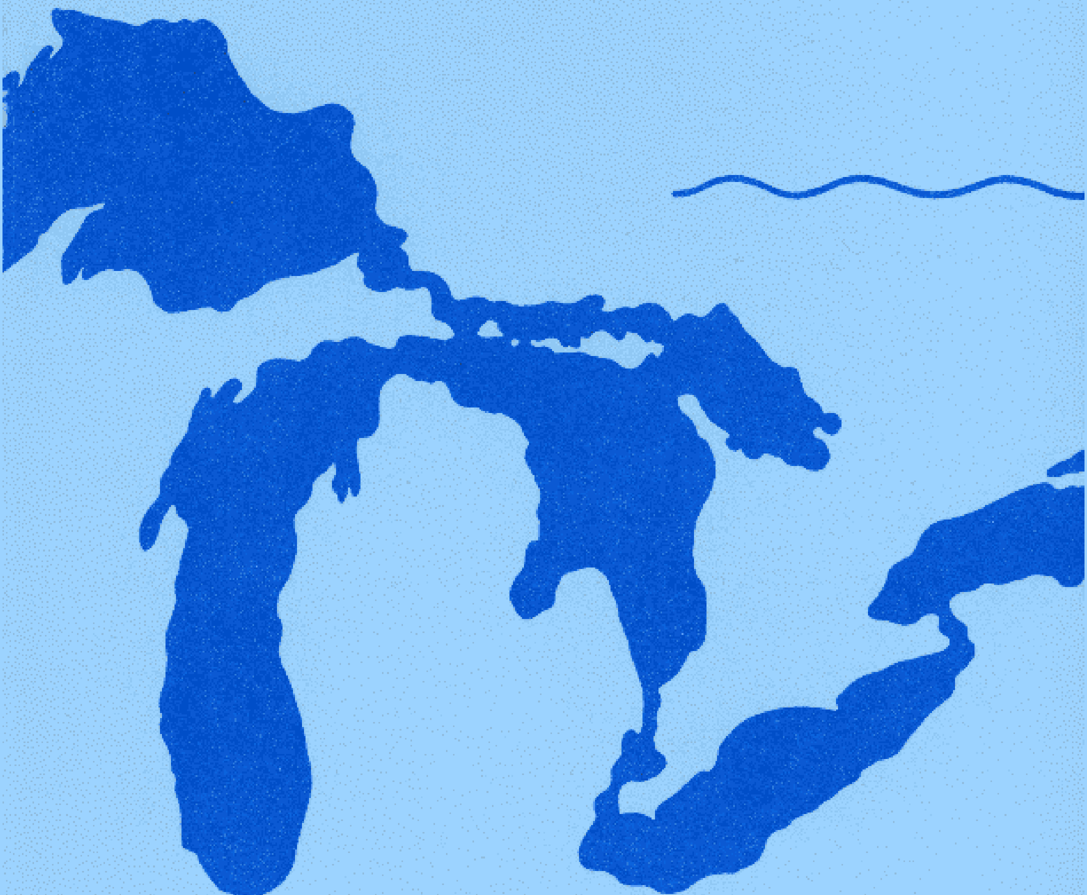
THE STATE OF LAKE SUPERIOR IN 1992



Great Lakes Fishery Commission

SPECIAL PUBLICATION 94-1

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

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

July 1994

THE STATE OF LAKE SUPERIOR IN 1992

edited by

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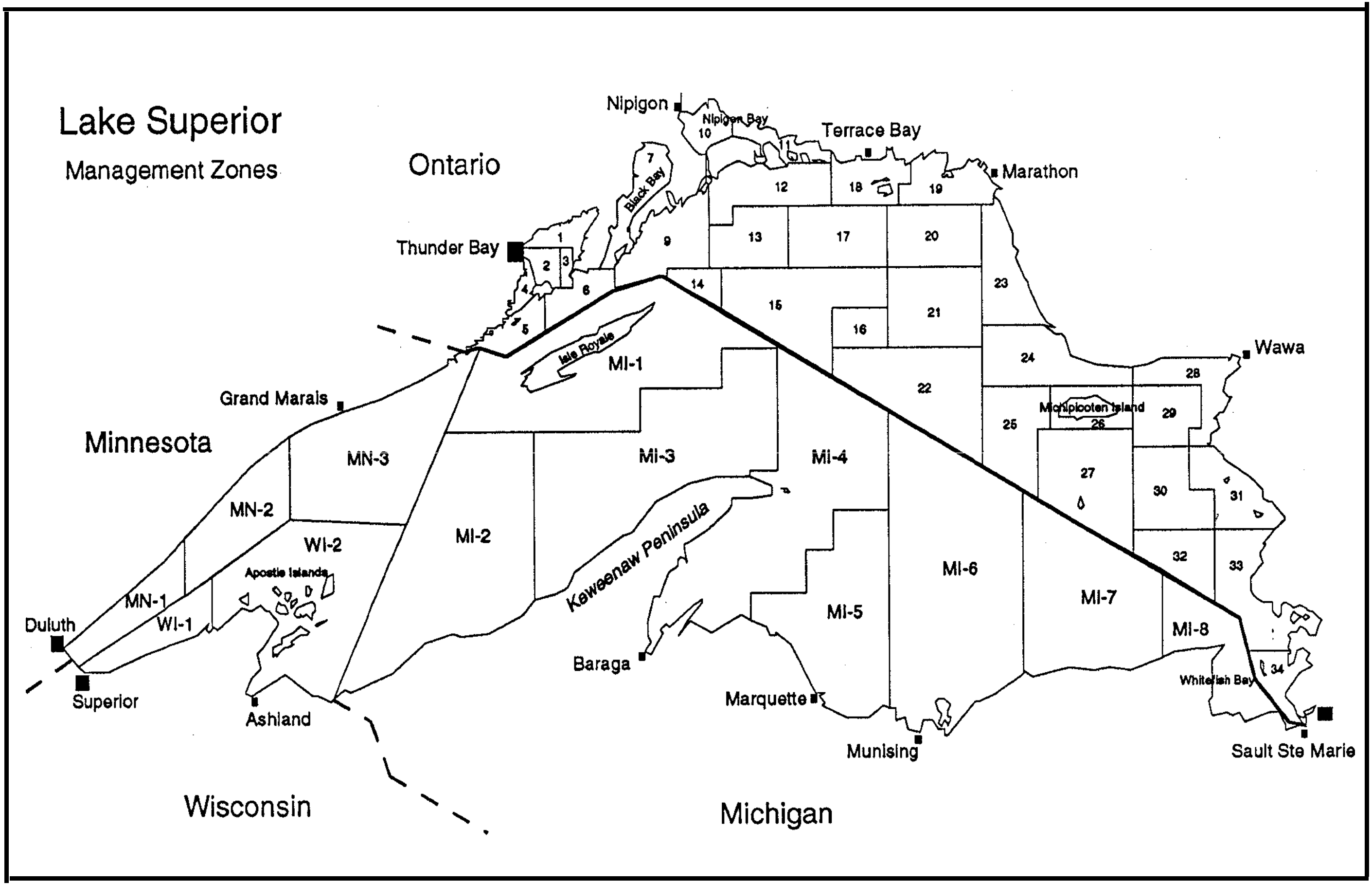
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Ontario
Minnesota
Wisconsin
Michigan
Nipigon
Nipigon Bay
Terrace Bay
Marathon
Thunder Bay
Black Bay
Isle Royale
Grand Marais
Wawa
Michipicoten Island
Duluth
Superior
Ashland
Apostle Islands
Keweenaw Peninsula
Baraga
Marquette
Munising
Whitefish Bay
Sault Ste Marie
MN-1
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EXECUTIVE SUMMARY

The Lake Superior fish community in 1992 is substantially different than it was a half century ago and is far from a state desired by management agencies. Fish-community objectives were established for Lake Superior in response to A Joint Strategic Plan for Management of Great Lakes Fisheries (Great Lakes Fishery Commission 1980) and are the template for this report on the state of the lake. Reporting on progress toward meeting stated goals and objectives will focus attention on critical fishery issues and enhance understanding among fishery- and environmental-management agencies, political bodies, and the public.

Objectives

Fish-community objectives for Lake Superior include:

- Restore lake herring *(Coregonus* artedi) stocks to historic levels of abundance for the purposes of lake trout *(Salvelinus namaycush)* restoration, production of other predators, and fishery harvest.

- Achieve a sustained annual yield of 1.8 million kg of lake trout from naturally reproducing stocks and an unspecified yield of other salmonid predators while maintaining a predator-prey balance that allows normal growth of lake trout.

- Manage exploitation of nondepleted stocks to maintain a stable, self-sustaining status for lake whitefish *(C. clupeaformis),* deepwater ciscoes *(Coregonus* spp.), suckers (Catostomus spp.), and walleye *(Stizostedion vitreum vitreum)* and reestablish depleted stocks of native species such as lake sturgeon *(Acipenser fulvescens),* brook trout *(Salvelinus fontinalis),* and walleye.

- Achieve a 50% reduction in parasitic:-phase sea lamprey *(Petromyzon marinus)* abundance by the year 2000 and a 90% reduction by the year 2010.

- Achieve no net loss of the productive capacity of habitats supporting Lake Superior fisheries, restore the productive capacity of habitats that have suffered damage, and reduce contaminants in all fish species to levels below consumption advisory levels.

Progress

Progress toward reaching fish-community objectives has been substantial, but target levels were not achieved by 1992.

- The annual yield of lake trout was 32.9% of the target level lakewide (25.2% in Canada and 32.4% in the United States) but was still substantially supported by stocking in many areas. Other salmonine predators reproduced widely and contributed 10% to the total yield of salmonine predators.

- Lake herring stocks rebounded in many areas of the lake, but it is unclear whether historic abundance levels have been reached

- Lake whitefish stocks supported greater commercial yields than any other period in history. Most walleye, lake sturgeon, and brook trout stocks remained depressed because of overharvest, habitat degradation, and competition with introduced species.

- Parasitic-phase sea lamprey abundance remained approximately 10% of precontrol levels but still accounted for 312% of the total lake trout yield in the United States.

- Numerous opportunities for achieving habitat objectives have become available in Lake Superior, including Remedial Action Plans (RAPS) in Areas of Concern (AOCs), licensing of hydropower facilities, a binational program to restore and protect the Great Lakes basin, and other smaller projects.

Lake Trout

Lake trout, the dominant predator in Lake Superior until the 1950s, sustained an annual yield in excess of 1.8 million kg from 1929 to 1943. Most inshore stocks of lake trout collapsed during the 1950s because of sea lamprey predation and uncontrolled commercial fishing. The current annual yield of lake trout is 32.9% of the fish-community goal, although stocked fish contribute substantially to yield in some areas. Sea lamprey predation accounts for 14.7% of the lake trout-yield goal in the United States and an unknown portion of the goal in Canada. Stocking began soon after the onset of the collapse of inshore lake trout stocks-in Michigan and Wisconsin in 1952 and in Minnesota in 1964. More than 27 million trout were stocked by 1970. More than 90 million trout were stocked by 1992.

Lake trout abundance increased in Lake Superior during the 1950s and 1960s where stocking was undertaken or where remnant native populations survived. During the 1970s and 1980s, abundance of hatchery fish in Michigan declined as stocking rates were decreased. Abundance of wild fish increased during the 1970s as reproduction expanded. During the 1980s, wild-fish abundance stabilized as fisheries became established. In Wisconsin, abundance of hatchery fish declined slowly during the 1970s and 1980s, while abundance of wild fish remained relatively stable. In Minnesota, wild- and hatchery-fish abundance increased steadily after 1970. Stockings in the United States and Canada during 1991 and 1992 were near target levels.

Lake trout mortality from fishing and sea lamprey predation was excessive during the period preceding the collapse of inshore stocks but was subsequently brought under control. During the 1970s and 1980s, total mortality remained above the target rate of 45% in most jurisdictions, and yield remained divided approximately equally between fishing and sea lamprey predation. Sea lamprey predation is a dominant component of total mortality in the United States west of the Keweenaw Peninsula. Lake trout growth rates were generally higher in the United States than in Canada during the early 1980s but eventually became more similar. Growth rates declined steadily in Michigan between 1970 and 1989 but remained more consistent in Wisconsin and Minnesota. The observed decline in growth rate coincides with the decline in rainbow smelt *(Osmerus mordax)* abundance. Rainbow smelt remain the Ipreferred prey of lake trout in spite of rebounding lake herring abundance in some areas.

Other Salmonines

Introductions of rainbow trout (Oncorhynchus *mykiss)* and brown trout *(Salmo trutta)* in the late 1800s, pink salmon *(0. gorbuscha)* in 1956, coho salmon *(0. kisutch)* in 1966, and chinook salmon *(0. tshawytscha)* in 1967 were successful in establishing populations across Lake Superior by the 1980s. However, these anadromous fishes comprised only 10% of the total yield of predators between 1988 and 1990. Abundance of rainbow trout and pink salmon declined recently; however, abundance of the other species is stable or increasing. Splake (a fertile hybrid resulting from a brook trout and lake trout cross) are stocked for put-grow-take local fisheries, particularly in Wisconsin. Brook trout. are native to Lake Superior, but populations were reduced to low levels in most areas through overfishing, habitat loss, and competition with introduced anadromous salmonids. Atlantic salmon (S. *salar)* were stocked for put-grow-take local fisheries in

Minnesota. Lakewide fin clipping of all chinook salmon stocked in Lake Superior between 1988 and 1990 was conducted to ascertain the level of natural reproduction.

Forage Species

Lake herring was the dominant forage fish until the 1950s but declined when rainbow smelt colonized the lake and grew in abundance during the 1960s and 1970s. During the latter half of the 1980s and early 1990s, lake herring populations rebounded. Although they are now far more abundant than rainbow smelt, they still have not increased to historic levels of abundance. Total biomass of lake herring increased greatly from 1984 to 1986 and remained high from 1987 to 1992. Biomass of rainbow smelt has been low since 1980 because of excessive mortality on older-aged individuals. Diets of larger predators remain dominated by rainbow smelt, but lake herring consumption is increasing in areas where abundance is improving. Limited bioenergetics analysis shows that prey consumption by salmonine predators may be excessive in some areas.

Other Species

Because of increased abundance and expanded fisheries, lake whitefish stocks currently support greater commercial harvest than at any other time in the twentieth century. Lake trout restoration efforts have been negatively impacted by expanded lake whitefish fisheries in some areas-a situation that bears further examination by management agencies. Lake sturgeon and walleye exist mostly as suppressed, localized populations-management agencies continue restoration efforts of historically important stocks. Stocks of deepwater ciscoes declined continuously through the 1980s as siscowet *(Salvelinus namaycush* siscowet), a deepwater form of lake trout, stocks expanded. Brook trout restoration efforts have been largely unsuccessful.

Sea Lamprey

Current control methods reduced sea lamprey abundance by 90% from precontrol levels. Intensified chemical treatments and integration of new control methods (including sterile-male releases, barrier construction, and increased trapping) will be used to further reduce sea lamprey populations. Integrated management of sea lamprey initiatives will attempt to refine objectives to control sea lamprey abundance and define an optimal sea lamprey-control program to meet those objectives. The initiatives include:

- detailed evaluations of historic data on sea lamprey abundance,
- salmonid wounding and mortality, and
- chemical treatment to link control efforts to levels of fishery damage.

Ruffe

The ruffe *(Gymnocephalus cernuus)* is a Eurasian percid fish that was introduced into Lake Superior during the 1980s - most likely through ballast water from an ocean-going vessel. Ruffe distribution is currently restricted to the Duluth-Superior Harbor in western Lake Superior, several river mouths as far as 80 km east of Duluth, and Thunder Bay Harbor in Ontario. Ruffe abundance in the Duluth-Superior Harbor has grown steadily since its introduction. Predation on ruffe by native predators was virtually nil in 1989, however, ruffe comprised 20% of all fish eaten by predators in 1992.

Habitat

To help achieve no net loss of existing habitat, inventory and mapping of important spawning grounds in Lake Superior were initiated. To restore damaged habitat, Stage 1 of the RAPs were completed or initiated for six AOCs in Ontario and Michigan. In addition, Stage 2 of the RAP for the St. Louis Bay and River system was completed. Also, Federal Energy Regulatory Commission relicensing was in progress in eight hydropower facilities. To reduce contaminant levels, sources of point-source pollution were identified (some within AOCs) as locations where regulatory actions should be sought. These regulatory actions should help to reduce toxic substances so aquatic-organism health is not impaired, nor is the health of humans and wildlife jeopardized by consuming these aquatic organisms.

HISTORY

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Introduction

Fish-community objectives were established for Lake Superior (Busiahn 1990) in response to A Joint Strategic Plan for Management of Great Lakes Fisheries (Joint Plan) (Great Lakes Fishery Commission 1980). Fish-community objectives serve as templates for state of the lake reports produced every three to five years. Fish-community objectives will be revised, strengthened, and made more specific between each report. The process of reporting on progress toward meeting stated goals and objectives will focus attention on critical fisheries issues and enhance communication and understanding among fishery and environmental agencies, political bodies, and the public.

The first state of the lake report (Hansen 1990) described the progress through 1989 toward reaching fish-community objectives established by the Lake Superior Committee (Busiahn 1990). The 1989 report also presented a comprehensive compilation of information. This report is modeled after the first report and presents relevant conclusions drawn from summaries of the larger 1989 data sets. The 1992 report is intended to present a summary of key findings about Lake Superior through 1992.

An alphabetical list of common fish names and their corresponding scientific names are given in Table 1. The table lists all fish species referred to throughout this publication.

Table 1. A list of common and scientific fish names used in this publication.

Common name	Scientific name
Atlantic salmon	*Salmo salar*
brook trout	*Salvelinus* fontinalis
brown bullhead	*Ameiurus nebulosus*
brown trout	*Salmo trutta*
burbot	*Lota lota*
chinook salmon	*Oncorhynchus tshawytscha*
coho salmon	*Oncorhynchus kisutch*
deepwater cisco	*Coregonus* spp.
deepwater sculpin	*Myoxocephalus thompsoni*
johnny darter	*Etheostoma nigrum*
lake herring	*Coregonus artedi*
lake sturgeon	*Acipenser fulvescens*
lake trout	*Salvelinus namaycush*
lake whitefish	*Coregonus clupeaformis*
muskellunge	*Esox masquinongy*
northern pike	*Esox lucius*
Pacific salmon	*Oncorhynchus* spp.
pink salmon	*Oncorhynchus gorbuscha*
rainbow smelt	*Osmerus mordax*
rainbow trout	*Oncorhynchus mykiss*
ruffe	*Gymnocephalus cernuus*
salmon	*Oncorhynchus* spp.
sea lamprey	*Petromyzon marinus*
siscowet	*Salvelinus namaycush* siscowet
slimy sculpin	Cottus cognatus
splake (brook trout x lake trout hybrid)	*Salvelinus fontinalis x S. namaycush*
Spoonhead sculpin	*Cottus ricei*
stonecat	*Noturus flavus*
trout-perch	*Percopsis omiscomaycus*
walleye	*Stizostedion vitreum vitreum*
white sucker	*Catostomus commersoni*
yellow perch	*Perca flavescens*

Goals and Objectives

The basis for Lake Superior fish-community objectives is provided in the common goal statement for Great Lakes fishery agencies given in the Joint Plan:

> *To secure fish communities, based on foundations of stable self-sustaining stocks, supplemented by judicious plantings of hatchery-reared fish, and provide from these communities an optimum contribution of fish, fishing opportunities and associated benefits to meet needs identified by society for:*
>
> *wholesome food,*
> *recreation,*
> *employment and income, and*
> *a healthy human environment.*

The fish-community objectives established for Lake Superior (Busiahn 1990) include:

- Restore lake herring stocks to historic levels of abundance for purposes of lake trout restoration, production of other predators, and fishery harvest.

- Achieve a sustained annual yield of 1.8 million kg of lake trout from naturally reproducing stocks, and an unspecified yield of other salmonid predators, while maintaining a predator-prey balance that allows normal growth of lake trout.

- Manage exploitation of nondepleted stocks to maintain a stable, self-sustaining status (lake whitefish, deepwater ciscoes, suckers, and walleye) and reestablish depleted stocks of native species (lake sturgeon, brook trout, and walleye).

- Achieve a 50% reduction in parasitic-phase sea lamprey abundance by the year 2000 and a 90% reduction by the year 2010.

- Achieve no net loss of the productive capacity of habitats supporting Lake Superior fisheries, restore the productive capacity of habitats that have suffered damage, and reduce contaminants in all fish species to levels below consumption advisory levels.

In addition, the Great Lakes Water Quality Agreement of 1978 (International Joint Commission 1989) states that Lake Superior should be maintained as a balanced and stable oligotrophic ecosystem with lake trout as the top aquatic predator of a cold-water community and the benthic crustacean (*Diporeia* spp.) as a key organism in the food chain. The 1978 Agreement goes on to establish the following ecosystem-health indicators for Lake Superior lake trout and *Diporeia* spp.:

- Achieve lake trout productivity greater than 0.38 kg/ha from stable, self-producing stocks free of contaminants at concentrations that adversely affect the trout themselves or the quality of the harvested products.

- Maintain *Diporeia* spp. abundance throughout the lake at the following levels:

    - **220-320/m²** in water less than 100 m deep, and

    - **30-160/m²** in water more than 100 m deep.

Background

Lake Superior is the largest body of fresh water in North America and lies at the head of the St. Lawrence River drainage (Lawrie and Rahrer 1973). The shoreline is almost evenly divided between the United States and Canada but nearly two-thirds of the surface area lies in the United States (Table 2). In contrast, more than two-thirds of the drainage basin lies in Canada. There are approximately as many tributary streams in Canada as in the United States; however, the Canadian streams are generally larger than the United States streams.

Lake Superior is oligotrophic because of its low temperature, low dissolved solids, great mean depth, and small littoral zone. Primary production is near the low end of the range for freshwater lakes. Water clarity is very high with visibility typically 10 m deep, or more. Fish production averaged only 0.93 kg/ha during its peak from 1916 to 1940. Fish production averaged only 0.80 kg/ha during the much-longer 90-year period from 1879 to 1969. The original fish community was dominated by lake trout, lake whitefish, lake herring, and several species of deepwater ciscoes.

During the 1950s, excessive fishing and predation by sea lampreys (an invader introduced from the Atlantic Ocean) caused the collapse of lake trout, lake herring, and deepwater cisco populations (Hile et al. 1951; Pycha and Ring 1975; Jensen 1978; Coble et al. 1990). Restoration of lake trout stocks was attempted through sea lamprey control, lake trout stocking, and more restrictive regulation of commercial fishing. Inshore lake trout abundance increased tenfold between 1961 and 1971 in Michigan and Wisconsin where stocking rates were highest, increased more slowly in Ontario where stocking rates were lower, and increased little in Minnesota where initiation of stocking was delayed. Remnant native stocks of lean lake trout continued to decline through the 1960s, but stocks of siscowet lake trout increased off shore in the United States and Canada. Siscowet stocks are now nearly fully recovered. The only lean lake stocks that survived were at Gull Island Shoal and Cat Island in Wisconsin; Thunder Bay, Superior Shoal, and Slate Island in Ontario; and Stannard Rock, Isle Royale, and Munising in Michigan.

Table 2. Lake Superior morphometry and hydrology (Lawrie and Rahrer 1973).

Length:	668.3 km	350 mi
Breadth:	305.5 km	160 mi
Depth:		
maximum	406.3 m	1,333 ft
mean	148.3 m	487 ft
Shoreline:		
United States	1463.0 km	909 mi
Canada	1,475.7 km	917 mi
Total	2.938.7 km	1,826 mi
Surface area:		
United States	53,613.0 km^2	20,700 mi^2
Canada	28,800.8 km^2	11,120 mi^2
Total	82.413.8 km^2	31,820 mi^2
Volume:	12,233.3 km^3	2.927 mi^3
Drainage area:		
United States	43,770.8 km^2	16,900 mi^2
Canada	101,786.6 km^2	39,300 mi^2
Total	145,557.4 km^2	56,200 mi^2
Tributaries:		
United States		840
Canada		685
Total		1.525
Mean annual discharge:	2,124.7 m^3/s	75,051 cfs
Retention time:		82 yr

During and after the 1970s, lake trout restoration was slow because of reduced stocking and ineffective control of fishing. Recruitment of stocked fish declined in Wisconsin where stocking was reduced in the late 1960s and in Michigan where stocking was reduced in 1971. In contrast, recruitment of planted fish increased in Minnesota where intense stocking continued in the late 1960s and 1970s. Recruitment of stocked fish stabilized at a low level in Ontario (where stocking rates were lower). Lake trout formerly stocked in Michigan and eastern Wisconsin were stocked in Minnesota and western Wisconsin because fishery managers thought that stocked fish would be better protected from fishing-with a better chance to mature and reproduce. However, fishing in the United States increased steadily in the 1960s and 1970s, and commercial catches in Ontario generally exceeded quotas imposed for the first time in 1961. During the 1970s, stocked fish were reproductively less efficient than native fish in Wisconsin (Krueger et al. 1986). This reproductive inefficiency probably resulted from holding juvenile fish in hatcheries at a time when they normally imprinted to their natal spawning shoal.

In 1970, inshore stocks of lake trout in most areas of the lake were still supplemented by stocking. Natural reproduction, though increasing slowly in many areas and rapidly in a few, was still inadequate to maintain stocks or sustain a substantial yield. Fishery agencies recognized that lake trout restoration was more difficult and time consuming than originally anticipated and would require continued stocking, increased regulation of exploitation, increased control of sea lampreys, development of new sea lampreycontrol methods, and additional knowledge.

Progress toward fishery objectives was substantial in 1989 (Hansen 1990) but remained far below target levels. Herring stocks rebounded in many areas of the lake but remained below historic levels of abundance. The annual yield of lake trout approached half the target level but was still largely supported by stocking in many areas. Yield of other predators approached 15% of total predator yield, but lake trout growth declined in Michigan. Stocks of lake whitefish supported greater commercial yields than at any previous time. However, stocks of walleye, lake sturgeon, and brook trout remained depressed from overfishing, habitat degradation, and competition with introduced species. Parasitic-phase sea lampreys remained at approximately 10% of precontrol populations but still accounted for a substantial portion of total lake trout mortality-particularly in United States waters west of the Keweenaw Peninsula. Habitat management and restoration were focused on Areas of Concern that had been identified as sites for Remedial Action Plans.

LAKETROUT

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Introduction

The fishery objective for lake trout in Lake Superior is to achieve a sustained annual yield of 1.8 million kg from naturally reproducing stocks (Busiahn 1990). The average annual reported yield of lake trout to humans in 1990, 1991, and 1992 was 32.9% of the goal (25.2% in Canada and 32.4% in the United States), but planted fish made a large contribution to the yield in some areas. Sea lamprey predation accounted for approximately 14.7% of the goal in the United States and an unknown portion of the goal in Canada.. Yield to humans could therefore be increased if sea lampreys could be reduced below current levels.

Stocking

The lake trout restoration plan for Lake Superior adopted by the Lake Superior Committee in March 1986 set forth a stocking policy to rebuild and maintain lake trout stocks (Lake Superior Technical Committee 1986). The lake was divided into subareas for planning, setting priorities, and reporting (Fig. 1). Subareas in the United States were modified from statistical reporting districts (Smith et al. 1961) and those in Canada were taken from the Ontario quota-management plan. The plan recommended that yearling lake trout derived from wild parents native to the stocking areas should be planted at a size of 40-55 kg and at a density of 232-347/km^2 of lake trout habitat.

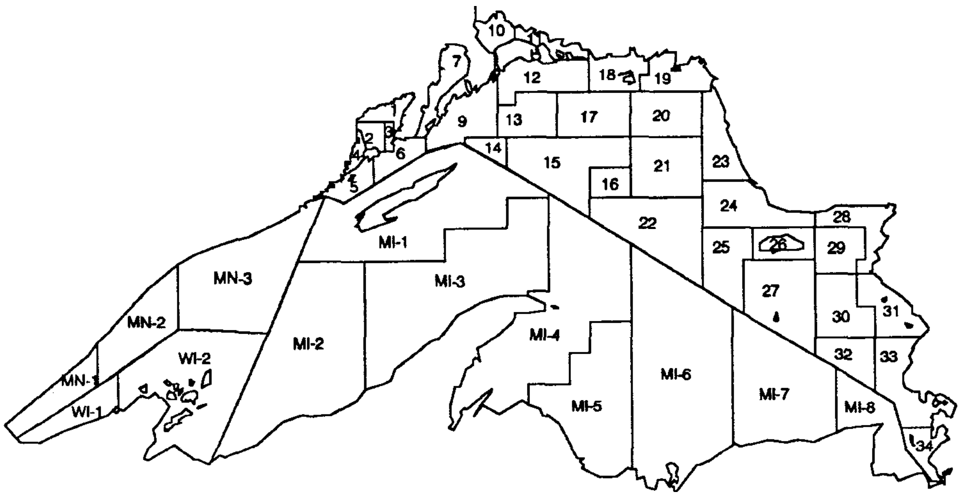

Fig. 1. Lake Superior fishery-management areas.

Lake trout planting in Lake Superior began shortly after native stocks collapsed. Lake trout have been planted almost continuously in Michigan and Wisconsin since 1952, in Ontario since 1958, and in Minnesota since 1962 (Lawrie and Rahrer 1973; Great Lakes Fishery Commission 1985; Ebener 1989) (Fig. 2). By 1970, more than 27 million lake trout had been planted in Lake Superior-52% in Michigan, 22% in Ontario, 19% in Wisconsin, and 7% in Minnesota. An additional 1.6 million fingerlings were planted in the United States. Lake trout planting between 1970 and 1983 ranged from less than two million in 1973 to three million in 1982 (an average of 2.5 million). Changes in United States planting rates from 1970 to 1983 were made to better protect stocked fish from exploitation so they could mature and reproduce. Planting rates in Michigan were reduced 50% in 1971. In Wisconsin, planting was shifted during the 1970s from an area of the Apostle Islands with low survival and high reproductive potential to an area in the west with high survival and low reproductive potential. Plantings between 1984 and 1992 averaged 3.3 million-ranging from a low of 2.6 million in 1989 to a high of 3.9 million in 1985. In Ontario, construction at Tarentorous Hatchery resulted in low plantings during 1989.

In the United States, an outbreak of epizootic epitheliotropic disease (Hnath 1993) in state and federal hatcheries resulted in low plantings during 1990. More than 90 million lake trout have been planted through 1992--39% in Michigan, 34% in Ontario, 16% in Wisconsin, and 11% in Minnesota.

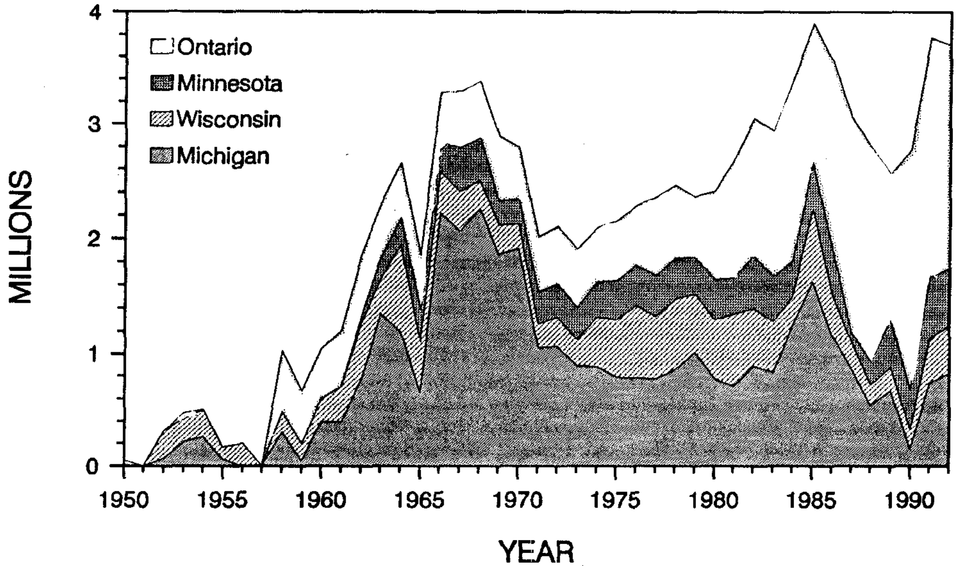

Fig. 2. Lake trout planted in Lake Superior, 1950-92.

Planting priorities for lake trout were based on the quantity of quality spawning habitat, historic production, total annual mortality rate, and level of natural reproduction. Planting quotas were reduced for some management areas in Michigan and Wisconsin because survival of stocked lake trout declined, and planting priorities were revised because of exploitation changes. Planting quotas were not met in western Minnesota (MN-l), eastern Wisconsin (WI-2), or Michigan (MI-2 to MI-6) in 1990. Planting quotas were also not met in Keweenaw Bay (MI-4) in 1991 but were equaled or exceeded in other areas in 1990, 1991, and 1992 (Fig. 3).

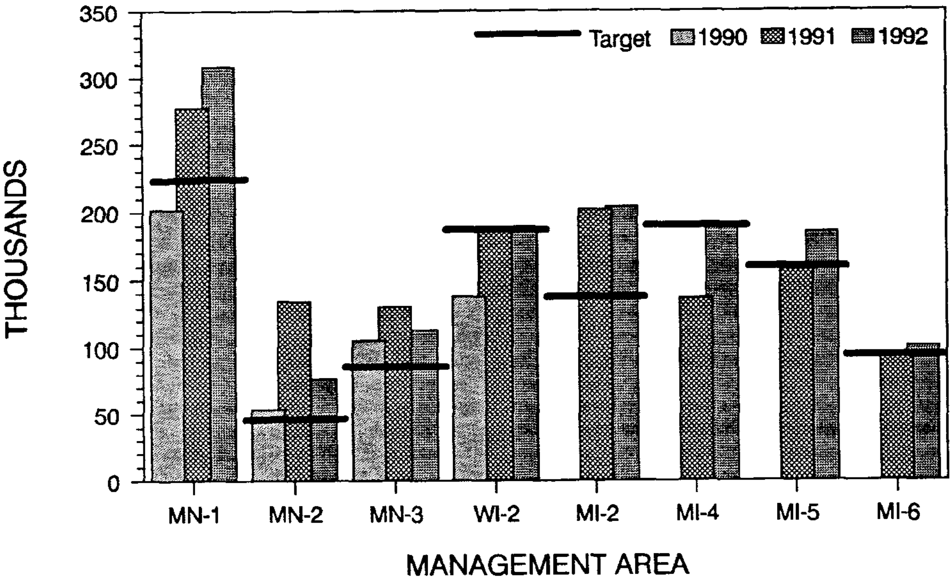

Fig. 3. Lake trout planted compared to target planting quotas in selected management areas of Lake Superior, 1990-92.

Abundance

Trends in relative abundance of lake trout in the United States were developed from lake trout-assessment fishing conducted by or for the various states. Catches were with 114-mm stretch-measure gillnet except from 1970 to 1984 in Minnesota where some nets were 126-mm, 138-mm, and 151-mm mesh. Generally, a number of lifts were made in each management area each year. Catch per effort (CPE) was adjusted to the no. of fish/km of multifilament gillnet fished for one night. However, CPE distribution was highly skewed and normalized by transformation into natural logarithms. Transformed, standardized CPE was averaged across lifts within management areas and years and then averaged across management areas in each jurisdiction for wild and planted lake trout. Relative abundance within each United States jurisdiction is shown as a three-year moving average.

In Ontario, no comparable data on abundance are available. Lake trout abundance in Ontario was monitored as an incidental catch in inshore commercial lake whitefish fisheries and in offshore targeted lake trout fisheries. However, substantial misreporting of lake trout catches occurred in these fisheries so trends in abundance are not reliable.

In Michigan (MI-3 to MI-7), abundance of wild lake trout generally increased between 1970 and 1992. However, abundance of planted lake trout generally decreased (Fig. 4). Wild lake trout abundance increased rapidly during the 1970s as strong year-classes of wild fish were recruited. Abundance was relatively stable during the 1980s as recruitment of wild fish declined, but abundance has decreased since 1990 as adult mortality increased. Abundance of planted lake trout was greatest in 1970 but then declined. The reduced recruitment of wild fish and abundance of planted fish resulted in reduced total abundance of lake trout after 1980. Abundance of wild lake trout in Michigan (MI-3 to MI-7) now greatly exceeds stocked-fish abundance. Planted lake trout abundance in extreme eastern Michigan (MI-8) was low during the last half of the 1970s. Wild lake trout remain scarce because restoration of lake trout was deferred because of the presence of a large gillnet fishery for lake whitefish. Lake trout abundance in western Michigan (MI-2) has not been extensively monitored, but generally follows the same pattern as seen in management areas MI-3 to MI-7.

In eastern Wisconsin (WI-2), abundance of planted lake trout declined gradually during the early 1970s, remained relatively stable during the late 1970s and early 1980s, and declined again during the late 1980s and early 1990s (Fig. 4). Abundance of wild lake trout varied without trend between 1970 and 1985, and has remained stable since 1986. Wild lake trout now outnumber planted lake trout in eastern Wisconsin although not to the same extent as in Michigan. Eggs have been stocked on offshore reefs since 1980 because planted lake trout in these areas failed to reestablish self-reproducing populations on the numerous offshore spawning reefs typical of the area. Lake trout have been planted primarily to maintain predation pressure on rainbow smelt and to absorb sea lamprey predation and fishing effort.

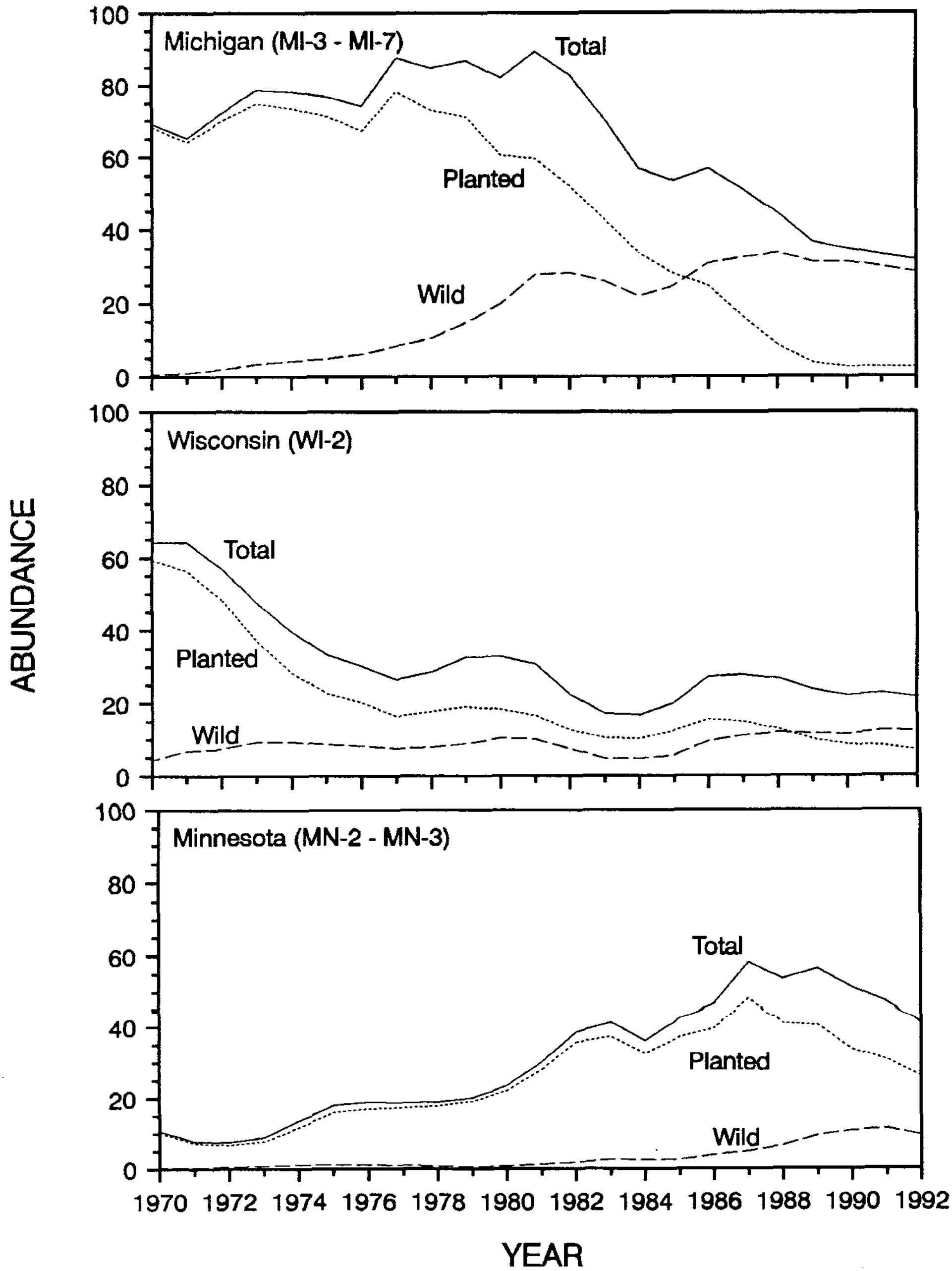

Fig. 4. Spring abundance of wild and planted lake trout (no. of fish/km of 114-mm stretch-measure gillnet) in United States waters of Lake Superior, 1970-92.

In Minnesota, abundance of both wild and planted fish generally increased between 1970 and 1992 (Fig. 4). Abundance of wild lake trout increased most after 1980. Abundance of planted fish has been relatively consistent since 1980. Current abundance of wild fish is still less than in Michigan or Wisconsin, but abundance of planted fish is much higher. Abundance is highest in western Minnesota (MN-l), intermediate in eastern Minnesota (MN-3), and lowest in central Minnesota (MN-2).

Lake trout were not planted around Isle Royale (MI-l), but stocks there recovered rapidly following implementation of sea lamprey-control programs. Abundance of juvenile wild lake trout (as indexed in periodic small-mesh gillnets) increased steadily between 1958 and 1992 (Fig. 5). Low abundance of recruits in 1968 resulted from extremely low abundance of spawners in the early 1960s caused by sea lamprey predation. Reproduction during the 1960s precipitated the recovery that began during the 1970s and continued through 1992.

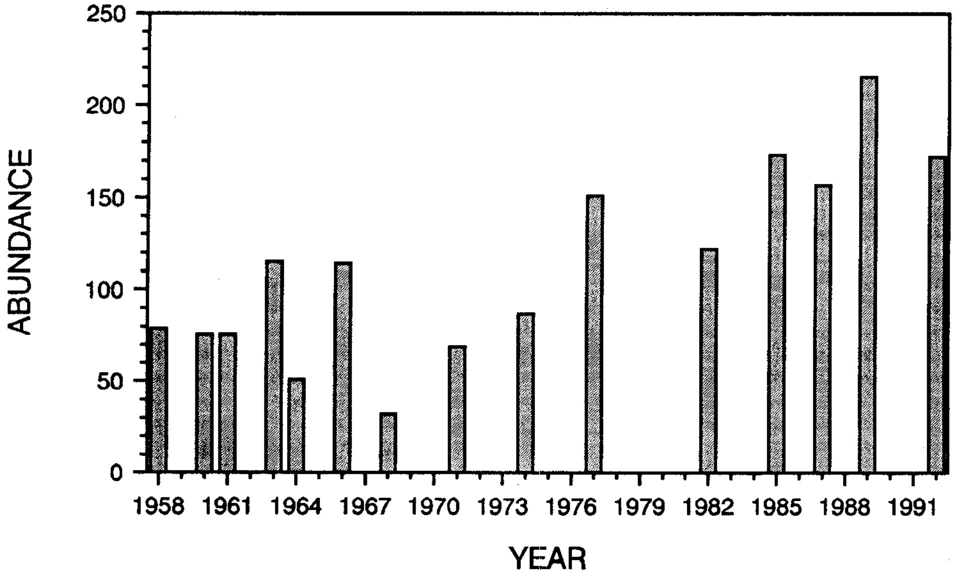

Fig. 5. Lake trout abundance (no. of fish/km of small graded-mesh gillnet) off Isle Royale, Lake Superior, 1958-92.

Offshore stocks of siscowets also recovered rapidly after the onset of sea lamprey-control programs. Siscowets are a race of lake trout that inhabits deep water (76-213 m) with a 20%-80% fat content. Siscowet abundance increased in most areas of Lake Superior and have become more important in commercial catches. Summer catches in graded-mesh gillnets indicate that siscowets were uncommon in central Michigan (MI-4, MI-5, and MI-6) in 1975, 1978, and 1981. However, siscowets have become abundant since 1984. Surveys were conducted every three years before 1984, and they have been conducted annually since 1984 (Fig: 6). -

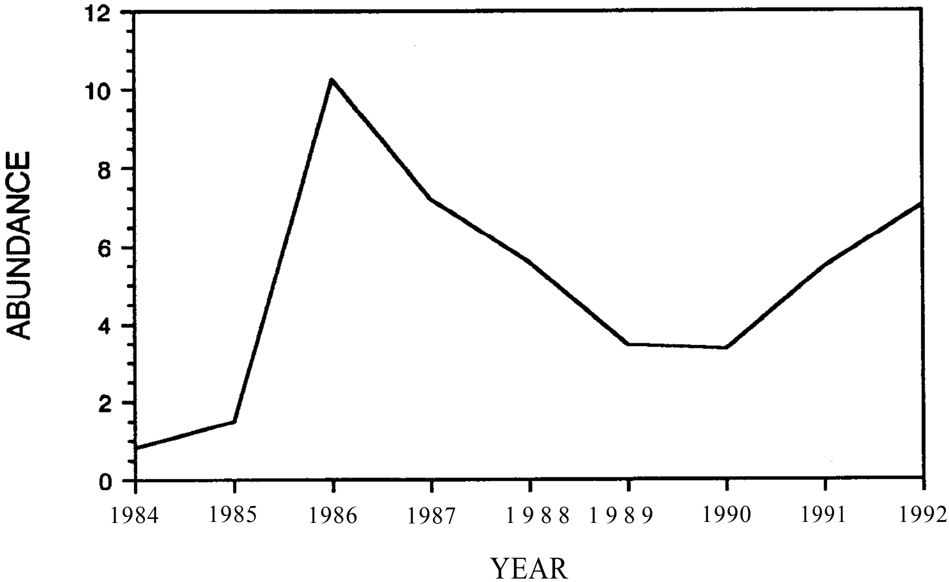

Fig. 6. Siscowet abundance (no. of fish/km of graded-mesh gillnet) in Michigan waters of Lake Superior, 1984-92.

Abundance of wild lake trout spawners larger than 63.5 cm in central Michigan (Keweenaw Bay, MI-4) has declined since 1980-a contrast to the abundance of smaller fish (less than 43.2 cm) (Fig. 7). Numbers of large lake trout:

- increased gradually between 1970 and 1980,
- declined gradually between 1981 and 1987, and
- stabilized between 1988 and 1992.

Numbers of small lake trout increased through 1981 and have not increased much since then. This pattern of abundance is similar throughout much of Michigan suggesting that wild-fish abundance will not likely improve unless numbers of spawners can be enhanced.

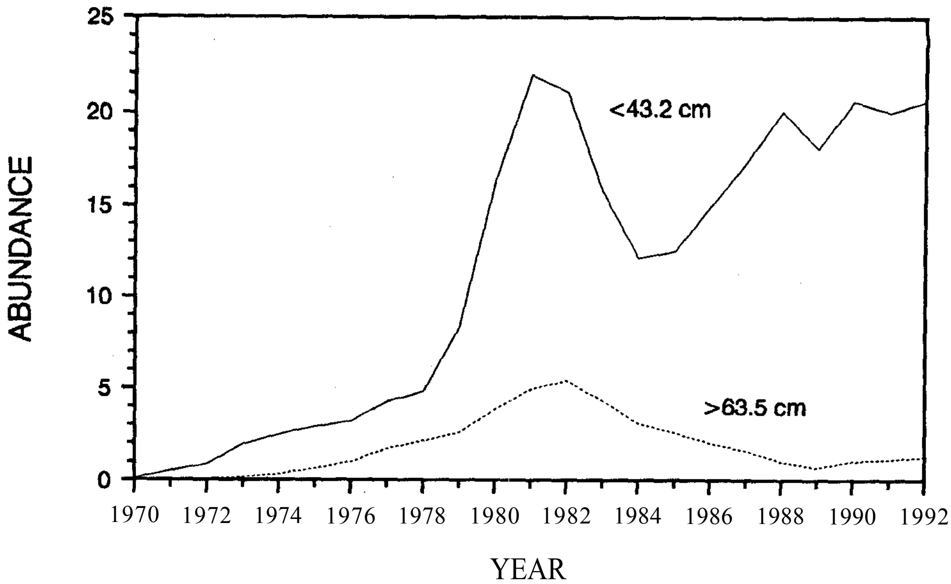

Fig. 7. Spring abundance of small and large lake trout (no. of fish/km of 114-mm stretch-measure gillnet) in Keweenaw Bay, Lake Superior, 1970-92.

Mortality

Mortality is calculated by fitting a regression line to the descending limb of a catch curve for age-7-11 lake trout caught in 114-mm gillnet. The target mortality rate is 45% when computed by this method. However, true mortality is over-estimated because of gillnet-mesh selectivity. In recent years, age-8-12 lake trout were used to calculate mortality because age-7 fish were not fully recruited. Mortality rates were not corrected for trends in recruitment. Mortality of wild fish computed in this way is biased upward partly because of increasing recruitment. In contrast, abundance of stocked lake trout was not corrected for declining stocking rates or survival-resulting in deflated estimates of true mortality. Therefore, actual mortality of both wild and stocked lake trout is closer to the target rate than indicated. Mortality of wild fish is lower, and mortality of stocked fish is higher. Mortality within each jurisdiction is displayed as a three-year moving average.

Mortality rates of wild lake trout in Ontario have only been available since 1985 for management areas near Thunder Bay (ON-l), Black Bay (ON-7), Wawa (ON-28), and Sandy Island (ON-33). These mortality rates exceeded the target rate with the exception of Black Bay. Mortality in Black Bay was lower than the target rate in four of five years between 1987 and 1991 (Fig. 8). Lake trout catch in these areas is restricted because of use of bycatch quotas for the lake whitefish fisheries.

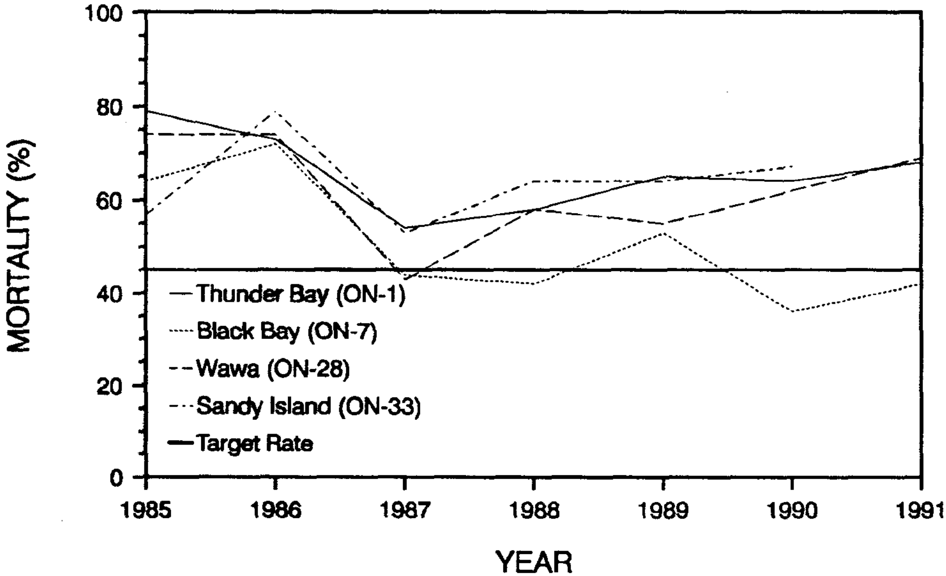

Fig. 8. Total annual mortality of lake trout in selected Ontario management areas of Lake Superior, 1985-91.

In Michigan, mortality of wild lake trout often exceeded the target rate between 1970 and 1992. However, mortality of stocked fish in recent years has generally been lower (Fig. 9). Average mortality of wild lake trout exceeded the target rate every year between 1970 and 1992. Average mortality of stocked lake trout declined during the 1970s. During the 1980s and early 1990s, average mortality of stocked lake trout remained close to the target rate.

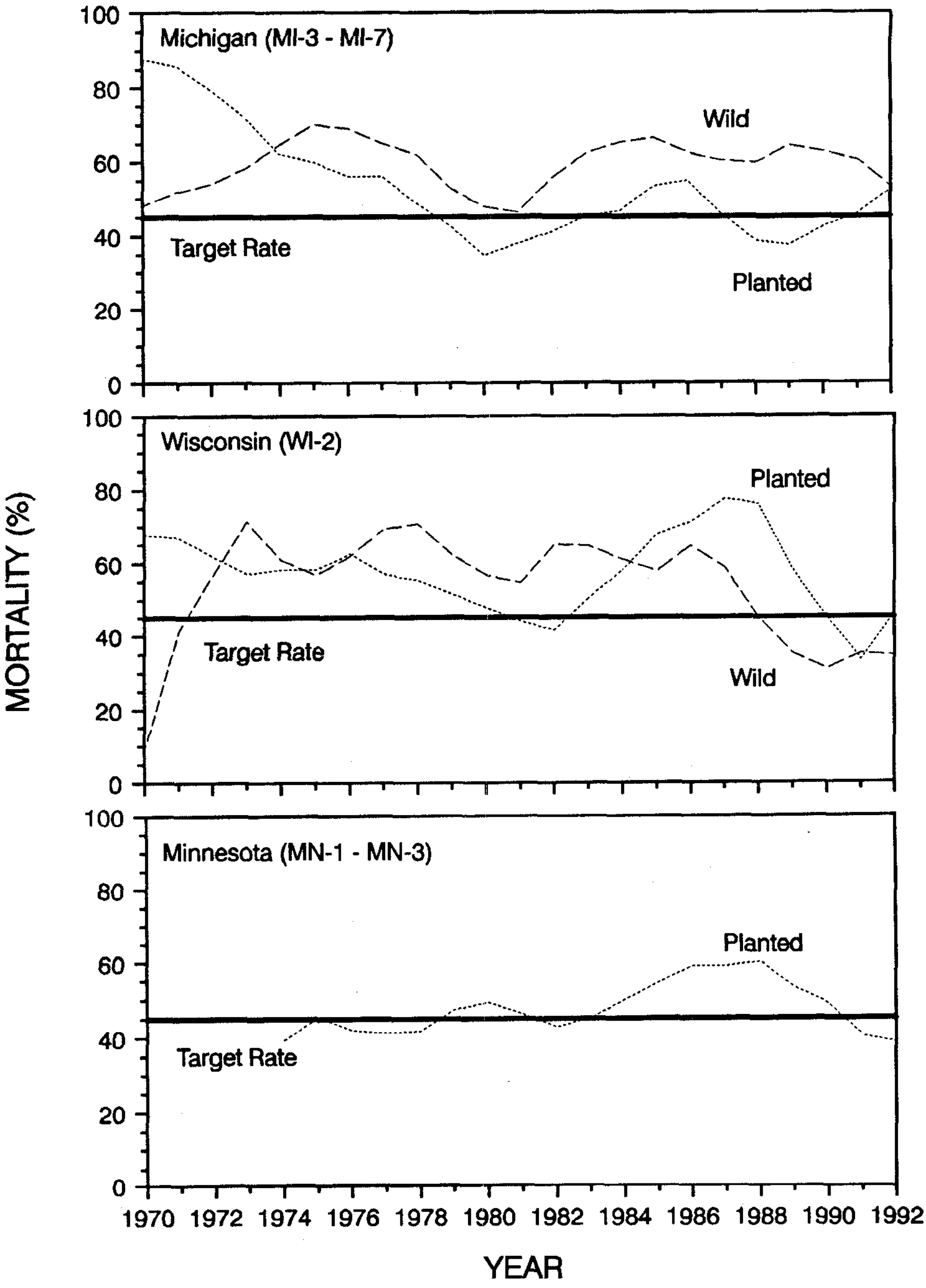

Fig. 9. Total annual mortality of lake trout in United States waters of Lake

In eastern Wisconsin (WI-2), mortality of both wild and planted fish exceeded the target rate between 1970 and 1986. However, wild fish have been below the target rate since 1988, and planted fish have been below the target rate since 1990 (Fig. 9). The recent decline in mortality reflects a change from using scales instead of otoliths for determining age. Mortality rates are lower, more accurate, and more reliable when based on otolith-aged fish than when based on scale-aged fish. Mortality in western Wisconsin (WI-l) since 1987 was generally higher for wild lake trout than for planted lake trout.

In Minnesota, mortality rates are available only for planted lake trout. Mortality was relatively near the target rate from 1974 to 1983, above the target rate from 1984 to 1990, and below the target rate since 1991 (Fig. 9). There has been an overall decline in mortality since 1988.

Growth

Lake trout growth can be expressed in a variety of ways, most of which require either aging or back-calculation. Growth is expressed as the mean length of age-7 lake trout caught in 114-mm stretch-measure-gillnet. In the United States, fish were from assessment fisheries; in Ontario, fish were from commercial fisheries. This definition of growth is the only measure available across nearly all areas and years that incorporates a substantial growth history. However, in areas where fisheries have increased, length-at-age may be suppressed by selective harvest of faster-growing individuals. Growth within each United States jurisdiction is displayed as a three-year moving average.

In Ontario, growth rates between 1981 and 1986 were slower than in the United States-age-7 lake trout were considerably smaller than those in Michigan, Wisconsin, or Minnesota (Figs. 10, 11). However, growth rates in Ontario increased sharply in 1987 and 1988 but then fell again between 1989 and 1991. Lake trout growth was generally lower near Wawa than Thunder Bay, Black Bay, or near Sandy Island.

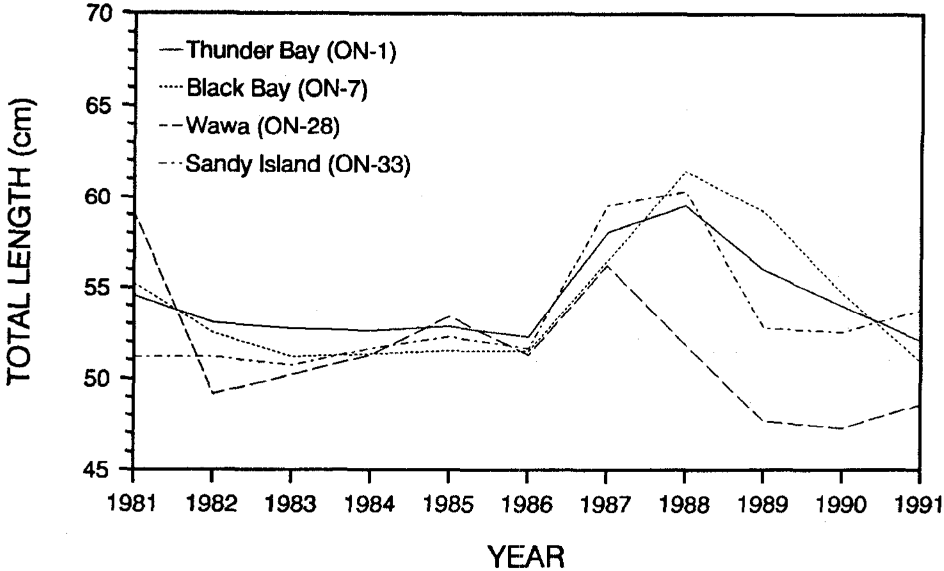

Fig. 10. Length of age-7 lake trout in selected Ontario management areas of Lake Superior, 1981-91.

During the early 1970s, lake trout in Michigan were generally larger at age 7 than lake trout in Minnesota and Wisconsin. By 1992, however, lake trout in all three states were similar in length. In Michigan, mean length of age-7 lake trout declined during the 1980s for both wild and stocked fish (Fig. 11). Wild lake trout growth declined between 1970 and 1975, increased between 1976 and 1980, declined again between 1980 and 1989, and has remained stable since 1990. For hatchery trout, growth declined gradually from 1970 to 1992 - except for an increase between 1977 and 1979. In Wisconsin, average length of age-7 lake trout declined more gradually than in Michigan (Fig. 11). Growth of wild lake trout was generally better than growth of stocked fish between 1970 and 1988. However, growth of wild lake trout fell below growth of stocked fish between 1989 and 1992. In Minnesota, age-7 fish were generally smaller than fish in Michigan and Wisconsin (Fig. 11). Growth increased gradually between 1970 and 1983, decreased between 1984 and 1986, and gradually increased between 1987 and 1992.

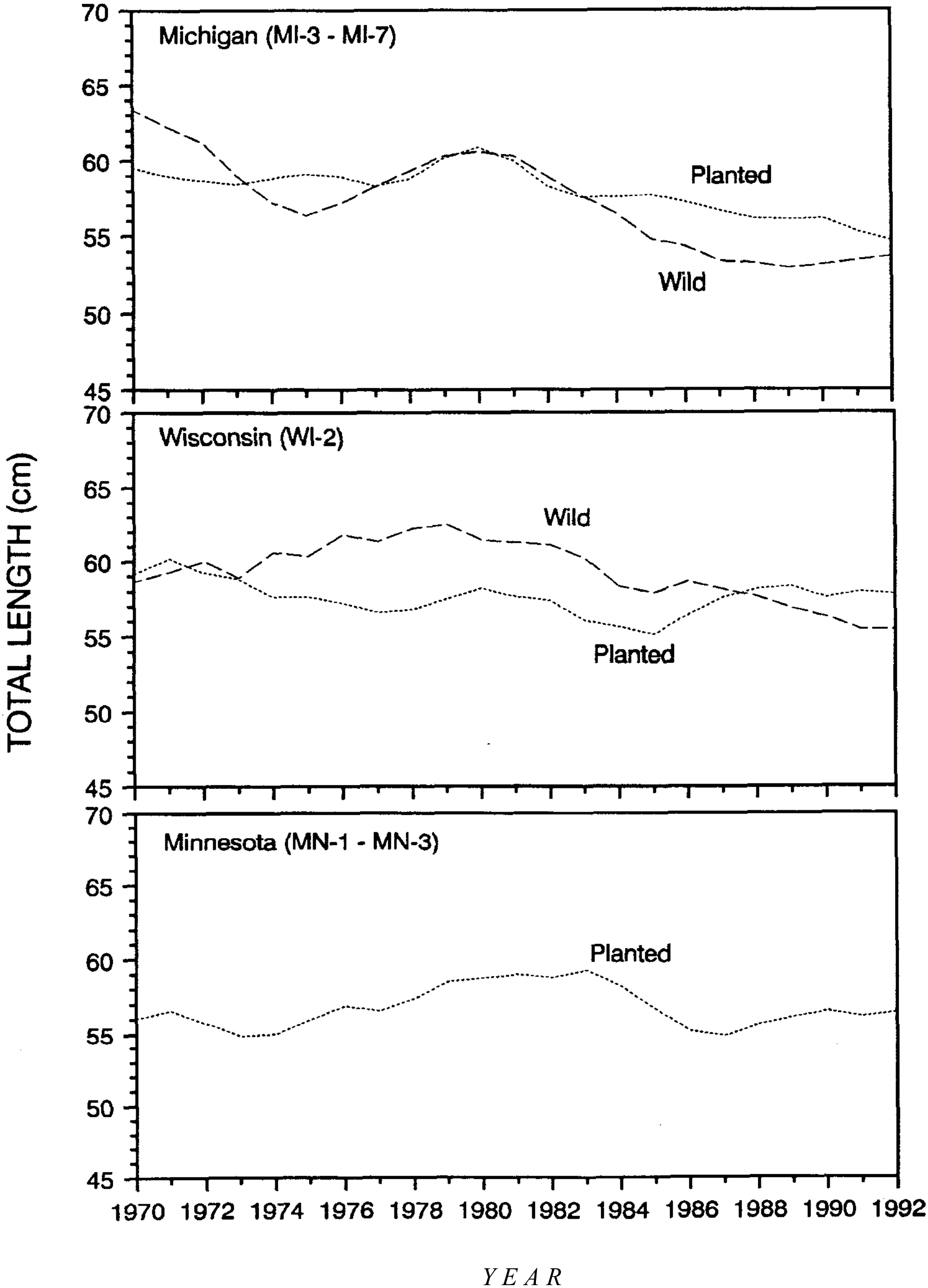

Fig. 11. Length of age-7 lake trout in United States waters of Lake Superior, 1970-92.

Wounding

The incidence of sea lamprey wounds on lake trout in Lake Superior is derived from observed numbers of Type A, Stage I, II, and III sea lamprey marks (King and Edsall 1979) on every 100 lake trout caught during April and May. The standardized sea lamprey wounding rate (no. of wounds/100 fish) was initiated in 1986 by all fishery-management agencies with jurisdiction on Lake Superior. In the United States, the sea lamprey wounding rate is determined from annual assessment fisheries conducted by each management agency. In Ontario, sea lamprey wounding rate is determined from catches of lake trout in commercial fisheries. Average sea lamprey wounding of lake trout larger than 43 cm in the United States and Canada was derived as the quotient of the sum of sea lamprey wounds in all management areas divided by the sum of the number of lake trout sampled in all management areas.

Sea lamprey wounding of lake trout is usually greater in the United States than in Canada. In the United States, average annual sea lamprey wounding between 1986 and 1992 was 5-9 wounds/100 fish. In Canada, the rate was l-6 wounds/100 fish for the same period. Wounding of lake trout has slowly increased since 1986 in both the United States and Canada. In the United States, sea lamprey wounding of lake trout larger than 43 cm peaked in 1989, declined slightly in 1990 and 1991, and increased again in 1992 (Fig. 12). In Canada, sea lamprey wounding of lake trout larger than 63 cm has increased significantly since 1990. On fish larger than 73 cm, sea lamprey wounding has increased significantly since 1989. Wounding of lake trout 43-53 cm long was about the same in 1992 as in 1986.

In the United States, average annual sea lamprey wounding of lake trout between 1986 and 1992 was consistently greater in western Minnesota (MN-l) and Wisconsin (WI-l) than elsewhere. Wounding of lake trout decreased in the area from eastern Wisconsin (WI-2) to central Michigan (MI-2, MI-3, and MI-4). Wounding increased from central Michigan (MI-2, MI-3, and MI-4) to eastern Michigan (MI-6 and MI-7). In Canada, wounding of lake trout was higher in the west (ON-l, ON-2, and ON-4) than in the east. The average and range of annual sea lamprey wounds on lake trout were consistently similar between adjacent management areas (Fig. 13).

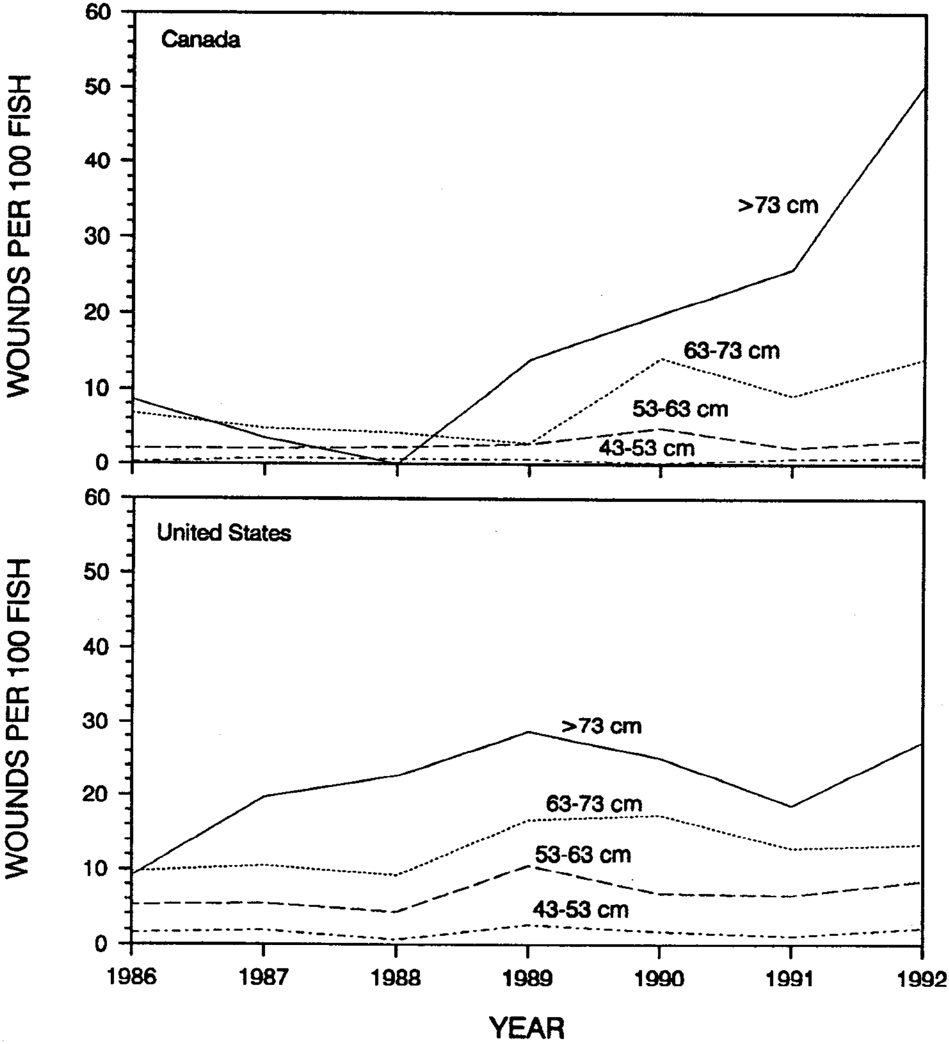

Fig. 12. Average number of sea lamprey wounds on a variety of sizes of lake tro
(no. of wounds/100 fish) in Canadian and United States waters of Lake Superi
1986-92.

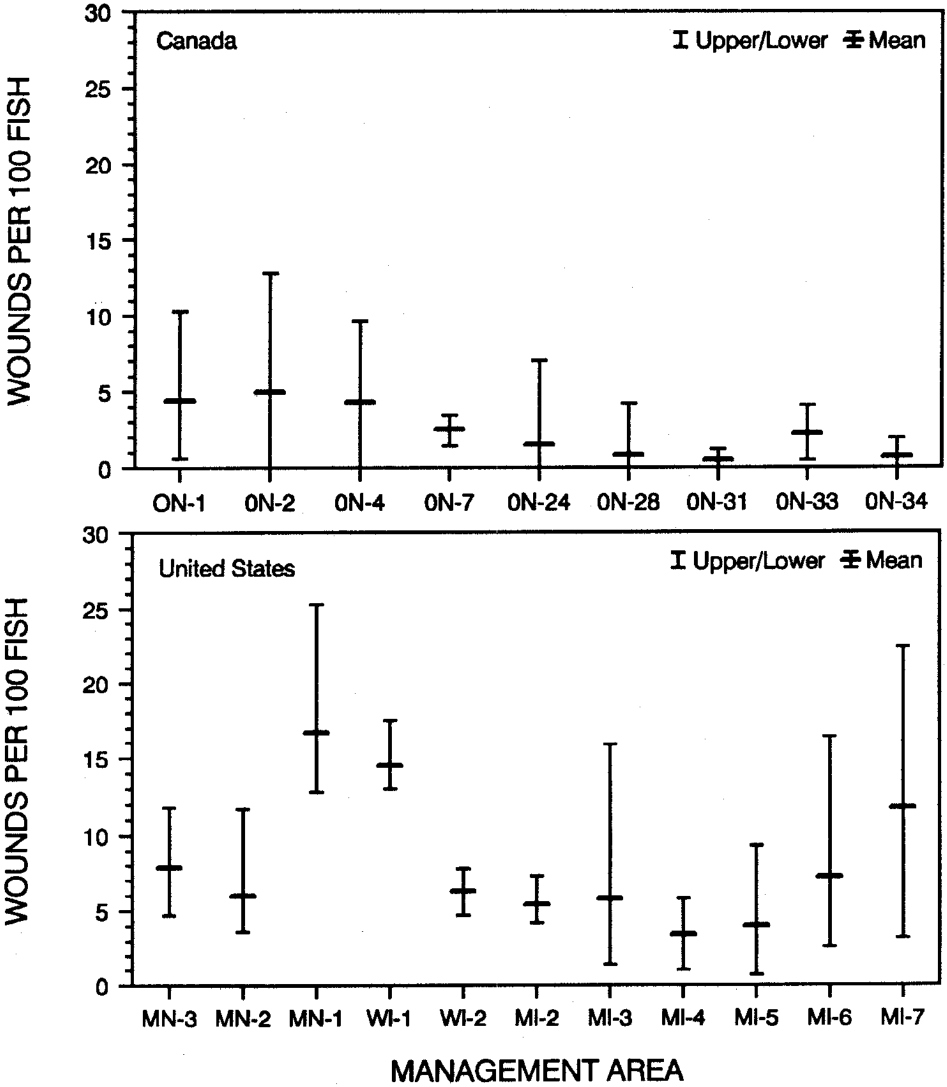

Fig. 13. Average number of sea lamprey wounds on lake trout (no. of wounds/100 fish) in Canadian and United States waters of Lake Superior, 1986-92.

We used a statistical relationship between sea lamprey wounding and the probability of surviving a sea lamprey attack *(P)* and a model of lake trout interactions with sea lampreys to estimate the number of lake trout killed by sea lamprey attacks each year in selected areas of Lake Superior. The P-values derived from laboratory studies of lake trout deaths as a result of single attacks were 0.35 for lake trout 43-53 cm long, 0.45 for lake trout 53-63 cm long, and 0.55 for lake trout 63 cm and longer (Swink and Hanson 1986). However, the probability of surviving sea lamprey attacks could be as low as 14% (J. Koonce, Case Western Reserve University, 2080 Adelbert Rd., Cleveland, OH 44106-7080, pers. commun.), which would result in higher estimates of lake trout deaths. In Minnesota, lake trout deaths from sea lamprey attacks were higher in the 1980s than the 1970s. Since 1981, the average death rate is estimated at 50,000 fish/yr (Fig. 14). Annual lake trout deaths from sea lamprey predation between 1980 and 1991 averaged approximately 10,000 in Michigan (MI-3, MI-5, and MI-6) and 30,000 in eastern Wisconsin (WI-2).

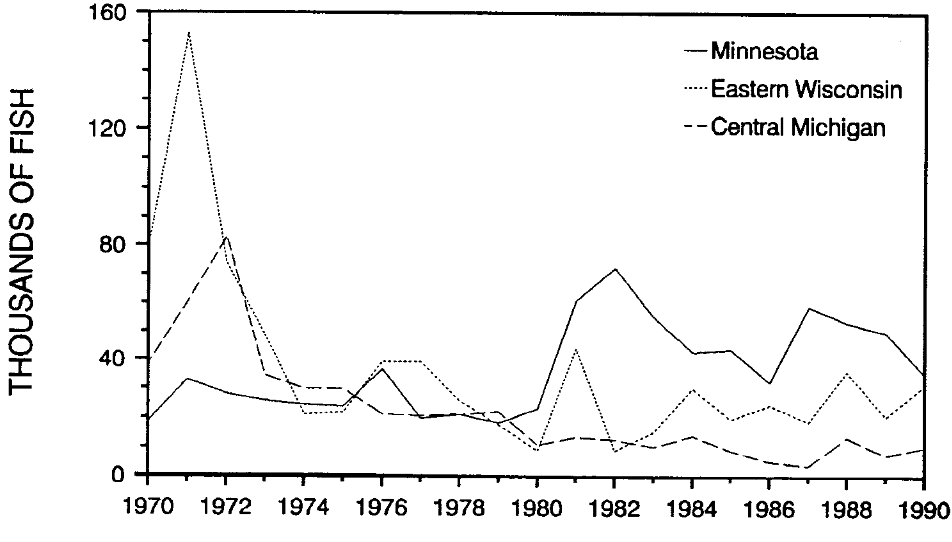

Fig. 14. Estimated number of lake trout killed by sea lampreys in selected areas of United States waters of Lake Superior, 1970-90.

Fishery and Lamprey-Induced Mortality

The fishery objective for lake trout in Lake Superior is to achieve a sustained annual yield (human extraction) of 1.8 million kg from naturally reproducing stocks. This objective was based on the historic average annual harvest from 1929 to 1943, which included all lake trout races. In the United States, the historic yield of lake trout was approximately 1.3 million kg. In Ontario, the historic yield of lake trout was approximately 0.6 million kg.

To measure the progress of lake trout restoration, lake trout yield was summarized in each jurisdiction for three years-1990, 1991, and 1992. The total average reported yield of lake trout (1990-92) was 596,144 kg-32.9% of the historic average. In Ontario, the average annual yield (1990-92) was 160,107 kg-25.2% of the historic average annual yield. In the United States, the average annual yield (1990-92) was 436,037 kg-32.4% of the historic average yield. The historical average, however, was based entirely on naturally produced fish (Fig. 15).

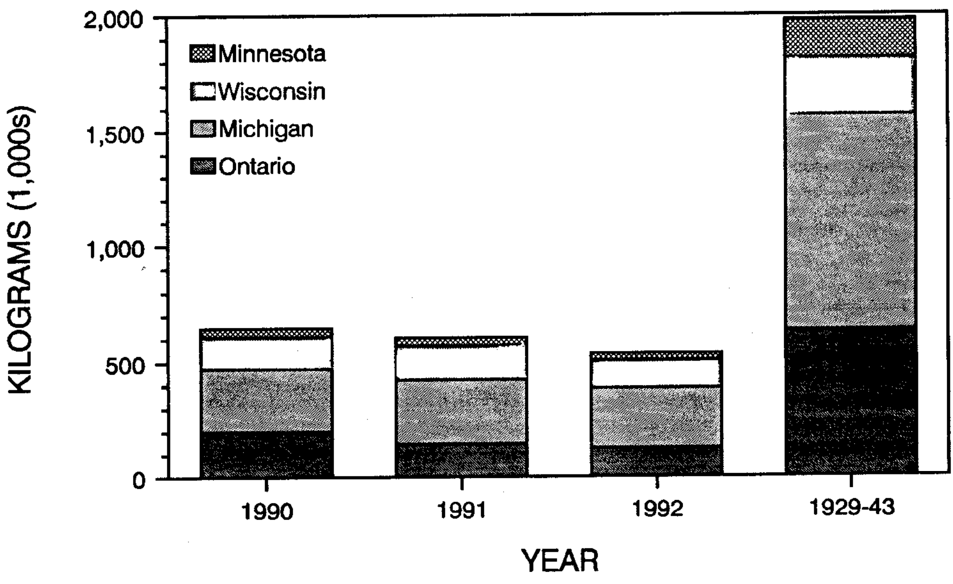

Fig. 15. Lake trout yield (dressed weight) for 1991, 1992, and 1993 compared to the historic yield (1929-43) in Canadian and United States waters of Lake Superior.

Based on mark-recapture surveys and regression relationships, the average number of parasitic-phase sea lampreys in the United States (199092) was 29,010 (Schleen et al. 1991; Klar and Schleen 1992). Based on an analysis of sea lamprey-induced mortality on lake trout in eastern Wisconsin, the estimated average weight of lake trout killed each year by each sea lamprey was 6.75 kg. Therefore, the average annual biomass of lake trout killed by sea lampreys in the United States (1990-92) was 197,383 kg-14.7% of the historic average annual yield. The combined annual lake trout take by sea lampreys and humans in the United States (1990-92) was 633,420 kg - 47.1% of the historic annual yield. Therefore, sea lampreys accounted for 31.2% of the total annual yield of lake trout from the United States (1990-92) (Fig. 16).

The majority of sea lampreys (74.8%) in the United States (1990-92) were estimated to occur west of the Keweenaw Peninsula. Average take of lake trout by sea lampreys was 147,571 kg - 41.6% of all lake trout yield (Fig. 17). In comparison, east of the Keweenaw Peninsula (1990-92) sea lampreys took only 49,812 kg-17.9% of the combined sea lamprey and human take.

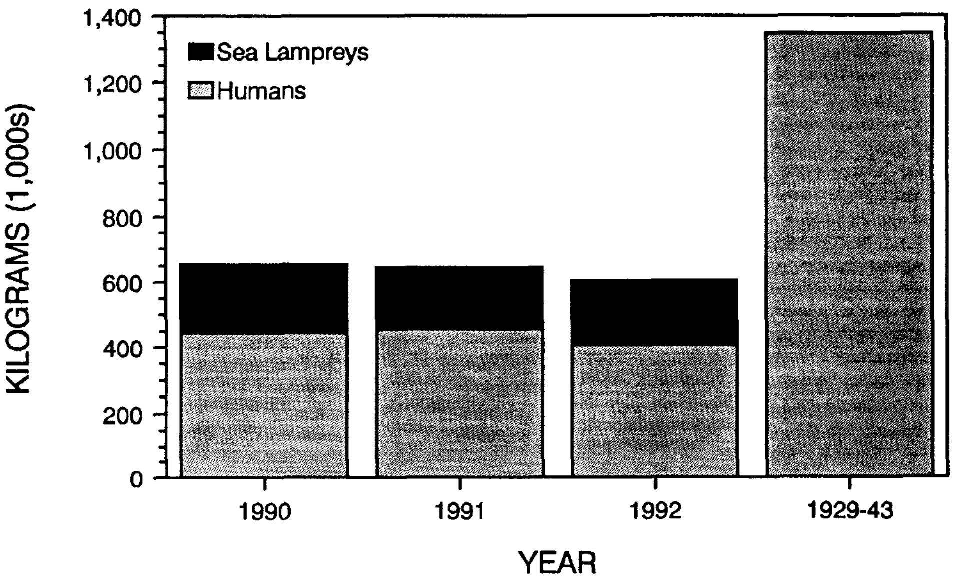

Fig. 16. Lake trout yield by sea lampreys and humans (1990-92) compared to the historic yield (1929-43) in United States waters of Lake Superior.

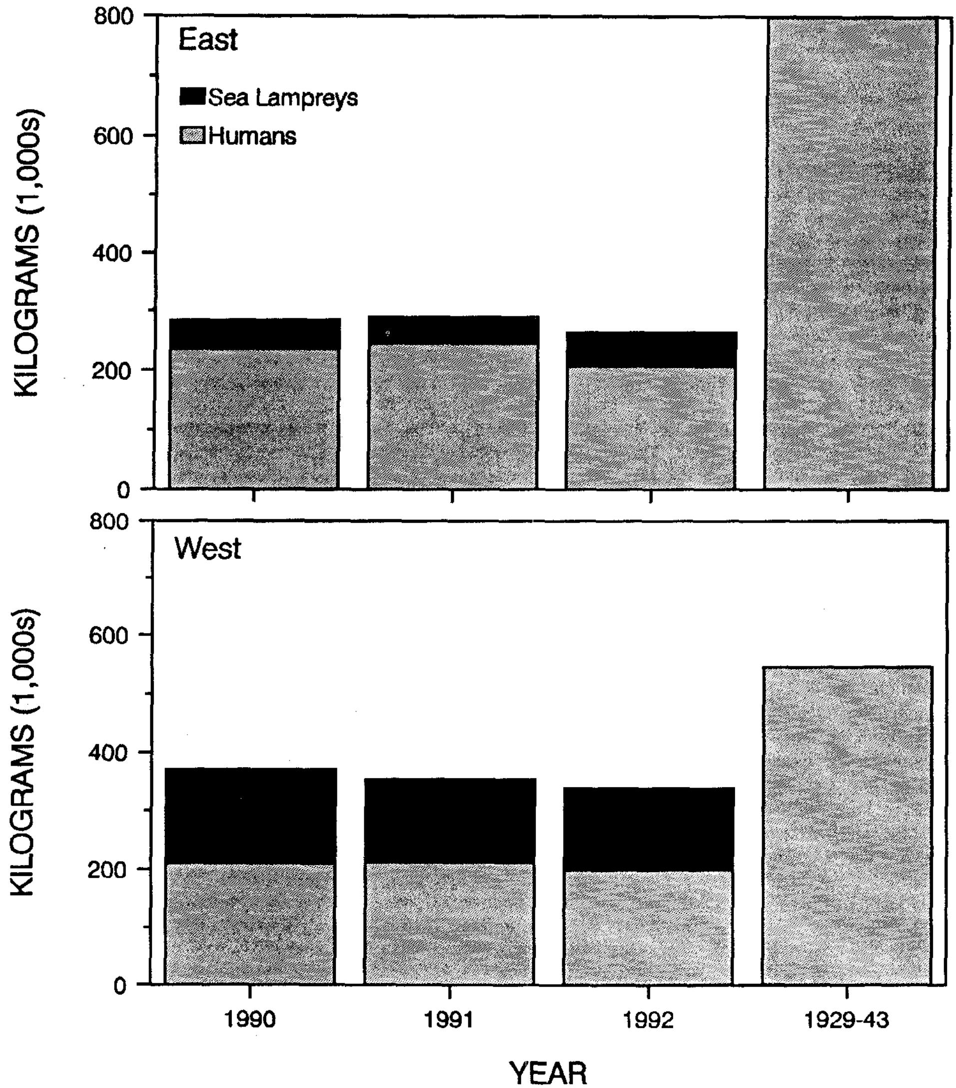

Fig. 17. Lake trout yield by sea lampreys and humans (1990-92) compared to the historic yield (1929-43) in United States waters east and west of the Keweenaw Peninsula of Lake Superior.

Recommendations

The following list of recommendations has been established:

1) The fish-community objective for lake trout in Lake Superior should be revised to reflect independent targets for lean and siscowet lake trout.

2) Sea lamprey control should be enhanced in the United States west of the Keweenaw Peninsula and in the extreme east (MI-6 and MI-7) where losses due to sea lampreys rival yield to humans.

3) All sources of fishing mortality should be examined in areas where total allowable catches and annual mortality rates are excessive, and the adequacy of fishery regulations should be evaluated.

4) Estimates of the probability of surviving a sea lamprey attack should be refined because they are an essential component of the integrated management of sea lamprey program.

5) Causes of declining survival of stocked lake trout in Michigan and Wisconsin (such as predation, competition, habitat changes, and contaminants) should be identified, and if possible, mitigated to ensure that hatchery-reared fish can be used for stock restoration in these areas when necessary.

6) Sport- and commercial-fishing regulations should be made more stringent in the central United States (WI-2, MI-2, MI-3, MI-4, and MI-5) and in Whitefish Bay in Canada where fishing mortality is greatest.

OTHER SALMONINES

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Introduction

The fishery objective for other salmonines in Lake Superior is to sustain an unspecified yield while maintaining a predator-prey balance that allows normal growth of lake trout (Busiahn 1990). Between 1988 and 1990, the total annual yield (harvest) of all salmonines was composed of 90% lake trout (including siscowets) and 10% other salmonines. Wisconsin and Minnesota specified harvest goals for other salmonines from Lake Superior and its tributaries in management plans (Wisconsin Department of Natural Resources 1988; Minnesota Department of

Natural Resources, 5351 North Shore Drive, Duluth, MN 55804, unpubl. data). Salmonine predators in Lake Superior other than lake trout are all non-native species (except for brook trout) and are all anadromous (except for splake).

Most species of other salmonines are routinely planted into Lake Superior; however, except for splake and Atlantic salmon, most species maintain their populations through natural reproduction (Peck 1992). Agencies conduct assessments of the relative abundance of other salmonines, but do not generally determine total abundance. Lakewide marking of chinook salmon planted between 1988 and 1990 and coho salmon planted between 1992 and 1994 should provide a basis for determining the abundance of these species.

Creel surveys have been used to estimate angler harvest and to provide an index of abundance of other salmonines in Lake Superior, Creel surveys on Lake Superior have been conducted annually in Minnesota and Wisconsin since 1969, in Michigan since 1984, and in Ontario since 1986. Surveys were lakewide in Minnesota and Wisconsin but in Michigan were restricted to Marquette from 1984 to 1986. Surveys included all areas west of Munising since 1987. Surveys in Ontario were restricted to Sault Ste. Marie and Michipicoten Bay at Wawa. However, data were also obtained from derbies at Thunder Bay, Wawa, and Rossport, In Minnesota, creel surveys were conducted on tributaries in spring (1980-90) and fall (1986, 1987, 1989, and 1991).

Michigan, Minnesota, Wisconsin, and Ontario prohibit the sale of other salmonines by commercial fisheries, but pink salmon can be taken in Ontario. Nonetheless, incidental catch and mortality occurs in all of these fisheries. These incidentally caught fish must be returned to the water dead or alive. The incidental catch and mortality of other salmonines by Michigan-licensed fisheries are presented for each species. Tribal commercial fisheries in Minnesota and Wisconsin harvest other salmonines incidentally but prohibit sale to nontribal members. The tribal fishery in Michigan allows for the targeting and commercial sale of chinook and coho salmon but not of brook trout, brown trout, and rainbow trout.

Annual spawning runs of adult salmonines were estimated at weirs on the Brule River, Wisconsin (since 1986), and on the French River, Minnesota (since 1974). Juvenile populations were estimated in Michigan streams since 1967 and Wisconsin streams from 1977 to 1983. Studies are under way in Michigan to determine if juvenile production is related to adult abundance, especially for coho salmon. Ontario has conducted aerial counts of dead salmon in the Michipicoten River since 1987 as a means of assessing spawning runs.

Rainbow (Steelhead) Trout

Anadromous rainbow trout (also called steelhead) became widely distributed after being introduced into Lake Superior in 1895 (MacCrimmon 1971), and are now naturalized in most Lake Superior tributaries (Moore and Braem 1965; Hassinger et al. 1974; Biette et al. 1981). Original rainbow trout introductions were of uncertain origin. Recently, numerous known varieties have been introduced, including:

- Kamloops, Madison, and Donaldson strains in Minnesota in 1972 (Close and Hassinger 1981);

- Siletz strain in Michigan in 1984 (Fielder 1987); and

- Skamania strain in Michigan in 1986 (Peck 1992), Minnesota in 1988, and Wisconsin in 1991.

Wild steelhead populations exhibited significant genetic differentiation among populations from different drainages and from within the Brule River drainage (Krueger and May 1987a).

Between 1989 and 1991, the range of plants of yearling steelhead was 104,000 to 135,000 in Michigan, 166,000 to 247,000 in Minnesota, and 51,000 to 107,000 in Wisconsin. In Ontario, the average was 42,000. Most steelhead yearlings planted in Michigan have been Lake Michigan strain-the rest have been domestic rainbow and Skamania summer-steelhead strains. Yearling steelhead planted in Minnesota were mostly Kamloops strain, but some were Knife River (Lake Superior) strain. Wisconsin has planted only wild Brule River-steelhead strain. Fingerlings were not routinely stocked by any agency, but 0.8-3.7 million steelhead fry were stocked annually by Minnesota during the 1980s and early 1990s. Age-2 steelhead were planted in Minnesota in 1989 (943) and in Wisconsin in 1990 (51,000).

Fewer than 2% of steelhead planted in Michigan have been caught by the sport fishery. A similar number contributed to spawning runs (Hansen and Stauffer 1971; Wagner and Stauffer 1978a; Peck 1992). An exception has been the Chocolay River, where Lake Michigan-strain steelhead planted between 1983 and 1985 contributed the most adult steelhead to the 1986-89 spawning runs. There has been no evidence of natural reproduction by Kamloops - strain rainbow trout in Minnesota, but they have been found in spawning runs in streams throughout Lake Superior. In Michigan, planted steelhead averaged 15% of the Lake Superior sport catch and 24%-43% in two tributaries near Marquette in the 1980s (Peck 1992). The steelhead sport catch in Wisconsin in recent years has been from naturally produced fish. In Minnesota, some of the steelhead catch may be from fry plants in Minnesota streams. Kamloops strain contributed 91% of the 1990 rainbow trout harvest in Minnesota.

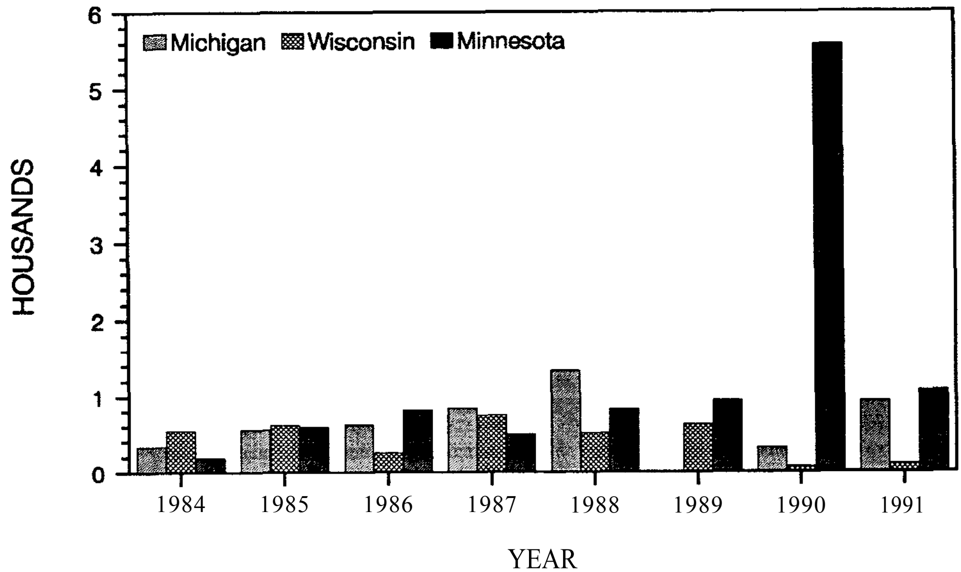

Fig. 18. Sport-fishery harvest of rainbow trout in Michigan, Wisconsin, and Minnesota waters of Lake Superior, 1984-91.

Wisconsin and Michigan have recommended annual harvest goals for rainbow (steelhead) trout of 13,000 and 15,000 fish, respectively. Numbers of steelhead harvested in Lake Superior from 1984 to 1991 averaged 705 in Michigan, 432 in Wisconsin, and 1,312 in Minnesota (Fig. 18). The low harvest in Wisconsin in 1990 and 1991 was because of a restriction in regulations. The high harvest of Kamloops strain in Minnesota in 1990 was because of the addition of a winter creel survey. The average annual incidental catch and kill of steelhead in the Michigan commercial fishery from 1983 to 1989 was 11 fish and 6 fish, respectively. The total harvest of Lake Superior steelhead is not known because most fish are caught in tributary sport fisheries, few of which have been surveyed. The average harvest in tribal commercial and home-use fisheries in Wisconsin was 4 fish between 1988 and 1992. In eastern Michigan, the harvest was 73 fish between 1989 and 1991. The average catch of steelhead in two tributaries at Marquette, Michigan, between 1984 and 1987 (790 fish) (Peck 1992) equaled or exceeded the 1984-91 mean lakewide catch in Michigan (705 fish). The mean catch in the Brule River, Wisconsin, between 1987 and 1991 (7,180 fish) contributed approximately 65% of all wild steelhead in Wisconsin. The spring catch in Minnesota tributaries contributed approximately 66% of the total harvest.

Anglers and biologists have been concerned about an apparent decrease in Lake Superior-steelhead numbers in recent years but survey results have been contradictory. Harvest in Wisconsin (Fig. 18) and runs of steelhead in the Brule River (Fig. 19) did not decrease during the 1980s. However, spawning runs in the Brule River during the 1980s were less than the estimated sport harvest in the Brule River in 1978 and 1979 (Scholl et al. 1984). Rainbow trout harvest in Minnesota increased between 1984 and 1991 (Fig. 18), but most of this increase was because of the increased catch of Kamloops rainbow trout. Steelhead runs in the French River, Minnesota, increased slightly between 1981 and 1991 (Fig. 20) - possibly because of increased fry plants. The steelhead harvest in Michigan did not decrease (Fig. 18).

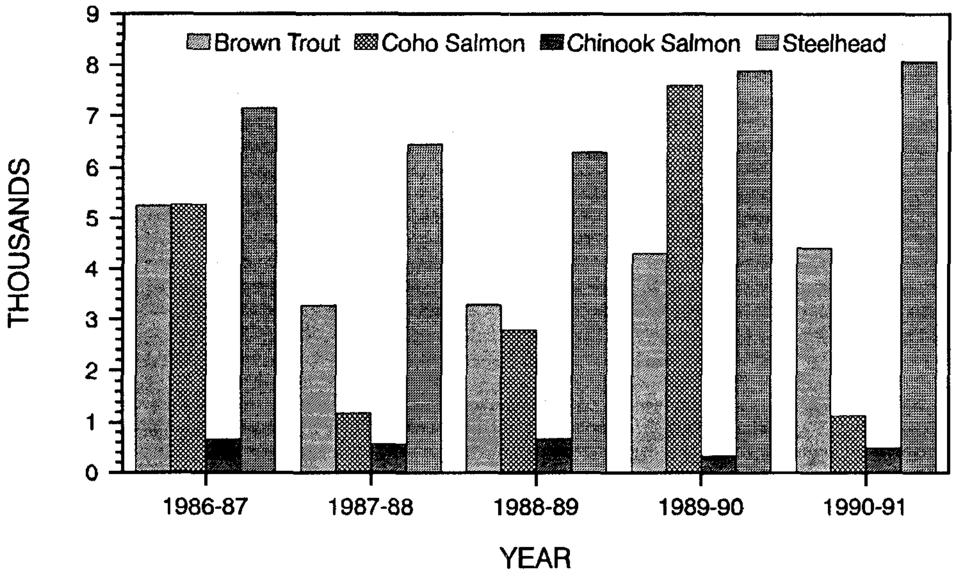

Fig. 19. Numbers of trout and salmon in spawning runs in the Brule River, Wisconsin. 1986-91.

In the Big Huron River, Michigan, the average angling catch rates in 1973 and 1988-89 were similar. However, a 60% reduction in fishing effort from 1973 to 1988-89 may indicate a decline in the steelhead stock. Abundance of age-0 rainbow trout in Chinks Creek (a Big Huron River tributary) was higher between 1982 and 1991 than between 1967 and 1974 (Fig. 21). The opposite was true in the Little Garlic River, 80 km to the east (Fig. 21), where sand in-filling of upstream spawning areas may have reduced juvenile production.

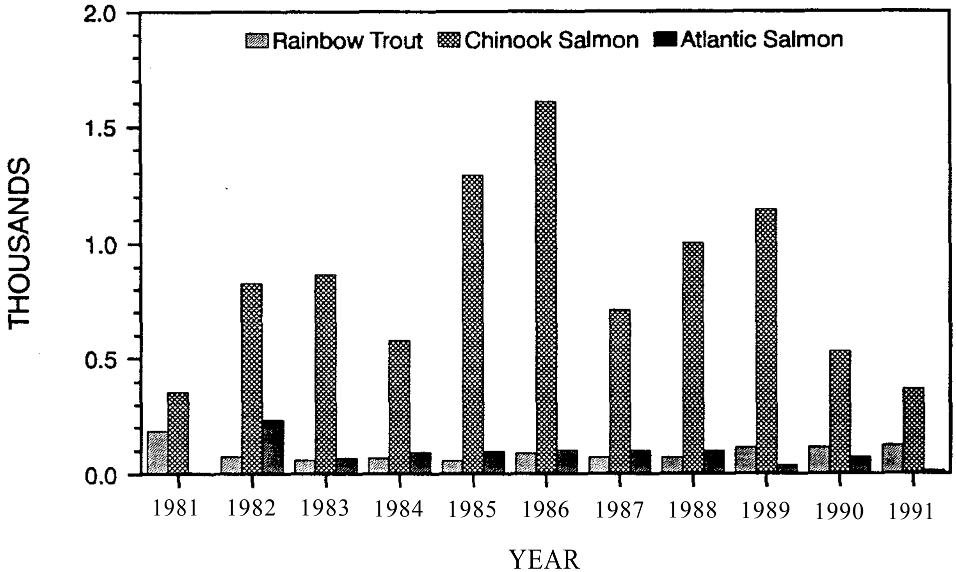

Fig. 20. Numbers of trout and salmon in spawning runs in the French River, Minnesota, 1981-91.

To protect steelhead stocks, daily bag limits were reduced in Michigan in 1989, Wisconsin in 1990, and Minnesota in 1991. The daily bag limit of steelhead was reduced in Michigan from 5 fish to 3 fish for each trout and salmon species. In Wisconsin, the limit was reduced from 5 fish of any size to 1 fish at least 711 mm long. In Minnesota, a management plan was developed to enhance steelhead populations along the north shore. It included a daily bag limit that was reduced from 5 fish to 3 fish, of which only 1 fish could be a wild (unclipped) steelhead. The minimum-length limit was 406 mm for planted (clipped) fish and 711 mm for (unclipped) wild fish.

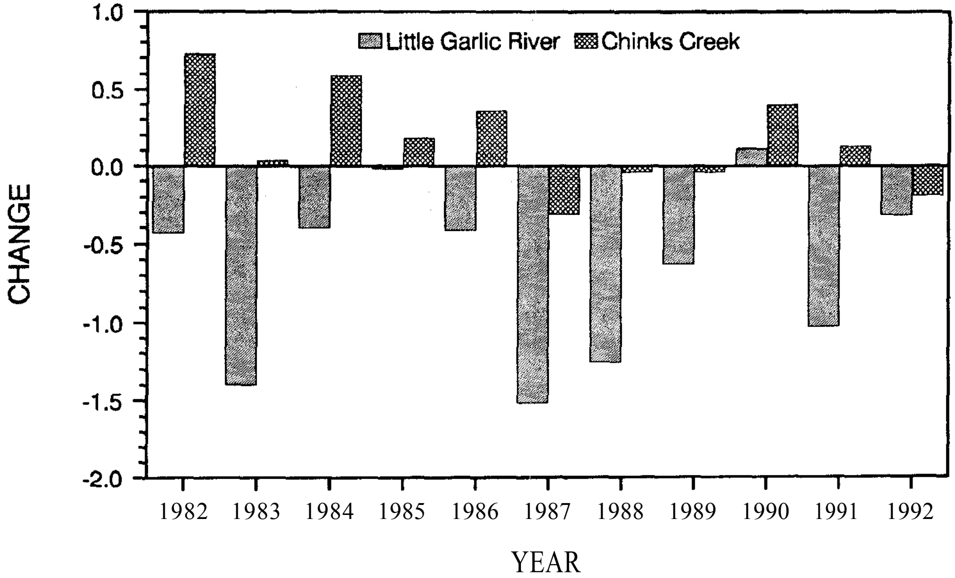

Fig. 21. Abundance of age-0 rainbow trout (no./m^2) in the Little Garlic River and Chinks Creek, Michigan, 1982-92 - expressed as the change from the 1968-74 average.

Coho Salmon

Coho salmon were first planted into Lake Superior in 1966 by the state of Michigan. Coho salmon were planted in Minnesota and Ontario between 1969 and 1972 (Hassinger 1974) but are currently planted only in Michigan. Annual releases of coho salmon were reduced in 1990 from 325,000 to 200,000 yearlings; were distributed at one site each in MI-2, MI-3, and MI-5; and were progeny of Lake Michigan parents. Coho salmon planted in 1992 were marked by removal of the right ventral fin to give agencies an opportunity to evaluate the contribution of hatchery fish in the total catch.

Coho salmon planted in Michigan in 1984 and 1985 contributed 80% of the sport catch in a planted tributary but made up less than 10% of the catch in Lake Superior and nonplanted tributaries (Peck 1992). Some of these fish strayed to Wisconsin and Minnesota in Lake Superior, Wisconsin and Michigan in Lake Michigan, and Ohio in Lake Erie. In addition to extensive straying, diseases and disabilities of hatchery-reared coho salmon have likely reduced their survival in Lake

Superior. Coho salmon of Lake Michigan origin planted in Lake Superior have been infected with bacterial kidney disease (BKD). BKD may cause anemia and cataracts and can be transmitted through the water between fish (J. Hnath, Michigan Department of Natural Resources, Fish Health Lab, 34270 CR 652, Route 1, Mattawan, MI 49071, pers. commun.). Therefore, BKD threatens natural populations of coho salmon and other salmonines in Lake Superior.

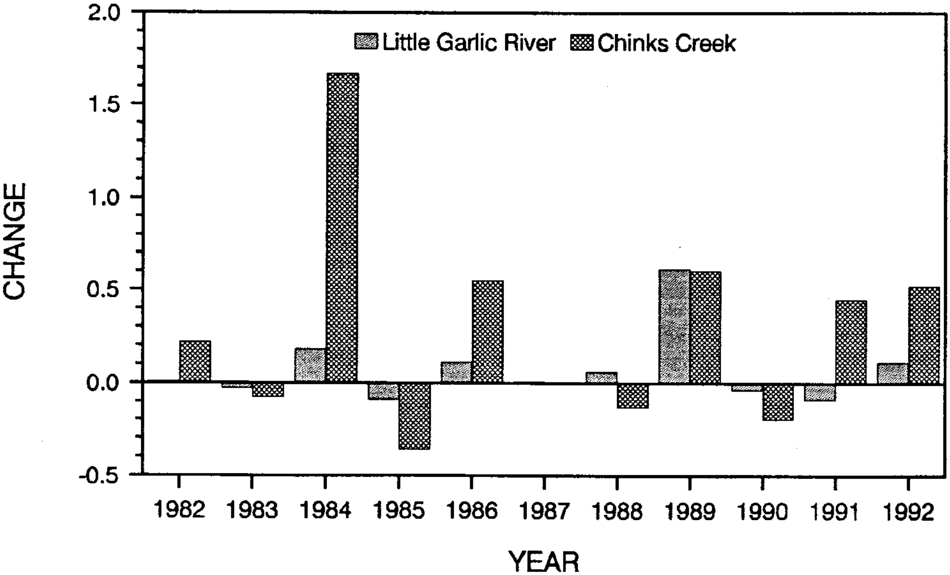

Fig. 22. Abundance of age-0 coho salmon (no./m^2) in the Little Garlic River and Chinks Creek, Michigan, 1982-92--expressed as the change from the 1968-74 average.

Coho salmon reproduce widely in Lake Superior. Initial plants of coho salmon in the 1960s strayed extensively and reproduced successfully in many Lake Superior streams (Peck 1970). Coho salmon reproduced successfully in all five streams studied by Stauffer (1977); and, by 1968, production rivaled good West Coast coho salmon streams (Peck 1970). Abundance of juvenile coho salmon varied without trend between 1982 and 1992 and was greater than average between 1968 and 1974 in the Little Garlic River and Chinks Creek in Michigan (Fig. 22). Coho salmon likely reproduce in all Lake Superior streams that have suitable spawning substrate and are accessible during the spawning period. Coho salmon spawning runs in Wisconsin's Brule River varied greatly between 1986 and 1990 and were similar to steelhead spawning runs in some years (Fig. 19). Few coho salmon have been found during surveys for juvenile and adult anadromous salmonines in Minnesota streams.

Wisconsin and Michigan recommended that the annual harvest of coho salmon should be approximately 15,000 fish and 95,000 fish, respectively. Between 1984 and 1991, the number of coho salmon harvested annually in the United States was generally second only to lake trout-14,148 in Michigan, 9,847 in Wisconsin, and 4,205 in Minnesota (Fig. 23). In Wisconsin in 1988, harvest of coho salmon exceeded that of lake trout. Anglers caught most coho salmon in the winter and early spring when the fish concentrated inshore at bays and river mouths. Fewer fish were caught in the fall as mature fish-either in the lake or in streams. The average tribal commercial and home-use harvest of coho salmon was:

- 115 fish in Wisconsin in 1988 and 1989,
- 1,728 fish in western Michigan between 1988 and 1992, and
- 3,394 fish in eastern Michigan between 1989 and 1991.

The estimated annual incidental catch and mortality of coho salmon by the Michigan-licensed commercial fishery was 37 fish and 26 fish, respectively.

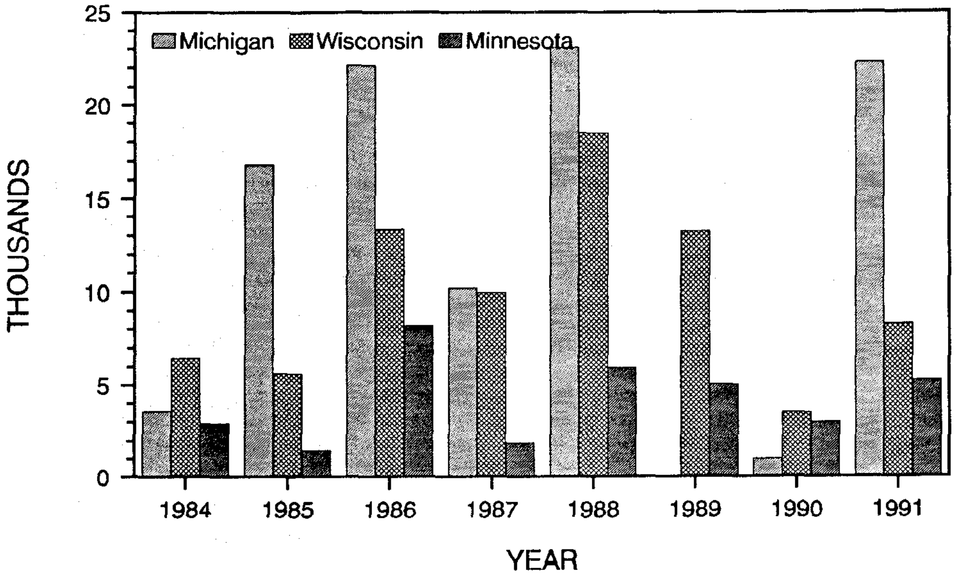

Fig. 23. Sport-fishery harvest of coho salmon in Michigan, Wisconsin, and Minnesota waters of Lake Superior, 1984-91.

Chinook Salmon

Chinook salmon were first planted into Lake Superior in 1967 by the state of Michigan. This introduction was extended to Minnesota in 1974, Wisconsin in 1977, and Ontario in 1988. Annual plants of spring fingerlings between 1989 and 1991 averaged approximately 350,000 in Michigan, 509,000 in Minnesota, 384,000 in Wisconsin, and 300,000 in Ontario. Chinook salmon planted by Michigan and Wisconsin were progeny of fall-spawning Lake Michigan parents, those planted by Minnesota were progeny of Lake Superior parents caught at the French River weir, and those planted by Ontario were from Lake Huron parents. Initial plants in Minnesota were from spring-spawning parents (Close et al. 1984); but since 1979, plants have been from fall-spawning parents. Some of the progeny of Lake Michigan chinook salmon planted in Lake Superior were infected with BKD, and the disease has also been found in naturally reproduced fish. Minnesota has monitored the incidence of BKD in chinook salmon returning to the French River weir since 1989, and Michigan monitored BKD incidence in spawning-run and sport-caught chinook salmon in 1991 and 1992. Agencies now routinely screen chinook salmon' brood stock for BKD and eliminate any fish with detectable levels of the disease.

Chinook salmon harvest ranks from third to fifth among salmonine sport catches in the United States and second or third after lake trout in Ontario. Wisconsin and Michigan recommended harvest goals of 12,000 fish and 21,000 fish, respectively. The number of chinook harvested annually in Lake Superior between 1984 and 1991 averaged 1,413 in Michigan, 2,609 in Wisconsin, and 1,806 in Minnesota (Fig. 24). In Ontario, important sport fisheries for chinook salmon occur in Goulais Bay, the Michipicoten River and Bay (at Wawa), the Nipigon River, and Thunder Bay. In 1986, the estimated catch in Michipicoten Bay was 3,316. The number of chinook salmon caught in the Wawa Salmon Derby peaked in 1986 (499 fish) then decreased each year since then (64 fish in 1992). The sport-fishery decline paralleled chinook dead-fish counts in the Michipicoten River which decreased from 10,000 in 1987 to less than 600 in 1992. Sport-fishery harvest of chinook salmon may be greater in streams than in Lake Superior-as was the case between 1984 and 1987 at Marquette, Michigan (Peck 1992). The tribal commercial and home-use harvest of chinook salmon in Wisconsin averaged 47 fish from 1988 to 1992. In Michigan, the average was 796 fish from 1989 to 1992. The estimated annual incidental catch and mortality of chinook salmon in the Michigan-licensed commercial fishery was 15 fish and 6 fish, respectively.

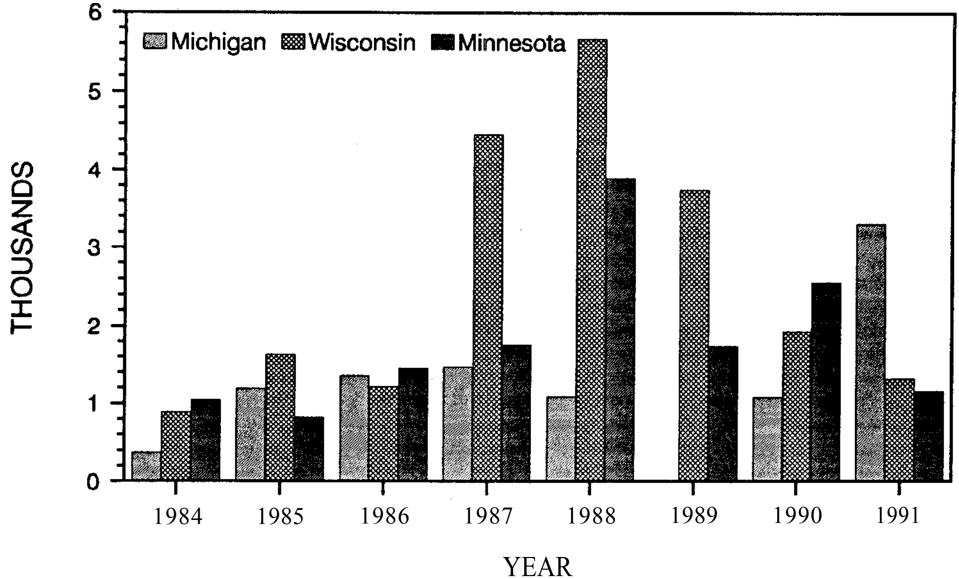

Fig. 24. Sport-fishery harvest of chinook salmon in Michigan, Wisconsin, and Minnesota waters of Lake Superior, 1984-91.

Chinook salmon have been observed spawning in numerous streams in the United States and in most large rivers in Canada. Peak runs of chinook salmon in the Brule River, Wisconsin, occurred from late August to early September, and numbered from 343 fish to 679 fish between 1986 and 1990 (Fig. 19). Chinook salmon runs in the French River, Minnesota, were highest in the mid-1980s and have decreased more recently (Fig. 20). Juvenile production has been difficult to quantify since most young chinook salmon leave streams soon after emerging in May and June (Carl 1984; Seelbach 1985). Consequently, all planted fish were marked in 1988, 1989, and 1990 to evaluate the relative abundance of marked (planted) and unmarked (wild) chinook salmon in the sport fishery and in spawning runs. Preliminary results indicate that most chinook salmon in Lake Superior are produced in the wild. Hatchery fish contribute from less than 10% in Canada to approximately 50% in Wisconsin and Minnesota.

Brown Trout

Brown trout were introduced into Lake Superior during the 1890s and established self-sustaining populations across Lake Superior-particularly in streams of the western United States (Lawrie and Rahrer 1972). In Michigan, brown trout were found in only 22 of Lake Superior's 120 tributaries during the early 1960s (Moore and Braem 1965). A number of these were likely resident populations, but anadromous brown trout populations are found in the Ontonagon River (MI-2) and the Sturgeon River (MI-4) (R. Juetten, Michigan Department of Natural Resources, Baraga, MI 94908, pers. commun.). In contrast, most Wisconsin streams have anadromous brown trout populations (Moore and Braem 1965). However, abundance has been depressed in Wisconsin during the last 20 years-possibly because of furunculosis-induced mortality (Wisconsin Department of Natural Resources 1988). Anadromous brown trout runs in the Brule River, Wisconsin, ranged from 3,290 fish to 5,265 fish between 1986 and 1990 (Fig. 19). Wild brown trout populations in Wisconsin streams exhibit significant genetic differentiation among stocks from different drainages and between anadromous and resident fish in the Brule and Sioux Rivers (Krueger and May 1987b). In Ontario, small, anadromous brown trout populations occur in the Steel and Michipicoten Rivers. Brown trout have not established anadromous populations in Minnesota.

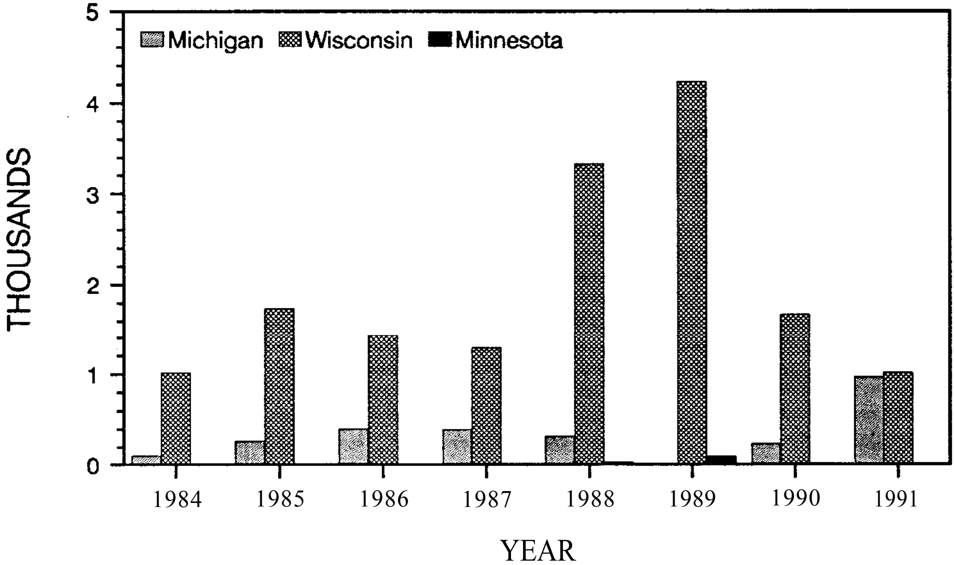

Fig. 25. Sport-fishery harvest of brown trout in Michigan, Wisconsin, and Minnesota waters of Lake Superior, 1984-91.

Only Michigan and Wisconsin planted brown trout in Lake Superior between 1989 and 1991 - averaging 88,000 fish and 145,000 fish (mainly yearlings), respectively. These were all domestic-strain progeny from hatchery brood stock. Wisconsin and Michigan have recommended harvest goals of 6,000 fish and 2,300 fish, respectively. From 1984 to 1991, the number of brown trout harvested by the sport fishery averaged 388 in Michigan, 1,970 in Wisconsin, and 22 in Minnesota (Fig. 25). The lakewide brown trout harvest in Ontario is probably small&only 3 fish were reported in a creel survey at Michipicoten Bay in 1986. The contribution of hatchery brown trout to the sport harvest was 50% in Wisconsin and 40% in Michigan. The annual incidental catch and mortality of brown trout in the Michigan-licensed commercial fishery was 55 fish and 12 fish, respectively. The harvest in tribal commercial and home-use fisheries in Wisconsin averaged 174 fish between 1988 and 1992. In eastern Michigan, the harvest averaged 24 fish between 1989 and 1991.

Splake

Splake is a fertile hybrid resulting from the cross of a female lake trout and male brook trout. Fish culturists have known about splake since the late 1800s (Lawrie and Rahrer 1972). However, splake have not been used extensively in enhancement programs until recent decades. Splake were first planted in Lake Superior (Michigan) in 1971, and approximately 60,000 yearlings have been planted in most years since then. In Wisconsin, splake were planted for the first time in 1973-150,000-300,000 were planted annually during the 1980s and approximately 120,000 were planted annually in 1990 and 1991. Splake have not been planted in Minnesota and Ontario. The percentage of splake planted and harvested was at least ten times greater than other salmonines in Michigan (Peck 1992). No natural reproduction by splake has been found in Lake Superior, but sexually mature splake have been found in spawning aggregations of lake trout.

The harvest of splake in Lake Superior occurs primarily near the sites where they were planted-Marquette (MI-5) and Munising (MI-6) in Michigan and the Apostle Islands (WI-2) in Wisconsin. Wisconsin and Michigan have recommended harvest goals of 10,000 fish and 17,000 fish, respectively. Average annual sport harvest of splake between 1984 and 1991 was 4,678 in Wisconsin and 530 in Michigan (Fig. 26). The sharp decrease in the 1991 splake catch in Wisconsin was because there were no splake planted in 1989, and only fall fingerlings were planted in 1990. No splake have been harvested in Minnesota or Ontario. Most splake in Michigan are caught in the late fall through early spring. No incidental catch of splake has been found in the Michigan-licensed commercial fishery. The harvest in tribal commercial and home-use fisheries in Wisconsin averaged 17 fish between 1988 and 1992.

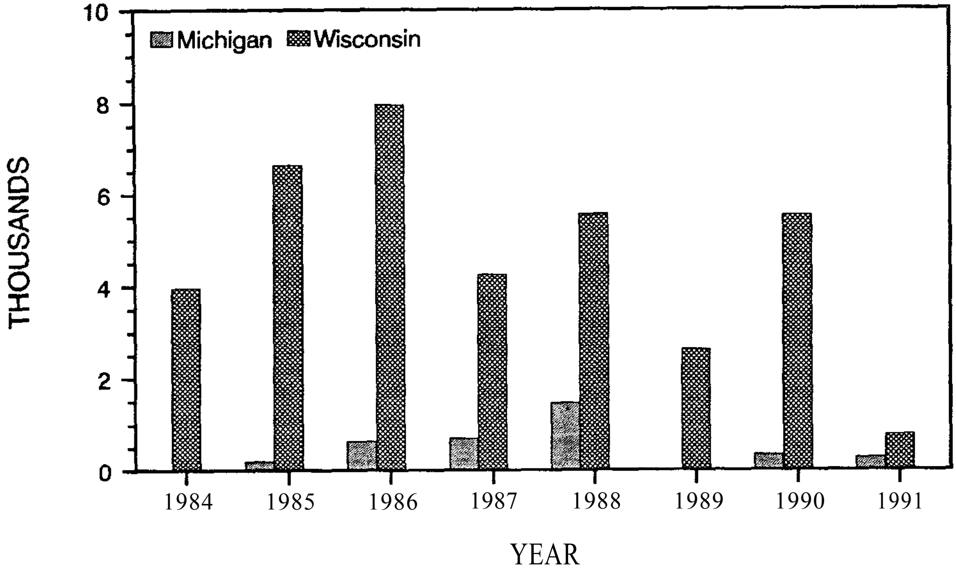

Fig. 26. Sport-fishery harvest of splake in Michigan and Wisconsin waters of Lake Superior, 1984-91.

Brook Trout

Anadromous brook trout (coasters) are native to Lake Superior, but became much less abundant and narrowly distributed in recent years because of overfishing, loss of suitable habitat, and competition with other introduced salmonines. The largest extant stock of coaster brook trout is in the Nipigon River, Ontario. Small populations occur near the Nipigon in the Cypress, Gravel, and Little Gravel Rivers. In Michigan, brook trout were found in 93 of Lake Superior's 120 tributaries (Moore and Braem 1965) but most were resident populations. More than 16 Michigan tributaries had coaster brook trout populations in the past, but the only remaining spawning runs in recent years are in the Salmon Trout River (MI-5) and in Washington Creek and Grace Creek on Isle Royale (MI-l). Coaster brook trout no longer occur naturally in Wisconsin or Minnesota.

Restoration of coaster brook trout in Lake Superior has been attempted in Wisconsin where 12,000-80,000 Lake Nipigon brook trout yearlings have been planted annually since 1984 to reestablish coaster populations. In Michigan, 50,000-60,000 domestic brook trout yearlings were planted annually in the 1980s, and 16,000 were planted annually between 1989 and 1991. In Minnesota, 50,000 eggs and 30,000 fry of Nipigon brook trout were planted into five tributaries in 1992. Despite these efforts, brook trout have remained scarce in the sport fishery in Lake Superior, and coaster brook trout populations have not been enhanced or established. A Lake Superior brook trout workshop was held in July 1992 to bring together agencies and share management concerns and strategies.

The state of Michigan has recommended an annual harvest goal for brook trout of 2,000 fish. Brook trout harvest estimates between 1984 and 1990 ranged from 4 to 14 in Michigan, 0 to 291 in Wisconsin, and 0 to 31 in Minnesota. No brook trout were found in the Michigan-licensed commercial fishery. Ontario harvest data were not available. Wisconsin tribal commercial and home-use fisheries took only 9 fish in 1991 - other commercial harvests are likely to be quite small because of the low abundance and limited distribution of brook trout in Lake Superior.

Pink Salmon

Pink salmon of an odd-year spawning population were introduced into Lake Superior (Canada) in 1956, developed naturally reproducing populations from this single introduction, and were distributed throughout the Great Lakes by 1979 (Emery 1981). Spawning runs of pink salmon in Lake Superior occurred in at least 56 Michigan streams by 1980 (Wagner and Stauffer 1982). Pink salmon generally spawn at age 2 during September and October. However, in Lake Superior some remain in the lake an extra year and spawn at age 3 resulting in the establishment of an even-year spawning population (Wagner and Stauffer 1978b).

Pink salmon have never attracted a sport fishery in Lake Superior probably because of their small average size (0.5 kg). The annual catch between 1984 and 1990 averaged less than 50 in Michigan, 0 in Wisconsin, and less than 50 in Minnesota. The catch in Ontario is unknown, but a dipnet fishery in the Michipicoten River yielded:

- 3,449 pink salmon in 1979,
- 392 pink salmon in 1980,
- 12,671 pink salmon in 1981,
- 1,016 pink salmon in 1982, and
- 3,807 pink salmon in 1983.

By 1987, the run had declined substantially, and no more permits for dipnetting were issued. Sport harvest from the major spawning streams in Wisconsin and Michigan is largely unknown. The annual catch in three streams at Marquette, Michigan, averaged less than 100 fish between 1984 and 1987 (Peck 1992). The harvest of pink salmon in Minnesota streams ranged from 106 fish to 734 fish between 1986 and 1991. Pink salmon were not caught in the Michigan-licensed commercial fishery. The commercial fishery in Ontario harvests approximately 300-3,000 fish annually (odd-year harvests are greater). Pink salmon harvest in tribal commercial and home-use fisheries averaged 6 fish in Minnesota in 1989 and 1990. In eastern Michigan, the harvest averaged 52 fish between 1989 and 1991.

Abundance of pink salmon in Lake Superior has been based on their abundance in stream spawning runs. Abundance in the lake is difficult to assess because pink salmon are not abundant, they occupy various depths in the pelagic zone, and they leave the stream immediately after emergence (usually in May) (Bagdovitz et al. 1986). Abundance in spawning runs in Michigan streams increased between 1967 and 1989, then decreased to early-1970 levels or disappeared entirely by 1989 (Bagdovitz et al. 1986; Kocik et al. 1991). Similar decreases in spawning runs were reported in Wisconsin and Minnesota streams. Spawning runs in two Ontario streams in eastern Lake Superior were greater than in Michigan streams but decreased 50%-75% between 1981 and 1987 (Kelso and Nolte 1990).

Atlantic Salmon

Atlantic salmon have not been planted extensively in Lake Superior. Atlantic salmon were planted in Wisconsin in 1972, 1973, and 1978; in Michigan in 1976; and in Minnesota since 1980. Releases in Minnesota were from Grand Lake, Maine, parents. In the French River:

- 10,000 yearlings were planted in 1980,

- 31,000 yearlings and 111,000 fingerlings were planted in 1989, and

- 52,000 yearlings and 37,000 fingerlings were planted in 1991.

Atlantic salmon initially returned to Minnesota tributaries in late August and early September but have not returned until early November in recent years. Return of adults to the French River averaged approximately 8.5 fish/yr (Fig. 20), less than 0.5% of the number planted. These returns provided approximately 25% of the 200,000 eggs needed to sustain the planting program. In Lake Superior, no natural reproduction by Atlantic salmon has been reported.

Annual harvest of Atlantic salmon in the sport fishery between 1984 and 1991 averaged less than 200 in Minnesota. The average was less than 100 in Wisconsin, Michigan, and Ontario. Atlantic salmon were not found in the Michigan-licensed commercial fishery between 1983 and 1989. The only known catch of Atlantic salmon in tribal fisheries was incidental to commercial catches in Minnesota. Sale is permitted only to tribal members.

Recommendations

The following list of recommendations has been established:

1) Fish-community objectives for anadromous salmonines should be revised to recognize that stocking programs and fisheries should not compromise the genetic integrity, health, abundance, or restoration plan of any naturally reproducing population of salmonine species--including lake trout.

2) Harvest of anadromous salmonines from Lake Superior and its tributaries by sport fisheries and by state and tribal commercial fisheries should continue to be monitored.

3) Fishing regulations should be adequate to allow survival of sufficient spawning populations of salmonines.

4) Spawning habitat for salmonines in Lake Superior tributaries should be protected and enhanced.

5) Hatchery-reared salmonines should not be planted in streams or areas of Lake Superior where wild populations are at carrying capacity.

6) Fish that are classified as diseased, as defined in the Great Lakes Fish Disease Control Policy and Model Program (Hnath 1993), should not be planted to prevent widespread straying that could infect healthy Great Lakes stocks.

7) Agencies should strive to minimize the loss of genetic variability of hatchery salmonines by applying sound fish-culture and stocking practices.

8) Agencies should mark hatchery-reared trout and salmon to permit evaluation of wild production.

FORAGE SPECIES

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Introduction

The fishery objective for forage species in Lake Superior is to restore lake herring stocks to historic levels of abundance, to provide forage for lake trout and other predators, and to provide fishery harvest (Busiahn 1990). In 1986, interagency committees recommended that harvests of lake herring should be held at or below the 1974-83 average until stocks were fully recovered and methods for determining safe-harvest levels were available (Lake Superior Technical Committee 1986). In 1992, interagency committees recommended that spawning-season closures or quotas should be instituted until stocks recovered.

Lake herring stocks are presently increasing in some areas but have not yet reached historic levels. Diets of larger inshore predators remain dominated by rainbow smelt in spring. However, lake herring consumption is increasing in areas and in seasons where their abundance is increasing (Conner et al. 1993; Gallinat 1993). Total biomass of rainbow smelt and lake herring increased substantially between 1982 and 1986 and declined between 1987 and 1989. Total forage biomass in Minnesota and eastern Ontario is dominated by rainbow smelt. Biomass is dominated by lake herring in western Ontario, Wisconsin, and Michigan.

Lake Herring

Lake herring in Lake Superior historically yielded larger commercial harvests than all other species combined. Catches in the United States peaked at 8.6 million kg in 1941, declined slowly during the remainder of the 1940s, and declined sharply to only 100,000 kg between 1981 and 1983. Analysis of commercial fishing records for Wisconsin (Selgeby 1982) and Michigan (Peck et al. 1974) indicated these declines were because of sequential overharvest of discrete stocks. Declines in Minnesota and eastern Ontario were likely the result of similar fishing patterns.

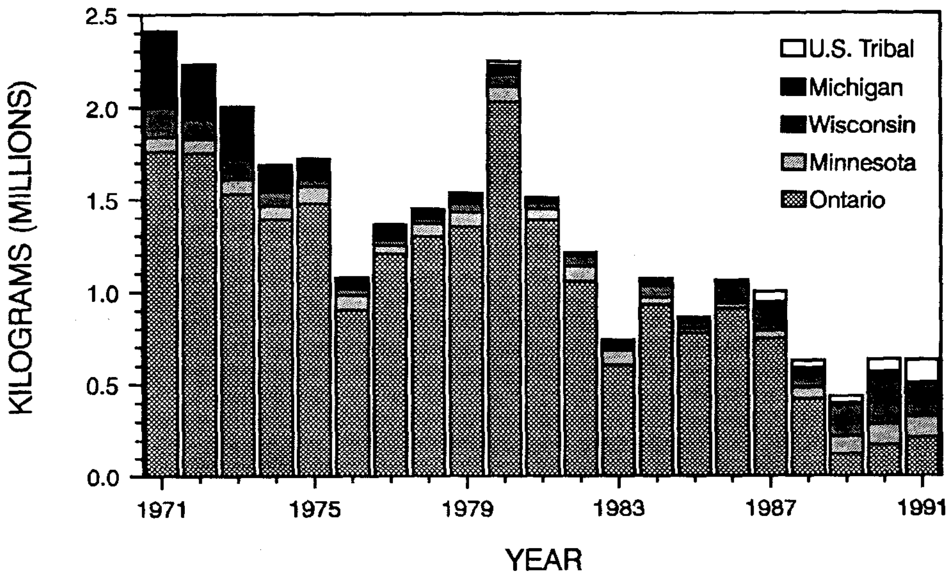

Fig. 27. Harvest of lake herring (round weight) from Lake Superior by various management authorities, 1971-91.

Lake herring harvest began to increase in the United States as abundance increased-the amount of increase varied among jurisdictions (Fig. 27). Fisheries in Michigan have remained small, while those in Minnesota and Wisconsin have increased beyond the targeted 1974-83 average. Michigan fisheries are regulated by limited entry, depth restrictions, and restrictive quotas. Minnesota fisheries are regulated by a closed spawning season and limited entry. Wisconsin fisheries are regulated by depth limits, mesh restrictions, limited entry, and special-use areas.

Tribal regulations are similar to state regulations in Wisconsin. Tribal fisheries in Keweenaw Bay (western Michigan waters) are regulated by quotas and in eastern Michigan by a closed spawning season. Fisheries in Wisconsin and Minnesota have grown as stocks recovered, but market conditions dictate the total catch. If market conditions become more favorable, new regulations may be needed to protect stocks from overharvest in Wisconsin and Minnesota.

In contrast to the declines seen in the United States, major lake herring stocks in western Ontario did not appear to be overharvested until very recently. The Black Bay stock sustained relatively stable catches between 1960 and 1981, but catches (kg/km) dropped by more than 80% between 1981 and 1988 (Fig. 28). Catches in Thunder Bay (kg/km) declined in the 1960s and early 1970s, rebounded to high levels between 1979 and 1981, and then declined sharply in 1983 and 1984. Catches in 1988 and 1989 were dominated (80%) by a single year-class (1984) which suggests that reproduction is threatened. Harvest was severely restricted between 1989 and 1992 in an attempt to restore the stocks.

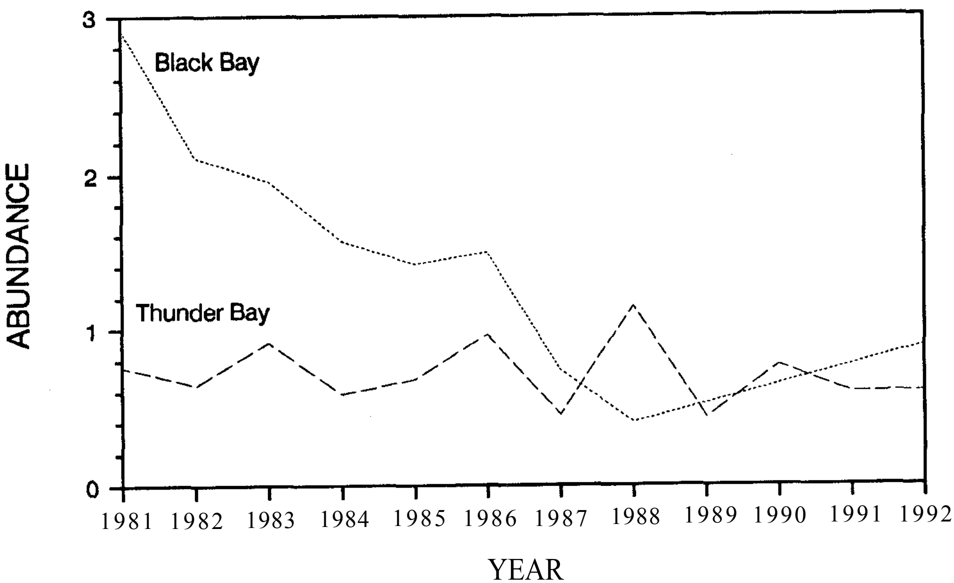

Fig. 28. Abundance of lake herring in Black Bay and Thunder Bay, Ontario, Lake Superior, 1981-92.

Strength of lake herring year-classes in the United States has increased greatly since 1977 (Fig. 29). Year-class strength was indexed beginning in 1978 from catches of yearlings in trawls at 40-53 locations along the United States shore. Beginning in 1989, year-class strength was indexed at 24-34 additional locations along the Canadian shore. Year-classes were strong in 1978, 1980, and especially 1984; moderate in 1983, 1985, and 1986; and weak in 1987. The 1988-90 year-classes were strong, while the 1991 year-class appears relatively weak. Catches of adults in gillnets at various locations in Lake Superior generally corroborate the year-class strength estimates made by trawls.

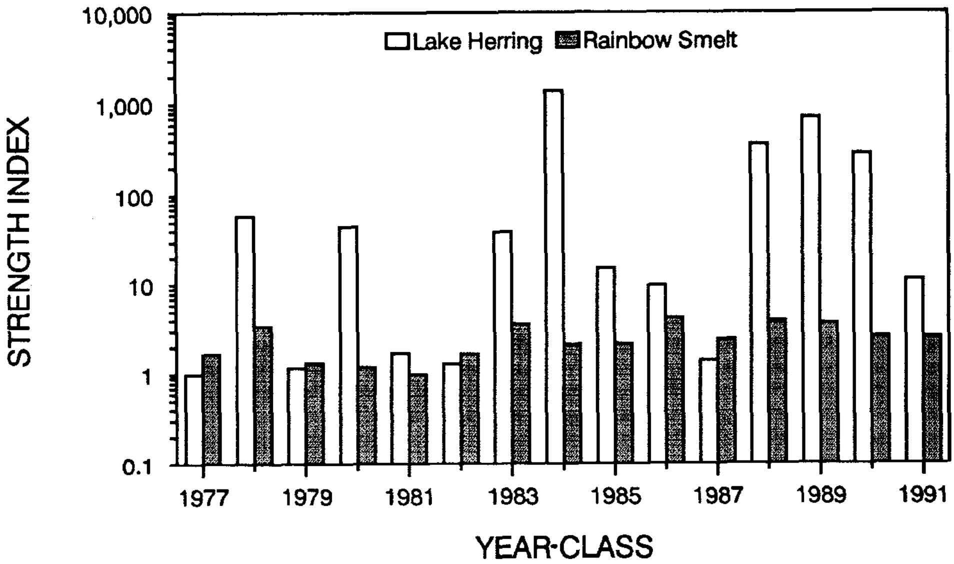

Fig. 29. Relative strength of lake herring and rainbow smelt year-classes in Lake Superior (1977-91).

Lake herring biomass was low between 1978 and 1984. Biomass increased in 1985 and 1986 as members of the 1984 year-class entered the catch. Biomass declined in 1987, remained stable between 1988 and 1991, and declined again in 1992 as a relatively weak 1991 year-class recruited (Fig. 30). Biomass was relatively low and stable in Minnesota with little evidence of recovery, while biomass in Wisconsin and Michigan was similar to lakewide trends. Recoveries were especially strong west of the Apostle Islands in Wisconsin and at Keweenaw Bay and Munising in Michigan. Biomass estimates presented here are from bottom, inshore sampling and are not representative of pelagic, offshore areas of the lake. These biomass estimates probably fluctuate more sharply than lakewide populations.

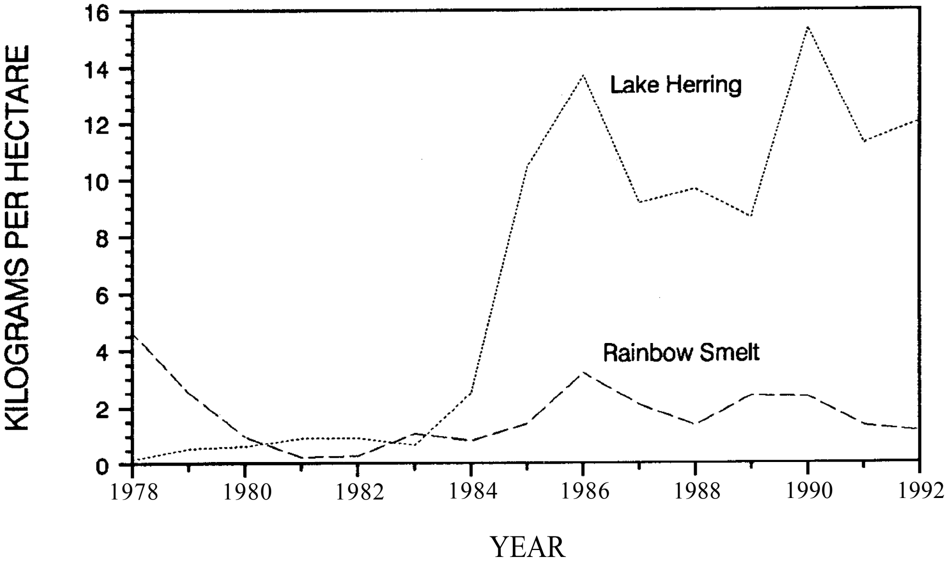

Fig. 30. Biomass of lake herring and rainbow smelt in trawls fished during spring in Lake Superior, 1978-92 (includes Ontario, 1989-92).

Rainbow Smelt

Rainbow smelt entered Lake Superior in the early 1930s, reached commercially harvestable levels in 1952, and continued to increase in abundance through the 1950s and 1960s. Commercial fisheries are mainly in western Lake Superior from Thunder Bay, Ontario, to Ashland, Wisconsin. Total landings increased to a peak in 1976 and then declined sharply. Commercial harvests have increased in recent years but remain far below harvests taken during the early and mid-1970s. The major decline in commercial catch during the late 1970s was because of a decline in abundance.

As a result of declining rainbow smelt abundance and increasing mortality, biomass estimated from trawl surveys declined more than 90% between 1978 and 1981 (Fig. 30). By 1981, stocks were dominated by age-l and age-2 fish, and spawning stocks that had declined sharply in abundance were almost all age-3 fish. After 1983, stocks began to recover and increased in abundance lakewide through 1986. By 1986, biomass was approximately 50% of that in 1978, but then declined. By 1992, biomass was approximately 25% of that in 1978.

In Minnesota, the general pattern of rainbow smelt decline and recovery was similar to the lakewide trend, but fluctuations were more erratic because of the difficulty of sampling along the steep, rocky shoreline. Biomass trends in Wisconsin and Michigan were similar to the lakewide trend, but biomass in both states is now much lower than in 1978. Biomass in eastern Ontario during 1989 was similar to that in the United States. Biomass was much higher in western Ontario, but declined more than 50% between 1990 and 1992.

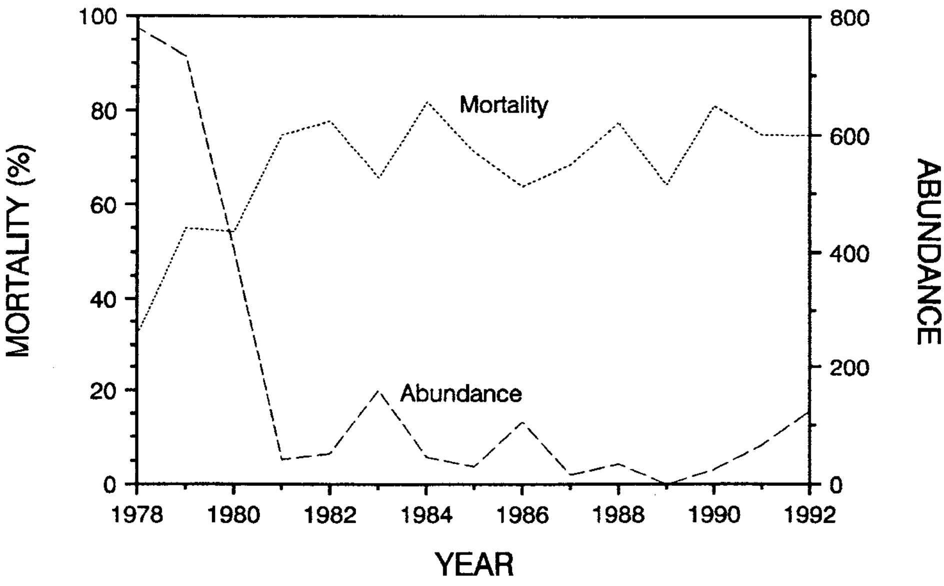

Fig. 31. Total annual mortality (age-l-4 fish) and abundance (no. of fish.000 ha) of large (more than 200 mm long) rainbow smelt in United States waters of Lake Superior, 1978-92.

The decline in rainbow smelt biomass is the result of high total mortality (Fig. 31). Mortality was low in 1978, increased through 1981, and stabilized at relatively high levels thereafter. Despite these high levels of mortality, a series of increasingly strong year-classes occurred between 1981 and 1991 (Fig. 29). This series of strong year-classes was partly because of inclusion of Ontario data between 1989 and 1992, where year-classes have been relatively stronger than in the United States.

The decline of biomass was accompanied by the loss of older-aged fish and an increase in mortality. As a result, there was a reduction in size composition of the population between 1978 and 1992. The loss of larger fish from the population occurred throughout the United States and eastern Ontario. Substantial numbers of large individuals existed only in western Ontario.

Other Species

Abundance of deepwater ciscoes declined substantially in Lake Superior by 1984 (MacCallum and Selgeby 1987), and this trend continued through 1992. Abundance of deepwater ciscoes declined by approximately two-thirds in Michigan and Wisconsin during a 20-year period. The decline is thought to be related to increased predation by expanding siscowet (deepwater form) lake trout populations.

Three species of sculpin (slimy sculpin, Spoonhead sculpin, and deepwater sculpin) are relatively abundant. These demersal species are eaten by young lake trout. Deepwater sculpins are a major forage of siscowets.

Sculpin biomass is greatest in Ontario-approximately one-half the level in Michigan and one-fourth the levels in Minnesota and Wisconsin. In the United States, total sculpin biomass declined by two-thirds from the 1970s to 1990s, while biomass in Ontario is still at United States levels of the 1970s.

Predator-Prey Interactions

Changes in the abundance of predator and prey species in Lake Superior have caused corresponding changes in their interactions:

- predator stocks have increased,
- forage-base composition has changed, and
- predator-prey dynamics have been altered as a result (Busiahn 1990).

Lake herring and deepwater ciscoes were the principal prey historically of lake trout in Lake Superior. Up to 90% of lake trout diet was composed of coregonines in the early 1950s (Dryer et al. 1965). As lake herring declined during the 1950s and early 1960s, rainbow smelt increased in abundance and replaced coregonines as the major food of lake trout (Dryer et al. 1965). By 1963, rainbow smelt composed 66% of the diet of lake trout, and coregonines composed only 8% (Dryer et al. 1965).

Rainbow smelt continued to dominate lake trout diets between 1981 and 1987. Lake trout consumed 71% rainbow smelt and 15% coregonines by weight (Conner et al. 1993). In the spring of 1991, inshore lake trout consumed (frequency of occurrence) 78% rainbow smelt and less than 5% coregonines lakewide (Bronte 1992). Diets of wild lake trout were more diverse than those of hatchery-produced fish. Wild fish consumed more sculpins, opossum shrimp *(Mysis **relicta**)*, burbot, and terrestrial insects. Wild fish also consumed less rainbow smelt than hatchery-produced fish (Bronte 1992). In 1992, diets of lake trout in eastern Wisconsin (WI-2) and western Michigan (MI-2) were dominated by smelt only in the spring. Diets were dominated by coregonines in winter, summer, and fall (Gallinat 1993).

Between 1981 and 1987, rainbow smelt were the principal prey in the seasonal and annual diets of chinook salmon, inshore lake trout, Atlantic salmon, brown trout, brook trout, and splake (Conner et al. 1993). Lake trout, chinook salmon, and coho salmon of similar size also ate rainbow smelt of different sizes. Inshore lake trout consumed mostly adult rainbow smelt, coho salmon ate mostly juvenile smelt, and chinook salmon ate equal numbers of juvenile and adult smelt. Diets of coho salmon, rainbow trout, and pink salmon were composed predominantly of invertebrates. Offshore lake trout consumed primarily coregonines, and siscowet ate mainly deepwater sculpins and slimy sculpins.

Predators did not consume rainbow smelt and lake herring in proportion to their abundance in Lake Superior. Rainbow smelt averaged 27% and coregonines averaged 68% of the spring-forage biomass during trawl surveys conducted by the U.S. Fish and Wildlife Service between 1981 and 1987 (Hansen 1990). Rainbow smelt composed 43% and coregonines only 15% of the prey consumed by all salmonine predators, although the consumption of lake herring by inshore lake trout near the Apostle Islands increased from 8% (by weight) in 1985 to 23% in 1987 (Conner et al. 1993). Conner et al. (1993) posed three possible explanations for the discrepancy between relative abundance of prey fish in the wild and in predator diets:

1) Predators may prefer familiar prey.

2) Predators may fail to recognize recently abundant prey as edible prey choices.

3) Lake herring may be better able to avoid predation by lake trout through co-evolved defense mechanisms.

One of the fish-community objectives for predators in Lake Superior is to maintain a predator-prey balance that allows normal growth of lake trout (Busiahn 1990). Lake trout growth is directly related to changes in prey-fish abundance, species composition, and interspecific competition with other salmonines. Therefore, growth may be affected by changes in any of these aspects of the Lake Superior fish community. Lake trout growth declined lakewide after 1980 because of a drastic decline in rainbow smelt abundance between 1978 and 1981 (Busiahn 1985; Hansen 1990). Changes in lake trout growth directly affect restoration efforts by altering stock structure, mortality rates, and age at maturity. Achieving the optimal balance between predator and prey stocks is critical to future fisheries management and lake trout restoration efforts on Lake Superior.

Strong year-classes of lake herring between 1988 and 1990 are expected to result in an increase in lake herring biomass between 1992 and 1994 (Selgeby 1992). If rainbow smelt abundance is stable and lake herring abundance increases as expected, trout and salmon predators may shift to more-abundant lake herring. Because of differences in size of these two prey species, growth rates of predators using these prey may be altered (Negus 1992). Lake herring are capable of much greater production than rainbow smelt in Lake Superior based on historic yield. A more stable predator-prey system may therefore result when salmonines shift from eating smelt to eating lake herring (Conner et al. 1993).

Bioenergetics modeling can provide insight into predator-prey dynamics and forage needs of predators (Christie et al. 1987; Hewett and Johnson 1992). Food consumption of predators is estimated from diet composition, temperature, growth, and prey caloric density and abundance (Kitchell 1983; Hewett and Johnson 1992). Bioenergetics modeling of predator-prey relationships in the Minnesota portion of Lake Superior showed that stocked trout and salmon could potentially consume a significant portion of the total forage base, and chinook salmon were likely to have the greatest predatory impact (Negus 1992). Individual chinook salmon were estimated to consume more than:

- 17 times the weight of rainbow smelt and coregonines by age 3 than lake trout,

- 18 times the weight of rainbow smelt and coregonines by age 4, and

- 12 times the weight of rainbow smelt and coregonines by age 5.

Model simulations showed that predator consumption of rainbow smelt and coregonines in 1989 was 13 times more than the estimated biomass and production of these species. Factors that could have contributed to the poor relation between consumption and production included underestimates of forage-fish biomass, erroneous parameterization of predator-species models, and inaccurate estimates of predator-species populations.

Recommendations

The following list of recommendations has been established:

1) Fishery-management agencies should institute and enforce regulations that limit commercial harvest of lake herring to levels that allow stocks to rebuild while supporting increasing predation by lake trout.

2) Restored lake herring stocks should be composed of at least three year-classes of spawners, each of which compose at least 20% of the harvest.

3) Critical data on specific stocks needed to properly manage lake herring should be obtained through interagency cooperative studies.

OTHER SPECIES

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Introduction

The fishery objective for other species in Lake Superior is to prevent overharvest of nondepleted stocks of native species (lake whitefish, deepwater ciscoes, suckers, and walleye) and to reestablish depleted stocks of native species (lake sturgeon, brook trout, and walleye) (Busiahn 1990). Lake whitefish stocks presently support greater commercial harvest than at any other time in the twentieth century because of increased abundance and expanded fisheries. Unfortunately, lake trout restoration has been hindered by increased incidental catch of lake trout in expanded lake whitefish fisheries (in some areas). Deepwater ciscoes declined continuously through 1989 as siscowet stocks expanded (Selgeby et al., this publication). Lake sturgeon and walleye populations are generally depressed and restoration should continue. Brook trout restoration has not been successful.

Lake Whitefish

The fishery objective for lake whitefish in Lake Superior is to manage lake whitefish (considering ecosystem productivity and target mortality rates) as self-sustaining stocks mostly for commercial harvest (Busiahn 1990). Historic harvests suggest that the productivity of lake whitefish should be approximately 0.11 kg/ha, and total annual mortality should be approximately 60%-65%. To compare fishing intensity among management areas, catches were summarized by zone and then divided by the area of the zone assumed to be lake whitefish grounds. Because data were readily available, it was assumed that lake whitefish grounds included all area less than 73 m in the United States and less than 91 m in Canada. Hydrographic charts show that the difference between the area of these two depths is not significant.

Commercial lake whitefish fisheries are conducted in all jurisdictions except Minnesota, where catches are almost nil. All of the catch in Ontario and the majority of the catch in the United States are taken in large-mesh gillnets (≥114-mm stretch-measure gillnet). State-licensed commercial fisheries in Michigan use impoundment gear exclusively. Tribal and state-licensed trapnet fisheries took 27% of the catch in eastern Michigan (MI-5 to MI-8) between 1985 and 1990. Approximately 50% of the catch in the Wisconsin state-licensed fishery is taken by impoundment gear. Small, winter sport fisheries for lake whitefish take several thousand kilograms in Whitefish Bay, the St. Marys River, and the Munising and Marquette areas.

Lake whitefish fisheries in Ontario and United States jurisdictions are managed differently. In Ontario, commercial fisheries have operated under individual transferable quotas (ITQs) since 1985 and are allowed to fish throughout the year. Zone quotas are determined and divided among fishers licensed for the various areas using pro *rata* formulae. Commercial fisheries in the United States are limited (depending on the jurisdiction) by total allowable catches, effort, and closure of the fishery during the November spawning season.

Lake whitefish commercial fisheries in all jurisdictions are constrained, to some extent, by the bycatch of lake trout. State-licensed fishers in Michigan are required to release lake trout caught in their trapnets. Wisconsin state-licensed and western tribal fishers are allotted tags for a given number of lake trout and are prohibited from possessing untagged lake trout. Eastern tribal members are required to have less than 30% lake trout in catches from primary lake trout restoration areas (MI-6). In Ontario, lake whitefish fisheries:

- have relatively small ITQs for lake trout,
- are encouraged to avoid lake trout, and
- are required either to release lake trout alive or turn over proceeds of sales to the government when ITQs are reached.

The average annual commercial harvest of lake whitefish in the past decade (1.45 million kg) is much larger than the average during the 1921-59 pre-lamprey period (0.47 million kg) (Fig. 32). The lake whitefish catch increased slowly from 205,000 kg in 1960 to 688,000 kg in 1982, then increased rapidly to 1,915,000 kg in 1986. The increased harvest observed in Lake Superior is also apparent in Lakes Huron and Michigan-the total annual harvest from the three lakes since 1985 is greater than any previous year (Fig. 33). Unlike Lake Superior, Lakes Huron and Michigan have produced higher yearly catches in the past than in the last decade, but the average annual catch in the 1980s for each lake is greater than for any previous decade since the turn of the century. Lake Superior produced an average of 20% of the total harvest from the three lakes during the 1980s. Lake whitefish in Lake Superior are affected by the lake whitefish fisheries in Lakes Huron and Michigan, because most of the sales are to the same markets in Chicago, Detroit, and New York.

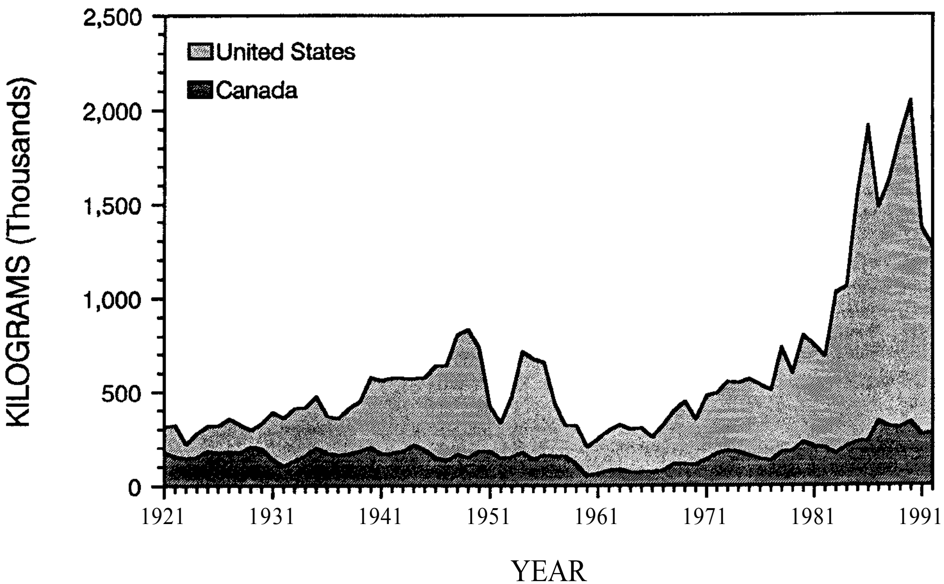

Fig. 32. Lake whitefish harvest from United States and Canadian waters of Lake Superior, 1921-91.

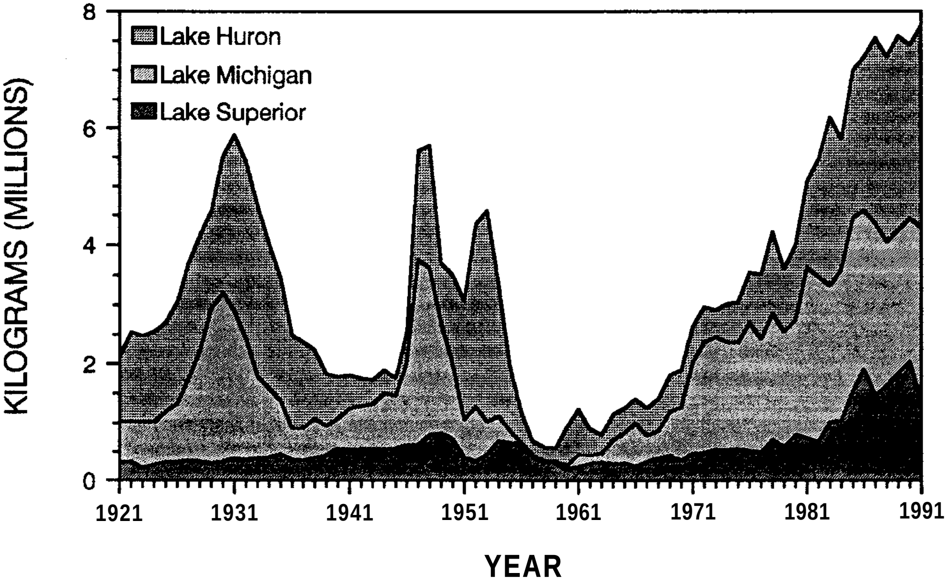

Fig. 33. Lake whitefish harvest from Lakes Huron, Michigan, and Superior, 1921-91.

Most of the increased catch of lake whitefish in Lake Superior resulted from fishing-up of previously unexploited or lightly exploited stocks. However, previously exploited stocks have also shown increased abundance or maintained their abundance in spite of increased catches. Abundance of Whitefish Bay (MI-8) stocks varied without apparent trend in the 1980s and early 1990s (Fig. 34). Abundance of Apostle Islands (WI-2) stocks remained relatively stable between 1981 and 1987, but they increased and remained higher between 1988 and 1992. Abundance of stocks on the western side of the Keweenaw Peninsula (MI-3) (which were not fished until the early 1980s) declined between 1984 and 1987 - probably from fishing-up of previously unexploited stocks. Abundance subsequently fell to levels similar to Whitefish Bay and the Apostle Islands. Abundance in the fall of lake whitefish in Canadian waters at opposite ends of the lake in Thunder Bay (zone 1) and Whitefish Bay (zone 34) follows the same trend. There were peaks in 1986 followed by declines and then peaks again in 1991 and 1992 (Fig. 34). The pattern in Whitefish Bay is similar in Canadian waters to that for the adjacent United States area (MI-8).

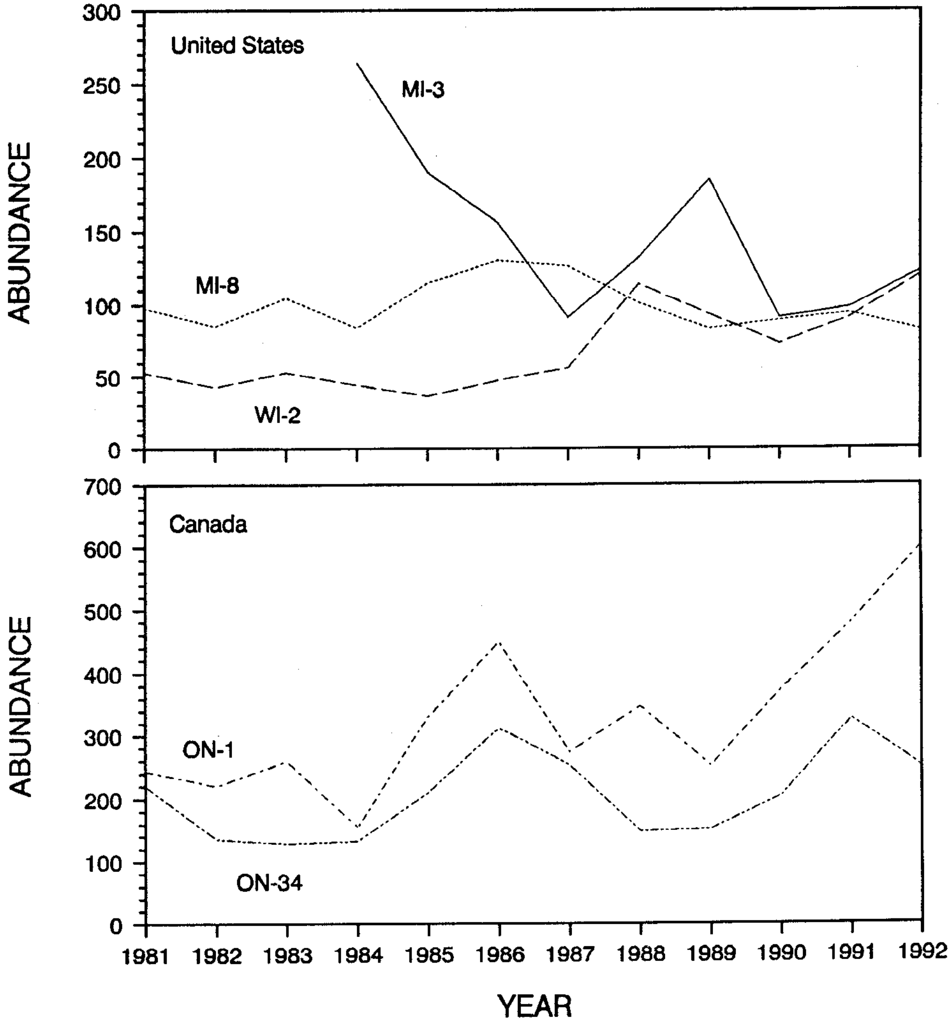

Fig. 34. Catch per effort of lake whitefish in selected areas of United States (kg/km net round weight) and Canadian (kg/ha) waters of Lake Superior, 1981-92.

The 1992 harvest of lake whitefish (1,267,002 kg, round weight) expressed per unit area, was 0.15 kg/ha which exceeds the target harvest rate of 0.11 kg/ha. On a lakewide basis, the target harvest rate (adjusted to include only lake whitefish waters) would be 0.51 kg/ha. In 1992, the most-intensively fished area (3.8 kg/ha) was along the western side of the Keweenaw Peninsula (MI-3) (Fig. 35). The next most-intensively fished areas (all 1.0-2.0 kg/ha) were along the eastern side of the Keweenaw Peninsula (MI-4), Whitefish Bay (MI-8, ON-34), and Thunder Bay (ON-l, ON-4, and ON-6).

Since 1987, lake whitefish in commercial fisheries ranged in age from 2 to 15 years, had mean ages from 5.0 to 9.2 years, and ranged in total annual mortality from 51% to 72% (Table 3). Growth rates (size at age) varied considerably around the lake from the fastest-growing stock in Whitefish Bay (MI-8) to the slowest-growing stock around the Apostle Islands (WI-2). The Black Bay stock (ON-7), which has the youngest mean age in Canada, grew as rapidly as the Whitefish Bay stock from the United States (Fig. 36).

Table 3. Age range, mean age, and annual mortality of gillnetted lake whitefish in selected areas of Lake Superior, 1981-92.

Area	Year	Age range	Mean age	Annual mortality (%)
WI-2	1988	5-11	7.6	79
WI-2	1992	5-13	7.7	70
Ml-3	1991	4-13	6.8	78
MI-4	1991	3-12	6.8	72
MI-5	1991	4-13	6.9	69
MI-8	1981	4-13	6.6	72
MI-8	19%	4-11	7.0	70
MI-8	1992	5-12	7.2	60
ON-l	1987	6-14	8.5	
ON-l	1989	4-12	8.0	71
ON-l	1991	4-15	9.2	
ON-7	1988	3-10	5.8	
ON-7	1990	2-12	5.0	54
ON-34	1986	5-12	6.7	
ON-34	1989	4-15	7.0	54
ON-34	1991	4-15	7.0	51

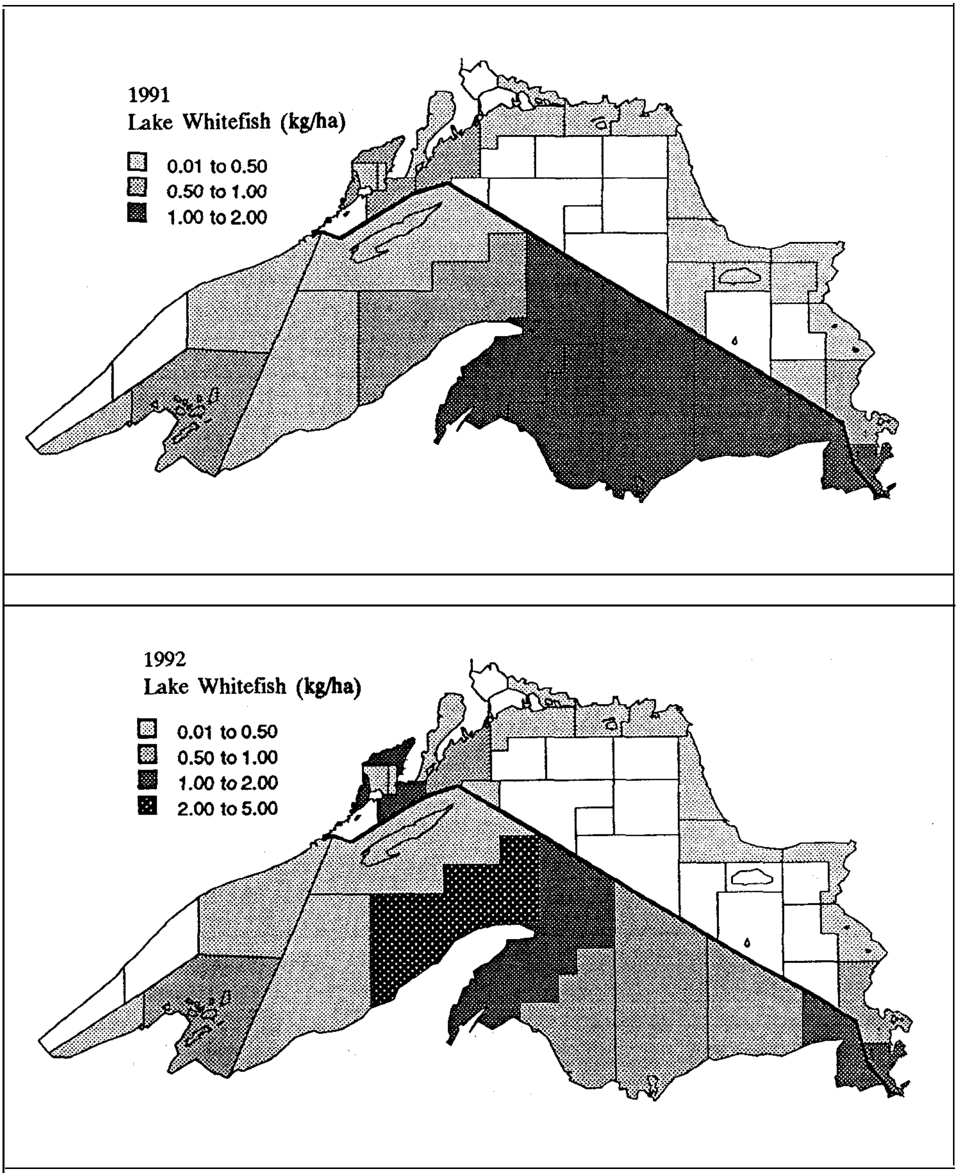

Fig. 35. Yield per unit area (kg/ha) of lake whitefish in Lake Superior management areas in 1991 and 1992 (see frontispiece for location names).

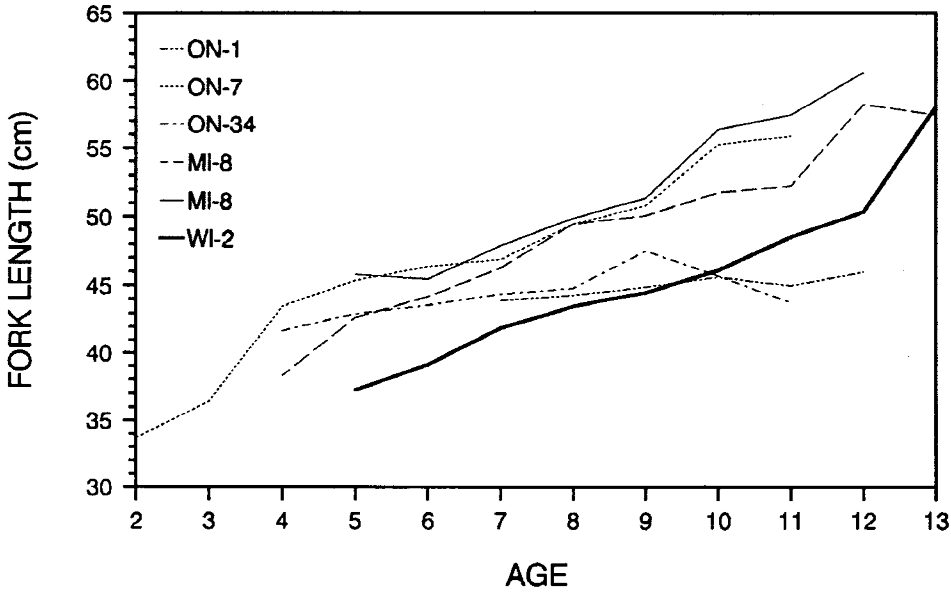

Fig. 36. Size at age of lake whitefish in commercial gillnets from selected management areas (two stocks in MI-8) of Lake Superior.

Walleye

Walleye were of only local importance in Lake Superior. The maximum commercial harvest from United States waters was 56,000 kg in 1885. The maximum commercial harvest from Canadian waters was 170,000 kg in 1966. Many of the walleye stocks in Lake Superior are slow growing, dominated by old individuals (Schram et al. 1992) and therefore unable to withstand high levels of exploitation (Fig. 37). Overharvest is a primary reason for declining abundance of several walleye populations (Schram et al. 1991). Exotic species have not been shown to adversely impact walleye. However, effects may not be detectable with present monitoring programs.

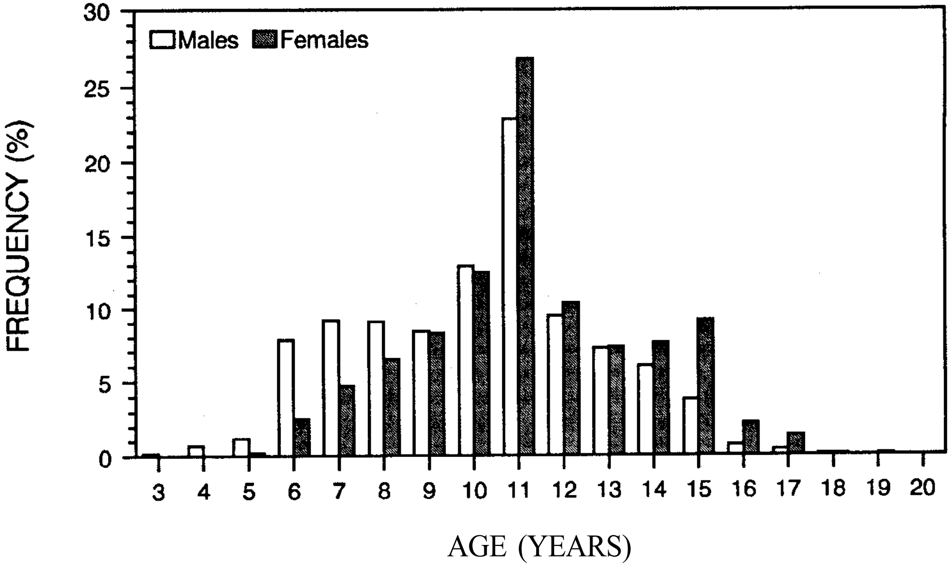

Fig. 37. Age distribution of spawning walleyes sampled from the St. Louis River in western Lake Superior in 1981 (Schram et al. 1992).

Despite reductions in their abundance, Lake Superior walleye are actively sought by anglers and tribal home-use fishers. Fishery managers have responded to the demand for walleye fishing by attempting to restore stocks through restrictive regulations, habitat restoration, and stocking (Table 4). Commercial fishing has been eliminated except for a quota fishery in Ontario and a tribal fishery in the United States. Reduced angler-bag and size limits are in effect in Ontario and Wisconsin. Habitat projects in Thunder Bay have been designed to increase spawning and nursery habitat. Relicensing criteria for hydroelectric dams on walleye spawning rivers should provide consistent spring river flows that may lead to increased hatching success. Restoration attempts in the Nipigon River and Nipigon Bay included transferring and releasing 12,000 adult fish and designing criteria for restoration of spawning shoals. Releases into the Goulais River included 1.3 million fry between 1984 and 1988. Fingerling walleye stocked in Wisconsin and Michigan waters have survived and grown well.

Walleye are being used in an attempt to control ruffe in the St. Louis River and estuary. Conservative regulations and fingerling stocking were designed to suppress the ruffe population. Evaluation of the effectiveness of this program is under way.

Table 4. Management problems, objectives, strategies, and results for major Lake Superior walleye populations.

Population	Management problem	Objective	Strategy	Result
St. Louis River	Exploitation of old stock. High mercury.	Maintain size structure. Control ruffe.	Stock fingerlings. Protect adults.	No change.
Chequamegon Bay-Kakagon River	Recovering population.	Provide sport and tribal fisheries. Rebuild stock.	Stock fry and fingerlings. Protect adults.	Good survival.
Bad River	Spawning run reduced. Insufficient data.	Provide sport and tribal fisheries. Rebuild stock.	Acquire data.	Unknown.
Ontonagon River	Spawning run reduced.	Rebuild stock.	Monitor spawning run.	Unknown.
Lac la Belle	Insufficient data.	Provide sport fishery.	Stock fingerlings.	Unknown.
Keweenaw Bay	Overharvest. Insufficient data.	Provide sport fishery.	Stock fingerlings. Acquire data.	Good survival.
Whitefish Bay	Overharvest. Insufficient data.	Provide sport fishery. Rebuild stock.	Stock fry and fingerlings. Acquire data.	Unknown
Nipigon Bay	Paper mill effluent. Overharvest. Insufficient data.	Rebuild stock.	Stock fry, fingerlings, and adults. Close fishery. Acquire data.	Unknown.
Black Bay	Overharvest. Insufficient data.	Rebuild stock.	Stock adults. Acquire data.	Failed.
Thunder Bay	Excessive contaminants. Habitat loss.	Maintain population and supporting habitats.	Protect and restore habitat.	No change.

Lake Sturgeon

Lake sturgeon are a threatened species in North America (Williams et al. 1989) and have a restricted distribution in Lake Superior. Populations most often identified in historic records were 64 records for the Sturgeon River (Michigan) and 131 records for the Bad River (Moore and Braem 1965). Early explorers also mentioned lake sturgeon runs in the Ontonagon River, Michigan (Schoolcraft 1821), and the St. Louis River where large numbers ascended for spawning (Kaups 1984). Commercial fishers reported lake sturgeon from:

- the ports of Brimley, Munising, Big Bay, Keweenaw Bay, and West Entry in Michigan;
- the Apostle Islands area in Wisconsin; and
- several points in Minnesota and Ontario.

Commercial landings for lake sturgeon exceeded 90,720 kg in 1885 and 45,360 kg in 1889 and 1890; however, reporting was inconsistent in the United States. Commercial fishing for sturgeon was closed in all United States waters in 1928, but Michigan allowed-retention of sturgeon again in between 1951 and 1969. The lakewide catch has been 454 kg or less since 1970 (Baldwin et al. 1979).

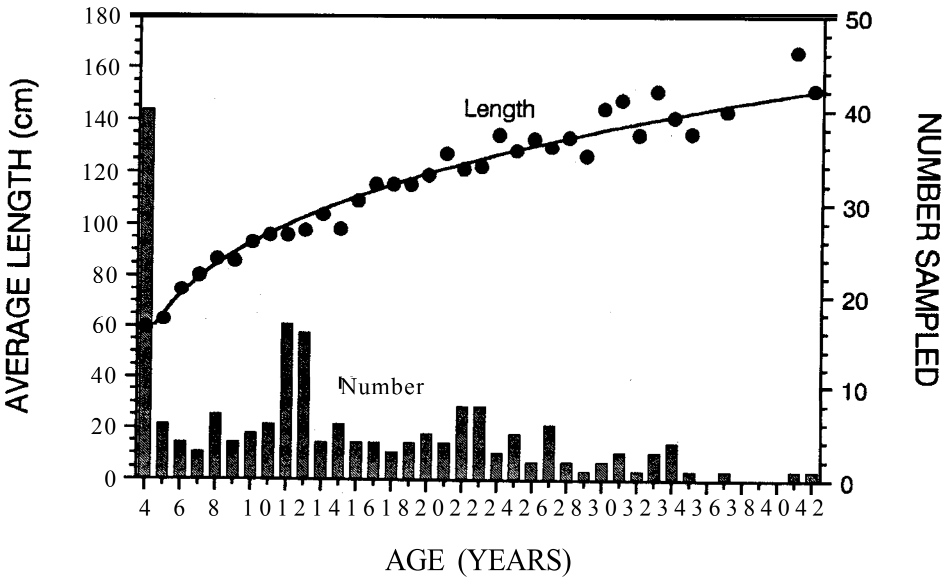

Fig. 38. Lake sturgeon length and number sampled in each age group in Chequamegon Bay and western Lake Superior.

Spawning populations of lake sturgeon in Lake Superior are found in the Sturgeon River (Michigan); Bad River (Wisconsin); and the Kaministikwia, Michipicoten, and Black Sturgeon Rivers (Ontario). In 1988, capture of age-0 lake sturgeon in the Sturgeon River indicated reproduction still occurred there (Auer 1988). In the fall of 1992, three juvenile lake sturgeon caught in the Bad River were 155-196 mm long (average 175 mm long)-indicating reproduction also occurred there (U.S. Fish and Wildlife Service, Ashland Fisheries Resources Office, 2800 Lake Shore Drive, East, Ashland, WI 54806, unpubl. data). Lake sturgeon from the Sturgeon River included six adult males (22-30 years old) and five adult females (31-36 years old) (Auer 1987). Sturgeon from Chequamegon Bay and near Duluth-Superior exceeded 130 cm for fish 30-40 years old (Wisconsin Department of Natural Resources, 141 South 3rd Street, Bayfield, WI 54814, unpubl. data) (Fig. 38). In the Bad River, 8 adult males were 8-21 years old (average 16.3 years) and 87-138 cm long (average 120 cm). There were 3 females 22-24 years old (average 23.3 years) and 133-140 cm long (average 137 cm) (Shively and Kmiecik 1989). Also in the Bad River in 1992, 17 adult males were 89-183 cm long (average 114 cm) and 4 females were 122-183 cm long (average 148 cm). An additional 13 fish of undetermined sex were 61-144 cm long (average 103 cm) (U.S. Fish and Wildlife Service, Ashland Fisheries Resources Office, 2800 Lake Shore Drive, East, Ashland, WI 54806, unpubl. data).

Dam construction on spawning streams and overharvest were the major factors historically limiting sturgeon populations (Priegel and Wirth 1971). Fishing mortality is currently composed of incidental catch in commercial nets, poaching on spawning grounds (Auer 1987), and tribal subsistence fishing-approximately 20 fish per year from the Bad River (J. D. Rose, Jr., Great Lakes Indian Fish and Wildlife Commission, P. 0. Box 9, Odanah, WI 54861, pers. commun.). Commercial and sport fisheries have restrictive regulations for most of Lake Superior.

Strategies for restoring depleted stocks of lake sturgeon include inventory, protection, restoration, and replacement of spawning and rearing habitat. Degraded habitat in the Sturgeon River may be restored by requiring a hydroelectric dam undergoing federal relicensing by the Federal Energy Regulatory Commission to operate at run-of-the-river flows. Peaking flows were replaced by run-of-the-river flows (1990-92) which reduced the length of time that lake sturgeon spawners spent in the river from 2-3 months to 2-3 weeks. More fish are caught annually, ripe-running fish are more common, and the number of large fish has increased (N. Auer, Michigan Technological University, Houghton, MI 49931, pers. commun.). Water quality has also improved through enactment of more-stringent water-pollution regulations.

Recent stocking efforts should help restore and enhance lake sturgeon in the St. Louis River (by the states of Wisconsin and Minnesota) and in the Bad River (1,500 fingerlings in 1988) by the Bad River Tribe. Attempts to capture adults for assessment and hatchery purposes in the Bad River were mostly unsuccessful between 1989 and 1992. All 22,900 lake sturgeon stocked by Minnesota in the St. Louis River between 1989 and 1991 were coded wire tagged. From 1971 to 1991, half of 238 fish captured in small-mesh-gillnet surveys in the river were tagged, and catch rates were 3.6, 4.4, and 2.0 fish/1,000 m, respectively (Minnesota Department of Natural Resources, 5351 North Shore Drive, Duluth, MN 55804, unpubl. data). Summer assessment netting in the St. Louis River from 1971 to 1991 indicates that lake sturgeon populations are building (Fig. 39) and that fish tend to leave the river after they reach a length of 53 cm (Wisconsin Department of Natural Resources, 141 South 3rd Street, Bayfield, WI 54814, unpubl. data). Lake sturgeon in the St. Louis River are believed to be all stocked fish.

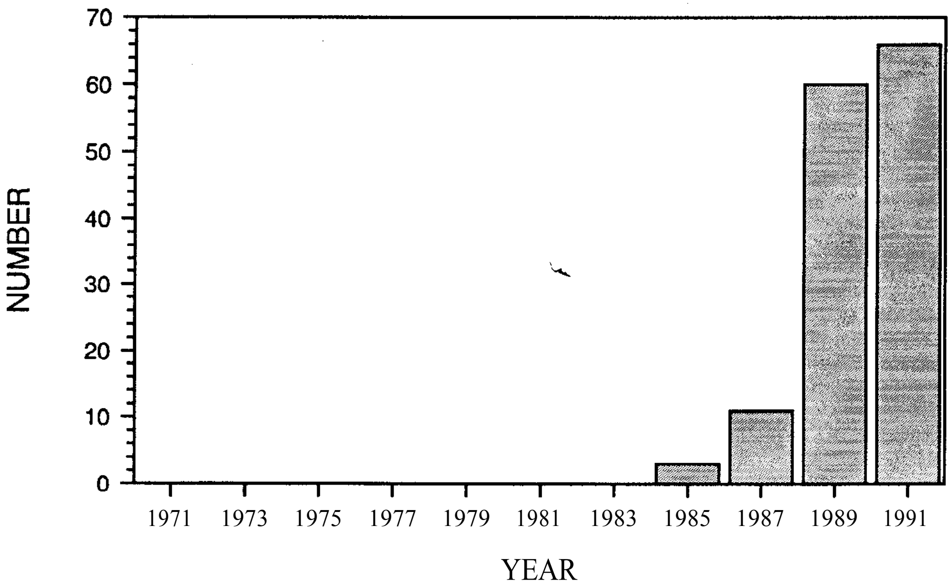

Fig. 39. Lake sturgeon catch in western Wisconsin waters of Lake Superior during summer assessment netting, 1971-91.

Recommendations

The following list of recommendations has been established:

1) The fishery objective for lake whitefish should be expanded to define parameters associated with self-sustaining stocks, especially those related to mortality rates and environmental productivity.

2) Walleye and lake sturgeon populations should be restored in streams that once had significant populations by use of habitat protection and restoration, judicious stocking, and harvest regulations.

3) Walleye and lake sturgeon stocking should be with fish of Lake Superior-watershed origin wherever possible.

4) Relicensing criteria for hydroelectric dams on walleye and lake sturgeon spawning rivers should provide spring flows that enhance recruitment.

5) Biological information about walleye and lake sturgeon populations should be obtained and used to develop restoration plans.

SEA LAMPREY

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Introduction

The fishery objective for sea lampreys in Lake Superior is to achieve a 50% reduction in current abundance of parasitic-phase sea lampreys by the year 2000 and a 90% reduction by 2010 (Busiahn 1990). Current control methods reduced sea lamprey abundance by 90% from precontrol levels. Integration of additional control methods including sterile-male releases, barrier-dam construction, increased chemical treatments, and additional trapping can be used to reduce populations toward these goals. The integrated management of sea lamprey (IMSL) program will define the objectives for sea lamprey abundance and recommend the optimal sea lamprey-control program. The IMSL initiative will include detailed evaluations of data on sea lamprey abundance, salmonid wounding and mortality, and chemical-treatment history to link control efforts to levels of damage to the fishery. Planning under the IMSL protocol is targeted to begin in 1994.

History

The first sea lamprey taken from Lake Superior was attached to a lake trout netted near Marquette, Michigan, in 1939. Sea lamprey numbers increased greatly during the following 20 years and reached peak abundance by 1960. The first attempts to control sea lampreys in Lake Superior occurred in 1950 and 1951 when mechanical weirs were placed in two streams on the south shore. These weirs were ineffective because of floods which allowed sea lampreys to pass upstream and spawn. Preliminary tests in 1952 demonstrated that electric barriers were effective in blocking spawning runs of sea lampreys, and by 1960 these barriers had been installed in 97 tributary streams of Lake Superior. Many electric barriers stayed in operation only a few years, but approximately 55 were operated between 1953 and 1960. The efficiency of these barriers as control devices was limited by mechanical, physical, and biological factors. Electric barriers were operated to assess spawning runs in reduced numbers. There were:

- 24 between 1958 and 1967,
- 16 between 1968 and 1970, and
- 8 between 1971 and 1979.

No electric barriers were operated after 1979. Since 1976, assessment traps placed in index tributary rivers have been used to measure abundance of spawning-phase sea lampreys.

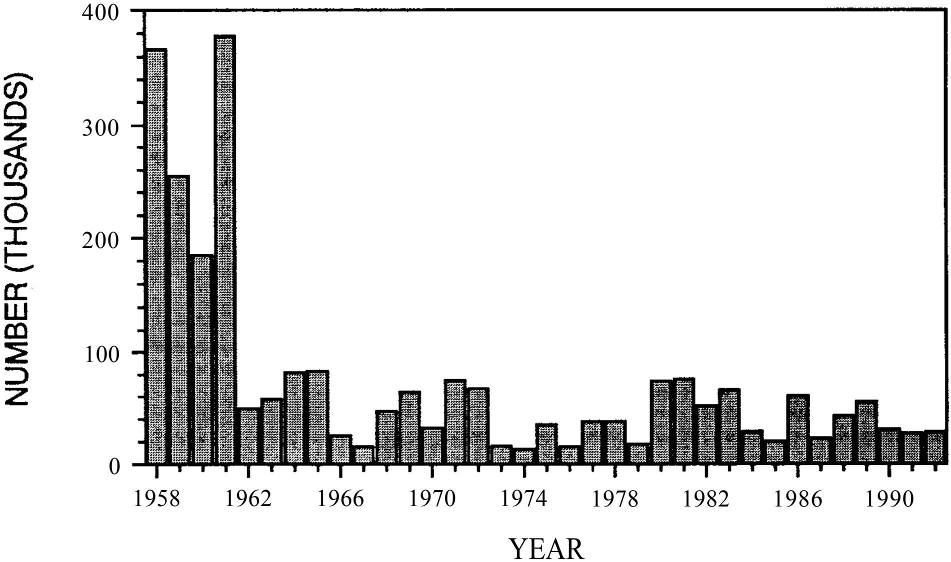

Fig. 40. Estimated number of spawning-phase sea lampreys in United States waters of Lake Superior, 1958-92.

The lampricide 3-trifhtoromethyl-4-nitrophenol (TFM) was developed by the U.S. Fish and Wildlife Service at the Hammond Bay Biological Station where 6,000 chemical compounds were screened in search of a selective toxicant (Applegate et al. 1957). Lampricide treatments of Lake Superior tributaries began in 1958 (Applegate et al. 1961), and 72 of the most-heavily infested streams were treated by

1960. Following these treatments, the number of adult sea lampreys estimated in Lake Superior declined by 85%-a level maintained through 1992 (Fig. 40). Intensified treatments between 1973 and 1979 reduced the number of adult sea lampreys to less than 10% of precontrol levels. Present abundance remains relatively similar to abundance from 1973 to 1979. Smith and Tibbles (1980) reviewed the sea lamprey invasion in Lake Superior and the control efforts and effects through 1979.

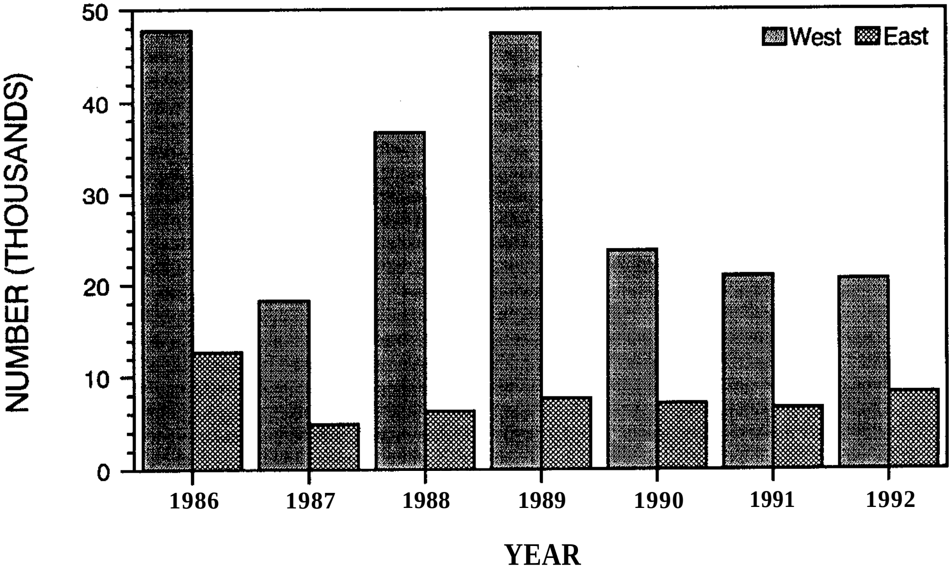

Fig. 41. Estimated number of spawning-phase sea lampreys in United States waters of Lake Superior east and west of the Keweenaw Peninsula, 1986-92.

Adult Populations

Relative abundance of spawning-phase sea lampreys is estimated using assessment traps fished in index tributary rivers. The number of traps varied between 1976 and 1992, but 9-23 Lake Superior streams have been trapped in most years. Traps were operated in 17 United States and 5 Canadian streams in 1992.

Between 1986 and 1992, the total abundance of adult sea lampreys in United States tributaries was projected from a relation between average stream discharge and the number of spawning-phase sea lampreys estimated to have entered certain streams. A single relation was developed for south-shore streams in 1986, and independent more-precise relations for streams west and east of the Keweenaw Peninsula were developed between 1987 and 1992 (Fig. 41). As a part of several studies preliminary to implementation of the sterile-male-lamprey technique in Lake Superior, mark-recapture estimates showed approximately 10,000 adult sea lampreys in Canadian streams in 1987. The estimated number of adult sea lampreys in the United States between 1958 and 1992 was developed by comparison of catches during the years when assessment traps and electric barriers were operated concurrently, and by back-calculation of estimated values between 1986 and 1992 through the previous years.

The number of sea lampreys in the lake during the early 1990s appears relatively unchanged from the 1970s and 1980s. Between 1980 and 1992, catches of adult sea lampreys taken in assessment traps varied similarly to catches at electric weirs between 1970 and 1979. Estimated numbers of adult sea lampreys in United States streams between 1986 and 1992 ranged from 23,000 to 60,500 (Fig. 40). Abundance between 1958 and 1992 is estimated to have ranged from 185,000 to 377,500 during the precontrol years (1958-61) and from 13,500 to 82,500 between 1962 and 1992.

Production Areas

In Lake Superior, sea lampreys have been found in 62 Canadian and 90 United States rivers, and in lentic areas off 14 Canadian and 17 United States rivers. Most sea lamprey larvae occur in:

- 14 Canadian river systems-the Goulais, Batchawana, Pancake, Michipicoten, Pic, Little Pic, Prairie, Pays Plat, Gravel, Jackfish, Nipigon, Wolf, Kaministikwia, and Pigeon, and

- 22 United States river systems-the Waiska, Two Hearted, Sucker, AuTrain, Chocolay, Salmon Trout, Huron, Ravine, Sturgeon, Traverse, Misery, East Sleeping, Firesteel, Ontonagon, Potato, Cranberry, Bad, Brule, Poplar, Middle, Amnicon, and Nemadji.

Major larval production also occurs in lentic areas off four Canadian river mouths (the Chippewa, Batchawana, Gravel, and Nipigon) and off two United States river mouths (the Sucker and Falls). Larvae escape treatments in some rivers because of oxbows, backwaters, and groundwater seeps where minimum lethal concentrations of lampricide are difficult to maintain. Delays or postponements of treatments because water levels are too high or low also contribute to larval escapement.

Larval Populations

Assessments of larval sea lamprey populations are conducted to determine:

1) the need for and effectiveness of lampricide treatments, and

2) the basic productivity in estimated numbers of larvae for the major lamprey-producing streams of the lake.

Relative abundance of larval sea lamprey populations are evaluated to identify streams that require lampricide treatments, areas within streams that need treatments, effectiveness of treatments, numbers of larvae escaping treatment, and year-class strength. Larval populations are sampled using backpack electroshockers in shallow water, and a bottom toxicant (Bayer 73) or deepwater electroshocker in water deeper than 1 m.

Estimates of larval abundance have been conducted on many streams in the United States and Canada since 1983. These estimates involved the capture, marking, and release of larvae for recapture during lampricide treatments and habitat-based assessments. Approximately 91,000 larvae were estimated in the Big Garlic River during the 1983 treatment. Estimates were made using mark-recapture methods for various 9.66-km zones stratified by habitat types and qualitative larval abundance. This effort was the first habitat-based estimate of a stream population of larvae in the Lake Superior drainage.

An extended field study was initiated in 1988 to systematically conduct habitat-based estimates of larval abundance to determine basic-productivity potential in the 32 primary lamprey-producing streams in the United States. Larval abundance was estimated in 26 tributaries through 1992 (Table 5). These abundance estimates range from 101 in the Salmon Trout River (Houghton County) to 1,048,208 in the Bad River (post-treatment abundance was 24,908). The information is an integral element of the IMSL process and is essential to refine and validate prediction models. Habitat-classification and population estimates will be completed in United States streams during 1994.

Table 5. Estimated number of sea lamprey larvae, date of estimate, and management area of 26 Lake Superior tributaries.

River	Area	Date	Number
United States:			
Amnicon River	WI-1	8/91	523,077
Middle River	WI-1	6/89	38,800
Brule River	WI-1	7/89	131,564
Red Cliff Creek	WI-2	6/89	5,421
Bad River	WI-2	7/91	1,071,872
Bad River	WI-2	8/92	24,904
Ontonagon River	MI-2	8/92	794,736
Firesteel River	MI-2	9/91	328,553
Firesteel River	MI-2	7/92	10,027
East Sleeping River	MI-2	6/92	24,659
Salmon Trout River	MI-3	9/92	101
Traverse River	MI-4	8/90	177,155
Sturgeon River	MI-4	8/89	352,066
Falls River	MI-4	7/89	5,511
Huron River	MI-4	7/88	614,869
Salmon Trout River	MI-5	5/91	236,866
Iron River	MI-5	5/91	69,859
Big Garlic River	MI-5	9/89	16,788
Little Garlic River	MI-5	5/89	27,292
Harlow Creek	MI-5	8/88	62,023
Chocolay River	MI-5	8/91	458,126
Miners River	MI-6	5/92	7,375
Sucker River	MI-6	7/90	765,392
Betsy River	MI-8	6/90	41,893
Tahquamenon River	MI-8	6/90	9,479
Galloway Creek	MI-8	5/90	2,428
Waiska River	MI-8	10/92	524
Canada:			
Pancake River	ON-33	6/89	181,401

Control Strategy

Between 1958 and 1992, 857 lampricide applications were made on 43 streams in Canada (280 treatments) and 84 streams in the United States (577 treatments). Approximately 20% of these streams were treated only once, but some were treated as many as 23 times. During the past ten years, treatments have been conducted regularly on 32 tributaries in Canada and 44 tributaries in the United States. In addition to stream treatments, lentic areas off the mouths of 13 Canadian rivers have been treated with granular Bayer 73.

Streams are scheduled for treatment to prevent metamorphosed larvae from migrating into Lake Superior. Preliminary scheduling is done two years in advance of treatment for administrative and logistical reasons, and schedules are established one year prior to treatment. Most streams are treated on a three- to four-year rotation.

Funds were requested in 1992, 1993, and 1994 to increase lampricide treatments on Lake Superior tributaries to assist in achieving the goal of a 50% reduction in sea lamprey numbers. The proposed strategy is to apply lampricide to major sea lamprey-producing streams two years in succession to eliminate the majority of larvae that survive the first treatment. No funds have been received to date to initiate this strategy.

Research at the Hammond Bay Biological Station indicated release of sterile-male sea lampreys may be an effective supplemental lamprey-control technique (Hanson and Manion 1980; Hanson 1981). In 1991, 3,434 sterile-male lampreys were released into ten tributaries in eastern Lake Superior. Because of equipment problems and delays, the sterile lampreys were released past the time of optimum effectiveness. In 1992, 21,299 sterile-male sea lampreys were released into 21 United States Rivers and six Canadian streams (Table 6). Numbers of resident sea lampreys and lampreys available for sterilization were estimated prior to the start of the field trial. A sterile-to-normal-male ratio of 1.8:1 was targeted and would theoretically reduce the reproductive capacity of the lamprey population by 64%. The predicted ratio was achieved on a lakewide basis and ranged from 0.9:1 to 2.5:1 among the 27 streams. Short- and long-term effectiveness of the technique is being evaluated.

Table 6. Predicted and actual numbers of sterile-male sea lampreys released, normal resident males present, ratio of sterile to normal males, and the predicted progeny in 27 tributaries of Lake Superior in 1992.

River	Predicted		Released		Reduction	
	Resident	Sterile	Resident	Sterile	Ratio	Percent
United States:						
Nemadji	800	1,418	1,574	1,417	0.9:1	47
Amnicon	972	1,723	771	1,723	2.2:1	69
Middle	202	359	161	318	2.0:1	67
Poplar	142	252	112	252	2.3:1	70
Bad	1,770	3,138	1,404	3,170	2.3:1	70
Cranberry	26	47	19	47	2.5:1	71
Potato	16	28	12	28	2.3:1	70
Ontonagon	2,000	3,544	3,311	4,624	1.4:1	58
East Sleeping	105	186	84	186	2.2:1	69
Firesteel	239	424	189	423	2.2:1	69
Misery	198	352	157	352	2.2:1	69
Traverse	26	47	28	47	1.7:1	63
Sturgeon	764	1,355	809	1,794	2.2:1	69
Silver	86	154	92	154	1.7:1	63
Huron	137	243	145	243	1.7:1	63
Salmon Trout	70	125	75	125	1.7:1	63
Chocolay	129	230	137	230	1.7:1	63
Au Train	134	239	143	239	1.7:1	63
Sucker	94	167	100	165	1.7:1	63
Two Hearted	273	485	289	696	2.4:1	71
Waiska	68	121	72	121	1.7:1	63
Canada:						
Pigeon	80	142	80	160	2.0:1	67
Wolf	200	354	200	369	1.8:1	64
Nipigon	1,000	1,772	1,000	2,611	2.6:1	72
Pancake	100	177	100	177	1.8:1	64
Batchawana	400	709	400	709	1.8:1	64
Goulais	400	709	400	919	2.3:1	70
Total/Average	10,431	18,500	11,864	21,299	1.8:1	64

Low-head barrier dams are the only alternative to TFM treatments on lamprey-producing streams. Barriers act by:

- blocking upstream migration of spawning-phase sea lampreys,

- eliminating production of sea lampreys in streams or sections of streams,

- eliminating the need for TFM treatments and any associated nontarget effects or water-use conflicts, and

- creating or enhancing trapping of spawning sea lampreys.

Barriers have been built on six Canadian and four United States streams to date. In addition, velocity barriers are being developed by the Canadian sea lamprey control agent. Velocity barriers exploit the relatively poor swimming ability of sea lampreys compared to other fish species. Water velocity is increased above the burst swimming speed of sea lampreys to prevent their upstream passage while allowing other fish species to pass. An experimental velocity barrier will be constructed and tested on the McIntyre River in 1993.

Nontarget Effects

Lampricide can be applied without affecting most nontarget aquatic vertebrates found in Lake Superior tributaries. Species such as stonecat, trout-perch, brown bullhead, mudpuppy (Necturus maculosus maculosus), and ruffe are sensitive to TFM and killed during treatment. The concentration of TFM that would begin to kill age-0 lake sturgeon is 1.3 times higher than the concentration that would kill 99.9% of sea lampreys. Successful treatments of sea lamprey have been conducted at these concentrations with no observed mortality of lake sturgeon. Mortality of less-sensitive fish species may occur if the lampricide is applied during their spawning, and frequent treatments may impede full recovery of some sensitive species. Mechanical or electric barriers used as alternatives to chemical treatment may block passage of fish migrating upstream to spawn. Fish-passage provisions will allow some fish species to ascend upstream. Barriers may pose a hazard if not designed and constructed carefully.

Several short- and long-term studies have been conducted in United States tributaries of Lake Superior between 1983 and 1992 to measure impacts of lampricide treatments to 64 taxa of nontarget macroinvertebrates. Short-term studies were conducted during treatments by:

- placing organisms in cages (Huron, Silver, Potato, Bad, and Brule Rivers),

- collection of benthos drift (Brule River), and

- toxicity tests in a mobile laboratory (Sturgeon and Brule Rivers).

The long-term impact to riffle invertebrate communities is being measured in the Brule River. Long-term impact on populations of *Hexagenia* mayflies is being measured in four Lake Michigan streams-indirectly relating to Lake Superior.

Most taxa of macroinvertebrates are not impacted during lampricide treatments. Of the 64 taxa, the numbers of Oligochaeta (aquatic worms), Simulidae (black flies), caddis *flies (Chimarra, Dolophilodes,* and *Glossosoma),* and mayflies *(Hexagenia* and *Litobrancha)* decline during treatments. In general, populations of impacted organisms recover to pretreatment abundance within scheduled treatment cycles. Treatment techniques are modified when appropriate to minimize impacts on invertebrates.

Recommendations

The following list of recommendations has been established:

1) Increased (sea lamprey) treatment frequency and barrier construction, improved treatment effectiveness, and implementation of experimental new technology should be used to meet the fish-community objective for sea lamprey in Lake Superior.

2) Integrated approaches to sea lamprey control should be emphasized in western waters of Lake Superior to address the higher lake trout wounding in these areas.

RUFFE

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Introduction

The ruffe (a Eurasian percid) is found in fresh and brackish water (Lind 1977) in lakes and slow-flowing rivers in England, eastern and northern Europe, and Asia; in rivers flowing into the Arctic Ocean; and in the Caspian and Aral seas (Berg 1949; Holcik and Mihalik 1968). The ruffe has become overly abundant where it has been introduced in Europe, and its growth may be stunted (Fedorova and Vetkasov 1973). Ruffe are highly fecund (Berg 1949; Bacmeister 1977) and prey on fish eggs and larvae (Nikolskii 1954; Mikkola et. al. 1979). European literature on the ruffe indicates that this species is of little or no value as a food or recreational fish and is frequently considered a pest and serious problem.

History

Ruffe were first found (31 small individuals) in North America in July 1987 and August 1987 at three locations in the 4,400-ha St. Louis River-Lake Superior's most-western tributary (Pratt et al. 1992). Individuals who had recently sampled the St. Louis River were notified of the discovery. Ichthyoplankton collections by an environmental consulting company included 66 ruffe larvae from three sites in the St. Louis River during 1986 and 101 ruffe larvae from four sites in 1987 that had been mistaken for johnny darters (Simon and Vondruska 1991). A single ruffe was killed during a lampricide (TFM) treatment of the upper St. Louis River estuary on September 1, 1987.

The likely vector for the exotic species was the ballast of an ocean-going vessel (Pratt et al. 1992). The Duluth-Superior Harbor is an international grain-shipping port located at the mouth of the St. Louis River. The harbor is used by many in-ballast grain ships each year-a total of 181 transoceanic vessels entered the Duluth-Superior Harbor in 1988. Many of these ships previously loaded and unloaded in the seaports of northern Europe. These ports are typically located in the lower reaches of large rivers where ruffe are common.

Between 1988 and 1991, ruffe spread slowly along the south shore of Lake Superior and into the mouths of the Amnicon, Brule, and Iron Rivers-located approximately 25,40, and 50 km east of the St. Louis River, respectively. An angler caught a ruffe on August 14, 1991, in the Kaministiquia River at Thunder Bay, Ontario located 300 km northeast of the St. Louis River (W. MacCallum, Ontario Ministry of Natural Resources, 435 James Street South, Thunder Bay, Ontario, Canada, P7C 5G6, pers. commun.). Six more specimens were subsequently caught in September and October 1991 in Thunder Bay-none were taken in 1992. It is unlikely that the ruffe moved along the shoreline from Duluth-Superior to Thunder Bay because of the length and hostility (cold water) of the coastline between the two areas. Instead, ruffe were most likely transported from Duluth-Superior to Thunder Bay via intralake shipping (ballast). Ruffe were caught in 1992 in the Flag and Sand Rivers-60 and 80 km east of Superior, Wisconsin, suggesting that the ruffe is expanding its range. Ruffe have not yet been taken in Chequamegon Bay, Wisconsin, although heavy sampling was conducted in 1992.

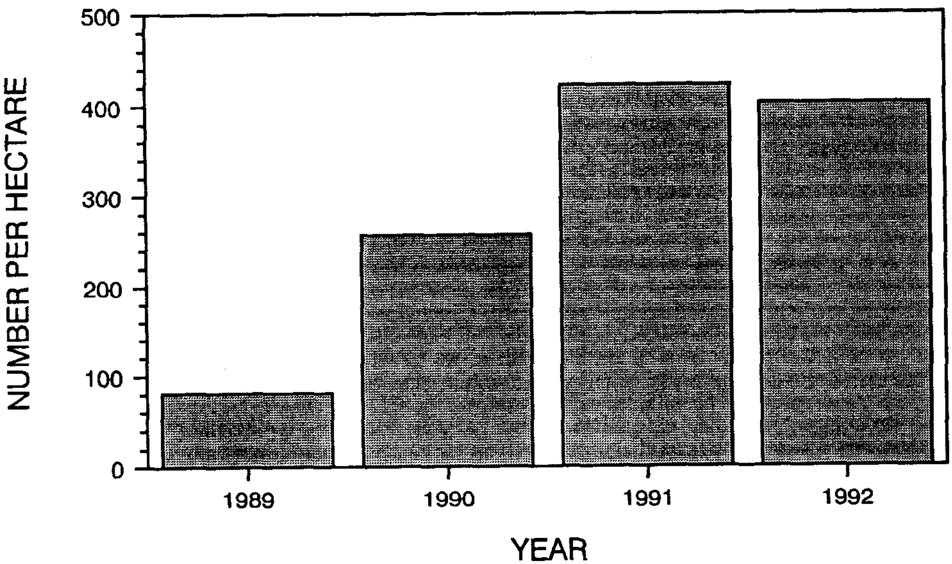

Fig. 42. Estimated ruffe abundance in the St. Louis River, Lake Superior, 1989-92.

Numbers of ruffe in the St. Louis River increased sharply between 1989 and 1992 (Fig. 42). The estimated spawning population increased from 0.2 million in 1989 to 1.8 million in 1992. As population density of ruffe increased, intraspecific and interspecific competition caused first-year growth of ruffe and the proportion of mature one-year-old ruffe to decline. Increasing population pressure within the St. Louis River also caused a buildup of ruffe numbers in Lake Superior proper. Summer gillnetting took no ruffe in the lake before 1991 but took ruffe at several locations in 1991 (Wisconsin Department of Natural Resources, 141 South 3rd Street, Bayfield, WI 54814, unpubl. data). A commercial trawler took large numbers of ruffe off Duluth-Superior in spring 1992, and substantial numbers of ruffe were consistently caught during trawling in Lake Superior in 1992 near the Superior entry to Duluth Harbor.

Interactions With Native Species

Lake Superior fishery scientists met in 1988 to evaluate the likely effects of ruffe on the native-fish community and options for its control. Results of research in Europe and Russia suggested that ruffe were likely to be deleterious to recreational and food fisheries. Chemical control was debated but then rejected as politically unfeasible, too expensive, and unlikely to succeed. Consequently, agencies chose to attempt top-down predator control-a technique used in the lower Great Lakes to greatly reduce overly abundant prey-fish species with Pacific salmon. During the winter (1988-89), public meetings were held to describe the problem and the top-down predator-control program. In spring 1989, emergency-harvest regulations were implemented to reduce annual catches of walleye and northern pike. Intensive stocking of walleye, northern pike, and muskellunge was initiated.

In 1988, studies were begun in the St. Louis River estuary to:

- evaluate the effects of invading ruffe on a native cool-water fish community,
- determine the biological and population characteristics of ruffe and interacting species, and
- evaluate the effectiveness of the top-down control strategy.

To collect population data on all fish species present, trawling was conducted at 40 randomly selected sites in the estuary during 9-11 cruises each year between 1989 and 1992. Intensive sampling in the spring and fall of each year was used to estimate population sizes and collect specimens for laboratory analysis. Trawling, electrofishing, fykenetting, and creel surveys provided samples of predator stomachs for determining food habits.

Ruffe are closely associated with the bottom. They are found in the deepest channels (8-10 m deep) at ice-out, move into the shallows to spawn, remain mainly in water l-3 m deep throughout the summer, and return to the deepest channels in September and October. Ruffe occupy all habitats in the St. Louis River estuary but appear to prefer mid-depth (3-5 m deep) channels during the day and shallower water at night to feed. Within the St. Louis River system, ruffe are widely distributed. They are most abundant in downstream sections of the river near Lake Superior and least abundant in upstream river areas. Upstream migration in the St. Louis River is blocked by a dam located approximately 40.2 km from the river mouth.

Ruffe in the estuary grow very rapidly and attain approximately 40%-50% of their ultimate length (approximately 180-200 mm) in their first year. Ruffe become sexually mature at an early age-of several thousand fish examined in 1988, all except two very small females were mature at age 1. Between 1989 and 1991, first-year growth slowed each year and higher proportions of yearlings were immature. Fecundity is moderately high but much less than reported in European literature.

Ruffe eat microcrustaceans, mostly Cladocera, in their first two months of life and then switch to macrobenthos in the late summer and fall (D. Ogle, University of Minnesota, Twin Cities, MN, pers. commun.). Adult ruffe less than 120 mm long eat mostly Chironomidae, other macrobenthos, and microcrustaceans early in the year. Adult ruffe more than 120 mm long eat mostly macrobenthos - especially midges and burrowing mayflies. Diel sampling showed that adult ruffe migrate into shallow areas at dusk (where they feed throughout the night) and then move back to deeper channels at dawn. Age-O ruffe also feed most heavily at night but also feed during the day (mostly on microcrustaceans).

The major predators of ruffe have been large (more than 200 mm long) yellow perch and brown bullheads (both of which eat smaller ruffe) and northern pike (which eat larger ruffe). Abundance of large perch and bullheads declined sharply between 1989 and 1992 for uncertain reasons. However, pike and walleye abundance increased slightly between 1989 and 1992 (Fig. 43), probably as a result of restrictive harvest regulations and stocking.

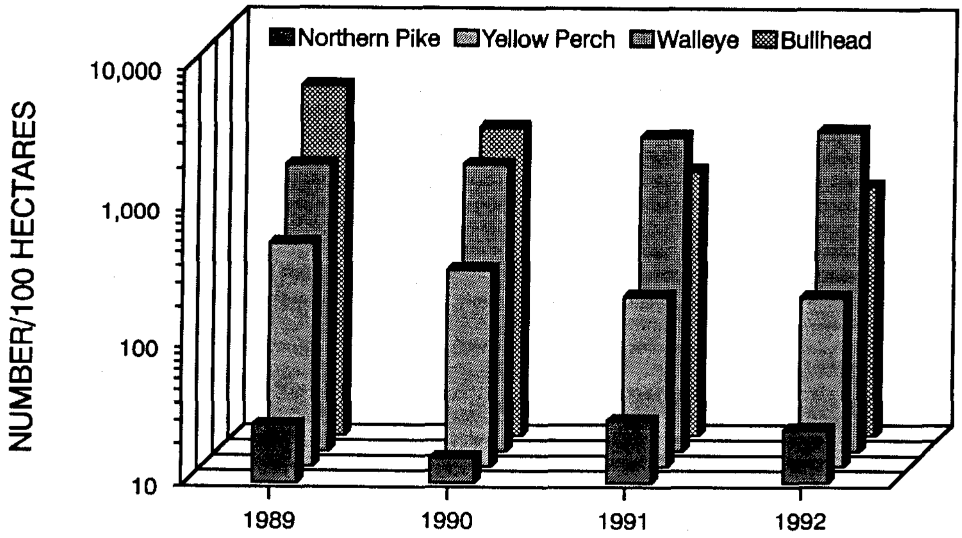

Fig. 43. Estimated abundance of northern pike, yellow perch, walleye, and bullheads in the St. Louis River, Lake Superior, 1989-92.

Predation on ruffe was studied beginning in 1989. However, 1992 data cover only the first six months of the year. Between 1989 and 1992, the contents pumped from thousands of predator stomachs were examined (mostly from fish released alive) but only 1,269 contained fish. Predation on ruffe increased from almost none in 1989 to over 20% of all fish eaten in 1992. In the early years of the invasion, ruffe found in predator stomachs were predominantly small and were consumed mostly by larger bullheads and yellow perch. Northern pike consumed increasing numbers of ruffe between 1989 and 1992. By early summer (1992), northern pike consumed substantial numbers of ruffe. Between 1989 and 1991, no ruffe were found in 356 walleye that ate fish. By early 1992, 28% of 18 walleye that ate fish had eaten ruffe. These results suggest that predators in the St. Louis River have not yet checked the expansion of ruffe.

Recommendations

The following list of recommendations has been established:

1) Changes in fish-community structure in the St. Louis estuary should continue to be described and the causes of these changes should be determined.

2) Competitive relationships between ruffe and native species should be researched.

3) Predation on ruffe by native species should be quantified using bioenergetics models to determine if top-down predator control is a viable control option.

4) Other control options should be investigated and implemented to slow the spread and reduce the range of ruffe.

HABITAT

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Introduction

The fishery objective for habitat in Lake Superior is to achieve no net loss of the productive capacity of habitats supporting Lake Superior fisheries, restore the productive capacity of habitats that have suffered damage, and reduce contaminants in all fish species to levels below consumption advisory levels (Busiahn 1990). An inventory of habitat types, in conjunction with continued fish-population monitoring, will be required to achieve no net loss of fish productivity. Involvement of fishery managers in remedial efforts coordinated by the International Joint Commission (IJC) will be required to restore the productive capacity of damaged habitat. Implementation of Remedial Action Plans (RAPS) and reduction of airborne toxins will be required to reduce contaminant levels in fish below consumption advisory levels.

Maintain Existing Habitat

Fish habitats most critical to achieving no net loss of Lake Superior fishery production include spawning grounds, wetlands, rivers, streams, and surrounding watersheds. Spawning substrates (such as rocky shoals in Lake Superior) support several of the most important species including lake trout, lake whitefish, and lake herring. Rivers and streams flowing into Lake Superior provide spawning and nursery habitat for anadromous species such as walleye, brown trout, rainbow trout, Pacific salmon, and lake sturgeon. Habitat degradation in these watersheds will ultimately affect the productivity and composition of the Lake Superior fish community.

General inventories of important fish habitat have been completed for many of the important spawning grounds in Lake Superior (Coberly and Horrall 1980; Goodyear et al. 1982) but need to be expanded to specific sites where detailed mapping could determine quality and quantity of habitat. Few inventories exist for fish habitat in rivers, streams, and important wetlands. Changes in any of these fish habitats need to be monitored and incorporated into fishery-management programs to determine if net losses occur. This will require those involved in fishery- and environmental-management programs to work together more closely. Mitigation should be a last resort when destructive works cannot otherwise be averted. To achieve no net loss, mitigation will be required for any proposed development that displaces or changes existing habitat. The potential for mitigation should not be construed as an opportunity to degrade fish habitat in Lake Superior.

Restore Damaged Habitat

To restore the productive capacity of damaged habitats in Lake Superior, seven areas were identified by the IJC as Areas of Concern (AOCs) for development of RAPS. In each AOC, Stage I of the RAP process defines and describes the intensity and scope of environmental problems, the causes for the impairment, and sources of the impairment. Stage II of the RAP process identifies remedial measures required to restore beneficial uses-particularly the key actions, time frame, and responsibilities needed to eliminate uncertainty of remediation.

In Ontario, AOCs include Peninsula Harbour, Jackfish Bay, Nipigon Bay, and Thunder Bay. The RAP process in each of these areas has completed Stage I and has proceeded to Stage II. In Michigan, the AOCs include Torch Lake and Deer Lake-Carp Creek/River. The RAPS for these areas have been submitted to the IJC for review and have progressed toward finalization. In Wisconsin and Minnesota, the AOC is shared for the St. Louis Bay and River system. This RAP has completed Stage I and proceeded to Stage II. Detailed information on the status of the various RAPS can be found in the Review and Evaluation of the Great Lakes Remedial Action Plan Program (International Joint Commission 1991).

In addition to these AOCs, several rivers flowing into Lake Superior have hydropower dams that block migration and reduce the productive capacity of these systems for anadromous species. Renewal of licenses for these facilities currently under review by the Federal Energy Regulatory Commission (FERC) may be contingent on a change in operation to run-of-the-river flows that should benefit anadromous species. The following rivers have hydropower dams in the process of FERC licensing that could improve degraded habitat for production of anadromous fishes:

St. Louis River-Minnesota

Data collection is essentially complete and the final application for licensing has been distributed. The application is in the final consultation stage. Upon completion, the environmental review process will begin.

Iron River-Wisconsin

The dam was removed from the FERC relicensing process at the request of the power company. Subsequently, dam removal was approved.

White River--Wisconsin

Fisheries studies were conducted in 1989 and 1990. The draft application has been completed and the final application is under review.

Montreal River-Michigan, Wisconsin

Studies of the Saxon Barrier Falls have been completed and licensing has been approved. The Superior Falls Hydroelectric Project draft application has been completed and the final application is being reviewed. Fisheries studies for both projects took place in 1987.

Autrain River-Michigan

Data collection is nearly complete. A draft application should be completed by midwinter, 1992-93.

Dead River-Michigan

Data collection has been under way for some time but is currently held up because of archeological concerns. Data collection is expected to be completed in late 1993.

Ontonagon River-Michigan

Flow studies were completed at the Bond Falls Dam, and results are being reviewed. Entrainment is being studied at the Victoria Dam and is expected to take approximately one year.

Sturgeon River-Michigan

Data collection is complete and a license application has been accepted by FERC. The application will undergo environmental review in winter, 1992-93.

Reduce Contaminant Levels

Excessive contaminant levels-especially of polychlorinated biphenyls (PCBs) and mercury-in Lake Superior fish require the setting of consumption advisories for several important species. These species include lake trout, siscowet, walleye, chinook salmon, northern pike, white sucker, lake whitefish, and yellow perch (Busiahn 1990). The consumption advisories are most severe in the seven AOCs, although some contamination is associated with aerial inputs and sediment recycling in the main lake.

A major area of point-source pollution not covered in the RAP process is the Copper Range Company in Ontonagon County, Michigan. This company emits aerial discharges into the Lake Superior ecosystem of 544.2 kg mercury, 22,675.7 kg lead, 8,163.3 kg copper, and annual deposition or more than 7.3 million kg of contaminated sediments (Michigan Department of Natural Resources, Air Pollution Control, Lansing, MI, file data). A lawsuit was filed by the National Wildlife Federation and Michigan United Conservation Clubs on August 14, 1992, for non-compliance to the Clean Air Act. Other sources of pollution in the Lake Superior watershed include Murphy Oil in Superior, Wisconsin, mining activity in Minnesota, and pulp- and paper-mill effluent in Ontario.

Concentrations of PCBs in lake trout have been declining since 1974-75 (D'Itri 1988), apparently in response to restricted use of these compounds in the early 1970s. Contaminant levels in fish associated with the AOCs will be reduced if RAPs are successfully implemented. Aerial inputs will continue to be a problem until in- and out-of-basin polluters are more fully regulated. Standardized health advisories among agencies on Lake Superior are being developed and will clarify the risk to the general public. Coordinated sampling and testing on a lakewide basis by all agencies may be more effective for comparing contaminant levels of various species. Standardized long-term monitoring must be initiated to document contaminant reductions.

Coordinate With Other Programs

A Binational Program to Restore and Protect the Lake Superior Basin (Binational Program) was initiated in September 1991 by the U.S. Environmental Protection Agency (USEPA) and Environment Canada; the Province of Ontario; and the states of Minnesota, Michigan, and Wisconsin. The goal of the Binational Program is to achieve zero discharge and emission of designated persistent, bioaccumulative toxic substances that degrade the Lake Superior ecosystem. This goal will be pursued through three types of actions including pollution prevention, special protection designations, and controls and regulations. After progress has been made toward the goal of zero discharge and emissions, the governments plan to undertake an integrated ecosystem-based program to protect and restore the basin. A process to plan for a Lakewide Management Plan (LAMP) process is scheduled to begin in 1992 to provide a framework for all discharge and emission-control programs, and to set the stage for development of a LAMP. The Habitat Advisory Board (HAB) of the Great Lakes Fishery Commission has advised the Lake Superior Committee (LSC) to get involved in formulating the Lake Superior LAMP before it is finalized.

The USEPA developed the Environmental Monitoring and Assessment Program (EMAP) in 1988 to monitor ecological status and trends and to develop methods for anticipating emerging environmental problems before they reach a crisis. Objectives of the EMAP program include:

1) Estimate current status, extent, changes, and trends in indicators of the condition of the nation's ecological resources on a regional basis with known confidence.

2) Monitor indicators of pollutant exposure and habitat condition, and associate human-induced stresses with ecological condition.

3) Provide statistical summaries and interpretive reports on ecological status and trends to resource managers and the public.

The Great Lakes is the newest of EMAP's seven basic resource groups. Planning was initiated in 1990 (Hedtke 1992). As the EMAP sampling plan for Lake Superior develops, it is imperative that all fishery agencies become involved with the project. It is important that previous work on the lake and expertise with the Lake Superior fish community not be ignored during the planning process. Ultimately the EMAP program may be contracting for or soliciting assistance from agencies to aid their project.

HAB has compiled documents that will be useful to the LSC, including drafts of habitat criteria for fish-community goals, a position statement on contaminants in the Great Lakes, and materials and advice to assist managers in representing fishery issues to RAPs and LAMPs. Increased interaction between HAB, the LSC, and Lake Superior Technical Committee will be beneficial.

Habitat Projects, 1989-91

Most of the habitat work for fisheries in Ontario has centered on the AOCs located at Thunder Bay, Nipigon Bay, Jackfish Bay and Peninsula Harbour. These projects include restoring fish habitat and spawning grounds, improving fish access to' spawning areas, creating fish habitat, stocking fish, and increasing public environmental awareness:

Thunder Bay

Habitat-restoration objectives defined and projects implemented (1989-91) include:

1) Restore walleye spawning habitat and increase access of anadromous fish to spawning habitat in the Current River.

2) Construct an island-wetland complex, stabilize creek banks, and remove debris to enhance spawning and improve fish access to McVicar Creek.

3) Create fisheries habitat, increase productivity, and enhance the carrying capacity of the Neebing-McIntyre Floodway for aquatic life.

4) Create instream cover, stabilize banks, expand diversity of aquatic flora, and enhance recreational use of the Kaministiquia River.

5) Excavate lagoons, extend the littoral zone, construct feeding and shelter areas, and improve fishing access to the McKellar River-Mission Island area.

6) Monitor and assess all affected tributaries and determine effectiveness of work completed.

Nipigon Bay

Habitat-restoration objectives defined and projects implemented (1989-91) include:

1) Transfer adult walleye from inland lakes to Nipigon Bay and River.

2) Inventory and describe walleye spawning habitat in the Nipigon River.

3) Clean up debris at the old mill site at the mouth of the Nipigon River.

4) Develop a water-management plan that will determine flow regimes for the Nipigon River.

5) Develop the Nipigon Creek Watershed Management Plan.

Jackfish Bay

Habitat-restoration objectives defined and projects implemented (1989-91) include:

1) Impose controls to improve effluent from the Kimberly-Clark pulp mill.

2) Develop a design to restore contaminated sediments and lost fish habitat.

Peninsula Harbor

The habitat-restoration objective defined and project implemented was to develop and evaluate ameliorative techniques for mercury and conduct an experimental treatment in the harbor.

In Michigan, FERC relicensing on the Sturgeon River has drawn attention to the flow regime that affects lake sturgeon spawning and use of high-quality spawning areas in the river. Adequate flow regimes to improve the spawning area are presently under debate with the power company. In Wisconsin, the U.S. Fish and Wildlife Service has conducted detailed mapping of Gull Island Shoal using side-scan sonar and a remotely operated submersible vehicle. Mitigation involving a fill in Fish Creek Sloughs, Chequamegon Bay, continues with controversy over removal of a power-generating dam on the Iron River. The Wisconsin Department of Natural Resources is investigating potential fishery benefits to the anadromous Lake Superior fishery as a result of dam removal. In Minnesota, a detailed map of the Gooseberry and Lester River watersheds has been completed, and a preliminary map of the Lake Superior coastal zone was constructed using geographical information system technology (Johnston et al. 1991). A North Shore Harbors Plan was completed, and the artificial reef located near the Duluth entry continues to be monitored each fall for spawning activity by lake trout.

Recommendations

The following list of recommendations has been established:

1) The Lake Superior Committee should endorse the International Joint Commission's goal for zero toxic discharge for Lake Superior.

2) Each fishery agency on Lake Superior should ensure they are represented on each of the Remedial Action Plans in their jurisdiction.

3) The Lake Superior Committee should support standard health advisories and long-term contaminant monitoring by all agencies on Lake Superior.

4) The Lake Superior Committee should coordinate with the Binational Program to restore and protect the Lake Superior basin, and participate in developing the Lake Superior lakewide management plan before it is final.

5) The Lake Superior Technical Committee should provide input to the fish-community objectives that will be addressed in the lakewide management plan.

6) The Lake Superior Committee should contribute to the Environmental Monitoring and Assessment Program planning process on Lake Superior.

7) Members of the Lake Superior Committee should request the use of new technologies (including hydroacoustics, satellite imagery, geographical information system mapping, and side-scan sonar) to identify, evaluate, and protect critical fisheries habitat in the Lake Superior watershed

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