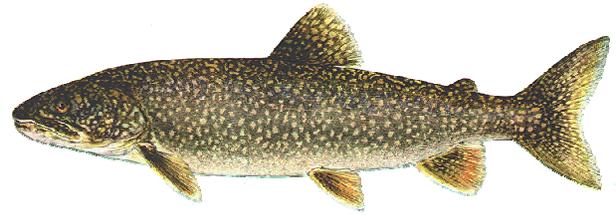


A Strategic Plan for the Rehabilitation of Lake Trout in Lake Erie, 2008-2020



Miscellaneous Publication 2008-02

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

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

COMMISSIONERS

Canada

Peter Wallace, Vice-Chair
Robert E. Hecky
Robert G. Lambe
Wendy Watson-Wright

United States

Michael J. Hansen, Chair
William James
Lyle Laverty
David A. Ullrich
William W. Taylor (Alternate)

December 2008

A Strategic Plan for the Rehabilitation of Lake Trout in Lake Erie, 2008-2020

**James L. Markham¹, Andy Cook², Tom MacDougall and Larry Witzel³, Kevin Kayle⁴,
Chuck Murray⁵, Michael Fodale⁶, Elizabeth Trometer⁷, Fraser Neave⁸, John Fitzsimons⁹,
Jim Francis¹⁰, Martin Stapanian¹¹**

Citation: Markham, J.L., Cook, A., MacDougall, T., Witzel, L. Kayle, K., Murray, M., Fodale, M., Trometer, E., Neave, F., Fitzsimons, J. Francis, J. Stapanian, M. 2008. A strategic plan for the rehabilitation of lake trout in Lake Erie, 2008-2020. Great Lakes Fish. Comm. Misc. Publ. 2008-02.

Great Lakes Fishery Commission
2100 Commonwealth Blvd., Suite 100
Ann Arbor, MI 48105-1563

December 2008

ISSN: 1090-106x (print)
1553-8087 (online)

¹**J.L. Markham.** Lake Erie Fisheries Unit, New York State Department of Environmental Conservation, 178 Point Drive North, Dunkirk, NY, 14048-1031, U.S.A.

²**H.A. Cook.** Lake Erie Management Unit, Ontario Ministry of Natural Resources, RR#2, 320 Milo Road, Wheatley, ON, N0P 2P0, Canada.

³**T. MacDougall and L. Witzel.** Lake Erie Management Unit, Ontario Ministry of Natural Resources, P.O. Box 429, Port Dover, ON, N0A 1N0, Canada.

⁴**K. Kayle.** Fairport Harbor Fisheries Research Station, , Ohio Department of Natural Resources, Division of Wildlife 1190 High Street, Fairport Harbor, OH, 44077, U.S.A.

⁵**C. Murray.** Lake Erie Research Unit, Pennsylvania Fish and Boat Commission, P.O. Box, 531, Fairview, PA, 16415, U.S.A.

⁶**M. Fodale.** Marquette Biological Station, U.S. Fish and Wildlife Service, 3090 Wright Street, Marquette, MI, 49855-9649, U.S.A.

⁷**E. Trometer.** Lower Great Lakes Fishery Resource Office. U.S. Fish and Wildlife Service. 405 N. French Road, Amherst, NY, 14228, U.S.A.

⁸**F. Neave.** Sea Lamprey Control Centre, Department of Fisheries and Oceans, 1 Canal Drive, Sault Ste. Marie, ON, P6A 6W4, Canada.

⁹**J. Fitzsimons.** Great Lakes Laboratory for Fisheries and Aquatic Sciences, Department of Fisheries and Oceans, Canada, 867 Lakeshore Road, P.O. Box 5050, Burlington, ON, L7R 4A6, Canada.

¹⁰**J. Francis.** Lake St. Clair Fisheries Station, Michigan Department of Natural Resources, 33135 S. River Road, Mount Clemens, MI, 48045, U.S.A.

¹¹**M. Stapanian.** Lake Erie Biological Station, NASA/Plum Brook Station, USGS—National Biological Service, 6100 Columbus Avenue, Sandusky, OH, 44870, U.S.A.

¹Corresponding author (e-mail: jlmarkha@gw.dec.state.ny.us).

Table of Contents

ABSTRACT	1
INTRODUCTION	1
WHY RESTORE LAKE TROUT?	2
PREVIOUS MANAGEMENT PLANS	3
HISTORY OF REHABILITATION	4
OVERVIEW OF CURRENT POPULATION	5
Stocking.....	5
Sea Lamprey Marking Rates	6
Abundance.....	8
Recruitment	11
Growth and Condition	12
Maturity	12
Survival	15
Strain Performance	17
Harvest	17
Natural Reproduction	18
IMPEDIMENTS TO LAKE TROUT REHABILITATION	19
Impediment 1: Insufficient Spawner Biomass	19
Impediment 2: Stocking Limitations	20
Impediment 3: Invasive Species	21
Impediment 4: Habitat.....	22
NEW GOALS AND OBJECTIVES	22
Purpose	22
Ultimate Goal	22
Interim Goal	23
MANAGEMENT STRATEGIES	24
ASSESSMENT NEEDS	29
INFORMATION NEEDS	31
MANAGEMENT ROLES AND RESPONSIBILITIES	32
LAKE ERIE COMMITTEE SUPPORT	33
REFERENCES	35
APPENDIX	41

ABSTRACT

This report is a revision of the original Lake Erie Lake Trout Restoration Plan of 1985. This revised plan comprises the history of lake trout (*Salvelinus namaycush*) rehabilitation efforts in Lake Erie, overview of current population, impediments to lake trout rehabilitation, new goals and objectives, and management strategies to achieve these new goals. The report also outlines assessment and research needs by jurisdiction as well as agency roles and responsibilities. The new goals recommend a combination of better sea lamprey (*Petromyzon marinus*) control, increased stocking of up to at least 200,000 yearlings annually, and identification of potential lake trout spawning areas. Other management strategies include: expanding the number of stocking sites, rotating stocking areas, maintaining genetic diversity of stocked fish, and maintaining adult survival rates of at least 60%. Progress toward rehabilitation objectives should be monitored through annual surveys and assessment of primary spawning areas with a focus on whether the goal of detecting naturally produced recruits by 2030 can be met.

INTRODUCTION

This report is an update and revision of the original Lake Erie Lake Trout Restoration Plan (Lake Trout Task Group 1985a). The original plan preceded the establishment of dreissenid mussels and other species that have been linked to major perturbations in the lake's ecosystem. Some of the perturbations were documented in a 1993 revision of the original plan (Pare 1993), but this revision was never adopted. Twenty years of additional knowledge about lake trout (*Salvelinus namaycush*), including how the species functions in the lake's fish community and the challenges of population rehabilitation, have been gained since the original plan was published. This experience and the retention of many of the goals and objectives in the original rehabilitation plan provided a framework for development of this report. This revised management plan will guide all future work toward rehabilitating a viable population of lake trout and, to be dynamic, will continue to change with advances in assessment technology, fisheries theory, and the understanding of the ecology of lake trout in Lake Erie.

In March 2006, a revision of the original plan was proposed to the Lake Erie Committee (LEC) by the Lake Erie Coldwater Task Group (CWTG). The LEC comprises a representative of each agency with responsibilities for fishery management on the lake. The revised plan was approved by the LEC in 2008. Similar reports prepared for other water bodies, in particular the Lake Michigan Lake Trout Restoration Plan (Bronte et al. 2008) and an impediments document for Lake Michigan (Bronte et al. 2003), provided valuable resource material for this revised plan.

The process for producing this revised plan involved first a redefining of the goals and objectives of the original plan. Then, impediments to rehabilitation were identified and management strategies that addressed the impediments were formulated. Next, assessments that evaluate the effectiveness of the management strategies and measure progress toward the rehabilitation goals were identified. These assessments will provide critical feedback to guide future modifications of the management strategies as this revised plan is implemented.

WHY RESTORE LAKE TROUT?

Although Lake Erie is generally considered a cool-water lake dominated by a percid fish community, native cold-water fishes, such as lake trout and lake whitefish (*Coregonus clupeaformis*), once supported important commercial fisheries (Hartman 1972) and were an important component of the ecosystem. Lake trout was the dominant cold-water predator in the eastern basin and utilized many food resources (e.g., benthic and pelagic invertebrates and fishes). Because it is not dependent on any single prey source, the lake trout can provide an important stabilizing influence on the fish community (Bronte et al. 2008). For this reason, the LEC (Ryan et al. 2003) identified the rehabilitation of lake trout as a key step in the restoration of a balanced cold-water community in the eastern basin.

Lake Erie is considered a popular destination for anglers seeking trophy-sized lake trout, despite their low abundance today. Individual hatchery-origin fish weighing over 20.0 lb are not uncommon. The current New York state record lake trout (41.5 lb) was caught in Lake Erie in 2003. Species such as lake trout have an important, intrinsic heritage value associated with being native, and, therefore, they warrant efforts, such as those recommended here, for their reestablishment. For some anglers, catching a naturally reproduced wild fish is of greater value than catching a hatchery-reared fish (Krueger et al. 1995).

Lake trout rehabilitation poses serious challenges because the species is long-lived (20+ years), matures at a late age (5-10 years), has narrow spawning requirements, and is, therefore, easily overfished (Bronte et al. 2008). Although these characteristics can make rehabilitation difficult, lake trout are an excellent indicator of overall ecosystem health (Ryder and Edwards 1985) and, if rehabilitated, should make the fish community more resilient to changes. As an ancillary benefit, the plight of lake trout and the quest for rehabilitation have brought a renewed public awareness for improved water quality and a reversal to the environmental degradation in all the Great Lakes (Kernen 1995).

PREVIOUS MANAGEMENT PLANS

Lake trout rehabilitation efforts in Lake Erie have been guided since 1985 by A Strategic Plan for the Rehabilitation of Lake Trout in Eastern Lake Erie (Lake Trout Task Group 1985a). The original 1985 plan provided a review of the decline of the lake trout population in Lake Erie, including the causes (see also Cornelius et al. 1995). The original plan also provided a good starting point for the goals and objectives in this revised plan.

The ultimate goal of the original plan was to:

Restore a naturally reproducing lake trout population in the eastern basin of Lake Erie that will eventually yield an annual harvestable surplus.

This goal was supported by three main objectives, or building blocks, that provide direction for management and research:

- By 1991, limit total annual mortality of lake trout to 40% or less
- By 2000, build an adult stock comprising about 75,000 individuals with females averaging 7.5 years of age and producing 10,000 yearlings annually
- By 2020, attain an annual harvestable surplus of 110,000 lb and an annual production of 200,000 naturally reproduced yearlings

These three objectives were measurable and allowed managers to determine progress toward achieving their goal. A rationale was provided for each of the three objectives and was based on maximum allowable mortality estimates (Schneider et al. 1983), annual yields of lake trout in Lake Erie in the 1800s before the population declined (Barnes 1982), and a Ricker-type yield model developed for eastern Lake Erie by C. Schneider (Lake Trout Task Group 1985a). The proposed strategies to accomplish the objectives included an annual stocking goal of 200,000 yearlings of suitable strains, maximizing recruitment of stocked fish, reducing annual mortality, and maximizing the reproductive potential of lake trout stocks through the identification of suitable spawning habitat. The original plan also addressed several issues/problems that needed to be considered to successfully achieve the objectives, including the potential lack of appropriate spawning habitat, inability to meet stocking needs, impaired homing of adults to suitable spawning sites, and excessive mortality due to pollution, sea lamprey (*Petromyzon marinus*) predation, and overfishing. Interestingly, all of these issues are as relevant today as they were at the time the original plan was written. Lastly, the original plan addressed the need for sufficient annual assessment to measure progress toward meeting the objectives and to guide management.

Much of the Pare (1993) plan, which was not adopted, was used to formulate this report. Pare (1993) consisted of a review of rehabilitation efforts and of available information as of 1992 and identified potential management and assessment strategies for facilitating achievement of rehabilitation goals. More importantly, Pare (1993) reaffirmed the continued commitment and cooperation of fishery agencies to lake trout rehabilitation in Lake Erie. At that time, lake trout were abundant, sea lamprey numbers were low, and rehabilitation seemed within reach. However, changes in the lake's ecological processes were occurring, which necessitated a review and a reevaluation of strategies and assessment needs. Additionally, the objectives and sub-objectives in Pare (1993) needed to be restated with revised dates for their achievement. Pare (1993) also provided an overview of the life history, infrastructure, and commitments needed to maintain lake trout stocks for successful rehabilitation.

HISTORY OF REHABILITATION

The lake trout was a major component of the fish community before colonization of the area by European settlers in the 1700s and was confined mostly to the eastern basin but was occasionally found in the central and western basins of the lake (Trautman 1981). Commercial exploitation began as early as the late-1700s, but populations did not start to decline until 1850-1900, when subjected to intense exploitation by a poorly regulated and expanding commercial fishery (Lake Trout Task Group 1985a; Cornelius et al. 1995). A directed fishery for lake trout continued into the 1930s, but catches thereafter were typically bycatch in the lake whitefish and cisco (*C. artedi*) (formerly lake herring) commercial fisheries. Habitat changes, mainly attributed to pollution-induced eutrophication, greatly increased in the 1930s (Hartman 1972) and, together with the invasion of exotic species such as sea lamprey, alewife (*Alosa pseudoharengus*), and rainbow smelt (*Osmerus mordax*) (Christie 1974), contributed to nearly eliminate lake trout by 1950. Complete loss of the native lake trout was thought to have occurred around 1965 (Cornelius et al. 1995).

Modern lake trout rehabilitation efforts began in 1969 when 17,000 yearlings were stocked by the Pennsylvania Fish Commission (PFC), and this level of stocking continued in an ad hoc manner through 1982 (Cornelius et al. 1995). Beginning in 1982, the U.S. Fish and Wildlife Service (FWS), in partnership with the New York Department of Environmental Conservation and the PFC, committed to an annual production and stocking of at least 160,000 yearlings. Sampling programs were also established then to monitor progress. Recruitment of stocked juveniles was good, but their survival to adulthood was poor due to excessive sea lamprey predation.

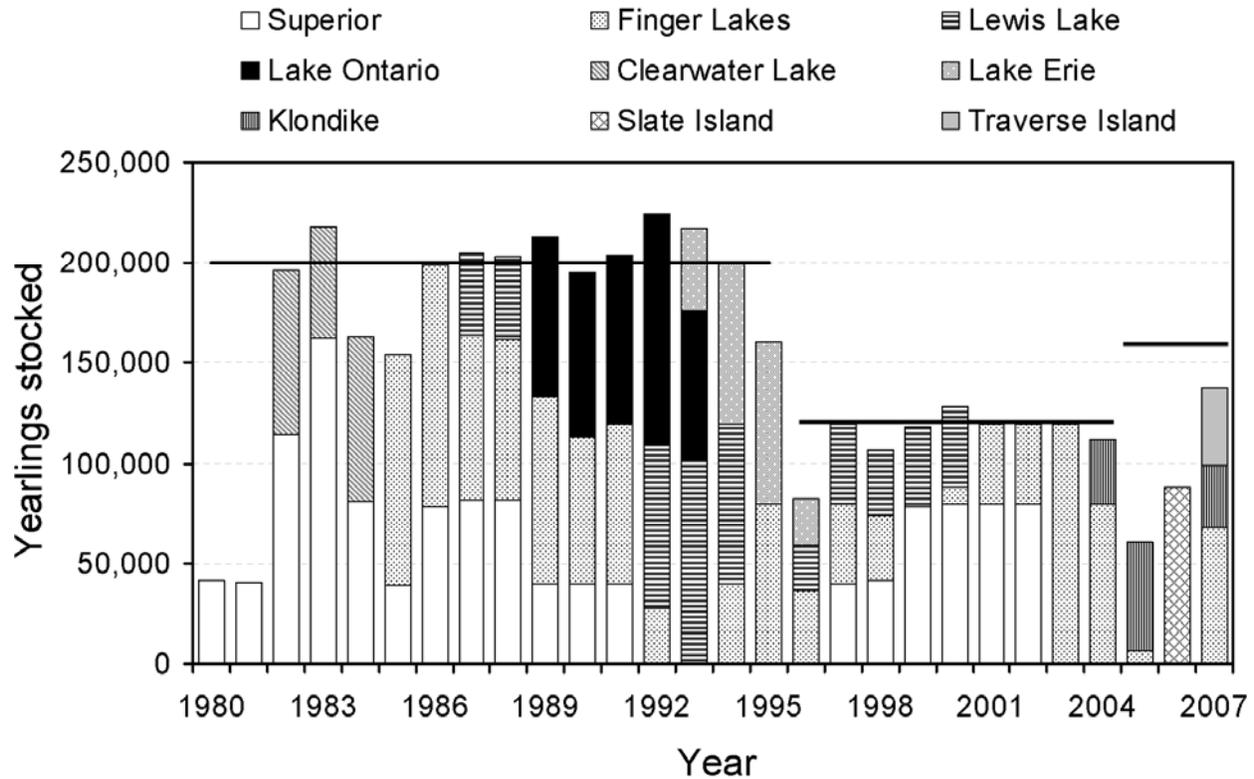
Intensification of rehabilitation efforts under the original 1985 plan and adoption and implementation of the Lake Erie Sea Lamprey Management Plan (Lake Trout Task Group 1985b) were very successful initially. Annual stockings of 200,000 yearling lake trout of several different lean strains and reductions in the abundance of sea lamprey resulted in the establishment of a large lake trout population. The adult lake trout population increased in New York's waters from zero in 1985 to over 4.5 fish/gillnet lift (one lift = 152.4 m (500 ft) of variable mesh (38-152 mm (1.5-6.0 in))) in 1990 and spawned on nearshore reefs and in harbors (Culligan et al. 1995; Fitzsimons and Williston 2000). Also promising, sea lamprey marking rates declined from over 50.0 fresh marks per 100 lake trout in 1986 to 1.0 fresh mark per 100 lake trout in 1989. These accomplishments, however, were short lived as stocking numbers were reduced from 200,000 yearlings in 1994 to 120,000 yearlings in 1996 due to concerns about a shortage of forage fishes (Einhouse et al. 1999), while, at the same time, sea lamprey control was relaxed (Sullivan et al. 2003). Adult lake trout numbers quickly began to decline while sea lamprey-induced mortality increased. By 2000, the abundance of adult lake trout was reduced to only 0.7 fish/lift (Coldwater Task Group 2001) and has since remained at comparatively low levels (Coldwater Task Group 2008). Also, sea lamprey abundance remained well above target numbers despite renewed control measures.

OVERVIEW OF CURRENT POPULATION

Stocking

The goal of stocking 200,000 yearlings of various strains per year (Lake Trout Task Group 1985a; Appendix), was within the production capacity of the Allegheny National Fish Hatchery (ANFH) and was generally met or exceeded from 1986 to 1994 (Fig. 1). The vast majority of the lake trout were stocked in New York's and Pennsylvania's waters; the first stocking in Ontario's waters did not occur until 2006 and consisted of surplus lake trout from Ontario's hatchery system. The rapid increase in the adult lake trout population in the early 1990s caused concerns about the predatory demand on rainbow smelt, a species important in the diet of walleyes (*Sander vitreus*) and the object of a commercial trawl fishery in Ontario's waters. To protect smelt, stocking was held at 120,000 yearlings per year from 1996 to 2004. Following a large decline in adult lake trout abundance in 2004, the LEC increased the stocking target to 160,000 yearlings per year, where it now remains. However, the number of fish stocked fell short of goals during 2004-2006 due to diseases and power failures at the ANFH. Currently, the hatchery remains closed for renovations, and the White River and Pittsford National Fish Hatcheries in Vermont are attempting to fill the gap. The future of the ANFH remains uncertain. Restoring production at this facility and a continued commitment of the FWS to rear and stock lake trout is essential for rehabilitation.

Fig. 1. Yearling lake trout stocked by strain in eastern basin waters of Lake Erie, 1980-2007. Stocking targets are shown by horizontal lines.

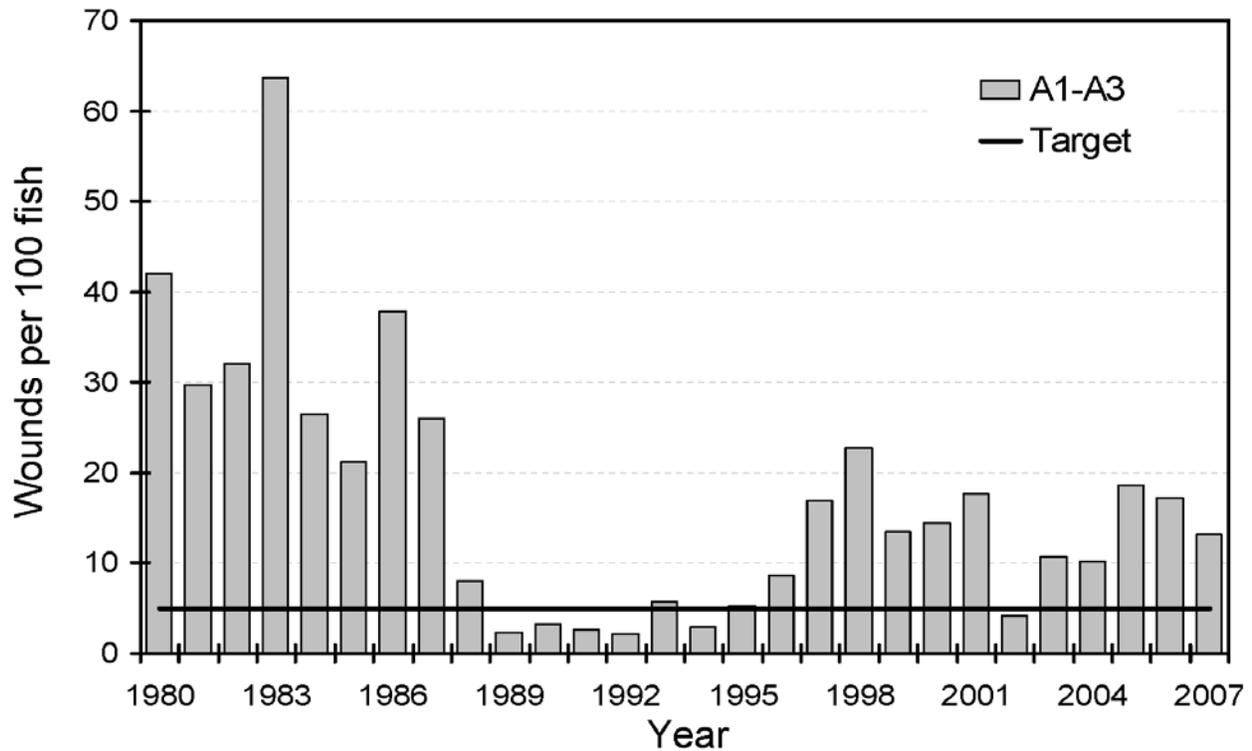


Sea Lamprey Marking Rates

Before sea lamprey control began in Lake Erie in 1986, the occurrence of A1-A3 sea lamprey marks (King and Edsall 1979) on lake trout averaged over 25.0 per 100 fish (>533-mm total length) and was as high as 63.0 per 100 fish in 1983 (Cornelius et al. 1995) (Fig. 2). At that time, sea lamprey attacked lake trout within two years of their being stocked, and age-5+ lake trout were virtually absent from gillnet assessments (Sullivan et al. 2003; Cornelius et al. 1995). Following the initial treatments in 1986-1987 of tributaries having high densities of sea lamprey larvae, sea lamprey marking rates rapidly declined to 1.0 per 100 fish in 1989. Marking rates remained low during 1989-1995, averaging 3.6 per 100 fish, and were meeting the original plan's objective of <5.0 per 100 fish. However, a reduction in sea lamprey treatments began in 1996, coinciding with the Great Lakes Fishery Commission's (GLFC) vision of reduced lampricide use and of a shift toward alternative control measures (Sullivan et al. 2003). Sea lamprey marking rates quickly increased to levels observed during the pre-treatment period, reaching 22.7 per 100 fish in 1998. Marking rates declined somewhat thereafter, but they remain

well above the target rate. Sea lampreys selectively feed on the largest >736-mm total length lake trout (Schneider et al. 1996) but also feed extensively on those 635–736 mm in total length (Einhouse et al. 2007). During the past five years, lake trout longer than 736 mm had an average marking rate of 19.8 per 100 fish, and those in the 635–736-mm length class had a rate of 11.4 per 100 fish.

Fig. 2. Number of A1-A3 sea lamprey marks per 100 adult lake trout >533-mm total length sampled in assessment gillnets in the eastern basin of Lake Erie, August-September 1980-2007. The target rate is 5 marks per 100 fish >533-mm total length.

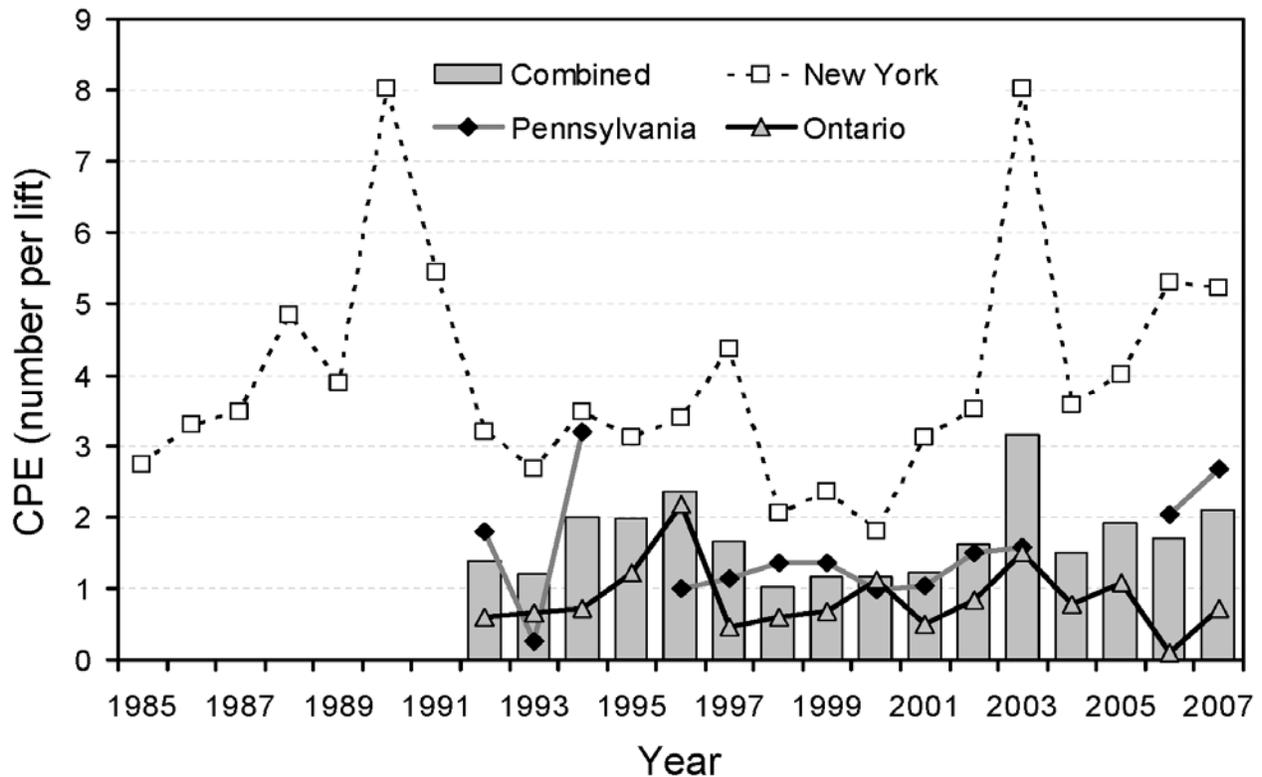


Abundance

In New York's waters, lake trout abundance, as measured in August gillnet surveys, increased rapidly following the initial treatments of sea lamprey-infested streams in 1986 and 1987 (Fig. 3). Abundance in New York assessments peaked in 1990 and declined thereafter, possibly due to increased water transparency, which may have affected the distribution of lake trout (Cornelius et al. 1995). Poorer survival of younger fish may also have been a contributing factor.

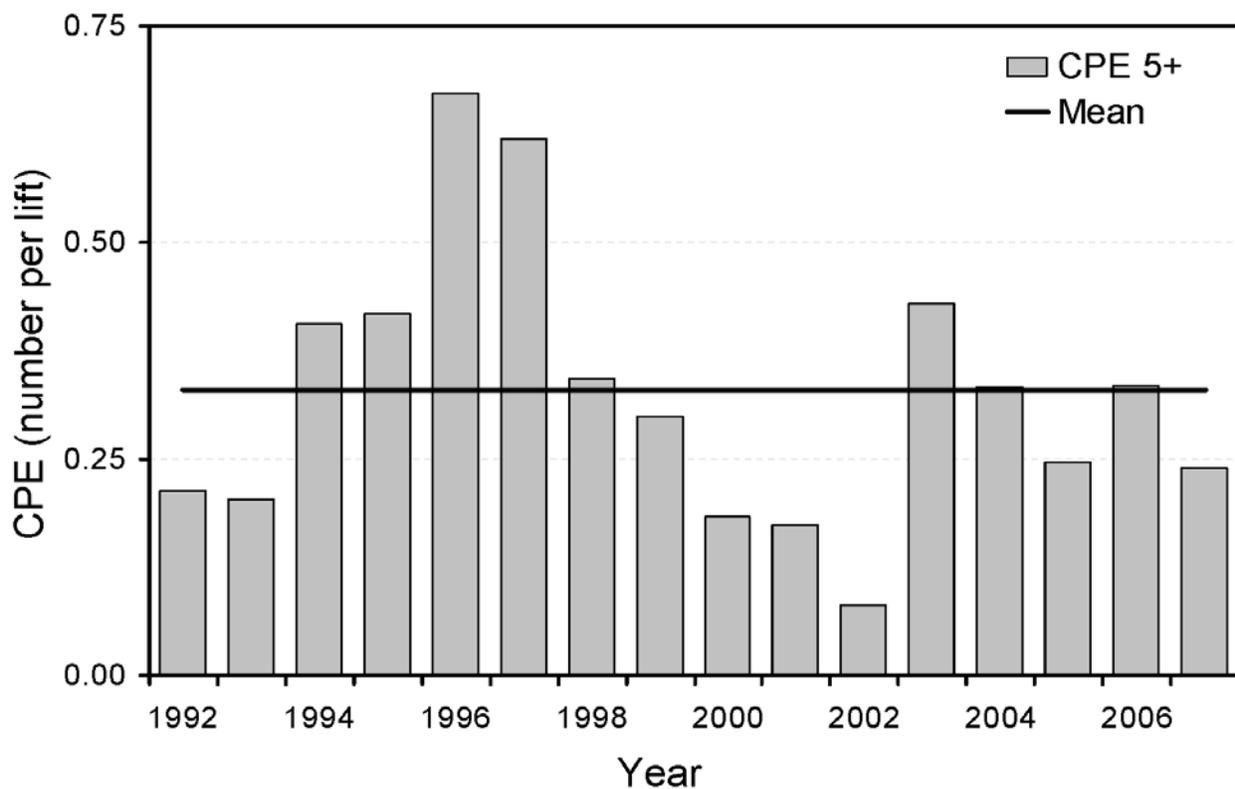
Abundance is substantially lower in Pennsylvania's and Ontario's waters than in New York's waters (Fig. 3) due to a lack of stocking in Ontario's waters and movement of lake trout away from stocking locations in Pennsylvania's waters. Lake trout abundance has been increasing in New York's waters since reaching a low in 2000 and appears to be comparable to the high levels seen in the early 1990s. Increases have also been observed in Pennsylvania's waters, but not in Ontario's waters. The mean abundance over the whole basin, weighted by jurisdictional area, has been generally increasing since 1998.

Fig. 3. Mean catch per effort (CPE) (number fish/lift) by jurisdiction and all jurisdictions combined (weighted by area) for lake trout (all ages) caught in assessment gillnets in the eastern basin of Lake Erie, 1985–2007. One lift is equal to 152.4 m of variable-mesh gillnet set overnight.



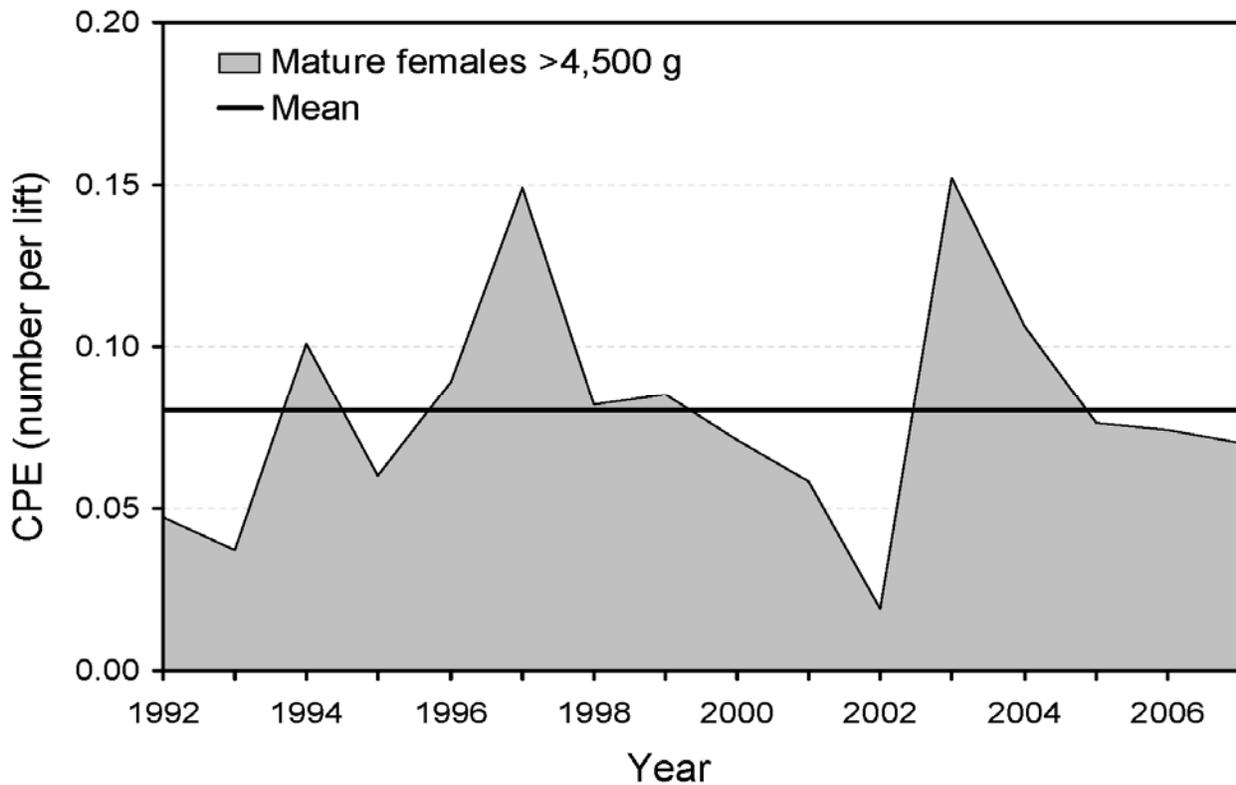
The adult population of lake trout, the fraction of the assessment-gillnet catch age 5+, generally increased from 1992 to 1997 in the eastern basin (Fig. 4). A significant ($P < 0.05$) decrease in abundance occurred in 1998 and was associated with increased numbers that spring of spawning sea lampreys, which would have killed lake trout in the preceding summer and fall, and with poorer survival of juvenile lake trout that began in the early 1990s. By 2002, adult abundance, and, hence, reproductive potential was at its lowest point in the time series. Adult abundance has improved modestly since 2002 and was closely linked to the recruitment of age-5 fish to the gillnets (Einhouse et al. 2007). Currently, the adult lake trout population comprises mainly age 6 and younger trout, while the abundance of age 7 and older trout has failed to increase from 2002 to 2007 (Coldwater Task Group 2008).

Fig. 4. Mean relative abundance weighted by jurisdictional area of age 5 and older lake trout sampled in assessment gillnets fished in the eastern basin of Lake Erie, August 1992-2007. One lift is equal to 152.4 m of variable-mesh gillnet set overnight.



The catch per effort (CPE) of mature female lake trout $>4,500$ g (CPE_{mf}) increased slowly from 1992 to 1997 but, by 2002, had declined to about one-sixth of the peak value (Fig. 5). This metric reflects the abundance of repeat-spawning females, which are age 6 and older. However, no target value for Lake Erie has yet been determined nor will it be until natural reproduction has been detected. CPE_{mf} values increased after 2002 and remain near the long-term average (Fig. 5).

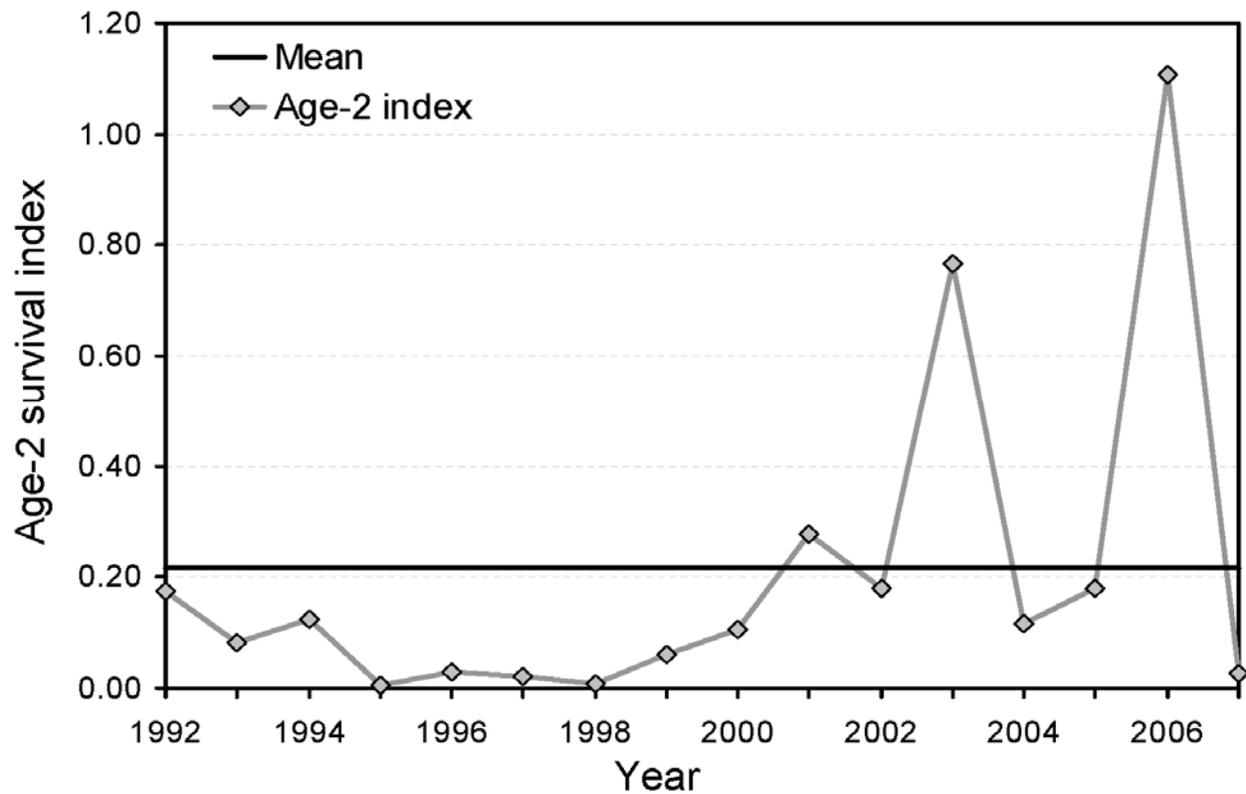
Fig. 5. Mean relative abundance weighted by jurisdictional area of mature female lake trout $>4,500$ g captured in assessment gillnets fished in the eastern basin of Lake Erie, August 1992–2007. One lift is equal to 152.4 m of variable-mesh gillnet set overnight.



Recruitment

An index of survival for age-2 lake trout (gillnet CPE at age 2 per 100,000 yearlings stocked) declined from 1992 (when first started) to 1998 and increased erratically from 1999 to 2006 (Fig. 6). Some of the erraticness, especially the peaks in 2003 and 2006, may be explained by differences in condition of stocked fish, stocking methods, size of stocked fish, and strain of trout stocked. Of interest, the 2006 survival index comprised only the Klondike strain, a deepwater variety from Lake Superior, and was the highest in the series. The 2007 index, however, was the lowest value since 1998 (Coldwater Task Group 2008). The missing fish, stocked in 2006 in Ontario's waters, were all of the Slate Island strain.

Fig. 6. Index of survival for age-2 lake trout caught in assessment gillnets in the eastern basin of Lake Erie, August 1992-2007. The index is the ratio of the catch of age-2 lake trout per lift divided by the number of fish of that cohort stocked in 100,000s.



Growth and Condition

Mean length-at-age and mean weight-at-age of lean strains of lake trout have remained unchanged over the past ten years (Coldwater Task Group 2008). Lake trout average over 700 mm (27.5 in.) in length and 4,300 g (9.48 lb) in weight by age 5 (Fig. 7). Growth slows down considerably thereafter as both males and females reach maturity. Klondike-strain lake trout, a deepwater variety, were significantly smaller at ages 3 and 4 (two sample *t*-test; $P < 0.01$) than lean strains.

Condition coefficients, *K* (Everhart and Youngs 1981), for age-5 male and female lake trout have remained above 1.0 for the time series (1986-2007), indicating that these fish have been heavy for their length (Fig. 8). Condition coefficients appeared to respond to decreases in stocking rates, and the ensuing reduced adult condition for both sexes was slightly lower in 1986-1994 than in 1995-2004.

Maturity

A mean-age target of 7.5 years for mature females was part of the original rehabilitation plan of 1985 and was derived from an analysis by Schneider et al. (1983) for Lake Ontario, based on the principle that for females the average age in the catch should be approximately two years more than the mean age at onset of sexual maturity. Although the mean age at onset of maturity for female lake trout was 4.5 in Lake Erie versus 5.5 in Lake Ontario, the original plan for Lake Erie adopted the Lake Ontario target of 7.5 years, based on the expectation that the mean age would increase as the population grew (Lake Trout Task Group 1985a). The mean age of mature female lake trout in the assessment catch increased steadily from 4.0 years in 1985 to 5.1 years in 1993, but then plateaued and remained nearly constant at just over 6.0 years through 1996 (Fig. 9). In the next two years, mean age of mature females increased to above the plan target of 7.5 years, where it remained until 2001. By 2003, mean age had declined to 6.0 and since then has changed little, reflecting the prevalence of the younger age-classes that currently dominate the population.

Fig. 7. Mean length-at-age (a) and weight-at-age (b) of lean-strain and Klondike-strain lake trout collected in gillnets from New York's waters of Lake Erie. The lean strains were collected in August 1998-2007 and the Klondike strain in August 2004-2007.

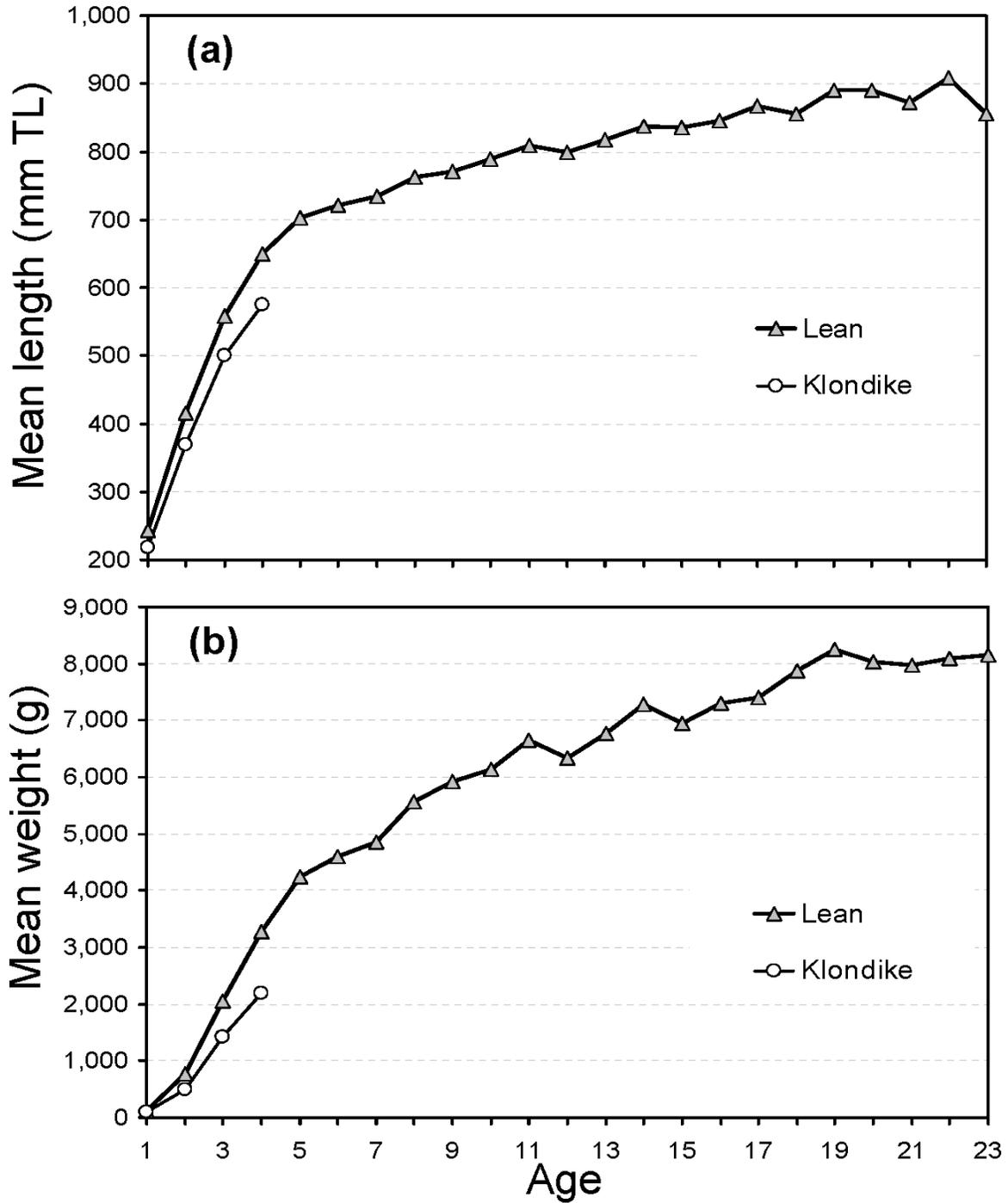


Fig. 8. Mean coefficients of condition (K) for age-5 male (filled diamonds) and female (open circles) lake trout collected in gillnet assessments in New York's waters of the eastern basin of Lake Erie, August 1986–2007.

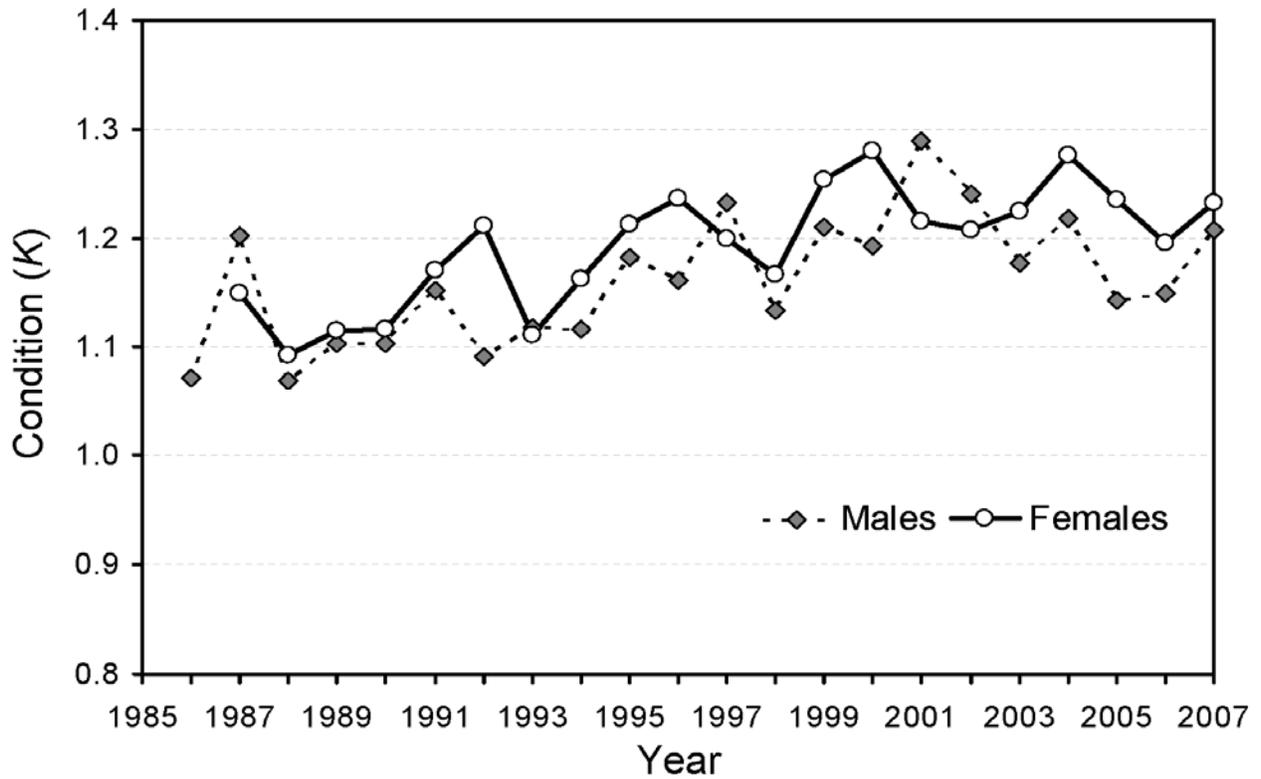
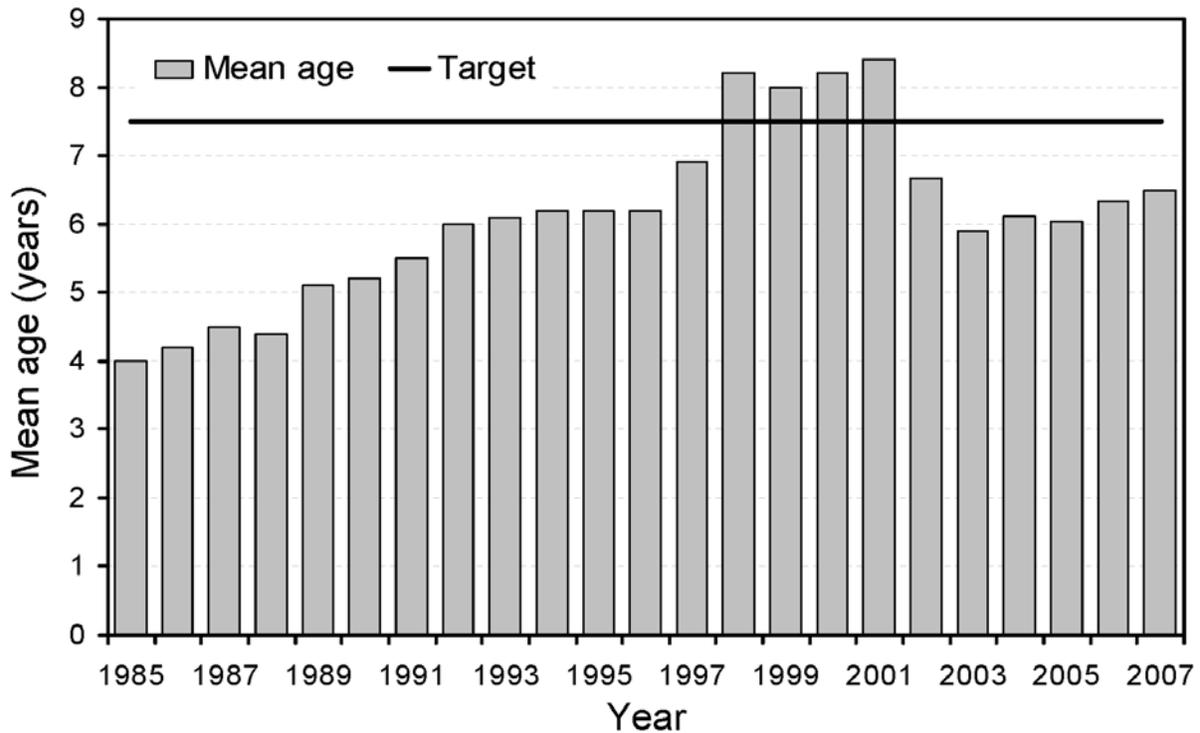


Fig. 9. Mean age of mature female lake trout sampled in assessment-gillnet surveys in the eastern basin of Lake Erie, 1985-2007. The target mean age is 7.5 years.



Survival

Based on a cohort analysis using a three-year running average of CPE for ages 4-10, mean adult survival was highest for the Lake Ontario strain (0.81) and lowest for the Lewis Lake strain (0.59) (Table 1). Survival rates for the Lake Erie strain were also high (0.79), but this estimate was based on only two year-classes with relatively low returns. The Finger Lakes and Superior strains, the most-heavily stocked, had overall mean survival estimates of 0.74 and 0.62, respectively. Survival estimates for the 1983-1985 year-classes were lower than those of subsequent year-classes, because they did not benefit until 1987 from the lower numbers of sea lampreys resulting from treatments in 1986-1987. Mean overall survival estimates for all strains met the original rehabilitation plan's target of 60% or higher, except for the Lewis Lake strain, which was just under the target.

Table 1. Cohort analysis estimates (three-year running averages of CPE for ages 4–10) of annual survival by strain and year-class for lake trout caught in assessment nets in New York’s waters of Lake Erie, 1985–2007. Asterisk (*) indicates exceptions: Finger Lakes 1997—simple averages ages 4-7; Superior 1997 and 1998—simple averages ages 5-8; Superior 1999—simple averages ages 4-8. Bold type indicates survival estimates that fall below the 0.60 target.

Year Class	Lake Erie	Lake Ontario	Lewis Lake	Superior	Finger Lakes
1983				0.687	
1984				0.619	0.502
1985				0.543	0.594
1986				0.678	
1987				0.712	0.928
1988		0.784		0.726	0.818
1989		0.852		0.914	0.945
1990		0.840		0.789	0.634
1991		0.763	0.616		
1992	0.719		0.568		
1993	0.857				0.850
1994					
1995					
1996					0.780
1997*				0.419	0.617
1998*				0.402	
1999*				0.287	
Mean	0.788	0.810	0.592	0.616	0.741

Recent estimates indicate that survival has declined well below target levels. Survival of the 1997-1999 year-classes of Lake Superior-strain lake trout ranged from 0.29-0.42 (Table 1). Also, survival of the 1997 year-class of the Finger Lake strain was the lowest seen for that strain (0.62) since the benefits of sea lamprey control were realized.

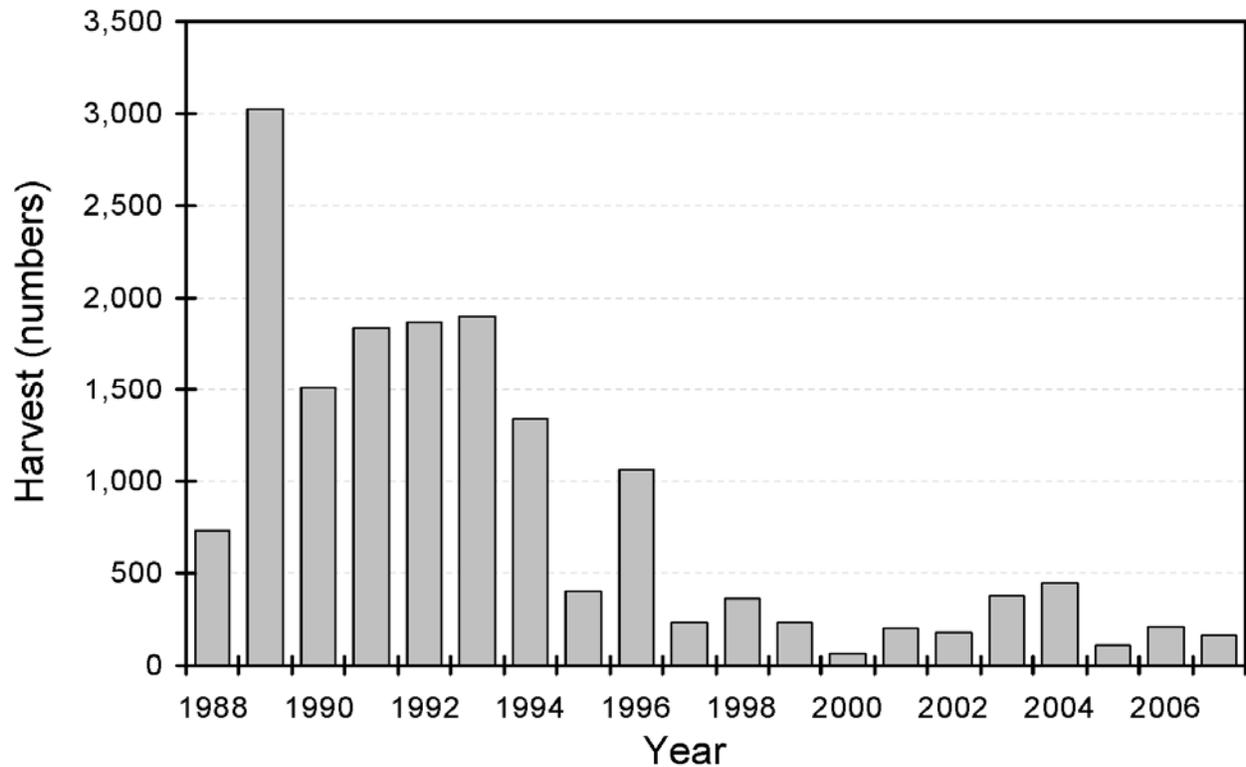
Strain Performance

Of the nine lake trout strains employed in Lake Erie (see Appendix for strain descriptions), the Lake Superior and Finger Lakes strains dominated stocking (Fig. 1). The Lake Superior strain, widely stocked in the 1980s and from 1997-2002, produced good returns as juveniles but not as adults. Conversely, the commonly stocked Finger Lakes strain produced poor returns as juveniles but good returns as adults. The current population consists mainly of the Finger Lakes and Klondike strains. Klondikes have been stocked in only small amounts in 2004, 2005, and 2007, but they have become one of the most-dominant strains in assessments (Coldwater Task Group 2008). Superior-strain lake trout have almost disappeared from assessments, presumably due to high mortality from sea lampreys. Lewis Lake, Lake Ontario, Lake Erie, Slate Island, and Traverse Island comprise minor portions of the assessment catch due to low stocking densities and/or poor survival. The Finger Lakes strain continues to provide the most-consistent returns, especially at older ages. Most of the adult population consisted of pure Finger Lakes or Finger Lakes x Lake Ontario crosses.

Harvest

Direct-contact-based estimates of lake trout sport harvest in New York's waters were high in the late 1980s through early 1990s and coincided with higher levels of fishing effort and more-robust populations of lake trout (Fig. 10). Harvest began to decline in 1994 and has remained below 500 fish per year since 1997. The fishery currently targets trophy-size lake trout exceeding 20 lbs, and many anglers practice catch and release.

Fig. 10. Creel survey estimates of annual lake trout harvest from New York's waters of Lake Erie, 1988–2007.



Natural Reproduction

Recruitment of naturally produced lake trout has not been detected in Lake Erie. Spawning has been documented with egg collection nets at several nearshore locations, and some of these eggs had reached the eyed stage of development at the time the nets were retrieved (Fitzsimons and Williston 2000). Egg densities (11-63 eggs•m⁻²) were similar to those in Lake Michigan (0.4-155 eggs•m⁻²) and in Lake Ontario (6-109 eggs•m⁻²), where natural recruitment, albeit low, has been observed consistently, but much less than in Parry Sound, Lake Huron (39-1,027 eggs•m⁻²), where the population is self-sustaining (Fitzsimons 1995; Fitzsimons et al. 2003; Jonas et al. 2005; Marsden et al. 2005). Survival of Lake Erie eggs collected in egg nets (25-56%) was similar to that reported for Lake Ontario (21-82%) using the same gear (Fitzsimons 1995). Eggs from females collected by trapnetting in New York's waters at Barcelona Harbor have been raised at the ANFH. The occurrence of early mortality syndrome (EMS) associated with thiamine deficiency (Fitzsimons et al. 1999), although detected in the progeny of Lake Erie lake trout, occurs at very low levels (Fisher et al. 1996). The low levels probably reflect the lower thiaminase activity in smelt, the major prey of lake trout in Lake Erie, relative to alewife, a

species with high thiaminase activity (Fitzsimons and Brown 1998). Otolith microchemistry of putative wild lake trout (non-tagged and non-clipped) indicated that some age-1+ fish from the lake were naturally reproduced (Ludsin et al. 2004). Although the presence of naturally produced fish shows that natural recruitment is possible, the numbers of such fish are inconsequential to the population.

IMPEDIMENTS TO LAKE TROUT REHABILITATION

Because the goals and objectives in the original plan of 1985 were not achieved, a reexamination of the factors potentially affecting natural reproduction and recruitment is warranted. Impediments to lake trout rehabilitation identified for Lake Michigan (Bronte et al. 2003), the guide for rehabilitation in Lake Michigan (Bronte et al. 2008), and the Lake Ontario Lake Trout Restoration Plan (J. Lantry, personal communication, 2007) were considered, along with other variables in this evaluation.

Impediment 1: Insufficient Spawner Biomass

Numbers Stocked Too Low—The total number of lake trout stocked has decreased since rehabilitation efforts began in 1978, and the current stocking objective (160,000 yearlings per year) is insufficient to build the adult population. Stocking numbers need to be high enough to allow lake trout to repopulate all suitable habitats, overcome biological and environmental impediments, and compensate for the behavioral and reproductive inefficiencies of stocked fish. Stocking rates should be increased to 200,000 yearlings per year or higher to increase spawning-stock biomass and egg deposition.

Sea Lamprey-Induced Mortality Too High—The high level of sea lamprey control in the late 1980s, combined with a high stocking rate, quickly increased the adult lake trout population. Conversely, the population decreased with reductions in both stocking rates and sea lamprey control. Consequently, lake trout rehabilitation will not be possible without a reduction in sea lamprey predation (<5 A1-A3 marks/100 fish). Treatments of the major sea lamprey-producing streams must be made consistently to minimize predation on lake trout.

Minimize Fishing/Bycatch Mortality—The lake trout sport-fishing regulations are already conservative so as to minimize losses to the spawning population. Directed commercial fishing is not allowed, but losses due to commercial bycatch are largely unknown. Management agencies must establish and maintain regulations that keep overall sport harvest and commercial bycatch to levels compatible with rehabilitation goals.

Impediment 2: Stocking Limitations

Stocking Locations Too Few—The vast majority of lake trout stocking has occurred in New York’s waters, off the ports of Dunkirk and Barcelona, while too few have been stocked in Pennsylvania’s waters. Aside from a stocking of fish deemed surplus in 2006, no lake trout have been stocked in Ontario’s waters. Despite the relatively small area of cold-water habitat in Lake Erie (compared to the other Great Lakes), summer assessments have shown that lake trout have not dispersed from stocking sites to other suitable areas in the eastern basin of the lake. Historical accounts of commercial fishing indicate that lake trout could be found throughout the lake during other times of the year (Cox 1992), indicating that areas outside of the eastern basin may have been important for reproduction. Stocking should occur throughout the eastern basin and possibly in the central and western basins, wherever spawning habitat is abundant, to increase the likelihood of natural reproduction.

Strain Diversity Inadequate—Until recently, management agencies stocked lean (shallow-spawning) forms of lake trout due to their availability in the U.S. hatcheries. We believe that this choice resulted in less genetic diversity than that which occurred historically (Krueger and Ihssen 1995) and may have inhibited the potential for reestablishment. The addition of the Klondike (deepwater) strain in 2004 has increased the genetic diversity of the population and increased the potential for colonization of deepwater habitats. Other available lake trout strains and forms, such as siscowets (*Salvelinus namaycush* siscowet), should be considered in the future to maintain high genetic diversity until rehabilitation is complete.

Hatchery Production Inadequate—Stocked lake trout have come almost entirely from the ANFH. This facility, on average, produced 200,000 yearlings per year from the 1980s through 1994 and produced lesser numbers thereafter as the stocking target decreased. Recently, however, this hatchery experienced serious water-quality and disease problems that reduced its capabilities and raised questions about its long-term capability to produce adequate numbers of quality lake trout. The ANFH is currently being upgraded to address some of these issues, but the facility is not scheduled to restart production until 2011, at the earliest. Therefore, a contribution of lake trout from hatcheries in Ontario for stocking Ontario’s waters is much needed at this time.

Natal Homing Impaired—Stocking fingerling or yearling lake trout may not allow for adequate imprinting to natal habitat. In addition, hatchery-reared lake trout may exhibit maladaptive behavior resulting in lower survival, as compared with wild fish. Stocking eyed eggs may be a viable alternative that addresses both issues (Bronte et al. 2002).

Poor Spawning Success—Krueger et al. (1986) found that hatchery-stocked lake trout failed to colonize nearshore spawning reefs in Lake Superior where native lake trout were absent or scarce, despite the availability of suitable spawning habitat. These authors concluded that differences in spawning behavior and reproductive success between wild and hatchery-origin adults were probably important determinants that influenced reef colonization. However, hatchery lake trout have successfully reproduced in Lakes Ontario (Elrod et al. 1993) and Huron (Reid et al. 2001; Desorcie and Bowen 2003) where population densities were high and spawning habitat was abundant. In Lake Erie, spawning habitat is patchy (as it is in Lake Superior), so the abundance of adults will need to be high to improve their chances of locating and using it.

Impediment 3: Invasive Species

Invasive Species Predation—Predation by non-native species (smelt and round gobies (*Neogobius melanostomus*)) on lake trout eggs and fry reduces potential recruitment; hence, stocking should be concentrated to achieve densities of adults and eggs that can overcome these mortality bottlenecks.

Lack of Predation on Fry and Egg Predators—Lake trout need to become the dominant predator in the cold-water fish community. This event will allow for suppression of native and, more importantly, non-native egg and fry predators, and thereby decrease predatory losses. Such dominance is important, especially in those regions where spawning habitat is less available.

EMS/Rehabilitation of Cisco—EMS is not thought to be a major impediment to lake trout rehabilitation. It occurs when lake trout eggs are deficient in thiamine and causes direct mortality just prior to and during emergence and indirect mortality thereafter, due to reduced growth and impaired foraging and predator avoidance. The presence of thiaminase, an enzyme that destroys thiamine and that is found in smelt and alewife, has been linked to EMS (Honeyfield et al. 2005). Because the alewife is not a major portion of the lake trout diet in Lake Erie (Coldwater Task Group 2007) and smelt (which are a major diet item) have approximately one half the thiaminase activity of alewife (Tillitt et al. 2005), EMS is not thought to be an issue. Rehabilitation of cisco, a native cold-water prey fish in Lake Erie that is thiaminase free, would alleviate any remaining EMS concerns and also increase the asymptotic size of lake trout and fecundity (Lake Huron Technical Committee 2005). Rehabilitation of cisco would also provide an alternate forage for other top predators and help to stabilize the cold-water prey community.

Impediment 4: Habitat

Identification of Spawning Areas—Most of the stocking has, thus far, centered on Brocton Shoal, located just west of Dunkirk, NY, which is the one known historical lake trout spawning site in Lake Erie. However, other potential sites, especially along the north shore, have been identified but not fully explored. Identification of the most-suitable spawning areas should be based on substrate, slope, depth, and current, and stocking should be focused on or near these sites to take advantage of a weak tendency of adult lake trout to return to the general area where they were stocked (Elrod et al. 1996).

Degradation of Spawning Habitat—Vast changes in the ecosystem have occurred since lake trout reproduced naturally in Lake Erie. Dreissenid mussels now cover almost all hard substrates, possibly causing the loss of the interstitial spaces, which lake trout eggs require for protection, as well as the accumulation of sediments and mussel pseudofeces, which may reduce egg survival, too.

NEW GOALS AND OBJECTIVES

Purpose

The goal for the eastern basin of Lake Erie is a balanced cold-water fish community with lake trout as the dominant predator (Ryan et al. 2003). Lake trout, once rehabilitated and having resumed its role as the dominant native predator, may provide the ecosystem stability required for recovery of native coregonines, burbot (*Lota lota*), and sculpins (Cottidae). To accomplish these ends, this revised plan is formulated around an ultimate and interim goal. These goals are broad, qualitative statements of the expected accomplishments from this revised plan, if it is implemented. Programmatic building blocks for accomplishments are provided in the form of specific objectives designed to achieve the goal. They are quantified in some cases and are necessary for establishing operational approaches and for measuring progress. Because the objectives are progressive, preceding objectives must be met and maintained before subsequent objectives can be accomplished.

Ultimate Goal

Reestablish a genetically diverse, self-sustaining lake trout population in the eastern basin that provides ecological dominance within the cold-water community and produces a harvestable surplus.

Interim Goal

As a demonstration of feasibility, by 2030, establish a lake trout population in the eastern basin that produces yearling offspring at a measurable level.

Objective 1: Increase Overall Lake Trout Abundance

Measureables

By 2020, achieve in all jurisdictions an average target CPE of 8 fish (all age groups combined) per 152.4 m of graded-mesh (38-152 mm) gillnet set overnight in summer. This is the minimum abundance recommended by Selgeby et al. (1995) for successful natural reproduction in the Great Lakes and equals values in New York's waters of Lake Erie in the early 1990s when egg deposition was detected. More recently, Jonas et al. (2005) and J. Fitzsimons (personal communication, 2008) suggest that much higher population densities may be needed due to high levels of interstitial egg predation, particularly by round gobies. Current CPE values range from about 1 fish per lift in Ontario's waters to 5 fish per lift in New York's waters.

Objective 2: Maintain Adult Spawning-Stock Abundance

Measureables

By 2024, achieve an abundance of adults (age 5+) that is equal to 25% (2 fish/lift) of the total CPE defined in Objective 1. The adult population should be at least 25% female of a size >4,500 g and comprise at least 10 year-classes. This target CPE is based on the maximum adult CPE values in New York's waters of Lake Erie during the 1990s. CPEs of spawning lake trout on reefs should be much higher, as adult fish are then aggregated.

Objective 3: Maximize Reproductive Potential

Measureables

By 2024, detect minimum egg densities of 25-500 eggs•m⁻² in at least four different suitable spawning locations and of 1,000 eggs•m⁻² in at least two high-quality locations. Although these deposition rates are comparable to those in Lakes Ontario, Michigan, and Huron (Fitzsimons 1995; Marsden et al. 2005), factors other than egg density will be needed to predict successful production of older offspring (Jonas et al. 2005; Marsden et al. 2005; J. Fitzsimons, personal communication, 2008). Jonas et al. (2005) suggested that egg densities exceeding 190 eggs•predator•m⁻² one month post spawning will likely result in emergent fry. Based upon these observations, adjustments to this objective may be needed as the levels of lake trout abundance and egg predation change at spawning locations.

Objective 4: Demonstrate that Natural Recruitment Is Possible

Measureables

By 2030 and thereafter, achieve and maintain a consistent, measurable contribution of naturally produced age-1 lake trout.

MANAGEMENT STRATEGIES

Strategy 1

Increase stocking rates to at least 200,000 yearlings per year.

Rationale

Increase annual production at the ANFH or at substitute hatcheries so as to supply at least 200,000 yearlings per year beginning in 2010. Additional lake trout may be supplied from Ontario's hatcheries. The lake trout population in Lake Erie was built initially through high stocking rates and suppression of the sea lamprey population. Population projections made using the Lake Erie Lake Trout Population Model indicate that stocking 200,000 yearlings per year is necessary to provide for an increased population under moderate levels of sea lamprey predation. This minimum level of stocking should be sustained until the interim goal is reached or until biological signals such as worrisome declines in growth or condition of lake trout or of other top predators indicate that predatory demand exceeds the supply of forage.

Strategy 2

Maintain sea lamprey populations at levels that result in no more than 5 A1-A3 marks per 100 lake trout >532 mm in length, and, in no case, should the sea lamprey population exceed 4,000 adults.

Rationale

The adult lake trout population immediately benefited from initial sea lamprey treatments in 1986 and 1987, and subsequent population growth continued as sea lamprey marking rates remained below the proposed target (<5 A1-A3 marks per 100 fish), and the sea lamprey population remained below 4,000 adults. However, changes can occur quickly in Lake Erie due to the relatively small area that lake trout inhabit in the eastern basin during the warmer summer months, making lake trout highly vulnerable to sea lamprey attacks. An increase from 3,000 to 15,000 adult sea lampreys over 1995 to 1998 caused the CPE of adult lake trout to decline from 4.1 in 1997 to 0.7 fish/lift in 2000. A large adult lake trout population will tolerate increases in

sea lamprey abundance for one or two years, but longer increases, such as those that occurred in the mid-1990s, will quickly set back lake trout abundance. The lapse in sea lamprey control during 1996-1998 set back rehabilitation more than a decade. Population projections made using the Lake Erie Lake Trout Population Model indicate that moderate lamprey control (current level) and stocking rates of less than 200,000 per year will do little more than keep the adult lake trout population at its current level (Coldwater Task Group 2006). Control efforts need to be intensified to reduce sea lamprey numbers to at or below target levels. Treatment of all sea lamprey-producing streams for two consecutive years may be necessary to bring marking rates back down to the levels of the early 1990s.

Strategy 3

Identify potential lake trout spawning habitats.

Rationale

Known spawning areas, some of which may be unsuitable, include Brocton Shoal (Edsall et al. 1992), Van Buren Shoal (Thibodeau and Kelso 1990), Bournes Beach, and Chautauqua Creek (Fitzsimons and Williston 2000), and all are located in New York's waters. Aside from Brocton Shoal, the other spawning areas are located in shallow, nearshore waters, and egg collections at these locations have been meager and variable, apparently in response to storm events (Fitzsimons and Williston 2000). Because of the prevailing west-to-northwest winter winds, spawning reefs located on the north side of the lake should be better suited for reproduction. A potential spawning area was identified at Nanticoke Shoal (Fitzsimons and Williston 2000), but evidence of lake trout spawning was not found, presumably due to the large distance (80 km) from stocking locations in New York's waters. Preliminary work using geographical information systems identified several potential lake trout spawning areas, including areas along the north shore (Habitat Task Group 2006). Additional studies using sidescan sonar and underwater imaging are under way to confirm these locations and to identify other potential areas. Future stockings should be concentrated on the largest areas of high-quality spawning habitat.

Strategy 4

Expand distribution of stocked fish to include potential spawning areas in Pennsylvania's and Ontario's waters.

Rationale

Hatchery-reared lake trout, when maturing, tend to return to the region where they were stocked (Elrod et al. 1996) and also tend to be most abundant where they were stocked. The current practice of stocking only in New York's waters limits the potential of lake trout to expand into all possible niches and decreases the probability that they will find suitable spawning and rearing habitats in other regions.

Strategy 5

Stock in the vicinity of quality spawning areas and rotate stockings among areas to maximize survival of stocked lake trout yearlings.

Rationale

Recruitment of stocked lake trout in Lakes Erie and Ontario declined when adult stocks were abundant (Coldwater Task Group 2006; Elrod et al. 1993), indicating cannibalism. To minimize cannibalism, the number of stocking locations should not only be expanded, but stocking should be rotated among them to oversaturate local predators and to avoid establishing a consistent source of prey in successive years. To implement the strategy, at least 135,000 yearlings per year should be stocked in one area, as was recommended for Lake Ontario (B. Lantry, personal communication, 2007). Due to the relatively low availability of fish for stocking (200,000), all stocked fish in a given year should be released at one site.

Strategy 6

Maintain adult survival rates of at least 60%.

Rationale

Stocked and naturally produced lake trout will need to be protected from high rates of mortality if the goals and objectives of this revised plan are to be realized. Healey (1978) suggested that, to sustain wild lake trout populations, the maximum annual mortality should not exceed 50% for populations with natural mortality rates of 20-30%. A lake trout spawning population comprising long-lived fish, characteristic of the species, cannot be maintained when fishing mortality exceeds 15%. To achieve rehabilitation, conditions must allow for population expansion. Thus, rehabilitation requires that fishing mortality including bycatch, sea lamprey predation, and natural mortality, the components of total mortality, be kept low to allow rebuilding of parental stocks. To achieve these conditions, rehabilitation guides for Lakes Michigan (Bronte et al. 2008) and Ontario (J. Lantry, personal communication, 2007), as well as the original Lake Erie rehabilitation plan, adopted a maximum mortality rate of 40% (i.e., a minimum survival rate of 60%). With the exception of the Lewis Lake strain and during the pre-lamprey control era, survival rates have typically exceeded 60% for all strains (Table 1); although more recently, survival rates for the 1997-1999 year-classes of the Lake Superior strain are lower than 60%.

Strategy 7

Maintain genetic diversity of stocked lake trout.

Rationale

It is essential that the genetic and phenotypic diversity of stocked lake trout be sufficient to allow for adaptation to the complexity of the eastern basin environment and to future changes in it. Schneider et al. (1983) suggested that the best approach for selecting an appropriate genetic strain was to introduce as much genetic variability as possible. Different lake trout types were reported to exist in the deeper waters of the eastern basin, which is surprising given the small amount of lake trout habitat available relative to the other Great Lakes (Krueger and Ihssen 1995). Herbert (1851) described two different forms of lean lake trout (rocky shallows and muddy shallows) while Jordan and Evermann (1937) and Nash (1908) reported siscowets. Strains should be selected from locally adapted stocks from the Great Lakes basin that have been transferred to and successfully established in other water bodies. This strategy assumes the genetic traits required for survival and reproduction are present in the hatchery stocks and will be expressed in Lake Erie. Selecting strains based on habitat preferences holds that, to achieve rehabilitation in deep and shallow waters, different types of lake trout need to be stocked. Therefore, three strains, the lean Seneca (or Finger Lakes) and Apostle Island strains and the deepwater Klondike strain, are recommended for Lake Erie. Recommended stocking rates are 80,000 each of the Klondike and Finger Lakes strains and 40,000 of the Apostle Island strain. Other strains that become available, such as the Parry Sound strain from Lake Huron and deepwater forms, such as siscowets, should also be considered as they become available from U.S. hatcheries.

Strategy 8

Stock a variety of life stages (eggs, fry, yearlings, and adults).

Rationale

Stocking lake trout at the egg and fry stages on selected habitats should increase the potential for imprinting and the likelihood that these fish at maturity will aggregate and spawn on appropriate spawning habitats. Yearlings have been, and probably always will be, the cornerstone of the stocking program due to the higher post-release survival as compared to other life stages. Stocking eyed eggs has not been widely implemented, and the results have been mixed (Bronte et al. 2002). However, stocking early life stages prior to imprinting may be necessary to achieve colonization of offshore and/or deepwater habitats. Adult transfers from the other Great Lakes is also a possible alternative (Krueger and Ebener 2004), although the transfer of diseases will be an issue. This technique has had success worldwide for birds and mammals, as well as for fish in small lakes.

Strategy 9

Establish sanctuaries around likely areas of aggregation.

Rationale

Establishing sanctuaries should be considered if harvest of lake trout near important spawning grounds is excessive. Sanctuaries would provide protection from fishing during periods when lake trout are aggregated near spawning areas and are especially vulnerable. Fishing closures around known spawning areas should be in effect from mid-October to mid-December.

Strategy 10

Stock sacrificial strains of lake trout.

Rationale

If sea lamprey mortality continues to hinder lake trout rehabilitation, stocking additional lots (40,000 fish per lot) of the Lake Superior or Lewis Lake strains, which are most vulnerable to sea lamprey predation, should be considered. This sacrificial stocking would, in theory, reduce losses of more-suitable strains. Close monitoring of marking rates would be needed to ensure that this strategy is working.

Strategy 11

Create artificial spawning habitat.

Rationale

Krueger and Ebener (2004) promoted creation of artificial spawning reefs to increase the amount of spawning substrates available to lake trout. This idea is especially appropriate for Lake Erie, where spawning habitats are patchy and limited. Large areas of rock rubble deposited in suitable nearshore lake trout areas are quickly discovered and utilized for spawning by hatchery-origin lake trout (Wagner 1981; Marsden 1994; Marsden et al. 1995; Marsden and Chotkowski 2001) and have been shown to produce measurable levels of recruitment to age 1+ (Peck 1986; Rybicki 1991). Man-made structures have had some of the highest reported egg abundances for Lakes Ontario (Fitzsimons 1995), Michigan (Marsden and Chotkowski 2001), and Superior (Fitzsimons 1996). However, construction of artificial reefs is costly, and their location is critical to success. Marsden and Chotkowski (2001) concluded that artificial reefs constructed in shallow water may not be productive areas for lake trout egg incubation and fry hatch due to the negative impacts of zebra mussels (*Dreissenid polymorpha*), egg predation, and storm surge. Oblong reefs, featuring layered cobble substrates, should be oriented parallel to prevailing currents and inclined downward and away from the direction of fall winds (Fitzsimons 1994).

Strategy 12

Seed spawning habitats with lake trout feces.

Rationale

Lake trout are thought to be attracted to areas with lake trout feces (Zhang et al. 2001), and seeding specific spawning grounds with feces from hatcheries may attract mature adults, increase egg deposition, and help overcome the demands of egg predators.

Strategy 13

Minimize harvest of non-clipped fish.

Rationale

West Coast salmonid fisheries employ selective angler harvest to protect naturally produced fish (unmarked fish are presumed to be of wild origin), maximizing natural reproduction of the most-valuable fish in a cohort. When naturally produced lake trout begin to recruit to fisheries, similar measures should be implemented in Lake Erie.

ASSESSMENT NEEDS

Coded Wire Tag All Fish

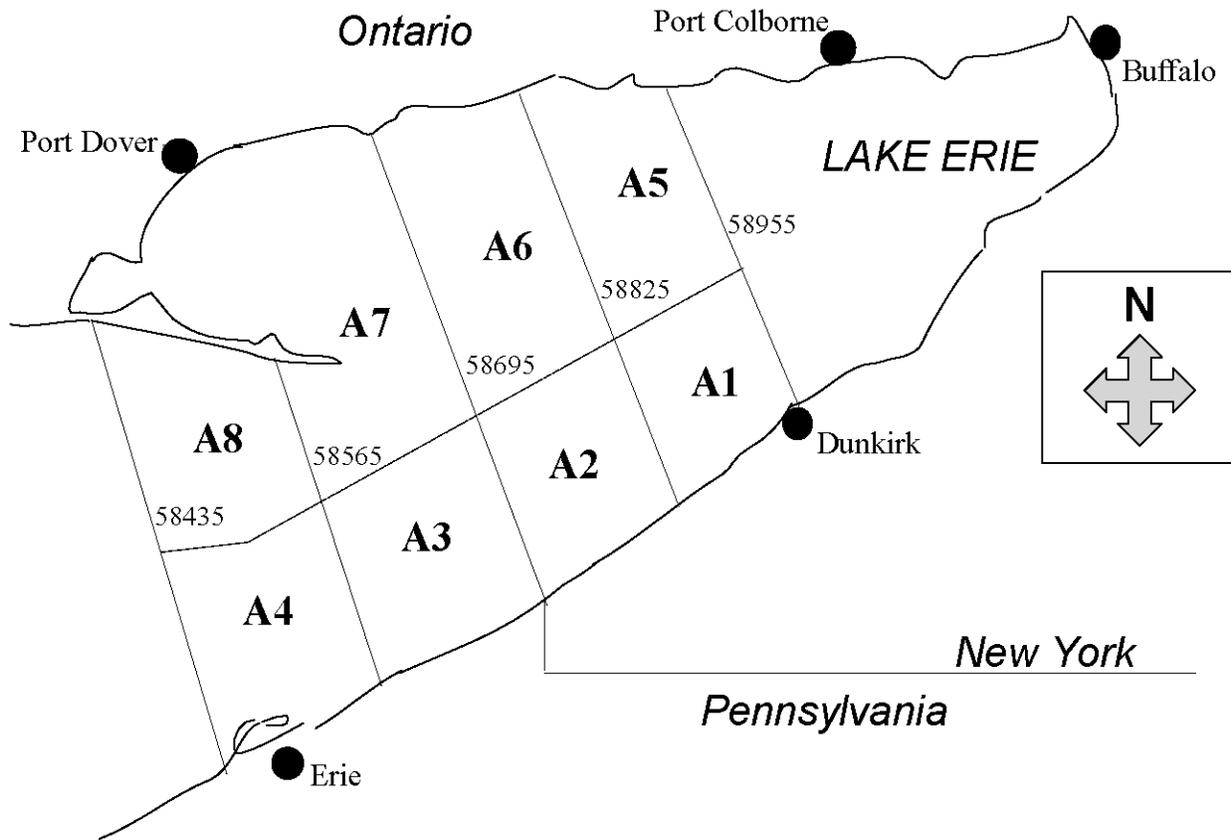
To evaluate the success of lake trout rehabilitation, all stocked lake trout must continue to receive coded wire tags and adipose fin clips. Such tagging allows for determination of growth, strain, best stocking strategy, early survival, survival to adulthood, and sea lamprey marking by strain. Tagging also allows for separation of wild from stocked fish.

Yearly Abundance Estimates

Standardized cold-water gillnet assessments have been conducted in New York's waters since 1985 and in Pennsylvania's and Ontario's waters since 1991 and 1992, respectively. The current survey design calls for 30 lifts per sampling area (Fig. 11), but this amount has only been accomplished on an annual basis in New York's waters. As outlined in the original rehabilitation plan, assessments must provide sufficient information on an annual basis to measure progress toward meeting rehabilitation objectives. To adequately assess lake trout population levels across all cold-water habitats in the eastern basin, effort should be more consistent from year to year in Pennsylvania's waters and increased in Ontario's waters. A minimum of 20 lifts per sampling

area per year is recommended. The CWTG will remain responsible for coordinating lake trout assessment activities in the eastern basin of Lake Erie and prepare annual reports outlining progress toward rehabilitation objectives. The results of this report will be presented at the annual meetings of the LEC.

Fig. 11. Standard sampling areas (A1-A8) used for assessment of lake trout in the eastern basin of Lake Erie. Five-digit numbers near the center of angled vertical lines describe Loran-C lines of position that form the east and west boundaries of the eight sample areas.



Spawning Surveys

An annual lake trout spawning survey should be developed to investigate the extent by strain that lake trout are utilizing identified spawning areas. This information is crucial for determining which strains should be stocked on which spawning habitats and whether adult abundances are adequate to meet the revised plan objectives. The Klondike strain of lake trout serves as a prime example of the need to determine spawning location, depth, and reproductive success for a strain not stocked elsewhere in the Great Lakes. Egg collection devices should be used to assess egg deposition and to provide for genetic testing of eggs as to source strain when gillnet CPEs reach targets established in Objective 1.

Juvenile Trawl Surveys

Early summer trawling for juveniles should be conducted over sand and mud flats adjacent to probable spawning areas to determine if naturally produced juveniles are present. Peck (1982) found from May through July young-of-the-year (YOY) lake trout over sandy substrates adjacent to a nearshore spawning reef in Lake Superior. These fish were mainly in shallow water (2-8 m), but other studies in Lake Superior (Eschmeyer 1956) and Lake Michigan (Jude et al. 1981) found most YOY lake trout at deeper depths (18-30 m in Superior, 12 m and deeper in Michigan). Trawling surveys should commence when egg densities on spawning reefs or adult abundances approach the target levels established in the objectives.

Forage and Prey-Species Surveys

Trawling and hydroacoustic surveys are currently conducted by all agencies in all basins of Lake Erie. The resulting estimates and tracking of the body condition of walleye (*Sander vitreus*) and lake trout should be used to evaluate the status of pelagic offshore forage fishes and to determine if predator populations need to be decreased.

INFORMATION NEEDS

Mapping of Spawning Grounds/Identification of Suitable Spawning Areas—Information on the extent and distribution of suitable lake trout spawning areas in Lake Erie is inadequate, and identification of additional areas for stocking is needed to improve the chances that lake trout will locate suitable spawning habitat and reproduce successfully.

Estimates of Commercial Bycatch

Bycatch is a source of mortality on lake trout that is largely unquantified. For better prediction of lake trout populations, estimates of commercial bycatch should be included in the Lake Trout Population Model. Such estimates may also be indicators of population size and distribution.

Early Mortality Syndrome (EMS)

EMS is generally not considered a major hurdle in Lake Erie because of the absence of alewife in lake trout diets. However, rainbow smelt are also high in thiaminase and comprise most of the lake trout diet. Research should determine if thiamine levels in lake trout eggs are sufficient to avoid the direct and indirect effects of EMS.

Identification of Early Life-Stage Bottlenecks

If adult stocks become abundant and egg production is commensurate with replacement levels of reproduction but offspring are not detected (Objectives 3 and 4), research will be needed to identify bottlenecks in the early ontogeny of lake trout.

MANAGEMENT ROLES AND RESPONSIBILITIES

The states of New York, Pennsylvania, Ohio, and Michigan and the Province of Ontario have management authority over all fish species, including lake trout, in Lake Erie. Their jurisdiction covers the lake and its watershed, and they are responsible for fishery regulation, stocking fish (other than lake trout), controlling pollution, management of physical habitat, and public education. Because fish know no jurisdictional boundaries, effective management in one jurisdiction requires collaboration among all jurisdictions. The LEC, a binational committee comprising four state and one provincial fishery agencies, provides for such collaboration. It operates under A Joint Strategic Plan for Management of Great Lakes Fisheries (Great Lakes Fishery Commission 2007), which was developed under the aegis of the GLFC.

Although within Lake Erie, lake trout are found primarily in the eastern basin, which borders New York, Pennsylvania, and Ontario, the roles and responsibilities for rehabilitation and management involve the states of Michigan and Ohio as well as federal agencies. The FWS and the U.S. Geological Survey (USGS) are important partners in lake trout rehabilitation. The FWS is the principal U.S. agency responsible for the rehabilitation of native species and their habitats, and it rears and stocks most of the lake trout for Lake Erie. The FWS is also responsible for sea lamprey assessment and control on Lake Erie. Without this partnership, lake trout rehabilitation would not be possible. The USGS provides stock assessment and research support for rehabilitation. Fisheries and Oceans Canada (DFO) provides research support, sea lamprey control, and fish-contaminant testing. Management and regulatory decisions are primarily made

by the LEC and are typically based on recommendations provided by the CWTG.

The GLFC, operating under the 1955 Convention on Great Lakes Fisheries, is responsible for management of the sea lamprey, and the interjurisdictional coordination of lake trout management and research is conducted under its umbrella. The GLFC contracts with the FWS and DFO to assess and control sea lamprey populations. Control is effected through application of lampricides, construction of barriers on 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 GLFC also has a longstanding history of promoting research to understand the processes associated with lake trout rehabilitation. It encourages interjurisdictional coordination of lake trout management by bringing federal, state, and provincial parties together via the LEC which, in turn, has established a technical committee and various task groups, such as the CWTG. This revised management plan was developed within this organizational structure.

LAKE ERIE COMMITTEE SUPPORT

Cisco Rehabilitation

The rehabilitation of the native cisco can have consequences for successful rehabilitation of lake trout. Cisco was the key prey species for lake trout in Lake Erie before both species were extirpated in the 1950s. Cisco, once restored, would provide an alternative prey species for lake trout and other top predators, relieve pressure on other prey species that lake trout now rely on (mainly rainbow smelt), and alleviate concerns about EMS. A cisco rehabilitation plan that compliments this revised plan should be written and adopted. Potential strategies for recovery of cisco in the eastern basin can be found in Oldenburg et al. (2007).

Water-Quality Agreement

The decimation of lake trout stocks in Lake Erie was caused by a myriad of factors, including pollution (Cornelius et al. 1995). The 1972 Great Lakes Water Quality Agreement (GLWQA) and its revision in 1978 provided the means for water-quality improvements that encouraged reestablishment of native fishes. Continued support of the GLWQA is essential for rehabilitation of lake trout stocks and should be supported by the LEC.

Stocking Support

Because lake trout has not achieved a sustainable level of reproduction, stocking remains essential for building an adult population large enough to overcome the bottlenecks impeding rehabilitation. The numbers stocked must also take into account possible detrimental effects to prey fishes. The LEC should encourage the production of lake trout at U.S. federal and Ontario hatcheries and promote the culture of new strains and forms needed for rehabilitation.

Sea Lamprey Control

Sea lamprey control has been identified here as a major obstacle to lake trout rehabilitation in Lake Erie. The LEC must continue to keep abreast of the control effort and ensure that sea lamprey treatments in major producing streams continue. The LEC should also promote implementation of new or alternative control methods that have promise for making control in Lake Erie more effective.

Impacts and Trade-offs

Rehabilitation of lake trout will undoubtedly cause changes to the fish community. Decisions will have to be made that may affect the abundance of forage species and other top predators. The LEC will need to weigh the importance of lake trout rehabilitation with regards to its effects on the fish community. Trade-offs should take into account the fish-community goals for the lake (Ryan et al. 2003), which the committee previously adopted.

REFERENCES

- Barnes, M.D. 1982. Lake Erie intensive study: fisheries status and response to water quality. Center for Lake Erie Area Research Tech. Rep. No. 240, Ohio State Univ., Columbus, OH.
- Bronte, C.R., Schram, S.T., Selgeby, J.H., and Swanson, B.L. 2002. Reestablishing a spawning population of lake trout in Lake Superior with fertilized eggs in artificial turf incubators. *North Am. J. Fish. Manage.* **22**: 796-805.
- Bronte, C.R., Jonas, J., Holey, M.E., Eshenroder, R.L., Toneys, M.L., McKee, P., Breidert, B., Claramunt, R.M., Ebener, M.P., Krueger, C.C., Wright, G., and Hess, R. 2003. Possible impediments to lake trout restoration in Lake Michigan [online]. Available from <http://www.glf.org/lakecom/lmc/lrestore.pdf> [accessed 2 April 2008].
- Bronte, C.R., Krueger, C.C., Holey, M.E., Toneys, M.L., Eshenroder, R.L., and Jonas, J.L. 2008. A guide for the rehabilitation of lake trout in Lake Michigan. [online]. Available from <http://www.glf.org/pubs/SpecialPubs/2008-01.pdf> [accessed 13 November 2008].
- Christie, W.J. 1974. Changes in the fish species composition of the Great Lakes. *J. Fish. Res. Board Can.* **31**: 827-854.
- Coldwater Task Group. 2001. Report of the Lake Erie Coldwater Task Group. Minutes of the 2001 (annual) meeting of the Lake Erie Committee, Attachment 5 (pp. 89-128). Great Lakes Fish. Comm., Ann Arbor, MI.
- Coldwater Task Group. 2006. Report of the Lake Erie Coldwater Task Group. Minutes of the 2006 (annual) meeting of the Lake Erie Committee, Attachment 6b. Great Lakes Fish. Comm., Ann Arbor, MI.
- Coldwater Task Group. 2007. Report of the Lake Erie Coldwater Task Group. Minutes of the 2007 (annual) meeting of the Lake Erie Committee [online]. Available from http://www.glf.org/lakecom/lec/CWTG_docs/annual_reports/CWTG_report_2007.pdf [accessed 28 April 2008].
- Coldwater Task Group. 2008. Report of the Lake Erie Coldwater Task Group. Minutes of the 2008 (annual) meeting of the Lake Erie Committee [online]. Available from http://www.glf.org/lakecom/lec/CWTG_docs/annual_reports/CWTG_report_2008.pdf [accessed 28 April 2008].
- Cornelius, F.C., Muth, K.M., and Kenyon, R. 1995. Lake trout rehabilitation in Lake Erie: a case history. *J. Great Lakes Res.* **21**(Suppl. 1): 65-82.
- Cox, E.T. 1992. An indexed chronology of some events in the development and administration of commercial fishing on Lake Erie. *Ont. Min. Nat. Resour.*, Lake Erie Fisheries Assessment Unit Rep. 1992-8.

- Culligan, W.J., Cornelius, F.C., Einhouse, D.W., Zeller, D.L., Zimar, R.C., Beckwith, B., and Wilkinson, M. 1995. NYSDEC Lake Erie Unit 1995 Annual Report. NY Dept. Env. Cons., Albany, NY.
- Desorcie, T.J., and Bowen, II, C.A. 2003. Evidence of offshore lake trout reproduction in Lake Huron. *North Am. J. Fish. Manage.* **23**: 1253-1256.
- Edsall, T.A., Brown, C.L., Kennedy, G.W., and French, III, J.R.P. 1992. Surficial substrates and bathymetry of five historical lake trout spawning reefs in nearshore waters of the Great Lakes [online]. Available from <http://www.glf.org/pubs/TechReports/Tr58.pdf> [accessed 13 November 2008].
- Einhouse, D.W., Bur, M.T., Cornelius, F.C., Kenyon, R., Madenjian, C.P., Rand, P.S., Sztramko, K.L., and Witzel, L.D. 1999. Consumption of rainbow smelt by walleye and salmonine fishes in eastern Lake Erie. *In State of Lake Erie: past, present, and future. Edited by M. Munawar, T. Edsall, and I.F. Munawar. Ecovision World Mono. Ser., Backhuys Publishers, Leiden, The Netherlands.* pp. 291-303.
- Einhouse, D.W., Markham, J.L., Zeller, D.L., Zimar, R.C., and Beckwith, B.J. 2007. NYSDEC Lake Erie Unit 2006 Annual Report [online]. Available from <http://www.dec.ny.gov/outdoor/32286.html> [accessed 2 April 2008].
- Elrod, J.H., Schneider, C.P., and Ostergaard, D.E. 1993. Survival of lake trout stocked in U.S. waters of Lake Ontario. *North. Am. J. Fish. Manage.* **13**: 775-781.
- Elrod, J.H., O’Gorman, R., Schneider, C.P., Eckert, T.H., Schaner, T., Bowlby, J.N., and Schleen, L.P. 1995. Lake trout rehabilitation in Lake Ontario. *J. Great Lakes Res.* **21**(Suppl. 1): 83-107.
- Elrod, J.H., O’Gorman, R., and Schneider, C.P., and Schaner, T. 1996. Geographical distributions of lake trout strains stocked in Lake Ontario. *J. Great Lakes Res.* **22**:871-833.
- Eschmeyer, P.H. 1956. The early life history of lake trout in Lake Superior. Mich. Dept. Conserv., Misc. Publ. 10, Ann Arbor, MI.
- Everhart, W.H., and Youngs, W.D. 1981. Principles of fishery science. 2nd ed. Cornell University Press, Ithaca, NY.
- Fisher, J.P., Fitzsimons, J.D., Combs, Jr., G.F., and Spitsbergen, J.M. 1996. Naturally occurring thiamine deficiency causing reproductive failure in Finger Lakes Atlantic salmon and Great Lakes lake trout. *Trans. Am. Fish. Soc.* **125**: 167-178.
- Fitzsimons, J.D. 1994. An evaluation of lake trout spawning habitat characteristics and methods for their detection. *Can. Tech. Rep. Fish. Aquat. Sci. No.* 1962.
- Fitzsimons, J.D. 1995. Assessment of lake trout spawning habitat and egg deposition and survival in Lake Ontario. *J. Great Lakes Res.* **21**(Suppl. 1): 337-347.
- Fitzsimons, J.D. 1996. The significance of man-made structures for lake trout spawning in the Great Lakes: are they a viable alternative to natural reefs. *Can J. Fish Aquat. Sci.* **53**(Suppl. 1): 142-151.

- Fitzsimons, J.D., and Brown, S.B. 1998. Reduced egg thiamine levels in inland and Great Lakes lake trout and their relationship with diet. *In* Early life stage mortality syndrome in fishes of the Great Lakes and the Baltic Sea. *Edited by* G. McDonald, J.D. Fitzsimons, and D.C. Honeyfield. Am. Fish. Soc., Symp. 21, Bethesda, MD. pp. 160-171.
- Fitzsimons, J.D., and Williston, T.B. 2000. Evidence of lake trout spawning in Lake Erie. *J. Great Lakes Res.* **26**(4): 489-494.
- Fitzsimons, J.D., Brown, S.B., Honeyfield, D.C., and Hnath, J.G. 1999. A review of early mortality syndrome (EMS) in Great Lakes salmonids: relationship with thiamine deficiency. *Ambio* **28**: 9-15.
- Fitzsimons, J.D., Lantry, B., and O’Gorman, R. 2003. A review of lake trout (*Salvelinus namaycush*) restoration in Lake Ontario from an early life history perspective. *In* State of Lake Ontario: past, present, and future. *Edited by* M. Munawar. Ecovision World Mono. Ser., Aquatic Ecosystem Health Manage. pp. 493-516.
- Gannon, J.E. 1990. International position statement and evaluation guidelines for artificial reefs in the Great Lakes [online]. Available from http://www.glf.org/pubs/SpecialPubs/Sp90_2.pdf [accessed 13 November 2008].
- Great Lakes Fishery Commission. 2007. A joint strategic plan for management of Great Lakes fisheries [online]. Available from <http://www.glf.org/pubs/jsp97.pdf> [accessed 2 April 2008].
- Habitat Task Group. 2006. Report of the Lake Erie Habitat Task Group. Minutes of the 2006 (annual) meeting of the Lake Erie Committee, Attachment 8b. Great Lakes Fish. Comm., Ann Arbor, MI.
- Hartman, W.L. 1972. Lake Erie: effects of exploitation, environmental changes and new species on the fisheries resources. *J. Fish. Res. Board Can.* **29**: 899-912.
- Healey, M.C. 1978. The dynamics of exploited lake trout populations and implications for management. *J. Wildl. Manage.* **42**(2): 307-328.
- Herbert, H.W. 1851. Frank Forester’s fish and fishing of the United States and British provinces of North America. Stringer & Townsend, NY.
- Honeyfield, D.C., Hinterkopf, J., Fitzsimons, J.D., Tillitt, D.E., Zajicek, J.L., and Brown, S.B. 2005. Development of thiamine deficiencies and early mortality syndrome in lake trout by feeding experimental and feral fish diets containing thiaminase. *J. Aquat. Anim. Health* **17**: 4-12.
- Jonas, J.L., Claramunt, R.M., Fitzsimons, J.D., Marsden, J.E., and Ellrott, B.J. 2005. Estimates of egg deposition and effects of lake trout (*Salvelinus namaycush*) egg predators in three regions of the Great Lakes. *Can J. Fish Aquat. Sci.* **62**: 2254-2264.
- Jordan, D.S., and Evermann, B.W. 1937. American food and game fishes: a popular account of all the species found in America north of the equator, with keys or ready identification, life histories, and methods of capture. Doubleday, Doran, and Company, Inc., Garden City, N.Y.

- Jude, D.J., Klinger, S.A., and Enk, M.D. 1981. Evidence of natural reproduction by planted lake trout in Lake Michigan. *J. Great Lakes Res.* **7**: 57-61.
- Kernen, L.T. 1995. Lake trout: valuable native fauna or just grease? *J. Great Lakes Res.* **21**(Suppl. 1): 198-201.
- King, L.E., Jr., and Edsall, T.A. 1979. Illustrated field guide for the classification of sea lamprey attack marks on Great Lakes lake trout [online]. Available from http://www.glfrc.org/pubs/SpecialPubs/SP79_1.pdf [accessed 13 November 2008].
- Krueger, C.C., and Ebener, M. 2004. Rehabilitation of lake trout in the Great Lakes: past lessons and future challenges. *In* *Boreal shield watersheds: lake trout ecosystems in a changing environment. Edited by J.M. Gunn, R.J. Steedman, and R.A. Ryder.* Lewis Publishers, Boca Raton, Florida. pp 37-56.
- Krueger, C.C., and Ihssen, P.E. 1995. Review of genetics of lake trout in the Great Lakes: history, molecular genetics, physiology, strain comparisons, and restoration management. *J. Great Lakes Res.* **21**(Suppl. 1): 348-363.
- Krueger, C.C., Swanson, B.L., and Selgeby, J.H. 1986. Evaluation of hatchery-reared lake trout for reestablishment of populations in the Apostle Islands region of Lake Superior, 1960-84. *Fish Culture in Fisheries Management.* Am. Fish Soc. pp. 93-107.
- Krueger, C.C., Jones, M.L., and Taylor, W.W. 1995. Restoration of lake trout in the Great Lakes: challenges and strategies for future management. *J. Great Lakes Res.* **21**(Suppl. 1): 547-558.
- Lake Trout Task Group. 1985a. A strategic plan for the rehabilitation of lake trout in eastern Lake Erie. Minutes of the 1985 (annual) meeting of the Lake Erie Committee, Appendix XXIV (pp. 407-428). Great Lakes Fish. Comm., Ann Arbor, MI.
- Lake Trout Task Group. 1985b. A sea lamprey management plan for Lake Erie. Minutes of the 1985 (annual) meeting of the Lake Erie Committee, Appendix XXV (pp. 429-436). Great Lakes Fish. Comm., Ann Arbor, MI.
- Ludsin, S.A., Fryer, B.J., Yang, Z., Melancon, S., and Markham, J.L. 2004. Exploration of the existence of natural reproduction in Lake Erie lake trout using otolith microchemistry [online]. Available from http://www.glfrc.org/research/reports/Ludsin_Fryer.pdf [accessed 2 April 2008].
- Marsden, J.E. 1994. Spawning by stocked lake trout on shallow, near-shore reefs in southwestern Lake Michigan. *J. Great Lakes Res.* **20**: 377-384.
- Marsden, J.E., and Chotkowski, M.A. 2001. Lake trout spawning on artificial reefs and the effect of zebra mussels: fatal attraction? *J. Great Lakes Res.* **27**(1): 33-43.
- Marsden, J.E., Casselman, J.M., Edsall, T.A., Elliott, R.F., Fitzsimons, J.D., Horns, W.H., Manny, B.A., McAughey, S.C., Sly, P.G., and Swanson, B.L. 1995. Lake trout spawning habitat in the Great Lakes—a review of current knowledge. *J. Great Lakes Res.* **21**(Suppl. 1): 487-497.

- Marsden, J.E., Ellrott, B.J., Claramunt, R.M., Jonas, J.L., and Fitzsimons, J.D. 2005. A comparison of lake trout spawning, fry emergence, and habitat use in Lakes Michigan, Huron, and Champlain. *J. Great Lakes Res.* **31**: 492-508.
- Nash, C.W. 1908. *Vertebrates of Ontario*. The Legislative Assembly of Ontario, Toronto, Canada.
- Oldenburg, K., Stapanian, M.A., Ryan, P.A., and Holm, E. 2007. Potential strategies for recovery of lake whitefish and lake herring stocks in eastern Lake Erie. *J. Great Lakes Res.* **33**(1):46-58.
- Pare, S.M. 1993. The restoration of lake trout in eastern Lake Erie. Administrative Report 93-02. U.S. Fish Wildl. Serv., Lower Great Lakes Fish. Res. Office, Amherst, NY.
- Peck, J.W. 1982. Extended residence of young-of-the-year lake trout in shallow water. *Trans. Am. Fish. Soc.* **111**:775-778.
- Peck, J.W. 1986. Dynamics of reproduction by hatchery lake trout on a man-made spawning reef. *J. Great Lakes Res.* **12**: 293-303.
- Reid, D.M., Anderson, D.M., and Henderson, B.A. 2001. Restoration of lake trout in Parry Sound, Lake Huron. *North Am. J. Fish. Manage.* **21**: 156-169.
- Ryan, P.A., Knight, R., MacGregor, R., Towns, G., Hoopes, R., and Culligan, W. 2003. Fish-community goals and objectives for Lake Erie. *Great Lakes Fish. Comm. Special Publication 03-02* [online]. Available from http://www.glfsc.org/lakecom/lec/LEC_docs/other_docs/Sp03_2.pdf [accessed 2 April 2008].
- Rybicki, R.W. 1991. Growth, mortality, recruitment and management of lake trout in eastern Lake Michigan. . Mich. Dept. Nat. Resourc. Fish. Res. Rep. No. 1979.
- Ryder, R.A., and Edwards, C.J. 1985. A conceptual approach for the application of biological indicators of ecosystem quality in the Great Lakes basin [online]. Available from <http://www.glfsc.org/pubs/SpecialPubs/RepMar85.pdf> [accessed 2 April 2008].
- Schneider, C.P., Kolenosky, D.P., and Goldthwaite, D.B. 1983. A joint plan for the rehabilitation of lake trout in Lake Ontario. Minutes of the 1983 (annual) meeting of the Lake Ontario Committee, Appendix XII (pp. 147-150). *Great Lakes Fish. Comm.*, Ann Arbor, MI.
- Schneider, C.P., Owens, R.W., Bergstedt, R.A., and O’Gorman, R. 1996. Predation by sea lamprey (*Petromyzon marinus*) on lake trout (*Salvelinus namaycush*) in southern Lake Ontario, 1982-1992. *Can J. Fish Aquat. Sci.* **53**(9): 1921-1932.
- Selgeby, J.H., Bronte, C.R., Brown, E.H., Hansen, M.J., Holey, M.E., VanAmberg, J.P., Muth, K.M., Makauskas, D.B., McKee, P., Anderson, D.M., Paola Ferreri, C., and Schram, S.T. 1995. Lake trout restoration in the Great Lakes: stock-size criteria for natural reproduction. *J. Great Lakes Res.* **21**(Suppl. 1): 498-504.

- Sullivan, W.P., Christie, G.C., Cornelius, F.C., Fodale, M.F., Johnson, D.A., Koonce, J.F., Larson, G.L., McDonald, R.B., Mullett, K.M., Murray, C.K., and Ryan, P.A. 2003. The sea lamprey in Lake Erie: a case history. *J. Great Lakes Res.* **29**(Suppl. 1): 615-636.
- Thibodeau, M.L., and Kelso, J.R.M. 1990. An evaluation of putative lake trout (*Salvelinus namaycush*) spawning sites in the Great Lakes. *Can. Tech. Rep. Fish. Aquat. Sci.* No. 1793.
- Tillitt, D.E., Zajicek, J.L., Brown, S.B., Brown, L.R., Fitzsimons, J.D., Honeyfield, D.C., Holey, M.E., and Wright, G.M. 2005. Thiamine and thiaminase status in forage fish of salmonines from Lake Michigan. *J. Aquat. Anim. Health* **17**: 13-25.
- Trautman, M.B. 1981. *Fishes of Ohio*. The Ohio State University Press, Columbus, OH.
- Wagner, W.C. 1981. Reproduction of planted lake trout in Lake Michigan. *North Am. J. Fish. Manage.* **1**: 159-164.
- Zhang, C., Brown, S.B., and Hara, T.J. 2001 Biochemical and physiological evidence that bile acids produced and released by lake char (*Salvelinus namaycush*) function as chemical signals. *J. Comp. Physiol.* **171**: 161-171.

APPENDIX

Origin and Description of Lake Trout Strains Stocked into Lake Erie Since 1978

Finger Lakes: FL or SEN (Shallow Water)

Lake trout descended from a naturally sustained population that coexisted with sea lamprey in Seneca Lake, NY. A captive broodstock has been maintained at the Allegheny National Fish Hatchery in Warren, PA, and production also relies on eggs collected from the population in Seneca Lake.

Klondike: KL (Deep Water)

Lake trout descended from a naturally sustained population on Klondike Reef in Lake Superior. A captive broodstock has been maintained at Iron River National Fish Hatchery in Iron River, WI, and eggs have been shipped to the Allegheny National Fish Hatchery and the White River National Fish Hatchery in Bethel, VT. This is the only lake trout strain currently available in the federal hatchery system that is a deepwater type.

Superior: SUP (Shallow Water)

A captive lake trout broodstock initially developed at the Marquette (MI) State Hatchery and derived from rehabilitated lean Lake Superior populations. A broodstock has also been maintained at the Allegheny National Fish Hatchery.

Traverse: TI Island (Shallow Water)

Similar to the Superior-strain, except that the broodstock was derived from the Traverse Island population of Lake Superior.

Apostle Island: AI (Shallow Water)

Similar to the Superior-strain, except that the broodstock was derived from the Apostle Island population of Lake Superior.

Slate Island: SI (Shallow Water)

Similar to the Superior-strain, except that the broodstock was derived from the Slate Island population of Lake Superior.

Clearwater Lake: CWL (Shallow Water)

Based on eggs collected from lake trout in Clearwater Lake, Manitoba, Canada, and raised to fall and spring yearling stages at the Allegheny National Fish Hatchery.

Lewis Lake: LL (Shallow Water)

Of northern Lake Michigan origin and stocked in 1890 as fall fingerlings into Lewis Lake, WY. Broodstock was obtained from the Jackson (WY) National Fish Hatchery and Saratoga (WY) National Fish Hatchery.

Lake Ontario: LO (Shallow Water)

Derived from mixed strains stocked into and surviving in Lake Ontario. Eggs were collected in the eastern basin in 1983-1987, and broodstocks were developed from these egg collections. A portion of the broodstock was developed from crosses of Lake Ontario-strain broodstock females with Finger Lake males (Elrod et al. 1995).

Lake Erie: LE (Shallow Water)

Derived from mixed strains stocked into and surviving in Lake Erie. Eggs were collected from spawning adults off Barcelona Harbor in 1992-1995 and raised to yearlings at the Allegheny National Fish Hatchery. It comprises mainly Finger Lake- and Superior-strain fish.

MISCELLANEOUS PUBLICATIONS

- February 1993 What's next? The prediction and management of exotic species in the Great Lakes (report of the 1991 workshop). E.L. Mills, J.H. Leach, C.L. Secor, and J.T. Carlton. 22 p.
- August 1993 A survey of fish-community and habitat goals/objectives/targets and status in Great Lakes areas of concern. J.H. Hartig. 95 p.
- August 1993 Toward integrating remedial-action and fishery-management planning in Great Lakes areas of concern. J.H. Hartig. 34 p.
- September 1994 Walleye-rehabilitation guidelines for the Great Lakes area. P.J. Colby, C.A. Lewis, R.L. Eshenroder, R.C. Haas, L.J. Hushak. 112 p.
- April 1996 A lake trout restoration plan for Lake Superior. M.J. Hansen [ED.]. 34 p.
- August 1998 A lake trout rehabilitation guide for Lake Huron. M.P. Ebener [ED.]. 48 p.
- 2003-01 A rehabilitation plan for walleye populations and habitats in Lake Superior. M.H. Hoff [ED.]. 22 p.
- 2003-02 A lake sturgeon rehabilitation plan for Lake Superior. N.A. Auer [ED.]. 28 p.
- 2003-03 A brook trout rehabilitation plan for Lake Superior. L.E. Newman, R.B. DuBois, and T.N. Halpern [EDS]. 40 p.
- 2006-01 A mid-decade review of progress under a “strategic vision of the Great Lakes Fishery Commission for the first decade of the new millennium.” 45 p.
- 2006-02 Application of a dichotomous key to the classification of sea lamprey marks on Great Lakes fish. Ebener, M.P., E.L. King, Jr., T.A. Edsall. 22 p.
- 2007-01 A joint strategic plan for management of Great Lakes fisheries. Great Lakes Fishery Commission [ED.]. 28 p.
- 2007-02 Application of a dichotomous key to the classification of sea lamprey *Petromyzon marinus* marks on lake sturgeon *Acipenser fulvescens*. Patrick, H.K., T.M. Sutton, and W.D. Swink. 24 p.
- 2008-01 A guide for the rehabilitation of lake trout in Lake Michigan. Bronte, C.R., C.C. Krueger, M.E. Holey, M.L. Toney, R.L. Eshenroder, and J.L. Jonas. 40 p.

Cover photograph from the New York State Department of Environmental Conservation,
Albany, NY, U.S.A.