LAKE SUPERIOR: THE STATE OF THE LAKE IN 1989

Edited by
Michael J. Hansen

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April 1990

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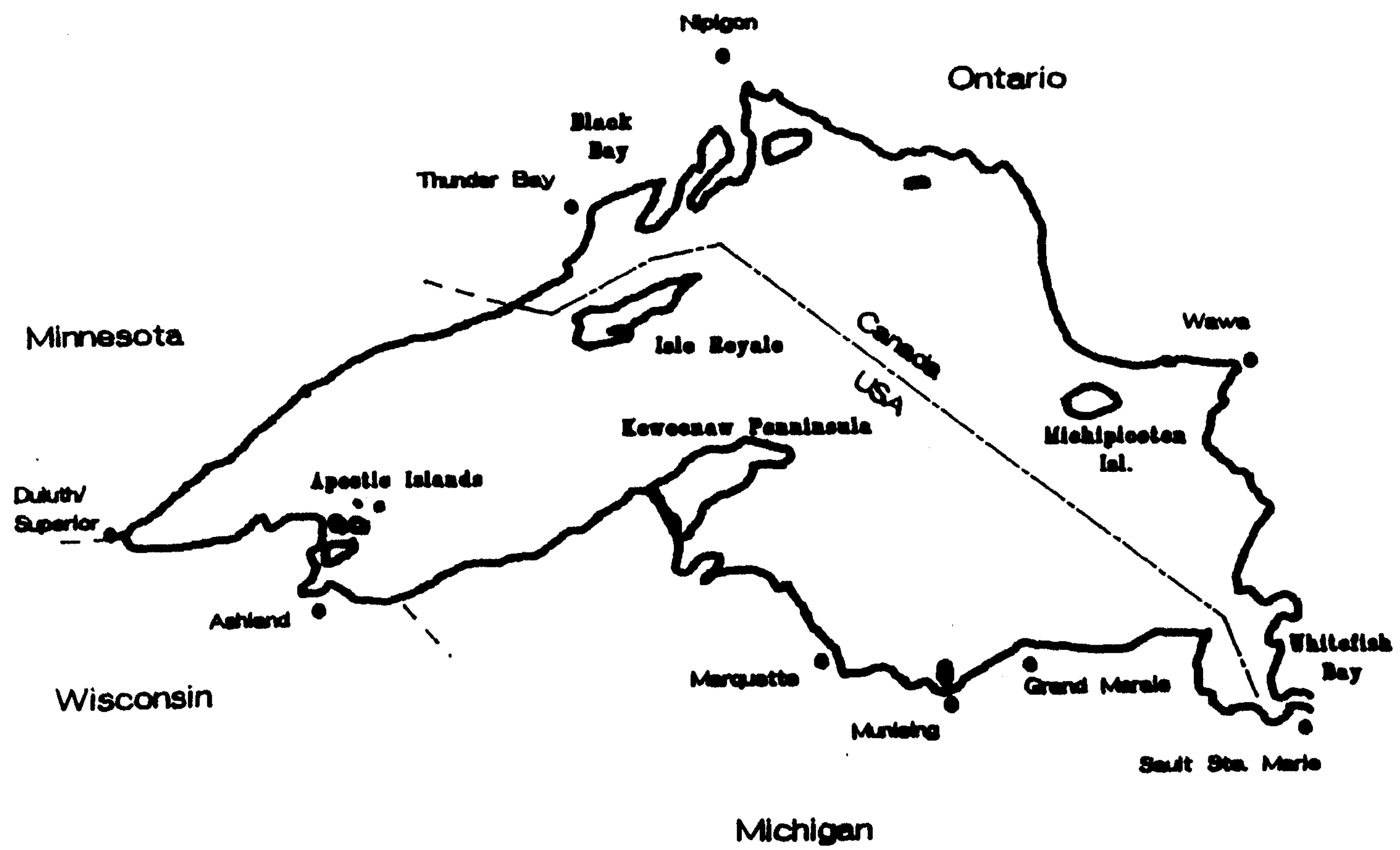

Lake Superior

FOREWORD

This report was prepared by the Lake Superior Technical Committee. Agencies with membership on the committee include:

Chippewa-Ottawa Treaty Fishery Management Authority (COTFMA);
Department of Fisheries & Oceans, Canada (DFO);
Great Lakes Indian Fish & Wildlife Commission (GLIFWC);
Michigan Department of Natural Resources (MDNR);
Minnesota Department of Natural Resources (MnDNR);
Ontario Ministry of Natural Resources (OMNR);
Wisconsin Department of Natural Resources (WDNR); and
United States Fish & Wildlife Service (USFWS).

Michael J. Hansen (WDNR), committee chairman, edited and produced the report from original material written by: Mark Ebener, GLIFWC (lake trout sea lamprey wounding and lake whitefish sections); Michael J. Hansen, WDNR (executive summary, goals and objectives, background, lake trout stocking, and habitat sections); Gerald Klar, USFWS (sea lamprey section); James Peck, MDNR (other salmonid predators section); Richard Schorfhaar, MDNR (lake sturgeon section); Stephen Schram, WDNR (walleye section); James Selgeby, USFWS (forage species and lake trout relative abundance, mortality, and growth sections): and Bruce Swanson, WDNR (lake trout extractions section). Thomas Gorenflo, COETMA; Wayne MacCallum, OMNR; Donald Schreiner, MnDNR; and Jerry Weise, DFO, assisted the original authors in Preparation of various sections. Original authors were supplied with data by committee representatives from the various agencies.

CONTENTS

EXECUTIVE SUMMARY

The Lake Superior fish community in 1989 is substantially different than it was as recently as half a century ago and is still far from reaching a state desired by management agencies. Fish community objectives were established for Lake Superior *in* response to the *Joint Strategic Plan for Management of Great Lakes Fisheries* and are the template for this state-of-the-lake report. The process of reporting on progress toward meeting stated goals and objectives will serve to focus attention on critical fisheries issues and to enhance communication and understanding among fishery management and environmental protection agencies, political bodies, and the public.

Objectives Fishery objectives for Lake Superior include: 1) rehabilitate lake herring *(Coregonus artedii)* stocks to historic levels of abundance for the purposes of lake trout *(Salvelinus namaycush)* rehabilitation, production of other predators, and fishery harvest; 2) achieve a sustained annual yield of 4 million pounds 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; 3) manage exploitation of non-depleted stocks to maintain a stable, self-sustaining status (lake whitefish, *Coregonus clupeaformis;* deepwater ciscos, *Coregonus* spp.; suckers, *Catostomus* spp.; *walleye, Stizostedion vitreum vitreum)* and re-establish depleted stocks of native species *(lake* sturgeon, *Acipenser* fulvescens; brook trout, *Salvelinus fontinalis;* walleye); and 4) achieve a 50% reduction in parasitic-phase sea lamprey *(Petromyzon marinus)* abundance by 2000 and a 90% reduction by 2010.

Progress Progress toward reaching the above objectives has been substantial but remained far below target levels in 1989: 1) lake herring stocks rebounded in many areas of the lake but remained below historic levels of abundance; 2) the annual yield of lake trout approached half of the target level, but was still substantially supported by stocking in many areas--the yield of other salmonid predators approached 15% of the total predator yield, but lake trout growth declined substantially in Michigan waters; 3) lake whitefish stocks supported greater commercial yields than at any previous time, while stocks of walleye, lake sturgeon, and brook trout remained at depressed levels due to overharvest, habitat degradation, and competition with introduced species; and 4) abundance of parasitic-phase sea lampreys remained at about 10% of pre-control levels but still accounted for a substantial portion of total lake trout mortality, particularly in U.S. waters west of the Keweenaw Peninsula.

Forage Species Lake herring was the dominant forage fish until the 1950s. It declined when rainbow smelt *(Osmerus mordax)* became established in the lake and, grew in abundance during the 1960s and 1970s. During the latter half of the 1980s, lake herring populations rebounded, and although they are now far more abundant

than rainbow smelt in Wisconsin and Michigan waters, they have still not increased [o historic levels of abundance. Diets of larger predators remain dominated by rainbow smelt, but consumption of lake herring is increasing in areas where their abundance is improving. Total biomass of rainbow smelt and lake herring increased greatly during 1982-1986 and declined during 1987-1989. Total forage biomass in Minnesota and eastern Ontario waters is dominated by rainbow smelt while biomass in western Ontario, Wisconsin, and Michigan waters is dominated by lake herring.

Predator Species Lake trout, the dominant predator in Lake Superior until the 1950s, sustained an annual yield in excess of 4.0-million lb (1.8-million kg) during 1929-1943. Most inshore stocks of lake trout collapsed during the 1950s due to sea lamprey predation and uncontrolled commercial fishing. Presently, the annual yield of lake trout is 41.4% of the fish community goal, though stocked fish contribute substantially to the yield in some areas. Sea lamprey predation amounts to another 6.3% to 31.1% of the yield goal in U.S. waters and an unknown portion of the goal in Canadian waters.

Stocking began soon after the onset of the collapse of inshore lake trout stocks, first in Wisconsin waters in 1952 and last in Minnesota waters in 1964; more than 28-million yearlings were stocked by 1970 and more than 60-million by 1983. Abundance of lake trout increased in Lake Superior during the 1950s and 1960s in areas where stocking was undertaken or where remnant native populations survived the collapse. During the 1970s and 1980s, abundance of hatchery fish in Michigan waters declined as stocking rates were decreased, while abundance of wild fish increased as reproduction expanded. In Wisconsin waters, abundance of hatchery fish declined slowly during this period, while abundance of wild fish remained relatively stable. In Minnesota waters, abundance of hatchery fish has increased steadily since stocking began in 1964. Recent stockings in some U.S. waters have been below target levels because of insufficient hatchery capacity, while stockings in Canadian waters have been more consistent.

Mortality of lake trout due to fishing and sea lamprey predation was excessive during the period preceding the collapse of inshore stocks. During the 1970s and 1980s, total mortality was above the target rate of 50% in most jurisdictions and yield remained divided about equally between fishing and sea lamprey predation. Sea lamprey predation is a dominant component of total mortality in U.S. waters west of the Keweenaw Peninsula.

Lake trout growth rates were generally higher in U.S. waters than in Canadian waters during the early-1980s but were at similar levels during 1987-1988. Growth rates declined steadily throughout Michigan waters during the 1970s and 1980s but remained relatively consistent in Wisconsin and Minnesota waters. The observed decline in growth coincides with the decline in rainbow smelt abundance. Rainbow smelt remain the preferred prey of lake trout in spite of rebounding lake herring abundance in some areas. Lake trout growth may also be adversely affected by increasing abundance of Pacific salmon.

Introductions of rainbow trout (Oncorhynchus mykiss) and brown trout (Salmo trutta) in the late-1800s, pink salmon (O. *gorbuscha) in* 1956, coho salmon (O. *kisutch) in 1966,* and chinook salmon (O. *tshawytscha) in* 1967 were successful in establishing populations across Lake Superior by the 1980s. However, these anadromous fishes comprised less than 15% of the total yield of predators during 1984-1987. Abundance of rainbow trout and pink salmon declined recently, whereas abundance of the other species is stable or increasing. Splake, a fertile hybrid resulting from the cross of a female lake trout and male brook trout *(Salvelinus fontinalis),* are stocked for put-grow-take local fisheries, particularly in Wisconsin waters, Brook trout are native to Lake Superior, but populations were reduced to low levels in most areas through competition with introduced anadromous salmonids. Atlantic salmon (Salmo *salar)* are stocked for put-grow-take local fisheries in Minnesota waters. Lakewide fin-clipping of all chinook salmon stocked in Lake Superior in 1988-1990 was conducted to ascertain the level of natural reproduction. Subsequent evaluations of predator-prey dynamics in Lake Superior and the impact of introduced salmonids on lake trout growth will be undertaken using bioenergetics models.

Other Species Due to increased abundance and expanded fisheries, Lake whitefish stocks presently support greater commercial harvest than at any other time in the 20th century. Lake trout rehabilitation efforts may be negatively impacted by the 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 rehabilitation efforts of historically important stocks. Deepwater cisco stocks declined continuously through the 1980s as siscowet (a deepwater form of lake trout) stocks expanded. Brook trout rehabilitation efforts have been largely unsuccessful.

Sea Lamprey Current control methods reduced sea lamprey abundance by 90% from pre-control levels. Intensified chemical treatments and integration of new control methods, including sterile-male releases, barrier dam construction, and increased trapping, will be used to further reduce populations. An integrated Management of Sea Lamprey initiative will seek to refine objectives for sea lamprey abundance and define the optimal sea lamprey control program to meet those objectives. The initiative will include detailed evaluations of historic data on sea lamprey abundance, salmonid wounding and mortality, and chemical treatment. to link control effort to levels of damage to the fishery.

GOALS AND OBJECTIVES

Fish community objectives were established for Lake Superior (Busiahn 1990) in response to the Joint *Strategic Plan for Management of Great Lakes Fisheries* (SGLFMP). These objectives were to serve as a template for State-Of-the-lake reports. Fish community objectives will be revised, strengthened and made more specific during the 3-year periods between state-of-the-lake reports. The Process of reporting on progress toward meeting stated goals and objectives will serve to focus attention on critical fisheries issues and to enhance communication and understanding among fishery and environmental management agencies, political bodies, and the public.

The basis for Lake Superior fish community objectives is derived from the SGLFMP common goal statement for Great Lakes fishery agencies:

> "To provide 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 fisheries objectives established for Lake Superior (Busiahn 1990) include:

A. Forage: Rehabilitate lake herring *(Coregonus artedii)* stocks to historic levels of abundance for the purposes of lake trout *(Salvelinus namaycush)* rehabilitation, production of other predators, and fishery harvest.

B. Predators: Achieve a sustained annual yield of 4 million pounds 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.

C. Other Species: Manage exploitation of non-depleted stocks to maintain a stable, self-sustaining status (lake whitefish, *Coregonus clupeaformis;* deepwater cisco, *Coregonus* spp.; sucker, *Catostomus* spp.; and walleye, *Stizostedion vitreum vitreum)* and re-establish depleted stocks of native species (lake sturgeon, Acipenser fulvescens; brook trout, *Salvelinus fontinalis;* and walleye).

D. Sea Lamprey: Achieve a 50% reduction in parasitic-phase sea lampreys (Petromyzon *marinus)* abundance by 2000 and a 99% reduction by 2010.

E. Habitat: 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 to these fish community objectives, the Great Lakes Water Quality Agreement of 1978 as amended by a protocol signed November 18, 1987 states that Lake Superior should be maintained as a balanced and stable oligotrophic ecosystem with lake trout as the top aquatic predator of a coldwater community and the benthic *crustacean, Pontoporeia hoyi,* as a key organism in the food chain (International Joint Commission 1989). The Agreement goes on to establish ecosystem health indicators for Lake Superior lake trout and *Pontoporeia hoyi.* The ecosystem health indicators for lake trout are: 1) productivity greater than 0.38 kilograms/hectare; and 2) stable, self-producing stocks, free from contaminants at concentrations that adversely affect the trout themselves or the quality of the harvested products. The ecosystem health indicators for *Pontoporeia hoyi* are: 1) the abundance of the crustacean maintained throughout the entire lake at present levels of 220-320/meters ^{2} (depths less than 100 meters); and 2) 30-160/meters^2 (depths greater than 100 meters).

This report describes progress through 1989 toward reaching the fisheries objectives established by the Lake Superior Committee (Busiahn 1990) and represents as comprehensive a compilation of information as is possible at this time. In the interest of conveying relevant conclusions without being overly burdensome on the reader, summarizations of larger data sets are presented.

BACKGROUND

Lake Superior is the largest body of fresh water in North America and lies at the head of the St. Lawrence River drainage (Table 1) (Lawrie and Rahrer 1973). The shoreline is nearly evenly divided between the U.S. and Canada, but nearly two-thirds of the surface area lies in the U.S. In contrast, more than two-thirds of the drainage basin lies in Canada. There are nearly as many tributary streams in Canada as in the U.S., but Canadian streams are generally larger.

Lake Superior is oligotrophic due to 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 33 ft (10 m) or more. Fish production is low and averaged 0.83 lb/acre (0.93 kg/ha) at its peak (1X6-1940) and only 0.71 lb/acre (0.80 kg/ha) over the long term (1879-1969). The original fish community was dominated by lake trout, lake whitefish, lake herring, and several species of deepwater cisco,

Table 1. The morphometry and hydrology of Lake Superior (from Lawrie and Rahrer 1973).

Length		668.3 km	350 mi
Breadth		305.5 km	160 mi
Depth	max.	406.3 m	1,333 ft
	mean	148.3 m	487 ft
Shoreline	U.S.	1,463.0 km	909 mi
	Can.	1,475.7 km	917 mi
	Total	2,938.7 km	1,826 mi
Surface Area	U.S.	53,613.0 km^2	20,700 mi^2
	Can.	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	U.S.	43,770.8 km^2	16,900 mi^2
	Can.	101,786.6 km^2	39,300 mi^2
	Total	145,557.4 km^2	56,200 mi^2
Tributaries	U.S.	840	
	Can.	685	
	Total	1,525	
Mean Annual Discharge		2,124.7 m^3/s	75,051 cfs
Retention Time		182 years	

During the 1950s, uncontrolled fishing and predation by sea lampreys, an invader from the Atlantic Ocean, caused the collapse of populations of lake trout, lake herring, and deepwater cisco (see Lawrie and Rahrer 1973 for a review). Rehabilitation of lake trout stocks was attempted through sea lamprey control based on application of lampricide in streams, lake trout stocking, and restrictive regulation of commercial fishing. Inshore lake trout abundance increased about tenfold from 1961-1971 in Michigan and Wisconsin waters where stocking rates were highest, increased more slowly in Ontario waters where stocking rates were lower, and increased little if at all in Minnesota waters where initiation of stocking was delayed. Remnant native lake trout stocks continued to decline through the 1960s in inshore waters but increased in offshore U.S. and Canadian waters. Offshore stocks are nearly fully recovered. The only inshore stocks of wild lake trout known to have recovered were those of Gull Island Shoal, Wisconsin; Stannard Rock, Michigan; and Thunder Bay, Ontario. Small wild stocks also persisted near Cat Island, Wisconsin; Munising, Michigan; and in several areas of Ontario waters.

During and after the 1970s, the rate of lake trout rehabilitation was affected by a combination of reduced stocking and ineffective control of exploitation. Recruitment of stocked fish declined in Wisconsin wafers where stocking was reduced in the late-1960s and in Michigan waters where stocking was reduced sharply in 1971. . Conversely, recruitment gradually increased in Minnesota wafers where intensive stocking continued into the late-1960s and 1970S. Recruitment of stocked fish leveled off at an unsatisfactory low level in Ontario waters where stocking rates were low, Planting stock formerly destined for Michigan and Wisconsin waters was diverted elsewhere because managers thought that stocked fish would be protected from exploitation and that they would mature and reproduce as the wild fish had. However, exploitation in the U.S. increased steadily in the 1960s-1970s and commercial catches in Ontario waters generally exceeded quotas imposed in 1961. During the 1970s, it became apparent that stocked fish were less efficient reproducers than native fish (Krueger et al. 1986). This reproductive inefficiency was believed to result from holding juvenile fish in hatcheries at a time when they normally imprint to their natal spawning shoal.

By 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 the stocks or sustain a substantial yield. Fishery agencies recognized that lake trout rehabilitation was more difficult and time-consuming than was anticipated and would require continued stocking, control of exploitation, increased control of sea lampreys, development of new sea lamprey control methods, and additional knowledge.

STATUS OF STOCKS

Forage Species

The fishery objective for forage species in Lake Superior is to rehabilitate lake herring stocks to historic levels of abundance to provide forage for lake trout and other predators and to provide fishery harvest. Presently, lake herring stocks are increasing in some areas but have not increased to historic levels. Diets of larger predators remain dominated by rainbow smelt (Osmerus mordax), but consumption of lake herring is increasing in areas where their abundance is increasing. Total biomass of rainbow smelt and lake herring increased substantially during 1982-1986 and declined during 1987-1989. Total forage biomass in Minnesota and eastern Ontario waters is dominated by rainbow smelt while that in western Ontario, Wisconsin, and Michigan waters is dominated by lake herring.

Lake Herring Lake herring in Lake Superior historically yielded larger commercial harvests than all other species combined. Catches in U.S. waters peaked at 19 million lb (8.6 million kg) in 1941, declined slowly during the remainder of the 1940s, and declined sharply to only 220,000 lb (100,000 kg) in 1981-1983. Analysis of commercial fishing records for Wisconsin waters indicated the decline there was due to sequential overharvest of discrete stocks (Selgeby 1982). Earlier declines in Minnesota waters and later ones in Michigan and eastern Ontario waters, were likely the result of similar fishing patterns.

In contrast to these declines in U.S. waters, major lake herring stocks in western Ontario waters did not appear to be overharvested until very recently. The Black Bay stock sustained relatively stable harvest levels during 1960-1981, but abundance dropped by more than 80% during 1981-1988 (Fig. 1) - Catches in Thunder Bay declined in the 1960s and early-1970s, rebounded to high levels in 1979-1981, and then declined sharply in 1983-1984 due to a very weak market. The 1988-1989 catches were dominated (80%) by a single year class (1984), suggesting that reproduction is threatened.

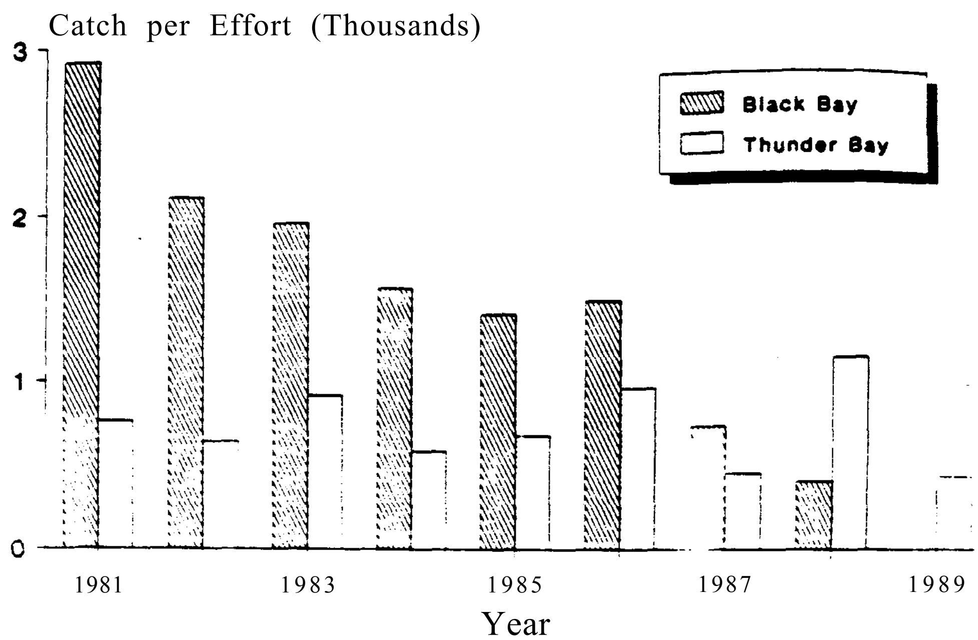

Figure 1. Relative abundance of lake herring in Ontario waters of Lake Superior, 19814989.

Strength of lake herring year classes in U.S. waters increased dramatically in the 1970s. Year class strength was indexed beginning in 1978 from catches of yearlings in trawls at 53 locations along the U.S. shore, and beginning in 1989 at 24 additional locations along the Canadian shore. Lake herring year classes were strong in 1978, 1980, and especially 1984; moderate in 1983, 1985, and 1986; and weak in 1987. The 1988 year class is the second strongest yet measured (Fig. 2). Catches of spawning lake herring in Wisconsin waters in 1988 corroborate the strength of the 1984 year class, as age-4 lake herring composed 87% of spawning females and 92% of spawning males. The 1984 year class is also abundant in Ontario and eastern Michigan waters. '

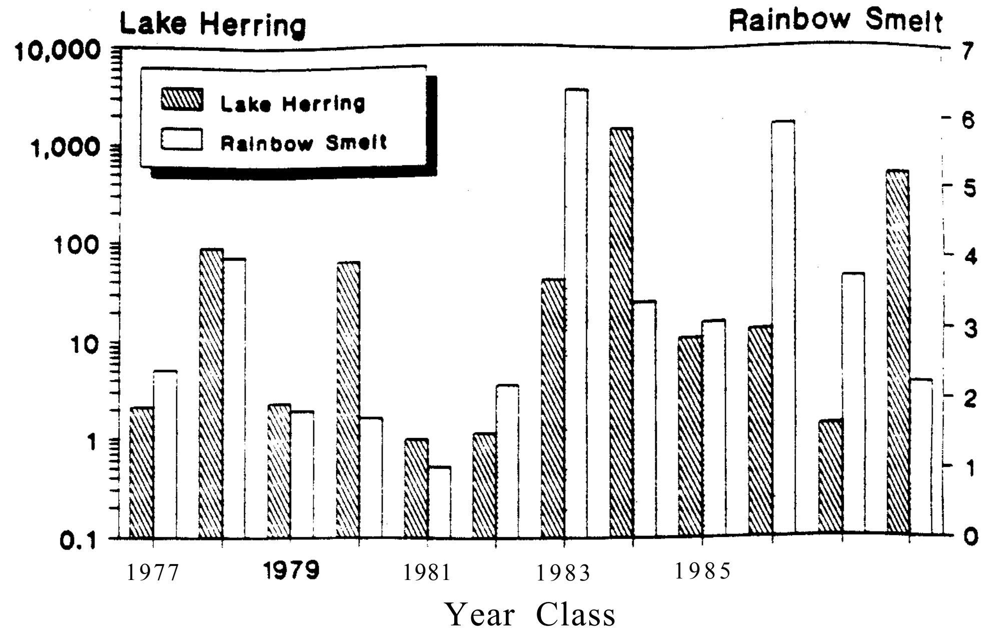

Figure 2. Relative year class strength of lake herring and rainbow smelt in Lake Superior, 1977-1988.

Lakewide lake herring biomass was low in 1978-1984, increased in 1985-1986 as members of the 1984 year class entered the catch, declined in 1987, and remained stable in 1988-1989 (Fig. 3). However, the patterns are quite different in the three

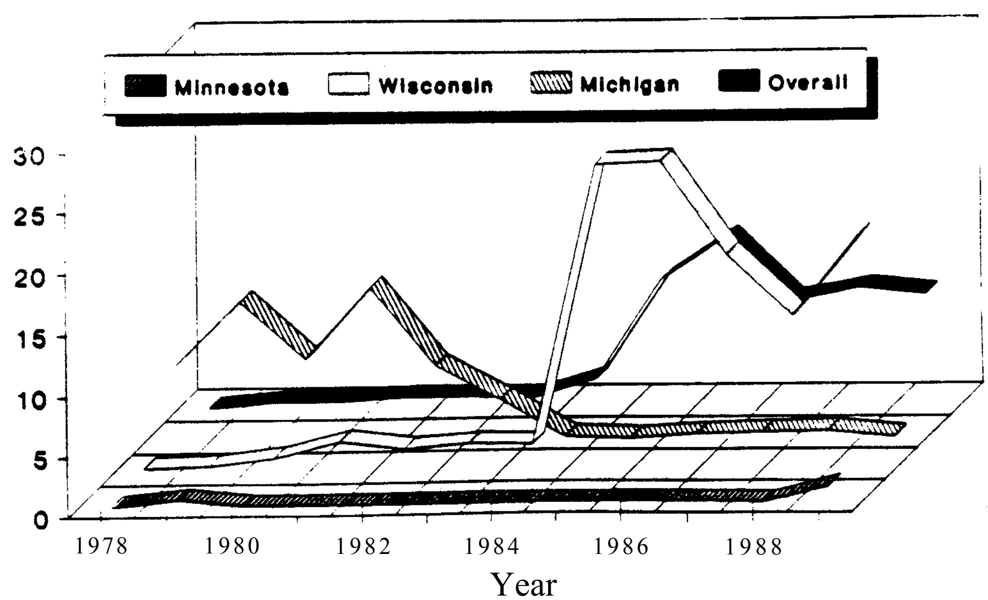

Figure 3. Relative biomass of lake herring in trawls fished during spring in U.S. waters of Lake Superior.

states. in Minnesota waters, lake herring biomass remained relatively low and stable. with little evidence of recovery, while patterns in Wisconsin and Michigan waters were similar to lakewide trends. Recoveries were especially strong in Wisconsin waters west of the Apostle Islands and in Michigan waters in the Keweenaw Bay and Munising areas. Lake herring biomass in 1989 was about 0.9 lb/acre (1 kg/ha) in eastern Ontario and Minnesota waters, 5.4 lb/acre (6 kg/ha) in Michigan waters, and 17.8 lb/acre (20 kg/ha) in Wisconsin and western Ontario waters

<u>Rainbow Smelt</u> Rainbow smelt entered Lake Superior in the early-1930s, reached commercially harvestable levels in 1952, and continued to increase in abundance through the 1950s-1960s. Rainbow smelt are fished commercially 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 harvest increased in recent years but remains far below levels taken in the early- to mid-1970s. The major decline in commercial catch in the late-1970s was due to a decline in rainbow smelt abundance.

As a result of declining rainbow smelt abundance and increasing mortality, rainbow smelt biomass as estimated from trawl surveys declined more than 90% from 1978-1981 (Fig. 4). By 1981, rainbow smelt stocks were dominated by age-l and age-2 fish and spawning stocks, which had declined sharply in abundance, were almost all age-3 fish. In 1982, rainbow smelt stocks began to recover and increased in abundance lakewide through 1986. By 1986, rainbow smelt biomass was about half that in 1978. However, lakewide biomass declined about 25% each year in 1987-1989.

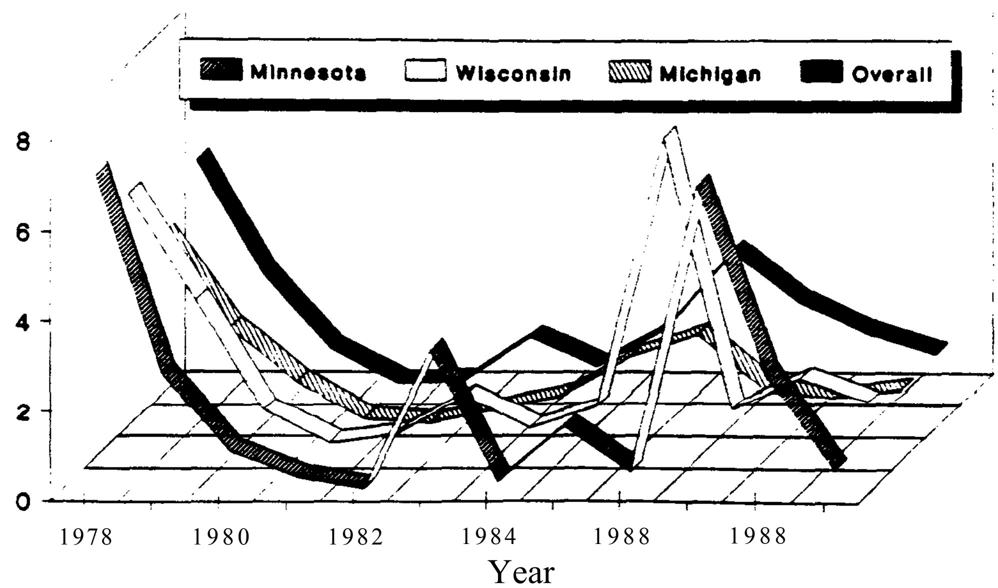

Figure 4. Relative biomass of rainbow smelt in trawls fished during spring in U.S. waters of Lake Superior.

In Minnesota waters, the general pattern of rainbow ***smelt*** decline and recovery was similar to the lakewide trend except that biomass increased in 1986-1987 and then declined in 1988-1989 (Fig. 4). Rainbow smelt biomass trends in Wisconsin and Michigan waters were similar to lakewide trends, but biomass in both states is now much lower than in 1978. Rainbow smelt biomass in eastern Ontario waters in 1989 was similar to that in U.S. waters, but was ten times higher in western Ontario waters and similar to abundance there in 1978.

The decline in rainbow smelt biomass is the result of high total mortality (Fig. 5). Mortality was low in 1978, increased through 1981, and stabilized at relatively high levels during 1982-1985. Despite these high levels of mortality, a succession of relatively strong year classes in 1983-1987 (Fig. 2) resulted in higher rainbow smelt biomass in 1986-1988 than in the preceding 5 years. A relatively weak year class in 1988 will not likely sustain this high biomass.

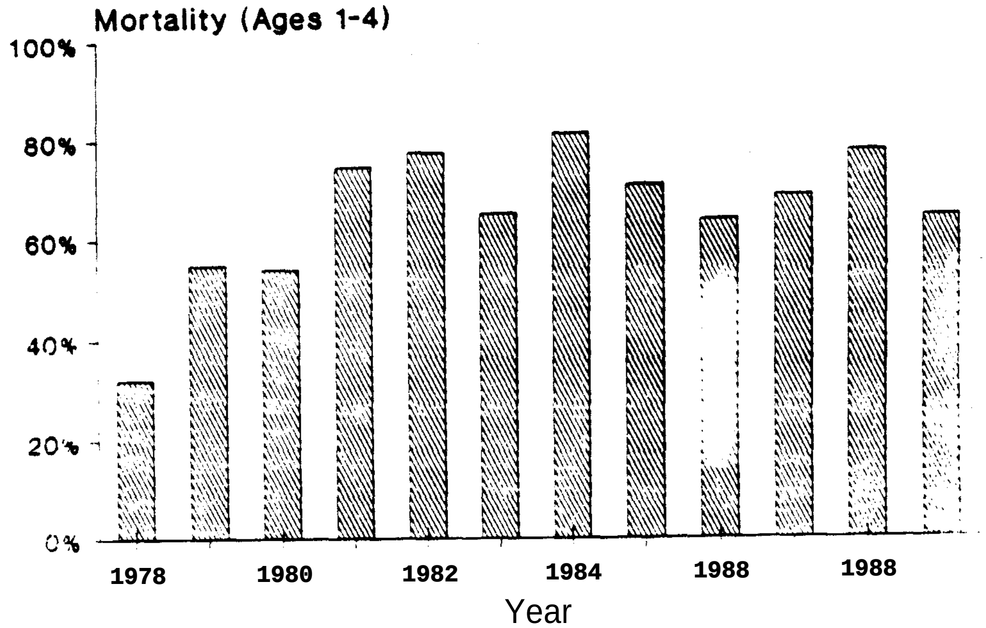

Figure 5. Total annual mortality of rainbow smelt in U.S. waters of Lake Superior, 1978-1989.

Other Species Abundance of deepwater **ciscos** declined substantially in Lake Superior through 1984 (MacCallum and Selgeby 1987). This trend continued through 1989, resulting in about a two-thirds drop in Michigan and Wisconsin waters over a 20-year period. The decline is thought to be related to increased predation by siscowet (deepwater form) lake trout, but the cause remains unknown. Three species of sculpin (slimy sculpin, Cottus cognatus; Spoonhead sculpin, Cottus ricei; and deepwater sculpin, ***Myoxocephalus thompsoni)*** are relatively abundant. These demersal species are eaten by young lake trout and are likely the major **forage** of siscowets.

sculpin biomass is greatest in Ontario waters, smaller by one-half in Michigan waters and smaller by one-fourth in Minnesota and Wisconsin waters. In U.S. waters, sculpin biomass declined by two-thirds from the 1970s to 1986-1989.

Lake Trout

The fishery objective for lake trout in Lake Superior is to achieve a sustained annual yield of 4 million pounds (1.8 million kg) from naturally reproducing stocks. Presently, the yield of lake trout to humans is 41.4% of that goal, though stocked fish contribute substantially to the yield in some areas. Sea lamprey predation amounts to 6.3% to 31.1% of the yield goal in U.S. waters and an unknown portion of the goal in Canadian waters (if sea lampreys had not become established, yields could be increased by these amounts).

Stocking Lake trout stocking in Lake Superior began shortly after the collapse of native stocks. Yearling lake trout were stocked almost continuously in Wisconsin waters since 1952, in Michigan waters since 1953, in Ontario waters since 1958, and in Minnesota waters since 1964 (Lawrie and Rahrer 1973, Great Lakes Fishery Commission 1985, Ebener 1989) (Fig. 6). By 1970, more than 28 million yearlings had been stocked in Lake Superior, of which 57% were stocked in Michigan waters, 22% in Ontario waters, 16% in Wisconsin waters, and 4% in Minnesota waters. An additional 1.6 million fingerlings were stocked in U.S. waters.

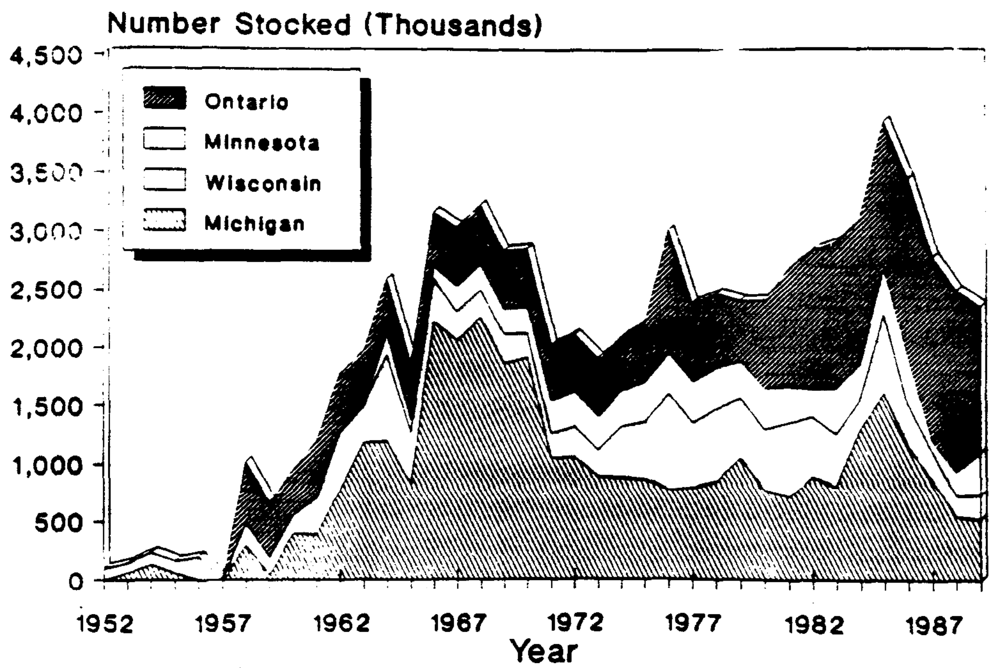

Figure 6. Lake trout stocking in Lake Superior, 1952-1989.

Lake trout stocking was relatively stable during 1970-1983, ranging from less than 2 million in 1973 to more than 3 million in 1976, and averaging 2.4 million (Fig. 6). However, stocking during 1984-1988 was higher and more erratic; increasing from 2.2 million in 1984 to nearly 3.6 million in 1985 then declining gradually to 2.3 million in 1988. Through 1983 nearly 60 million lake trout had been stocked as follows: 45% in Michigan waters, 27% in Ontario waters, 17% in Wisconsin waters, and 11% in Minnesota waters.

Changes in stocking rates in U.S. jurisdictions during 1970-1983 resulted from a belief that stocked fish would be protected from exploitation and would successfully mature and reproduce. Stocking rates in Michigan waters were reduced 50% in 1971. In Wisconsin waters, stocking was shifted during the 1970s from an area in the Apostle Islands of low survival and high reproductive potential to an area in western waters of high survival and low reproductive potential. Slow progress toward successful rehabilitation by the early-1980s encouraged fishery agencies to develop a comprehensive rehabilitation plan for lake trout.

The lake trout rehabilitation plan for Lake Superior, adopted by the Lake Superior Committee in March 1986 set forth a rational stocking policy to rebuild and maintain lake trout stocks. The lake was partitioned into management areas for. planning, establishing priorities, and reporting (Fig. 7). Management areas in U.S.

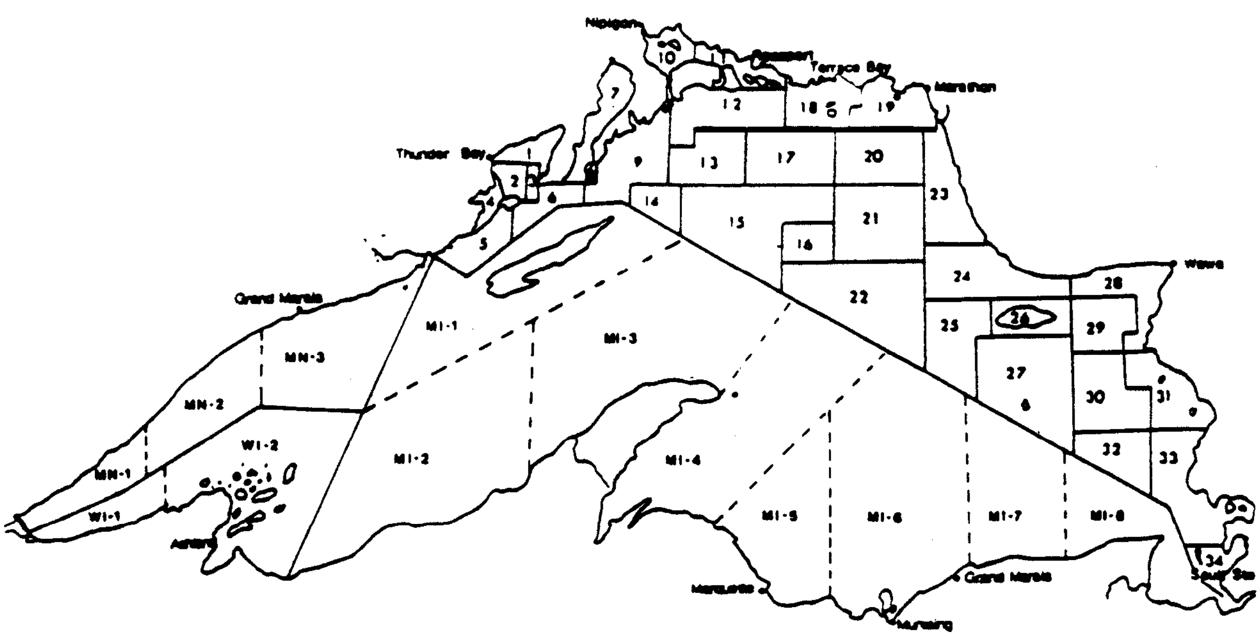

Figure 7. Lake Superior
lake trout management areas.

waters were modified from historic statistical reporting districts (Smith et al. 1961) while those in Canada were taken from an Ontario quota management plan, The plan recommended that yearling lake trout at a size of 18-25 per pound (40-55 per kg) and derived from wild strains that spawned in the stocking areas be stocked at 600-900 fish per $mile^2$ (232-347 per km^2) of lake trout habitat.

Area stocking priorities were based on the amount of quality lake trout spawning habitat, the historic production of lake trout, the current total annual mortality rate, and the recent degree of natural reproduction. Stocking rates were subsequently reduced for some management areas in Michigan and Wisconsin waters due to reduced survival of hatchery lake trout caused by intra-specific competition or predation. Stocking priorities were also revised due to changes in exploitation.

Stocking in some U.S. management areas during 1988-1989 has been below target levels because target levels exceeded hatchery capacity (Fig. 8). In Minnesota waters, all areas were stocked at target rates in 1989, but management areas MN-1 and MN-3 were stocked below target levels in 1988. In Wisconsin waters, only management area WI-2 was stocked in either year, and stocking was at or above the target rate only because the target rate was revised downward as a result of reduced survival of hatchery fish. In Michigan waters stocking occurred in most areas in 1988-1989; stocking was below target levels in MI-2 and MI4 and at or above target levels in MI-5 and MI-6.

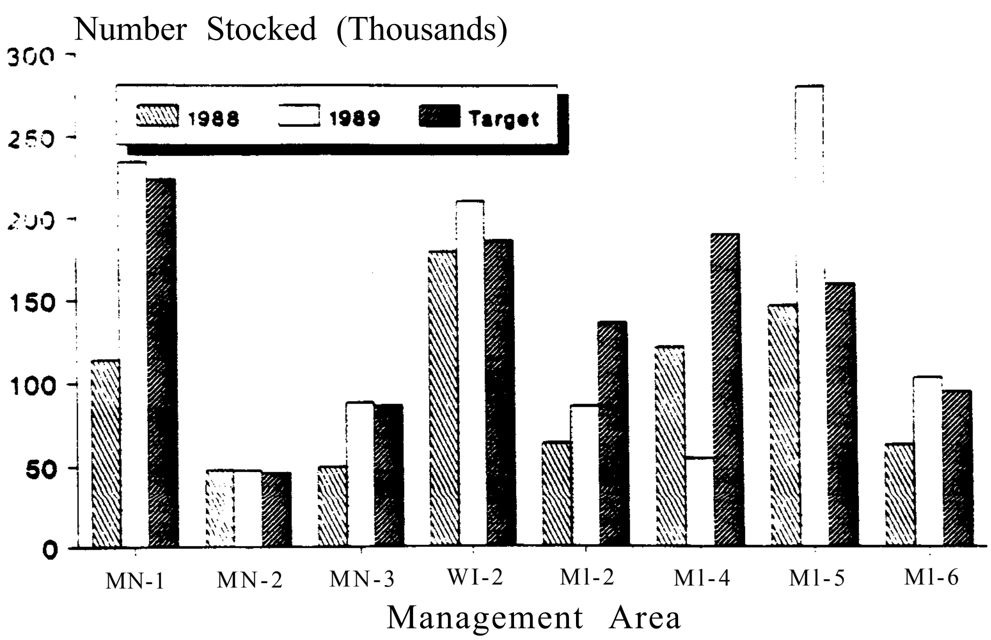

Figure 8. Lake trout stocking in U.S. management areas of Lake Superior, 1988-1989.

Relative Abundance Trends in relative abundance of lake trout in U.S. waters are developed from lake trout assessment fishing conducted by or for the various states. Catch data are from 4.5-inch (114-mm) extension measure gill nets except in Minnesota waters where nets in 1970-1984 included some 5.0-inch (126-mm), 5.5-inch (138-mm), and 6.0-inch (151-mm) mesh.

Generally, a number of lifts were made in each management area each year. Catch-per-unit-effort measurements (CPUEs) were adjusted to the number of fish caught per 3,281 feet (1,000 m) of multifilament gill net fished for one night, a conversion developed by the Lake Superior Technical Committee- Standardized CPUEs were distributed in a highly skewed fashion and were normalized by cube-root transformation. The transformed, standardized CPUEs were averaged across lifts within management areas and years. These average CPUEs were then averaged across management areas in each jurisdiction for wild and planted lake trout to display trends in relative abundance within each jurisdiction.

In Ontario waters, no comparable data on abundance are available. The Ontario Ministry of Natural Resources has historically tracked lake trout abundance by monitoring incidental commercial catches in inshore lake whitefish fisheries and in offshore targeted lake trout fisheries. Recent enforcement work has demonstrated sufficient misreporting of the lake trout catches to halt, at least temporarily, attempts to interpret trends in abundance.

In most Michigan waters of Lake Superior (MI-3 through MI-7), lake trout abundance generally declined in 1980-1989, primarily due to a decline in abundance of planted fish (Fig. 9). Abundance of planted lake trout peaked in 1970 and declined thereafter. Wild lake trout increased in abundance during 1970-1989 and increased rapidly in most areas in 1970-1980 as strong year classes of wild fish were recruited. However, even the strong recruitment of wild fish was not adequate to compensate for declining abundance of planted fish, and total abundance also declined after 1980. Abundance of wild lake trout in these waters now greatly exceeds the abundance of stocked fish. The abundance of planted lake trout in extreme eastern Michigan waters (MI-8) was comparatively low during the latter half of the 1970s, and wild lake trout remain scarce. Rehabilitation of lake trout in this management area has been deferred due to the presence of a large gill-net fishery for lake whitefish. Lake trout abundance in western Michigan waters (MI-2) has not been extensively monitored but generally follows the same pattern as in MI-3 through MI-7.

In eastern Wisconsin waters (WI-2), abundance of planted lake trout declined during the 1970s but remained relatively stable during the 1980s (Fig. 10). Abundance of wild lake trout has remained relatively stable throughout 1970-1989. Planted lake trout in these waters failed to reestablish self-reproducing populations on the numerous offshore spawning reefs typical of the area. As an alternative approach, eggs have been stocked on offshore reefs since 1980 to reestablish spawning lake trout; stocking of yearling lake trout has been continued primarily to maintain predation pressure on rainbow smelt and to deflect sea lamprey predation and fishing effort. Lake trout in western Wisconsin waters (WI-l) has only recently been monitored, but this effort suggests that planted fish are relatively abundant and wild fish are scarce.

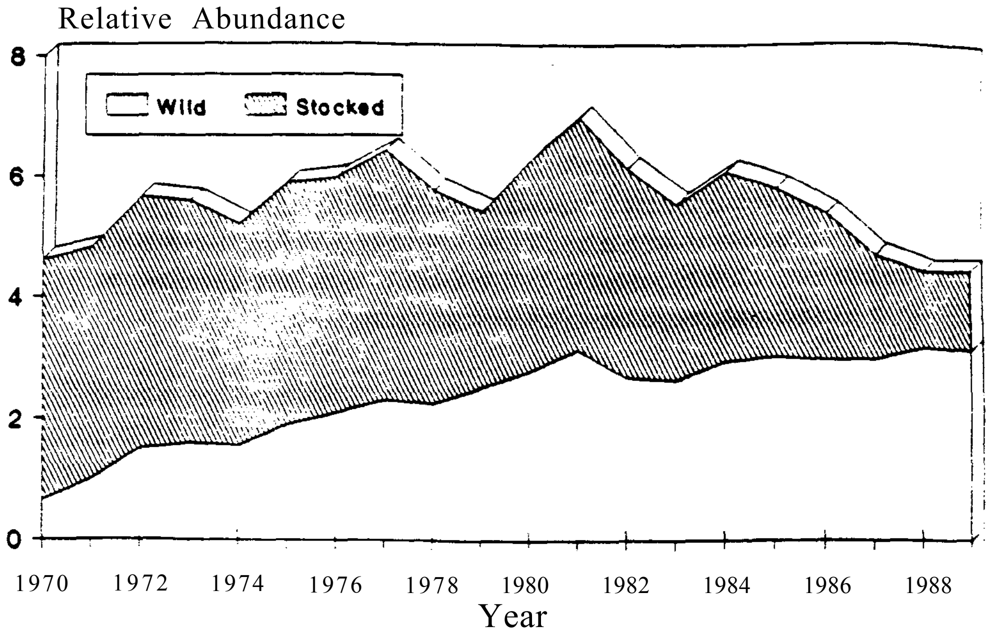

Figure 9. Relative abundance of lake trout in Michigan waters of Lake Superior, 1970-1989.

In Minnesota waters, abundance of wild and planted fish is combined (Fig. 11); however, the stocks are dominated by planted fish. Abundance has increassd strongly in both MN-2 and MN-3 during 1970-1989. Current levels of abundance are relatively high in both areas. More recent data from MN-1 suggest that abundance is lower and relatively stable.

Lake trout have not been stocked in the waters around Isle Royale (MI-l). Stocks there recovered rapidly following the onset of sea lamprey control. Offshore stocks of siscowet, a race of lake trout that inhabits deep water (250-700 ft, 76-213 m) and has a fat content of 20-80%, also recovered rapidly following the onset of sea lamprey control. Siscowet are apparently increasing in abundance in most areas of Lake Superior and are becoming more important in commercial catches.

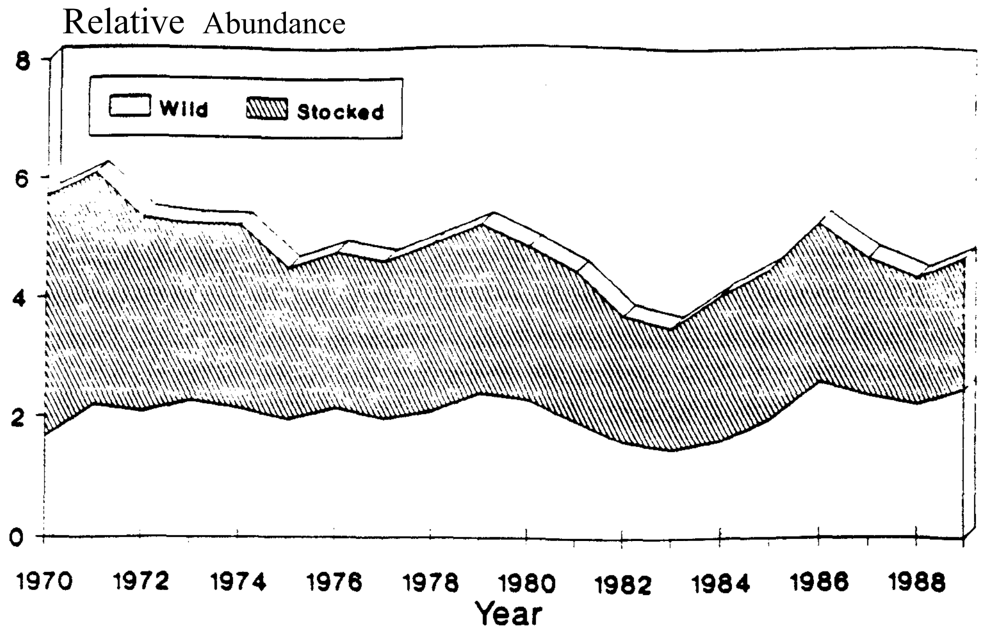

Figure 10. Relative abundance of lake trout in Wisconsin waters of Lake Superior, 1970-1989.

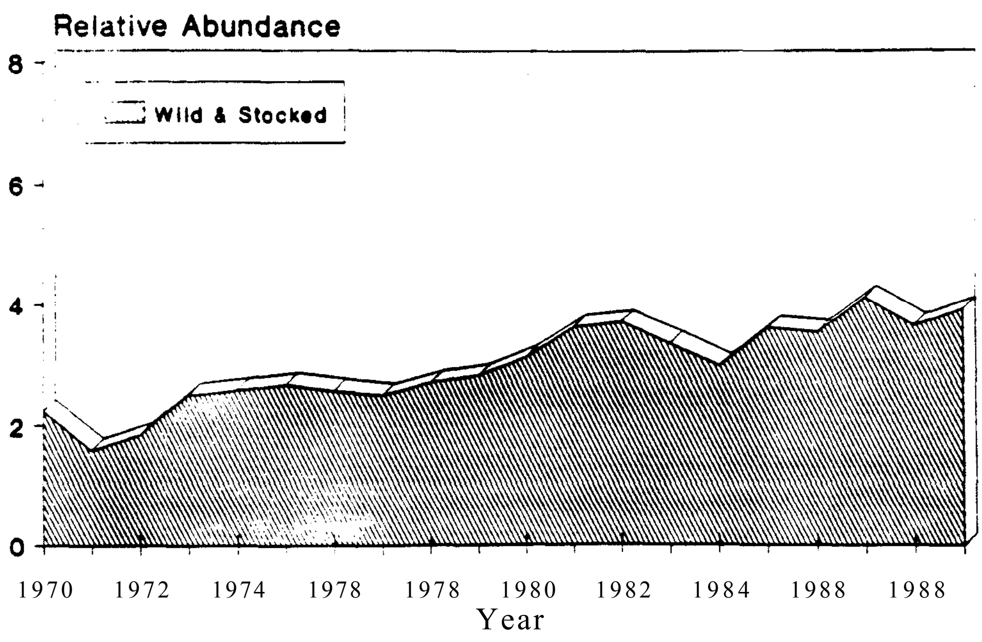

Figure 11. Relative abundance of lake trout in Minnesota waters of Lake Superior, 1970-1989.

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 4.5-inch (114-) gill net. The target mortality rate calculated in this way is 50%, and approximates an actual mortality rate of about 42% (Lake Superior Lake Trout Technical Committee 1986). In recent years age 8-12 lake trout were employed in the calculation because age-7 fish were not fully recruited.

mortality rates of wild lake trout for Ontario waters are available only for 1985-1988 and for management areas near Thunder Bay (area 11, Black Bay (area 7), Wawa (area 28), and Sandy Island (area 33). These mortality rates generally exceeded the target rate, but were declining during 1985-1988 (Fig. 12). The catch of lake trout in these areas is restricted by use of by-catch quotas for the lake whitefish fisheries.

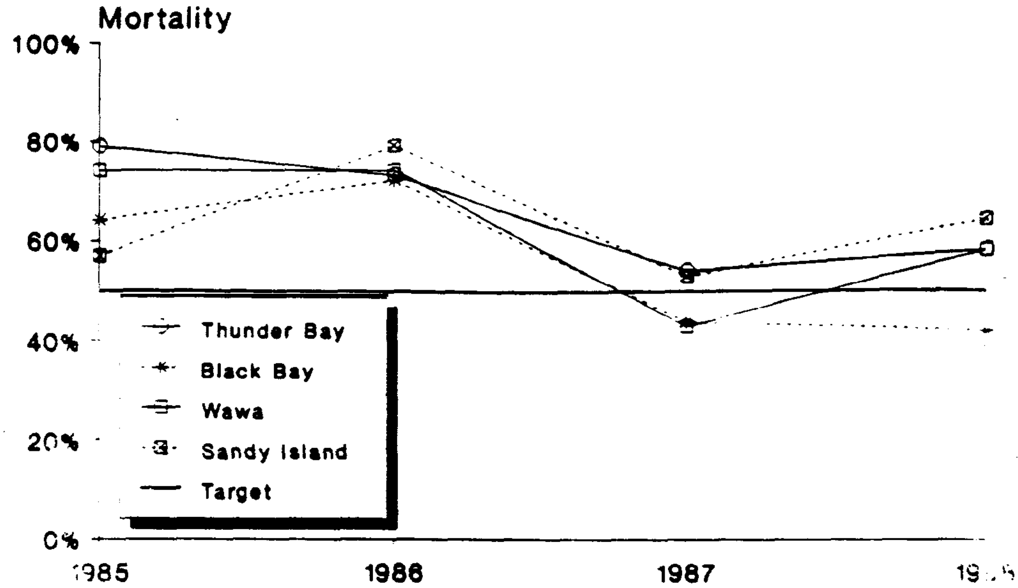

Figure 12. Lake trout mortality in selected Ontario waters of Lake Superior, 19851988.

In Michigan waters, mortality of wild lake trout generally exceeded the target rate during 1970-1989, but mortality of stocked fish was generally lower (Fig. 13). Average mortality of wild lake trout exceeded the target rate every year during 1970-1989 except for 1970, 1979 and 1980. This overshoot is partly due to increasing recruitment, which biased the estimates upward. The Lake Superior Technical Committee is currently evaluating methods to correct for recruitment trends. In contrast, abundance of stocked lake trout was not corrected for declining stocking rates, which deflates estimates of true mortality. Average mortality of stocked fish has been below the target rare each year since 1978 except for 1984 and 1985. Thus, actual mortality of both wild and stocked lake trout is closer to the target rate than indicated; mortality of wild fish is lower, while mortality of stocked fish is higher.

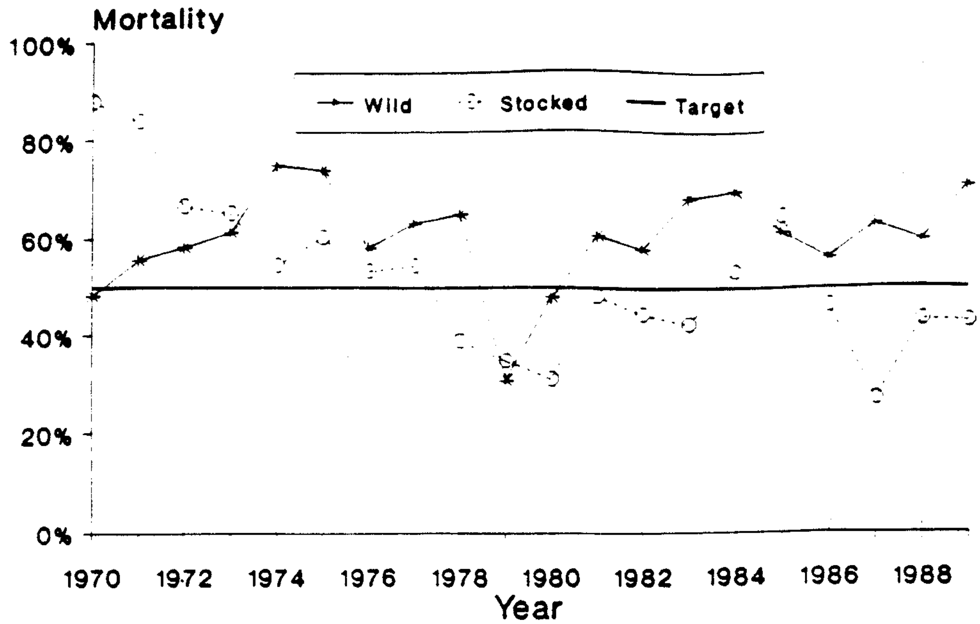

Figure 13. Lake trout mortality in Michigan waters of Lake Superior, 1970-1989.

In eastern Wisconsin waters (WI-2), mortality general;:: exceeded the target rate throughout 1970-1989 for both wild and planted fish, though it has been below the target since 1987 for wild fish and since 1988 for hatchery fish (Fig. 14). This apparent decline in mortality may be due to a change from scales to otoliths for age determination. Further examination of the effects of this change in aging will be completed in the future. Mortality in western Wisconsin waters (WI-l) was estimated only for 1987-1988. Mortality rates in WI-1 were higher for wild lake trout than for planted lake trout in both 1987 (57% vs. 39%, respectively) and in 1988 (43% vs. 40%, respectively) and are generally similar to those in adjacent western Minnesota waters (MN-1).

In Minnesota waters, mortality rates are available only for planted lake trout in western waters (MN-1) during 1982-1988, and in central (MN-2) and eastern (MN-3) during 1974-1988. Lake trout mortality is lowest in MN-1 and has remained at or below the target level during 1982-1989 (Fig. 15). In MN-2 and MN-3, mortality was higher and well above the target rare in the 1980s, and fell below the target only in 1989. Mortality exceeded the target rare each year since 1984 in MN-2 and each year since 1982 in MN-3. However, in 1989, mortality in both areas fell below the target due to recruitment of fish from increased plantings in previous years.

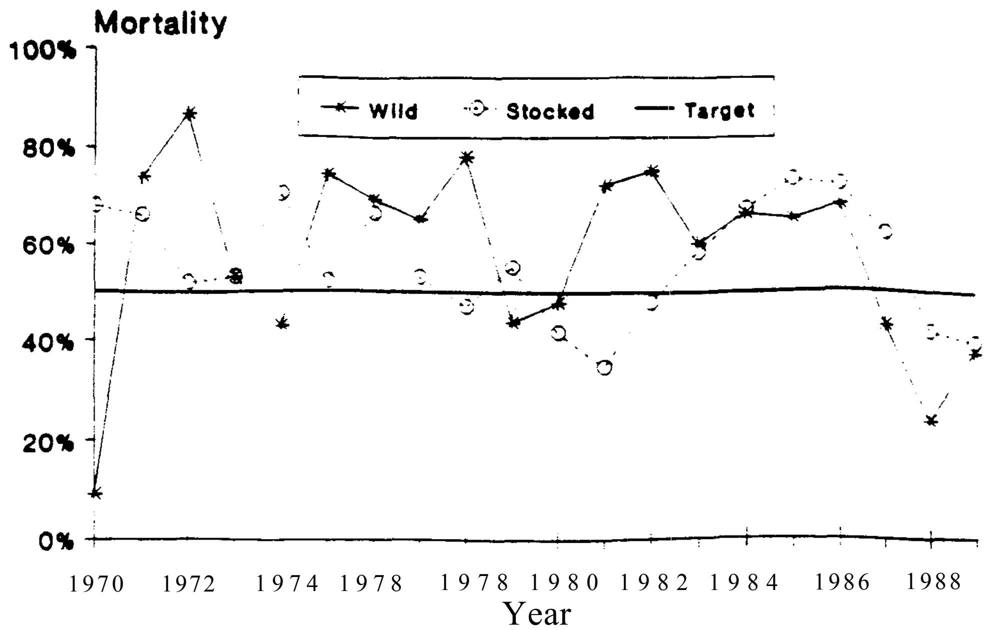

Figure 14. Lake trout mortality
in Wisconsin waters
of Lake Superior, 1970-1989.

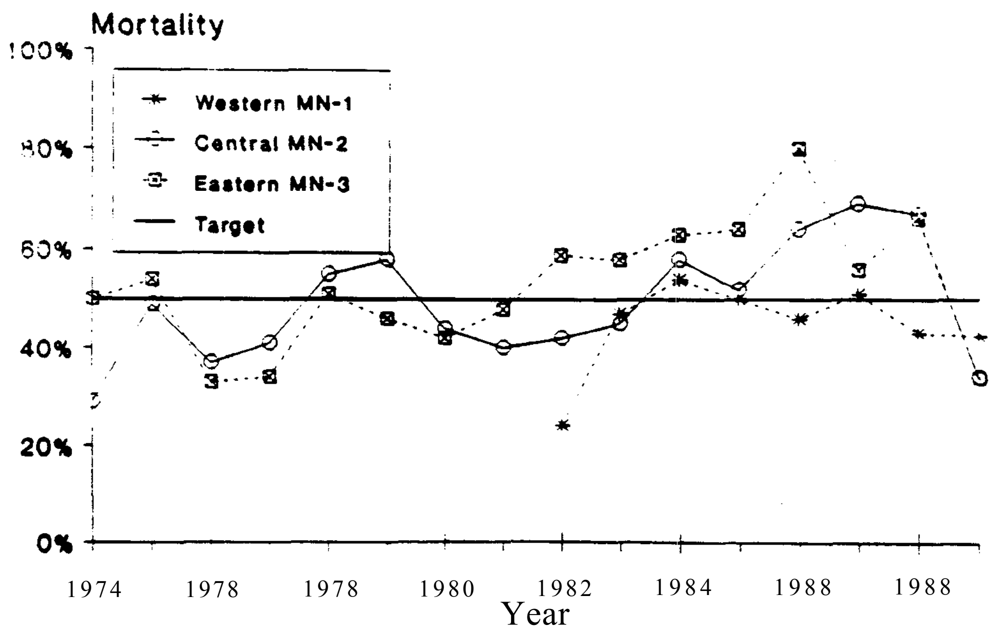

Figure 15. Lake trout mortality
in Minnesota waters
of Lake Superior, 1974-1989.

Growth Lake trout growth can be expressed in a variety of ways, most of which require either aging or back-calculation. The Lake Superior Technical Committee expresses growth as the mean length of age-7 lake trout taken in assessment fisheries in U.S. waters and in commercial fisheries In Ontario waters. Although a number of factors could affect this expression of growth, it is the only measure available across nearly all areas and years that incorporates the lifetime growth history of the fish. However, in certain areas where fisheries have increased, length-at-age may be suppressed by selective harvest of faster growing individuals.

In Ontario waters, growth rates during 1981-1986 were slower than in the U.S. (age-7 lake trout were considerably smaller than those in Michigan, Wisconsin, or Minnesota waters) (Fig. 16). However, mean length in Ontario waters increased sharply in 1987-1988 and is now about the same as in U.S. waters.

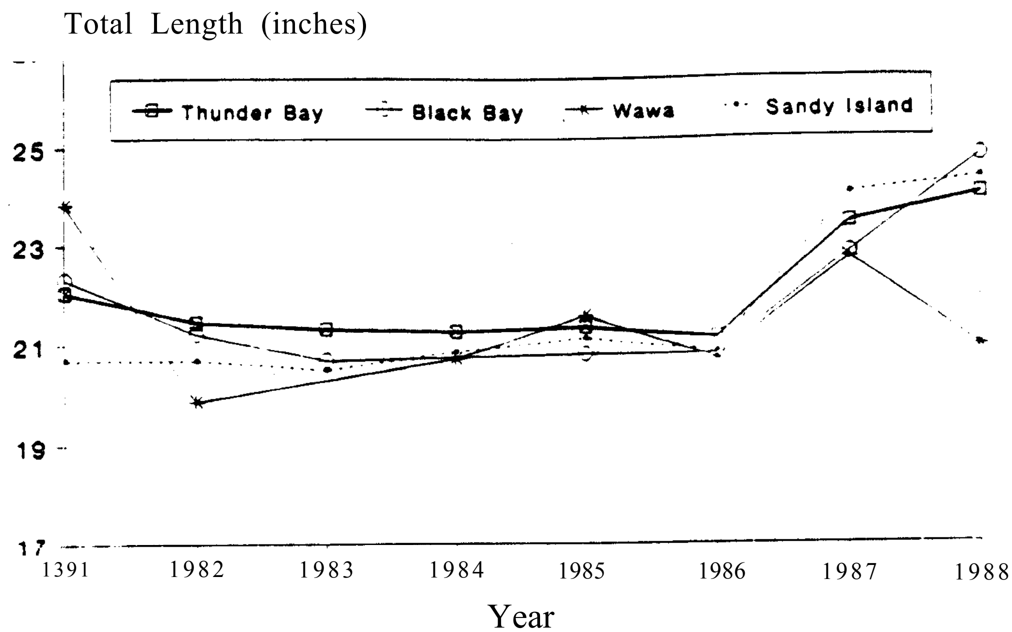

Figure 16. Length of age-7 lake trout in selected Ontario waters of Lake Superior 1981-1988.

In Michigan waters, mean length of age-7 lake trout declined during the 1980s for both wild and stocked fish (Fig. 17). For wild trout, growth declined during 1970-1974, increased during 19751979, and declined again during 1980-1989. For hatchery trout, growth declined gradually during 1970-1989 and was only interrupted by an increase during 1977-1979.

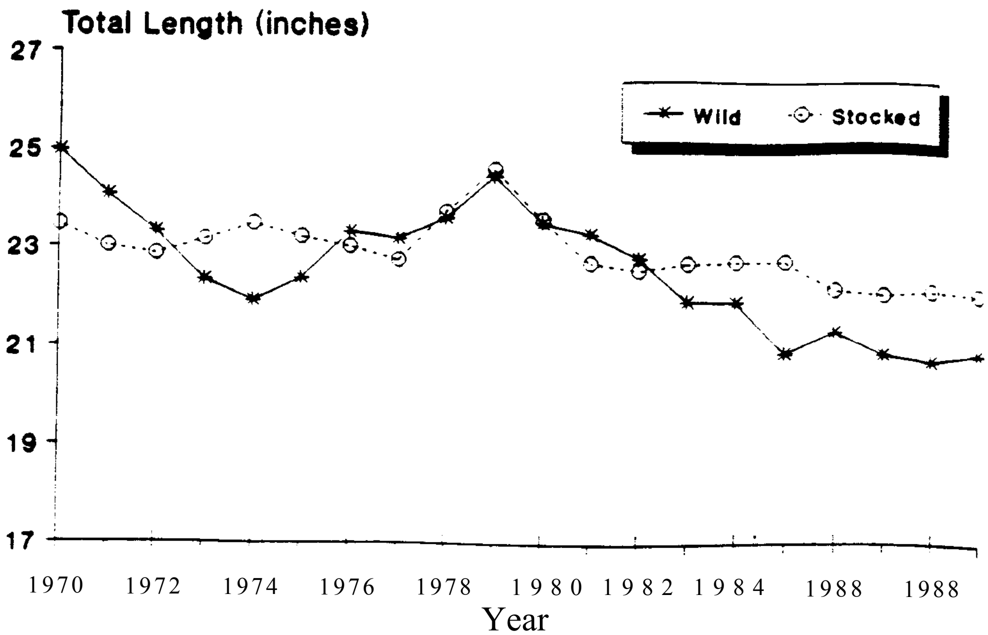

Figure 17. Length of age-7 lake trout
in Michigan waters of
Lake Superior, 19704989.

During the early-1970s, lake trout in Michigan waters were generally larger than in Minnesota and Wisconsin waters, but by the late 1980s trout in Michigan waters were smaller. In Wisconsin waters, average length of age-7 trout declined more gradually than in Michigan waters (Fig. 18). Also, growth of wild lake trout was generally better, yet more erratic, than that of stocked fish, and growth of wild fish fell below that of stocked fish during 1987-1989.

In Minnesota waters, data on average length of age-7 lake trout were available only for 1971-1979 and for 1988-1989, and in these points growth rates were stable (Fig. 19). As more data become available, patterns of lake trout growth in Minnesota waters may become apparent.

As an index of growth, average length of age-7 lake trout mirrors the cumulative feeding history of lake trout on available forage. The amount of available forage is in turn dependent on both the biomass of the various forage species and on the numbers of competitors present. Recent analyses of predator diets indicated that: 1) even in areas where lake herring are more abundant, the species of fish preferred as prey by lake trout and other salmonid predators was rainbow smelt and 2) diets of inshore lake trout most strongly overlapped with those of chinook salmon (Oncorhynchus tshawytscha). Declines in growth, particularly in, Michigan waters, parallel declines in rainbow smelt biomass.

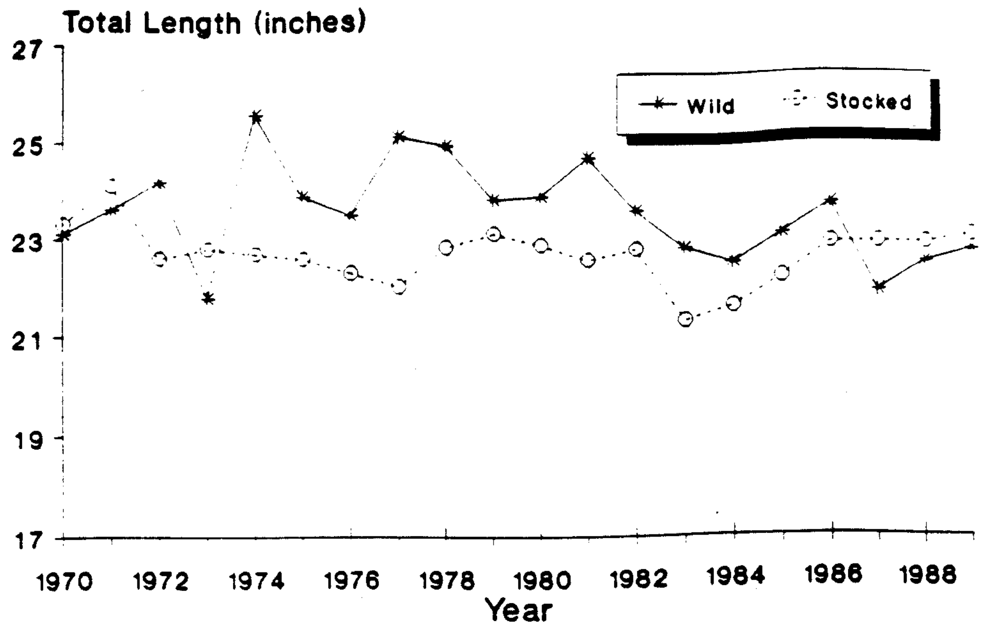

Figure 18. Length of age-7 lake trout
in Wisconsin waters of
Lake Superior, 19704989.

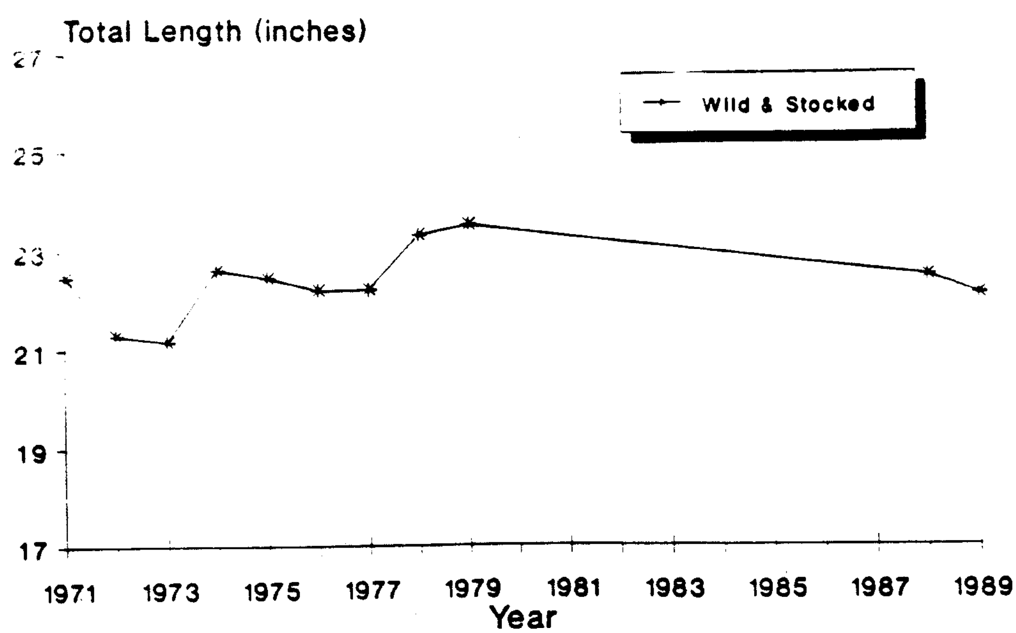

Figure 19. Length of age-7 lake trout
in Minnesota waters Of Lake Superior,
1971-1979, 1988-1989.

Sea Lamprey Wounding in recent years, sea lamprey wounding rates (percent wounded) varied greatly between eastern and western U.S. waters. Sea lamprey wounding rates on lake trout during 1986-1989 were 1.5 to 5.9 times greater in waters west of the Keweenaw Peninsula than in waters east of the Keweenaw Peninsula (Table 2). These data indicate a higher abundance of parasitic-phase sea lampreys in western U.S. waters.

Table 2. Average number of sea lamprey wounds Per 100 lake trout ≥ 17 inches (43 cm) TL in waters West (areas MN-1 through MI-2) and east (areas MI-4 through MI-7) of the Keweenaw Peninsula, Lake superior, 1986-1989.

Area	1986	1987	1988	1989
West of Keweenaw	6.3	8.5	8.9	7.8
East of Keweenaw	4.1	2.5	1.5	8.8

Trends in sea lamprey wounding rates during 1970-1989 varied among jurisdictions during 1970-1989. In Michigan waters, wounding rates on ail sizes of lake trout were highest during 1971-1973, lower during 1974-1988, and higher again in 1989 (Fig. 20). In 1988, wounding rates reached their lowest point in 18 years.

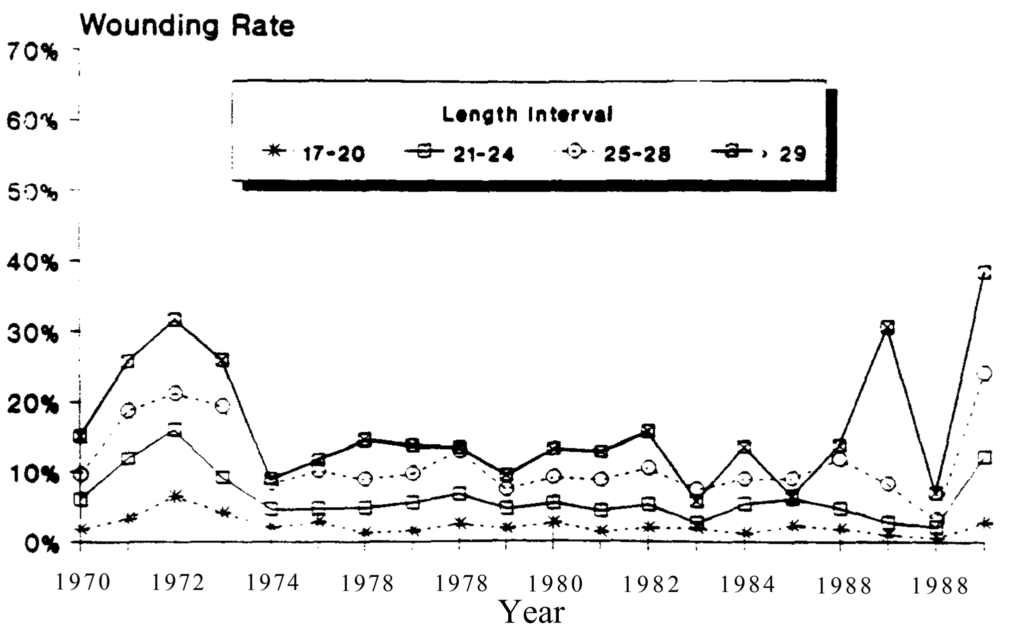

Figure 20. Sea lamprey wounding rates on lake trout in Michigan waters of Lake Superior, 1970-1989.

Wounding rates in U.S. waters were generally the lowest in Wisconsin (Fig. 21). Wounding rates of lake trout in Wisconsin waters declined erratically during 1970-1984 but generally increased across all sizes of lake trout during 1985-1989. In 1987-1989, wounding rates of all lengths of fish between 21-28 inches (53-71 cm) were typically higher than during the previous 13-18 years.

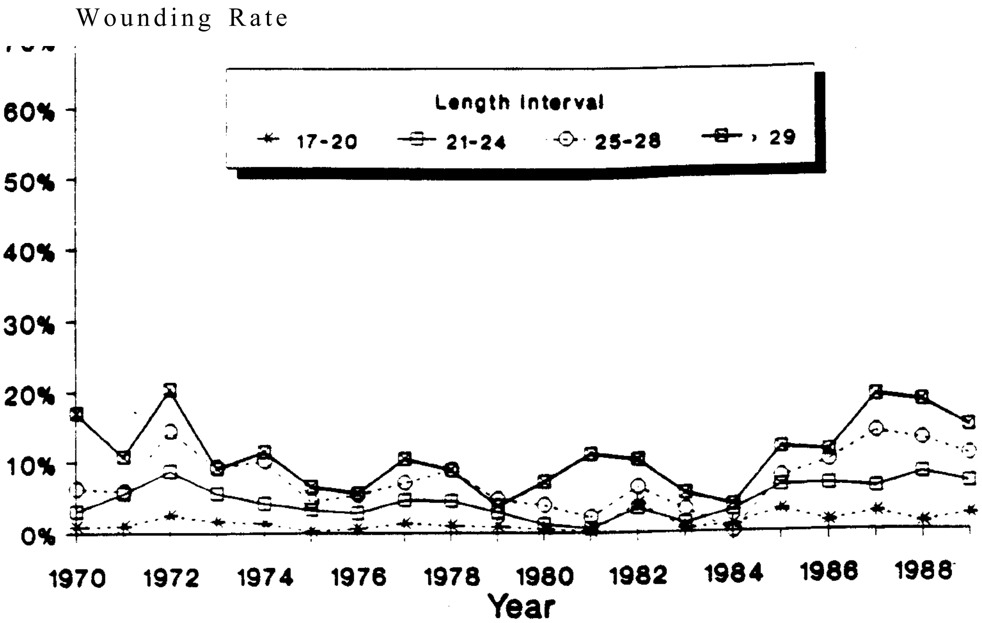

Figure 21. Sea lamprey wounding rates on lake trout in Wisconsin waters of Lake Superior, 1970-1989.

Wounding rates in Minnesota were higher than in any other area of U.S. waters (Fig. 22) Wounding rates of 17-28 inch (43-71 cm) lake trout in Minnesota waters declined during 1971-1988 and increased substantially in 1989. Wounding rates of 29-inch (74 cm) and larger trout declined from 1971-1980 and stabilized thereafter.

Based on statistical relationships between the number of wounds per fish and the probability (P) of a lake trout surviving a single sea lamprey attack, sea lamprey-induced mortality was estimated for two management areas in U.S. waters of the lake. P = 0.17 was derived from empirical data (Koonce and Pycha 1989) and P = 0.38 from a laboratory study (Swink and Hanson 1986). Sea lamprey-induced mortality varies by a factor of three, depending upon the value used for the probability of survival. If P = 0.17, sea lamprey-induced mortality ranged from 9% to 41% in Michigan waters west of the Keweenaw Peninsula (MI-3) and 11% to 53% in Michigan waters east of the Keweenaw Peninsula (MI-4) (Table 3). In contrast, if P 0.38, sea lamprey-induced mortality ranged from 3% to 16% in MI-3 and 4% to 22% in MI-4.

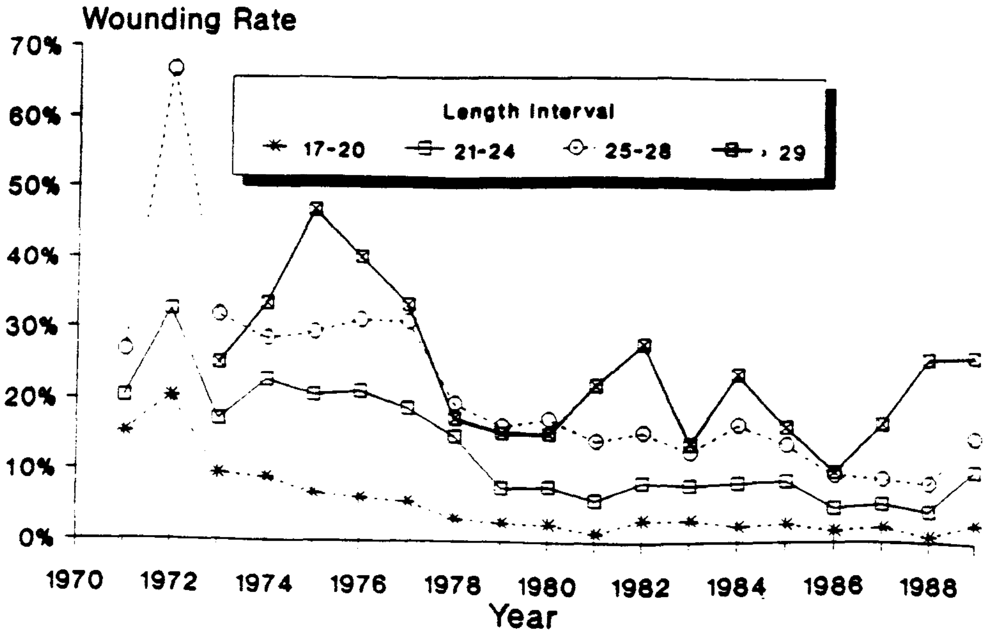

Figure 22. Sea lamprey wounding rates on lake trout in Minnesota waters of Lake Superior, 1971-1989.

Table 3. Estimated instantaneous, sea lamprey-induced mortality on lake trout by size and age in two management areas of Lake Superior, 1970-1988.

Group	Management Area, MI-3 P=0.38	P=0.17	Management Area, MI-4 P=0.38	P=0.17
Size class (inches)				
17-20	0.030	0.093	0.040	0.122
21-24	0.075	0.225	0.100	0.298
25-28	0.122	0.366	0.185	0.552
>28	0.176	0.527	0.254	0.757
Age class (years)				
4	0.045	0.137	0.057	0.172
5	0.066	0.200	0.081	0.244
6	0.066	0.200	0.086	0.257
7	0.092	0.276	0.116	0.348
8	0.116	0.348	0.142	0.425
9	0.126	0.378	0.142	0.422
10	0.133	0.39.7	0.167	0.497
11	0.167	0.500	0.231	0.690
12	0.170	0.508	0.231	0.689
13	0.176	0.527	0.254	0.757

Extractions The fishery objective for lake trout in Lake Superior is to achieve sustained annual yield (human extraction) of 4 million pounds (1.8 million kg) from naturally reproducing stocks (the 1929-1943 average annual harvest). To measure progress in achieving this goal lake trout yields were summarized for 1984-1989 for each jurisdiction. In 1988-1989, inshore and offshore races of lake trout were included in lake trout yields for U.S. waters; yield estimates for Ontario waters have always included all races. The total reported yield of lake trout in 1989 was 1,457,000 lbs (661,600 kg), which amounts to 36.4% of the Lake Superior goal (Fig. 23). Yield from Ontario waters in 1989 was 23.1% of the 19291943 average annual yield from these waters (1,399,000 lbs; 634,600 kg), while yield from U.S. waters was 38.3% of the 1929-1943 average annual yield from these waters (2,964,500 lbs; 1,344,700 kg).

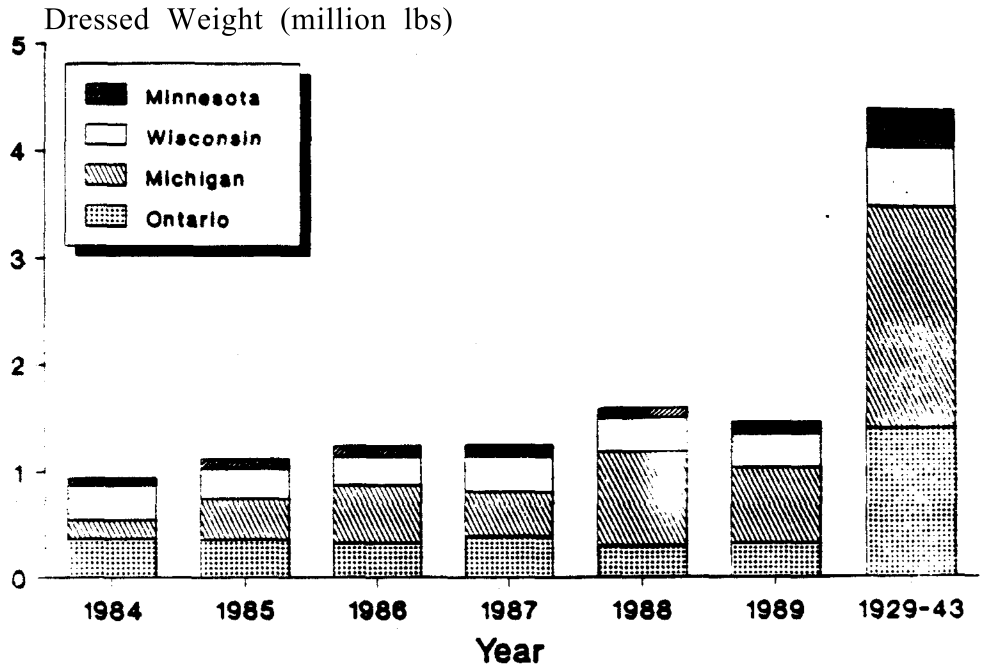

Figure 23. Yield of lake trout from Lake Superior, 1984-1989.

Based on mark-recapture surveys, the average number of parasitic-phase sea lampreys in U.S. waters was 44,700 during 1986-1989. Also, based on an analysis of sea lamprey-induced mortality on lake trout in eastern Wisconsin waters, the estimated weight of lake trout killed each year by each sea lamprey was 1O-20 lbs (459.1 kg). Thus, the average range of lake trout extraction by sea lampreys was 385,000-770,000 lbs (96,200-349,600 kg) each year in U.S. waters during 1986-1989 (Fig. 24) or 13-26% of the 1929-1943 average annual yield from U.S. waters. Assuming that each sea lamprey killed 20 lbs (9.1 kg) of lake trout in 1989, the total annual extraction by humans and sea lampreys in U.S. waters was 2,236,000 lbs (1,015,100 kg) or about 75.4% of the 1929-1943 average annual yield.

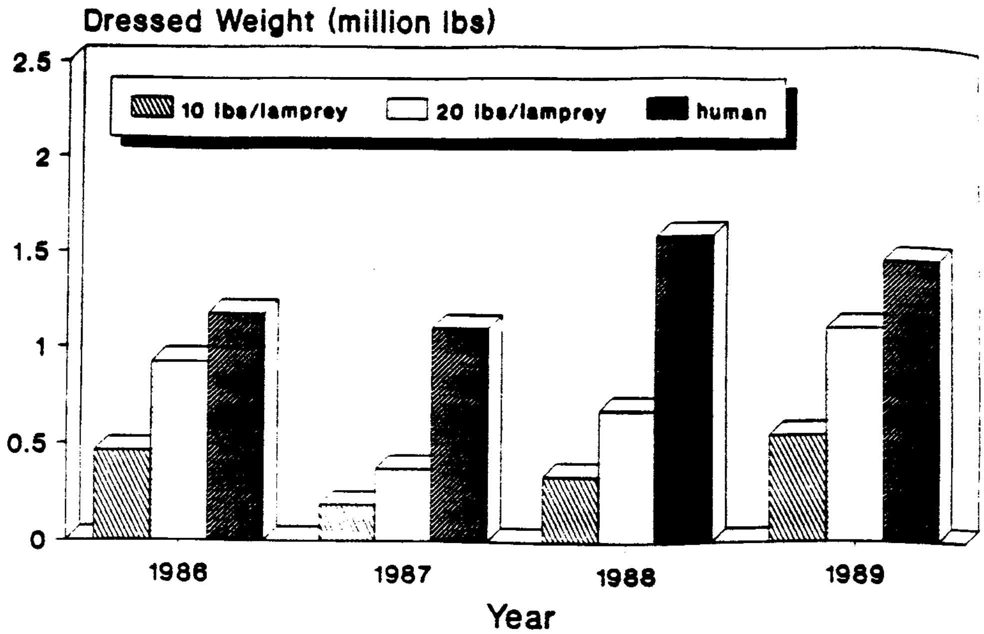

Figure 24. Pounds of lake trout killed by sea lamprey and humans in Lake Superior, 1986-1989.

The great majority (86.2%) of sea lampreys in U.S. waters (47,500 sea lampreys) Here estimated to occur west of the Keweenaw Peninsula in 1933. The extraction by humans during 1989 was 49.9% of the 1929-1943 average annual catch from these waters, and assuming sea lampreys fed in these waters, predation amounted to an additional 29.2-58.4%. Thus, the combined annual lake trout extraction by humans and sea lampreys in U.S. waters west of the Keweenaw Peninsula was 79.1-108.3% of historic catch levels. Because sea lamprey predation may now equal or exceed human extractions in U.S. waters west of the Keweenaw Peninsula, sea lamprey control efforts should be focused in this area of the lake.

Other Salmonid Predators

The fishery objective for other salmonid predators in Lake Superior is to sustain an unspecified yield that maintains a predator-prey balance and allows normal growth of lake trout. During 1984-1987, yield of other salmonid predators was less than 13% of the total yield of ail predators (Busiahn 1990). As noted previously, however, lake trout growth rates are presently declining in some areas of Lake Superior, particularly in Michigan waters. It is unclear whether other salmonid predators are presently abundant enough to be the primary cause for declining lake trout growth. The level of natural reproduction for many of these species is unknown. To assess the abundance of one important competitor, lakewide fin-clipping of all chinook salmon stocked in Lake Superior in 1988-90 was conducted. Evaluations of predator-prey dynamics in Lake Superior will be undertaken using bioenergetics models.

The status of other salmonid predator stocks is routinely assessed by creel surveys, Creel surveys were conducted in Minnesota and Wisconsin waters annually since 1969. Creel surveys were also conducted in Michigan waters during 1984-1986 at Marquette and during 1987-1988 lakewide. Creel surveys were not generally conducted in Ontario waters though catch data from the Wawa Salmon Derby, a three-day contest in late-August, provided an index of catch statistics for chinook salmon. In addition to creel surveys, a sea lamprey barrier and fish ladder was completed on the Brule River, Wisconsin, in 1986 and has been used to census runs of anadromous salmonids since that rime.

Rainbow (Steelhead) Trout Anadromous rainbow trout, also called steelhead (Oncorhynchus mykiss), became widely distributed after being introduced in Lake Superior in 1895 (MacCrimmon 1971). By the 1950s, steelhead were found in 88 of Michigan's 120 Lake Superior tributaries (Moore and Braem 1965). Steelhead also became naturalized in many of Wisconsin's (Wisconsin Department of Natural Resources 1988) and Minnesota's (Hassinger et al. 1974) tributary streams. The Brule River typically contributes 65% of all wild steelhead harvested in Wisconsin waters. The original introduction of steelhead was of uncertain origin but more recently several varieties of steelhead have been introduced, including the Siletz in 1984 and Skamania in 1986-1989 in Michigan waters and the Kamloops, Madison, and Donaldson in 1972, in Minnesota waters (Close and Hassinger 1981). Wild steelhead populations in Lake Superior now exhibit significant generic differentiation among populations from different drainages and from within the Brule River drainage (Krueger and May 1987a).

Steelhead typically enter spawning streams from late fall to late spring, though the Siletz and Skamania strains are summer-run, returning as early as July. Steelhead runs in the Brule River, Wisconsin, peak in late-October and again in mid- to late-April; fall runs ranged from 4,714 to 6,459 fish during 1986-1989 and spring runs ranged from 1,432 to 1,589 during 1987-1989 (Fig. 25). The bulk of the spawning runs in Lake Superior tributary streams occurs from April through May (Biette et al. 1981), though Kamloops strain rainbow trout congregate off of rivers in early winter and enter earlier in spring than do wild steelhead. Wild juveniles of all strains generally remain in natal streams 1-3 years, migrate to Lake Superior during May-June, and return to spawn 1-3 years later.

During 1984-1988, numbers of yearling rainbow trout planted ranged from 117,000 co 204,000 in' Michigan waters and from 173,000 to 379,000 in Minnesota waters. Fingerlings were not routinely stocked by any agency, but 2.6 to 4.2 million fry were stocked annually in Minnesota waters during 1984-1988. Rainbow trout

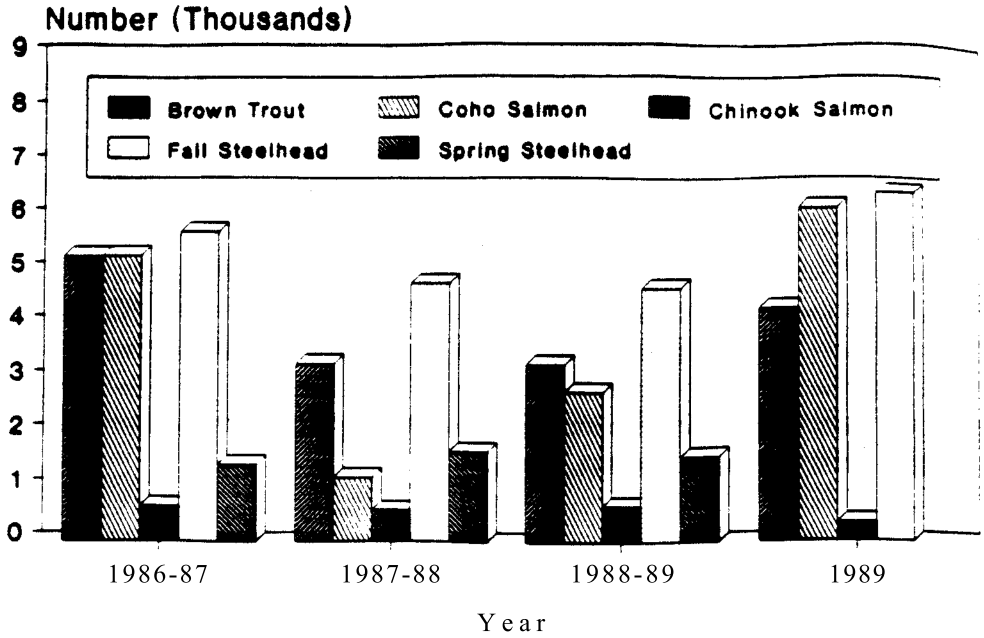

Figure 25. Spawning runs of trout and salmon in the Brule River, Wisconsin, 1988-1989.

have not been stocked in Wisconsin waters since 1985, but production of steelhead from wild Brule River parents was begun in 1988. Plants of yearling rainbow trout in Lake Superior generally provided a return to the creel of less than 1% and made little contribution to spawning populations (Wagner and Stauffer 1978). An exception has been the Chocolay River, Michigan, where returns from a plant of Siletz-strain summer steelhead was about 2% and plants of Lake Michigan strain steelhead contributed substantially to spawning runs. Harvest of steelhead during 1984-1988 averaged 738 fish in Michigan waters, 502 in Wisconsin waters, and 583 in Minnesota waters (Fig 26). Most steelhead are harvested in the tributary streams either as juveniles or spawning-run adults.

Runs of steelhead in the Brule River, Wisconsin, were less during 1986-1989 (Fig. 25) than the estimated sport harvest during 1978-1979 (Scholl et al. 1984). Similar declines in steelhead abundance have been reported by anglers in Michigan and Minnesota, though the declines have not always been evident in creel surveys. For example, steelhead harvest from the Big Huron River, Michigan, in 1988-1989 was lower than that estimated in 1973; however, greater fishing effort in 1973 produced similar catch rates. Nonetheless, the 60% reduction in fishing effort in the Big Huron River from 1973 to 1989 may indicate a decline in steelhead production.

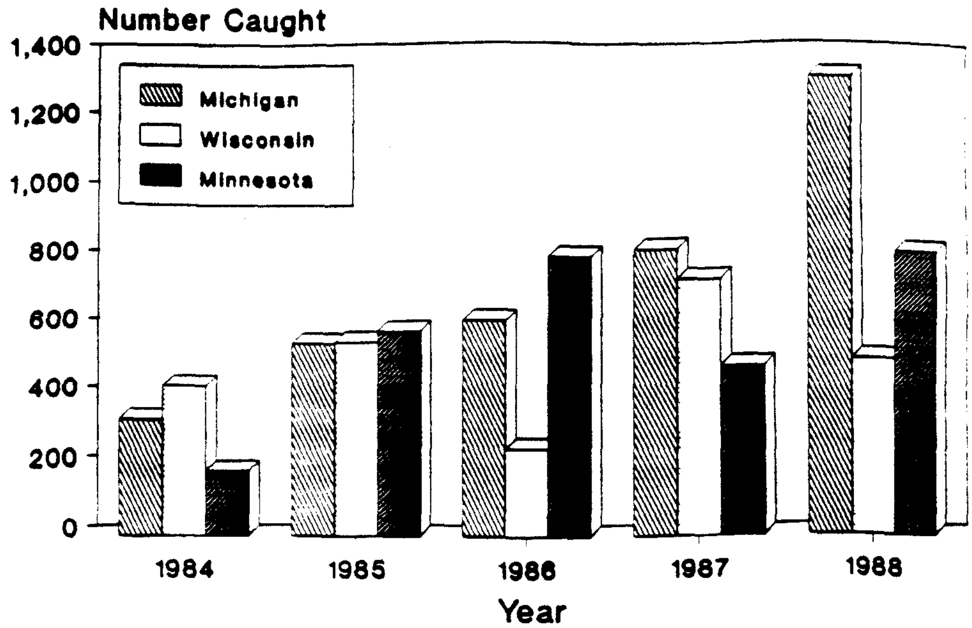

Figure 26. Rainbow trout sport catch from selected U.S. waters of Lake Superior, 1984-1988.

<u>Coho Salmon</u> Coho salmon *(Oncorhynchus kisutch)* were first planted in Lake Superior in 1966 by the State of Michigan. Coho salmon were subsequently planted in Ontario and Minnesota waters during 1969-1972 (Hassinger 1974). At present, coho salmon are planted only in Michigan waters of Lake Superior at an annual rate of about 325,000. Initial plantings by the State of Michigan strayed extensively and reproduced in many Lake Superior tributaries (Peck 1970). More recently, fin-clipped coho salmon stocked near Marquette, Michigan, strayed to Wisconsin and Minnesota waters of Lake Superior, Wisconsin and Michigan waters of Lake Michigan, and Ohio waters of Lake Erie.

Natural reproduction of coho salmon occurred in all five Lake Superior streams in Michigan studied by Stauffer (1977), and smolt production in 1968 approached that in good West Coast coho salmon streams (Peck 1970). In Wisconsin streams successful spawning, first documented in 1968, now occurs in 49 tributaries within 18 watersheds (Wisconsin Department of Natural Resources 1988). Reproduction in Minnesota streams is limited due to unsuitable habitat. It is very likely that coho salmon reproduce in all Lake Superior tributaries with suitable spawning substrate that are accessible during the spawning period. Coho salmon enter tributaries from September through March and spawn mostly during October. Runs in the Brule River, Wisconsin, peaked from late-September to late-October and ranged from 1,188 to 6,173 individuals during 1986-1989 (Fig. 25). Juvenile coho salmon usually migrate to Lake Superior as yearlings, but a few remain in streams an extra year. Wild coho salmon populations are widespread and, if not increasing, appear to remain plentiful in most waters.

Evaluation of fin-clipped coho salmon plants in Michigan waters indicated that more than 90% of the fish caught near Marquette (Mi-5), the major planting site, were naturally produced (Marquette Fisheries Station, unpublished). Average number of coho salmon harvested in 1984-1988 in Michigan (15, 151), Wisconsin (10,568), and Minnesota (4,077) waters ranks either first or second behind lake trout, indicating their importance in the Lake Superior sport fishery (Fig. 27). Most coho salmon are caught in late winter and early spring when they concentrate inshore at bay and river mouths; far fewer are caught in the fall as mature fish in the tributaries. In Wisconsin waters, harvest of coho salmon in 1988 exceeded that of lake trout for the first time. Coho salmon average 1-2 lb (0.5-0.9 kg) in weight in the spring and 3-4 lb (1.4-1.8 kg) in the fall.

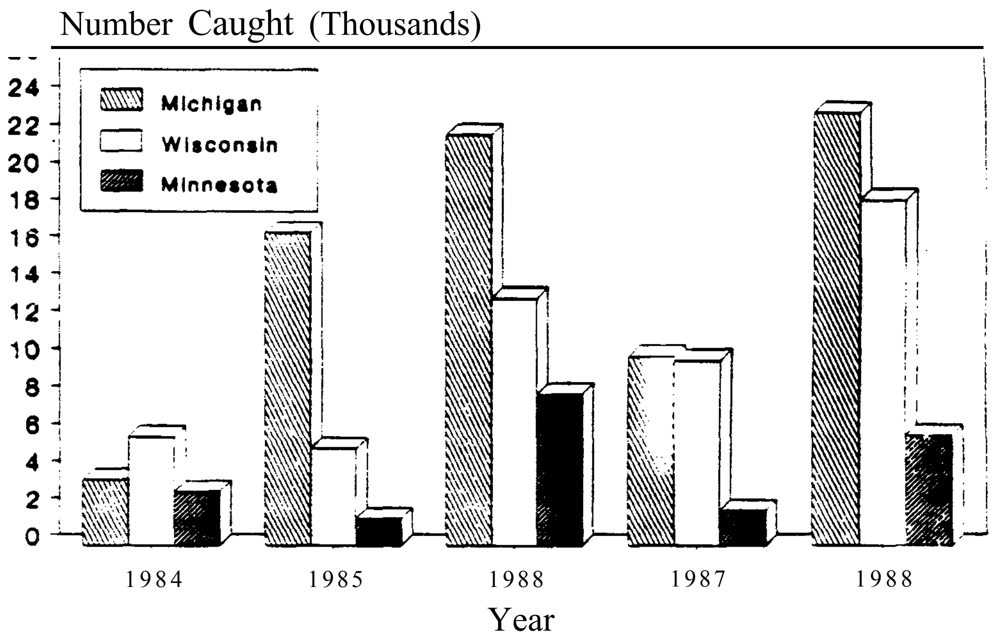

Figure 27. Coho salmon sport catch from selected U.S. waters of Lake Superior, 1984-1988.

Chinook Salmon Chinook salmon were first planted in Lake Superior by the State of Michigan in 1967. Planting was subsequently begun in Minnesota waters in 1974 and in Wisconsin waters in 1977. Plantings in Michigan and Wisconsin waters were derived from fall spawning stocks, whereas plantings in Minnesota waters were from spring spawning stocks (Close et al. 1984). Plantings in Minnesota waters were converted to a fall spawning strain in 1979.

Chinook salmon typically enter streams from August to April and spawn in numerous tributaries along the U.S. shore and in most large rivers along the Canadian shore. Peak runs in the Brule River, Wisconsin, occurred from late-August to early-September, and runs ranged from 343 to 658 fish during 1986-1989 (Fig. 25). Juvenile production has been difficult to ASSESS because most young leave the streams soon after emergence in May and June (Carl 1984, Seelbach 1985) and prior to the summer surveys that are designed to collect juvenile rainbow trout and coho salmon. The extent of natural reproduction by chinook salmon is being estimated from the ratio of marked (all planted fish were marked in 1988-1990) to unmarked fish in the sport fishery and in spawning runs.

Annual plantings of chinook salmon in the 1980s ranged from 250,000 to 372,000 in Michigan waters, 52,000 to 920,000 in Minnesota waters, and 80,000 to 400,000 in Wisconsin waters. Planting in Ontario waters was begun in 1988. In Michigan waters, chinook salmon have not been creeled in great numbers (Fig. 28) except in planted streams such as the Dead River, where catches raged from 328 to 1,771 fish during 1984-1987. in Wisconsin waters, the harvest has also been small (approximately 1,200 fish) relative to other salmonids, but harvest increased sharply in 1987 (4,462 fish) and 1988 (5,665 fish). In Minnesota waters, the average harvest was 1,796 fish during 1984-1988. On the Ontario shore, there are sport fisheries in Goulais Bay, in the Michipicoten River and Bay at Wawa, in the Nipigon River, and recently in Thunder Bay. The number of chinook salmon caught during the Wawa Salmon Derby peaked in 1986 (499 fish), and catches dropped each year to only 76 fish in 1989.

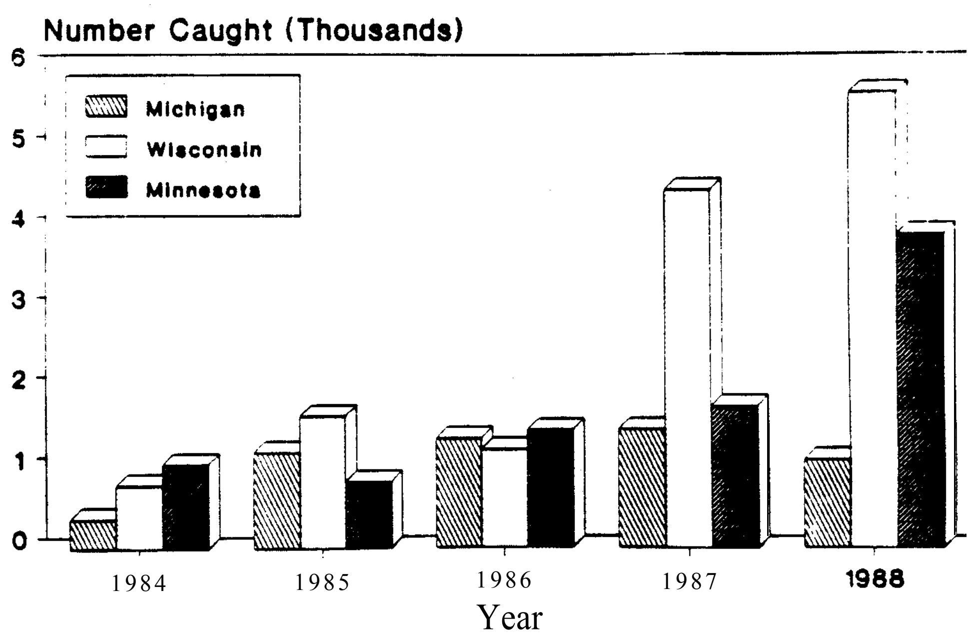

Figure 28. Chinook salmon sport catch from selected U.S. waters of Lake Superior, 1984-1988.

Brown Trout Brown trout *(Salmo trutta)* were introduced in Lake Superior during the 1890s and established self-sustaining populations throughout the lake, particularly in western U.S. streams (Lawrie and Rahrer 1972). Only 22 of Michigan's 120 Lake Superior tributaries contained brown trout in the early-1960s (Moore and Braem 1965); many are likely resident populations, but anadromous populations occur in the Ontonagon (MI-2) and Sturgeon (MI-4) Rivers. In contrast, many of Wisconsin's tributary streams have anadromous brown trout populations, though abundance has been depressed for 20 years, possibly due to furunculosis (Wisconsin Department of Natural Resources 1988). Runs of anadromous brown trout in the Brule River, Wisconsin, usually peak during late-August and ranged from 3,296 to 5,265 fish during 1986-1989 (Fig. 25). In Wisconsin, significant genetic differentiation exists among wild brown trout populations from different drainages and between anadromous and resident fish within the Brule and Sioux Rivers (Krueger and May 1987b). Brown trout have not established anadromous populations in Minnesota.

Planting of brown trout in Michigan waters averaged 50,000-100,000 yearlings annually, but harvest during 1984-1988 was only 100-400, mostly hatchery fish (Fig. 29). In Wisconsin waters, plantings ranged from 34,000 to 85,000 fish during the 1980s and harvest in 1984-1988 averaged 1,725. In an attempt to enhance harvest, stocking in Wisconsin waters during 1985-1988 included progeny of wild anadromous parents and of wild anadromous x domestic parents. Results of these experimental plantings are inconclusive. Very few brown trout were caught in Minnesota waters during 1984-1988 and none were stocked.

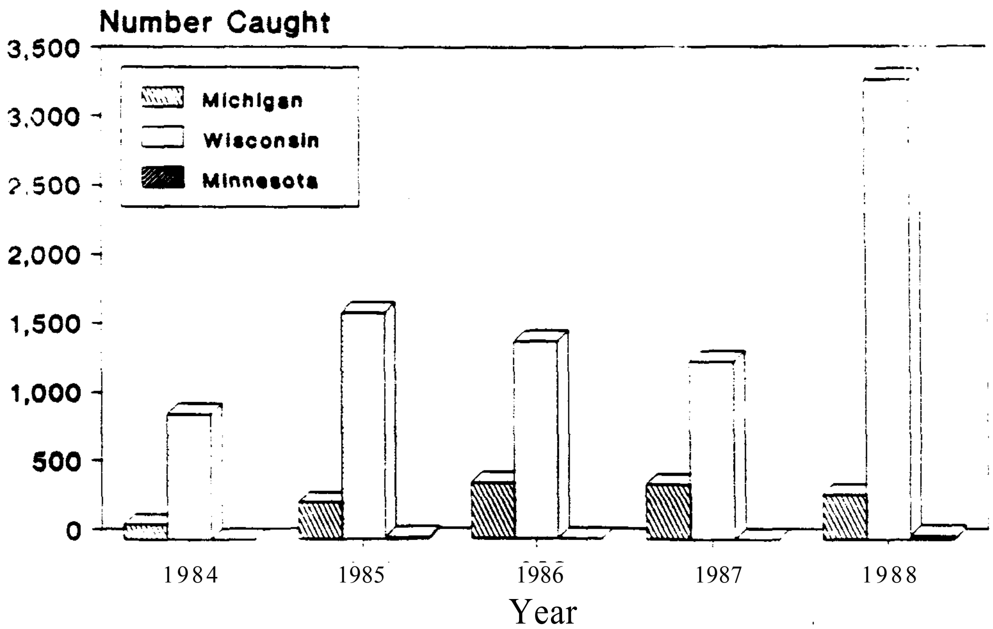

Figure 29. Brown trout sport catch from selected U.S. waters of Lake Superior, 1984-1988.

Splake The splake is a fertile hybrid resulting from the cross of a female lake trout and male brook trout. Although this hybrid had been known in fish culture since the late-1800s (Lawrie and Rahrer 1972), it had not been used extensively in enhancement programs until recent decades. Splake were first stocked in Michigan waters of Lake Superior in 1971, and about 60,000 yearlings were stocked in most years since 1981. Splake have been stocked in Wisconsin waters since 1973, and 150,000 to 300,000 were stocked annually during the 1980s. Splake have not been stocked in Minnesota waters.

Splake plants in Michigan waters have recently been split between sites near Marquette (MI-S) and Munising (MI-6); consequently, the splake catch has primarily been from these areas. Plants in Wisconsin waters have been in the Apostle Islands area (WI-2) where most of the harvest occurs. Average harvest of splake during 1984-1988 was 614 in Michigan waters and 5,550 in Wisconsin waters (Fig. 30). Most splake in Michigan and Wisconsin waters are taken from late fall through early spring. The survival to harvest of splake was at least 10 times better than for other trout and salmon species in Michigan waters (Marquette Fisheries Station, unpublished). Broodstock disease problems caused suspension of stocking in Michigan waters and reduced stocking in Wisconsin waters.

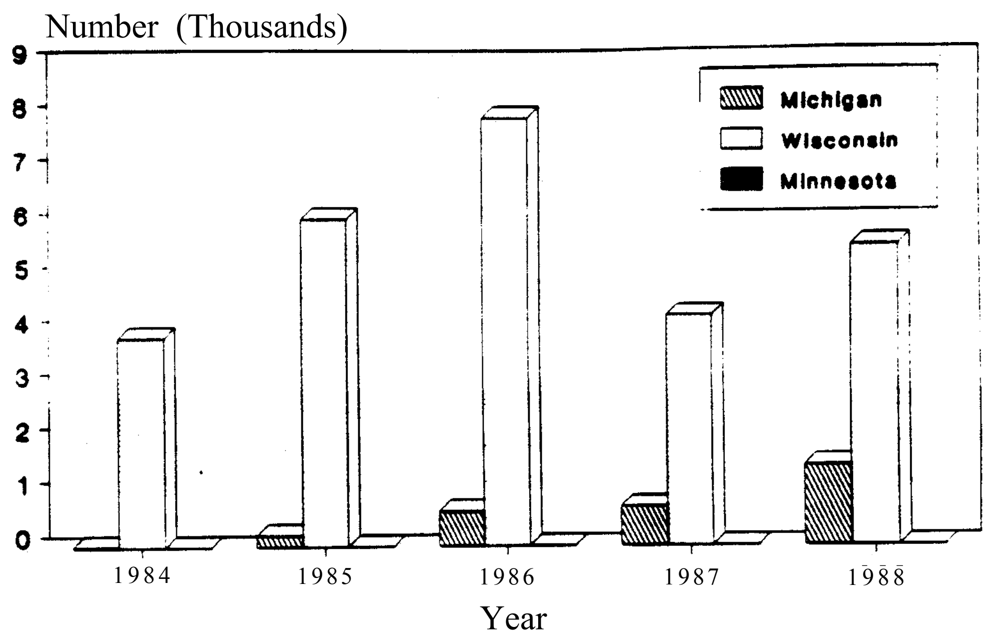

Figure 30. Splake sport catch from selected U.S. waters of Lake Superior, 1984-1988.

Brook Trout Brook trout are native tO Lake Superior and were once found in 93 of Michigan’s 120 Lake Superior tributary streams (Moore and Braem 1965). Anadromous brook trout, or coasters, were formerly common in inshore waters of

Lake Superior but became much less abundant and narrowly distributed in recent years due to competition with other introduced salmonids, overharvest, and loss of suitable habitat. At least 16 Michigan tributaries supported anadromous brook trout populations in the past, but none were found in electro-fishing surveys in several of these streams during the mid-1970s (Marquette Fisheries Station, unpublished), Currently, anadromous brook trout spawning runs are known to occur *only* in the Salmon Trout River (Mi-5), a Michigan tributary.

Reintroduction of brook trout was recently attempted in both Michigan and Wisconsin waters; Michigan plantings averaged 50,000-60,000 fish annually and Wisconsin plantings averaged 80,000. The Lake Nipigon strain of brook trout from the Province of Ontario has been stocked in Wisconsin waters since *1984* to re-establish anadromous stocks. However, harvest from plantings in Michigan and Wisconsin waters has been poor and enhancement of anadromous populations has been unsuccessful. Fewer than 100 brook trout were harvested annually from Michigan waters during 1987-1988. Fewer than 60 were taken from Wisconsin waters each year during 1984-1988, except 291 fish were creeled in 1985. A fishery for coaster brook trout may exist in the vicinity of the Salmon Trout River and along the Isle Royale shoreline (MI-l).

<u>Pink Salmon</u> A single introduction of odd-year spawning pink salmon *(Oncorhynchus gorbuscha)* in Canadian waters of Lake Superior in 1956 developed naturally reproducing populations throughout the Great Lakes (Emery 1981). Distribution in Michigan waters of Lake Superior included at least 56 tributaries by 1980 (Wagner and Stauffer 1982). Pink salmon enter tributaries at age-2 and spawn during September-October. However, some pink salmon remained in Lake Superior an extra year and spawned at age-3, establishing an even-year spawning population (Wagner and Stauffer 1982).

Abundance of pink salmon smolts is difficult to assess because they usually outmigrate as fry in May immediately after emergence (Bagdovitz et al. 1986). Abundance of juvenile pink salmon is also difficult to assess because they are believed to be scattered in the pelagic zone of the lake. Adult pink salmon abundance is most easily assessed during the fall spawning runs. In Michigan, pink salmon runs, which have been monitored since 1973, peaked in 1979 and declined substantially thereafter (Bagdovitz et, al. 1986). In Minnesota and Wisconsin waters, pink salmon followed a similar pattern of abundance. Most of Michigan's major pink salmon spawning streams of the 1970s had small or no spawning runs by 1989 (Marquette Fisheries Station, unpublished).

<u>Atlantic Salmon</u> Atlantic salmon *(Salmo* salar) are not native to Lake Superior and have not been stocked as extensively as the other salmonids. Atlantic salmon were stocked in Wisconsin wafers in 1972-l 973 and in 1978; a single stocking was

made in Michigan waters in 1976. A more extensive program was begun in 1980 in Minnesota with the Grand Lake strain from the Stare of Maine. Stockings in the French River have increased from 10,000 yearlings in 1980 to 21,000 yearlings and 111,000 fingerlings in 1989. Also, the Split Rock River was stocked with 32,000 fry each year in 1984-1985, 1,500 yearlings in 1986, and 10,800 yearlings in 1989. Reproduction has not been documented from any of these plantings.

The first plantings of Atlantic salmon returned to Minnesota waters in late-August and early-September, but more recent plants have returned in early-November. Returns of adult Atlantic salmon to the French River average less than 0.5% of fish stocked and only provide about 25% of the 200,000 eggs needed to sustain the stocking program. Harvest of Atlantic salmon during 1982-1988 never exceeded 140 fish and was restricted largely to Minnesota waters. Harvested fish averaged 4-S lbs (1.8-2.3 kg) after 6 years in the lake. The largest Atlantic salmon taken in Minnesota waters weighed 12.5 lbs (5.7 kg).

Other species

The fishery objective for other species in Lake Superior is to prevent overharvest of non-depleted stocks of native species (lake whitefish, deepwater ciscos, suckers, and walleye) and re-establish depleted stocks of native species (lake sturgeon, brook trout, and waileye). Due to increased abundance and expanded fisheries, lake whitefish stocks presently support greater commercial harvest than at any other time in the 20th century. Lake trout rehabilitation efforts may be negatively impacted by the expanded lake whitefish fisheries in some areas. Incidental catch of lake trout in the lake whitefish fishery should be closely monitored. Lake sturgeon and walleye populations are generally depressed and rehabilitation efforts should continue. As discussed earlier, deepwater ciscos declined continuously through 1989 as siscowet stocks expanded. Brook trout rehabilitation efforts have been largely unsuccessful.

<u>Lake Whitefish</u> Commercial fisheries targeted at lake whitefish occur in all jurisdictions of the lake except in Minnesota waters. The entire harvest from Ontario waters and 85% of the harvest from U.S. waters is taken with large-mesh gill nets. Trap nets and pound nets are also used in U.S. waters. Fishing with gill nets occurs throughout the year, even under the ice, whereas trap nets and pound nets are fished only from April through October.

Commercial harvest of lake whitefish increased from 400,000 lbs (181,400 kg) in 1959 to 3.2 million lbs (1.43 million kg) in 1989 (Fig. 31). Since 1982, each year's harvest has been greater than in any earlier year in the 20th century, and the harvest in 1989 was the largest ever recorded. Trends in harvest were similar in U.S. and Ontario waters up to 1973. After 1973, harvest from U.S. waters continued to and Ontario waters up to 1973. After 1973, harvest from U.S. waters continued to increase, while harvest from Ontario waters increased only through 1977 when quotas stabilized the catch. Harvest from U.S. waters made up 65-80% of the total catch since 1959.

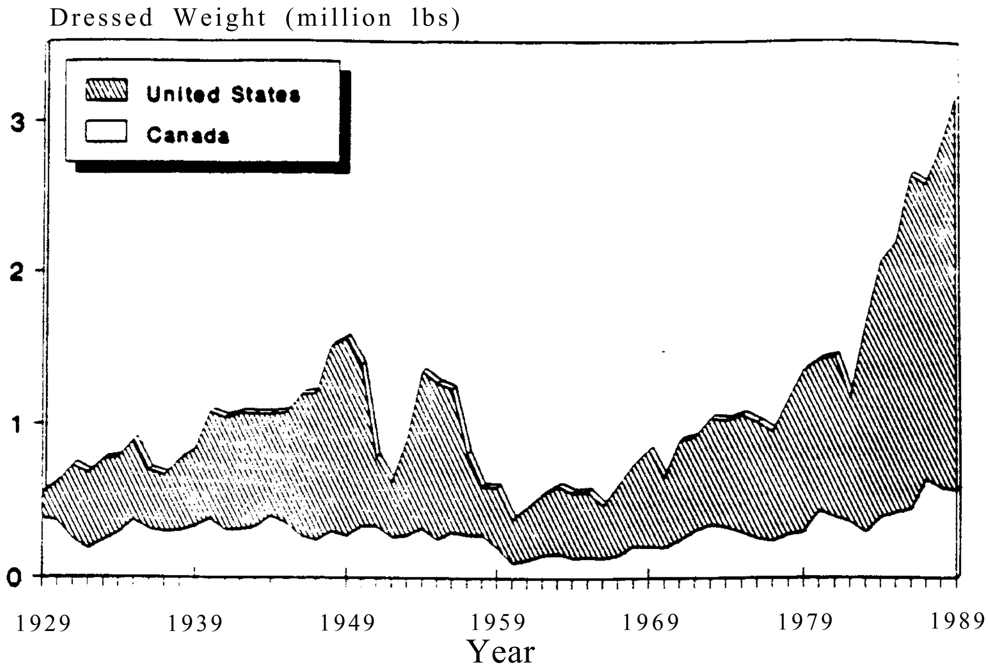

Figure 31. Lake whitefish harvest from Lake Superior, 1929-1989.

The record lake whitefish harvests of the 1980s are due to several factors. First, commercial harvest of lake trout and lake herring was severely curtailed after the collapse of those species in the 1960s-1970s. Remaining fishers had to convert to lake whitefish to continue so that in U.S. waters most of the commercial fishery remains exclusively targeted at lake whitefish. A second cause is the fishing-up of previously unexploited stocks around the Keweenaw Peninsula (areas MI-2, MI-3 and MI-4). Prior to 1983, the annual commercial harvest of lake whitefish from these areas was less than 50,000 lbs (22,680 kg), but current harvest averages about 700,000 lbs (317,500 kg). A third reason for the record harvests is actual increases in lake whitefish abundance. Catch rates of lake white&h in tribal gill-net fisheries increased in the Apostle Islands (W-2) and Whitefish Bay (MI-8) during 1980-1988 (Fig. 32). Lake whitefish abundance in WI-2 was greater in 1988 than in any other year during the 1980s, and in MI-8 was greater during 1986-1987 than in previous years.

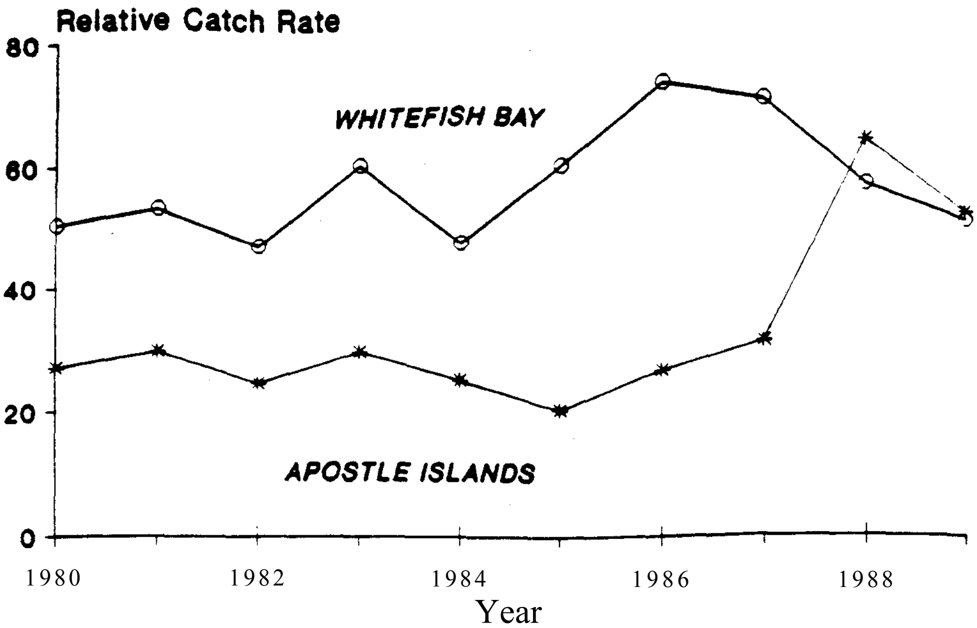

Figure 32. Lake whitefish catch rate in gill nets from two areas of Lake Superior, 1980-1989.

Harvested lake whitefish range in age from 4 to 17 years in Lake Superior, and mean age ranges from 6.6 to 9.3 years (Table 4). Annual mortality rates vary from 21% at Grand Portage (MN-3) to 79% in the Apostle Islands (WI-2). Mortality rates are less than 60% in six of eight U.S. management areas. Mean annual yields ranged from under 3,000 lbs (1,360 kg) in MN-3 to over 600,000 lbs (272,000 kg) in Whitefish Bay (MI-8) (Table 4). Yield per unit area (depths under 240 ft, 73 m) ranged from 0.1 to 2.4 lbs per acre (0.09-2.1 kg/ha). The most productive waters during 1986.1988 were *west* of the Keweenaw Peninsula (MI-3) and Whitefish Bay (MI-8), whereas the least productive U.S. waters were in eastern Minnesota (MN-3).

Growth rates of lake whitefish vary considerably in U.S. waters (Fig. 33); growth is fastest in Whitefish Bay (MI-8) and Grand Portage (MN-3) and slowest in the Apostle Islands (WI-2) and the west side of the Keweenaw Peninsula (MI-3). Because they have higher mortality rates than fish from other areas (Table 4) and have been subjected to heavy fishing for over 20 years, lake whitefish from the Apostle Islands (WI-2) reach 100% sexual maturity at a length that is 3 inches smaller than in other areas (Fig. 34). Fish from east of the Keweenaw Peninsula (MI-4). do not achieve 100% sexual maturity for any size group because they have low mortality rates and have been exploited for only S years. Maturity and mortality rates of lake whitefish from Whitefish Bay (MI-8) are intermediate compared to other Lake Superior stocks.

Table 4. Range of ages, mean age, annual mortality, mean yield and yield per acre for gill-netted lake whitefish in Lake Superior for various years during 1986-1988.

Area	Year	Age Range	Age Mean	Annual mortality A	ages	years	Mean yield 1986-1988 (lbs)	Yield/ acre
MN-3	1987	4-17	7.2	21%	7-11	1986-88	< 3,000	0.1
WI-2	1988	5-11	7.6	79%	7-11	1986-88	379,700	0.6
MI-2	1988	5-10	7.7	-insufficient data			104,272	0.4
MI-3	1988	5-12	7.7	29%	7-11	1986-88	211,412	2.4
MI-4	1988	4-17	7.1	39%	7-11	1986-88	391,632	1.1
MI-5	1987	6-15	9.3	28%	9-14	1986-87	131,887	0.8
MI-6*	1988	4-20	7.7	41%	7-20	1986-88	194,074	1.0
MI-7	1988	5-14	6.8	53%	7-12	1986-88	91,367	0.6
MI-8	1988	4-12	6.8	62%	7-12	1986-88	614,815	1.3
O-1	1987	6-14	8.5	---not available---			85,767	
o-4	1987	3-12	6.4	---not available---			29,880	
o-7	1988	3-10	5.8	---not available---			39,004	
O-31	1986	4-11	6.6	---not available---			31.,742	
o-33	1986	5-12	6.7	---not available---			139,779	
o-34	1986	5-12	6.9	---not available---			137,399	

*Trap net samples used for mean age and mortality calculations.

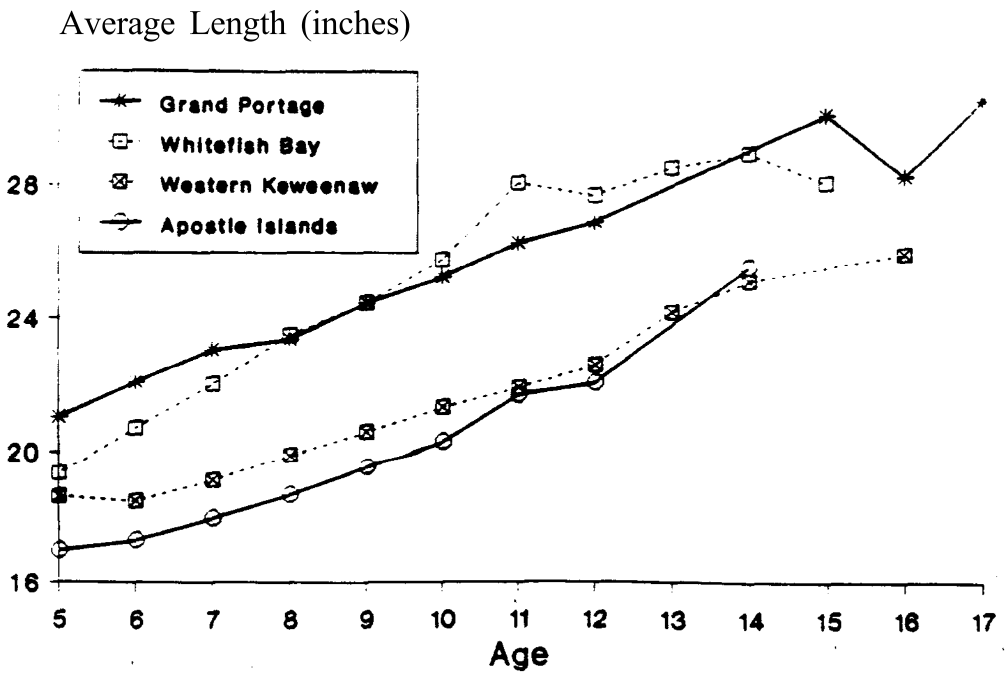

Figure 33. Lake whitefish growth in selected U.S. waters of Lake Superior.

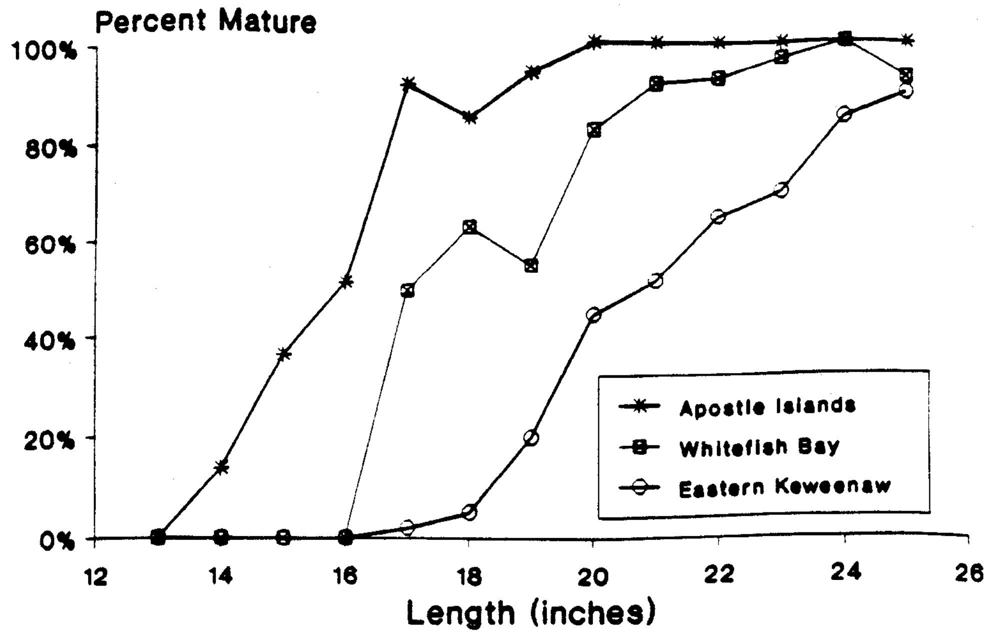

Figure 34. Lake whitefish length at maturity in selected U.S. waters of Lake Superior.

Walleye Walleye were of only local importance in Lake Superior; maximum commercial harvests were 123,200 lbs (56,000 kg) from US. waters in 1885 and 374,000 lbs (170,000 kg) from Canadian waters in 1966. Many of the walleye stocks in Lake Superior are slow-growing, dominated by old individuals (Fig. 35), and unable to withstand high levels of exploitation. Not surprisingly, Schram et al. (1990) identify overharvest as a primary reason for declining abundance of several populations (Table 5). Exotic species have not been shown to adversely impact walleye; however, effects may not be detectable with present monitoring programs.

Despite their secondary role and reductions in abundance, Lake Superior walleye are actively sought by anglers. Fishery managers have responded to the demand for walleye fishing and are attempting to rehabilitate stocks through regulations and stocking. Commercial fishing has been eliminated except for a small quota for incidental catches in Ontario waters and a tribal fishery in U.S waters. Reduced angler bag and size limits are in effect in Ontario waters. Fingerling walleye stocked in Wisconsin and Michigan waters have survived and grown well, but adult transplants in Ontario waters have failed to restore stocks.

Table 5. Management problems, objectives, strategies, and results for major Lake Superior walleye populations.

Population	Management Problem	Management Objective	Agency Strategy	Results
St. Louis River	Exploitation on old stock; high Hg.	Increase stock size.	Stock fingerlings; protect spawners.	Status quo.
Kakagon Slough	Overharvest.	Provide sport and tribal harvest.	stock fry and fingerlings; close fishery.	Survive well.
Bad River	Overharvest?; lack of data.	Acquire data.	Not known	Not Known.
Ontonagon River	Reduction in size of spawning run.	Acquire data.	Monitor spawning activity.	Not known.
Lac la Belle	Lack of data.	Provide sport fishery.	Stock fingerlings.	Not known
Keweenaw Bay	Overharvest; lack of data.	Provide sport fishery.	Stock fingerlings in adjoining bay.	Survive well.
Whitefish Bay	Overharvest; lack of data.	Provide sport fishery; rebuild population.	Stock fry and fingerlings; build spawning reef.	Not known.
Nipigon Ba	Paper mill effluent; overharvest; lack of data.	Rebuild stock.	Stock fry, fingerlings, and adults; close fishery.	Failed.
Black Bay	Overharvest; lack of data.	Rebuild stock.	Transfer adults.	Failed.
Thunder Bay	High contaminant levels; habitat loss.	Maintain present fishery; restore lost habitat.	Protect existing habitat.	Status quo.

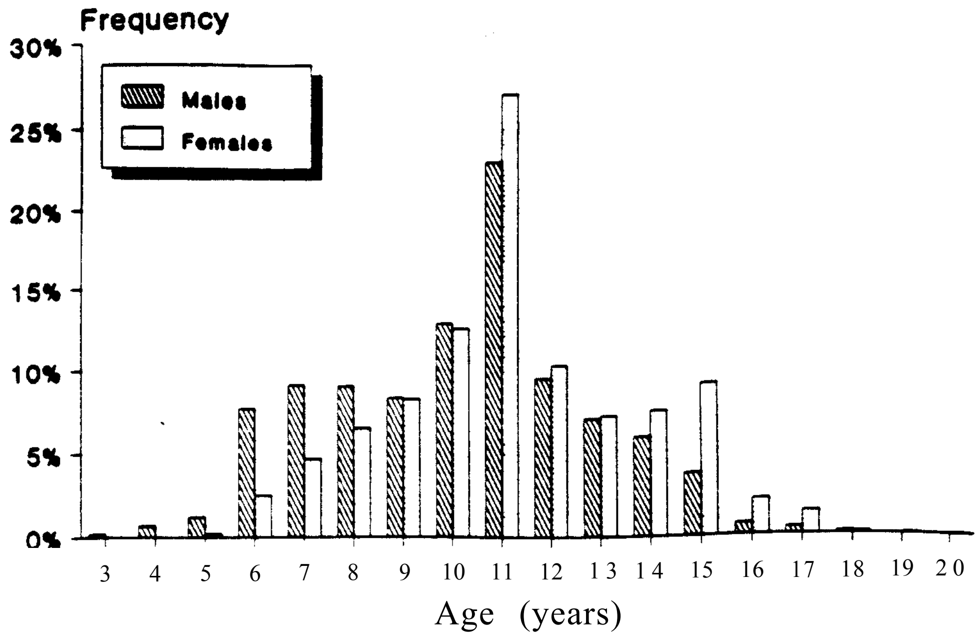

Figure 35. Age frequency of spawning walleyes from the St. Louis River Lake Superior, 1981.

Lake Sturgeon Lake sturgeon are classified as 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 the Sturgeon River, Houghton County, Michigan (64 records) and the Bad River, Ashland County, Wisconsin (131 records) (Moore and Braem 1965). Commercial fishers reported lake sturgeon from the ports of Brimley, Munising, Big Bay, Keweenaw Bay, and West Entry in Michigan waters, the Apostle islands area in Wisconsin waters, and several points along the Canadian shore. Commercial landings of lake sturgeon exceeded 200,000 lbs (90,720 kg) in 1885 and 100,080 lbs (45,360 kg) in 1889 and 1890, though reporting was inconsistent in U.S. waters. Commercial fishing for lake sturgeon was closed in all U.S. waters in 1928, though Michigan allowed retention of lake sturgeon during 1951-1969. The lakewide catch has been 1,000 lbs (454 kg) or less since 1970.

Spawning populations of lake sturgeon in Lake Superior tributaries occur in the Bad River, Wisconsin; the Sturgeon River, Michigan; and the Kaministikwia, Michipicoten, and Black Sturgeon Rivers, Ontario. There is also evidence of spawning along the harbor breakwall off Ashland, Wisconsin; surveys for lake sturgeon produced two ripe male and several non-ripe fish near the breakwall in 1989. Capture of young-of-the-year lake sturgeon in the Sturgeon River in 1988 indicated successful reproduction still occurs there (Auer 1988). Lake sturgeon from Chequamegon Bay and from near the Port of Duluth-Superior exceeded 40 inches (101.6 cm) after 30-40 years of age (Fig. 36). In the Sturgeon River, 6 adult males were 22-30 and five adult females were 31-36 years old (Auer 1987).

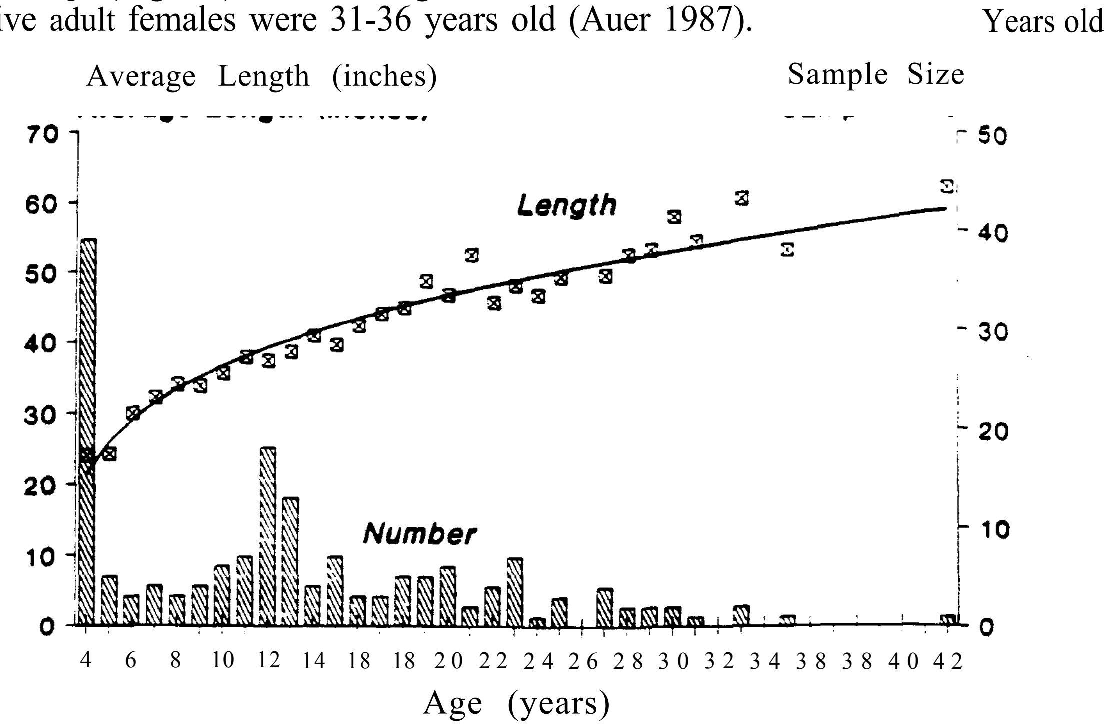

Figure 36. Lake sturgeon growth in Chequamegon Bay and western waters of Lake Superior.

Historically, dam construction on spawning streams and overharvest were the major factors limiting lake sturgeon populations (Priegel and Wirth 1971). Fishing mortality is currently composed of incidental catch in commercial nets and poaching on spawning grounds (Auer 1987). Regulation of commercial and sport fishing harvest is quite restrictive in most jurisdictions on Lake Superior (Table 6).

Strategies for restoring depleted stocks of lake sturgeon focus on inventory, protection, rejuvenation, and replacement of spawning and rearing habitat. Degraded habitat in the Sturgeon River may be restored by requiring an electric power company undergoing federal relicensing (Federal Energy Regulatory Commission) to operate a power dam at run-of-the-river. Also, water quality has been improved through enactment of more stringent water pollution regulations. Recent stocking efforts in the St. Louis River by the States of Wisconsin and Minnesota and in the Bad River (1,500 fingerlings in 1988) by the Great Lakes Indian Fish and Wildlife Commission should help restore these stocks.

Table 6. Commercial and sport fishing regulation for lake sturgeon on Lake superior.

Agency[a]	Commercial	Sport
COTFMA	May not offer for sale; home use permitted.	None.
GLIFWC	May not offer for sale; home use permitted.	None.
OMNR	Unspecified minimal quota (possession may be prohibited in 1990).	No size limit: 1 fish per day bag limit: open all yr except Christmas day.
MDNR	Possession prohibited.	So-inch minimum length limit: 2 fish per season bag limit; open July 1 to April 30 on Great Lakes and connecting waters.
WDNR	Possession prohibited.	400-inch minimum length limit (SO-inch minimum is being considered); 1 fish. per year bag limit; open year round; fish must be tagged: St. Louis River closed to fishing.
MnDNR	Possession prohibited.	Possession prohibited.

a Agencies: Chippewa-Ottawa Treaty Fishery Management Authority (COTFMA); Great Lakes Indian Fish & Wildlife Commission (GLIFWC); Ontario Ministry of Natural Resources (OMNR): Michigan Department of Natural Resources (MDNR); Wisconsin Department of Natural Resources (WDNR); Minnesota Department of Natural Resources (MnDNR).

Sea Lamprey

The fishery objective for sea lampreys in Lake Superior is to achieve a 50% reduction in parasitic-phase sea lamprey abundance by the year 2000 and a 90% reduction by 2010. Current control methods reduced sea lamprey abundance by 90% from pre-control levels. Integration of new control methods, including sterile-male releases, barrier dam construction, intensified chemical treatments, and increased trapping, can be used to reduce populations toward these goals. An Integrated

Management of Sea Lamprey (IMSL) initiative will seek to refine the objectives for sea lamprey abundance and define the optimal sea lamprey control program. The [MSL 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.

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 dramatically during the following 20 years and apparently reached peak abundance by 1960. The first attempts to control sea lampreys in Lake Superior occurred in 1950-1951 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 electrical barriers were effective in blocking spawning runs of sea lampreys, and by 1960 these barriers had been installed in 97 tributary streams. Many electrical barriers stayed in operation only a couple of years, but about 55 were operated during 1953-1960. The efficiency of these barriers as control devices was constrained due to mechanical, physical, and biological limitations. After 1969, reduced numbers of electrical barriers were operated to assess spawning runs as follows: 24 during 1958-1967, 16 during 1968-1970, and 8 during 1971-1979. After 1979, traps were used to measure abundance of spawning-phase sea lampreys.

The lampricide, 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 by 1960, 72 of the most heavily infested streams had been treated. Following these treatments, the number of adult sea lampreys captured at electric weirs declined by 85%. a level maintained through 1972 (Fig. 37). During 1973-79, intensified treatments reduced the number of adult sea lampreys caught at electrical weirs to less than 10% of pre-control levels. Present abundance remains similar to that during 1973-1979. Smith and Tibbles (1980) reviewed the sea lamprey invasion in Lake Superior and the control efforts and their effects through 1979.

Adult Populations Relative abundance of spawning-phase sea lampreys is estimated using index traps fished in tributary rivers. Though the number of rivers with traps has varied during 1980-1989, a core group of 9 to 23 traps has been in operation in most years. Traps were operated in 17 U.S. and S Canadian streams in 1989.

During 1986-1989, the total abundance of adult sea lampreys in U.S. 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 the south shore streams in 1986, but in 1987-l 989 independant relations for streams east and west of the Keweenaw Peninsula were used with better precision. Similar methods were used in an attempt to estimate sea lamprey abundance in Canadian streams in 1987, but the effort was successful due to a lack of good sites to deploy traps. Sea lampreys in Canadian streams may number about 10,000, a very rough estimate.

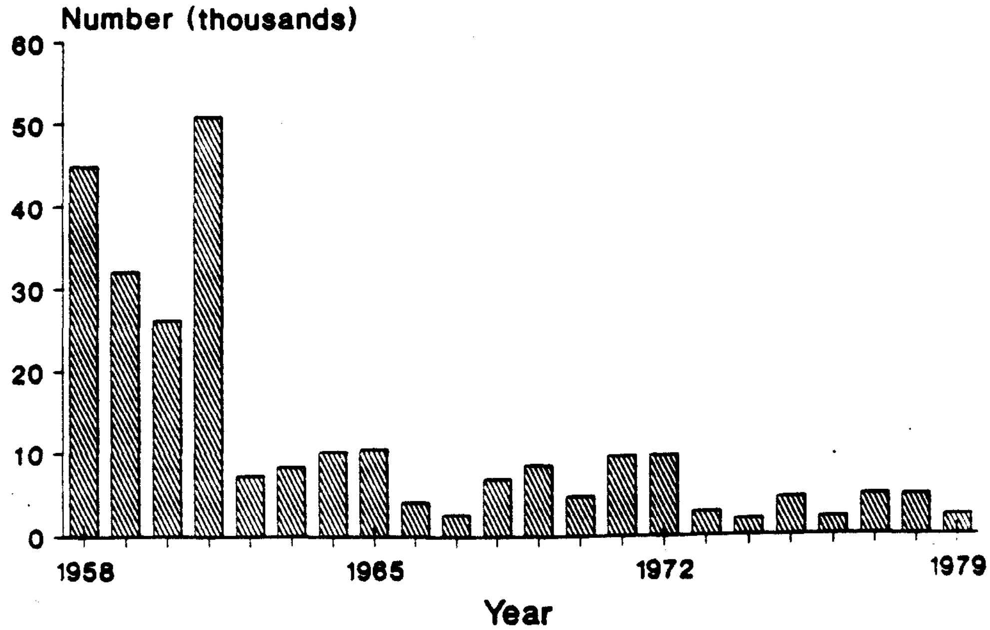

Figure 37. Spawning sea lamprey catch in 8 index tributaries of Lake Superior (from Smith and Tibbles 1980).

The numbers of sea lampreys in the lake during the 1980s appear unchanged from the 1970s. Catch variance of adult sea lampreys taken in assessment traps during 1980-1989 were similar to that associated with catches at electrical weirs during 1970-1979. Numbers of adult sea lampreys from U.S. streams during 1986-1989 fluctuated from 60,517 to 23,166.

Larval Populations Assessments of larval sea lamprey populations are used to determine streams that require lampricide treatments, areas within streams that need treatments, effectiveness of treatments, numbers of larvae escaping treatment, and strength of year classes. Larval populations are assessed using back-pack electro-shockers in shallow water and a bottom toxicant (Bayer-73) in deep water. Based on these assessments qualitative measurements are established.

Quantitative estimates of larval populations have recently been attempted on several streams in Canada and the U.S. Most approaches involved the release of marked larvae for recapture during lampricide treatments. Some 91,000 larvae were estimated to be in the Big Garlic River during the 1983 treatment. This estimate was made using mark-recapture methods for various six-mile zones stratified by habitat types and by qualitative larval abundance. This effort was the first habitat-based estimate of a stream population of larvae in the Lake Superior drainage.

In 1988-1989, habitat-based estimates of larval abundance in other streams were undertaken. Larval numbers were estimated in 1988 in the Huron River (480,000) and Harlow Creek (60,000) and in 1989 in the Middle (39,000), Brule (151,000), Sturgeon (352,000), Falls (6,000), Huron (615,000), Big Garlic (17,000), Little Garlic (56,000), and Pancake (735,000) Rivers and Red Cliff Creek (13,000). At present, several alternative estimation methods are being reviewed.

Production Areas Sea lampreys have been found in 62 Canadian and 90 U.S. rivers, and in lentic areas off 14 Canadian and 17 U.S. rivers. However, most sea lamprey larvae occur in 13 Canadian rivers (Goulas, Batchawana, Pancake, Michipicoten, Pic, Little Pic, Prairie, Pays Plat, Gravel, Jackfish, Nipigon, Wolf, and Pigeon Rivers) and 22 U.S. rivers (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 Rivers). Larval production also occurs in lentic areas off 4 major Canadian rivers (Chippewa, Batchawana, Gravel, and Nipigon Rivers) and 2 major U.S. rivers (Sucker and Falls Rivers). Larvae escape lampricide treatments in some rivers because of the presence of oxbows, backwaters, and groundwater seeps where minimum lethal concentrations of chemical are difficult to maintain. Delays or postponements of treatments due to wafer levels that are too high or low also contribute to larval escapement.

Control Strategy During 1958-1989, a total of 804 lampricide applications were made on 43 Lake Superior tributaries in Canada and 84 in the U.S. About 20% of these streams were treated only once, but some were treated as many as 23 times. During the past 10 years, treatments have been regularly conducted on 32 tributaries in Canada and 44 in the ‘U.S. In addition to stream treatments, lentic areas off the mouths of 10 Canadian rivers have been treated with granular Bayer-73.

Streams are scheduled for treatment to prevent metamorphosed larvae from recruiting to Lake Superior. Preliminary scheduling must be done 2 years in advance of treatment for administrative and logistical reasons, and firm schedules are made 1 year prior to treatment. Most streams are treated on a rotational cycle of 3 to 4 years.

Non-Target Effects Lampricides can be applied without affecting most non-target aquatic vertebrates found in Lake Superior tributaries. However, some species such as stonecat (Noturus flavus), trout-perch (Percopsis omiscomaycus), brown bullhead (Ictalurus nebulosus), and mudpuppy (Necturus maculosus maculosus) are sensitive to TFM, and some mortality OCCURS during treatment. Also, some mortality of less sensitive fish species may be caused if lampricide is applied when spawning occurs. Preliminary tests indicate that immature lake sturgeon may be sensitive to TFM. However, more toxicity resting is required to determine the effects of TFM on this species. Frequent treatments may impede full recovery of some sensitive species. Mechanical or electric barriers used as alternatives to chemical treatment may block passage of anadromous fish species. Fish passage provisions will allow some fish species upstream access. Barriers, if not designed and constructed carefully, may pose a hazard to humans.

Habitat

The fishery objective for habitat in Lake Superior is to: 1) achieve no net loss of the productive capacity of habitats supporting Lake Superior fisheries, 2) restore the productive capacity of habitats that have suffered damage, and 3) reduce contaminants in all fish species to levels below consumption advisory levels. Achieving no net loss of fishery productive capacity will require integration of habitat inventorying and monitoring with existing fish stock assessment programs. Restoring productive capacity of damaged habitat areas will require involvement of fish managers in remediation efforts coordinated by the International Joint Commission. Reducing contaminant levels in fish below consumption advisory levels will require implementation of remedial action plans and reduction of inputs from airborne toxics.

Achieve No Net Loss of Existing Habitat Fish habitats most critical to achieving no net loss of Lake Superior fishery production include wetlands, spawning grounds, and rivers. Wetlands are important to Lake Superior fish populations because they provide nutrients for lake production and spawning areas for species such as northern pike (Esox *lucius)* and yellow perch *(Perca flavescens).* Spawning grounds such as rocky shoals in Lake Superior support several of the most important species, including lake trout, lake whitefish, and lake herring. Rivers flowing into Lake Superior provide spawning and nursery habitat for anadromous species such as walleye, brown and rainbow trout, Pacific salmon, and lake sturgeon.

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 completed for important wetland areas and rivers. Following completion of these inventories, the current status (quality and quantity) of these important habitats needs to be determined for future reference against possible net losses. Monitoring changes in all of these fish habitats needs to be incorporated into fishery management programs in order to successfully determine if net losses are occurring. This will require closer integration among those involved in wetland and fishery management programs.

Two recent examples of the application of the principle Of no-net-loss are noteworthy. A fill in Duluth Harbor needed for shipping was mitigated by construction of a lake trout spawning reef. A fill in the Fish Creek Sloughs, Chequamegon Bay, Wisconsin, for highway expansion is planned to be mitigated by creation and restoration of other nearby wetlands. Mitigation in these cases is a last resort when destructive works cannot otherwise be averted. The potential for mitigation should not be construed as an opportunity to degrade fish habitat in Lake Superior.

<u>Restore Damaged Habitat</u> To restore the productive capacity of damaged habitats in Lake Superior, seven areas were identified by the International Joint Commission as Areas of Concern for development of Remedial Action Plans (RAPs): Torch Lake and Deer Lake, Michigan; St. Louis Harbor, Minnesota and Wisconsin; Thunder Bay, Nipigon River, Jackfish Bay and Peninsula Harbor, Ontario. Remedial actions have been implemented and are now being monitored at Torch and Deer Lakes, Michigan. Torch Lake is now an EPA super-fund copper-tailing site; contaminant levels and the incidence of tumors in fish have declined. At Deer Lake, fish stocking is occurring and mercury levels are declining. Documentation of environmental conditions in the St. Louis River is proceeding with state and public involvement, including fishery management agencies. The four Areas of Concern in Ontario are proceeding with identification of remedial action options. Public advisory committees have been established, and fishery concerns have been addressed.

In addition to these Areas of Concern, several rivers flowing into Lake Superior have hydro-Power dams that reduce the productive capacity of anadromous species. In particular. lake sturgeon were negatively affected by peaking operations of a dam on the Sturgeon River, Michigan. Renewal of the license for this facility, currently under review by the U.S. Federal Energy Regulatory Commission (FERC), may be contingent on a change in operation to run-of-river flows that should benefit lake sturgeon. Other rivers with hydro-power dams that can affect improvements in degraded habitat for production of anadromous fishes are in the process of FERC license renewals and include: St. Louis River, Minnesota and Wisconsin; Iron and White Rivers, Wisconsin; Montreal River, Wisconsin and Michigan; Dead, Autrain, and Ontonagon Rivers, Michigan.

<u>Reduce Contaminant Levels</u> Excessive contaminant levels, especially of PCBs and mercury, in Lake Superior fish require the setting of consumption advisories for several important species, including lake trout, siscowet, walleye, chinook salmon, northern pike, white sucker (Catostomus *commersoni),* lake whitefish, and yellow perch (Busiahn 1990). These consumption advisories are most severe in the seven Areas of Concern, though some contamination is associated with aerial inputs and sediment

recycling in the main lake. PCBs in lake trout have been declining since 1974-1975 (D'Itri 1988), apparently in response to restricted use or bans of these compounds in the early 1970s. Contaminant levels in fish associated with the Areas of Concern will be reduced if Remedial Action Plans are successfully implemented. Aerial inputs will continue to be a problem until out-of-basin polluters are more fully regulated.

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