FISH-COMMUNITY OBJECTIVES
FOR LAKE SUPERIOR

Great Lakes Fishery Commission

SPECIAL PUBLICATION 03-01

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PREFACE

The Sacred Shell rose up out of the water and told the people that this was the place they had been searching for. Here, the Waterdrum made its seventh and final stop on the migration. The Sacred Fire was carried here and here it burned brightly.

-The Mishomis Book, Edward Benton-Banai

Ojibwe teachings tell of the long migration that the Ojibwe people undertook guided by the Sacred Megis Shell to their ultimate destination, Madeline Island in Lake Superior. It was along the shore of Lake Superior that they found the precious food, manoomin (wild rice) and a land of beauty and abundance. It became their homeland. Today, it is the responsibility of all people to protect this great gift and resource, which nourishes us both spiritually and physically.

Those of us who work day-to-day on issues related to Lake Superior probably do not reflect often enough on this unique and magnificent resource. By virtue of its great size and geographic position, Lake Superior creates its own microclimate that distinctly influences the flora and fauna that fall within its reach. In the context of nature's beauty, diversity, power, and value, Lake Superior stands alone. As you learn of the cultural heritage, and travel its rugged, mostly undeveloped shoreline, it is easy to become captivated. It is also easy to imagine why native people and early European explorers alike so revered and respected this Great Lake.

Although managing Lake Superior fisheries has been—and will continue to be—a challenging endeavor, the ultimate challenge may rest in our ability to preserve the environment on which the fisheries depend. For, despite its relative isolation, the lake's great size and pristine nature make it exceptionally vulnerable to human activities. Some of the broader goals that must be pursued to support healthy and stable fish communities are:

- Restoration and protection of nearshore habitats

- Achievement and maintenance of water- and air-quality standards

- Rehabilitation of indigenous aquatic species

In this respect, achievement of our fish-community and habitat objectives will serve as an important measure of our progress toward rehabilitating and protecting this unique and fragile ecosystem.

To achieve our common goal of a healthy Lake Superior, cooperative action among governments, interest groups, and concerned citizens from many disciplines will be required. If we are successful, future revisions of fish-community objectives for Lake Superior will largely reflect a desire to simply maintain and preserve the existing fish community and the environment on which it depends.

TABLE OF CONTENTS

ABSTRACT

The development of fish-community objectives for each lake is mandated by A Joint Joint Plan for Management of Great Lakes Fisheries (Great Lakes Fishery Commission 1997). That multiagency agreement also reflects a commitment to habitat protection and restoration through the following statement:

> *The Parties must exercise their full authority and influence in every available arena to meet the ecological, chemical, and physical needs of desired fish communities.*

Accordingly, these fish-community objectives highlight habitat issues. The first objective summarizes the agencies' habitat concerns:

> *Achieve no net loss of the productive capacity of habitat supporting Lake Superior fishes. Where feasible, restore habitats that have been degraded and have lost their capacity for fish production. Reduce contaminants so that all fish are safe to eat. Develop comprehensive and detailed inventories of habitats.*

The fish-community objectives were developed in conformity with twelve guiding principles that summarize the values and practical realities that constrain or guide fisheries management on Lake Superior. Additional objectives pertain to prey species, lake trout (*Salvelinus namaycush*), lake whitefish (*Coregonus clupeaformis*), walleye (*Stizostedion vitreum vitreum)*, lake sturgeon (*Acipenser fulvescens)*, brook trout (*Salvelinus fontinalis)*, pacific salmon (*Oncorhynchus* spp.), and trout (*Salmonidae* spp.), sea

lamprey (*Petromyzon marinus)*, nuisance species, and species diversity. Habitat issues impeding achievement of any objective are described. The most-pressing habitat concerns are in streams and embayments, and accordingly affect:

- Tributary-spawning species, including brook trout, walleye, and lake sturgeon

- Warm- or cool-water species, including yellow perch (*Perca flavescens)*, northern pike (*Esox lucius)*, and smallmouth bass *(Micropterus dolomieu*)

Although numerous non-native species have invaded Lake Superior, with the effective control of sea lamprey, the offshore fish community has returned to a condition broadly similar to that which existed prior to the modern era. The agencies envision an offshore fish community dominated by lake trout as the top predator and requiring the continued control or eradication of sea lamprey.

INTRODUCTION

The Lake Superior fish community and our knowledge regarding its structure and function have changed substantially over the past decade. Recognizing this caveat and the central importance of habitat protection, the fishery-management agencies operating on the lake initiated an effort to update their vision for Lake Superior's fish community. This document is a product of that effort. It replaces the original Fish-Community Objectives for Lake Superior (Busiahn 1990).

Changes in the Lake Superior fish community and our knowledge of the lake converge around three themes:

- The fish community is reverting to a more natural state resembling historical conditions and requiring less management intervention and control

- Success in rehabilitating lake trout (*Salvelinus namaycush*) and the recovery of many lake herring (*Coregonus artedi*) populations have allowed management attention to shift toward depleted species in embayments and tributaries, which are more likely to be limited in both quantity and quality of habitat (Appendix D)

- The fish community has been permanently altered by non-indigenous nuisance species and remains at risk from further introductions; for example, progress in restoring the lake and its indigenous species rests upon successful control of sea lampreys, which requires continuous, expensive intervention

This document reflects these three themes in its emphasis on natural reproduction, habitat protection, and prevention of additional introductions of non-indigenous species.

The development of fish-community objectives for each of the Great Lakes is mandated in A Joint Strategic Plan for Management of Great Lakes Fisheries (Joint Plan) (Great Lakes Fishery Commission 1997). That document was adopted in 1981 and revised in 1986 and 1997. The Joint Plan represents a commitment to cooperative management on the Great Lakes by all state, federal, tribal, and provincial agencies involved in the management of the Great Lakes fisheries. As required by the Joint Plan, these fish-community objectives have been adopted by a consensus of the Lake Superior Committee (LSC), representing the Wisconsin Department of Natural Resources, the Michigan Department of Natural Resources, the Minnesota Department of Natural Resources, the Ontario Ministry of Natural Resources, the Chippewa-Ottawa Resource Authority, and the Great Lakes Indian Fish and Wildlife Commission.

This document reflects the "Ecosystem Approach to Fisheries Management Strategy" articulated in the Joint Plan:

> *The Parties must exercise their full authority and influence in every available arena to meet the biological, chemical, and physical needs of desired fish communities*

This concept was added to the Joint Plan in 1997 in recognition of the fact that actions outside the immediate control of fishery agencies can have profound impacts on fish communities. The revised Joint Plan called for the establishment of an ongoing dialogue among lake committees and various environmental agencies. The present document acknowledges the ecosystem-approach strategy by specifically addressing habitat and water-quality issues and by promoting coordination with the Binational Program to restore and protect the Lake Superior basin (Lake Superior Binational Program 1998).

This document is intended to provide a framework for future decision making. It is not a management plan. Specific management strategies, developed to meet the various objectives identified here, will be determined within each management jurisdiction by agencies working with interested citizens. The vast array of biological, political, and socioeconomic issues involved in the management of a complex ecosystem like Lake Superior makes consensus-based management challenging. In addition, an incomplete understanding of the Lake Superior ecosystem and the likelihood that the fish community will continue to change makes predicting the fish community's response to various management actions imperfect and sometimes contentious. This document will assist agencies and the interested public in developing management strategies by:

- Promoting a common understanding of how the Lake Superior ecosystem functions

- Providing a unified direction to guide management practices

This document will also serve as a mechanism to focus attention on the major issues facing Lake Superior fisheries and to communicate priority issues to governments, stakeholders, and the general public. This document should be viewed in its entirety—much of the rationale used in formulating individual objectives is woven throughout the document.

As an expression of our increased knowledge and experience with lakewide fisheries management, this update of the fish-community objectives for Lake Superior represents a timely evolution of the original version. In recent years, agency biologists have jointly developed comprehensive research and assessment strategies, data-exchange protocols, and cooperative planning processes. These advances will provide better measures to gauge progress toward achievement of the objectives and to help refine them in the future. Recent efforts to coordinate programs with environmental organizations have also been fruitful further encouraging fishery and environmental interests to work together toward a healthy and productive Lake Superior. While this document represents current expectations and desires for the Lake Superior fish community, we anticipate that future revisions will be needed as the fish community changes and/or new information becomes available. Comprehensive state-of-the-lake reports on progress toward achieving these objectives will be given at five-year intervals.

DESCRIPTION OF LAKE SUPERIOR

Although Lake Superior is the least altered of the Great Lakes, its fish community, fish habitats, and the surrounding watershed have been significantly altered. Management actions have restored lake trout and suppressed sea lampreys (*Petromyzon marinus*), and, today, important sport and commercial fisheries are active in all jurisdictions. However, many challenges remain.

Physical Characteristics

Lake Superior is large and its waters are clear, cold, and unproductive. The lake has (Bennet 1978):

- The largest surface area (82,100 km^2 (32,070 mi^2)) of any lake in the world
- Water transparency that can reach a depth of 23 m (75 ft)
- A mean annual water temperature of 3.6^o C (34^o F), which is the lowest among the Great Lakes

The lake's high water clarity reflects extremely low biological productivity (Vollenweider et al. 1974), which is a consequence of low water temperatures, low levels of organic pollution, a narrow littoral zone, and low levels of dissolved minerals. Most of Lake Superior's relatively small drainage area is composed of igneous rock that is resistant to weathering with the result that only small quantities of minerals are dissolved into stream discharges. The mineral composition of the water is similar to that of rainwater (Matheson and Munawar 1978) and has remained relatively constant for the past 80 years (Table 1).

Table 1. Physical attributes of Lake Superior (Anonymous 1995).

Attribute	Data
Length	563 km (352 mi)
Breadth	257 km (161 mi)
Average depth	147 m (478 ft)
Maximum depth	406 m (1320 ft)
Volume	12,000 km^3 (2927 mi^3)
Surface area	82,100 km^2 (32,070 mi^2)
Drainage area	127,700 km^2 (49,883 mi^2)
Shoreline length (including islands)	4,385 km (2741 mi)
Elevation	183 m (595 ft)
Outlet	St. Marys River (to Lake Huron)
Retention/replacement time	191 years

The geological and climatic factors that created this unique water body have also helped to preserve it. Because of the cool climate and poor soils, most of the basin is sparsely populated and heavily forested with little agriculture. Lake Superior has not suffered from high nutrient loadings or industrial pollution to the same extent as the other Great Lakes.

Ecological Structure of the Fish Community

The fish community of Lake Superior occupies three major trophic levels, each having its own species complex (Table 2). Energy captured from sunlight by phytoplankton flows upward from one trophic level through a complex food web. Biological production generally decreases approximately tenfold from a lower trophic level to the next higher level. The most sought-after sport fishes of Lake Superior—lake trout and Pacific salmon (*Oncorhynchus* spp.)—are top-level predators and, therefore, represent only a small fraction of the lake's energy production.

The low productivity of Lake Superior, in comparison with the other Great Lakes, is reflected in its lower primary production estimates and historically low fish yields (Table 3). Therefore, expected fish yields from the current fish communities will be much lower for Lake Superior than for the other Great Lakes. During 1916-40—a period of high and stable fish yields—Lake Superior produced an average annual yield of 0.9 kg/ha (0.8 lb/acre), which is probably near or above the maximum sustainable level. The current annual yield is about 0.45 kg/ha (0.4 lb/acre) reflecting primarily lower catches of lake herring, which historically dominated yields.

Table 2. Ecological roles of important Lake Superior fishes as adults.

Ecological Role	Fish
Planktivore—diet predominantly zooplankton or phytoplankton	Bloater (*Coregonus hoyi*) Lake herring Rainbow smelt (non-indigenous) (*Osmerus mordax*)
Benthivore—diet predominantly macroinvertebrates	Deepwater sculpin (*Myoxocephalus thompsoni*) Kiyi (*Coregonus kiyi*) Lake sturgeon (*Acipenser fulvescens*) Lake whitefish (*Coregonus clupeaformis*) Longnose sucker (*Catostomus catostomus*) Ninespine stickleback (*Pungitius pungitius*) Slimy sculpin (*Cottus cognatus*) White sucker (*Catostomus commersoni*)
Piscivore—diet predominantly fish	Brown trout (non-indigenous) (*Salmo trutta*) Burbot (*Lota lota*) Chinook salmon (non-indigenous) (*Oncorhynchus kisutch*) Coho salmon (non-indigenous) (*Oncorhynchus kisutch*) Lake trout Northern pike (*Esox lucius*) Rainbow trout (non-indigenous) (*Oncorhynchus mykiss*) Sea lamprey (non-indigenous) Smallmouth bass (*Micropterus dolomieu*) Walleye (*Stizostedion vitreum*) Yellow perch (*Perca flavescens*)

Table 3. Primary production (Vollenweider et al. 1974) and average annual fish yields (Matuszek 1978; Baldwin et al. 1979) from each of the Great Lakes during the 15-year period of maximum commercial harvest.

Lake	Primary production ($g/m^2/yr$)	Fish yield (g/ha)
Lake Erie	240-250	9710
Lake Ontario	180-190	1240
Lake Michigan	140-150	2230
Lake Huron	80-90	2090
Lake Superior	40-50	1190

CHANGES IN THE FISH COMMUNITY

Lake Superior is the least altered of the Great Lakes yet the lake, its watershed, and its fishery have been significantly degraded. Recovery has been incomplete. The following describes Lake Superior and its fisheries at two points in the past and compares these descriptions to current conditions.

Prior to European Settlement

Prior to the mid-1800s, the fish community of Lake Superior had evolved without significant human impact since deglaciation, a period of nearly 10,000 years. The indigenous fish community of the lake and its tributaries included over 70 species—some with unique locally adapted forms. At the time of European settlement, lake trout, the top predators, were present throughout the lake over a wide range of depths. Especially prominent were two deepwater forms of lake trout called humpers and siscowets (*Salvelinus namaycush* siscowet). Lake whitefish occupied waters less than 100 m (325 ft) deep, a small part of the lake's total surface area. Planktivorous species such as lake herring and deepwater ciscoes (*Coregonus* spp.) occupied most of the water column in the pelagic zone and provided a food source for lake trout. Benthic habitats were occupied by sculpins (*Cottidae* spp.), sticklebacks (primarily ninespine sticklebacks), burbot, suckers (*Catostomus* spp. and *Moxostoma* spp.) and pygmy whitefish (*Prosopium coulteri*). Rivers, bays, and coastal waters were occupied by brook trout (*Salvelinus fontinalis*), walleye, lake sturgeon, yellow perch, and northern pike. Hay-Chmielewski and Whelan (1997) estimated that Lake Superior supported 12.3 kg (27 lb)/acre of lake sturgeon in nearshore waters less than 12.3 m (40 ft) deep prior to 1870. Roosevelt (1865) found an "abundance of [brook] trout, averaging above two pounds, [along] the entire rocky shore of the lake, along both coasts...." Arctic grayling (*Thymallus arcticus*), now extirpated from the watershed, were present in tributaries (Hubbs and Lagler 1964). Two large-bodied zooplankters, *Mysis relicta* and *Diporiea* spp., were major components of this food web.

The offshore and nearshore open waters were characterized by a simple food web where lake herring fed on zooplankton and were in turn eaten by lake trout, which occupied the offshore zone during most of the growing season. In the offshore zone, deepwater ciscoes and deepwater sculpin were the primary prey of siscowet lake trout. A large quantity of energy and biomass was accumulated in lake herring and lake trout. Reproductive rates of these fish were low and their growth was slow.

Human impacts on the fish community were probably minimal. Native Americans used gillnets made with strands of willow bark. They fished from birch bark canoes in summer and fall and through the ice in winter (Waters 1987). They also baited hooks and speared by torchlight, but the gillnet provided the bulk of their catch.

Period of Maximum Degradation (1960s)

Lake Superior experienced dramatic changes caused by the activities of the burgeoning human population. The lake and its fisheries reached a point of maximum degradation around the 1960s before beginning to recover. Many factors contributed to the degradation.

Commercial fishing began in the 1830s and increased in intensity over the 19th century and well into the 20th century. Poorly controlled fishing by "aggressive and enterprising commercial fisheries" produced the destabilizing effects of intense size-selective predation (Lawrie 1978). All exploited species—including lake trout, lake sturgeon, lake herring, lake whitefish, and deepwater ciscoes—were affected, and some became rare. Sport angling was also a major factor in the early and rapid decline of brook trout that were easily caught in nearshore waters (Roosevelt 1865).

Destruction and degradation of habitat were severe, especially in bays and tributaries. The deposition of woody debris from sawmill operations "ruinously affected" spawning sites for sturgeon, lake whitefish, brook trout, and other species (Lawrie 1978):

- Logging in the Lake Superior watershed caused erosion and sedimentation as well as higher temperatures and more variable flows in tributary streams

- Dams blocked access to spawning sites and changed downstream flows in streams

- Paper mill waste blanketed spawning habitat

- Toxic contaminants (heavy metals and organic compounds) entered the lake from point sources and aerial deposition and caused widespread low-level contamination of fishes

- Mining, agriculture, urban development, and road and railroad construction all affected adjacent fish habitat

The fish community was also greatly affected by non-indigenous species. The expansion of waterborne commerce and, especially, the creation of the Welland Canal and St. Lawrence Seaway provided entry routes for numerous non-indigenous species (Mills et al. 1993). Sea lampreys reached Lake Erie and the upper Great Lakes via the Welland Canal. They colonized Lake Superior in the 1940s and, by the late 1950s, had, in conjunction with fishing, nearly destroyed the lean lake trout population (Lawrie and Rahrer 1973; Pycha and King 1975). Non-indigenous species were also intentionally introduced to either provide or enhance sport- and commercial-fishing opportunities. Sport-fishing opportunities were diversified by the introduction of Atlantic salmon (*Salmo salar*), brown trout, rainbow trout, and Pacific salmon (chinook), coho, and pink (*Oncorhynchus gorbuscha*). The effects of these species on the ecosystem have still not been fully assessed. Rainbow smelt, introduced into the Lake Michigan watershed in 1912, colonized Lake Superior during the 1930s and 1940s. By the 1950s, in nearshore waters, rainbow smelt had largely replaced lake herring and other coregonids (members of the whitefish subfamily) as the major prey item for lake trout (Van Oosten 1937; Beckman 1942; Dryer et al. 1965; Selgeby et al. 1994). The effect of this displacement was enormous because lake herring had historically channeled energy to top-level predators throughout the lake, whereas smelt were accessible only to nearshore predators. The behavior and distribution of lake trout may have changed to reflect the distribution of their major prey—the rainbow smelt.

This period from early settlement through the 1960s reflects a very unstable, rapidly changing fish community that had poor prospects for long-term sustainability. Lake trout and brook trout populations were reduced throughout the lake, and many local populations of these species were eliminated. Lake herring and deepwater cisco populations were greatly reduced, and the formerly most-abundant species of deepwater cisco became rare. Lake sturgeon and walleye, once abundant in bays, were virtually eliminated from some areas.

Current Conditions

The fish community of Lake Superior is closer now to what the lake committee desires than at any time since the early 1960s when sea lamprey control began. Several reports have documented the recovery of the Lake Superior fish community (MacCallum and Selgeby 1987; Hansen 1990, 1994, 1996; Hansen et al. 1995). Critical factors in the recovery are:

- Suppression of sea lampreys
- Better regulation of fisheries by provincial, state, and tribal governments
- Stocking lake trout
- Improved recruitment of lake herring
- Abatement of pollution
- Lessening habitat destruction
- Reforestation

Recovery of lake trout, the most economically valuable species in the historical catch, has progressed to a level where fishery agencies believe that supplemental stocking is no longer required at most locations in the lake (Hansen et al. 1995; Schreiner and Schram 1997). Lake herring populations that historically supported the bulk of the total commercial catch produced very abundant year-classes in the late 1980s, which replaced the weaker year-classes of the 1960s and 1970s. However, lake herring year-class strength remains extremely variable (Selgeby et al. 1994; Charles R. Bronte, U.S. Fish and Wildlife Service, Green Bay Fishery Resources Office, 1015 Challenger Ct., Green Bay, WI 54311, unpubl. data). Rainbow smelt abundance has declined dramatically from the high levels reached in the 1970s.

Introduced brown trout and all the Pacific salmon species have become naturalized in Lake Superior. None of the management agencies currently stocks coho or pink salmon. Chinook salmon stocking continues; however, some of the largest stockings, which occurred during 1988-90, provided only 25% of the lakewide sport catch for this species (Peck et al. 1999). Rainbow trout, brown trout, and splake (*Salvelinus fontinalis* x *S. namaycush* hybrid) are stocked in various locations to supplement natural reproduction or to enhance sport fisheries. Some nearshore fish populations—especially of lake sturgeon (J. Slade, Ludington Sea Lamprey Control, 229 South Jebavy Drive Station, Ludington, MI 49431, personal communication), walleye (Hoff 1996), and brook trout (Newman and DuBois 1997)—remain below historical levels. However, rehabilitation efforts are being pursued by most management agencies.

State and tribal management agencies are combining long-term assessment information with newly developed numerical models to set harvest controls for commercial and sport fisheries to eliminate overfishing. Bioenergetics models have recently been applied to portions of Lake Superior (Negus 1995; Mark P. Ebener, Intertribal Fisheries Assessment Program, Chippewa/Ottawa Treaty Fishery Management Authority, 179 W. Three Mile Rd., Sault Ste. Marie, MI 49783, personal communication) to provide a better understanding of predator-prey dynamics, fish-community function, and future information needs. Lakewide simulation models (for example, ECOPATH and ECOSIM) have been applied to the Lake Superior fish community, and strategies that may impact achievement of the fish-community objectives are being explored (Kitchell et al. 2000).

Non-indigenous species (Appendix D) have had perhaps the greatest irreversible effect on the Lake Superior fish community. Even today, sea lamprey continue to kill thousands of lake trout each year, and rainbow smelt still comprise a significant portion of the nearshore forage. Ruffe (*Gymnocephalus cernuus*) and round gobies (*Neogobius melanostomus*) have colonized some areas and have the potential to negatively impact the nearshore cool-water fish community.

Fish habitat, with some notable exceptions, is generally good throughout the Lake Superior. The majority of impairments to water quality are found in embayments and tributaries—commonly near mining and logging operations. These conditions have resulted in the identification of eight Areas of Concern (International Joint Commission 1987) in the Lake Superior basin. Lake Superior also receives inputs of atmospheric pollutants such as PCBs and DDT that originate outside the Lake Superior basin (Suns et al. 1993; Swain 1978; Eisenreich and Strachan 1992). Some climatologists anticipate that the climate of the basin in the next century will be warmer by 2° C-4° C (3.6° F-7.2° F). Models indicate that lake levels could decline 0.2-0.5 m (0.65-1.60 ft) (Magnuson et al. 1997), while nearshore epilimnion temperatures could rise 1.8° C-5.7° C (3.2° F-10.3° F) for the July-September period (Hill and Magnuson 1990). Tributary streams—important for the spawning of many fishes—remain significantly degraded by activities in the watershed, including logging, agriculture, mining, and hydroelectric dams.

GOALS AND GUIDING PRINCIPLES

The guiding principles listed below support the previously established goals of the:

- Joint Plan (as amended in 1997)

- Great Lakes Water Quality Agreement (GLWQA) of 1978 (as amended in 1987)

- Binational Program's Aquatic Community Objective (Lake Superior Binational Program 2000).

The Joint Plan provides a common goal statement for the management of Great Lakes fisheries that serves as a fundamental concept for Lake Superior:

> *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 the needs identified by society for: wholesome food, recreation, cultural heritage, employment and income, and a healthy aquatic ecosystem.*

The GLWQA, adopted by the International Joint Commission, contains an important goal related to water quality that must be achieved and maintained to ensure healthy fish communities:

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

Finally, the Binational Program adopted the following overall objective for the aquatic community of Lake Superior:

> *Lake Superior should sustain diverse, healthy, reproducing and self-regulating aquatic communities closely representative of historical conditions.*

Consistent with those goals, the Lake Superior fishery-management agencies adopt the following fish-community goal:

> *To rehabilitate and maintain a diverse, healthy, and self-regulating fish community, dominated by indigenous species and supporting sustainable fisheries.*

Along with agreement on the overall goals, complex fishery management requires agreement on specific principles to guide the development of policies and programs. A combination of fisheries science, management experience, and public participation has led to the development of a number of widely accepted management concepts that are essential for establishing a consistent, cooperative management approach for Lake Superior. The LSC has adopted the following principles as a guide for formulating management policy and fish-community objectives (the order of listing does not indicate relative importance):

- Fish habitats must be protected—healthy fish communities require diverse and abundant physical habitats, including clean water

- Lake productivity is limited—the numbers and species of fish that can be supported by a healthy Lake Superior ecosystem are limited; healthy, naturally reproducing fish communities that support fisheries can only be sustained by managing the entire ecosystem within the bounds of its biological productivity

- Naturalized species are part of the ecosystem—non-indigenous species that are self-sustaining are likely to remain indefinitely, and those that are compatible with achievement of these fish-community objectives should be considered part of the fish community and managed for sustainability

- Further introductions of non-indigenous species must be prevented—non-indigenous species, especially the sea lamprey, have harmed the Lake Superior fish community; others, including ruffe and gobies, may also prove damaging; further introductions must be prevented

- Fish and fisheries are culturally important—fisheries are a precious cultural heritage; therefore, the social, cultural, and economic benefits and costs to present and future societies are important considerations in decision making

- Unexploited fishes are also important—all fish species, not just those that are exploited by man, are important to the integrity of the fish community

- All citizens have a stake in Lake Superior fisheries—citizens, whether engaged in fishing or not, have an interest and a role in management decisions that affect Lake Superior fishes

- Management decisions should be supported by science—the application of the scientific method, through experimentation and organized data collection, should lead to good management decisions; sources of data and information include traditional knowledge and conventional surveys

- Management must be coordinated among agencies—Lake Superior fisheries-management agencies must share information, work toward consensus, and be accountable for their actions

- Our ability to manage these fish communities is limited—because our knowledge is incomplete and because Lake Superior is influenced by forces beyond our control, our ability to shape the fish community of Lake Superior will always be limited

- Preservation of indigenous species is of the highest concern—those indigenous species that are presently abundant should be maintained, and those that are depleted should be protected and enhanced

- Genetic diversity and fitness must be maintained—management agencies have a responsibility to maintain the genetic diversity of fish through protection of individual populations and the careful selection and stocking of only those strains of fish already present

FISH-COMMUNITY OBJECTIVES

Achievement of the goals and objectives described in this document requires emphasis on habitat restoration and protection—particularly for those fish that rely on tributary, embayment, and nearshore habitats. Achievement and maintenance of excellent water quality is essential not only to support fish-community objectives but also to ensure achievement of the Joint Plan's goal of healthy, self-sustaining fish populations and wholesome food. It is important, therefore, that habitat- and water-quality concerns are adequately pursued so they do not impede achievement of the goals and objectives described in this document. In recognition of the importance of habitat, a separate habitat objective is described followed by broad objectives for individual fish species or species groups.

Given our limited ability to manipulate the Lake Superior fish community or predict its future, the following objectives encompass broad ecological concepts that provide the framework for development of specific fisheries-management plans and strategies. The LSC also recognizes that much progress has been made in rehabilitating some Lake Superior fish communities. Therefore, maintenance and protection of existing conditions or trends is also emphasized.

In describing fish-community objectives, we also recognize the following:

- The abundance and composition of fish within a community as large and diverse as that of Lake Superior are strongly influenced by physical habitat features (for example, lake area, depth, and thermal characteristics) that cannot be changed

- The list of options for successfully influencing the fish-community structure in Lake Superior is short; the primary means by which fishery managers can effectively manipulate the Lake Superior fish community are:

    - Regulating harvests
    - Stocking fish
    - Protecting and enhancing habitat
    - Suppressing nuisance species (sea lamprey, in particular)

- Management actions are inexact; the ecological effects of management decisions and subsequent actions can sometimes cascade to species well beyond those targeted and produce effects over time scales different from what was intended; it is recognized that short-term responses can sometimes be deceptive and that long-range predictions are extremely difficult to make with precision; time scales for achievement of objectives are sometimes measured in decades

- Non-indigenous species (for example, sea lamprey and ruffe) can result in significant and sometimes catastrophic, negative impacts in the fish community; such perturbations are unpredictable and make long-range management planning and quantification of objectives difficult

Habitat

Objective: Achieve no net loss of the productive capacity of habitat supporting Lake Superior fishes. Where feasible, restore habitats that have been degraded and have lost their capacity for fish production . Reduce contaminants so that all fish are safe to eat. Develop comprehensive and detailed inventories of fish habitats.

The Joint Plan calls upon the Lake Committees to identify the habitat needs for desired fish communities and to work in cooperation with other ecosystem initiatives, such as the Lake Superior Binational Program. The identification, restoration, and protection of important habitat for all species living in the Lake Superior basin are primary objectives of this program. The habitat requirements of individual Lake Superior fish species or of the overall fish community have not been quantified. However a great deal is known about the specific requirements of individual species. Koonce et al. (1999) have proposed a methodology for identifying and classifying the habitats most important for sustaining not only individual species but also fish communities as a whole.

Resources for the identification, restoration, and protection of important habitat include:

- Atlas of the Spawning and Nursery Areas of Great Lakes Fishes (Goodyear et al. 1982)

- Habitat 2001 (Graham and Iwachewski 1997)

- A Summary of Important Habitat Conditions in the Lake Superior Basin (Wisconsin Department of Natural Resources 1996)

- Environmental Objectives Workshop Report (Koonce 1994)

- Biodiversity Investment Areas in the Great Lakes Basin (Koonce et al. 1998)

- Coastal Wetland Biodiversity Investment Areas (Chow-Fraser and Albert 1998)

Future work will be assisted by the newly formed Great Lakes Fish Habitat Conservation Committee organized by the Great Lakes Fishery Commission (GLFC).

Habitat can be classified into four zones in Lake Superior, each with its own characteristic fish assemblage. The categories below are somewhat arbitrary but useful for establishing a framework for discussion:

- Offshore (>80 m (260 ft) deep)
- Nearshore (0-80 m (260 ft) deep)
- Embayments (harbors, estuaries, and bays subject to seiches)
- Tributary reaches not subject to seiches

Any categorization of this sort is somewhat arbitrary but useful in describing and understanding this vast and diverse body of water. There is much interchange of material and energy among the zones due to wind, currents, upwellings, and movements of fish and other organisms. Each of these habitat zones is subject to distinct stresses, which have been identified in the Lakewide Management Plan (Lake Superior Binational Program 2000).

Approximately 77% of the surface area of Lake Superior is considered offshore habitat. It contains nearly all of the spawning and feeding habitat for siscowet lake trout, humper lake trout, deepwater ciscoes, and deepwater sculpins. The offshore fish community also includes burbot, Pacific salmon, sea lamprey, and lake herring.

Roughly 23% of Lake Superior's surface area is nearshore habitat. Most of the important and critical habitat for lean lake trout, lake herring, and lake whitefish is found in this zone (Figs. 1a-1c). This fish community is comprised of lean lake trout, siscowet lake trout, humper lake trout, burbot, Pacific salmon, brown trout, lake herring, lake whitefish, round whitefish (*Prosopium cylindraceum*), rainbow smelt, lake sturgeon, ninespine sticklebacks, pygmy whitefish, deepwater ciscoes, slimy and deepwater sculpins, trout perch (*Percopsis omiscomaycus*), and longnose and white suckers. The major sport and commercial fisheries in Lake Superior are also located in the nearshore zone.

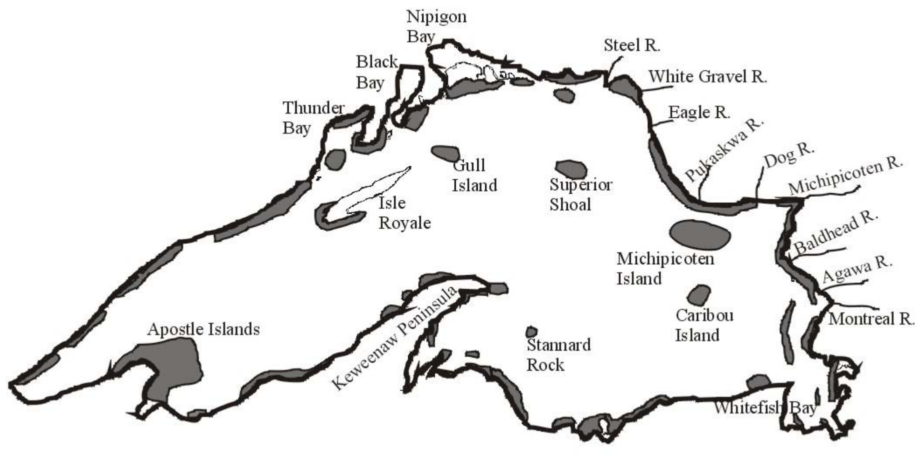

Fig. 1a. Locations of known historic lake trout spawning grounds (shaded areas) in Lake Superior (Coberly and Horral 1980; Goodier 1981; Goodyear et al. 1982).

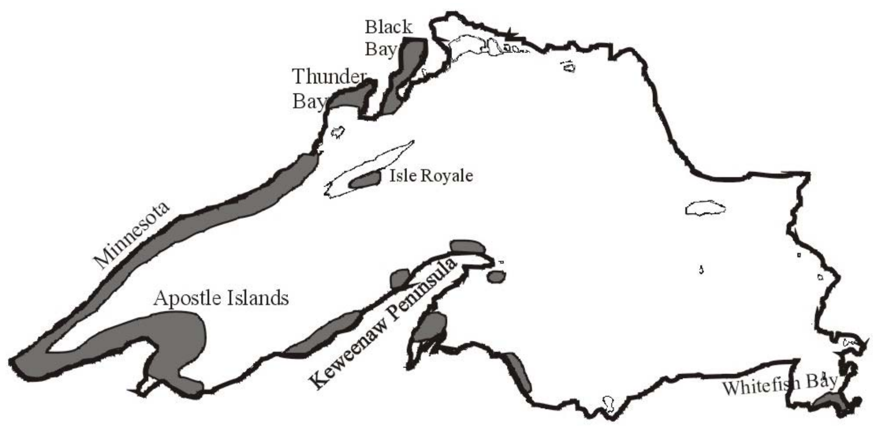

Fig. 1b. Locations of known historic lake herring spawning grounds (shaded areas) in Lake Superior (Coberly and Horral 1980; Goodier 1981; Goodyear et al. 1982).

Fig. 1c. Locations of known historic lake whitefish spawning grounds (shaded areas) in Lake Superior (Coberly and Horral 1980; Goodier 1981; Goodyear et al. 1982).

The fish communities occupying embayments are more diverse than those in the offshore and nearshore habitats primarily because the embayments are warmer, more productive, and more physically diverse than other zones in the lake. Embayments support both warm- and cool-water species including walleye, smallmouth bass, yellow perch, rock bass (*Ambloplites rupestris*), northern pike, trout-perch, lake sturgeon, brook trout, ninespine sticklebacks, johnny darters (*Etheostoma nigrum*), emerald shiners (*Notropis atherinoides*), longnose dace (*Rhinichthys cataractae*), sand shiners (*Notropis stramineus*), bullheads (*Ameiurus* spp.), carp (*Cyprinus carpio*), and redhorse suckers (*Moxostoma* spp).

Approximately 3,300 km (2,063 mi) of tributaries are available to Lake Superior fishes. Some fish that live in offshore, nearshore, and embayment zones also spend part of their life in tributaries. The fish communities of tributaries may include walleye, brook trout, burbot, lake sturgeon, Pacific salmon, longnose and white suckers, redhorse suckers, mottled sculpin (*Cottus bairdi*), bullheads, sea lamprey, and many species of minnows (*Cyprinidae* spp.). Tributaries provide critical habitat for lake sturgeon, walleye, brook trout, brown trout, rainbow trout, Pacific salmon, and sea lamprey. Rainbow trout and brook trout are found in more tributaries of Lake Superior than the other species listed here, while lake trout and lake whitefish are uncommon.

Some populations of Lake Superior fish are currently limited by habitat—others are limited by competition or predation by other species. Presently, the following populations are not limited by habitat:

- All lake-spawning populations of lake trout, lake herring, lake whitefish, deepwater ciscoes, and round whitefish
- Salmonines, other than lake trout, that spawn in Lake Superior and live in the offshore, nearshore, or embayment habitats (note: salmonines that either spawn or live in tributaries could be limited by habitat loss)
- Rainbow smelt, sculpins, trout perch, pygmy whitefish, and ninespine stickleback populations that spawn in Lake Superior

In contrast, the following fish populations have been affected by habitat loss in the Lake Superior basin, and achievement of fish community objectives may not be possible under current habitat conditions:

- Lake trout stocks that spawn in eastern Ontario tributaries of the lake
- The lake whitefish stock that historically spawned in the St. Louis estuary—this stock of lake whitefish was extirpated over 100 years ago because of habitat destruction
- Brook trout, brown trout and Pacific salmon stocks that spawn in tributaries
- Walleye and lake sturgeon stocks that spawn in tributaries
- Yellow perch, northern pike, and smallmouth bass
- Rainbow smelt stocks that spawn in tributaries

The principal stresses to habitats in Lake Superior include:

- Atmospheric deposition of contaminants
- Dams
- Industrial effluents and waste
- Wetland dredging and filling
- Nonpoint source pollution
- Shoreline development
- Land-use practices that lead to increased runoff and erosion

Specific stresses and affected species are listed in Table 4. Generally, loss of habitat is an issue only in the embayment and tributary habitat zones of Lake Superior. However, discharges of mine chemicals and tailings have degraded a few local areas of the nearshore habitat zone along the Minnesota and Michigan shorelines. Further, atmospheric deposition of contaminants lakewide, over time, has degraded all habitat zones to some degree. There is probably enough high-quality habitat in the offshore and nearshore zones in Lake Superior to allow achievement of the fish-community objectives described below. By contrast, the tributary and embayment zones do not have sufficient amounts of suitable habitat.

Table 4. Stresses to fish habitat and the species affected at specific sites around Lake Superior.

Site	Environmental Stress	Affected Species
Whitefish Bay	Dredging of spawning grounds	Eggs of lake whitefish
Batchawana Bay	Removal of aquatic vegetation	Yellow perch, smallmouth bass, cyprinids
Current River	Removal of spawning substrate	Walleye
Montreal River	Hydroelectric peaking dam	Eggs of walleye and lake trout
Nipigon River	Hydroelectric development	All life stages of brook trout
Peninsula Harbor	Mercury contamination from pulp mill	All species
Terrace Bay	Wood fiber effluent from pulp mill	Eggs of lake trout
Thunder Bay	Urban development and loss of wetlands	Walleye, yellow perch
Kaministiquia River	Wood fiber effluent and chemicals	All species

Table 4, *continued*

Site	Environmental Stress	Affected Species
St. Louis River	Hydroelectric dams, breakwalls, industrial effluents, vessel discharge, loss of wetlands	Walleye, sturgeon, perch, northern pike, lake whitefish
North and South Entry	Mine tailings, loss of wetlands	Lake trout, lake whitefish
Ontonagon River	Hydroelectric development, loss of wetlands, industrial effluents	Walleye, sturgeon, salmonines
Sturgeon River	Hydroelectric development, industrial effluents	Walleye, sturgeon
L'Anse Bay	Loss of wetlands	Yellow perch
Bete Gris Bay	Loss of wetlands	Yellow perch, walleye, northern pike
Huron Bay	Loss of wetlands	Yellow perch
Falls River	Industrial effluents	All species
Dead River	Industrial effluents, hydroelectric dams	All species
AuTrain River	Hydroelectric dams	Anadromous species
Numerous streams	Landscape changes altering stream hydrology	Stream species, notably brook trout

Prey Species

Objective: A self-sustaining assemblage of prey dominated by indigenous species at population levels capable of supporting desired populations of predators and a managed commercial fishery.

The prey fish assemblage of Lake Superior is comprised mostly of lake herring, three species of deepwater ciscoes (primarily bloater, slimy and deepwater sculpins, ninespine sticklebacks, and rainbow smelt (Lawrie 1978).

Historically, lake herring was the dominant prey fish in Lake Superior (Dryer et al. 1965). They supported lake trout populations and comprised most of the commercial fishery landings (Baldwin et al. 1979). Populations of lake herring declined drastically in United States waters during the mid-1960s. The collapse has been attributed to overfishing (Selgeby 1982) and to predation by, and competition with, rainbow smelt (Anderson and Smith 1971). Rainbow smelt became abundant during the 1930s, 1940s, and 1950s and were the main component of the nearshore prey community until the early 1980s when a significant decline was observed in United States waters (MacCallum and Selgeby 1987; Selgeby et al. 1994). Rainbow smelt densities have remained low for the past 17 years and are not expected to recover to former levels. Although recruitment of rainbow smelt has remained relatively stable, predation limits the number of fish living beyond age 4 (Bronte and Hoff 1997). Recent surveys in Ontario waters indicate that densities there are much higher, and mortality is lower than in United States waters. Even though rainbow smelt densities are depressed, this fish still comprises a large portion of the diets of nearshore predators (Conner et al. 1993; Bronte et al. 1996; Gallinat and Bronte 1996).

Lake herring began to recover in Lake Superior in 1978 with recruitment of the 1977 year-class. Densities increased further in the 1980s because of large year-classes produced in 1984, 1988, 1989, 1990, and 1998 (Selgeby et al. 1994; Hoff 2001). Moderate to large parental stock sizes have been present since the late 1980s, but their progeny are few. Some of the weakest year-classes have been produced under the highest stock sizes, suggesting a density-dependent effect on the survival of young. Similar patterns in recruitment across jurisdictions, combined with the contrast between recruitment events, also suggest that some lakewide, density-independent factor(s) may be important to recruitment rather than simply total egg deposition. Despite the abundance of parental stocks, recruitment from 1991 to 1998 has been poor, resulting in an 80% reduction in biomass since a peak was reached in 1990 (Hoff and Bronte 1998). Adult lake herring are now too large to be consumed by any but the largest predators. The low biomass of both rainbow smelt and lake herring has resulted in a shift of predation to sculpins, ninespine sticklebacks, terrestrial insects, and other previously underutilized food resources, emphasizing the importance of these species as a reserve forage base.

Management agencies are limited in what can be done to affect change in Lake Superior's prey-fish populations, but continuing to limit the commercial harvest of lake herring can minimize mortality of spawning populations. Predation cannot be controlled because populations of lake trout, salmon, and other predators are maintained primarily by natural reproduction. Current fisheries for bloaters and rainbow smelt remove only a fraction of the biomass, so elimination of fishing would not result in significant increases in either biomass or recruitment. Stocking prey species is not an option because the biological, financial, and logistical requirements to make an impact are prohibitive. There are no recognized habitat-related impediments to lake herring recruitment. Habitat loss in tributaries may be a problem for small, localized populations.

Lake Trout

Objective: Achieve and maintain genetically diverse self-sustaining populations of lake trout that are similar to those found in the lake prior to 1940, with lean lake trout being the dominant form in nearshore waters, siscowet lake trout the dominant form in offshore waters, and humper lake trout a common form in eastern waters and around Isle Royale.

Lake trout management is guided by A Lake Trout Restoration Plan for Lake Superior (Hansen 1996). Lake trout have been, and continue to be, the dominant predator in Lake Superior. At least three forms of lake trout have been recognized in the lake—leans, siscowets, and humpers (Moore and Bronte 2001), although up to 12 morphological variants have been reported (Goodier 1981). Lean lake trout are the most commonly recognized form and, along with siscowet lake trout, are the dominant predator in nearshore waters less than 80 m (260 ft) deep and over shallow offshore reefs. Siscowet lake trout inhabit mainly offshore waters deeper than 80 m (260 ft), but they are also common in nearshore waters throughout the lake. Humpers are the least abundant of the three forms of lake trout and live primarily on deep, offshore underwater reefs around Isle Royale and in the eastern waters of the lake around Caribou Island. These three forms of lake trout are distinguished from each other by differences in the shape of the snout and body, fat content, size of the eye, and thickness of the abdominal wall (Lawrie and Rahrer 1973; Burnham-Curtis 1993). The current lake trout rehabilitation plan for Lake Superior calls for the development of specific objectives for each of the three lake trout forms.

All three forms of lake trout were represented in the historic commercial harvest that averaged 1.8 million kg (4 million lb) during 1929-43—the time period just before the collapse of the lean lake trout populations began. Lake trout populations were believed to have been stable during 1929-43, but recent analysis of historic commercial catch data suggests that populations were declining in several areas of Lake Superior during this time period (Bronte 1998; Wilberg 2000). Analysis of historical commercial catch data indicates that the lean form of lake trout comprised the bulk of the historic harvest, although the proportion of each form of lake trout represented in historic catches varied among locations. Lean lake trout comprised:

- 87% of the historic harvest from Wisconsin waters (Swanson et al. 1994)
- 75% in Michigan waters (Bronte 1998)

Thus, siscowet lake trout and humper lake trout could have comprised 20% or more of the historic yield from Lake Superior (Bronte 1998). Fishery-management agency efforts to rehabilitate lake trout populations in Lake Superior have focused on the lean form for the last 40 years. Siscowet lake trout are currently the most-abundant form in Lake Superior. Surveys in 1996 and 1997 indicate that they are expanding their distribution into nearshore waters and outnumbering lean lake trout in some areas (Lake Superior Technical Committee, 2100 Commonwealth Blvd., Suite 100, Ann Arbor, MI 48105, unpubl. data; Charles R. Bronte, U.S. Fish and Wildlife Service, Green Bay Fishery Resources Office, 1015 Challenger Ct., Green Bay, WI 54311, unpubl. data).

Impediments to fully achieving and maintaining the lake trout objective include:

- Predation by sea lamprey
- Overfishing
- Habitat degradation or loss in tributaries

Sea lampreys continue to kill significant numbers of lake trout. They may have accounted for 31% of the total number of lake trout killed in the United States waters of Lake Superior from 1990-92 (Hansen 1994). Lakewide, exploitation is not excessive (Hansen 1994). Habitat loss or degradation is an impediment to lake trout rehabilitation only in isolated areas. Fortunately, much of the nearshore and most of the offshore habitat of lake trout has remained relatively unchanged over time, and is not an impediment to lake trout restoration. However, habitat impairment may be an impediment to lake trout recovery in some embayments and tributaries. There is concern that hydroelectric peaking operations on the Montreal River in eastern Ontario waters may be affecting spawning activity and survival of lake trout eggs. Wood fiber effluent from paper mills may be affecting survival of lake trout eggs in Terrace Bay, Ontario. Although atmospheric deposition of chemicals (for example, PCBs) affects the consumption of lake trout by humans, the effect of these chemicals on achieving the lake trout objective for Lake Superior is still being debated and examined within the scientific community.

Nearly the entire lake is important habitat for lean, siscowet, and humper lake trout (Coberly and Horrall 1980; Goodier 1981; Goodyear et al. 1982). In offshore areas, important spawning habitat is found on Gull Islands, Superior Shoal, Stannard Rock, Caribou Island, Michipicoten Island, and in eastern Ontario waters. Lake trout spawning grounds are found throughout the nearshore waters and amount to roughly 140,000 ha (345,940 acres) in United States waters alone. There are:

- 337 locations in Lake Superior where lake trout historically spawned

- 9 tributaries to eastern Ontario waters of Lake Superior that lake trout historically ascended to spawn

Lake Whitefish

Objective: Maintain self-sustaining populations of lake whitefish within the range of abundance observed during 1990-99.

Lake whitefish populations in Lake Superior were reduced in the early part of the 20th century—possibly as a consequence of the progressive elimination of discrete stocks (Lawrie and Rahrer 1972) and/or habitat degradation caused by the deposition of woody debris in rivers and embayments. Over the past two decades, populations have increased significantly, as reflected by the increased commercial catch per effort. This species, which is considered resilient to exploitation (Smith 1972; Healey 1975), has recovered to the point where commercial harvests have been in excess of 1,000 tons annually since 1990. Maintenance of the relatively high abundance observed during the 1990s would provide an economically viable commercial fishery with stable catch rates. In addition, the species would continue to be a significant component of the fish community.

Lake whitefish home to spawning grounds from locations typically within 40 km (25 mi) of the grounds. This behavior has resulted in the creation of distinct stocks (Walker et al. 1993). In Lake Superior, lake whitefish spawn in early November over coarse sand or rubble in shallow water in embayments and nearshore areas. River-spawning populations have also been documented (Lawrie and Rahrer 1972), for example:

- St. Marys River rapids above the control gates
- St. Louis River in the United States
- Michipicoten, Dog, and Kaministiquia rivers in Ontario

We do not know the quantities of the various habitats required to support the desired lake whitefish populations, but it is possible to describe their habitat needs qualitatively. The offshore habitat zone appears not to be important to the species. Nearshore areas are used by adult lake whitefish for foraging and spawning. Embayments and the nearshore areas also provide habitat for developing larvae and juveniles. Streams—at least those that can be identified as having historic spawning runs—are important spawning habitat in addition to shallow areas with gravel bottoms.

Commercial fishing is currently the major cause of mortality in adult lake whitefish in Lake Superior. Sea lamprey can kill lake whitefish and significantly reduce lake whitefish populations, but current wounding rates in Lake Superior are low. Lake whitefish have rarely been found in the diet of salmonine predators in Lake Superior (Conner et al. 1993; Lake Superior Technical Committee, 2100 Commonwealth Blvd., Suite 100, Ann Arbor, MI 48105, unpubl. data).

Walleye

Objective: Maintain, enhance, and rehabilitate self-sustaining populations of walleye and their habitat over their historical range.

The status of walleye in Lake Superior and its tributaries has been summarized by the Lake Superior Technical Committee (LSTC) (Hoff 1996). In addition, the LSC has endorsed a walleye-rehabilitation plan for Lake Superior (Hoff 2001). Walleye were important in regional fisheries in large bays, estuaries, and rivers of Lake Superior and were likely important predators in the respective fish communities. Historically, the largest populations of walleye were found in Black Bay (Ontario) and the St. Louis River (Minnesota and Wisconsin) and its embayment. Walleye in the St. Louis River are already considered rehabilitated. Walleye are currently found in about 79 tributaries and in most bays on Lake Superior.

Achievement of the fish-community goal for walleye will depend upon the availability of sufficient and usable habitat. Survival of walleye populations depends on the existence of suitable habitat in embayments and tributaries, where, unfortunately, the most-negative impacts have occurred.

Impediments to achieving the walleye goal include fishing-induced mortality and habitat degradation, including poor water quality. These stresses have affected walleye populations in every major bay and tributary of Lake Superior. Overfishing has been identified as a factor limiting stocks of walleye in most of the major tributaries. Winter navigation and shipping have negatively affected walleye populations in the upper St. Marys River by causing:

- Sedimentation of spawning and nursery areas

- Loss of submerged and emergent vegetation in nursery areas near commercial shipping channels

Walleye habitat has also been degraded in Huron Bay, the Ontonagon River, the St. Marys River, Goulais Bay, Nipigon Bay, and Thunder Bay by:

- Logging and agricultural practices
- River bank erosion
- Wetlands development
- Hydroelectric power development
- Sedimentation

Poor water quality has limited the walleye in parts of the St. Louis River. Levels of toxic contaminants in walleye have resulted in advisories regarding consumption of walleye in many bays of Lake Superior.

Lake Sturgeon

Objective: Rehabilitate and maintain spawning populations of lake sturgeon that are self-sustaining throughout their native range.

The status of lake sturgeon has been summarized by the LSTC (J. Slade, Ludington Sea Lamprey Control, 229 South Jebavy Drive Station, Ludington, MI 49431, personal communication). The LSC has endorsed a lake sturgeon rehabilitation plan for Lake Superior (Auer, in press). The lake sturgeon is the only species of sturgeon indigenous to the Great Lakes. It is also the largest and longest-lived fish in the basin. Sturgeon are distributed throughout the Lake Superior basin with concentrations found near tributaries where the species spawns. At least 17 tributaries within the Lake Superior basin were known (based on catches made by native Americans and documented by 17th century explorers) to contain spawning concentrations of lake sturgeon (J. Slade, Ludington Sea Lamprey Control, 229 South Jebavy Drive Station, Ludington, MI 49431, personal communication). Lake sturgeon populations likely began to decline prior to the first commercial catch records of the late 1880s due to the combined effects of pollution from sawmills, log drives on spawning tributaries, and bycatch in other commercial fisheries. In the late 1920s, hydroelectric dams were constructed on several tributaries used for spawning by lake sturgeon, and industrial developments on other tributaries further destroyed spawning and rearing habitat.

Currently, nine tributaries to Lake Superior are known to support self-sustaining populations of lake sturgeon: Sturgeon, Bad, Big Pic, Black Sturgeon, Goulais, Gravel, Kaministiquia, Michipicoten, and Nipigon rivers. Populations in all nine tributaries are reduced from historic levels, but they appear to be recovering. Lake sturgeon abundance in the St. Louis River estuary and along the south shore of Lake Superior has been increasing since 1988. An increase in abundance of lake sturgeon in western Lake Superior waters has been attributed to stocking fingerling lake sturgeon in the St. Louis River embayment. The population of juveniles in this area is stable (J. Slade, Ludington Sea Lamprey Control, 229 South Jebavy Drive Station, Ludington, MI 49431, personal communication; Schram et al. 1999).

Our objective for lake sturgeon will be considered achieved when at least 1,500 adults, with equal numbers of males and females and representing 20 year-classes, spawn in each of the 17 tributaries known to have once supported spawning populations. These adult fish should produce annual evidence of reproduction that can be measured by collecting viable eggs and age-0-5 lake sturgeon in tributaries. Impediments to achievement of this objective may include:

- Excessive sport and commercial harvests
- Mortality during sea lamprey control activities
- Habitat destruction
- Dams

Most of the impediments to achieving the objective for lake sturgeon occur in embayment and tributary habitats. Stresses to the embayment habitat include dredging, break walls, vessel discharges, industrial discharges, and filling of wetlands and sloughs. These activities may affect all life stages of lake sturgeon with the exception of the egg in all the bays around Lake Superior. Stresses to the tributary habitats are hydroelectric development, landscape changes that affect surface hydrology and point-source and nonpoint-source pollution, including sedimentation. Alterations of tributary habitat affect all life stages of lake sturgeon from egg to adult.

Brook Trout

Objective: Maintain widely distributed, self-sustaining populations in as many of the historical habitats as is practical.

The status of brook trout in Lake Superior has been summarized by the LSTC (Newman and DuBois 1997). A rehabilitation plan has been endorsed by the LSC (Newman et al., in press). A large anadromous or lake-dwelling form of brook trout, called a coaster, was historically widespread and common in the very nearshore waters of Lake Superior. Brook trout provided a highly valued and productive fishery along shoreline areas of the lake and in tributaries with spawning populations. These lake-run brook trout were known to inhabit at least 118 streams tributary to Lake Superior (Newman and DuBois 1997). Those fish were extirpated rapidly by fishing and habitat degradation during the 1880s, and, by the end of the 1920s, just a handful of streams supported viable populations of lake-run brook trout. Contemporary lake-run populations of brook trout are found in remote areas including populations around Isle Royale and in the Cypress, Big Gravel, and Little Gravel rivers in Ontario. The Nipigon River in Ontario contains the most-robust population in the Lake Superior basin.

Because very little is known about the ecology of brook trout in Lake Superior, specific strategies to achieve the goal should be flexible. Restrictive harvest regulations, stocking hatchery-reared fish, and habitat restoration may all be required.

The lakewide brook trout rehabilitation plan (Newman et al., in press) adopted in 1999 lists the following objectives:

- Populations will be self-sustaining and capable of coexisting with naturalized salmonines

- Populations will be geographically widespread, inhabiting areas that historically held viable populations if tributary and lake habitat conditions in these areas are still suitable or can be restored

- Populations will be comprised of six or more age groups—including at least two spawning year-classes of females—and will be sufficiently large to ensure viable gene pools

- Populations will exhibit genetic profiles consistent with those of populations currently inhabiting the Lake Superior basin

- Essential habitats in tributaries will be protected and, where necessary, rehabilitated

- Populations will be capable of supporting managed fisheries

Restoration and protection of tributary habitat is essential for achieving the brook trout goal. Hydroelectric development and operation, barrier dams, land-use practices, timber harvesting, and sedimentation all contribute to the loss of habitat for brook trout. Additional impediments to brook trout in Lake Superior may be splake and/or naturalized salmonines that occupy tributaries during their life cycle (Newman et al., in press).

Pacific Salmon, Rainbow Trout, and Brown Trout

Objectives: Manage populations of Pacific salmon, rainbow trout, and brown trout that are predominantly self-sustaining but that may be supplemented by stocking that is compatible with restoration and management goals established for indigenous fish species.

Non-indigenous top predators currently living in Lake Superior include rainbow trout, brown trout, chinook salmon, coho salmon, splake, pink salmon, and Atlantic salmon. Splake is stocked in some areas of the lake to provide a sport fishery. The annual yield of all these species accounts for 15%-20% of the total harvest of all salmon, trout, and chars (lake trout and brook trout) from Lake Superior. All of these species are sustained by a combination of natural reproduction and stocking, except splake, which are not thought to reproduce in the wild. Stocking coho salmon has been discontinued throughout the lake, yet they continue to be an important sport fish. They spawn in at least 79 Lake Superior tributaries. Returns of chinook salmon to sport fisheries in the areas where they were stocked have declined (Schreiner 1995). A recent study by the LSTC found that naturally reproduced chinook salmon made up over 75% of the sport harvest of this fish from Lake Superior (Peck et al. 1999). Pink salmon were accidentally stocked in Lake Superior but became established and have colonized spawning streams around the entire lake. Rainbow trout have become naturalized in over 200 of 1,525 Lake Superior tributaries.

Non-indigenous salmon and trout have developed self-sustaining populations throughout the lake. They require suitable habitat in tributaries to Lake Superior for successful reproduction and rearing of juveniles. Hydroelectric development limits the amount of tributary habitat available to salmon and trout for spawning and also produces erratic flow regimes that lower the survival rate of eggs and diminish the amount of protective cover available to juveniles. Forestry and agricultural practices often increase stream temperatures and sedimentation in tributaries. After emigration from streams, salmon and trout are found throughout the nearshore areas of Lake Superior, where they feed extensively on terrestrial insects, smelt, and young lake herring (Conner et al. 1993).

The effects of competition and/or predation on lake trout and brook trout by both stocked and wild salmon and trout remain a concern for management agencies (Lake Superior Lake Trout Technical Committee 1986; Busiahn 1990); however, that concern does not apply to the offshore waters of the lake. If salmon and trout are depressing lake trout or brook trout populations, the effects would most likely occur in the nearshore zone where introduced salmon and trout are most abundant. Non-indigenous salmon and trout, however, may compete with lake trout or brook trout in tributaries.

The use of non-indigenous predators has led to concerns regarding the potential for introducing pathogens to the lake. Fish health concerns in the Great Lakes are addressed by the Fish Health Committee of the GLFC. Guidance regarding the control of fish diseases and the minimization of the risk of introducing pathogens is contained in two documents, Great Lakes Fish Disease Control Policy (Hnath 1993) and Model Program and Protocol to Minimize the Risk of Introducing Emergency Disease Agents with Importation of Salmonid Fishes from Enzootic Areas (Horner and Eshenroder 1993). Management agencies on the Great Lakes have, acting through the Council of Lake Committees, adopted a Procedures for Consultation, to be followed when any jurisdiction wishes to introduce any species into the Great Lakes basin (Council of Lake Committees 1992).

Sea Lamprey

Objective: Suppress sea lampreys to population levels that cause only insignificant mortality on adult lake trout.

The sea lamprey, a parasitic fish from the Atlantic Ocean first seen in Lake Superior in 1938, has been suppressed to less than 10% of pre-control population levels, mainly through the application of the lampricide TFM in tributaries (Fig. 2). The TFM applications, begun in 1958, undoubtedly saved inshore and likely some offshore lake trout populations from extirpation and set the stage for lake trout recovery to near pre-control numbers in most areas. Despite persistent suppression, sea lampreys remain a significant cause of mortality in lake trout. During the ten-year period from 1985-94, sea lampreys accounted for 16% of the annual mortality in lake trout. If suppression could be increased, more lake trout would be available for harvest and reproduction.

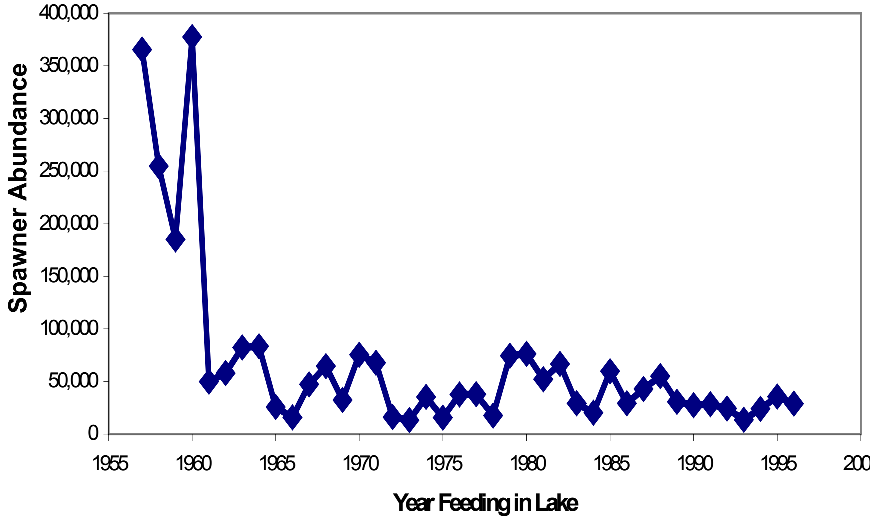

Fig. 2. Abundance of parasitic-phase sea lamprey in United States waters of Lake Superior.

The management objective for sea lampreys is to suppress populations until annual lamprey-induced adult lake trout mortality is essentially insignificant (< 5%). This objective is clearly desirable, but intensified control efforts with TFM are unlikely to achieve it. All of the major lamprey-producing tributaries are presently being treated. Model projections of sea lamprey abundance against treatment costs indicate that more stream treatments will yield only small benefits (Fig. 3). With new methods of application, however, the same level of suppression is being achieved with 25% less TFM. Now that granular Bayluside has been reformulated, lamprey-infested areas outside of river mouths can be effectively treated. The extent of those infestations is currently being assessed and methods to inventory lentic habitats are being developed (Fodale et al., in press).

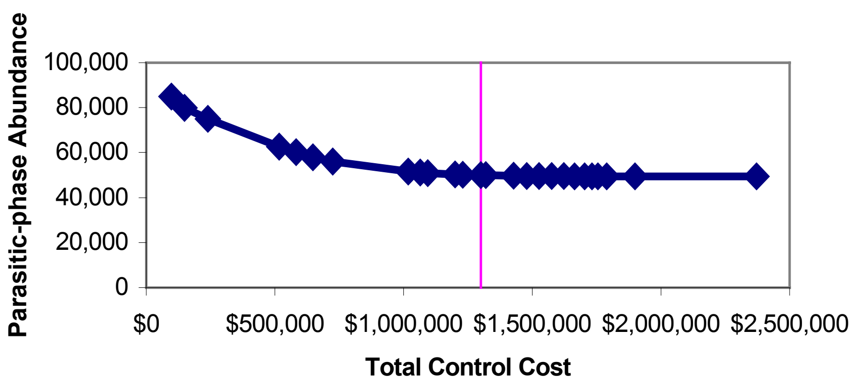

Fig. 3. Abundance of parasitic-phase sea lampreys in relation to costs of stream treatments in Lake Superior. The vertical line shows costs of the 1997 program.

Alternative methods of control offer the best prospects for gains in suppression. More barriers that block adult sea lampreys from their spawning grounds can be constructed. The top five sites for barriers are the:

- Goulais River (Ontario)
- Betsy and Two Hearted Rivers (Michigan)
- Bad and Iron Rivers (Wisconsin)

Well-placed barriers can reduce the need for lampricide treatments, but improved designs are needed to minimize effects on nontarget fishes. The introduction of sterilized male sea lampreys is currently being researched, and early results indicate that sterile males compete with normal males and impede reproduction. Unfortunately, the current supply of males for sterilization is inadequate to meet our needs.

The objective of reducing sea lamprey populations in Lake Superior to ecological insignificance is unlikely to be fully achieved until new control technologies become available. Of the candidate technologies being researched, pheromone-based control is the most promising, but it has not yet been field-tested. Other approaches are now only at the conceptual stage. Moving a candidate technology from “promising concept” to “operational feasibility” can take 6-10 years—provided that major bottlenecks are not encountered and funding is adequate. In summary, achievement of the management objective of ecological insignificance for sea lampreys is promising but challenging and will require a long-term commitment of time and money.

Nuisance Species

Objective 1: Prevent the introduction of any non-indigenous aquatic species that is not currently established in Lake Superior.

Objective 2: Prevent or delay the spread of non-indigenous nuisance species, where feasible.

Objective 3: Eliminate or reduce populations of non-indigenous nuisance species, where feasible.

Since the 1800s, at least 139 non-indigenous aquatic organisms, including 25 species of fish, have become established in the Great Lakes (Mills et al. 1993). Of the 96 fish species present in Lake Superior and its tributaries, 16 are non-indigenous (Appendix D). The rate of introductions has increased over the past 40 years—nearly a third of the non-indigenous species have been introduced into the Great Lakes since the opening of the St. Lawrence Seaway in 1959. Most non-indigenous species enter the Great Lakes either by unintentional release or in ships ballast. The effects of established and abundant non-indigenous species are instability and unpredictability in a previously stable ecosystem and a loss of diversity in biotic communities (Mills et al. 1993).

The ecological and economic impacts of non-indigenous nuisance species have been enormous. The sea lamprey alone has cost hundreds of millions of dollars in losses to fisheries and costs of control—in addition to the depletion or extirpation of lake trout populations. Ruffe colonized the St. Louis River in the 1980s (Pratt et al. 1992) and became very abundant in some western embayments, raising concerns about competition with indigenous species (Ruffe Task Force 1992; Bronte et al. 1998). Zebra mussels and round gobies have affected the other Great Lakes and may yet have local effects in Lake Superior bays and harbors.

Management agencies are hampered by a lack of technology for controlling aquatic nuisance species after they become established. The integrated pest management approach advocated by Marsden (1993) and others requires a set of management tools from which to choose. By and large, these tools do not exist for most aquatic pests. An economic injury analysis is not appropriate for application to common property resources and non-economic values, such as biodiversity. Research and development leading to new analytical and management tools are needed for an adequate response to non-indigenous aquatic nuisance species (Busiahn 1993).

Species Diversity

Objective: Protect and sustain the diverse community of indigenous fish species not specifically mentioned earlier (burbot, minnows, yellow perch, northern pike, and suckers). These species add to the richness of the fish community and should be recognized for their ecological importance and cultural, social, and economic value.

There are 86 species, of which 70 are indigenous, in the fish community of Lake Superior (Appendix D). Most of these species are not specifically identified in this document because they are not considered directly relevant to the management of recreational and commercial fisheries. However, each species is recognized as having an important ecological role and, therefore, an intrinsic value. The loss of populations of all indigenous species should be prevented and those species that have been depleted or lost should be restored, where feasible.

Some of these species are of uncertain status because little effort has been expended to assess trends in their lakewide distribution or population status (for example, minnows). Others may be considered rare, threatened, or endangered. Some of these species are of economic value, while others are noted mostly for their integrative function within the Lake Superior ecosystem. As prey and predators, they act as energy vectors and provide balance and stability.

Specific objectives for the lower profile indigenous species are difficult to develop, but these species should be self-sustainable and protected. Management and protection of these species can be accomplished by:

- Protecting and rehabilitating habitat—particularly in nearshore zones—to provide adequate conditions for the diversity of indigenous fishes

- Regulating harvests (for example, bag limits for yellow perch and bait-fish harvest control)

- Preventing further unintentional introductions of non-indigenous aquatic species and, where feasible, controlling aquatic nuisance species

- Collecting baseline population data on abundance and distribution that will allow for detection of any serious population fluctuations or declines

LITERATURE CITED

Anderson, E.D., and L.L. Smith, Jr. 1971. Factors affecting abundance of lake herring (*Coregonus artedi* LeSueur) in western Lake Superior. Trans. Am. Fish. Soc. 100: 691-707.

Anonymous 1995. The Great Lakes. An environmental atlas and resource book. Environ. Can. and U.S. Environ. Prot. Agency. Government of Canada, Toronto, Ont., Canada and U.S. Environmental Protection Agency, Great Lakes National Prog. Office, Chicago, Ill. Third Edition.

Auer, N.A. (ED.). A lake sturgeon rehabilitation plan for Lake Superior. Great Lakes Fish. Comm. Tech. Rep. In press.

Baldwin, N.S., R.W. Saalfeld, M.A. Ross, and H.J. Buettner. 1979. Commercial fish production in the Great Lakes 1867-1977. Great Lakes Fish. Comm. Tech. Rep. 3.

Beckman, W.C. 1942. Length-weight relationship, age, sex ratio, and food habits of the smelt (*Osmerus mordax*) from Crystal Lake, Benzie County, Michigan. Copeia 2: 120-124.

Bennet, E.B. 1978. Characteristics of the thermal regime of Lake Superior. J. Gt. Lakes Res. 4: 310-319.

Bronte, C.R. 1998. Evaluation of historic lake trout harvests from Lake Superior. Lake Superior Committee Annual Meeting (Minutes). March 17-18, 1998. Great Lakes Fish. Comm.

_____, and M.H. Hoff. 1997. Population status and trends for Lake Superior forage fishes, 1978-96. Lake Superior Committee Annual Meeting (Minutes). March 19-20, 1997. Great Lakes Fish. Comm.

_____, L.M. Evrard, W.P. Brown, K.R. Mayo, and A.J. Edwards. 1998. Fish community changes in the St. Louis River estuary, Lake Superior, 1989-1996: is it ruffe or population dynamics? J. Great Lakes Res. 24: 309-318.

_____, M.P. Gallinat, M.C. Donofrio, M.P. Ebener, S.T. Schram, R.G. Schorfaar, and D. R. Schreiner. 1996. Results of the interagency assessment of the diet of lake trout in Lake Superior, 1991-1994. Lake Superior Committee Annual Meeting (Minutes). March 28-29, 1996. Great Lakes Fish. Comm.

Burnham-Curtis, M.K. 1993. Intralacustrine speciation of *Salvelinus namaycush* in Lake Superior: an investigation of genetic and morphological variation and evolution of lake trout in the Laurentian Great Lakes. Ph.D. thesis. University of Michigan, Ann Arbor, MI.

Busiahn, T.R. 1990. Fish-community objectives for Lake Superior. Great Lakes Fish. Comm. Spec. Pub. 90-1.

_____. 1993. Can the ruffe be contained before it becomes *your* problem? Fisheries 18(8): 22-23.

Chow-Fraser, P., and D.A. Albert. 1998. Coastal wetland biodiversity investment areas. Presentation at the State of the Lake Ecosystem Conference (SOLEC), Buffalo, N.Y. http://www.epa.gov/glnpo/solec/98/present

Coberly, C.E., and R.M. Horrall. 1980. Fish spawning grounds in Wisconsin waters of the Great Lakes. Marine Studies Center, University of Wisconsin—Madison. Univ. Wisc. Sea Grant Inst., Madison, WI.

Conner, D.J., C.R. Bronte, J.H. Selgeby, and H.L. Collins. 1993. Food of salmonine predators in Lake Superior, 1981-87. Great Lakes Fish. Comm. Tech. Rep. 59.

Council of Lake Committees. 1992. Fish communities and introductions in the Great Lakes basin: draft procedures or model for consultation. Attachment XII, Minutes of the Council of Lake Committees Executive Summary, 1992. Great Lakes Fish. Comm.

Cudmore-Vokey, B., and E.J. Crossman. 2000. Checklists of the fish fauna of the Laurentian Great Lakes and their connecting channels. Can. Misc. Rep. Fish. Aquat. Sci. 2550.

Dryer, W.R., L.F. Erkkila, and C.L. Tetzloff. 1965. Food of lake trout in Lake Superior. Trans. Am. Fish. Soc. 94: 169-176.

Eisenreich, S.J., and W.M.J. Strachan. 1992. Estimating atmospheric deposition of toxic contaminants to the Great Lakes: an update. Environ. Can./Great Lakes Protection Fund. Burlington, Ont.

Fodale, M.F., C.R. Bronte, R.A. Bergstedt, D.W. Cuddy, and J.V. Adams. Classification of lentic habitat for sea lamprey (*Petromyzon marinus*) larvae using a remote seabed classification device. J. Gt. Lakes Res. In press.

Gallinat, M.P., and C.R. Bronte. 1996. Food habits of lake trout in management units WI-2 and MI-2 in Lake Superior, 1985-1994. Lake Superior Committee Annual Meeting (Minutes). March 28-29, 1996. Great Lakes Fish. Comm.

Goodier, J.L. 1981. Native lake trout stocks in the Canadian waters of Lake Superior, prior to 1955. Can. J. Fish. Aquat. Sci. 28: 1724-1737.

Goodyear, C.D., T. A. Edsall, D.M. Ormsby Dempsey, G.D. Moss, and P.E. Polanski. 1982. Atlas of the spawning and nursery areas of Great Lakes Fishes, Vol. 2: Lake Superior. U.S. Fish and Wildl. Serv., Washington, D.C. FWS/OBS-82-52.

Graham, J., and E. Iwachewski. 1997. Habitat 2001. A workshop on the future of habitat restoration and protection on the upper Great Lakes. February 25-27, 1997. Sault Ste. Marie, Ont. www.glsc.usgs.gov/library/new.htm

Great Lakes Fishery Commission. 1997. A joint plan for management of Great Lakes Fisheries. Great Lakes Fish. Comm. http.www.GLFC.org/pubs_out/docs.htm

Hansen, M.J. (ED.). 1990. Lake Superior: the state of the lake in 1989. Great Lakes Fish. Comm. Spec. Pub. 90-3.

_____. (ED.). 1994. The state of Lake Superior in 1992. Great Lakes Fish. Comm. Spec. Pub. 94-1.

_____. (ED.). 1996. A lake trout restoration plan for Lake Superior. Great Lakes Fish. Comm. Misc. Pub.

_____. 1999. Lake trout in the Great Lakes: basin-wide stock collapse and binational restoration. *In* Great Lakes Fishery Policy and Management: A Binational Perspective. W.W. Taylor and C.P. Ferrari (eds.). Michigan State Univ. Press. East Lansing, MI. pp. 417-453.

_____, J.W. Peck, R.G. Schorfhaar, J.H. Selgeby, D.R. Schreiner, S.T. Schram, B.L. Swanson, W.R. MacCallum, M.K. Burnham-Curtis, G.L.Curtis, J.W. Heinrich, and R.J. Young. 1995. Lake trout (*Salvelinus namaycush*) populations in Lake Superior and their restoration in 1959-1993. J. Gt. Lakes Res. 21 (Suppl. 1): 152-175.

Hay-Chmielewski, E.M. and G.E. Whelan, (EDS.). 1997. Lake sturgeon rehabilitation strategy. Mich. Dept. Nat. Resour. Fish. Div. Spec. Rep. No. 18.

Healey, M.C. 1975. Dynamics of exploited whitefish populations and their management with special reference to the Northwest Territories. J. Fish. Res. Board Can. 32: 427-428.

Hill, D.K., and J.J. Magnuson. 1990. Potential effects of global climate warming on the growth and prey consumption of Great Lakes fishes. Trans. Am. Fish. Soc. 119: 265-275.

Hnath, J.G. (ED.). 1993. Great Lakes fish disease control policy and model program (supercedes September 1985 edition). Great Lakes Fish. Comm. Spec. Pub. 93-1.

Hoff, M.H. (Ed.). 1996. Status of walleye in Lake Superior and its tributaries. Attachment 4g. Lake Superior Committee Annual Meeting (Minutes). March 28-29, 1996. Great Lakes Fish. Comm.

_____. 2001. Population status and trends for economically and ecologically important fishes in Lake Superior, 1978-1999. Lake Superior Committee Annual Meeting (Minutes). March 19-20, 2001. Great Lakes Fish. Comm.

_____, and C.R. Bronte. 1998. Population status and trends for economically and ecologically important fishes in Lake Superior, 1978-97. Lake Superior Committee Annual Meeting (Minutes). March 17-18, 1998. Great Lakes Fish. Comm.

Horner, R.W., and Eshenroder, R.L. (EDS.). 1993. Protocol to minimize the risk of introducing emergency disease agents with importation of salmonid fishes from enzootic areas. Great Lakes Fish. Comm. Spec. Pub. 93-1.

Hubbs, C.L., and K.F. Lagler. 1964. Fishes of the Great Lakes region. Univ. Michigan Press. Ann Arbor, MI.

International Joint Commission. 1987. Great Lakes Water Quality Agreement of 1978, as amended by protocol signed November 18, 1987. Office of Consolidation. International Joint Commission, Windsor, Ont.

Kitchell, J.F, S.P. Cox, C.J. Harvey, T.B. Johnson, D.M. Mason, K.K. Schoen, K. Aydin, C. Bronte, M. Ebener, M. Hanson, M. Hoff, S. Schram, D. Schreiner, and C.J. Walters. 2000. Sustainability of the Lake Superior fish community: analysis of interactions in a food web context. Ecosystems 3: 545-560.

Koonce, J.F. 1994. Environmental objectives workshop report. *In* Great Lakes Fish. Comm. Ecosystem Partnership Coordination Final Report. Appendix 2.

_____, C.K. Minns, and H.A. Morrison. 1998. Biodiversity investment areas in the Great Lakes basin: identification and validation. Discussion draft presented at SOLEC 98. http://www.on.ec.gc.ca/solec/pdf/abia.pdf

_____, C.K. Minns, and H.A. Morrison. 1999. A methodology for identifying and classifying aquatic biodiversity investment areas: application in the Great Lakes basin. Great Lakes Fish. Comm. Proj. Compl. Rep. <http://www.glfc.org/research/rcr.htm>

Lake Superior Binational Program. 2000. Lake Superior Lakewide Management Plan 2000. Chapter 8, aquatic community. Part I: fish and their habitat. http://www.epa.gov/glnpo/lakesuperior/lamp2000/#contents

_____. 1998. Ecosystem principles and objectives, indicators and targets for Lake Superior. Lake Superior Work Group. Thunder Bay, Ont.

Lake Superior Lake Trout Technical Committee. 1986. A lake trout rehabilitation plan for Lake Superior. Lake Superior Committee Annual Meeting (Minutes). March 20, 1986. Great Lakes Fish. Comm.

Lawrie, A.H. 1978. The fish community of Lake Superior. Intl. Assoc. Gt. Lakes Res. 43: 513-549.

_____, and J.F. Rahrer. 1972. Lake Superior: effects of exploitation and introductions on the salmonid community. J. Fish. Res. Board Can. 29: 765-776.

_____, and J.F. Rahrer. 1973. Lake Superior: a case history of the lake and its fisheries. Great Lakes Fish. Comm. Tech. Rep. 19.

MacCallum W.R., and J.H. Selgeby. 1987. Lake Superior revisited, 1984. Can. J. Fish. Aquat. Sci. 44(Suppl 2): 23-36.

Magnuson, J.J., K.E. Webster, R.A. Assel, C.J. Bowser, P.J. Dillon, J.G. Eaton, H.E. Evans, E.J. Fee, R.I. Hall, L.R. Mortsch, D.W. Schindler, and F.H. Quinn. 1997. Potential effects of climate changes on aquatic systems: Laurentian great lakes and Precambrian shield region. Hydrol. Proc. 2: 825-871.

Marsden, J.E. 1993. Responding to aquatic pest species: control or management? Fisheries 18(1): 4-5.

Matheson, D.H., and M. Munawar. 1978. Lake Superior basin and its development. J. Gt. Lakes Res. 4: 249-263.

Matuszek, J.E. 1978. Empirical predictions of fish yields of large North American lakes. Trans. Am. Fish. Soc. 107: 385-294.

Mills, E.L., J.H. Leach, J.T. Carlton, and C.L. Secor. 1993. Exotic species in the Great Lakes: a history of biotic crises and anthropogenic introductions. J. Gt. Lakes Res. 19(1): 1-54.

Moore, S.A., and C.R. Bronte. 2001. Delineation of sympatric morphotypes of lake trout in Lake Superior. Trans. Am. Fish. Soc. 130: 1233-1240.

Negus, M.T. 1995. Bioenergetics modeling as a salmonine management tool applied to the Minnesota waters of Lake Superior. N. Am. J. Fish. Manage. 15: 60-78.

Newman, L.E. and DuBois, R.B. (Editors). 1997. Status of brook trout in Lake Superior. Lake Superior Committee Annual Meeting (Minutes). March 19-20, 1997. Great Lakes Fish. Comm.

_____, DuBois, R.B. and Halpern, T.N. (EDS.). A brook trout rehabilitation plan for Lake Superior. Great Lakes Fish. Comm. Misc. Pub. In press.

Peck, J.W., T.S. Jones, W.R. MacCallum, and S.T. Schram. 1999. Contribution of hatchery-reared fish to chinook salmon populations and sport fisheries in Lake Superior. N. Am. J. Fish. Manage. 19: 155-164.

Pratt, D.M., W.H. Blust, and J.H. Selgeby. 1992. Ruffe, *Gymnocephalus cernuus*: newly established in North America. Can. J. Fish. Aquat. Sci. 49: 1616-1618.

Pycha, R.L., and G.R. King. 1975. Changes in the lake trout population of southern Lake Superior in relation to the fishery, the sea lamprey, and stocking, 1950-70. Great Lakes Fish. Comm. Tech. Rep. 28.

Roosevelt, R.B. 1865. Superior fishing. Originally published by G.W. Carleton. Minnesota Historical Soc. Press. St. Paul, MI. 1985.

Ruffe Task Force. 1992. Ruffe in the Great Lakes: a threat to North American Fisheries. Great Lakes Fish. Comm. http.www.GLFC.org/pubs_out/docs.htm

Schram, S.T., J. Lindgren, and L.M. Evrard. 1999. Reintroduction of lake sturgeon in the St. Louis River, western Lake Superior. N. Am. J. Fish. Manage. 19: 815-823.

Schreiner, D.R. (ED.). 1995. Fisheries management plan for the Minnesota waters of Lake Superior. Minnesota Dept. Nat. Resour. Div. Fish. Wildl., Sect. Fish. Spec. Pub. 149.

_____, and S.T. Schram. 1997. Lake trout rehabilitation in Lake Superior: maintaining our progress. Fisheries 22: 12-14.

Selgeby, J.H. 1982. Decline of lake herring (*Coregonus artedi*) in Lake Superior: an analysis of the Wisconsin herring fishery. Can. J. Fish. Aquat. Sci. 39: 554-563.

_____, C.R. Bronte, and J.W. Slade. 1994. Forage species. *In* The state of Lake Superior in 1992. M.J. Hansen (ed.). Great Lakes Fish. Comm. Spec. Pub. 94-1. pp. 53-62.

Smith, S.H. 1972. Factors of ecological succession in oligotrophic fish communities of the Laurentian Great Lakes. J. Fish. Res. Board Can. 29: 717-730.

Suns, K.R, G.G. Hitchin, and D. Toner. 1993. Spatial and temporal trends of organochlorine contaminants in spottail shiners from selected sites in the Great Lakes (1975-1990). J. Gt. Lakes Res. 19(4): 703-714.

Swain, R.W. 1978. Chlorinated organic residues in fish, water, and precipitation from the vicinity of Isle Royale, Lake Superior. J. Gt. Lakes Res. 4(3-4): 398-407.

Swanson, B., M. Halverson, and S. Fischer. 1994. Historical lake trout catch for Wisconsin waters of Lake Superior, 1936-41. Lake Superior Committee Annual Meeting (Minutes). March 22-23, 1994. Great Lakes Fish. Comm.

Van Oosten, J. 1937. The dispersal of smelt, *Osmerus mordax* (Mitchill) in the Great Lakes region. Trans. Am. Fish. Soc. 66: 160-171.

Vollenweider, R.A., M. Munawar, and P. Stadelmann. 1974. A comparative review of phytoplankton and primary production in the Laurentian Great Lakes. J. Fish. Res. Board Can. 31: 739-762.

Walker, S.H., M.W. Prout, W.W. Taylor, and S.R. Winterstein. 1993. N. Am. J. Fish. Manage. 13: 73-85.

Waters, T.F. 1987. The Superior North Shore. Univ. Minnesota Press. Minneapolis, MI.

Wilberg, M. 2000. Historic and modern lake trout abundance, effects of fishing on lake trout, and dynamics of the commercial lake trout fishery in Michigan waters of Lake Superior. Master's Thesis. University of Wisconsin—Stevens Point, MI.

Wisconsin Department of Natural Resources. 1996. A summary of important habitat conditions in the Lake Superior basin. PUBL-WT-472 96. Bureau of Watershed Management, Wisc. Dept. Nat. Resour., Madison, WI.

APPENDIX A

Estimated quantity of total, spawning, and nursery habitat and biological parameters for lake trout in each management unit in Lake Superior. Number of spawning sites taken from Coberly and Horrall (1980), Goodyear et al. (1982) and Goodier (1981), and includes present and historically important areas. Spawning habitat is defined is waters < 9.1 m deep. Average CPE, wild fish, and mortality for United States and Canadian waters adjusted for area < 73 m and < 91 m deep, respectively.

Appendix A begins on the next page.

Mgt. Unit	Total Habitat (ha)		No. Spawning Sites		Spawning Habitat		Nursery Habitat		Biological Parameters			
	Total	< 40 fa[1]	Onshore	Offshore	(ha)	% Area[2]	(ha)	% Area[2]	Years	Survey CPE[3]	Wild Fish[4]	Annual Mortality[5]
U.S. Waters												
MI-1	573,003	49,645	18	2	13,600	27%	1,200	2%	1993-95	16	98%	29%
MI-2	636,599	87,786	7	0	4800	5%	1,200	1%	1996	34	87%	45%
MI-3	620,654	64,674	10	0	4625	7%	1,200	2%	1996	7	91%	41%
MI-4	622,657	132,146	15	7	15,213	12%	2,300	2%	1996	14	88%	51%
MI-5	367,935	76,385	13	0	4,290	6%	14,500	19%	1996	32	83%	42%
MI-6	761,196	74,934	7	3	36,600	49%	71,500	95%	1996	45	90%	58%
MI-7	411,881	81,697	1	5	31,300	38%	42,800	52%	1996	18	94%	54%
MI-8	179,626	176,868	2	1	14,300	8%	40,100	23%	1996	10	17%	68%
WI-1	107,408	48,513	1	0	12	0%	0	0%	1995, 1997	20	42%	36%
WI-2	400,703	231,797	12	23	7,773	3%	266,131	115%	1995, 1997	18	71%	37%
MN-1	107,723	57,185	8	0	5,700	10%	1,190	2%	1996	34	45%	45%
MN-2	173,567	7,955	9	0	400	5%	430	5%	1996	7	20%	40%
MN-3	358,789	14,899	21	0	1,200	8%	4,500	30%	1996	26	70%	45%
Subtotal	5,321,741	1,104,485	124	41	139,813	13%	447,051	40%	1993-1997	21	69%	48%

Mgt. Unit	Total Habitat (ha)		No. Spawning Sites		Spawning Habitat		Nursery Habitat		Biological Parameters			
	Total	< 40 fa[1]	Inshore	Offshore	(ha)	% Area[2]	(ha)	% Area[2]	Years	Survey CPE[3]	Wild Fish[4]	Annual Mortality[5]
Canadian Waters												
1	33,366	33,046	4	2					1992-96	90		<45%
2	22,451	22,440	0	4					1992-96	47		<45%
3	10,922	9,765	1	1					1992-96	100		<45%
4	13,871	13,871	3	3					1992-96	44		
5	41,614	25,361	5	1						22		
6	46,285	5,875	3	2					1992-96	46		
7	60,139	60,139	2	0					1992-96	16		
8	4,431	3,409										
9	101,191	28,759	11	3					1992-96	37		
10	39,818	39,818	3	6								
11	35,627	31,229	1	6					1992-96	34		
12	105,284	14,218	0	10					1992-96	36		
13	91,264	0										
14	27,415	2,784	0	3					1992-96	185		
15	209,058	0										
16	45632	2,192	0	4					1992-96	318		
17	119784	919										
18	67,572	17,485	9	8						110		
19	72,227	26,510	9	0					1992-96	27		
20	119,784	13,209										

Mgt. Unit	Total Habitat (ha)		No. Spawning Sites		Spawning Habitat		Nursery Habitat		Biological Parameters			
	Total	< 40 fa[1]	Inshore	Offshore	(ha)	% Area[2]	(ha)	% Area[2]	Years	Survey CPE[3]	Wild Fish[4]	Annual Mortality[5]
Canadian Waters, continued												
21	159,712	23										
22	204,436	0										
23	99,844	10,240	8	0					1992-96	68		<45%
24	137,912	26,158	5	0					1992-96	51		<45%
25	109,766	6,347										
26	49,287	15,657	0	15						291		
27	182,150	57,232	0	3					1992-96	270		
28	88,909	43,661	10	0					1992-96	52		23%
29	79,856	10,681	0	0						280		
30	114,080	0	0	0					1992-96	229		<45%
31	90,303	51,997	2	11					1987-92	11	45%	42%
32	77,099	2,552	0	0					1992-96	273		<45%
33	131,729	90,707	4	3					1987-92	8	35%	69%
34	47,452	44,409	6	1					1987-92	7	2%	63%
Subtotal	2,840,270	710,693	86	86	0	0	0	0	1992-96	61		<45%
Total	8,162,011	1,815,178	210	127	139,813	0	447,051	0				

[1]Canadian waters is < 50 fa deep.
[2]Percent of areas < 40 fa deep in U.S. waters.
[3]CPE is fish/1,000 ft. of survey gillnet in U.S. waters; in Canada, CPE is based on commercial catches and expressed as kg/km.
[4]In MN-1, MN-2, and MN-3 is percent of fish ≤635 mm total length.
[5]Mortality rates are for Ages 5-9 in 1996-97 for MI-8; Ages 9-12 for MI-3 through MI-7.

APPENDIX B

Estimated quantity of total, spawning, and nursery habitat, and biological parameters for lake whitefish in each management unit of Lake Superior. Number of spawning sites taken from Coberly and Horrall (1980), Goodyear et al. (19820 and includes current and historically important areas. Spawning habitat is considered to be < 9.1 m deep. Average CPE and mortality in U.S. and Canadian waters adjust for area < 73 m and < 91 m deep, respectively.

Appendix B begins on the next page.

Mgt. Unit	Total Habitat (ha)		No. Spawning Sites		Spawning Habitat		Nursery Habitat		Biological Parameters		
	Total	< 40 fa[1]	Onshore	Offshore	(ha)	% Area[2]	(ha)	% Area[2]	Years	CPE[3]	Annual Mortality
U.S. Waters											
MI-1	573,003	49,645	9	0	628	1%			1978-81		55%
MI-2	636,599	87,786	0	0	300	0%	700	1%	1996	160	45%
MI-3	620,654	64,674	7	0	400	1%	600	1%	1996	130	78%
MI-4	622,657	132,146	14	2	500	0%	800	1%	1996	72	73%
MI-5	367,935	76,385	2	1	18,600	24%	4,700	6%	1994-96	71	30%
MI-6	761,196	74,934	9	0	52,500	70%	37,000	49%	1996	57	50%
MI-7	411,881	81,697	1	0	13,000	16%	20,000	24%	1996	156	53%
MI-8	179,626	176,868	6	0	25,500	14%	39,500	22%	1996	93	57%
WI-1	107,408	48,513	2	0	162	0%	0	0%		20	
WI-2	400,703	231,797	4	35	8,500	4%	187,023	81%	1996	126	73%
MN-1	107,723	57,185	0	0	0	0%	0	0%			
MN-2	173,567	7,955	5	0	0	0%	7,955	100%			
MN-3	358,789	14,899	2	0	3,000	20%	0	0%			
Subtotal	5,321,741	1,104,485	61	38	123,090	11%	298,278	27%		104	63%

Mgt. Unit	Total Habitat (ha)		No. Spawning Sites		Spawning Habitat		Nursery Habitat		Biological Parameters		
	Total	< 40 fa[1]	Onshore	Offshore	(ha)	% Area[2]	(ha)	% Area[2]	Years	CPE[1]	Annual Mortality
Canadian Waters											
1	33,366	33,046	1	0					1992-96	427	<45%
2	22,451	22,440	1	0					1992-96	184	
3	10,922	9,765							1992-96	102	
4	13,871	13,871							1992-96	132	
5	41,614	25,361							1992-96	129	
6	46,285	5,875							1992-96	88	
7	60,139	60,139							1992-96	88	<45%
8	4,431	3,409									
9	101,191	28,759							1992-96	140	
10	39,818	39,818									
11	35,627	31,229							1992-96	74	
12	105,284	14,218							1992-96	200	
13	91,264	0									
14	27,415	2,784							1992-96	5	
15	209,058	0									
16	45,632	2,192							1992-96	0	
17	119,784	919									
18	67,572	17,485							1992-96	59	
19	72,227	26,510							1992-96	79	
20	119,784	13,209									

Mgt. Unit	Total Habitat (ha)		No. Spawning Sites		Spawning Habitat		Nursery Habitat		Biological Parameters		
	Total	< 40 fa[1]	Onshore	Offshore	(ha)	% Area[2]	(ha)	% Area[2]	Years	CPE[1]	Annual Mortality
Canadian Waters, continued											
21	159,712	23									
22	204,436	0									
23	99,844	10,240							1992-96	143	<45%
24	137,912	26,158							1992-96	76	<45%
25	109,766	6,347									
26	49,287	15,657							1992-96	109	
27	182,150	57,232									
28	88,909	43,661							1992-96	152	<45%
29	79,856	10,681									
30	114,080	0									
31	90,303	51,997							1992-96	108	68%
32	77,099	2,552									
33	131,729	90,707	2	1					1992-96	99	39%
34	47,452	44,409	1	1					1992-96	151	36%
Subtotal	2,840,270	710,693	5	2					1992-96	131	<45%
Total	8,162,011	1,815,178	66	40	123,090	0	298,278	0			

[1]Canadian waters is <50 fa deep.
[2]Percent of areas <40 fa deep in U.S. waters.
[3]CPE is expressed as kilograms/kilometer of gillnet.

APPENDIX C

Known spawning and foraging habitat for selected fish species in Lake Superior.

Habitat Zone	Species	Life Stage	Foraging Habitat	Spawning Habitat
Offshore	Lean lake trout	Juvenile	All water < 91 m	Stannard Rock, Superior Shoal, Caribou Island (Fig. 1a)
(> 80 m)		Nonspawning adult	All water < 146 m	Stannard Rock, Superior Shoal, Caribou Island (Fig. 1a)
	Siscowet	Egg	All water > 110 m	Caribou Island
		Juvenile	All water 80-128 m	Caribou Island
		Nonspawning adult	All water > 110 m	Caribou Island
		Spawning adult	All water > 110 m	Caribou Island
	Humper	Egg	Rock substrate < 60 m in offshore areas	Caribou Is., Isle Royale, Superior Shoal (Fig. 1a)
		Juvenile	Unknown	None
		Nonspawning adult	Unknown	None
		Spawning adult	Rock substrate < 60 m in offshore areas	Caribou Is., Isle Royale, Superior Shoal (Fig. 1a)
	Lake herring	Egg	Unknown	Unknown
		Juvenile	All water 80-220 m	None
		Nonspawning adult	All water 80-220 m	None
		Spawning adult	Unknown	Unknown
	Burbot	Egg	Unknown	Unknown
		Juvenile	All water > 80 m	None
		Non-spawning adult	All water > 80 m	None
		Spawning adult	Unknown	Unknown
	Deepwater ciscoes	Egg	All water 80-220 m	Unknown
		Juvenile	All water 80-220 m	None
		Nonspawning adult	All water 80-220 m	None
		Spawning adult	All water 80-220 m	Unknown
	Deepwater sculpin	Egg	Unknown	Unknown
		Juvenile	All water > 80 m	None

Appendix C continued

Habitat Zone	Species	Life Stage	Foraging Habitat	Spawning Habitat
		Nonspawning adult	All water > 80 m	None
		Spawning adult	All water > 80 m	Unknown
Nearshore	Lean lake trout	Egg	Rock substrates 0.5-30 m	Rock substrates 0.5-30 m, DO > 6mg/l, Fig. 1a
(< 80 m)		Juvenile	All water 35-80 m	None
		Nonspawning adult	All water 35-80 m	None
		Spawning adult	Rock areas 0.5-30 m	Rock substrates 0.5-30 m, Fig. 1a
	Siscowet	Egg	Unknown	Unknown
		Juvenile	All water < 80 m	None
		Nonspawning adult	Water 36-80 m	None
		Spawning adult	Unknown, probably very little	Unknown
	Humper	Egg	Rock substrate < 60 m	Water < 60 m Caribou Is., Isle Royale, Superior Shoal (Fig. 1a)
		Juvenile	Offshore banks Isle Royale, Caribou Is.	None
		Nonspawning adult	Offshore banks Isle Royale, Caribou Is.	None
		Spawning adult	Rock substrate < 60 m	Water < 60 m Caribou Is., Isle Royale, Superior Shoal (Fig. 1a)
	Lake whitefish	Egg	Sand to rock substrates < 9 m	Areas identified in Fig. 1c
		Juvenile	All water < 73 m	None
		Nonspawning adult	All water < 73 m	None
		Spawning adult	Sand to rock substrates < 9 m	Areas identified in Fig. 1c
	Lake herring	Egg	Unknown	Unknown
		Juvenile	All water < 80 m	Areas identified in Fig. 1b
		Nonspawning adult	All water < 80 m	None
		Spawning adult	All water < 80 m	Areas identified in Fig. 1b

Appendix C continued

Habitat Zone	Species	Life Stage	Foraging Habitat	Spawning Habitat
	Walleye	Juvenile	Near tributaries (Fig. 2)	None
		Nonspawning adult	Near tributaries (Fig. 2)	None
	Lake sturgeon	Nonspawning adult	Superior to Munising (Fig. 2)	None
Harbor, bays, & estuaries	Lake whitefish	Eggs	Sand to rock substrates < 9 m	Areas identified in Fig. 1c
		Juvenile	All water < 73 m	None
		Nonspawning adult	All water < 73 m	None
		Spawning adult	Sand to rock substrates < 9 m	Areas identified in Fig. 1c
	Lake herring	Egg	Gravel to rock substrates	Thunder, Black, Keweenaw, Whitefish Bays
		Juvenile	All water	None
		Nonspawning adult	All water	None
		Spawning adult	Gravel to rock substrates	Thunder, Black, Keweenaw, Whitefish Bays
	Brook trout	Egg	Upwelling areas along shore	Tobin Harbor and Siskiwit Bay on Isle Royale
		Juvenile	Water < 15 m	None
		Nonspawning adult	Water < 15 m	None
		Spawning adult	Upwelling areas along shore	Tobin Harbor and Siskowit Bay on Isle Royale
	Walleye	Juvenile	bays indicated on Fig. 2	Black, Thunder, Chequamenon, Whitefish Bays, St. Louis estuary
		Nonspawning adult	Bays indicated on Fig. 2	None
		Spawning adult	Bays indicated on Fig. 2	Black, Thunder, Chequemenon, Whitefish Bays, St. Louis estuary
	Lake sturgeon	Juvenile	13 bays identified in Fig. 2	None
		Nonspawning adult	13 bays identified in Fig. 2	None

Appendix C continued

Habitat Zone	Species	Life Stage	Foraging Habitat	Spawning Habitat
Tributaries	Lake trout	Egg	Eastern Lake Superior tributaries	Montreal, Dog (University) Rivers
		Spawning adult	Eastern Lake Superior tributaries	Montreal, Dog (University) Rivers
	Lake sturgeon	Egg	19 rivers identified, Fig. 2	Bad, Sturgeon, Gravel, Kaministiquia, Nipigon Rivers
		Juvenile	19 rivers identified, Fig. 2	None
		Nonspawning adult	19 rivers identified, Fig. 2	None
		Spawning adult	19 rivers identified, Fig. 2	Bad, Sturgeon, Gravel, Kaministiquia, Nipigon Rivers
	Brook trout	Egg	106 streams, Fig. 3	Nipigon, Current, Jackpine, Cypress, Pancake, Salmon-Trout Rivers; Isle Royale
		Juvenile	106 streams, Fig. 3	None
		Nonspawning adult	106 streams, Fig. 3	None
		Spawning adult	106 streams, Fig. 3	Nipigon, Current, Jackpine, Cypress, Pancake, Salmon-Trout Rivers; Isle Royale

APPENDIX D

Fish species list for Lake Superior based on Cudmore and Crossman (2000) and reports of possible additional species. N = native, I = introduced and reproducing, R = reported to occur but non-reproducing, P = possible occurrence/native, U = reported but unlikely occurrence.

Species	Status
PETROMYZONTIDAE	
Ichthyomyzon unicuspis (silver lamprey)	N
I. fossor (northern brook lamprey)	N
Lampetra appendix (American brook lamprey)	N
Petromyzon marinus (sea lamprey)	I
ACIPENSERIDAE	
Acipenser fulvescens (lake sturgeon)	N
LEPISOSTEIDAE	
Lepisosteus osseus (longnose gar)	N
AMIIDAE	
Amia calva (bowfin)	P
ANGUILLIDAE	
Anguilla rostrata (American eel)	R
CLUPEIDAE	
Alosa pseudoharengus (alewife)	I
Dorosoma cepedianum (gizzard shad)	I

Appendix D continued

Species	Status
CYPRINIDAE	
Couesius plumbeus (lake chub)	N
Cyprinus carpio (common carp)	I
Luxilus cornutus (common shiner)	N
Margariscus margarita (pearl dace)	N
Nocomis biguttatus (hornyhead chub)	N
Notemigonus crysoleucas (golden shiner)	N
Notropis atherinoides (emerald shiner)	N
N. buccatus (silverjaw minnow)	U
N. dorsalis (bigmouth shiner)	P
N. heterodon (blackchin shiner)	N
N. heterolepis (blacknose shiner)	N
N. hudsonius (spottail shiner)	N
N. rubellus (rosyface shiner)	P
N. stramineus (sand shiner)	N
N. volucellus (mimic shiner)	N
Opsopoeodus emiliae (pugnose minnow)	U
Phoxinus eos (northern redbelly dace)	N
P. neogaeus (finescale dace)	N
Pimephales notatus (bluntnose minnow)	N
P. promelas (fathead minnow)	N
Rhinichthys atratulus (blacknose dace)	N
R. cataractae (longnose dace)	N
Semotilus atromaculatus (creek chub)	N

Species	Status
CATOSTOMIDAE	
Catostomus catostomus (longnose sucker)	N
C. commersoni (white sucker)	N
Moxostoma anisurum (silver redhorse)	N
M. macrolepidotum (shorthead redhorse)	N
M. valenciennesi (greater redhorse)	N
ICTALURIDAE	
Ameiurus melas (black bullhead)	N
A. natalis (yellow bullhead)	N
A. nebulosus (brown bullhead)	N
Ictalurus punctatus (channel catfish)	N
Noturus flavus (stonecat)	N
N. gyrinus (tadpole madtom)	N
N. miurus (brindled madtom)	U
ESOCIDAE	
Esox lucius (northern pike)	N
E. masquinongy (muskellunge)	N
OSMERIDAE	
Osmerus mordax (rainbow smelt)	I
UMBRIDAE	
Umbra limi (central mudminnow)	N

Appendix D continued

Species	Status
SALMONIDAE	
Coregonus artedi (lake herring)	N
C. clupeaformis (lake whitefish)	N
C. hoyi (bloater)	N
C. kiyi (kiyi)	N
C. zenithicus (shortjaw cisco)	N
Oncorhynchus kisutch (coho salmon)	I
O. gorbuscha (pink salmon)	I
O. mykiss (rainbow trout)	I
O. tshawytscha (chinook salmon)	I
Prosopium coulteri (pygmy whitefish)	N
P. cylindraceum (round whitefish)	N
Salmo trutta (brown trout)	I
S. salar (Atlantic salmon)	R
Salvelinus fontinalis (brook trout)	N
S. namaycush (lake trout)	N
S. namaycush siscowet	N
PERCOPSIDAE	
Percopsis omiscomaycus (trout-perch)	N
GADIDAE	
Lota lota (burbot)	N
ATHERINIDAE	
Labidesthes sicculus (brook silverside)	R

Appendix D continued

Species	Status
GASTEROSTEIDAE	
Apeltes quadracus (fourspine stickleback)	I
Culaea inconstans (brook stickleback)	N
Gasterosteus aculeatus (threespine stickleback)	I
Pungitius pungitius (ninespine stickleback)	N
COTTIDAE	
Cottus bairdi (mottled sculpin)	N
Cottus cognatus (slimy sculpin)	N
Cottus ricei (spoonhead sculpin)	N
Myoxocephalus thompsoni (deepwater sculpin)	N
MORONIDAE	
Morone americana (white perch)	I
Morone chrysops (white bass)	N
CENTRARCHIDAE	
Ambloplites rupestris (rock bass)	N
Lepomis cyanellus (green sunfish)	N
L. gibbosus (pumpkinseed)	N
L. macrochirus (bluegill)	N
Micropterus dolomieu (smallmouth bass)	N
M. salmoides (largemouth bass)	N
Pomoxis annularis (white crappie)	P
P. nigromaculatus (black crappie)	N

Appendix D continued

Species	Status
PERCIDAE	
Etheostoma exile (Iowa darter)	N
E. flabellare (fantail darter)	N
E. microperca (least darter)	N
E. nigrum (johnny darter)	N
Gymnocephalus cernuus (ruffe)	I
Perca flavescens (yellow perch)	N
Percina caprodes (logperch)	N
P. maculata (blackside darter)	U
Stizostedion canadense (sauger)	N
S. vitreum (walleye)	N
SCIAENIDAE	
Aplodinotus grunniens (freshwater drum)	I
GOBIIDAE	
Neogobius melanostomus (round goby)	I

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

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

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

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

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

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

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

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

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

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

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

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

Special Publications

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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