A MANAGEMENT STRATEGY FOR THE RESTORATION OF LAKE TROUT IN LAKE ONTARIO, 2014 UPDATE

PREPARED BY:

Jana Lantry[1]

Ted Schaner[2]

Tracy Copeland[3]

[1] New York State Department of Environmental Conservation – Lake Ontario Unit, Cape Vincent Fisheries Station, 541 East Broadway, Cape Vincent, NY 13618

[2] Ontario Ministry of Natural Resources, Lake Ontario Management Unit, RR # 4, Picton, Ontario, K0K 2T0

[3] U.S. Fish and Wildlife Service – Lower Great Lakes Fish and Wildlife Conservation Office, 1101 Casey Road, Basom, NY 14013

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EXECUTIVE SUMMARY

- This document is a revision of the Lake Trout Rehabilitation Plan for Lake Ontario (Schneider et al. 1983), originally published in 1983, and updated in 1990 and 1998. This revision was prompted by significant changes in Lake Ontario's ecosystem and its Lake Trout population.
- The Lake Ontario Committee of the Great Lakes Fishery Commission's 2013 Lake Ontario Fish Community Objectives (FCO), more specifically FCO 3.1, serves as a management guide for this component of the benthic fish community (Stewart et al. 2014a).
- FCO 3.1: Restore a self-sustaining population of Lake Trout in Lake Ontario (Appendix 1; Stewart et al. 2014a).
    - Increase abundance of stocked Lake Trout to a level allowing for significant natural reproduction.
    - Increase populations of wild Lake Trout across a range of age groups.
- This Management Strategy for the Restoration of Lake Trout provides additional detail, measures and strategies needed to achieve FCO 3.1 and to restore a self-sustaining population which is consistent with the Deep Pelagic and Offshore Benthic Zone Goal (Stewart et al. 2014a). This Management Strategy serves to coordinate and direct bi-national restoration efforts and is an integral component of the Lake Ontario Lakewide Management and Action Plan (LaMP).
- The most important changes in this strategy are:
    - increased stocking in U.S. waters
    - renewed emphasis on assessment of stocking methods
    - recommended reinstatement of coded wire tag use for Ontario stockings
    - recognition of the need for suitable prey base, including restoration of native prey fishes
- This document also identifies:
    - impediments to Lake Trout restoration
    - research needs
    - action items
    - roles and responsibilities of state, provincial and federal agencies
- We recommend annual evaluations of the status of the Lake Trout population and natural reproduction. The next review of this Management Strategy should be initiated and completed by 2024.

PREAMBLE

IMPORTANCE OF LAKE TROUT RESTORATION IN LAKE ONTARIO

Lake Trout and Atlantic Salmon are the only two pelagic salmonines native to Lake Ontario. Lake Trout is a top predator in the cold-water fish community, and historically played a pivotal role in energy cycling in the offshore benthic and pelagic zones, exerting a stabilizing influence on the fish community (Ryder and Kerr 1990). Restoration of a self-sustaining, naturally reproducing Lake Trout population will improve ecological function of the offshore benthic and pelagic zones, enhance biodiversity, and promote a more diverse, productive, and long-term fishery (Stewart et al. 1999; USEPA 2008; Stewart et al. 2014a). Lake Trout also serves as a biological indicator of overall ecosystem quality (Ryder and Edwards 1985).

The lake's fisheries management is guided by the Lake Ontario Committee of the Great Lakes Fishery Commission's Fish Community Objectives (FCO) document which calls for restoration of self-sustaining Lake Trout populations (Appendix 1; Stewart et al. 2014a). Additionally, Lake Trout populations sustained through natural reproduction is a specific objective outlined the Lake Ontario Lakewide Management Plan (LaMP; USEPA 2008). Measures of the Lake Trout population (e.g., abundance indices, Sea Lamprey wounding rate, numbers harvested, catches of naturally produced) are indicators of FCOs 3.1 and 3.4, and are LaMP indicators of ecosystem health.

HISTORICAL OVERVIEW

Early history: Lake trout were once abundant and widely distributed; however, significant exploitation by Lake Ontario's commercial fisheries began in the 1830s and stocks were greatly diminished by the 1900s (Pritchard 1931; Schneider et al. 1983). By the1950s, Lake Trout were extirpated in Lake Ontario due to uncontrolled fishing and Sea Lamprey predation (Schneider et al. 1983). Between 1953 and 1964 attempts were made to re-introduce Lake Trout, but survival of the stocked fish remained poor due to Sea Lamprey mortality and high exploitation rates (Christie 1973; Schneider et al. 1983).

The 1983 Plan: This phase of Lake Trout restoration in Lake Ontario began in the early 1970s with initiation of Sea Lamprey control and the resumption of stocking by the U.S. and Canada (Elrod et al. 1995). Early monitoring indicated that Sea Lamprey predation and fishery exploitation were excessive (Bergstedt and Schneider 1988), and that stocking levels were inadequate (Schneider et al. 1983). In 1980, state, provincial and federal agencies began formal planning for Lake Trout restoration in Lake Ontario. In 1983, a joint plan was completed (Schneider et al. 1983; hereafter referred to as the 1983 Plan; Appendix 2). The 1983 Plan's ultimate objective called for establishment of a population of 0.5-1.0 million adult fish, a natural annual recruitment level of 2-3 million yearlings, and 450,000 kg of annual usable surplus. The interim objective, which was to be achieved by year 2000 to demonstrate the feasibility of restoration, called for establishing an adult population of 0.5-1.0 million fish and modest natural recruitment (100,000 yearlings annually). Details of the 1983 Plan are summarized in Appendix 2.

1983-1990: Following the 1983 Plan, agencies increased stocking levels and used several different strains to maximize genetic diversity in an attempt to develop a strain well adapted to Lake Ontario. Use of coded wire tag (CWT) marking began in 1979 (Elrod and Schneider 1986), enabling biologists to evaluate fish culture and stocking practices, identify environmental factors affecting survival of hatchery-reared fish, and estimate strain-specific survival and growth rates, maturity statistics, relative mortality due to Sea Lamprey attacks and bathythermal distributions (Elrod 1987; Elrod and Schneider 1987; Bergstedt and Schneider 1988; Elrod et al. 1988; Elrod et al. 1989; Elrod and Schneider 1992; Elrod et al. 1993; Elrod et al. 1995; Elrod et al. 1996; Schneider et al. 1996; Elrod 1997; O'Gorman et al. 1998). Sea Lamprey control improved with initiation of lampricide treatments of the Oneida Lake (1984) and Lake Erie (1986) watersheds (Elrod et al. 1995), both of which continue to be potential sources of lamprey for Lake Ontario. The incidence of fresh Sea Lamprey wounds on Lake Trout in Lake Ontario declined during this period, and estimated numbers of Lake Trout killed by Sea Lamprey declined by about two-thirds (Elrod et al. 1995; Schneider et al. 1996). Restrictive harvest regulations implemented in New York waters of Lake Ontario in 1988 significantly reduced angler harvest (Krueger et al. 2013). These actions benefited Lake Trout restoration by enhancing Lake Trout survival which led to increased abundance of mature females (Elrod et al. 1995). By 1989 survival of stocked fish had improved, the relative abundance of mature fish increased, and spawning adults were abundant on reefs. Despite these improvements, there was still little evidence of successful natural reproduction. Fry were emerging and collected annually (Marsden and Krueger 1991), but natural recruits were rare in assessment surveys.

Evaluation and draft revision of the 1983 Plan was completed by 1990 (Schneider et al. 1990), however, it was never formally adopted. The Lake Trout restoration goal and ultimate objective remained unchanged from the 1983 Plan, but the interim natural recruitment objective (to be achieved by year 2000) was reduced to a less ambitious "measurable level of yearling recruits", because in spite of successful detection of emergent fry, there was not yet any evidence of yearling recruits. The 1990 draft revision also acknowledged the need for deepwater coregonids to diversify the forage base available to Lake Trout and recommended their reintroduction. The 1990 draft plan is summarized in Appendix 2.

1990-1997: By 1990, ecosystem changes and a decline in prey fish caused concern about sustainability of the Lake Ontario salmonine fishery. Reductions in productivity of lower trophic levels combined with intense salmonine predation were implicated as causes for declining condition and abundance of Alewife (Johengen et al. 1994; Rand et al. 1994; O'Gorman et al. 1997; Johannsson et al. 1998; O'Gorman et al. 2004). In 1992, a scientific review examined sustainability of salmonine populations given reduced lake productivity, Alewife trends and predatory demand. Jones et al. (1993) inferred that an extreme weather event together with intense predation could collapse the Alewife population. Consequently, managers reduced salmonine stocking levels over a period of two years (1993-1994) to reduce predatory demand on prey fish by 50% (Jones et al. 1992; Sprules et al. 1994). The annual Lake Trout stocking level was reduced from one million yearlings per nation to 500,000 yearlings each. Despite reduced salmonine stocking levels, Alewife abundance and biomass continued to decline through the 1990s.

During this same time, Lake Trout began to produce detectable levels of natural recruits. Bottom trawling assessments revealed four consecutive years (1993-96 year classes) of successful natural reproduction with catches of young wild Lake Trout recorded at most US trawling locations. These signals of improved natural reproduction were attributed to ecosystem changes that occurred through the 1990s (Schneider et al. 1998). Reduced lake productivity may have improved the quality of spawning habitat. Declines in non-native Alewife and Rainbow Smelt populations and a shift in their spring distribution to deeper waters (O'Gorman et al. 2000) following colonization of invasive zebra and quagga mussels (dreissenids) likely eased predation on Lake Trout fry, as evidenced by increased abundance of other species with vulnerable fry stages like Three-Spine Stickleback, Burbot and Yellow Perch. Lower numbers of Alewives may have also eased thiaminase effects on natural reproduction.

Many objectives identified in the 1983 Plan and 1990 draft plan were achieved by the mid-1990s (Schneider et al. 1998). In 1995, survival rate of the adult population was greater than 60%, with much of this improvement due to increasing numbers of Seneca Lake strain fish (also known as Finger Lakes strain; Schneider et al. 1998; Lantry and Lantry 2014). With improved survival, the stock of mature females increased and their average age increased to greater than seven years old, two years older than the age of first maturity as was recommended in the 1983 Plan. Sea Lamprey wounding rates remained near or below the target level of two A1 wounds per 100 fish. Harvest levels were at approximately 40,000 fish (10,000 fish from Ontario waters and 30,000 from New York), which was well below the 60,000 fish per nation target. Changing ecosystem conditions concurrent with successful natural reproduction and improved Lake Trout population status indicated future successes in restoration.

The 1998 Plan: The strategy for Lake Trout restoration was revised in 1997 based on encouraging information about the ecosystem and status of Lake Trout (Schneider et al. 1998). The revision was presented to GLFC's LOC in 1998, has since been the operational guide for Lake Trout restoration (Lantry et al. 2014a), and hereafter, is referred to as the 1998 Plan. The goal remained unchanged from previous versions; however, the term "usable" was emphasized to relay a stronger commitment that no health risk be incurred through consumption of Lake Trout by humans or wildlife. Objectives were revised given reductions in overall productivity of the Lake Ontario ecosystem, reduced stocking levels and the improved status of the Lake Trout population observed at that time. The emphasis was on maintaining established stocked population and promoting natural reproduction. The 1998 Plan suggested that a 10% level of replacement of stocked fish with wild by 2017 would indicate Lake Trout restoration was on a slow but positive course of progress. There was a shift from objectives based on age determination from CWTs to objectives that could be based on surrogate measures such as maturity, thereby allowing discontinuation of the CWT marking program. When the 1998 Plan was written, abundance and age structure of mature females had reached levels that were producing wild juvenile recruits detectable in assessments. The recommended measure of reproductive potential was the catch rate (i.e., in 1992-1994) of mature females weighing $\geq$ 4000 g because it reflected a spawning stock that produced the detectable level of recruits. The 1998 Plan also recognized that a long-term strategy for restoration should "consider the re-establishment of ciscoes in the pelagic fish community". The 1998 Plan is summarized in Appendix 2.

RECENT LAKE TROUT POPULATION TRENDS

Stocking: The original lake-wide stocking target identified in the 1983 Plan was 2.5 million Lake Trout, but based on concerns about prey fish availability (Jones et al. 1993), the target was reduced to 1.0 million fish (0.5 million per nation) in 1993, a target reaffirmed in the 1998 Plan (Schneider et al. 1998; Fig. 1). The effect of reduced stocking on the adult population was first observed in 1999 when adult catch-per-unit effort (CUE) in assessment netting decreased 30% and CUE of mature females $\geq$4000g decreased 27% from the previous year (Lantry and Lantry 2014). Since the late 1990s, the combined number of fish actually stocked into U.S. and Canadian waters was below the 1.0 million target by more than 100,000 fish for six of the last 16 years (1998-2013) because of fish disease concerns and technical problems.

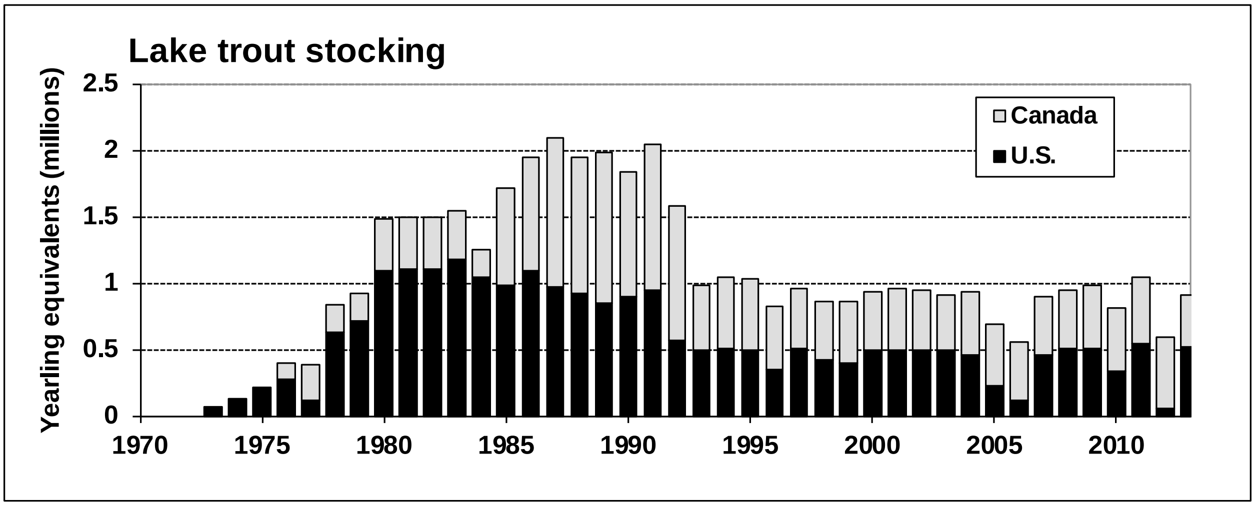

Fig. 1. *Numbers of Lake Trout stocked in U.S. and Canadian waters expressed as spring yearling equivalents (1 fall fingerling = 0.41 spring yearling; Elrod et al. 1995).*

Through the 1980s and early 1990s, several strains were stocked to maximize genetic diversity and attempt to develop a strain well adapted to Lake Ontario, as was recommended in previous restoration plans. Since the mid-1990s, stockings were dominated by Seneca Lake strain in both U.S. and Canadian waters, with lesser contributions from Lake Superior lean strains (i.e., the Superior Marquette strain in U.S. stockings, and the Slate, Michipicoten and Mishibishu strains in Canadian stockings). Seneca Lake strain became the preferred strain after demonstrating natural production of fry (Marsden et al. 1989) and better adult survival in Lake Ontario, which was due mainly to lower mortality from Sea Lamprey predation and likely associated with their bathythermal preferences (Schneider et al. 1996). By the mid-2000s, however, there were no improvements in the status of Lake Trout (see 'Early survival' and 'Abundance' sections below). In 2005, the USFWS Alleghany National Fish Hatchery (ANFH), charged with rearing the 500,000 Lake Trout for U.S. stockings, had an outbreak of Infectious Pancreatic Necrosis (IPN) which required elimination of all fish on station including broodstock, and closure of the hatchery for disinfection and renovation. Beginning with the 2006 year class, which was reared by USFWS Eisenhower (formerly called Pittsford) and White River National Fish Hatcheries in Vermont and stocked in spring 2007, the strain composition for U.S. stockings was changed to 50% Seneca Lake strain and 50% Lake Superior strains (i.e., Traverse Island, Apostle Island, and Klondike Reef) when possible (i.e., 2006-2008 year classes).

Early survival: Survival of Lake Trout during the first year following stocking declined in the 1990s, and remains low as determined from independent U.S. and Canadian assessments (Fig. 2). In U.S. waters juvenile survival is measured as bottom trawl catch of age-2 fish adjusted to 500,000 stocked. This index decreased to approximately 80-90% below 1980s levels (Lantry and Lantry 2014). In Canadian waters, the juvenile survival index is based on gillnet catches of age-3 fish and shows a decline in survival in the

1990s to less than 10% of previous levels. Although this trend appeared to have reversed in the early 2000s, survival of the 2008 and 2009 year classes was again poor.

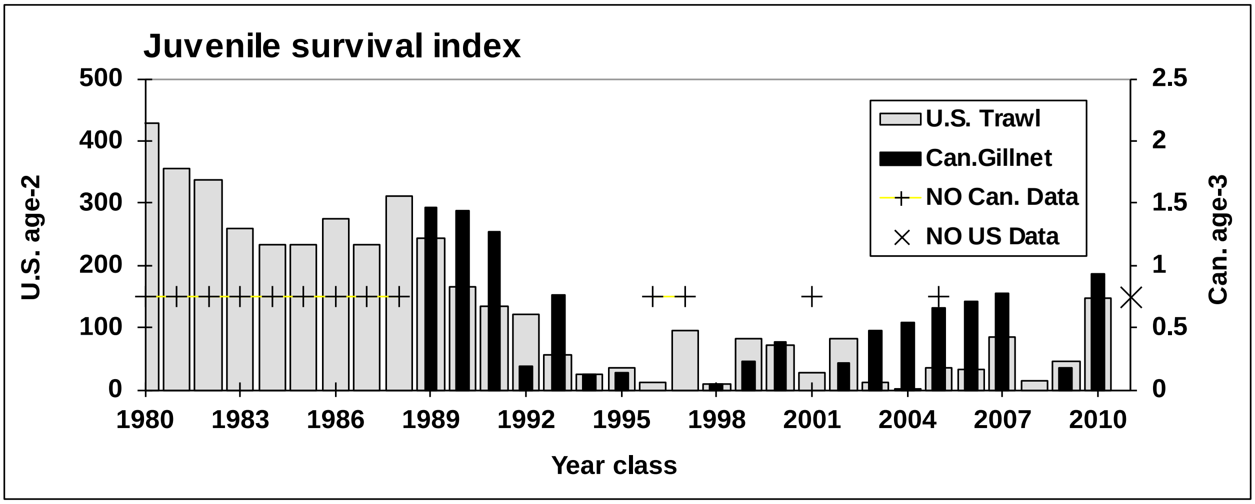

Fig. 2. *Juvenile survival index of fish stocked into U.S. and Canadian waters. The index is the CUE of juvenile fish corrected for the number originally stocked. In U.S. waters the index is the overall catch of 2-year old fish per 500,000 yearlings stocked a year earlier; in Canadian waters the index is the CUE (per standard gillnet) of 3-year old fish per 500,000 yearlings stocked two years earlier.*

Adult survival: Annual survival rate of adult fish rose above the 60% target level in the 1990s, but recent trends are difficult to measure due to lack of age information that was previously obtained from CWT marking. The ability to evaluate growth and survival of Lake Trout was compromised in the mid 1990s when there was a substantial reduction in CWT marking.

Sea Lamprey wounding rate remained near or below two A1 wounds per 100 fish for 10 of the last 16 years (1998-2013; i.e., years since the 1998 Plan; Lantry and Lantry 2014). An increase in wounding rate during 2005-2007 was likely due to recent low host density (i.e., fewer large Lake Trout) coinciding with an increase in Sea Lamprey spawner abundance (Sullivan and Adair 2014). Wounding rates in Canadian surveys have generally been below target over the last decade with only one year exceeding the target; however, the Canadian surveys are conducted during summer when Sea Lamprey predation and wounding are expected to be low. Angler harvest in both Canadian and U.S. waters remains well below the 1998 Plan target value of 30,000 per nation (1998-2013 average annual harvest: U.S. < 10,000; Canada [western lake] < 600).

Abundance: Abundance of adult fish, determined from independent U.S. and Canadian gill netting assessments, has declined since the 1998 Plan was written. The decline was related to the 1993 stocking cuts and to decreased post-stocking survival ongoing since the early 1990s. In U.S. waters, adult abundance declined precipitously during 2005-2007, reaching a level 71% below 1986-1998 peak levels (Fig. 3; Lantry and Lantry 2014). Along with declines in total abundance, abundance of mature females (≥4000g) declined below target levels outlined in the 1998 Plan (CUE's ≥ 2.0 in U.S. waters and 1.1 in Canadian waters) during 2005-2009 in U.S. waters and 2002-2013 in Canadian waters (Fig. 4). Adult abundance subsequently recovered, such that the 2010-2013 mean CUE (mean CUE = 10.3; 43% below peak levels) was similar to levels observed in1999-2004 (mean CUE = 11.0; Lantry and Lantry 2014). Abundance in Canadian waters declined to less than 10% of peak levels seen in the early 1990s, but a slight increase occurred in 2010-11 (Fig. 3; Ontario Ministry of Natural Resources 2012). Although improved, adult Lake Trout abundance remains below early 1990s levels when wild recruits were caught in their greatest numbers during assessment sampling.

Natural reproduction: Assessments targeting prey fish and Lake Trout began as early as 1982 in U.S. waters, however, naturally produced Lake Trout did not begin to appear as by-catch in assessment catches until 1994. Since 1994, 19 year classes of naturally produced Lake Trout were observed, but catches remain low (Lantry and Lantry 2014; Fig. 5). In Canadian waters there is limited opportunity to observe juvenile Lake Trout because no targeted bottom trawling program exists, and although naturally produced fish have been caught in the past, catches are not sufficient to discern a trend.

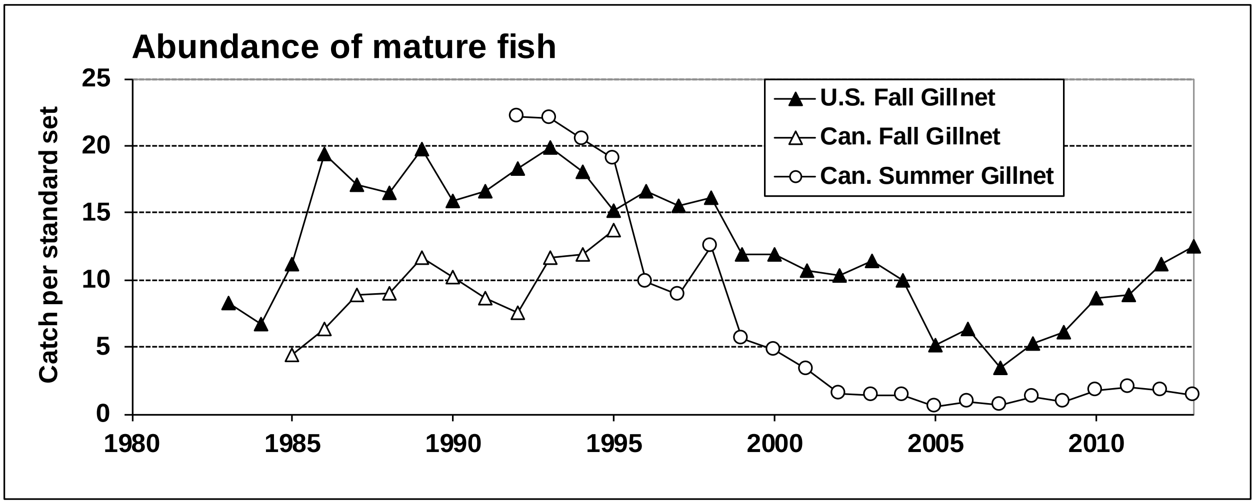

Fig. 3. *Abundance of mature fish in U.S. and Canadian waters, measured as catch per standard gillnet. Fall gillnet Lake Trout surveys have been conducted in the U.S. and Canadian waters since the early 1980s; in Canadian waters the fall surveys were discontinued in 1995 and Lake Trout are now assessed in summer fish community gillnet surveys.*

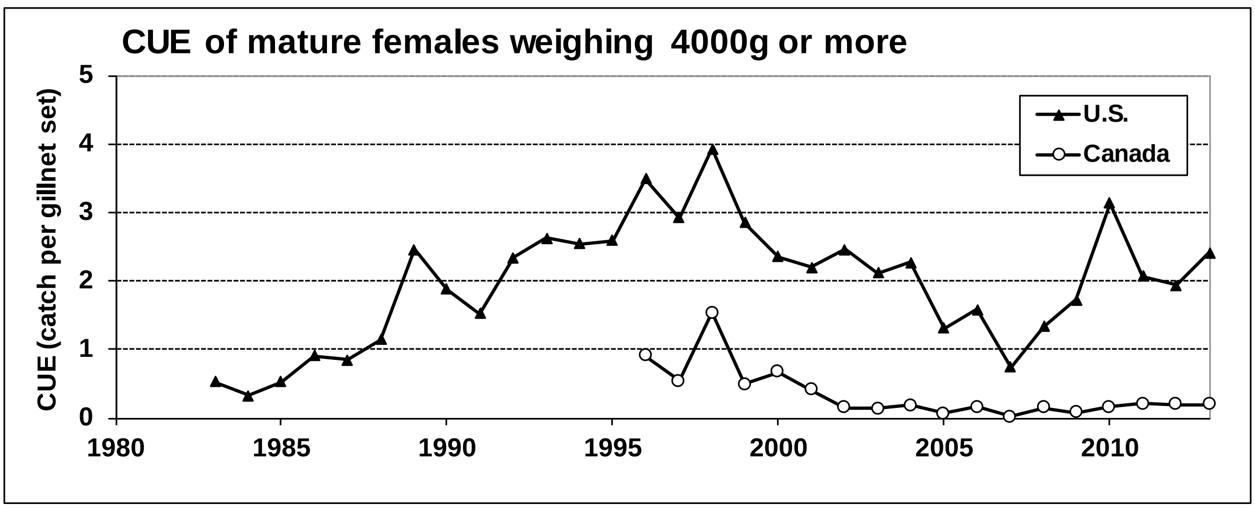

Fig. 4. *Abundance index of mature female Lake Trout $\geq$ 4000g, from September U.S. adult Lake Trout gillnetting assessment and summer Canadian fish community index gillnetting.*

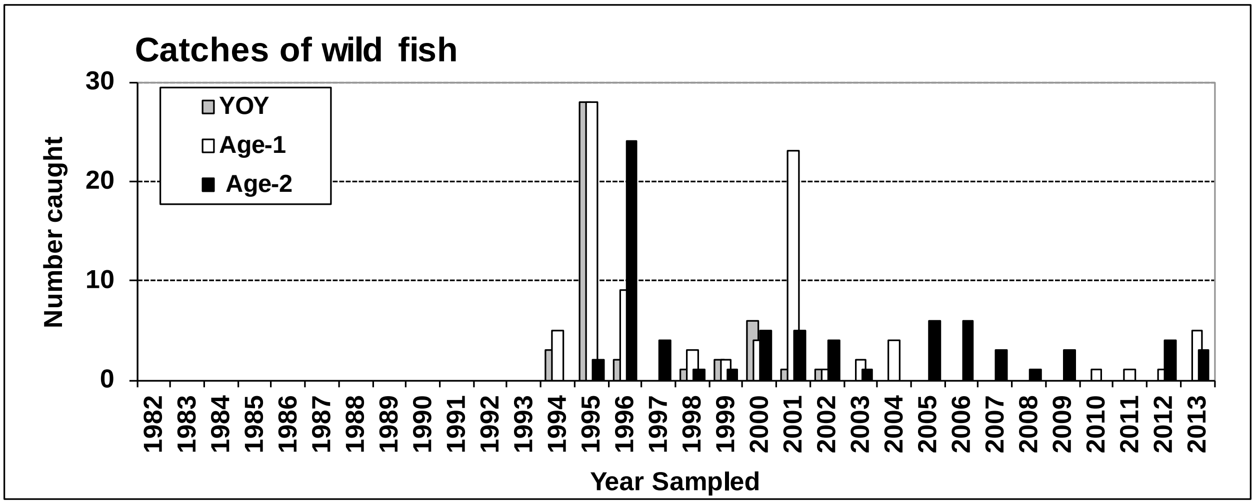

Fig. 5. *Numbers of wild fish caught annually in U.S. bottom trawling (four total) and gillnetting (one total) surveys. Wild juveniles (age 0-2) can be distinguished from hatchery fish by size, color, shape, and lack of tag or fin clip.*

RECENT TRENDS IN LAKE ONTARIO'S ECOSYSTEM

Invasive species: Since the late 1980s Lake Ontario has undergone a series of invasions by exotic species, notably the cladocerans *Bythotrephes longimanus* and *Cercopagis pengoi*, dreissenid mussels (zebra and quagga), and Round Goby (Stewart et al. 2014b). These invaders have contributed to significant ecosystem changes (see "Recent Trends in Lake Ontario Ecosystem-Lower Food Web" section). The impact of other recent invasive species, *Echinogammarus ischnus* (amphipod), *Potamopyrgus antipodarum* (New Zealand mud snail), Viral Hemorrhagic Septicemia virus (VHSv), and *Hemimysis anomala* (mysid) are not well understood.

The Round Goby is closely linked to the Lake Trout life cycle by acting as both predator and prey. As predator, it can consume Lake Trout eggs and fry (Chotkowski and Marsden 1999; Fitzsimons et al. 2006). Round Goby has been observed in Lake Trout diets in recent years (Dietrich et al. 2006; Rush et al. 2012; B.F. Lantry, U.S. Geological Survey [USGS] Lake Ontario Biological Station, per. comm.; J. Markham, New York State Department of Environmental Conservation [NYSDEC] Lake Erie Unit, per. comm.). As an alternative to Alewife and Rainbow Smelt, Round Goby may mitigate thiaminase-related reproductive problems associated with Alewife consumption (see "Impediments – Egg and Fry Survival").

Lower food web: Lake Ontario water quality continues to improve; however, reduced phosphorus levels and reduced lower trophic level productivity have resulted in overall declines in ecosystem productivity (Mills et al. 2005; Stewart et al. 2014b) and piscivore carrying capacity. Since the early 1990's the effect of reduced nutrients has likely been exaggerated by dreissenid proliferation, which is suspected as playing a role in increased water clarity, reduced phytoplankton size composition, changes in nearshore and offshore primary production, and a spring-time deepening of Alewife and smelt distributions (O'Gorman et al. 2000; Mills et al. 2005). The loss of the native burrowing amphipod *Diporeia* has also been linked to dreissenid proliferation (Dermott 2001; Lozano et al. 2001; Owens and Dittman 2003; Nalepa et al. 2005). Elrod and O'Gorman (1991) reported that *Diporeia* was an important food item for stocked Lake Trout during their first few months in the lake, and its loss may be linked to poor recruitment of stocked Lake Trout. The exotic predatory zooplankters *Bythotrephes longimanus* and *Cercopagis pengoi* potentially act as both competitors and prey to forage fish (Bushnoe et al. 2003; Warner et al. 2006), and their impacts on zooplankton and prey fish dynamics in Lake Ontario are not fully understood (Bushnoe et al. 2003; Kane et al. 2003; Laxson et al. 2003; Mills et al. 2005; Holeck et al. 2012; Stewart et al. 2014b).

Prey fish: Lake Ontario's native prey fish species, including Slimy Sculpin and coregonids, are currently at low abundance levels or extirpated (Elrod 1983; Christie et al. 1987; Owens and Dittman 2003; Hoyle 2005; Lantry et al. 2007; Weidel et al. 2014). The native Deepwater Sculpin was once considered extirpated; however, increased abundance and distribution has been documented in recent years (Weidel et al. 2014; Lantry et al. 2014a). Non-native Alewife is the most abundant pelagic prey fish in Lake

Ontario, and dominates the diet of adult Lake Trout (Lantry 2001). Their abundance and biomass declined through the 1990s and remains low relative to pre-1990s levels (Walsh and Connerton 2014; Connerton et al. 2014). The decline is likely due to reduced lake productivity, heavy predation pressure, and poor recruitment over several years (1992-1997; Mills et al. 2005; Walsh and Connerton 2014). Rainbow Smelt (also non-native) abundance and biomass declined during the same time period and have remained at the lowest levels recorded for fifteen consecutive years (1999-2013; Weidel and Connerton 2014; Lantry et al. 2014a). Conversely, the Round Goby population has increased dramatically since it was first detected in bottom trawl assessments in 2002 (Weidel et al. 2014; Lantry et al. 2014b).

CURRENT AND POTENTIAL IMPEDIMENTS TO LAKE TROUT RESTORATION

There are numerous impediments to Lake Trout restoration in Lake Ontario, and fishery managers should, whenever possible, implement solutions to these impediments. The following list of impediments was generated during meetings with state, provincial and federal agencies.

Competing Interests: Efforts to restore Lake Trout in Lake Ontario are proceeding in parallel with efforts to maintain a Chinook Salmon population (e.g., Stewart et al. 2014a). This presents a set of inter-related issues that are difficult to reconcile. Public surveys, dominated by angler respondents, showed that although there is strong support for native species restoration, Chinook Salmon was the most frequently targeted and preferred salmonine species while Lake Trout was among the least frequently targeted species (Brown and LaPan 2003, Ontario Ministry of Natural Resources, stakeholder survey, unpubl. data). Both species currently depend on Alewife, the most abundant and preferred prey fish; but Alewife production may not be sufficient to simultaneously sustain the two predators at satisfactory levels (i.e., numbers of Lake Trout necessary for restoration and numbers of Chinook Salmon desired by anglers). Furthermore, although Alewife currently sustains the salmonine populations, it hinders the reproductive cycle of Lake Trout (see “Egg and fry survival” below).

Prey quantity and quality: The quantity and quality of prey are likely hindering Lake Trout growth and survival at all life stages, as well as reproductive success. The amphipod *Diporeia* has essentially disappeared from Lake Ontario (Lozano et al. 2001; Mills et al. 2005; Watkins et al. 2007). Its decline has not only deprived juvenile Lake Trout of an important prey item (Elrod 1983; Christie et al. 1987), but it has also contributed to the decline of Slimy Sculpin and whitefish populations (Owens and Dittman 2003; Hoyle 2005), both of which have been important prey for Lake Trout (VanOosten 1943, Elrod 1983, Elrod and O’Gorman 1991). Alewife is the principal prey of all salmonines in Lake Ontario including Lake Trout (Lantry 2001); however, the high thiaminase content of Alewife is implicated in reproductive failure in Lake Trout (e.g., Early Mortality Syndrome [EMS], see below). The reduced Alewife population levels observed since the mid-1990s and proliferation of Round Goby since the mid-2000s may help to enhance Lake Trout reproduction; however, currently Round Goby is the only abundant low thiaminase prey fish and is only available to Lake Trout when distributions overlap. A hypolimnetic, low thiaminase prey fish alternative is needed to mitigate the prey quantity and quality problem.

Egg and fry survival: Fitzsimons et al. (2003) examined factors that affect early life stage survival of naturally produced Lake Trout in Lake Ontario. Survival from egg stage to emergence is a function of many factors including sensitivity to physical disturbance, spawning habitat quality (e.g., dissolved oxygen levels, *Cladophora* growth, sediment deposition, and dreissenid colonization), egg quality, and predation on eggs and fry. Egg quality in Lake Ontario suffers from reduced thiamine levels caused by a maternal diet dominated by Alewife, resulting in Early Mortality Syndrome (EMS) and lower fitness in emerging fry (Fitzsimons et al. 2003; Madenjian et al. 2008). Eggs and fry that survive through emergence may face intense predation by Alewife and Round Goby (Krueger et al. 1995; Chotkowski and Marsden 1999; Strakosh and Krueger 2005; Fitzsimons et al. 2006; Madenjian et al. 2008), however reduced Alewife abundance has mitigated this problem somewhat. Nuisance quantities of *Cladophora* that once fouled spawning shoals (Casselman 1995) had disappeared with declines in phosphorus loadings since the 1970s, but a recent resurgence in *Cladophora* biomass linked with dreissenid mediated increased water column transparency may again threaten shoals. Dreissenid mussels may also reduce available spawning habitat by infilling of spawning shoal interstices.

Juvenile survival: During the first years of life Lake Trout face predation from Lake Ontario’s abundant salmonine populations, and possibly a reduced food supply (e.g., loss of *Diporeia,* reduced Slimy Sculpin population). This problem affects not only naturally produced Lake Trout, but also stocked fish, whose survival during the first year post-stocking has been poor for over a decade. Survival of stocked fish may also be affected by their health at stocking (e.g., stress, ability to feed, size at stocking) and likely by the total quantity released (i.e., site-specific stocking numbers). Stocking locations, strain composition and stocking method are also factors affecting post-stocking survival.

Reduced spawner density: Adult Lake Trout abundance during the mid 2000s declined to the lowest levels observed in over 20 years, and although abundance increased recently, it remains near or below restoration objectives from the previous plans. The spawning stock is expected to remain at these low levels given recent low stocking levels (i.e., 2005, 2006, and 2010) and more than 15 years of poor juvenile recruitment.

Future Habitat Alteration/Impairment: Areas of Lake Ontario are under consideration for development of wind power generation using offshore towers. Construction and the operation of wind power generators have the potential to affect natural reproduction of Lake Trout, and this issue should be carefully considered in any offshore wind power studies.

Round Goby: Round Goby is a predator on Lake Trout eggs and fry (Chotkowski and Marsden 1999; Fitzsimons et al. 2006), and may negatively impact Lake Trout reproductive success where goby distribution overlaps with Lake Trout spawning and nursery habitat. Bottom trawl surveys conducted in April, June, and October in Lake Ontario indicate broad depth distribution of Round Goby and seasonal depth distribution shifts, with densities highest in nearshore waters (<40m) during June, and highest in deeper offshore waters during April and October (Weidel et al. 2012; Weidel et al. 2014). Pennuto et al. (2012) also found evidence of an offshore migration of Round Goby in late summer. Despite their apparent offshore migration prior to Lake Trout spawning, Round Goby density on Lake Trout spawning habitat and potential impacts to reproductive success are unknown.

Sea Lamprey: Continued suppression of Sea Lamprey abundance remains essential to Lake Trout restoration in Lake Ontario. The Lake Ontario Fish Community Objective for Sea Lamprey control (Stewart et al. 2014a) identifies indicators for spawning-phase adult Sea Lamprey abundance, and number of A-1 wounds on Lake Trout > 432 mm and other species. Sea Lamprey spawner abundance was above the specified target level for eight of the last ten years (2002-2011). This combined with coinciding low host density (i.e., near record low abundance of Lake Trout > 432mm) contributed to an A1 wounding rate nearly 2-fold above the recommended target level in 2005 and 2007, and increased lamprey attacks on non-target species since 1996 (Lantry and Eckert 2014).

Contaminants: Contaminants likely impact reproductive success of fish in the Great Lakes (e.g., Niimi 1983; Wilson and Tillitt 1996; Mac and Edsall 1991), however, impacts to Lake Trout natural reproduction in Lake Ontario remain undetermined. Advisories continue to restrict Lake Trout consumption (MOE 2007; NYSDOH 2014), despite a general declining trend in contaminant levels in Lake Trout (Neilson et al. 2003; Bhavsar et al. 2007; Bhavsar et al. 2008; Crimmins et al. 2012). Increased concentration of polybrominated diphenyl ethers (PBDEs) in Lake Ontario Lake Trout was documented (Batterman et al. 2007), however, more recent evidence indicates a declining trend in PBDE concentrations in Lake Ontario's Lake Trout (Burniston et al. 2011; Crimmins et al. 2012). Impacts of contaminants on Lake Trout restoration are unstudied.

THE 2014 REVISED MANAGEMENT STRATEGY

MANAGEMENT GOAL: Restore a self-sustaining population of Lake Trout in Lake Ontario.

MANAGEMENT OBJECTIVE 1: Increase abundance of stocked Lake Trout to a level allowing for significant natural reproduction.

Measure: CUE of mature females ≥ 4000g greater than 2.0 and 1.1 fish per standard assessment gill net set in U.S and Canadian waters, respectively[1].

MANAGEMENT OBJECTIVE 2: Increase populations of wild Lake Trout across a range of age groups.

Measure: Measureable increase in catches of wild juveniles and adults in assessment catches, with values exceeding those observed during 1994-2011.

Management Strategy 1: Stock 800,000 spring yearling equivalents per year in U.S. waters and 500,000 spring yearlings per year in Canadian waters.

Management Strategy 2: Minimize stocking and juvenile mortality by optimizing

- Stage, size, and condition at stocking
- Stocking methods
- Stocking locations

Measures:

- U.S.: adjusted catch rate of age-2 fish per 500,000 stocked ≥ 200 fish per standard survey
- Canada: adjusted catch rate of age-3 fish per standard gillnet per 500,000 stocked ≥ 1.5 fish per standard gillnet set.

Management Strategy 3: Maintain high survival of older fish by controlling Sea Lamprey and fishing mortality.

Measures:

- Yearly survival of adult fish >60%
- Maintain the Sea Lamprey wounding rate in fall gillnetting at ≤2 A1 wounds per 100 Lake Trout >432 mm total length
- Maintain annual harvest to <10,000 fish in U.S. waters and <5,000 fish in Canadian waters.

Management Strategy 4: Emphasize strains that show the best combination of low post-stocking, juvenile, and adult mortality.

Management Strategy 5: Emphasize strains that are successfully producing a measureable level of wild recruits.

Management Strategy 6: Protect naturally produced fish

Management Strategy 7: Continue efforts to restore populations of native prey for Lake Trout.

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[1] A standard Canadian gillnet set is a graded series of 10 monofilament panels of mesh sizes from 38 mm (1 ½ in.) to 152 mm (6 in.) at 13 mm (½ in.) intervals, fished in the Canadian waters of Eastern Lake Ontario in June-September (Ontario Ministry of Natural Resources 2012 , Section 2.2). Only sets with 12^{o}C or lower temperature are used for lake trout assessment. A standard U.S. gillnet set is a net with nine monofilament panels (15.24 m [50 ft] long, 2.44 m [8 ft] high) with stretch-mesh sizes ranging from 50.8 mm to 152.4 mm (2 to 6 in) by 12.7 mm (½ in) increments, fished in 14 zones of U.S. waters of Lake Ontario (Lantry and Lantry 2014). For each zone, the first net is set where the 10° C isotherm intersects the bottom, and the other 3 nets are set successively deeper at 10 m depth intervals.

DISCUSSION AND RATIONALE

MANAGEMENT GOAL (FCO Benthic Zone Goal and FCO 3.1): Restore a self-sustaining population of Lake Trout in Lake Ontario.

The purpose of this Management Strategy is to guide and coordinate bi-national efforts to restore a self-sustaining population of Lake Trout in Lake Ontario as directed in the FCO document's Deep Pelagic and Offshore Benthic Zone Goal which calls for a benthic fish community with self-sustaining native fishes including Lake Trout, and is consistent with FCO 3.1 "to restore self-sustaining [Lake Trout] populations to function as the top deepwater predator…." (Appendix 1; Stewart et al. 2014a). A self-sustaining population is one that that persists without stocking. This population will consist of multiple year classes, and generate surplus production. The eventual population characteristics, particularly abundance, cannot be fully predicted because the ecosystem of Lake Ontario has changed substantially since the time Lake Trout thrived. Once restored, Lake Trout should resume the role as dominant hypolimnetic predator.

***MANAGEMENT OBJECTIVES*:**

Objective 1 (FCO 3.1 Status/Trend Indictor): Increase abundance of stocked Lake Trout to a level allowing for significant natural reproduction.

Establishing a population of hatchery-reared adult fish capable of producing wild offspring is the central principle behind FCO 3.1 (Appendix 1; Stewart et al. 2014a). Management Strategies 1 through 4 (see below) work toward increasing abundance across a range of ages and recommend measures to assess FCO 3.1 Status/Trend Indicators. Objective 1 of this Management Strategy is specific to increasing the abundance of stocked adults. The size of such a population was first discussed in the 1983 Plan, where, based on historical data from Lake Ontario and information from other lakes, it was recommended that 2.0 to 3.0 million yearlings be stocked annually and adult survivorship be maintained at or above 60% per year. These measures were anticipated to result in a population of 0.5 to 1.0 million adult Lake Trout. In the 1990s, target values from previous plans were met, the survivorship objective was achieved, the adult population was abundant, and wild recruits were relatively abundant (Schneider et al. 1998), indicating that the spawning stock had reached a level sufficient for reproductive success.

Objective 1 is consistent with an objective in the 1998 Plan, recognized and endorsed as an indicator in Stewart et al. (1999), to maintain abundance of stocked Lake Trout at 1990s levels so that sufficient numbers of adults would successfully spawn on quality habitat to sustain and increase observed levels of reproductive success. In the absence of an absolute population estimate, the 1998 Plan recommended that the index of spawner abundance (CUE of mature females $\geq$ 4000g) be based on standard survey[2] CUEs observed during 1992-1994, since that level of spawner abundance reproduced successfully (Schneider et al. 1998) as indicated by a detectable level of wild age-0 to age-2 recruits beginning in 1994. These catches were higher in U.S surveys due to differences in survey design and Lake Trout habitat; therefore, we recommend different target CUEs for the two nations (>2.0 and 1.1 mature females larger than 4000g for U.S. and Canadian waters, respectively). This objective and targets were recommended because: 1) they are measurable through existing assessment programs; 2) nearly all Lake Trout $\geq$4000g are mature fish age-7 and older, mostly excluding lower-quality first-time spawners (ages 5-6); and 3) current data indicate that these criteria are still applicable today.

Objective 2 (FCO 3.1 Progress Indicator): Increase populations of wild Lake Trout across a range of age groups.

Improved production of wild offspring and their recruitment to the adult population to a level sufficient for maintaining self-sustaining populations is central to meeting the Benthic Zone Goal of Lake Ontario's Fish Community Objectives and FCO 3.1 (Appendix 1; Stewart et al. 2014a). Surveys have documented 19 year classes of wild recruits since the early 1990s; however, each cohort was caught only in low numbers (Fig. 5). For future successes in Lake Trout restoration, production and recruitment of wild offspring must improve from levels observed over the last decade and be sustained until wild fish begin replacing the adult population of stocked fish. The recommended measure for this objective is to have a demonstrable

[2] See footnote 1

increase in catches of wild juveniles and adults in assessment catches, with values exceeding those observed during 1994-2011. This metric should be re-considered when wild catches are better quantifiable.

***MANAGEMENT STRATEGIES*:**

Management Strategy 1: Stock 800,000 spring yearling equivalents per year in U.S. waters and 500,000 spring yearlings per year in Canadian waters.

The 1983 Plan recommended that 2.5 million Lake Trout be stocked annually (Schneider et al. 1983). This recommendation was changed to 2 million (1 million per nation) in the 1990 draft plan, based on satisfactory results at that time. Stocking level, improved Sea Lamprey control, and harvest restrictions contributed to the high level of adult stock observed from the late 1980s through most of the 1990s. In 1993, the stocking was reduced to 1 million annually (500,000 per nation) as part of overall salmonine stocking reduction to address decreased lake productivity.

Declines in adult Lake Trout abundance observed after 1998 were related to stocking cuts and poor first-year survival of stocked fish. As was the situation in the early 1980s, it is now necessary to rebuild the adult stock and current stocking levels appear inadequate for successful Lake Trout restoration. It is not realistic to resume pre-1993 stocking levels given declines in lake productivity and continued concerns of predator-prey imbalance. A modest stocking increase, however, is recommended. Ongoing studies indicate that site-specific stocking levels >135,000 yearling fish may improve survival of Lake Trout the first year following stocking (B.F. Lantry, USGS Lake Ontario Biological Station, unpublished data) and enhance recruitment to the adult stock; therefore, we proposed to increase stocking levels to 160,000 spring yearlings (800,000 total spring yearling equivalents stocked in US waters; 160,000 is based on minimum target and hatchery logistics). A similar site-specific increase in stocking level should be considered for stockings in Canadian waters if the U.S. evaluations show improved survival.

Management Strategy 2: Minimize stocking and juvenile mortality by optimizing:

- **stage, size, and condition at stocking**
- **stocking methods**
- **stocking locations**

The decline in the adult stock from 1986-1998 levels is largely attributed to poor juvenile recruitment (Lantry et al. 2005). Survival of stocked fish during their first year in the lake declined dramatically in the early 1990s and has remained low since then. Predation on juvenile Lake Trout by salmonines, including Lake Trout, is thought to be an important cause for the decline and the potential for mitigation may be limited. Nevertheless, maximizing the post-stocking survival remains a high priority, and it is essential for rebuilding the adult spawning stock.

Stocking strategies were investigated in the past by evaluating the CWT returns from year classes stocked prior to 1997. Unfortunately, the use of coded wire tags on all stocked Lake Trout was discontinued from the 1997 to 2004 stockings in the US and from 1997 to the present in Ontario. This coincided with major ecosystem shifts in Lake Ontario. Some aspects of these ecosystem changes likely affected post-stocking survival; therefore, we recommend a thorough assessment of stocking methods followed by timely implementation of the findings. Recommended evaluations include:

- The **developmental stage at stocking** (fall fingerling or spring yearlings) was examined by Elrod et al. (1988), and it was concluded that stocking spring yearlings was more cost-effective than stocking fall fingerlings. The study was conducted using 1979-82 year classes, at a time when the abundance of adult Lake Trout was low, similar to the situation today. There have been major ecological changes since that time, including a dramatic increase in water clarity, proliferation of *Dreissena* sp., loss of *Diporeia*, decline of Slimy Sculpin, and proliferation of Round Goby, which is now an important item in Lake Trout diet. We recommend that the merits and cost-effectiveness of life stage-specific stocking be re-examined.

- The effect of **quality of the stocked fish** (physiology, size, etc.) on recruitment has been examined in Lake Ontario (e.g., Elrod et al. 1989; Elrod et al. 1993) and in the other Great Lakes (Bronte et al. 2006), but investigations should be re-evaluated given ecosystem changes, changes in strain availability, and the recommendation to alter the strain composition (see 'Selection of Strains to stock' section).
- Evaluations of **pulse stockings** (i.e., increased site-specific stocking level in US waters from 80,000 spring yearlings to 160,000) are needed to examine their effects on juvenile survival. Analysis of post-stocking survival of hatchery fish indicates that site-specific stocking levels >135,000 may improve survival the first year following stocking (as indicated by the number of returns) and enhance recruitment to the adult stock; therefore, we proposed to increase site-specific stocking levels to 160,000 spring yearlings (160,000 is based on minimum target and hatchery logistics).
- **Stocking locations** need to be evaluated to identify those with highest juvenile survival. Past stocking site evaluations may no longer be valid due to ecosystem changes in the lake.

In the past decade our ability to address these issues was hampered by reduced coded wire tag use, and more recently by hatchery-related problems that compromised U.S. stocking numbers. Resumption of the use of coded wire tags by both jurisdictions and consistent hatchery production are necessary for evaluating relative survival using various stocking strategies and stocking sites.

Post-stocking survival should continue to be measured as the catch rate of young fish relative to the number of fish originally stocked. This serves as a measure of FCO 3.1 Status/Trend Indicator (Appendix 1; Stewart et al. 2014a). In the U.S waters the USGS/NYSDEC mid-summer bottom trawling program indexes age-2 fish to determine whether the target catch rate of >200 age-2 fish per standard survey per 500,000 fish stocked has been attained. In Canadian waters gillnets are used to assess Lake Trout, generally capturing fish 3-years old and older. We propose a target catch rate of ≥ 1.5 age-3 fish per standard assessment gillnet set per 500,000 fish stocked. These targets are consistent with survival rates observed in the late 1980s, prior to the major decline in juvenile survival, and which resulted in an adult population that produced the first detectable level of wild recruits. It remains to be seen whether these catch rates of young fish are achievable under current ecosystem conditions, although recent observations suggest that early survival of stocked fish may be improving (Fig. 2).

Management Strategy 3: Maintain high survival of older fish by controlling Sea Lamprey and fishing mortality.

A target annual survival rate of >60% for adult fish was first identified in the original 1983 Plan, and was reaffirmed in the 1990 draft plan. The survival rate was based on examination of rates that appeared tolerable in other populations (50%), and the target rate was boosted to 60% to allow for population expansion (Schneider et al. 1983). The spawning stock objective was achieved by the time the 1998 Plan was written. In that plan, the survival target was removed because in the absence of CWT marking, survival rates would be difficult to measure. In addition, two other principal factors determining survival – Sea Lamprey predation and angler harvest – remained measurable and below target levels. With the current reduced population of Lake Trout, however, the same number of fish killed by Sea Lampreys or anglers will likely have a more severe impact on survival rate. This Strategy reinstates the annual survival target rate >60% for adult fish. The survival rate integrates all sources of mortality and provides guidance in our efforts to control Sea Lamprey (FCO 3.4; Appendix 1; Stewart et al. 2014a) and fishing mortality. Measurement of the survival rates will be initially difficult, due to absence of age information that was provided by CWT marking in the past, but will again become possible as CWT marked fish propagate through the population in coming years (the first fully tagged cohort stocked in U.S. waters since 1997, the 2003 year class, reached age 10 in 2013).

Mortality due to Sea Lamprey: Suppressing Sea Lamprey abundance is the central principle behind FCO 3.4 (Appendix 1; Stewart et al. 2014a). Sea Lamprey abundance in Lake Ontario has been controlled at levels resulting in wounding rates at or near the 1998 Plan target rate of ≤2 A1 wounds per 100 Lake Trout >432 mm total length. Achievement of the Lake Trout survival target (>60%) was obtained only after the wounding target level was met. The wounding rate increase in the mid-2000s is likely attributable to a relatively moderate increase in spawning Sea Lamprey abundance during 2004-2006, which coincided with decreased host abundance (Lantry and Lantry 2014; Sullivan and Adair 2014). Past evidence suggests that maintaining wounding rate at or below target is essential to maintaining adult

Lake Trout abundance at levels suitable for restoration. The target level of $\leq$2 A1 wounds per 100 fish >432 mm should be retained (FCO 3.4 Status/Trend Indicator; Appendix 1).

Fishing mortality: The 1998 Plan established a harvest target level of no more than 30,000 Lake Trout harvested per nation. This level, however, was commensurate with significantly higher adult Lake Trout abundance and higher survival and recruitment of juvenile fish. Since the 30,000 fish per nation target was established, there have been several years of poor juvenile recruitment, a subsequent decline in adult Lake Trout abundance, and ecosystem changes that have altered spawning habitat and prey availability. Lake Trout harvest in U.S. waters has been well below 30,000 fish since 1993, and was less than 10,000 fish for 12 of the 14 years from 2000-2013. Over the same period, documented harvest in Canadian waters (middle and western Lake Ontario) averaged below 500 fish. Based on approximately 3-fold and 18-fold decreases in indices of abundance in the U.S. and Canadian waters, respectively, the allowable annual harvest should be maintained at <10,000 fish harvested from U.S. waters and <5,000 fish harvested from Canadian waters, as estimated from existing angler surveys and commercial fishery monitoring. Commercial fishing mortality should be monitored to ensure that it remains at acceptable levels. Krueger and Ebener (2004) recommended that harvest regulations be consistent with the goal of restoration. If adult annual survival falls below 60% and increased mortality is not attributed to increased Sea Lamprey predation, then recreational and commercial fishing regulation changes must be considered.

Management Strategy 4: Emphasize strains that exhibit the best combination of low post-stocking, juvenile and adult mortality.

Low mortality is only one of the criteria considered in the strain strategy, the other being reproductive success (Management Strategy 5). The overall stocking strategy is discussed in section “Selection of Strains to Stock” below.

Management Strategy 5: Emphasize strains that are successfully producing a measureable level of wild recruits.

Reproductive success is the ultimate criterion in evaluating strain performance, however, strain-related survival characteristics must also be considered in the restoration process. The overall stocking strategy is discussed in section “Selection of Strains to Stock” below.

Management Strategy 6: Protect naturally produced fish.

Special protection for naturally produced fish should be considered, as they may be more successful reproductively and could create a “snowballing” effect in natural reproduction. Unclipped (wild) fish are becoming more prominent not only as a proportion of the decreasing total population of adults, but also in absolute numbers (Ontario Ministry of Natural Resources, unpubl. data). Angler education programs should emphasize the importance of these fish and the need to release them. Commercial by-catch should also be monitored, and, if necessary, regulated to minimize mortality of wild fish. If deemed necessary, we recommend reevaluation of recreational angling regulations to protect wild Lake Trout.

Management Strategy 7: Continue efforts to restore populations of native prey for Lake Trout, including deepwater cisco (i.e., Bloater) and Lake Herring.

The extirpated, historical population of Lake Trout in Lake Ontario was supported by native sculpins and coregonids (Pritchard 1931; Elrod 1983; Christie et al. 1987), which are now extirpated or severely depleted. The lack of prey base that is functionally similar to what was historically available to Lake Trout may be a key factor in limited success of restoration efforts to date. Although it is outside the scope of this document, we stress the importance of ongoing efforts to restore native coregonids in Lake Ontario.

Concerns about prey availability for Lake Ontario salmonines and the need for restored native prey fish populations were discussed in the 1990 draft plan. Reintroduced Lake Trout have depended on Alewife and to lesser degree on Rainbow Smelt (Lantry 2001), and compete with other salmonines for these prey. High thiaminase content of Alewife compromises Lake Trout reproduction and hinders restoration efforts (Fitzsimons et al. 2003; Madenjian et al. 2008). Round Gobies have recently become an important component of the Lake Trout diet. Although gobies provide a dietary benefit to Lake Trout in that they are a low thiaminase alternative to Alewife, they may functionally replace native sculpins and are only available when distributions overlap.

Reestablishing abundant native hypolimnetic prey fish populations with low thiaminase levels, like deepwater ciscoes (e.g., Bloater), would provide a co-adapted prey alternative essential to mitigating low-thiamine impacts on Lake Trout reproduction, and would likely enhance stability and resiliency in the planktivore community. Restoring a population deepwater cisco in Lake Ontario is directed in FCO 3.3 of Lake Ontario Fish Community Objectives (Appendix 1; Stewart et al. 2014a). Efforts to reintroduce deepwater coregonids into Lake Ontario began in earnest in 1999. The first stockings of Bloater (i.e., the most abundant species of deepwater cisco in the upper Great Lakes) occurred in U.S. waters in fall 2012 and 2013 (Connerton 2013; Connerton 2014) and in Canadian waters in fall 2013 (Ontario Ministry of Natural Resources 2014). A document with strategies for deepwater cisco restoration is nearing completion (Connerton and Stewart, in prep.).

Lake Herring (also called Cisco) is another coregonid that declined in Lake Ontario in the 1940s and can serve as an alternative, low-thiaminase Lake Trout prey (Fitzsimons and Brown 1998). The Hamilton Harbour and Watershed Fisheries Management Plan proposed a comprehensive restoration effort that would include increasing the spawning and productive capacities for Lake Herring in Hamilton Harbor (Bowlby et al. 2009). In addition, a collaborative effort between the USGS and the NYSDEC is underway to re-establish Lake Herring spawning populations in south shore embayments (i.e., Sodus and Irondequoit bays). If successful, these actions may benefit Lake Trout restoration.

SELECTION OF STRAINS TO STOCK

Several factors play a role in the choice of strains to be stocked during the restoration process. Ideally, the best strain strategy would balance the following (and not necessarily mutually compatible) considerations:

- A **diversity of strains** will increase the chances that some will be successful in the new Lake Ontario ecosystem. This approach is especially applicable to Lake Ontario where no local genotype exists (Krueger et al. 1981). The focus on stocking Seneca Lake strain fish for nearly two decades has not significantly advanced Lake Trout restoration. Consideration of the available genetic strains and their phenotypic traits are recommended (Krueger and Ihssen 1995, Krueger and Ebener 2004). Additionally, a diversity of strains may result in higher genetic diversity in a restored population.
- **High survival** during all life stages (stocking, juvenile and adult) is important in the initial phase of the restoration process when the objective is to build reproductive potential. This is the rationale for Management Strategy 4. In Lake Ontario differences in strain-specific survival were observed. The Seneca Lake strain fish suffered lower mortality from Sea Lamprey predation as adults than Lake Superior strain fish, possibly due to differences in bathythermal distribution (Schneider et al. 1996). Superior-Marquette strain fish, however, appear to have higher survival at younger ages than Seneca Lake strain fish (B. Lantry, USGS Lake Ontario Biological Station, pers. comm.). The resulting net relative contribution of one strain over the other to reproductive potential is not clear in this case. Emphasis on Seneca Lake strain fish since the mid-1990s, concurrent with ecosystem changes, has likely contributed to poor recruitment of stocked fish.
- **Reproductive success** becomes an issue in the next phase of the restoration process, the production of wild progeny. The ability to reproduce may ultimately outweigh the ability to survive, and this is the rationale for Management Strategy 5. The first natural progeny documented in Lake Ontario were fry caught off Stony Island in the mid 1980s, and genetic analysis of these fish suggested a disproportionate contribution by Seneca Lake strain fish (Marsden et al. 1989). Analysis of wild Lake Trout caught in Lake Ontario from 1995-2002 determined that Seneca Lake and Superior strains were the primary progenitors; however, sample size was insufficient to determine the contribution of other strains (C. Krueger, Great Lakes Fishery Commission [GLFC], pers. comm.). Strain availability and strains stocked changed in recent years. Collection of tissue samples suitable for parental determination could be invaluable in implementing Management Strategy 5.

- **Logistic constraints** related to production planning, disease control, and development of broodstocks limit the hatchery manager's ability to respond to changing demands. Any stocking strategy must be long-term, and changes can only be gradual.

The strains stocked in the past have largely been based on considerations of survival, diversity, and availability in the hatchery system. These factors will play a role in strain selection, but reproductive success should be taken into account when relevant information becomes available. For the immediate future we recommend the following mix of strains, based on good survival, genetic diversity, and current availability:

- Canadian stocking (500,000 yearlings)
  - 60% Seneca Lake Strain
  - 40% Lake Superior strains (approximately 25% Slate Island and 15% Michipicoten)
- U.S. Stocking (800,000 spring yearling equivalents)
  - 50% Seneca Lake strain (i.e., a mix of Seneca Lake and Lake Champlain strains)
  - $\geq$25% Superior-like lean morphotype (e.g., Apostle Island and Huron-Perry Sound strains)
  - $\leq$25% Klondike Reef strain

To minimize the potential for domestication of stocks, brood stocks should be refreshed from wild sources regularly. We recognize that logistic constraints may, at times, impact the recommended stocking numbers, stage, and strain composition.

The strain strategy should be adjusted, based on continued assessment of all aspects of strain performance and strain availability. It is essential that all Lake Trout receive CWTs to allow for evaluation of growth, survivorship, and other strain-specific information (e.g., lipid content, susceptibility to Sea Lamprey predation, fecundity). It is equally essential that identification of wild fish be extended to all life stages (i.e., include adult fish), and followed up by genetic determination of parental strains of wild individuals.

EVALUATION AND MONITORING OF RESTORATION PROGRESS

This document provides the measures and strategies needed to achieve FCO 3.1 and to restore a self-sustaining population. Annual monitoring and evaluation are essential to evaluate progress towards restoration. We recommend the following assessment programs:

Assessment of adult fish: A gill netting assessment has been conducted annually since 1983 in U.S. waters of Lake Ontario to assess the population of age-3 and older Lake Trout. The survey provides information on abundance, maturity, survival, growth, condition, Sea Lamprey wounding, occurrence of wild fish, and ancillary data (e.g., contaminants, genetics, diet, disease). We recommend continuation of this survey.

In Canadian waters, age-3 and older Lake Trout are assessed in a Community Index Gill Netting program that covers eastern Lake Ontario and the Kingston Basin (Ontario Ministry of Natural Resources 2014). This program is designed for assessment of the broader fish community, both warm- and coldwater. Declines in Lake Trout abundance in combination with limited effort expended in suitable habitat have, in recent years, resulted in Lake Trout catches that are not sufficient to monitor the status of the Lake Trout population. We recommend that the design of this survey be modified to improve adult Lake Trout population assessment. The survey should also be expanded to Canadian waters of central and western Lake Ontario (this may require revision of abundance targets based on this survey to reflect the expansion).

Sea Lamprey Wounding: The U.S. gill net assessment (above) provides data on Sea Lamprey wounding rates. Because wounding rates vary systematically over the course of the year, are increasing in the fall, and fall A-1 wounding rates are correlated with lamprey mortality later in the season (Bergstedt and Schneider 1988; Schneider et al. 1996), continuation of this program is crucial for assessing Sea Lamprey impacts on Lake Trout. We recommend continued annual reporting of Lake Trout host density and wounding rates to the GLFC. The NYSDEC Lake Ontario Fishing Boat Survey should continue to collect Sea Lamprey observation data from anglers (Lantry and Eckert 2014). We also recommend enhanced Sea Lamprey monitoring in tributaries where dam removal/deterioration has taken place.

Harvest: Creel surveys estimate fishing effort, catch and harvest for Lake Trout and other species, and provide data for stocking strategy evaluations. An open lake creel survey is conducted annually by NYSDEC covering waters from the Niagara River to the Association Island cut in New York waters of the eastern basin (approximately 190 miles of shoreline; Eckert 2006, Lantry and Eckert 2014). NYSDEC also conducts a creel survey in the New York waters of the eastern basin approximately every five years. OMNR conducted annual creel surveys in the western portion of the lake until 2005, then in 2008 and 2011-2013 (Ontario Ministry of Natural Resources 2014). In the eastern waters, OMNR conducted periodic (5-year cycle) creel surveys, but no survey was done since 1998. The angler surveys provide a wealth of information on other species and are a source of Lake Trout CWT returns; therefore, they should continue in both U.S. and Canadian waters.

There is no targeted commercial Lake Trout fishery in either jurisdiction, but Lake Trout are taken as by-catch in other fisheries. The Lake Whitefish gillnet fishery in Canadian waters has the greatest potential for Lake Trout by-catch, and should be monitored to ensure that Lake Trout mortality remains at acceptable levels.

Assessment of juvenile stocked fish: A bottom trawl survey has been conducted annually in U.S. waters of Lake Ontario since 1980 to assess juvenile Lake Trout (Lantry and Lantry 2014). This program provides an index of abundance for age-2 Lake Trout, allows us to monitor growth and condition of juvenile fish, evaluate strain performance and stocking methods, and collect samples for various analyses (i.e., contaminants, genetics, diet, and disease). We recommend continuation of this sampling program in U.S. waters. No similar survey exists in Canadian waters, but early life survival is monitored through catches of age-3 fish in the Community Index Gill Netting program (Ontario Ministry of Natural Resources 2014), which should be continued.

Assessment of wild production: To assess wild production, we first need to properly identify a wild from a hatchery produced Lake Trout. All Lake Trout stocked into Lake Ontario for more than three decades should have received a fin clip and/or CWT; however, a small portion of fish from each stocking did not receive the intended clip or CWT (i.e., likely <2% stocked per year). For a few stockings, fin clip quality and tag retention was poor (i.e., up to 20% of some lots may appear as unclipped and untagged fish at older ages) making it impossible to determine origin of an unmarked fish older than age 2. For juvenile Lake Trout up to age 2, naturally produced fish are visually recognizable. Juvenile fish are captured not only in the juvenile Lake Trout survey (above) but also in bottom trawling surveys targeting other species (i.e., Walsh and Connerton 2014, Weidel et al. 2014). Data from these surveys are the only source of information on wild reproduction to date, and we strongly recommend that the surveys be continued. Older Lake Trout are captured in other existing surveys; however, as Lake Trout age visual inspection of an unmarked fish does not permit determination of origin (hatchery vs. wild). A new method of determining the origin (hatchery vs. wild) of Lake Trout has become available, based on stable isotope composition of the otoliths, and it can be applied to fish of all sizes (Schaner et al. 2007). This stable isotope method extends the sample of fish whose origin can be examined, resulting in a better measurement of natural reproduction and a targeted sample of known origin fish for genetics analysis. Combined with age estimates it may allow for assessment of wild fish mortality. Finally, the ability to examine archived otoliths can provide a chronology of natural reproduction. We recommend that the stable isotope methodology be applied to all unmarked fish in the future, as well as to archived otoliths.

ASSESSMENT AND RESEARCH NEEDS

Coded Wire Tags: We strongly recommend continued CWT marking of U.S. stocked Lake Trout and resumed CWT marking of Ontario stocked Lake Trout. Discontinuation of CWT marking in 1997 was predicated on the perception of achieved adult stock management objectives; however, since that time both the survival of stocked juvenile fish and the abundance of adult fish have decreased markedly. If CWT marking had continued these changes could have been evaluated. CWT marking is required to execute Management Strategies 1, 2, 3, 4, and 5 of this restoration strategy. The following are monitoring needs to guide us in Lake Trout restoration, and all require CWT marking:

- Evaluation of stocking methods
- Evaluation of strain performance
- Assessment of adult mortality

- CWT marking will also facilitate detection of naturally produced fish

Retrieval of CWTs is essential for evaluation and monitoring of restoration progress and meeting research needs. Tag retrieval will be effectively accomplished with existing U.S. surveys and with continued gillnetting effort in Canadian waters that ensures Lake Trout habitat is sampled at an adequate level each year.

Poor Recruitment of Stocked Fish: Survival of hatchery fish during the first year after stocking has declined dramatically since the early 1990s and hampers our efforts to rebuild the spawning stock. Factors affecting survival of stocked fish may also be affecting naturally produced fish. The following research is needed:

- Determine if recruitment is poor for both stocked and wild Lake Trout.
- Determine if the quality and/or quantity of prey are contributing to poor juvenile survival.
- Determine if predation by top piscivores (e.g., Chinook Salmon, Lake Trout) is contributing to poor survival during the first year following stocking.
- Optimize stocking methods to improve survival. Factors include developmental stage (spring yearlings or fall fingerlings) and condition of stocked fish, and stocking methods and locations.
- Re-evaluate the index of juvenile survival based on mid-summer bottom trawling.

Round Goby Interactions: Round Goby can have a significant impact on the success of Lake Trout restoration efforts by acting as both predator and prey. Both interactions have potential consequences to the reproductive success of Lake Trout, the former an obvious impediment while the latter could improve reproductive success as round gobies provide a low-thiaminase alternative to Alewife. Dynamics between the two species need evaluation, including:

- Investigate predation on Lake Trout eggs and fry by Round Goby.
- Determine the contribution of Round Goby in Lake Trout diets.
- Determine the nutritional quality of Round Goby (e.g., thiaminase levels, contaminants, energy density).

Spawning habitat location, quantity, and quality: The need to examine and evaluate spawning habitat was discussed in each of the previous plans (Schneider et al. 1983, 1990, and 1998). Many historic spawning shoals were identified and evaluated (Goodyear et al. 1982, Thibodeau and Kelso 1990; Marsden and Krueger 1991; Elrod et al. 1995; Fitzsimons 1995), however, a survey of spawning habitat and its utilization has not been conducted since the early 1990s (Fitzsimons 1995, Perkins and Krueger 1995). Drastic ecosystem changes that occurred since that time include dreissenid mussel colonization, proliferation of the Round Goby, and the recent introduction of the bloody red shrimp (*Hemimysis anomala*). The distribution of invasive species directly overlaps potential Lake Trout spawning habitat, and their behavior may directly affect the Lake Trout reproductive cycle through habitat alteration, predation and competition. These effects remain largely undocumented in Lake Ontario. Additionally, the current location, quantity and quality of spawning habitat are unknown. Given recent ecosystem changes, principally those related to dreissenid invasion, utilization of spawning habitats and the conditions on those habitats require reassessment, including:

- Determine where Lake Trout spawning aggregations currently exist.
- Determine the quality of Lake Trout spawning habitat, both historical and currently utilized.
- Identify what constitutes good quality spawning habitat (e.g., substrate composition, egg density, predator density).
- Determine dreissenid effects on spawning and nursery habitat and reproductive success.
- Determine if stocking strategy affects spawning site selection.

The early 1990s marked the start of detectable levels of wild recruitment, which continues. The locations and conditions under which this successful reproduction has been occurring, however, are not known, even though such information would be useful in attempts to enhance wild recruitment. Elrod et al. (1996) evaluated the distribution of Lake Trout stocked into Lake Ontario, noting that although their broad distribution indicated that the tendency to return to the stocking location was weak, the proportion of total catch nearest the stocking location was higher for mature fish than for immature fish. Thus stocking near known successful spawning locations could promote wild recruitment. Other means of increasing use of productive spawning habitat should also be considered. Preliminary investigations indicate that seeding spawning habitat with Lake Trout feces (collected from a hatchery) may be an effective method of attracting spawners and increasing egg deposition rates (Foster 1985; J. Fitzsimons, Department of Fisheries and Oceans [DFO], pers. comm.), but further evaluation is needed. Increasing site-specific spawning and egg density could increase fry production above levels needed to overcome impediments (e.g., early mortality syndrome (EMS), egg and fry predation, juvenile survival), and boost wild recruitment.

Man-made structures also provide spawning opportunities for Lake Trout. Some structures were created explicitly as spawning habitat, but others attract spawning Lake Trout as well (e.g., piers, J. Fitzsimons, DFO, pers. comm.; Marsden et al. 1995). The contribution of man-made structures to the overall level of reproduction is not well documented, although it has been suggested that it may be substantial (Fitzsimons 1995, Krueger and Ebener 2004). Investigation of the use and success of existing and newly constructed artificial substrates should be an integral part of the of the spawning habitat assessment in Lake Ontario. Knowledge gained should guide any future development of offshore wind power generation, and such development should be monitored to assess losses or gains in Lake Trout spawning habitat.

Natural reproduction: The ultimate measure of the progress of restoration is successful natural reproduction. The reproductive phase in the life cycle of Lake Trout is currently poorly monitored in Lake Ontario. Egg deposition rates are unknown. Survival at all stages up to and including swim-up, including predation on eggs and fry is unknown. Currently some natural reproduction occurs in Lake Ontario, but our ability to monitor it is limited by inability to visually recognize wild fish older than age-2, therefore, the following are needed:

- Collection of otoliths from unmarked fish for stable isotope analysis to distinguish between wild and hatchery fish of all ages (i.e., Schaner et al. 2007), and for genetic analysis (below).
- Determine parental origin of wild fish through genetic analysis to identify successfully reproducing strains, and potentially adjust strain composition of stocked fish to optimize wild production.

Thiaminase: Thiamine deficiency in eggs and fry, caused by thiaminase-rich maternal diet, is one of the most significant impediments to Lake Trout restoration in Lake Ontario.

- Monitor thiamine levels in Lake Trout, eggs, and fry collected in Lake Ontario.

Other Research Needs:

- Continue investigation of factors contributing to poor reproductive success, including thiaminase and sublethal effects of contaminants. Synergistic effects of multiple contaminants should also be investigated.
- Continue investigation into effects of disease in spawner population (i.e., bacterial kidney disease [BKD], furunculosis, viral hemorrhagic septicemia virus [VHSv])
- Continue to improve models that quantify predator demand and prey supply.

ACTION ITEMS (FISH CULTURE, ASSESSMENT, MANAGEMENT)

It should be noted that actions stated in this section are recommendations only, and do not constitute mandates for the cooperating agencies.

Fish Culture

- Produce 800,000 spring yearling equivalents for stocking into U.S. waters and 500,000 spring yearling fish for stocking into Canadian waters. U.S. stockings should consist of 50% Seneca Lake strain (i.e., a mix of Seneca Lake and Lake Champlain strains), ≥25% Superior-like lean morphotype (e.g., Apostle Island and Huron-Perry Sound strains), and ≤25% Klondike Reef strain. Canadian stockings should consist of 60% Seneca Lake strain, 40% Lake Superior strains (approximately 25% Slate Island and 15% Michipicoten). Strain mixes should be periodically re-evaluated to determine if strain performance is meeting management objectives.
- Continue efforts to acquire/propagate multiple acceptable disease free strains of Lake Trout to improve genetic diversity.
- Mark all Lake Trout stocked into Lake Ontario with CWTs and adipose clip.
- Continue efforts to monitor Lake Trout health (e.g., diseases, genetics).
- Establish alternative source of (disease free) gametes and/or brood stock rearing facilities to use in the event of disease or mechanical problems.
- Monitor fish condition at stocking, and water quality at stocking site and in hatchery transport tank.

Assessment

- Monitor abundance of stocked and wild age-3 and older adults.
- Monitor abundance of wild and stocked juveniles.
- Monitor the frequency and severity of Sea Lamprey wounding.
- Monitor Sea Lamprey larval and adult abundance.
- Monitor angler harvest and commercial by-catch.
- Develop a formal study plan for stocking strategy evaluations that includes consideration of all proposed stocking studies and strain performance evaluations.
- Continue evaluation of pulse stocking.
- Establish the cause of poor performance of hatchery stockings in U.S. waters (problem with hatchery product, increased predation at time of stocking, etc.).
- Monitor Alewife and other prey fish stocks
- Monitor lower trophic level parameters (i.e., phosphorus, primary production, and zooplankton populations).
- Monitor Lake Trout health (e.g., diseases, juvenile and adult condition) in the lake.
- Monitor contaminant levels (PCB, DDT, PBDE, etc.) in Lake Trout.

Management

- Seek financial resources for Lake Trout restoration efforts
- Promote harvest regulations and angler outreach programs that prevent excessive harvest mortality; particularly for wild fish.
- Continued support of and participation in re-introduction of deepwater coregonids.
- Protect Lake Trout spawning and nursery areas.
- Communicate Lake Trout host density and Sea Lamprey wounding rates to the GLFC in support of continued, aggressive Sea Lamprey control.

AGENCY ROLES AND RESPONSIBILITIES

Successful Lake Trout restoration depends on the continuation of longstanding collaborative efforts between the NYSDEC, OMNR, USFWS, USGS, DFO, and academics. This document re-states a commitment from fisheries agencies to work together to restore a self-sustaining population of Lake Trout in Lake Ontario. Agencies and institutions must work to satisfy funding in support of Lake Trout stocking, assessment, management and research. The following outlines respective roles and responsibilities of each agency in support of Lake Trout restoration:

- U.S. Fish and Wildlife Service: maintain brood stocks; rear and mark (adipose clip and CWT mark) 800,000 spring yearling equivalents stocked into U.S. waters; and collaborate with agencies and institutions involved with deepwater coregonid reintroduction and other native prey fish restoration efforts in Lake Ontario.
- U.S. Geological Survey: lower trophic level monitoring; prey fish assessments; juvenile and adult Lake Trout assessments; coregonid reintroduction and restoration (deepwater coregonids, Lake Herring, Lake Whitefish); and research.
- Ontario Ministry of Natural Resources: maintain brood stocks; rear, mark (adipose clip and CWT mark) and stock 500,000 spring yearling Lake Trout into Canadian waters; hydroacoustic prey fish assessment; gill net assessments; and monitor and regulate recreational harvest and commercial by-catch of Lake Trout.
- New York State Department of Environmental Conservation: stock Lake Trout reared by USFWS into U.S. waters of Lake Ontario; prey fish assessments (trawl and hydroacoustics); juvenile and adult Lake Trout assessments; monitor and regulate recreational Lake Trout harvest; and lower trophic level monitoring.
- Great Lakes Fishery Commission: continue an aggressive Sea Lamprey control program and monitor abundance of larvae and adults in Lake Ontario and its tributaries.
- Lake Ontario Committee: facilitate international efforts in support of Lake Trout stocking, assessment, management and research.

FUTURE PLANNING

This Management Strategy provides additional detail, measures and strategies needed to restore a self-sustaining population and to achieve the Lake Ontario Committee's Fish Community Objective 3.1. It also serves to coordinate and direct bi-national restoration efforts. We recommend that a formal evaluation and revision be completed by 2024. Annual evaluation of the status of Lake Trout is essential for successful Lake Trout restoration. We recommend that results of annual assessments be presented in agency annual reports and to the Great Lakes Fishery Commission by the Lake Ontario Committee.

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APPENDIX 1: LAKE ONTARIO FISH COMMUNITY GOALS AND OBJECTIVES (Stewart et al. 2014a)

Note: Only goals and objectives specific to Lake Trout and are presented here. A complete listing of all fish community goals and objectives for Lake Ontario are found in Stewart et al. (2014a).

DEEP PELAGIC AND OFFSHORE BENTHIC ZONE GOAL: **Protect and restore the diversity of the offshore benthic fish community composed of a mix of self-sustaining native species including Lake Trout, Burbot, Lake Whitefish, Round Whitefish, deepwater ciscoes, Slimy Sculpin, and Deepwater Sculpin.**

Deep Pelagic and Offshore Benthic Zone Objectives:

FCO 3.1. **Restore Lake Trout populations** – restore self-sustaining populations to function as the top deepwater predator that can support sustainable recreational fisheries.

- **Status/Trend indicator:** increasing abundance of stocked Lake Trout across a range of age groups**.**
- **Status/Trend indicator:** catch/harvest rates of Lake Trout in the lake fishery.
- **Progress indicator:** increasing populations of wild Lake Trout across a range of age-groups sufficient to maintain self-sustaining populations.

FCO 3.3. **Increase prey fish diversity** – maintain and restore a diverse prey-fish community that includes deepwater ciscoes, Slimy Sculpin, and Deepwater Sculpin.

- **Status/Trend indicator**: increasing populations of native prey fish (e.g. Slimy Sculpin, Deepwater Sculpin).
- **Status/Trend indicator:** maintaining or increasing populations and increasing species diversity of the deepwater and benthic prey fish community including Deepwater Sculpin, Slimy Sculpin, and deepwater ciscoes.
- **Progress indicator:** detection of stocked adult and wild juvenile deepwater ciscoes.

FCO 3.4. **Control Sea Lamprey** – suppress abundance of Sea Lamprey to levels that will not impede achievement of objectives for Lake Trout and other fish.

- **Status/Trend indicator:** spawning-phase adult Sea Lamprey abundance in Lake Ontario tributaries below targets identified in Sea Lamprey Management Plan.
- **Status/Trend indicator:** number of A-1 wounds on Lake Trout and other species below targets.

APPENDIX 2: SUMMARY OF THE 1983, 1990, AND 1998 LAKE REHABILITATION PLANS

1983 A Joint Plan for the Rehabilitation of Lake Trout in Lake Ontario (Schneider et al. 1983)

Goal: To rehabilitate the lake trout population of Lake Ontario such that the adult spawning stock(s) encompasses several year classes, sustains itself at a relatively stable level by natural reproduction and produces a useable annual surplus.

Ultimate Objective: To develop a lake trout population in Lake Ontario of 0.5 to 1.0 million adults that produce 2 to 3 million yearlings annually and provide 450,000kg (1 million lbs.) of useable surplus.

Interim Objective: By the year 2000, demonstrate the rehabilitation is feasible by developing a Lake Ontario lake trout stock consisting of 0.5 to 1.0 million adult fish with adult females that average 7.5 years of age and produce 100,000 yearlings annually.

Strategies to attain the objectives:

1) Annually stock 2.5 million yearlings of Lake Ontario strains.
2) Maximize recruitment of stocked fish.

3) Maintain total annual mortality at 35 to 40%
4) Maximize reproductive potential of lake trout

Lake Ontario Lake Trout Rehabilitation Plan: 1990 Revision (Schneider et al. 1990)

Goal: same as above for "1983 A Joint Plan for the Rehabilitation of Lake Trout in Lake Ontario"

Ultimate Objective: same as above for "1983 A Joint Plan for the Rehabilitation of Lake Trout in Lake Ontario"

Interim Objective: By the year 2000, demonstrate the rehabilitation is feasible by developing a lake trout stock in Lake Ontario consisting of 0.5 to 1.0 million adult fish which produce a measurable level of yearling recruits.

Sub-objectives that support the Interim Objective:

1) Maintain an adult spawning stock of 0.5-1.0 million individuals composed of selected strains of multiple year classes.
2) Ensure that annual survival of adult lake trout is at least 60% by:
   i) Controlling sea lamprey so that fresh wounding rates (A1) of lake trout larger than 431mm (17.0 in) are less than 2 marks/100 fish
   ii) Limiting angler and commercial exploitation so that annual harvest does not exceed 120,000 fish (60,000 per nation).
3) Establish adults stocks on existing spawning habitat that result in egg densities in the range of 25 – 500 eggs/m^2.
4) Demonstrate that recruitment is possible by achieving a 3% per year class contribution of naturally produced lake trout in assessment surveys (equivalent to 60,000 stocked yearlings).

1998 Plan: A Management Strategy for Lake Ontario Lake Trout (Schneider et al. 1998)

Goal: To rehabilitate the lake trout population of Lake Ontario such that the adult spawning stock(s) encompasses several year classes, sustains itself at a relatively stable level by natural reproduction, and produces a useable annual surplus.

Rehabilitation Strategy through the year 2017: During the next 20 years, maintain suitable levels of harvest and sea lamprey control, and current levels of spawner density and size composition (reference period: 1992-94), while at the same time promote the replacement of hatchery-origin spawners with wild adults.

The objectives and tactics in the 1998 Plan:

Objective 1: Maintain a population of stocked lake trout. Measure: Maintain density of mature females over 4000 grams at 2.0 and 1.1 fish per standard assessment gillnet set in U.S. and Canadian waters, respectively.

> Tactic 1.1: Stock 500,000 hatchery raised yearlings per year, per nation.
>
> Tactic 1.2: Maintain annual harvest of hatchery lake trout below 30,000 fish per nation.
>
> Tactic 1.3: Control sea lamprey so that there are no more than two A1 wounds per 100 lake trout larger than 433 mm total length.

Objective 2: Maximize production of wild offspring. Measures: Sustain the density of wild lake trout in U.S. waters at a catch of 26 age-2 fish in the bottom trawling conducted during July, and increase the abundance of wild age-2 lake trout above current levels in Canadian waters.

> Tactic 2.1: Adjust strain composition of hatchery fish to favor successfully reproducing strains.

Tactic 2.2: Maintain existing spawning and nursery habitats.

Objective 3: Enhance the survival of wild fish. Measures: Establish a population of naturally produced mature fish, and increase the density of naturally-produced mature females over 4,000 grams to 0.20 and 0.11 fish per standard assessment gill net in U.S. and Canadian waters, respectively.

Tactic 3.1: Minimize fishing mortality on wild fish.

Tactic 3.2: Control sea lamprey so that there are no more than two A1 wounds per 100 lake trout larger than 433 mm total length.