1993).

Until 1984, nonindigenous salmonine stocking levels continued to increase rapidly, while lake trout and Atlantic salmon stocking has increased at a much slower rate (Figure 23). High abundances of primarily nonindigenous salmon and trout have resulted in fewer large alewife and rainbow smelt (Lange and Smith 1993). By 1992, fishery management and research agencies determined that the alewife population could not support stocking levels of predator species. Although a reduction in alewife could benefit indigenous prey and predator species in Lake Ontario, there is a need for more scientific information and the development of lakewide fish community goals and objectives by the management agencies, before such actions are initiated. Currently, efforts are being made by management agencies to protect alewife through reduced stocking of all predator species.

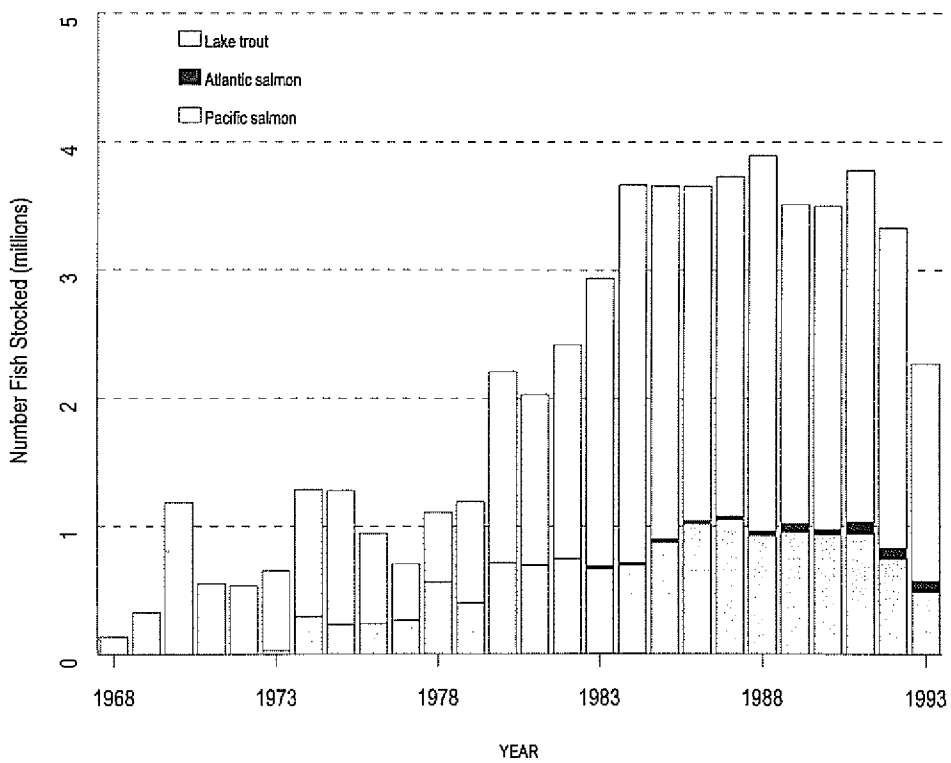


Figure 23. Millions of indigenous and nonindigenous piscivorous fish stocked annually in Lake Ontario, (1968-1993). Atlantic salmon and lake trout are indigenous species (New York Department of Environmental Conservation 1994 Annual Report).

In the early 1800s, the greatest inland Atlantic salmon population in the world was supported by the St. Lawrence River, Lake Ontario and their tributaries (Webster 1982). Most or all of the tributaries in New York and Ontario

flowing into the St. Lawrence River and Lake Ontario supported indigenous Atlantic salmon. In 1657-72, Jesuits reported observing Indians with boatloads of large Atlantic salmon (Webster 1982). A few of the major Atlantic salmon spawning and nursery tributaries were the Chateauguay, Raquette, Grasse and Oswegatchie rivers. Atlantic salmon, as a valuable source of food and income, were an important factor in early settlement of the area. The following accounts illustrate the wealth of Atlantic salmon in the early 1800s:

> *"In October, 1836, two men took (on the Salmon River at Pulaski) two hundred and thirty Salmon between 8 p.m. and 12, with spears and fire-jacks, and after 12 till morning two other men in the same skiff took two hundred odd, the average weight of the entire lot being fourteen and three-quarters pounds. We have had fifteen hundred fresh Salmon in the fish-house at one time. When a freshet occured (sic) in June a few would always come up, and sometimes a few early in the spring. Any time from June till winter when there was a freshet they were sure to come. The principle time, however, was in fall, during September, October, and November. Twelve skiffs in one night have taken an average of three hundred Salmon each"* (Goode 1884:473; Webster 1982).

During the mid-1800s, habitat necessary for rearing Atlantic salmon progeny was either destroyed or rendered inaccessible, and the population declined sharply. By 1900, Atlantic salmon in the St. Lawrence River and Lake Ontario were extinct primarily due to the obstruction of spawning grounds by mill dams and overfishing, as well as deforestation and pollution:

> *" The cause of the disappearance, practically, of salmon from the streams of the St. Lawrence Basin has been chiefly and primarily the erection of obstructions in all of the rivers, which have prevented the salmon from reaching their spawning grounds, and so natural reproduction has been absolutely inhibited."* (Marshall McDonald U.S. Commissioner of Fish and Fisheries. 1891 Report to the Senate) (Webster 1982).

The historic Atlantic salmon population in Lake Ontario is believed to have consisted of a landlocked variety, with intermittent influxes of a sea-run variety entering the lake and tributaries via the St. Lawrence River. Genetic strain and diversity play a crucial role in the successful re-establishment of Atlantic salmon. In Lake Ontario, the emphasis is on initially determining the feasibility of restoring populations in historic spawning tributaries that flow into the lake and in the upper St. Lawrence River.

In 1993 the Service Atlantic Salmon Broodstock Development Program was initiated at Allegheny National Fish Hatchery in Warren, Pennsylvania. Grand Lake strain (Maine landlocked) eggs were obtained in 1993 and 1994 for future Atlantic salmon restoration work in Lake Ontario and its tributaries. Grand Lake Atlantic salmon are downstream spawners (typically move from the lake down a stream to spawn), and may be most suited for the upper St. Lawrence River. In 1995, two upstream spawning strains will be incorporated into the broodstock program. The Sebago (Maine landlocked) and Penobscot (Maine sea-run) strains may have the greatest spawning success in large tributaries flowing into Lake Ontario.

The Penobscot strain (from Maine) is suspected to immediately migrate to the ocean once stocked, due to its sea-run origin. Physiologically, the sea-run strain is not required to spend any part of its life in the ocean environment. This has been observed in Maine hatcheries where Penobscot strain broodstock spend their entire lives in freshwater. Also, hatcheries rearing Penobscot strain Atlantic salmon frequently have escapees into bordering freshwater lakes. These fish survive and grow to adulthood, and even in those lakes where migration to the ocean environment is possible, migration does not always occur.

Increasing variation in broodstock strain will assist in determining the role spawning traits play in return rate and spawning success. All possible strains and their characteristics need to be examined in order to determine the most suitable strain for the Lake Ontario ecosystem and its various habitats.

Atlantic salmon plantings

A portion of the fry that were hatched from 1993 broodstock eggs were incorporated into a study in the Oswego River drainage. The cooperatively conducted activity by the State University of New York - College of Environmental Science & Forestry, the New York State Department of Environmental Conservation, and the Service, examined fry survival and growth rates, and habitat suitability for Atlantic salmon.

Twenty-three thousand (23,000) yearlings were marked and planted into the Black River, a historic spawning tributary at the eastern end of Lake Ontario. The Black River was chosen jointly by the Service and New York State Department of Environmental Conservation as a planting site for several reasons: 1) the Black River is a historic spawning tributary and contains some spawning habitat for returning adults; 2) fish ladders are present on the first two dams to allow access to the spawning habitat between the second and third dams, and provide for the assessment of fish that return to the river; 3) optimum flow rates allow for early spring stocking, reducing predation and increasing imprinting on the river; and 4) reduced competition from introduced Pacific salmonines no longer stocked in the Black River, with the exception of rainbow trout (steelhead in the stream spawning stage), which present management concerns regarding competition.

In 1994, the New York State Department of Environmental Conservation supported proactive Atlantic salmon management through development of *Fisheries Enhancement Plans* for Lake Ontario and St. Lawrence River tributaries, the New York State Atlantic Salmon Management Plan, as well as other management plans that are currently in place or being developed, such as the *Ontario Ministry of Natural Resources Atlantic Salmon Restoration Plan*. These interagency plans provide guidance for evaluating rehabilitation potential.

Various life stages of fish will be available from the broodstock program and have the potential to be used to initiate some of the strategies identified in these plans as follows:

- Assessment of potential habitat available for Atlantic salmon spawning and juvenile rearing (draft *Atlantic Salmon Management Plan for New York*);
- Demonstration projects aimed at documenting the suitability of Lake Ontario tributaries to support natural reproduction and recruitment of Atlantic salmon (draft *Atlantic Salmon Management Plan for New York*);
- New York State Department of Environmental Conservation field studies, scheduled to begin in 1994, using Atlantic salmon fry in two streams to demonstrate the ability of potential nursery habitat to support growth and survival of salmon through the smolt stage (draft *Atlantic Salmon Management Plan for New York*);
- Identification of smolt stocking strategies to optimize adult returns to the Black River (draft *Atlantic Salmon Management Plan for New York*);
- Examination of the performance of different strains to enhance the success of restoration (draft *Atlantic Salmon Management Plan for New York*);
- Identify and Quantify potential salmon spawning and rearing habitat;
  - to determine carrying capacity
  - prioritize favorable locations for restoration
  - collect habitat suitability measurements and trial plantings of juvenile Atlantic salmon (draft *Atlantic Salmon Management Plan for New York*)
- Determine mileage and acreage of water available to or occupied by salmonines on a year-round basis that formerly supported Atlantic salmon runs (draft *Atlantic Salmon Management Plan for New York*);
- Man-made barriers identified and intervening reaches quantified (draft *Atlantic Salmon Management Plan for New York*);
- Determine the most suitable stream candidates for feasibility projects based on;
  - suitability to rear to smolt stage
  - suitability for smolt emigration and produce returning adults

- ability to allow adults to return to spawning grounds (draft *Atlantic Salmon Management Plan* for New York)

- *Ontario Ministry of Natural Resources Atlantic Salmon Technical Advisors Workshop Meeting*, held in November, 1993 determined that despite the constraints and current knowledge level, Atlantic salmon restoration for Lake Ontario is feasible. Development of a plan and determination of goals and objectives of an Atlantic salmon program are currently underway;
- A total of 200,000 Atlantic salmon are allocated for Lake Ontario, but this target has not been met due to the lack of availability of fish. It could be met if feasibility studies relating to the establishment of Atlantic salmon populations in Lake Ontario tributaries were incorporated with the targets;
- Investigate the potential for Atlantic salmon restoration in the Raquette River by 2000 (*Raquette River Fisheries Enhancement Plan*);
- If ecologically feasible, restore Atlantic salmon to the Oswego River watershed with adults ascending the system from Lake Ontario and reproducing naturally in headwater tributaries (*Oswego River Fisheries Enhancement Plan*); and
- If ecologically feasible, restore Atlantic salmon to the Black River from Black River bay to Watertown with adults ascending the system from Lake Ontario and reproducing naturally (*Black River Fisheries Enhancement Plan*).

Rainbow trout are the Pacific coast ecological equivalent of the Atlantic salmon. Both species spend a significant portion of their juvenile life in streams, migrate in the spring from the stream to ocean or lake at similar sizes, and remain there for a year or more making long migrations (Gibson and Cutting 1992). They eat similar prey species, spawn more than once, and both species have sea-run as well as landlocked forms. Habitat preferences, behavior, and feeding are conspicuously similar in early life stages of the two species. These similarities would indicate potential for competitive interactions with Atlantic salmon (Gibson and Cutting 1992).

Atlantic salmon are fall spawners and eggs hatch six months later, in April. Rainbow trout spawn primarily during April, in similar habitat areas, and eggs hatch in 18 days. It is possible that adult rainbow trout spawning activity could disturb Atlantic salmon redds (nests) and developing fry (Gibson and Cutting 1992). Yearling Atlantic salmon and rainbow trout are known to occupy similar habitat and compete for space, which may cause reductions in Atlantic salmon production (Hearn and Kynard 1986). Juveniles of both species feed on aquatic and terrestrial insects while in the stream, and emigrate downstream in the spring. Emigrating Atlantic salmon yearlings serve as potential prey to the upstream migrating adult rainbow trout (Gibson and Cutting 1992).

Ecosystems where healthy Atlantic salmon populations exist, have not been successfully colonized by introduced rainbow trout. In areas of Lake Ontario where habitats for Atlantic salmon are marginal, or where Atlantic salmon populations are low, or where rainbow trout have replaced Atlantic salmon, the presence of rainbow trout could negatively impact efforts to reintroduce Atlantic salmon (Gibson and Cutting 1992) and the feasibility of such an attempt would have to be closely examined.

Summary of guild analyses

Guild analyses show that a number of important trophic levels are currently very unstable. The highly managed, very productive pelagic system of the 1980s is changing as a result of lower, open-water nutrients. Nonindigenous prey species such as alewife and rainbow smelt are decreasing in abundance and in their physical condition. Although these species can be expected to continue to be a significant part of the "offshore planktivorous guild," their decreased abundance will not be able to support the currently abundant predator pressure. The "offshore macroinvertivorous guild" faces similar problems and opportunities. Although lake whitefish are increasing in abundance, most of the other historic species in this guild are either totally absent or at low numbers. This guild, therefore, is unable to repeat its historic function.

Habitat conditions are improving, verified by increasing abundance of lake whitefish. Remanent populations of other native species may show similar responses. If this does not happen naturally, re-establishing some native pelagic prey species would increase use of the available energy and effectiveness of energy transfer between trophic levels.

The "offshore piscivorous guild" is nearly as artificial as the planktivorous guild. Effective stocking has increased the number of species and total abundance. However, since prey numbers are down, predator stocking has been reduced by management agencies and is being closely monitored. The need for predator stocking is due to the lack of naturally reproducing species, especially native species. The recent increase in burbot is a promising sign that habitat conditions are improving and lake trout are also showing some progress in their rehabilitation. Atlantic salmon rehabilitation will continue to face major hurdles if their tributary habitats are used for other, incompatible purposes. When some of these issues are resolved, Atlantic salmon could again be an important component of the "piscivorous guild."

Nearshore/tributary fish community

Within the nearshore areas of Lake Ontario, including the tributary reaches, 113 fish species have been recorded. Trends are evaluated by utilizing commercial catch data and tributary species abundance indices developed from literature searches of fishery investigations. Table 5 displays species where data are available and analyses discussed. Tributary species trends were compiled from five *River Enhancement Plans* produced by the Service for New York State Department of Environmental Conservation. Four of the rivers flow into Lake Ontario and one into the St. Lawrence River, and have historically been an important contributors to the lake. The purpose of the reports was to describe historic and present fishery resource conditions, provide recommendations for the benefit of those resources, and recommend management goals and objectives as part of the Federal Energy Regulatory Commission's re-licensing process.

Four guilds present in the nearshore area are shown as cumulative commercial catch (Figure 24). The general upward trend in total catch for nearshore species is most likely due to the demise of the offshore fishery. Also noticeably present, is the decline in catch of piscivorous fishes and increase in catch of omnivorous and macroinvertivorous species.

Table 5. List of select fish species from Lake Ontario nearshore/tributary habitats according to trophic guild. Total number of species per guild is in parenthesis. Origin and current status is designated; I=Indigenous; N=Nonindigenous; C=Increasing; D=Decreasing; S=Stable; X=Extinct; U=Unknown.

GUILD COMMON NAME	ORIGIN	STATUS
HERBIVORE (1)		
Central Stoneroller	I	C
OMNIVORE (21)		
Goldfish	N	C
Lake Chub	I	D
Common Carp	N	C
Common Shiner	I	D
Spottail Shiner	I	S
Sand Shiner	I	D
Mimic Shiner	I	D
Bluntnose Minnow	I	D
Fathead Minnow	I	D
Creek Chub	I	D
Fallfish	I	C
Brown Bullhead	I	D
PLANKTIVORE (6)		
Gizzard Shad	N	C
Golden Shiner	I	D
White Crappie	I	U
Black Crappie	I	U
PISCIVORE (14)		
American Eel	I	D
Grass Pickerel	I	D
Northern Pike	I	D
Muskellunge	I	S
Chain Pickerel	N	C
Smallmouth Bass	I	S
Largemouth Bass	I	U
Walleye	I	S
MACROINVERTIVORE (50)		
Lake Sturgeon	I	D
Longnose Sucker	I	U
White Sucker	I	D
Lake Chubsucker	I	U
Silver Redhorse	I	D
Golden Redhorse	I	U
Shorthead Redhorse	I	C
Greater Redhorse	I	U
White Perch	N	C
Pumpkinseed	I	D
Yellow Perch	I	S

Nearshore herbivorous guild

The central stoneroller is the only species in this category. It is a forage species which inhabits stream riffle areas and, since the mid-1920s, has increased in abun-

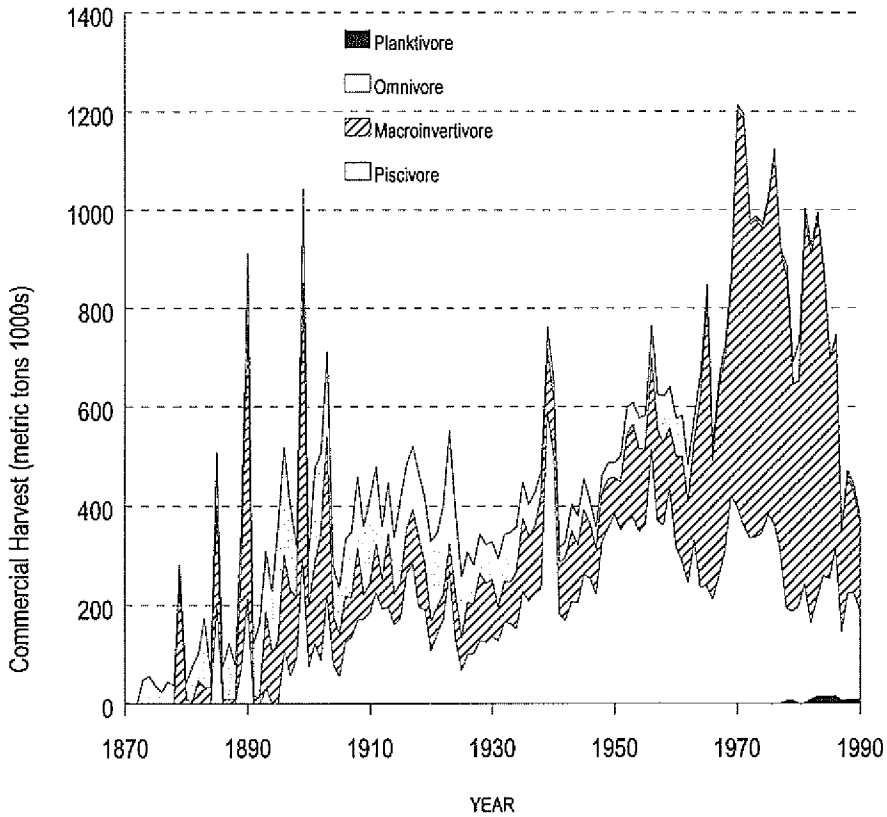


Figure 24. Trends in the Lake Ontario nearshore/tributary trophic fish communities (guilds) for Lake Ontario as represented by commercial harvest records, (1870-1990). Guilds were defined by the primary diet item. Guilds include planktivores, omnivores, macroinvertivores, and piscivores (data from Great Lakes Fishery Commission).

dance. The herbivorous community is lacking in species diversity. Species specializing in vascular plants are rare.

Nearshore omnivorous guild

The omnivorous guild has the second largest number of species present in Lake Ontario's nearshore habitats. Species where data are available include: catfishes, bullheads, several minnow species, common carp, and goldfish. Figure 25 exhibits total catch and species data for omnivorous fishes from 1867 to 1990. Nonindigenous common carp and goldfish, and indigenous fallfish have increased in abundance. All other species have declined (Figure 26). Fallfish have no value to the commercial fishers, however, adults serve as a sportfish when trout are unavailable.

Bullheads and catfishes also made significant contributions to commercial catches. Declines in harvest occurred after 1952 from the earlier 1900s. Since 1952, bullheads have dominated bullhead/catfish harvest. Abundance indices for brown bullhead show a decline from abundant to moderately common. Brown bullhead most likely made up the majority of bullhead commercial catch (Figure 25). Numerous forage species and the northern hognose sucker have a demonstrated a general trend toward lower abundances (Figure 26). Particularly, common shiner and creek chub declined from abundant to moderately common. Other forage species such as brassy minnow, eastern silvery minnow, bridle shiner and creek chubsucker have incomplete data sets for the three time periods; a general trend is difficult to determine.
Goldfish were not present in the nearshore area until recent years. Common carp, a commercially important species,

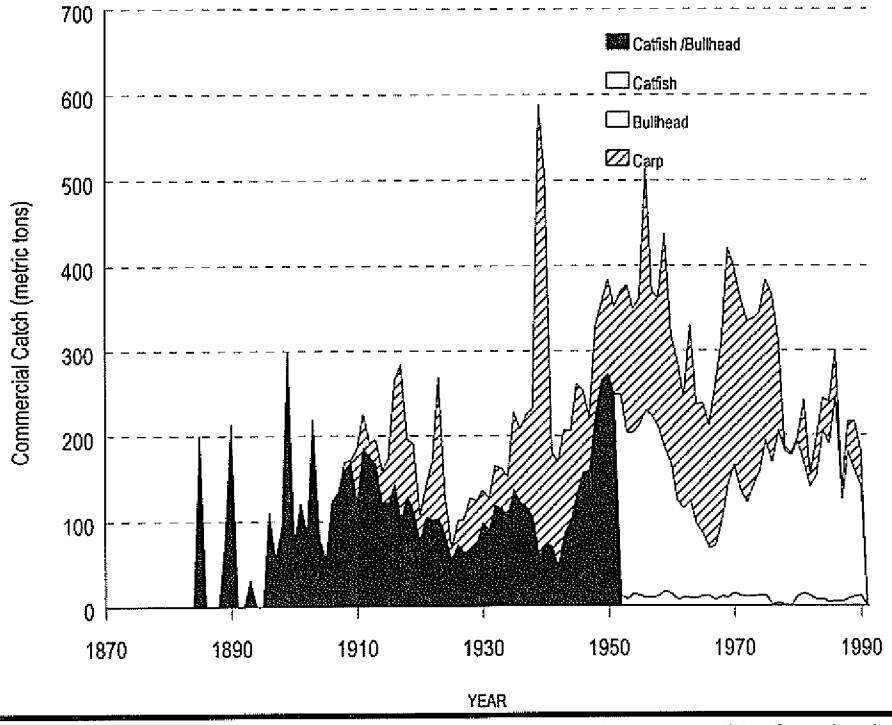


Figure 25. Trend of the Lake Ontario nearshore/tributary, omnivorous guild. Species include catfish, bullheads and common carp. Prior to 1954 catfish and bullhead were not differentiated (data from Great Lakes Fishery Commission).

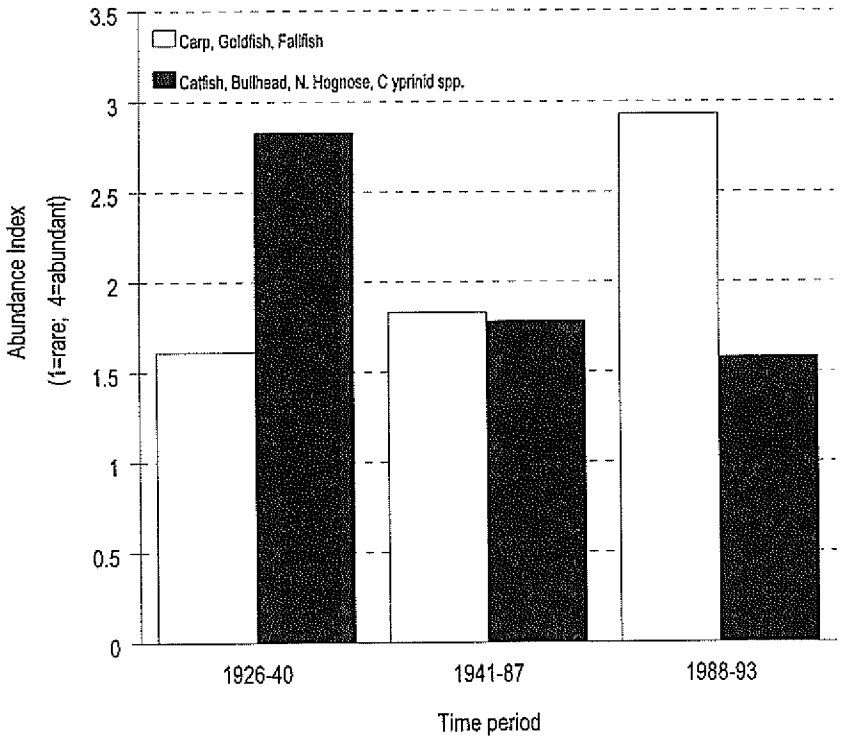


Figure 26. Abundance index of omnivorous fishes in Lake Ontario tributaries. Species which have increased include carp, goldfish, and fallfish. Species which have decreased include catfish, bullhead, northern hognose sucker, minnows, and shiners.

peaked in 1939, followed by its decline after 1952. Common carp was chiefly fished in the western basin. Integration of common carp in the late 1800s provides information about its effects in the ecosystem. Some impacts may have occurred during this period of infestation, particularly with regard to water quality and loss of spawning habitat for other fishes.

Nearshore planktivorous guild

The planktivorous guild includes golden shiner, gizzard shad, emerald shiner, brook silverside, white crappie, and black crappie. The crappies were the only commercially important species; however, the limited data are insufficient to perform a trend analysis of the population and little information is available from fishery assessments.

The demise of golden shiners and an increasingly abundant population of gizzard shad were the most significant changes to this community (Figure 27). Golden shiner, an extremely important bait fish, was the prominent forage species for nearshore piscivorous fish. Gizzard shad, a nonindigenous species, is now an important forage species for

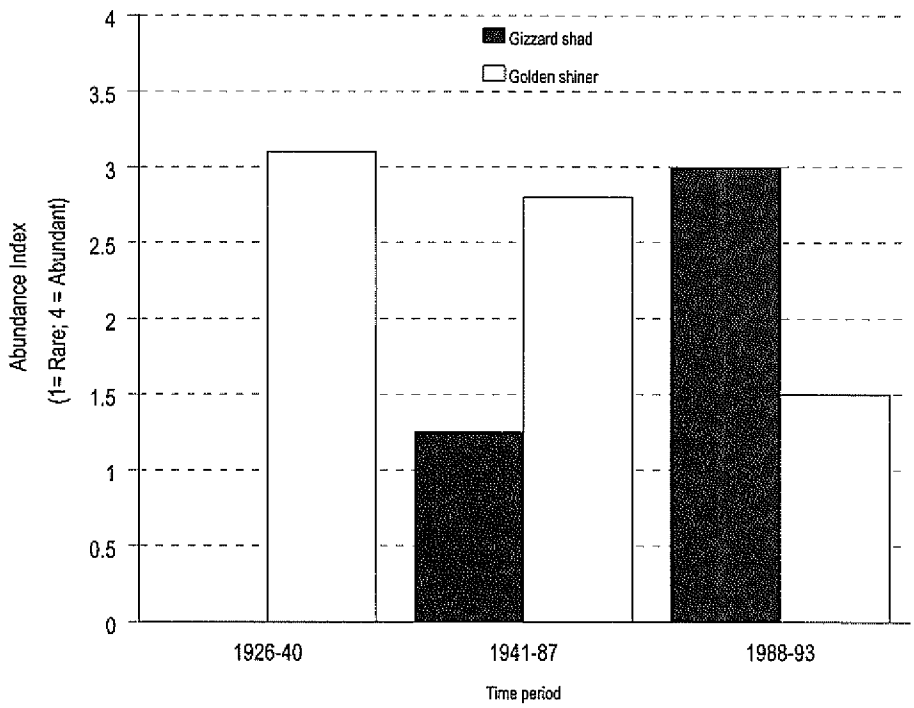


Figure 27. Abundance index of gizzard shad and golden shiner. These fish are in the Lake Ontario nearshore/tributary planktivorous guild.

these fish. This replacement of species is probably a result of increased turbidity due to habitat degradation; the gizzard shad is more tolerant of turbid conditions (Smith 1985).

The emerald shiner population has been relatively stable, and brook silverside and northern redbelly dace data are limited; the latter being an upper river inhabitant.

Nearshore macroinvertivorous guild

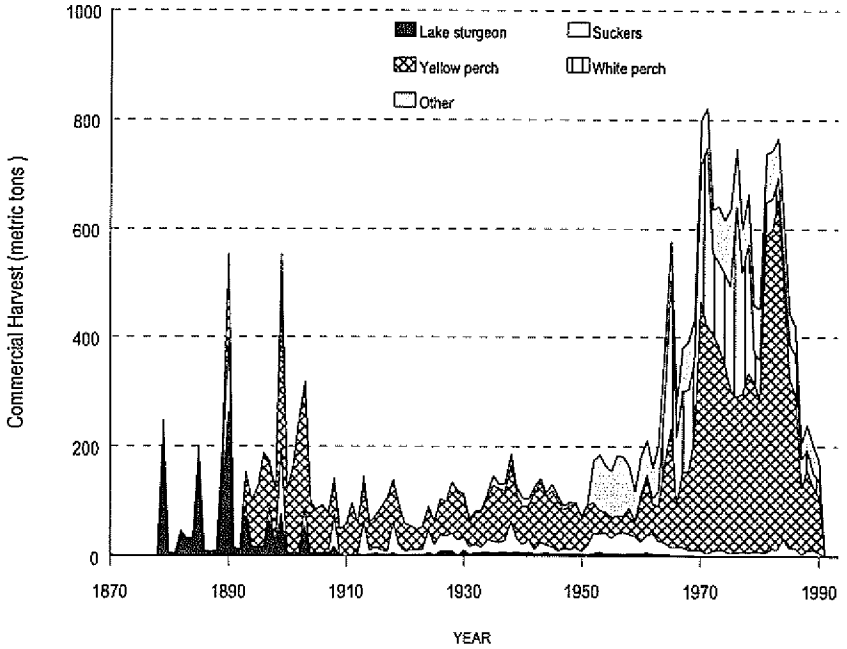


Figure 28. Abundance index of macroinvertivorous fishes in Lake Ontario tributaries. Lake Ontario nearshore macroinvertivores include lake sturgeon, yellow perch, suckers and white perch (data from Great Lakes Fishery Commission).

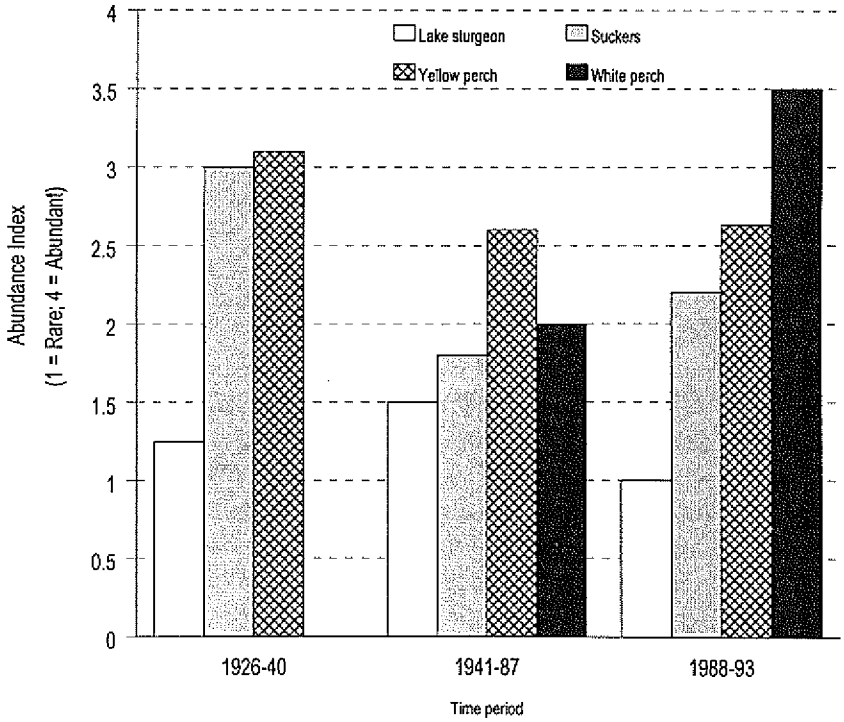


Figure 29. Trend in U.S. Lake Ontario tributary, macroinvertivorous guild. Species include lake sturgeon, yellow perch, suckers and white perch.

The macroinvertivorous guild represents the largest number of species present in Lake Ontario's nearshore area. Species of this community include lake sturgeon, suckers, yellow perch, and white perch. Commercial catch data for this guild has increased since historical time periods (Figure 28). The increase in catch is reflected by only two species; yellow perch, and white perch, a nonindigenous species. However, according to the New York State Department of Environmental Conservation, recent data suggest that a marked decrease in yellow and white perch has occurred over the past 6-10 years in the New York waters of Lake Ontario.

Lake sturgeon, an indigenous species, is the largest fish in Lake Ontario when fully mature. Historically, lake sturgeon supported a small commercial fishery; however, due to overexploitation and habitat degradation, populations declined significantly by 1900 (Figure 28). The lake sturgeon fishery was closed in New York waters in 1976 and the species declared a state threatened species in 1983. Lake sturgeon are currently rare in abundance (Figure 29), suggesting only remnant populations remaining in Lake Ontario. The St. Lawrence River however, hosts a self-sustaining population, particularly below the R.H. Saunders Dam (New York State-Canada border). Lake sturgeon are a Candidate (2) species, throughout its range, as defined by the *Endangered Species Act*. The Service has initiated a diver and angler sighting survey for lower Great Lake waters in order to estimate lake sturgeon distribution.

Over-fishing was likely the primary cause of lake sturgeon demise, due to their vulnerability to gill nets. However, pollution from saw mills, discharge of waste, and damming of rivers also influenced the loss of riffle spawning habitat and nursery areas (Jolliff and Eckert 1970). An age of maturity of over 12 years contributes to the slow rate of lake sturgeon rebound. At this time, there are areas of 1.6 to 30.6 kilometers (1 to 19 miles) below the first dams on several Lake Ontario tributaries accessible to lake sturgeon; however, even though the habitat may be suitable, lake sturgeon may not be using these areas because they are highly sensitive to disturbances on the spawning grounds (Jolliff and Eckert 1970). For example, historic spawning areas are now centers which sturgeon may be avoiding (Jolliff and Eckert 1970).

Overall reduction in suitable lake sturgeon spawning habitat and accessibility continues to limit reproductive success and survival in Lake Ontario, prolonging re-establishment of the species. It has been suggested that introduction of carp may have replaced or filled the niche of lake sturgeon (Christie 1973).

Yellow perch has the highest commercial catch among macroinvertivore species (Figure 28). Yellow perch were known to be fished when the offshore fishery was poor. For example, in the early 1920s and late 1950s when perch harvest was low, the fishery probably targeted whitefish and lake trout. In contrast, after 1960, whitefish collapsed and the fishery for yellow perch increased (Figures 28 and 19). Yellow perch abundance in the tributaries has remained relatively constant since 1926.

Suckers within this guild include longnose sucker, white sucker, lake chubsucker and four redhorse species. Suckers were a small portion of the commercial catch. Over the period of record, dramatic changes were not noticed (Figures 28 and 29). However, a decline in white sucker and an increase in shorthead redhorse is noted. In some specific river sections, white sucker has been reduced from abundant to moderately common and the exact opposite occurred for shorthead redhorse (Lowie *et al.* 1994a; 1994b; 1994c; Priest *et al.* 1994b). Causes for this observed trend are unknown. Both species require similar habitats for reproduction and neither are considered a prominent game fish. No matter what caused the change, young sucker species are an extremely important component of a tributary, warmwater system as forage for piscivorous fishes.

White perch commercial catch is increasing (Figure 28). The catch of white perch is a good indication of population abundance due to its more recent presence. White perch is a nonindigenous species which was first reported in Lake Ontario after 1940 (Figure 29). From 1965, the population (catch) has risen dramatically, reaching near abundant levels (Figures 28 and 29) (Christie 1973). The increase in white perch was most likely influenced by eutrophic

conditions which existed in the late 1970s and 1980s and decreased abundance of walleye and northern pike (Christie 1973). The white perch population are decreasing now due to phosphorous abatement programs and a rejuvenated walleye population.

Other species of this trophic guild include 14 minnow species, madtoms, central mudminnow, trout, banded killifish, sticklebacks, four sunfishes, seven darters, freshwater drum, and a few others. The only species indicating a change are the pumpkinseed, which has declined from abundant to moderately common, and the 3-spined stickleback, which increased in abundance in 1994. Causes for these trends are unknown.

Nearshore piscivorous guild

Within the piscivorous community, 14 species exist in Lake Ontario's nearshore area. Species include walleye, American eel, northern pike, muskellunge and smallmouth bass; the former three being commercially important (Figure 30), except in New York waters, where sale is prohibited. Unlike all other guild analysis which show an increase in catch after 1930, piscivorous fishes have declined (Figure 24).

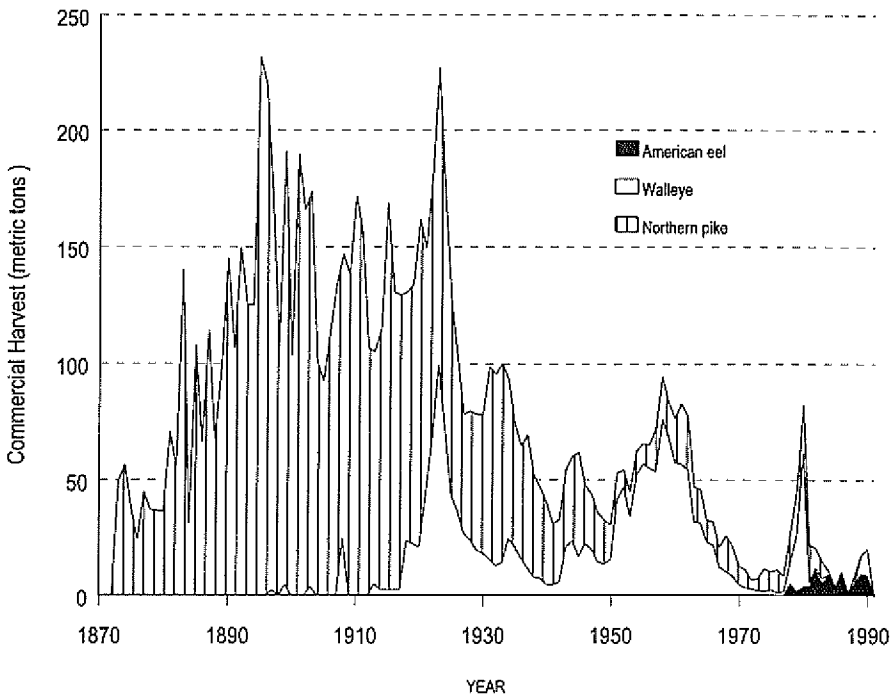


Figure 30. Trends in the Lake Ontario nearshore/tributary, piscivorous guild, as represented by commercial harvest (1870-1990). Species include American eel, walleye, and northern pike (data from Great Lakes Fishery Commission).

Northern pike was the primary commercial species until the 1920s when walleye catch increased and the northern pike harvest declined. Subsequent to the 1920s, northern pike commercial harvest was discouraged and after 1966 gill net fishing was discontinued (Christie 1973). As a result, insufficient information exists to infer abundance trends for northern pike from commercial data (Figure 31).

Walleye played an important role in the commercial fishery of eastern Lake Ontario and continues to prevail as a prominent game species; however, the population has fluctuated since white perch became abundant. White perch predation on walleye eggs and larvae may contribute to walleye fluctuations. Where white perch populations are low,

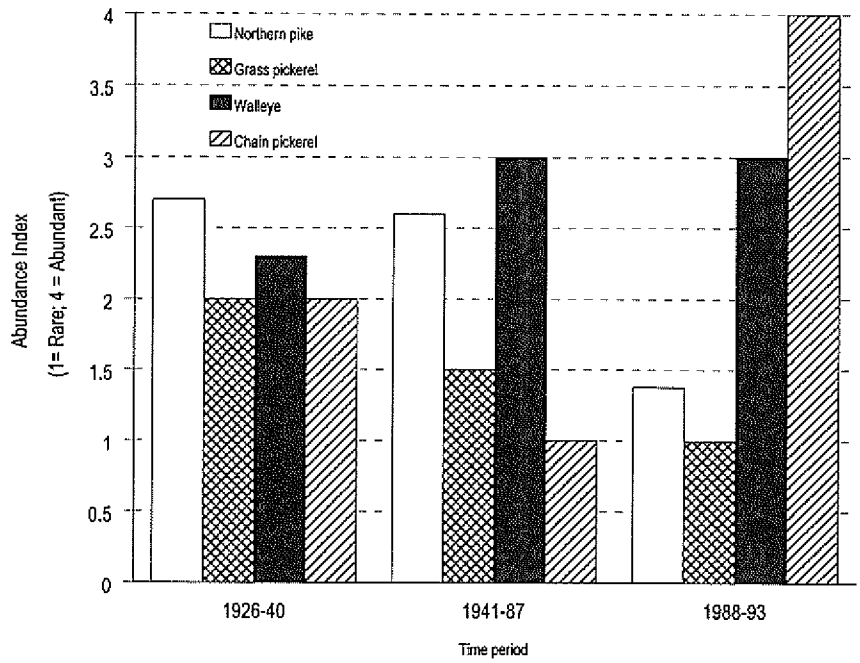


Figure 31. Abundance index of piscivorous fishes in Lake Ontario tributaries. Species include northern pike, grass pickerel, walleye, and chain pickerel.

walleye prosper and vise versa. Walleye are also highly susceptible to climatic cycles (Busch *et al.* 1975). During long winters and fast-warming spring periods, walleye recruitment is often strong compared to when winter ends early and waters warm more slowly. Overall, walleye populations have increased slightly in nearshore areas of Lake Ontario (Figure 31). The Service has established a Challenge Grant Program with the St. Lawrence County Sportsmen Group to rehabilitate a State hatchery and produce walleyes to restore tributary spawning in the St. Lawrence River population. The project has been very successful; the hatchery is now operating and producing fish.

American eel is one of the most unique indigenous species in Lake Ontario. They spawn in the Sargasso Sea at around 20 years of age. At two to eight years of age, eels enter the St. Lawrence River and Lake Ontario to spend the next 12-18 years, feeding in the tributaries. Migrations into Lake Ontario were blocked in 1958 by the R.H. Saunders generating plant and dam on the St. Lawrence River. During the 1970s, the commercial fishery expanded and the number of eels in the lake was not enough to support the fishery. Therefore, in 1974, Canadian officials had an eel ladder constructed to allow upstream migrations. In recent years (since 1973), eel harvest in Canadian waters has increased, while according to the numbers at the Saunders dam eel ladder, a radical drop in the number of migrating eels into the river has occurred since 1982 (Figure 32). Causes for the continuous drop in migrating eels are unknown. It is suggested that contaminants may play an important role. Adults eels leaving the St. Lawrence contain higher levels of mirex, PCB's and DDT than do eels entering the system. Habitat modifications in the St. Lawrence River are also implicated; however, habitat changes occurred in the 1950s and eel declines were not observed until the 1980s. Another issue of concern is the lack of knowledge of oceanic conditions in the Sargasso Sea which may be impacting the success of American eels at the egg and larval stages.

Smallmouth bass populations have remained relatively stable throughout history. For the last 19 years, the New York State Department of Environmental Conservation has conducted annual gillnet assessments in eastern Lake Ontario. Since 1981, smallmouth bass has shown good age class structure with 60-80 percent of the population consisting of three to eight year old fish each year. The Service is also cooperating with the New York State Department of Environmental Conservation by tagging smallmouths in the lower Genesee River, Rochester, New York. During the spring spawning period, large smallmouth bass move into the river. The ongoing tagging study will verify fish move-

ments and determine the contribution Genesee River fish make to the lake population.

One other notable change in this guild is the decline in grass pickerel and increase in chain pickerel abundance (Figure 31). A possible cause of this change is that chain pickerel are more tolerant of changing conditions.

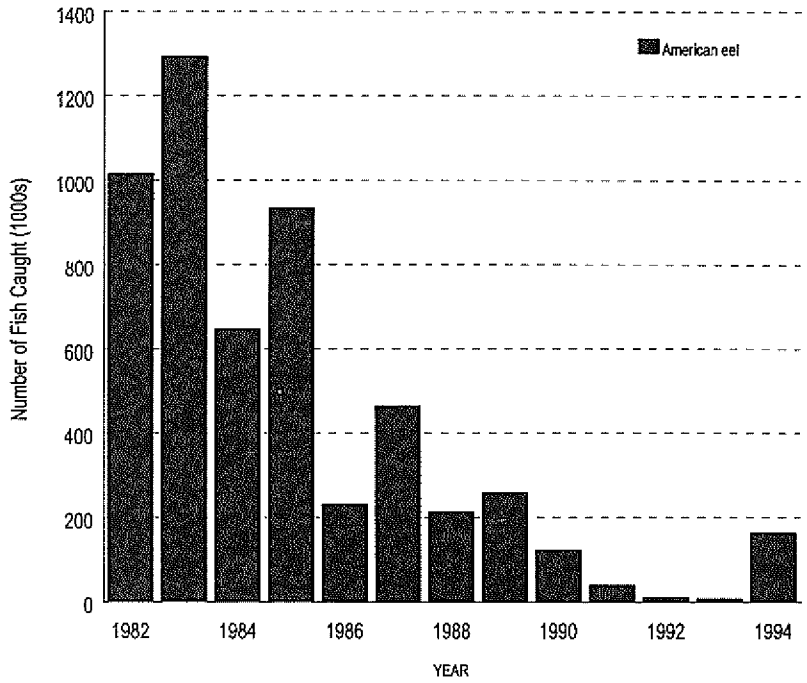


Figure 32. Numbers of American eel caught at the R.H. Saunders dam eel ladder, St. Lawrence River, Quebec.

Summary of guild analyses

The fishery trends within Lake Ontario's nearshore area is examined by fish species composition and distribution. Nonindigenous species are now present that were not in the system historically, and other indigenous species have been lost. Although there have been changes in species diversity; the dominant nearshore species (walleye, smallmouth bass, northern pike, redhorse, largemouth bass, rock bass, and yellow perch) have remained part of the community; however, at fluctuating abundances. In contrast, a drastic replacement of species has occurred in the forage fish community of the nearshore area. Historically, native common shiner, creek chub, and bluntnose minnow were the prominent forage fish. Currently, the emerald shiner, spottail shiner, various darters, and nonindigenous gizzard shad and alewife are the important forage species.

Changes are expected to continue within the nearshore area of Lake Ontario. Zebra mussel impacts, pollution abatement and increased productivity in tributaries, plankton reductions and a general change in the energy flow from a pelagic to a more benthic system are anticipated. Trophic guilds will be positively and negatively affected by these changes. For example, the macroinvertivorous guild will benefit from more benthos. This may be a positive step toward the restoration of the native lake sturgeon which is presently low in numbers. Lake sturgeon could refill the niche it once held if habitat is restored and passageways around dams are constructed. The species would also benefit from expected increases in food supply in the benthos.

The planktivorous guild consists of the important forage species necessary to sustain a healthy nearshore sport fishery.

Gizzard shad are expected to remain as the abundant species; however, population size and condition is expected to go down resulting from lower plankton abundances (New York State Department of Environmental Conservation data indicate a decline in abundance since the early 1980s). Indigenous forage species such as golden shiner and emerald shiner need to be enhanced to help supplement the potential loss.

Predicting an increase or decrease in species diversity and/or abundance is difficult. Expected changes in the piscivorous guild will depend heavily on prey species changes, exploitation rates and water quality inputs from tributaries.

The nearshore/tributary community is an extremely important component/contributor to the Lake Ontario ecosystem. This area provides critical spawning and nursery grounds for nearshore and offshore species; however, it is ever changing, more drastically than the open lake, because it is the initial recipient of tributary, shoreline, and climatic variations. Habitat modifications and/or enhancement needs to focus on appropriate species indicative of less productivity, as the lake continues to reach a more natural state of oligotrophic conditions with abundant benthos.

Causes of Changes in Lake Ontario Fishery Resources and Management Strategies

It is often difficult to attribute changes in species abundances to one controlling or overriding factor. Environmental and human-induced activities that stress aquatic systems can be classified as either biological, chemical, or physical. Critical modifications have occurred within the Lake Ontario watershed, causing irreparable impacts to fishery resources. These impacts may be manifested as changes in species density, diversity, and composition due to direct effects on year class strength, recruitment, spawning success, spawning or nursery habitat, and/or competition.

Physical factors

A summary of Lake Ontario habitat information indicates that physical changes caused the greatest stress among river/tributary habitats followed by chemical changes. Physical alterations in the basin began in the late 1700s and early 1800s, when dredging and dam construction were initiated to create and maintain navigational canals for the shipping industry. Dams for hydroelectric facilities were the focus of construction in the late 1800s and early 1900s.

Comparing fishery trends with hydrologic modification events, fluctuations in fish diversity appear to follow habitat changes. The diversity of the fishery can clearly be separated into three time periods representing a diverse fishery, a degraded fishery, and a diverse, recovering fishery.

Hydropower generation and operation has been a major alteration affecting the riverine habitats of Lake Ontario. Within the river systems of Lake Ontario, over 322 kilometers (200 miles) are impacted by hydropower operation. On the Beaver River, a major tributary to the Black River, approximately 88 percent of the river and its natural resources have been affected by hydropower projects according to the Federal Energy Regulatory Commission (1988).

Information assessing the specific effects alterations have had on these systems is limited; however, studies have been performed on other North American rivers demonstrating chronic impacts on fish and fish habitat. For example, damming of rivers hinders upward and downward migrations. Even if fish ladders are installed to assist upward migrations, downward migration may be hindered by fish entrainment through hydropower facilities or over dams, causing mortality. Fish entrainment and mortality have been found at every hydropower facility in the United States that has been investigated (Priest *et al.* 1994). Damming also results in losses of riffle-run habitats, reduced water velocities, siltation of cobble and gravel substrate critical to the spawning success of many fish, and changes to the benthic community. For example, on the Raquette River, New York, damming of tributaries has greatly reduced riverine habitat and replaced it with numerous impoundments.

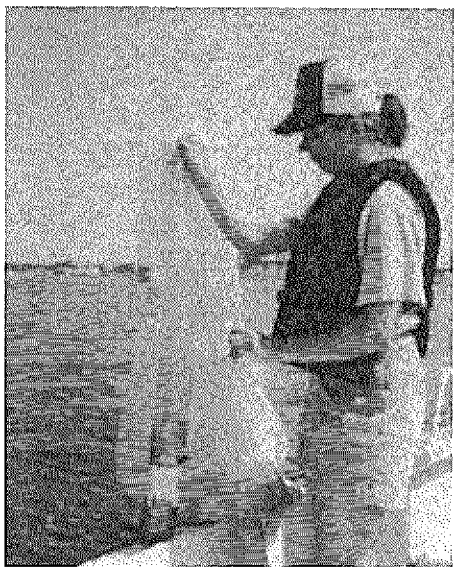
The large range of storage and release operations results in continuous water-level fluctuations on both sides of dams, preventing the establishment of stable environments (Priest *et al.* 1994). Water-flow manipulation creates dewatered areas, which may strand fish and fish eggs. Dewatered and low flow areas may result in stagnant environments which reduce oxygen levels, total usable habitat, and benthos drift, increase water temperatures, concentrate pollutants, prevent vegetative and desirable algal growth, produce crowding, and increase stress further enhancing diseases (Tyus 1989; Peters 1982). These effects occur on a large scale in rivers or tributaries; however, the lake-wide impacts may affect a broader base area of shoreline and organisms.

Through the Federal Energy Regulatory Commission's re-licensing process for hydropower facilities, the above issues are addressed. However, licenses are granted for periods of 30 to 50 years without requiring intermittent evaluations, subsequently eliminating routine monitoring of habitat conditions.

Snagging, clearing, and stone revetment projects have also been conducted within the basin according to the U.S. Army Corps of Engineers. Preferred habitats among warmwater fishes include snags, vegetated edge pools, backwaters, and riffles (Lobb and Orth 1991). Snags and overhanging trees provide essential cover for riverine species. Clearing projects include removal of this cover reducing potential habitat within the area. Also, clearing can cause bank instability through the removal of riparian vegetation, resulting in higher erosion and turbid waters. Soil erosion may impair the overall production of the system by reducing sunlight penetration and reducing plant productivity, possibly affecting fish food availability. Impacts of soil erosion and sedimentation include: prolific weed growth, decreased oxygen levels, changes in species composition (plants and animals), fish kills, smothering of benthic organisms, contaminant transport and reduced aesthetic character (Great Lakes Fishery Commission 1993).

The continuous dredging in numerous ports of the basin also produces a perpetual unstable habitat for resident fish populations. Dredging resuspends sediment often containing contaminants, and temporarily increases turbidity. Dredging also disrupts benthic invertebrates and aquatic macrophytes.

The agriculture industry during European settlement imposed physical modifications to the basin. Lands were cleared for farming, causing soil erosion, siltation, loss of canopy, and uncontrolled runoff, which contained the waste of live-stock, increasing the load of nutrients. In the Lake Ontario Basin, 32 percent of the land use is for agricultural purposes. In the Genesee River Basin, over half (52 percent) the land use is for agriculture (Monroe County, unpublished). This river is renowned for its turbid conditions, especially after storm events and spring melt-downs. Turbidity is one of the leading limiting factors to restoring some indigenous species to the Genesee River.



Lower Great Lakes Fishery Resources Office photo

Although the above impacts due to physical alterations induced by human activities indicate only negative effects, some alterations can have beneficial consequences. Stone revetments and breakwalls may also provide necessary fish cover and underwater sills needed for refuge from predation.

In accordance with an ecosystem approach to examining the Great Lakes, physical alterations including abiotic interactions, such as climate effects, are being investigated. Unlike the physical alterations previously discussed, and with the exception of possible global warming, the impacts due to a changing climate are not directly induced by human activities. Management of the natural resources in the Great Lakes can be facilitated through understanding

the effects of climate on trophic guilds and their interactions. In Lake Ontario, alewife play a significant role in the food web structure as a primary prey species. Alewife are indigenous to more temperate waters and are considered to be at the northern extent of their distribution range in the Great Lakes. Survival or success of alewife populations is believed to be temperature dependent (O'Gorman *et al.* 1994). The number of alewives in Lake Ontario has been correlated with cooling-degree days based on monthly mean air temperatures. This correlation assumes that water temperatures experienced by alewife are closely related to air temperatures.

The Service examined relationships between winter water temperatures in Lake Ontario and air temperatures and other climatological variables in an effort to develop a better predictor of deepwater temperatures, and hence potential survival of alewife.

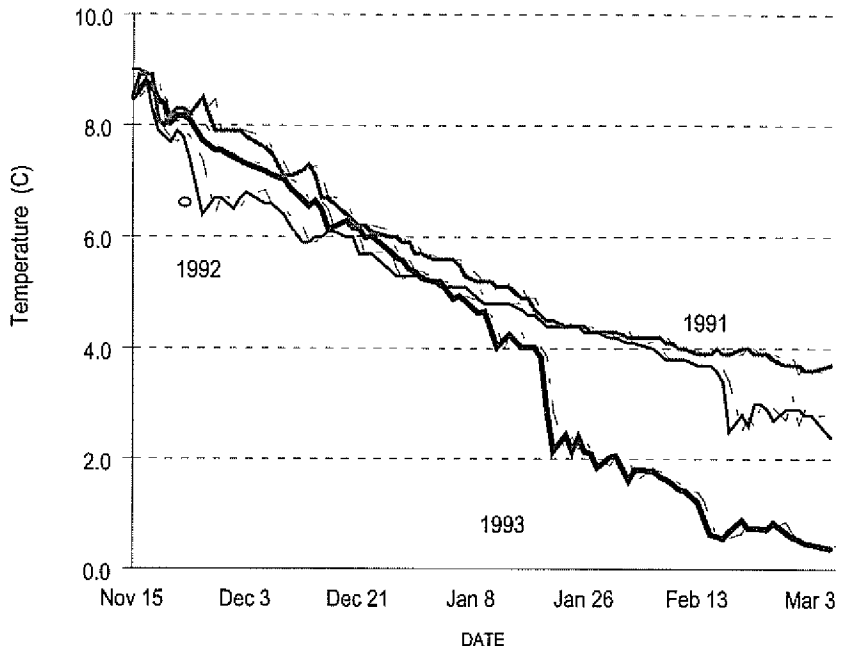


Figure 33. Lake Ontario empirical (solid) and predicted (dashed) winter water temperatures (November to March, 1991-1993) at Oswego Pt, New York (40 m depth).

Water temperatures at depths of 40 meters (131 feet), 60 meters (197 feet), 80 meters (262 feet), 100 meters (328 feet), and 120 meters (394 feet) off Oswego Pt, New York were recorded from November 15 through March 15 each year from 1991 to the present. Corresponding climatological data (air temperature, water levels, precipitation and wind) were obtained from a series of fixed weather stations located around the lake. Time-series regression analyses were used to develop an accurate model for winter water temperatures. The 40 meter temperature model was used to hindcast the winter water temperatures in the lake for the last 17 years and to then compare these values to alewife abundances. Alewife numbers were obtained from National Biological Survey and New York Department of Environmental Conservation (O'Gorman *et al.* 1994).

The 40 meter temperature model predictions closely simulated the empirical data ($p = .001$ for temperature at 40 meters, $r^2 \simeq 0.3$), demonstrating the implied water temperature relation to air temperature (Figure 33). Statistical tests, including cluster analysis and Analysis of Variance, indicate that water temperature is significant when explaining the variance in forage populations in Lake Ontario; however it does not account for all of the variance.

The model has potential to be a useful management tool, realizing that climate is only one factor influencing the ecosystem. This simple model allows managers to estimate deepwater temperatures from easily obtained weather information. Alternative or traditional means of obtaining empirical water temperature measurements is expensive and hazardous if at all possible, especially in inclement weather. Also, examining large systems, such as Lake Ontario, over long periods of time, may provide information regarding global warming trends.

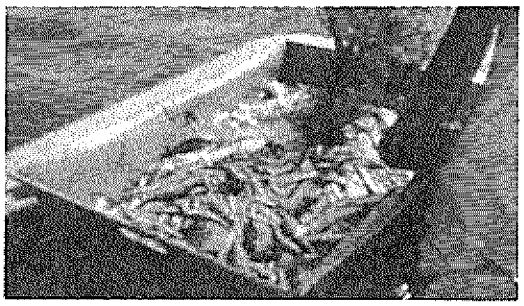
Chemical factors

Water and sediment quality play a major role in species diversity and abundance. Nutrient and contaminant loadings are primary issues fishery managers and researchers must address. These loadings include direct, or point source, via industrial and municipal discharges and indirect, or non-point source, via urban and agricultural runoff, ground water, Upper Great Lakes, and atmospheric deposition. Nutrients limit the amount of primary productivity in an aquatic system. When nutrient loadings are high, phytoplankton biomass is high. If nutrients approach very high levels, increased oxygen consumption by decaying material may deplete available oxygen resulting in anoxic conditions. Contaminants, however, are more chronic in nature and impacts can be hidden for long periods of time. Contaminants discharged into the air and water column reside in the sediment and biota. Contaminants accumulate through the food web structure, increasing in concentration, eventually reaching proportions affecting the reproductive success of top level predators such as fish and waterfowl, and considered too high for human consumption of these species. Contaminant impacts on ecological functions are still being explored, however to protect human health, fish and wildlife consumption advisories exist, recommending that persons eat only a limited amount of fish and game from the Great Lakes basins. New York and the Province of Ontario have implemented some of the most restrictive policies on fish consumption on Lake Ontario.

Areas of highest priority for remediation are designated Areas of Concern. These Areas of Concern are primarily river mouth harbors and bays that exhibit environmental degradation and where some beneficial uses of the water or biota are impaired (New York State Department of Environmental Conservation 1989). Lake Ontario's basin has nine Areas of Concern; three U.S., four Canadian, and two joint Areas of Concern. Onondaga Lake has a significant impact on the water quality of the Oswego River and Lake Ontario. The poor water quality of Onondaga Lake is a major constraint to achieving healthy fish populations in the Oswego River. Pollutants are transported to Lake Ontario through water currents, sediment transport and fish migration.

Biological factors

Overexploitation


Lower Great Lakes Fishery Resources Office photo

Impacts of over-exploitation of targeted fisheries of Lake Ontario have been manifested through loss of some species such as lake trout, lake whitefish, burbot, blue pike, lake herring, and the deep water ciscoes. Although it is possible that other factors, both environmental and human-induced, may have contributed to the eventual loss of these species, the major impetus for their disappearance is believed to be overexploitation (Christie 1973). The effects of overexploitation have increased with advancing technology for harvesting fish, including better fishing gear and boats and improved access to major markets via railroads. Species targeted by the commercial and sports fisheries are now monitored and harvest regulations have been established. Gear regulations have also been implemented. Stocking to enhance recruitment into indigenous and nonindigenous adult populations and increase spawning potential was widely used in the late 1800s and early 1900s and is now considered to have been a total failure. Recently, the ecological cost of stocking to fulfill these needs has been challenged (Hartig *et al.* 1991). Although a large population of adults

may be established, its reproductive success may be minimal due to a variety of problems including inappropriate species range, inability to recognize spawning locations (homing ability impaired), mixing of genome with indigenous fish and resultant production of offspring with diminished genetic fitness.

Nonindigenous species

The Great Lakes have been subject to the invasion of nonindigenous species since settlement by the Europeans. Since the 1800s, at least 139 nonindigenous aquatic organisms have become established in the Great Lakes (Mills *et al.* 1993). Nonindigenous species include any species or other viable biological material that enters an ecosystem beyond its historic range (PL 101-646). The rate of introductions into the Great Lakes has increased since the early 1800s with advances and development of transport technology (Figure 34). For example, completion of the Erie Canal in 1825, the Welland Canal in 1829 and finally, the St. Lawrence Seaway in 1959 facilitated increased numbers of introductions through the shipping industry, and species migrations.

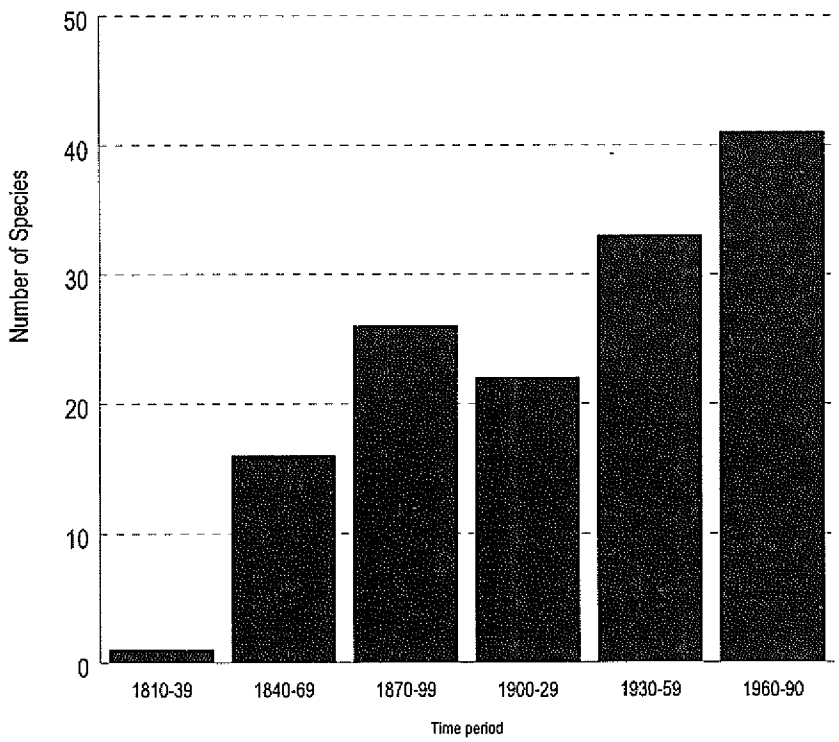


Figure 34. Number of nonindigenous aquatic species introductions into the Great Lakes, 1810-1990.

The majority of species introduced into the Great Lakes have been aquatic plants (42 percent), fish (18 percent), algae (17 percent), and mollusks (10 percent). Other types of organisms introduced into the Great Lakes, although fewer in number, include oligochaetes, disease pathogens, hydrozoans, insects and flatworms (Figure 35).

Nonindigenous species have entered the Great Lakes Basin through a number of pathways, including both intentional and unintentional means of transport. An intentional introduction is defined as the import or introduction of nonindigenous species into, or transport through, an area or ecosystem where it is not established in open waters for a specific purpose such as aquaculture, aquarium display, or fishery enhancement (stocking). Even when the purpose of such an import or transport is not direct introduction into an open ecosystem, eventual introductions into open

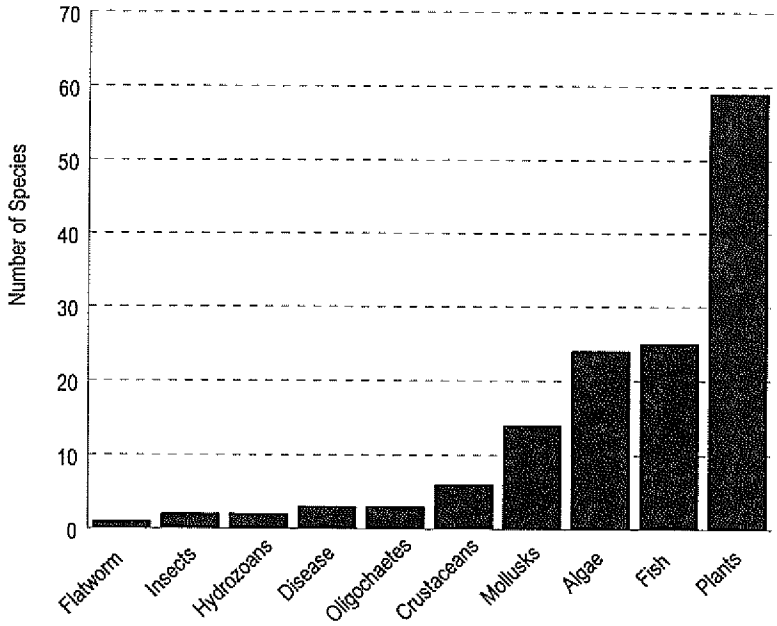


Figure 35. Number and type of nonindigenous aquatic species introduced into the Great Lakes (Mills *et al.* 1993).

waters as the result of escapement, accidental release, improper disposal, or similar releases are the virtual inevitable consequence of the original import or transport, and are therefore considered intentional according to the Aquatic Nuisance Species Task Force (1994).

Conversely, an unintentional introduction is defined as the introduction of a nonindigenous species that occurs as a result of activities other than the purposeful importation, transport, or introduction of that species. Generally, nonindigenous species are released unknowingly without any specific purpose (e.g. ballast water discharge, or discharge of water used to transport live fish, mollusks, or crustaceans) (Aquatic Nuisance Species Task Force unpublished). Unassisted movement through navigation canals, interbasin water transfers, and natural pathways such as waterfowl and storm events are considered unintentional. Using these definitions and the pathways determined by Mills *et al.* (1993) for the documented 139 species introductions into the Great Lakes, approximately 34 percent of the species introduced have been unintentional, while 38 percent have been intentional. The rest were either unknown (10 percent), or a single pathway could not be distinguished based on historical information (19 percent) (Figure 36).

The impacts of some introduced nonindigenous species have been severe, while others are unknown or have gone unrecognized. The introduction and spread of the sea lamprey, for example, imposed severe and costly impacts to the Great Lakes fishery resources. Lake trout populations were nearly extirpated throughout the Great Lakes. The severity of ecological and economic costs resulting from declining lake trout populations and the changing fishery captured the attention of both the U.S. and Canadian federal governments. A joint Great Lakes Fishery Commission between the two countries was formed in 1956 to respond and advise on issues affecting fish stocks of common concern; and to develop and implement integrated control strategies to minimize or eradicate sea lamprey populations in the Great Lakes. This marked the first time the government acted on nonindigenous aquatic species issues.

In 1990, following the introduction of zebra mussels into the Great Lakes in 1986, Congress took further action, enacting the *Nonindigenous Aquatic Nuisance Prevention and Control Act* (PL101-646). The immediate economic threat as well as the potential ecological impacts associated with the invasion of the zebra mussel provided the neces-

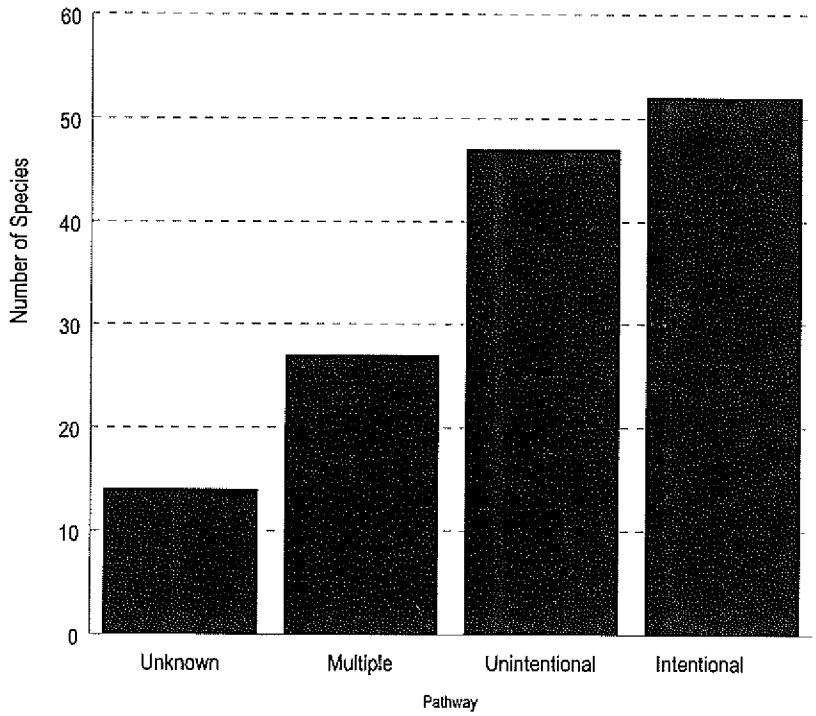


Figure 36. Introduction pathways for nonindigenous aquatic species in the Great Lakes.

sary catalyst to initiate the Act. The purposes of the *Nonindigenous Aquatic Nuisance Prevention and Control Act* are:

> *to prevent unintentional introduction and dispersal of nonindigenous species into waters of the U.S. through ballast water management and other requirements;*
>
> *to coordinate federally conducted, funded or authorized research, prevention control, information dissemination and other activities regarding the zebra mussel and other aquatic nuisance species;*
>
> *to develop and carry out environmentally sound control methods to prevent, monitor and control unintentional introductions of nonindigenous species from pathways other than ballast water exchange;*
>
> *to understand and minimize economic and ecological impacts of nonindigenous aquatic nuisance species that become established, including the zebra mussel; and*
>
> *to establish a program of research and technology development and assistance to States in the management and removal of zebra mussels.*

Through the *Nonindigenous Aquatic Nuisance Prevention and Control Act*, nonindigenous aquatic species introduced to a system can be qualified as a nuisance, as defined by law, warranting the implementation of control programs that minimize harm to the environment and to the public health and welfare. An aquatic nuisance species, as defined by law, refers to a nonindigenous species that threatens the diversity or abundance of indigenous species or the ecological stability of infested waters, or commercial, agricultural, aquacultural, or recreational activities dependent on such waters.

In response to mandates of the *Nonindigenous Aquatic Nuisance Prevention and Control Act*, the Coast Guard enacted ballast water regulations in May 1993 for all vessels entering the Great Lakes from outside the Exclusive Economic Zone. These vessels are now required to exchange their ballast water beyond the zone prior to entering the St.

Lawrence Seaway. Similar regulations were enacted in December 1994 for ships entering the Hudson River, north of the George Washington Bridge.

State regulations regarding the possession and transport of specific nonindigenous species, such as the zebra mussel, have been instituted by most of the Great Lakes states. These laws however, remain species specific, and vary between states.

The impacts of both intentional and unintentional introductions are evident in the Lake Ontario ecosystem. To examine all of the species and their associated impacts would be redundant and would fail to meet the objectives of this report. Instead, a fewer number of targeted species that have impacted Lake Ontario, either beneficially or detrimentally, will provide the focus of this discussion.

Intentional introductions

Trout and salmon

Intentional introductions into Lake Ontario through stocking have targeted nonindigenous salmonines since the 1870s. After several unsuccessful attempts, an intensive stocking program was initiated in the late 1960s primarily in response to high abundances of alewife (Lange and Smith 1993). This program currently remains in progress, although modifications have been made through technological developments and advances. By the mid- to late- 1980s, Pacific salmonines (coho and chinook salmon, rainbow trout) and European brown trout played significant roles in the ecosystem dynamics of Lake Ontario as well as the economic value of the sportfishery.

Recently, it is estimated that prey consumption by stocked salmon and trout species, both indigenous and nonindigenous, likely exceeds sustainable prey abundances (Lange and Smith 1993). Changes in prey abundance, specifically alewife and rainbow smelt (also nonindigenous species), may be due to a number of interacting factors, including increased predator demands, changes in water quality, and subsequent changes in the plankton community. In response to this changing system, targeted stocking rates were reduced by 31 percent in 1993 by both New York State Department of Environmental Conservation and Ontario Ministry of Natural Resources (Ontario Ministry of Natural Resources 1994).

Rudd

Lower Great Lakes Fishery Resources Office photo

The potential for impacts associated with the intentional introduction of rudd into the Lake Ontario Basin have only recently been recognized. The rudd was stocked in the Roeliff-Jansen Kill in eastern New York within the Hudson River drainage in 1936. Escape from waters where rudd was introduced, extensive propagation as a bait species in the southern states, and subsequent importation and bait bucket transfer have resulted in a substantial range expansion of this species. Rudd are now found in at least 11 states (MacNeill 1993). Unfortunately, fishery managers were not alerted to or aware of the spreading populations until distribution as bait was well underway. In 1989, rudd were collected in Lake Ontario and the St Lawrence River and in 1990, an established population was found in Oneida Lake, New York. The spread of rudd, although not a major concern to fishery managers at this time, does pose a potential threat to indigenous species through food web alterations, changes in nutrient cycling, deterioration of nearshore spawning and nursery habitats due to consumption of aquatic vegetation, and changes in reproductive success through hybridization and the consequential production of sterile offspring.

Unintentional introductions

Zebra and quagga mussels

The zebra mussel, *Dreissena polymorpha*, is thought to have been introduced in 1986 into Lake St. Clair through ballast water discharge from trans-oceanic shipping. The zebra mussel was first collected in Lake Ontario and the St. Lawrence River in 1989. In 1991, a second dreissenid species, genetically different from the zebra mussel, was confirmed and collected in Lake Ontario. This second mussel was dubbed the quagga mussel and later identified as *Dreisssena bugensis*. Both dreissenid species have since been shown to have been present along the southern shore of Lake Ontario in 1990.

These mussels are highly fecund and possess a planktonic veliger stage facilitating their ability to reproduce and spread rapidly. Once settled, the mussels attach themselves to almost any hard substrate through the secretion of byssal threads. By attaching to the hulls of boats, ships, or barges, the mussels can further expand their range.

Surveys to monitor the abundance and distribution of zebra mussels in Lake Ontario were conducted in 1991 and 1993 through diver surveys. The 1993 results indicated an increase in mussel density for all sites sampled, however, the amount of increase varied from relatively little to ten-fold. Mussel densities are highest in western Lake Ontario, in the Niagara area, and the southern shoreline. Densities are relatively moderate in northeastern Lake Ontario, while very low along the north-central shoreline. Quagga mussel densities were generally lower than those of zebra mussels, with the highest densities occurring in western and eastern Lake Ontario. The quagga mussel is reportedly being found in higher abundances than the zebra mussel at colder, deeper sites. The addition of the quagga mussel's potential range may have associated impacts in areas originally thought to be safe from zebra mussels. Zebra mussels have spread throughout much of the inland waters of the Lake Ontario Basin, including Lake Champlain, the Erie Canal system, and the Finger Lakes of New York.

Monitoring programs have been initiated by a variety of agencies including federal, state, provincial, private, and public organizations. The Service has maintained a leadership role in the monitoring and detection of nonindigenous species. The Service established a Zebra Mussel Monitoring Network through which assistance was provided in developing standardized monitoring protocols, educating potential monitors, identifying zebra mussels, and providing monitors with the necessary equipment to conduct an effective program when necessary. A Reference Collection was established in cooperation with the Academy of Natural Sciences and a pamphlet entitled, *Tracking the Zebra Mussel: A User's Guide* was developed as an educational tool to assist water users track or monitor zebra mussel distributions and inform them of the potential impacts of zebra mussel populations.

As stated previously, the potential ecological and economic impacts associated with the introduction of the zebra mussel are severe. The threat posed by the spread and increase of zebra mussels and quagga mussels is typically associated with the settled stage. However, according to research conducted by Mills *et al.* (1993, draft), as a cooperative work order agreement between the Service and Cornell University, the abundance of settled mussels in Lake Ontario could be related to planktivory by alewife and rainbow smelt on veligers. Both rainbow smelt and alewife were found to be consuming zebra mussel veligers, potentially placing sufficient predation pressure on veliger densities evidenced by a west to east decline in veliger densities and a corresponding decline of settled mussels. As veligers enter the Lake from the Niagara River, their numbers are substantially cut, possibly by predation. An examination of the proportion of zooplankton biomass accounted for by zebra mussel veligers should be made and the nutritional value of these veligers as a food item should be examined in correlation with the condition and health of Lake Ontario planktivores (e.g. growth rate, health, etc).

Settled mussels have also provided a new food source for some benthic fish (macroinvertivores). However, fish predation as a biological control does not appear to be feasible based on current fish population composition, abun-

dance, and rate of consumption, relative to the mussel's ability to reproduce and disperse. As an addition to the food web structure of Lake Ontario, bioaccumulation of contaminants within the mussels may impact species consuming mussels and hence continue through the food web. Zebra mussels, as benthic organisms, have been indicated as contaminant "sinks", capable of accumulating toxic materials. Investigations focussing on the impacts of this accumulation through the food web are currently being initiated, however, additional work is needed examining both waterfowl and fish community impacts.

Food web alterations and the resultant shifts in nutrient cycling to the benthos is one of the most apparent changes the Lake Ontario nearshore and reef areas will likely undergo in response to zebra mussels. Zebra mussels are efficient filter-feeders, removing phytoplankton and small zooplankton (rotifers) from the water column. Consumed material is either digested and wastes are deposited as feces, or rejected and deposited as pseudofeces. Energy, as plankton removed from the water column, is transferred to the benthos as deposits of feces, pseudofeces and mussel biomass. Although zebra mussels have replaced amphipods as the numerically dominant taxon, the total abundance of macroinvertebrates, excluding zebra mussels, has been shown to be significantly greater on both cobble and artificial reefs.

If this shift in energy continues through the food web structure, changes could eventually mean economic losses to the sport and commercial fishery. For example, recovering populations of lake whitefish may be hindered through the indirect effects of zebra mussel colonization of spawning and nursery habitat. The survival of lake whitefish fry is apparently dependent on the zooplankton community structure. If this community is substantially changed by the removal of phytoplankton, recruitment of lake whitefish may be impeded. The economic costs already incurred by industry, associated with the zebra mussel introduction have been extraordinary. Their ability to adhere to hard surfaces including the water intakes of industrial facilities (power plants, municipality water, etc) have forced such industries into emergency or periodic shut-downs due to massive encrustations completely occluding the intake opening. Industrial facilities have implemented costly control alternatives, monitoring programs, and maintenance programs.

Rainbow smelt and alewife

Rainbow smelt and alewife, both considered nonindigenous to the Great Lakes, are currently the two primary prey species in the Lake Ontario offshore community. The origin of Lake Ontario rainbow smelt populations is uncertain. Rainbow smelt are thought to have been either indigenous to the lake or to have migrated through the Erie Canal system from the Atlantic drainage. The alewife was discovered in Lake Ontario in 1873, its origin is also debated. As with rainbow smelt, alewife are thought to have either expanded through the Erie Canal system into the Great Lakes from the Atlantic drainage (Emery 1985) or to have been indigenous to Lake Ontario but depressed by Atlantic salmon and lake trout. Current populations of alewife are declining due to diminishing system productivity and high predation pressure of stocked salmonids, originally introduced in response to the need for large predators to control increasing abundances of planktivorous species, including alewife.

Large populations of alewife in near-shore spawning areas may hinder lake trout restoration efforts through predation on lake trout fry (Krueger *et al.* 1994). Predation by alewives probably caused complete mortality of lake trout fry from spawning areas where alewife were abundant. Based on these findings, lake-wide rehabilitation of lake trout may not be possible unless alewife populations continue to decline and abundance remains low. Management strategies to reduce predation pressure on alewife (and rainbow smelt) have been implemented in an attempt to prevent the collapse of these nonindigenous species for the benefit of the stocked nonindigenous trout and salmon fishery. Other indigenous species with larval stages vulnerable to predation by these planktivorous fish may also be adversely affected by these management strategies.

Spiny water flea

The spiny water flea (*Bythrotrephes cederstromi*) was first found in Lake Ontario in 1985 and established in the offshore waters of the lake in 1987. This cladoceran is believed to have been introduced into the Great Lakes via ballast water discharge from trans-oceanic shipping. Its rapid spread throughout the Great Lakes is thought to be the result of multiple introductions or inter-lake shipping. Spiny water flea abundances have remained relatively low in Lake Ontario. Populations may be limited by several factors including thermal preferences as well as planktivory by alewife (H. Riessen, personal communication) As a large zooplankter and highly visible, the spiny water flea is subject to predation by planktivorous fish, and is typically not found under conditions of high planktivory. The appearance of spiny water flea in the offshore waters in 1987, was coincidental with a 65 percent decline in adult alewife abundances. In 1988, alewife abundance increased 50 percent and spiny water flea was not present in zooplankton assessments (Makarewicz and Jones 1990). If populations of alewife continue to decline, spiny water flea may become more abundant in Lake Ontario.

Ruffe

The ruffe was first collected and identified in 1987 by the Wisconsin Department of Natural Resources, during standard assessment work in the St. Louis River, Lake Superior (Pratt *et al.* 1992). It is believed to have been introduced into the Duluth/Superior Harbor, Minnesota, in the far western basin of Lake Superior via ballast water from trans-oceanic shipping sometime during the early to mid-1980s. Since then, population abundances have increased sharply and distribution has spread along the southwestern shore of Lake Superior. Because of the potential threat posed by the ruffe and to avoid duplication, a full description of the invasion and current management strategies of the ruffe can be found in the *Causes of Changes in Lake Erie Fishery Resources and Management Strategies* section of this document.

During the 1993 and 1994 field seasons, ruffe surveys were conducted in the dredged area of the Genesee River in Rochester, New York by the Service. No ruffe were found in the 1993 samples. Larval fish identification and data analyses have not been completed for the 1994 samples.

The thermal habitat utilized by ruffe is approximately the same as that used by walleye and yellow perch. This overlap allows managers to predict the amount of habitat available for ruffe based on that available for walleye and yellow perch. Of the estimated total of 6.6 million hectares of thermal habitat area available to walleye in the Great Lakes, 7.4 percent of that total is in Lake Ontario. Although much of Lake Ontario is not expected to be suitable habitat for ruffe, nearshore indigenous species including yellow perch, walleye, and shiners may be impacted if ruffe colonize Lake Ontario. Yellow perch and walleye are important ecologically as well as economically to the Lake Ontario sportfishery.

Waterfowl

The Double-crested cormorant (*Phalacrocorax auritus*) is a colonial water bird, first observed in Lake Ontario in 1938, that has populated Little Galloo Island in the Kingston Basin of eastern Lake Ontario and other adjacent areas. Cormorants and other piscivorous birds have historically been seen as competitors by society; rivals vying for the fisheries. Cormorants have recently reached population levels in eastern Lake Ontario that have resulted in increased public concern over their affect on the ecosystem.

Cormorant colonies characteristically nest in large aggregates, typically resulting in the decimation of vegetation in the inhabited area. This decimation, along with a pungent odor associated with these colonies, is perceived as an annoyance. Of perhaps greater concern to the fishing public is the impact that the cormorant population may have on natural fish populations and the survivability of stocked fish. Cormorants generally feed mostly on fish species with little or no direct economic value. However, as a consumer of forage fish, they may indirectly impact the available food supply of more desirable sportfish. Cormorants may also feed on stocked fish where an artificially high concentration of young fish, possibly stressed from transport, is introduced into the system at one time.

Table 6. Colonial nesting birds on man-made natural sites in the U.S. Great Lakes (from Scharf, W.C., COE Technical Report D-78-10, Report Number FWS/OBS-78/15. May 1978).

1976 Number of nests		1977 Number of nests	
+ 76	Double-crested cormorant	96	Double-crested cormorant
121	Black-crowned night heron	130	Black-crowned night heron
200	Herring gull	200	Herring gull
+30,000	Ring-billed gull	27,308	Ring-billed gull
		2	Cattle egret

The double-crested cormorant entered the Great Lakes region between 1910 and the early 1930s and reached peak numbers during the 1940s and early 1950s with Eastern and Central Lake Ontario being a major breeding center. In the 1950s and 1960s these populations drastically declined due, in part, to reproductive failures caused by toxic contaminant levels. Table 6 summarizes an inventory conducted in 1976-77 and shows the composition of the colonial nesting bird population on Little Galloo Island at that time, by number of nests.

Status of population

Cormorants were added to the list of birds protected under the *1918 Migratory Bird Act* (16 U.S.C. 703-711; 40 Stat. 755) in 1972. The islands of Lake Ontario and the abundant alewife population throughout the 1980s were conducive to the nesting habits of the cormorants. As such, their unhindered growth has resulted in 28,000 individuals in eastern Lake Ontario in 1992 and 1993.

The bird population on Little Galloo Island, as inventoried by New State Department of Environmental Conservation, in 1992 (Bob Miller, unpublished data) places the number of cormorant at 11,000 (similar numbers in 1993) along with a significant ring-billed gull population (+80,000 pairs). Also occupying the island are caspian terns (1010 adults), 200 herring gulls, black crowned night heron (12 nests), and approximately 6 great black-backed gulls.

Effect on fish stocks

A fishery predation study to determine the diet of the eastern Lake Ontario cormorant population, was started in 1992 by the Fish and Wildlife Service, Canadian Wildlife Service and New York State Department of Environmental Conservation. The study was continued in 1993 and 1994 by the National Biological Survey and New York State Department of Environmental Conservation. Results to date show that alewife is the most abundant prey species taken, followed by yellow perch and centrarchids. Salmonids made up less than 1 percent of the overall diet. Although the effect of cormorants on newly stocked fish was noted in 1993 (estimated 5,000 lake trout lost), the impact is being decreased through changes in the stocking protocols.

The predatory effect of cormorants in terms of biomass taken from the Lake Ontario system was addressed by a special Task Group of the Lake Ontario Committee in a report on the status of the offshore pelagic fish community. Bioenergetic simulations by Rand and Stewart (Lake Ontario Committee 1992) estimate that cormorants consumed 1,650 metric tons of pelagic prey fish annually (the available biomass of rainbow smelt, alewife and other prey fish in

Lake Ontario is estimated at 418,000 metric tons as compared to a demand of 64,500 metric tons of prey from all salmonine predators. This would mean that the effect of cormorants in Lake Ontario accounts for 2-3 percent of the total annual predation of pelagic prey fish. This does not appear to be a major contributor to lake-wide predation effects (Status of the Lake Ontario Offshore Pelagic Fish Community and Related Ecosystem, *in* 1992 Task Group for Technical Evaluation for the Lake Ontario Committee of the Great Lakes Fishery Commission, Kingston, Ontario 28-29 July 1992).

The results of the cormorant diet study show that alewife, not sportfish, are the principal part of the cormorant diet. Therefore, their feeding habits do not directly impact more desirable sport fish species. However, their indirect effect should be considered as the alewife population is currently stressed by factors such as decreased productivity and high piscivorous demand. In light of the fact that cormorants account for 2-3 percent of the total predatory demand, their impact on other fish populations with which they compete is limited.

Current situation

The productivity of the Lake Ontario ecosystem is changing. Reductions in nutrient loading, coupled with the energy redirection caused by zebra mussels, is impacting the size of the prey community. Therefore, the system can not support the numbers of top-level predator species at levels maintained in the recent past.

The sportfishing community has expressed concern over the expansion of the cormorant population. The perception is that cormorants are consuming large amounts of stocked sport fish. After reviewing the scientific information currently available, participants of the Lake Ontario Cormorant Symposium did not believe the take of sportfish by cormorants to be a significant impact on the ecosystem, but rather, a perceived problem. Educational programs and public forums concerning current aquatic ecosystem issues would be advantageous. New York State Department of Environmental Conservation has conducted public meetings to address these concerns. A task group has been formed to assimilate information regarding the impacts on the fishery and if necessary, recommend ways to reduce those impacts.

Lake Erie

Historic and Current Fishery Resource and Trends

Appendix II lists species composing the Lake Erie fish community (past and present), and current status of stocks being monitored. One hundred and forty-three fish species have been documented in the Lake Erie basin. One indigenous species is extinct and eight have been extirpated (approximately 6 percent), and five species of accidentally or intentionally introduced species never became permanently established. Of the remaining species, 22 (17 percent) are accidental or intentional introductions. Unintentional introductions include sea lamprey, American eel, alewife, suckermouth minnow, rainbow smelt, white perch, round goby, rudd, and tubenose goby. Extant intentional introductions include goldfish, common carp, ghost shiner, chain pickerel, coho salmon, rainbow trout, sockeye salmon, chinook salmon, brown trout, eastern mosquitofish, orangespotted sunfish, redear sunfish, and rainbow darter.

Trends were analyzed using combined commercial harvest from each country for the lake, starting in 1867, and recent agency stock assessment data from each State and Provincial Ontario. The agency stock assessment data collected by Michigan, Ohio, Pennsylvania, New York and Provincial Ontario have been used because biases associated with commercial harvest data are not present, and therefore, assessment trends are a more realistic picture of recent population trends. These data generally only go back to the mid- to late-1970s. Sampling procedures and fishing gear differ between States and Ontario, and cannot easily be combined into one annual index of abundance for each species; although extensive efforts by resource agency partners have been made to standardize assessment methodologies.

Offshore fish community

Three major trophic guilds occur in offshore Lake Erie: planktivore, macroinvertivore and piscivore (Table 7). The offshore area include those waters that become thermally stratified in summer; in Lake Erie, these are essentially deep waters of the eastern and central basins and, for the most part, contain the coldwater fish community. Phytoplankton drives the offshore fish community via transfer of the sun's energy to available carbon. Therefore, the planktivore guild yields the highest biomass and, coupled with the macroinvertivore guild, serves as prey for piscivore guild species.

In consideration of energy (or carbon) transfer through an ecosystem, an approximate, tenfold difference between trophic levels occurs in a normally functioning energy flow system with limited emigration. To illustrate the general concept of energy transfer in a changing Lake Erie ecosystem, commercial harvests were averaged for the three offshore guilds in three different time periods: overall (from 1867-1990); 1911-1930 (selected based on completeness of available data, fishing effort

Table 7. List of select fish species from Lake Erie offshore habitats according to trophic guild. Total number of species per guild is in parenthesis. Origin and current status is designated; I=Indigenous; N=Nonindigenous; C=Increasing; D=Decreasing; S=Stable; X=Extinct; U=Unknown.

GUILD COMMON NAME	ORIGIN	STATUS
HERBIVORE (0)		
OMNIVORE (0)		
PLANKTIVORE (5)		
Alewife	N	D
American Shad	I	X
Emerald Shiner	I	S
Rainbow Smelt	N	D
Lake Herring or Cisco	I	X
MACROINVERTIVORE (7)		
Fourhorn Sculpin	I	X
Lake Whitefish	I	C
Mottled Sculpin	I	X
Northern Madtom	I	U
Slimy Sculpin	I	C
Spoonhead Sculpin	I	X
Johnny Darter	I	U
PISCIVORE (11)		
Atlantic Salmon	N	X
Blue Pike	I	X
Brown Trout	N	D
Burbot	I	C
Chinook Salmon	N	D
Coho Salmon	N	D
Lake Trout	I	C
Rainbow Trout	N	D
Sea Lamprey	N	S/D
Sockeye Salmon	N	D
Trout-perch	I	U

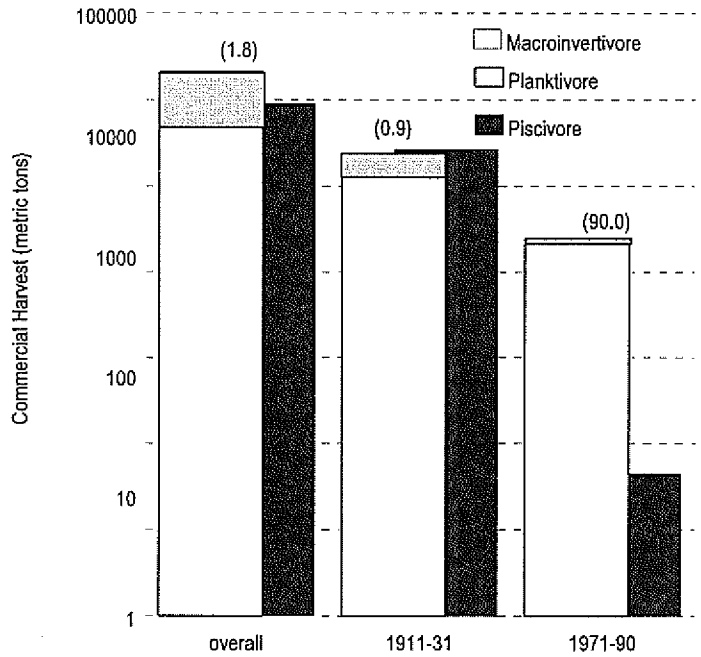


Figure 37. Production of trophic guilds in three time periods based on commercial harvest data. A ratio comparing forage fish (consisting of the planktivorous and macroinvertivorous guilds) to piscivores is in parentheses (data from Great Lakes Fishery Commission). In a stable ecosystem a ratio of approximately 10:1 is expected.

involved, a changing economic period with wars and depressions, and when most of indigenous species were still available); and 1971-1990 (selected because of improved water quality and initiation of stricter regulations in commercial harvest such as limited entry, quota management and various gear restrictions and gill net prohibitions). However, biases of commercial harvest data constrain guilds to only a few species, limiting interpretation. The "overall" and "1911-1930" periods (Figure 37) indicate that the system may have over-accommodated the piscivorous guild (e.g. too many predators for available prey) with commercial harvest of piscivores being greater than 50 percent to over 100 percent in weight for the two respective periods. In recent times, piscivores on the U.S. side, walleye in particular, have been managed principally for sport fishing, so commercial landings for this period inject substantial bias in these analyses.

Offshore herbivorous/omnivorous guilds

The Lake Erie offshore fish community does not have species which represent herbivorous or omnivorous fish guilds as defined in this approach. Phytoplankton is consumed by zooplankton, and plankton in general is consumed by the planktivorous guild, which drives the offshore system. Omnivorous fish, such as catfish, do not typically inhabit offshore waters (the coldwater fish community); benthic organisms including annelids, molluscs, and crustaceans completely serve the omnivorous function in offshore habitat when plant and animal material from surface waters settle.

Offshore planktivorous guild

The offshore Lake Erie planktivorous guild was historically dominated by lake herring. Rainbow smelt replaced lake herring in the planktivorous guild, after lake herring abundances declined as a result of over-exploitation and degradation of habitat (Figure 38). In many lake systems alewife and rainbow smelt co-occur and have replaced indigenous forage fish; however, only one of these two species will dominate a planktivore guild. The mechanism of this predominance is not well understood; interaction may be related to a lake's over-winter heat retention. Deeper lakes, such as Lakes Ontario and Michigan, are able to retain more heat over winter than the shallower Lake Erie. Although

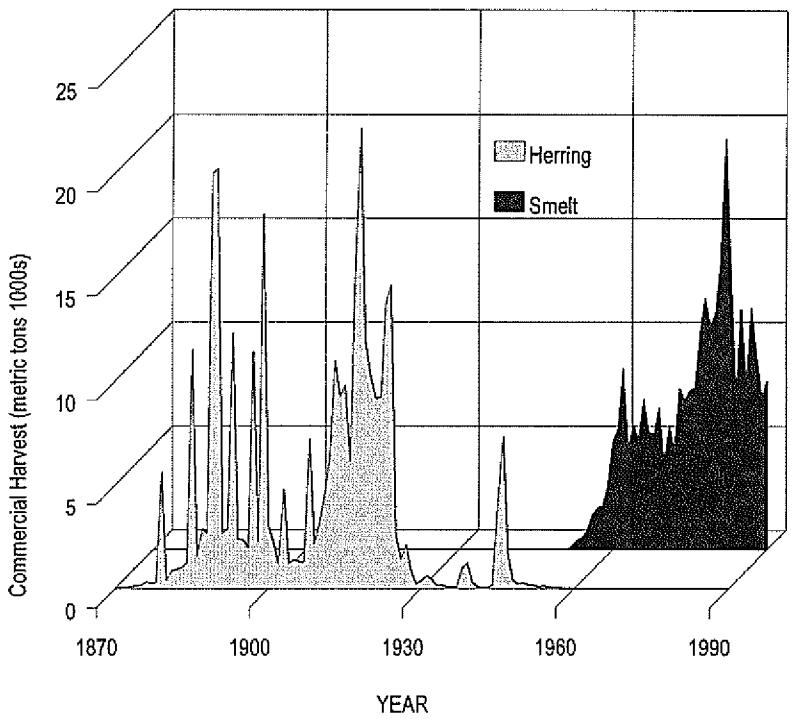


Figure 38. Annual commercial harvest of lake herring and rainbow smelt from Lake Erie, 1870-1990 (data from Great Lakes Fishery Commission).

alewife are present in Lake Erie, their numbers are far lower than rainbow smelt. Alewife have been suggested to be more efficient and selective than rainbow smelt when they predate large bodied zooplankton (H. Riessen, personal communication). Currently, alewife could be an important controlling factor of the newly-introduced spiny water flea. Riessen (personal communication) has indicated that negative correlations occur between the abundances of alewife and spiny water flea, suggesting that the planktivorous alewife could significantly reduce the numbers of spiny water flea. Alternatively, increased numbers of spiny water flea would enhance production of alewife, especially in the face of a declining population of rainbow smelt; and if heat retention is not limiting, alewife abundance should increase.

Nonindigenous rainbow smelt abundance is decreasing along with an apparent change in predominant distribution throughout Lake Erie (Figure 39). Recent trends indicate that a shift is occurring from the formerly productive eastern basin to the central basin. Two hypotheses exist regarding decline in rainbow smelt abundance in the eastern basin of Lake Erie. The first hypothesis, supported by the Ontario Ministry of Natural Resources, suggests that rainbow smelt are being consumed by an increasing lake trout population. The second hypothesis, expresses rainbow smelt distributional changes as a reflection of their seeking mesotrophic waters where food (zooplankton) supplies are higher (i.e. emigration from the eastern to the central basin). The eastern basin has returned to an oligotrophic state brought about initially by restrictions on phosphorous loadings into Lake Erie. Oligotrophic waters are not conducive to production of food for rainbow smelt, therefore the decrease and distributional changes are probably more in line with the second proposed hypothesis.

Today, lake herring occur as a rare event in Lake Erie, the few caught presumably come from the Upper Great Lakes. Their demise was mainly through over-fishing, although habitat degradation also contributed to recruitment failure. Siltation of spawning shoals, low dissolved oxygen, and chemical pollution are a few of the factors attributed to degradation of habitat.

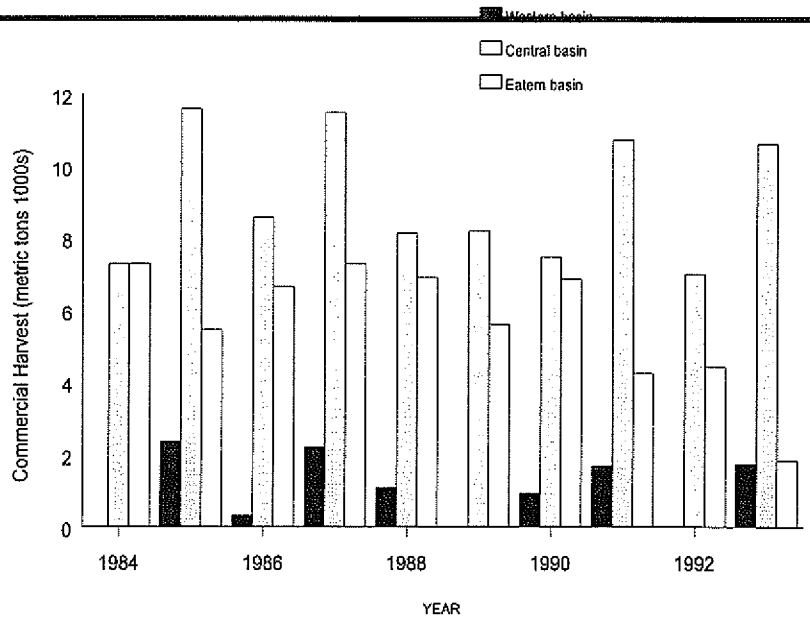


Figure 39. Annual commercial harvest in Canadian waters of rainbow smelt, in Lake Erie, by three management basins, 1984-1993 (data provided by Ontario Ministry of Natural Resources).

Although the Lake Erie Committee, Forage Task Group has been specifically concerned with forage fish (primarily rainbow smelt), lower trophic organisms (e.g. prey for forage fish) are implicated in current changes in the Lake Erie ecosystem. As a member of the Forage Task Group, the Service is currently surveying researchers throughout the Lake Erie community for density and diversity data for phytoplankton, zooplankton, and benthic organisms. An understanding of lower trophic level organisms is critical to and compatible with the ecosystem approach identified in the Act.

Offshore macroinvertivorous guild

The macroinvertivorous guild had historically been dominated by lake whitefish. Lake whitefish peaked in the late 1940s and declined to the point of jurisdictional closures, resulting in no commercial catch during the 1960s and 1970s (Figure 40). Only recently, have resource agencies noticed a resurgence in numbers. Increased abundance of lake whitefish is probably linked to improved water quality and overall habitat conditions and increases in benthic organisms resulting from zebra and quagga mussel establishment. Dreissenid mussels provide greater structural and functional complexity to the benthos. In addition, declining rainbow smelt numbers may enhance the increase in lake whitefish, since rainbow smelt are known to prey on larval coregonids. Pseudofeces and feces produced by zebra and quagga mussels serve as food to the benthic community of annelids, crustaceans, and insects. These organisms are readily consumed by macroinvertivores. Sculpins are also members of this guild; Lake Erie previously had four sculpin species. Sculpin abundance is not currently assessed, even though they probably provide a vital link in the flow of benthic energy to the piscivore guild.

Offshore piscivorous guild

Historically, blue pike was the dominant fish predator in the Lake Erie offshore fish community (Figure 41). Overexploitation of the stock and habitat degradation has resulted in extinction.

Currently, the major fish predators are walleye and lake trout: the latter being in the offshore Lake Erie fish community, are reared by the Service and stocked by New York and Pennsylvania fishery agencies. Other Pacific salmon

species are also stocked by State agencies. Most of the focus has been on establishment of self-sustaining lake trout populations. Although, limited historic records are available (Great Lakes Fishery Commission does not give commercial landings of lake trout in Lake Erie; Baldwin *et al.* 1979), average lake trout harvest before 1900 has been estimated to be near 110,000 pounds annually (Moenig *et al.* 1974; Barnes 1982; Coldwater Task Group 1993). Therefore, overall lake trout yields were less than 1.5 percent of blue pike yield (from average yields during 1911-1930) and less than 0.7 percent when blue pike were at their peak in harvest 1948-56.

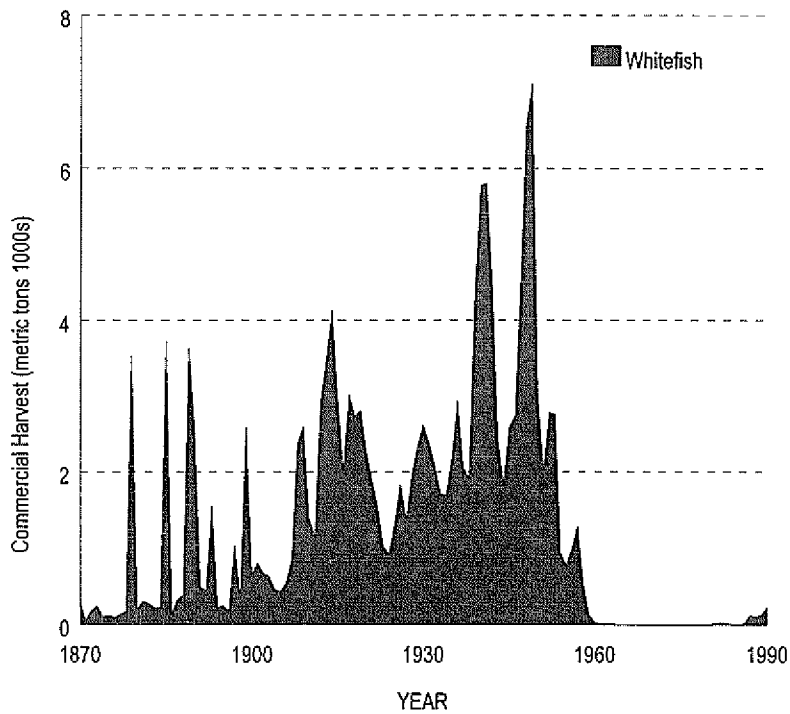


Figure 40. Annual commercial harvest of lake whitefish from Lake Erie, 1870-1990 (data from Great Lakes Fishery Commission).

Best estimates on current populations of lake trout are given by the Coldwater Task Group at the annual Lake Erie Committee meeting. Figure 42 demonstrates increases in older age groups of lake trout until 1991. The distribution of lake trout is currently under scrutiny. In addition, some concerns are expressed over other population parameters, such as survival and mortality (Coldwater Task Group 1994). Because of recent declines in rainbow smelt abundance, agencies have decided to reduce the annual stocking rate of lake trout from 200,000 yearlings to 160,000 yearlings and may further reduce this rate in 1996.

The Service actively participates in coordination, technical advisement, and dissemination of information on lake trout rehabilitation efforts in Lake Erie. Over the past four years, staff of the Service chaired the Coldwater Task Group and Lower Lakes Lake Trout Task Group, members of which include Canadian and U.S. Federal agencies, State and Provincial resource agencies, and universities. A revised lake trout rehabilitation plan was drafted by the Service, for and accepted as a "resource document" by the Coldwater Task Group and the Lake Erie Committee partners in 1993. In support of New York State Department of Environmental Conservation concerns, staff from the Service have implemented a lake trout fry assessment in Lake Erie. Currently, the program is determining best sampling methodology; but also, the fry program will identify recruitment of naturally spawned lake trout, a key goal in establishment of a self-sustaining lake trout population.

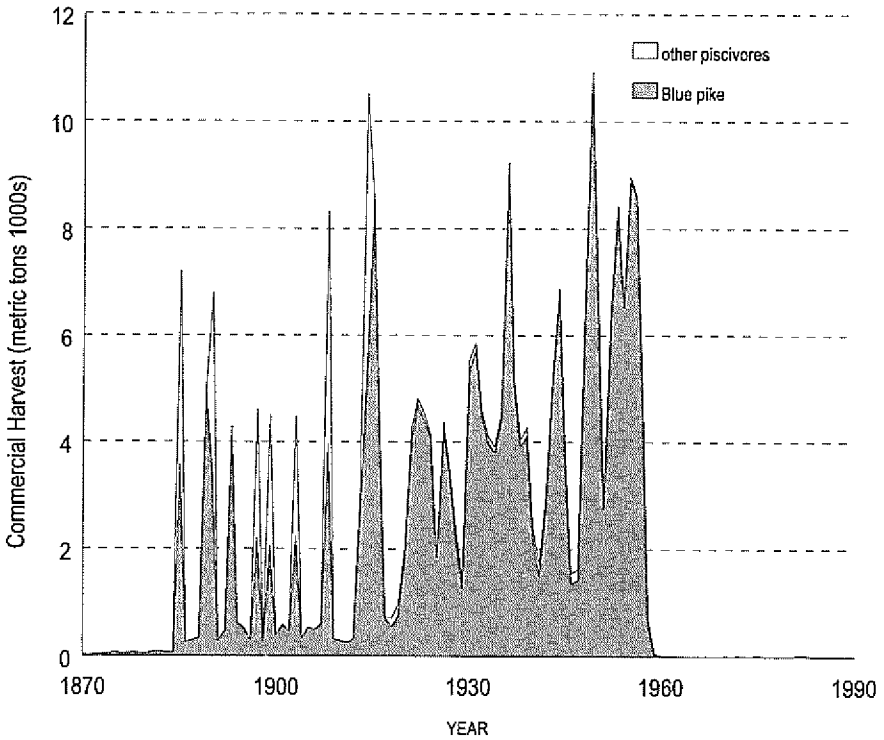


Figure 41. Annual commercial harvest of blue pike and other species of the offshore piscivorous guild, excluding lake trout, from Lake Erie, 1870-1990 (data from Great Lakes Fishery Commission).

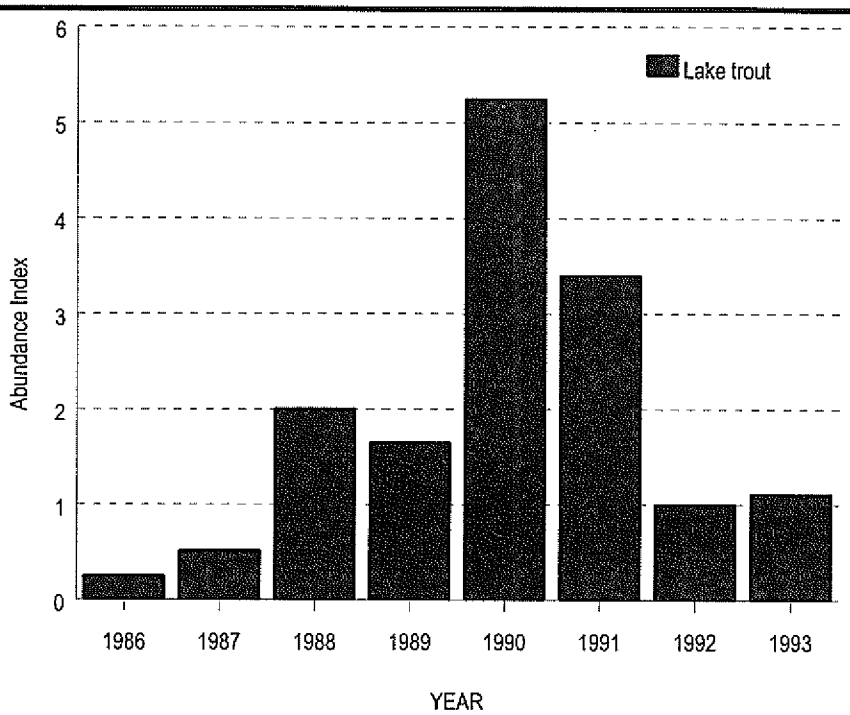


Figure 42. Lake trout abundance in eastern basin Lake Erie, 1986-1993 (data provided by the Coldwater Task Group, Lake Erie Committee, Great Lakes Fishery Commission).

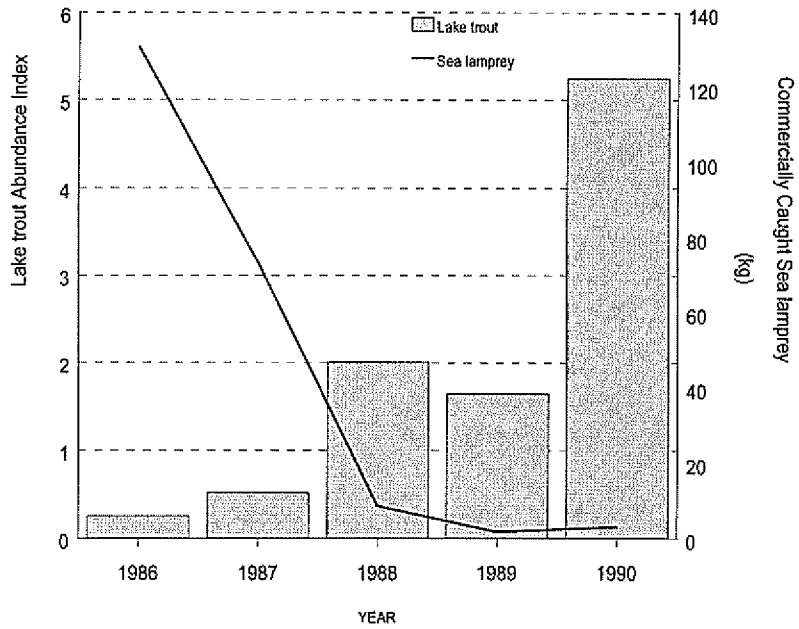


Figure 43. Lake trout abundance compared to annual commercial catch of sea lamprey from Lake Erie, 1986-1993 (lake trout data provided by the Coldwater Task Group, Lake Erie Committee, Great Lakes Fishery Commission, lamprey data provided by Department of Fisheries and Oceans Canada).

Sea lamprey are also part of the piscivorous guild, however there are only limited data on their abundance in the offshore fish community. In a Great Lakes Fishery Commission cooperative program delivered by the Service and the Department of Fisheries and Oceans, assessments of abundance are normally taken as sea lamprey enter tributaries to spawn. Sea lamprey data, from commercial fishing vessels provided by the Department of Fisheries and Oceans Canada (Rod MacDonald, personal communication), negatively correlates (r^2 =-0.687, p=0.200, n=5) with an increased lake trout abundance index (Figure 43).

Summary of guild analyses

Current trends in decreasing nutrients within the Lake Erie system favor oligotrophic conditions for offshore waters, except in the western basin. Reductions in productivity in the planktivorous guild are also expected with continued nutrient abatement and filtering rates of zebra mussels, limiting available plankton on which these fish feed. Continued declines in overall productivity will enlarge the impacts of decreasing planktivores and probably alter rehabilitation procedures for lake trout and stocking management of Pacific salmonines. An increase in the macroinvertivorous guild is expected via an increased food supply with establishment of zebra and quagga mussels providing a more complex structural and functional benthos. If sea lamprey treatment continues, a moderate piscivorous production would be expected particularly with a supported effort in lake trout stocking. Fishery resource managers need to prepare for changes in abundance and diversity; current conditions will favor indigenous species such as lake herring, lake whitefish, and sculpins rather than nonindigenous rainbow smelt and alewife.

Lake Erie's relative size and position within the Great Lakes makes it more susceptible to changes than the other Great Lakes; these changes generally occur more quickly in Lake Erie. As a result of nutrient abatement programs and point source pollutant loading restrictions, Lake Erie's water quality is much improved over water quality in the 1960s and 1970s. These improvements are demonstrated as downward trends in primary production. Concern is being expressed by some of the management agencies that the downward trend in nutrients may not have bottomed out. If this trend continues, the water quality success story will further impact the planktivorous guild and

nonindigenous species will enhance the macroinvertivorous guild. Lake Erie is at the cusp of its next era of ecosystem function and fishery trends. While the lake ecosystem is adjusting to its changing production levels, fish species will have the chance to expand, or the misfortune to decline dependent on water quality conditions. Opportunity therefore exists for fisheries and environmental resource managers to take a broad ecosystem look at Lake Erie and modify their programs to align with common and maintainable production levels; determined by a healthy energy flow and species important to society. Current water quality trends are moving toward diminished productivity. Water quality goals should be set in accordance with all resource management goals; not only those goals of water quality agencies.

Nearshore/tributary fish community

Approximately 104 species have been classified as being part of the nearshore/tributary fish community. These fish fall under five major trophic guilds described earlier: herbivore, planktivore, piscivore, omnivore, and macroinvertivore. Table 8 lists those species which are highlighted in this section as representatives of trends within each guild and in the nearshore/tributary fish community as a whole.

Commercial harvest includes only a few nearshore species. Those which have been targeted in the past by the commercial fishing industry include carp, channel catfish, northern pike, muskellunge, sauger, walleye, yellow perch, white bass, freshwater drum, lake sturgeon, and suckers (Figure 44). The commercial harvest records for species in the nearshore area were sporadic before 1910. From 1911 to 1950, harvest was equally split between the omnivorous, piscivorous, and macroinvertivorous guild species. Overall commercial harvest peaked around 1957, followed a few years later by a sharp decline in the piscivorous harvest and declining harvests in the other guilds, indicating some species may have been unable to sustain their populations at these high commercial harvest rates.

For the past few decades the commercial fishery has targeted mainly yellow perch from the macroinvetivorous guild and walleye from the piscivorous guild. This shift may indicate a general decline in abundance of other species within the piscivorous and macroinvertivorous guilds, and an apparent decrease in diversity in the nearshore community. Since the mid-1970s, increasing harvests are evident in these two guilds. If this trend continues, population declines in harvested species from these guilds are inevitable.

Table 8. List of select fish species from Lake Erie nearshore/tributary habitats according to trophic guild. Total number of species per guild is in parenthesis. Origin and current status is designated; I=Indigenous; N=Nonindigenous; C=Increasing; D=Decreasing; S=Stable; X=Extinct; U=Unknown.

GUILD COMMON NAME	ORIGIN	STATUS
HERBIVORE (1)		
Central Stoneroller	I	U
OMNIVORE (18)		
Goldfish	N	D
Common Carp	N	D
Spottail Shiner	I	D
Brown Bullhead	I	C
Channel Catfish	I	S
PLANKTIVORE (10)		
Gizzard Shad	I	U
Emerald Shiner	I	D
MACROINVERTIVORE (60)		
Lake Sturgeon	I	U
White Sucker	I	U
Silver Redhorse	I	U
Black Redhorse	I	U
Golden Redhorse	I	U
Shorthead Redhorse	I	U
Greater Redhorse	I	U
Brook Trout	I	U
Yellow Perch	I	D
White Bass	I	D
White Perch	N	D
PISCIVORE (15)		
Northern Pike	I	U
Muskellunge	I	U
Walleye	I	D
Smallmouth Bass	I	S
Largemouth Bass	I	U
Sauger	I	U

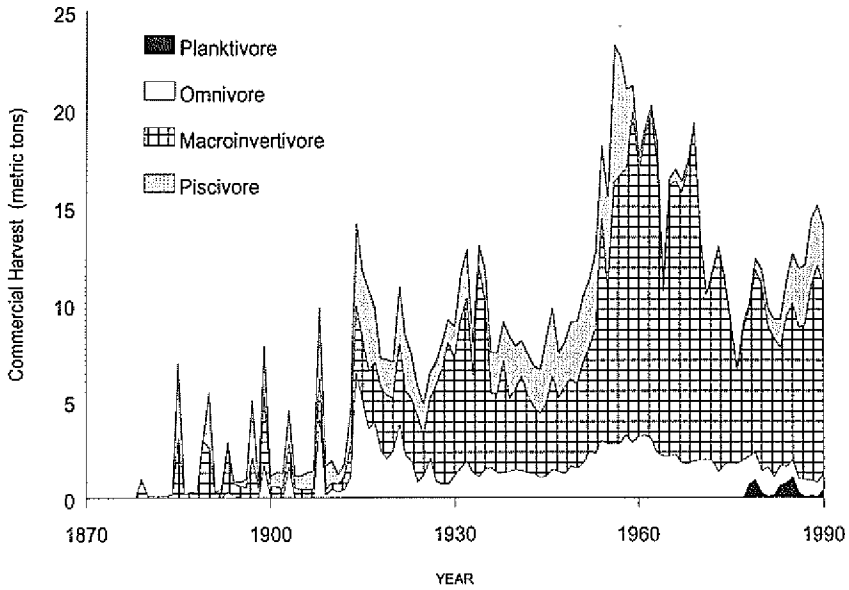


Figure 44. Nearshore trophic fish communities (guilds) for Lake Erie as represented by commercial harvest records (1870-1990). Guilds were defined by the primary diet item of non-spawning adults. Guilds represented are planktivores, omnivores, macroinvertivores and piscivores (data from Great Lakes Fishery Commission).

Nearshore herbivorous guild

Only one species has been identified as herbivorous and assigned to this guild, the central stoneroller. It is found in tributaries of Lake Erie, including the Buffalo River. Little information is available on distribution of central stoneroller in Lake Erie tributaries.

Nearshore omnivorous guild

Eighteen species in the Lake Erie basin have been assigned to this guild. These include goldfish, common carp, spottail shiner, channel catfish, black bullhead, and brown bullhead. These species are found in both tributaries and nearshore areas. Species which have long term commercial harvest records include common carp, goldfish, channel catfish, and bullheads (Figure 45). Long term agency stock assessments that include the nearshore omnivore guild are lacking for most of the lake. These stock assessment programs tend to target economically important species, but sometimes report incidental catches of species from the omnivore guild. Current trend information from agency stock assessments is available for common carp, goldfish, channel catfish, brown bullhead, and spottail shiner. Information on trends for other species in this guild are not available.

Common carp and goldfish were both intentionally introduced around the 1870s-1880s and have become "established" and abundant throughout the basin. An "established" species is defined as a nonindigenous species that has become self-sustaining. No apparent adverse effects have been attributed to introduction of goldfish, but common carp tend to uproot plants and stir up sediment while they feed (Emery 1985). This feeding habit has been blamed for deteriorating nearshore habitat by increasing turbidity and destroying aquatic vegetation used by other fish and waterfowl for food and cover (Emery 1985).

Common carp make up the majority of the commercial catch, with channel catfish the second most abundant (Figure 45). For both species there appear to be two peaks in commercial catch, during the time periods 1900-25 and 1950-60. After 1960, commercial catch declined, but this may be more of a reflection of changes in gear and targeted fish within the commercial fishery than actual changes in these populations.

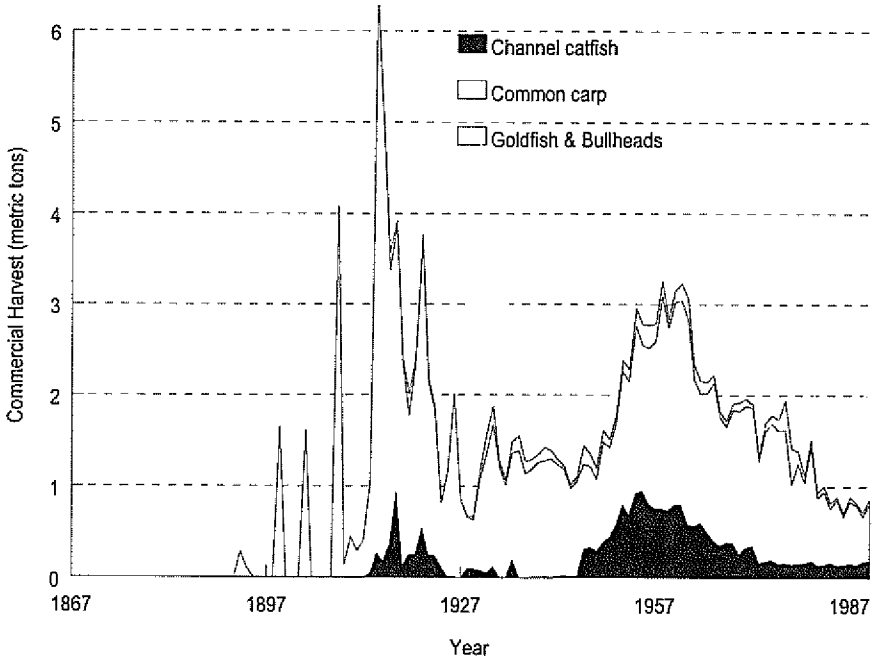


Figure 45. Trends in the Lake Erie nearshore omnivorous guild as represented by commercial harvest records (1870-1990). Lake Erie omnivores include the common carp, channel catfish, goldfish and bullheads (data from Great Lakes Fishery Commission).

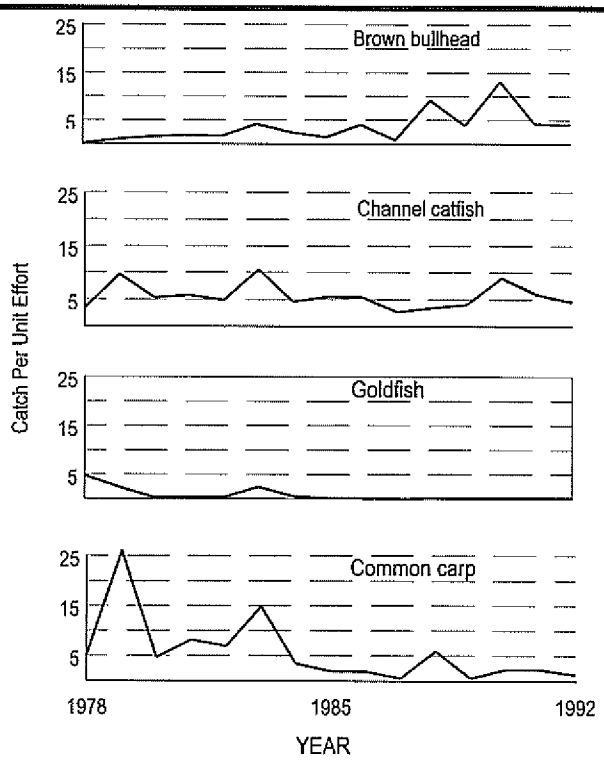


Figure 46. Index of abundance for several nearshore omnivore guild species in the western basin of Lake Erie, 1978-1992 (data from Michigan Department of Natural Resources).

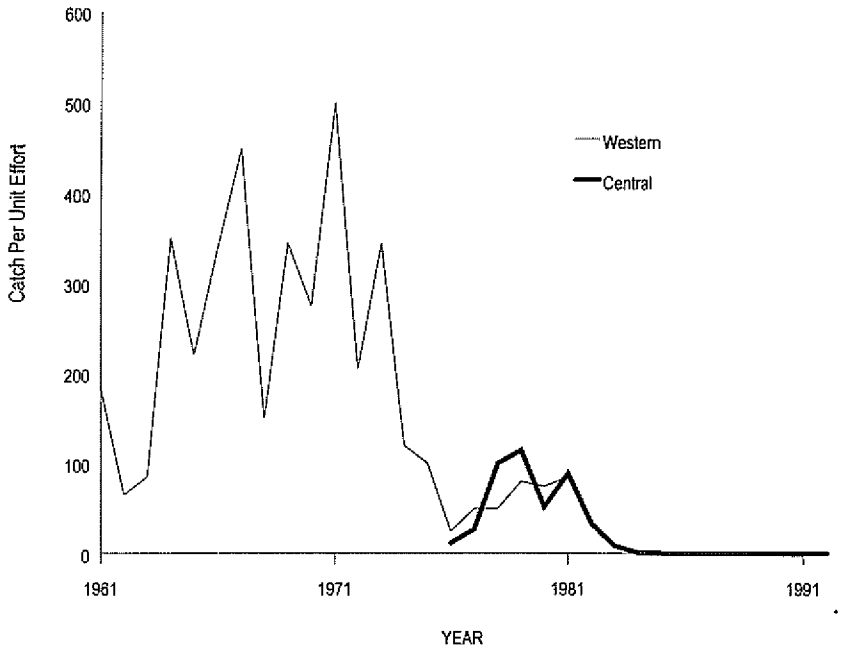


Figure 47. Representative index of abundance for spottail shiners, as determined from agency assessment data, in Lake Erie, 1961-1992 (data from Muth 1985 and Ohio Department of Natural Resources).

A nearshore trapnet survey for walleye conducted from 1978 to the present in Michigan waters of the western basin, recorded catches of fish in this guild. Trends from this stock assessment show a decrease in common carp and goldfish catch-per-unit-effort, a relatively constant channel catfish catch-per-unit-effort, and an increase in brown bullhead catch-per-unit-effort from 1978 to 1992 (Figure 46) (Thomas and Haas 1993). The causes for these trends are unknown.

Bottom trawl and trapnet fish stock assessments conducted in each of the basins have reported spottail shiners, an important prey species in Lake Erie, in their catch. Figure 47 contains data from two agencies that illustrate the general lakewide trend observed by all agency stock assessments. Spottail shiner abundance was high in the western basin throughout the 1960s and early 1970s. From 1976 to 1981, abundance of spottail shiner began to increase in the catch for the western and central basins, but declined by 1982 to catch-per-unit-efforts generally lower than those in 1976. Since the early 1980s, populations have steadily declined and remained low through 1992. The decreased abundance after 1973 may be a result of predation by increasing walleye populations (Muth 1985).

The Service initiated a ruffe monitoring survey of several harbors in Lake Erie in 1993 and 1994 to monitor for presence of ruffe in Lake Erie. Data on all fish species are recorded. In the first year of the program, 15 species were collected, including four in the omnivorous trophic guild.

Nearshore planktivorous guild

Ten species from the Lake Erie basin have been assigned to this guild. Several species are found only in tributaries; while other species, like gizzard shad and emerald shiner are found in both tributary and nearshore areas. Like the omnivore guild, there has been relatively little agency stock assessment for fish species in this guild and commercial harvest data only goes back to 1978. Warmwater or forage fish stock assessments include information on gizzard shad and emerald shiner; important forage fish in Lake Erie.

Historically, gizzard shad have been common throughout the lake, although annual abundance fluctuates greatly (Trautman 1981). Increases in abundance in the 1950s are thought to have been due to decreases in competitive and predatory fish species, and increased phytoplankton production.

Figure 48 shows abundance of gizzard shad observed in commercial harvest and a representative agency stock assessment in the western basin. Agency stock assessment data from the western and eastern basins, from 1978 to the present, identified a peak in abundance in all areas sampled in 1983; followed by high commercial catches in 1985. A smaller peak in abundance in 1988, observed only in the western basin, may have resulted in the rise in commercial catch observed in 1990. There appears to be a two year lag in commercial harvest peaks from agency stock assessment peaks. This lag indicates that the commercial fishing industry is only harvesting the largest gizzard shad, and may give a biased picture of population abundances over time.

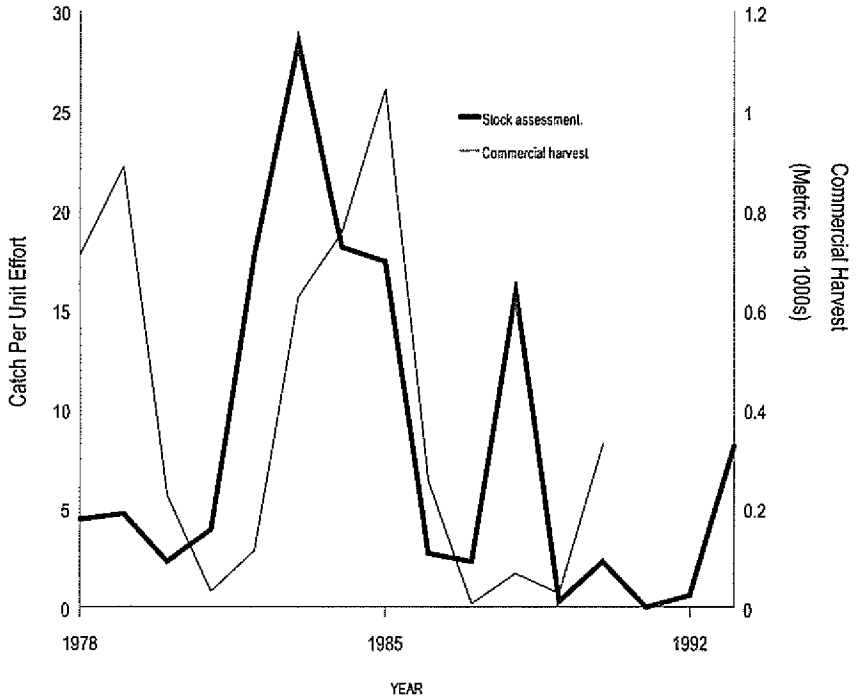


Figure 48. Index of abundance for gizzard shad in the western basin of Lake Erie, 1978-1993, compared with commercial harvest of gizzard shad for all of Lake Erie, 1978-1990 (data from Michigan Department of Natural Resources and Great Lakes Fishery Commission).

In general, gizzard shad abundance declined by 1987 in both agency stock assessment data and commercial catch. From 1970 to 1987, offshore phytoplankton biomass declined in Lake Erie by as much as 52 to 89 percent due to water quality improvements (Makarewicz 1993). Phytoplankton is the major component of gizzard shad diet. Since 1988, the dreissenid population has reduced phytoplankton abundance even further. Reductions in phytoplankton may be contributing to recent low abundances of gizzard shad.

Western and eastern basin stock assessments conducted in 1993 indicated an increase in gizzard shad abundance (Figure 48). Nearshore phytoplankton biomass changes may be affecting gizzard shad populations.

Between 1920 and 1950, the emerald shiner was extremely abundant in Lake Erie (Trautman 1981). Agency stock assessments from the 1960s indicate relatively high abundances with a peak in 1972. From 1976 to the present, western basin abundance remained low, and abundance in the central and eastern basins fluctuated annually (Figure 49). The decrease in abundance seen after 1976 may be a result of increases in walleye abundance (Muth 1985). Declines in phytoplankton biomass mentioned above may also be impacting emerald shiners.

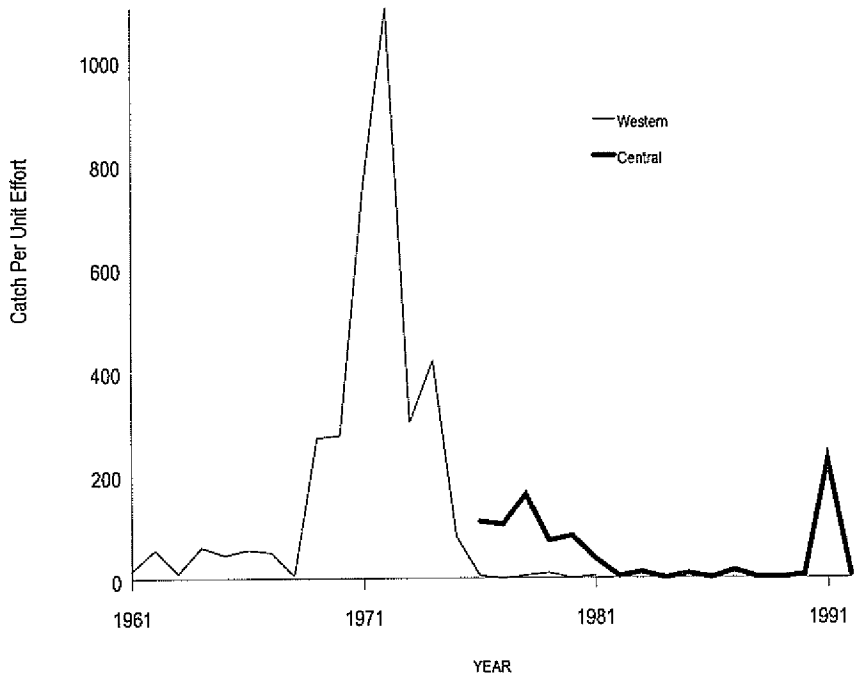


Figure 49. Representative indices of abundance, as determined from agency assessment data, for emerald shiner in the western basin (1961-81) and the central basin (1976-92), in Lake Erie (data from Muth 1985 and Ohio Department of Natural Resources).

Knowledge of trends in nearshore prey species abundances, like gizzard shad, emerald shiner, and spottail shiner, hinge upon initiation of an assessment program that principally targets these species. Currently these fish generally represent incidental catch in juvenile percid assessments (New York State Department of Environmental Conservation 1992 annual report).

An ecosystem approach is needed to relate changes in the plankton community with changes in the planktivore trophic guild. Long term assessment of the offshore and nearshore plankton community and abundances, in association with nearshore fish assessments, is necessary. A program for zooplankton monitoring has begun in Lake Erie at four stations. In 1993 and 1994, the Service assisted the monitoring program by making collections at the Buffalo Harbor station. The New York State Department of Environmental Conservation monitors stations off Dunkirk. Currently data are not completely analyzed.

Nearshore macroinvertivorous guild

The macroinvertivorous guild includes fish species whose diet consists of greater than 75 percent macroinvertebrates, such as insects, annelids, molluscs, and crustaceans. Approximately 60 species from the Lake Erie basin have been assigned to this guild. Species in this guild for which long-term data are available include lake sturgeon, suckers, yellow perch, and white bass. Trend information for white perch is available from 1978 to the present.

Before 1850, lake sturgeon were considered abundant in Lake Erie. The lake-wide population at the end of the 19th century was estimated to be around 2.5 million fish, which was much greater than in any other Great Lake. Their decline has been attributed to damming of tributaries that prevented access to spawning areas; destruction of lake-spawning areas by siltation, pollution, or drainage; destruction of great quantities of molluscs in both tributaries and the lake; and over-fishing (Trautman 1981). Tributaries historically supporting spawning runs included Huron River, Michigan; Maumee, Portage, Sandusky, Cuyahoga and Conneaut Rivers, Ohio; and Grand River and Clear Creek, Ontario (Goodyear *et al.* 1982a, Trautman 1981). These runs virtually disappeared by the late 1800s. Spawning was observed at the head of the Niagara River on rocky ledges in the late 1800s, but ended by 1890 because of pollution from the City of Buffalo (Goodyear *et al.* 1982b). Lake-spawning areas included: off the mouth of Detroit River, and off Stony Point, Michigan; off Walnut Creek, Pennsylvania; off Dunkirk and the mouth of Silver Creek, and along the shore from Irving to Buffalo, New York; around Pelee Island, Point Pelee, Rondeau Harbor and Long Point Bay, Ontario (Goodyear *et al.* 1982). Spawning runs were observed in some of these areas up until 1960.
Commercial harvest began around 1879, peaked between 1885 and 1893, and declined steadily afterward (Figure 50). Commercial catches were reported up to 1977, but at very low numbers after 1956.

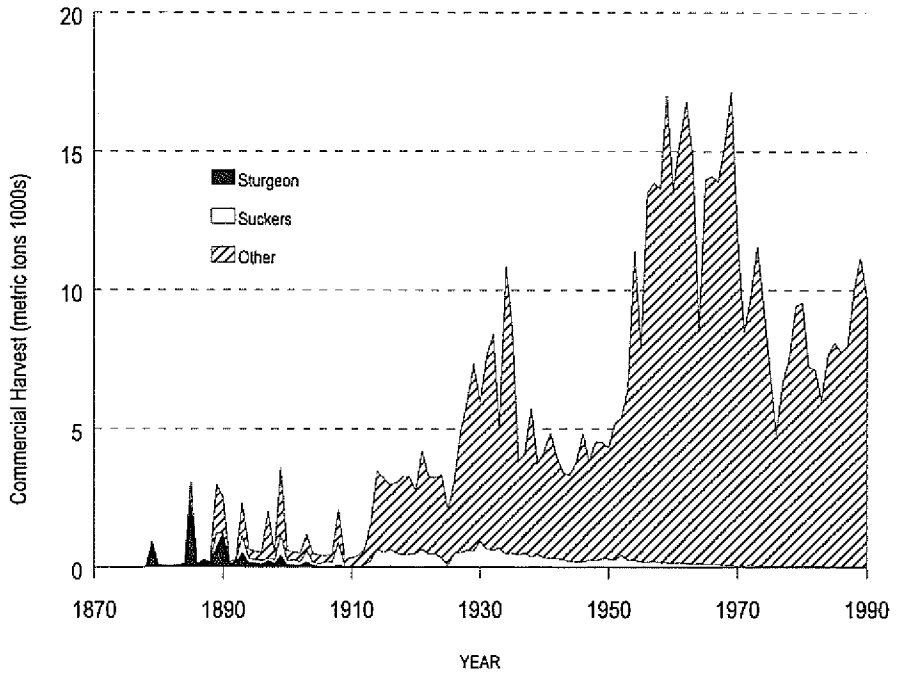


Figure 50. Trends in the Lake Erie nearshore macroinvertivore guild species, as represented by commercial harvest (1870-1990), showing portions that are lake sturgeon and suckers harvest (data from Great Lakes Fishery Commission).

Today, lake sturgeon are listed as endangered in Ohio and Pennsylvania and threatened in New York and Michigan (Walker unpublished). They are not given protected status in Canada (Walker, unpublished). Lake sturgeon are occasionally observed throughout Lake Erie. In 1979, several spawning sites were identified in the Detroit River between Grosse Isle and Fighting Island, but only one active spawning site was identified in Lake Erie off Stony Point, Michigan (Walker, unpublished). From 1989 to 1994, twelve fish have been collected or sighted in the western basin (Cavender 1994). Sightings have also occurred in the central and eastern basins. During the fall of 1994, a juvenile lake sturgeon was collected in a trawl off Sturgeon Point, New York, and blood samples were obtained for genetic testing. They are occasionally observed by divers in the Upper Niagara River, and are also observed below the first dam during spring migration in the Grand River, Ontario.

The Service is involved in several projects related to lake sturgeon rehabilitation and is acting as an information clearinghouse on research and other information related to lake sturgeon. This information is compiled for distribution to approximately 90 offices around the Great Lakes. The Service initiated a survey of SCUBA diver and angler sightings in Lake Erie and the Upper Niagara River in 1994. The survey was distributed to 34 divers/dive shops and angler groups in New York, Ohio, and Ontario. This continuing survey has resulted in ten lake sturgeon sightings reported from the Upper Niagara River in 1994. The Service began preliminary work on a population assessment in the Upper Niagara River during the summer of 1994, using gill nets. The diver/angler survey program demonstrates the need for cooperative and unique methods to assess certain fish populations; as shown by apparent differences in abundance between lakewide and Niagara River sightings.

White sucker and several redhorse species comprise the majority of suckers in Lake Erie. Historically, these suckers were considered to be abundant in the lake. The commercial catch of suckers increased after the decline of lake sturgeon, and then declined after 1930 (Figure 50). Recently, sucker species have not shown any increasing or decreasing trends in agency stock assessments. Information on tributary populations is scant and not compiled. In the Buffalo River assessment, suckers constituted approximately 5-15 percent of the adult fish community.

The warmer and shallower western basin of Lake Erie is the major spawning area for yellow perch, while the greatest concentration of yellow perch inhabit the central basin. The eastern basin hosts an adequate population which supports an important sport fishery, particularly in winter months. Historically, yellow perch constituted the majority of harvest of macroinvertivore species (Figure 51). There were two peak periods in commercial harvest. The first occurred from 1928 to 1935. During this period, an average of around 2.3 million kilograms (5 million pounds) were

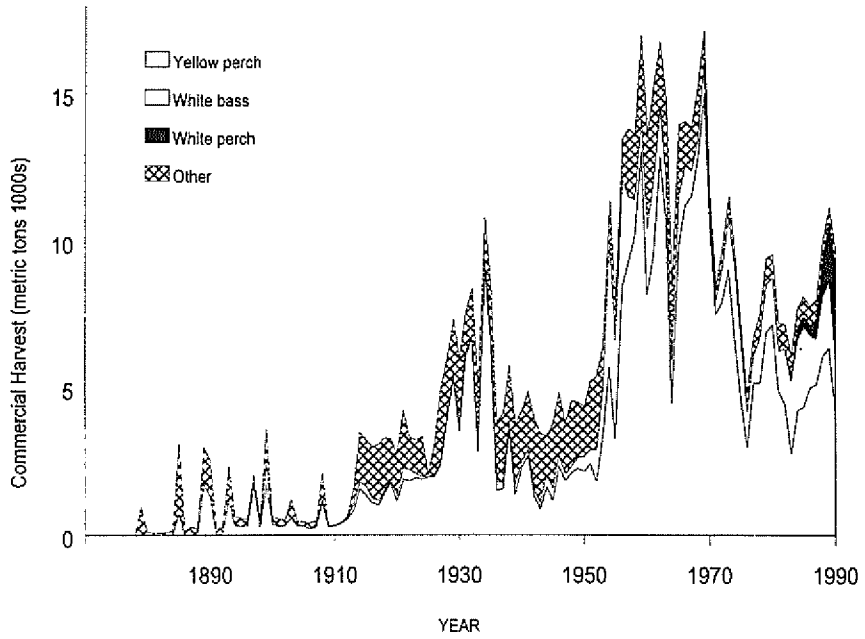


Figure 51. Trends in the Lake Erie nearshore macroinvertivore guild species, as represented by commercial harvest (1870-1990), showing portions that are yellow perch, white bass and white perch harvest (data from Great Lakes Fishery Commission)

caught. The second peak period began by the mid-1950s, when harvest increased dramatically. Increased harvest of yellow perch resulted from a shift in target species because of the collapse of blue pike, lake herring, and lake whitefish fisheries, and post-war gear improvements which increased catch-per-unit-effort. Beginning in the early 1970s,

yellow perch harvest steadily declined. Factors thought to be suppressing the yellow perch population were continued intensive fishing; and competition with and predation by increasing populations of nonindigenous rainbow smelt and white perch (Hartman 1988). Declining productivity is now also thought to be a likely factor.

Yellow perch commercial and angling harvest from Lake Erie has been used to estimate population size since 1980. These analyses indicate that population size has remained stable at 150 to 200 million fish, except for a peak from 1986 to 1988 when populations were estimated to range from 330 to 500 million fish (Figure 52). Analyses of trends by basin indicates there has been a decline in the western basin population since 1988 and in the eastern basin population since 1990, while the central basin population varies over the period. These trends may be related to year class strength, water quality improvements, introduction of nonindigenous species, or a combination thereof.

White perch is an unintentionally introduced nonindigenous species believed to have entered Lake Erie through canals. It was first collected in Lake Erie in 1953, but not reported again until 1973; it did not show up in commercial catches until 1977. Since 1977, harvest has increased rapidly (Figure 51). Studies have indicated that white perch may compete with yellow perch, but the relationship between their changing population abundances has not been analyzed. Sampling in the Buffalo River (eastern basin) in 1992 and 1993 by the Service, found small numbers of adult white perch in the fish community. Larval white perch constituted approximately nine percent of total catch in the Buffalo River, indicating spawning activity in the eastern basin.

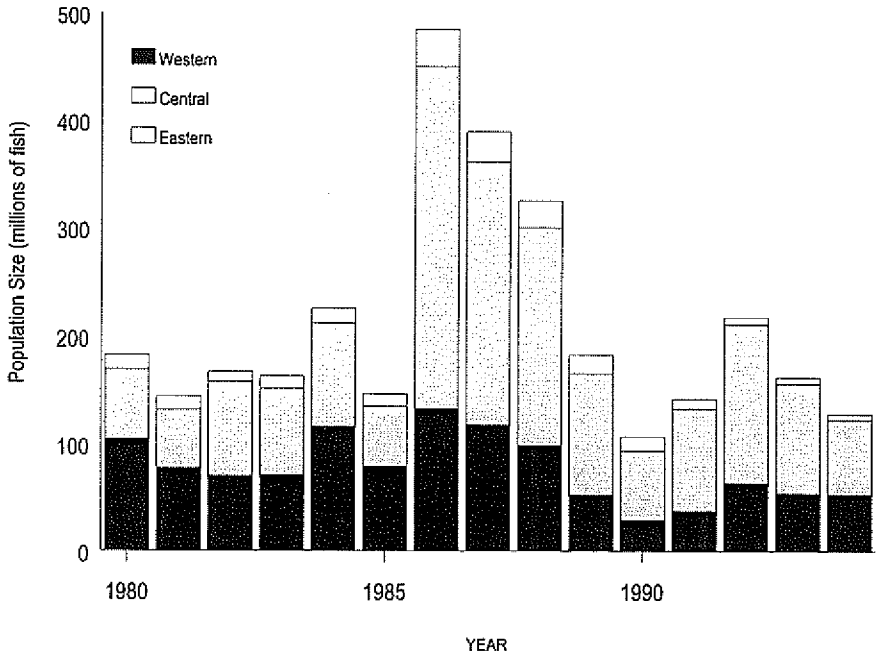


Figure 52. Lake Erie yellow perch population size estimated using CAGEAN (Catch at AGE ANalysis) model which combines data from commercial harvest and angling harvest, 1980-1994 (data from Lake Erie Yellow Perch Task Group).

Agency stock assessments for white perch in the western and eastern basins of Lake Erie indicate an increase in abundance beginning in 1982 and peaking in 1989; also recorded in the commercial catch (Figure 53). This peak corresponded with peak walleye abundance. Stock assessments indicate that abundance of white perch declined in both basins from 1990 to 1993. Causes for this trend are unknown, but could be related to year class strength, water quality improvements, introduction of zebra mussels, or a combination of these factors.

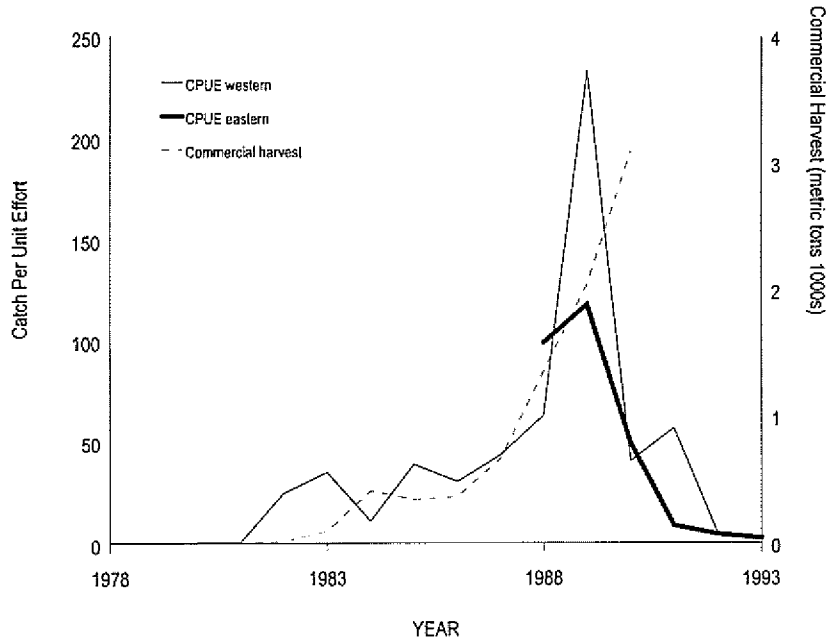


Figure 53. Representative indices of abundance for white perch in Lake Erie, 1978-1993, as determined from agency assessment data, compared with the commercial harvest, 1978-1990 (data from Michigan Department of Natural Resources, Ontario Ministry of Natural Resources and Great Lakes Fishery Commission).

White bass commercial harvest was low until the early 1950s (Figure 51). Increase in harvest at that time may have occurred for the same reasons that yellow perch harvest increased. Harvest has remained relatively unchanged through 1990. Since 1978, agency stock assessments revealed that white bass abundances have remained relatively stable (Figure 54). However, from 1990 through 1993, abundances dropped below the average abundance from previous years in all three basins. This trend was also similar for white perch, possibly indicating similar causes for decline.

Indigenous brook trout are found in lakes and streams where water temperature remains below 24 °C (75 °F) (Smith 1985). They also require considerable oxygen, limiting them to lakes where oxygen depletion does not occur below the thermocline. A few tributaries flowing into Lake Erie from the Canadian shore and the eastern basin are capable of supporting brook trout. In New York, thirty stream sections have been identified by the New York State Department of Environmental Conservation as potential wild brook trout streams. Of those sections, ten are known to have viable brook trout populations (S. Cornett, New York State Department of Environmental Conservation, personal communication). Populations have declined due to degraded habitat and water quality, and replacement by stocked brown trout and rainbow trout.

Nearshore piscivorous guild

Fifteen species from the nearshore Lake Erie basin have been assigned to this guild including northern pike, muskellunge, smallmouth bass, largemouth bass, sauger, and walleye. Historically, northern pike, muskellunge, sauger, and walleye were the major species commercially fished in Lake Erie (Trautman 1981), but only walleye continues to be important in the commercial fishery today. This fishery exists in the western and central basins and is a point of continued quota and allocation concern among the States and Provincial Ontario. In the eastern basin walleye are critical to anglers with pressure from angling groups for resource agencies to provide higher catches. Northern pike and muskellunge were among the first species to be commercially fished in Lake Erie, primarily because they could be

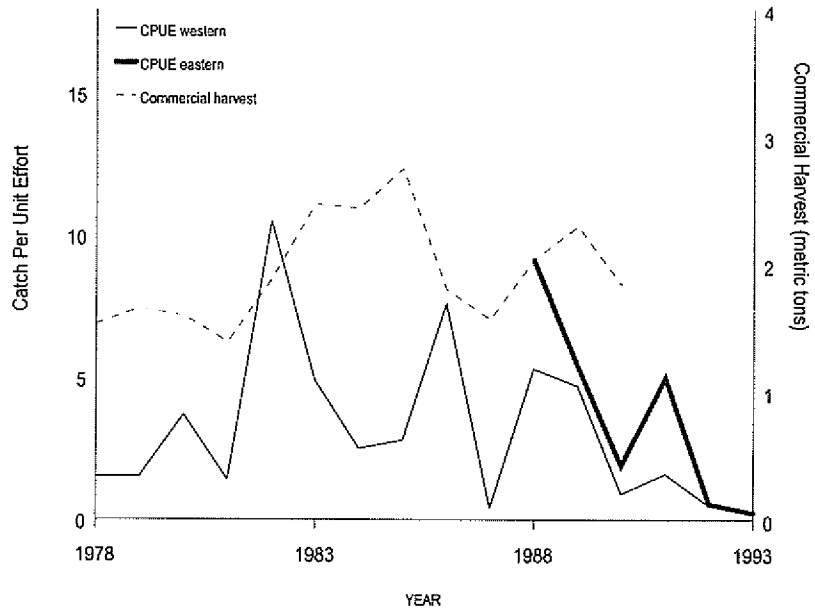


Figure 54. Representative indices of abundance, as determined from agency assessment data, for white bass in Lake Erie, 1978-92, compared with the commercial harvest for 1978-90 (data from Michigan Department of Natural Resources and Great Lakes Fishery Commission).

readily seined in shallow waters, speared, and caught by hook and line (Trautman 1981). Agency stock assessments have targeted walleye, and to a lesser degree, smallmouth bass.

Historically, northern pike and muskellunge were considered abundant in Lake Erie (Trautman 1981). The main reasons for their decline in abundance is considered to be loss of suitable spawning and nursery habitats. They spawn in heavily vegetated marshes, bays, and floodplains of rivers (Trautman 1981; Scott and Crossman 1973). These habitats were lost due to dams, pollution, ditching, draining, and diking of marshes, increased siltation, and turbidity resulting in loss of vegetation (Trautman 1981). Even in less developed areas like Old Woman Creek Estuary, located on the south central shore of Lake Erie, where large populations once existed, northern pike are now rare (Hoffman 1985). Siltation and increased turbidity are changes that have occurred in that estuary which may have lead to their decline (Hoffman 1985).

Commercial harvest has been reported for northern pike since 1869 (Figure 55). It made up the majority of nearshore piscivorous commercial harvest from 1899 to 1913, after which harvest dropped off to comprise a minor portion of this guild. Continued commercial harvest at a time when abundance of this species was declining due to habitat loss has led to today's depressed populations.

Recently, both northern pike and muskellunge have been reported spawning in Buffalo Harbor (Spotila *et al.* 1987), and are probably feeding in the Buffalo River. High turbidity and lack of vegetated areas in the Buffalo River may be preventing northern pike and muskellunge from using the river as a spawning and nursery area.

Several areas in the Upper Niagara River are known for their concentrations of spawning northern pike and muskellunge, particularly the shallows downstream of Strawberry Island. This island has been reduced in size from 80 to 8 hectares (200 to 20 acres) from past gravel mining. Today, the island is owned by the New York Office of Parks, Recreation, and Historic Preservation, and is important for its associated fishery as well as a nesting and resting site for migratory birds. Recent erosion problems have endangered the existence of the island. As a result of concerns voiced by local citizens, the Service and other cooperating agencies formed a committee in 1993 to develop plans for

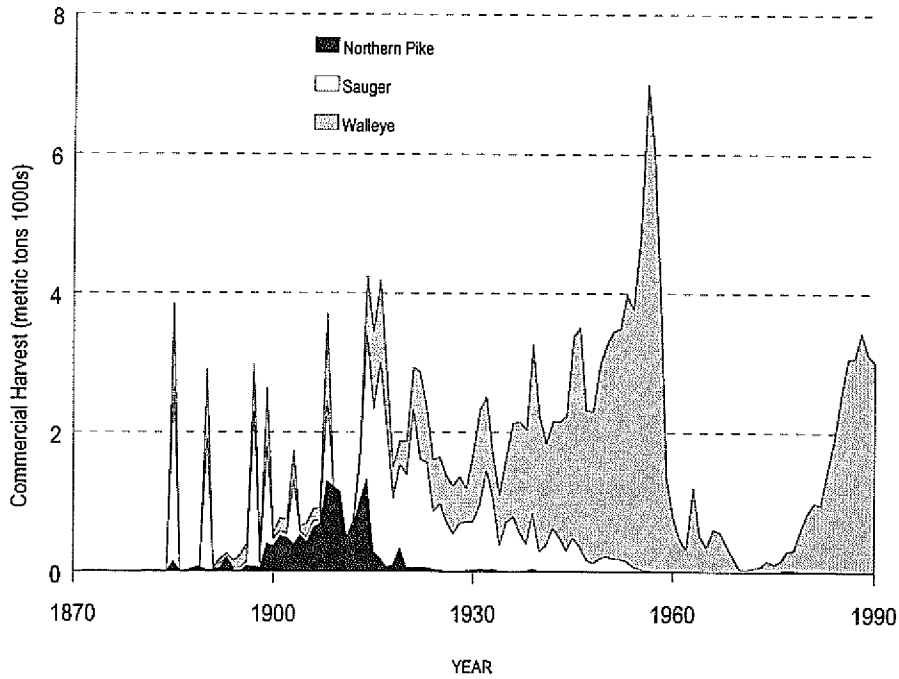


Figure 55. Trends in the Lake Erie nearshore piscivorous guild as represented by commercial harvest (1870-1990). Lake Erie nearshore piscivores include northern pike, sauger and walleye (data from Great Lakes Fishery Commission).

emergency repairs and long term solutions to erosion problems. A breach in the island was repaired in the fall of 1993, through coordination of private and public entities, and indigenous vegetation was planted in the spring of 1994. The committee continues to advise the New York State Office of Parks, Recreation, and Historic Preservation on protection of fish and wildlife using the island.

Information on fish and wildlife using Strawberry Island and the shallows is not available. The Service is currently investigating use and function of submerged aquatic vegetation with two interns from State University of New York - Syracuse, Environmental Science and Forestry. Also, a project has been proposed by the Service to map habitats and fish and wildlife uses in the Upper Niagara River on a Geographic Information System. This information could be used to identify future restoration projects.

In Lake Erie, the largest populations of sauger occurred in the shallower and more turbid water of the western basin (Trautman 1981). Commercial harvest was first recorded in 1885, but it was not commercially important until 1915 (Figure 55). The harvest steadily declined after 1915, and by 1960 sauger were considered biologically extinct in Lake Erie (Hartman 1973). Factors cited as leading to sauger decline include pollution and siltation of spawning areas, damming of tributaries, over-fishing, and finally, introgressive hybridization with walleye (Hartman 1973). In the 1970s, the Ohio Department of Natural Resources began stocking sauger in the western basin, and successful spawning was observed in the Maumee and Sandusky Rivers (Trautman 1981).

Historically, walleye were abundant in Lake Erie. The western basin is the major breeding and nursery area for both tributary and lake-spawning populations (Hartman 1973). By 1945, mill dams, siltation, and pollution had greatly reduced tributary spawning populations, but the remaining lake-spawning population continued to provide a valuable commercial fishery. After the decline of sauger, walleye became the only species in this guild represented in the commercial harvest (Figure 55). Increased harvest during the 1950s has been attributed to increased fishing intensity made possible through technological improvements in commercial fishing gear. Around 1954, declines in year-class

strength accompanied by a decrease in the number of years which a year class contributed to the commercial fishery were observed. By 1957, the fishery began collapsing from overexploitation. Loss of habitat due to increased anoxia in the western and central basins, disappearance of burrowing mayfly, an important food source, and possible competition and/or predation by rainbow smelt also contributed to the decline (Hartman 1973, Schneider and Leach 1977). A small walleye population inhabiting the eastern basin began to increase in commercial catch in the 1960s. This basin was not as greatly affected by environmental degradation occurring in the rest of the lake. Reduced competition from extinct blue pike and an increase in forage provided by rainbow smelt likely contributed to east basin walleye increases. Closure of the fishery in the western and central basins, as a result of mercury contamination and habitat restoration, allowed the population to increase. When fishing was opened, the species was listed as a sport fish by Ohio and implementation of quotas on commercial and sport fishing by the States and Ontario led to the continued recovery of the walleye population. In addition, river spawning populations in the western basin substantially increased during the 1970s as a consequence of pollution control and decreased siltation (Hartman 1988).

Walleye commercial harvest and angling harvest data for the western and central basins of Lake Erie has been analyzed since 1976 to monitor recent population trends for the purpose of setting quotas on commercial harvest by the Lake Erie Committee's, Walleye Task Group. The commercial data show walleye catch increasing from 1976 to 1980, declining slightly for three years, increasing to a peak in 1987, and then declining to pre-1980 catches in 1993 (Figure 56). The angling catch-per-unit-effort data showed a similar pattern, but peaked a few years earlier, and have

Figure 56. Walleye commercial fishery catch per unit effort (CPUE), as determined from agency assessment data, compared to angler CPUE for walleye in Lake Erie, 1976-1993 (data from Lake Erie Walleye Task Group).

shown an increasing trend in 1992 and 1993 (Figure 56). These trends may be related to year class strength, water quality improvements, introduction of nonindigenous species during this time, over-fishing or a combination of these factors.

In eastern Lake Erie, walleye recruitment has been highly variable since the 1970s. This variability is generally seen in large lake-spawning populations. It is believed that by adding or enhancing stream spawning populations in this basin, recruitment variability would dampen and the existing population would be enhanced. Some New York tributaries were historically used by walleye for spawning; and recently, there has been anecdotal reports of adult walleye entering some streams. A two-year fishery assessment conducted by the Service in 1992-1993 in the Buffalo River recorded a few adults, including one ripe female. Consideration is currently being given to enhancing the population by stocking streams with larval fish to produce a stream-spawning subpopulation. The Service is cooperating with the New York State Department of Environmental Conservation in a program to rehabilitate the stream-spawning stock. In 1993-1994, surveys were conducted in six tributaries to identify existing and potential spawning habitat. In 1994, walleye fry collected from the New York lake-spawning population were stocked in two tributaries, one of which was selected based on the stream habitat survey results, and the other based on historical records as a spawning tributary.

Adult walleye have been hypothesized to imprint to a new spawning site (Einhouse 1994). The second component of the cooperative program included transferring several radiotagged adults in spawning condition to the Buffalo River in order to test the hypothesis of establishing a spawning stock using adults, and adult-learned homing behavior. The fish were tracked using a radio receiver to monitor their movements in the river. All fish remained in the river several weeks, but it was not determined if spawning occurred during that time. Radiotracking will resume in the spring of 1995, to determine if these fish return to the Buffalo River.

The Service has been involved in an interagency tagging program, monitoring lake-wide distribution and angling exploitation of walleye since 1986. The Service has cooperated with the New York State Department of Environmental Conservation by conducting the tagging program at the Smoke Creek site off Lackawanna, New York, since 1992. In addition, the Service uses this opportunity to educate the public via a volunteer program.

Smallmouth bass tend to inhabit cooler and clearer water than largemouth bass. Warmwater fishery assessments in New York and Michigan have recorded smallmouth bass in catches since 1978 (Figure 57). The smallmouth bass

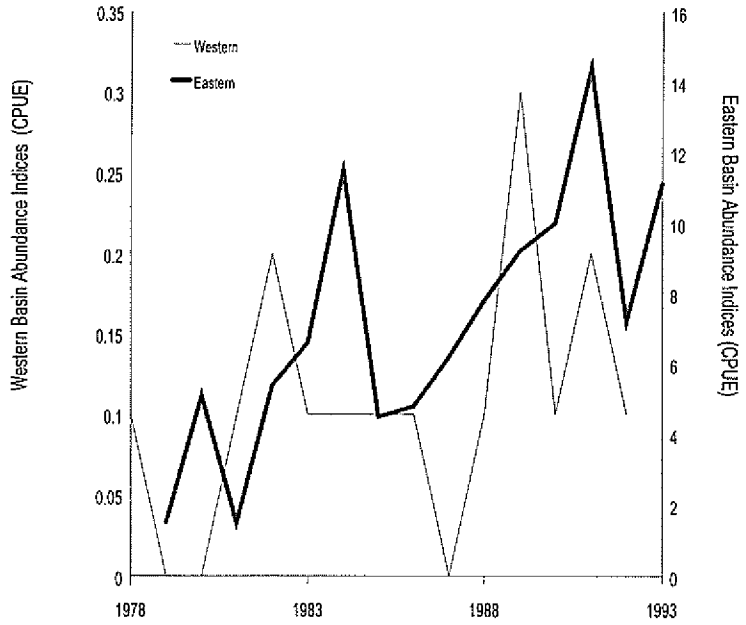


Figure 57. Smallmouth bass indices of abundance (CPU), as determined from agency assessment data, in the western and eastern basins of Lake Erie, 1978-1992/3. Though catch rates differ between basins, relative trends are similar (data from Michigan Department of Natural Resources and New York Department of Environmental Conservation).

abundance has not changed greatly during this time in the western basin, however, the population has increased steadily in the eastern basin until 1992, then it levels off. The causes for differences between basins are unknown. Continued assessment of these populations is needed.

Largemouth bass, like muskellunge and northern pike, depend heavily on aquatic vegetation. Populations in Lake Erie have been declining since the early 1900s. Historically, declines in Sandusky Bay and East Harbor populations have paralleled decreasing submerged aquatic vegetation (Trautman 1981).

Presently, there are no long term stock assessments geared toward monitoring largemouth bass, muskellunge, or northern pike. Short term river or stream fisheries assessments, similar to the Service's Buffalo River fishery assessment, can provide information on presence and abundance in particular streams. Data needs to be compiled for systems being investigated, and assessments should be broadened to include tributaries not currently studied.

Summary of guild analyses

Lake Erie is a changing system. The plankton community is undergoing changes in diversity, composition, and abundance due to phosphorous loading reductions and shunting of energy to the benthos by zebra mussels. Potential effects on the fish community will vary between trophic guilds. The planktivorous guild will most likely continue to decrease in abundance, but nearshore communities may not be as affected, due to input of nutrients from tributaries which are also being rehabilitated by State agencies. Subsequent increases in water clarity may increase area available for macrophytic growth in the nearshore area and possibly into the open lake. This will favor increases in omnivorous species and particular species that require submerged aquatic vegetation such as largemouth bass, northern pike, and muskellunge. Shunting of energy to the benthos will likely lead to increased abundance of benthic community organisms, which would favor increases in macroinvertivorous species, especially for macroinvertivores that include zebra mussels in their diet. Species in the nearshore piscivorous guild will likely shift to prey from the macroinvertivorous or omnivorous guilds. Those that cannot shift will decline in abundance.

Tributaries are experiencing increased productivity due mainly to contaminant abatement programs. With improvements in tributary habitat, additional productivity may be possible. As productivity declines in the offshore area, productivity in tributaries will become a more important component of the overall productivity of Lake Erie.

Causes of Changes in Lake Erie Fishery Resources and Management Strategies

It is often difficult to attribute changes in species abundance to one controlling or overriding factor. Environmental and human-induced activities stressing aquatic systems can be classified as biological, chemical or physical. Critical modifications have occurred within the Lake Erie watershed, causing irreparable impacts to fishery resources. These impacts may be manifested as changes in species density, diversity, and composition due to direct effects on year class strength, recruitment into the adult population, spawning success, spawning or nursery habitat, and competition.

Physical factors

During European settlement, lands were deforested and prairies were burned, causing soil erosion, siltation, and uncontrolled runoff which contained waste of live-stock and increased nutrient input. Streams became turbid and clean spawning grounds and aquatic plant growth were sharply reduced. Currently in the Lake Erie Basin, 67 percent of land use is for agricultural purposes including fruit, vegetable, tobacco, and dairy products.

Dredging and canal construction were initiated to create and maintain navigational channels for the shipping industry. In an attempt to maintain necessary depth requirements for shipping, dredging must be conducted periodically,

producing unstable habitat for resident fish populations. Although bottom sediments are removed (and typically dumped in open water) sediment and toxic contaminants are resuspended, temporarily creating highly turbid waters. Dredging also disrupts the benthic invertebrate community and aquatic macrophytes. The construction of canals opened the Great Lakes to invasion of nonindigenous species from previously closed system areas.

Hundreds of dams for sawmills, gristmills and other industries were constructed on streams in the mid-1800s. These dams prevented fish migrations to spawning habitats required to sustain these populations. Water level fluctuations due to damming and hydropower activities created unstable aquatic environments.

Wetland reclamation and shoreline modification has been occurring since the 1700s. Today only 10 percent of original coastal marshes remain along Lake Erie. Wetland filling and construction of breakwalls, stone revetments, and piers occurred around the lake to allow access for shipping, industrial, and recreational activities. Although these projects sometimes have positive impacts on fish and wildlife by creating cover or solid substrate; more often, major areas of fish habitat necessary for spawning and nursery are eliminated.

Mining operations within the Lake Erie Basin may have impacted local fish communities. For example, gravel mining on Strawberry Island, in the Niagara River, has reduced the island from its original 80 to 8 hectares (200 acres to 20 acres). It has recently been designated as significant habitat, by the New York State Coastal Zone Management Program, to protect and preserve remaining critical habitat.

Activities that will immediately or eventually alter the physical nature of the Lake Erie Basin typically require environmental impact statements quantifying potential impacts to the system prior to implementation. Based on analyses of these impact statements accounting for need or benefits expected from the proposed activity, permits may or may not be granted.

Chemical factors

Water quality and sediment characteristics play a major role in species diversity and abundance. Historically, numerous mills, breweries, slaughterhouses, and municipalities discharged waste directly into the lake or its tributary streams. Sawdust discharge into Ohio streams was reported to asphyxiate fish by compacting their gills.

More recently, nutrient and contaminant loadings are primary issues addressed by fishery managers and researchers. These loadings include direct, or point source, via industrial and municipal discharges, and indirect, or non-point source, via urban and agricultural runoff, ground water, and atmospheric deposition. Nutrients limit the amount of primary productivity in an aquatic system. When nutrient loadings are high, primary productivity increases, leading to potentially toxic algal blooms and increased oxygen consumption. If oxygen is completely depleted from the water (anoxia), aerobic species can not survive. In the 1950s-1960s, deep waters of Lake Erie's central basin were anoxic during summer months. Die-offs of benthic organisms and coldwater fish were attributed to lack of oxygen in lake bottom waters.

Contaminants are more chronic in their impact and are often hidden for long periods of time, residing in sediment and biota. They accumulate through the food web structure, increasing in concentration, eventually reaching proportions affecting reproductive success of top level predators such as fish and waterfowl, and eventually, levels considered too high for human consumption of these species. Contaminant impacts on ecological functions are still being explored, however, to protect human health, fish and wildlife consumption advisories exist. These advisories recommend that persons eat only a limited amount of fish and game from the Great Lakes Basin.

Areas of highest priority for remediation of contaminant problems are designated Areas of Concern. These Areas of Concern are primarily river mouth harbors and bays that exhibit environmental degradation and where some benefi-

cial uses of water or biota are impaired (New York State Department of Environmental Conservation 1989). Lake Erie's basin has ten Areas of Concern; seven U.S., one Canadian, and two joint Areas of Concern (the Detroit and Niagara Rivers). The Buffalo River, New York provides a classic example of problems associated with an Area of Concern. Impairments in the Buffalo River include degradation of fish and wildlife populations and loss of fish and wildlife habitat (New York State Department of Environmental Conservation 1989). Degradation of the river started with growth of the City of Buffalo and use of the river for municipal wastes in the early 1800s. It continued with pollution loadings from manufacturing industries built along the river (Sauer 1979). The pollution problem was compounded by deepening and widening of the river for use as a harbor, increasing hydraulic residence time and sedimentation (Sauer 1979). By the 1920s, the Buffalo River was described as a septic basin, with zero percent dissolved oxygen and high carbon dioxide (Wagner 1929). No fish were found in the river at this time (Figure 58)

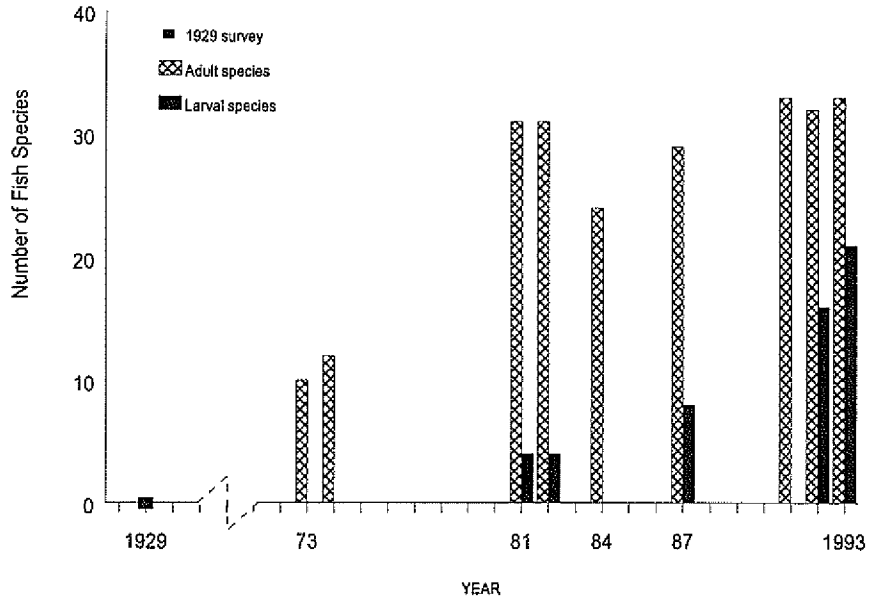


Figure 58. Number of adult and larval fish species identified in the lower 12.8km (8 mi) of the Buffalo River from past and present fishery surveys (data from Lower Great Lakes Fishery Resources Office).

(Greeley 1929). These conditions remained virtually unchanged until the late 1960s. The pollutants that had accumulated in the river over the summer were carried in a "slug" into the Buffalo Harbor and Niagara River. To alleviate these problems the Buffalo River Improvement Corporation was formed in 1967. In the 1970s, loadings from industrial wastes declined due to pollution abatement programs. These changes resulted in an almost immediate improvement in water quality. By 1972, for the first time in over 40 years, oxygen was present throughout the water column, there was a measured increase in abundance and diversity of invertebrates, and fish were observed in the river having migrated from Lake Erie. The fish community has continued to increase in diversity, and there is evidence of increased spawning by more species (Figure 58).

The fish community established in the Buffalo River is currently comparable to other less impacted tributaries of Lake Erie. Some species common in other tributaries, however remain absent or in very low abundance in the Buffalo River. Long-term chemical impacts potentially limiting fish communities may include surface water temperatures, dissolved oxygen depletion and contaminated sediment (Mikol *et al.* 1993). In order to protect and enhance the present fish community of the Lower Buffalo River these factors need to be addressed throughout the watershed.

Biological factors

Overexploitation

Impacts of over-fishing or overexploitation of the targeted fisheries of Lake Erie have been manifested through loss of some species such as lake trout, lake herring and blue pike. Although other factors may have contributed to the eventual loss of these species, the major impetus for their disappearance is believed to be overexploitation. Effects of overexploitation have increased with advancing technology for harvesting fish, including better fishing gear and boats. Species targeted by commercial and sports fisheries are now monitored and harvest regulations have been established. Gear regulations have also been implemented by some States in the Basin. Recently, the ecological cost of stocking nonindigenous species to fulfill sport fishing needs has been raised as a concern. Often, although a large population of adults may be established, their reproductive success may be minimal due to a variety of problems including inappropriate species range, and inability to recognize spawning locations due to impaired homing ability.

Nonindigenous species

The Great Lakes have been subject to the invasion of nonindigenous species since settlement by Europeans. Since the 1800s, at least 139 nonindigenous aquatic organisms have become established in the Great Lakes (Mills *et al.* 1993). Nonindigenous species include any species or other viable biological material that enters an ecosystem beyond its historic range (PL 101-646). The rate of introductions into the Great Lakes increased with colonization of the Basin and with advances and development of transport technology (Figure 34). A full description of the history of intentional and unintentional introductions of nonindigenous species, including enactment of the *Nonindigenous Aquatic Nuisance Prevention and Control Act*, can be found in the *Causes of Changes in Lake Ontario Fishery Resources and Management Strategies* section of this document.

Impacts of both intentional and unintentional introductions are evident in the Lake Erie ecosystem. To examine all of the species and their associated impacts would be redundant and would fail to meet objectives of this report. Instead, selected targeted species that have impacted Lake Erie, either beneficially or detrimentally, will be the focus of this discussion.

Intentional introductions

Trout and Salmon

Intentional introductions into Lake Erie through stocking have targeted trout and salmon since 1870. After several unsuccessful attempts, an intensive stocking program was initiated in the late 1960s. This program continues, although modifications have been made through technological developments and advances. By the mid- to late-1980s, Pacific salmonids (coho and chinook salmon), rainbow trout, and brown trout played significant roles in the ecosystem dynamics of Lake Erie and in the economic value of the sport fishery. The introduction of these species was and continues to be primarily driven by increased angler demands. However, brown trout are no longer stocked in Lake Erie.

Recently, experiences in Lake Ontario and Lake Michigan have indicated that prey consumption by current populations of stocked salmon and trout species, both indigenous and nonindigenous, likely exceeds sustainable prey abundance. Changes in prey abundance in these lakes, specifically in alewife and rainbow smelt, may be due to a number of interacting factors, including increased predator demands, changes in water quality, and subsequent changes in the plankton community. In response to concern that Lake Erie may be headed in a similar direction, fishery managers are reviewing current stocking levels and prey abundance. Stocking cuts have been made, including the elimination of the coho salmon and brown trout stocking programs, and reduced lake trout stocking by the New York State Depart-

ment of Environmental Conservation. Consumption indices are being determined for the predator species of Lake Erie and harvest regulations for prey species are reviewed annually.

Rudd

The potential impacts associated with the introduction of rudd into the Lake Erie Basin have only recently been recognized. The rudd was stocked in the Roeliff-Jansen Kill in eastern New York within the Hudson River drainage in 1936. Escape from waters where rudd were introduced, possible migration through the Erie Canal, extensive propagation as a bait species in the southern States and subsequent importation and bait bucket transfer have resulted in a substantial range expansion of this species. Rudd are now found in at least 11 States (MacNeill 1993). Unfortunately, fishery managers were not alerted to or aware of spreading populations until distribution as bait was well underway. In 1991, rudd were collected in lower reaches of the Buffalo River and in 1994, rudd were collected in the Dunkirk Harbor during impingement analyses at a local power plant. The spread of rudd, although not a major concern of fishery managers at this time, might threaten or influence indigenous species through: food web alterations; changes in nutrient cycling; deterioration of nearshore spawning and nursery areas due to consumption of aquatic vegetation; and changes in reproductive success through hybridization and consequent production of sterile offspring.

Unintentional introductions

Zebra and quagga mussels

The zebra mussel, *Dreissena polymorpha*, is thought to have been introduced in 1986 into Lake St. Clair through ballast water discharge from trans-oceanic shipping. The zebra mussel was first collected in the western basin of Lake Erie in 1988. Veligers were collected in the eastern basin in 1989.

In 1991 a second dreissenid species, genetically different from zebra mussel, was confirmed and collected in western Lake Ontario. This mussel was dubbed the quagga mussel and later identified as *Dreisssena bugensis*. Quagga mussels were collected from Lake Erie as early as 1989, although their phenotypic differences had gone unnoticed. Quagga mussels appear to have been present when the first zebra mussels were settling in eastern Lake Erie in 1989. Quagga mussel abundance exhibit an east to west gradient in Lake Erie with the heaviest colonization occurring in the eastern basin. By October 1991, quagga mussels had been collected in central Lake Erie, where they represented over 60 percent of mussels attached to a buoy situated near the middle of the lake. In the western basin, quagga mussels comprise <1 percent of the mussel population as far west as Middle Sister Island. Quagga mussels are reportedly more abundant than zebra mussels at deeper, colder sites. The added potential range of the quagga mussels may have associated impacts in areas originally thought to be safe from zebra mussels.

Surveys to monitor abundance and distribution of zebra mussels in western and west-central Lake Erie have been conducted by the Ontario Ministry of Natural Resources since their discovery, including larval abundance, settlement on rocky reefs, and settling and growth rates on artificial substrates. Veliger populations have fluctuated considerably in both basins since 1990. In 1993, in the western basin, mean (May to November) veliger abundance nearly doubled from 1992 levels to all time peak of approximately 113,000 per square meter (1,255,556 per square foot) while numbers declined in the west-central basin (Figure 59). Populations of settled mussels, measured in the spring and fall, declined dramatically in October 1992. The reduction was mainly in mussels with shell lengths <5 millimeters (<0.2 inches) dictating a decline in successful recruitment. However, 1993 measurements indicated a resurgence of recruitment with total abundances of 295,000 per square meter (3,277,778 per square foot); a new peak, with 86 percent of the total measuring <5 millimeters (<0.2 inches).

Monitoring programs have been initiated by a variety of other agencies including Federal, State, Provincial, private, and public organizations. The Service has maintained a leadership role in monitoring and detection of nonindigenous

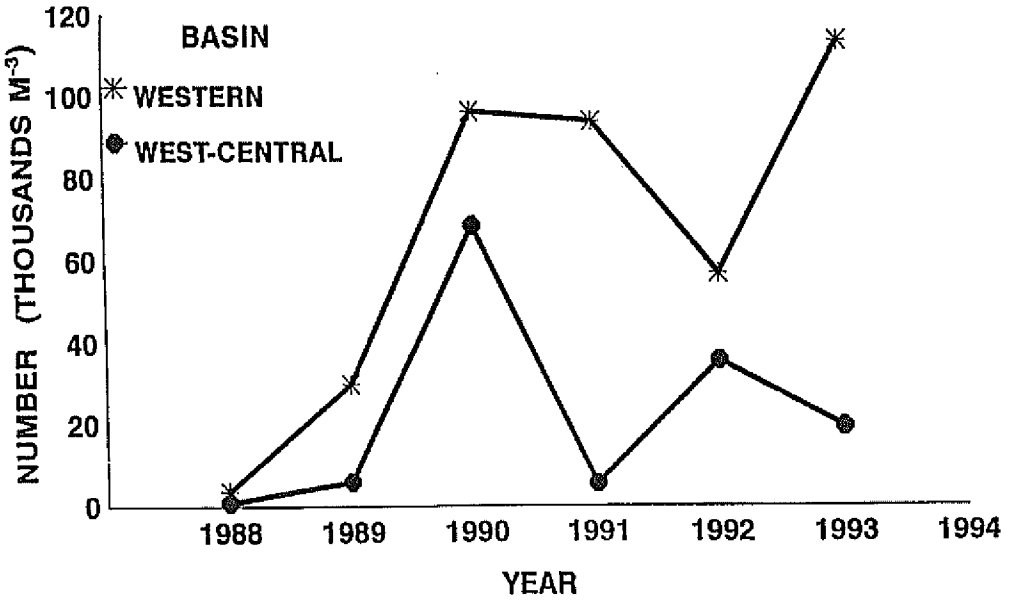


Figure 59. Mean abundance (May to November) of zebra mussel veligers in the western and west-central basins of Lake Erie (Ontario Ministry of Natural Resources 1993).

species. The Service established a Zebra Mussel Monitoring Network through which assistance was provided in developing standardized monitoring protocols, educating potential monitors, identifying zebra mussels and providing monitors with the necessary equipment to conduct an effective program. A reference collection was established in cooperation with the Academy of Natural Sciences and a pamphlet entitled, *Tracking the Zebra Mussel: A User's Guide* was developed as an educational tool to assist water users in tracking or monitoring zebra mussel distributions and to inform them of potential impacts of zebra mussel populations.

Impacts associated with spread and increase of zebra mussels and quagga mussels are typically associated with the settled stage. A general description of these mussels' biological characteristics, their role in food web dynamics and some of the associated economic and ecological costs to industrial facilities and fishery resources can be found in the *Causes of Changes in Lake Ontario Fishery Resources and Management Strategies* section of this document.

Zebra mussels have become the dominant benthic taxon throughout most of Lake Erie, forming a new bottom habitat structure. Concerns regarding the potential for successful spawning and egg development on reefs and rocky shoals have been expressed, especially for indigenous species such as walleye and lake trout. Oxygen depletion and increasing ammonia production were considered a potential threat to successful reproduction. According to laboratory investigations, however, walleye and lake trout reproduction do not appear to be significantly hindered by the presence of zebra mussels.

Zebra mussels have had a detrimental impact on indigenous freshwater mussels; to the extent that indigenous mussels have been nearly extirpated from the western basin of Lake Erie. As many as 10,000 zebra mussels have been found attached to a single unionid, and in some cases the weight of attached zebra mussels has exceeded the weight of the unionid by three times. Zebra mussels may impact indigenous mussels in a number of ways. Most dramatically, zebra

mussel colonies can prevent valves from opening and closing and can completely overgrow and occlude the siphonal region, reducing or eliminating the unionid's ability to feed. Due to the size and weight of zebra mussel colonies, they may hinder locomotion and burrowing, disrupting balance and equilibrium, possibly causing the mussel to sink into substrate or be washed up onto shore during storm events.

Settled mussels have provided a new food source for some benthic fish (macroinvertivores). However, fish predation as a biological control does not appear to be feasible based on current fish population composition, abundance, and rate of consumption, relative to the mussel's ability to reproduce and disperse. As an addition to the food web structure of Lake Erie, bioaccumulation of contaminants within the mussels may impact species consuming mussels. Zebra mussels, as benthic organisms, have been indicated as contaminant "sinks", capable of accumulating toxic materials. Investigations focussing on impacts of this accumulation through the food web are currently being initiated, however, additional work is needed to examine both waterfowl and fish community impacts.

Food web alterations and resultant shifts in nutrient cycling to benthos are the most apparent changes the Lake Erie nearshore and reef areas will likely undergo in response to zebra mussels. Evidence of this cycle is apparent. Water clarity, measured as transparency using a secchi disk, can be used as an indicator of chlorophyll levels and hence phytoplankton. Data collected by the New York State Department of Environmental Conservation in the eastern basin of Lake Erie indicates substantial increases in transparency from 1991 through 1994 (Figure 60). Water clarity in the western basin has followed similar trends. Direct measurements of phosphorous and chlorophyll have shown declines indicating a loss of energy in the pelagic community. Benthic macroinvertebrates, especially amphipods and aquatic macrophytes, have shown increasing population trends testifying to transfer of energy to the benthos.

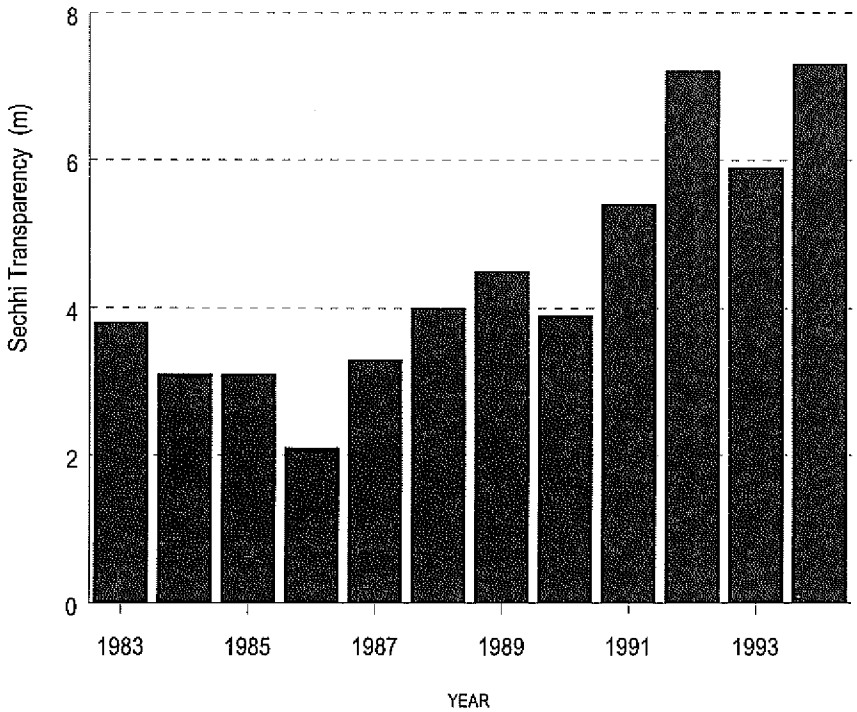


Figure 60. Mean annual secchi disk transparency (m) for New York waters of Lake Erie.

Rainbow Smelt

The origin of rainbow smelt in the Lower Great Lakes is uncertain. Rainbow smelt are thought to have been either indigenous to Lake Ontario, to have migrated through the Erie Canal system from the Atlantic drainage, or to have entered Lake Erie via the Detroit River from Lake Michigan populations. Rainbow smelt were first reported in Lake Erie in 1935. Although overexploitation is typically associated with loss of indigenous prey species such as lake herring, the introduction of rainbow smelt may have contributed through competition. Since their introduction, a valuable commercial fishery has been sustained in Canadian waters. Allocation of rainbow smelt is currently an issue of concern. Rainbow smelt are the primary prey species of walleye and lake trout in eastern Lake Erie. Efforts to restore self-sustaining populations of lake trout are currently underway. These efforts would be threatened if rainbow smelt populations declined significantly and were not replaced with suitable, indigenous prey species, present historically, for lake trout consumption. The Canadian commercial fishery, however, depends heavily on harvest of rainbow smelt. Stricter limits on harvest, if enforced, may impose significant economic losses on the commercial fishery; however, without strict limits, the rainbow smelt population will likely collapse.

Alewife

The alewife was discovered in Lake Erie in 1931. Populations in Lake Erie have never approached levels found in Lake Michigan or Lake Ontario. The inability of alewife to sustain high population levels may be due to abundance of predators and low heat retention of Lake Erie. The availability of deep-water regions where alewife could concentrate in winter is limited in Lake Erie. As with rainbow smelt, origins of alewife in the Lower Great Lakes are debated. It is thought that populations may have either expanded through the Erie Canal system into the Great Lakes from the Atlantic drainage or may have been indigenous to Lake Ontario.

Gobiidae

Two species of goby have recently been introduced into the Great Lakes. Both tubenose and round goby are Eurasian benthic species thought to have been introduced into Lake St. Clair via ballast water discharge from trans-oceanic ships originating from their indigenous range in the Black Sea.

The tubenose goby was first collected in April 1990 in the St. Clair River from travelling screens of a power plant. Although this species is considered endangered in its indigenous European range, it has become established in the St. Clair River and will likely expand its range further into the Great Lakes Basin.

The round goby was first collected in July of 1990 by anglers in the St. Clair River near Sarnia, Ontario. In 1993, round goby were caught by anglers in the Grand River, near Fairport, Ohio. Although round goby were not collected in standard assessments conducted by Ohio Department of Natural Resources in 1993, electroshocking assessments near the breakwall of the Fairport Harbor conducted by the Environmental Protection Agency confirmed expansion of gobies into Lake Erie. The pathway of expansion is uncertain. These fish may have been transported via inter-lake shipping. In 1994, round goby were collected in standard river mouth and lake assessments throughout the summer in increasing numbers. Also in 1994, a specimen was collected by an angler fishing in the Rocky River, west of Cleveland, Ohio. The impacts that these benthic species may have on Lake Erie indigenous populations is unclear, however, due to overlapping habitat, diet and reproductive patterns, some impact is expected. Goby are aggressive feeders and possess a well developed lateral line system and may outcompete indigenous species. Also, as repeat spawners with a long spawning period, they can take advantage of optimal environmental conditions increasing their reproductive success and recruitment.

Spiny water flea

The spiny water flea was first found in Lake Erie in 1985. This cladoceran is believed to have been introduced into the Great Lakes via ballast water discharge from trans-oceanic shipping. Its rapid spread throughout the Great Lakes is thought to be the result of multiple introductions or inter-lake shipping. The spiny water flea is a large, highly visible zooplankter and is therefore vulnerable to predation by planktivorous fish, and typically do not coexist under conditions of intense zooplanktivory. Summer abundances of the spiny water flea in Lake Erie are among the highest in all the Great Lakes. The high abundance of spiny water flea may be attributable to lower population abundances of alewife in Lake Erie (H. Reissen, personal communication). Although other planktivorous fish species consume spiny water flea, the rate at which consumption occurs in Lake Erie does not appear to impede spiny water flea populations.

The spiny water flea is a carnivorous planktivore, consuming smaller zooplankton. The impacts of spiny water flea on these species has not been clearly defined. There are apparently two schools of thought associated with potential impacts of this zooplankter. Spiny water flea was first found in Lake Michigan in 1986. In 1987, a dramatic decline in late summer *Daphnia* sp. was reported. This decline was attributed to the introduction and zooplanktivory of spiny water flea (Lehman 1991). However, when the rate of *Daphnia* consumption by spiny water flea was examined relative to fecundity of *Daphnia* sp., such a dramatic decline could not be attributed to the predatory impacts of spiny water flea (H. Reissen, personal communication). Utilizing this approach, 3-5 percent of *Daphnia* sp. mortality can be attributed to spiny water flea predation.

Ruffe

The ruffe was first collected and identified in 1987 by the Wisconsin Department of Natural Resources, during standard assessment work in the St. Louis River, the western most tributary of Lake Superior (Pratt *et al.* 1992). It is believed to have been introduced into the Duluth/Superior Harbor, Minnesota, in the far western basin of Lake Superior via ballast water from trans-oceanic shipping sometime during the early to mid-1980s. Since then, population abundances have increased sharply and distribution has spread along the southwestern shore of Lake Superior.

By 1991, ruffe had been found in the Amnicon, Brule, and Iron Rivers. Also, in 1991, ruffe were collected in Thunder Bay, Ontario by an angler who turned the specimen in to the Ontario Ministry of Natural Resources. Due to the distance and likely unsuitable habitat along the north shore, it is thought that ruffe may have been introduced to the Bay via intra-lake shipping ballast discharge. By 1992, ruffe had spread as far east as Sand River, Wisconsin. In 1993, ruffe continued their eastward expansion, with populations being detected in Raspberry River, Red Cliff Creek, Sioux River and finally, the Bad River, Wisconsin. Expansion to the Bad River raised concern due to its location east of Chequamegon Bay, Wisconsin, where ruffe are likely to establish large populations. In 1994, collections confirmed presence of ruffe in Chequamegon Bay and revealed populations in Saxon Harbor, Wisconsin, and Black River Harbor, Michigan. This Black River Harbor sighting represented the first in Michigan waters. And most recently in September 1994, specimen were collected in Ontonagon River, Michigan, approximately 257 kilometers (160 miles) east of Duluth.

As density of ruffe has been increasing in Duluth Harbor since its introduction, assessment data indicates declines in densities of yellow perch, spottail shiner, emerald shiner and trout-perch. By 1991, declines were evident and the trend continued through 1992. In 1993, the mean catch-per-unit-effort of these four species combined, yellow perch, spottail shiner, emerald shiner, and trout-perch, was only about 10 percent of the mean level five years ago. From 1989 to 93, spawning populations of yellow perch declined about 75 percent in the St. Louis River.

On April 21, 1992, the National Aquatic Nuisance Species Task Force, established through the *Nonindigenous Aquatic Nuisance Prevention and Control Act of 1990*, declared the ruffe a nuisance species as defined by law, warranting control. The Ruffe Control Committee was subsequently formed to develop, coordinate and oversee implementation

of a Ruffe Control Program that minimizes harm to the environment and public health and welfare. The overall goal of the Ruffe Control Program is to prevent or delay spread of ruffe through the Great Lakes and inland waters by containing the species to western Lake Superior. If ruffe are found outside this range, program strategies will be re-evaluated, modified or terminated. Currently, the Ruffe Control Program awaits approval for full implementation. It was listed on the Federal Register in January, 1994 for public review and comment.

The Ruffe Control Program calls for conducting surveillance sampling in locations where newly established populations of ruffe may be likely to occur in each of the Great Lakes. Surveillance programs should target sites likely to be colonized by natural movement and those sites vulnerable to other pathways. To provide the earliest possible warning of ruffe presence in the lower Great Lakes, the Service initiated a monitoring program in spring 1993. The Program consisted of both educational and field sampling components.

During the 1993 field season, ruffe surveys were conducted in the ports of Ashtabula, Ohio; Buffalo, New York; Conneaut, Ohio; and Erie, Pennsylvania, in Lake Erie. These harbors are active shipping ports and apparently offer suitable habitat for ruffe survival. No ruffe were found at any of the locations surveyed. In 1994, the Lower Great Lakes Monitoring Program field survey component was expanded. Three additional harbor sites on Lake Erie were surveyed including Toledo, Sandusky and Cleveland, Ohio. Larval fish identification and data analyses have not been completed.

The educational component of both the 1993 and 1994 programs, focuses on increasing public awareness of the presence and current distribution of ruffe in the Great Lakes. Special emphasis has been given to identification of ruffe and what to do if a ruffe is caught, so that anglers and other public water users can recognize ruffe and take appropriate actions. A ruffe identification poster entitled, *WANTED: Dead or Alive*, was developed and distributed to resource managers, public and private organizations, public access areas, marinas and bait and tackle shops throughout the Lower Great Lakes. Assistance was provided in development and distribution of wallet-sized ruffe identification cards entitled *Ruffe WATCH.*

Lake Erie has been described as having the most available habitat for ruffe colonization based on their thermal niche requirements. The thermal habitat utilized by ruffe is approximately the same as that used by walleye and yellow perch. This overlap allows managers to predict the amount of habitat available for ruffe based on that available for walleye and yellow perch. Of the estimated total of 6.6 million hectares (16.3 million acres) of thermal habitat area available to walleye in the Great Lakes, 57.6 percent of that total is in Lake Erie.

Lake Huron

Historic and Current Status of Fishery Resources and Trends

Appendix II lists species composing the Lake Huron fish community (past and present), and current status of stocks being monitored. Berst and Spangler (1973) provided an overview of the Lake Huron ecology and fish community through 1970, but no update has since been made. The Great Lakes Fishery Commission's, Lake Huron Technical Committee, as directed by the Lake Huron Committee, recently completed a final draft of *State of the Lake Huron Fish Community in 1992*, (Ebener 1994). Contained within the document is a summary of the historic and current status for each principal fish species, and discussion of management strategies to meet fish community objectives. Inter-agency management activities address principal sport and commercial species, and the major components of the forage base. In many cases trends vary among regions of the lake and management strategies are targeted to specific locations. For management purposes, the lake has been broken into statistical districts to facilitate reporting of specific activities (Figure 61). Information contained in the following discussion comes largely from Ebener (1994).

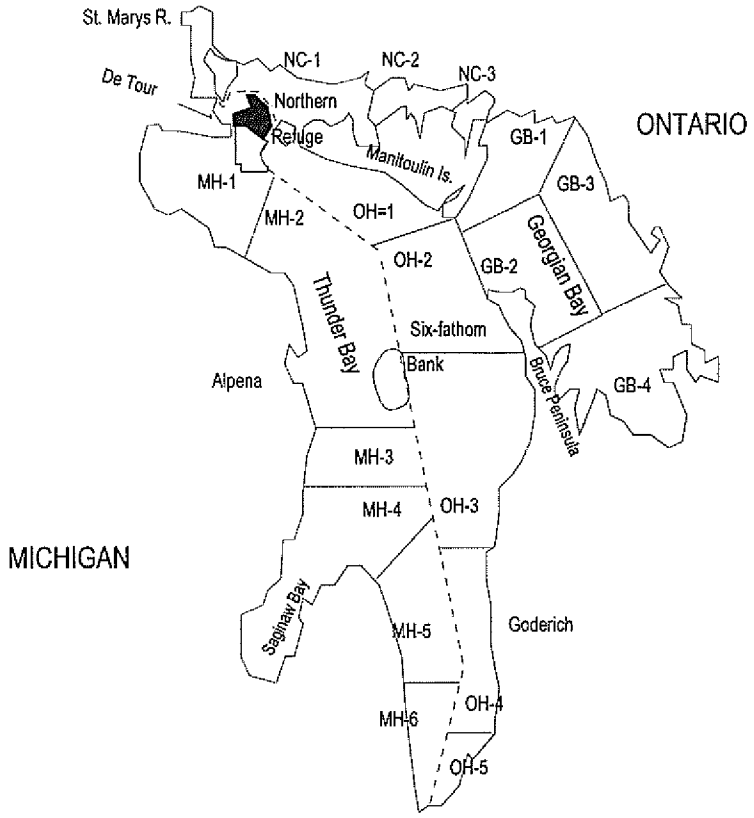


Figure 61. Map of the Lake Huron basin showing statistical districts with U.S. and Canadian points of reference.

The historic fish community of Lake Huron consisted of a diversity of coldwater, coolwater, and warmwater species. Lake trout, lake whitefish, deepwater coregonids, burbot, longnose sucker and deepwater sculpin were predominant in the coldwater (offshore) habitats of the lake. Species such as walleye, northern pike, lake sturgeon, muskellunge, and yellow perch dominated the coolwater areas of the lake (nearshore), while smallmouth and largemouth bass, bullheads, rock bass, white sucker and freshwater drum were restricted to the warm littoral zones and warm-water bays (nearshore-warmwater bays).

Lake Huron fish species were important to Native American Tribes inhabiting the region, both, for food and trade (Kinietz 1940). Native Americans were involved in some form of commercial fishing as early as the 1700s, followed by expanding nonindigenous commercial fishing in the 1800s (Berst and Spangler 1973; Kinietz 1940). Abundance and composition of the Lake Huron fish community underwent dramatic change during the 20th century (Smith 1972; Berst and Spangler 1973). Commercial fishers targeted species such as lake trout, lake whitefish, lake sturgeon, deepwater coregonids, and walleye during the early 1900s (Figure 62). Total commercial harvest declined continually between 1930-1966; from 11 million kilograms (24 million pounds) in 1930 to 3.6 million kilograms (8 million pounds)

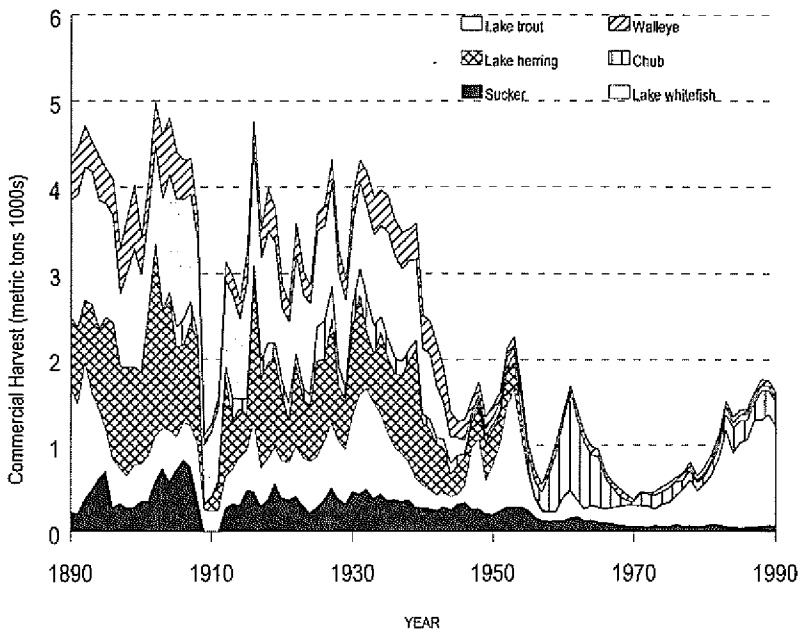


Figure 62. Annual commercial harvest of principal Lake Huron fish species, 1890-1990. Species include walleye, lake trout, chub, lake herring, lake whitefish, and suckers (data from Baldwin *et al.* 1979 and Great Lakes Fishery Commission)

in 1966. With the exception of two isolated populations in Canadian waters, lake trout had been extirpated from Lake Huron waters by 1966. In addition, four species of deepwater coregonids had become extinct (Bailey and Smith 1981), and stocks of lake whitefish, lake herring, and walleye were severely depressed by the 1960s (Berst and Spangler 1973). Declines of species such as deepwater coregonids, lake whitefish, lake trout, and lake herring have been linked to over-exploitation (Van Oosten *et al.* 1946; Berst and Spangler 1973; Brown *et al.* 1987; Eshenroder *et al.* 1992). A combination of over-exploitation and loss of habitat is blamed for declines of lake sturgeon, lake herring, and walleye (Ono *et al.* 1983; Keller *et al.* 1987).

Three species of ocean-dwelling fish gained access to Lake Huron during the 20th century, either as a result of construction of the Welland Canal (lamprey and alewife) or through accidental introduction (rainbow smelt), and are

suggested as having significant impacts on the indigenous fish community. Abundance of these species increased dramatically and resulted in direct or indirect interaction with indigenous species already under considerable stress due to over-exploitation or habitat loss. The collapse of lake trout and burbot populations due to sea lamprey predation resulted in subsequent reduction in predation pressure on rainbow smelt and alewife, with the latter flourishing as a result. Declining abundance of lake whitefish, lake herring, and yellow perch has been linked with concurrent increases in populations of rainbow smelt and alewife and is thought to be a result of predation and/or competition early in the life history of the indigenous species (Smith 1970).

Intensive fishery management activities were undertaken in the 1960s and 1970s in response to the deteriorated fish community of Lake Huron. Management activities included sea lamprey control, regulation of commercial fisheries, and stocking programs to restore the predator base to the fish community.

The status and trends of principal fish species, as well as current management activities, was presented in Ebener (1994) and has been assembled by community (offshore, nearshore, and nearshore-warmwater bays).

Offshore fish community

The Lake Huron offshore prey base is dominated by three primary species, rainbow smelt, alewife, and bloater, and was discussed by Argyle (1994). Estimates of forage abundance are provided by annual trawling surveys at index stations by the National Biological Service - Great Lakes Science Center and are illustrated in Figure 63. Abundance

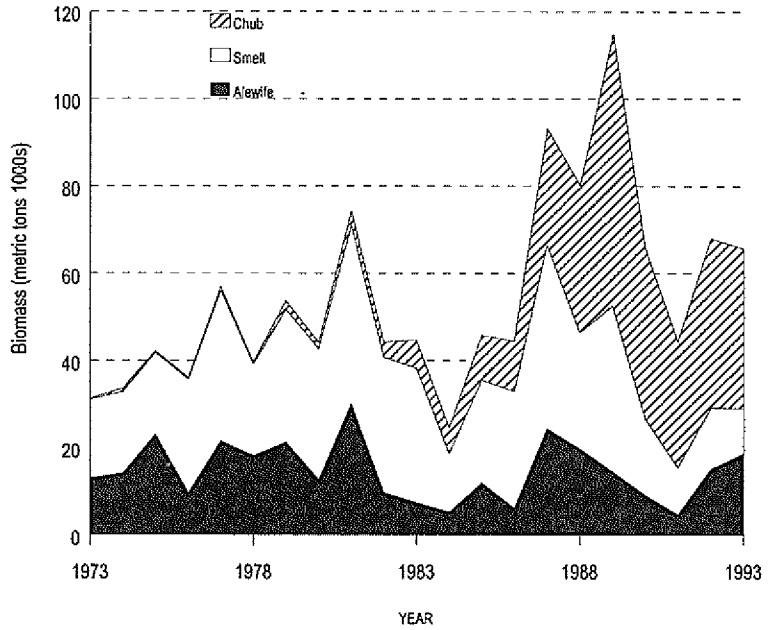


Figure 63. Biomass of alewife, rainbow smelt and bloater chub in Michigan waters of Lake Huron based on fall bottom trawl surveys, 1973-1993 (National Biological Service - Great Lakes Science Center).

of rainbow smelt has fluctuated as a result of relative year class strength in the 1970s and 1980s, but has been more stable than either alewife or chub. Through the mid-1980s, rainbow smelt were considered to be the most abundant planktivore in Lake Huron. Adult populations have been smaller since 1987 when chubs became more abundant. There appears to be an interspecific interaction between rainbow smelt and the other two dominant prey species, alewife and chub. Weaker year classes of rainbow smelt in recent years increased the instability of the lake-wide population, and could result in significant declines in abundance if the trend continues.

Although important as a major component of the diet of predatory fishes, alewives are the least abundant of the three principle prey species. Alewives were relatively abundant in the mid to late-1970s, declined to low abundance in the early 1980s, then began to recover in the mid-1980s. Abundance has recently declined to near the lows of the early 1980s. In addition to the decline in abundance, the age structure has also changed, with the mean age below the 1973-1991 average of 2.5 years.

Deepwater coregonids are an important component of the fish community, both, as a prey species for Lake Huron salmonines, and as a species targeted by commercial fisheries. Of the seven species of deepwater coregonids listed as indigenous to Lake Huron, only the bloater remains relatively abundant and was discussed by Johnson *et al.* (1994) in a description of the cold water fish community. Following the invasion of sea lamprey, alewife, and rainbow smelt, most of the species in this group disappeared completely. Smith (1972), and Brown *et al.* (1987) discussed possible negative interaction between the nonindigenous species and these coregonines. Status and trends of boater chub are provided in the discussion of the coregonine community.

Other principle prey species include deepwater sculpins, trout-perch, and sticklebacks. Subsequent to increased abundance from 1973-1979, deepwater sculpin declined somewhat after 1982, but have since remained relatively stable. Trout-perch abundance has increased since the early 1980s, and remained relatively stable. Catches of ninespine sticklebacks have fluctuated greatly, but may be related more to gear efficiency than abundance. Slimy sculpin abundance is difficult to determine due to low catch rates in sampling activities.

Historically, the coregonine community has served as the backbone of the commercial fishery in the Great Lakes, and although significant change in composition of that harvest has occurred, they continue to be extremely important to Native American Tribal and immigrant fishers. Historic trends and current status of the coregonine community were extensively discussed by Johnson *et al.* (1994). Annual harvest of chubs has varied widely over time (Figure 64). The

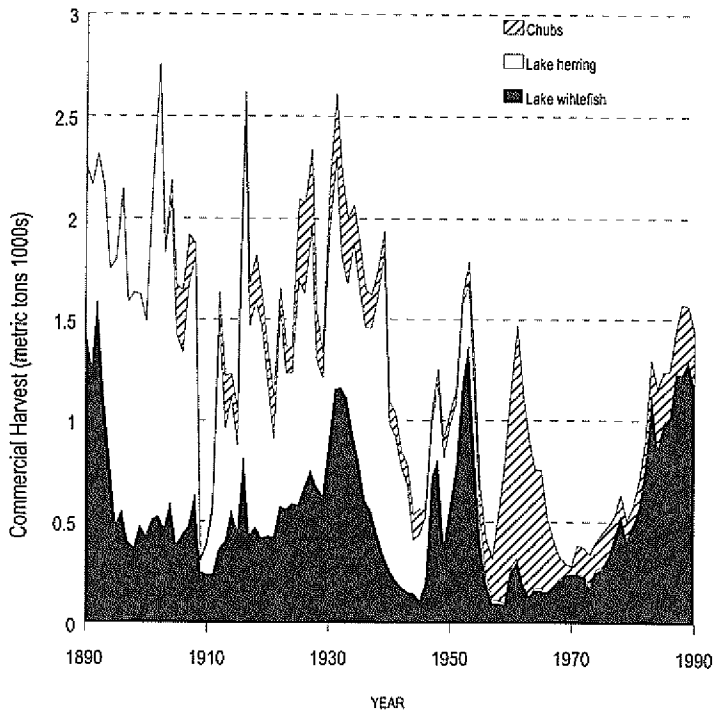


Figure 64. Annual commercial harvest of coregonines from Lake Huron, 1890-1990. Coregonine species include chubs, lake herring, and lake whitefish. (data from Baldwin *et al.* 1979 and Great Lakes Fishery Commission)

period following collapse of lake trout and burbot populations was marked by a chub abundance increase dramatically through the 1950s. Abundance of chubs once again collapsed in the 1960s, following years of increased harvest. Beginning in the late 1970s, bloater abundance underwent a dramatic recovery with levels rivaling years of record harvest. However, relatively weak year classes in 1990-1993 may be once again signaling declining trends. The lack of strength in these year classes will be reflected in overall biomass as they reach adult size. No strong hypotheses have been offered for these poor year classes.

Annual harvest of lake whitefish has undergone several major changes, both, in quantity and in distribution within the three basins of Lake Huron (Figure 64). Stable harvests in the 1922-1929 period, averaging 1.4 million kilograms (3.1 million pounds), were followed by dramatic increases in 1931 and 1932, resulting from the introduction of the deep-water trap net in Michigan waters (Van Oosten *et al.* 1946). Within the decade following the introduction of the new gear, the Michigan fishery experienced a near total collapse.

A large 1943 year-class allowed for a brief recovery period followed by decline until the mid-1970s. Since 1975, commercial harvest has increased, chiefly in the main basin and the North Channel. The main basin now accounts for 90 percent of the total lake whitefish harvest in Lake Huron.

Generally speaking, the lake-wide abundance of lake whitefish is being supported by consistent recruitment of strong year classes. Recovery, even in Georgian Bay where abundance had been lagging, appears to be consistently improving since 1987 (Johnson *et al.* 1994). No strong hypotheses have been developed to fully explain the increasing abundance. While growth rates and subsequent recruitment to the fishery varies around the lake, essentially all Lake Huron lake whitefish are fully vulnerable at age-5.

Sea lamprey wounding rates decline from north to south and, until recently, have not been particularly high. However, North Channel wounding rates increased dramatically in 1992, to levels comparable to pre-control years. If this trend continues, the lake-wide recovered main basin and North Channel lake whitefish populations may be in jeopardy.

Once an important commercial species, lake herring have declined to inconsequential levels in most basins of the lake (Figure 64). There were signs of some recovery in Georgian Bay in the 1970s but declines, believed to be related to fishing pressure, have occurred since 1987 (Johnson *et al.* 1994). Indications of recent recovery in the North Channel have been observed. Post 1940 declines of lake herring in Lake Huron may be related to invasion of nonindigenous species such as alewife and rainbow smelt (Smith 1972). All three basins of Lake Huron contain remnant stocks of lake herring that could serve as a nucleus for recovery if abundance of nonindigenous planktivores is suppressed by salmonines.

Round whitefish have never been a species actively sought by commercial fishers because of their low marketability. Abundance has continued to remain relatively stable.

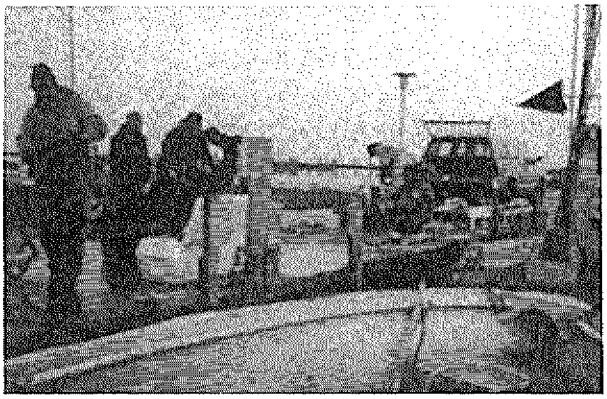
Once consisting of a single member (lake trout), the offshore salmonine community is now composed of several species. The salmonine community is described by Johnson *et al.* (1994). Although the lake trout is one of two salmonine species indigenous to Lake Huron (brook trout being the other), it is the only species receiving active interagency management attention. Extirpated with the exception of two small populations in Ontario waters, lake trout are envisioned by the Lake Huron Committee and the Service as becoming the most abundant salmonine predator in the future fish community of Lake Huron (Lake Huron Committee 1993). Lake trout rehabilitation efforts are monitored through multi-agency assessment indexing and monitoring of sport and commercial harvest.

Average estimated lake trout harvest over the 1986-1992 period was 204,000 kilograms (449,000 pounds) and represents only 10 percent of the historic harvest. These estimates are probably conservative, since sport harvest in

Ontario waters is not known, and Michigan data are incomplete. However, lake trout abundance has been decreasing at a rate of approximately 12 percent per year in Michigan waters of Lake Huron in spite of near constant stocking rates. Abundance in Ontario waters has been variable without well defined trends and appears to be more closely related to stocking levels. Declining lake trout abundance is most pronounced in northern Lake Huron and appears to be closely related to increasing sea lamprey populations. Lake trout abundance in central Lake Huron is not well-related with stocking levels and may indicate poor survival of hatchery fish and/or movement of fish into the northern zones. Abundance in the south-central region of the lake is well-related with stocking rates.

Survival increases from north to south, especially in older fish. While survival is good through age-4 in the north, few fish are surviving to maturity in this region of the lake, again, assumed to be a result of extensive sea lamprey predation. Successful lake trout rehabilitation assumes total annual mortality of no greater than 45 percent. Currently, total annual mortality exceeds this level in most areas of the lake.

Growth increases from north to south, probably in response to water temperature. Lake trout mature at an earlier age in the south as a result of the difference in growth rate. Lake-wide, the age at which the population reaches full sexual maturity averages age-7 for males and age-9 for females.


Alpena Fishery Resources Office photo

The first evidence of natural reproduction was identified in the Rockport area of Lake Huron in 1981 when young-of-the-year lake trout were captured in assessment surveys. Also, since 1984 young-of-the-year lake trout have been regularly taken near a small reef in Thunder Bay, off Alpena. Numbers of young-of-the-year fish have been declining over the last few years and may represent declining abundance of adult fish. Significant numbers of unclipped adult fish are still collected on the reef in Thunder Bay, and are presumed to be the result of natural recruitment from early hatchery plantings in this region of the lake. Significant numbers of spawning lake trout are observed on an artificial reef in the Tawas Bay area of Lake Huron, and egg and fry production have been documented. To date no yearling, or older, unclipped fish have been recovered from this region of the lake.

In 1985, experimentation was initiated in two regions of Lake Huron with stocking of various strains of hatchery lake trout. The intent of the studies was to evaluate genotypes for relative contribution to the rehabilitation effort. Hatchery fish for this experimentation are implanted with binary-coded wire tags for later evaluation of parameters such as survival, growth, and reproductive effectiveness. The experimental areas are the Drummond Island region of the lake, and the Six Fathom Bank (Figure 61). These areas contain significant amounts of suitable historic spawning habitat. Data that have been collected since 1985 indicate superior performance of the Seneca Lake strain, and this information may be used to guide the stocking program in Lake Huron in the future. An apparent ability to avoid sea lamprey attacks in the first three to four years of lake life is resulting in significantly higher numbers of the Seneca Lake strain in the spawning population on both Six Fathom Bank reef and in the Drummond Island region of Lake Huron. Spawning lake trout abundance at the Six Fathom Bank reef complex is currently higher than in any other region of Lake Huron and is dominated by the Seneca Lake strain (Figure 65). Significant numbers of young-of-the-year lake trout were captured on the reef complex in the spring of 1994, indicating successful reproduction is occurring, and providing encouragement for future rehabilitation efforts.

Reproductive success is being measured in South Bay, Ontario, on the south shore of Manitoulin Island. Unmarked juvenile lake trout are now regularly sampled in this region of Lake Huron. This success may be the result of stocking an indigenous Manitoulin Island strain. Population abundance and expansion is being closely monitored by Ontario Ministry of Natural Resources researchers.

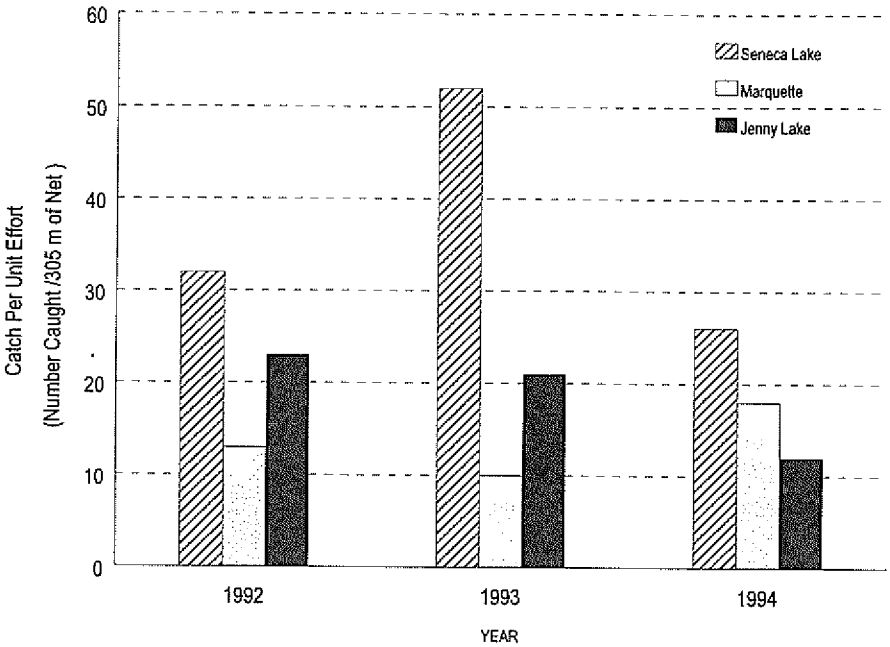


Figure 65. Total catch per unit of effort (CPUE) for three strains of lake trout captured during fall spawning surveys on Six Fathom Bank, 1992-1994 (National Biological Service-Great Lakes Science Center).

Without doubt, the most serious impediment to lake trout rehabilitation efforts in Lake Huron is sea lamprey abundance in the northern end of the lake. Sea lamprey wounding data are monitored by assessment surveys of various agencies working on Lake Huron, and used to quantify mortality rates attributable to sea lamprey. Wounding rates decrease from north to south, particularly in Michigan waters. Wounding rates also increase with host size, and are highest in fish larger than 61 centimeters (24 inches) (Figure 66).

Although brook trout is one of only two indigenous Lake Huron salmonines, there are no existing management plans for the species. The Michigan Department of Natural Resources initiated stocking of brook trout in the Rogers City area in 1984 to provide increased diversity of fishing opportunities. The program was discontinued in 1991 due to poor survival and little contribution to the creel. Some Michigan and Ontario streams have resident brook trout populations, but they are confined to headwater regions with little to no access to Lake Huron due to blockage of streams with dams or natural barriers.

Chinook salmon are not indigenous to Lake Huron but have become an important component of the fish community. First stocked in Michigan waters of Lake Huron in 1968 and in Ontario in 1985, estimated lake-wide harvest of chinook salmon has been relatively stable at 780,000 kilograms (1.7 million pounds) since 1986. In Michigan waters sport harvest has decreased from 50 percent in the mid-1980s to 26 percent of the total harvest in the early 1990s. Native American Tribal commercial harvest, on the other hand, has increased from 1 percent in 1986 to 40 percent in 1992. As a component of the *1985 Consent Decree* (U.S. v Michigan) the State of Michigan agreed to stock, on an annual basis, up to 500,000 salmon fingerlings in ceded waters to be accessed by sport and commercial fishers, and to provide a source of eggs for continued propagation (weir harvests). The increased commercial harvest by Native American Tribal fishers, through gillnet fisheries and weir harvests, has resulted from these plants. Lake-wide stocking has been capped at 4.0 million fish until a sound, ecologically-based model capable of determining optimum stocking levels in relation to available prey can be applied in Lake Huron (Figure 67).

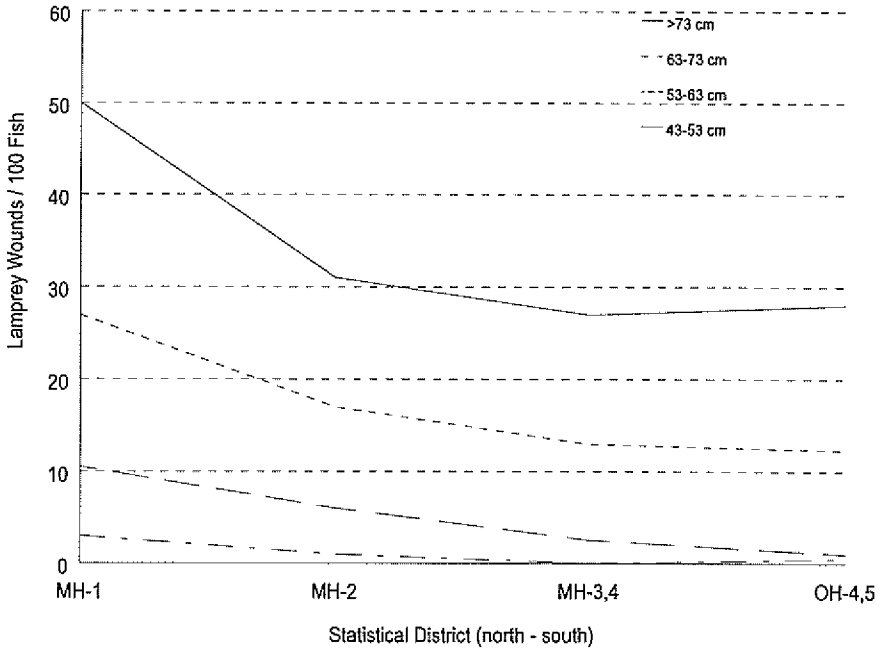


Figure 66. Average sea lamprey wounding on various sizes of lake trout caught during index gill net surveys from Michigan and Ontario statistical districts of Lake Huron, 1986-1992 (Ebener 1994).

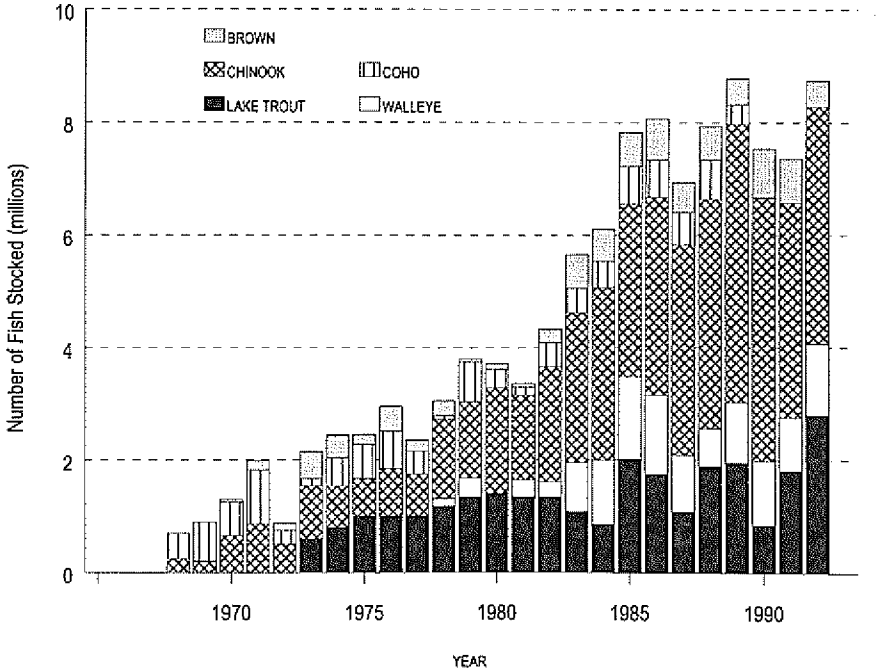


Figure 67. Millions of predator fish stocked annually in Lake Huron, 1968-1992. Species include lake trout, walleye, brown trout, chinook salmon and coho salmon (Ebener 1994).

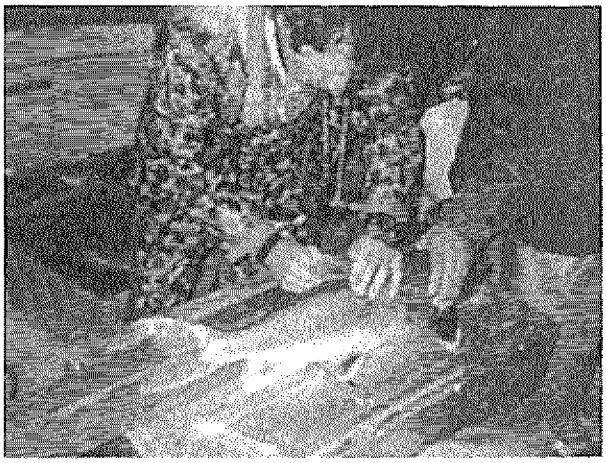
While there are no data on sport harvest of chinook salmon in most of Ontario waters, fisheries do exist in the North Channel, Manitoulin Island, and Bruce Peninsula areas of the lake. Sport harvest in southern Georgian Bay has ranged from 13,600 fish in 1992 to 18,000 in 1991. Sport harvest estimates in Michigan waters are incomplete for several years, but creel surveys conducted at all major fishing ports and locations during the years 1986-1988, reported catches ranging from 84,390 in 1986 to 105,406 in 1988 (Rakoczy 1991).

Considerable biological data gaps exist in regard to chinook salmon in Lake Huron. Little biological information is available to describe growth during the open water phase of their life cycle. Most growth data are collected from pre-spawning fish at the weirs. These data indicate relatively stable growth rates since the 1970s. In addition, food habits of chinook salmon are not well known but presumed to be primarily limited to alewife and rainbow smelt.

The extent of natural reproduction in Lake Huron is not known. Large numbers of adult chinook are observed in most Ontario streams known to support rainbow trout (steelhead) reproduction. While most of the major streams tributary to Michigan waters of Lake Huron are blocked by dams, there is evidence of some natural reproduction. Wild young-of-the-year chinook have been captured in St. Martins Bay in northern Lake Huron, and ongoing studies in the central basin are producing estimates of wild production as high as 30 percent.

Sea lamprey wounding rates are 18-33 per 100 chinook salmon in the northern portion of the lake, but research is needed to determine the lethality of these attacks.

Michigan Department of Natural Resources stocked an average of 509,000 yearling coho from 1968-1989 (Figure 67). The 1969 harvest in Michigan waters was estimated at 34,000. However, poor survival of subsequent year classes coupled with concerns regarding negative interaction with other riverine species prompted cessation of stocking in 1986. Few data are available on the fishery in Ontario, but it is considered a minor contributor to the sport fishery.


Alpena Fishery Resources Office photo

The future of coho salmon in Lake Huron, as defined by the fish community objectives, is to persist at levels attainable by natural reproduction alone (Lake Huron Committee 1993). Little management effort is directed at coho salmon and as a result, very little biological information exists regarding the species in Lake Huron.

Pink salmon have never been stocked in Lake Huron but have established themselves as a sport fishery of regional significance. Existing pink salmon populations have become established as a result of immigration from Lake Superior. Pink salmon were first introduced in Thunder Bay, Ontario in 1956 (Scott and Crossman 1973), and first identified in the Carp River, Lake Huron in 1969 (Parsons 1973).

Sport harvest of pink salmon fluctuates bi-annually, with the significant harvests coming in the odd years (1985, 1987, 1989, etc.). No recent studies have been conducted in Ontario waters, and limited creel data suggest that pink salmon are either not abundant, or are not sought by local anglers. Very limited biological information has been developed on pink salmon in Lake Huron. Abundance is monitored only through creel surveys in Michigan, and no data exist on survival, growth, or sea lamprey wounding rates.

Rainbow trout are viewed by the Lake Huron State and Provincial management agencies as having an increasing role in the fish community. There are three different types of rainbow trout are being managed for in Lake Huron.

"Domestic" rainbow trout occupy open waters of the lake on a year-around basis and are stocked in harbors and off breakwalls to provide excellent angling opportunities, with little potential for natural reproduction. "Steelhead" are a genotype of rainbow trout that spend most of their life in the open water of the lake but enter tributaries to spawn. A Lake Michigan "winter-run" steelhead is the strain currently being stocked in Lake Huron. Skamania is a strain of steelhead that enters streams earlier than the conventional steelhead, and generally spawns earlier.

Stocking of rainbow trout resulted in establishment of naturalized populations in many locations of Lake Huron by 1930 (Berst and Spangler 1973). Since 1986, annual stocking of rainbow trout (domestic, steelhead, and Skamania) has averaged 1.85 million, and has been increasing in recent years (Figure 67). Various life stages have been planted (fry, fingerling, and yearling) but survival appears best in the larger yearling smolts. Beginning in 1993, stocking of large smolts will replace fry and fingerling plants in Michigan waters of Lake Huron, to the extent possible. Skamania were stocked in Michigan waters from 1983-1991, but stocking was discontinued due to concerns about survival in the face of warm summer stream temperatures, and genetic interaction with existing steelhead populations. Ontario has stocked Skamania in Georgian Bay, but results have not been encouraging.

While rainbow trout provide important seasonal fisheries in some locations, harvests are still a small portion of total lake-wide salmonid harvest. Nearly one-half of the total Michigan harvest of rainbow trout is from the AuSable River. Harvest data from the Ontario side of the lake is limited but catch rates have been documented from the Saugeen and Bighead Rivers.

Abundance of naturally reproducing rainbow trout has been declining in many regions of Ontario waters of the lake. Reasons for these declines have not been identified, but may be the result of poor year-class production during the late 1980s, coinciding with low stream flows and high water temperatures. There is no information to describe survival or growth of rainbow trout in Lake Huron. Sea lamprey wounding of rainbow trout decreases from north to south, coinciding with sea lamprey abundance.

Brown trout constitute a relatively minor role in the overall Lake Huron salmonid community, but do provide an important regional fishery in areas such as Thunder Bay, Michigan, and Georgian Bay, Ontario. Due to declining harvests, Michigan Department of Natural Resources has initiated a strain evaluation study in Thunder Bay to enhance that fishery. In addition, management strategies have been altered to improve early survival. Stocking in Thunder Bay has been delayed until June, when alewife abundance is greatest, to buffer predation effects on early survival. There are no data to describe lake-wide abundance, growth, or food habits of brown trout in Lake Huron.

Most of the natural reproduction of brown trout in Lake Huron is on the Ontario side. Lack of homing and instream recruitment on the Michigan side may be due to genetics, lack of imprinting, competition for spawning and rearing habitat by other salmonids, or a combination of factors.

Brown trout seem to be less susceptible to sea lamprey wounding than many of the other Lake Huron salmonids as the wounding rates are relatively low.

Atlantic salmon are considered a minor component of the Lake Huron fish community, and stocking is suggested only for experimental purposes. An experimental stocking program has been initiated in the St. Mary's River, the results of which have not been analyzed.

Due to the severity of the sea lamprey problem in Lake Huron, an entire section of this report, and in Ebener (1994), is dedicated to describing the situation. The discussion is based on information provided by Morse *et al.* (1994). Sea lamprey control was initiated in Lake Huron tributaries in 1960, but due to budget constraints control was interrupted from 1963-1965. Routine treatments were resumed in 1966, and have continued annually. Abundance of sea lamprey decreased significantly following the routine treatments and remained stable through 1982. However,

beginning in 1983 abundance began to increase as a result of increased production of transformers in the St. Mary's River, the largest tributary to Lake Huron.

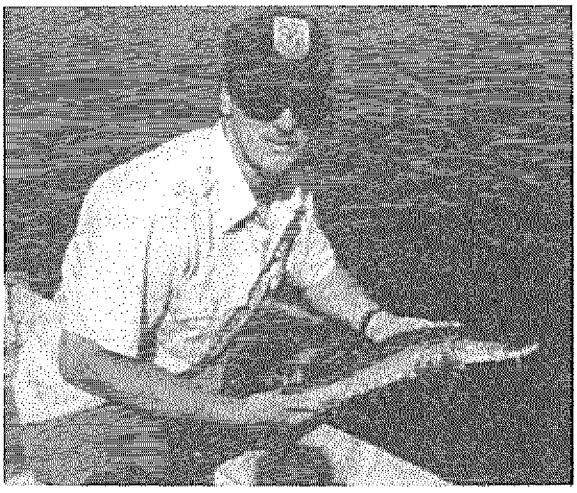
Without question the sea lamprey problem in northern Lake Huron, associated with increased production from the St. Mary's River, is the most severe impediment to a healthy fish community in the lake. Although sea lamprey control efforts on all Lake Huron tributaries, excluding the St. Mary's, are comparable with the other Great Lakes, there are more parasitic sea lamprey in Lake Huron than in the other lakes combined (Schleen 1992). Schleen (1992) noted that one in five chinook salmon caught in Lake Huron has a sea lamprey attached to it, compared to one in one hundred in the other lakes. As discussed in the section on lake trout, sea lamprey attacks on this species are having devastating effects on the rehabilitation effort. In addition to lake trout and chinook salmon, sea lamprey are now impacting other fish populations.

Due to the size of the St. Mary's River, conventional chemical treatment/trapping strategies are not practical for controlling this parasite. As a result, in 1991 the Great Lakes Fishery Commission directed the Sea Lamprey Integration Committee to recommend alternate control strategies for the St. Mary's River. A St. Mary's River Control Task Group was formed to make recommendations for control of sea lamprey in the river for 1992-1995, addressing the following: 1) identify control options; 2) predict the effectiveness and costs of the control options; and 3) identify information needs required to assess the control options prior to and after implementation. A multi-faceted integration program has been devised with both short and long-term strategies.

Nearshore fish community

Native American Tribes inhabiting the Lake Huron region relied heavily on lake sturgeon as a food source and actively sought them in several regions (Kinietz 1940). Early European commercial fishers considered lake sturgeon to be a nuisance, but when the market value of their flesh and roe was realized, harvest soared. Lake-wide commercial harvest in Lake Huron was 453,000 kilograms (997,000 pounds) in 1885, with 80 percent of the catch coming from Canadian waters. By 1928, commercial fishing for sturgeon was prohibited in Michigan waters of the lake.

The rapid increase in harvest effort in the late 1800s, coupled with construction of dams in the early 1900s, which blocked access to spawning and nursery waters on many of the historically important sturgeon spawning streams, resulted in a precipitous decline in abundance in Lake Huron (Ono *et al.* 1983). Some commercial harvest continues in the North Channel and the southern main basin of Canadian waters. While no documented spawning populations are known in Lake Huron, the lower 30 kilometers (20 miles) of the Mississagi River contain suitable spawning habitat and may be producing the sturgeon fished in the North Channel. Sturgeon spawning is known to occur in the St. Clair River and may be producing the fish harvested in the southern main basin.



Ashland Fishery Resources Office photo

No active management plans exist for lake sturgeon in Lake Huron, but there is considerable inter-agency interest in a recovery program. Inventory and protection of remnant stocks, as well as restoration and rehabilitation of habitat are the main focus of current activities. The Michigan Department of Natural Resources has developed a draft recovery plan for their waters, including Lake Huron, and it is being reviewed by other interested agencies.

Yellow perch are an important component of sport and commercial harvest lake-wide and are widely distributed in Lake Huron. Commercial catch of yellow perch has been relatively stable since 1920, averaging 370,000 kilograms (814,000 pounds) (Baldwin *et al.* 1979). Estimates of sport harvested yellow perch in U.S. waters are restricted to certain areas such as Saginaw Bay, Les Cheneaux Islands, St. Mary's River, DeTour-Drummond Island and a few other ports. Additionally, estimates are considered conservative because basin-wide creel surveys are not conducted, and the ice fishery is not always surveyed. Reported harvest has ranged from 200,000 fish in 1989 to 1.0 million in 1987.

Abundance estimates are restricted to Saginaw Bay and the Les Cheneaux Islands. Abundance of yearling and adult fish in both regions appears to be declining in recent years.

Growth rates vary between areas of the lake. Yellow perch in Saginaw Bay have shown a general decrease in growth rate over time that appears to be linked to water quality changes and subsequent changes in food supply. Eutrophication of Saginaw Bay waters appears to be responsible for near elimination of the large burrowing mayfly considered to be important for perch growth in those waters (Haas and Schaeffer 1992). Growth of yellow perch in other regions of U.S. waters, where data are available, appears stable and near the state-wide average.

The goal of walleye management in Lake Huron is to restore the species to its historic importance as the dominant near-shore predator. Walleye have always been an economically important species for both commercial and sport fisheries.

Prior to the collapse of the Saginaw Bay walleye fishery in the late 1940s, lake-wide harvests of 450,000 to 900,000 kilograms (990,000 to 1.98 million pounds) occurred regularly. With the recovery of the Saginaw Bay fishery, current lake-wide harvest averages 329,000 kilograms (721,000 pounds), and is equally split between sport and commercial fishers. Commercial walleye fishing exists only in Ontario waters, since Michigan halted its commercial walleye licensing in 1967 (Baldwin *et al.* 1977).

Stocking programs for reestablishment of the walleye fishery in Lake Huron were initiated in Saginaw Bay in 1978 (Michigan Department of Natural Resources), North Channel and Georgian Bay in 1984 (Ontario Ministry of Natural Resources), and by the Chippewa-Ottawa Treaty Fishery Management Authority in the northern waters in 1985. Both fry and fingerling stocking strategies have been employed but fingerling stocking is considered to be the most efficacious. Sport harvest of walleye in Saginaw Bay has increased dramatically from near zero in 1980, to 80,000 per year in the early 1990s. Currently it is estimated that there are 884,000 sexually mature (age-3 and older) walleye in Saginaw Bay. Other areas where walleye recovery efforts have been successful include Thunder Bay and St. Martin Bay.

Growth rates of Lake Huron walleye have remained relatively stable since recovery efforts were initiated, although there is some variability between areas of the lake. Walleye from St. Martin Bay grow somewhat slower than in either Thunder Bay or Saginaw Bay. In spite of the abundance of walleye in Saginaw Bay, the fact that growth has remained constant indicates that the carrying capacity has yet to be reached.

Some natural reproduction has been documented in the St. Mary's and Cheboygan River system in the north, and some reproduction is occurring in the Saginaw Bay tributaries. While the reproduction occurring in the St. Mary's and Cheboygan Rivers is sustaining a population, the extent of the contribution in the Saginaw Bay region is not known. Attempts have been made by the Michigan Department of Natural Resources to quantify the "wild" component of the Saginaw Bay walleye population but results have not been conclusive. Public perception that walleye populations in Saginaw Bay are being maintained by the stocking program has hindered Michigan Department of Natural Resources efforts to fully evaluate the question through an "alternate-year stocking program".

In areas of Lake Huron where suitable habitat remains for reproduction and nursery areas, northern pike are a prominent predator and desirable sport fish. Unfortunately, loss of coastal marsh habitats throughout the lake has been a major factor contributing to decline of this species.

Historically, a significant commercial harvest of northern pike existed in the Canadian waters of the Georgian Bay and North Channel. Lake-wide commercial harvest in 1921 was 136,000 kilograms (299,000 pounds) (Baldwin *et al.* 1979), but has steadily declined since that time. Commercial harvest of northern pike in Michigan waters ceased in 1966.

Sport harvest data for northern pike is incomplete because creel surveys are not conducted annually or on a lake-wide basis in many areas due to budget constraints of the various agencies. Most (95 percent) of the reported sport harvest comes from the St. Mary's River/Drummond Island area of northern Lake Huron.

Information regarding abundance of northern pike in Lake Huron is limited, and generally obtained only through incidental catch in surveys for other species. There appear to be sizeable populations in the St. Mary's River system, St. Martin Bay, around the Les Cheneaux Islands, Georgian Bay, Cheboygan, and Saginaw Bay. Again, availability of spawning habitat is the main criteria for maintaining populations of this species. Efforts are being made to restore access to remaining marshes in U.S. waters.

Limited data are available on abundance of muskellunge in Lake Huron. Some reproducing populations exist in Canadian waters of Georgian Bay, the North Channel, and the St. Mary's River.

Nearshore fish community (warmwater bays)

Channel catfish inhabit nearshore waters of the warmer Lake Huron bays. Commercial harvest of channel catfish has increased since 1952, especially in Saginaw Bay, where nearly 90 percent of the current harvest occurs. Sport harvest is not closely monitored but is thought to be below its potential, due primarily to Michigan Department of Public Health consumption advisories for Saginaw Bay. In summary, little biological information is available on channel catfish in Lake Huron, with the exception of Saginaw Bay.

Smallmouth bass are present in most nearshore waters of Lake Huron, and are a highly desirable sport species. In Ontario waters, smallmouth bass may be the single most important sport species. Michigan ranks them as one of the top ten sport species sought by anglers.

Very little biological information exists on smallmouth bass in Lake Huron. It is generally believed that reproductive success, and consequently overall abundance, is directly related to water temperatures. Year class strength varies depending on annual climatic conditions at the time of reproduction and early rearing. Summer temperatures also affect annual growth rates.

Distribution and abundance of largemouth bass is considered to be much more restricted than smallmouth bass, and probably restricted to the inner Saginaw Bay and similar habitats around the lake. They are considered to be locally important to sport fishers in Saginaw Bay.

Rock bass, pumpkinseed, black crappie, bluegill, and both longear and green sunfish are considered to be important centrarchids to sport fishing in some areas. Rock bass are probably the most abundant, making up approximately 75 percent of the centrarchid harvest in Michigan waters of Lake Huron in some years.

Causes of Changes in Lake Huron Fishery Resources and Management Strategies

Causes of changes in Lake Huron fishery resources

Overexploitation, habitat impairment, and loss and instability of fish stocks due to invasion of undesirable aquatic species have combined to cause declines in many of the indigenous Lake Huron fish species. Human development and the perturbations resulting from habitat alteration for the benefit of non-aquatic inhabitants have been instrumental in declines of species relying on the near-shore environments and tributaries for critical phases of their respective life cycles. Blocking of streams by hydro-power facilities; draining and diking of wetlands for residential and agricultural development; and physical alteration to the system to provide shipping industry access to urban centers on the Great Lakes, have in many cases caused changes that are almost impossible to correct. Disregard or oversight of the importance of genetic diversity and integrity of indigenous species has led to reduced fitness of stocks. Hatchery programs directed at restoring indigenous species or filling niches vacated by extirpated species have, in some cases, actually resulted in accelerating declines of some of those stocks.

Certainly no one factor can be blamed for the losses or declines that have occurred, but each in its own way has been instrumental. While any one of the factors may have been overcome, the combined effects have been more than the system could handle and the fish community suffered the consequences.

Management strategies in Lake Huron

The *Strategic Plan for Management of Great Lakes Fisheries* charged the Great Lakes Fishery Commission's, Lake Huron Committee with development of objectives for definition of what the fish community of the lake should look like in the future, and to develop means for measuring progress. These objectives were drafted in 1993 and accepted by the Great Lakes Fishery Commission in 1994 (Lake Huron Committee 1993). As defined, the overall fish community objective for Lake Huron is to; *over the next two decades restore an ecologically balanced fish community dominated by top predators and consisting largely of self-sustaining, indigenous and naturalized species capable of sustaining annual harvests of 8.9 million kilograms (19.6 million pounds).*

Fish Community Objectives for Lake Huron presented twelve statements summarizing actions needed to attain the desired fish community:

- *Establish a diverse salmonine community which can sustain an annual harvest of 2.4 million kilograms (5.3 million pounds), with lake trout the dominant species and anadromous (stream spawning) species also having a prominent place.*

- *Re-establish and/or maintain walleye as the dominant coolwater predator in its traditional area with populations capable of sustaining a harvest of 0.7 million kilograms (1.5 million pounds).*

- *Maintain the yellow perch as the dominant nearshore omnivore, and sustain a harvestable annual surplus of 0.5 million kilograms (1.1 million pounds).*

- *Maintain the northern pike as a prominent predator throughout its natural habitat; maintain the muskellunge in numbers and at sizes which will safeguard and enhance its special status and appeal; sustain a harvestable annual surplus of 0.1 million kilograms (0.2 million pounds) of esocids.*

- *Maintain channel catfish as a prominent predator throughout its natural habitat; and sustain a harvestable annual surplus of 0.2 million kilograms (0.4 million pounds).*

- *Maintain the present coregonine diversity; manage stocks of lake whitefish and ciscoes at levels capable of sustaining annual harvests of 3.8 million kilograms (8.5 million pounds); restore lake herring to a significant level, and protect, where possible, rare deepwater coregonids.*

- *Sustain smallmouth and largemouth bass and the remaining assemblage of sunfishes at recreationally attractive levels over their natural range.*

- *Increase the abundance of lake sturgeon to the extent that the species is removed from its threatened status (U.S. waters); maintain or rehabilitate populations in Canadian waters.*

- *Maintain a diversity of prey species at population levels matched to primary production and to predator demands.*

- *Reduce sea lamprey abundance to allow the achievement of other fish community objectives; obtain a 75 percent reduction in parasitic sea lamprey by the year 2000 and a 90 percent reduction by the year 2010 from present levels.*

- *Maintain and promote genetic diversity by conserving locally adapted strains and by ensuring that strains of fish being stocked are matched to the environments they are to inhabit.*

- *Protect and enhance fish habitat and rehabilitate degraded habitats; achieve no net loss of the productive capacity of habitat supporting Lake Huron fish communities and restore damaged habitats; and support the reduction or elimination of contaminants.*

Alpena Fishery Resources Office photo

Lake Michigan

Historic and Current Status of Fishery Resources and Trends

Appendix II lists species composing the Lake Michigan fish community (past and present), and current status of stocks being monitored. Lake Michigan's indigenous fish community resulted largely from recolonization of species and evolution of endemic species following retreat of the Laurentian Glacier, about 11,000 years ago. By the European settlement era, 79 fish species inhabited Lake Michigan and an additional 40 were recorded from tributaries (Bailey and Smith 1981). The most abundant and well-known species were those commercially fished. At the time of first contact (after 1650) between Native American Tribes and Europeans in the Lake Michigan basin, Native Americans were fishing for lake whitefish, lake trout, and lake sturgeon with a variety of gears: nets (made of nettles), spears, hook and line, and weirs (in streams) (Kinietz 1940). Wells and McLain (1973) give a detailed account of the non-aboriginal fisheries through 1970. The earliest fishery was primarily for lake whitefish, which were abundant inshore. By 1879, the first year of reliable records, lake whitefish were already considered depleted in some nearshore locations and other species became commercially important: sturgeon, lake trout, lake herring, and deepwater coregonids (Figure 68).

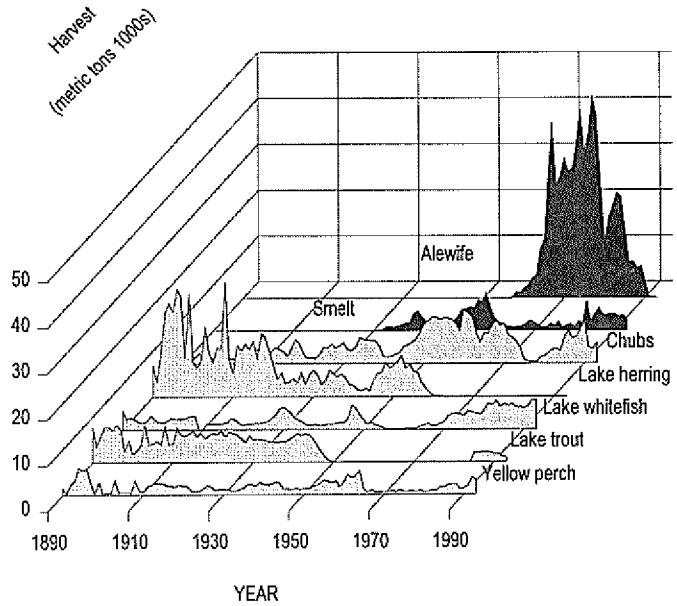


Figure 68. Annual harvest of the major commercial fish species from Lake Michigan, 1890-1993 (data from Lake Michigan Committee).

Lake Michigan's food web can be viewed as consisting of two separate but overlapping parts, the pelagic food web associated with off-shore, open water, and the benthic food web associated with the bottom. Both originate with planktonic algae and phototrophic bacteria produced in the photic zone surface waters, where light penetration is adequate for photosynthesis. The pelagic food web is based on consumption of algae by invertebrates (zooplankters); mostly cladocerans and copepods, including copepod species that prey on other small invertebrates. The benthic food web is based on direct conversion of detritus (decomposing algae and other organisms) which rains down to the bottom from the photic zone. Especially prominent in the benthic zone are two large forms, *Mysis relicita* (*Mysis*) the opossum shrimp, and *Diporieia hoyi* (*Diporieia*), an amphipod. Mysis, besides feeding on detritus, also migrates

vertically at night and preys on zooplankton. *Mysis* and *Diporieia* evolved during deglaciation and their distribution is now discontinuous and restricted to large, deep, glacial-scoured lakes, like the Great Lakes. Because of their relatively large size and high lipid levels, these macrobenthic invertebrates have made the benthic food web an important high-energy food source in offshore waters for all but larval and juvenile fishes.

In the historic fish community small cladocerans and copepods in the pelagic zone supported production of larval and juvenile fish: deepwater coregonids, lake whitefish, lake herring, deepwater sculpin, and burbot, all of which have pelagic larvae. None of the common indigenous species fed exclusively, as adults, on small particles like cladocerans and copepods. Adult deepwater coregonids and lake whitefish became benthivores, feeding primarily on *Mysis* and *Diporieia*, and the lake trout and burbot became piscivores, feeding primarily on other fish, such as ciscoes and sculpins. The lake herring, continued to use the pelagic food web as adults (Dryer and Beil 1964).

Offshore fish community

Lake herring and deepwater coregonids were the most abundant fishes in the off-shore pelagic community, feeding on zooplankton along with the pelagic fry and young of many other important fishes (Crowder 1980). This characteristic of indigenous fishes to produce pelagic fry might have made them vulnerable to excessive predation when the introduced alewife, became prominent in the 1950s. Lake trout also fed extensively on herring and young deepwater coregonids in the warmer pelagic zone. Among Great Lakes piscivores, lake trout was the species best adapted to occupy all depths of the lake.

In the benthic community, deepwater coregonids, deepwater sculpin, *Mysis*, and *Diporieia* created a food web supporting lake trout and burbot, the major deepwater piscivores. The deepwater coregonids were a complex of six closely related species, two of which suffered severe declines from overfishing before the turn of the century (Smith 1968). Burbot were also abundant and probably competed with lake trout for prey, but catches of this important predator were infrequently recorded because of low market demand. Lake trout and burbot also likely preyed on each other as observed in Lake Superior (Bailey 1972; Conner *et al.* 1993).

Lake Herring production often was the highest of any species in the early Lake Michigan fishery. During the early 1900s harvest reached 11 million kilograms (24 million pounds) (Figure 68). Production dropped shortly thereafter and has never returned to such levels. The annual catch averaged around 4 million kilograms (9.0 million pounds) from 1901-1918 and about 2 million kilograms (4.5 million pounds) from 1919-1938. Except for a brief resurgence in catch in the early 1950s, lake herring harvest continually declined to almost nothing by the 1970s. Green Bay has contributed 87 percent of the lake herring harvest in Lake Michigan since about 1936 when reliable records of Green Bay's portion of the catch were first available (Smith 1956).

Early declines of lake herring in Lake Michigan were largely a result of heavy exploitation, however, pollution must have been a factor in southern Green Bay. It is likely that the resurgence of rainbow smelt to considerable abundance by the early 1950s, in combination with the explosive increase of alewife which began in the mid-1950s, have reduced lake herring to its present insignificance in Lake Michigan.

Seven species of deepwater coregonids were once recognized from the Great Lakes, but Lake Michigan was the only lake to contain all seven (Koelz 1929; Smith 1964). The plastic morphometric and meristic characters of the different species made their taxonomic status questionable and their identification as juveniles difficult, if not impossible (Smith and Todd 1984). The bloater, smallest of the seven species, is the only cisco that has persisted in significant harvestable quantities in Lake Michigan since the 1950s (Brown *et al.* 1987). Hence, the term bloater and chub are now nearly synonymous in reference to the commercial harvest in Lake Michigan.

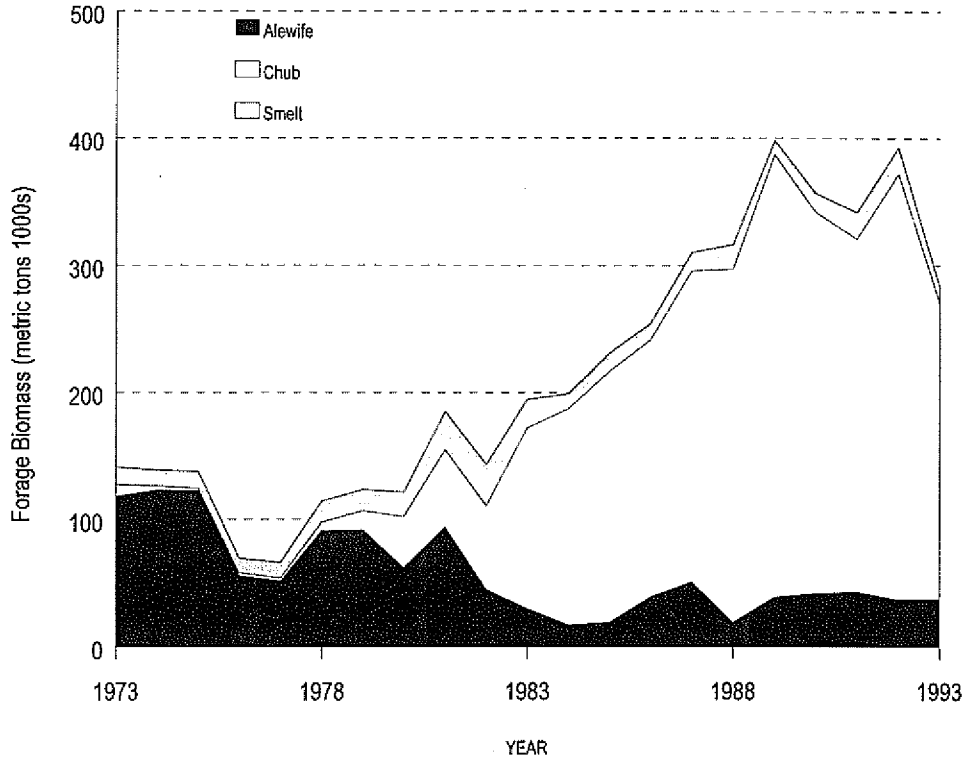


Figure 69. Forage biomass in Lake Michigan, as assessed by U.S.Fish and Wildlife Service bottom trawls, 1973-1993.

Deepwater cisco harvest ranged from around 0.9-2.7 million kilograms (2-6 million pounds) annually from the early 1900s to the early 1950s (Figure 68). In the 1950s and early 1960s, annual harvest averaged approximately 4.5 million kilograms (10 million pounds) with a peak of 5.4 million kilograms (12 million pounds). By the mid-1950s, lake trout and burbot populations were all but extinct, which nearly removed predatory demand on ciscoes; commercial exploitation switched to deepwater coregonids from the collapsing lake herring stocks. Shortly after the peak population explosion and die-off of alewife in the late 1960s, deepwater coregonids experienced year class failure that drove them to near extinction in the 1970s (Figure 68). Environmental conditions favoring recruitment of bloater over alewife, and increasing predation on alewife by stocked trout and salmon populations, allowed the bloater population to rebound significantly during the 1980s to the extent that bloater are the most abundant forage again in Lake Michigan (Figure 69).

Rainbow smelt and alewife are the present nonindigenous components of the offshore pelagic forage community. Rainbow smelt in Lake Michigan originated from a planting in Crystal Lake, Michigan, in 1912 (Van Oosten 1937). The first rainbow smelt reported in Lake Michigan was caught in a commercial net in 1923, near the mouth of the stream through which Crystal Lake drains into Lake Michigan. Rainbow smelt occupied the entire lake by 1936 (Wells and McLain 1972). Commercial production, which had been centered in Green Bay, increased from 39,009 kilograms (86,000 pounds) in 1931 (the first year of record) to 2.2 million kilograms (4.8 million pounds) by 1941 (Figure 68). Harvest dropped abruptly to 2,268 kilograms (5,000 pounds) in 1944 as a result of an epidemic die-off (apparently caused by disease) in the winter of 1942-1943 (Van Oosten 1947). Rainbow smelt stocks quickly recovered and produced a harvest of 4.1 million kilograms (9.1 million pounds) in 1958. Abundance dropped again and has stayed fairly stable since the 1970s. Harvest, which is driven more by market conditions, has remained relatively low until the early 1980s when Lake Erie rainbow smelt production dropped.

The first alewife was recorded in Lake Michigan in 1949 (Miller 1957). By 1957, alewife had dispersed throughout the lake. The population increase was explosive in the late 1950s and early 1960s. Commercial production increased from 99,790 kilograms (220,000 pounds) in 1957 to 2.1 million kilograms (4.7 million pounds) in 1962 and reached a peak of 19 million kilograms (41.9 million pounds) in 1967. Major die-offs of alewife occurred in the spring after spawning and caused major refuse problem for public beaches and even plugged some water intake structures. The abundant and seemingly uncontrollable alewife was also the impetus for introducing Pacific salmon in Lake Michigan. As the trout and salmon stocking program developed a large predator biomass, predation and environmental conditions, such as cold winters, resulted in reduced alewife recruitment in the early 1980s and an eventual decline in their abundance to an estimated 40,000 metric tons (43,956 short tons) (Figure 69).

The lake trout was the most valuable commercial species in Lake Michigan from 1890 until the mid-1940s, and supported the largest lake trout fishery in the world before it was driven to extinction by nonindigenous sea lamprey attacks in the 1940s and 1950s. Beginning in 1890, the fishery was characterized by exceptional stability for several decades (Wells and McLain 1972). In 1890-1911 the catch was consistently high, averaging 3.7 million kilograms (8.2 million pounds). The average annual yield then dropped to 3.2 million kilograms (7.0 million pounds) in 1912-26, and declined further to 2.4 million kilograms (5.3 million pounds) in 1927-1939. The trend was reversed in 1940-1944 when the catch averaged 3.0 million kilograms (6.6 million pounds). The year 1945 marked the beginning of a precipitous decline that culminated in the extermination of the species by 1956. Though fishing pressure was increasing in intensity during the 1940s, sea lamprey predation remains the prime culprit in the dramatic decline of Lake Michigan's indigenous lake trout (Coble *et al.*; Hile *et al.* 1951; Eschmeyer 1957; Holey *et al.* 1995).

Control of sea lamprey was the first step necessary to restore lake trout in the Great Lakes. In Lake Michigan, sea lamprey spawning runs had been confirmed in 79 streams by the end of 1949 (Smith and Tibbles 1980) and initial attempts to control the burgeoning sea lamprey population were targeted on these migrations; first with mechanical weirs (7 were installed in streams along the west and south shore) and later with more effective electromechanical weirs (65 of these combination electrical barrier and mechanical traps were installed and operational by 1958). The impact of these control devices was limited due to a variety of mechanical, physical, and biological problems and many were operated only for a few years. The development of a chemical method to destroy the stream-dwelling larval phase of the sea lamprey (Applegate *et al.* 1961) hastened the demise of the weirs. Only three weirs remained operational beyond 1960, as assessment devices to measure annual changes in the number of spawning migrants. Experimental chemical treatment of tributaries to Lake Michigan began in 1960 and by the close of 1965 most lamprey-producing streams had been treated once. The completion of this first round of treatments and the resultant destruction of stream larval lamprey populations caused the number of adult lampreys captured at index electric weirs to decline by 80-90 percent by 1966.

Reintroduction of lake trout began in 1959, with the release of 35.6 thousand fish on the Sheboygan Reef (Holey *et al.* in press). Major hatchery production of lake trout from the National Fish Hatchery System began in 1965 with 1.07 million fish. The numbers of lake trout stocked into the lake increased steadily until the early 1970s, then leveled off at about 2.4 million fish. As the sport fishery in Lake Michigan grew, so did lake trout harvest. In the early 1980s, a Federal Court upheld lake trout harvest rights of the Chippewa/Ottawa Indians granted in the 1836 Treaty. Chippewa/Ottawa Indians commercial lake trout fishery harvest has averaged around 1.1 million kilograms (2.4 million pounds) (Figure 70).

The environmental catastrophe created by the previously mentioned millions of dead alewife on the beach, caused resource managers to search for solutions. The opportunity made it easy to argue for stocking new species to prey on abundant alewife and provide put-grow-and-take angling opportunities (Tody and Tanner 1966). Coho salmon and chinook salmon stockings, were initiated in 1966 and 1967 respectively. Other non-indigenous trout and salmon stocked since the late 1960s include Atlantic salmon, rainbow trout, and brown trout, tiger trout (brook trout X brown trout) and splake (lake trout X brook trout). Brook trout, indigenous to the tributary streams of Lake Michi-

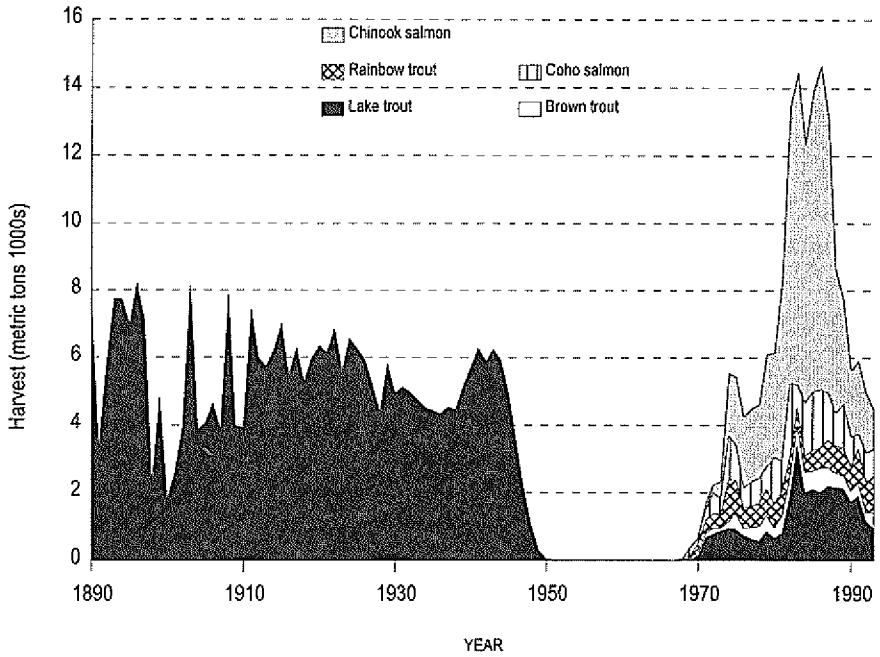


Figure 70. Harvest of the major sport fish species from Lake Michigan, (1890-1993) (data from Lake Michigan Committee).

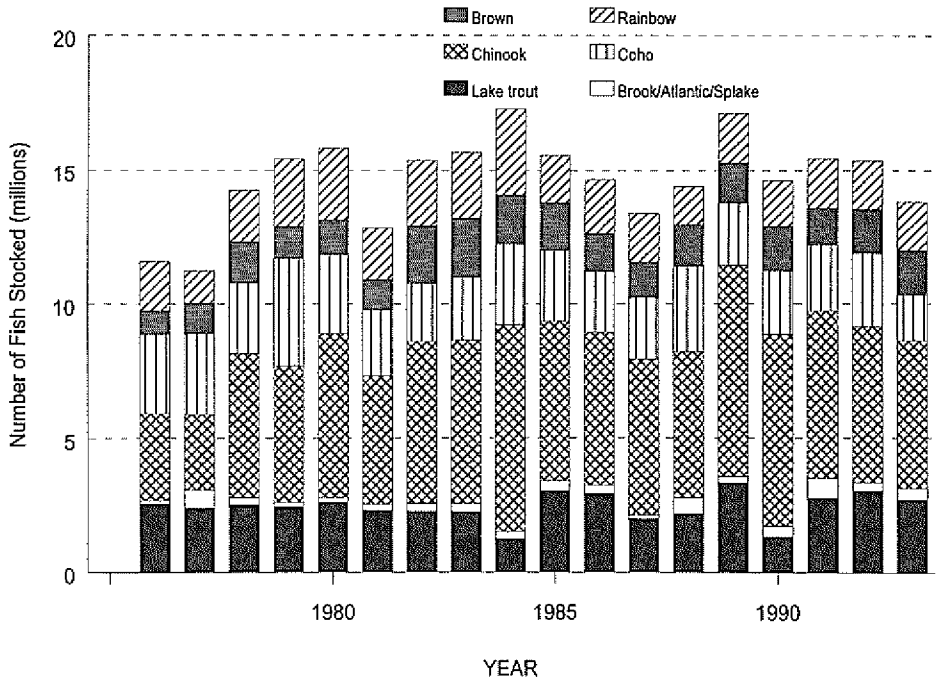


Figure 71. Millions of trout and salmon stocked annually in Lake Michigan,(1976-1993). Species include lake trout, Atlantic salmon, splake, chinook salmon, coho salmon, brown trout, and rainbow trout (data from Lake Michigan Committee).

gan, were also stocked. Numbers of salmon and trout stocked increased through the 1970s, but have remained fairly constant since 1980 (Figure 71). A phenomenal sport fishery followed stocking. As the Pacific salmon reached maturity, lakewide harvest increased dramatically. Interest in the fishery that developed stimulated tourism and recreation economies along the lake shore previously diminished by dead alewife on the beach. Chinook salmon, with its large size and well known fighting reputation soon became the focus of the sport fishery. Total harvest of trout and salmon increased steadily to a peak of 7.3 million kilograms (16.1 million pounds) in 1986 (Figure 70). Average annual harvest during the early 1980s from this multi-species fishery exceeded historical averages for the lake trout fishery by at least three times. Many factors could have contributed to higher harvests in recent years, including: (1) an increase in the primary productivity of the lake due to nutrient enrichment associated with pollution and waste discharge; (2) a more efficient use of food resources by multiple versus single species; (3) higher vulnerability of salmon due to their habit of returning to natal streams; (4) a higher production to biomass ratio for salmon than for lake trout; and/or (5) higher allowable mortality rates, since hatcheries required fewer broodfish than would self-sustaining populations.

In 1988 the first of a series of spring die-offs of chinook salmon occurred, closely matching major drops in catch, which started in 1987 in Michigan waters and 1988 in Wisconsin waters. Many of the dead salmon exhibited severe infections of bacterial kidney disease. The causes of disease outbreak remain unknown. One hypothesis is that inadequate nutrition resulting from a scarcity of alewife triggered disease onset. Another hypothesis is that the disease spread as a result of hatchery rearing practices. Regardless of cause, harvest of chinook salmon was reduced 90 percent by 1992 (Figure 70). With chinook salmon catch down, angling effort also dropped and harvest of all trout and salmon declined to a total catch of around 2.7 million kilograms (6 million pounds); approximately equal to historic indigenous lake trout production (Figure 70).

Of the stocked salmonines, lake trout were assumed to be the species with the greatest potential for self-sustainability, because they were indigenous to the lake (Wells and McLain 1973). Lake trout failure to establish self-sustaining reproduction is disconcerting. Scientists have not been able to conclusively identify the problem. Hypotheses for explaining failure of lake trout reproduction include incorrect stocking locations or procedures, failure to control overfishing, bio-accumulation of chemical contaminants, alewife predation on eggs and larvae, spawning habitat degradation, and/or use of the wrong genetic strains of lake trout. Prior to 1985, changes in stocking approaches and fishing effort confounded the problem, making it impossible to isolate the reason for reproductive failure. However, a comprehensive plan for lakewide rehabilitation was developed and approved by the Lake Michigan agencies in 1985 (Great Lakes Fishery Commission 1985). The rehabilitation plan had a long-term goal of establishing a self-sustaining population capable of yielding 1.1 million kilograms (2.5 million pounds) annually, and emphasized stocking lake trout in the best spawning habitats and controlling fishing mortality. Especially large plants were made in two offshore refuges beginning in 1986 (Figure 72). Some momentum in implementing the new plan, which called for stocking a mixture of lake trout strains, was lost because of mortality in the supplying hatcheries. A full evaluation of the 1985 lake trout rehabilitation plan will not be completed until the late 1990s.

Nearshore fish community

Nearshore fish communities were generally considered more diverse and productive than the offshore communities due to warmer temperatures and higher nutrient levels. Important inshore fish species and their ecological classifications based on feeding strategy are: lake sturgeon, benthivore; lake whitefish, benthivore; emerald shiner, planktivore (Hartman *et al.* 1992); suckers, benthivores; yellow perch, omnivore; and walleye, piscivore. Of all the inshore areas of the lake, the most productive fish communities probably existed in southern Green Bay, other shallow embayments, and in estuaries. Green Bay was also an important spawning ground and nursery area for lake herring, in what otherwise is classified as a percid community (Ryder and Kerr 1990) with walleye, yellow perch, suckers, and northern pike being key species.

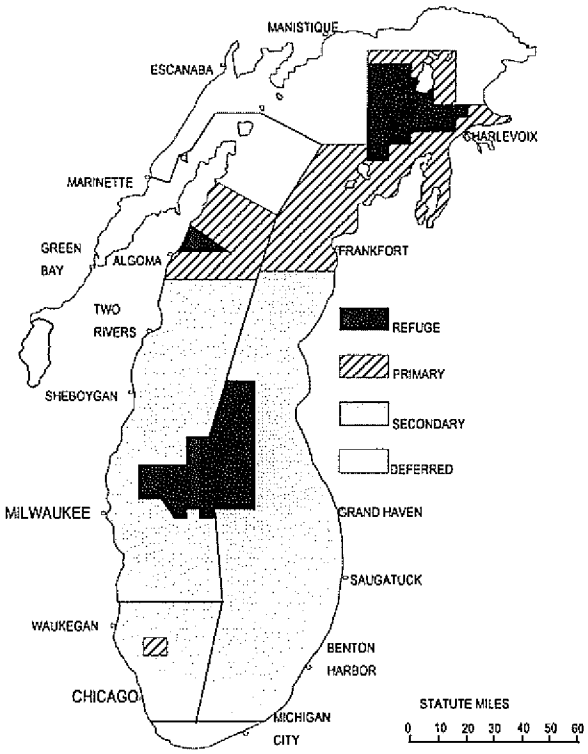


Figure 72. Map of Lake Michigan illustrating lake trout rehabilitation zones (Lake Michigan Technical Committee).

Yellow perch were abundant in nearly all the shallow areas of Lake Michigan, and were important to both sport and commercial fisheries. An abrupt decline occurred in the early and middle 1960s, progressing from north to south, so that by the late 1960s, substantial populations existed only in the extreme southeastern portion of Green Bay (Wells and McLain 1973). The reason for the decline was greatly diminished reproduction, which in turn appears to have been associated with concurrent build-up of alewife. Perch stocks remained low until the 1980s when the alewife population declined. Average total harvest of perch in 1985-1987 was 1.8 million kilograms (3.9 million pounds), but historic commercial yield through 1956, before alewife became prominent, was only half that amount (Figure 68). Poor larval recruitment has led to a series of weak year classes (1990-1994) in the southern basin. A dramatic decline in the population has occurred and alewife predation is again a suspected factor.

Lake whitefish was the mainstay of the early commercial fishery in Lake Michigan (Wells and McLain 1973). It was easily taken in large quantities even in shore seines. Early accounts indicate a substantial decline in the abundance of lake whitefish well before commercial production figures were available. Lake whitefish harvest averaged between 0.5 and 1.4 million kilograms (1 and 3 million pounds) from the early 1900s through the 1950s, before their collapse during the period of alewife increase (Figure 68). Since the mid 1960s, however, lake whitefish stocks and harvest have recovered. Since 1981, the annual harvest has been steady and has not dropped below 2.3 million kilograms (5 million pounds).

Causes of Changes in Lake Michigan Fishery Resources and Management Strategies

Causes of changes in Lake Michigan fishery resources

Combined effects of fishing, habitat destruction, and introduced species have severely disrupted the indigenous fish community (Smith 1972). Before the 1950s these losses were incremental and did not change fundamental food web linkages, except for fishes dependent upon tributaries for spawning such as brook trout, various minnows, and red horse suckers. Of 12 introduced fishes (Bailey and Smith 1981), the unintentional introduction of sea lamprey, first observed in 1936, caused the most disruption because it contributed to the collapse of top predator populations (lake trout and burbot) by the late 1940s (Wells and McLain 1973). Elimination of top predators allowed the alewife, which invaded in 1949, to proliferate and further disrupt the indigenous food webs (Smith 1970).

Alewife are planktivores and their overabundance probably resulted in depression of plankton populations for other planktivores and themselves. Their grazing on pelagic larval fish is believed to have resulted in extinctions of three species of deepwater coregonids and suppression of emerald shiner, lake herring, yellow perch, and deepwater sculpin (Crowder 1980; Eck and Wells 1987). Alewife also have been recently implicated as a possible factor inhibiting success of lake trout reproduction, as they have been observed eating lake trout fry (Krueger *et al.* 1995). Burbot and spoonhead sculpin may also have been depressed by alewife. By the 1960s, the lake was dominated by alewife and to a lesser extent rainbow smelt, another introduced species. By then, the indigenous fish community was severely disrupted and important commercial and angler fisheries had collapsed.

Stocked salmonines were likely responsible for much of the reduction observed in the overabundant alewife population during the 1970s. Alewife were further reduced by low recruitment during the early 1980s, probably due to unfavorable weather conditions (Eck and Wells 1987). Which of these factors, predation or weather, had the biggest effect on reducing alewife abundance is uncertain, but alewife populations declined. Jude and Tesar (1985) reported that alewife declined 86 percent between 1980-1982, and Eck and Wells (1987) reported a six-fold decline during 1981-1983. The alewife decline appeared to have a number of desirable effects. Increases in abundance were observed for several indigenous species, including deepwater coregonids (now reduced to a single species), the bloater, yellow perch, and deepwater sculpin. By 1982, bloaters were more abundant than alewife (Eck and Wells 1987) -- a dramatic change in the Lake Michigan fish community. Despite the declines in alewife and improvements in availability of alternative prey during this period, the salmonines continued to rely primarily on alewife as prey (Figure 73; Jude *et al.* 1987).

Progress in fish community rehabilitation began in 1960, with extension of the sea lamprey control program to Lake Michigan. Smith and Tibbles (1980) provide a thorough history of the sea lamprey invasion of the upper Great Lakes and of control measure implementation. Suppression of sea lamprey was a necessary prelude to re-establishment of piscivores and remains essential. Lake trout planting began in 1965 and coho salmon and chinook salmon were introduced from the Pacific Northwest in 1966 and 1967, respectively. Brown trout and rainbow trout were also extensively stocked (Figure 71). Of the five major salmonines planted, only lake trout was released with the main objective being to re-establish reproducing populations. The main objective for stocking the others was to provide put-grow-take angling opportunities and to control alewife (Tody and Tanner 1966). Sporadic evidence of possible lake trout reproduction has been reported over the years, but sustainable reproduction has not developed. A brief increase in recoveries of unclipped and possibly naturally reproduced lake trout occurred in Grand Traverse Bay in the early 1980s, but recoveries of unclipped fish declined again by the mid-1980s (Rybicki 1983). Natural reproduction of brown trout has also been very limited (Lake Michigan Task Force 1990), but significant reproduction has been established for rainbow trout (Seelbach 1986; Carl 1983), chinook salmon (Carl 1982, 1983; Seelbach 1985), and coho salmon (Carl 1982; Seelbach 1985; Patriarche 1980). In association with salmonine stocking programs, lake whitefish made a spectacular recovery in northern waters (Figure 68).

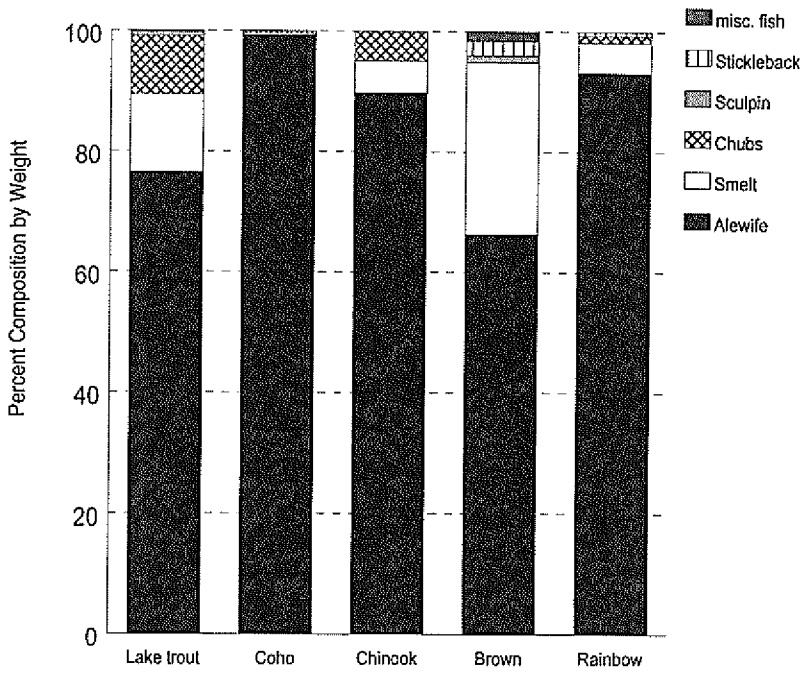


Figure 73. Percent weight composition of diet items for lake trout, coho salmon, chinook salmon, brown trout and rainbow trout in Wisconsin waters for the years 1990 and 1991 combined (Wisconsin Department of Natural Resources).

The collapse of the chinook fishery in the late 1980s raises questions about the sustainability of hatchery-based salmonine fisheries as we have known them since establishment of alewife in Lake Michigan. Recent problems with low egg viability of coho salmon and steelhead eggs in Lake Michigan hatcheries supports concern for the sustainability of the trout and salmon fisheries. As many as 80 percent of coho salmon fry have died at some hatcheries. Management agencies are concerned whether the spawning runs of coho salmon will be large enough to provide enough eggs to compensate for the poor egg survival. As a result, they have recently agreed to reduce the daily limit lakewide. Lakewide predation has maintained alewife at a comparatively low level, even with drastically reduced chinook salmon abundance. The increase of self sustaining stocks of trout, salmon, burbot, bloater, and perch may result in diminished ability to create the desired fish community through stocking. Future fish management in Lake Michigan will need to consider the fish community as a whole, not focus on single species management.

Lake Michigan's fish community will also continue to change as nonindigenous species continue to invade and exert their influence throughout the lake. Yellow perch recruitment has been absent since 1989 in the southern basin of Lake Michigan, even though fry have been found shortly after hatching. Possible causes include interactions with nonindigenous species such as alewife, zebra mussel and spiny water flea, as well as environmental factors. The spiny water flea, a large cladoceran that preys on small-bodied zooplankton, became prominent in 1986 in Lake Michigan. It entered the Great Lakes in ballast water discharged from ocean-going ships (Lehman 1991). The spiny water flea may compete with larval bloater for zooplankton and disrupt the pelagic food web (Lehman 1991). Other invaders from ballast water that may perturb the fish community are the zebra mussel; the ruffe, a perch-like fish that is presently confined to western Lake Superior (Pratt *et al.* 1992); and the round goby, one of two introduced gobies discovered in the St. Clair River in 1990-1991 (Jude *et al.* 1992).

Management strategies in Lake Michigan

The overall goals for the restoration of ecosystem integrity to the Great Lakes have been established primarily through the *Great Lakes Water Quality Agreement of 1978*, as amended in 1987, and the *Strategic Plan for Management of Great Lakes Fisheries* (Great Lakes Fishery Commission 1980). The water quality agreement contains an important goal relating to pollution control which must be attained before healthy fish and wildlife communities can be realized:

> *to restore and maintain the chemical, physical, and biological integrity of the waters of the Great Lakes Basin Ecosystem.*

Fish Community Objectives for Lake Michigan presented seven statements summarizing actions needed to attain the desired fish community:

- *Establish a diverse salmonine community capable of sustaining an annual harvest of 6 to 15 million pounds, of which 20 to 25 percent is lake trout. Establish self-sustaining lake trout populations.*

- *Maintain a diversity of planktivore (prey) species at population levels matched to primary production (autotrophic production) and to predator demands. Expectations are for a lakewide planktivore biomass of 1.2 to 1.7 billion pounds.*

- *Maintain self-sustaining stocks of yellow perch, walleye, smallmouth bass, esocids, catfish, and panfish. Expected annual yields should be 2 to 4 million pounds for yellow perch and 200,000 to 400,000 pounds for walleye.*

- *Maintain self-sustaining stocks of lake whitefish, round whitefish, sturgeon, suckers, carp, and burbot. The expected annual yield of lake whitefish should be 4 to 6 million pounds.*

- *Suppress sea lamprey to allow the achievement of other fish community objectives.*

- *Protect and sustain a diverse community of native fishes, including other species not specifically mentioned earlier (e.g. cyprinids, gar, bowfin, brook trout, and sculpins). These species contribute to the biological integrity of the fish community and should be recognized and protected for their ecological significance, and cultural and economic values.*

- *Protect and enhance fish habitat and rehabilitate degraded habitats. Achieve no net loss of the productive capacity of habitat supporting Lake Michigan's fish communities. High priority should be given to the restoration and enhancement of historic riverine spawning and nursery areas for migratory species. Pursue the reduction and elimination of contaminants where possible to enhance fish survival rates and allow for the promotion of human consumption of safe fish.*

Lake Superior

Historic and Current Status of Fishery Resources

Due to the its great size and depth, many of the biological resources of Lake Superior have been more difficult to study than in the other Great Lakes. Until recently, studies of phytoplankton, zooplankton, and invertebrates have been limited in scope and significance (Matheson and Munawar 1978). Life history studies of important commercial fishes had been done by the 1950s, but did not address the unforeseen interactions among indigenous and nonindigenous species that transformed the fisheries in later years. Appendix II lists species composing the Lake Superior fish community (past and present), and current status of stocks being monitored.

Since the early 1970s, fisheries studies on Lake Superior have been well-coordinated with the formation of the Great Lakes Fishery Commission. Coordination, however, is difficult because management responsibilities are fragmented among several U.S. and Canadian jurisdictions. Under the broad guidance of the *Strategic Plan for the Management of Great Lakes Fisheries*, the agencies of the Lake Superior Technical Committee have made much progress in understanding Lake Superior's fishery ecosystem, in restoring habitats and species, and in joint inter-agency planning (Hansen 1994).

The summary of the history and status of Lake Superior's fish community provided here is not a comprehensive review. For more complete treatments, the reader is referred to Lawrie and Rahrer (1973), Lawrie (1978), MacCallum and Selgeby (1987), and Hansen (1990, 1994).

A total of 94 fish species from 24 families are known from Lake Superior and its tributaries (Appendix II). Seventy-six of the species are indigenous (defined as occurring in 1885, or having entered the system without human influence). Twenty-three of the species are known only from tributary streams, so 71 fish species have inhabited the lake during the past century. Two tributary species have been extirpated from the watershed.

For purposes of description, Lake Superior can be divided into depth zones, each of which is characterized by a unique fish community. There is much interchange of material and energy among the zones due to currents, upwellings, and movements of fish and other organisms.

Offshore fish community

The offshore zone is defined as waters deeper than 73 meters (240 feet) and comprises about 80 percent of Lake Superior or 6.4 million hectares (16 million acres). This zone is occupied by pelagic fishes in the mid- to upper-water column, and bottom-dwelling fishes in the demersal habitat, where darkness is constant and temperatures are stable at 3.9 °C (39 °F). The offshore fish community, consists of 13 species from eight families.

A simple food chain was responsible for most historical fish production in Lake Superior: primary production by phytoplankton in the open lake supported zooplankton, which was eaten by lake herring, which are pelagic in offshore waters. Lake herring made up about half of the historical fishery yield. They were eaten by lake trout, the primary predator and the species of highest commercial value in the fishery, until their decline in the 1950s. Historically some lake trout suspended over deep water during the growing season to prey on lake herring.

Horizontal and vertical movements of invertebrates and fish are important in the energy flow of the Lake Superior fishery ecosystem. Most primary production occurs in the offshore zone because of its huge surface area, and despite its low fertility and phytoplankton density. Zooplankton and the opossum shrimp *Mysis relicta* move vertically in response to light, and fish of the offshore zone, such as lake herring and lake trout, follow these movements. The rain

of organic particles from upper water layers nourishes bottom-feeding fish, such as deepwater coregonids and sculpins. Through seasonal horizontal movement, lake herring and lake trout transfer tons of biomass to inshore areas in the form of sex products, thus benefitting inshore bottom feeders that feed on eggs deposited on the bottom. These energy flow patterns were disrupted when lake trout and lake herring stocks were depleted.

Lake trout were widely distributed in Lake Superior, and formed many local discrete populations, varying in morphology, behavior, and life history (Goodier 1981). These include the "lean" lake trout, the "fat" lake trout (or siscowet), "halfbreeds", and "humpers" (also known as "bankers" or "paperbellies"). Other variants historically pursued by fisheries are now probably extinct.

Lake trout stocks supported large commercial fisheries (Figure 74), with relatively stable harvests of about 1.8 million

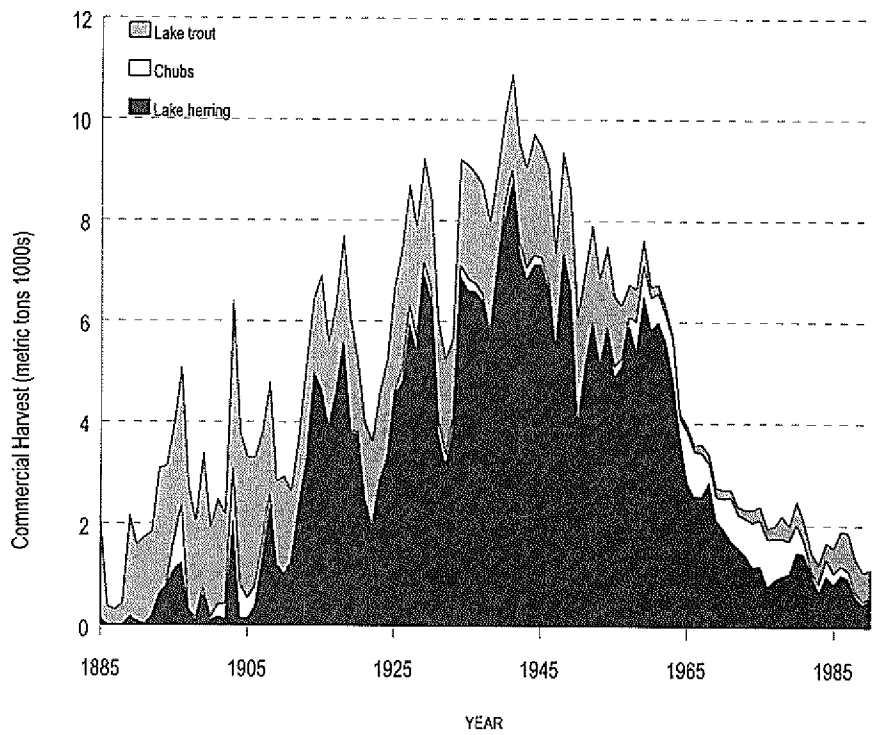


Figure 74. Annual commercial harvest of offshore fishes from Lake Superior, 1885-1990. Offshore fishes are those typically inhabiting waters deeper than 73 m (240 ft). Species include lake trout, chubs, and lake herring (data from Baldwin *et al.* 1979 and Great Lakes Fishery Commission).

kilograms (4 million pounds) per year from 1920 to 1950 (Lawrie and Rahrer 1972, 1973). Abundance declined sharply during the 1950s because of commercial fishing and predation by the sea lamprey (Pycha and King 1975), which had colonized Lake Superior during the 1940s and 1950s (Smith and Tibbles 1980). Harvest of lake trout declined more that 90 percent from 1953 to 1962, when management agencies severely curtailed commercial fishing for lake trout (Pycha and King 1975). Curtailment of commercial fishing for lake trout (approximately in 1962) was associated with the effective chemical treatments to suppress sea lamprey that began in 1958 in Lake Superior tributaries. By 1961, these treatments had reduced sea lamprey numbers by 85 percent (Smith *et al.* 1974).

By the time sea lamprey control became effective, lake trout stocks had been extirpated or reduced to remnant populations. Stocking of hatchery lake trout caused abundance to increase rapidly in parts of the lake in the 1960s and 1970s

(Pycha and King 1975). Stocking of hatchery lake trout averaged 2.5 million annually between 1970 and 1983, and 3.3 million between 1984 and 1992 (Ebener 1989; Hansen 1994). However, survival of stocked lake trout declined significantly in the 1980s (Hansen *et al.* 1994), probably due to competition or predation experienced soon after stocking. Remnant wild stocks have recovered slowly but steadily since 1961 (Swanson and Swedberg 1980; Curtis 1990; Hansen 1990). Now the maintenance of lake trout stocks in Lake Superior depends mostly on natural reproduction, rather than stocking (Hansen *et al.* 1994). Reproduction has increased markedly since 1970, but the increase has slowed since the mid-1980s (Hansen *et al.*, in press), and numbers of wild lake trout have decreased in some zones, probably due to commercial fishing (Peck and Schorfhaar 1991). According to Hansen *et al.* (1994), "Lake trout restoration may now depend on prudent management of naturally reproducing stocks, through reduction of fishing effort and sea lamprey abundance."

Ashland Fishery Resources Office photo

Lake herring stocks declined drastically in the 1950s and 1960s (Figure 74), after lake trout stocks had crashed. From 1916 to 1940, a historical reference period used as a benchmark by Lake Superior fishery managers, lake herring made up 64 percent of the total commercial landings (Baldwin *et al.* 1979). However, by the 1970s, lake herring were scarce in much of Lake Superior. The decline began in Minnesota, perhaps as early as 1941, when harvest first fell below that State's historical average of 2.7 million kilograms (5.9 million pounds). Similarly, landings dropped below the historical Wisconsin average in 1963 of 0.7 million kilograms (1.5 million pounds) and in Michigan in 1970 of 0.7 million kilograms (1.5 million pounds). In Ontario, commercial landings remained near the historical average of 0.9 million kilograms (2.0 million pounds) until 1988, when harvest fell to 0.4 million kilograms (0.9 million pounds), due to a sharp decline in the important Black Bay stock. The lake herring's niche of pelagic grazer was virtually vacant for about 30 years. In the other Great Lakes, this niche had been filled by the nonindigenous immigrant alewife and rainbow smelt, but low temperatures limited alewife abundance to a very low level in Lake Superior (Bronte *et al.* 1991).

Since about 1983, however, lake herring biomass has increased more than tenfold, though not in all parts of the lake (Hansen 1994). Fishery managers view the strong recovery of lake herring as one of the most important and positive occurrences in Lake Superior in recent decades.

Lake Superior supports three species of deepwater coregonids, close relatives of the lake herring also known as "chubs". Some literature (e.g. Lawrie 1978) lists additional species in Lake Superior, but specimens of bluefin, blackfin, or shortnose ciscoes have been re-classified as shortjaw ciscoes (Becker 1983). The chubs are less pelagic than lake herring, and generally feed near the bottom. They are important forage for lake trout and burbot.

Commercial harvest of chubs (Figure 74) has never been separated by species, because they are so similar in appearance. However, shortjaw cisco made up about 90 percent of commercial harvest in the 1920s (Koelz 1929). After 1950 the commercial harvest shifted to the smaller kiyi and bloater (hoyi) as the shortjaw declined (Lawrie 1978). Currently the shortjaw cisco is a Category 2 species under consideration for Federal endangered or threatened status by the Service. Since the 1970s, commercial harvest and abundance of chubs have declined markedly (MacCallum and Selgeby 1987; Hansen 1994). Increasing predator stocks, especially the siscowet lake trout (Hansen 1994), may be exerting heavy predation on chub populations.

Introduced species of Pacific salmon have been important in the Lake Superior fish community since the late 1960s. Pink salmon were inadvertently introduced in 1956, and coho salmon and chinook salmon have been stocked for sport fishing since 1967. The pink salmon is a relatively small fish that feeds mostly on plankton. It reproduced in Lake Superior and became quite abundant in the late 1970s, but has since declined (Bagdovitz *et al.* 1986). However, conclusions of a general decline in pink salmon may be premature (Kelso and Noltie 1990).

Coho and chinook salmon range widely in Lake Superior, becoming pelagic as adults. They spawn in tributary streams, and have both established self-sustaining populations. Coho salmon likely reproduce in all Lake Superior streams that have suitable spawning substrate and are accessible during the spawning period (Hansen 1994), but little reproduction occurs in Minnesota streams. Coho salmon spawning runs are highly variable from year to year, resulting in high variation in sport harvest. Chinook salmon have been observed spawning in numerous streams in the U.S. and in most large rivers in Canada (Hansen 1994), though spawning runs have declined in recent years. Recent studies of marked stocked fish revealed that most coho and chinook salmon in Lake Superior are produced through natural reproduction. Both species are known to be infected with bacterial kidney disease, which may threaten their natural populations (Hansen 1994).

Inshore fish community

The inshore habitat of 9-73 meters (30-240 feet) depth makes up 18 percent of Lake Superior, or about 1.4 million hectares (3.6 million acres). This zone is very narrow in some parts of the lake, especially the Minnesota north shore, the northeast shore in Ontario, and portions of Michigan waters. The most productive portions of Lake Superior have a relatively broad inshore zone, such as southwestern Lake Superior (Apostle Islands and Chequamegon Bay), the three large bays, Nipigon, Black, and Thunder Bays in Canada, and Whitefish Bay in the southeast.

The inshore fish community is dominated by 14 species, of which half also occur in the offshore zone. Seven families are represented in this fish community. The inshore habitat is occupied by important bottom-feeders, including lake whitefish and longnose sucker. Several fishes of the offshore and nearshore zones use the inshore seasonally for spawning or feeding. For example, spawning lake herring congregate over reefs and flats in the inshore area, depositing eggs that are fed upon by inshore fishes. Walleye and other nearshore fishes move into water deeper than 9 meters (30 feet) in warm summers when temperatures are favorable.

Lake whitefish have been and continue to be an important Lake Superior commercial species (Figure 75). The fishery has passed through several episodes, characterized by different trends in harvest (Lawrie 1978). Harvest increased since 1961, the year sea lamprey control became effective, until about 1990, and in recent years has been at historically high levels (Hansen 1994). Most of the increase resulted from fishing-up of previously unfished or lightly fished stocks; however, heavily fished stocks have also maintained or increased their abundance (Hansen 1994). Recent commercial harvest has exceeded 1.1 million kilograms (2.5 million pounds) per year.

Adult rainbow smelt occupy the inshore, and since the 1950s been the major food of salmonid predators (Dryer *et al.* 1965; Conner *et al.* 1993). After lake herring stocks collapsed, the lean lake trout utilized inshore habitat to prey on rainbow smelt. Rainbow smelt abundance remained high in inshore waters, especially in western Lake Superior, until 1978-1981, when biomass declined by 90 percent due to high mortality of rainbow smelt older than 2 years (Selgeby 1985). Abundance has varied considerably since 1981, as rainbow smelt have produced strong year classes, but have continued to undergo high levels of mortality (Hansen 1994).

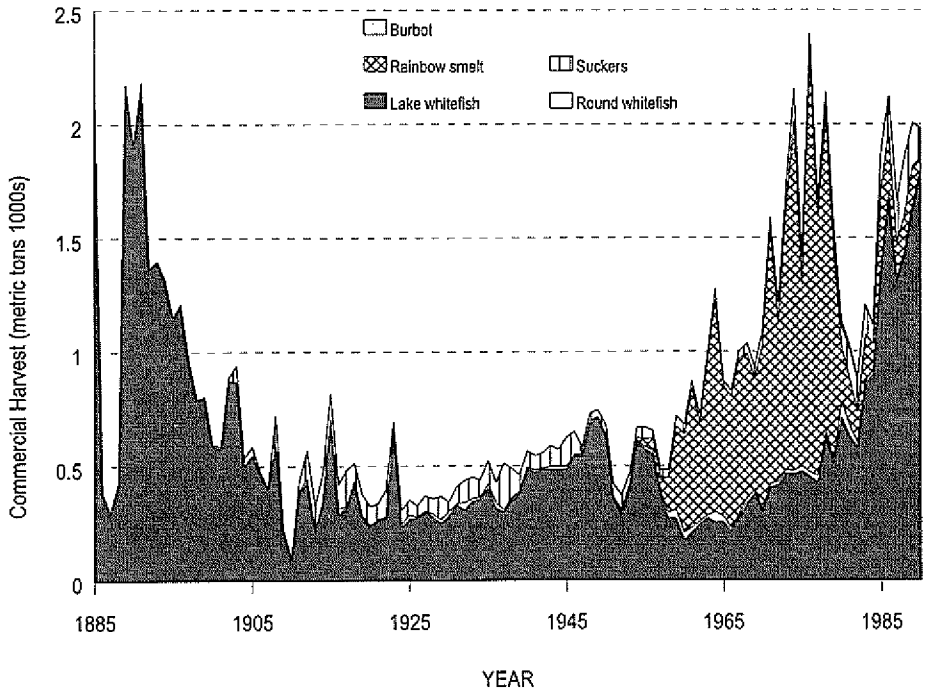


Figure 75. Annual commercial harvest of select inshore fishes from Lake Superior, 1885-1990. Inshore fishes are those typically inhabiting waters between 9 and 73 m (30-240 ft) in depth. Species include burbot, suckers, rainbow smelt, round whitefish and lake whitefish (data from Baldwin *et al.* 1979 and Great Lakes Fishery Commission),

Nearshore fish communities

The nearshore habitat less than 9 meters (30 feet) in depth makes up only 2 percent of Lake Superior, or about 160,000 hectares (400,000 acres). Its importance is much greater than its proportion of the lake, being the most productive habitat, with the most diverse biota. Fifty-two fish species of 19 families are recorded from the nearshore habitat. Nine of the species are nonindigenous, including five that were probably introduced accidentally via ship ballast water.

The nearshore should be further subdivided into the open nearshore and coolwater bays. The open nearshore is a coldwater habitat subject to strong currents and wind-generated turbulence. This habitat supports a less diverse fish community, with coldwater species that prefer temperatures of 10-15.5 °C (50-60 °F). The fish community of coolwater bays resembles that of many northern inland lakes, with species that prefer temperatures of 18.3-23.9 °C (65-75 °F) during the growing season.

Rainbow trout and brown trout are nonindigenous to Lake Superior, but are long-time residents that have reproduced in the lake since about 1900. Both species occupy open nearshore habitat while in the lake, and spawn in tributary streams. They are popular sport fish in lake or stream, and continue to be stocked for sport fishing.

Lake sturgeon has been recommended for official threatened status (Williams *et al.* 1989), and is a Category 2 species under consideration for Federal listing by the Service. The sturgeon was once abundant in estuaries and nearshore waters, but was nearly extirpated from Lake Superior (Lawrie 1978). A commercial harvest of 101,605 kilograms (224,000 pounds) was recorded in 1885, and fell steadily thereafter (Lawrie and Rahrer 1973) due to overfishing and

habitat destruction (Figure 76). Lake sturgeon first mature and spawn at an age of over 20 years, so many years of protection are required to restore stocks. The extirpated stock in the St. Louis River of Minnesota and Wisconsin is being restored through stocking. Abundance is increasing steadily, but the fish have not yet reached the age of sexual maturity. In the U.S., the Bad River in Wisconsin and the Sturgeon River in Michigan are the only two remaining tributaries supporting naturally reproducing stocks.

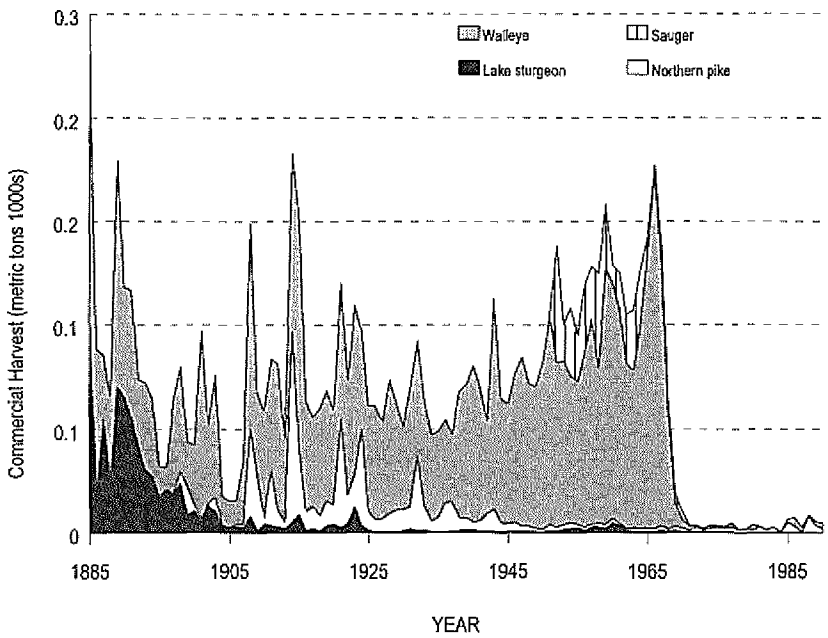
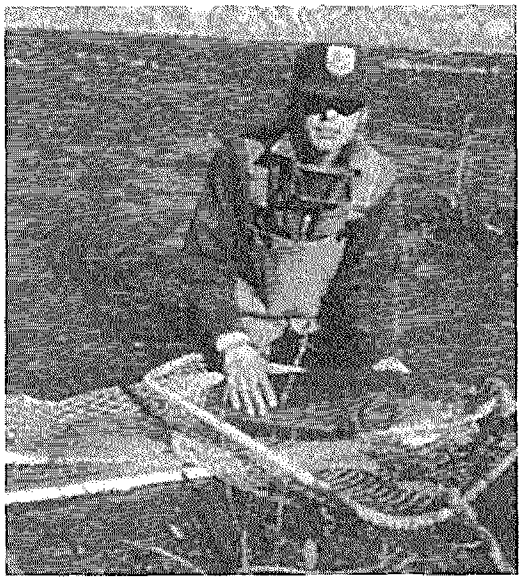


Figure 76. Annual commercial harvest of nearshore fishes from Lake Superior, 1885-1990. Nearshore fishes are those typically inhabiting waters less than 9 m (30 ft) in depth. Species include sauger, walleye, northern pike, and lake sturgeon. (data from Baldwin *et al.* 1979 and Great Lakes Fishery Commission)

"Coaster" brook trout were once the only trout of nearshore waters, before the introduction of rainbow and brown trout. Coaster brook trout were abundant in the catches of early anglers. Robert Barnwell Roosevelt (1865) wrote:

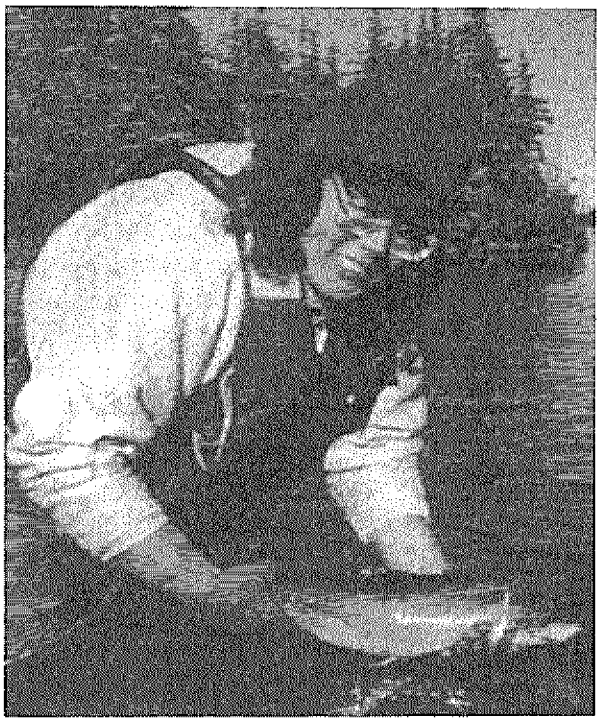
> *"The finest trout fishing in the world is to be obtained at Lake Superior; ... nowhere is to be found the same abundance of trout, averaging above two pounds, and wonderfully game and vigorous.... The entire rocky shore of the lake, along both coasts, is one extensive fishing grounds, where the skillful angler can at any point find delightful sport; the innumerable tributaries, large and small, of the British or American territory, unless shut out by precipitous falls, are crowded with myriads of the speckled beauties; and the rapids at the outlet furnish trout of the largest size...."*



Ashland Fishery Resources Office photo

Roosevelt also warned that coaster populations were declining, as early as the mid-1800s. Abundance of coaster brook trout fell to very low levels due to overfishing, loss of suitable habitat, and competition with introduced trout and salmon (Hansen 1994). The largest existing population spawns in the Nipigon River, Ontario. Remnant populations also exist in some other Ontario and Michigan streams (Hansen 1994).

Walleye are locally important in the nearshore waters of Lake Superior, especially in coolwater bays. Walleye in Lake Superior tend to be slow-growing and long-lived (Schram *et al.* 1992). Most walleye stocks in Lake Superior declined due to fishing (Schram *et al.* 1991), though habitat degradation has also been a significant problem (Ryder 1968). Walleye have partially recovered with the assistance of fishing regulations, habitat restoration, and stocking (Hansen 1994).



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Tributary fish communities

Lake Superior has a small, steep watershed, so tributary streams are relatively short and numerous. Lawrie and Rahrer (1973) counted 1,525 tributary streams, of which 840 are in the United States. Many of these streams are intermittent, but all convey runoff to the lake at some time each year.

Stream habitat is diverse, due to the diverse geological formations that make up the watershed. Many high-gradient coldwater streams support low-diversity fish communities of trout, salmon, dace, and sculpins, while a lesser number of low gradient streams support cool and warmwater fish communities. Twenty-three species of eight families are known only from tributary streams. All but two of these species are indigenous, and 13 of the 23 are members of the minnow family, Cyprinidae. However, many fishes of Lake Superior enter tributaries to spawn, or are found in both streams and nearshore lake waters. Two tributary species of limited distribution, the Arctic grayling and paddlefish, have been extirpated from the watershed.

Moore and Braem (1965) recorded fish collected coincident to sea lamprey investigations on 175 tributaries. They found 71 species of 20 families. Among the most widely distributed were sea lamprey, rainbow trout, brook trout, rainbow smelt, longnose dace, blacknose dace, common shiner, creek chub, white sucker, longnose sucker, mottled sculpin, and burbot.

Causes of Changes in the Lake Superior Fishery Resources and Management Strategies

Causes of changes in Lake Superior fishery resources

The Lake Superior fish community has been subjected to a series of stresses that affected it temporarily or permanently. During the logging era of the late 19th and early 20th centuries, "shallow-water benthic environments were

ruinously affected by the deposition of sawdust and other woody, allochthonous materials" (Lawrie 1978). Sturgeon, whitefish, and some other river and estuarine stocks were lost or adversely affected.

Later in the 20th century, widespread low-level contamination of fishes by organic compounds and heavy metals has been measured. Contaminants entered from point sources, and from aerial deposition. Adverse effects on fish have not been observed in Lake Superior, but cannot be ruled out. Several of the contaminants, notably mercury, dioxin and PCBs, are known to cause chronic and acute human health effects at sufficiently high levels. Excessive levels of mercury and PCBs have caused State health agencies to issue advisories, warning people to limit consumption of lake trout, siscowet, walleye, chinook salmon, northern pike, white sucker, lake whitefish, and yellow perch (Busiahn 1990). Point sources of contaminants still exist; the Copper Range Company in Ontonagon County, Michigan, about 8 kilometers (5 miles) from Lake Superior, continues aerial discharges of large quantities of mercury, lead, and copper, as well as contaminated sediments. Other continuing sources of pollution in the Lake Superior watershed include the Murphy Oil Company in Superior, Wisconsin, mining activity in Minnesota, and pulp- and paper-mill effluent in Ontario (Hansen 1994)

A third stress on the fish community was the fishery itself. Uncontrolled fishing by the "aggressive and enterprising commercial fisheries" produced the destabilizing effects of intense size-selective predation (Lawrie 1978). The fishery was probably too intensive to persist for long at that level, but the invasion of the sea lamprey doomed the fishery. According to Waters (1987):

> *"[I]t is now generally accepted that, by 1950, the fish community of Lake Superior had been brought to the sharp edge of a catastrophe, ready to give way at any time. A system of instability, lacking the checks and balances that had evolved over millennia of natural evolution, had gradually crept up over a mere 100 years, unseen in the euphoria of abundance. The sea lamprey was the factor that caused the sharp edge to crumble, and the biological system collapsed."*

Sea lamprey were first noted in Lake Superior in 1946, and by the late 1950s had nearly destroyed the lake trout population. A successful search for a control method culminated in the treatment of sea lamprey spawning streams with the toxicant TFM starting in 1958. The ensuing history of the sea lamprey has been extensively documented (e.g. Smith *et al.* 1974; Smith and Tibbles 1980).

Lake herring declined dramatically in the 1950s and 1960s. Researchers have debated the cause of the lake herring declines. Anderson and Smith (1971) argued that increasing populations of rainbow smelt and bloater influenced lake herring through competition during larval stages. Rainbow smelt were first recorded in Lake Superior in 1930 and became abundant during the 1950s. However, Selgeby *et al.* (1994) found competition between larval rainbow smelt and lake herring to be "almost nonexistent". Anderson and Smith (1971) argued that overfishing was not correlated with the decline of lake herring, but Selgeby (1982) showed that lake herring stocks in the Apostle Islands of Wisconsin were sequentially "fished-up" during the fall while segregated into discrete spawning stocks. Peck *et al.* (1974) reached the same conclusion when they studied the Michigan commercial fishery. Thus commercial harvest and catch rates remained deceptively high as the fishery depleted discrete stocks and then moved on to yet productive ones. Neither Anderson and Smith (1971) nor Selgeby *et al.* (1978) found predation on young lake herring to be a major factor in suppressing lake herring stocks.

Lake herring abundance in U.S. waters has increased sharply since 1981, though the recovery has not occurred in all areas. A demonstrated preference by most trout and salmon for rainbow smelt may have allowed the strong resurgence of lake herring. Since the 1960s, rainbow smelt have dominated the diets of inshore lake trout and other salmonid predators (Dryer *et al.* 1965; Conner *et al.* 1993). Rainbow smelt and coregonines (e.g. lake herring and chubs) have not been consumed in proportion to their abundance; most salmonine predators consistently selected rainbow smelt during the 1980s, though coregonine biomass was more than double that of rainbow smelt (Conner *et al.* 1993). Only offshore lake trout diets were dominated by coregonines. More recently, increased occurrence of coregonines in

the diets of lake trout has been observed (Gallinat 1993), and wild lake trout have been found to have a more diverse diet, consuming fewer rainbow smelt than hatchery-produced fish (Hansen 1994).

Stocking of fish has caused major changes in the fish community. Angling opportunities have been diversified by introduced trout and salmon species, but ecosystem effects have been unpredictable and difficult to monitor. According to Waters (1987):

> *"At one time or another, almost every salmon, Atlantic and Pacific, was tried in the Great Lakes, but all failed. We think today that the reason for these early failures was that the indigenous lake trout-whitefish-lake herring-chub system was so well established and stable that nonindigenous species could not penetrate it. But that indigenous stability was lost.... New predators now successfully share the position of top predators with the lake trout and burbot; new forage species replace the old as food for the predators. The system is more complex now, and more difficult to understand, for the newcomers have different environmental requirements with respect to ... water depth, temperature, food, and spawning needs."*

Several introduced predator species reproduce naturally, but stocking continues. The impact of stocked predators on the forage base, and ability of the forage base to sustain projected stocking levels are poorly known (Busiahn 1985, Negus 1992). In recent years, rainbow smelt have been the primary prey of most trout and salmon species (Conner *et al.* 1993), and rainbow smelt populations have experienced a sharp decline and continuing high mortality (Hansen 1994). Lake trout growth rates were lower in the 1970s, when rainbow smelt dominated their diets, than in the 1950s, when lake herring were the major food (Busiahn 1985). Chinook salmon consume large amounts of food in a short time, and could be formidable competitors if the supply of forage fish is limited (Negus 1992). Conner *et al.* (1993) found that coho salmon consume large amounts of rainbow smelt, but selected rainbow smelt of a smaller size than did lake trout or chinook salmon. Diets of coho salmon also included large numbers of terrestrial and aquatic insects. Long-term stability in the fish community will likely depend on the coregonine forage base, especially lake herring.

The nearshore fish community has been most affected by human land use activities in the Lake Superior basin. Relationships between land use and the fish community can be direct and obvious, or subtle and difficult to discern. They can be of a positive nature, though most are negative. Fifteen uses of land in the Lake Superior basin were identified, and placed into four categories. Thirteen effects on the fish community were identified, and grouped into eight categories. A matrix of land uses and effects was constructed to examine the interactions (Tables 9-11). The tables indicate interactions among land uses and nearshore fish community effects, but do not describe those effects. Nevertheless, they indicate some interesting patterns.

For example, trapping of furbearers, a major industry in the Lake Superior country in the early 1800s, may have had several effects on the fish community, most probably positive (Table 9). The depletion of beaver would have resulted in the eventual breakdown of dams that obstructed streams. As a result, many small streams may have been opened to migratory fish passage. Removal of dams may also have reduced other negative effects such as widening and warming of streams, and siltation of spawning areas. The removal of otters would have reduced a source of mortality of nearshore and stream-dwelling fishes. On the other hand, fur companies were the first major commercial exploiters of fish for market, and began the ruinous "fishing-up" of Lake Superior's valuable fish stocks (Waters 1987).

The negative effects of logging (Table 9) were pervasive, though mostly indirect. The removal of the forest canopy opened streams to direct sunlight, and exposed soils to erosion. Fires that followed the liquidation of the forest led to further erosion and sedimentation, which buried productive riffle areas with sand. Stream flows became more variable with higher water temperatures. The transportation of logs in log drives caused short-term devastation of stream habitat. Perhaps the only positive thing to be said about logging was that runoff from the logged-out, burned-up landscape may have temporarily increased fertility of receiving waters through increased nutrient levels.

Table 9. Effects of extractive land uses on the nearshore fish community of Lake Superior (X = effect present).

	Extractive Land Use				
	Subsistence	Trapping	Logging	Mining	Agriculture
Habitat Destruction					
Filling			x	x	
Damming		x			
Habitat Alteration					
Spawning substrate		x	x	x	x
Stream flows		x	x		x
Temperature		x	x		x
Species Introductions					
Nutrification			x		x
Secondary Effects					
Food Chain			x	x	x
Tainting				x	x
Direct Mortality	x	x			
Fishery Harvest	x	x			
Low Level Stressors					
Chemical				x	x
Biological					

Table 10. Effects of industrial land uses on the nearshore fish community of Lake Superior (X = effect present).

	Industrial Land Uses				
	Sawmills	Pulp/Paper	Oil/Chemical	Power Plants	Hydropower
Habitat Destruction					
Filling					
Damming					x
Habitat Alteration					
Spawning substrate	x	x			
Stream flows					x
Temperature				x	x
Species Introductions					
Nutrification					
Secondary Effects					
Food chain		x			
Tainting		x	x		
Direct Mortality			x	x	x
Fishery Harvest					
Low Level Stressors					
Chemical		x	x	x	
Biological			x		

Table 11. Effects of transportation and social land uses on the nearshore fish community of Lake Superior (X = effect present).

	Transportation and Social Land Uses				
	Highways	Marine	Railroad	Urbanization	Recreation
Habitat Destruction					
Filling	x	x		x	
Damming					
Habitat Alteration					
Spawning substrate	x	x		x	
Streamflows				x	
Temperature				x	
Species Introductions		x	x		x
Nutrification				x	x
Secondary Effects					
Food chain					
Tainting					
Direct Mortality					
Fishery Harvest	x		x	x	x
Low Level Stressors					
Chemical	x			x	
Biological					

Hydropower dams were built on several rivers flowing into Lake Superior (Table 10). Dams may block migration and reduce the productive capacity of these systems for anadromous fishes. In the U.S., these include the St. Louis River in Minnesota; the Iron, White and Montreal Rivers in Wisconsin; and the Autrain, Dead, Ontonagon and Sturgeon Rivers in Michigan. In Canada, the Nipigon River and others have been similarly affected. Several of the dams were constructed at high-gradient sites, where fish migration was naturally blocked, in which case most impacts were experienced through alteration of downstream flow. Manipulation of flow to meet peak electrical demand has often left fish stranded and fish eggs and fry desiccated. Examples include coaster brook trout in the Nipigon River, Ontario; walleye in the St. Louis River, and lake sturgeon in the Sturgeon River, Michigan.

Most effects of land use are reversible, but irreversible effects have the greatest long-term impact. The introduction of non-indigenous species (Table 11) through deliberate planting, accidental planting, ship ballast water, or opening of waterways to colonization produces effects that will likely never be reversed.

Management strategies in Lake Superior

Agencies responsible for managing Lake Superior fisheries agreed on the desired state of the fish community when they adopted the *Fish Community Objectives for Lake Superior* (Busiahn 1990), as directed in the *Strategic Plan for Management of Great Lakes Fisheries*. Signed by all agencies with management responsibilities for Great Lakes fisheries, the plan commits signatory agencies to plan for restoration and maintenance of desirable fish communities using a strategy of consensus. *Fish Community Objectives for Lake Superior* is a product of the consensus process.

The fish community objectives serve as a template for *State of the Lake* reports for Lake Superior. It is expected that the fish community objectives will be revised, strengthened, and made more specific during the period between *State of the Lake* reports. Two *State of Lake Superior* reports have been produced by the Lake Superior Technical Committee (Hansen 1990, 1994). The latter report includes recommendations for revision of the fish community objectives based on changing conditions and new knowledge.

By systematically setting objectives and reporting on progress for the whole-lake fish community, the Lake Superior Committee focuses attention on critical fisheries issues, and enhances communication and understanding on those issues among agency personnel, habitat protection agencies, political bodies, and the general public.

Fish Community Objectives for Lake Superior presented eight statements summarizing actions needed to attain the desired fish community:

> *Rehabilitate stocks of lake herring to historical levels of abundance for the purposes of lake trout rehabilitation, production of other predators, and fishery harvest. (Reference period: 1929-1943).*
>
> *Achieve a sustained annual yield of 4 million pounds of lake trout from naturally reproducing stocks (Note: historic yield probably included siscowets), and an unspecified yield of other salmonid predators, while maintaining a predator/prey balance which allow normal growth of lake trout.*
>
> *Manage exploitation of non-depleted stocks of other species to maintain stable self-sustaining status, for example lake whitefish, chubs (deepwater coregonids), suckers and walleye.*
>
> *Re-establish depleted stocks of other indigenous species, for example lake sturgeon, brook trout and walleye.*
>
> *Achieve a 50 percent reduction in parasitic-phase sea lamprey abundance by 2000 and a 90 percent reduction by 2010. (Reference point: 1986)*
>
> *Achieve no net loss of the productive capacity of habitats supporting Lake Superior fisheries. (No reference point identified; no habitat inventory currently available).*
>
> *Restore the productive capacity of habitats that have suffered damage.*
>
> *Reduce contaminants in all fish species to levels below consumption advisory levels.*

In addition to the objectives, the Lake Superior Committee identified issues that must be addressed in future joint planning for the fish community:

> *Habitat quality and quantity are the ultimate constraints on future benefits ... from the fish community.... Existing habitat [should be inventoried] for the purpose of measuring change, and ... fish habitat needs [should be placed] high on the agenda of environmental decision-makers.*
>
> *The management status of rainbow smelt must be agreed upon to guide coordinated fishery harvest and predator stocking strategies.*
>
> *The Lake Superior Committee must move toward a system of allocating forage stocks toward production of predators and fishery harvest...to guide stocking and harvest decisions.*
>
> *Lake Superior predator stocks can likely be totally supported by natural reproduction, though stocking may be necessary to provide harvest opportunities in some geographic areas.*

During later discussions, Lake Superior Committee agencies agreed that rainbow smelt are an undesirable species that should not be protected from harvest.

To coordinate management of non-depleted stocks and restoration of depleted stocks, the Lake Superior Committee has established subcommittees dealing with walleye, lake sturgeon, brook trout, and steelhead (anadromous rainbow trout), with the following charges: 1) exchange management information among Lake Superior agencies; 2) develop a lakewide status report; 3) develop lakewide objectives for inclusion in the Fish Community Objectives; 4) develop a lakewide restoration plan to achieve the objectives; and 5) report on progress through the *State of the Lake* reports.

In 1986 the Lake Superior Committee approved the first *Lake Trout Rehabilitation Plan for Lake Superior*, including requirements for stocking of hatchery fish and for controlling fishing and sea lamprey-induced mortality. The goal of the plan, to achieve a 1.8 million kilogram (4 million pound) yield of lake trout from self-sustaining stocks, was incorporated into the fish community objectives. One of the primary measures of progress toward the goal was a total annual mortality rate not exceeding 50 percent, as measured using standard gillnet assessment techniques in spring. (This figure is recognized as an index to mortality, because the standard technique over-estimates actual mortality.) Later the Lake Superior Committee revised the maximum allowable mortality rate downward to 45 percent, based on advice from the Lake Superior Technical Committee.

At this writing, a revised *Lake Trout Restoration Plan for Lake Superior* has been drafted by the Lake Superior Technical Committee and is in the final stages of approval by the Lake Superior Committee. Quantitative goals for management of lake trout and associated species include:

- *Restore self-sustaining stocks of lake trout (including siscowets) that can yield an average of 1.8 million kilograms (4 million pounds), the average annual yield in 1929-43.*

- *Restore lake herring abundance to historic levels that can sustain an annual yield of 4.9 million kilograms (10.9 million pounds).*

- *Achieve recruitment of at least 3.6 million 1.5-year-old lake trout lakewide, with adequate recruitment in each management area.*

Though Lake Superior fishery agencies have recognized the need to allocate forage stocks for production of predators and fishery harvest (Busiahn 1990), the scientific basis for allocation of forage is poorly developed. In Minnesota waters, Negus (1992) used a bioenergetics model to relate predation to available prey, and found large unexplained discrepancies. Estimates of available rainbow smelt and coregonines (lake herring and chubs) were far lower than estimates of consumed and harvested rainbow smelt and coregonines. Negus identified and prioritized information needed for effective bioenergetics modeling, the most critical being improved estimates of forage fish biomass at all depths and positions in the water column.

Even with improved information, however, managers have few ways to allocate forage stocks. The sport and commercial harvest of predators and prey can be controlled to some degree. Lake Superior fishery managers have recommended that lake herring be protected through appropriate commercial fishing regulations so that stocks can recover, while supporting increased predation by lake trout (Hansen 1994). However, lake herring harvest is not regulated in some jurisdictions; in those cases, low market prices have provided the only real protection from the commercial fishery. Fishery management agencies have also agreed that rainbow smelt are an undesirable species that should <u>not</u> be protected from harvest. Strict regulations on lake trout harvest are in place throughout Lake Superior. Generally, State and Native American Tribal governments and their constituents have made great strides in controlling lake trout harvest.

Stocking of predators also provides some control over the allocation of forage. The Lake Superior fishery management agencies have recognized that predator stocks can likely be totally supported by natural reproduction, though stocking may be necessary to provide harvest opportunities in some geographic areas (Busiahn 1990). More recently,

fishery managers jointly recommended that stocking programs and fisheries should not compromise any naturally reproducing salmonine population, including lake trout (Hansen 1994). Lake trout stocking criteria have been proposed in the revised restoration plan. Stocking of other salmonids continues in most jurisdictions, but managers and many of the general public increasingly realize the limitations of stocking.

Implementation of fishery habitat objectives "no net loss of productive capacity and restoration of damaged habitats" is hampered by inadequate habitat inventories (Hansen 1994). General inventories of important spawning grounds have been completed, partly based on anecdotal information (Coberly and Horrall 1980; Goodyear *et al.* 1982). However, few inventories exist for fish habitat in tributaries and wetlands. Changes in fish habitats need to be monitored and incorporated into fishery management programs to prevent net loss. Mitigation should be incorporated into any projects involving habitat alteration. However, physical alteration of fish habitat in Lake Superior should be limited to cases of restoration of degraded habitat (Busiahn 1990).

Restoration of degraded habitat is being pursued through designation of Areas of Concern to be the subject of *Remedial Action Plans*. Stage I of the *Remedial Action Plan* process describes the intensity and scope of environmental problems and the causes for the impairment. Stage II identifies remedial measures required to restore beneficial uses. Four Areas of Concern have been designated in Ontario: Peninsula Harbor, Jackfish Bay, Nipigon Bay, and Thunder Bay. The *Remedial Action Plan* process in each of these areas has completed Stage I and has proceeded to Stage II. In Michigan, the Areas of Concern are Torch Lake and Deer Lake-Carp Creek/River. The *Remedial Action Plans* for these areas have been submitted to the International Joint Commission for review and have progressed toward finalization. The St. Louis River system is an Area of Concern shared by the States of Minnesota and Wisconsin. This *Remedial Action Plan* has completed Stage I and proceeded to Stage II (International Joint Commission 1991).

Fishery agencies have also addressed habitat concerns through active involvement in hydropower relicensing processes. Numerous fisheries studies have been done to address the impact of dams (Hansen 1994). Fishery agencies have advocated for licenses contingent on a change in operation to run-of-the-river flows that should benefit migratory species.

Ecosystem objectives for Lake Superior were also established by the U.S. and Canada in the *Great Lakes Water Quality Agreement of 1978, as amended* (International Joint Commission 1989). The nations agreed that:

> *Lake Superior 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 Diporeia hoyi as a key organism in the food chain...*

The Agreement further specified that lake trout and *Diporeia* would be used as indicators of ecosystem health. Lake trout should have productivity greater than 0.38 kilograms/hectare (0.34 pounds/acre) from stable, self-sustaining stocks, and be "free from contaminants at concentrations that adversely affect the trout themselves or the quality of the harvested products." *Pontoporeia hoyi* should be maintained throughout the entire lake at densities of 220-320 per square meter (262-381 per square yard) in depths less than 100 meters (328 feet), and 30-160 per square meter (36-190 per square yard) at depths greater than 100 meters (328 feet).

Basin-wide Research on Fish Population Dynamics: A Critical Evaluation of Historical Data

The Great Lakes Science Center (Center) of the National Biological Service has long played a key role in conducting research on fish communities of the Great Lakes. The Center, in cooperation with its Great Lakes partners, initiated three research projects in 1992:

- the restoration ecology of lake trout,
- the dynamics of Great Lakes forage-fish communities, and
- the community dynamics of commercially-harvested species in the Great Lakes.

The primary goals of these studies are to provide insight on factors associated with changes in fish population abundance, and to aid in the identification of impediments to restoration of native Great Lakes species, such as lake trout. The following sections describe basin-wide research efforts under the Act. These projects address the second objective of The Study by critically evaluating the sufficiency of historical databases in addressing questions on population dynamics of Great Lakes fishes. Research activities continue on all three projects and therefore final results can not be described here.

Restoration Ecology of Lake Trout

In the Great Lakes, efforts to restore lake trout stocks have focused on supplemental stocking of hatchery fish in areas that sustain remnant populations of naturally reproduced fish (Lake Superior), and in areas that were traditionally used by native lake trout (Lake Michigan; see, e.g., Lake Michigan Lake Trout Technical Committee 1985, or Eck and Brown 1985). One approach useful in ecological studies is to compare and contrast populations from two or more environments (e.g., two or more lakes), thereby delineating commonalities and contributing to an understanding of fundamental processes that govern populations (such as intrinsic birth rates and death rates). Comparative approaches are important in determining which part of the life cycle is critical to the persistence of the species and therefore, determining which restoration efforts will most likely succeed. Studies on the restoration ecology of native species focus on understanding the factors crucial to the recovery of these species and their habitats. An evaluation and comparison of the survival of hatchery and native lake trout will contribute to the understanding of the population biology of this species. The reestablishment and perpetuation of lake trout stocks in the Great Lakes may be jeopardized if researchers and managers continue to approach the challenge single-handedly. Eventually, populations may be restored, but the time required to achieve the goal and the lessons learned may be lost along the way. Alternatively, through cooperative efforts with our partners, the information necessary to identify the factors important to lake trout restoration can be gathered and analyzed.

Two study areas have been identified in the Great Lakes region: one has sustained a small, but growing population of native lake trout (Gull Island Shoal, Lake Superior), and the other is composed entirely of hatchery fish (Clay Banks, Lake Michigan). Prior to 1976, lake trout populations in the Gull Island Shoal area of Lake Superior had been subjected to natural and fishing mortality. In 1976, a refuge was established in the area (Swanson and Swedberg 1980) to restrict fishing; lake trout in the refuge area were subjected only to natural and sea lamprey induced mortality. Efforts to supplement and enhance population abundance at Gull Island Shoal have focused on the release of hatchery fish and the maintenance of the refuge. A study of the survival rates of this population before and after establishment of

the refuge (in conjunction with estimates of population abundance) would reveal the effect of removing most of the component of mortality due to fishing. Knowledge of the survival rate in the absence of fishing mortality would be beneficial to those wishing to know the time required for the population to reach a particular abundance, size, or age structure.

The Clay Banks area of Lake Michigan once supported a viable native lake trout population. Now, all lake trout in this lake are hatchery fish. The harvest of lake trout in Lake Michigan, which is restricted to sport fisheries and commercial fisheries operated by Native Americans, is controlled by a quota system (Lake Michigan Lake Trout Technical Committee 1985). Thus, this population experiences both natural, sea lamprey induced, and fishing mortality. Survival rates of Clay Banks fish will be compared to those for Lake Superior hatchery fish. When considered together with stocking rates, survival rate estimates can be used directly by resource managers to evaluate the likelihood of attaining the long-term goal of a self-sustaining lake trout population, and to establish harvest quotas for this species (Lake Michigan Lake Trout Technical Committee 1985).

Lake trout populations in Lakes Superior and Michigan have been monitored annually by resource management agencies in the region. Typically, assessment surveys are conducted annually or semi-annually and catch rates are used as indices of abundance. In addition, mark-recapture studies have been conducted to obtain information on survival rates. Mark-recapture studies have been conducted annually in Lake Superior in the Gull Island Shoal area since 1969, and in Lake Michigan in the Clay Banks area since 1983.

The purpose of the research study is to estimate survival rates of adult lake trout in Lake Superior and Lake Michigan and to evaluate the effect of the Gull Island Shoal refuge on survival rates. Secondarily, the study will serve to compare survival rates of hatchery and native fish where they co-occur (Gull Island Shoal), and to compare survival rates of hatchery fish from two lakes. These results will permit resource agencies to evaluate the efficacy of lake trout stocking programs and the role of refuges in management of lake trout.

In 1992, as a result of collaborative efforts with the Bayfield and Sturgeon Bay offices of the Wisconsin Department of Natural Resources, researchers at the Center began work on two long-term data sets describing an intensive tag-recapture program. Initially, research activities focused on designing the study, and acquiring and reformatting information for subsequent analysis. The task was not trivial and is likely to be a reason contributing to the few (and unsuccessful) previous attempts at long-term, basin-wide studies of lake trout survival.

Until 1992, data existed in various stages of readiness for computer analysis. Some of the data (1969-1975) for Lake Superior existed only on field sheets maintained at the Bayfield office; these were coded and entered into computer files. Another portion of the data existed in modified ASCII format on Apple diskettes; data on these disks were transferred from Apple-compatible media to IBM-compatible media. The remainder of the data from Lake Superior existed in Lotus spreadsheets; these data required translation to a dBaseIV spreadsheet. The three databases were translated into a file structure and format compatible with the software selected for analysis (the SAS system for OS/2). Data checking, verification, modification, management, and preliminary analyses were performed with the SAS system.

Quality assurance tests were performed with the data, including verification of codes (initial tag numbers, tag numbers on recaptured fish, length, sex, maturity stage, and date), and elimination of records of fish tagged by other agencies or in other areas. Additionally, fish that were part of several double-tagging experiments were identified and data on these fish were reformatted to permit accurate tracking of tag shedding information. A large number of modifications of the primary database was made after verification with field sheets by Wisconsin Department of Natural Resources personnel. All modifications and deletions were recorded.

The data collected from the Clay Banks population were received as dBase files; these were read directly into a SAS data set. Data checking included verification of coded information (species, tag numbers, tag type, whether the fish was a first capture or recapture, location, length, and date). All modifications to the data set were performed after verification by personnel who collected the data, and records were maintained of such changes.

Survival models, which will be fit to the lake trout data, require input on the number of tagged fish that are subsequently recaptured. This information will be used to construct capture histories which are the primary data used in tag-recapture models to estimate survival rate (Burnham *et al.* 1987; Nichols 1992).

Prior to estimating survival rates, it is critical to test the assumption that tags are not shed; e.g., once inserted into a fish, a tag is not damaged or shed. If fish lose a tag, then the number of recaptured fish bearing a tag will be less that the actual number of fish that were originally tagged and subsequently recaptured. Thus, tag shedding rates are necessary for adjustment of survival rate estimates; otherwise, survival rates are underestimated. Because the structure of the Lake Superior database did not permit extraction of information concerning fish tagged with more than one tag, the SAS data set was transformed into a relational database (Fabrizio and Nelson 1994). Using Structured Query Language in SAS for OS/2, information on double-tagged fish was compiled. These data were used to estimate tag shedding rates. In Lake Superior, three types of tags were used, so three shedding rates were estimated. A two-parameter nonlinear model was developed to describe long-term tag shedding rates for lake trout. In general, about 35 percent of the tags attached to lake trout appear to be permanently affixed; the remaining 65 percent are shed at annual rates varying between 25.9 percent and 48.1 percent, depending on the type of tag (Figure 77). Tag shedding rates will be used to adjust estimates of survival rates of lake trout.

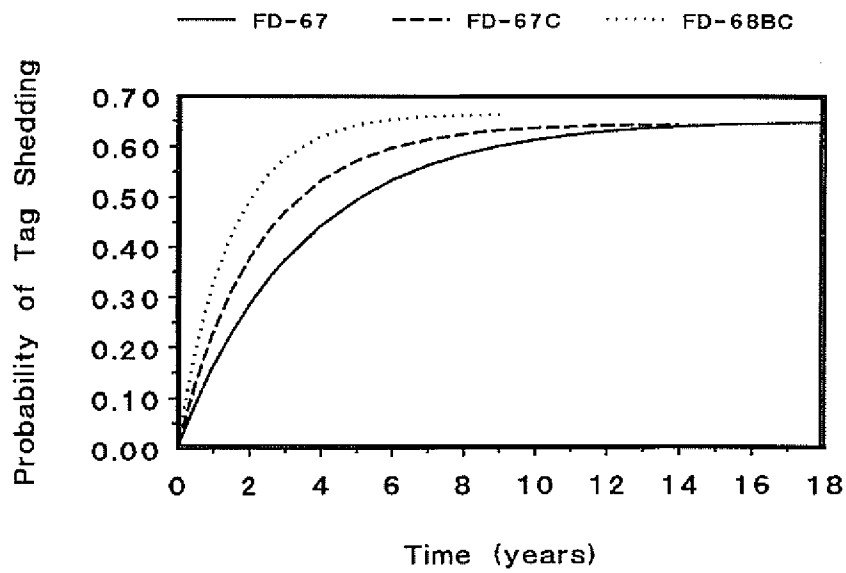

Figure 77. Probability of tag shedding for three types of anchor tags used to tag individual lake trout from Gull Island Shoal, Lake Superior.

Dynamics of Great Lakes Forage-fish Communities

Great Lakes fish communities are part of a complex ecosystem that has been subjected to dramatic changes since the early to mid-19th century. Fish communities today are composed of a mixture of exotic and native species, reflecting the outcome of purposeful introductions and undesirable invasions. State and federal hatcheries have been releasing

large numbers of young non-native salmonids (e.g., coho salmon, chinook salmon, rainbow trout or steelhead, and brown trout) into the Great Lakes for about 25 years (Wells and McLain 1972). As hatchery techniques and production capabilities improved, more and more fish were stocked. For many years, it was assumed that the forage fish base in the Great Lakes was sufficient to sustain growth of these salmonids and indeed, a put-grow-and-take fishery was successfully established. Now, however, agency personnel are beginning to question the adequacy of the forage base in terms of the quantity (biomass) of forage fish available and the species composition of the forage fish community.

In response, the Great Lakes Fishery Commission recently supported a modeling exercise to explore the effect of stocking Pacific salmonids on forage fish populations of Lake Michigan. The study, referred to as the SIMPLE [Sustainability of Intensely Managed Populations in Lake Ecosystems] modeling exercise, provided predictions of population size for the major fish species in the Great Lakes under various stocking scenarios. Results of the execution of the SIMPLE model have been used to guide managers in decisions regarding continued stocking of non-native salmonids. The key role of forage fish species (alewife, bloater, rainbow smelt, and deepwater sculpin) in supplying energy to predators was continually highlighted by these exercises, and the negative feedback between stocking predatory fish and sustainability of prey populations was readily apparent.

Models of fish community dynamics, such as the SIMPLE model, rely heavily on fisheries data. The Center, along with other agencies, has been assembling and collecting such data. As information becomes more precise and our understanding of the factors that control community interactions improves, the utility of models improve. At this stage, most models (including SIMPLE) do not take into account possible interactions among forage fish species. Researchers at the Center, working cooperatively with partners at Michigan State University, can provide a better understanding of fish community dynamics by identifying the factors and interactions that are critical to controlling the abundance of forage fish species. Modelers can then "re-tune" models so as to reflect current scientific understanding of the population dynamics of forage species, thereby providing a more accurate tool for making fishery management decisions and for evaluating fish community objectives for the Great Lakes.

The purpose of this study is to identify and describe those factors contributing to changes in population abundance of the major forage species in Lake Michigan. Important biotic factors that may affect fish abundance include growth, fecundity, mortality, predation, competition, and food availability (Hewett and Stewart 1989; Jude *et al.* 1987; Miller *et al.* 1990). Abiotic phenomena such as temperature, duration of ice cover, and winter severity could affect fish abundance as well (Garling and Masterson 1985; Henderson and Brown 1985; Scavia *et al.* 1986; Taylor *et al.* 1987). Recruitment of alewife was higher after warm growing seasons and mild winters, but cold winters tended to suppress alewife recruitment (Eck and Brown 1985). Both biotic and abiotic effects may work in concert. For example, the abundance of rainbow smelt in Green Bay, Lake Michigan, was related to spawner abundance, mean solar intensity in April and May of the previous year, and mean air temperature in April of the previous year (Sluka 1991).

Sainsbury's (1988) observation that a single approach to understanding fish community dynamics is not "universally accepted" provides the motivation to examine fish communities in an empirical, exploratory manner. As a complement to the bioenergetics approach currently pursued by several Great Lakes researchers (e.g., Jones *et al.* 1993), this study will focus on empirical models based on stock assessment data for Great Lakes fishes. The approach is a time series analysis, a statistical technique first developed and described for forecasting economic indicators.

A time series of fish population abundances will be evaluated for indications of possible abiotic and biotic influences. Abundance indices for key species – alewife, bloater, and rainbow smelt – will be examined from Lake Michigan. This lake was selected first because of the importance of sport fisheries for non-native salmonids and the need to provide additional information to the SIMPLE model. The approach is to identify common cycles in the relative abundance of forage fish species, to determine community-wide patterns in abundance, and to relate these patterns to abiotic factors. Skud (1982) demonstrated the importance of considering multispecies assemblages when examining the role of abiotic factors: he found that climatic factors can affect species abundance but that a species' response to

abiotic change was dependent on its position in the dominance hierarchy. Thus, multispecies models similar to those described in Stone and Cohen (1990) will be developed and the resultant models will permit testing and formulation of hypotheses concerning perturbations of aquatic ecosystems.

The nature of this study is retrospective because it relies on analysis of data that are already collected. Several sources of data were identified and will be used in this investigation:

- the Center has information on the relative abundance of forage fish species for Lake Michigan based on bottom trawl surveys conducted annually in the fall;
- various agencies and private vendors have collected information on climatic factors; and
- State and international agencies have compiled data on stocking rates for salmonid predators in the Great Lakes.

Annual fish abundance data from standardized assessment surveys include information on total numbers, weight, and effort expended for each species at each sampling site. Sampling sites and methods of collection were selected so as to remain constant throughout the period of study – 1977 to 1991. Fish abundance data from assessment surveys are maintained at the Center on a Data General minicomputer. Information on species, port, date, depth of station, numbers, weight, length frequencies, life stage, and bottom temperature was downloaded onto ASCII files and sent to cooperators at the Department of Fisheries and Wildlife, Michigan State University, for statistical analysis.

Abundance indices as indicated by catch rates for Lake Michigan alewife, bloater, and rainbow smelt were examined for sources of variation. Large variations in catch rates could result from an inadequate survey design, measurement error, or noise. The survey design was identified and changes in design were noted for their effect on variation in catch rates. Trawl surveys were consistent between 1977 and 1991 at eight stations (Frankfort, Ludington, Saugatuck, Benton Harbor, Waukegan, Port Washington, Sturgeon Bay, and Manistique), and between 9-110 meters (30-361 feet). The effect of using three vessels to perform bottom trawling was tested and found to be insignificant. Catch data from the three vessels can therefore be used to monitor abundance of prey fishes in Lake Michigan.

Data representing biotic factors were identified and include creel survey estimates of salmonid abundance (Wisconsin Department of Natural Resources and Michigan Department of Natural Resources), and annual stocking rates for salmonids (Great Lakes Fishery Commission). Four States surrounding Lake Michigan have contributed to stocking of Pacific salmonids (Michigan, Wisconsin, Indiana and Illinois), and appropriate agency personnel were contacted for permission to access the databases.

Annual statistical summaries of weather conditions (e.g., air temperature, cooling degree days, heating degree days) were obtained for six weather stations along Lake Michigan (Benton Harbor, Ludington, Waukegan, Port Washington, Sturgeon Bay, and Manistique). Although surface water temperatures are more likely to accurately portray temperature cycles in the lakes, data from the National Data Buoy Center are available only for the 10-year period, 1979-1989 (Lesht and Brandner 1992). Therefore, air temperatures will be used as surrogates for surface water temperatures. (Additionally, weather buoys provide *daily* surface water temperatures and this temporal scale may be too fine to be readily used in this study.) Because of the high variability in temperature data, a robust model (Cleveland 1979) was used to identify trends and cycles in weather data. A temperature gradient exists over the lake such that the most southern stations are the warmest (Figure 78). The overall trend in air temperature can be seen from analysis of the Sturgeon Bay data set, which covers a period of about 90 years: there has been a pronounced warming trend in this region, with a maximum rise between 1940 and 1960 followed by a short cooling period in the 1970s. This cooling period was a feature of all six time series examined (Figure 78). The weather over Lake Michigan is regulated by the position of the polar jet front (Eichenlaub 1979), such that mean air temperatures may be depressed or increased with changes in jet stream position.

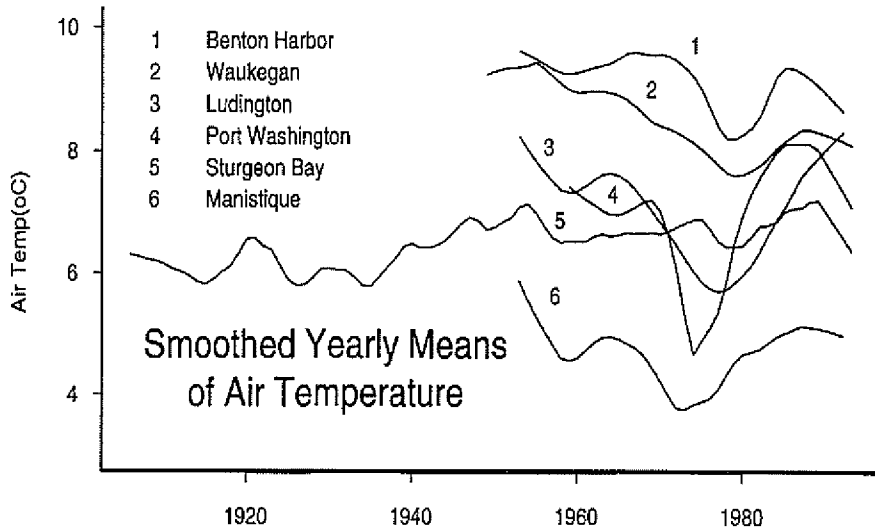

Figure 78. Time series of annual mean air temperature for six stations around Lake Michigan. The smoothed lines are LOWESS lines. LOWESS is an abbreviation for robust locally weighted regression; it is used to graphically display a pattern in noisy data.

Preliminary exploratory analysis of forage fish abundance has focused on identification of the depth, geographical, and temporal distribution of forage fish biomass in Lake Michigan. Catch rates of the three major species are similar among ports sampled in Lake Michigan and no striking patterns exist. However, catch rates vary by depth for each species. Alewife abundance is fairly consistent with depth except that numbers are more variable in shallower waters from 5-30 meters (16-98 feet). Rainbow smelt abundance is higher at intermediate depths from 18-55 meters (59-180 feet) and begins to decrease at 46 meters (151 feet); few rainbow smelt are taken in deep waters. The distribution of bloater biomass is similar to that of rainbow smelt. Temporal changes in abundance of these three species indicated a general increase in bloater abundance in the early- to mid-1980s, coupled with a decrease in alewife abundance beginning in the mid- 1980s (Figures 79 and 80). Rainbow smelt abundance remained fairly constant, but low.

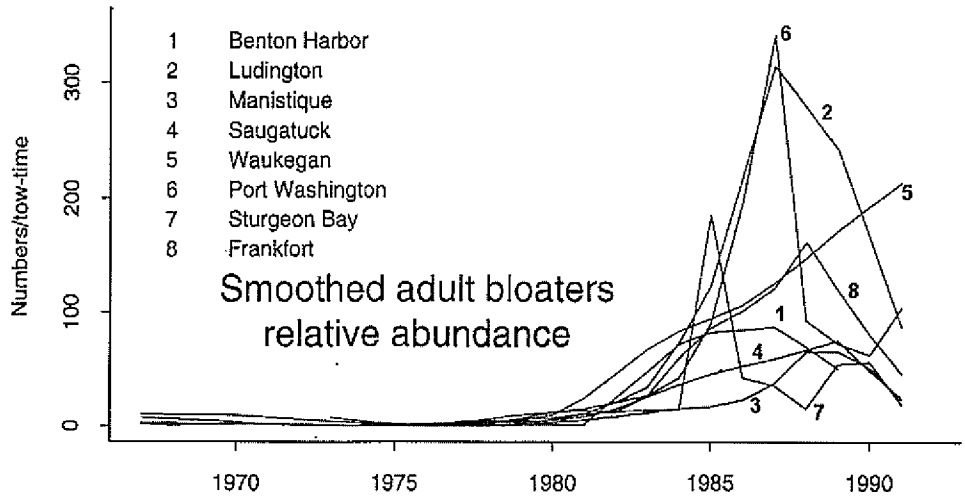

Figure 79. Relative abundance of bloater as indicated by bottom trawl surveys at eight ports. The lines were smoothed using LOWESS. LOWESS is an abbreviation for robust locally weighted regression; it is used to graphically display a pattern in noisy data.

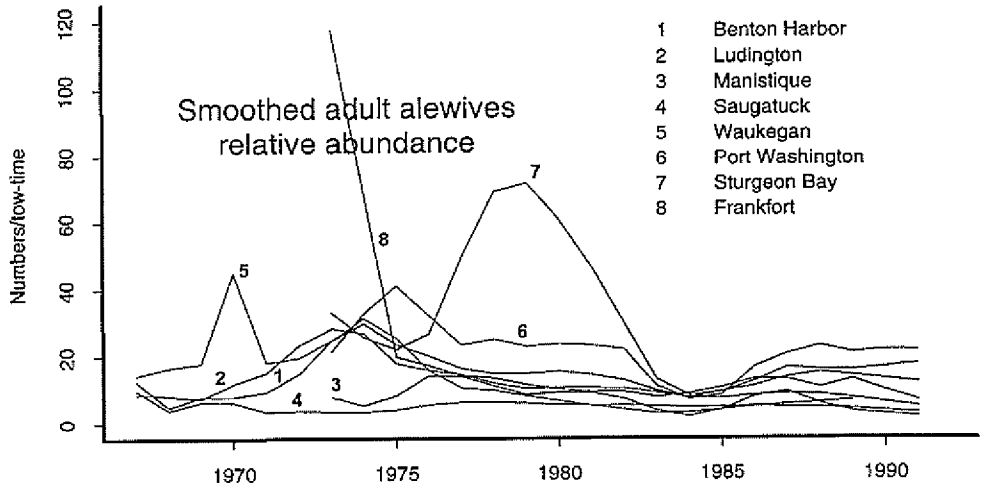

Figure 80. Relative abundance of alewife as indicated by bottom trawl surveys at eight ports. The lines were smoothed using LOWESS. LOWESS is an abbreviation for robust locally weighted regression; it is used to graphically display a pattern in noisy data.

Changes in length-frequencies of the three key species have been examined; most notable, the average size of bloater decreased from 1973 to the mid-1980s; rainbow smelt and alewife show no changes in average size through time.

Formal time series analysis will be used to decompose temporal fluctuations in fish abundance into a trend plus irregular fluctuations about the trend. Likewise, a time series analysis of air temperature will yield information on a trend, a seasonal cycle, and irregular fluctuations. Once a trend or cycle is identified, the pattern of residuals must be investigated: these residuals often reveal additional cyclic changes, such as oscillations of longer periods. A technique known as spectral analysis can then be used to determine the presence of dominant (significant) cycles. Dominant cycles in fish abundance will be cross-correlated with cycles or trends determined from time series analysis of biotic and abiotic factors. Additionally, lagged cross-correlations of fish abundances with weather data (air temperature) may provide insight on the time frame during which fish are most sensitive to changes in weather conditions. Simple and lagged cross-correlations of forage fish abundance and stocking indices will be computed to examine interactions between prey fish and their stocked predators.

Community Dynamics of Commercially-harvested Fishes

The goal of this study is similar to that described in the previous section on Dynamics of Great Lakes Forage-Fish Communities, except that it is not restricted to Lake Michigan. This is because commercial fishery records for all five Great Lakes will be used to investigate biotic interactions among fish populations in each lake. As in the previously described study, a time series analysis will be performed (assuming the data are sufficient). Commercial fishery records have been published for key species in the Great Lakes by the Department of Commerce and the Department of the Interior, however, there are three major difficulties with these records:

- the type of information published changes through time (depending on which agency handled the data),
- the time series of data is incomplete (some years, particularly the years during World War II, are missing entirely), and
- the accuracy of these data is unknown.

To use commercial fishery data for analysis of population dynamics, the data must include information on species, total weight landed, and effort expended by gear type for each lake. Furthermore, these data must be available on at least an annual basis and in a continuous series for any given species. The availability of a complete series of commercial catch and effort data from all five lakes was assessed, and data for several species were selected on the basis of total

Table 12. Commercially-important species in the Great Lakes. An "X" indicates inclusion in the data set describing the fish community for a particular lake.

	Lake				
Species	Superior	Michigan	Huron	Erie	Ontario
Alewife		x			
Blue pike				x	
Carp			x	x	x
Chubs	x	x	x		x
Lake herring	x	x	x	x	x
Lake trout	x	x	x		x
Lake whitefish	x	x	x	x	x
Rainbow smelt	x	x		x	
Walleye				x	
Yellow perch		x		x	x

catch and species dominance in the overall harvest for each lake (Table 12). Commercial catch data for Great Lakes fisheries were first published for 1917. These annual reports include total annual catch and beginning in 1927, effort by gear for each State and lake. Extensive searches uncovered several limitations of the commercial fishery data for the Great Lakes.

- Incomplete catch data were published in 1923-1925, 1933, and 1935: total catch by species was not reported by gear in these summary reports, which were published by the U.S. Department of Commerce, Bureau of Fisheries.

- Effort data were not reported prior to 1927 or in 1941-1949, and 1952-1953. In addition, catch was not documented by gear prior to 1930.

- The U.S. Fish and Wildlife Service, Bureau of Commercial Fisheries, published consistent and complete records from 1954 to 1967. From 1968 to 1970, the National Oceanic and Atmospheric Administration (NOAA), National Marine Fisheries Service, published similar records.

- Since 1971, the Center has compiled and entered annual summaries of commercial catch and effort data into computer data files (ASCII and SAS files); the files are delivered to NOAA for subsequent publication. In general, the information available in computer files is more detailed than that published in annual summaries.

This turnover of reporting responsibility spawned several non-trivial changes in the manner in which records were maintained and in the amount of information reported. Considering these observations as a whole, it is clear that complete data compilation and reporting by species for a specific gear type began, in effect, in 1954. Hile (1962) provides a description of methods used to report commercial fishing statistics for the early years (e.g., estimation of

effective fishing effort, delineation of statistical districts and exceptions to standard procedures).
Although other summaries of annual commercial fisheries statistics exist (e.g., Comptroller General 1977 and Baldwin *et al.* 1979), these typically do not include effort data and are generally restricted to a few species per lake. In addition to annual sources of data, the Center has a microfiche library of monthly catch and effort forms completed by licensed commercial fishers. None of this information has been computerized in a monthly form; it has been estimated that 2 person-years for each year of data are required to complete coding and entry of these records (A. Frank and E. Moore, personal communication). The availability of such records is noted here for possible future research needs.

All annual catch and effort data (by gear) for the years 1954 to 1970 were entered manually from published records (e.g., Anderson and Power 1956) into EXCEL spreadsheet files. These records are complete for all species identified in Table 12 and for all five lakes. Commercial fishery data from 1971 to 1992 were keypunched into ASCII files by Center personnel using monthly reports from commercial fishers. The 1971-1992 data were available as summarized SAS files which had been stored in a compressed format.

Attempts were made to use the summarized SAS file information on catch and effort, but it was determined that total effort estimates by gear type were incalculable, and mesh size for important gear types was unavailable, although all this information existed in the original ASCII files. Therefore, catch and effort data were extracted from the original ASCII files for 1971-1992. (Comparisons of total effort estimates from corresponding SAS and ASCII files indicated inaccurate estimates of total effort from the SAS summaries -- some estimates were biased by an order of magnitude.) The database management system on the Data General minicomputer at the Center was used to prepare ASCII files for transfer to a personal computer. On the personal computer, the files were reformatted into a relational database using Structured Query Language in SAS. The resulting database consisted of four tables: *Catch* (containing landings by species and gear), *Effort* (containing effort by gear), *Identify* (containing operation codes and date) and *Price* (containing monetary value of landings). Other data were included in these tables and all data could be accessed using a unique identification variable assigned to each net operation. Some of the Wisconsin commercial fishery data from recent years (1989 to 1992) required additional re-formatting prior to table construction because the information recorded in those years was different from previous years.

Preliminary quality control checks revealed possible inconsistencies in measurement units used to report catch: landings for some species were reported as round weight, some as dressed weight, and others as filleted weights. Commercial fishery biologists from all States using the various reporting units were contacted to verify use and determine appropriate conversion factors so that all weights could be converted to round weights.

Additional quality control checks are required prior to using the tables to extract catch per unit of effort information from the commercial fisheries. Because the database is so large and requires intensive computing resources, these checks have not yet been possible. Plans to implement a local-area network and purchase a more powerful PC for the Center should improve accessibility. Once the 'hardware' problems are solved, the 1971-1992 data will be summarized and merged with the pre-1970 database. Time series analyses will be attempted with the complete database of commercial catch and effort (1954-1992). It should be noted that catch and effort estimates from 1971-1992 will be more detailed than those available from 1954 to 1970. Also, total effort for 1954-1970 was reported across species, whereas in 1971-1992, it was reported for each of the key species identified in Table VII-1. Some of these inconsistencies must be addressed in future research.

Basin-wide Evaluation of Existing Management Plans

Interagency Fishery Management Plans

The following material is excerpted from Dochoda and Koonce (1994). In all cases "Strategic Plan" has been replaced with *"Strategic Plan for the Management of Great Lakes Fisheries"* and "Commission" has been replaced with Great Lakes Fishery Commission" to be consistent with the rest of this report.

The *Strategic Plan for the Management of Great Lakes Fisheries* can be used by Great Lakes fishery managers to anticipate issues and opportunities, to react collectively to crises and opportunities, and to be more efficient in management and assessment. The *Strategic Plan for the Management of Great Lakes Fisheries* can be used as a coordination vehicle among fishery managers from various jurisdictions and as a communication tool for informing other users or managers of the Great Lakes about the impacts of their activities or about fisheries' needs. In the *Strategic Plan for the Management of Great Lakes Fisheries'* fourteen year history, fish managers have accomplished all of the above, unevenly but consistently enough to demonstrate the promise of the *Strategic Plan for the Management of Great Lakes Fisheries* approach.

Great Lakes managers have three primary avenues for effecting change in fish populations: (1) balancing predators and prey (e.g., catch regulation, stocking, and sea lamprey control); (2) preventing unplanned or ill-considered introductions; and (3) optimizing habitat. This section will review examples of managers' successes in accomplishing the above in fish management planning, in fish management coordination, and in fisheries and environmental management coordination, all tasks set for them by the *Strategic Plan for the Management of Great Lakes Fisheries*. Contributions and shortcomings of the *Strategic Plan for the Management of Great Lakes Fisheries* and its three principal actors (agencies, Lake Committees, and the Great Lakes Fishery Commission) are discussed primarily from a Great Lakes Fishery Commission staff perspective.

Fish management planning

To anticipate issues and opportunities to balance predator and prey, to prevent unplanned or ill-considered introductions, and to optimize habitat, fish managers and users must first have agreed on fish community objectives for a particular lake. Second, information must have been gathered and analyzed in such a manner that issues and opportunities for management action have been recognized. Thirteen years after the *Strategic Plan for the Management of Great Lakes Fisheries* was signed, all but two Lake Committees have common objectives for their fish communities. Environmental objectives are the next significant task under the *Strategic Plan for the Management of Great Lakes Fisheries*.

The development of fish community objectives has been very slow. Agencies might have developed fish community objectives more quickly had they established this task as a priority with agency representatives on Lake Committees, perhaps by explicitly listing the production of objectives in Lake Committee representatives' work plans in their home agencies and by providing planners to assist Lake Committees. Lake Committees did not at first recognize that approved fish community objectives would not only ease their own individual management efforts, but would influence allied disciplines such as environmental management, as well. For example, Lake Huron's lake trout rehabilitation objective and related plan became the basis for a 1985 consent decree establishing the management framework for all the fisheries in the treaty area, thereby strengthening efforts toward a common objective for the resource and easing a potentially volatile situation.

A state of the lake report is required of each Lake Committee by the Committee of the Whole every three years beginning in 1990. Seen as a measure of accountability to agency directors, this reporting requirement may well be the most effective mechanism to ensure that fish community objectives reflect managers' current beliefs, that fishery programs remain true to their objectives, and that policy makers, both fishery and environmental managers, as well as the general public can be well briefed on the fisheries, the status of stocks, and their needs. In 1990, Lakes Superior and Ontario produced state of the lake reports, although the Lake Ontario report could have been even more infor-

mative with finalized fish community objectives. Complete reporting did not occur in 1993, due to preoccupation with fish community and other management concerns, but the commitment is there, and full reporting by all Lake Committees is expected by 1996.

Technical support by both the Great Lakes Fishery Commission and the technical subcommittees of the Lake Committees has been crucial to the successful implementation of the *Strategic Plan for the Management of Great Lakes Fisheries*. As described earlier, technical subcommittees have been instrumental in gathering and analyzing information in such a manner that issues and opportunities for management are recognized and can be addressed. Technical subcommittees have made substantial contributions to Lake Committee products, such as fish community objectives on Lake Superior, lake trout rehabilitation plans on the four oligotrophic lakes, and Total Allowable Catch resolutions for Lake Erie. The Great Lakes Fishery Commission has played an active support role to Lake Committees and technical subcommittees in development of fish community models, in support of agency development of common databases, in technical transfer of new science, in analysis of issues such as introduction of exotic organisms, and in the role of purchasing agent for standard gear.

Lakes Erie and Superior have been particularly successful under the *Strategic Plan for the Management of Great Lakes Fisheries*. Both lakes are blessed with (1) largely intact native fish communities (which could be irrevocably lost without collective stewardship) [eastern basin of Lake Erie native fish community is an exception], (2) a binational character (that seems to engender a more formal consultative approach) and (3) a critical mass of agencies (and thus biologists to staff technical subcommittees). Agency commitment to joint initiatives appears strongest on Lake Erie, where agencies expect both management and assessment to be integrated with activities of lake and technical subcommittees.

Coordinated fisheries management

Lake Committees have been effective in reacting to crises and opportunities such as: (1) responding to the depletion of bloaters and other deepwater ciscoes in Lake Michigan with a lakewide ban on chub fishing; (2) responding to the closure of the Lake Erie walleye fishery because of mercury contamination by developing and jointly implementing a Total Allowable Catch that, upon reopening, allowed complete rehabilitation of an exhausted fishery; (3) following up on lake trout rehabilitation plans by establishing and stocking refuges; and (4) preventing the establishment in the Great Lakes of several non-endemic fish diseases.

The *Strategic Plan for the Management of Great Lakes Fisheries* consensus strategy has been effectively applied to management of fish introductions and to disease control. Agencies, obliged under the *Strategic Plan for the Management of Great Lakes Fisheries* to achieve consensus when any management proposal may significantly influence the interests of another jurisdiction, consult with each other when planning an introduction. Planned introductions of striped bass, grass carp and arctic char have been reconsidered after concerns were expressed by other Great Lakes jurisdictions. However, more progress is needed to deal with introductions made for reasons unrelated to management of the Great Lakes fishery. Lake Committees have adopted inter-agency consultation procedures for all jurisdictions to use when contemplating a new introduction. Unfortunately, collective stewardship cannot be fully effective unless either it is captured in agencies' internal procedures when contemplating irrevocable changes to the ecosystem or it is forcefully communicated to politicians and the public.

Non-binding arbitration by the Great Lakes Fishery Commission is the fallback under the *Strategic Plan for the Management of Great Lakes Fisheries* for management agencies which cannot agree on management objectives or actions for a shared resource. The *Strategic Plan for the Management of Great Lakes Fisheries* states that if a consensus decision cannot be reached by a Lake Committee "the problem will be taken to the Great Lakes Fishery Commission for arbitration (non-binding) at the request of one or more of the parties in the dispute at the lake committees level." In 1992, the Ohio Department of Natural Resources requested that the Great Lakes Fishery Commission arbitrate a dispute between Ohio and the Ontario Ministry of Natural Resources to decide whether the Lake Erie yellow perch harvest should be shared on a historical use or a geographical area basis. The Great Lakes Fishery Commission was unable to serve as arbitrator because of concerns raised by the Canadian Party to the Convention which created the Great Lakes Fishery Commission. This withholding of arbitration services is of significant concern to the Committee of the Whole.

Ecosystem Partnership Coordination

The Service, in partnership with the Great Lakes Fishery Commission and the U.S. Environmental Protection Agency, created a temporary position 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* and *Fish Management Plans* 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 *Lakewide Management Plans 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 *Fish Management Plans* 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 Ecosystem Partnership Coordination 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 (Koonce 1994).**

Impediments to Restoring a Healthy Ecosystem

Philosophical, Ethical and Decision-making Considerations

Lack of historic knowledge and expertise

Due to lack of time and a continuing need to address emergent challenges, natural resource managers do not, as a rule, have the resources to study the failures of their own decisions. Without applying institutional memory and learning there is a tendency to repeat the mistakes of the past. Natural resource management, as a discipline, needs better mechanisms to apply historic knowledge.

Managers often believe that recommendations and decisions based on sound scientific study are most justified, but realize that human needs expressed through political systems can impact actions. Natural resource managers are, by their training, predisposed to readily implement actions only when scientific evidence is complete and unequivocal. However, because large natural systems are unique and inherently complex, they are not amenable to science-based experimental design.

When management decisions are made and techniques that affect the system applied, there is absolutely no potential for replication and control; cause and effect relationships are obscured and subject to misinterpretation. Consequently, resultant learning ("management decision and technique A results in system change B") is uncertain; natural resource managers simply do not have complete confidence that their successes or failures are the result of their decisions and actions. Acknowledged uncertainties and imprecise predictions have led the public to conclude that its collective judgement is just as good as the manager's on technical questions.

Changing ethos

For the past 40 years the foundation of natural resource value priorities has been undergoing substantial change, driven by resource professionals and their agencies, toward a moral position based on heightened concern for the total environment. As a result, the public is placing more value on components of natural systems and ascribing "rights" for these components to exist. Society is now demanding that natural resources be managed to meet a wider array of values, beyond the previous ethics of either "utilitarian development" or "lock up and reserve". The new ethic is beginning to influence policy and decision-makers.

Many natural resource managers adhere to a view of decision-making which operates according to objective scientific criteria. Some natural resource managers have become fully aware of the importance of ethics in their work and dynamic change in environmental values. After a century of development, today's natural resource manager has inherited an assortment of differing environmental ethical ideals and moral precepts. To traditional resource managers this new polymorphic ethic seems vague, arbitrary, and unrelated to science. They are struggling to function within an acceptable range of social, economic, and ecological conditions while carefully guarding against dramatic changes in direction.

The social, economic, and ecological components of natural resources are often managed independently, or only loosely coordinated. These components may be managed by separate agencies in local, State, Native American Tribal or Federal governments. This disjointed, compartmentalized, piece-meal approach to natural resource management is responsible for many persistent and profound environmental and resource allocation problems affecting the Great Lakes.

Sometimes, an agency's specific responsibilities and management techniques conflict with its broader interests in restoring ecological integrity. Special management considerations for a single aquatic species that occupies a large range will almost inevitably engender conflict with the requirements of other species. Most fisheries managers realize that broader, more long-term objectives are desirable, but are forced to concentrate on game fish because funding and staffing are available to manage these species. One of the major keys to addressing restoration of ecosystem integrity is the provision of adequate funding and staffing to address the task.

Many of the methods of problem identification, decision-making processes, and strategies necessary to meet the new, wider array of goals and objectives are outside the narrow discipline of traditional natural resource management. Natural resource managers need to work together and with environmental scientists, economists, and social scientists to:

define increasingly intrinsic values and concepts (e.g. ecological integrity) in a structural, functional, and dynamic sense;

formulate clear, narrative criteria, based upon scientific principles, that can be used to evaluate the consequences of management decisions on the total range of conditions;

address funding and staffing needs; and

apply techniques that can effectively restore and enhance ecological integrity.

Decision-making and public expectations

The most pervasive single feature of natural resource decision-making is uncertainty; ecological, economic, social, and political conditions for decisions are fluid. Where such decisions are well-woven into the social fabric, the task of the resource manager is relatively straightforward. However, when decisions represent a departure from normal practice, or there are two or more competing uses, they are difficult.

In the transition to a "values" perspective, policy development and decision-making appear immediately as matters of value arbitration. Values are not objects that can be listed and counted; a value is, rather, a statement of relationship, an estimation of worth of some object to an individual or in a particular situation. The importance of held values in policy development is recognized by decision-makers and resource managers; but clear bases for decision-making such as a coherent technical set of concepts to apply, remain elusive. The more complex the environment of policy choice becomes, the more likely it is that decision-makers and natural resource managers will turn to techniques of measurement to provide systematic and uniformly manipulable information; tending to reinforce the primacy of tangible versus inherent values.

For example, fisheries managers are increasingly relying on deterministic models as a bases for decision-making. Numerical models, often having unrealistically high data requirements for accurate results, have indoctrinated the minds of many decision-makers and natural resource managers who confuse quantification, objectivity, and sophistication with ecological reality. Many decision-makers and resource managers have become aware of this fact, but the appeal for standardization is strong as are arguments made concerning the relative merits of various methods in relation to negotiability, defensibility, and justification.

When different segments of society place competing demands on nature, conflicts are inevitable and often contentious. Interested publics should be involved in developing long-term goals and briefed on rationales and implications during the planning process. Agencies and publics are often prevented from realizing resource potential when special interest groups fail to recognize public trust responsibilities, resource limitations based upon scientific assessment, and the legitimacy and roles of other users.

Effects of Impediments on Ecosystem Restoration

Great Lakes ecosystem restoration

A synergistic effect created by a number of factors impedes the restoration of a healthy Great Lakes ecosystem. The introduction of nonindigenous species such as sea lamprey, alewife, and rainbow smelt have altered the fish community. While the latter two species are now considered to be naturalized and important as a forage base for management of the predator stocks, the interaction and potential negative impacts upon other indigenous species needs to be more closely studied. Sea lamprey on the other hand are widely viewed as a nonindigenous species with no beneficial value and continue to exert extensive negative impacts on the fish community. Loss and degradation of critical habitat essential for self-sustaining populations of many fish species has resulted in greater dependence on artificial propagation, or in severe depletion of stocks. Depletion and loss of endemic stocks has degraded the genetic variability necessary for a stable and healthy fish community. Environmental contamination resulting from industrial development within the watershed has resulted in degraded habitat, physiological harm to the inhabitants of the aquatic community, and consumption advisories to the public.

Although a great deal of progress has been made in removing or diminishing these impediments, fiscal costs have made the progress slow. Agencies charged with managing and restoring a healthy and stable ecosystem, and its fish community, have been hampered by budget constraints that prevent adequate collection and evaluation of biological information necessary for the development of comprehensive planning. In many cases a lack of technology, or rapidly accelerating costs of technology tend to exacerbate the situation.

Lake trout restoration

Lake trout are endemic to all the Great Lakes, and have always been among the most valuable components of the fishery, both economically and ecologically. They were driven to extirpation in Lakes Michigan, Erie and Ontario by a combination of sea lamprey predation and commercial fishing. In Lakes Superior and Huron, remnant stocks remained when the sea lamprey control program and stocking of hatchery-reared fish were initiated.

Optimism was high that restoration of self-sustaining lake trout stocks would proceed quickly in the 1960s; however, unforeseen problems prevented the expected progress. Offshore spawning reefs were not re-populated by hatchery-reared fish. Hatchery-reared lake trout often returned to the site of stocking and spawned in these nearshore areas which were unsuitable for survival and incubation of eggs. Renewed interest in harvesting the stocked fish occurred among sport anglers and Native American commercial fishers, who possessed treaty harvesting rights. Nonindigenous forage fish species including alewife and rainbow smelt proved to be unstable when preyed upon by lake trout and introduced coho and chinook salmon.

After about three decades of effort, lake trout restoration has made much progress, but remains far from complete. Lessons learned from long and painful experience will be summarized in the proceedings of the 1994 "RESTORE" conference, to be published by the International Association for Great Lakes Research in 1995. A continued basin-wide commitment to lake trout restoration is needed to attain ultimate success.

Examples of Impediments to Restoring a Healthy Ecosystem

Inadequate information on fish harvests

Fish harvest data are essential for informed management of Great Lakes fishery resources. Harvest data are significant for ecosystem and population management, for social and economic concerns and for planning and evaluation of

management programs. Harvest monitoring by multiple jurisdictions must be coordinated to be useful in lake-wide management planning.

Historically, most harvest on the Great Lakes was taken commercially, and monitored through regular reports by fishermen, and through commercial market records. In recent decades, commercial fishing has declined and recreational fishing has become dominant. Harvest records from recreational fisheries are much less complete. Creel surveys are conducted regularly by some states on some parts of the Great Lakes, but monitoring is of uneven quality due to the inter-jurisdictional nature of the fisheries and inadequate funding in some jurisdictions.

Problems encountered researching the *Population Dynamics of Great Lakes Forage Fishes*

Difficulties encountered in researching the population dynamics of Great Lakes forage fishes included gaining access to databases and detecting changes in data quality. Although a great deal of information has been gathered and catalogued in a formal manner, much has been catalogued only informally. There are five impediments to gaining access to catalogued data for a research study:

- lag time in publishing data;
- limited distribution;
- incompatible storage media;
- unreadable storage format; and
- inefficient or inadequate data structure.

Many databases consist of a table or tables of numbers, arranged in a logical manner so the user can locate a particular piece of data quickly; for example, the Bureau of Commercial Fisheries published commercial landings for selected Great Lakes species from 1954 to 1967. To find the weight of lake whitefish harvested in Lake Michigan in 1967, one simply locates the volume containing records for 1967, identifies the table containing entries for Lake Michigan, and locates the column containing harvests of lake whitefish. The *distribution* of these published tables is generally restricted to specialized libraries, such as the Van Oosten library at the Great Lakes Science Center or large libraries, such as those at universities.

The *storage media* of the information refers to the physical device or instrument containing the data. In this case, the data are stored on the printed page. Some databases can be stored on microfiche or electronically. Monthly logs from commercial fishers in the Great Lakes have been transferred to microfiche to preserve their integrity and facilitate storage of these detailed records. Since 1971, commercial fishery data have been stored electronically on a mini-computer at the Great Lakes Science Center. The storage medium of the more recent data is computer tape.

Databases that are stored electronically can also be characterized by their *storage format*; in the case of the 1971-1993 commercial fishery database, data have been stored in SAS data set formats. To find the total landings of lake whitefish from Lake Michigan in 1990, the computer tapes containing information on Lake Michigan for 1990 must be located, loaded onto the mini-computer and read electronically. If the user is unfamiliar with SAS or the user's computer cannot read SAS data sets, then a major effort must be initiated to translate the data to another more usable format. Clearly, access to the computer is critical. But the process does not end there. The user must specify (usually via computer code) the information desired, but this requires knowledge of the contents of the database and various other programmatic details.

One of the greatest technical obstacles to synthesizing historical data is the *structure* of the database. Even if the user was familiar with software formats and could read these files, there is still no guarantee that the structure of the data would permit extraction of the necessary information (e.g., Fabrizio and Nelson 1994). This is because the type of information sought must be retrievable in a logical manner. For example, if a user needs to determine catch by species and gear type for each lake in each year, and the catch by species for each lake and year is available, but the type of gear used to harvest each species is not available, then the structure of the data is unsuitable.

These examples illustrate that retrieval of information is linked to the distribution, storage medium, storage format and structure of the data. Research studies typically require access to large amounts of data and a great deal of flexibility in working with the data. The printed page becomes an obstacle, and data must be translated to some type of electronic medium. If the data exist on electronic media already, then access to and familiarity with the computer system and appropriate software must be obtained in order to work with the data.

Assuming the researcher has found the appropriate database and can read the electronic medium and format, and the structure of the database is such that information can be obtained, then the researcher must carefully assess the quality of the data prior to their use. The quality of the data is highest when the following conditions are met:

- there is no missing information;
- the units of measurement for any particular parameter are consistent throughout the database;
- the same information is recorded in the same manner throughout the database; and
- there are no data entry errors.

Quality assurance controls must be used to identify inconsistencies, missing information and mistakes. These controls usually require extensive testing of the database, followed by research as to the source of the problem and resolution of the issue. Sometimes inconsistencies can be adjusted and errors can be corrected, but the identification of the problem and follow-up to determine course of action often require much more time than the actual analysis of the data. The time invested in locating, translating, re-formatting and re-structuring databases can be significant, particularly when the database contains information gathered before micro-computers were commonly used (about the mid-1980s). Thus, just because data have been collected, coded and electronically recorded, doesn't mean the information exists. If it does, it may not be extracted readily or accurately. The saying that we are 'data rich and information poor' is quite applicable to fisheries databases for the Great Lakes region.

Recent introductions of nonindigenous species

Since the 1800s, 139 nonindigenous aquatic organisms have become established in the Great Lakes, including 25 species of fish (Mills *et al.* 1993). The rate of introduction has increased; nearly a third of the organisms were introduced since the opening of the St. Lawrence Seaway in 1959. The most common mechanisms for entry into the Great Lakes are unintentional releases and ships. The effects of successful nonindigenous species -- defined as reproducing organisms transported by humans to regions where they did not previously exist -- may be instability and unpredictability in previously stable ecosystems, and a loss of diversity in biotic communities (Mills *et al.* 1993).

The impacts of nonindigenous species have been enormous. The sea lamprey has cost millions of dollars in losses to fisheries and in control costs, in addition to the extirpation or severe depletion of lake trout throughout the Great Lakes. The population of alewife grew unchecked by predators after introduction to the Great Lakes, and underwent massive die-offs, polluted shorelines, blocked water intakes and suppressed populations of indigenous chubs, perch and shiners. The pervasive ecological and economic impacts of zebra mussel are still being measured.

Management agencies are hampered by a lack of technology to control aquatic nuisance species once they have become established. The integrated pest management approach advocated by some requires a set of management tools from which to choose. By and large, these tools do not exist for aquatic pests. The economic injury analysis required by integrated pest management is ill-suited to common property resources and non-economic values such as biodiversity. New analytical and management tools are desperately needed for an adequate response to nonindigenous aquatic nuisance species (Busiahn 1993).

Ruffe

A fish indigenous to Eurasia, the ruffe was introduced to the Duluth-Superior harbor in the ballast water of an ocean-going ship in the early 1980s (Pratt *et al.* 1992). This relative of walleye, yellow perch and darters has become very abundant in the harbor and has spread 290 kilometers (180 miles) along the south shore of Lake Superior, through Wisconsin and into Michigan waters. Research indicates that ruffe may be displacing indigenous fishes as its population grows (Ruffe Task Force 1992). Introduced ruffe populations have also been successful in other waters, such as Loch Lomond, the largest lake in Scotland (Maitland and East 1989).

Fish management agencies, anglers and commercial fishers are alarmed at the prospect of ruffe displacing yellow perch or lake whitefish in the Great Lakes and inland waters. Since ruffe were discovered in 1987, a series of task forces and committees has grappled with the difficult question; what to do? The initial management response by the Wisconsin and Minnesota Departments of Natural Resources was to restrict the taking of baitfish in infested waters, and to attempt to build up predator fish populations by stocking and restricting harvest.

A task force appointed by the Great Lakes Fishery Commission issued a report, *Ruffe in the Great Lakes: A Threat to North American Fisheries*, and urgently recommended a program of research and control (Ruffe Task Force 1992). Currently a Ruffe Control Committee appointed by the national Aquatic Nuisance Species Task Force is nearing completion of a *Ruffe Control Program*, the first control program authorized under the *Non-indigenous Aquatic Nuisance Prevention and Control Act of 1990.*

The potential range of ruffe in North America extends from the Great Plains to the eastern seaboard and north into Canada. Prime areas for colonization in the Great Lakes include Lake Erie, Lake St. Clair, Saginaw Bay and Green Bay. If ruffe colonize southern Lake Michigan, they have access to the Mississippi River basin via the Chicago River.

Sea lamprey

While new introductions of nonindigenous pests are alarming, previous introductions continue to impose enormous costs and impediments to restoring and managing Great Lakes fishery resources. The sea lamprey is a continuing problem in all five Great Lakes, and is an increasing problem in some areas, such as northern Lake Huron and northern Lake Michigan where the effects of uncontrolled St. Mary's River population are most severe.

The sea lamprey control program, conducted by the U.S. and Canada through the Great Lakes Fishery Commission, has been very successful in suppressing sea lamprey populations with relatively few side effects; where conventional piscicide treatments are effective. This very success has bred complacency, as many in the public and in government assume that the sea lamprey problem has been "handled". This attitude is impeding budget increases necessary to address the St. Mary's River problem. Many of today's managers do not even remember the time when the Great Lakes fishery had been practically destroyed by the sea lamprey, in conjunction with other problems. Rapidly increasing costs have limited program capabilities, even while lamprey populations have increased in areas of improved water quality.

Commitment of the U.S. and Canada to sea lamprey control must be maintained. Research on new and refined control techniques must be carried out to reduce dependence on lampricides. New nonindigenous species and other problems must not divert attention from the continuing need for sea lamprey control.

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Glossary

biota
the living components of habitat, including plants and animals.

EPA
U.S. Environmental Protection Agency.

habitat
the sum total of the physical, chemical and biological attributes of a specific location, which constitutes a distinct fish or wildlife refuge, feeding site, or breeding location.

nearshore sub-system
all coastal features, as well as islands and shallow water features such as reefs and shoals.

beach
the zone of unconsolidated material, or debris, between the low water mark and the bottom of the cliff.

coast
the zone landward of the base of the cliff, with the line of demarcation known as the coastline.

shore
that zone, from the low water mark landward to the base of the cliff, large or small, which marks the landward limit of effective wave action (cliff, in this sense, refers to the abrupt change in gradient, no matter how small, indicating where wave erosional forces cease, and is usually demarcated by a change in vegetation and substrate).

open water sub-system
includes circulatory basins and extends shoreward, to either the sand/silt sediment boundary or the attached plant boundary, whichever reaches the greater depth.

impairments to habitat
stresses which interfere with normal life processes of organisms living within a specific habitat unit.

introduction

intentional
import or introduction of nonindigenous species into, or transport through, an area or ecosystem where it is not established in open waters for a specific purpose such as aquaculture, aquarium display, or fishery enhancement (stocking).

unintentional
introduction of a nonindigenous species that occurs as a result of activities other than the purposeful importation, transport, or introduction of that species.

nonindigenous species
any species or other viable biological material that enters an ecosystem beyond its historic range.

PCB
poly-chlorinated biphenyl compound.

rehabilitation
altering an ecosystem to restore elements of structure, function, diversity, and dynamics without necessarily attempting complete restoration to specified prior conditions.

restoration
the reestablishment of self-sustaining populations of fish and wildlife. It may involve enhancement and/or rehabilitation of the structure, function, diversity, and dynamics of the biological system.

TFM
the selective sea lampricide, 3-triflouromethyl-4-nitrophenol.

trophic guild

herbivore
greater than 75 percent of the diet consists of plants from substrate (diatoms and blue-green algae associated with substrate) and vascular plants.

omnivore
diet consists of at least 25 percent plant and equal to or greater than 25 percent animal material.

planktivore
greater than 75 percent of the diet consists of zooplankton and/or phytoplankton.

carnivore

piscivore
greater than 75 percent of the diet consists of fish.

macroinvertivore
greater than 75 percent of the diet consists of macroinvertebrates (insects, crustaceans, annelids, etc.)

veliger
the free-swimming larval stage of the zebra mussel (for the purposes of this report).

Summary of Recommendations

	Recommendation	Period
1	Develop and Adopt Aquatic Community and Habitat Goals and Objectives to Support Ecosystem Management	Multi-year
2	Fully Implement the *Strategic Plan for Management of Great Lakes Fisheries*	Multi-year
3	Conduct Comprehensive and Standardized Ecological Monitoring	Multi-year
4	Standardize Fish Community Assessment Data and Establish Comprehensive Fishery Databases	Multi-year
5	Develop Offshore Capabilities	One-time
6	Fish Community Assessment Program	Multi-year
7	Fish Community Modelling	Multi-year
8	Coordinate State and Native American Tribal Harvest Monitoring and Management: Measure Commercial and Recreational Fish Catches	Multi-year
9	Evaluate Ecological Effects of Stocking and Revise Stocking Strategies, as Necessary, to be Consistent with Proposed Aquatic Community and Habitat Goals and Objectives	Multi-year

Numbers are included for reference only and do not indicate priority.

Summary of Recommendations

	Recommendation	Period
10	Ecological Information Clearinghouse/Geographic Information System	Multi-year
11	Identify, Inventory, Protect and Rehabilitate Significant Habitats	Multi-year
12	Develop and Implement Action, Restoration and/or Enhancement Plans for Exploited, and/or Declining Indigenous Aquatic Species	Multi-year
13	Develop and Implement Action/Restoration Plans for Forage Fish	Multi-year
14	"Close the Door" on Nonindigenous Species Introductions	Three years
15	Implement and Expand Effective Sea Lamprey Control	Multi-year
16	Great Lakes Fishery Commission Line Item Funding for Sea Lamprey Control Efforts in the St. Mary's River	Multi-year
17	Fund Implementation of the Great Lakes Fishery Commission's Basin-wide Sea Lamprey Barrier Plan	Multi-year
18	Prevent or Delay the Spread of Ruffe	Multi-year
19	Determine the Impacts of Hydroelectric Facilities and Dam Operations on Fishery Resources	Three years

Numbers are included for reference only and do not indicate priority.

Summary of Recommendations

	Recommendation	Period
20	Increase Involvement in the Binational Program to Restore and Protect Lake Superior and Expand this Mechanism to Lakes Huron, Erie, and Ontario	Multi-year
21	Establish Uniform Tissue and Sediment Contaminant Levels Used by Various Agencies for Ecosystem Health	Two years
22	Broaden the Scope of Current State Antidegradation Policies, Regulations, and Strategies	One year
23	Develop and Implement an Action Plan to Analyze Contaminant Level Effects on Aquatic Resources	Multi-year
24	Participate in Remedial Action Plans, Lake-wide Management Plans, and the Environmental Monitoring and Assessment Program	Multi-year
25	Salmonine Egg Viability	Multi-year
26	Establish an Isolation or Quarantine Facility	One year
27	Develop an Epizootic Epitheliotrophic Disease (EEDV) Diagnostic Test	Two years
28	Fish Health	Multi-year

Numbers are included for reference only and do not indicate priority.

Summary of Recommendations

	Recommendation	Period
29	Fish Genetics	Multi-year
30	Lethality of Sea Lamprey Attacks	Three years
31	Develop Aquatic Resource Education Programs	Multi-year
32	Conduct a Cormorant Fishery Predation Study	Three years

Numbers are included for reference only and do not indicate priority.

These recommendations address issues common to all five of the Great Lakes and their watersheds and identify priorities not currently funded through any of the agencies, but considered essential to meet the *Fish Community Goals and Objectives* for each of the Great Lakes. Funding necessary to accomplish some of these tasks would be provided to the partners on an equal cost-share basis by the Service, as funds become available. Funding of projects would be accomplished based upon priorities established via a multi-agency committee project approval process to be developed by the Service, the Great Lakes Fishery Commission, the State and Native American Tribal partners, and other interested parties.

All recommendations assume the effective establishment of the aforementioned project approval process, are not limited to funding through or implementation by the Service, and rely heavily on input from and future cooperation among Great Lakes Basin partners. It is expected that future projects addressing these recommendations will focus first on implementation where information is sufficient and on data collection where information is lacking.

Great Lakes Fishes Status and Trends

COMMON NAME	SCIENTIFIC NAME	LAKE SUPERIOR		LAKE MICHIGAN		LAKE HURON		LAKE ERIE		LAKE ONTARIO	
		Status	Trend	Status	Trend	Status	Trend	Status	Trend	Status	Trend
Chestnut lamprey	*Ichthyomyzon castaneus*			R							
Northern brook lamprey	*Ichthyomyzon fossor*	C		C							
Silver lamprey	*Ichthyomyzon unicuspis*	R		R						R	
American brook lamprey	*Lampetra appendix*	R		R						R	
Sea lamprey	*Petromyzon marinus*	*C	◆	*C	◆	*A	▲	*C	◆▶▼	*C	◆
Lake sturgeon	*Acipenser fulvescens*	R	▲	R	◆	R				R	▼
Paddlefish	*Polyodon spathula*	E									
Spotted gar	*Lepisosteus oculatus*										
Longnose gar	*Lepisosteus osseus*	R		C		C	◆			R	
Shortnose gar	*Lepisosteus platostomus*			*R							
Bowfin	*Amia calva*	R		R						R	
Mooneye	*Hiodon tergisus*			R							
American eel	*Anguilla rostrata*	*R	▲	*R		*		*		R	▼
Alewife	*Alosa pseudoharengus*	*C	◆	*A	◆	*A	◆	*C	▼	*C	▼
American shad	*Alosa sapidissima*							*X		X	
Gizzard shad	*Dorosoma cepedianum*	R		*C	◆	*C				*C	▲
Central stoneroller	*Campostoma anomalum*									C	▲
Largescale stoneroller	*Campostoma oligolepis*	R		R	▼						
Goldfish	*Carassius auratus*			*R		*	*	*C	▼	*R-C	▲
Redside dace	*Clinostomus elongatus*			R						R-C	
Lake chub	*Couesius plumbeus*	C		C						R-C	▼
Grass carp	*Ctenopharyngodon idella*			*R		*					
Satinfin shiner	*Cyprinella analostanus*									R-C	
Spotfin shiner	*Cyprinella spilopterus*									C	
Steelcolor shiner	*Cyprinella whipplei*										
Common Carp	*Cyprinus carpio*	*R	◆	*C	◆	*A	◆	*C	▼	*C	◆
Tonguetied minnow	*Exoglossum laurae*									R-C	

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Great Lakes Fishes Status and Trends

COMMON NAME	SCIENTIFIC NAME	LAKE SUPERIOR		LAKE MICHIGAN		LAKE HURON		LAKE ERIE		LAKE ONTARIO	
		Status	Trend	Status	Trend	Status	Trend	Status	Trend	Status	Trend
Cutlips minnow	*Exoglossum maxillingua*									C	
Brassy minnow	*Hybognathus hankinsoni*										
Eastern silvery minnow	*Hybognathus regius*									R	
Striped shiner	*Luxilus chrysocephalus*			R							
Common shiner	*Luxilus cornutus*	C		C	◆					R-C	▼
Redfin shiner	*Lythrurus umbratilis*									R-C	
Silver chub	*Macrhybopsis storeriana*										
Pearl dace	*Margariscus margarita*	R		C							
Hornyhead chub	*Nocomis biguttatus*	C	▼	C						R-C	
River chub	*Nocomis micropogon*										
Golden shiner	*Notemigonus crysoleucas*	C		C						R-C	▼
Bigeye chub	*Notropis amblops*										
Pugnose shiner	*Notropis anogenus*										
Popeye shiner	*Notropis ariommus*										
Emerald shiner	*Notropis atherinoides*	C	▼	R				A	◆▼	R-C	
Bridle shiner	*Notropis bifrenatus*										
Bigeye shiner	*Notropis boops*										
Silverjaw minnow	*Notropis buccatus*										
Ghost shiner	*Notropis buchanani*										
Bigmouth shiner	*Notropis dorsalis*	*		*R				*		*R-C	
Blackchin shiner	*Notropis heterodon*										
Blacknose shiner	*Notropis heterolepis*										
Spottail shiner	*Notropis hudsonius*	A	▼	C		A		A	▼	R-C	◆
Silver shiner	*Notropis photogenis*										
Swallowtail shiner	*Notropis procne*										
Rosyface shiner	*Notropis rubellus*									R	
Sand shiner	*Notropis stramineus*									R-C	▼

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		Status	Trend	Status	Trend	Status	Trend	Status	Trend	Status	Trend
Mimic shiner	*Notropis volucellus*	C		R						R	▼
Pugnose minnow	*Opsopoeodus emiliae*			R						R-C	
Suckermouth minnow	*Phenacobius mirabilis*									R-C	
Northern redbelly dace	*Phoxinus eos*	C								R-C	
Southern redbelly dace	*Phoxinus erythrogaster*										
Finescale dace	*Phoxinus neogaeus*	R								R-C	
Bluntnose minnow	*Pimephales notatus*	C		C						R-C	▼
Fathead minnow	*Pimephales promelas*			C						R	▼
Bullhead minnow	*Pimephales vigilax*										
Blacknose dace	*Rhinichthys atratulus*	C	◆	C						C	
Longnose dace	*Rhinichthys cataractae*	C		C						R-C	
Rudd	*Scardinius erythrophthalmus*									R-C	
Creek chub	*Semotilus atromaculatus*	C		C						R-C	▼
Fallfish	*Semotilus corporalis*									A	▲
Quillback carpsucker	*Carpiodes cyprinus*									R-C	
Riverback carpsucker	*Carpiodes carpio*										
Longnose sucker	*Catostomus catostomus*	A	◆	C	◆					R-C	
White sucker	*Catostomus commersoni*	A	◆	C	◆					C	▼
Creek chubsucker	*Erimyzon oblongus*										
Lake chubsucker	*Erimyzon sucetta*										
Northern hogsucker	*Hypentelium nigricans*			R	▼					R-C	▼
Bigmouth buffalo	*Ictiobus cyprinellus*										
Hairlip sucker	*Lagochila lacera*										
Spotted sucker	*Minytrema melanops*										
Silver redhorse	*Moxostoma anisurum*	C								R-C	▼
River redhorse	*Moxostoma carinatum*										
Black redhorse	*Moxostoma duquesnei*										

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		Status	Trend	Status	Trend	Status	Trend	Status	Trend	Status	Trend
Golden redhorse	*Moxostoma erythrurum*			C						R	
Shorthead redhorse	*Moxostoma macrolepidotum*	C								A	▲
Greater redhorse	*Moxostoma valenciennesi*										
White catfish	*Ameiurus catus*										
Black bullhead	*Ameiurus melas*	C		C						R-C	
Yellow bullhead	*Ameiurus natalis*	R									
Brown bullhead	*Ameiurus nebulosus*	C						C	▲	R-C	▼
Channel catfish	*Ictalurus punctatus*	R	▲	R			▼	C	◆	R-C	
Stonecat	*Noturus flavus*	R								R	
Tadpole madtom	*Noturus gyrinus*	R									
Margined madtom	*Noturus insignis*	*R								*R	
Brindled madtom	*Noturus miurus*									R-C	
Northern madtom	*Noturus stigmosus*										
Flathead catfish	*Pylodictis olivaris*										
Grass Pickerel	*Esox americanus vermiculatus*			R						R	▼
Northern pike	*Esox lucius*	C	◆	C	◆	C				R	▼
Muskellunge	*Esox masquinongy*	R		R		R				R-C	
Chain pickerel	*Esox niger*							*		*A	▲
Central mudminnow	*Umbra limi*	C								R-C	
Rainbow smelt	*Osmerus mordax*	*A	▼	*C	◆	*A	◆	*A	▼	*R	▼
Lake herring or cisco	*Coregonus artedii*	A	▲	R		R	▼	X		R	▼
Lake whitefish	*Coregonus clupeaformis*	A	◆	A	◆	A	▲	C	▲	R	▲
Bloater	*Coregonus hoyi*	C	◆	A	◆	C	◆			X	
Deepwater cisco	*Coregonus johannae*			E		E					
Kiyi	*Coregonus kiyi*	R	▼	E		R				X	
Blackfin cisco	*Coregonus nigripinnis*			E		E				X	
Shortnose cisco	*Coregonus reighardi*			E		R				X	

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		Status	Trend	Status	Trend	Status	Trend	Status	Trend	Status	Trend
Shortjaw cisco	*Coregonus zenithicus*	R	▼	E		E				X	
Pink salmon	*Oncorhynchus gorbuscha*	*C	▼	*R	◆	*C	◆				
Coho salmon	*Oncorhynchus kisutch*	*C	◆	*C	◆	*R	▼	*R	▼	*C	▲
Rainbow trout	*Oncorhynchus mykiss*	*C	▼	*C	◆	*C	▲	*R	▼	*C	▲
Kokanee	*Oncorhynchus nerka*			*R		*R		*R	▼	*X	
Chinook salmon	*Oncorhynchus tshawytscha*	*C	◆	*C	▼	*C	◆	*R	▼	*C	▲
Pygmy whitefish	*Prosopium coulteri*	C	◆								
Round whitefish	*Prosopium cylindraceum*	A	◆	C	◆	C	◆				
Atlantic salmon	*Salmo salar*	*R	▼	*R	▼	*R	◆	*X		X	
Brown trout	*Salmo trutta*	*C	▼	*C	◆	*C	▲	*R	▼	*R-C	▲
Brook trout	*Salvelinus fontinalis*	R	▼	C	◆	R				R	
Lake trout	*Salvelinus namaycush*	C	◆	C	◆	C	▼	R	▲	R-C	▲
Arctic grayling	*Thymallus arcticus*	E				E					
Trout-perch	*Percopsis omiscomaycus*	A	◆	C		A				R-C	▼
Pirate-perch	*Aphredoderus sayanus*										
Burbot	*Lota lota*	C	▼	A	▲			C	▲	C	
Banded killifish	*Fundulus diaphanus*	R								R	
Blackstripe topminnow	*Fundulus notatus*										
Eastern mosquitofish	*Gambusia holbrooki*										
Brook silverside	*Labidesthes sicculus*	*R								R	
Fourspine stickleback	*Apeltes quadracus*	*R	▲	*							
Brook stickleback	*Culaea inconstans*	C								R-C	▼
Threespine stickleback	*Gasterosteus aculeatus*	*R		*		*					
Ninespine stickleback	*Pungitius pungitius*	A	◆	R							
Mottled sculpin	*Cottus bairdi*	C	◆	C	◆			X		R	
Slimy sculpin	*Cottus cognatus*	A	▼	C		A		C	▲	R-C	▼
Spoonhead sculpin	*Cottus ricei*	A	◆	R				X		X	

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		Status	Trend	Status	Trend	Status	Trend	Status	Trend	Status	Trend
Fourhorn sculpin	*Myoxocephalus quadricornis*							X		X	
Deepwater sculpin	*Myoxocephalus thompsoni*	A	◆	C	▼					X	
White perch	*Morone americana*	*R	▲	*R	▲	*C	◆	*C	▼	*A	▲
White bass	*Morone chrysops*	R		R		C	◆	C	▼	*R-C	
Yellow Bass	*Morone mississippiensis*			*							
Striped Bass	*Morone saxatilis*									*X	
Rock bass	*Ambloplites rupestris*	A	◆	C	◆	C				C	◆
Redbreast sunfish	*Lepomis auritis*									R-C	
Green sunfish	*Lepomis cyanellus*										
Pumpkinseed	*Lepomis gibbosus*	C		C	◆	C				R-C	▼
Warmouth	*Lepomis gulosus*			*				*			
Orangespotted sunfish	*Lepomis humilis*										
Bluegill	*Lepomis macrochirus*	R		C	◆	C				C	
Longear sunfish	*Lepomis megalotis*										
Redear sunfish	*Lepomis microlophus*										
Smallmouth bass	*Micropterus dolomieu*	C	◆	C	▲	C		C	◆	C	◆
Largemouth bass	*Micropterus salmoides*	R		R		C				R-C	
White crappie	*Pomoxis annularis*									C	
Black crappie	*Pomoxis nigromaculatus*	C		C	◆	C				R-C	
Western sand darter	*Ammocrypta clara*										
Eastern sand darter	*Ammocrypta pellucida*										
Greenside darter	*Etheostoma blennioides*									R	
Rainbow darter	*Etheostoma caeruleum*									R-C	
Iowa darter	*Etheostoma exile*	R									
Fantail darter	*Etheostoma flabellare lineolatum*									R-C	
Least darter	*Etheostoma microperca*										
Johnny darter	*Etheostoma nigrum*	A	◆	C		C				C	

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		Status	Trend	Status	Trend	Status	Trend	Status	Trend	Status	Trend
Tessellated darter	*Etheostoma olmstedi*									A	
Orangethroat darter	*Etheostoma spectabile*										
Banded darter	*Etheostoma zonale*									R	
Yellow perch	*Perca flavescens*	C	◆	A	▼	A	▼	A	▼	C	◆
Ruffe	*Gymnocephalus cernuus*	*C	▲								
Logperch	*Percina caprodes*	C								R-C	
Channel darter	*Percina copelandi*									R-C	
Gilt darter	*Percina evides*										
Blackside darter	*Percina maculata*									R	
Slenderhead darter	*Percina phoxocephala*										
River darter	*Percina shumardi*			*				*			
Sauger	*Stizostedion canadense*	R									
Walleye	*Stizostedion vitreum vitreum*	C	▲	C	◆	A	▲	A	▼	C	▲
Blue pike	*Stizostedion vitreum glaucum*							X		X	
Freshwater drum	*Aplodinotus grunniens*	*R		C	◆	C	◆			C	▲
Round goby	*Neogobius melanostomus*			*R	▲						
Tubenose goby	*Proterorhinus marmoratus*			*		*		*		*	

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Note: all previously published lists of Great Lakes fishes are incomplete, due to introductions and invasions. This list was compiled by the Service through literature searches and consultation with agency biologists. By necessity, it incorporates subjective judgments of status and trends, which may not apply in all localities. Nevertheless, it provides an overview of the state of our knowledge, or lack thereof, on the fish communities of the Great Lakes Basin.

This Great Lakes Fishes Status and Trends list will be revised and published on a biennial basis in the Great Lakes Fish and Wildlife Restoration Act Report to Congress.

Statutory Mandates and Authorities

Part I - General Authorities

ANADROMOUS FISH CONSERVATION ACT OF 1985
(16 U.S.C. 757a-757g) Directs the Fish and Wildlife Service to conserve, develop, and enhance with States the anadromous fishery resources of the Nation that are subject to depletion from water resources developments and other causes. The Act also includes anadromous fish resources conservation addressed in international agreements and in the Great Lakes. This will be accomplished by entering into cooperative agreements with the States for which the Federal cost shall not exceed 50 percent.

BOUNDARY WATERS TREATY BETWEEN THE UNITED STATES AND GREAT BRITAIN OF 1909
(36 STAT. 2448) States that neither country shall divert or pollute the waters on their side so as to cause injury of health or property (including commercial fishing) on the other side. This Treaty is the basis for the International Joint Commission and the Great Lakes Water Quality Agreements.

COASTAL BARRIER RESOURCES ACT
(16 U.S.C. 3051 et.seq.) Designated various undeveloped coastal barrier islands, depicted by specific maps, for inclusion in the Coastal Barrier Resources System (System). Areas so designated were made ineligible for direct or indirect Federal financial assistance that might support development, including flood insurance, except for emergency life-saving activities. Exceptions for certain activities, such as fish and wildlife research are provided. The Coastal Barrier Improvement Act of 1990 included in the System additional areas along the Great Lakes.

COASTAL ZONE MANAGEMENT ACT
(16 U.S.C. 1451-1464) Authorized in 1990, the Act provides assistance to the coastal states in developing coastal zone management programs that will protect, develop and enhance coastal resources. The primary tool used to achieve this objective is a grant program with guidance and oversight provided by the Office of Ocean and Coastal Resource Management, National Oceanic and Atmospheric Administration, Department of Commerce.

EMERGENCY WETLANDS RESOURCES ACT OF 1986
(P.L. 99-645) Enacted to intensify cooperative and acquisition efforts among private interests and local, State, and Federal governments for the protection, management, and conservation of wetlands.

ENDANGERED SPECIES ACT OF 1973
(As amended, 16 U.S.C. 1531-1543) Implemented the Convention on International Trade in Endangered Species of Wild Fauna and Flora and the Convention on Nature Protection and Wildlife Preservation in the Western Hemisphere. The Act provides for the conservation of threatened and endangered species of fish, wildlife, and plants by Federal action and by encouraging the establishment of State programs.

ESTUARY PROTECTION ACT
(16 U.S.C. 1221-1226) Highlights the values of estuaries and the need to conserve their natural resources. It authorizes the Secretary of the Interior, in cooperation with other Federal agencies and the States, to study and inventory estuaries of the United States, including land and water of the Great Lakes, and to determine whether such areas should be acquired by the Federal government for protection.

FEDERAL WATER POLLUTION CONTROL ACT AMENDMENTS
(33 U.S.C. 1251-1365, 1281-1292, 1311-1328, 1342-1345, 1361-1376) The 1972 amendments represented a major initiative to restore the quality of the Nation's waters. A major national goal established by the amendments was the achievement of water quality which provides for protection and propagation of fish, shellfish, and wildlife. The 1987 amendments of this Act included section 320 entitled "National Estuary Program." This section provided the mechanism by which the Governor of any State could nominate to the Administrator of EPA, an estuary within its boundaries as an estuary of national significance and request a management conference to develop a comprehensive management plan for the estuary. The Service's Bay/Estuary program coordinates closely with EPA's established programs.

FISH AND WILDLIFE ACT OF 1956
(As amended, 16 U.S.C. 742a-742j) Established a comprehensive national fish and wildlife policy; directs the Secretary of the Interior to provide continuing research, extension, and information services, and to take any necessary steps to develop, manage, protect, and conserve fishery and wildlife resources, including research, acquisition of refuge lands, development of existing facilities, and other means.

FISH AND WILDLIFE COORDINATION ACT
(As amended, 16 U.S.C. 661-666c) Authorizes assistance to Federal, State, and other agencies in development, protection, rearing, and stocking of fish and wildlife and controlling losses thereof. Authorizes surveys of fish and wildlife of all Federal lands and on effects of pollution. Authorizes surveys to prevent losses of, and to enhance, fish and wildlife at water-use projects constructed or licensed by the Federal government.

LACEY ACT OF 1900
(As amended, 16 U.S.C. 7001) States that the duties of the Department of the Interior include conservation, preservation, and restoration of "game birds and other wild birds," and authorizes measures for their restoration from such funds as Congress may appropriate. Authorization is also provided to "regulate the introduction of American or foreign birds or animals into new locations, and to collect and publish information on wild birds." It provides enforcement authorities and penalties for violation of various wildlife related Acts and regulations. It prohibits the transportation of wildlife or their parts or products taken or possessed in violation of Federal, State, or foreign laws or regulations.

NATIONAL WILDLIFE REFUGE SYSTEM ADMINISTRATION ACT OF 1966
(As amended, 16 U.S.C. 668dd-668ee) Constitutes an "Organic Act" for the National Wildlife Refuge System and provides guidelines and directives for the administration and management of all areas in the system including "wildlife refuges, areas for the protection and conservation of fish and wildlife that are threatened with extinction, wildlife ranges, game ranges, wildlife management areas, and waterfowl production areas."

NONINDIGENOUS AQUATIC NUISANCE PREVENTION AND CONTROL ACT OF 1990
(16 U.S.C. 4701-4741) Mandates and provides comprehensive authority for a national program to address problems related to unintentional introductions of nonindigenous aquatic species into waters of the United States. Authorized is the establishment of a national program to reduce the risk of such introductions and to control, when warranted, aquatic nuisance species that become established. Also authorized are several related efforts, including coordination of nonindigenous species activities in the Great Lakes, a review of policies for addressing intentional introductions, and brown tree snake control.

NORTH AMERICAN WETLANDS CONSERVATION ACT OF 1989
(16 U.S.C. 4401-4412) Enacted to encourage partnerships among public agencies and other interests to: 1) protect, enhance, restore, and manage an appropriate distribution and diversity of wetlands ecosystems and other habitats for migratory birds and other fish and wildlife in North America; 2) maintain current or improved distributions of migratory bird populations; and 3) sustain an abundance of waterfowl and other migratory birds consistent with the

goals of the North American Waterfowl Management Plan and the international obligations contained in the migratory bird treaties and conventions and other agreements with Canada, Mexico, and other countries.

OIL POLLUTION ACT OF 1990
(P.L. 101-380) This Act mandates the Service to: 1) assist the Coast Guard in revising the National Contingency Plan and the accompanying fish and wildlife response plan; 2) assist in developing Area Contingency Plans; 3) assist NOAA in preparing damage assessment regulations and conducting damage assessments; 4) review vessel and facility response plans; and 5) conduct research on environmental effects of oil spills.

Part II - Specific Authorizations

GREAT LAKES FISHERY ACT OF 1956
(16 U.S.C. 931-939c) Implements the Convention on Great Lakes Fisheries between the United States and Canada covering Lake Ontario (including the Saint Lawrence River from Lake Ontario to the forty-fifth parallel of latitude), Lake Erie, Lake Huron (including Lake Saint Clair), Lake Michigan, and Lake Superior.

PERE MARQUETTE RIVER AMENDMENT
(P.L. 98-444) Amended the Wild and Scenic Rivers Act to permit control of the "lamprey eel" in the Pere Marquette River, Michigan, by allowing the installation and operation of dams and other control facilities in accordance with requirements prescribed by the Secretary of Agriculture for the protection of water quality and the value of the river.

GREAT LAKES FISH AND WILDLIFE RESTORATION ACT OF 1990
(16 U.S.C. 941a-941g) Enacted to: 1) carry out a comprehensive study of the status, and the assessment, management, and restoration needs, of the fishery resources of the Great Lakes Basin; 2) develop proposals to implement recommendations resulting from the study; and 3) provide assistance to the Great Lakes Fishery Commission, States, Native Americans, and other interested entities to encourage cooperative conservation, restoration, and management of the fish and wildlife resources and their habitats of the Great Lakes Basin.

Great Lakes Fish and Wildlife Restoration Act of 1990

PUBLIC LAW 101-646-NOV.29, 1990

"TITLE II—GREAT LAKES FISH AND WILDLIFE RESTORATION

SECTION 2001. SHORT TITLE
"This title may be cited as the "Great Lakes Fish and Wildlife Restoration Act of 1990.

"SEC. 2002 FINDINGS.
"The Congress finds and declares the following:

"(1) As the human population of the Great Lakes Basin has expanded to over 36,000,000 people, great demands have been placed on the lakes for use for boating and other recreation, navigation, municipal and industrial water supply, waste disposal, power production, and other purposes. These growing and often conflicting demands exert pressure on the fish and wildlife resources of the Great Lakes Basin, including in the form of contaminants, invasion by nonindigenous species, habitat degradation and destruction, legal and illegal fishery resource harvest levels, and sea lamprey predation.

"(2) The fishery resources of the Great Lakes support recreational fisheries enjoyed by more than 5,000,000 people annually and commercial fisheries providing approximately 9,000 jobs. Together, these fisheries generate economic activity worth more than $4,400,000,000 annually to the United States.

"(3) The availability of a suitable forage base is essential to lake trout, walleye, yellow perch, and other recreational and commercially valuable fishery resources of the Great Lakes Basin. Protecting and restoring productive fish habitat, including by protecting water quality, is essential to the successful recovery of Great Lakes Basin fishery resources.

"(4) The Great Lakes Basin contains important breeding and migration habitat for all types of migratory birds. Many migratory bird species dependent on deteriorating Great Lakes Basin habitat have suffered serious population declines in recent years.

"(5) Over 80 percent of the original wetlands in the Great Lakes Basin have been destroyed and such losses continue at a rate of 20,000 acres annually.

"(6) Contaminant burdens in the fish and wildlife resources of the Great Lakes Basin are substantial and the impacts of those contaminants on the life functions of important fish and wildlife resources are poorly understood. Concern over the effects of those contaminants on human health have resulted in numerous public health advisories recommending restricted or no consumption of Great Lakes fish.

"(7) The lower Great Lakes are uniquely different from the upper Great Lakes biologically, physically, and in the degree of human use and shoreline development, and special fishery resource assessments and management activities are necessary to respond effectively to these special circumstances.

"SEC.2003. PURPOSE.
"The purposes of this Act are -

"(1) to carry out a comprehensive study of the status, and the assessment, management, and restoration needs, of the fishery resources of the Great Lakes Basin;

"(2) to develop proposals to implement recommendations resulting from that study; and

"(3) to provide assistance to the Great Lakes Fisheries Commission, States, Indian Tribes, and other interested entities to encourage cooperative conservation, restoration and management of the fish and wildlife resources and their habitat of the Great Lakes Basin.

"SEC.2001. DEFINITIONS.

"In this Act -

"(1) the term "Administrator" means the Administrator of the Environmental Protection Agency;

"(2) the term "Director" means the Director of the United States Fish and Wildlife Service;

"(3) the term "fish stock" means-

"(A) a taxonomically distinct species or subspecies of fish;or

"(B) any other aggregation of fish that are geographically, ecologically, behaviorally, or otherwise limited from breeding with individuals from other groups of fish and are capable of management as a unit;

"(4) the term "Great Lakes Basin" means the air, land, water, and living organisms within the drainage basin of the Saint Lawrence River at or upstream from the point at which the river becomes the international boundary between Canada and the United States;

"(5) the term "Indian tribe" means any Indian tribe, band, village, nation, or other organized group or community that is recognized by the Bureau of Indian Affairs is eligible for the special program and services provided by the United States to Indians because of their status as Indians;

"(6) the term lower Great Lakes" means the region in which is located that portion of the Great Lakes Basin which is downstream from the confluence of the Saint Clair River and Lake Huron near Port Huron, Michigan;

"(7) the term "upper Great Lakes" means that portion of the Great Lakes Basin which is upstream from the confluence of the Saint Clair River and Lake Huron near Port Huron, Michigan;

"(8) the term "nonindigenous species" means a species of plant or animal that did not occur in the Great Lakes Basin before European colonization of North America;

"(9) the term "Secretary" means the Secretary of the Army; and

"(10) the term "State Director" means the head of the agency department, board, commission, or other governmental entity of each of the States of New York, Ohio, Indiana, Illinois, Michigan, Wisconsin, Minnesota, and the Commonwealth of Pennsylvania which is responsible for the management and conservation of the fish and wildlife resources of that State.

"SEC. 2005. GREAT LAKES FISHERY RESOURCES RESTORATION STUDY.

"(a) IN GENERAL. - The Director shall conduct a comprehensive study of the status of, and the assessment, management, and restoration needs of, the fishery resources of the Great Lakes Basin and shall provide the opportunity for the Secretary, the Administrator, State Directors, Indian tribes, the Great Lakes Fishery Commission, appropriate Canadian Government entities, and other appropriate entities to participate in the study. The Director shall complete the study by October 1, 1994.

"(b) MEMORANDUM OF UNDERSTANDING. - To provide opportunities for the full participation of all affected entities in the planning and conduct of the study. the Director shall invite the entities identified in subsection (a) to enter into a memorandum of understanding regarding the scope and focus of the study and the responsibilities of each participant for conducting the study.

"(c) CONTENT OF STUDY. - A study under this section shall include, but not be limited to -

"(1) identifying and describing the component drainages of the Great Lakes Basin (including the drainage for each of the Great Lakes, analyzing how the characteristics and current or expected land and water uses of those drainages have affected, and can be expected to affect in the future, the fishery resources and fish habitats of the Great Lakes Basin;

"(2) analyzing historical fishery resource data for the Great Lakes Basin to identify the causes of past and continuing declines of the fishery resources and the impediments to restoring those resources;

"(3) evaluating the adequacy, effectiveness, and consistency of current Great Lakes interagency fisheries management plans and Federal and State water quality programs, with respect to their effects on Great Lakes fishery resources;

"(4) analyzing the impacts of, and management control alternatives for, recently introduced nonindigenous species, including the zebra mussel, the ruffe, and the spiny water flea in accordance with the Aquatic Nuisance Prevention and Control Act of 1990;

"(5) developing recommendations regarding -

"(A) an action plan to analyze the effects of contaminant levels on fishery resources;

"(B) an action plan for the cooperative restoration and enhancement of depleted, nationally significant fish stocks, including lake trout, yellow perch, lake sturgeon, walleye, forage fish, and Atlantic salmon;

"(C) planning and technical assistance that should be provided to the Great Lakes Fisheries Commission, States, and Indian Tribes to assist their fishery resource restoration efforts;

"(D) mitigation measures to restore and enhance fishery resources adversely affected by past Federal (including federally assisted or approved) water resource development projects and other activities;

"(E) increasing the involvement of the International Joint Commission, the Great Lakes Commission, the Great Lakes Fishery Commission, and other interjurisdictional entities regarding fishery resources protection, restoration, and enhancement;

"(F) research projects and data gathering initiatives regarding population trends of fish stocks, including population abundance and structure, interspecific competition, survival rates, and behavioral patterns;

"(G) important fishery resource habitat and other areas that should be protected, restored, or enhanced for the benefit of Great Lakes fishery resources;

"(H) how private conservation organizations, recreational and commercial fishing interests, the aquaculture industry, and the general public could contribute to the implementation of the fishery resource restoration and enhancement recommendations developed pursuant to this Act; and

"(I) appropriate contributions that should be made by States and other non-Federal entities to the cost of activities undertaken to implement the recommendations, including a description of -

"(i) the activities that shall be cost-shared;

"(ii) the entities or individuals which shall share the costs of those activities;

"(iii) the proportion of appropriate project and activity costs that shall be borne by non-Federal interests; and

"(iv) how the entities or individuals who share costs should finance their contribution.

"(d) PROPOSALS FOR IMPLEMENTING RECOMMENDATIONS. - The Director shall develop proposals for implementing the recommendations of the study developed under subsection (c)(5). The proposals shall be consistent with the goals of the Great Lakes Water Quality Agreement, as revised in 1987, the 1964 Great lakes Fisheries Convention, State and tribal fishery management jurisdiction, and the 1980 Joint Strategic Plan for the management of Great Lakes fishery resources.

"SEC. 2006. GOALS OF THE UNITED STATES FISH AND WILDLIFE SERVICE PROGRAMS RELATED TO GREAT LAKES FISH AND WILDLIFE RESOURCES.
"In administering programs of the United States Fish and Wildlife Service related to the Great Lakes Basin, the Director shall seek to achieve the following goals:

"(1) Restoring and maintaining self-sustaining fishery resource populations.

"(2) Minimizing the impacts of contaminants on fishery and wildlife resources.

"(3) Protecting, maintaining, and, where degraded and destroyed, restoring fish and wildlife habitat, including the enhancement and creation of wetlands that result in a net gain in the amount of those habitats.

"(4) Stopping illegal activities adversely impacting fishery and wildlife resources.

"(5) Restoring threatened and endangered species to viable, self-sustaining levels.

"(6) Protecting, managing, and conserving migratory birds.

"SEC. 2007. ESTABLISHMENT OF OFFICES.
"(a) GREAT LAKES COORDINATION OFFICE. - The Director shall establish a centrally located facility for the coordination of all United States Fish an Wildlife Service activities in the Great Lakes Basin, to be known as the "Great Lakes Coordination Office". The functional responsibilities of the Great Lakes Coordination Office shall include intra- and interagency coordination, information distribution, and public awareness outreach. The Great Lakes Coordination Office shall include all administrative and technical support necessary to carry out its responsibilities.

"(b) LOWER GREAT LAKES FISHERY RESOURCES OFFICE. -The Director shall establish an office with necessary administrative and technical support services to carry out all United States Fish and Wildlife Service operational activities related to fishery resource protection, restoration, maintenance, and enhancement in the Lower Great Lakes. The office shall be known as the "Lower Great Lakes Fishery Resources Office", and shall be centrally located in the lower Great Lakes so as to facilitate fishery resource restoration and enhancement activities relating to the lower Great Lakes.

"(c) UPPER GREAT LAKES FISHERY RESOURCES OFFICES. - The Director shall establish one or more offices with necessary administrative and technical support services to carry out United States Fish and Wildlife Service operational activities related to fishery resource protection, restoration, maintenance, and

enhancement in the upper Great Lakes. Each of the offices shall be known as an "Upper Great Lakes Fishery Resources Office", and shall be appropriately located so as to facilitate fishery resource activities in the upper Great Lakes.

"SEC. 2008. ANNUAL REPORTS.
"Not later than 1 year after the date of the enactment of this Act and annually thereafter, the Director shall submit a report to the Committee on Merchant Marine and fisheries of the House of Representatives and the Committee on Environment and Public Works of the Senate. Each such report shall describe -

"(1) the progress and findings of the studies conducted under section 2005, including recommendations of implementing activities, where appropriate, that would contribute to the restoration or improvement of one or more fish stocks of the Great Lakes Basin; and

"(2) activities undertaken to accomplish the goals stated in section 2006.

"SEC. 2009. AUTHORIZATION OF APPROPRIATIONS.
"(a) There are authorized to be appropriated to the Director

"(1) for conducting a study under section 2005 not more than $4,000,000 for each of fiscal years 1991 through 1994;

"(2) to establish and operate the Great Lakes Coordination Office under section 2008(a) and Upper Great Lakes Fishery Resources Offices under section 2008(c), not more than $4,000,000 for each of fiscal years 1991 through 1995; and

"(3) to establish and operate the Lower Great Lakes Fishery Resources Offices under section 2008(b), not more than 2,000,000 for each of fiscal years 1991 through 1995.

"(b) There are authorized to be appropriated to the Secretary to carry out this Act, not more than $1,500,000 for each of fiscal years 1991 through 1995.".

MEMORANDUM OF UNDERSTANDING

BETWEEN

ILLINOIS DEPARTMENT OF CONSERVATION
INDIANA DEPARTMENT OF NATURAL RESOURCES
MICHIGAN DEPARTMENT OF NATURAL RESOURCES
MINNESOTA DEPARTMENT OF NATURAL RESOURCES
NEW YORK STATE DEPARTMENT OF ENVIRONMENTAL CONSERVATION
OHIO DEPARTMENT OF NATURAL RESOURCES
PENNSYLVANIA FISH AND BOAT COMMISSION
WISCONSIN DEPARTMENT OF NATURAL RESOURCES
BAD RIVER TRIBAL COUNCIL
BAY MILLS INDIAN COMMUNITY OF MICHIGAN
FOND DU LAC RESERVATION
GRAND PORTAGE RESERVATION
GRAND TRAVERSE BAND OF OTTAWA AND CHIPPEWA INDIANS
KEWEENAW BAY INDIAN COMMUNITY
RED CLIFF BAND OF LAKE SUPERIOR CHIPPEWA INDIANS
SAULT STE. MARIE BAND OF CHIPPEWA INDIANS
GREAT LAKES FISHERY COMMISSION

AND

THE U.S. FISH AND WILDLIFE SERVICE[1]

FOR THE COORDINATION AND JOINT IMPLEMENTATION OF THE GREAT LAKES FISH AND WILDLIFE RESTORATION ACT OF 1990

I. AUTHORITY

This Memorandum of Understanding (MOU) between the: Illinois Department of Conservation; Indiana Department of Natural Resources; Michigan Department of Natural Resources; Minnesota Department of Natural Resources; New York State Department of Environmental Conservation; Ohio Department of Natural Resources; Pennsylvania Fish and Boat Commission; Wisconsin Department of Natural Resources; Bad River Tribal Council; Bay Mills Indian Community of Michigan; Fond Du Lac Reservation; Grand Portage Reservation; Grand Traverse Band of Ottawa and Chippewa Indians; Keweenaw Bay Indian Community; Red Cliff Band of Lake Superior Chippewa Indians; Sault Ste. Marie Band of Chippewa Indians; and Great Lakes Fishery Commission, hereafter referred to as "partners" and the U.S. Fish and Wildlife Service, Department of the Interior, hereafter referred to as "Service," is hereby entered into under the authority of section 1 of the Fish and Wildlife Coordination Act (48 Stat/401, as amended; 16 USC 661 et seq.), section 7 of the Fish and Wildlife Act of 1956, 16 USC 742f (a)(4), section 2003 of the Great Lakes Fish and Wildlife Restoration Act of 1990 (104 Stat/4774); 16 USC 941a., and respective applicable partner authorities.

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[1] The U.S. Fish and Wildlife Service acknowledges the assistance of the **Great Lakes Indian Fish and Wildlife Commission** and the **Chippewa-Ottawa Fishery Treat Management Authority** in the development and review of this Memorandum of Understanding.

The parties to this agreement are the partners and the Service. The parties recognize that any references to cooperation with the partners or to obligations on the part of those partners are to the extent allowed by the agreement between the Service and each partner.

Nothing in this agreement is intended to enlarge or diminish the authority of any of the parties with respect to the protection and management of the Great Lakes fishery resources or to affect in any way the jurisdiction of either party under existing State, Federal or Tribal law. In addition, signing this MOU does not commit any signatory to a specific position regarding the reauthorization of the Act.

It is recognized by partners and the Service that the restoration of Great Lakes fish and wildlife resources and their supporting ecosystems is a cooperative effort involving a number of entities including State, Tribal, Federal and International organizations. Congress recognized that an ecosystem approach would be beneficial to further these cooperative relationships. The Great Lakes Fish and Wildlife Restoration Act directs a study of the status of, and the assessment, management, and restoration needs of, the fishery resources of the Great Lakes Basin, hereafter referred to as "Study". The Act requires completion of the Study by October 1, 1994 (Section 2005). A six-month extension has been requested to make the due date April 1, 1995. However, due to limited funding, the Study will only be partially completed.

Any proposals developed for implementing recommendations of the Study, or in other areas related to the Act, shall be consistent with State and Tribal fishery management jurisdictions, the goals of the Great Lakes Water Quality Agreement, as revised in 1987, the 1954 Great Lakes Fisheries Convention, and the 1980 Joint Strategic Plan for the management of Great Lakes fishery resources. Furthermore, partners are not obligated to participate in any program developed for implementing recommendations of the Study unless specific Memoranda of Agreement (MOA) are developed between the Service and the partners (per Section III..F. of this document). These MOAs should specify goals and objectives of any work needed to be done, source of funding for the work, and which agency is responsible for carrying out various parts of the work.

The Act also directs the Fish and Wildlife Service to work with the Great Lakes Fishery Commission, States, Indian tribes, and other interested partners to encourage cooperative conservation, restoration and management of the fish and wildlife resources and their habitat of the Great Lakes Basin. (Section 2003). In response, the Service has opened a number of lower and upper lakes Fishery Resources Offices and a Great Lakes Coordination Office. In cooperation with State and Tribal fishery managers, the Fishery Resources Offices are developing and implementing mutually identified projects. The Great Lakes Coordination Office is charged with coordination of the diverse fish and wildlife Great Lakes programs of the Service and coordinating accomplishment of the Study with the assistance of the Fishery Resources Offices, the Great Lakes Science Center, and the other Great Lakes entities.

II. PURPOSE

The purpose of this MOU is to facilitate cooperation and communication between the parties concerning fish and wildlife resource issues in the Great Lakes Basin. It will be used to guide Service and partner cooperative efforts to develop proposals and to implement resource recommendations within the Basin. If and when funds become available this MOU will provide the basic instrument for distribution of funds to partners to accomplish priority Study and ecosystem objectives identified by the partners.

III. SCOPE OF WORK

For the period set forth in Section IV, the partners and the Service shall coordinate activities under the Great Lakes Fish and Wildlife Restoration Act of 1990 consistent with the following guidelines.

A. Scope and Focus of Study.

1. The scope and focus of the Study will address all elements of Section 2005(c) for each of the five Great Lakes and connec ing waterways. However, since full funding of the Act and the Study was not forthcoming, the depth to which each Study component is addressed by lake will vary based on the funds available and the relative priorities of the components as identified by the Study participants.

2. The partners agree the Study will rely heavily on existing information and data bases and will identify recommendations that are necessary to accomplish the purposes of the Act. The recommendations will include proposals and suggestions for new research and data gathering initiatives, restoring habitats, addressing fishery management information needs, nonindigenous species control and research needs, improvements needed to better coordinate and carry out interjurisdictional responsibilities and public information/education needs to help protect and restore the Great Lakes ecosystems.

3. While the primary focus of the Study will be on fisheries restoration, it is agreed by partners and the Service that the Study will address and include recommendations related to aquatic and wetland habitat protection and restoration needs, coordination of wildlife and fisheries interactions, and fisheries law enforcement.

4. The analysis required under Section 2005(c)(3) requires an evaluation of the adequacy, effectiveness, and consistency of current Great Lakes interagency fisheries management plans and Federal and State water quality and quantity allocation programs, with respect to their effects on Great Lakes fishery resources. The partners and the Service agree that this analysis is restricted to the interconnection between fisheries and water quality and quantity allocation plans and recommendations for integration of the two types of plans. The Service currently has a three party agreement with the Environ mental Protection Agency and the Great Lakes Fishery Commission to accomplish this analysis.

B. Participation/Responsibilities.

1. The Service agrees to work in partnership with the partners on activities to complete the Study. This will include providing copies of written materials related to Study development, periodic briefings and coordination/working sessions by telephone and in person, and opportunity for review and comment on all Study products. The partners agree to provide the Service with available information that can readily be obtained without additional cost and to provide input to the review of Study components, action plans and recommendations.

2. The partners will be offered the opportunity to review and comment upon the final Study Report to Congress when it is submitted. If the Study is continued upon reauthorization of the Act, then these terms will apply to all subsequent Study Reports or Service recommendations to Congress.

C. Proposals to Implement Study Recommendations. The Service, in consultation with the partners, will negotiate priorities and then develop proposals to Congress for implementing Study recommendations recognizing that these recommendations will contain appropriate recommendations from previous efforts. It is agreed that the partners are not obligated to participate in any program aimed at implementing the recommendations of the Study unless new and specific MOAs (sub-agreements) are negotiated as described in Section III.F. of this document. Such proposals shall be consistent with State and Tribal fishery management jurisdictions, the goals of the Great Lakes Water Quality Agreement, as revised in 1987, the 1954 Great Lakes Fisheries convention, and the 1980 Joint Strategic Plan for the management of Great Lakes fishery resources and shall avoid duplication of effort.

D. Communication and Consultation.

1. The partners and the Service will encourage open lines of communication on issues important to each party. Techniques used in support of this objective include, but are not limited to the following:

   a. **Coordination Meetings.** Jointly sponsored coordination meetings will be held as mutually deemed necessary to review Service activities under the Act. Attendance at these meetings will include field and managerial-level personnel from each signatory.

   b. **Routine Communication and Correspondence.** Routine correspondence and general information concerning each party's activities should be exchanged at the signatories office level for further dissemination as needed. This does not preclude field offices from communicating freely on day-to-day issues.

   c. **Conflict Resolution.** It is in the best interest of the parties to avoid conflict on interpretation, application, or implementation of this agreement whenever possible. Significant State, Tribal, or Federal issues of concern should be settled at the lowest possible field level. Issues needing higher level resolution will be elevated to the signatories of this agreement for action. The parties will use every effort to resolve concerns at the annual coordination meeting or by conference calls or similar means of electronic communication.

E. **Technical Assistance.**

1. The Service agrees to cooperate and coordinate, to the extent possible, in providing technical assistance to signatory agencies based upon priorities negotiated by the partners. State and Tribal management authorities and responsibilities will be recognized by the Service during all resource activities.

2. The Service agrees to consult with Lake Technical Committees in developing work programs for fishery related activities conducted by the Great Lakes Fishery Resources Offices. The partners agree to support continued Service participation in interjurisdictional planning or technical meetings concerning Great Lakes programs and agree that the current arrangements for Service participation in Great Lakes Fishery Commission activities remain unaltered.

F. **Sub-Agreements.** This MOU authorizes sub-agreements, referred to collectively as Memoranda of Agreement, to be developed to implement the recommendations of the Study or in other areas related to the Act provided that such agreements:

   1. create cooperative partnerships;

   2. clarify roles and responsibilities, including funding mechanisms and cost-sharing formulas;

   3. serve to clarify need to enhance resource conservation.

G. **Contractual Relationships.** This MOU authorizes the Service to enter into contractual relationships with the signatory parties to expend funds authorized and appropriated under the Act to implement the recommendations of the Study or other recommendations related to the Act.

IV. PERIOD OF PERFORMANCE AND TERMINATION

This MOU shall become effective upon a party when it signs and remain in force until formally terminated by either party. Any party may terminate this MOU as to itself upon 30 days of written notice to the other party.

V. PROJECT OFFICERS

Project officers, for the purpose of administering this MOU, including the receiving and reviewing of documents, speaking for their respective entities and the handling of termination notices are:

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VI. SPECIAL PROVISIONS

The scope of work and terms of agreement may be modified or amended at any time by collective consent of the signatory parties.

VII. SIGNATORY PARTIES [Note: MOU was circulated for signature in April of 1995]

For the Service:

Region 3, Director — Date

Region 5, Director — Date

For the Partners:

Director — Date
Illinois Department of Conservation

Commissioner — Date
New York State Department of Environmental Conservation

Director — Date
Indiana Department of Conservation

Director — Date
Ohio Department of Natural Resources

Director — Date
Michigan Department of Natural Resources

Executive Director — Date
Pennsylvania Fish and Boat Commission

Director — Date
Minnesota Department of Natural Resources

Director — Date
Wisconsin Department of Natural Resources

Chairperson — Date
Bad River Tribal Council

Chairman — Date
Grand Traverse Band of Ottawa and Chippewa Indians

Chairman — Date
Bay Mills Indian Community of Michigan

Chairman — Date
Keweenaw Bay Indian Community

Chairman — Date
Fond Du Lac Reservation

Chairperson — Date
Red Cliff Band of Lake Superior Chippewa Indians

Chairman — Date
Grand Portage Reservation

Chairman — Date
Sault Ste. Marie Band of Chippewa Indians

Executive Director — Date
Great Lakes Fishery Commission

☆ U.S. Government Printing Office: 1995 — 659-184