

A Guide for the Rehabilitation of Lake Trout in Lake Michigan



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A GUIDE FOR THE REHABILITATION OF LAKE TROUT IN LAKE MICHIGAN

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ABSTRACT

Over the past 40 years, efforts to rehabilitate lake trout (*Salvelinus namaycush*) populations in Lake Michigan have met with minimal success. Suspected impediments include inadequate numbers of stocked fish, suboptimal stocking practices, excessive mortality from sea lamprey (*Petromyzon marinus*) and fishing, and interactions between lake trout and native and non-native species. This guide is intended to provide technical direction for the ongoing effort to rehabilitate the lake trout population of Lake Michigan. By 2037, rehabilitated populations in specified deep- and shallow-water habitats should be phenotypically diverse, composed predominately (>75%) of wild fish for age groups <10 years old, and capable of sustaining fisheries. Stocking should be focused in priority areas of limited geographic extent that potentially have the best reproductive habitat and where exposure to mortality is lessened. In these defined areas, hatchery-reared fish should be concentrated to provide a density of adults sufficient for successful reproduction and to reestablish lake trout as a dominant local predator. Selected morphotypes introduced from Lake Superior are expected to augment the population in deep, offshore waters. Continued control of fishing and increased control of sea lamprey populations are needed to achieve the population densities required for sustainable natural reproduction. Progress toward achievement of rehabilitation should be reviewed annually and reported.

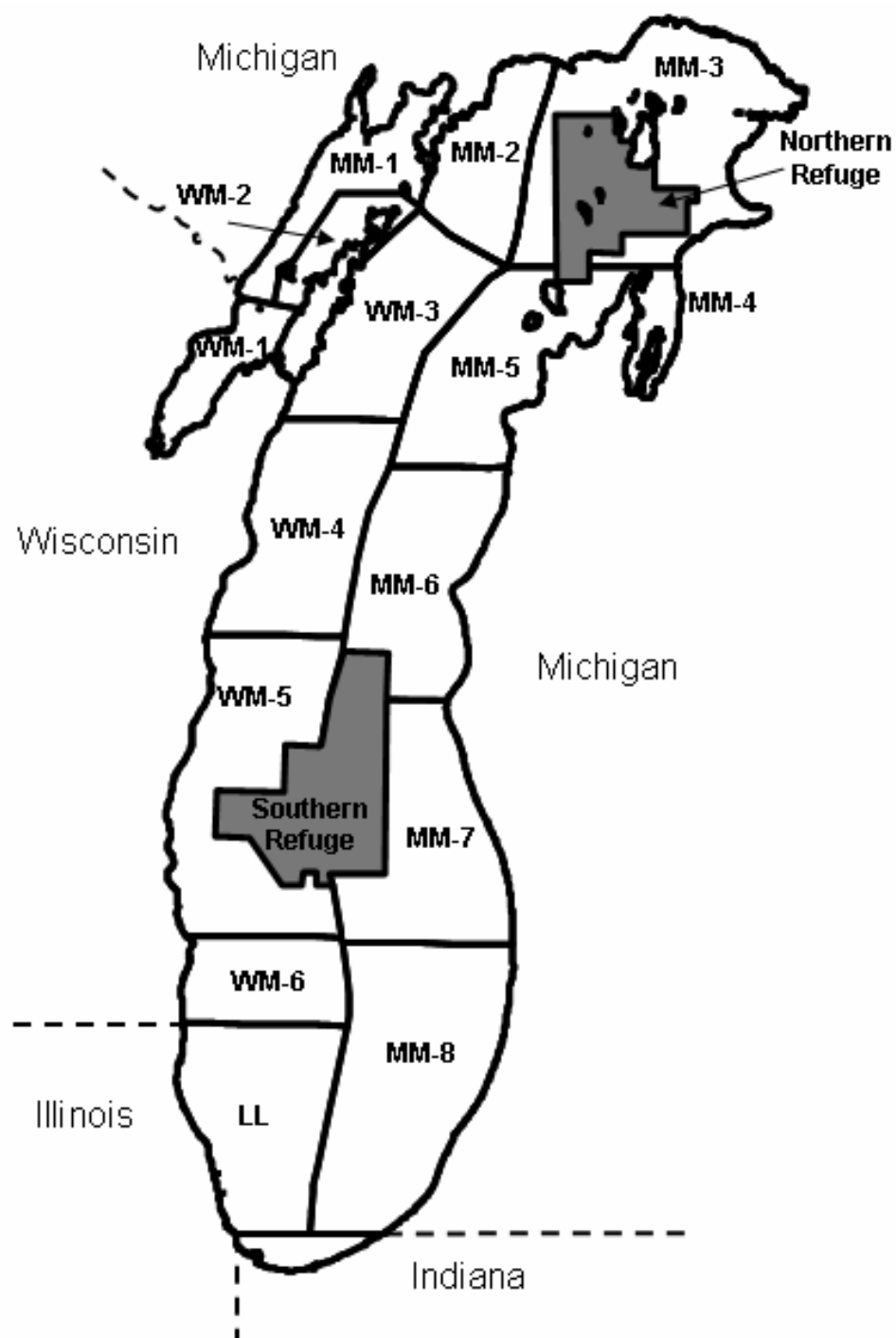


Fig. 1. Statistical districts and refuges in Lake Michigan.

INTRODUCTION

This guide provides biological recommendations to the Lake Michigan Committee (LMC) of the Great Lakes Fishery Commission (GLFC) for the rehabilitation of self-sustaining populations of lake trout (*Salvelinus namaycush*) in Lake Michigan. These recommendations were based on knowledge of the effects of past stocking and management practices, the new challenges posed by exotic species, and the fundamental role that lake trout play in Great Lakes ecosystems. This guide is the first step in a linear sequence of policy development wherein science-based technical advice is offered to policy makers (the lake committee). The second step is for the lake committee to reconcile these recommendations with a wide variety of social, economic, cultural, and political considerations to develop a policy and management approach. This guide does not take into account these other important nonbiological issues. This linear approach deliberately avoids having technical or scientific advice that is *a priori* molded, shaped, and worded to support a predetermined policy. Such molding of science and policy has impeded the rehabilitation of Pacific salmon (*Oncorhynchus* spp.) on the West Coast (e.g., Fraidenburg and Lincoln 1985). Thus, this guide should be used as biological input to a larger process of formulating lake trout policy under which fish-management agencies can implement their strategies. These recommendations represent solely the biological opinions of the authors and may or may not reflect or represent the policies of their agencies.

HISTORICAL BACKGROUND OF LAKE TROUT REHABILITATION

Lake Michigan contained one of the largest populations and fisheries for lake trout in the world just prior to the combined impacts of overfishing, sea lamprey (*Petromyzon marinus*) predation, alewife (*Alosa pseudoharengus*) invasion, and habitat degradation (Hile et al. 1951; Eschmeyer 1957; Wells and McClain 1973; Holey et al. 1995; Eshenroder and Amatangelo 2002). By the early 1950s, all lake trout populations and the diversity of forms adapted to specific areas (Brown et al. 1981) were gone, sport and commercial fisheries had collapsed, and the lake was left without its dominant native predator. In addition, populations of cisco (formerly lake herring) (*Coregonus artedii*), one of the major preys of lake trout, were being displaced by the non-native alewife and rainbow smelt (*Osmerus mordax*).

Major lake trout rehabilitation efforts in Lake Michigan began in 1965 with widespread stocking of yearling lake trout produced mostly by U.S. federal hatcheries. Fish managers assumed that these hatchery-reared fish would find and spawn on appropriate habitat, and their young would repopulate the lake. These stocked fish survived well and spawning was evident, but virtually no recruitment of wild fish to older age classes occurred. Concurrently, the introduction of Pacific salmon by the states bordering Lake Michigan (Kocik and Jones 1999) reduced alewife populations and fueled the development of popular and economically valuable sport fisheries that harvested lake trout. The increased harvest by sport fisheries, combined with targeted and incidental commercial harvest and sea lamprey predation, led to increased mortality on stocked lake trout such that the viability of the rehabilitation effort was questioned (Holey et al. 1995). A Lakewide Rehabilitation Plan (Lake Michigan Lake Trout Technical Committee 1985) was

developed, and it adopted a long-range goal “of a self-sustaining lake trout population, able to yield an annual harvest projected conservatively at 500-700 thousand fish weighing 2.5 million lbs.” In the 1985 plan, lake trout rehabilitation efforts became better focused and coordinated by:

1. Stocking promising strains at selected densities in defined rehabilitation zones
2. Establishing two large refuges (Fig. 1) that were intended to protect stocked fish from exploitation
3. Recommending a maximum total mortality target of 40%
4. Conducting experimental stockings of eggs and fry to assess their potential for re-colonizing spawning reefs

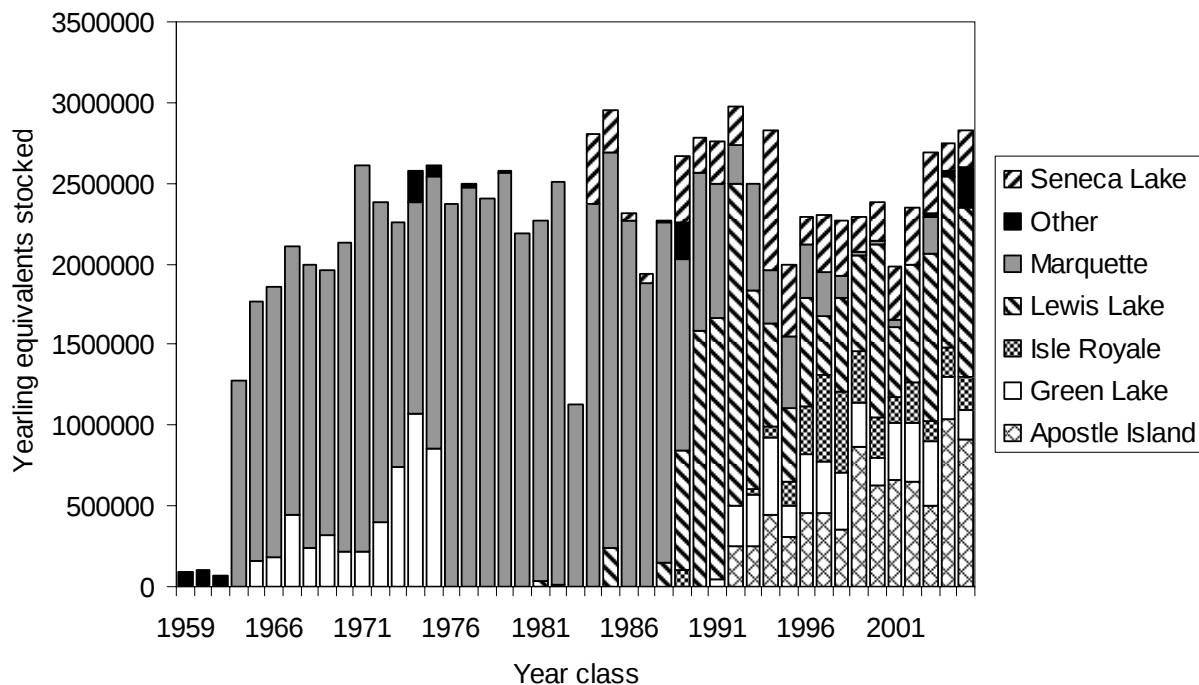


Fig. 2. Numbers of lake trout (yearling equivalents) stocked into Lake Michigan by year class and strain.

Unfortunately, full implementation of the 1985 plan was never realized. Hatchery production fell short of the recommended target of 6.2 million yearlings per year; only 2.4 million fish, on average, were stocked annually (Fig. 2). Total mortality was higher than the 40% target (Holey et al. 1995), which impeded building of adult populations. Changes in the fish-community structure and ecology of Lake Michigan also impeded successful natural reproduction and/or survival of early-life stages of lake trout. Alewife populations continued to dominate the forage base and, although reduced from historical levels, were believed to have impeded lake trout reproduction.

EVIDENCE OF NATURAL REPRODUCTION IN LAKE MICHIGAN

Although substantial natural recruitment to the adult life stage has not yet occurred in Lake Michigan, natural reproduction has been detected at a few locations. Naturally produced fry were collected from man-made rubble deposits at two locations in Grand Traverse Bay (Wagner 1981), at the Campbell Power Plant intake structure near Port Sheldon (Jude et al. 1981), and at Burns Waterway Harbor in Indiana (Marsden 1994). Viable fertilized eggs have been recovered from several locations along the east and west shorelines as well as in Traverse Bay and at Julian's Reef (Holey et al. 1995; Marsden and Janssen 1997; Jonas et al. 2005). Wild age-1+ lake trout of the 1976, 1981, and 1983 year classes were caught in Grand Traverse Bay and in nearby Platte Bay during 1983-1989 (Rybicki 1991). Additionally, natural reproduction has been observed at the mid-lake reef complex within the Southern Refuge (Fig. 1). Beginning in the mid-1990s, large numbers of mature lake trout have been netted there during the spawning season by the Wisconsin DNR, and their spawning behavior has been observed with a remotely operated vehicle. Fertilized eggs and fry were observed (video) and collected (suction sampling) from this reef complex in 2003 and 2004 (Janssen et al. 2006). These recent observations suggest that substantial natural recruitment could come from this area because of several factors: the large numbers of adults observed, the extensive area of spawning habitat, and the favorable offshore location where fishing and sea lamprey (Bronte et al. 2007) mortality are low.

WHY SHOULD LAKE TROUT BE REHABILITATED?

Several ecological and cultural reasons favor lake trout rehabilitation in Lake Michigan. First, from an ecological standpoint, lake trout, as a native species, are well-adapted to the Great Lakes. Because of their phenotypic diversity, lake trout are capable of using the wide variety of inshore and offshore habitats, including the deepest waters of the lake. This broad use of habitat allows lake trout to exploit different food resources (e.g., benthic and pelagic invertebrates and fishes), eliminates their dependence on any single prey source, and provides a stabilizing influence on the fish community. Second, from a historical perspective, lake trout supported culturally important commercial, sport, and tribal fisheries, and, once rehabilitated, the species can do so again. Even now, while in the process of rehabilitation, hatchery-reared lake trout provide fishing opportunities for anglers and treaty fishers. Third, for some individuals, lake trout have an important intrinsic value associated with being native and, therefore, warrant the efforts to reestablish them. For some anglers, catching a naturally reproduced wild fish is of greater value than catching a hatchery-reared fish. Lake trout rehabilitation, however, poses serious challenges because these fish are long lived, mature at a late age, have specialized spawning requirements, and are easily overfished. Although these characteristics make rehabilitation difficult, they make lake trout an excellent indicator of overall ecosystem health (Ryder and Edwards 1985).

MANAGEMENT ROLES AND RESPONSIBILITIES

The roles and responsibilities for the rehabilitation and management of lake trout in Lake Michigan are complex and involve state, tribal, federal, and international organizations. Lake trout freely cross jurisdictional boundaries in Lake Michigan; therefore, effective management within the waters of one management jurisdiction requires cooperation and collaboration among all entities. The states of Illinois, Indiana, Michigan, and Wisconsin and the Chippewa/Ottawa Resource Authority have management authority over lake trout. Their responsibilities pertain to the lake and its watershed and include fishery regulation, stocking (other than lake trout), water-quality regulation, physical-habitat management, and public education. This multi-jurisdictional situation is further complicated by the U.S. District Court 2000 Consent Decree (Enslen 2000), negotiated among the Sault Ste. Marie Tribe of Chippewa Indians, the Bay Mills Indian Community, the Grand Traverse Band of Ottawa and Chippewa Indians, the Little River Band of Ottawa Indians, the Little Traverse Bay Band of Odawa Indians, the U.S., and the state of Michigan. The seven parties to the decree affirmed their commitment to lake trout rehabilitation within the 1836 Treaty waters—especially to waters in northern Lake Michigan that were historically important to lake trout reproduction (Dawson et al. 1997). The decree specifies certain actions related to lake trout, including stocking and exploitation.

The federal government, through the U.S. Fish and Wildlife Service (USFWS) and the U.S. Geological Survey (USGS), is an important partner with the Lake Michigan states and tribes in lake trout rehabilitation. The USFWS is the principal federal agency responsible for the restoration of native species and their habitats and has been responsible for rearing and stocking most of the lake trout in Lake Michigan since the inception of widescale stocking. The USGS and the USFWS also provide stock assessment and research support for the rehabilitation program.

The GLFC, through the 1955 Convention on Great Lakes Fisheries, is responsible for management of sea lamprey and for assisting with the inter-jurisdictional coordination of lake trout management and research. The commission works with the service to deliver sea lamprey population assessment and control, primarily through the use of lampricides, barriers placed in streams, adult trapping, and release of sterile males. These efforts seek to minimize the damage to lake trout and other fishes caused by the sea lamprey. The commission also encourages coordination of lake trout management by bringing federal, state, and tribal parties together through the LMC and its technical committee—this guide was developed within this organizational structure. The commission also has a long-standing history of promoting research related to lake trout rehabilitation.

PROCESS USED TO DEVELOP THE GUIDE

This guide provides technical direction to assist the ongoing program of lake trout rehabilitation. To provide a framework for developing recommendations, a retrospective analysis of the impediments to rehabilitation was conducted (Bronte et al. 2003b). This analysis also considered the potential of agencies to solve well-known obstacles (e.g., sea lamprey predation) and to identify new problems (e.g. egg and fry predation by new invasive species such as round goby (*Neogobius melanostomus*)), which may impede rehabilitation. Based on this framework, actions that addressed the impediments were identified. Various studies were also recommended to provide for an evaluation of the effectiveness of the actions and for measurement of progress toward rehabilitation. These evaluations should provide critical feedback to allow for future modification of the actions.

PROPOSED GOAL AND OBJECTIVES

Goal: In targeted rehabilitation areas, reestablish genetically diverse populations of lake trout composed predominately of wild fish able to sustain fisheries.

The following objectives follow logically from the above goal.

Objective 1 (Increase genetic diversity): Increase the genetic diversity of lake trout by introducing morphotypes adapted to survive and reproduce in deep-water offshore habitats while continuing to stock a variety of shallow-water morphotypes.

Objective 2 (Increase overall abundance): By 2014, increase lake trout population densities in targeted rehabilitation areas to levels observed in other Great Lakes locations where recruitment of wild fish to the adult population has occurred. To achieve this objective, catch-per-unit-effort (CPUE) in spring assessments should consistently exceed 25 lake trout/1,000 feet of graded-mesh gillnet (2.5-6.0-inch mesh).

Objective 3 (Increase adult abundance): By 2020, increase densities of spawning adult lake trout in targeted rehabilitation areas to that observed in other Great Lakes locations where recruitment of wild fish to the adult population has occurred. To achieve this objective, CPUE in fall assessments should consistently exceed 50 lake trout/1,000 feet of graded-mesh gillnet (4.5-6.0-inch mesh).

Objective 4 (Detect deposition of viable eggs): By 2021, detect a minimum density of 500 viable eggs/m² (eggs with thiamine concentrations >4 nmol/g) in targeted rehabilitation areas stocked prior to 2008. This milestone should be achieved by 2025 in areas newly stocked, as specified in this guide.

Objective 5 (Build spawning populations): By 2024, spawning populations in targeted rehabilitation areas stocked prior to 2008 should be at least 25% female and contain 10 or more age groups older than age 7. These milestones should be achieved by 2032 in areas stocked after 2008.

Objective 6 (Detect recruitment of wild fish): Consistent recruitment of wild lake trout in targeted rehabilitation areas should occur as follows: by 2022, detect age-1 fish in bottom trawls; by 2025, detect age-3 fish in spring graded-mesh-gillnet assessments; and, by 2028, detect subadults in gillnet assessments.

Objective 7 (Achieve rehabilitation): By 2037, 75% or more of the lake trout in targeted rehabilitation areas should be age 10 or younger and of wild origin.

IMPEDIMENTS TO LAKE TROUT RESTORATION

The failure to achieve the goal and objectives of the 1985 plan indicated a need to identify and examine the factors limiting recruitment of wild lake trout. In 2000, the LMC directed its Lake Trout Task Group to review the available information on lake trout biology as a precursor to developing a list of potential impediments to rehabilitation in preparation for the development of this guide. Fourteen such impediments were examined (Bronte et al. 2003b) based, in part, on a previous identification of research priorities for lake trout rehabilitation in the Great Lakes (Eshenroder et al. 1999) and on a review of current management. The major findings of the impediment analysis, along with other, recent information, were used to develop this guide and are summarized below.

Poor Survival of Early-Life Stages

Early Mortality Syndrome (EMS): Consumption of alewife, a non-native fish, by adult lake trout causes EMS in progeny. Reducing alewife numbers in selected rehabilitation areas through predation by lake trout kept at higher densities than in the past should encourage lake trout to diversify their diet. Rehabilitation of native coregonines (e.g., cisco) should be encouraged as these fishes can serve as a prey alternative to alewife and reduce the prevalence of EMS.

Predation: Predation by native and non-native species on lake trout eggs and fry reduces potential recruitment; hence, stocking should be concentrated in selected areas to achieve the high densities of eggs and fry needed to overcome these losses.

Lakewide Population Too Low

Numbers stocked too low: The total number of lake trout stocked is low compared to the historical level of recruitment and is inadequate to repopulate the available habitat, overcome biological and environmental impediments, and compensate for the behavioral and reproductive inefficiencies of stocked fish. Stocking should be increased in selected rehabilitation areas.

Total mortality too high: Losses of stocked lake trout to sea lamprey predation and fishing have been excessive and have resulted in total mortality rates exceeding target levels. Sea lamprey control must be increased and management agencies must continue to keep fishing mortality at levels compatible with rehabilitation.

Inappropriate Stocking Practices

Stocking in the wrong places: Many sites commonly used by stocked lake trout during spawning are high-energy zones inappropriate for egg incubation. Some nearshore areas, however, are protected and were historically important for spawning. Stocking should be concentrated in areas with good spawning habitat and where populations are expected to experience low mortality.

Only yearlings stocked: The stocking program has relied almost exclusively on yearling fish; other life-history stages were never fully investigated. Stocking fry near optimal spawning habitat should be attempted in pilot studies to determine whether these life stages offer advantages over yearlings, and, if so, under what conditions.

Limited genetic diversity: The genetic diversity of stocked fish has been limited compared with the diversity present historically. This deficiency inhibited recolonization of inshore and offshore habitats and the reestablishment of historical predator-prey relationships, especially in deep water. The genetic diversity within and among lake trout forms should be increased to encourage recolonization of deep waters and offshore habitats, where fishing and sea lamprey predation are expected to be less severe.

Special Concern for EMS as an Impediment

EMS occurs when lake trout eggs are deficient in thiamine, causing direct mortality during hatching and indirect mortality afterward. Clinical signs of EMS include loss of equilibrium, swimming in a spiral or corkscrew pattern, lethargy, dark pigmentation, hyper-excitability when touched, and failure to feed (Marcquenski and Brown 1997). The presence of thiaminase (an enzyme that destroys thiamine) in alewives consumed by female lake trout is a main cause of EMS (Honeyfield et al. 2005). Low levels of thiamine also cause abnormal behavior in adult lake trout (Brown et al. 2005). Thiaminase-producing algae (Grigor et al. 1977) or bacteria (Honeyfield et al. 2002) are the suspected sources of this enzyme in the alewife food web. Studies are under way to determine if zooplankton consumption of thiaminase-producing algae or bacteria is the vector for transfer of thiaminase to alewives. Annual and spatial variations in the prevalence of EMS in lake trout, and in Pacific salmon, may result from ecosystem changes that favor elevated thiaminase activity in the lower food web.

Even though the role that thiaminase plays in EMS is not completely understood, research on lake trout captured from the wild or reared in controlled laboratory experiments have clearly shown that, when alewives are prominent in the diet, EMS impairs reproductive potential (Fitzsimons and Brown 1998; Honeyfield et al. 2005). Direct mortality of lake trout fry is observed when thiamine concentrations are below 1.5 nmol/g (Brown et al. 1998; Honeyfield et al. 2005). Indirect mortality of fry occurs when thiamine levels are below 4.0 nmol/g (Brown and Honeyfield 2004; Brown and Honeyfield 2006). Symptoms are impaired vision, reduced ability to avoid predators, susceptibility to bacterial pathogens, slower swimming speed, slower growth, and impaired immune function. Amelioration of EMS in lake trout likely requires egg thiamine levels above 4 nmol/g. Of 191 ripe females sampled from Lake Michigan during 1996-2003, the mean egg thiamine concentration was 3.4 nmol/g, and only 24% of the females were at or above

4.0 nmol/g (D. Honeyfield, personal communication, 2006). Strategies that reduce the occurrence of alewife in the diet of lake trout or decrease the availability of thiaminase to alewife need to be developed. Otherwise, poor lake trout fry survival will continue to hinder the rehabilitation effort.

RECOMMENDED MANAGEMENT ACTIONS

Stocking Locations, Strains, Life Stages, and Amounts

Action: Stock in high-priority areas that have high-quality spawning habitat and that are managed with an expectation that total mortality of lake trout will be below target levels.

Rationale: Stocking should be concentrated in areas where spawning reefs are aggregated or are protected from high-energy events and where excessive mortality is not expected. Areas of the lake identified for stocking comprise three separate regions that differ in habitat quality and mortality exposure. Historical commercial-fishing records (Dawson et al. 1997) and more-recent evaluations of stocking practices (Bronte et al. 2007) and habitat (Marsden et al. 2005) were used to prioritize regions for their ability to support lake trout rehabilitation. Most of the lake trout spawning habitat is located offshore within and around the Northern Refuge and within the Southern Refuge (Fig. 1).

First Priority. These areas have the highest likelihood of supporting self-sustaining populations. They are located predominately offshore, are mostly closed to lake trout harvest, have the largest area of quality habitat, and historically supported the largest spawning aggregations of native lake trout.

1. Shallow-water (<50-m depths), offshore reefs in statistical district MM-3, including the Northern Refuge. Reefs are grouped based on location and adjacency to neighboring reefs, as follows (Fig. 3):
 - a. West Beaver Group—Trout Island, High Island, Gull Island Shoal, and Boulder Reef
 - b. East Beaver Group—Hog Island Reef, Ile aux Galets, and Dahlia Shoal
 - c. Charlevoix Group—Irishmen's Ground, Big Reef, Fisherman Island, and Middle Ground
2. Deep-water (>50-m depths), offshore reefs that make up the mid-lake reef complex in the Southern Refuge, including nearby reefs in Illinois (Fig.3)—Sheboygan Reef, Northeast Reef, East Reef, Milwaukee Reef, and Julian's Reef (IL).
3. Deep (>50-m depths), offshore habitat on either side of the Fox Islands (Fig.3):
 - a. Inner Fox Trench—between the Fox Islands and the mainland
 - b. Outer Fox Trench—west of the Fox Islands toward the open lake

Second Priority. These locations have high likelihoods of harboring self-sustaining populations, are predominately in shallow nearshore water (some are protected by embayments), historically possessed spawning aggregations of lake trout, and have fishing regulations less protective than those in first priority areas. Specific spawning sites are listed by statistical district:

- MM-2—Point aux Barques Reef, Point Detour, and Portage Bay Reef
- MM-3—Medusa Cement Plant
- MM-4—Cherry Home, Ingalls Point, Old Mission Point, and Lee Point
- MM-5—Good Harbor Bay, Cat Head Point and Reef, North Reef, North Manitou Island, South Manitou Island, North Manitou Shoals
- WM-3—Cardy’s Reef, Whitefish Bay, Cana Island, North Bay, and Four Foot Shoal

Third Priority. All remaining areas of the lake are in this group and are considered to have a lower likelihood of allowing for self-sustaining populations. These areas have sparse spawning habitat and historically did not have aggregations of spawning lake trout.

Impediments addressed: Stocking numbers too low, stocking in the wrong places

Objectives addressed: Increase overall abundance, build spawning populations

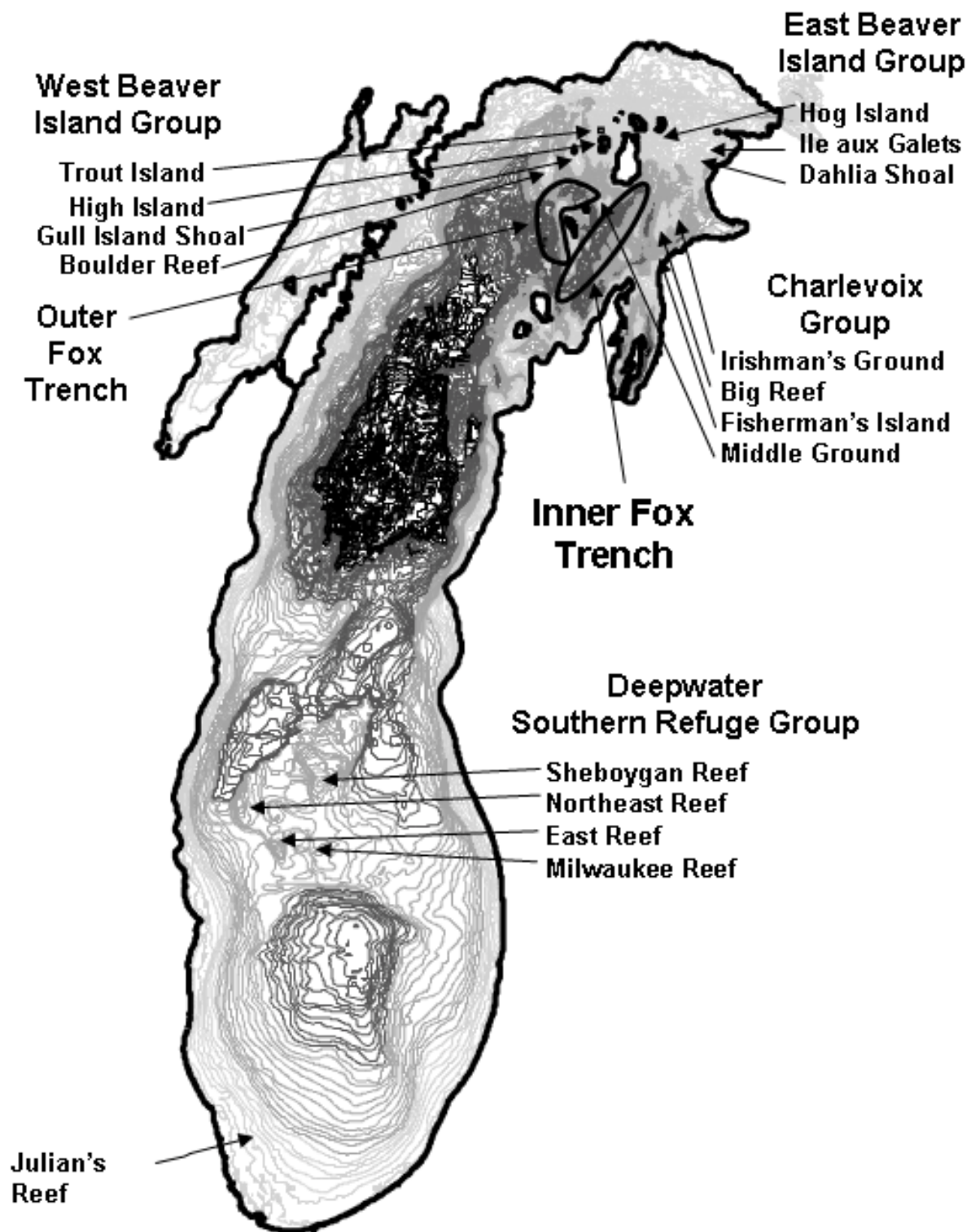


Fig. 3. First-priority rehabilitation areas to be stocked.

Action: Stock the strains listed below in equal proportions by life stage and number within each habitat type in first-priority areas:

- Shallow-water habitats (0-50-m depth; 25% each):
 - Apostle Islands (SAW; Lake Superior origin)
 - Lewis Lake (LLW; Lake Michigan origin)
 - Seneca Lake (SLW; Lake Ontario drainage)
 - Parry Sound (Lake Huron origin; brood stock under development with first year class available in 2013)
- Deep-water habitats (>50-m depth; 50% each):
 - Seneca Lake (SLW; Lake Ontario drainage)
 - Klondike Reef strain (SKW; Lake Superior origin)

Rationale: Page et al. (2004) showed that an important component of genetic diversity among wild populations in Lake Superior was organized by morphotype (lean, humper, and siscowet). These morphotypes use different habitats (e.g., shallow water, deep water, steep banks) and food sources (Lawrie and Rahrer 1972; Conner et al. 1993; Krueger and Ihssen 1995; Moore and Bronte 2001; Harvey et al. 2003). The choice of morphotypes and strains within morphotypes was based on matching the native habitats of donor sources to the deep and shallow-water habitats of Lake Michigan (Krueger et al. 1983, 1995; Lake Michigan Lake Trout Technical Committee 1985). The strains chosen also reflected new information on the greater diversity among morphotypes (lean and humper) than within morphotypes and among lake basins (e.g., Lake Superior, Lake Huron, and Seneca Lake) than within lake basins than was documented at the time of the 1985 plan.

Strains were selected from stocks capable of inhabiting both shallow (<50 m) and deep water (>50 m). They are progeny of populations that reproduced successfully either in the other Great Lakes, in inland lakes in the basin (Seneca Lake), or in lakes where Lake Michigan stocks were introduced (Lewis Lake, Wyoming). This strategy assumes that the genetic traits required for survival and reproduction are present in the hatchery stocks and will be expressed after stocking. This approach, the introduction of genotypes of geographically proximate populations, is comparable to strategies suggested for restoration of Pacific salmon and other species (Krueger et al. 1981; Miller and Kapuscinski 2003; Reisenbichler et al. 2003).

Selecting strains based on habitat preferences implies that if rehabilitation is to occur in both deep and shallow waters, different forms of lake trout need to be stocked. Many different shallow-water forms were recognized by commercial fishermen and were found on the various shallow reefs in northern Lake Michigan (Brown et al. 1981). Deep-water forms of lake trout were known in fisheries adjacent to the Beaver–Manitou Island region of northern Lake Michigan. Smith and Snell (1891) stated that the “siscowet or deep-water variety of the trout”

occurred “throughout the northern portion of the lake...especially between the Manitou and Beaver Islands. In some places fully half the trout taken are of this kind.” Shallow- and deep-water forms were also reported to occur on both sides of the northern (around Grand Traverse Bay and in the vicinity of Two Rivers, WI) and southern areas of the lake (Goode 1884) and in Illinois waters (Coberly and Horrall 1982). According to reports by commercial fishermen who fished during 1920-1950, deep-water lake trout spawned on the Sheboygan, Northeast, East, and Milwaukee Reefs over clay, gravel, and limestone outcroppings at depths of 55-79 m (cited in Brown et al. 1981).

The choice of shallow-water strains was based on knowledge of lake trout survival after stocking in Lake Michigan and elsewhere in the Great Lakes. A recent comparison of relative survival of fish recovered from spawning reefs in Lake Michigan indicated that Lewis Lake, Apostle Islands, and Seneca Lake strains survived better than the Green Lake and Superior-Isle Royale strains (Bronte et al. 2007). Based on these results, the space constraints in federal hatcheries, and the rationale described above, the former three strains are recommended for stocking the shallow-water habitats of Lake Michigan. The Marquette strain from Lake Superior had similar post-release survival as did the Lewis Lake and Seneca Lake strains, but it is being replaced by the Apostle Islands strain.

The Seneca Lake strain is recommended for stocking into both shallow- and deep-water habitats. Royce (1951) reported that lake trout in Seneca Lake spawned in water >50-m deep in late September and early October. Although, when introduced in the Great Lakes, this strain spawned in shallow water; it should retain the capability to successfully occupy deep-water habitats. The Seneca strain has survived consistently well in other Great Lakes, including Lake Michigan (Bronte et al. 2007) and has produced detectable recruitment whereas other strains did not (e.g., Grewe et al. 1994; Perkins et al. 1995; Page et al. 2003; DeKoning et al. 2006).

The Klondike strain is also recommended for stocking deep-water habitats because of the ecological similarity between deep offshore reefs in Lake Superior and the mid-lake reef complex in Lake Michigan. Klondike Reef is located about 57 km northeast of Grand Marais, MI, and is an underwater hill that ranges from 40- to 60-m deep at the top, and from 90- to 250-m deep at the bottom. The Klondike brood stock was developed from humper lake trout, a distinct form of lake trout from deep waters of Lake Superior that should be ideal for stocking the deep waters of Lake Michigan.

One new source of shallow-water lean lake trout, the Parry Sound strain, which is now under development, should be introduced into Lake Michigan. This strain is from a remnant population in Lake Huron that has rebounded since the mid-1980s (Reid et al. 2001) after fishing and sea lamprey mortality were controlled. Parry Sound has a maximum depth of 112 m and an average depth of 41 m, and, therefore, these fish should be ideal for restoring the shallow-water populations of Lake Michigan.

The siscowet lake trout is another deep-water form for future consideration. It is an important predator in Lake Superior (Lawrie and Rahrer 1973; Bronte et al. 2003a), is found typically in water deeper than 75 m (Moore and Bronte 2001; Bronte et al. 2003a), and appears to comprise multiple stocks (Bronte and Moore 2007), some of which spawn at different times of the year

(Bronte 1993). The siscowet may be ideal for re-colonizing the large amount of habitat formerly used by native deep-water lake trout in Lake Michigan, because of its consistent use of deep, offshore waters, resistance to the effects of sea lamprey mortality, potential to use a variety of habitats, and potential ability to suppress predators such as burbot (*Lota lota*) (Bronte et al. 2003a).

Impediments addressed: Limited genetic diversity

Objectives addressed: Increase genetic diversity

Action: Stock a variety of life stages (fry, fingerlings, and yearlings) to increase the potential for imprinting and the likelihood that these fish at spawning will aggregate on the highest-quality habitat and thereby decrease the time for rehabilitation.

Rationale: Life stages that are readily available for stocking are eggs or sac fry, fingerlings, and yearlings. Yearlings have been and should remain the cornerstone of the stocking program. This life stage has the highest post-release survival and contributed to the restoration of nearshore populations of Lake Superior and reproduced successfully in Lakes Ontario and Huron (Hansen 1999). Stocking fertilized eggs, fry, and fingerlings has not been widely implemented, and the results from egg stocking have been mixed (CRB and JLJ, unpubl. data). We emphasize stocking fry rather than eggs. Stocking early-life stages onto reefs will likely enhance their potential for imprinting and may result in greater densities of adults on spawning reefs (especially those offshore) than densities achieved from stocking yearlings alone. We advocate increased use and evaluation of early-life stages to enhance colonization of spawning habitats.

Fry (Experimental)	Fry (3-4 months old) stocking should be considered where returns from yearlings were poor, yet habitat and other factors indicate favorable conditions for reproduction. The goal is to place fry on optimal habitat to maximize their potential to imprint and, as adults, return for spawning. Because this technique has not been adequately tested, an experimental approach is recommended and discussed below.
Fall Fingerlings	Fingerlings (10-12 months old) are recommended for stocking in second- and third-priority areas in habitats where prospects for their survival and reproduction are highest.
Yearlings	Yearling lake trout (15-18 months old) are the preferred life stage for reintroduction and are recommended for stocking in first-priority areas. Their larger size results in better post-release survival, and this life stage is most likely to produce the adult densities required for reproduction. As more yearlings become available, they can be stocked in second- and third-priority areas after the needs of first-priority areas are met.

Adults (Experimental) Adult transfers from Lake Superior were recommended in the 1985 plan but were never undertaken. This technique has had much success in bird and mammal reintroductions worldwide and has been successful for fish introductions in small lakes. Experimental transplants of wild adult lake trout can best be made on a small, isolated reef surrounded by deep water where egg deposition and fry emergence can readily be assessed. Recent new disease outbreaks throughout the Great Lakes may limit the implementation of this approach.

Impediment addressed: Only yearlings stocked

Objectives addressed: Increase overall abundance, increase adult abundance, build spawning stocks

Action: Stock high-quality fish that are as genetically diverse as the donor stock used to create the captive broodstock.

Rationale: Hatchery rearing methods and conditions can affect the quality and survival of stocked fish. Goede's fish health index (Goede 1991) has been the standard for evaluating the quality of hatchery-reared fish. Studies at federal hatcheries around the Great Lakes indicate that factors such as fat index, percentage of abnormal eyes and fins, and condition (KTL) are significantly improved by rearing protocols that focus on fish quality rather than size. Because of these results, target criteria for selected measures of quality have been developed and adopted for the federal lake trout hatcheries that provide fish for Lakes Michigan and Huron (Table 1). Similar quality criteria are recommended for all hatcheries, including tribal and state facilities that supply lake trout to Lake Michigan, and should be further evaluated and improved.

Table 1. Quality targets established by the National Fish Hatchery System for lake trout stocked into the upper Great Lakes (based on Goede 1991).

Metric	Target
Visceral fat	85% classified with a fat index of 2.0 or greater; 0% classified with a fat index of 0.0
Eyes	≥90% classified as normal
Gills	≥90% classified as normal
Fins	≥85% classified as normal

Broodstocks and their progeny should be propagated to minimize the loss of genetic variation. The objectives over three generations are to lose <1% of genetic variability and have a 95% chance of possessing an allele that occurs at 1% in the donor stock. More details regarding genetic guidelines for the establishment of broodstocks and the propagation of fish for stocking are provided by Holey (2000), Page (2001), Miller and Kapuscinski (2003), and Reisenbichler et al. (2003).

Impediment addressed: Mortality too high, limited genetic diversity

Objectives addressed: Increase overall abundance

Actions: Stock life stages as follows:

- Stock yearling lake trout at a density of 4.5 fish/hectare (1.8 fish/acre), a density that produced positive results in Lake Huron (Reid et al. 2001). A total of 3.72 million yearling lake trout should be stocked in first-priority areas as specified in Tables 2 and 3. The National Fish Hatchery system has been the primary source of lake trout for the upper Great Lakes and is currently capable of producing about 4 million yearlings each year, of which 67% are reserved for Lake Michigan. Facility improvements are under way and, when completed, production is expected to be about 5.1 million fish.
- (Experimental) Stock sac fry of the Seneca strain at a density of 500/m² at Hog Island and Dahlia Shoal and/or at Omena Point for six consecutive years. This density is based on estimates of the number of eggs/m² needed to survive about four weeks of predation prior to the onset of winter and is intended to ensure adequate fry numbers in spring (Jonas et al. 2005). Fry are relatively easy to produce and require little hatchery space. Hatch dates should be delayed until mid-April to facilitate deployment.
- Stock fall fingerlings, as they become available, in second- and third-priority areas. Fall fingerlings often become surplus to the hatchery system as fish grow and rearing capacities are exceeded.

Rationale: During the past decade, knowledge has improved regarding the required density of stocked lake trout and the location of high-priority areas where management should focus its efforts. This improved understanding was based on analysis of historical data (e.g., Holey et al. 1995; Dawson et al. 1997) and of the potential impediments to rehabilitation (Bronte et al. 2003b). Consistent with this information and analysis, the 2000 Consent Decree directs the tribes, the state of Michigan, and the U.S. to increase stocking as soon as possible in statistical districts MM-1, MM-2, MM-3, MM-4, and MM-5 (Fig. 1) to a level consistent with lake trout rehabilitation, which amounts overall to about 1.7 million yearlings annually in these districts. Increased stocking densities should result in intensified predation on alewives, which should lessen the incidence of EMS.

Impediments addressed: Numbers stocked too low, only yearlings stocked, EMS, predation, lack of predation on egg and fry predators

Objectives addressed: Increase overall abundance, increase adult abundance

Action—Yearlings: Stock as early as practical in spring by boat at a minimum depth of 30 m adjacent to designated spawning sites (see above), and distribute fish evenly to avoid creating aggregations potentially attractive to predators. Those trout with coded wire tags (CWT) should be stocked experimentally on multiple spawning reefs. Their survival should be compared with that of CWT fish released at minimum depths of 30 m, in close proximity to but not on the reef, to test the effects of release depth on survival and rate of return as adults (Tables 2, 3).

Rationale—Yearlings: Releasing an entire tank of fish all at once may increase the vulnerability of the fish to predation by attracting predators. Spreading fish over a wider area is expected to lower predatory losses, as has been hypothesized for Lake Huron, where survival increased for year classes that were spread out when stocked by boat (Johnson et al. 2004). The ability of yearling lake trout to imprint to a stocking site has been questioned. In Lake Michigan, stocked reefs developed significantly larger spawning aggregations than reefs that were not stocked (Bronte et al. 2007). Ninety percent of CWT fish recovered during spawning were captured within a range of 24-146 km (14-90 mi) from where they were stocked. Although stocking directly on reefs appears to be effective, homing back to near the site of release may be moderate, at best, as was observed in Lake Ontario (Elrod et al. 1996). This weak tendency could be lost entirely if fish are stocked too far from spawning reefs. Survival of yearlings may be enhanced if they are released over deeper water (Johnson et al. 2004) as opposed to over shallower water on spawning reefs—deep water being the preferred habitat of age-1 lake trout (Eschmeyer 1956; Van Oosten and Eschmeyer 1956; Selgeby and Hoff 1996).

Action—Fall Fingerlings: Stock fall fingerlings in late October-early November in second- and third- priority areas in amounts that can be accommodated by hatchery production.

Rationale—Fall Fingerlings: The limited number of yearling trout available from federal hatcheries requires favoring their use in first-priority areas. Fall fingerlings, which typically experience lower post-release survival, should be used in lower-priority areas to provide fishing opportunities. These fish should be shore stocked from hatchery trucks to reduce costs associated with distribution.

Action—Sac Fry (Experimental): Stock sac fry as soon as possible after ice-out on the reefs designated above. Stock sac fry directly over high-quality spawning habitat at densities of approximating 500/m².

Rationale—Sac Fry (Experimental): Stocking of sac fry minimizes potential domestication effects associated with hatchery rearing and should enhance imprinting and subsequent return as adults. Predation on sac fry will be lessened if they can immediately hide in spawning substrates. Improved methods for planting sac fry need to be researched.

Impediments addressed: Numbers stocked too low, only yearlings stocked, predation

Objective addressed: Increase overall abundance

Action—Adults (Experimental): From the Michigan waters of Lake Superior, capture 500 lake trout in spawning condition for three consecutive years and transport them to an isolated, but accessible, offshore reef otherwise devoid of lake trout. All fish should be tagged prior to introduction into Lake Michigan, and their subsequent use of the reef for spawning and egg deposition should be monitored for five years.

Rationale—Adults (Experimental): Adult transfer addresses several challenges associated with lake trout rehabilitation. In particular, rehabilitation takes a long time in part because lake trout require five or more years to attain maturity. The proposed approach will accelerate this process by as much as 5-7 years, because the stocked fish are already mature. Natural seeding of the reef with eggs from transferred adults may occur immediately, and these eggs would have the rearing advantages associated with natural substrates (e.g., fry imprinting). If adult transfers are successful, populations could become established rapidly as has been predicted for other reintroduction programs (Sarrazin and Legendre 2000). Stocked lake trout may suffer from domestication effects (Reisenbichler et al. 2003) because they have been raised in hatcheries for up to 1.5 years and are themselves the products of domesticated brood stocks. Transplantation of wild adults avoids these effects by circumventing domestication.

Action: Deep- and shallow-water strains of lake trout should be stocked in areas of Lake Michigan (Tables 2, 3). In the Southern Refuge, stock Klondike and Seneca Lake strains in equal numbers on (over the apex) and adjacent to (45-m depth) the four principal reefs (Table 3). Stocking should be deferred at East Reef for five years from the implementation of this plan because this site already has high densities of lake trout.

Table 2. Recommended stocking levels of yearling lake trout in northern Lake Michigan by geographic area, habitat, and strain (see Fig. 3 for release site). Strains to be stocked are Lewis Lake (LLW), Seneca Lake (SLW), Apostle Islands (SAW), and Klondike Reef (SKW).

Geographic AREA	Habitat Targeted	Number by Strain			
		LLW	SLW	SAW	SKW
West Beaver Group	Shallow water, on reef	80,000	80,000	80,000	
	Shallow water, off reef	80,000	80,000	80,000	
East Beaver Group	Shallow water, on reef	80,000	80,000	80,000	
	Shallow water, off reef	80,000	80,000	80,000	
Charlevoix Group	Shallow water, on reef	40,000	40,000	40,000	
	Shallow water, off reef	40,000	40,000	40,000	
Outer Fox Trench	Deep water		200,000		200,000
Inner Fox Trench	Deep water		200,000		200,000
Total by strain		400,000	800,000	400,000	400,000

Table 3. Stocking levels by strain in the Southern Refuge and on Julian's Reef by habitat and release site. Strains are Klondike Reef (SKW) and Seneca Lake (SLW).

Geographic Area	Habitat Targeted	Number Stocked by Strain and Habitat	
		SKW	SLW
East Reef (after 5 years)	Over reef summit	100,000	100,000
	Off to side	100,000	100,000
Northeast Reef	Over reef summit	100,000	100,000
	Off to west side	100,000	100,000
Sheboygan Reef	Over reef summit	100,000	100,000
	Off to northeast side	100,000	100,000
Milwaukee Reef	Over reef summit	100,000	100,000
	Off to south side	100,000	100,000
Julian's Reef	Over reef summit	60,000	60,000
	Off to side	60,000	60,000
Total by strain		860,000	860,000

Rationale: See page 13..

Impediments addressed: Numbers stocked too low, stocking in the wrong places

Objectives addressed: Increase overall abundance, increase adult abundance, build spawning populations

Further Stocking Considerations

To ensure judicious use of the limited hatchery production of yearling lake trout, modifications to the baseline stocking strategy presented here should be implemented upon review of the performance of hatchery-reared fish and other pertinent factors. Increased priority for stocking is also recommended for areas that receive additional protection from exploitation (i.e., refuges). In reviewing the effectiveness of current stocking strategies, a variety of factors should be considered, including:

- Trends in total annual mortality (relative to the mortality objective of 40-45%)
- Return of adults to suitable spawning sites
- Trends in survival of stocked fish, particularly density-dependent declines in survival (i.e., when relative survival is 25% of the highest level)
- Magnitude and sustainability of natural recruitment in targeted locations
- Long-term trends in egg thiamine levels (relative to a threshold level of 4 nmol/gram)
- Egg-predator abundance in spawning locations (Claramunt et al. 2005)

Additional impediments addressed: Mortality too high, stocking in the wrong places, EMS

Additional objectives addressed: Increase overall abundance, increase adult abundance, build spawning populations

Diversification of Lake Trout Diet

Action: Devise a strategy to restore or enhance cisco in Lake Michigan for the purpose of lowering the prominence of alewife in lake trout diets.

Rationale: Recruitment of lake trout is most successful in those areas of the Great Lakes (Lake Superior and parts of Lake Huron) harboring healthy populations of native coregonines and exhibiting low incidences of EMS in lake trout fry. Strategies to restore or enhance cisco in Lake Michigan are consistent with efforts to provide alternative prey for top predators to reduce thiamine deficiencies in their progeny. Coregonines made up 19% by weight of the diet of Chinook salmon (*Oncorhynchus tshawytscha*) in Lake Superior during 1981-1987 (Conner et al. 1993), indicating that salmon will feed on them. In addition, strains of lake trout that live in deeper, offshore waters (Klondike), or that live deeper in the water column (i.e., Seneca Lake strain (Royce 1951; Bergstedt et al. 2003)), are more likely to encounter alternative prey like bloater (*C. hoyi*) and, thereby, are less likely to be affected by EMS.

Impediments Addressed: EMS, predation

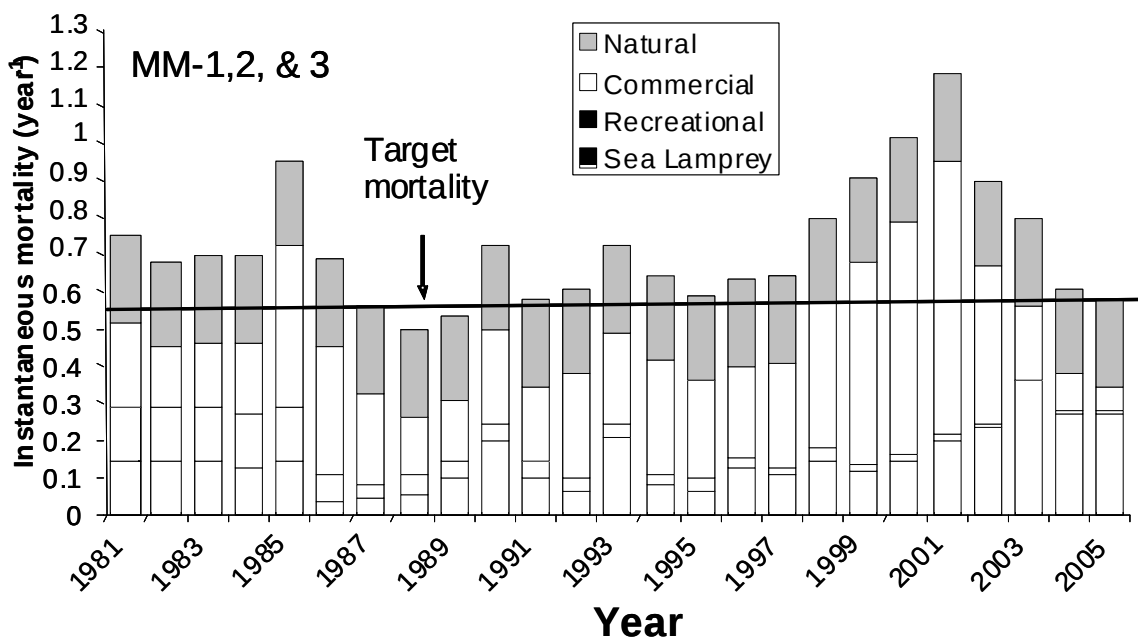
Objectives Addressed: Increase overall abundance, detect recruitment of wild fish

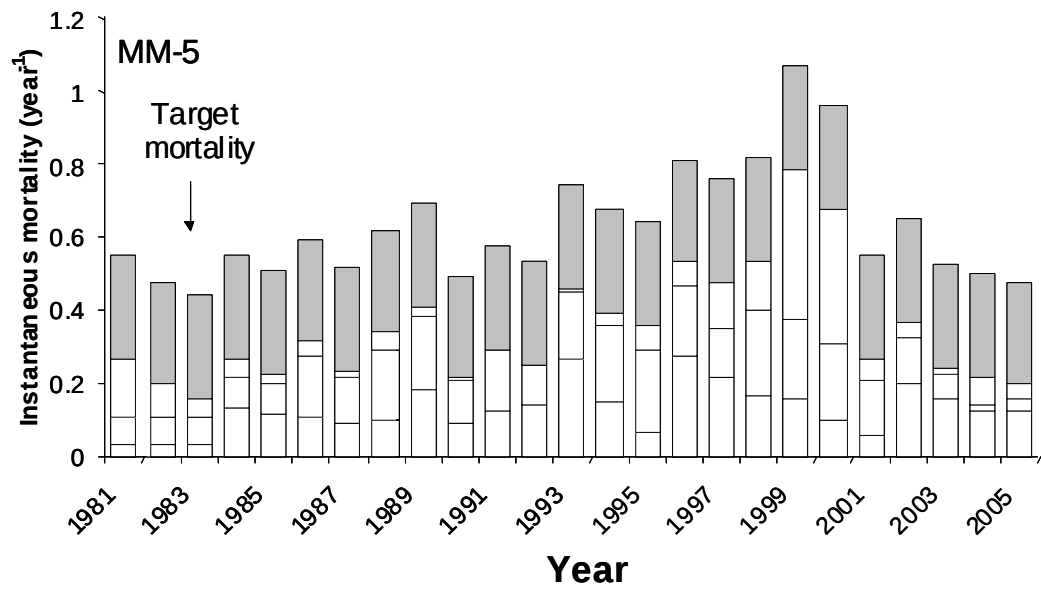
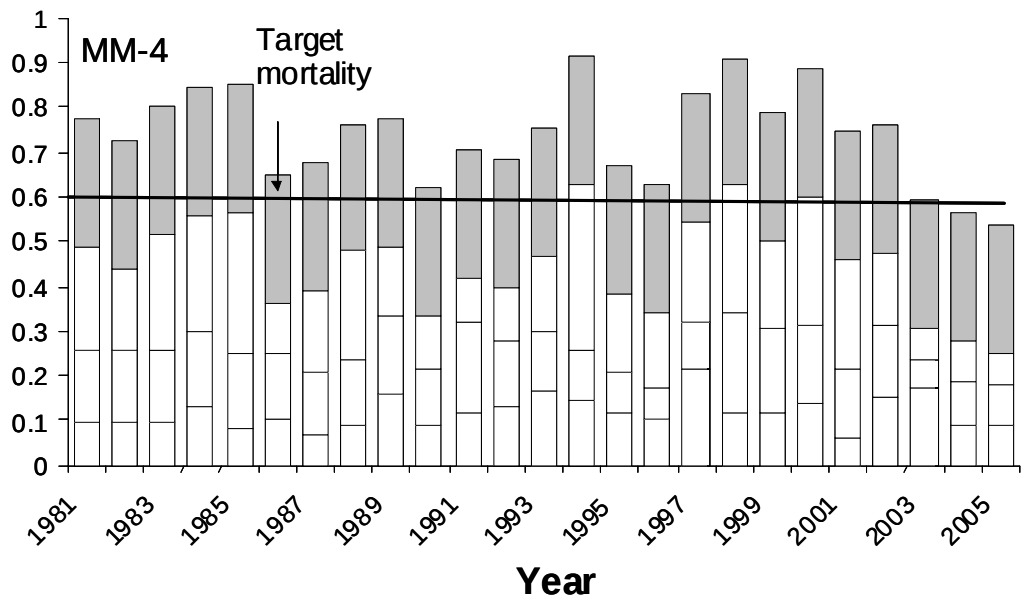
Controls on Mortality

Stocked lake trout and their progeny must be protected from overfishing if the goal and objectives of this guide are to be realized. Lake trout are long-lived, late to mature, and have low fecundity; recruitment in wild populations is likely to decrease when fishing mortality exceeds 15%. Species with these life-history attributes are sensitive to overharvest (Jennings et al. 1998; Rochet et al. 2000; Winemiller 2005). To achieve rehabilitation, conditions must allow for population expansion. Thus, rehabilitation requires that total mortality (fishing and sea lamprey) be low to allow for adequate escapement and rebuilding of parental stocks. To achieve these conditions, the restoration plan for Lake Superior (Hansen 1996) recommended a maximum allowable mortality of 45%, and the 1985 plan for Lake Michigan (Lake Michigan Lake Trout Technical Committee 1985) recommended a maximum mortality of 40%. Both of these mortality rates are lower than the 50% total mortality suggested by Healey (1978) for self-sustaining populations and, therefore, appear to be compatible with rehabilitation (Nieland 2006). We recommend that total mortality on adult lake should not exceed 40% in Lake Michigan. Estimates of total mortality and its constituent parts, based on statistical catch-at-age (SCAA) models for the 1836 treaty waters of Lake Michigan, are given in Fig. 4. These estimates indicate that natural mortality has ranged from 18-27%, while mortality from sea lamprey predation has

ranged from 6-22%. Significant decreases in fishing mortality beginning in 2002 resulted from the resolve of the parties to implement the coordinated management called for in the 2000 Consent Decree.

Mortality, especially that caused by fishing and sea lampreys, should be reduced even further. Fisheries targeted on lake trout should be avoided prior to establishment of self-sustaining populations. Population recovered will be impeded if excessive mortality of subadults and adults is permitted. Control of all forms of mortality, such as from sea lampreys, is important, but fishing mortality is typically the one component of overall mortality that managers can most readily control (Krueger and Ebener 2004). Refuge status (no harvest) and severe angling restrictions were believed to be responsible for the successful restoration of the Parry Sound population in Lake Huron (Reid et al. 2001) and led to a rebuilding of a depleted wild population at Gull Island Shoal, Lake Superior (Schram et al. 1995). The GLFC must maintain an effective level of sea lamprey control on Lake Michigan if lake trout population increases are to occur. Although SCAA models have not been developed to assess mortality rates in other waters, the abundance of spawning adults in the Southern Refuge and in other areas of southern Lake Michigan suggests that mortality is below the target there.





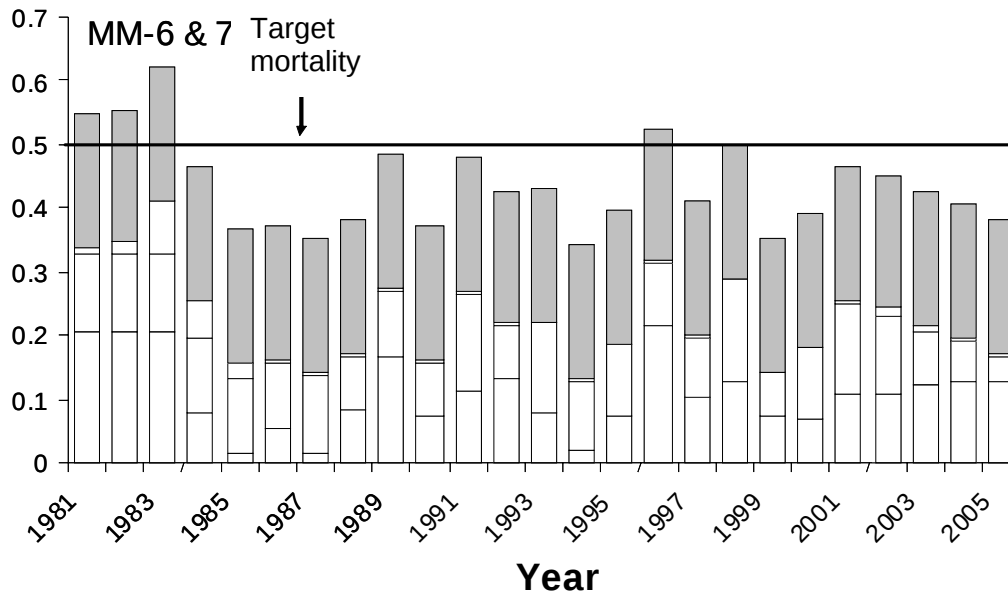


Fig. 4. Estimates of total, natural, fishing (recreational and commercial), and sea lamprey-induced annual mortality of lake trout for selected statistical districts in Lake Michigan from 1981-2005 (Modeling Subcommittee, Technical Fisheries Committee, unpubl. data).

Action: Improve sea lamprey control to reduce mortality on adult lake trout and to allow the achievement of other fish-community objectives (Eshenroder et al. 1995).

Rationale: Suppression of sea lampreys has contributed significantly to improved survival of lake trout and other salmonines in Lake Michigan. However, the sea lamprey population increased over the past two decades (Lavis et al. 2003), and its numbers have tripled since 2000. Currently, sea lampreys kill more lake trout than all fisheries combined, and this loss is considered a major impediment to lake trout rehabilitation. The LMC defined a general objective for sea lamprey calling for suppression to achieve their fish-community objectives, including lake trout rehabilitation (Eshenroder et al. 1995). The target abundance of sea lampreys compatible with the objectives was 58,000 ($\pm 13,000$). It was based on estimates of wounding rates, subsequent mortality of lake trout, and the abundance of sea lampreys during 1989-1993. Sea lamprey abundance has been consistently above this target since 2000 (Fig. 5). The GLFC increased control during 2001-2004 by treating previously untreated lentic areas and the large Manistique River system. This increase should achieve the sea lamprey population target and result in a decrease in marking on lake trout. Since the mid-1990s, Type A, Stages I-III, marks have been more frequent than the 5-marks/100 fish target, and marking overall remains on an upward trend (Fig. 6).

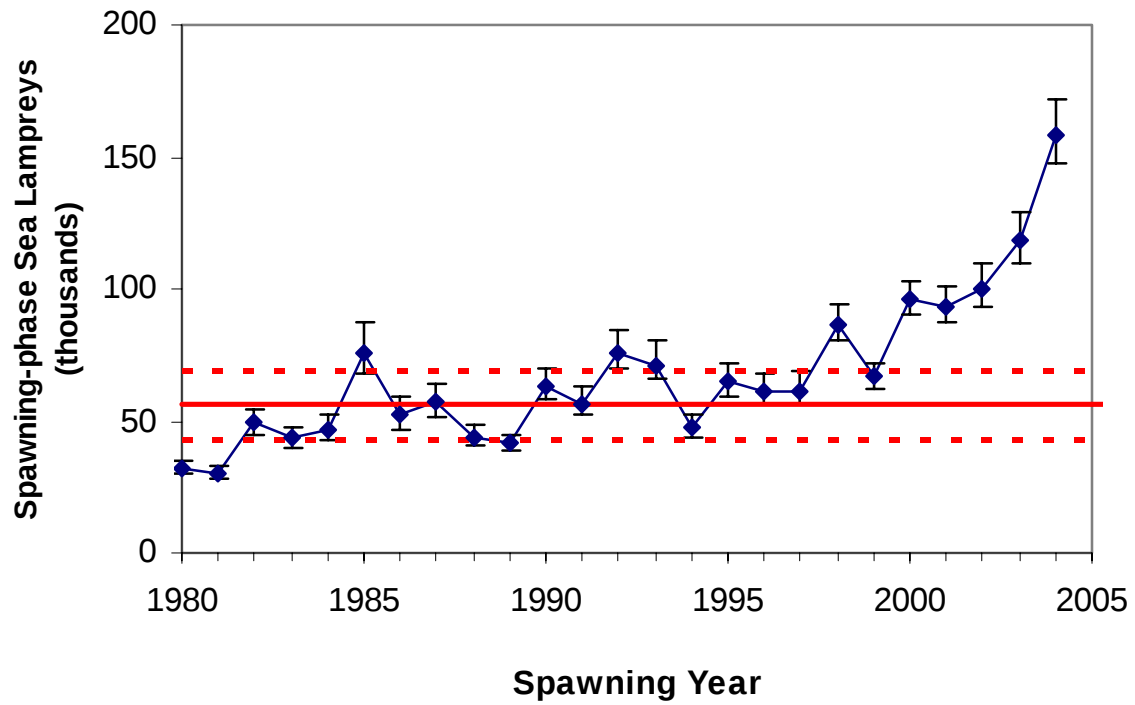


Fig. 5. Number ($\pm 95\%$ CI) of spawning-phase sea lampreys in Lake Michigan estimated from a regression model that extrapolates individual river trap catches to lakewide abundance based on river discharge and treatment history (Mullett et al. 2003). The horizontal lines represent the target abundance ($\pm 95\%$ CI).

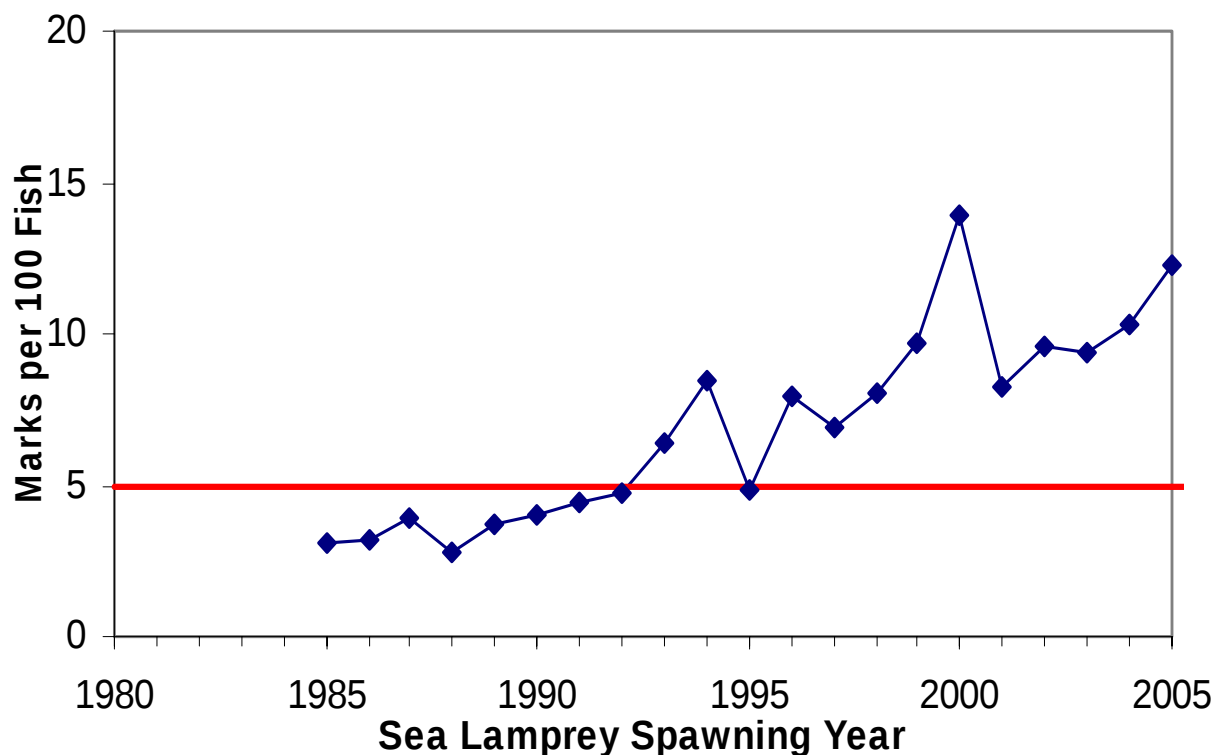


Fig. 6. Number of Type A, Stages I-III, marks per 100 lake trout >21 inches total length taken in standardized assessments during August-November. These data are plotted on the year of observation plus one to allow direct comparison to estimates of spawning-phase sea lamprey abundance (Fig. 5).

Impediments addressed: Mortality too high

Objectives addressed: Increase adult abundance, build spawning populations

Action: Regulate fisheries to protect all adult lake trout (age 7+) and all wild lake trout from overexploitation.

Rationale: Adult (age 7+) lake trout should be protected more than juvenile fish as adults can contribute immediately to reproduction. Older fish are more fecund than fish that have just matured (O’Gorman et al. 1998), so lake trout populations with old adults are better able to withstand a nominal harvest of younger adults, which are more abundant and less fecund. When possible, harvest efforts should be directed away from large, older fish. Slot size limits, which permit harvest of immature fish and minimize harvest of adult fish, should be encouraged for recreational fisheries.

Impediments addressed: Mortality too high

Objectives addressed: Increase overall abundance, increase adult abundance, build spawning populations.

Action: All unmarked lake trout (those without fin clips) should be immediately released unharmed to minimize fishing mortality on presumptive wild fish.

Rationale: The absence of fin clips on recaptured lake trout indicates that these fish were of natural origin. Although unclipped fish may be those missed during hatchery marking (marking efficiencies are about 95%), all lake trout with intact fins should be considered wild and released alive when captured in sport and commercial fisheries. Reducing fishing mortality on these fish, which presumably survived the impediment bottlenecks, increases the chance of passing the genetic and behavioral traits responsible for their survival to the next generation. This strategy is being widely used in efforts to conserve and enhance wild salmon populations along the West Coast of North America and wild steelhead (*Oncorhynchus mykiss*) populations in Lake Superior (Schreiner et al. 2006).

Impediments addressed: Mortality too high

Objectives addressed: Increase overall abundance, increase adult abundance, build spawning populations

Action: Develop SCAA models to identify regulations consistent with mortality and abundance targets.

Rationale: Political and social realities require some level of harvest concurrent with the rehabilitation effort, but such levels need to be compatible with the spirit of rehabilitation. Survey data, along with information on harvest and other losses, need to be scaled to the population level to determine population trajectories. SCAA models partition mortality among commercial and recreational fisheries, sea lamprey, and natural sources. They track how these components have changed over time and are widely viewed as a state-of-the-art approach (e.g., Fournier and Archibald 1982; Hilborn and Walters 1992; Methot 1990, 2000; National Research Council 1998; Quinn and Deriso 1999). The approach is currently employed to manage lake whitefish (*C. clupeaformis*) and lake trout fisheries in the 1836 Treaty waters of Lakes Superior, Huron, and Michigan (Modeling Subcommittee, Technical Fisheries Committee 2004) and lake trout fisheries in the Wisconsin and Minnesota waters of Lake Superior. We recommend model development for all waters of Lake Michigan to evaluate progress toward achieving rehabilitation objectives and to allow for informed decisions on allowable harvest.

Impediments addressed: Mortality too high

Objectives addressed: Increase overall abundance, increase adult abundance, build spawning populations

EVALUATION

A variety of assessment methods are needed to evaluate progress toward reaching the objectives of this guide. Some evaluations, such as the spring and fall lake trout assessments described in the Lakewide Assessment Plan (LWAP) for Lake Michigan (Schneeberger et al. 1997), are already in place. The current LWAP protocol will have to be modified to respond to any changes in stocking locations recommended in the implementation plan. Outputs from SCAA models are currently available for statistical districts in Michigan waters and should be used to evaluate progress toward achieving population objectives. Outputs of interest include population size, spawner biomass, spawner-stock-biomass per recruit, and mortality separated into sea lamprey, natural, and fishing components. Models should be developed as soon as possible for populations in other statistical districts.

Fishery agencies should make long-term commitments for evaluation to ensure that the rehabilitation program will have the needed information to guide future decision making. Agency responsibilities for conducting assessments will be developed and reviewed annually by the technical committee. Agencies should be prepared to assist each other in conducting assessments as cooperation will be critical when problems arise regarding mechanical failure of vessels, availability of crew, and constraints caused by inadequate funding. Methods for evaluating each objective follow:

Objective 1 (increase genetic diversity): The 1985 plan recommended securing, stocking, and evaluating a variety of lake trout strains to determine those best suited for colonizing Lake Michigan. To date, the strains reared and introduced have been primarily lean forms that are best adapted for shallow-water habitats. The analysis of rehabilitation impediments clearly indicated that future stocking should use a variety of strains to maximize colonization of not only shallow, but also intermediate and deep-water habitats used historically by lake trout. The national fish hatcheries currently hold a variety of lean strains and one deep-water strain. All stocked fingerling and yearling lake trout should be fin clipped to facilitate selective fisheries as recommended under harvest practices, and at least 50% should have a CWT to allow evaluation of strain performance, movements, and stocking-location effects. Fish stocked in refuges and first-priority areas should have a distinctive CWT series to evaluate their performance. All strains should be tagged for at least five consecutive years, and recapture frequencies should be evaluated for 12 years after the last year class is stocked. Reproductive performance of the different strains should be assessed genetically using mixed-stock analysis of recovered wild fish.

Objective 2 (increase overall abundance): The CPUE estimates from spring graded-mesh gillnet assessments, as described in the LWAP, should be used to evaluate progress toward reaching the target CPUEs for refuges and high-priority areas. All CPUE estimates must be accompanied by variance statistics that show the level of uncertainty.

Objective 3 (increase adult abundance): Annual CPUE estimates from the spring graded-mesh gillnet survey will serve as an index of overall status of the adult population. Fall spawner-abundance assessments will be used to measure progress toward reaching the benchmark CPUE of >50 fish/1,000 ft of gillnet on designated reefs. The frequency of such fall assessments will vary from annually to once every three to five years, depending on the age composition of the population at each reef. After SCAA models are developed for non-treaty waters, estimates of spawner biomass or potential egg deposition should also be tracked for these areas.

Objective 4 (build spawning populations): Evaluation procedures are the same as for objective 3.

Objective 5 (detect viable egg deposition): Standard egg bags should be deployed on spawning reefs to measure egg deposition as per Perkins and Krueger (1994). Bags should be retrieved and live and dead eggs counted. Selection of reefs will be made by the Lake Trout Task Group, which will request that agencies undertake the work. Egg thiamine levels should be monitored from a minimum of 16 mature females collected from representative spawning locations throughout the lake on an annual basis, and, when possible, egg thiamine levels should be measured in eggs collected in egg bags.

Objective 6 (detect recruitment of wild fish): Recruitment of juvenile and adult wild fish should be detected in the spring graded-mesh gillnet survey 2 to 4 years after recruitment of wild yearlings is detected. Beam trawling, or other appropriate procedures, should be used to sample age-1 fish during the summer in the Southern Refuge, on Julian's Reef, and on designated reefs in northern waters to provide more-immediate detection of recruitment. The fall trawl survey of forage fishes conducted by the USGS and the new summer trawl survey proposed by the USFWS will be used to detect age-2-6 wild juveniles. The absence of fin clips, slow growth as indicated on calcified structures, small size at age 1, and other potential measures, yet to be developed (e.g., stable isotopes and genetic analysis), will be used to differentiate wild from stocked fish. A tissue sample should be collected from all suspected wild fish for genetic determination of parental origin.

Objective 7 (achieve rehabilitation): Same assessments as described in objective 6.

Assessing Progress

Successful rehabilitation is dependent on the willingness of the participating agencies to cooperatively assume and carry out their respective responsibilities for producing hatchery fish; reducing sea lamprey populations; controlling fishing mortality; and collecting, processing, and analyzing data. The task group will annually review progress toward achievement of guide objectives and report findings to the Lake Michigan Committee at its March meeting. The task group may periodically propose refinements of the guide to the lake committee. The lake committee should regularly review the guide to gauge progress toward the population objectives and should consider updating its management strategy when findings suggest that changes are warranted.

Reporting

Data collected during all lake trout assessments should be archived in a single, standardized, relational database and be accessible only to participating agencies. Such data will be used to further develop SCAA models and to allow comparisons of model outputs with guide benchmarks. The task group should establish timelines, procedures, and standards for data collection, assembly, analysis, and reporting. Benchmarks should be reported by geographical units specified by the task group. The task group will create a standard format for brief written annual reports to the technical and lake committees. More-detailed reports should be prepared and presented to the lake committee every three to five years and especially at the time of the lake committee's state-of-the-lake report. These reports should be used to identify any needed changes in the guide or in the implementation plan.

Review and Revision

By 2020, a major review and revision of the guide should be conducted based on the new information obtained from annual evaluations. This scheduled review may indicate a need for changes in the implementation plan that respond to changes in the lake (i.e., invasions of new species) or to an improved understanding of community ecology and of the impediments to rehabilitation.

RESEARCH AND INFORMATION NEEDS

To overcome the impediments to lake trout rehabilitation, further research is required. The following is a list of research questions that will advance an understanding of actions required for lake trout rehabilitation. This list is not all-inclusive nor is it prioritized. The technical committee will annually review, prioritize, and make indicated changes in the list.

1. To what extent are bottlenecks in recruitment created by inadequate egg deposition and excessive mortality on eggs and fry?
2. What is the potential of early life-stage stocking to increase the effective number of lake trout stocked in Lake Michigan and/or to improve homing and reproductive responses?
3. What are the important cues (e.g., pheromones, physical characteristics of a site) used by lake trout to select locations that result in successful reproduction? Can attractants be developed to improve/increase use of appropriate spawning sites?
4. How do movements of lake trout vary by age and region?
5. What phenotypes of lake trout are best suited for reintroduction? What strains are contributing most to egg deposition, fry emergence, and recruitment?
6. How abundant are gobies on spawning reefs and what impacts do they have on lake trout reproduction?
7. What are the levels of egg deposition and egg predation on spawning reefs? Is there a level of egg deposition below which recruitment cannot be sustained?
8. What is the young-of-the-year production from sites where lake trout are spawning?

9. What are the absolute population size, spawner biomass, mortality rate, and age structure of lake trout in each management unit?
10. What is the threshold egg thiamine concentration above which lake trout fry survival is no longer impaired?
11. What is the threshold level of thiaminase in alewife below which EMS no longer impairs lake trout fry survival?
12. What is the source of thiaminase in Lake Michigan, and what environmental conditions enhance its occurrence in alewife and rainbow smelt?
13. What is the annual and regional variation in thiamine levels in lake trout eggs, and what is the relationship between thiamine levels in eggs and fry and EMS?
14. Can lines of thiaminase-resistant lake trout be developed?
15. What factors are limiting the population growth or reestablishment of cisco and deep-water coregonines in Lake Michigan?

LITERATURE CITED

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