FISH-COMMUNITY GOALS AND OBJECTIVES FOR LAKE ERIE

SPECIAL PUBLICATION 03-02

The Great Lakes Fishery Commission was established by the Convention on Great Lakes Fisheries between Canada and the United States, which was ratified on October 11, 1955. It was organized in April 1956 and assumed its duties as set forth in the Convention on July 1, 1956. The Commission has two major responsibilities: first, develop coordinated programs of research in the Great Lakes, and, on the basis of the findings, recommend measures which will permit the maximum sustained productivity of stocks of fish of common concern; second, formulate and implement a program to eradicate or minimize sea lamprey populations in the Great Lakes.

The Commission is also required to publish or authorize the publication of scientific or other information obtained in the performance of its duties. In fulfillment of this requirement the Commission publishes the Technical Report Series, intended for peer-reviewed scientific literature; Special Publications, designed primarily for dissemination of reports produced by working committees of the Commission; and other (non-serial) publications. Technical Reports are most suitable for either interdisciplinary review and synthesis papers of general interest to Great Lakes fisheries researchers, managers, and administrators, or more narrowly focused material with special relevance to a single but important aspect of the Commission's program. Special Publications, being working documents, may evolve with the findings of and charges to a particular committee. Both publications follow the style of the *Canadian Journal of Fisheries and Aquatic Sciences.* Sponsorship of Technical Reports or Special Publications does not necessarily imply that the findings or conclusions contained therein are endorsed by the Commission.

March 2003

FISH-COMMUNITY GOALS AND OBJECTIVES FOR LAKE ERIE

P. A. Ryan
Lake Erie Management Unit
Ontario Ministry of Natural Resources
P.O. Box 429
Port Dover, ON N0A 1N0

R. Knight
Sandusky Fisheries Research Unit
Ohio Division of Wildlife
Ohio Department of Natural Resources
305E Shoreline Dr.
Sandusky, OH 44870

R. MacGregor
Fish and Wildlife Branch
Ontario Ministry of Natural Resources
P.O. Box 7000
Peterborough, ON K9J 8M5

G. Towns
Michigan Department of Natural Resources
38980 Seven Mile Rd.
Livonia, MI 48152-1006

R. Hoopes
Lake Erie Research Unit
Pennsylvania Fish and Boat Commission
P.O. Box 531
Fairview, PA 16415

W. Culligan
New York Department of Environmental Conservation
178 Point Drive N.
Dunkirk, NY 14048-1031

Citation: Ryan, P.A., R. Knight, R. MacGregor, G. Towns, R. Hoopes, and W. Culligan. 2003. Fish-community goals and objectives for Lake Erie. Great Lakes Fish. Comm. Spec. Publ. 03-02. 56 p.

Great Lakes Fishery Commission
2100 Commonwealth Blvd., Suite 100
Ann Arbor, Michigan 48105-1563

March 2003

Printed on recycled paper.
SP 03-03-03—03/600

TABLE OF CONTENTS

FISH-COMMUNITY GOALS AND OBJECTIVES FOR LAKE ERIE

ABSTRACT

The Lake Erie Committee (LEC), representing five fisheries-management agencies comprised of New York, Pennsylvania, Ohio, Michigan, Ontario have developed a set of fish-community goals and objectives for Lake Erie in accordance with the Joint Strategic Plan for Management of Great Lakes Fisheries (Great Lakes Fishery Commission 1997). Agencies recognized nine guiding principles during development related to self-sustaining stocks, the stock concept, indigenous species, aversion to introductions, preservation and restoration of habitat, preservation of rare and endangered species, recognition of naturalized species, requirement to harvest on a sustainable basis, and recognition of the limit on productivity. Lake Erie has had a long history of fish- community instability and subsequent change in its fisheries. Restoration of fish-community stability can be best achieved through management to promote healthy stocks of top predators, reduction in and/or prevention of the establishment of aquatic nuisance species, and protection and/or restoration of important coastal nearshore and tributary habitats. The LEC endorsed two goals. The first is to secure a balanced, predominantly cool-water fish community characterized by self-sustaining indigenous and naturalized species that occupy diverse habitats, provide valuable fisheries, and reflect a healthy ecosystem. Walleye (*Stizostedion vitreum*) would be a key predator in the western basin, central basin, and the nearshore waters of the eastern basin. The second goal is to secure a predominantly cold-water fish community in the deep, offshore waters

of the eastern basin with lake trout *(Salvelinus namaycush)*, and burbot *(Lota lota)* as key predators. Further, the LEC has endorsed additional objectives concerning desired ecosystem conditions; the composition of fisheries and their link to supporting habitat; contaminants in fish; conservation of genetic diversity and of rare, threatened and endangered species; and the ecology of fish production. The committee strongly endorses the cooperative, inter-jurisdictional approach to fisheries management, as facilitated through the Great Lakes Fishery Commission (GLFC).

INTRODUCTION

The Joint Strategic Plan for Management of Great Lakes Fisheries (Joint Plan) (Great Lakes Fishery Commission 1997) directed each lake committee to prepare a set of fish-community objectives for their respective Great Lakes. Lake committees work under the umbrella of the Great Lakes Fishery Commission (GLFC). The committees are made up of representatives from each of the fishery-management agencies with jurisdiction on a particular lake. Within the Joint Plan, the following common goal has been established:

> *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, cultural heritage, employment and income, and a healthy aquatic ecosystem (Great Lakes Fishery Commission 1980, 1997).*

This document presents fish-community objectives for Lake Erie as developed by the Lake Erie Committee (LEC). The document is not intended to be a management plan. Rather, the goals and objectives will guide the development of strategies and management actions within a framework of sound ecological concepts and basic guiding principles.

The management of Lake Erie fish communities and related fish habitat must consider the entire lake, including contiguous rivers, streams, and embayments that provide important spawning and nursery habitat for many fish species that inhabit the open waters of Lake Erie. The management of all contiguous waters within the basin will be guided by the objectives and principles in this document. However, because the fish communities of rivers and bays may differ from those of the open lake, more detailed objectives may be developed for such areas by individual agencies.

The emphasis of fisheries management for the Great Lakes has been shifting gradually from individual fish species to the entire fish community. There are two reasons for this:

- First, the single-species approach often does not allow accurate predictions of population dynamics and fishery yields—this is because the measures used to describe the characteristics of single populations are themselves influenced by interactions among species (Pimm and Hyman 1987)

- Second, many management options involve trade-offs among interacting fish species that are difficult to comprehend and address without an understanding of fish-community dynamics

This document embraces these ideas and takes into account community interactions while also recognizing the socioeconomic importance of species-specific fisheries.

LAKE OVERVIEW

Lake Erie is the shallowest and most southerly of the Great Lakes (Hartman 1972). The lake has a surface area of 25,690 km^2 (10,035 mi^2) and is divided into three basins with the following mean depths (Fig. 1):

- Western basin: 7.4 m (24.1 ft)

- Central basin: 18.5 m (60.1 ft)

- Eastern basin: 24.4 m (79.3 ft)

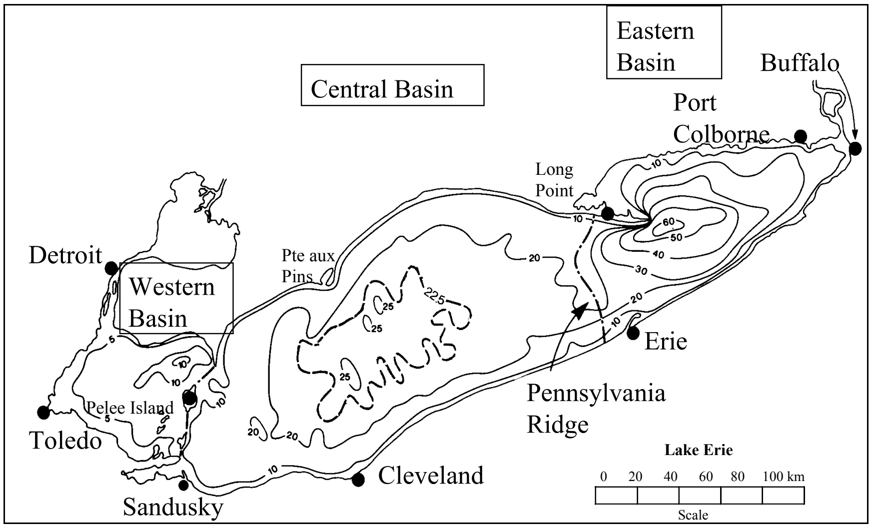

Fig. 1. Lake Erie bathymetry with bottom contours in meters (Mortimer 1987).

The maximum depth of 64 m (204 ft) is located off the tip of Long Point in Ontario. Lake Erie's main source of water comes from the upper lakes by way of the Detroit River. The lake discharges into Lake Ontario through the Niagara River (Fig. 1). Theoretical flow-through time or flushing rate is approximately 2.5 years.

The nutrient concentrations in a lake affect the composition of the food web, including the fish community. Phosphorus, the key nutrient for Lake Erie, varies along gradients from west to east (Charlton 1994) and from nearshore to offshore (Bolsenga and Herdendorf 1993). Charlton's data indicate that the western basin and western half of the central basin have moderate levels of phosphorus and are classified as mesotrophic (> 10 but < 20 *u*g·L^{-1} total phosphorus) according to criteria from Leach et al. (1977). The eastern half of the central basin and the eastern basin are nutrient poor and are classified as oligotrophic (< 10 *u*g·L^{-1} total phosphorus). In some areas of the lake during the 1990s, phosphorus approached levels associated with ultra-oligotrophic conditions (< 5 *u*g·L^{-1} total phosphorus) according to data from Dahl et al. (1995). In addition to differences among basins, smaller-scale patterns occur in nutrient levels within basins. The northern waters of the western basin are strongly influenced by flows from Lake Huron via the Detroit River. The southern waters of the western basin are strongly influenced by nutrient-rich waters from the Maumee River (Ohio) and other rivers (Charlton 1994). Strong gradients exist in productivity (Bolsenga and Herdendorf 1993) and transparency (Fish et al. 1960; Leach 1981) within the eastern basin. Nearshore waters are more productive than offshore waters in part because embayments are strongly influenced by inflowing rivers (Leach 1981; T. Howell, Environment Monitoring and Reporting Branch, Ontario Ministry of the Environment, 125 Resources Road, Toronto, ON, Canada, M9P 3V6, unpubl. data).

Most waters in Lake Erie are classified seasonally as cool water (20°-28° C (68°-80° F)) (Hokanson 1977). Cold-water habitat (< 20° C (68° F)) occurs only in the eastern basin and in a limited depth range offshore in the central basin (Fig. 2).

Fish habitat in the western and central basins of Lake Erie, including their tributaries, has undergone extensive changes over time. The loss of wetlands in southwestern Lake Erie, channelization of major streams, oxygen depletion, shoreline modification, siltation of spawning areas, nutrient enrichment, deterioration in water quality, and sand and gravel extraction all have contributed to the decline in the quality and quantity of fish habitat at many locations in the lake (Trautman 1981; Hartman 1972; Bolsenga and Herdendorf 1993).

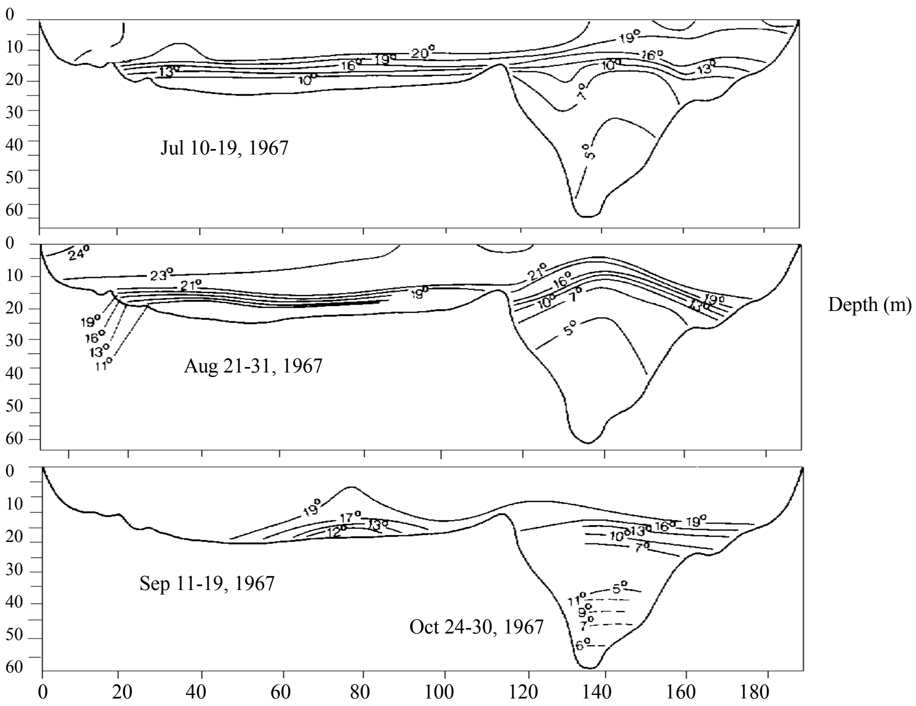

Fig. 2. Longitudinal cross sections of Lake Erie with water temperature isopleths (Mortimer 1987).

Some tributaries, embayments, and harbors of Lake Erie have received high levels of toxic discharges and have been listed as Areas of Concern by the International Joint Commission. A review of contaminant issues undertaken within the international Lake Erie Management Plan, as mandated by the Great Lakes Water Quality Agreement (GLWQA) (Environmental Protection Agency 1995), will be useful in understanding the impact of contaminants on the Lake Erie fish community. Although the historical role of contaminants in Lake Erie has not been fully assessed (Gilbertson 1997), current data consistently show that levels of contaminants in fish flesh are relatively low.

The surface area of Lake Erie is approximately evenly divided between the United States and Canada (Figs. 1, 3). The Canadian waters of Lake Erie are entirely within the Province of Ontario. United States waters are divided among the states of New York, Pennsylvania, Ohio, and Michigan. Ohio's portion exceeds that of the other three states combined. The fisheries of Lake Erie are managed on a highly successful, cooperative basis by the five state and provincial agencies through the LEC.

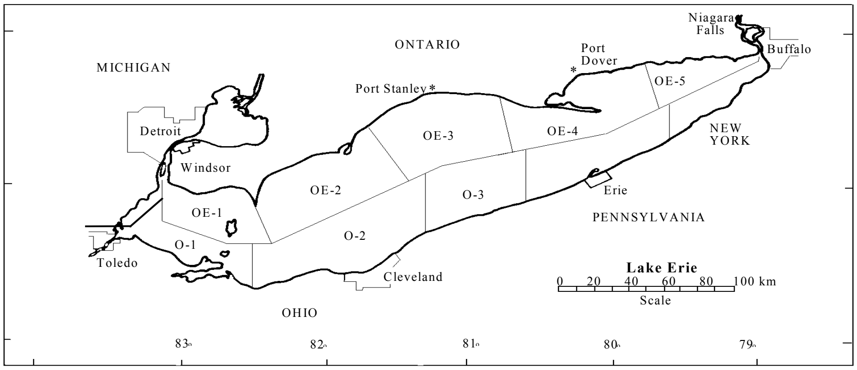

Fig. 3. Lake Erie fishery statistical districts (Smith et al. 1961).

FISH COMMUNITY, PAST AND PRESENT

The fish community of Lake Erie has changed significantly since the mid-1800s in response to numerous stresses (Hartman 1972; Leach and Nepszy 1976; Nepszy 1977, 1999; Hatch et al. 1987; Edwards and Ryder 1990; Cornelius et al. 1995; MacIssac 1999; Ludsin et al. 2001):

- Overexploitation
- Watershed deforestation
- Invasion by exotic species
- Contaminants
- Dams
- Deterioration of tributary streams
- Nutrient enrichment
- Reversal of nutrient enrichment

The most dramatic changes in the Lake Erie fish community have been the loss of many highly valued native species and the invasion and proliferation of exotic (non-indigenous) species. Many important terminal predators have either disappeared or their numbers have been severely reduced. The affected species include lake trout (*Salvelinus namaycush*), sauger (*Stizostedion canadense*), and blue pike (*Stizostedion vitreum glaucum*). The lake herring (*Coregonus artedi*), an important planktivore, approached extirpation. Populations of lake whitefish (*Coregonus clupeaformis*) and lake sturgeon (*Acipenser fulvescens*), both benthivores, were severely reduced in number. As populations of native terminal predators, planktivores, and benthivores declined, small-bodied, short-lived exotic fishes—rainbow smelt (*Osmerus mordax*), white perch (*Morone americana*), and alewife (*Alosa pseudoharengus*)—proliferated and remain present in relatively high numbers.

Loss of native fish stocks and species from Lake Erie began with the demise of lake trout and lake sturgeon in the early 1900s followed by lake herring and lake whitefish during the 1940s and early 1950s. The losses continued with blue pike extirpation in the late 1950s and culminated with declines in walleye (*Stizostedion vitreum*) through the 1960s and early 1970s (Regier et al. 1969; Regier and Hartman 1973).

Native lake trout had virtually disappeared from the eastern basin by the start of the 20th century and are considered extirpated. The lake herring fishery collapsed in the 1920s. It recovered somewhat in the mid-1940s, but the species is now extremely rare. Lake whitefish populations also declined to very low levels leaving a remnant population that recovered in the mid-1980s (Fig. 4). Lake sturgeon declined by the turn of the 20th century, and abundance has remained very low, although recent information suggests that the sturgeon population may be recovering. Overexploitation, changes in habitat, and the introduction of exotic species all contributed to the decline of these species (Hartman 1972; Leach and Nepszy 1976).

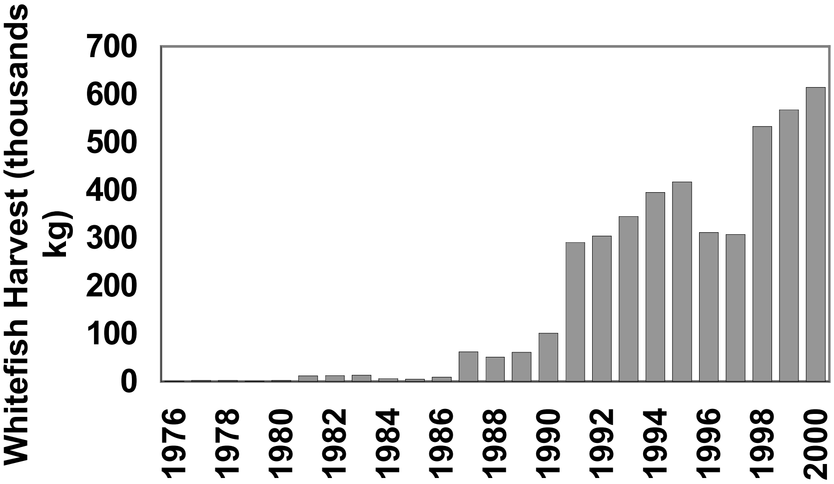

Fig. 4. Lakewide harvest of lake whitefish (Murray et al. 2001).

Sauger was the first of the four principal Lake Erie percids (the family Percidae includes yellow perch *(Perca flavescens)*, walleye, sauger, and blue pike) to show a steep population decline. Commercial landings reached a peak in 1916 and declined to near zero by 1960. Sauger spawning reefs in Maumee Bay, Ohio, had been degraded by pollution and siltation, and access to river habitat had been limited by dams. The slow growth and relatively late sexual maturity of sauger and increased fishing pressure between 1930 and 1940, probably contributed to its demise. Edwards and Ryder (1990) felt that contaminants were implicated in the decline of the sauger population. Stocking of sauger was undertaken by the state of Ohio in the 1970s, but success was limited (Rawson and Scholl 1978).

The blue pike was endemic to Lake Erie and the western waters of Lake Ontario. Moderate numbers of blue pike were taken by the fishery from the late 1800s until 1915 when production started to fluctuate widely. The fishery collapsed in the late 1950s. A blue pike recovery effort in the 1970s was unsuccessful. The species is now considered extinct (Campbell 1987), although some blue-colored walleye occasionally appear in catches.

In the late 1950s and early 1960s, the fishery for walleye in the western basin showed trends similar to those in blue pike. As the abundance of walleye declined, they were confined almost entirely to the western basin. International management efforts to reduce exploitation after the mid-1970s and improved environmental conditions have resulted in a strong recovery of the western basin stocks (Fig. 5) (Hatch et al. 1987; Knight 1997).

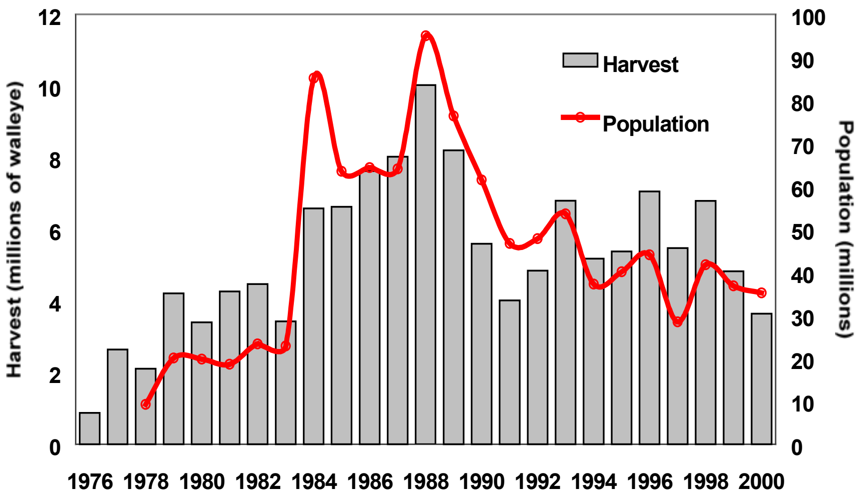

Fig. 5. Lakewide harvest of walleye (bars) and population estimates (line) (Turner et al. 2001).

Studies of fish movement patterns (by tagging) have provided strong evidence for the existence of discrete stocks of walleye (Ferguson and Derksen 1971; Wolfert and Van Meter 1978; Todd and Haas 1993; Einhouse and Haas 1995). Genetic analysis has provided additional evidence for existence of walleye stocks (Todd and Haas 1993; Stepien 1995; McParland 1996; C. Wilson, Aquatic Biodiversity and Conservation, Ontario Ministry of Natural Resources, Trent University, 1600 West Bank Drive, Peterborough, Ontario, CANADA, K9J 8N8, unpubl. data). Shoal and river spawning stocks of walleye have been shown to have different habitat preferences through manipulation studies (Jennings et al. 1996). Local stocks are expected to be better adapted to local conditions than fish from more remote stocks.

The walleye stocks of the eastern basin have historically been much smaller than those of the western basin, although they did not suffer the sharp decline seen in the western basin stocks during the 1950s and 1960s. A study of spawning stocks of walleye in New York waters showed that these walleye were seasonally distributed across the eastern basin, but most tag returns came from New York waters (Wolfert and VanMeter 1978). Eastern basin stocks are genetically distinct from the western basin populations (McParland 1996), which range throughout the lake when stock sizes are large. Both eastern and western walleye populations contribute to the eastern basin fishery.

Efforts to rehabilitate a spawning stock of walleye in Ontario's Grand River are under way and, if successful, may reduce fluctuations in walleye abundance in eastern Lake Erie. Other rehabilitation efforts in eastern Lake Erie are either planned or have already been undertaken in New York (Cattaraugus and Big Sister Creeks). Introductions of adult Thames River walleye into Ontario waters (Big and Nanticoke Creeks) were not successful in establishing spawning populations. Intensive monitoring and coordinated management by both countries are needed to ensure that the walleye will continue to be a valuable sport and commercial species in the lake.

Yellow perch have provided a strong fishery in Lake Erie since at least 1900. Peak harvests occurred from 1928-35 and from the mid-1950s to the mid-1970s following the decline of blue pike and walleye. During the 1960s, fluctuations in year-class strength and reduced recruitment created instability in the yellow perch population causing, by 1970, great concern among Lake Erie fishery agencies. After a period of higher abundance in the 1980s, yellow perch stocks declined sharply lakewide in the 1990s (Fig. 6). Eutrophication, and the later reversal of eutrophication (nutrient abatement), loss of macrophyte beds, recruitment failure, overexploitation, and competition with the exotic white perch are believed to have contributed to the changing abundance of yellow perch over time. Interagency efforts to reduce exploitation and protect spawning perch have resulted in the rebuilding of stocks, steady harvest, and several recent (through the year 2000) strong year-classes.

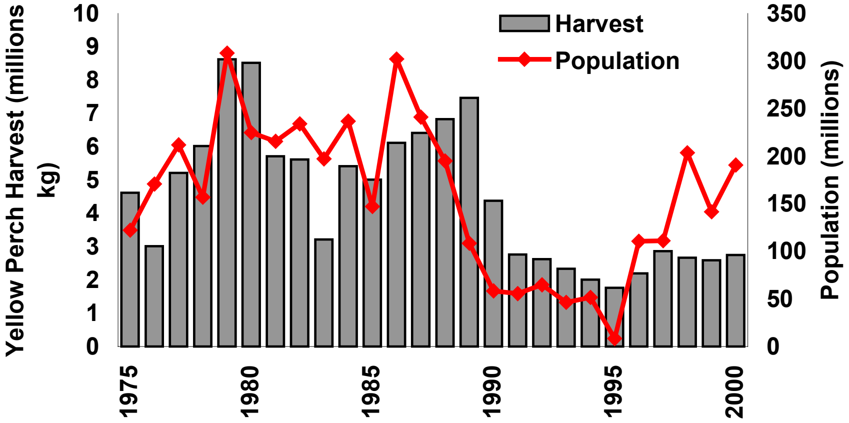

Fig. 6. Lakewide harvest of yellow perch (bars) and population estimates (line) (Einhouse et al. 2001).

Efforts to restore a self-sustaining lake trout population in eastern Lake Erie began in the late 1970s with the stocking of lake trout reared by the United States Fish and Wildlife Service (Cornelius et al. 1995). Native Lake Erie lake trout were unavailable so other strains were used. The condition of former lake trout spawning areas was unknown until recently. Evaluation of one suspected spawning area, Brocton Shoal, revealed suitable spawning habitat for lake trout (Edsall et al. 1992). Survival of stocked lake trout beyond age 4 was low prior to 1987 and was mainly attributed to high sea lamprey (*Petromyzon marinus*) attack rates. The GLFC extended sea lamprey control to Lake Erie in 1986, and streams have since been treated with lampricides, as required. Survival of age-5 and older lake trout improved markedly beginning in 1987. The changes in survival clearly indicated that sea lampreys had been negating efforts to rehabilitate lake trout (Cornelius et al. 1995). Efforts to rehabilitate lake trout continue, as outlined below.

At present, the age structure of stocked lake trout populations shows strong representation from age-groups 5-14. Current stocking efforts include planting fry on traditional spawning habitat and stocking yearlings. The impact of the increasing numbers of lake trout and other terminal predators was examined by the Forage Task Group of the LEC for the years 1984-91 (Einhouse et al. 1993, 1999). The Forage Task Group is now evaluating forage use in the 1990s. Lake trout abundance has declined since 1997 in New York waters (Fig. 7).

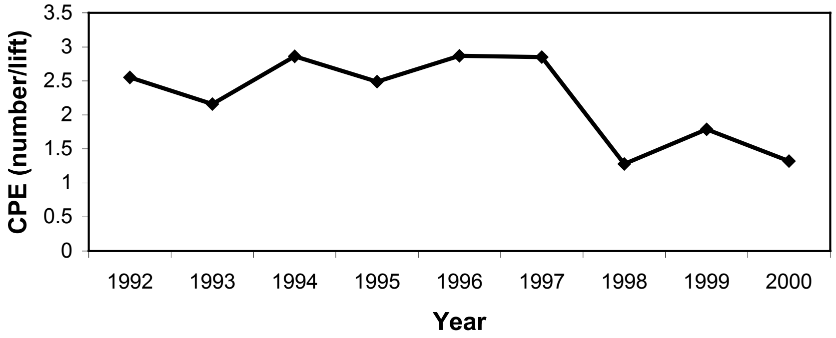

Fig. 7. Trend in abundance of lake trout from index fishing in New York waters (Culligan et al. 2001).

Smallmouth bass *(Micropterus dolomieu)* are distributed throughout the nearshore regions of Lake Erie. During the last 20 years, modest oscillations in abundance have been observed. However, the population has generally experienced stable recruitment and abundance despite the profound changes observed elsewhere in the Lake Erie food web. Tagging studies have indicated limited movement of smallmouth bass in the lake (Hair 1978; MacGregor and Witzel 1987; L. Witzel, unpubl. data, Lake Erie Management Unit, P.O. Box 429, 1 Passmore Street, Port Dover, ON, N0A 1N0, Canada), suggesting that the population is comprised of a continuous series of locally adapted stocks. Research indicates that nesting success is greatly affected by strong winds (Goff 1986), angling, and nest predation (G. Steinhart, unpubl. data, Ohio State University, Department of Evolution, Ecology and Organismal Biology, 1314 Kinnear Road, Columbus, OH, 43212-1156). In the eastern basin, recruitment has been linked to mean summer water temperature (Einhouse et al. 2002). Smallmouth bass fill the niche of a nearshore, benthic predator that eats crayfish (Hair 1978) and a variety of fish species, including the round goby *(Neogobius melanostomus),* an introduced fish (Johnson et al. 2001). Apparent energy shifts from pelagic to benthic areas over the past decade may be beneficial to this species and increase its ecological significance in the lake.

Management of the smallmouth bass fisheries is conducted independently by agency with jurisdiction in Lake Erie. New York, Pennsylvania, and Ohio agencies have revised their smallmouth bass angling regulations within the last ten years to address local management objectives. Presently, all agencies restrict smallmouth bass harvest by setting bag limits—most agencies impose size limits and closed seasons. In addition, Ontario regulations provide for no-fishing sanctuaries in the spring as an additional protection for spawning bass.

The round goby was introduced via ballast water discharges at multiple locations around the lake in the 1990s. Round goby have become established across the lake and have reached high densities in many nearshore and harbor areas (Ohio Department of Natural Resources 1998). The round goby represent an important new energy pathway in the Lake Erie food web because their primary diet item is zebra mussels (*Dreissena polymorpha*) (Ohio Department of Natural Resources 1996). Energy that had previously been "locked up" for a time in zebra mussels is now being incorporated back into the food web. Recent research has focused on:

- Interference of round goby with native species such as smallmouth bass (Stein et al. 2001)
- Incorporation of gobies into the food web via predation (Ohio Department of Natural Resources 1998; Johnson et al. 2001)
- Possible bioaccumulation of toxins that may cause endocrine disruption (S. Fisher, Ohio State University, Department of Entomology, 103 Botany and Zoology Building, 1735 Neil Ave., Columbus, Ohio, 431210, personal communication)

The role of pelagic planktivore in Lake Erie has probably not been adequately filled since the decline of lake herring in the 1920s. This species is adapted to existence in epilimnetic waters in early life and to metalimnetic and hypolimnetic waters as adults (Ryan et al. 1999). O'Brien (1979) characterized lake herring and alewife as highly efficient planktivores capable of controlling zooplankton composition. Smelt are not efficient planktivores when compared with herring or alewife, and their intolerance of warm temperatures leaves them even more poorly adapted for the role of epilimnetic planktivore. Although alewife typically occupy epilimnetic waters in other Great Lakes, alewife abundance in Lake Erie is often constrained by overwinter temperatures that frequently prove lethal (Ryan et al. 1999). White perch may have filled the role of epilimnetic planktivore as they increased in abundance in the 1980s but this was followed by a strong decline in the 1990s (Fig. 8). The gizzard shad (*Dorosoma cepedianum*) is a significant planktivore in early life before shifting toward a detritivore role (Stein et al. 1995). Gizzard shad are probably not native to Lake Erie (Trautman 1981; Herdendorf 1983), and, while they can be abundant, they are concentrated in nearshore and riverine habitats and exhibit major fluctuations in overwinter survival (Ryan et al. 1999).

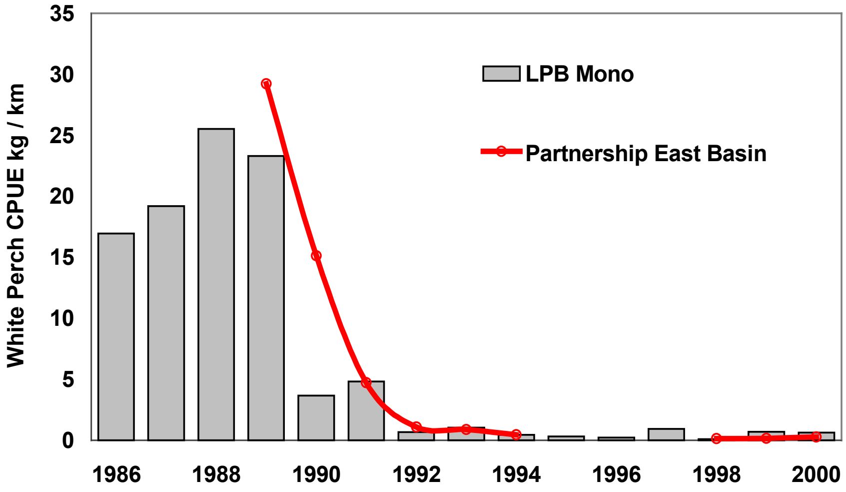

Fig. 8. Recent trends in the white perch stock in eastern Lake Erie as shown by survey gillnet indices (Long Point Bay monofilament and East Basin Partnership, Ontario Ministry of Natural Resources 2001).

The spiny water flea (*Bythotrephes cederstroemi)* established itself in Lake Erie in the 1980s (Bur et al. 1986). Now, the fishhook waterflea (*Cercopagis pengoi*), a second exotic and ecologically similar species, was recorded in Lake Erie's western basin in 2001 (D. Culver, Ohio State University, Department of Zoology, 1735 Neil Ave., Columbus, Ohio, 43210, personal communication). Johannsson et al. (1999) found that the spiny water flea was present at densities high enough that their predation on zooplankton could substantially alter the production available to fish. The presence of spines and large size are characteristics that allow zooplankton to avoid predation by gape-limited predators (Zaret 1980). The success of these species indicates that the role of epilimnetic planktivore is not being adequately filled by the current mix of smelt, alewife, and white perch.

Steep declines or extirpations of important terminal predators and native planktivores, along with the invasion and proliferation of exotic species, have demonstrated the instability of the fish communities of Lake Erie. Such stresses have led to an unpredictable and dynamic assemblage of fish species. Much of the fish biomass is comprised of opportunistic invaders (alewife, rainbow smelt, and white perch) that inhabit the offshore pelagic zone and use food resources similar to those formerly used by the now extirpated lake herring. Studies in Lake Erie have shown how top predators can structure the fish community (Knight and Vondracek 1993; Knight et al. 1984; Makarewicz and Bertram 1993). The lakewide resurgence of walleye and increases in smallmouth bass abundance should increase the stability of the food web in epilimnetic waters through top-down predation effects. The deepwater community of the eastern basin should be similarly affected by the restoration of lake trout and the natural recovery of burbot (*Lota lota*), another important terminal predator.

The recovery of lake whitefish, lake sturgeon, and muskellunge (*Esox masquinongy*) populations may also contribute to the restructuring and stabilizing of the fish community. Whitefish populations began a recovery in the mid-1980s, and sturgeon, once on the verge of extirpation, have been more commonly seen in recent years. Muskellunge are resurging in specific habitats where aquatic macrophytes have increased due to improvements in water quality.

A CASE FOR MESOTROPHY AND HARMONIC PERCID COMMUNITIES

Two well-defined types of harmonic fish communities were formerly found within the Great Lakes:

- A salmonid harmonic community (Ryder and Edwards 1985)
- A percid harmonic community (Ryder and Kerr 1978, 1990; Edwards and Ryder 1990)

A harmonic community is a co-evolved, integral biotic community that is resistant to change and that maintains its composition over time. The species composition and yield from harmonic communities are considered to be more predictable and relatively stable—desirable traits for fisheries. Such communities are efficient in their use and transfer of energy within lake food webs—a feature that favors productive fisheries. The communities may also be more resistant to invasion by exotic species. A percid-dominated community is likely optimum for Lake Erie because of its latitude, morphology, and productivity. Christie and Regier (1988) used predictive modelling to indicate that cool-water species would represent 63% of the total yield of walleye, northern pike, lake whitefish, and lake trout from Lake Erie. Percids prevail today as the most important components of Lake Erie fisheries.

Lake trophic state can be identified along a continuum of lake productivity by ranges of nutrient concentrations (total phosphorus and total nitrogen), primary production, phytoplankton biomass or chlorophyll *a* concentration, transparency, hypolimnetic oxygen demand, and organic content of sediments (Leach et al. 1977).

Measure	Unit	Oligo-trophic	Meso-trophic	Eutrophic	Hyper-eutrophic
Total P	$\mu g \cdot L^{-1}$	< 9	9-18	18-50	> 50
Chlorophyll *a*	$\mu g \cdot L^{-1}$	< 2.5	2.5-5	5-10	> 10
Transparency (Secchi depth)	m	> 6	6-3	3-1	< 1

Grazing by zooplankton (Mazumder 1994) or *Dreissena* spp. (biological oligotrophication) (Holland et al. 1995) affects the amount of phytoplankton present per unit phosphorus (Millard et al. 1999). Because food-web structure affects the abundance of planktivorous fish and *Dreissena* spp., the management of terminal predators and the composition and abundance of planktivores and benthivores influence the lake trophic state.

Percid-dominated communities are usually found in mesotrophic (moderately productive), cool-water habitats (Ryder and Kerr 1978). Optimal conditions for percid growth occur within a (cool-water) range of 20^{o}-28^{o} C (68°-82° F) (Hokanson 1977). Walleye and other percids were abundant in Lake Erie when the lake was first being fished by Europeans (Trautman 1981; Burns 1985). Paleolimnological evidence indicates that the bottom waters of the central basin were periodically anoxic (without oxygen) prior to settlement (Delorme 1982; Reynoldson and Hamilton 1993). The dominance of walleye and other percids (Hartman 1972; Ryder 1972; Edwards and Ryder 1990) indicates that much of the lake, in contrast to the other Great Lakes, was mesotrophic before European settlement.

Although Edwards and Ryder (1990) identify in general terms the historically dominant fishes in each of Lake Erie's three basins and in Lake St. Clair, movements of fish among basins make it difficult to define a fish community by basin. Migrations of fish within the system are important. Walleye that spawn in the western basin migrate both eastward to the central and eastern basins and northward into the Detroit River to feed (Ferguson and Derksen 1971; Todd and Haas 1993).

Whitefish migrate in the fall from the eastern and east-central basin to spawning shoals in the western basin (Hardy 1994).

Establishment of harmonic communities within Lake Erie is clearly the best approach for achieving balanced, stable, and predictable fish communities. A gradient of high-quality mesotrophic conditions within the western and central basins and in nearshore waters of the eastern basin are prerequisites for achieving this goal of a harmonic percid community. Walleye abundance should reflect environmental conditions and indicate progress toward achieving favorable mesotrophic conditions (Edwards and Ryder 1990). Moreover, walleye is a key top predator in mesotrophic systems and is essential for the well being of a harmonic percid community. Similarly, provision of oligotrophic conditions offshore in eastern Lake Erie is a prerequisite for achieving the goal of a harmonic salmonid community. A reduction of the role of walleye as the terminal predator in the fish community implies the loss of the principal regulator in a system that, in its pristine state, was largely controlled from the top down (McQueen et al. 1986; Edwards and Ryder 1990). In this light, the striking population declines of the principal terminal predators in Lake Erie (sauger, walleye, blue pike, and lake trout) may have provided an opportunity for the opportunistic increases in rainbow smelt during the 1950s and 1960s. Reductions in populations of terminal predators typically lead to increases in pelagic prey fishes because of the lack of predation control (Regier and Loftus 1972; Christie et al. 1987; Edwards and Ryder 1990). The virtual collapse of the pelagic lake herring and lake whitefish populations in Lake Erie was likely also linked to the alewife/rainbow smelt invasion and subsequent expansion of these species (Leach and Nepszy 1976; Crowder 1980; Evans and Loftus 1987). Rainbow smelt proliferated in Lake Erie at a time when terminal predators were at a lower abundance, and the abundance of native pelagic species was very low. The abundance of rainbow smelt increased to a point in the 1960s that a commercial fishery was developed for this species in the Canadian waters of the lake.

Walleye can take the role of key species for large areas of the lake, controlling fish-community structure via predation. The changes in fish-community composition after the walleye population increase in the 1980s are strong evidence of the effectiveness of this species (Makarewicz and Bertram 1993; Ryan et al. 1999). Similarly, lake trout can take the role of key species in eastern Lake Erie. The composition of the fish community lakewide and the resultant fish harvests should be more predictable and more stable under such conditions.

CHANGES IN PHOSPHORUS, MAYFLIES, BENTHOS, AND TROPHIC STATE

Phosphorus Reduction

Excessive nutrient enrichment has been identified as the single greatest water-quality problem in Lake Erie during the 1950s and 1960s (Burns and Ross 1972). Overenrichment was due largely to:

- Increased phosphorus loading from agricultural fertilizers
- Urban runoff
- Domestic sewage
- Industrial wastewater

Phosphorus is the key nutrient that limits the amount of phytoplankton and attached algae in aquatic ecosystems.

Total phosphorus concentrations in Lake Erie doubled between 1942 and 1958 (Beeton 1969). This increase was one of the major causes of accelerated eutrophication and increased oxygen depletion (anoxia) in the hypolimnion of the central basin. The likelihood of anoxic conditions developing depends on the amount of phytoplankton settling to the bottom, the duration of stratification, and the thickness of the hypolimnion. The central basin hypolimnion has a limited capacity for storage of dissolved oxygen because of its shallow depth (Burns and Ross 1972). In 1970, anoxia extended across the western half of the central basin by early August and was basinwide by mid-August. In recent years, anoxia has occurred in a more limited area of the central basin and later in the season (Bertram 1993). Past overenrichment of Lake Erie caused undesirable effects on water supplies, recreation, and fish communities. Overproduction of nuisance planktonic and attached algae was severe in the 1950s and 1960s. Currents and wave action dislodged and deposited large quantities of attached algae on the shoreline. Decomposition of the decaying biomass resulted in unsightly beaches and obnoxious odors.

To control phytoplankton abundance and anoxic conditions in the central basin, Canada and the United States agreed to manage phosphorus loading to Lake Erie through the GLWQA (International Joint Commission 1987). The two countries agreed to reduce phosphorus loading to 11,000 tonnes/year. Target concentrations of phosphorus for the lake were set at 15 $\mu g \cdot L^{-1}$ for the western basin and 10 $\mu g \cdot L^{-1}$ for the central and eastern basins. A principal goal of the GLWQA is the development of year-round aerobic conditions in the hypolimnion of the central basin.

Both countries made major efforts to enlarge and improve wastewater treatment plants and to reduce nutrient loadings from nonpoint sources by implementing soil conservation practices. Modified land-use practices have reduced silt loading and improved the quality of fish habitat in tributaries and embayments. Phosphorus control efforts have been highly successful—phosphorus loadings and concentrations since the mid-1980s have either met or been lower than target levels.

Recent paleolimnological evidence suggests that the GLWQA goal of an oxygenated hypolimnion at all times was unrealistic for the open waters of Lake Erie. Reynoldson and Hamilton (1993) concluded that bouts of anoxia in the central basin preceded European settlement, although the duration and areal extent of anoxia was aggravated by nutrient enrichment. This finding supports earlier research by Delorme (1982) who found that preserved ostracods in sediments indicated an historical pattern of anoxia. Phosphorus loads would need to be reduced to about 5,000 metric tonnes per year to achieve the goal of establishing year-round aerobic conditions in the hypolimnion. Reductions in phosphorus loadings of this magnitude could reduce the productivity of the system to abnormally low levels.

Recovery of Burrowing Mayflies

The burrowing mayfly (*Hexagenia limbata*) is an indicator organism for mesotrophic environments (Edwards and Ryder 1990). Burrowing mayfly nymphs once dominated the benthos of the western basin of Lake Erie. *Hexagenia* were so numerous at one time in coastal areas of Lake Erie that, when emerging, they were a nuisance to residents (Burns 1985). In 1953, large numbers of dead *Hexagenia* nymphs were observed, particularly in the Bass Islands region. The population subsequently dwindled to a point where surveys of the western basin in 1973 and 1974 did not find a single mayfly (Britt et al. 1980). Bouts of temporary anoxia in the western basin are commonly cited as the most important factor leading to the near extirpation of *Hexagenia*, although contaminated sediments and pesticides may also have contributed to losses and may yet pose impediments to their recovery (Burns 1985). The absence of mayfly tusks (exoskeleton parts that persist in sediments) in cores taken offshore in the central basin shows that *Hexagenia* were absent there historically and indicates that anoxia of the central basin predates settlement (Reynoldson and Hamilton 1993). Recent surveys have shown an increase in *Hexagenia* abundance in the western basin, but their distribution is restricted compared to historical conditions (Kreiger et al. 1996; Lake Erie Mayfly Research Group 1998; MacDougall et al. 2001). The importance of burrowing mayflies as a food source for percids has been well documented (Ritchie and Colby 1988; Hayward and Margraf 1987; Scott and Crossman 1973; Burns 1985).

Expansion of *Dreissena*

The recent invasion and proliferation in Lake Erie by zebra and quagga (*Dreissena bugensis*) mussels has caused further dramatic changes in the ecosystem, including recent increases in water transparency and declines in chlorophyll *a* throughout the lake (Leach 1992; Nicholls and Hopkins 1993). The character of substrates on rocky reefs used by fish for spawning has been completely altered by zebra mussels (Leach 1992), and quagga mussels are now abundant on soft sediments in deeper waters (Dermott and Munawar 1993). The effects of these exotic mussels on Lake Erie's fish community are not yet fully determined, but preliminary indications include the following:

- Diversion of phytoplankton production away from zooplankters
- Decline and disappearance of the burrowing amphipod (*Diporeia* spp.) in profundal waters as *Dreissena* colonization occurred
- Shifts of energy from pelagic food webs to benthic food webs
- Reductions in fish production and growth rates in many important fish species because of shifts in energy flow
- Shifts in depth distributions of negatively phototactic fish (for example, walleye to deeper water)
- Shifts in fish-community composition and structure

Reduced phosphorus loadings in the 1970s and 1980s were expected to diminish production of plankton and planktivorous fish (e.g., alewife, smelt, gizzard shad) consumed by salmonid and percid predators (Barnes 1982). Commercial harvests of yellow perch from Ontario waters provide the best comparative index for a measure of the response in the fish community to changes in lake trophic state caused by reduced phosphorus loading. Yellow perch harvests from Ontario waters of Lake

Erie fell rapidly during the initial rapid decrease in phosphorus loading (1968-75). Harvests from the western and central basins leveled off after phosphorus loading reached GLWQA targets in the early 1980s. Yellow perch harvests from the eastern basin paralleled the long-term decline in phosphorus loading more closely than did the harvests from the western and central basins stocks (Figs. 9a, b, c, d), although the eastern basin harvest continued to decline after phosphorus loading stabilized. The initial declines in yellow perch harvest correlate with declines in phosphorus loading, but other factors are apparently involved in declining harvests after the mid-1980s.

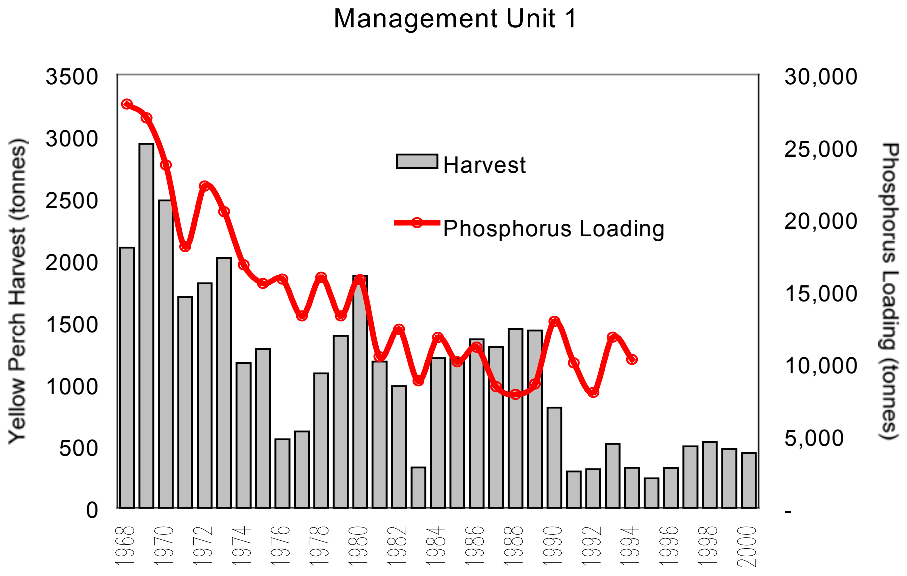

Fig. 9a. Commercial harvest of yellow perch (bars) by Ontario commercial fisheries in Management Unit 1 (western basin) (Einhouse et al. 2001) and lakewide phosphorous loading (trend line), 1968-94 (Fraser 1987, Lesht et al. 1991, Dolan 1993, and D. Dolan, unpubl. data, University of Wisconsin at Green Bay, 2420 Nicolet Drive, Green Bay, WI, 54311).

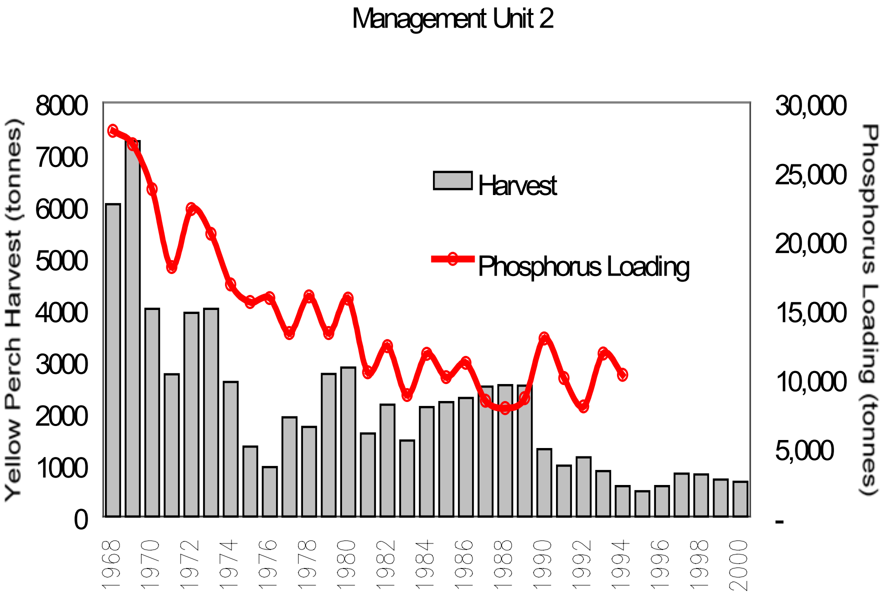

Fig. 9b. Commercial harvest of yellow perch (bars) by Ontario commercial fisheries in Management Unit 2 (central basin) (Einhouse et al. 2001) and lakewide phosphorous loading (trend line), 1968-94 (Fraser 1987, Lesht et al. 1991, Dolan 1993, and D. Dolan, unpubl. data, University of Wisconsin at Green Bay, 2420 Nicolet Drive, Green Bay, WI, 54311).

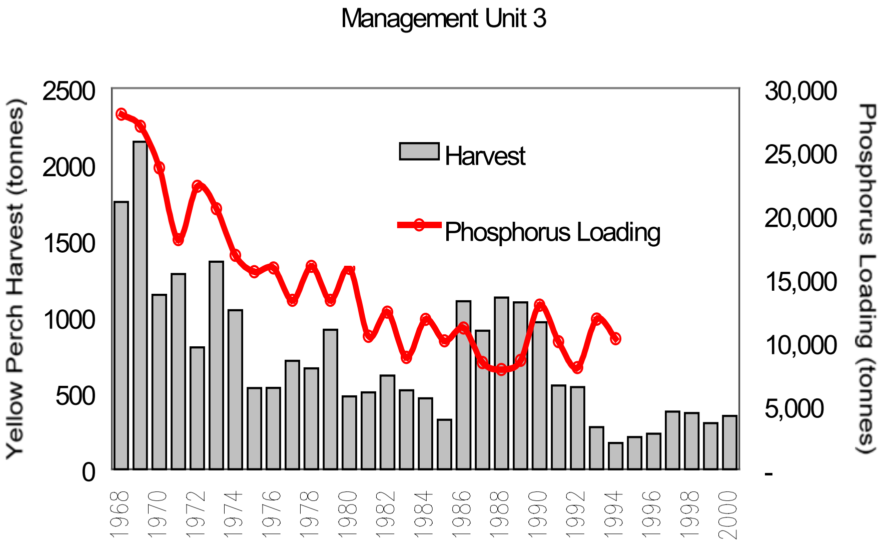

Fig. 9c. Commercial harvest of yellow perch (bars) by Ontario commercial fisheries in Management Unit 3 (central basin) (Einhouse et al. 2001) and lakewide phosphorous loading (trend line), 1968-94 (Fraser 1987, Lesht et al. 1991, Dolan 1993, and D. Dolan, unpubl. data, University of Wisconsin at Green Bay, 2420 Nicolet Drive, Green Bay, WI, 54311).

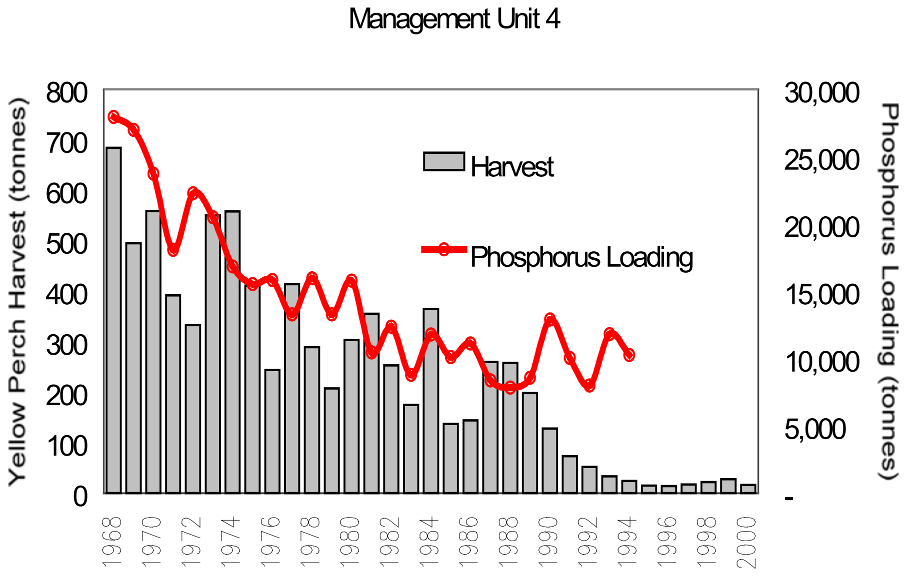

Fig. 9d. Commercial harvest of yellow perch (bars) by Ontario commercial fisheries in Management Unit 4 (eastern basin) ((Einhouse et al. 2001) and lakewide phosphorous loading (trend line), 1968-94 (Fraser 1987, Lesht et al. 1991, Dolan 1993, and D. Dolan, unpubl. data, University of Wisconsin at Green Bay, 2420 Nicolet Drive, Green Bay, Wisconsin, 54311).

Filtering by zebra and quagga mussels appears to have exacerbated the effects of reduced phosphorus loading—and reduced productivity. Yellow perch harvests began another decline in all areas of the lake after 1989 because of failure to recruit large year-classes after those of 1984 and 1986. Lakewide declines in white perch abundance and the eastern basin smelt stock were observed after 1990 (Ryan et al. 1999). These declines in populations of planktivorous fish are likely a consequence of food web changes brought about by zebra and quagga mussels.

Changes in Trophic State

The trophic status of Lake Erie has changed significantly from mesotrophic in pre-settlement times to hyper-eutrophic in the western basin, eutrophic in the central basin, and mesotrophic in the eastern basin by the 1960s. In response to phosphorus controls (post-1972) and *Dreissena* proliferation (post-1987), the western basin has returned to a mesotrophic state (as measured by phosphorus concentration) favorable for percids. Leach (1992) reported that the mean chlorophyll *a* concentrations in the western basin declined by 54% between 1988 and 1990, which he suggested was a response to zebra mussel proliferation. The Oglesby et al. (1987) model relating walleye yield to chlorophyll *a* suggests that declines in walleye production and yield may continue in the western basin.

The central basin reached a mesotrophic state in the 1980s and an oligotrophic state unfavorable for percids in the late 1980s (Bertram 1993), which continued into the 1990s (Charlton 1994). Walleye are adapted to a low-light environment (Ryder 1977) and prefer turbid waters or depths in the water column where light is attenuated. With increased transparency, walleyes are now found further offshore in deeper water, forcing sport and commercial fishermen to change their fishing techniques (e.g., Ontario commercial gillnets suspended at 0.9-7.3 m (2.9-23.7 ft) in the 1980s were suspended at 4.9-14.6 m (15.9-47.5 ft) in the 1990s).

The eastern basin, mesotrophic in the 1970s (Yaksich et al. 1985), became oligotrophic in the 1980s (Lesht et al. 1991) and ultra-oligotrophic periodically in the 1990s (Charlton 1994; MacDougall et al. 2001). Oligotrophy does not favor a dominance of percids as is evident from the depressed commercial harvest of yellow perch during the 1990s in the eastern basin (Fig. 9). The decline and disappearance of the deepwater amphipod *Diporeia* was also associated with mussel invasion. *Diporeia* was also an important food for smelt in the eastern basin Lake Erie (Dermott et al. 1999) and is typically important for whitefish, deepwater ciscoes (*Coregonus* spp.), and deepwater sculpins (*Myoxocephalus thompsoni*) in north-temperate oligotrophic lakes (Scott and Crossman 1973; Ryder and Edwards 1985). Because *Mysis relicta,* the other key deepwater species used as food by these fish, are already rare in eastern Lake Erie, the loss of *Diporeia* has been an important constraint on smelt abundance (Dermott et al. 1999). The loss of *Diporeia* will seriously affect efforts to rehabilitate the deepwater fish community of the eastern basin (Ryan et al. 1999).

BOTTOM-UP AND TOP-DOWN FORCES

Fish communities can be structured from the top by terminal predators that regulate the abundance of planktivores or from the bottom by the supply of nutrients that eventually determines the biomass of planktivores (McQueen et al. 1986; Carpenter and Kitchell 1988). With the initiation of phosphorus reduction and walleye recovery in the 1970s, both the bottom-up and top-down forces on the fish community of Lake Erie intensified (Makarewicz and Bertram 1993). This intensification persisted into the 1990s as phosphorus levels edged even lower and filtering by proliferating populations of *Dreissena* reduced production of planktonic algae—the food source for zooplankton, which is the food of planktivorous fishes.

Although mesotrophic conditions have been re-established in parts of Lake Erie, the ecosystem cannot be described as stable. Although walleye and lake trout have been reestablished as terminal predators, the fish community cannot be described as harmonic—that is, well integrated, resilient, or resistant to invasion by exotic species. Lake trout are now more abundant but are not self-sustaining. The trophic status of all basins within Lake Erie continues to vary. Yellow perch populations have made strong progress towards recovery. Rainbow smelt, alewife, and white perch populations have declined significantly in recent years.

The burrowing mayfly has made a substantial recovery in western Lake Erie. The exotic round goby has expanded across the lake and has become a significant part of the food web. Many of the recent changes in Lake Erie toward improved water quality have been induced by exotic mussels, but it is uncertain whether these changes will be permanent. Similarly, the system effects of the recent invasions by round and tube-nosed *(Proterorhinus marmoratus)* gobies are unclear, and the lake will likely be invaded by the ruffe *(Gymnocephalus cernuus*)—a Eurasian percid introduced in Lake Superior and recently found in northwestern Lake Huron.

The rainbow smelt is likely the fish most affected by intensified bottom-up and top-down forces in Lake Erie. Not native to the lake, smelt have been an important planktivore since the 1950s and an important commercial species since the 1960s. Commercial harvests peaked in 1982 at about 18 million kg (40 million lb) but have declined to about 3.6 million kg (8 million lb) in recent years (Fig. 10). Severe infections of the parasite *Glugea* have resulted in large post-spawning die-offs (Henderson and Nepszy 1989; Nsembukya-Katuramu et al. 1981) contributing to wide fluctuations in smelt abundance. Recent declines in smelt growth and condition in the eastern basin are associated with intensified bottom-up effects (Dermott et al. 1999). Moreover, these effects may have been aggravated by steep declines in *Diporeia* abundance. Smelt now enter the winter in poorer condition and more post-spawning die-offs have occurred. The combined effects of fishery exploitation, increased predation, and more frequent die-offs result in total mortality rates that have exceeded 90% in the eastern basin (Ryan et al. 1999). Rainbow smelt flourished in Lake Erie when productivity was higher and predator populations were lower.

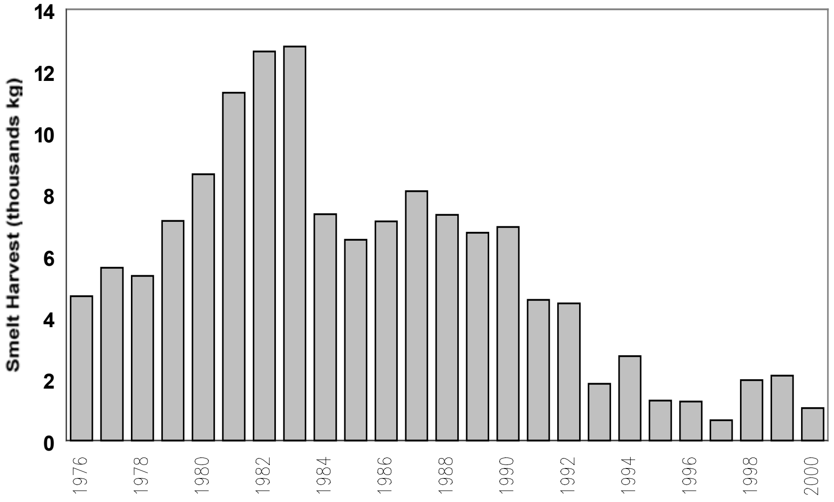

Fig. 10. Commercial harvest of rainbow smelt from eastern Lake Erie.

Yellow perch are also affected by bottom-up and top-down forces but to a lesser degree than smelt. A linkage between the abundance of yellow perch and of their predators is well established in other systems (Edwards and Ryder 1990; Mills et al. 1987). Parsons (1971) found that yellow perch were important in the diet of age-0 walleye in July. Hartman and Margraf (1993) hypothesized that walleye predation can play a major role in structuring the year-class strength of yellow perch in the lake. Nevertheless, the strength of the predator-prey linkage between walleye and yellow perch is not clear. Walleye in the lake show a dietary preference for soft-rayed fish such as alewife, gizzard shad, and rainbow smelt (Knight et al. 1984; Wolfert and Bur 1992; Knight and Vondracek 1993). This preference by walleye for soft-rayed fish is strong and persists despite shifts in their availability (Wolfert and Bur 1992). The evidence suggests that strong top-down effects should only occur if soft-rayed fish are not present to buffer predation.

A return of the walleye population to the high abundance seen in the early 1990s may not be possible given the decline in planktivores. Walleye abundance has declined from an estimate of 100 million fish (age 2 and older) in 1990 to 35 million in 2000, one of the lowest population estimates since 1983 (Turner et al. 2001).

The relatively clear and unproductive waters of the central and eastern basins now favor salmonids. In contrast, the thermal environment of the central basin is poor or marginal for cold-water (salmonid) species during the summer months because of the shallow depth of the central basin and the southerly latitude of Lake Erie for north-temperate fishes. The eastern basin is more favorable to cold-water species (lake trout, burbot, whitefish, herring, smelt) because it has a large volume of cold-water habitat. The eastern basin also provides a large volume of nearshore and epilimnetic (surface waters) cool-water habitat.

Can a harmonic percid community be reestablished in eastern and central Lake Erie? Trautman (1981) concluded that the blue pike was a subspecies of the walleye and noted that there were many intergrades in the population. However, confusion existed for many years regarding whether blue pike was a species or subspecies. The loss of blue pike appears to be attributable to introgression with walleye (Regier et al. 1969) so it is unlikely that its genome still exists. No expectation exists for a natural recovery of blue pike; however, walleye have shown that they can at least, in part, replace the blue pike as a pelagic piscivore in the harmonic percid community of central and eastern Lake Erie.

The maintenance of walleye as an abundant and highly valued terminal predator is viewed with optimism by fishery managers as strong sport and commercial fisheries flourish around this species. However, the ecosystem continues to change rapidly in response to the factors discussed, such that the future fish community remains unpredictable.

Under the present conditions of declining productivity, continuing high abundances of terminal predators such as walleye may imply some trade-offs in the abundance of secondary predators and forage fish. On the other hand, bottom-up forces on young walleye (which feed exclusively on plankton as larvae) may lead to negative effects on their early survival and reduced recruitment to the walleye fisheries. Increased water transparencies may reduce suitable habitat volume for walleye as observed in Lake St. Clair following the invasion of zebra mussels (D. MacLennan, Lake Erie Management Unit, 320 Milo Road, RR #2, Wheatley, Ontario, N0P 2P0, Canada, unpubl. data). However, as water transparencies increase, the abundance of macrophytes may also be expected to increase (particularly in the western basin) with potentially positive effects on yellow perch, esocid, walleye, and bass populations.

Because bottom-up and top-down forces have not stabilized in Lake Erie, the fish communities must be managed cautiously. Fishery benefits will be variable from year to year. The dramatic changes in the lake provide an opportunity for learning. These changes do complicate the development of quantifiable fish-community objectives. Notwithstanding this problem, these changes highlight the need for the development of complementary fishery and water-quality objectives.

DEVELOPING FISH-COMMUNITY GOALS

The LEC believes that maintenance of mesotrophic conditions across much of Lake Erie will provide optimal environmental conditions for a more balanced, stable, and predictable fish community with maximum potential benefits for fisheries. These attributes clearly point to harmonic percid communities in the western, central, and nearshore waters of the eastern basins as the logical starting points for developing fish-community goals and related objectives. Accordingly, the LEC endorses, in principle, the mesotrophic concept of Edwards and Ryder (1990)—the restoration and perpetuation of a cool-water community of organisms dominated by a balanced and harmonic percid community in which the walleye is the dominant predator. Where suitable conditions exist, salmonid or centrarchid species will be appropriate secondary components of the harmonic percid community (Ryder and Kerr 1978).

The burrowing mayfly should be the dominant large benthic invertebrate in this community.

For the cold, profundal waters of the eastern basin, the LEC seeks the rehabilitation of a balanced cold-water community where lake trout—restored to self-sustainability—is the dominant predator, and coregonines, burbot, and sculpins are important ecologically. The return of a terminal predator, ideally the native lake trout, to the historic levels recorded for the eastern basin would set the stage for structuring the deepwater community. *Diporeia* should be the dominant benthic invertebrate in the deepwater community. A return of the lake herring as a dominant planktivore would also improve community structure.

GUIDING PRINCIPLES

The LEC recognizes the following principles as being important for determining fish-community objectives for Lake Erie:

a. Self-sustaining stocks—naturally reproducing indigenous species provide the most predictable, sustainable, and cost-effective benefits to society

b. The stock concept—stocks (or populations) are the basic unit for conservation and management and should, where feasible, be identified, monitored, and appropriately managed

c. Indigenous species—where competitive interactions between indigenous and non-indigenous species are limiting, priority will be given to indigenous species

d. Introductions—no non-native animals or plants will be intentionally introduced into Lake Erie; although each member agency has its own review mechanisms for proposed introductions and the conduct of aquaculture within the Lake Erie watershed, no agency will approve such proposals without review by all other agencies on the LEC, a procedure consistent with the Joint Plan

e. Preservation and restoration of habitat—maintenance of quality habitat is fundamental to fish and fish-community conservation; preservation and restoration of habitat must be the foremost concern for achieving these objectives

f. Preservation of rare and endangered species—rare and endangered indigenous fish species add to the richness of a fish community through biodiversity and should be safeguarded in recognition of their ecological significance and intrinsic value

g. Recognition of naturalized species—a number of non-indigenous species such as rainbow trout, brown trout, coho salmon, rainbow smelt, alewife, carp, white perch, round goby, and sea lamprey have become established and must be considered part of the fish community; the sea lamprey, although naturalized, is considered a pest species requiring control

h. Harvest—species of value to sport and commercial fishermen should be harvested on a sustainable basis

i. Recognition of the limit on productivity—a biological limit exists to ecological productivity and fishery sustainable yield; managers must be guided by the best approximation of that limit to maintain a healthy fish community; fish yields are ultimately limited by lake productivity and the efficiency of trophic transfer, which is a function of the composition and structure of the fish community

FISH-COMMUNITY GOALS AND OBJECTIVES

The two broad goals for the Lake Erie fish community and ecosystem are listed below. Based on these goals and the guiding principles of the LEC, more specific fish-community objectives are developed that are critical for achieving a dominant percid harmonic community and an important, but more limited, cold-water community. All of the objectives presented are interrelated. They are not all-inclusive, but their achievement would provide a clear indication that a broad variety of additional benefits have been provided. We do not present harvest targets for individual fish.

Such forecasting has little value when a system is still responding to changes in trophic conditions and to newly established invaders. As stated in the goal, the ultimate purpose is to provide for valuable, sustainable fisheries that provide the broadest benefits. Some aspects of these goals and objectives are beyond the mandates of the LEC member agencies. In such cases, the LEC will advocate for the achievement of those objectives by ensuring that the responsible agencies are aware of their significance to the Lake Erie fish community. The LEC, in collaboration with other environmental agencies, is committed to developing the key measures of success that support these objectives. Close coordination and cooperation among agencies and resource interest groups will be required to successfully achieve these goals and the related objectives.

Lake Erie Goals

- To secure a balanced, predominantly cool-water fish community with walleye as a key predator in the western basin, central basin, and the near-shore waters of the eastern basin, characterized by self-sustaining indigenous and naturalized species that occupy diverse habitats, provide valuable fisheries, and reflect a healthy ecosystem

- To secure a predominately cold-water fish community in the deep, offshore waters of the eastern basin with lake trout and burbot as key predators

Fish-Community Objectives

a. Ecosystem conditions—maintain mesotrophic conditions (10-20 $\mu g \cdot L^{-1}$ phosphorus) that favor a dominance of cool-water organisms in the western, central, and nearshore waters of the eastern basins; summer water transparencies should range from 3-5 m (9.75-16.25 ft) in mesotrophic areas

b. Productivity and yield—secure a potential annual sustainable harvest of 13.6-27.3 million kg (30-60 million lb) of highly valued fish

c. Nearshore habitat—maintain nearshore habitats that can support high quality fisheries for smallmouth bass, northern pike, muskellunge, yellow perch, and walleye

d. Riverine and estuarine habitat—protect and restore self-sustaining, stream-spawning stocks of walleye, white bass, lake sturgeon, and rainbow trout

e. Western basin—provide sustainable harvests of walleye, yellow perch, smallmouth bass, and other desired fishes

f. Central basin—provide sustainable harvests of walleye, yellow perch, smallmouth bass, rainbow smelt, rainbow trout, and other desired fishes

g. Eastern basin—provide sustainable harvests of walleye, smallmouth bass, yellow perch, whitefish, rainbow smelt, lake trout, rainbow trout, and other salmonids; restore a self-sustaining population of lake trout to historical levels of abundance

h. Contaminants—reduce contaminants in all fish species to levels that require no advisory for human consumption and that cause no detrimental effects on fish-eating wildlife, fish behavior, fish productivity, and fish reproduction

i. Fish habitat—protect, enhance, and restore fish habitat throughout the watershed to prevent degradation and foster restoration of the fish community

j. Genetic diversity—maintain and promote genetic diversity by identifying, rehabilitating, conserving, and/or protecting locally adapted stocks

k. Rare, threatened, and endangered species—prevent extinction by protecting rare, threatened, and endangered fish species (for example, lake sturgeon and lake herring) and their habitats

l. Forage fish—maintain a diversity of forage fishes to support terminal predators and to sustain human use

m. Food web structure—manage the food web structure of Lake Erie to optimize production of highly valued fish species; recognize the importance of *Diporeia* and *Hexagenia* as key species in the food web and as important indicators of habitat suitability

GENERAL IMPLEMENTATION STRATEGIES

All agencies should continue the highly successful multijurisdictional, cooperative approach to fisheries management under the LEC. The Standing Technical Committee (STC) is the agent of the LEC created to advise it and to meet its needs for science and strategy development. The STC will continue to accomplish this role by maintaining permanent (Yellow Perch, Walleye, Forage, Habitat, Cold Water) or ad hoc (Statistics and Modeling, Index Fishing) subcommittees.

a. Coordination—continue participation in the STC; ensure continued sharing of information generated by all agencies and coordinated evaluation of the status of resources

b. Advocacy and cooperation—work closely with agencies responsible for environmental and water-quality issues to ensure fish and wildlife concerns are a priority

c. Assessment—improve coordinated assessment capabilities and techniques, use improved modeling techniques, and report findings in a timely fashion; further refine measurement criteria to better assess whether goals and objectives have been met

d. Enforcement—effectively enforce existing legislation, recommend legislative changes, and continue cooperative enforcement through combined enforcement teams

e. Exploitation—ensure that harvest policies for fish species are consistent with restoration and sustainability objectives

ENVIRONMENTAL CONCERNS AND OTHER LIMITATIONS

The following are existing or emerging issues that may affect attainment of the goals and objectives for the lake:

a. Failure to rehabilitate or to stop destruction or impairment of fish habitat and environmental quality

b. Toxic substances that impair the use of a fishery resource and adversely affect the health of fishes

c. Changes in water quality

d. Climate change (for example, global warming)

e. Overexploitation of fish stocks because of inadequate controls

f. Inadequate knowledge and resources for management agencies to conduct programs and measure progress toward objectives

g. Introductions of fish and other organisms

h. Insufficient interagency cooperation

i. Unrealistic expectations of harvest

j. Ineffective enforcement of existing legislation and ineffective legislation

ACKNOWLEDGMENTS

This manuscript has been a living document and has evolved over more than 12 years within the LEC with significant support and assistance from Bob Lange, Don Einhouse, Del Graf, Roger Kenyon, Carl Baker, Ken Paxton, Doug Jester, Bob Haas, Mike Bur, Dieter Busch, Joe Leach, Tim Johnson, Jerry Paine, and Larry Halyk. Dick Ryder, Chuck Krueger, and Natalie Moir helped us with thoughtful reviews and encouragement. We thank Cheryl Orr who prepared the manuscript for submission and Erin Arnold who prepared the final version for their dedication and good humor under duress. Staff at the Great Lakes Fishery Commission have been patient and proactive, and we thank Randy Eshenroder, Chuck Krueger, and Chris Goddard for their dialogue and very considerable support.

REFERENCES

Barnes, M.D. 1982. Lake Erie intensive study: fisheries status and response to water quality. Ohio State University. CLEAR Tech. Rep. No. 240.

Beeton, A.M. 1969. Changes in the environment and biota of the Great Lakes. *In* Eutrophication: causes, consequences and correctives. Nat. Acad. Sci. Washington, DC: 150-187.

Bertram, P.E. 1993. Total phosphorus and dissolved oxygen trends in the central basin of Lake Erie, 1970-91. J. Great Lakes Res. 19: 224-236.

Bolsenga, S.J., and C.E. Herdendorf. 1993. Lake Erie and Lake St. Clair handbook. Wayne State Univ. Press, Detroit, MI.

Britt, N.W., A.J. Pliodzinskas, and E.M. Hair. 1980. Record low dissolved oxygen in the island area of Lake Erie. Ohio J. Sci. 68: 175-179.

Bur, M.T., D.M. Klarer, and K.A. Krieger. 1986. First records of a European cladoceran, *Bythotrephes cederstroemi*, in Lakes Erie and Huron. J. Great Lakes Res. 12: 144-146.

Burns, N.M. 1985. Erie the lake that survived. Roman & Allanheld, Totowa, NJ.

_____, and C. Ross. 1972. Project Hypo. Canada Centre for Inland Waters, Burlington, Ont. Paper No. 6 and U.S. Environ. Prot. Agency Tech. Rep. TS-05-71-208-24.

Campbell, R.R. 1987. Status of the blue walleye, *Stizostedion vitreum glaucum*, in Canada. Can. Field-Nat. 101(2): 245-252.

Carpenter, S.R., and J.F. Kitchell. 1988. Consumer control of lake productivity. BioScience 38: 764-769.

Charlton, M.N. 1994. The case for research on the effects of zebra mussels in Lake Erie: visualization of information from August and September 1993. J. Biol. Systems 2: 467-480.

Christie, W.J., G.R. Spangler, K.H. Loftus, W.L. Hartman, P.J. Colby, M.A. Ross, and D.R. Talhelm. 1987. A perspective on Great Lakes fish community rehabilitation. Can. J. Fish. Aquat. Sci. 44(Suppl. 2): 486-499.

Christie, G.C., and H.A. Regier. 1988. Measures of optimal thermal habitat and their relationship to yields for four commercial fish species. Can. J. Fish. Aquat. Sci. 45: 301-314.

Cornelius, F.C., K.M. Muth, and R. Kenyon. 1995. Lake trout rehabilitation in Lake Erie: a case history. J. Great Lakes Res. 21(Suppl. 1): 65-82.

Crowder, L.B. 1980. Alewife, rainbow smelt and native fishes in Lake Michigan: competition or predation? Environ. Biol. Fish. 5: 225-233.

Culligan, W.J., J.L. Markham, D.W. Einhouse, D.L. Zeller, R.C. Zimar, and B.J. Beckwith. 2001. 2000 Annual Report to the Lake Erie Committee. NY Dept. Env. Conserv., Lake Erie Unit.

Dahl, J.A., D.M. Graham, R. Dermott, O.E. Johannsson, E.S. Millard, and D.D. Myles. 1995. Lake Erie 1993, western, west central and eastern basins: change in trophic status, and assessment of the abundance, biomass and production of the lower trophic levels. Can. Tech. Rep. Fish. Aquat. Sci. 2070.

Delorme, L.D. 1982. Lake Erie oxygen: the prehistoric record. Can. J. Fish. Aquat. Sci. 39: 1021-1029.

Dermott, R., and M. Munawar. 1993. Invasion of Lake Erie offshore sediments by *Dreissena*, and its ecological implications. Can. J. Fish. Aquat. Sci. 50: 2298-2304.

_____, M. Munawar, L.Witzel, and P. Ryan. 1999. An assessment of food web changes in eastern Lake Erie: impact of *Dreissena* on smelt. *In* State of Lake Erie (SOLE)—past, present, and future. M. Munawar and T. Edsall (eds.). Ecovision World Monograph Series. Backhuys, The Netherlands: 367-385.

Dolan, D. 1993. Point source loadings of phosphorus to Lake Erie: 1986-1990. J. Great Lakes Res. 19: 212-223.

Edsall, T.A., C.L. Brown, G.W. Kennedy, and J.R.P. French, III. 1992. Surficial substrates and bathymetry of five historical lake trout spawning reefs in nearshore waters of the Great Lakes. Great Lakes Fish. Comm. Tech. Rep. 58.

Edwards, C.J., and R.A. Ryder (EDS.). 1990. Biological surrogates of mesotrophic ecosystem health in the Laurentian Great Lakes. Report to the Great Lakes Science Advisory Board. Intl. Joint Comm., Windsor, Ont., Canada.

Einhouse, D., and R. Haas. 1995. A preliminary examination of walleye distribution and exploitation in the eastern basin of Lake Erie using tag-recapture data. Bureau of Fisheries Report. NY Dep. Env. Conserv., Albany, NY.

_____, M. Bur, F. Cornelius, R. Kenyon, R. Knight, C. Madenjian, K. Muth, S. Pare, P. Rand, M. Rawson, L. Sztramko, and L. Witzel. 1993. Consumption of rainbow smelt by walleye and salmonine fishes in the central and eastern basins of Lake Erie. Report to the Lake Erie Committee and the Great Lakes Fish. Comm. Lake Erie Committee 1993 Annual Meeting (Minutes) Appendix V, pp. 81-104.

_____, M.T. Bur, F.C. Cornelius, R. Kenyon, C.P. Madenjian, P.S. Rand, K.L. Sztramko, and L.W. Witzel. 1999. Consumption of rainbow smelt by walleye and salmonine fishes in eastern Lake Erie. *In* State of Lake Erie (SOLE)—past, present, and future. M. Munawar and T. Edsall (eds.). Ecovision World Monograph Series. Backhuys, The Netherlands. pp. 291-303.

_____, K. Kayle, R. Kenyon, C. Knight, P. Ryan, S. Sandstrom, B. Sutherland, M. Thomas, B. Morrison, and A. Cook. 2001. Report of the Lake Erie Yellow Perch Task Group. Report to the Lake Erie Committee and the Great Lakes Fish. Comm. Lake Erie Committee 2001 Annual Meeting (Minutes). Attachment 4, pp. 41-88.

_____, W.J. Culligan, and J. Prey. 2002. Changes in the smallmouth bass fishery of New York's portion of Lake Erie with initiation of a spring black bass season. *In* Black bass: ecology, conservation and management. D.P. Philipp and M.S. Ridgway (eds.). Am. Fish. Soc. Symp. 31, Bethesda, MD: 603-614.

Environmental Protection Agency. 1995. Lake Erie lakewide management plan concept paper. U.S. Environ. Prot. Agency, Chicago, IL.

Evans, D.O., and K.H. Loftus. 1987. Colonization of inland lakes in the Great Lakes region by rainbow smelt, *Osmerus mordax*: their freshwater niche and effects on indigenous species. Can. J. Fish. Aquat. Sci. 44 (Suppl. 2): 249-266.

Ferguson, R.G., and A.J. Derksen. 1971. Migrations of adult and juvenile walleyes (*Stizostedion vitreum vitreum*) in southern Lake Huron, Lake St. Clair, Lake Erie, and connecting waters. J. Fish. Res. Bd. Can. 28: 1133-1142.

Fish, C.J., and Associates. 1960. Limnological survey of eastern and central Lake Erie 1928-29. U.S. Fish Wildl. Serv. Spec. Sci. Rep. Fish. No. 334.

Fraser, A.S. 1987. Tributary and non-point total phosphorus loading to Lake Erie. J. Great Lakes Res. 13: 659-666.

Gilbertson, M. 1997. Are causes knowable? Some consequences of successional versus toxicological interpretations of the Great Lakes Water Quality Agreement. Can. J. Fish. Aquat. Sci. 54: 483-495.

Great Lakes Fishery Commission. 1980. A Joint Strategic Plan for Management of Great Lakes Fisheries. Great Lakes Fish. Comm. http://www.glfc.org/pubs_out/docs.htm

_____. 1997. A Joint Strategic Plan for Management of Great Lakes Fisheries. Great Lakes Fish. Comm. http://www.glfc.org/pubs_out/docs.htm

Goff, G.P. 1986. Reproductive success of male smallmouth bass in Long Point Bay, Lake Erie. Trans. Am. Fish. Soc. 115: 415-423.

Hair, D. E. 1978. Smallmouth bass survey. D-J Project F-35-R. Study 5. Final Report. Ohio Dept. Nat. Resour. Div. Wildl. Columbus, OH.

Hardy, M.B. 1994. The resurgence of lake whitefish (*Coregonus clupeaformis*) and its relationship to rainbow smelt and other factors in Lake Erie. M.Sc. Thesis, University of Waterloo, Waterloo, Ont., Canada.

Hartman, W.L. 1972. Lake Erie: effects of exploitation, environmental changes, and new species on the fishery resources. J. Fish. Res. Bd. Can. 29: 899-912.

Hartman, K.J., and F.J. Margraf. 1993. Evidence of predatory control of yellow perch (*Perca flavescens*) recruitment in Lake Erie, U.S.A. J. Fish Biol. 43: 1009-1019.

Hatch, R.W., S.J. Nepszy, K.M. Muth, and C.T. Baker. 1987. Dynamics of the recovery of the western Lake Erie walleye (*Stizostedion vitreum vitreum*) stock. Can. J. Fish. Aquat. Sci. 44(Suppl. 2): 15-22.

Hayward, R.S., and F.J. Margraf. 1987. Eutrophication effects on prey size and food available to yellow perch in Lake Erie. Trans. Am. Fish. Soc. 116: 210-223.

Henderson, B.A., and S.J. Nepszy. 1989. Factors affecting recruitment and mortality rates of rainbow smelt (*Osmerus mordax*) in Lake Erie, 1963-85. J. Gt. Lakes Res. 15: 357-366.

Herdendorf, C.E. 1983. Our changing fish species history. Inland Seas 39: 276-286.

Hokanson, K.E.F. 1977. Temperature requirements of some percids and adaptions to the seasonal temperature cycle. J. Fish. Res. Board Can. 34: 1524-1550.

Holland, R.E., T.H. Johengen, and A.M. Beeton. 1995. Trends in nutrient concentration in Hatchery Bay, western Lake Erie, before and after *Dreissena polymorpha*. Can. J. Fish. Aquat. Sci. 52: 1202-1209.

International Joint Commission. 1987. Great Lakes Water Quality Agreement as Amended by Protocol Signed November 18, 1987. Washington, DC and Ottawa, Ont.

Jennings, M.J., J.E. Claussen, and D.P. Philipp. 1996. Evidence for heritable preferences for spawning habitat between two walleye populations. Trans. Am. Fish. Soc. 125: 978-982.

Johannsson, O.E., D.M. Graham, D.W. Einhouse, and E.L. Mills. 1999. Historical and recent changes in the Lake Erie zooplankton community and their relationship to ecosystem function. *In* State of Lake Erie (SOLE)—past, present, and future. M. Munawar and T. Edsall (eds.). Ecovision World Monograph Series. Backhuys, The Netherlands. pp. 169-196.

Johnson, T.B., M. Bur, J. Deller, D. Einhouse, R. Haas, C. Murray, L. Rutsdam, M. Thomas, B. Trometer, J. Tyson, and L.D. Witzel. 2001. Report of the Lake Erie Forage Task Group to the Lake Erie Committee and the Great Lakes Fish. Comm. Lake Erie Committee 2001 Annual Meeting (Minutes). Att. 6, pp. 129-162.

Knight, R.L. 1997. Successful interagency rehabilitation of Lake Erie walleye. Fisheries 22: 16-17.

_____, F.J. Margraf, and R.F. Carline. 1984. Piscivory by walleyes and yellow perch in western Lake Erie. Trans. Am. Fish. Soc. 113: 677-693

_____, and B. Vondracek. 1993. Changes in prey fish populations in Western Lake Erie, 1969-88, as related to walleye, *Stizostedion vitreum*, predation. Can. J. Fish. Aquat. Sci. 50: 2189-2198.

Kreiger, K.A., D.W. Schloesser, B.A. Manny, C.E. Trisler, S.E. Heady, J.J.H. Ciborowski, and K.M. Muth. 1996. Recovery of burrowing mayflies (Ephemeroptera: Ephemeridae: *Hexagenia*) in western Lake Erie. J. Great Lakes Res. 22: 254-263.

Lake Erie Mayfly Research Group. 1998. *Hexagenia* mayfly populations in western Lake Erie: status and research needs—1998. Summary document and discussion paper. Department of Biological Science, University of Windsor, Windsor, Ont.

Leach, J.H. 1981. Comparative limnology of inner Long Point Bay, Lake Erie, and adjacent waters of the outer bay. J. Gt. Lakes Res. 7: 123-129.

_____. 1992. Impact of zebra mussel, *Dreissena polymorpha*, on water quality and spawning reefs in western Lake Erie. *In* Zebra mussels: biology, impacts and control. D.W. Schloesser and T. Nalepa (eds.). Lewis Publishers Inc., Chelsea, MI.

_____, and S.J. Nepszy. 1976. The fish community in Lake Erie. J. Fish. Res. Bd. Can. 33: 622-638.

_____, M.G. Johnson, J.R.M. Kelso, J. Hartman, W. Numan, and B. Ents. 1977. Responses of percid fishes and their habitats to eutrophication. J. Fish. Res. Board Can. 34: 1964-1971.

Lesht, B.M., T.D. Fontaine, III, and D.M. Dolan. 1991. Great Lakes total phosphorus model: post audit and regionalized sensitivity analysis. J. Great Lakes Res. 17: 3-17.

Ludsin, S.A., M.W. Kershner, K.A. Blocksom, R.A. Stein, and R.L. Knight. 2001. Life after death in Lake Erie: nutrient controls drive fish species richness, rehabilitation. Ecol. Appl. 11: 731-746.

MacDougall, T.M., H.P. Benoit, R. Dermott, O.E. Johannsson, T.B. Johnson, E.S. Millard, and M. Munawar. 2001. Lake Erie 1998: Assessment of abundance, biomass and production of lower trophic levels, diets of juvenile yellow perch and trends in the fishery. Can. Tech. Rep. Fish. Aquat. Sci. No. 2376.

MacGregor, R.B., and L.D. Witzel. 1987. A twelve year study of the fish community in the Nanticoke region of Long Point Bay, Lake Erie: 1971-1983 summary report. Ont. Min. Nat. Resour. Lake Erie Fisheries Assessment Unit Rep. 1987-3.

MacIssac, H.J. 1999. Biological invasions in Lake Erie: past, present, future. *In* State of Lake Erie (SOLE)—past, present future. M. Munawar and T. Edsall (eds.). Ecovision World Monograph Series. Backhuys, The Netherlands. pp. 305-322.

Makarewicz, J. C. and P. Bertram. 1993. Evidence for the restoration of the Lake Erie ecosystem. Bio Science 41: 216-223.

Mazumder, A. 1994. Patterns of algal biomass in dominant—odd vs. even—link ecosystems. Ecology 75: 1141-1149.

McParland, T.L. 1996. Genetic population structure and mixed stock analysis of walleye (*Stizostedion vitreum*) in the Lake Erie-Lake Huron corridor. M.Sc. Thesis. University of Guelph, Guelph, Ont.

McQueen, D.J., J.R. Post, and E.L. Mills. 1986. Trophic relationships in freshwater pelagic ecosystems. Can. J. Fish. Aquat. Sci. 43: 1571-1581.

Mills, E.L., J.L. Forney, and K.J. Wagner. 1987. Fish predation and its cascading effect on the Oneida Lake food chain. *In* Predation. W.C. Kerfoort and A. Sih (eds.). University Press of New England, Hanover, NH. pp. 118-131.

Millard, E.S., E.J. Fee, D.D. Myles, and J.A. Dahl. 1999. Comparison of phytoplankton methodology in Lakes Erie, Ontario, the Bay of Quinte and the northwest Ontario lake size series. *In* State of Lake Erie (SOLE)—past, present, and future. M. Munawar and T. Edsall (eds.). Ecovision World Monograph Series. Backhuys, The Netherlands. pp. 441-468.

Mortimer, C.H. 1987. Fifty years of physical investigations and related limnological studies on Lake Erie, 1928-1977. J. Great Lakes Res. 13: 407-435.

Murray, C., P. Ryan, M. Bur, A. Cook, F. Cornelius, J. Fitzsimmons, M. Fodale, J. Heinrich, K. Kayle, A. Murry, P. Sullivan, E. Trometer, J. Heinrich, and M. Stapanian. 2001. Report of the Lake Erie coldwater task group. 2000 Report to the Lake Erie Committee and the Great Lakes Fish. Comm. Lake Erie Committee 2000 Annual Meeting (Minutes). Att. 4: 113-158.

Nepszy, S.J. 1977. Changes in percid populations and species interactions in Lake Erie. J. Fish. Res. Board Can. 34: 1861-1868.

_____. 1999. The changing fishery regime in Lake Erie. *In* State of Lake Erie (SOLE)—past, present, and future. M. Munawar and T. Edsall (eds.). Ecovision World Monograph Series. Backhuys, The Netherlands. pp. 233-239.

Nicholls, K.H., and G.J. Hopkins. 1993. Recent changes in Lake Erie (north shore) phytoplankton: cumulative impacts of phosphorus loading reductions and the zebra mussel introduction. J. Great Lakes Res. 19: 637-647.

Nsembukya-Katuramu, S., E.K. Balon, and R. Mahon. 1981. A comparison of spawning, harvested and die-off smelt, *Osmerus mordax*, in eastern Lake Erie. J. Great Lakes Res. 7: 144-154.

O'Brien, W.J. 1979. The predator-prey interaction of planktivorous fish and zooplankton. Am. Scientist 67: 572-581.

Oglesby, R.T., J.H. Leach, and J. Forney. 1987. Potential *Stizostedion* yield as a function of chlorophyll concentration with special reference to Lake Erie. Can. J. Fish. Aquat. Sci. 44(Suppl. 2): 166-170.

Ohio Department of Natural Resources. 1996. Ohio's Lake Erie Fisheries. 1995. Columbus, OH.

_____. 1998. Ohio's Lake Erie fisheries. 1997. Columbus, OH.

Ontario Ministry of Natural Resources. 2001. Lake Erie Fisheries Report 2000 to the Lake Erie Committee and the Great Lakes Fish. Comm. http://www.glfc.org/pubs_out/docs.htm

Parsons, J.W. 1971. Selective food preferences of walleyes of the 1959 year class in Lake Erie. Trans. Am. Fish. Soc. 100: 474-485.

Pimm, S.L., and J.B. Hyman. 1987. Ecological stability in the context of multispecies fisheries. Can. J. Fish. Aquat. Sci. 44(Suppl. 2): 84-94.

Rawson, M.R., and R.L. Scholl. 1978. Reestablishment of sauger in western Lake Erie. Am. Fish. Soc. Spec. Pub. 11.

Regier, H.A., V.C. Applegate, and R.A. Ryder. 1969. The ecology and management of the walleye in western Lake Erie. Great Lakes Fish. Comm. Tech. Rep. No. 15.

_____, and K.H. Loftus. 1972. The ecological role of fisheries exploitation in salmonid communities. J. Fish Res. Board Can. 29: 959-968.

_____, and W.L. Hartman. 1973. Lake Erie's fish community: 150 Years of cultural stresses. Science 180: 1248-1255.

Reynoldson, T.B., and A.L. Hamilton. 1993. Historic changes in populations of burrowing mayflies (*Hexagenia limbata*) from Lake Erie based on sediment tusk profiles. J. Great Lakes Res. 19: 250-257.

Ritchie, B.J., and P.J. Colby. 1988. Even-odd year differences in walleye year-class strength related to mayfly production. North Am. J. Fish. Manage. 8: 210-215.

Ryan, P.A., L.D. Witzel, J.R. Paine, M.J. Freeman, M. Hardy, S. Scholten, J.L. Sztramko, and R. MacGregor. 1999. Recent trends in fish populations in eastern Lake Erie in relation to changing trophic state and food web. *In* State of Lake Erie (SOLE)—past, present, and future. M. Munawar and T. Edsall (eds.). Ecovision World Monograph Series. Backhuys, The Netherlands. pp. 241-289.

Ryder, R.A. 1972. The limnology and fishes of oligotrophic glacial lakes in North America (about 1800 AD). J. Fish. Res. Board Can. 331: 663-688.

_____. 1977. Effects of ambient light variations on behaviour of yearling, subadult, and adult walleyes (*Stizostedion vitreum vitreum*). J. Fish. Res. Board Can. 34: 1481-1491.

_____, and C.J. Edwards (EDS.). 1985. A conceptual approach for the application of biological indicators of ecosystem quality in the Great Lakes Basin. Great Lakes Science Advisory Board, International Joint Commission, Windsor, Ont., and Great Lakes Fish. Comm., Ann Arbor, MI.

_____, and S.R. Kerr. 1978. Adult walleye in the percid community—a niche definition based on feeding behaviour and food specificity. Am. Fish. Soc. Spec. Pub. 11.

_____, and S.R. Kerr. 1990. Harmonic communities in aquatic ecosystems: a management perspective. *In* Management of freshwater fisheries. W.L.T. van Densen, H. Steinmetz, and R.H. Hughes (eds.). Proceedings of a symposium organized by the European Inland Fisheries Advisory Commission, Goteborg, Sweden, May 31 - June 3, 1988. Centre for Agricultural Publishing and Documentation. Wageningen, The Netherlands. pp. 594-623.

Scott, W.B., and E.J. Crossman. 1973. Freshwater fishes of Canada. Bull. Fish. Res. Board Can. 184.

Smith, S.H., H.J. Buettner, and R. Hile. 1961. Fishery statistical districts of the Great Lakes. Great Lakes Fish. Comm. Tech. Rep. 2.

Stein, R.A., D.R. DeVries, and J.H. Dettmers. 1995. Food-web regulation by a planktivore: exploring the generality of the trophic cascade hypothesis. Can. J. Fish. Aquat. Sci. 52: 2518-2526.

_____, E.A. Marschall, and G. Steinhart. 2001. Exploring ecological mechanisms underlying recruitment of smallmouth bass in Lake Erie. Annual report. Ohio Federal Aid in Fish Restoration Project F-69-P. Columbus, OH.

Stepien, C.A. 1995. Population genetic divergence and geographic patterns from DNA sequences: examples from marine and freshwater fishes. Am. Fish. Soc. Symp. 17: 263-287.

Todd, T.N., and R.C. Haas. 1993. Genetic and tagging evidence for movement of walleyes between Lake Erie and Lake St. Clair. J. Great Lakes Res. 19: 445-452.

Trautman, M.B. 1981. The fishes of Ohio. Ohio State University Press, Columbus, OH.

Turner, M., D. MacLennan, D. Einhouse, R. Haas, T. Johnson, R. Kenyon, R. Knight, and M. Thomas. 2001. Report of the Lake Erie Walleye Task Group 2000. Report to the Lake Erie Committee and the Great Lakes Fish. Comm. Lake Erie Committee 2000 Annual Meeting (Minutes). Attachment 1, pp. 13-38.

Wolfert, D.R., and H.D. Van Meter. 1978. Movements of walleyes tagged in eastern Lake Erie. NY Fish Game J. 25: 16-22.

_____, and M.T. Bur. 1992. Selection of prey by walleyes in the Ohio waters of the central basin of Lake Erie, 1985-1987. U.S. Dept. of the Interior, Fish. Wild. Serv. Res. Publ. 182.

Yaksich, S.M., D.A. Melfi, D.B. Baker, and J.W. Kramer. 1985. Lake Erie nutrient loads, 1970-1980. J. Great Lakes Res. 11: 117-131.

Zaret, T.M. 1980. Predation and freshwater communities. Yale University Press, New Haven, CT.

90-4 An ecosystem approach to the integrity of the Great Lakes in turbulent times (proceedings of a 1988 workshop supported by the Great Lakes Fishery Commission and the Science Advisory Board of the International Joint Commission). 1990. Edited by C. J. Edwards and H. A. Regier. 302 p.

91-1 Status of walleye in the Great Lakes: case studies prepared for the 1989 workshop. 1991. Edited by P. J. Colby, C. A. Lewis, and R. L. Eshenroder. 222 p.

91-2 Lake Michigan: an ecosystem approach for remediation of critical pollutants and management of fish communities (report of a round table sponsored in 1990 by the Great Lakes Fishery Commission, the Science Advisory Board of the International Joint Commission, and the Lake Michigan Federation). 1991. Edited by R. L. Eshenroder, J. H. Hartig, and J. E. Gannon. 58 p.

91-3 The state of the Lake Ontario fish community in 1989. 1991. S. J. Kerr and G. C. LeTendre. 38 p.

93-1 Great Lakes fish disease control policy and model program. 1993. Edited by J. G. Hnath. 38 p.
Protocol to minimize the risk of introducing emergency disease agents with importation of salmonid fishes from enzootic areas. 1993. Edited by R.W. Horner and R. L. Eshenroder. 15 p.

94-1 The state of Lake Superior in 1992. 1994. Edited by M. J. Hansen. 110 p.

94-2 An introduction to economic valuation principles for fisheries management. L. G. Anderson. 98 p.

95-1 Fish-community objectives for Lake Huron. 1995. R. L. DesJardine, T. K. Gorenflo, R. N. Payne, and J. D. Schrouder. 38 p.

95-2 The state of Lake Huron in 1992. Edited by M. P. Ebener. 140 p.

95-3 Fish-community objectives for Lake Michigan. R.L. Eshenroder, M.E. Holey, T.K. Gorenflo, and R.D. Clark, Jr. 56 p.

99-1 Fish-community objectives for Lake Ontario. T.J. Stewart, R.E. Lange, S.D. Orsatti, C.P. Schneider, A. Mathers, M.E. Daniels. 56 p.

03-1 Fish-community objectives for Lake Superior. W.H. Horns, C.R. Bronte, T.R. Busiah, M.P. Ebener, R.L. Eshenroder, T. Groenflo, N. Kmiecik, W. Mattes, J.W. Peck, M. Petzold, D.R. Schreiner. 86 p.

Special Publications

79-1 Illustrated field guide for the classification of sea lamprey attack marks on Great Lakes lake trout. 1979. E. L. King and T. A. Edsall. 41 p.

82-1 Recommendations for freshwater fisheries research and management from the Stock Concept Symposium (STOCS). 1982. A. H. Berst and G. R. Spangler. 24 p.

82-2 A review of the adaptive management workshop addressing salmonid/lamprey management in the Great Lakes. 1982. Edited by J. F. Koonce, L. Greig, B. Henderson, D. Jester, K. Minns, and G. Spangler. 58 p.

82-3 Identification of larval fishes of the Great Lakes basin with emphasis on the Lake Michigan drainage. 1982. Edited by N. A. Auer. 744 p. (Cost: $10.50 U.S., $12.50 CAN)

83-1 Quota management of Lake Erie fisheries. 1983. Edited by J. F. Koonce, D. Jester, B. Henderson, R. Hatch, and M. Jones. 40 p.

83-2 A guide to integrated fish health management in the Great Lakes basin. 1983. Edited by F. P. Meyer, J. W. Warren, and T. G. Carey. 262 p.

84-1 Recommendations for standardizing the reporting of sea lamprey marking data. 1984. R. L. Eshenroder and J. F. Koonce. 22 p.

84-2 Working papers developed at the August 1983 conference on lake trout research. 1984. Edited by R. L. Eshenroder, T. P. Poe, and C. H. Olver.

84-3 Analysis of the response to the use of "Adaptive Environmental Assessment Methodology" by the Great Lakes Fishery Commission. 1984. C. K. Minns, J. M. Cooley, and J. E. Forney. 22 p.

85-1 Lake Erie fish community workshop (report of the April 4-5, 1979 meeting). 1985. Edited by J. R. Paine and R. B. Kenyon. 58 p.

85-2 A workshop concerning the application of integrated pest management (IPM) to sea lamprey control in the Great Lakes. 1985. Edited by G. R. Spangler and L. D. Jacobson. 98 p.

85-3 Presented papers from the Council of Lake Committees plenary session on Great Lakes predator-prey issues, March 20, 1985. 1985. Edited by R. L. Eshenroder. 134 p.

85-4 Great Lakes fish disease control policy and model program. 1985. Edited by J. G. Hnath. 24 p.

85-5 Great Lakes Law Enforcement/Fisheries Management Workshop (report of the 21, 22 September 1983 meeting). 1985. Edited by W. L. Hartman and M. A. Ross. 26 p.

85-6 TFM vs. the sea lamprey: a generation later. 1985. 18 p.

86-1 The lake trout rehabilitation model: program documentation. 1986. C. J. Walters, L. D. Jacobson, and G. R. Spangler. 34 p.

87-1 Guidelines for fish habitat management and planning in the Great Lakes (report of the Habitat Planning and Management Task Force and Habitat Advisory Board of the Great Lakes Fishery Commission). 1987. 16 p.

87-2 Workshop to evaluate sea lamprey populations "WESLP" (background papers and proceedings of the August 1985 workshop). 1987. Edited by B. G. H. Johnson.

87-3 Temperature relationships of Great Lakes fishes: a data compilation. 1987. D. A. Wismer and A. E. Christie. 196 p.

88-1 Committee of the Whole workshop on implementation of the Joint Strategic Plan for Management of Great Lakes Fisheries (reports and recommendations from the 18-20 February 1986 and 5-6 May 1986 meetings). 1988. Edited by M. R. Dochoda. 170 p.

88-2 A proposal for a bioassay procedure to assess impact of habitat conditions on lake trout reproduction in the Great Lakes (report of the ad hoc Committee to Assess the Feasibility of Conducting Lake Trout Habitat Degradation Research in the Great Lakes). 1988. Edited by R. L. Eshenroder. 13 p.

88-3 Age structured stock assessment of Lake Erie walleye (report of the July 22-24, 1986 Workshop). 1988. R. B. Deriso, S. J. Nepszy, and M. R. Rawson. 13 p.

88-4 The international Great Lakes sport fishery of 1980. 1988. D. R. Talhelm. 70 p.

89-1 A decision support system for the integrated management of sea lamprey. 1989. J. F. Koonce and A. B. Locci-Hernandez. 74 p.

90-1 Fish community objectives for Lake Superior. 1990. Edited by T. R. Busiahn. 24 p.

90-2 International position statement and evaluation guidelines for artificial reefs in the Great Lakes. 1990. Edited by J. E. Gannon. 24 p.

90-3 Lake Superior: the state of the lake in 1989. 1990. Edited by M. J. Hansen. 56 p.