FISH-COMMUNITY OBJECTIVES FOR LAKE MICHIGAN

Great Lakes Fishery Commission

SPECIAL PUBLICATION 95-3

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November 1995

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TABLE OF CONTENTS

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 km^2, 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 m^3/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 28 1 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 mainly a problem in specific localities-for example, in southern Green Bay where excessive loadings have degraded the sediments. The lake has also been subjected to a plethora of toxic chemicals (contaminants)-most notably a complex mixture of polychlorinated biphenyls (PCBs). Although Lake Michigan proper has not been severely impacted physicochemically by human settlement around the basin, the alteration of streams by deforestation, damming, draining of swamps, and pollution has seriously impaired its usefulness for fish reproduction. Many native species of fish, such as the lake whitefish *(Coregonus clupeaformis),* spawned in the lake and in streams, but the river-spawning forms are now greatly depleted or extinct (Smith 1972). Despite these impairments, Lake Michigan remains a magnificent resource. If the lake is managed wisely, it can produce high sustainable yields of valuable fishery products.

LAKE MICHIGAN FOOD WEB

Lake Michigan's food web can be viewed as consisting of two separate but overlapping parts:

- the pelagic food web associated with offshore, open water, and

- the benthic food web associated with the bottom.

Both parts of the food web are based on planktonic algae (including bacteria that photosynthesize) produced in surface waters where light penetration is adequate for photosynthesis. The pelagic food web is based on consumption of algae by:

- small (<3 mm body length) invertebrates (zooplankters)-mostly cladocerans, and

- copepods, including copepod species that prey on other small invertebrates.

The benthic food web is based on the direct conversion of detritus (decomposing algae and other organisms) that rains down to the bottom from the photic zone. Especially prominent in the benthic zone are two large (macrobenthic) forms, opossum shrimp *(Mysis relicta)* and *Diporeia* spp.-a closely related group of amphipods. *Mysis,* besides feeding on detritus, also migrates vertically at night, preys on zooplankton, and is itself consumed by several fish species.

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 198 1). 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 relicts are species that evolved or proliferated during deglaciation. Their distribution is now discontinuous and restricted to large, deep, glacial-scoured lakes. These glacial relicts included:

- invertebrates *(Limnocalanus, Mysis,* and *Diporeia);* and

- fish (deepwater ciscoes and the deepwater sculpin).

Because of their large size and high lipid levels, the glacial-relict invertebrates have made the benthic food web important in offshore waters for all but larval and juvenile fishes. Zooplankters usually have body lengths < 1 mm and are energetically costly for larger fish to consume. By contrast:

- adult Mysis achieves body lengths of 12-22 mm (Sell 1982),

- *Diporeia* reaches maximum lengths of 9 mm, and

- *Limnocalanus* adults range from 2.0 to 3.2 mm in length (Pennak 1953).

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).

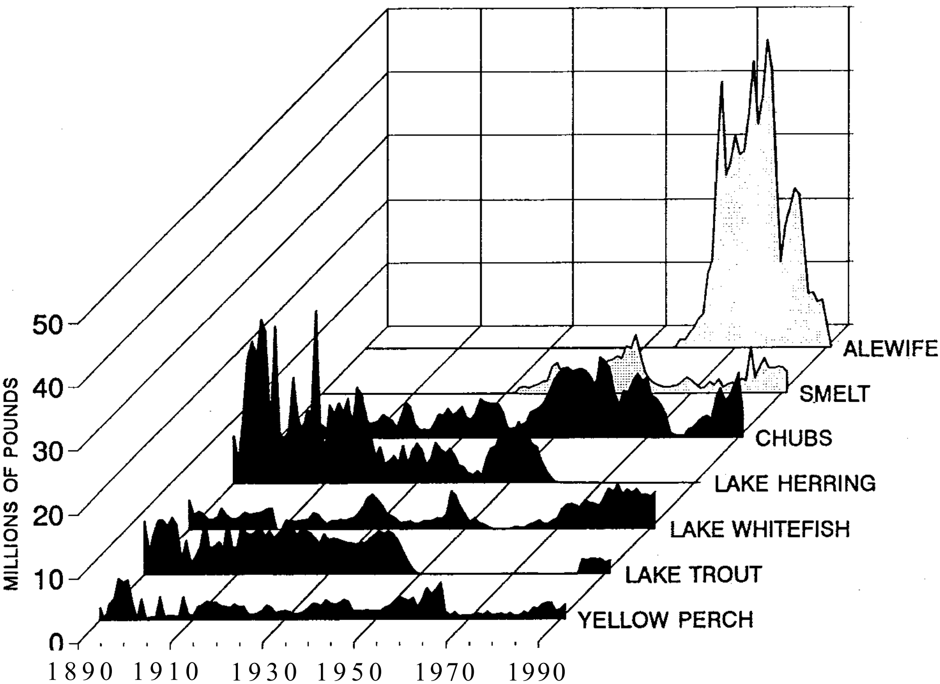

Fig. 1. Commercial catch of alewife, smelt, chubs (deepwater ciscoes), lake herring, lake whitefish, lake trout, and yellow perch from Lake Michigan, 1890- 1991.

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 burbot was also abundant and probably competed with lake trout for prey, but catches of this important predator were infrequently recorded because of low market demand. Lake trout and burbot also likely preyed on each other as observed in Lake Superior (Bailey 1972; Conner et al. 1993).

The combined effects of fishing, habitat destruction, and introduced species severely disrupted the native fish community (Smith 1972). Before the 1950s, these losses were incremental and did not change the fundamental linkages in the food webs-except for fishes dependent upon tributaries for spawning. These fishes included brook trout *(Salvelinus fontinalis),* various minnows *(Notropis* spp.), and redhorse suckers *(Moxostoma* spp.). Of the 17 introduced fishes (Appendix), the unintentional introduction of the sea lamprey *(Petromyzon marinus)-first* observed in 1936 - caused the most disruption. The sea lamprey introduction contributed to the collapse of top predator populations (lake trout and burbot) by the late 1940s (Wells and McLain 1973). Elimination of top predators allowed the alewife, which invaded in 1949, to proliferate and further disrupt the native food webs (Smith 1970).

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 *(Oncorynchus 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 (0. *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, a comprehensive plan for lakewide rehabilitation was developed and approved by the Lake Michigan agencies in 1985 (Great Lakes Fishery Commission 1985). The rehabilitation plan had three long-term goals:

1) Establish a self-sustaining population capable of yielding 1.1 million kg annually.

2) Emphasize planting lake trout in the best spawning habitats.

3) Control fishing mortality.

Table 1. Numbers (x 1,000) of trout and salmon planted in Lake Michigan each year, 1976-94.

Year	Lake trout	Brook trout	Brown trout	Chinook salmon	Coho salmon	Rainbow/ steelbead	Total
1976	2,548	80	881	3,264	2,937	1,831	11,541
1977	2,390	623	1,152	2,818	3,014	1,202	11,199
1978	2,501	243	1,535	5,365	2,630	1,937	14,211
1979	2,427	185	1,213	5,085	4,000	2,511	15,421
1980	2,604	188	1,307	6,106	2,943	2,661	15,809
1981	2,295	208	1,140	4,797	2,463	1,939	12,842
1982	2,264	24.5	2,159	6,035	2,180	2,442	15,325
1983	2,241	297	2,219	6,380	2,364	2,441	15,942
1984	1,245	233	1,853	7,710	3,028	3,192	17,261
1985	3,024	316	1,791	5,955	2,659	1,764	15,509
1986	2,917	197	1,431	5,693	2,291	2,022	14551
1987	1,984	118	1,342	5,800	2,304	1,831	13,379
1988	2,180	497	1,545	5,417	3,210	1,443	14,292
1989	3,332	150	1,504	7,859	2,334	1,844	17,023
1990	1,317	360	1,675	7,125	2,380	1,710	14,567
1991	2,779	326	1,384	6,237	2,471	1,841	15,038
1992	3,027	272	1,644	5,795	2,744	1,823	15,305
1993	2,699	294	1,673	5,491	1,709	1,806	13,672
1994	3,010	269	2,166	5,894	1,471	2,100	14,910

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.

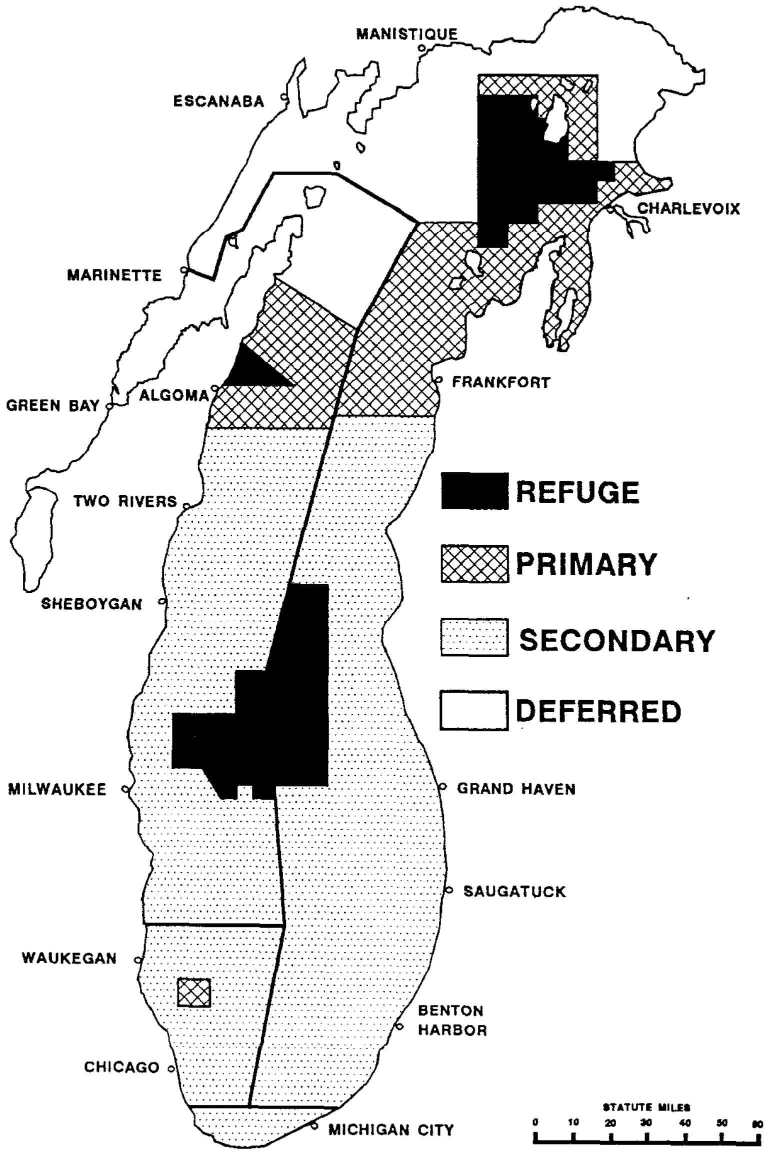

Fig. 2. Lake Michigan lake trout management zones. Refuges receive the highest priority for planting, and fishing for lake trout is prohibited. Total mortality on lake trout is targeted not to exceed 40% in Primary and Secondary Zones, but Primary Zones have a higher priority for planting. Deferred Zones 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 198 1 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.

In 1988, the first of a series of spring die-offs of chinook salmon occurred-corresponding closely in time with major drops in its catch that had started in 1987 in Michigan waters and in 1988 in Wisconsin waters. Dead salmon exhibited severe infections of bacterial kidney disease (BKD). What caused the disease outbreak is still unknown. One hypothesis is that inadequate nutrition (a scarcity of alewife) triggered the virulence of the disease. Another hypothesis is that the disease was spread through hatchery rearing practices. Regardless of the cause, the disease contributed to a 90% reduction in harvest of chinook salmon between 1986 and 1992.

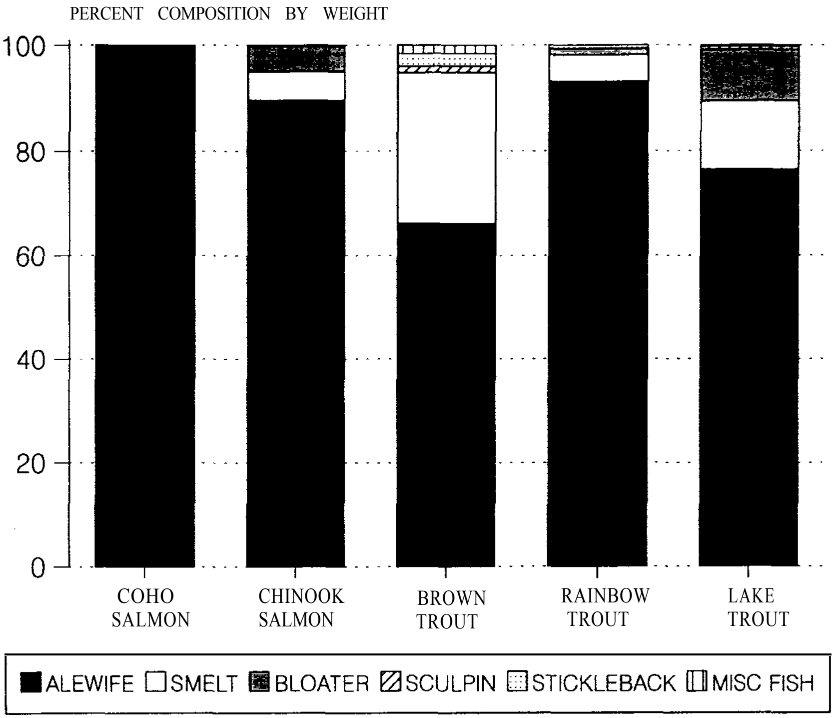

Fig. 3. Percent composition by weight of fish prey items in salmonine diets in Lake Michigan, 1990 and 1991 combined (M. Toneys, Wisconsin Department of Natural Resources, 110 S. Neenah Ave., Sturgeon Bay, WI, 54235, unpubl. data).

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 entered the Great Lakes in ballast water discharged from ocean-going ships (Lehman 199 1). The spiny water flea may compete with larval bloater for zooplankton and disrupt the pelagic food web (Lehman 1991). Other invaders from ballast water that may perturb the fish community are:

- the zebra mussel *(Dreissena polymorpha),*
- *the* ruffe *(Gymnocephalus* cernuus)-a perch-like fish that is presently confined to western Lake Superior (Pratt et al. 1992), and

- 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,
- degradation of phytoplankton and zooplankton populations, and
- loss of fish habitat.

Each of the ecosystem stresses needs to be addressed using a comprehensive and systematic ecosystem approach as specified in the GLWQA. One recognized vehicle for such an approach is the Remedial Action Plan (RAP) process for ten Areas of Concern affecting Lake Michigan. Fishery-management-agency participation in RAPs will be important for restoring physical and chemical integrity.

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 and Drug Administration standards. New advisories based on risk assessment are being considered by all the Great Lakes states. Regardless of analytical basis, consumption advisories for some Great Lakes fishes will likely be needed for the foreseeable future.

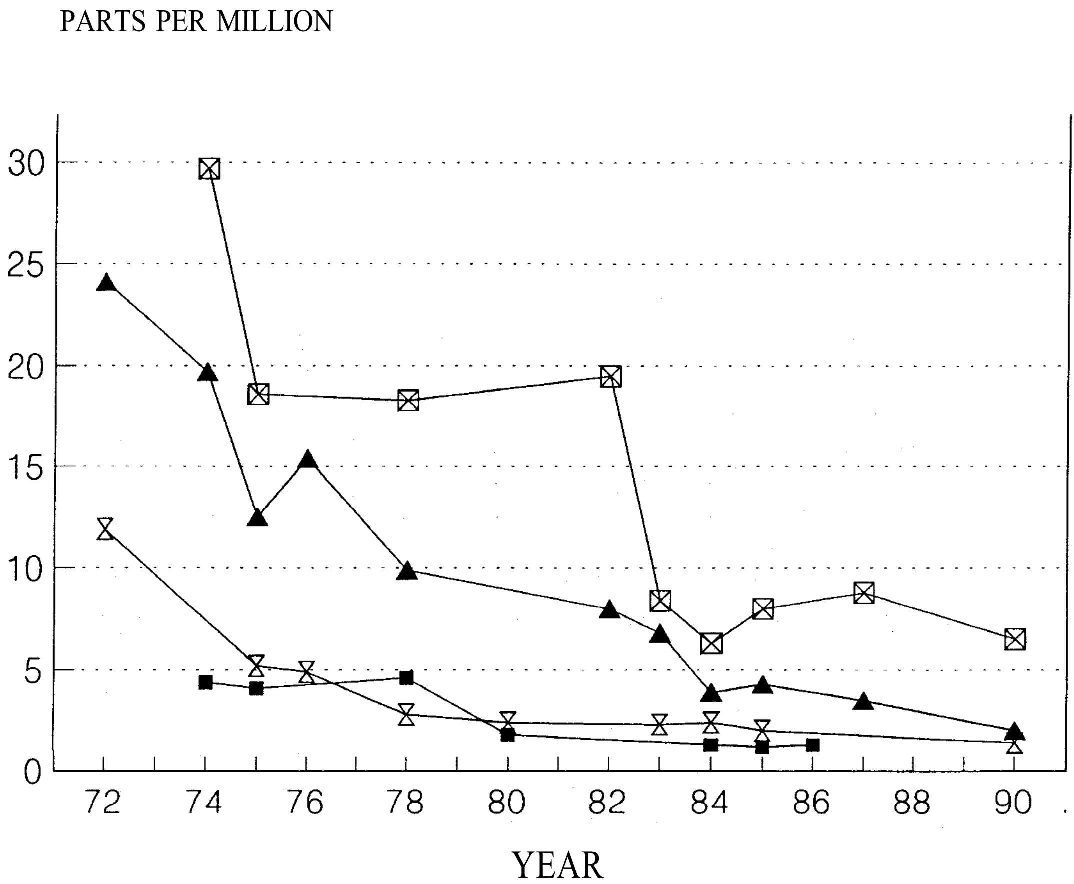

Fig. 4. PCB levels in lake trout fillets from Wisconsin waters of Lake Michigan by size-class of fish in cm, 1972-90.

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 environmental processes and survive many major disruptions induced by humans. Systems that lack integrity are often already degraded and when further perturbed by natural and human-induced events are likely to change rapidly to even more undesirable states. . Measuring the biotic integrity of a [fish community] is in a sense analogous to measuring human health. When bloodpressure readings, white blood cell counts, and the results of stress tests fall within acceptable ranges, good health is indicated. Good health, however, is not a simple function of these attributes. Rather, a biological system-whether it is a human system or a [fish community-can be considered healthy when its inherent potential is realized, its condition is stable, its capacity for self-repair when perturbed is preserved, and minimal external support for management is needed (Toth et al. 1982).*

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
- fishery regulation.

The failure of one or more of these programs could cause the fish community to lose integrity and revert to a less-desirable state.

GOALS AND GUIDING PRINCIPLES

Goals and principles governing the development of the fish-community objectives for Lake Michigan must support and be derived from previously established goals in the GLWQA of 1978, as amended in 1987, and the Joint Plan (Great Lakes Fishery Commission 1980). The GLWQA contains an important goal relating to pollution control that must be attained before healthy fish communities can be realized. Fisheries-management agencies around Lake Michigan reaffirm their support for the water-quality goal:

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

The Joint Plan provides a common goal statement for the management of Great Lakes fisheries. It was endorsed by all fishery agencies and serves as a fundamental concept for Lake Michigan:

To secure fish communities, based on foundations of stable, self-sustaining stocks, supplemented by judicious plantings of hatchery-reared fish, and provide from these communities an optimum contribution of fish, fishing opportunities and associated benefits to meet needs identified by society for:

wholesome food,
recreation,
employment and income, and
a healthy human environment.

Substantial progress has been made towards reaching this goal:

- recovery from the highly degraded, nearly single-species (alewife) fish community of the early 1960s is evident;

- sea lampreys are being suppressed;

- deepwater ciscoes, yellow perch, and whitefish have recovered-in some cases to near-historic levels;

- state and federal governments have invested in modern fish-production facilities to help maintain ongoing fisheries and rehabilitation efforts; and

- loadings of phosphorous and toxic chemicals have declined.

Nonetheless, several of the problems discussed earlier still remain, including:

- not enough natural reproduction of salmonines, especially lake trout;

- low abundance or complete loss of many native fish stocks;

- continued problems with unintentional introduction of undesirable exotic species;

- continued difficulties in suppression of sea lampreys; and

- continued unacceptable levels of pollution and toxic chemicals.

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.

3. Preserve Native Species

Where possible, there should be an attempt to restore native fishes to their pre-settlement geographical ranges and abundances. In some cases, introduced species might substitute for extinct native species or be encouraged by management at some expense to native species. Where interactions between native and introduced species prove to be endangering native species, priority should be accorded to native species. To help prevent any additional loss of species, the abundance of native fishes should always be maintained at levels well above those requiring their listing as threatened or endangered.

4. Enhance Natural Reproduction of Native and Desirable Introduced Fishes

Self-sustainability is important to the biological integrity of the fish community. Natural feedbacks between predator and prey can provide more-effective self-organization and system resilience than external controls can provide. Changes in harvest or planting are often too late because of the time required for detection (Christie et al. 1987). Also, genetic fitness of self-sustaining populations is likely to exceed that of planted populations because they may benefit from natural selection through adaptations to unique and specific conditions in localized environments. Therefore, wild reproducing populations can be expected to have better survival and productivity than planted populations.

5. Acknowledge the Role of Planted Fish

Planted fish are vital for:

continuing progress in restoring the biological integrity of the fish community,

developing spawning populations of species needing rehabilitation, and

providing fishing opportunities.

As stated in the Joint Plan, planting must be conducted judiciously to satisfy a variety of needs identified by society.

6. Recognize Naturalized Species

A number of introduced fish have now achieved various levels of self-sustainability in Lake Michigan and should be considered naturalized components of the fish community. Included are rainbow trout, smelt, alewife, pink salmon *(Oncorhynchus gorbuscha),* chinook salmon, coho salmon, brown trout, carp *(Cyprinus carpio),* and sea lamprey. Some of these introductions are considered desirable, and their continued sustainability should be encouraged. Others, such as the sea lamprey, need to be suppressed to tolerable levels.

7. Adopt the Genetic Stock Concept

The genetic diversity of locally adapted fish stocks should be protected. Outbreeding depression can occur when hatchery fish interbreed with wild fish. Although the total genetic diversity increases with outbreeding, fitness usually declines (Waples 1991). Also, ifplanted fish are very abundant in comparison to wild fish, the fishing effort needed to harvest the planted fish may deplete the wild fish (Evans and Willox 199 1). The study of interactions between wild and hatchery fish is an emerging area of research that already suggests more effort will be required to protect wild stocks.

8. Recognize That Fisheries Are an Important Cultural Heritage

Recognize that social, cultural, and economic benefits to various stakeholders-both in the present and the future-are important considerations in making fishery-management decisions.

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 developed for species that are threatened, endangered, or of special concern.

FISH-COMMUNITY OBJECTIVES

In describing fish-community objectives, certain realities must be considered:

1) The number and relative abundance of species in a fish community are strongly influenced by habitat features (for example, lake area, depths, and thermal characteristics) that are beyond human control.

2) Only a few options exist for altering community structure in any of the Great Lakes. Habitat manipulation is usually limited to remedial action in nearshore environments and tributary streams. Beyond this, managers exert an influence through the regulation of fisheries, fish planting, and sea lamprey control.

3) Management actions are inexact. Their effects cascade through the food chain to species well beyond those targeted, and those effects can have different time scales for different species. Short-term responses can be deceptive and long-range predictions can prove difficult.

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 troutpopulations.

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. (198 1) 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 19 11 to 1925. Scaling from Brown et al. (1981), the mean harvestable production from 19 11 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 *(Oncorhynchus* spp.), brown trout, and rainbow trout. Evidence for this supposition is the historical coexistence of Atlantic salmon *(Salmo salar)* and lake trout in Lake Ontario (Christie 1972). Comparative yields for lake trout and Atlantic salmon (also a pelagic piscivore) in Lake Ontario are lacking because the salmon's spawning and reproductive habitat were destroyed before accurate catch records were compiled. However, anecdotal accounts suggest that the Atlantic salmon was historically very abundant in Lake Ontario (Webster 1982). Therefore, Atlantic salmon must have been ecologically compatible with lake trout. Without the Niagara Escarpment and the associated falls blocking access to the upper lakes, Lake Michigan would likely have supported a natural population of a pelagic piscivore-Atlantic salmon.

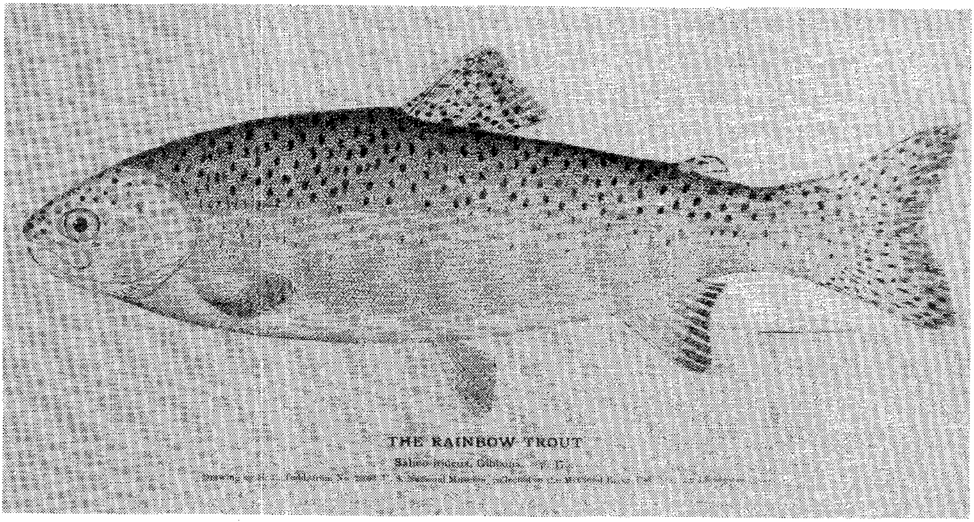

Fig. 5. The rainbow trout (photo of illustration from Goode (1884)).

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.

The key concept inherent in these estimates is that considerable latitude in yield (approximately 4.4 million kg) is potentially possible depending on food-web dynamics and management policies such as planting rates and fishing regulations. Recent discussions among fisheries managers have used a mid-range, lakewide yield of 5.5 million kg as a preliminary guide to establish desirable species mixes. On that basis, managers have agreed that the following yields are desirable, near-term expectations for salmonines from Lake Michigan:

- chinook salmon, 3.1 million kg;
- lake trout, 1.1 million kg;
- coho salmon, 0.7 million kg;
- steelhead, 0.3 million kg; and
- brown trout, 0.2 million kg.

However, all major piscivores, including the burbot, must be included in the final analysis.

Planktivore Objective

Maintain a diversity of planktivore (prey) species at population levels matched to primary production and to predator demands. Expectations are for a lakewide planktivore biomass of 0.5 to 0.8 billion kg (I.2 to I. 7 billion lb).

Alewife, rainbow smelt, and bloater in varying proportions constitute the bulk of the planktivore (forage) biomass available to salmonines in offshore regions of the lake. Biomass size-spectrum models suggest that total biomass of planktivores amounting to 0.5 to 0.8 billion kg is a reasonable range for Lake Michigan (Borgmann 1987; Sprules et al, 1991). Abundances of individual species may vary naturally within wide limits. Trying to manage the planktivore community for any single species, such as alewife, is not recommended. Diversity imparts some overall stability to the forage base by serving to minimize the effects of year-to-year variation within single species.

The balance implied in the planktivore objective is normally achieved by manipulation of predator numbers through harvest control and planting. On one hand; planting too many salmonines could lead to problems, for example, decreased growth 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 (199 1) 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. 199 1; Stewart and Ibarra 199 1) 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 from 1985 to 1987 - similar to the historic range. However, much of the recent harvest is composed of planted fish.

The yellow perch made a recovery in the early 1980s (Eck and Wells 1987) and it is the only inshore species capable of affecting the pelagic food web. Evans (1986) reported that inshore zooplankton standing stocks were reduced by perch predation in the summer of 1984 (when juvenile perch were near a maximum) to 3% of their level between 1975 to 1981,

The recovery of perch in the early 1980s did not persist. Reproduction since 1990 has been so poor that restrictions were put on fisheries in 1995. Facing tremendous demand for perch, managers want to maintain the yields experienced in the late 1980s, but these catches were based on a few exceptional year-classes. The historical average commercial yield of approximately 0.9 million kg represents a minimum, long-term objective. In view of the poor reproduction experienced in the 1990s, it will not be realized in the near future.

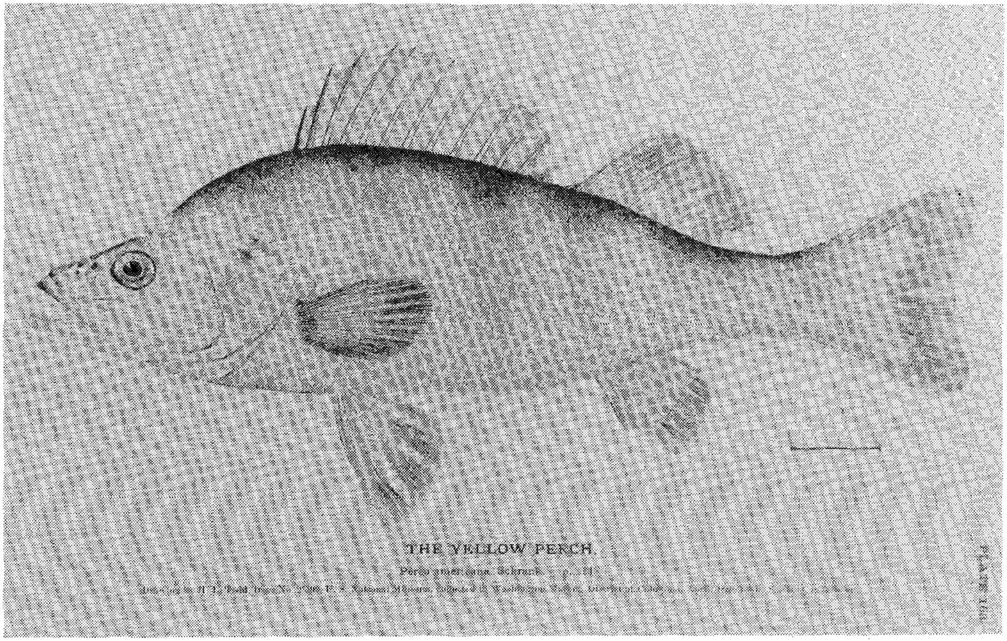

Fig. 6. The yellow perch (photo of illustration from Goode (1884)).

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. 199 1), 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

Maintain self-sustaining stocks of lake whitefish, round whitefish, sturgeon, suckers, and burbot. The expected annual yield of lake whitefish should be 1.8-2.7 million kg (4 to 6 million lb).

The demand for lake whitefish will continue to foster a desire to sustain the current 1.8-2.7 million kg yield, but the amount of variability around that yield is not well understood. To the extent possible, river-running lake whitefish populations should be restored where they were historically important. Sturgeon populations should be enhanced by:

- improving lake and stream habitat,
- assuring fish passage over barriers in historically used spawning streams, and
- devising protective regulations.

Increased harvest and market development of burbot and suckers should be encouraged.

Recent catches of whitefish, averaging 2.7 million kg between 1985 and 1987, exceed historical levels by nearly a factor of three. A continuation of high yields from this valuable food fish is very desirable. Surprisingly, the food habitats of whitefish in Lake Michigan are poorly documented-although *Diporeia* and *Mysis are known* to be important in their diet. These two invertebrates are estimated to have a combined biomass (11% Mysis) of 0.6 billion kg (Sprules et al. 1991). Changes in the structure of the benthic fish community may have provided whitefish a larger share of the benthic food web. Without knowing why whitefish yields are so high or how changes in community structure could affect them, a long-term continuation of current yields is uncertain.

The round whitefish *(Prosopium cylindraceum)* is apparently ecologically similar to the whitefish-but less abundant and even less well understood. Expectations of its future yield are even more uncertain than for whitefish because historical records for this lower-valued fish may underestimate potential yield.

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. Some of these species are of uncertain status (for example, certain cyprinids) while others may be rare, threatened, or endangered. Some species may be of economic value, but mostly they are noted for their intrinsic worth and their integrative function within the fish community. As prey and predators, other species act as energy vectors and provide balance and stability.

Specific objectives for other species are difficult to develop, but there is an expectation that they will be protected. This will occur through several means:

- protect species of primary socioeconomic interest so that other species will enjoy some measure of protection;

- develop programs to designate some species as rare, threatened, or endangered to raise their profile and engender specific management actions;

- ensure protection and rehabilitation of habitat to protect the overall well being of a diverse fish community;

- develop regulatory programs directed at specific species or families of fishes (for example, bait-fish harvest control and restoration of sucker runs).

Physical/Chemical Habitat Objectives

Protect and enhance fish habitat and rehabilitate degraded habitats.

Achieve no net loss of the productive capacity of habitat supporting Lake Michigan's fish communities. High priority should be given to the restoration and enhancement of historic riverine spawning and nursery areas for anadromous species.

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 unchanging habitat; the connotation is that change should be neutral or beneficial in its effect on fish production. In other words, the requirement is no net loss and preferably a net gain from any physical or chemical alteration of the lake environment. Habitat management is an integral component of the fish-community objectives, and their ultimate achievement will hinge on protection and rehabilitation of habitats. The no-net-loss objective is firmly anchored in this belief Desirable habitat enhancements include such things as:

- wetland improvement,
- site restoration involving the removal of physical structures,
- spawning-ground reconstruction, and
- improved access by fish to riverine habitat.

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APPENDIX
FISHES OF LAKE MICHIGAN PROPER [1]

P = Planned introduction   A = Accidental introduction   E = Extinct

Petromyzontidae	
chestnut lamprey	*Ichthyomyzon castaneus*
silver lamprey	*I. unicuspis*
sea lamprey (A)	*Petromyzon marinus*
Polyodontidae	
paddlefish (E)	*Polydon spathula*
Acipenseridae	
lake sturgeon	*Acipenser fulvescens*
Lepisosteidae	
longnose gar	*Lepisosteus osseus*
shortnose gar (A)	*L. platostomus*
Amiidae	
bowfin	*Amia calva*
Anguillidae	
American eel (A)	*Anguilla rostrata*
Hiodontidae	
mooneye	*Hiodon tergisus*
Clupeidae	
alewife (A)	*Alosa pseudoharengus*
gizzard shad	*Dorosoma cepedianum*

1 Modified from Bailey and Smith (1981).

Salmonidae (Salmoninae)	
pink salmon (A)	*Oncorhynchus gorbuscha*
coho salmon (P)	*0. kisutch*
chinook salmon (P)	*0. tshawytscha*
rainbow trout (P)	*0. mykiss*
Atlantic salmon (P)	*Salmo salar*
brown trout (P)	*S. trutta*
brook trout	*Salvelinus fontinalis*
lake trout	*S. namaycush*
Salmonidae (Coregoninae)	
lake whitefish	*Coregonus clupeaformis*
lake herring (cisco)	*C. artedi*
bloater	*C. hoyi*
deepwater cisco (E)	*C. johannae*
kiyi (E)	*C. kiyi*
blackfin cisco (E)	*C. nigripinnis*
shortnose cisco (E)	*C. reighardi*
shortjaw cisco (E)	*C. zenithicus*
round whitefish	*Prosopium cylindraceum*
Osmeridae	
rainbow smelt (A)	*Osmerus mordax*
Umbridae	
central mudminnow	*Umbra limi*
Esocidae	
grass pickerel	*Esox americanus*
northern pike	*E. lucius*
muskellunge	*E. masquinongy*
Cyprinidae	
northern redbelly dace	*Phoxinus eos*
lake chub	*Couesius plumbeus*
grass carp (A)	*Ctenopharyngodon idella*
carp (P)	*Cyprinus carpio*
goldfish (A)	*Carassius auratus*
pearl dace	*Margariscus margarita*

golden shiner	*Notemigonus crysoleucas*
emerald shiner	*Notropis atherinoides*
common shiner	*N. cornutus*
blackchin shiner	*N. heterodon*
blacknose shiner	*N. heterolepis*
spottail shiner	*N. hudsonius*
rosyface shiner	*N. rubellus*
spotfin shiner	*N. spilopterus*
sand shiner	*N. stramineus*
mimic shiner	*N. volucellus*
bluntnose minnow	*Pimephales notatus*
fathead minnow	*P. promelas*
longnose dace	*Rhinichthys cataractae*
blacknose dace	*R. atratulus*
creek chub	*Semotilus atromaculatus*
Catostomidae	
quillback	*Carpiodes cyprinus*
longnose sucker	*Catostomus catostomus*
white sucker	*C. commersoni*
northern hogsucker	*Hypentelium nigricans*
lake chubsucker	*Erimyzon sucetta*
black buffalo	*Ictiobus niger*
silver redhorse	*Moxostoma anisurum*
golden redhorse	*M. erythrurum*
greater redhorse	*M. valenciennesi*
shorthead redhorse	*M. macrolepidotum*
Ictaluridae	
yellow bullhead	*Ictalurus natalis*
black bullhead	*I. melas*
brown bullhead	*I. nebulosus*
channel catfish	*I. punctatus*
Percopsidae	
troutperch	*Percopsis omiscomaycus*
Gadidae	
burbot	*Lota lota*

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

Cottidae	
mottled sculpin	*Cottus bairdi*
slimy sculpin	*C. cognatus*
Spoonhead sculpin	*C. ricei*
deepwater sculpin	*Myoxocephalus thompsoni*

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
The process of adding unnatural amounts of nutrients to a water body.

exotic species
A species not native to the environment in question.

fishing rate
The proportion of catchable-size fish, including fish just reaching catchable size that are caught (usually) within a year.

fitness
A measure of the reproductive success of an individual.

food-conversion efficiency
The portion of food eaten that becomes new tissue.

forage base
Prey species forming the food supply for predators.

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
Accounting for all inputs, outputs, storage, and cycling of a substance(s) in a system.

native fish
Fish species that naturally occurred in an ecosystem before settlement by Europeans.

natural mortality rate
The proportion of fish of the same age-class that die from natural (nonfishing) causes within a year.

naturalized
Having achieved permanent residency through natural reproduction.

no net loss
A policy on habitat that requires replacement for any losses.

oligotrophic lake
A lake low in nutrients and usually deep.

omnivore
Both plankton and fish comprise the diet.

outbreeding
Interbreeding of genetically distinct populations.

pelagic
Living or occurring in open waters away from the shore or the bottom.

phytoplankton
The plant organisms in plankton.

piscivore
Feeding on fishes.

planktivore
Feeding on plankton.

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 regardless of their perception of their relationship to the Great Lakes.

top predator

Occurring at the top of the food chain.

toxic chemicals

A term referring to synthetic chemical substances capable of causing harm at very low levels of exposure, while providing little or no benefit to plants or animals of the ecosystem.

trophic level

A level within a food pyramid within which organisms have a common nutrient source.

zooplankter

A planktonic animal.

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.

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.

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