

LAKE MICHIGAN FISH COMMUNITY OBJECTIVES FOR



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FISH-COMMUNITY OBJECTIVES FOR LAKE MICHIGAN

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INTRODUCTION

The interagency management of fishery resources in the Great Lakes was formalized in the 1980s when A Joint Strategic Plan for Management of Great Lakes Fisheries (Joint Plan) (Great Lakes Fishery Commission 1980) was ratified by the heads of federal, state, provincial, and tribal resource agencies-the Committee of the Whole (COMW) - concerned with these water bodies. The Joint Plan implemented a framework for cooperative fishery management under the aegis of the Great Lakes Fisheries Commission (GLFC) by establishing procedures for achieving a consensus approach among fisheries-management agencies. The Joint Plan also recognized that the fish community in each lake must be managed as a whole. Prior to adoption of the Joint Plan, individual agencies were less committed to considering how their actions might affect fisheries in other jurisdictions. The Joint Plan, however, espoused a philosophy that each agency had a stake in the whole system and some abridgment of the expression of individual rights (such as the right to introduce new species) was necessary for the common good. Also, fish management had traditionally been conducted on a species-by-species basis, and the Joint Plan acknowledged what was becoming increasingly evident-interactions among fish species are important in the overall management of the lakes' fisheries.

Much of the responsibility for implementing a consensus approach to fish-community management was delegated to individual lake committees by the COMW. Lake committees are composed of a single representative from each management agency with jurisdiction on a Great Lake and were established in 1965 by the GFLC. The Lake Michigan (Lake) Committee (LMC) has representatives from the states of Illinois, Indiana, Michigan, and Wisconsin along with the Chippewa-Ottawa Treaty Fishery Management Authority. Paraphrasing from the Joint Plan, a key task for the LMC is to:

- define objectives for the structure and function of the Lake Michigan fish community, and
- identify environmental and other issues that have the potential to prevent achievement of these objectives.

This document is the LMC's recommendation on goals and objectives for Lake Michigan's fish community. The intent of this document is to provide a framework for future decision making. Although seemingly straightforward, consensus management of complex systems like Lake Michigan is challenging. Scientific understanding of the

ecology of the lake will always be incomplete. Managers, their clients (participants in the fishery), and others concerned about the lake will continually face uncertainty about the best management policies. Establishment of fish-community objectives will help define a unified direction and purpose for the multitude of management activities (for example, habitat improvement or planting of fish) occurring around the lake. Also, this document will focus attention on important issues and help communicate priorities to fishery and environmental managers, researchers, and public-policy makers. Major reports on progress toward achieving the objectives are scheduled at 3-yr intervals. Interim reports are given each year at the annual meeting of the LMC.

DESCRIPTION OF THE LAKE

Lake Michigan, with a surface area of 57,750 km², is the third largest of the Great Lakes and the sixth largest lake in the world' (Beeton 1984). It is the only Great Lake wholly within the United States, but because of movement of fish between Lake Michigan and Lake Huron and of its discharge to Huron (1,560 m³/s), the lake is important internationally. Elongated in shape (494 km long by a maximum width of 190 km), Lake Michigan is divided into:

- a southern basin that is relatively smooth in contour sloping to a maximum depth of 170 m, and
- an irregularly shaped northern basin with a maximum depth of 281 m.

Wells and McLain (1973) provide an excellent summary of the limnology of Lake Michigan, and the brief description provided below is excerpted from their paper.

Green Bay, a major embayment connected to the northern basin, is 118 miles long, relatively shallow, and more productive on a surface-area basis than is Lake Michigan proper. Lake Michigan is classified as oligotrophic with features characteristic of deep, cold lakes. Biological production in oligotrophic lakes is low compared to shallow and nutrient-rich lakes such as Lake Erie. Lake Michigan has been a major producer of fish more because of its great size than its fertility.

The waters of Lake Michigan were enriched with loadings of municipal and industrial waste and agricultural runoff. However, the bottom waters remain well oxygenated and, with the implementation of the 1972 Great Lakes Water Quality Agreement (GLWQA), estimated loadings of phosphorus appear to be low enough to

preserve its oligotrophic state (International Joint Commission 1989). Enrichment is

In the historic fish community, small cladocerans and copepods in the pelagic zone supported the production of larval and juvenile fish of important species: deepwater ciscoes (*Coregonus* spp.), lake whitefish, lake herring (*C. artedi*), deepwater sculpin (*Myoxocephalus thompsoni*), and burbot (*Lota lota*) - all of which have pelagic larvae. One of these species, the lake herring, used the pelagic food web even as adults (Dryer and Beil 1964). As adults, none of the common native species fed exclusively on small particles like cladocerans and copepods. Adult deepwater ciscoes and whitefish are considered benthivores, feeding primarily on *Mysis* and *Diporeia*. Lake trout (*Salvelinus namaycush*) and burbot became piscivores—feeding primarily on other fish (such as ciscoes and sculpins). By feeding on both benthic and pelagic prey fishes, the piscivores use both the pelagic and benthic food webs.

The benthic food web is particularly significant in Lake Michigan because of the zoogeography of deglaciation. Towards the end of the Ice Age (the Pleistocene), Lake Michigan was part of a system of proglacial lakes that fronted ice sheets stretching from Alaska to the Atlantic Ocean (Bailey and Smith 1981). The environment of the frontal lakes was one of prolonged cold, which favored high lipid levels in macroinvertebrates and in small-bodied fishes. Following deglaciation, a number of so-called glacial-relict species persisted in the deep waters of Lake Michigan. Glacial

Limnocalanus, *Mysis*, and *Diporeia* provided an important source of high-energy food consumed directly by glacial-relict fishes (the deepwater ciscoes and the deepwater sculpin) and indirectly by piscivores (the lake trout and burbot). Also, whitefish abundance would be much reduced in the Great Lakes without the food resource provided by glacial-relict invertebrates. An exact quantification of the pelagic and benthic food webs in Lake Michigan is not critical for this exercise, but an appreciation of food-web structure is important for developing a fish-community objective.

PAST AND PRESENT FISH COMMUNITY

Lake Michigan's native fish community was largely a result of recolonization of species and evolution of endemics following retreat of the Laurentian Glacier, which began approximately 11,000 yr ago. By the time of European settlement in the mid-1800s, 79 fish species inhabited Lake Michigan proper and an additional 40 were recorded from tributaries (Bailey and Smith 1981). The most-abundant and well-known species were those commercially fished. At the time of first contact (after 1650) between aboriginal (Indian) peoples and Europeans in the Lake Michigan basin, Indians were fishing for whitefish, lake trout, and lake sturgeon (*Acipenser fulvescens*) with a variety of gears (Kinietz 1940):

- nets made of nettles,
- spears,
- hook and line, and
- weirs (*in streams*).

Wells and McLain (1973) give a detailed account of the non-aboriginal fisheries through 1970. The earliest fishery was primarily for whitefish, which were extremely abundant inshore. By 1879 (the first year of reliable records), Milner (1874) had already reported that whitefish were depleted in some nearshore locations. In addition, other species had become commercially important: sturgeon, lake trout, lake herring, and deepwater ciscoes (Fig. 1).

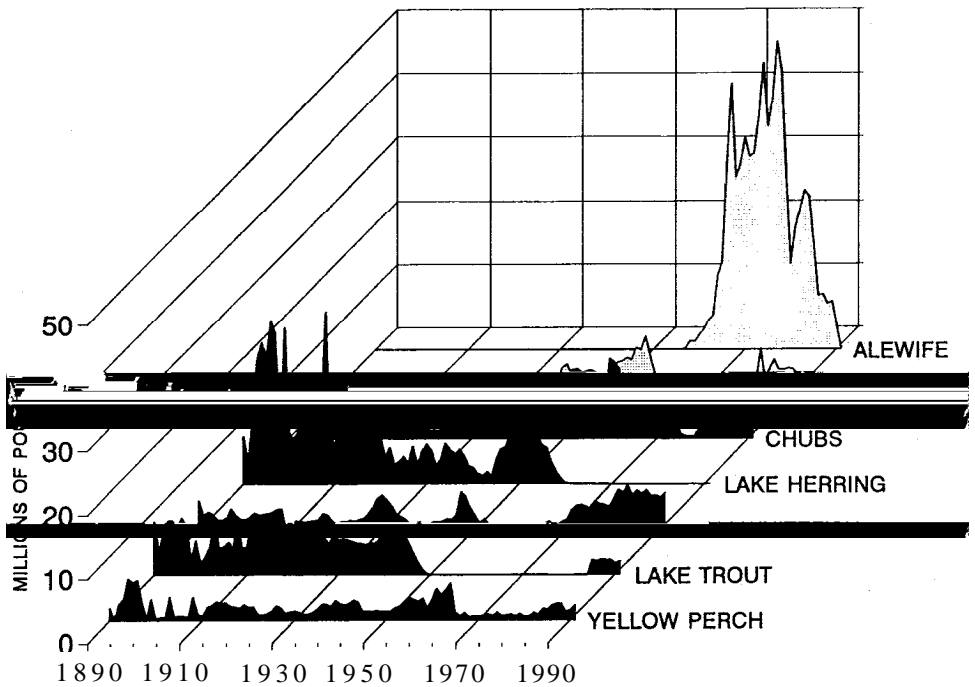


Fig. 1. Commercial catch of alewife, smelt, chubs (deepwater ciscoes), lake herring, lake whitefish, lake trout, and yellow perch from Lake Michigan, 1890- 1991.

Inshore fish communities were generally considered more diverse and productive than the offshore communities because of warmer temperatures and higher nutrient levels. Important inshore fish species and their ecological classifications based on feeding strategy are:

- lake sturgeon-benthivore
- emerald shiner (*Notropis atherinoides*)-planktivore (Hartman et al, 1992)
- suckers (*Catostomus* spp.) - benthivores
- yellow perch (*Perca flavescens*) - omnivore
- walleye (*Stizostedion vitreum vitreum*)-piscivore

Of all the inshore areas of the lake, the most-productive fish communities probably existed in southern Green Bay, other shallow embayments, and in estuaries of large rivers. Green Bay was also an important spawning ground and nursery area for lake herring in what otherwise is classified as a percid community (Ryder and Kerr 1990) with walleye, yellow perch, suckers, and northern pike (*Esox lucius*) as the key species.

Juvenile lake herring and deepwater ciscoes were the most-abundant fishes in the offshore pelagic community. They fed on zooplankton along with the pelagic fry and young of other important fishes (Crowder 1980). This ability of native fishes to produce pelagic fry made them vulnerable to excessive predation when introduced (exotic) species-particularly the alewife (*Alosa pseudoharengus*)-became prominent in the 1950s. Lake trout also fed extensively on lake herring and young deepwater ciscoes in the warmer pelagic zone. Among Great Lakes piscivores, lake trout was the species best adapted to occupy all depths of the lake.

In the benthic community, adult deepwater ciscoes, deepwater sculpin, Mysis, and *Diporeia* created a food web supporting lake trout and burbot-the major piscivores. The deepwater ciscoes were a complex of six closely related species, two of which suffered severe declines from overfishing before the turn of the century (Smith 1968).

The alewife is a planktivore and its great abundance probably depressed plankton populations. Also, alewife consumption of pelagic larval fish (Crowder 1980; Eck and Wells 1987) is believed to have contributed to:

- extinction of three species of deepwater ciscoes (two species were rare or extinct before alewife became abundant), and
- suppression of emerald shiner, lake herring, yellow perch, and deepwater sculpin.

The alewife has also been implicated recently as a possible factor inhibiting success of lake trout reproduction as they have been observed eating lake trout fry (Krueger et al., in press). The burbot and the Spoonhead sculpin (*Cottus ricei*) may also have been depressed by the alewife (Eck and Wells 1987; Eshenroder and Bur&m-Curtis, in press). By the 1960s, the lake was dominated by the alewife and, to a lesser extent, rainbow smelt (*Osmerus mordax*) - another introduced species. By then, the native fish community was severely disrupted and important commercial and sport fisheries had collapsed.

Progress in rehabilitation of the fish community began in 1960 with the expansion of the sea lamprey-control program (previously conducted solely in Lake Superior) into Lake Michigan. Smith and Tibbles (1980) provide a thorough history of the sea lamprey invasion of the upper Great Lakes and the implementation of control measures. Suppression of sea lampreys was a necessary prelude to the reestablishment of piscivores and this suppression remains essential today. Lake trout planting began in 1965 and coho salmon (*Oncorhynchus kisutch*) and chinook salmon (*O. tshawytscha*)-introduced from the Pacific Northwest in 1966 and 1967, respectively-were extensively planted. Brown trout (*Salmo trutta*) and rainbow trout (*O. mykiss*) were also extensively planted (Table 1). Of the five major salmonines planted, only lake trout was released with the main objective being to reestablish reproducing populations. The main objective for planting the other species was to provide put-grow-take sport-fishing opportunities and to control (eat) alewives (Tody and Tanner 1966). Ironically, the lake trout was one of the least successful of those original five salmonines in establishing reproducing populations. Sporadic evidence of possible lake trout reproduction has been reported over the years, but sustainable reproduction has not developed. For example, a brief increase in recoveries of unclipped (possibly naturally reproduced) lake trout occurred in Grand Traverse Bay in the early 1980s, but recoveries of unclipped fish declined again by the mid- 1980s (Rybicki 1983). Natural reproduction of brown trout has also been very limited, but significant reproduction has been established for:

- rainbow trout (Seelbach 1986; Carl 1983),
- chinook salmon (Carl 1982, 1983; Seelbach 1985), and
- coho salmon (Carl 1982; Seelbach 1985; Patriarche 1980).

Concurrent with the salmonine planting programs, lake whitefish made a spectacular recovery in northern waters (Fig. 1).

Of the planted salmonines, the lake trout was assumed to be the species with the greatest potential for self-sustainability because they were native to the lake (Wells and McLain 1973). The failure of lake trout to become self-sustaining is disconcerting, and scientists have not been able to conclusively identify the problem. Explanations for the failure of lake trout to become self-sustaining include:

- incorrect planting locations or procedures,
- failure to control overfishing,
- bioaccumulation of toxic chemicals,
- alewife predation on eggs and larvae,
- spawning-habitat degradation, and
- use of inappropriate genetic strains of trout.

The correct explanation could be any one or any combination of these factors--or something not yet considered. Prior to 1985, changes in planting approaches and fishing effort confounded the problem, which made it impossible to isolate the reason for reproductive failure. However,

Beginning in 1986, large plants were made in two offshore refuges and in areas classified as primary zones (Fig. 2). Some momentum in implementing the new plan, which called for planting a mixture of lake trout strains, was lost because of mortalities in the supplying hatcheries. A full evaluation of the 1985 lake trout rehabilitation plan will not be completed until the late 1990s.

Numbers of planted salmon and trout increased during the 1970s but remained fairly constant after 1980 (Table 1). Harvest peaked in 1986 when an estimated 7.3 million kg of salmon and trout were harvested. Average annual harvest during the early 1980s from this multi-species fishery exceeded historical averages for the lake trout fishery. Many factors could have contributed to higher harvests in recent years, including:

- an increase in the primary productivity of the lake because of modest nutrient enrichment,
- a more-efficient use of food resources by multiple vs. single species,
- higher vulnerability of salmon because of their habit of returning to natal streams, or
- a higher production/biomass ratio for salmon than for lake trout.

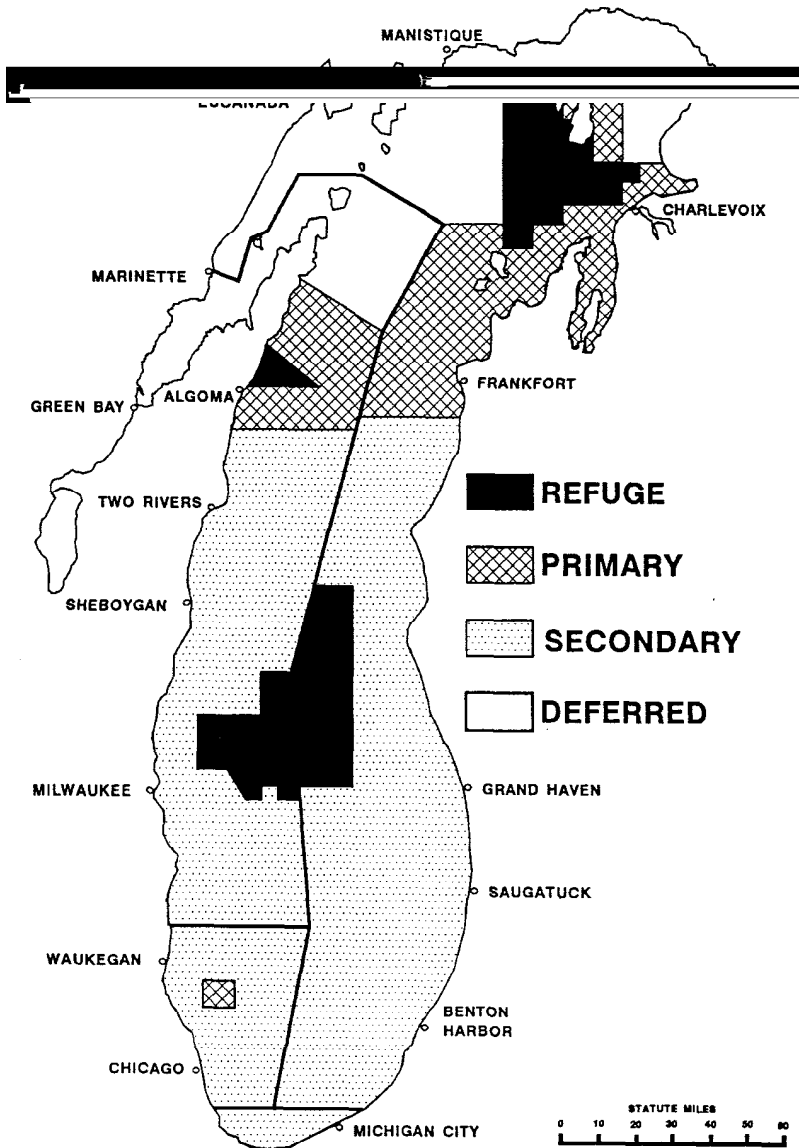


Fig. 2. Lake Michigan lake trout management zones. Refuges receive the highest priority for planting, and fishing for lake trout is prohibited. Total mortality on lake trout is targeted not to exceed 40% in Primary and Secondary Zones, but Primary Zones have a higher priority for planting. Deferred Zones do not have an objective for total mortality and are not planted.

Planted salmonines were probably responsible for much of the reduction observed in the overabundant alewife population during the 1970s. The alewife population was further reduced by low recruitment during the early 1980s-probably because of unfavorable weather conditions (Eck and Wells 1987). Which of these factors, predation or bad weather, had the biggest effect on reducing alewife abundance is uncertain, but it is certain that alewife populations declined. Jude and Tesar (1985) reported that the number of alewives declined 86% between 1980 and 1982. Eck and Wells (1987) reported a sixfold decline between 1981 and 1983. The alewife decline appeared to have a number of desirable effects. Increases in abundance were observed for several native species, including:

- deepwater ciscoes-now reduced to a single species, the bloater (*Coregonus hoyi*),
- yellow perch, and
- deepwater sculpin.

By 1982, bloaters were more abundant than alewives (Eck and Wells 1987)-a dramatic change in the Lake Michigan fish community. Despite the declines in alewife and improvements in availability of alternative prey during this period, the salmonines seemed to prefer the alewife as prey (Jude et al. 1987) (Fig. 3). One of the primary management challenges of the future will be to keep:

- the salmonine community in balance with the available forage base, and
- the alewife suppressed to levels where it does not threaten native species.

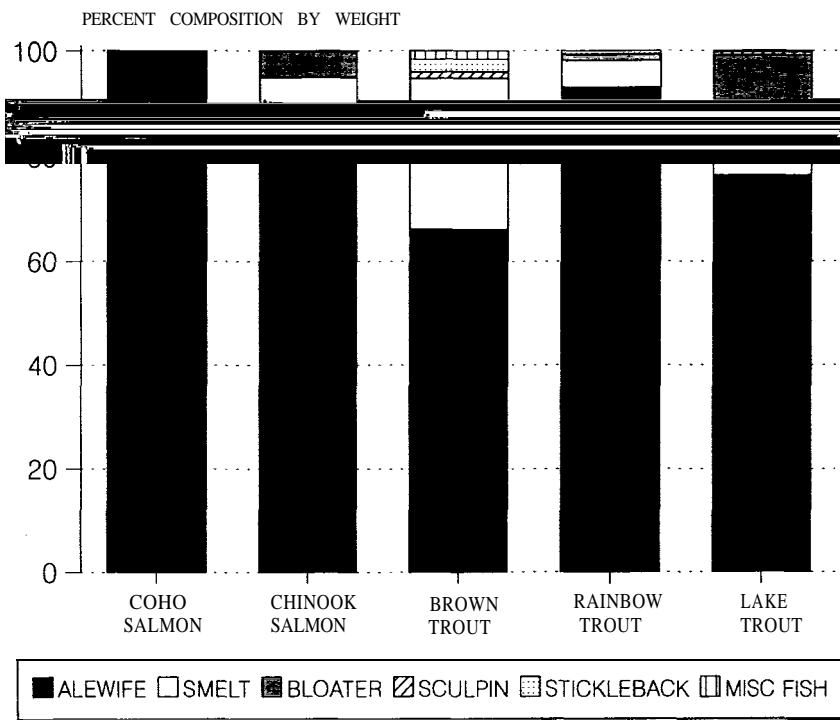


Fig. 3. Percent composition by weight of fish prey items in salmonine diets in Lake Michigan, 1990 and 1991 combined (M. Toney, Wisconsin Department of Natural Resources, 110 S. Neenah Ave., Sturgeon Bay, WI, 54235, unpubl. data).

Lake Michigan's fish community is changing as exotic species continue to invade and exert their influence throughout the lake. The spiny water flea (*Bythotrephes cederstroemi*), a large cladoceran that preys on small-bodied zooplankton, became prominent in 1986. It

- the round goby (*Neogobius melanostomus*) - one of two introduced gobies discovered in the St. Clair River in 1990 and 1991 (Jude et al. 1992).

Another major challenge for fishery managers will be to prevent invasion of the Great Lakes by exotic species.

ECOSYSTEM INTEGRITY

The GLWQA of 1978 calls for the restoration and maintenance of the chemical, physical, and biological integrity of the waters of the Great Lakes basin ecosystem. Although this goal divides the ecosystem into three components (chemical, physical, and biological), it is implied that integrity also must be an attribute or quality of the ecosystem as a whole. Ecosystem integrity can mean different things to different people. Perspectives on the meaning and policy implications of ecosystem integrity were topics of a workshop sponsored by the GLFC and the Science Advisory Board of the International Joint Commission (Edwards and Regier 1990). Basically, integrity refers to the ability of an ecosystem to maintain its structure when confronted with environmental change. Systems that cannot maintain their structure following perturbation are said to have lost their integrity.

Physical and Chemical Integrity

The primary purpose of this document is to address fish-community objectives that are more directly related to biological integrity. Success in achieving fish-community objectives will inevitably be limited, however, by the physical and chemical integrity of the Great Lakes. For example, blocking Great Lakes tributaries with dams has decreased the physical and biological integrity of the entire Great Lakes system by diminishing reproduction of river-spawning fishes. The physical and chemical goals of the 1978 GLWQA (as amended by Protocol in 1987) are, therefore, common goals of the lakes' fishery managers.

Francis et al. (1979) identify 15 stresses of a physical or chemical nature that are relevant to the Lake Michigan ecosystem:

- 1) microcontaminants (toxic chemicals), toxic wastes, and biocides from industry and agriculture;
- 2) nutrients and eutrophication from sewage plants, agricultural runoff, and urban runoff;
- 3) organic inputs and oxygen demand from sewers, canneries, and other sources;
- 4) sediment loading and turbidity from agriculture, construction sites, and resuspension;
- 5) stream modification (including dams, channelization, and logging) and changes in land use;
- 6) **dredging**;
- 7) filling, shoreline structure, and offshore structure;
- 8) dyking and draining of wetlands;
- 9) weather modification (mostly industrial);
- 10) water diversions among the Great Lakes basin and other basins;
- 11) entrainment and impingement in water-intake structures;
- 12) thermal loading from cooling water (mostly in electric power plants);
- 13) ice control for navigation;
- 14) major degradative incidents or catastrophes; and
- 15) acids and toxic chemicals transported by the atmosphere.

These stresses, in turn, impair beneficial uses of Lake Michigan fish as defined in the GLWQA:

- restrictions on fish and wildlife consumption,
- tainting of fish,
- degradation of fish and wildlife populations,
- fish tumors or other deformities,
- bird or animal deformities or reproduction problems,
- degradation of benthos,
- degradation of aesthetics,
-

Another newer initiative with great potential to serve as a vehicle for conducting remediation programs was established in the 1987 Protocol to the GLWQA. Lakewide Management Plans (LAMPs) are intended to reduce loadings of critical pollutants in open waters to restore beneficial uses. Responsibility for steering the LAMP process on Lake Michigan is vested in the U.S. Environmental Protection Agency (USEPA). Attractive features of LAMPs are that they:

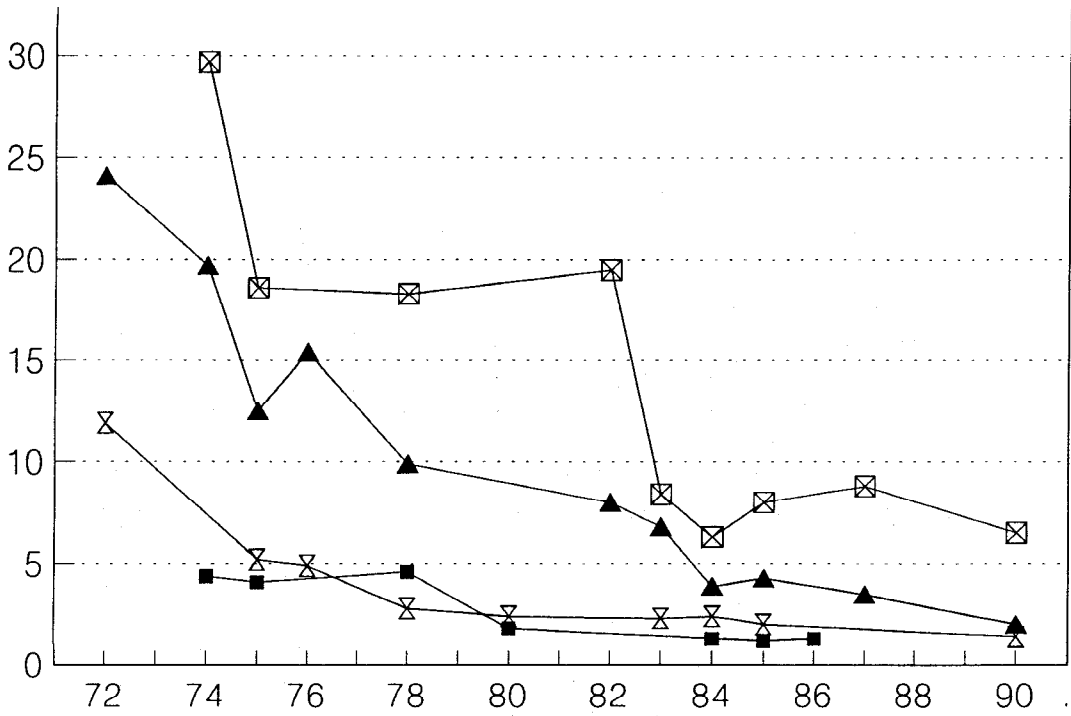
- 1) have a lakewide perspective;
- 2) are based on a mass-balance approach that can quantify costs and benefits;
- 3) provide coordination among concerned agencies and allow public input; and
- 4) are, in fact, the only vehicle recognized by governments with terms of reference broad enough to engage remediation using an ecosystem approach.

As originally envisioned in the GLWQA, the scope of LAMPs was restricted to chemical integrity, or critical pollutants--especially toxic chemicals. However, a group of experts representing fishery and environmental managers, academia, and nongovernmental organizations concluded that the Lake Michigan LAMP should enlarge its scope of activities to encompass a true ecosystem approach (Eshenroder et al. 1991). Also, Donahue et al. (1991) reviewed six other remediation initiatives that predated the 1987 Protocol and concluded that the LAMP process should be used as a planning framework where many activities are pursued-including, but not limited to, control of critical pollutants.

Fishery and environmental management need to be more directly linked. Establishment of environmental objectives that allow achievement of fish-community objectives can be most effectively undertaken within the LAMP process. Once established, such environmental objectives can be endorsed in subsequent updates of this document. Effective linkage of environmental- and fishery-management planning efforts will be challenging and require resources and institutional commitment. Close coordination among the USEPA, GLFC, state environmental-management agencies, and the LMC will be required.

Bioaccumulation of toxic chemicals from the water column into fish remains a problem for the lakes' fish managers although levels of PCBs and other toxic chemicals have declined appreciably in response to control measures (Fig. 4). Uncertainties remain about the human-health effects of consuming Lake Michigan fish. The Lake

Michigan states have developed a common consumption advisory based on U.S. Food



Biological Integrity

Because the focus of this document is fish communities, biological integrity is addressed separately from physical and chemical integrity. Changes in ecological integrity are not always related to physical or chemical changes. They can also be caused directly by living organisms-such as by invasion of exotic species.

The term biological integrity, when included in the water-quality legislation of the 1970s, was at best abstract and somewhat ambiguous (Karr et al. 1986). The concept of biological integrity has since been developed for river ecosystems (Karr et al. 1986; Angermeier and Schlosser 1987; Fausch et al. 1990; Lyons 1992) and for ecosystems in general (Kay 1990). A review of these works will aid in an understanding of integrity as it relates to the fish-community goals for Lake Michigan. Karr et al. (1986) defined biological integrity as:

the ability to support and maintain a balanced, integrated, adaptive community of organisms having a species composition, diversity, and junctional organization comparable to that of natural habitat of the region (Karr and Dudley 1981). Systems possessing biological integrity can withstand or rapidly recover from most perturbations imposed by natural

Kay (1990) suggested that ecosystems would be expected to exhibit the characteristics of other complex systems. He defined biological integrity as:

The integrity of a system refers to our sense of it as a whole. If a system is able to maintain its organization in the face of changing environmental conditions, then it is said to have integrity. If a system is unable to maintain its organization, then it has lost its integrity. . . Such a definition would necessarily have an anthropocentric component. .that reflects which changes in the ecosystem are considered acceptable by the human observers.

As an example to help clarify the concept of biological integrity, the history of Lake Michigan's fish community can be portrayed in the context of the foregoing discussion. First, consider Lake Michigan at the retreat of the Laurentian Glacier. Events acted to create the organization of the early food webs. Such events were:

- fish recolonization,
- perseverance of glacial-relict species, and
- evolution of deepwater ciscoes.

By the time of European settlement, the Lake Michigan fish community was highly stable and organized with benthic and pelagic food webs as described earlier. Gradually increasing levels of fishing effort and human-induced environmental degradation decreased community stability over time. When the community was subjected to the additional stresses of the sea lamprey and alewife invasions, it could not maintain its organization-in other words, it lost its integrity. The fish community reorganized into a new state that was less complex, more unstable, and less desirable to human observers.

By the 1960s, most of the fish biomass was concentrated in a single species-the alewife. The top trophic level consisting of piscivores was essentially absent. There was a greatly reduced energy flow to human users of the fish community as measured by commercial catches. Control of the sea lamprey and planting of salmonines restored the piscivore trophic level-increasing the stability and integrity of the system and making it more acceptable and useful to humans.

However, there are important differences between the present state of the ecosystem and its state prior to European settlement. A number of native species are now extinct, and present community stability (and integrity) is dependent on the maintenance of management programs including:

- pollution control,
- habitat protection,
- sea lamprey control,
- fish planting, and

In conjunction with the goals in the International Joint Commission's GLWQA and the Joint Plan, the following fish-community goal is established for Lake Michigan:

Restore and maintain the biological integrity of the fish community so that production of desirable fish is sustainable and ecologically efficient.

Ecological efficiency is a function of the connections between secondary production of pelagic and benthic invertebrates and planktivorous fish that can be directly harvested and/or consumed by the largest piscivores. Highly connected (diverse) systems exhibit more species at each trophic level. Competition is more intense in diverse systems where the twin forces of competition within levels and predation from higher levels act to stabilize a fish community. Although single-species fish communities may be stable because of the lack of interspecies competition and predation, they do not provide the diversity of fishery products sought by society. These products range from bait minnows and whitefish fillets to pier and offshore fishing opportunities.

Along with agreement on goals, the ecological and institutional complexity of fishery management on Lake Michigan requires agreement on guiding principles for management. A set of ten guiding principles is provided to establish a decision-making framework for restoring and maintaining the integrity of Lake Michigan's fish community. These principles are well-accepted, fundamental concepts and are recognized as having wide application to the Great Lakes. They are essential for defining a consistent approach for cooperative fishery management on Lake Michigan.

1. Recognize the Limits on Lake Productivity

The productivity of the lake's ecosystem is limited. Fish populations at all trophic levels can be endangered by factors causing excessive mortality, such as:

- overfishing of top predators,
- planting more predators than the forage base can sustain, or
- failing to control undesirable exotic predators.

Historical levels of harvest and analysis of contemporary data provide approximations of the limits for different trophic levels.

2. Preserve and Restore Fish Habitat

The physical and chemical integrity of Lake Michigan (as defined in the GLWQA) is important for achieving biological integrity. Identification of habitat impairments that impede the achievement of fish-community objectives is specifically mentioned in the Joint Plan. Rehabilitation of riverine spawning and nursery habitats used by Great Lakes fishes is a high priority for the management agencies.

5. Acknowledge the Role of Planted Fish

9. Prevent the Unintentional Introduction of Exotic Species

The unintentional establishment of exotic species has been devastating to the native fish communities of the Great Lakes. The impact of the invasion of sea lamprey and alewife is well documented. The final impact of the zebra mussel, spiny water flea, and ruffe remains to be seen. The rate at which exotic species invade the Great Lakes is directly related to human activities, such as the exchange of ballast water from ocean-going ships. Work should be done to identify and control human activities that lead to unintentional introduction of exotics. Where feasible, the spread of unwanted exotics already introduced should be prevented.

10. Protect and Enhance Threatened and Endangered Species

Loss of threatened and endangered fishes should be avoided. At least five native species are now extinct from Lake Michigan proper and another three species have disappeared from tributaries (Bailey and Smith 1981). Recovery plans should be

- 4) Species invasions (for example, zebra mussel and ruffe) may substantially alter the community. Fish-community objectives for an entire lake cannot be taken to a high level of exactness—they are reasoned likelihoods. Management initiatives aimed at achieving objectives will continue to have a large experimental component, and the time frame needed to meet some objectives will be measured in decades.

The historic perspective of the Lake Michigan fish community was largely gained through harvest records. Fish harvest levels provide one measure of the ecological efficiency of the lake's food webs and a measure of progress in achievement of the fish-community objectives. For these reasons, and also because public attention is focused on the harvesting of fish, fish-community objectives will necessarily incorporate some reference to future harvest expectations including, in some cases, single-species considerations. However, the structure and function of the fish community ultimately determines its capacity to support fisheries. Also, meaningful fish-community objectives must also express characteristics (such as ecological efficiency) that relate to ecological integrity.

Collectively, the following objectives encompass broad ecological concepts that provide for the development of a framework for more-specific fisheries-management objectives.

Salmonine (Salmon and Trout) Objectives

Establish a diverse salmonine community capable of sustaining an annual harvest of 2.7 to 6.8 million kg (6 to 15 million lb), of which 20-25% is lake trout.

Establish self-sustaining lake trout populations.

The salmonine community will consist of both wild and planted salmonines and exhibit increasing growth of, and reliance on, natural reproduction. Short-term restrictions of harvest may be required to achieve long-term goals of natural reproduction. Salmonine abundance should be great enough to keep the alewife below levels associated with the suppression of native fishes (that is, below levels of the early 1980s). However, salmonine abundance should also be below levels where predatory demand threatens the integrity of the system. Annual harvest of salmonines will depend on specific management objectives concerning the exact species mixes and on how efficiently those species utilize the available forage. More analysis of existing data and evaluation of management alternatives through mathematical modeling is

needed before specific management plans and species-by-species harvest levels can be defined. Management agencies need to coordinate their management plans or develop a lakewide plan. The lake as a whole has finite prey and habitat resources for salmonine production. Each salmonine species, while adding to the species mix, will exist at some expense to the others.

One of the challenges for fishery managers is to estimate the productive capacity of Lake Michigan to establish planting plans and harvest regulations. Historical yields of lake trout provide one measure of the capacity of Lake Michigan to produce salmonines. During the 1927-44 period (commonly used as a baseline because fishing-effort data were recorded and catch was reasonably stable), annual yield averaged 2.6 million kg. Brown et al. (1981) estimated that mean harvestable production during this same period was 8.7 million kg. Production is defined here as the total weight of all new growth within a year including the growth of fish that do not survive to the end of the year. Harvestable production is defined as the new growth from fish large enough to be caught. Lake trout catch was tending downward since the turn of the century, however, and earlier intervals show slightly higher mean yields. Christie and Regier (1988) give a mean yield of 3.3 million kg from 1911 to 1925. Scaling from Brown et al. (1981), the mean harvestable production from 1911 to 1925 would be 11.0 million kg. A catch of 2.6-3.3 million kg is considered here to be a minimum measure of the lake's innate capacity to yield salmonines—secondary production has probably changed little from the years when those catches of lake trout were made.

Manipulation of the mix of salmonines should, in theory, result in higher catches than those produced solely by lake trout. The lake trout historically inhabited the whole water column, but its use of the pelagic food web (although substantial) could not have been as efficient as the contemporary species mix of lake trout and of pelagic piscivores-Pacific salmon

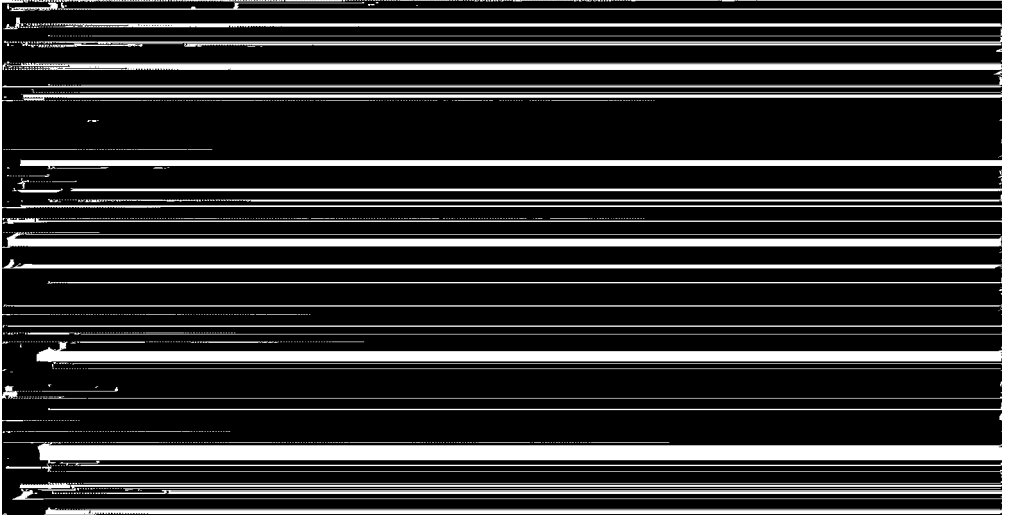


Fig. 5. The rainbow trout (photo of illustration from Goode (1884)).

An upper bound (or maximum) of salmonine yield from Lake Michigan is useful in defining the trophic scope of the fish community. Sprules et al. (1991), using a biomass size-spectrum model, provide an estimate of potential piscivore production (piscivores larger than 208 g) of 29.0 million kg. This model projects biomass and production of planktivorous fishes and their predators (the five salmonines) based on the 1987 biomass of plankton including *Diporeia*. Their model values of biomass and/or production for phytoplankton, zooplankton, *Diporeia*, and planktivorous fish compare favorably with observed values from their own and other studies. Estimated potential production assumes that all production at lower trophic levels is consumed by the next level—essentially a predator-prey system with 100% efficiency. Their production estimate for all salmonines can be converted to yield by correcting potential production for fish too small to be harvested and by applying a harvest-to-production multiplier (optimum fishing rate) to the harvestable fraction. Harvestable production was calculated from Leach et al. (1987): harvestable production of all large Lake Michigan fish (5.6 kg/ha) divided by the total production of large fish (13.2 kg/ha) equals 42.4%. Likewise, their 0.57 harvest multiplier is used here. Empirically, this multiplier makes the fishing rate slightly higher than the natural mortality rate. Using these adjustments, the potential yield of the salmonine community under conditions of 100% ecological efficiency is 7.0 million kg. The range of yield and production values for salmonines is given in Table 2.

Table 2. Summary of the range of yield and production values (millions of kg) for salmonines.

Period	Species	Total production	Harvestable production	Yield
1927-44	Lake trout	12.9	8.7	2.6*
1911-25	Lake trout	16.5	11.0	3.3*
1987	All salmonines	29.0	12.3	7.0**

* Actual.

** Theoretical maximum.

The estimated maximum yield of 7.0 million kg (15.5 million lb) is obviously a rough approximation, but it has utility in providing an upper bound for yield expectations. Several criticisms (there are others) about this theoretical yield are:

- it does not include production from sculpins or *Mysis*,
- the fishing rate is probably high for lake trout-rehabilitation objectives (self-sustaining populations capable of yielding 1.1 million kg), and
- the use of the pelagic food web by burbot is not recognized.

Some of these problems tend to cancel each other out, but the challenge for management is not to produce a refined estimate but to determine with more-complex models the tradeoffs between ecological integrity and social preferences for various planting mixes so that optimum planting and harvest rates can be established.

- A first approach will be to determine what mix of species provides the largest sustainable yield.
- Next, alternative species mixes can be compared with the mix that provides the maximum to identify an optimum that meets the needs identified by society.

or increased mortality of predators and collapse of planktivore populations. Some recently observed problems, such as the virulence of BKD in chinook salmon, may have been caused by over-planting. Stewart and Ibarra (1991) examined the bioenergetics of salmonine fishes in Lake Michigan and concluded that increased planting would lead to a collapse of the alewife population. Mean yield of salmonines from 1985 to 1987 was estimated to be 7.0 million kg-an amount near the estimated maximum theoretical yield. However, yield fell to 2.9 million kg by 1990. Several studies (Sprules et al. 1991; Stewart and Ibarra 1991) suggested that alewife production was inadequate to sustain chinook salmon at the high levels of 1985-87. On the other hand, too little planting of salmonines could allow alewife populations to expand again to the intolerable levels of the 1960s.

The apparent fragility of the alewife poses a paradox-manage for low yield and integrity to maintain alewives as long as possible. Or, manage for higher yields recognizing that a loss of the alewife could impair recovery of chinook salmon unless alewives are replaced in salmon diets with a native planktivore such as the lake herring.

Positive features of alewives in the Great Lakes are that they:

- possess versatile foraging behaviors-gulping, filtering, and particle feeding (Janssen 1978);
- do not grow beyond sizes suitable as prey;
- are preferred by predatory fish (Jude et al. 1987); and
- support the pelagic piscivores at this time.

Negative features are that they:

- suppress valuable native species (Eck and Wells 1987);
- are vulnerable to catastrophic die-offs following cold winters apparently because of inadequate lipid reserves (Flath and Diana 1985); and
- show poor food-conversion efficiency, which causes lower lipid reserves (Stewart and Binkowski 1986).

Native planktivores should be encouraged now that alewife populations are reduced. Rehabilitation of native planktivores is a desirable objective that would increase the biological integrity and diversity of the planktivore community. Two species of special concern are lake herring and emerald shiner. Whether or not the alewife can be suppressed enough to allow these species to recover is unknown, but the prospects for a recovery seem more favorable now than at any time since alewife populations peaked in the mid-1960s. Lake herring populations have recovered in Lake Superior and are becoming more prominent in the diet of lake trout and Pacific salmon (Conner et al. 1993).

Inshore Fish Objective

Maintain self-sustaining stocks of yellow perch, walleye, smallmouth bass, pike, catfish, and panfish. Expected annual yields should be 0.9 to 1.8 million kg (2 to 4 million lb) for yellow perch and 0.1-0.2 million kg (0.2 to 0.4 million lb) for walleye.

The inshore fish community is of great human value. Only a few species, however, are monitored closely enough to provide reasonable expectations of long-term, lakewide yield. Demand for yellow perch will cause the desired yield to remain near the 1985 -87 average harvest (sport and commercial) of 1.8 million kg. However, the average commercial yield before the invasion of alewife was only 0.9 million kg. Walleye yield averaged 0.1 million kg 195 0 0 10.kg.

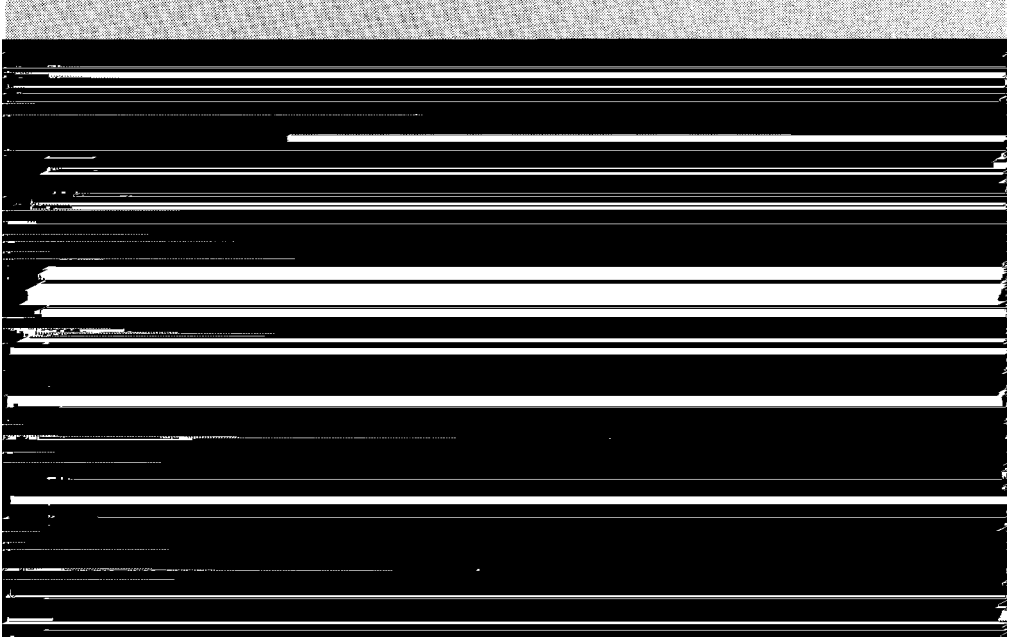


Fig. 6. The yellow perch (photo of illustration from Goode (1884)).

Walleye predation normally regulates perch stock structure in unperturbed north temperate lakes, but in Lake Michigan the record of catch (which extends back to 1885) suggests that the walleye was not a major predator. Current yields (mean catch of 0.2 million kg from 1985 to 1987) are within the historic range, but much of the recent catch is comprised of planted fish. Planted walleye have reproduced in southern Green Bay (Schneider et al. 1991), and planting has been discontinued there to assess recruitment of wild fish. Achieving a higher level of self-sustainability is at present considered more important than increasing yield from planting. Schneider et al. (1991), in their detailed account of the Lake Michigan walleye, expressed optimism for improved natural recruitment because of

- increased egg production,
- improved balance in fish communities, and
- continuing improvements in water quality.

If self-sustainability improves, planted fish could be diverted to other locations within historic ranges, thereby increasing total yield.

Benthivore Objective

The burbot is piscivorous, and some managers are concerned that it could become so abundant as to negatively impact on lake trout or alewife populations. Managers need to:

- study the role of burbot in the fish community,
- encourage the development of markets for them, and
- attempt to maintain a burbot population compatible with the rehabilitation and natural reproduction of lake trout.

Sea Lamprey Objective

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

The sea lamprey must be controlled in order to achieve other fish-community objectives because of the high mortalities it inflicts on other fishes. Chemical treatment has provided sufficient control of the sea lamprey for the past 25 yr. However, a recent increase in lamprey wounding rates on lake trout in the northern waters of the lake is a concern. Reproduction of sea lampreys in the St. Marys River is suspected to be contributing to the problem in northern Lake Michigan.

Other Species Objective

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

A diverse array of species is necessary to maintain the biological integrity of Lake Michigan's fish community. Each species has an ecological role and, therefore, an intrinsic value. These fishes can become either too scarce or too abundant, and they need to be managed accordingly.

Many fishes were not specifically mentioned in this document, but all of them have ecological worth and need to be identified and appreciated.

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Pursue the reduction and elimination of toxic chemicals, where possible, to enhance fish survival rates and allow for the promotion of human consumption of safe fish.

In a changing and growing society, protection of habitat does not mean an

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APPENDIX
FISHES OF LAKE MICHIGAN PROPER ¹

P = Planned introduction

A = Accidental introduction

E = Extinct

Petromyzontidae

chestnut lamprey

silver lamprey

sea lamprey (A)

Ichthyomyzon castaneus

I. unicuspis

Petromyzon marinus

Polyodontidae

paddlefish (E)

Polydon spathula

Acipenseridae

lake sturgeon

Lepisosteidae

longnose gar

shortnose gar (A)

Amiidae

bowfin

Anguillidae

Salmonidae (Salmoninae)

pink salmon (A)

coho salmon (P)

chinook salmon (P)

rainbow trout (P)

Atlantic salmon (P)

brown trout (P)

brook trout

lake trout

Oncorhynchus gorbuscha

O. kisutch

O. tshawytscha

O. mykiss

Salmo salar

S. trutta

Salvelinus fontinalis

S. namaycush

Salmonidae (Coregoninae)

lake whitefish

lake herring (cisco)

bloater

deepwater cisco (E)

kiyi (E)

blackfin cisco (E)

shortnose cisco (E)

shortjaw cisco (E)

round whitefish

Coregonus clupeaformis

C. artedi

C. hoyi

C. johanna

C. kiyi

C. nigripinnis

C. reighardi

C. zenithicus

Prosopium cylindraceum

Osmeridae

rainbow smelt (A)

Osmerus mordax

Umbridae

central mudminnow

Umbra limi

Esocidae

grass pickerel

northern pike

muskellunge

Esox americanus

E. lucius

E. masquinongy

Cyprinidae

northern redbelly dace

lake chub

grass carp (A)

carp (P)

goldfish (A)

pearl dace

Phoxinus eos

Couesius plumbeus

Ctenopharyngodon idella

Cyprinus carpio

Carassius auratus

Margariscus margarita

Cyprinodontidae	
banded killifish	<i>Fundulus diaphanus</i>
Atherinidae	
brook silverside	<i>Labidesthes sicculus</i>
Gasterosteidae	
brook stickleback	<i>Culaea inconstans</i>
threespine stickleback (A)	<i>Gasterosteus aculeatus</i>
ninespine stickleback	<i>Pungitius pungitius</i>
Percichthyidae	
white perch (A)	<i>Morone americana</i>
white bass	<i>M. chrysops</i>
Centrarchidae	
rock bass	<i>Ambloplites rupestris</i>
pumpkinseed	<i>Lepomis gibbosus</i>
bluegill	<i>L. macrochirus</i>
smallmouth bass	<i>Micropterus dolomieu</i>
largemouth bass	<i>M. salmoides</i>
white crappie	<i>Pomoxis annularis</i>
black crappie	<i>P. nigromaculatus</i>
Percidae	
yellow perch	<i>Perca flavescens</i>
sauger	<i>Stizostedion canadense</i>
walleye	<i>S. vitreum vitreum</i>
Iowa darter	<i>Etheostoma exile</i>
johnny darter	<i>E. nigrum</i>
fantail darter	
logperch	
Sciaenidae	
freshwater drum	
Gobiidae	
round goby (A)	

Cottidae

mottled sculpin

slimy sculpin

Spoonhead sculpin

deepwater sculpin

GLOSSARY

amphipod

Members of the crustacean order with laterally compressed bodies and in freshwater chiefly living on the bottom.

anthropocentric

Regarding the world in terms of human values and experiences.

benthic

Living or occurring in bottom waters.

benthivore

Feeding primarily on animals living on the bottom of a body of water.

benthos

Collectively, the invertebrates living on the bottom of a water body.

bioaccumulate

A process by which substances retained by organisms become increasingly concentrated with movement through the food chain.

bioenergetics

Analysis of fish populations based on feeding and growth.

biological production (also production)

The amount of new tissue formed by a group of organisms.

biomass

The combined weight of a group of living organisms.

biomass size spectrum

An ordering of the organisms in a system by their size.

cope pod

Members of the crustacean order containing many freshwater, planktonic species.

deglaciation

The process of glacial melting and retreat.

ecological efficiency

The rate at which energy is transferred between levels in an ecosystem.

ecosystem

A system formed by the interaction of a community of organisms with the environment.

ecosystem approach

A whole-system approach to management that recognizes that all living organisms, including humans, are connected to their environment and to each other.

endemic species

Occurring only in one place or region.

entrainment

Process of passive transport of usually small organisms in water such as that diverted for human use.

eutrophication

genetic diversity

A measure of the variation among genes that control hereditary characteristics in individuals, populations, and species.

Great Lakes Water Quality Agreement (also GLWQA)

A pact between the United States and Canada to maintain and restore the physical, chemical, and biological integrity of the Great Lakes.

harvestable production

The amount of production that can be harvested on a sustainable basis.

Ice Age (also Pleistocene)

A period marked by cooler climate and expansion of glaciers occurring from approximately 2 million to 10,000 years ago.

impingement

Collection of entrained organisms on screening devices in water intakes.

introduction (also introduced species)

The release of a species into an environment where it previously did not occur.

invasion

Entry of a new species into an environment by means of some natural or man-made route.

A Joint Strategic Plan for Management of Great Lakes Fisheries (also Joint Plan)

A plan originally signed in 1980 and adopted by federal, provincial, state, and tribal natural-resources agencies to guide management of fisheries in the Great Lakes.

Lakewide Management Plan (also LAMP)

A plan established under the Great Lakes Water Quality Agreement to achieve environmental improvement of the open waters of the Great Lakes.

Laurentian Glacier

The glacier that covered northern North America from the Atlantic Ocean to the Rocky Mountains during the Ice Age.

mass balance

plankton

Passively floating or weakly swimming small organisms (some of microscopic size) in a body of water.

primary production

The production of new tissue by photosynthesis.

production (also biological production)

The amount of new tissue formed by a group of organisms.

production to biomass ratio

The ratio of the amount of new tissue produced to the amount of existing tissue for an organism or a group of organisms.

proglacial lake

Water bodies formed by glacial melting and existing at the front of a glacier.

recolonization

Taking up residence in a place formerly occupied.

recruitment

Addition of juvenile fish to the adult population or to the catchable stock.

Remedial Action Plan (also RAP)

Established under the Great Lakes Water Quality Agreement to achieve environmental improvement in specific locations (Areas of Concern) designated by the International Joint Commission.

risk assessment

A process of establishing differences in susceptibility for different groups.

salmonine

Of the subfamily of trout and salmon (does not include the whitefish and related species).

secondary production

In aquatic systems, the production of new tissue by invertebrates that consume plants.

stakeholders

People affected by the quality and productivity of the Great Lakes ecosystem

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