A LAKE TROUT RESTORATION PLAN FOR LAKE SUPERIOR

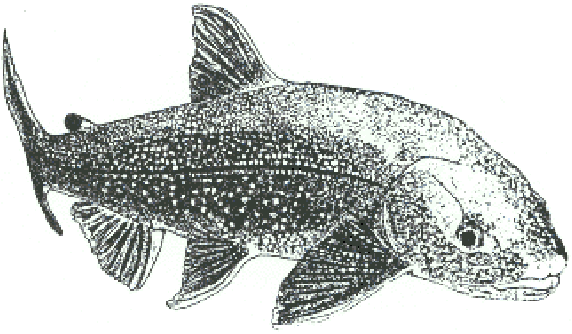

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TABLE OF CONTENTS

A LAKE TROUT RESTORATION PLAN FOR LAKE SUPERIOR

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ABSTRACT. The objective for lake trout *(Salvelinus namaycush)* restoration in Lake Superior is to restore self-sustaining stocks that can annually yield approximately 2 million kg (4 million lb), the average annual yield in 1929-43. Progress toward the goal should be measured by the number of age-l juveniles produced in each lake trout management area and by the average density of adults caught in gillnets. Progress toward the goal will require prudent regulation of sport- and commercial-fishery harvests and increased control of the sea lamprey *(Petromyzon* marinus). Stocking of yearling lake trout should be phased out in response to progress in restoration and to declining survival of stocked yearlings. Interactions with other salmonine predators should be the focus of future research. Prey species should be managed conservatively to ensure that their abundance is adequate to provide for the maturation of lake trout at reasonably young ages. Habitat should be surveyed to ensure that key habitats for reproduction and survival are protected.

INTRODUCTION

The lake trout *(Salvelinus namaycush)* supported an annual commercial harvest of 2 million kg (4 million lb) in Lake Superior from 1920 to 1950 (Lawrie and Rahrer 1972, 1973). Commercial harvest declined sharply in the 1950s as lake trout stocks collapsed from overfishing and sea lamprey (Petromyzon *marinus)* predation (Hile et al. 195 1; Smith 1971; Smith et al. 1974; Pycha and King 1975). Harvest of lake trout declined more than 90% from 1953 to 1962 when management agencies closed commercial lake trout fisheries (Pycha and Ring 1975). Chemical control of the sea lamprey began in 1958 and reduced their abundance 87% by 1961 (Smith et al. 1974). Hatchery-reared lake trout were stocked nearly continuously after 1952 (Hansen et al. 1995).

The lake trout was expected to recover quickly in Lake Superior because:

- intensive stocking was under way,
- sea lamprey control was achieved, and
- commercial fisheries for lake trout were closed while some native lake trout still survived.

In the 1960s, abundance of inshore lake trout increased sharply in Wisconsin and Michigan where stocking rates were highest (Pycha and King 1975). In contrast, lake trout abundance increased slowly in Ontario (where stocking rates were lower) and less in Minnesota (where stocking began several years later). Stocked lake trout sustained high abundance in Michigan throughout the 1970s but declined sharply in Wisconsin in the early 1970s (Hansen et al. 1995). Remnant stocks of native lake trout persisted at:

- Gull Island Shoal and Cat Island in Wisconsin;
- Thunder Bay, Superior Shoal: and the Slate Islands in Ontario; and
- Stannard Rock, Isle Royale, and Munising in Michigan.

In the 1980s and early 1990s, increased fishery exploitation, continued sea lamprey predation, and reduced stocking rates affected lake trout restoration. Abundance of stocked lake trout declined sharply in Michigan in the 1980s because of reduced stocking rates and poor survival (Hansen et al. 1994b, 1995). Wisconsin, abundance of stocked lake trout declined more slowly during the same period for similar reasons. However, in Minnesota abundance increased because stocking was stable and survival remained good. Abundance of stocked fish declined in Ontario where stocking rates were low. Managers reduced stocking rates in Wisconsin and Michigan because they expected that stocked fish would be protected from exploitation and would mature and reproduce. Reduced stocking rates in Lake Superior also resulted from increased demand for lake trout, which were reared in United States federal hatcheries in Lakes Michigan and Huron.

Stocked lake trout were unable to locate and colonize many spawning reefs in Wisconsin. Surviving wild stocks accounted for most of the natural reproduction at Gull Island Shoal (Krueger et al. 1986). In contrast, stocked fish reproduced on most historical spawning reefs in Michigan (Peck 1979; Hansen et al. 1995) and Minnesota (Hansen et al. 1995). Abundance of wild fish has been stable in Wisconsin since the 1970s. In Michigan, abundance of wild fish increased throughout the 1970s, as reproduction expanded, and stabilized in the 1980s as fisheries became established. Abundance of wild fish in Minnesota increased slowly in the 1980s but remains lower than in Wisconsin or Michigan. In much of Ontario, wild fish dominate the incidental catches in commercial fisheries, but abundances are still below target levels. Wild fish are rarely caught in the commercial fishery in Whitefish Bay where a 1985 court-ordered settlement between the state of Michigan and several native tribes deferred lake trout-restoration programs.

Though progress has been substantial, lake trout restoration still requires:

- stringent control of fisheries,
- increased control of sea lampreys, and
- better survival of stocked fish.

Fishery managers must prudently regulate the harvest of wild lake trout stocks, especially because the survival of stocked fish declined so drastically in many areas (Hansen et al. 1994a). Much has been learned since the first lake trout-restoration plan for Lake Superior was accepted in 1986 (Lake Superior Lake Trout Technical Committee 1986). Standardized stock-assessment methods, along with annual reporting of key stock statistics, are now used to measure progress in lake trout restoration. Catch data for all commercial and some sport fisheries allow documentation of sources of exploitation. A lake trout-population model allows evaluation of factors that affect lake trout restoration-such as fishing, sea lamprey predation, and stocking (Ebener et al. 1989). The model also helps with predicting the effects of management actions and with setting allowable-harvest limits.

Restoration of inshore (lean) lake trout in Lake Superior has been affected by fishing, hatchery diseases, sea lampreys, and burgeoning siscowet stocks. Fishing mortality is too high in some areas--especially where two or more agencies regulate fisheries (Hansen et al. 1995). An outbreak of epizootic epitheliotrophic disease (EED) reduced hatchery production of the 1984-87 lake trout year-classes (McAllister and Herman 1989). Sea lampreys are too abundant in some areas-especially in western Lake Superior where they killed as many lake trout as humans did in 1994 (Hansen et al. 1994b). Siscowets increased greatly in abundance and may now compete with or prey on lean lake trout. Survival of stocked yearling lake trout declined in many areas for reasons not fully understood (Hansen 1994; Hansen et al. 1994a).

This lake trout-restoration plan for Lake Superior updates a plan adopted in 1986 (Lake Superior Lake Trout Technical Committee 1986). The revised plan addresses impediments to further progress in lake trout restoration in Lake Superior and recommends future management actions based on the results of ongoing stock assessments and previous research. Lake trout restoration in Lake Superior has evolved from a program that was dominated by stocking to a program that relies on prudent management of wild lake trout stocks. The plan reflects this shift in emphasis. The plan was prepared by the Lake Superior Technical Committee (Appendix A) and accepted by the Lake Superior Committee (Appendix B).

MANAGEMENT AREAS

Lake Superior is divided into management areas for planning and reporting (Fig. 1) because lake trout stocks and the factors that affect them differ across the lake. Management areas in the United States are statistical districts (Smith et al. 1961) with borders modified to conform to statistical grids and to better reflect the total area occupied by individual lake trout stocks. Management, areas in Ontario are from the provincial quota-management plan. Adoption of grid boundaries simplifies catch reporting and data summarization.

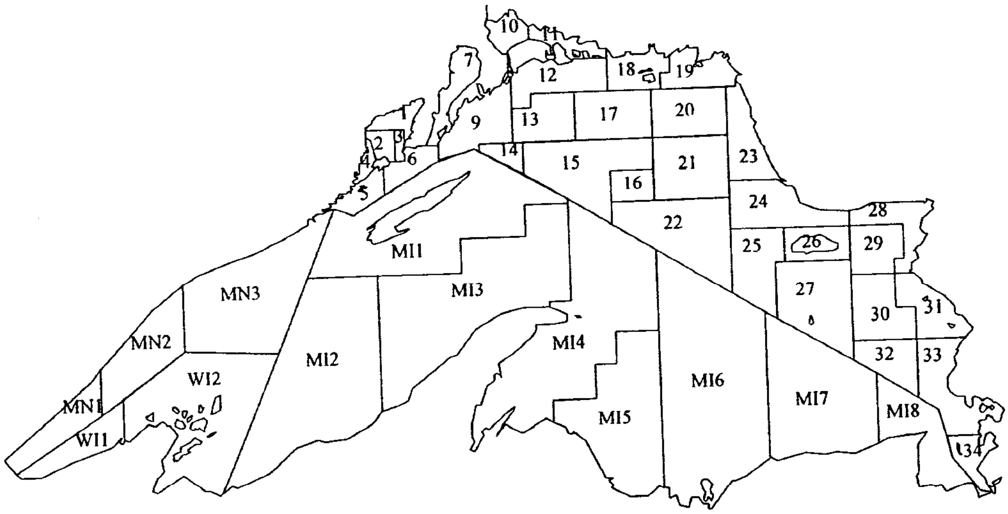

Fig 1. Lake Superior lake trout-management areas.

GOALS FOR RESTORATION

The goal of lake trout restoration in Lake Superior is to restore self-sustaining stocks that can provide an annual catch of 2 million kg (4 million lb)-the average annual yield in 1929-43 (Busiahn 1990). In the future, objectives will be developed for each of the three lake trout forms that were historically caught in Lake Superior: lean, siscowet, and humper (Bur&m-Curtis 1993; Burnham-Curtis and Smith 1994). In the interim, the goal refers only to lean lake trout. Lean lake trout typically live inshore in water shallower <73 m deep (<40 f). Siscowets typically live offshore in water ranging 50-150 m deep (27-82 f). Humper lake trout live over isolated shoals 50 m (27 f) deep surrounded by waters >100 m (>55 f) deep.

- Lean lake trout have a straight, pointed snout; slender body; and low fat content.

- Siscowets have a convex snout, robust body, and high fat content.

- Humper lake trout have a snout similar to that of the lean lake trout with large eye, thin body wall, and intermediate fat content.

To achieve the goal of lake trout restoration in Lake Superior:

- populations of parasitic sea lamprey will need to be decreased 50% by the year 2000 and 90% by the year 2010, and

- lake herring *(Coregonus artedi)* stocks will need to recover to historic (19 16-40) numbers that can sustain restored lake trout stocks (Busiahn 1990).

Lake trout restoration may fall short of the goal if sea lamprey-induced mortality does not decline or if lake herring do not recover to levels that will support self-sustaining lake trout stocks. Lake trout restoration may also fall short of the goal if other salmonine predators eat part of the lake herring production needed by lake trout. Fish-community models will be used to investigate these and other tradeoffs.

Progress toward the long-range goal should be measured by the number of recruits that are produced by the spawning stock in an individual management area. For lake trout stocks to sustain an average annual yield of 2 million kg (4 million lb), they must produce 3.6-10.1 million yearling recruits if instantaneous natural mortality is 0.10-0.25 (Sakagawa and Pycha 197 1). Lake trout-population modeling shows that natural mortality is approximately 0.12 (Ebener et al. 1989); modem lake trout stocks should, therefore, produce approximately 3.6 million recruits if the goal is to be achieved (Table 1). The number of wild recruits in an area should be estimated with the lake trout-population model for that area or with a direct measure such as trawling. Achievement of the target level of recruitment would suggest that the long-range goal for lake trout restoration in that area had been achieved.

Comparison of lake trout abundance between historic and modem times permits evaluation of the status of lake trout stocks. Hansen et al. (1995) updated previous analyses of lake trout abundance (Hile et al. 195 1; Pycha and King 1975) to directly compare lake trout abundances in Michigan and Wisconsin during 1929-93 (Fig. 2). Lake trout abundance similar to the 1929-43 average should permit restoration. Progress this way can be judged only for Michigan and Wisconsin, however, because historical lake trout data have yet to be analyzed for Minnesota and Ontario.

Table 1. Total area of lean lake trout habitat ≤73 m (≤40 f) deep and estimated numbers of wild yearling lake trout recruits necessary for sustaining restored stocks in Lake Superior management areas (assuming a 0.12 natural mortality rate).

Area	km^2	No. of recruits
MN-1	386	82,363
MN-2	80	16,981
MN-3	149	31,806
MN total	614	131,149
WI-1	520	111,126
WI-2	2,612	557,897
WI total	3,133	669,023
MI-1	481	102,718
MI-2	1,162	248,194
MI-3	455	97,076
MI-4	1,430	305,444
MI-5	756	161,462
MI-6	749	159,857
MI-7	372	79,431
MI-8	1,508	321,983
MI total	6,912	1,476,164
ON-1,2,3, and 4	689	147,135
ON-4 and 5	212	45,357
ON-6	62	13,275
ON-7	210	44,804
ON-7 and 8	171	36,507
ON-9, 12, and 13	373	79,652
ON-10 and 11	355	75,780
ON-l 1	220	47,017
ON-14	21	4,425
ON-17 and 18	161	34,295
ON-16	34	7,191
ON-l 9 and 20	262	55,867
ON-23 and 24	280	59,739
ON-25,26, and 27	855	182,536
ON-28,29,30, and 31	738	157,644
ON-33	1,015	216,831
ON-34	412	87,949
ON-34	129	27,657
ON total	6,198	1,323,664
Lake total	16,856	3,600,000

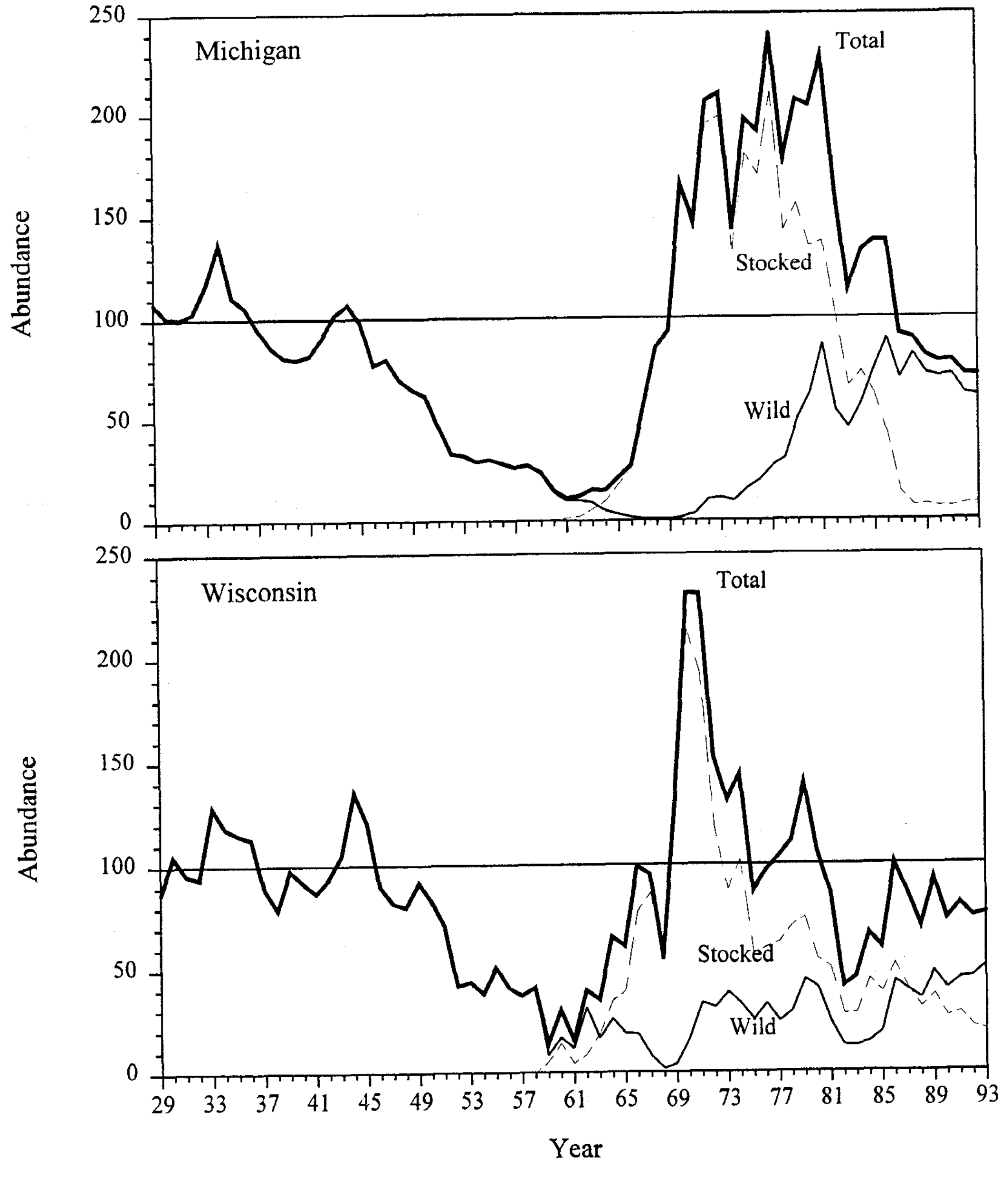

Fig. 2. Abundance of lake trout in Michigan and Wisconsin waters of Lake Superior during 1929-93 (Hansen et al. 1995). The horizontal line depicts the 1929-43 average.

ISSUES AND STRATEGIES

Control Fishery Exploitation

Fishery-management agencies should limit the harvest of lake trout-especially of spawning-sized fish-that is, those ≥ 64 cm (≥ 25 in) in length-so that total mortality on adults is less <45% per yr. In the 1950s, before the sea lamprey invaded, excessive fishing mortality caused lake trout stocks to collapse in Lake Superior (Hile et al. 195 1; Pycha and Ring 1975; Jensen 1978; Coble et al. 1990). Fishing mortality can still affect progress on lake trout restoration (Hansen 1994). Self-sustaining lake trout stocks now exist in much of Lake Superior, and 8 to 20 year-classes of wild spawners use many spawning reefs (Hansen et al. 1995). Excessive fishing mortality inhibits recovery and causes stocks to decline. Fishery managers should continue to protect all stocks of spawning-sized fish (including lean, siscowet, and humper forms) within a management area.

The plan target for total mortality is a compromise between the value that most quickly restores the stock (no fishing mortality) and the value that allows the maximum sustainable yield (Ricker 1975). The total mortality target was 50% in the previous version of the lake trout-restoration plan because Healey (1978) suggested that a lake trout stock that suffered >50% total mortality would decline. That value was reduced to 45% because the simulated (modelled) abundance of lake trout spawners declined when mortality exceeded 45% but increased when mortality was <45% (Technical Fisheries Review Committee 1992; Ebener et al. 1989).

Low fishing mortality (10%- 15%) is recommended for species such as lake trout that live long, grow slowly, and mature late (Ricker 1975). Historically, the failure to adequately control exploitation of such species occurred partly because managers and fishers believed that high yields were sustainable (Hilborn and Walters 1992). As a result, commercial fisheries frequently overfished a stock to a point where recovery was inhibited before declining catch rates forced switching to a new stock. A major challenge for fishery managers will be to convince commercial fishers and anglers not to increase their catch when fishing is temporarily good. Failure to convince them will:

- impede restoration,
- cause large variations in catch, and
- limit yield

Total annual mortality should be partitioned into natural, sea lamprey-induced, and fishing-induced components for fishery management. The population model, used to predict allowable-harvest limits, estimates fishing mortality by subtracting natural and sea lamprey-induced mortalities from total annual mortality (Ebener et al. 1989). Accurate estimates of natural and sea lamprey-induced mortalities are essential for predicting allowable harvests and managing the fishery. Based on simulations of lake trout-population dynamics, natural mortality of lake trout in Lake Superior is approximately 12%/yr for fish age 1 and older. Sea lamprey-induced mortality is estimated from observed wounding rates and the size-specific probabilities of lake trout surviving sea lamprey attacks.

Lake trout harvest should remain within allowable limits to protect lake trout stocks. A cohort-specific population model was used to derive allowable lake trout surpluses for management areas in the United States, including:

- Michigan areas MI-2 through MI-6,
- Minnesota areas MN-l through MN-3, and
- Wisconsin area WI-2.

Estimated allowable surpluses are used to set regulations that prevent Overharvest of lake trout stocks within each agency's jurisdiction. Ontario originally set commercial-fishery quotas that were based on the number of lake trout needed to estimate sea lamprey wounding rates but later adjusted the quotas to reflect estimates of allowable harvest.

Fishery agencies with Lake Superior jurisdiction regulate their sport- and commercial-fishery harvests in a variety of ways (Hansen et al. 1995).

- In some areas, commercial limits are based on the length of gillnets and number of trapnets used.
- In other areas, quotas are enforced by issuing tags that must be affixed to all lake trout landed by commercial fishers.
- In most areas, size and bag limits are used to restrict the harvest of lake trout by anglers, and the lake trout spawning season is closed to both sport and commercial fishing. Refuges and restricted-use areas afford added protection to specific lake trout-spawning stocks in Wisconsin. Each of these fishery-management practices protects spawning-size lake trout and helps reduce total annual mortality.

Quantifying the numbers of siscowet and lean lake trout caught in commercial and sport fisheries will allow measurement of progress in restoring lake trout. In some areas, the commercial harvest of siscowets is less restricted than that of lean lake trout. The illegal and intentional identification of lean lake trout as siscowets should, therefore, be investigated by law enforcement agencies. In addition, the harvest of leans and siscowets should be accurately quantified for all sport and commercial fisheries to ensure compliance with allowable harvest limits for leans.

Control Sea Lamprey Populations

The fish-community objective for sea lamprey populations in Lake Superior is to reduce parasitic-phase abundance 50% by the year 2000 and 90% by the year 20 10, compared to their abundance in 1990 (Busiahn 1990). The contribution of sea lamprey predation to the collapse of lake trout stocks in Lake Superior in the 1950s (Hile et al. 195 1; Pycha and King 1975; Jensen 1978; Coble et al. 1990) prompted the United States and Canadian governments to sign the Great Lakes Fishery Convention of 1955, which created the Great Lakes Fishery Commission (GLFC). One of the primary initiatives of the GLFC was to control the sea lamprey. Chemical treatments of tributaries began in the Lake Superior basin in 1958 and reduced sea lamprey abundance 87% by 1961 (Smith 1971; Smith et al. 1974). Continued chemical control, together with barriers on tributaries, has maintained this reduction in sea lamprey numbers to the present (Klar and Weise 1994). However, sea lampreys still kill as many lake trout as humans catch in some areas of Lake Superior (Hansen et al. 1994b). Further reductions in sea lamprey abundance are needed to reach the long-term goal for lake trout restoration.

The severity of sea lamprey-induced mortality on lake trout depends on lake trout size, sea lamprey size, and water temperature (Farmer 1980; Kitchell and Breck 1980; Pycha 1980; Bergstedt and Schneider 1988; Kitchell 1990; Swink 1990, 1993). Each sea lamprey can kill up to 2 1 kg (46 lb) of fish/yr—most of which occurs in October-November when feeding is greatest (Kitchell and Breck 1980). Sea lampreys prefer larger over smaller lake trout (Swink 1991), and survival from a single sea lamprey attack is inversely related to lake trout length (Swink 1990).

Fish length (cm)	Fish length (in)	Survival %
<56	<22	36
56-64	22-25	56
>64	>25	57

Sea lamprey-induced mortality of lake trout in Lake Superior was 20%-82% during 1968-78 in Michigan (Pycha 1980) and 7%-56% during 1964-76 in Wisconsin (Swanson and Swedberg 1980).

Sea lamprey-attack rates are expressed as the percentage of wounded lake trout caught in spring. Calculation of sea lamprey-induced mortality is based on the number of attacks and the probability of surviving an attack (Ebener et al. 1989), which may vary between single and multiple attacks. Improvements in mortality estimation will depend on a better understanding of survival probabilities and the relation between wounding rates and survival. Current levels of sea lamprey-induced mortality on lake trout of all sizes in Lake Superior are estimated at:

- 3%-13% for eastern United States waters,
- 5%-19% for western United States waters, and
- 0- 13% for Canadian waters.

The GLFC initiated an integrated management of sea lamprey (IMSL) program to rationalize control costs in relation to fishery benefits. Mathematical models of sea lamprey-control levels and allowable limits of lake trout harvest are currently being developed. These models incorporate data on lake trout and sea lamprey-population dynamics, wounding rates, and sea lamprey control. Sea lamprey-control specialists increased quantitative estimation of larval and adult sea lamprey numbers to validate the IMSL model and the sea lamprey-control program. Sea lamprey numbers can be further reduced by:

- applying lampricide more frequently in major sea lamprey-producing tributaries,
- treating offshore larval populations annually, and
- expanding the use of barriers.

Other new techniques, such as the release of sterilized male sea lampreys, may further enhance sea lamprey control.

Stock Hatchery-Reared Lake Trout

Stocking Criteria and Rates

Emphasis within the lake trout-restoration program in Lake Superior has shifted since the first lake trout-rehabilitation plan was adopted (Lake Superior Lake Trout Technical Committee 1986). The previous plan defined stocking priorities and rates; the new plan establishes procedures that can be used to define when stocking should cease. This change was needed because in many areas lake trout are now self-sustaining, and the survival of stocked lake trout has declined greatly (Hansen et al. 1994a). In the future, data on stocked lake trout should be used to define the effect of population density and other factors on yearling survival, which can be helpful for developing new stocking criteria. Additional work is needed to determine if either stocking lake trout at a larger average size or reducing other sources of mortality can improve survival.

Stocking strategies for individual management areas should be based on the success of lake trout restoration and the status of the fish community in each area. Bioenergetics models should be used to estimate the energy dynamics of the fish community and the number of lake trout to stock. However, the population dynamics of all predator and prey species are too poorly understood to use them for Lake Superior. Until better biological information is available, lake trout stocking in the United States (see below for stocking in Ontario) should only be pursued where:

- agencies are committed to lake trout restoration
- mortality is effectively controlled,
- stocks show progress in restoration, and
- stocked fish survive adequately.

Application of the following criteria is recommended to determine whether lake trout stocking should be discontinued in United States management areas. The criteria only apply to lake trout stocked as part of the restoration plan. Some fishery-management agencies also stock lake trout to enhance fisheries in their jurisdictions. The appropriateness of such stocking should not be evaluated under these criteria. Although stocking can be discontinued based on any one of the following criteria, all four criteria should be examined before action is taken.

1) Agency Commitment

There must be a political commitment to lake trout restoration. Stocking should be discontinued in any area where the management agency or agencies fail to support lake trout restoration.

2) Harvest Control

Agencies committed to lake trout restoration should institute programs of fishery regulation and enforcement, Discontinuance of stocking should be considered for any area where the allowable harvest is exceeded by more than 10% for three successive years.

3) Wild-Fish Abundance

Evaluation of lake trout restoration is based on the relative numbers of wild and stocked fish in the spawning stock and the stability of the wild component of the stock. Stocking should be discontinued in any area where:

- wild fish compose at least 50% of the catch of spawning-size lake trout in the spring assessment fishery,
- wild-fish abundance is stable or increases for three consecutive years.

4) Stocked-Fish Survival

Even exceptional commitment and regulatory enforcement by managers may be inadequate to ensure the survival of stocked fish in Lake Superior. Stocking should be discontinued in any area where the survival index for stocked fish falls below 1.0 for three successive years. Relative survival is calculated as the number of age-7 stocked lake trout caught per 304 m (1,000 ft) of gillnet divided by the number (in 100,000s) of lake trout stocked seven years earlier.

In management areas where these criteria show that stocking should end, agencies should inform affected users as to why the change is needed. In areas where the criteria suggest that stocking should be continued, lake trout should be stocked as shown in Table 2. These stocking rates were developed based on the survival of lake trout stocked in Lake Superior (Hansen 1988, 1989). Change in these stocking rates may be needed if fish are released at larger sizes than they were in the 1970s or mortality on lake trout changes significantly.

Table 2. Numbers and strains of yearling lake trout recommended for stocking in Minnesota (MN), Wisconsin (WI), Michigan (MI), and Ontario (ON) management areas of Lake Superior.

Area	No.	Strain
MN-I	223,800	Isle Royale
MN-2	46,200	Isle Royale
MN-3	86,400	Isle Royale
WI-1	89,400	Gull Island Shoal
WI-2	186,500	Gull Island Shoal
MI- 1	0	Isle Royale
MI-2	136,200	Gull Island Shoal
MI-3	0	Gull Island Shoal
MI-4	189,600	Marquette
MI-5	159,500	Marquette
MI-5	94,500	Marquette
MI-7	98,400	Marquette
MI-8	0	Marquette
ON-4	32,000	Michipicoten Island
ON-9	100,000	Slate Island
ON-31’	182,000	Michipicoten Island
ON-33	210,000	Michipicoten Island

‘Stocking in management area ON-31 should be decreased to 120,000 after five years

Powell and Atkinson (1992) recently reviewed lake trout stocking in Ontario waters of Lake Superior. They recommended that lake trout should not be stocked in an area if

- wild fish composed at least 50% of the lake trout catch,
- the mean age of the catch was greater than eight years, and
- the risk of excessive exploitation was low.

Exploitation risk was low if the:

- commercial lake trout-harvest quota was <0.25 kg/ha
- angler harvest was less than 0.1 kg/ha, and
- commercial lake whitefish (Coregonus clupeaformis) harvest quota in areas <91 m (50 f) was less than five times the lake trout quota.

Based on their review, the Ontario Ministry of Natural Resources (OMNR) reduced its annual stocking target for yearling lake trout from 1,820,000 in 1986 to 524,000 in 1993 (Table 2).

Brood Stocks and Strains

Fishery agencies stock lake trout only from brood stocks that originated in Lake Superior. These brood stocks should be protected from catastrophic loss. Lake trout hatcheries in the United States suffered severe losses of adults and juveniles due to an outbreak of EED in the late 1980s and early 1990s (McAllister and Herman 1989). This event illustrated the vulnerability of the lake trout restoration program to losses of brood stocks at individual hatcheries. Fishery agencies should develop strategies that do not allow a mass mortality at a single hatchery to reduce egg production of any strain >50% or to suppress the production of more than two strains.

To preserve the genetic adaptation of wild Lake Superior lake trout, only strains of native lake trout should be stocked. Strains from outside the Lake Superior basin may interbreed with wild stocks and destroy important, locally adapted traits (Ferguson 1990; Krueger and May 1991). Interbreeding between introduced and native stocks, termed outbreeding depression, could reduce genetic variability between stocks resulting in reduced fitness. Krueger and May (199 1) suggested that the consequences of outbreeding depression could be severe but acknowledged that only a few studies have documented its occurrence. They concluded that stocking is appropriate for species restoration but cautioned that stocking should end when self-sustaining stocks are restored.

Evans and Willox (199 1) inferred from model simulations that stocking lake trout could eliminate native stocks in inland lakes. They found that displacement of wild stocks might also occur when:

- the number stocked exceeded natural recruitment,
- high exploitation reduced the reproductive stock,
- stocked adults cannibalized wild juveniles,
- stocked fish interfered with spawning of wild fish, or
- stocked juveniles preyed on or competed with wild juveniles.

They recommended that the genetic integrity of wild lake trout stocks should be protected and that stocking in the presence of self-sustaining stocks should be banned.

Brood stock strains recommended for Lake Superior (Table 2) are:

- Michipicoten Island native stock for eastern Ontario waters,
- Slate Islands native stock for western Ontario waters,
- Mishibishu strain (originally from the Dog River and presently existing only in an Ontario inland lake) for Ontario rivers,
- southern Isle Royale native stock for Minnesota waters,
- Gull Island Shoal native stock for Wisconsin and Michigan waters west of the Keweenaw Peninsula, and
- inshore Michigan wild stock for Michigan waters east of the Keweenaw Peninsula.

New year-classes of each brood stock should be developed to ensure an adequate supply of eggs for production and to replace older brood stocks. Eggs should be obtained from spawning stocks in the wild. Disease policies for the Great Lakes (Hnath 1993) prevent hatcheries from bringing in wild gametes until they have been isolated for two years and shown to be disease free. Therefore, a facility is needed where gametes from wild stocks can be isolated for two years (U.S. Fish and Wildlife Service 1992). Until such a facility is available, United States federal hatcheries will develop new brood stock year-classes by making reciprocal crosses among the available year-classes of each strain. At least 50 randomly selected pairs will be mated whenever possible. When the number of pairs is limited, two consecutive year-classes will be developed and then crossed to limit inbreeding. Brood stocks will be divided randomly for holding at separate facilities.

Brood stocks in Ontario will be developed from matings between randomly selected females and males. When pairing adult fish, genetically related individuals will not be crossbred to prevent sibling mating and subsequent inbreeding. Genetic diversity of brood stocks will be maximized by randomly sampling eggs from at least 50 matings and then pooling the eggs for hatching and rearing. A final random selection of brood fish will usually occur at age 1.

Size and Age

Yearling lake trout should be stocked at the largest possible average size, such as 38-45 g (10-12/lb). In the 1960s, yearling lake trout stocked at an average size of 18-25 g (18-25/1b) reestablished self-sustaining stocks on inshore reefs in Minnesota and Michigan waters (Hansen et al. 1995). Survival of yearling lake trout stocked at this average size declined in the 1970s and 1980s (Hansen et al. 1994a). The cause of the decline in yearling lake trout survival has not been fully identified, but larger yearlings might survive better (Hansen 1994). For example, yearling lake trout, stocked at an average size of 38-45 g (10-12/lb) in the Apostle Islands in 1985, survived 3-6 times better than did young-of-the-year stocked at a size of 13 g (34/lb) (S. Schram, Wisconsin Department of Natural Resources, Lake Superior Office, 141 South 3rd Street, P. 0. Box 589, Bayfield, WI, 548 14, unpubldata). Therefore, increasing the average size at stocking to 38-45 g (10-12/lb) might improve the survival of stocked lake trout.

Fingerling and yearling lake trout, whether stocked inshore or offshore, failed to colonize offshore shoals in the Apostle Islands in Wisconsin (Krueger et al. 1986). From 1952 to 1983, more than 2.3 million fingerlings and 7.3 million yearlings were stocked in the Apostle Islands region. Stocked lake trout did not use historically important spawning shoals that lacked remnant native stocks. The lack of success in the Apostle Islands probably occurred because fingerling and yearling lake trout were not imprinted on and could not locate the offshore reefs in the area. In contrast, fingerling and yearling lake trout more easily located and colonized the inshore reefs in Minnesota and Michigan (Hansen et al. 1995).

Experimental stocking of early life stages of lake trout has provided encouraging results and should be continued. Newly fertilized eggs from wild Lake Superior spawners have been stocked on Apostle Island reefs in astro-turf bundles since 1980 to reestablish reef-specific stocks on historical, but no longer productive, offshore reefs (Swanson 1982). Early results suggest that a stocking rate of from 2,000 to 10,000 eggs/ha is needed to restore reproduction on a reef. The Minnesota Department of Natural Resources plans to stock thermally marked sac fry to reestablish a spawning stock on an inshore reef.

Prey Species

The fish-community objective for prey species in Lake Superior calls for rehabilitation of lake herring stocks to historical (19 16-40) levels of abundance to provide food for lake trout and other predators and for fishery harvest (Busiahn 1990). Agencies should establish and enforce regulations on the harvest of prey species to ensure that prey supplies are adequate for lake trout to achieve sexual maturity at a reasonably young age (Selgeby et al. 1994). Slow growth lengthens the time that lake trout are exposed to mortality before reaching sexual maturity and greatly reduces the number of spawners that survive from a given number of recruits. Optimum sustainable yields of prey species should be computed from commercial- and assessment-fishery statistics. Prey stocks should be surveyed annually, and improved methods for estimating total stock sizes should be developed (Selgeby et al. 1994). Methods for estimating prey consumption by salmonine predators are needed to assure optimal use of prey species for commercial harvest and predator food.

Coregonines were historically the most significant prey of larger lake trout in Lake Superior (Dryer et al. 1965). The lake herring was the most common coregonine caught in commercial fisheries, and because their distribution broadly overlaps that of lake trout, they were probably its major prey species. Deepwater ciscoes (Coregonus spp.)-such as the bloater (C. hoyi), kiyi (C. kiyi), and shortjaw cisco (C. zenithicus)-may have been important prey for lake trout that inhabited deep water-specially for siscowet. In the 1950s and 1960s, however, lake herring stocks declined and rainbow smelt *(Osmerus mordax)* stocks increased. As a result, rainbow smelt, an exotic species, became and remained the major prey of most inshore lake trout after 196 1. Rainbow smelt are not important prey in deep or offshore areas of Lake Superior, where they are uncommon. Since 1978, rainbow smelt stocks declined more than 50%, whereas lake herring stocks nearly reached historic abundances in some areas.

Lake trout have increased their feeding on lake herring in recent years, but consumption is not in proportion to the increased abundance of lake herring. Lake trout and other salmonine predators still eat mainly rainbow smelt in spring (Conner et al. 1993), though more lake herring are eaten in other seasons (Gallinat 1993). Lake trout living offshore eat mostly coregonines and deepwater sculpins *(Myoxocephalus thomsoni)* (Conner et al. 1993). Small juvenile lake trout prey on invertebrates. Larger juveniles-up to a length of 3 8 cm (15 in&eat small slimy sculpins *(Cottus cognatus),* rainbow smelt, opossum shrimp *(Mysis relicta)* and burrowing amphipods *(Diporeia* spp.) (Eschmeyer 1956; Dryer et al. 1965; Swedberg and Peck 1984).

Non-Native Salmonines

The fish-community objective for other salmonine predators in Lake Superior seeks to achieve an unspecified yield that maintains a predator-prey balance and allows normal growth of lake trout (Busiahn 1990). Coho salmon *(Oncorhynchus kisutch),* chinook salmon (0.

tshawytscha), pink salmon (0. gorbuscha), Atlantic salmon *(Salmo* salar), rainbow trout (0. *mykiss),* brown trout (S. trutta), and splake *(Salvelinus namaycush x S. fontinalis)* have been stocked sporadically in Lake Superior since the late 1800s and intensively since the 1950s (Peck et al. 1994). Currently, these non-native salmonines are not known to adversely affect lake trout growth or survival (Selgeby et al. 1994). However, in some areas of the lake during the 1980s, survival and growth of stocked lake trout declined-perhaps because of predation by and competition with non-native salmonines or wild lake trout (Hansen et al. 1994a, 1994b). Such potential interactions between non-native salmonines and wild lake trout should be better described to determine if changes in lake trout growth and survival were caused by interspecific competition or predation.

All non-native salmonine species except pink salmon were intentionally introduced into Lake Superior, all are stocked annually, and all but splake are reproducing. Coho salmon, rainbow trout, and chinook salmon are the most abundant species. Lake trout do not substantially overlap spatially with other salmonines, but they all consume mostly the same food, especially rainbow smelt, the principal prey species since the 1960s (Conner et al. 1993). Feeding and bioenergetics studies show that chinook salmon and lake trout diets overlap the most (Negus 1992, 1995; Conner et al. 1993). Declining lake trout growth in Michigan and Wisconsin in the 1980s (Hansen et al. 1994b) may have resulted from competition with other salmonines, such as chinook salmon-particularly if prey was limited (Negus 1992, 1995). Rainbow smelt biomass increased from 198 1 through 1986, and lake herring biomass increased from 198 1 through 1992 (Selgeby et al. 1994). Perhaps these changes caused the growth of wild lake trout to stabilize in Michigan after 1986 (Hansen et al. 1994b).

During the past decade, knowledge of the Lake Superior salmonine community has been greatly improved. Salmonine abundances, sizes, and age compositions are routinely estimated through creel surveys of sport fisheries in Minnesota and Wisconsin, parts of Michigan, and selected ports in Ontario (Peck et al. 1994). Similar data are also obtained from lake trout surveys and commercial catches in most areas (Hansen et al. 1994b). Recent studies show that most salmonines are self-sustaining (Peck et al. 1994). These studies, along with data on survival of stocked fish, may provide a basis for estimating total abundance. Surveys should be conducted annually or semiannually because abundances of some species fluctuate greatly (Wagner and Stauffer 1978; Peck and Schorfhaar 1991; Peck 1992).

Habitat

Habitat that is critical for lake trout reproduction and survival should be identified, mapped, and protected from change. Lake trout spawned historically in Lake Superior on offshore rock and rubble reefs, on rocky shorelines, on points extending into deep water, and in a few rivers (Loftus 1958; Lawrie 1978). In recent years, self-sustaining lake trout stocks have returned to many areas of Lake Superior but not to all historical spawning reefs or rivers. Successful lake trout restoration requires more than just spawning habitat. Optimal habitat is also needed for other life stages of fishes (Everhart et al. 1975). Toxic pollutants, poor water quality, watershed misuse, sedimentation, eutrophication, and residential and commercial developments can adversely affect lake trout reproduction and survival in other parts of the Lake Superior ecosystem. Accurate description of the quantity and quality of habitat required for lake trout reproduction and survival will allow restoration of these habitats where they are degraded.

ROUTINE ASSESSMENT

Lake trout abundance, mortality, wounding, growth, diet, recruitment, and harvest should be monitored annually to track the progress of restoration and to help develop management strategies. The collection, analysis, and reporting of the data for each of these statistics should be standardized.

- Abundance of stocked (fin-clipped) and wild (not fin-clipped) lake trout should be indexed in each management area from the catch per effort (CPE) for 11.4 cm (4.5 in) stretch-measure gillnets made of 210/2 nylon multifilament twine, 18 meshes deep, hung on the one-half basis, and fished in late April through May for three nights per lift. For ease of comparison, CPE from individual management areas should be multiplied by the total lake surface in a management area that is ≤73 m (≤40 f) deep.

- Total annual mortality of stocked and wild lake trout should be estimated from the right-hand limb of within-year, age-frequency catch curves based on spring gillnet assessment surveys. Mortality should be based on the first fully recruited age-class and (at least) the next four older age-classes. Ages should be based on otoliths but may be based on scales for fish ≤ 58 cm (≤23 in) in total length.

- Sea lamprey wounding rates should be expressed as the mean number of Stage A- 1 to A-3 wounds (King and Edsall 1979) per 100 lake trout caught in spring. Wounding rates should be summarized for length groups (total length) of

  - 43.2-53.1 cm (17.0-20.9 in),
  - 53.3-63.3 cm (21.0-24.9 in),
  - 63.5-73.4 cm (25.0-28.9 in), and
  - ≥73.7 cm (≥29.0 in).

- Growth of lake trout should be indexed as the average length at age 7 in spring until a more meaningful measure is developed.

- Lake trout diets, including counts and lengths of minimally digested food items, should be monitored from stomach samples collected during spring assessments. Year-round diet surveys should be conducted whenever possible.

- Recruitment of wild lake trout should be computed in each management area as the CPE in 5.1 cm (2.0 in) and 6.4 cm (2.5 in) stretch-measure gillnets of 2 10/2 nylon multifilament twine, 1.8 m (6.0 ft) high, hung on the half basis, and fished one night from late July through August. For ease of comparison, CPE from individual management areas should be multiplied by the total lake surface in a management area ≤73 m (≤40 f) deep.

- Catches of lake trout in all sport, subsistence, and commercial fisheries should be estimated for comparison to allowable-harvest limits. Creel surveys of sport fisheries should be intensified where needed in order to more precisely estimate lake trout harvest. Unreported catches in all fisheries should be investigated by law enforcement officials to document the amount of illegal lake trout harvest. Fisheries targeted for other species should be monitored to estimate the incidental kill of lake trout. The accuracy of reporting by commercial fishers should be improved where needed to better estimate the total kill of lake trout. To enhance joint management of the fishery in Ontario, the OMNR and First Nations should pursue a sharing of fishery harvest data.

RESEARCH NEEDS

The following scientific information is needed to improve the lake trout-restoration program in Lake Superior:

- Determine the composition of lean, siscowet, and humper lake trout in the historic (1929-43) commercial catches on which the 2 million kg (4 million lb) restoration goal is based. Composition data are needed to determine restoration goals for the three forms of lake trout in Lake Superior.

- Determine the probabilities of lake trout survival from single and multiple sea lamprey attacks. These probabilities are needed to estimate sea lamprey-induced mortality on lake trout and are likely only obtainable by laboratory studies.

- Determine the average age at maturity of male and female lake trout for all important wild stocks. Maturity data are needed to develop stock-specific population models and are best obtained from summer (August-September) surveys.

- Determine relative abundance, mortality, sea lamprey wounding rates, growth rates, diet composition, fecundity, recruitment rates, and stock definition for siscowet and humper lake trout. These data are needed to determine the importance of siscowet and humper lake trout in the Lake Superior ecosystem.

- Develop a dynamic model of the Lake Superior fish community (Jones et al. 1993). This model is needed to examine interactions between lake trout and other salmonine predators and their collective effects on prey-fish stocks.

- Determine the average fecundity of female lake trout for all important wild stocks. Fecundity data are needed to develop stock-specific population models and are best obtained from fall (September-October) spawning surveys.

- Determine a more meaningful expression of lake trout growth than length at age 7. Average length at age, currently used to index annual changes in growth, may not be as sensitive to changes in growth as other measures are. Other measures should be studied to determine if one or more of them should be used instead of, or in addition to, average length at age.

- Derive a new estimate of the potential yield-per-recruit from a restored lake trout stock. The potential yield per recruit was previously estimated from a 1948 collection of lake trout scales (Sakagawa and Pycha 1971). That analysis is a good benchmark for pre-collapse lake trout stocks but may be biased because scale ages likely under-estimate true ages. The analysis should be repeated using otolith-aged samples from several restored stocks of siscowet, humper and lean lake trout (for example, Isle Royale, Gull Island Shoal, Stannard Rock and Superior Shoal). Some of these samples are available, but others must be obtained.

- Determine the survival of yearling lake trout larger than those previously stocked in Lake Superior. Yearlings stocked at 18-25 g (18-25/lb)—the old target size—currently survive very poorly in Lake Superior, but larger yearlings may survive better. These estimates are only obtainable from large-scale field releases and must be made from studies on experimental stockings.

- Determine the usefulness of autopsy-based health and condition profiles for juvenile lake trout. These profiles may provide insight into the declining survival of stocked fish and may help provide a more fit hatchery product. These studies will likely involve large field releases and must be undertaken as experimental stockings.

- Determine the distribution, abundance, growth, mortality, reproduction, caloric densities, and food habits of lake trout and other salmonines throughout the lake. Fishery surveys are currently restricted to inshore areas of the lake, and little is known about offshore areas. Future attempts to model system bioenergetics will fail without an understanding of the (dominant) offshore areas. Collection of these data depends on the acquisition of a capable offshore research vessel by one or more of the agencies.

- Determine the abundances and caloric densities of prey species throughout the water column in all areas of the lake. Currently, prey species are surveyed with bottom trawls, which probably under sample fish in the water column. Data from bottom trawls should be integrated with data from midwater trawls and hydroacoustics to better estimate biomass and distribution of all species. These data are needed to reliably model the bioenergetics of the Lake Superior fish community. Modelling also depends on the acquisition of sampling equipment.

- Determine the extent that stocked and wild lake trout use known spawning grounds and develop an atlas of lake trout-spawning grounds (Goodyear et al. 1982). The atlas should rank the most suitable locations based on actual use by lake trout and on surveys of habitat suitability (substrate types, sedimentation rates, contaminants, current velocity, and depth). Side-scan sonar, SCUBA, hydroacoustics, and other methods should be used to construct maps of spawning locations (Edsall et al. 1992). The atlas should define areas critical for restoring self-sustaining lake trout stocks and display progress toward meeting the habitat objectives for Lake Superior (Busiahn 1990).

REPORTING

Technical information from routine assessments and research and recommendations to management agencies should be provided to the Lake Superior Committee in an annual report on progress in lake trout restoration. The progress report should contain information that describes:

- allowable limits of lake trout harvest,

- reported and estimated catches,

- total annual mortalities,

- relative abundance of spawners and recruits,

- growth, and

- sea lamprey wounding rates.

Annual progress reports should be synthesized every five years into a report on the state of the lake as required by guidelines from the GLFC.

REFERENCES

Bergstedt, R. A., and C. P. Schneider. 1988. Assessment of sea lamprey *(Petromyzon marinus)* predation by recovery of dead lake trout *(Salvelinus namaycush)* from Lake Ontario, 1982-85. Can. J. Fish. Aquat. Sci. 45: 1406-1410.

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

Burnham-Curtis, M. K., and G. R. Smith. 1994. Osteological evidence of genetic divergence of lake trout *(Salvelinus namaycush)* in Lake Superior. Copeia 1994: 843-850.

Busiahn, T. R. [ED.] 1990. Fish community objectives for Lake Superior. Great Lakes Fish. Comm. Spec. Pub. 90- 1. 24 p.

Coble, D. W., R. E. Bruesewitz, T. W. Fratt, and J. W. Scheirer. 1990. Lake trout, sea lampreys, and overfishing in the upper Great Lakes: a review and reanalysis. Trans. Am. Fish. Soc. 119: 985-995.

Conner, D. J., C. R. Bronte, J. H. Selgeby, and H. L. Collins. 1993. Food of salmonine predators in Lake Superior, 198 l-87. Great Lakes Fish. Comm. Tech. Rep. 59. 19 p.

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

Ebener, M. P., J. H. Selgeby, M. P. Gallinat, and M. Donofrio. 1989. Methods for determining total allowable catch of lake trout in the 1842 treaty-ceded area within Michigan waters of Lake Superior, 1990-1994. Great Lakes Indian Fish and Wildl. Comm. Admin. Rep. 89-11. 38 p.

Edsall, T. A., R. H. Brock, R. P. Bukata, J. J. Dawson, and F. J. Horvath. 1992. State-of-the-art techniques for inventory of Great Lakes aquatic habitats and resources, p. 179- 190. In W.-D. N. Busch and P. G. Sly [ed.] The development of an aquatic habitat classification system for lakes. CRC Press, Boca Raton, FL.

Eschmeyer, P. H. 1956. The early life history of lake trout in Lake Superior. Mich. Dept. Conserv. Misc. Publ. 10. 3 1 p.

Evans, D. O., and C. C. Willox. 1991. Loss of exploited indigenous populations of lake trout, *Salvelinus namaycush,* by stocking of non-native stocks. Can. J. Fish. Aquat. Sci. 48(Suppl. 1): 134-147.

Everhart, H. W., A. W. Eipper, and W. D. Youngs. 1975. Principles of fishery science. Cornell Univ. Press, Ithaca, NY. 288 p.

Farmer, G. J. 1980. Biology and physiology of feeding in adult lampreys. Can. J. Fish. Aquat. Sci. 37: 1751-1761.

Ferguson, M. M. 1990. The genetic impact of introduced fishes on native species. Can. J. Zool. 68: 1053-1057.

Gallinat, M. P. 1993. Food habits of lake trout in management units WI-2 and MI-2 of Lake Superior, 1992. Red Cliff Fish. Dept. Assess. Rep. 93-2, Bayfield, WI.

Goodyear, C. S., T. A. Edsall, D. M. Ormsby-Dempsey, G. D. Moss and P. E. Polanski. 1982. Atlas of spawning and nursery areas of great lakes fishes: vol. 2 - Lake Superior. U. S. Fish Wildl. Serv. FWS/OBS/52. Washington, DC. 114 p.

Hansen, M. J. 1988. Report to the Lake Superior committee by the Lake Superior technical committee, p. 9-22. *In* C. R. Bronte [ed.] Lake Superior Committee Annual Meeting (Minutes). March 15-16, 1988. Great Lakes Fish. Comm.

1989. Report to the Lake Superior committee by the Lake Superior technical committee, p. 43-64. *In* Lake Superior Committee Annual Meeting (Minutes). March 15, 1989. Great Lakes Fish. Comm.

1994. Dynamics of the recovery of lake trout *(Salvelinus namaycush)* in U.S. waters of Lake Superior. Ph.D. thesis. Mich. State Univ., East Lansing, MI.

Hansen, M. J., M. P. Ebener, R. G. Schorfhaar, S. T. Schram, D. R. Schreiner, and J. H. Selgeby. 1994a. Declining survival of lake trout stocked in U.S. waters of Lake Superior during 1963-1986. N. Am. J. Fish. Manage. 14: 395-402.

Hansen, M. J., M. P. Ebener, J. D. Shively, and B. L. Swanson. 1994b. Lake trout, p. 1O-30. *In* M. J. Hansen [ed.] The state of Lake Superior in 1992. Great Lakes Fish. Comm. Spec. Pub. 94-l.

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

Healey, M. C. 1978. The dynamics of exploited lake trout populations and implications for management. J. Wildl. Manage. 42: 307-328.

Hilborn, R., and C. J. Walters. 1992. Quantitative fisheries stock assessment: choice, dynamics and uncertainty. Chapman and Hall, New York, NY. 570 p.

Hile, R., P. H. Eschmeyer, and G. F. Lunger. 195 1. Status of the lake trout fishery in Lake Superior. Trans. Am. Fish. Soc. 80: 278-3 12.

Hnath, J. G. [ED.] 1993. Great Lakes fish disease control policy and model program. Great Lakes Fish. Comm. Spec. Pub. 93-l. 38 p.

Jones, M. L., J. F. Koonce, and R. O'Gorman. 1993. Sustainability of hatchery-dependent salmonine fisheries in Lake Ontario: the conflict between predator demand and prey supply. Trans. Am. Fish. Soc. 122: 1002-1018.

Jensen, A. L. 1978. Assessment of the lake trout fishery in Lake Superior, 1929-1950. Trans. Am. Fish. Soc. 107: 543-549.

King, E. L., Jr., and T. A. Edsall. 1979. Illustrated field guide for the classification of sea lamprey attack marks on Great Lakes lake trout. Great Lakes Fish. Comm. Spec. Pub. 79-l. 41 p.

Kitchell, J. F. 1990. The scope for mortality caused by sea lamprey. Trans. Am. Fish. Soc. 119: 642-648.

Kitchell, J. F., and J. E. Breck. 1980. Bioenergetics model and foraging hypothesis for sea lamprey *(Petromyzon marinus). Can.* J. Fish. Aquat. Sci. 37: 2159-2168.

Klar, G. T.. and J. G. Weise. 1994. Sea lamprey, p. 77-86. In M. J. Hansen [ed.] The state of Lake Superior in 1992. Great Lakes Fish. Comm. Spec. Pub. 94-1.

Krueger, C. C., and B. May. 199 1. Ecological and genetic effects of salmonid introductions in North America. Can. J. Fish. Aquat. Sci. 48 (Suppl. 1):66-77.

Krueger, C. C., B. L. Swanson, and J. H. Selgeby. 1986. Evaluation of hatchery-reared lake trout for reestablishment of populations in the Apostle Islands region of Lake Superior, 1960-84, p. 93-107. *In* R H. Stroud [ed.] Fish culture in fisheries management. Am. Fish. Soc. Bethesda, MD.

Lake Superior Lake Trout Technical Committee. 1986. A lake trout rehabilitation plan for Lake Superior., p. 47-62. *In* S. D. Morse [ed.] Lake Superior Committee Annual Meeting (Minutes). March 20, 1986. Great Lakes Fish. Comm.

Lawrie, A. H. 1978. The fish community of Lake Superior. J. Great Lakes Res. 4: 5 13-549.

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

1973. Lake Superior: a case history of the lake and its fisheries. Great Lakes Fish. Comm. Tech. Rep. 19. 69 p.

Loftus, K. H. 1958. Studies on river-spawning populations of lake trout in eastern Lake Superior. Trans. Am. Fish. Soc. 87: 259-277.

McAllister, P. E., and R. L. Herman. 1989. Epizootic mortality in hatchery-reared lake trout *Salvelinus namaycush* caused by a putative virus possibly of the herpesvirus group. Dis. Aquat. Org. 6: 113-l 19.

Negus, M. T. 1992. Evaluation of bioenergetics modeling in the study of predator-prey dynamics in Minnesota waters of Lake Superior. Minn. Dept. Nat. Resow. Div. Invest. Rep. 414. 65 p.

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

Peck, J. W. 1979. Utilization of traditional spawning reefs by hatchery lake trout in the upper Great Lakes. Mich. Dept. Nat. Resour. Fish. Res. Rep. 1871. 33 p.

1992. The sport fishery and contribution of hatchery trout and salmon in Lake Superior and tributaries at Marquette, Michigan, 1984-87. Mich. Dept. Nat. Resour. Fish. Res. Rep. 1975. 62 p.

Peck, J. W., W. R MacCallum, S. T. Schram, D. R. Schreiner, and J. D. Shively. 1994. Other salmonines, p. 35-52. *In* M. J. Hansen [ed.] The state of Lake Superior in 1992. Great Lakes Fish. Comm. Spec. Pub. 94-1.

Peck, J. W., and R G. Schorfhaar. 1991. Assessment and management of lake trout stocks in Michigan waters of Lake Superior. Mich. Dept. Nat. Resour. Fish. Res. Rep. 1956. *39* p.

Powell, M. J., and J. Atkinson, 1992. Lake Superior lake trout stocking review. Ont. Min. Nat. Resour., Toronto, Ontario, CANADA. 49 p.

Pycha, R. L. 1980. Changes in mortality of lake trout *(Salvelinus namaycush)* in Michigan waters of Lake Superior in relation to sea lamprey *(Petromyzon marinus)* predation, 1968-78. Can. J. Fish. Aquat. Sci. 37: 2063-2073.

Pycha, R. L., and G. R. King. 1975. Changes in the lake trout population of southern Lake Superior in relation to the fishery, the sea lamprey, and stocking, 1950-70. Great Lakes Fish. Comm. Tech. Rep. 28. 34 p.

Ricker, W. E. 1975. Computation and interpretation of biological statistics of fish populations. Fish. Res. Board Can. Bull. 191. 382 p.

Sakagawa, G. T., and Pycha, R. L. 1971. Population biology of lake trout *(Salvelinus namaycush)* of Lake Superior before 1950. J. Fish. Res. Board Can. 28: 65-71.

Selgeby, J. H., C. R. Bronte, and J. Slade. 1994. Forage species, p. 48-57. *In* M. J. Hansen [cd.] The state of Lake Superior in 1992. Great Lakes Fish. Comm. Spec. Pub. 94-l.

Smith, B. R. 1971. Sea lampreys in the Great Lakes of North America, p. 207-247. *In* M. W. Hardisty and I. C. Potter [eds.] The biology of lampreys, vol. 1. Academic Press, New York, NY.

Smith, B. R., J. J. Tibbles, and B. G. H. Johnson. 1974. Control of the sea lamprey *(Petromyzon marinus)* in Lake Superior, 1953-70. Great Lakes Fish. Comm. Tech. Rep. 26. 60 p.

Smith, S. H., H. J. Buettner, and R. Hile. 1961. Fishery statistical districts of the Great Lakes. Great Lakes Fish. Comm. Tech. Rep. 2. 24 p.

Swanson, B. L. 1982. Artificial turf as a substrate for incubating lake trout eggs on reefs in Lake Superior. Prog. Fish-Cult. 44: 109-l 11.

Swanson, B. L., and D. V. Swedberg. 1980. Decline and recovery of the Lake Superior Gull Island Reef lake trout *(Salvelinus namaycush)* population and the role of sea lamprey *(Petromyzon marinus)* predation. Can. J. Fish. Aquat. Sci. 37: 2074-2080.

Swedberg, D. V., and J. W. Peck. 1984. Food of young-of-the-year lake trout *(Salvelinus namaycush)* in Presque Isle Harbor, Lake Superior. J. Great Lakes Res. 10: 280-285.

Swink, W. D. 1990. Effect of lake trout size on survival after a single sea lamprey attack. Trans. Am. Fish. Soc. 119: 996-1002.

1991. Host-size selection by parasitic sea lampreys. Trans. Am. Fish. Soc. 120: *637-643.*

1993. Effect of water temperature on sea lamprey growth and lake trout survival. Trans. Am. Fish. Soc. 122: 1161-1166.

Technical Fisheries Review Committee. 1992. Status of the fishery resource-1991. A report by the Technical Fisheries Review Committee on the assessment of lake trout and lake whitefish in treaty-ceded waters of the upper Great Lakes: State of Michigan. Mimeo. Rep. 97 p.

United States Fish and Wildlife Service. 1992. Great Lakes lake trout broodstock management plan. U.S. Fish Wildl. Serv., Twin Cities, MN.

Wagner, W. C., and T. M. Stauffer. 1978. Survival of rainbow trout stocked in a Lake Superior tributary, 1971-1973. Mich. Dept. Nat. Resour. Fish. Res. Rep. 1859.

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