Lake Trout (*Salvelinus namaycush*) Rehabilitation in Lake Ontario, 2021

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Abstract

*Each year we report on the progress toward rehabilitation of the Lake Ontario lake trout (*Salvelinus namaycush*) population, including the results of stocking, annual assessment surveys, creel surveys, and evidence of natural reproduction observed from standard surveys performed by U.S. Geological Survey (USGS) and New York State Department of Environmental Conservation (NYSDEC). The catch per unit effort (CPUE) of adult lake trout in gill nets increased each year from 2008-2014, recovering from historic lows recorded during 2005-2007. Adult abundances declined each year from 2015 to 2017; and in 2017 were about 35% below the 2014 peak and 17% below the 1999-2004 mean. Adult abundance increased in 2018 by 51% over the 2017 value and remained nearly stable between 2018 and 2021. The 2021 rate of wounding by sea lamprey (*Petromyzon marinus*) on lake trout caught in gill nets was 1.68 A1 wounds (fresh wound) per 100 lake trout and was near target (2 wounds per 100 lake trout). Condition values for adult lake trout, indexed in September from the predicted weight for a 700 mm lake trout from annual length-weight regressions and Fulton's K for age-6 males, were among the highest levels observed for the 1983-2021 time series. Reproductive potential for the adult stock indexed from the CPUE of mature females ≥ 4000 g was again above the target in 2021, continuing the trend observed since 2010. The 2021 catch of young wild lake trout marked the 27th cohort observed in the last 28 years and the recent large catches observed off the mouth of the Niagara River persisted in 2021.*

Introduction

Restoration of a naturally reproducing population of lake trout (*Salvelinus namaycush*) is the focus of a major international effort in Lake Ontario. Coordinated through the Lake Ontario Committee of the Great Lakes Fishery Commission, representatives from cooperating agencies (New York State Department of Environmental Conservation [NYSDEC], U.S. Geological Survey [USGS], U.S. Fish and Wildlife Service [USFWS], and Ontario Ministry of Northern Development, Mines, Natural Resources and Forestry [NDMNRF]) developed the Joint Plan for Rehabilitation of Lake Trout in Lake Ontario (Schneider et al. 1983, 1997), which guided restoration efforts and evaluation through 2014. A revised document, *A Management Strategy for the Restoration of Lake Trout in Lake Ontario, 2014 Update* (Lantry et al. 2014), guides current efforts. This report documents progress towards restoration by reporting on management plan targets and measures through 2021.

The data associated with this report are currently under review and will be publicly available in 2022 when all USGS research vessel data collected between 1930 and 2021 are released. Refer to U.S. Geological Survey, Great Lakes

Science Center, 2022, Great Lakes Research Vessel Catch (RVCAT) Database: U.S. Geological Survey data release, https://doi.org/10.5066/P9XVOLR1. Please direct questions to our Data Management Librarian, Sofia Dabrowski, at sdabrowski@usgs.gov. All USGS sampling and handling of fish during research are carried out in accordance with guidelines for the care and use of fishes by the American Fisheries Society (http://fisheries.org/docs/wp/Guidelines-for-Use-of-Fishes.pdf). Any use of trade, firm, or product names is for descriptive purposes only and does not imply endorsement by the U.S. Government.

Methods

Gill Net Survey

In September of most years during 1983-2021, adult lake trout were collected with gill nets at random transects within each of 17 (1983-1993) and 14 (1994-2021) geographic areas distributed uniformly within U.S. waters of Lake Ontario. Due to vessel availability in 2018 and to concerns over the COVID-19 pandemic in 2020, abbreviated surveys were conducted at 7 of the 14 geographic locations From Rochester to Cape Vincent along the U.S. shore in Lake Ontario. Survey design (size of geographic areas) and gill net construction (multi- vs. mono-filament netting) have changed through the years. For a description of survey history, including gear changes and corrections, see Elrod et al. (1995) and Owens et al. (2003).

During September 2021, the NYSDEC R/V Seth Green and the USGS R/V Kaho fished standard monofilament gill nets for adult lake trout at the 14 standard geographic locations from the Niagara River to Cape Vincent along the U.S. shore in Lake Ontario (Figure 1). Survey gill nets consisted of nine 15.2 x 2.4 m (50 x 8 ft) panels of 51 to 151 mm (2- to 6-in stretched measure) mesh in 12.5 mm (0.5 in) increments. At the 12 sites in the lake's main basin and two sites in the eastern basin, four survey nets were fished along randomly chosen transects parallel to depth contours beginning at the 10ºC (50ºF) isotherm and proceeding deeper in 10-m (32.8-ft) increments.

For all lake trout captured, total lengths and weights were measured, body cavities were opened, and prey items were removed from stomachs, identified, and enumerated. Presence and types of fin clips were recorded, and when present, coded wire tags (CWTs) were removed and decoded to retrieve information on age and strain (see Appendix 1 for strain descriptions). Sex and maturity of lake trout were determined by visual inspection of gonads. Sea lamprey (*Petromyzon marinus*) wounds on lake trout were counted and graded according to King and Edsall (1979) and Ebener et al. (2006).

A stratified catch per unit effort (CPUE) was calculated using four depth-based strata, representing net position from shallowest to deepest. The unit of effort was one overnight set of one net. Depth stratification was used because effort was not equal among years and catch per net decreased uniformly with increasing depth below the thermocline (Elrod et al. 1995). To examine variability in CPUE between years, the relative standard error (RSE) was calculated (RSE = 100 * {standard error / mean}).

In past reports, population reproductive potential was estimated by calculating annual egg deposition indices (O'Gorman et al. 1998) from catches of mature females in September gill nets using length-fecundity relationships, and by accounting for observed differences in mortality rates among strains (Lantry et al. 2019). CPUE of mature females ≥ 4000 g and egg indices were generally very well correlated from 1983-2017 (Figure 10 in Lantry et al. 2019). Beginning with the 2018 report (Lantry et al. 2019) and continuing forward, we use the CPUE for females ≥ 4000 g to index population reproductive potential.

Adult condition was indexed from both the predicted weights of a 700-mm (27.6 in) fish calculated from annual length-weight regressions based on all lake trout caught that did not have deformed spines, and from Fulton's K (Ricker 1975, Nash et al. 2006) for age-6 males:

$K = (WT/ TL^3) * 100{,}000;$

where WT is weight (g) and TL is total length (mm). Condition was grouped across strains because Elrod et al. (1996) found no difference between strains in the slopes or intercepts of annual length-weight regressions in 172 of 176 comparisons for the 1978 through 1993 surveys. Lake trout in those comparisons were of the lean morphotype, the only morphotype stocked into Lake Ontario until 2009. Since 2009, eight year-classes of the Klondike (SKW) strain lake trout (2008, 2013-2019) were stocked into Lake Ontario. The SKW strain originated from a native, deep spawning "humper" morphotype of Lake Superior lake trout that are intermediate in fat content to lean and fat (siscowet) morphotypes with the potential to have a higher condition factor than the leans. Fulton's K value of SKWs at age-6, the 2008 and the 2013-2015 year-classes (1.07, 1.12, 1.12, and 1.11), were similar to Seneca Lake strain (SEN; 1.08, 1.13, 1.12, and 1.07), one of the most prominent strains in the population. Thus, SKW was included in the population calculation of age-6 Fulton's K.

Annual survival of various year-classes and strains was estimated by taking the antilog of the slope of the linear regression of ln (CPUE) on age for fish ages 7 to 11 that received coded wire tags. Catches of age-12 and older lake trout were not used in calculations because survival often seemed to increase after age 11 and catch rates were too low to have confidence in estimates using those ages (Lantry and Prindle 2006).

Creel Survey

Catch and harvest by anglers fishing from boats on Lake Ontario is measured by a direct-contact creel survey, which covers the open-lake fishery from the Niagara River in the western end of the lake to Association Island near Henderson Harbor in the eastern basin (Connerton et al. 2020). The survey uses boat trips as the primary unit of effort. Boat counts are made at boat access locations and interviews are based on trips completed during April 15 - September 30, 1985-2019. Due to concerns over the COVID-19 pandemic, the creel survey was not completed in 2020, but was resumed in 2021 (Connerton et al. 2022).

Indices of Natural Reproduction

In previous reports, indices of natural reproduction were based on either the total catch (reports through 2017) or the CPUE (2018-2020) of juvenile unclipped and untagged ages-0 to -2 lake trout captured during April, June, July, and October USGS and NYSDEC bottom trawl surveys (for a description of the surveys see O'Gorman et al. 2000; Owens et al. 2003). Only ages 0 to 2 were used because we had the most confidence in assigning them to natal origin (hatchery or in-lake reproduction) based on absence of clips and tags, color, shape, fin quality, and size (Schaner et al. 2007).

Catch was not corrected for effort in the earlier reports due to the low catch in most years and a relatively constant level of effort expended within the depth range (20 m - 100 m) where age-0 to age-2 naturally reproduced lake trout were most often encountered in Lake Ontario. Changes in recent annual survey design and effort necessitated changing to CPUE (the number caught per 10 minutes of tow time) to correct for varying levels of effort. For survey results for wild juveniles based on total catch and on CPUE, see the 2017 and 2020 reports (Lantry et al. 2018 and 2021).

During 2021 the Lake Ontario Technical Committee, Lake Trout Working Group recommended discontinuing the July bottom trawl survey focused on juvenile lake trout. As a result, July bottom trawling in 2021 aimed at assessment of wild juvenile lake trout and was only performed by USGS at the two sites off the mouth of the Niagara River, West Niagara and East Niagara, to examine the persistence of the uniquely large catches experienced there since 2014. In the current report we focus on comparisons of catch at these two sites during 2014-2019 and 2021. For comparisons, we used age-1 to age-2 sized fish based on monthly length and weight distributions of putative wild lake trout caught in survey bottom trawls (85mm to 313mm TL). We dropped age-0 lake trout from these analyses due to low catches during 2014-2021 relative to catches prior to a trawl gear change in 1997.

Trawling effort was split over two days at each site in 2021 with the depth range covering the area between where the bottom of the thermocline intersected the lake bottom (20m at West Niagara and 30m at East Niagara) and the 75m contour. Trawls were fished along contour proceeding deeper at 10m increments (e.g., 20m, 30m, 40m, 50m, 60m, and 70m fished on one day and the 25m, 35m, 45m, 55m, 65m, and 75m on the other day). Depths fished were altered within sites between days by 5m to minimize the probability of diminished catches due to localized disturbance. Tow duration was 10 minutes for all but one tow which was 5 mins in duration. For each site, day was considered the treatment and depth fished the replicate. ANOVA was used to examine differences in the catch within sites and between days with tow depth being a fixed effect and day and the interaction between day and tow depth as random effects. To accommodate small differences in effort between days, the catch for each trawl tow was expressed as the sqrt(catch/tow time).

For indices of natural reproduction based on adult lake trout catches, from the September gill net assessments were used to examine trends in the proportion of unclipped to untagged mature lake trout in annual catches (see above for survey methods).

Results and Discussion

Stocking

Stocking information was derived from annual correspondence with the managers of the USFWS Alleghany National Fish Hatchery (ANFH, Pennsylvania), USFWS Eisenhower National Fish Hatchery (ENFH, Vermont), the White River National Fish Hatchery (WRNFH, Vermont), and the NYSDEC Bath Fish Hatchery; and from summaries presented in Elrod et al. (1995), Eckert (2001) and Connerton (2022). For a more thorough description of stocking during 1973-2020, see Lantry et al. (2021).

From 1973 to 1977, lake trout stocked in Lake Ontario were raised at several NYSDEC and USFWS (Michigan and Pennsylvania) hatcheries with annual releases ranging from 0.07 to 0.28 million (Figure 2). By 1978 (1977 year-class), the USFWS was raising nearly all lake trout stocked in U.S. waters of Lake Ontario and annual releases exceeded 0.60 million fish. An annual U.S. stocking target of 1.25 million yearlings was established in 1983 with the release of the first rehabilitation plan (Schneider et al. 1983). Stockings approached the target during 1979-1987 (about 1.07 million stocked annually), but numbers declined by about 22% between 1981 and 1989. Stocking again declined by 47% in 1992 and in 1993 the stocking target was reduced to 500,000 yearlings (Lantry et al. 2014). Annual stockings were near the revised target in 18 of 26 years during 1993-2016 (Figure 2). Hatchery infrastructure issues and disease outbreaks caused stocking shortfalls in 2005, 2006, 2012, and 2014. In 2014, the stocking target was increased to

800,000 spring yearling equivalents (Lantry et al. 2014) which was met through combinations of fall fingerlings and spring yearling stockings for the 2014 and 2015 year-classes. In fall 2016, fisheries managers reduced the stocking target to 400,000 spring yearlings which was met for the 2018 and 2019 stockings but not the 2017 stocking. The 2020 stocking target was further reduced to 320,000 yearlings, which was nearly met during the May 2020 stocking in which four of the five stocking sites (Olcott, Oak Orchard, Sodus, Stony) received fish.

In 2021, production shortfalls at ANFH lead to a stocking total of 260,700 spring yearlings which were released at four of the five stocking sites (Olcott, Sodus, Oswego, Stony) with the Oak Orchard site not receiving any lake trout (Connerton 2022). All stockings occurred offshore. Strain totals included 99,900 Huron Parry Sound (HPW), 80,200 Lake Champlain Domestic (LCD), and 80,600 SEN.

Abundance Indices

A total of 959 lake trout were captured in 56 nets set at 14 sites during the September 2021 gill net survey, resulting in a total mature adult CPUE of 13.77 (Figure 3). Catches of lake trout among sample locations were similar within years with the RSE for the CPUE of adult males and females (generally ≥ age 5) averaging only about 9.3% and 10.7% respectively, for the entire data series (Figure 4). The CPUE of mature lake trout had remained relatively stable from 1986 to 1998, but then declined by 31% between 1998 and 1999. Declines in adult numbers after 1998 were likely due to poor survival of hatchery fish in their first year post-stocking and lower numbers of fish stocked since the early 1990s. After the 1998-1999 decline, the CPUE for mature lake trout remained relatively stable during 1999-2004 (mean = 11.1), but then abundance declined by 54% between 2004 and 2005. The 2005-2007 CPUEs of mature lake trout coincided with a nearly two-fold increase in the rate of wounding by sea lamprey on lake trout (See Figure 7 and the sea lamprey section on page 6) and were similar to the 1983-1984 CPUEs, which pre-dated effective sea lamprey control. Appearing to respond to enhanced sea lamprey control, the CPUE of mature lake trout increased each year during 2008-2014, but then declined during 2015-2017. Adult abundance in 2017 was 35% below the 2014 peak and 17% below 1999-2004 average. Abundance was similar during 2018-2021, measuring 55% greater than the 2017 value, and was similar to the value in 2014 before the declines between 2015 and 2017. Those abundance declines were in-part driven by the absence of fish from the missing 2011 stocked year-class, which would have been ages 4, 5, and 6 in years 2015, 2016, and 2017, respectively.

Schneider et al. (1997) established a target gill net CPUE of 2.0 for sexually mature female lake trout ≥ 4,000 g reflecting the level of abundance at which successful reproduction became detectable in the early 1990s. Building off observations in the 2017 report that the trends in the mature female CPUE and the egg deposition index were similar (see Figure 10 in Lantry et al. 2018), we only present the CPUE of mature females to index population reproductive potential. The CPUE for mature females reached the target value in 1989 and fluctuated about that value until 1992 (Figure 5). From 1992 until 2004, the CPUE exceeded the target, but fell below target during 2005 to 2009, coincident with the decline of the entire adult population. As the adult population abundance increased during 2008-2014, the CPUE of mature females ≥ 4,000 g also increased. During 2010-2021, CPUEs of mature females remained near or above target.

Growth and Condition

The predicted weight of a 700-mm lake trout (from length-weight regressions) decreased during 1983 to 1986 but increased irregularly from 1986 to 1996 and remained relatively constant through 1999 (Figure 6). Predicted weight declined by 158.8 g (5.6 oz) between 1999 and 2006 but increased again in 2007 and remained high through 2015. Predicted weight rose sharply after 2015 so that 2016-2021 mean (3828.6 g, 8.4 lb) was at the highest level for the data series. The trend of improving condition through 1996 and from 2007 to 2021 corresponded to periods when the age and size composition of the population was shifting to higher levels. Our data suggested that for lake trout of similar length, older fish were heavier. To examine whether age was the primary driver of condition changes, we calculated annual means for Fulton's K for age-6 mature male lake trout, which removed the effects of age and sex (Figure 6). However, values of K for age-6 males followed a similar trend as predicted weights and indicated that age alone was not the sole determinant of condition for this population.

Sea Lamprey Predation

Percentage of A1 sea lamprey marks on lake trout (fresh wounds where the sea lamprey has recently detached) was low in most years since the mid-1980s. However, wounding rates (Figure 7) in 9 out of 11 years between 1997 and 2007 were above the target level of 2 wounds per 100 fish ≥433 mm (17.1 in). Wounding rate rose well above target in 2005, reaching a maximum of 4.7 wounds in 2007, which was 2.35 times the target level. Wounding rates fell below target again in 2008 (1.47) and remained there through 2011 (0.62). While the rate was slightly above target again in 2012 (2.41) and 2013 (2.26), it fell below target during 2014-2019 and the 2017 through 2019 wounding rates (0.50, 0.61, and 0.53, respectively) were the lowest for the data series. Wounding measured from the 2020 abbreviated survey (2.27) was above but near target, however, interpreting the increased level should be exercised with caution since sample size (n = 441) of host-sized lake trout was 53% lower than that in 2019. Wounding in 2021 once again fell below target at 1.68 A1 wounds per 100 lake trout ≥433 mm.

Angler Catch and Harvest

The NYSDEC fishing boat survey has been conducted each year from 1985 to 2019, but was not conducted in 2020 because of the COVID-19 pandemic. The survey resumed in 2021 and herein we report on lake trout catch and harvest trends during 1985-2021.

Fishing regulations, lake trout population size, and availability of other trout and salmon species influenced angler harvest through time (Connerton et al. 2022). During 1988-1992, managers instituted and adjusted a slot size limit to decrease harvest of mature lake trout and increase the number and ages of spawning adults in the population (Elrod et. al. 1995). The slot limit from 1992 persisted through 2006, permitting a limit of three lake trout harvested outside of the protected length interval of 635 to 762 mm (25 to 30 in). Effective October 1, 2006, the lake trout creel limit was reduced to two fish per day per angler, one of which could be within the 635 to 762 mm slot.

Annual catch and harvest of lake trout from U.S. waters of Lake Ontario (Figure 8) declined over 84% from 1991 to the early-2000s (Connerton et al. 2020). Catch and harvest declined further from the early to the mid-2000s, reaching the lowest levels in the NYSDEC Fishing Boat Survey data series in 2007. Harvest at that time was more than 97% below the 1991 estimate. This low point in harvest coincided with lower adult abundance in the index gill netting survey (Figure 3). Good fishing quality for other salmonids (i.e., anglers targeted other salmonids more frequently) may also have led to lower catch and harvest of lake trout during this period (Connerton et al. 2020). After 2007, however, catch and harvest and catch rate and harvest rate increased for six consecutive years, then were relatively stable during 2013-2016. Increases from 2007 through 2016 followed the October 2006 regulation change and coincided with an increase in lake trout abundance and anecdotal reports of anglers targeting lake trout more frequently during 2013-2016. While catch and harvest totals have been low recently relative to the late 1980s, harvest during 2013-2016 exceeded the U.S. 10,000 lake trout target for restoration (Lantry et al 2014). Catch rates of lake trout declined between 2016 and 2019, trending from 0.94 to 0.39 fish per boat trip, as did total catch, dropping from 36,336 in 2016 to 16,354 in 2019 (Connerton et al. 2020). The 2017-2019 declines in lake trout catch, harvest, and catch and harvest rates coincided with good to excellent fishing quality for other trout and salmon species (especially Chinook salmon *Oncorhynchus tshawytscha*), which may have reduced fishing effort directed at lake trout in those years. In 2021, catch rates of lake trout increased to 0.56 per boat trip, as did lake trout catch (22,398, Figure 8) and harvest (11,368), once again exceeding restoration targets. These increases coincided with lower catch rates of both Chinook salmon and brown trout *Salmo trutta* in the fishery in 2021 (Connerton et al 2022).

Adult Survival

Survival of SEN strain lake trout (ages 7 to 11) was consistently greater (20-51%) than that of the Lake Superior (SUP) strain for the 1980-2003 year-classes (Table 1). Lower survival of SUP strain lake trout was likely due to higher mortality from sea lamprey (Schneider et al. 1996). Survival of both Jenny (JEN) and Lewis Lake (LEW) strains (1984-1995 year-classes) were similar to the SUP strain, suggesting that those strains may also be highly vulnerable to sea lamprey. Lake Ontario strain (ONT) were developed from collections of eggs from feral adults at a time when the composition of survey catches was predominantly SUP, SEN and Clear Water Lake (CWL) strains (Appendix 1; Elrod et al. 1995; Schneider et al. 1996); and the survival of the 1983-1991 year-classes was intermediate to that SENs and SUPs.

Population survival was based on catches for all strains combined for the 1983-1995 and 2003-2012 cohorts, as all fish stocked during those periods received coded wire tags. Population survival exceeded the restoration plan target value of 0.60 beginning with the 1984 year-class and remained above the target for most year-classes thereafter.

The SUP strain was no longer available in 2006 and Traverse Island strain (STW) and Apostle Island strain (SAW), also both of Lake Superior origins, replaced SUPs in stockings from 2007-2009 and in 2009 and 2013, respectively. Strains from Seneca Lake origins included feral and domestic Lake Champlain strains (LCW and LCD, respectively) beginning with the 2009 stockings. Survival for LCD 2008-2010 and 2012 year-classes (71-87%) resembled their mostly SEN origins. Only one year-class of LCWs (not shown in Table 1) was stocked (2009) and its survival for ages 7-10 (73%) also was similar to SENs. Survival rates could not be calculated for the first large stocking of STWs (225K of the 2006 year-class) as they disappeared from survey catches after age-8. Survival for the 2007 (36%, ages 7-11) and the 2008 (41%, ages 7-11) year classes of STWs was low and similar to the early values for SUPs. Survival rates for SAW (53%, 2008 year-class, age 7-9 only) strains were also low and no 2008 SAWs were caught in 2018 or 2019. There were no SAWs stocked 2010 through 2012 (2009-2011 year-classes), but the 2012 year-class of SAWs (2013 stockings) observed in survey catches at ages 7-9 during 2019-2021 also experienced low survival (0.61%).

The first stocking of Klondikes (SKW) occurred in 2009 with the release of the 2008 year-class which reached age-11 in 2019. SKW survival for the 2008 year-class was 82 % (ages 7-11) in 2019 and similar to survival for SENs from the 2007 and 2008 year-classes, which were 91% and 96% in 2019. Further stockings of SKWs occurred during 2014-2018 (2013-2017 year-classes) with the 2013 year-class reaching age-7 in 2020, the first survival estimates for those year-classes will be available in 2022.

Natural Reproduction

Evidence of survival of naturally spawned lake trout past the fall fingerling stage occurred only once during bottom trawl surveys during 1980-1993 with the catch of one age-1 lake trout in July 1990 (1989 year-class; Owens et al. 2003). Following that early catch, evidence of natural reproduction occurred each year during 1994-2021 representing production of 27 year-classes.

The distribution of catches of age-1 and 2 sized wild fish suggests that lake trout are reproducing throughout New York waters of Lake Ontario with the greatest concentrations near the mouth of the Niagara River (see Figure 11, Lantry et 2021). Catches from at least 27 cohorts of wild lake trout and survival of those year-classes to older ages implies feasibility of lake trout rehabilitation in Lake Ontario (Schneider et al. 1997). The recent large catches of wild lake trout off the mouth of the Niagara River are encouraging, but those occurred in only one portion of the lake and abundance appeared to decline there between 2014 and 2019 (July data was not available in 2020). While the full July survey was discontinued after 2019, July trawling was conducted by USGS over four days (July 13-16, 2021) at the West Niagara and East Niagara sites to find out whether the large catches observed there in previous years were persisting.

During repetitive sampling at the two sites off the mouth of the Niagara River, ANOVA indicated that depth and the day by depth interactions were not significant and that catches between days were not significantly different within either site ($p = 0.213$ and $p = 0.259$ for the west and east sites, respectively). Despite combining catches over both days at each site, differences between sites also were not detectable ($p = 0.253$). Peak catches occurred at 4 adjacent trawl depths within the 40 to 75m contours at the West Niagara site. At the East Niagara site there were two catch peaks, one at 65 to 75m, similar to catches from West Niagara, and another concentrated near the thermocline at 30 to 35m (Figure 9).

From 2014-2021, during the period of high catches off the Niagara Bar, catches on the west side of the bar were generally deeper than those from the east side (Figure 10). Peak catches from the West Niagara site occurred between 45 and 75m, whereas peak catches from the East Niagara site occurred over 25 to 65m. Within years, the catch was generally concentrated on one side of the bar shifting from high catches at East Niagara during 2014-2015 to high catches at West Niagara during 2016-2021 (Figure 11). The large catches from the bar in 2021 indicated that reproduction is persisting in that area.

Achieving the goal of a self-sustaining population requires consistent production of relatively large wild year-classes across the range of spawning habitat and survival of those fish to reproductive ages. During the same time period (1993-2021) that young naturally reproduced lake trout were being caught in bottom trawls, an annual average of eight (range 0-17) unclipped and untagged mature lake trout were observed in September gill net catches (Figure 12). That low number of unclipped and untagged individuals represented a mean of 1.64% of all mature lake trout sampled with a range of 0 - 5.98%. Increases in catches of mature wild lake trout following the relatively large catches of juveniles beginning in 2014 would have been expected to show up in gill net catches by now, however, reduced survey effort in 2018 and 2020 likely influenced our ability to detect those changes. Survey effort returned to normal in 2021, however, the proportion of the catch of mature adults that were not clipped and not tagged remained low at 2.08%.

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References

Connerton, M. J. 2022. New York Lake Ontario and Upper St. Lawrence River Stocking Program 2021. Section 1 *In* 2021 NYSDEC Annual Report, Bureau of Fisheries Lake Ontario Unit and St. Lawrence River Unit to the Great Lakes Fishery Commission's Lake Ontario Committee.

Connerton, M.J.., N.V. Farese and R. J. Moore. 2022. Lake Ontario Fishing Boat Survey 1985-2021. Section 2 *In* NYSDEC 2021 Annual Report, Bureau of Fisheries, Lake Ontario Unit and St. Lawrence River Unit to the Great Lake Fishery Commission's Lake Ontario Committee.

Connerton, M.J.., N.V. Farese and R. J. Moore. 2020. Lake Ontario Fishing Boat Survey 1985-2019. Section 2 *In* NYSDEC 2019 Annual Report, Bureau of Fisheries, Lake Ontario Unit and St. Lawrence River Unit to the Great Lake Fishery Commission's Lake Ontario Committee.

Ebener, M. P., E. L. King, Jr., and T. A. Edsall. 2006. Application of a dichotomous key to the classification of sea lamprey marks on Great Lakes Fish. Great Lakes Fishery Commission Miscellaneous Publication 2006-2.

Eckert, T. H. 2001. Lake Ontario Stocking and Marking Program 2000. Section 1 *In* 2000 NYSDEC Annual Report, Bureau of Fisheries Lake Ontario Unit and St. Lawrence River Unit to the Great Lakes Fishery Commission's Lake Ontario Committee.

Elrod, J. H., Schneider, C. P., and Ostergaard, D. A. 1988. Comparison of hatchery-reared lake trout stocked as fall fingerlings and as spring yearlings in Lake Ontario. N. Amer. J. Fish. Manage. 8:455-462.

Elrod, J. H., O'Gorman, R., Schneider, C. P., Eckert, T. H., Schaner, T., Bowlby, J. N., and L. P. Schleen. 1995. Lake trout rehabilitation in Lake Ontario. J. Great Lakes Res. 21 (Supplement 1):83-107.

Elrod, J. H., O'Gorman, R. and C. P. Schneider. 1996. Bathythermal distribution, maturity, and growth of lake trout strains stocked in U.S. waters of Lake Ontario, 1978-1993. J. Great Lakes Res. 22:722-743.

King, E. L. Jr. and T. A. Edsall. 1979. Illustrated field guide for the classification of sea lamprey attack marks on Great Lakes lake trout. Great Lakes Fishery Commission Special Publication 70-1.

Krueger, C. C., Horrall, R. M. and Gruenthal, H. 1983. Strategy for use of lake trout strain in Lake Michigan. Report 17 of the Genetics Subcommittee to the Lake Trout Technical Committee for Lake Michigan, Great lakes Fish. Comm., Madison, WI.

Lantry, B. F., Weidel, B. C., Minihkeim, S., Connerton, M. J., Goretzke, J. A., Gorsky, D., and Osborne, C. 2021. Lake trout rehabilitation in Lake Ontario, 2020. Section 5 *in* 2020 NYSDEC Annual Report, Bureau of Fisheries Lake Ontario Unit and St. Lawrence River Unit to Great Lakes Fishery Commission's Lake Ontario Committee.

Lantry, B. F., Lantry, J. R. and Connerton, M. J. 2018. Lake trout rehabilitation in Lake Ontario, 2017. Section 5 *In* 2017 NYSDEC Annual Report, Bureau of Fisheries Lake Ontario Unit and St. Lawrence River Unit to the Great Lakes Fishery Commission Lake Ontario Committee.

Lantry, B. F., Lantry, J. R. and Connerton, M. J. 2019. Lake trout rehabilitation in Lake Ontario, 2018. Section 5 *In* 2018 NYSDEC Annual Report, Bureau of Fisheries Lake Ontario Unit and St. Lawrence River Unit to the Great Lakes Fishery Commission Lake Ontario Committee.

Lantry, B. F. and Prindle, S. P. 2006. Lake trout rehabilitation in Lake Ontario, 2005. Section 5 *In* 2005 NYSDEC Annual Report, Bureau of Fisheries Lake Ontario Unit and St. Lawrence River Unit to the Great Lakes Fishery Commission Lake Ontario Committee.

Lantry, J., Schaner, T., and Copeland T. 2014. A management strategy for the restoration of lake trout in Lake Ontario, 2014 Update. Available from http://www.glfc.org/lakecom/loc/lochome.php.

Nash, D. M., A. H. Valencia, and A. J. Geffen. 2006. The origin of Fulton's condition factor – setting the record straight. Fisheries 31:236-238.

O'Gorman, R., Elrod, J. H., Owens, R. W., Schneider, C. P., Eckert, T. H. and B. F. Lantry. 2000. Shifts in depth distributions of alewives, rainbow smelt, and age-2 lake trout in southern Lake Ontario following establishment of dreissenids. Trans. Am. Fish. Soc. 129:1096-1106.

O'Gorman, R., Elrod, J. H. and C. P. Schneider. 1998. Reproductive potential and fecundity of lake trout strains in southern and eastern Lake Ontario, 1977-94. J. Great Lakes Res. 24:131-144.

Owens, R. W., O'Gorman, R., Eckert, T. H., and Lantry, B. F. 2003. The offshore fish community in southern Lake Ontario. Pages 407-441, *In* Munawar, M. (ed.), State of Lake Ontario: Past, Present, and Future. Ecovision World Monograph Series. Backhuys Publishers, Leiden, The Netherlands.

Page, K. S., Scribner, K. T., Bennett, K. R., and Garzel, L. M. 2003. Genetic assessment of strain-specific sources of lake trout recruitment in the Great lakes. Trans. Am. Fish. Soc. 132:877-894.

Ricker, W. E. 1975. Computation and interpretation of biological statistics of fish populations. Bulletin of the Fisheries Research Board of Canada 191:1-382.

Schaner, T., Patterson, W. P., Lantry, B. F., and O'Gorman, R. 2007. Distinguishing wild vs. stocked lake trout (Salvelinus namaycush) in Lake Ontario: evidence from carbon and oxygen stable isotope values of otoliths. Journal of Great Lakes Research 33: 912-916.

Schneider, C. P., Kolenosky, D. P. and D. B. Goldthwaite. 1983. A joint plan for the rehabilitation of lake trout in Lake Ontario. Great Lakes Fishery Commission, Lake Ontario Committee. Spec. Publ. 50 p.

Schneider, C. P., Owens, R. W., Bergstedt, R. A. and R. O'Gorman. 1996. Predation by sea lamprey (*Petromyzon marinus*) on lake trout (*Salvelinus namaycush*) in southern Lake Ontario, 1982-1992. Can. J. Fish. Aquat. Sci. 53:1921-1932.

Schneider, C. P., Schaner, T., Orsatti, S., Lary, S. and D. Busch. 1997. A management strategy for Lake Ontario lake trout. Report to the Lake Ontario Committee.

Visscher, L. 1983. Lewis Lake lake trout. U. S. Fish Wild. Ser., Denver, CO.

Appendix 1.

Strain Descriptions
SEN - Lake trout descended from a native population that coexisted with sea lamprey in Seneca Lake, NY. A captive brood stock was maintained at the USFWS Alleghany National Fish Hatchery (ANFH) which reared lake trout for stocking in Lakes Erie and Ontario beginning with the 1978 year-class. Through 1997, eggs were collected directly from fish in Seneca Lake and used to supplement SEN brood stocks at the USFWS Alleghany National Fish Hatchery (ANFH) and USFWS Sullivan Creek National Fish Hatchery (SCNFH). Beginning in 1998, SEN strain broodstocks at ANFH and SCNFH were supplemented using eggs collected from both Seneca and Cayuga Lakes. Since 2003, eggs to supplement broodstocks were collected exclusively from Cayuga Lake.

LC - Lake trout descended from a feral population in Lake Champlain. The broodstock (Lake Champlain Domestic; LCD) is maintained at the State of Vermont's Salisbury Fish Hatchery and is supplemented with eggs collected from feral Lake Champlain fish. Eggs taken directly from feral Lake Champlain fish (Lake Champlain Wild; LCW) were also reared and stocked.

SUP - Captive lake trout broodstocks derived from "lean" Lake Superior lake trout. Broodstock for the Lake Ontario stockings of the Marquette strain (initially developed at the USFWS Marquette Hatchery; stocked until 2005) was maintained at the USFWS Alleghany National Fish Hatchery until 2005. The Superior – Marquette strain is no longer available for Lake Ontario stockings. Lake Ontario stockings of "lean" strains of Lake Superior lake trout resumed in 2007 with Traverse Island strain fish (STW; 2006-2008 year-classes) and Apostle Island strain fish (SAW; 2008 and 2012 year-classes). Traverse Island strain originated from a restored "lean" Lake Superior stock. The STW brood stock was phased out of production at USFWS Iron River National Fish Hatchery (IRNFH) and is no longer be available as a source of eggs for future Great Lakes stockings. The Apostle Island strain was derived from a remnant "lean" Superior stock restored through stocking efforts, was phased out of production at USFWS Iron River National Fish Hatchery (IRNFH) and is no longer be available as a source of eggs for future Great Lakes stockings.

SKW - Originated from a native, deep spawning "humper" morphotype of Lake Superior lake trout that are intermediate in fat content to lean and fat (siscowet) morphotypes. Captive brood stocks have been held at the USFWS Sullivan Creek National Fish Hatchery and USFWS Iron River National Fish Hatchery. The USFWS Berkshire National Fish Hatchery developed a SKW brood stock to supply fertilized eggs to ANFH for rearing and stocking into Lake Ontario.

CWL - Eggs collected from lake trout in Clearwater Lake, Manitoba, Canada and raised to fall fingerling and spring yearling stage at the USFWS Alleghany National Fish Hatchery in Warren, Pennsylvania (see Elrod et al. 1995).

JEN-LEW - Northern Lake Michigan origin stocked as fall fingerlings into Lewis Lake, Wyoming in 1890. Jenny Lake is connected to Lewis Lake. The 1984-1987 year-classes were from broodstock at the Jackson (Wyoming) National Fish Hatchery and the 1991-1992 year-classes were from broodstock at the Saratoga (Wyoming) National Fish Hatchery

ONT - Mixed strains stocked into and surviving to maturity in Lake Ontario. The 1983-1987 year-classes were from eggs collected in the eastern basin of Lake Ontario. The 1988-1990 year-classes were from broodstock developed from the 1983 egg collections from Lake Ontario. Portions of the 1991-1992 year-classes were from ONT strain broodstock only and portions were developed from crosses of ONT strain broodstock females and SEN males (see Elrod et al. 1995).

HPW - "Lean" lake trout strain originated from a self-sustaining remnant population located in Parry Sound on the Canadian side of Lake Huron in Georgian Bay. A captive HPW broodstock is maintained at the USFWS Sullivan Creek National Fish Hatchery and is the source of eggs for HPW reared at USFWS Alleghany National Fish Hatchery in Warren, Pennsylvania for stocking into Lake Ontario. The first HPW lake trout stocking into Lake Ontario occurred in fall 2014.

For further discussion of the origin of strains used in Lake Ontario lake trout restoration see Krueger et al. (1983), Visscher, L. (1983), and Page et al. (2003).

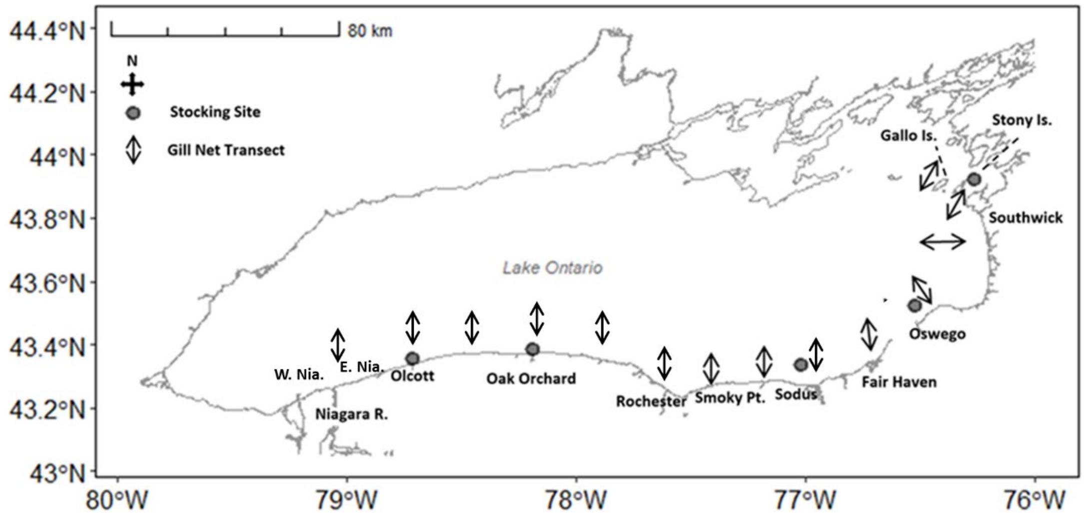

Figure 1. Lake Ontario map displaying 2021 locations for the NYSDEC May lake trout stockings (circles), the USGS July bottom trawling at W. Nia. (West Niagara) and E. Nia. (East Niagara), and the USGS-NYSDEC September gill netting survey (arrows).

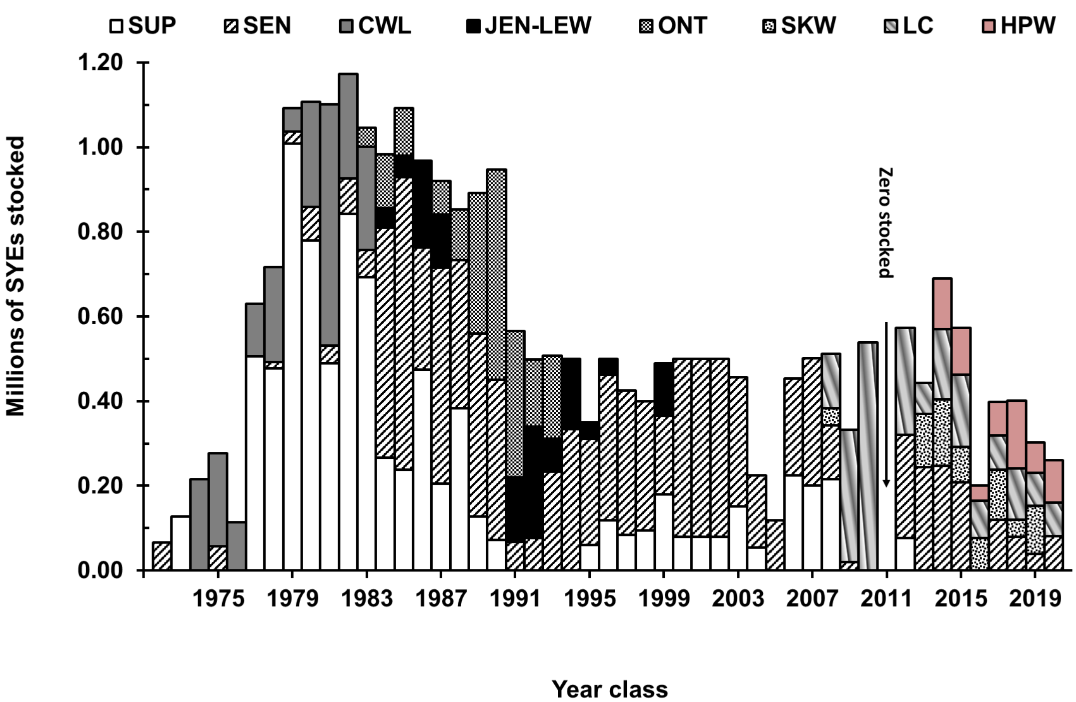

Figure 2. Total spring yearling equivalents (SYE) for lake trout strains stocked in U.S. waters of Lake Ontario for the 1972 – 2020 year-classes. Strain descriptions for ONT (Lake Ontario), JEN-LEW (Jenny-Lewis Lakes), CWL (Clearwater Lake), SEN (Seneca Lake), LC (Lake Champlain), SUP (Lake Superior), SKW (Lake Superior Klondikes), HPW (Lake Huron-Parry Sound) appear in Appendix 1. For year-classes beginning in 2006, SUP refers to Lake Superior the lean strains SAW (Lake Superior, Apostle Islands) and STW (Lake Superior, Traverse Islands) other than the Superior Marquette Domestics stocked prior to that time. SYE = 1 spring yearling or 2.4 fall fingerlings (Elrod et al. 1988). No lake trout from the 2011 year-class were stocked in 2012.

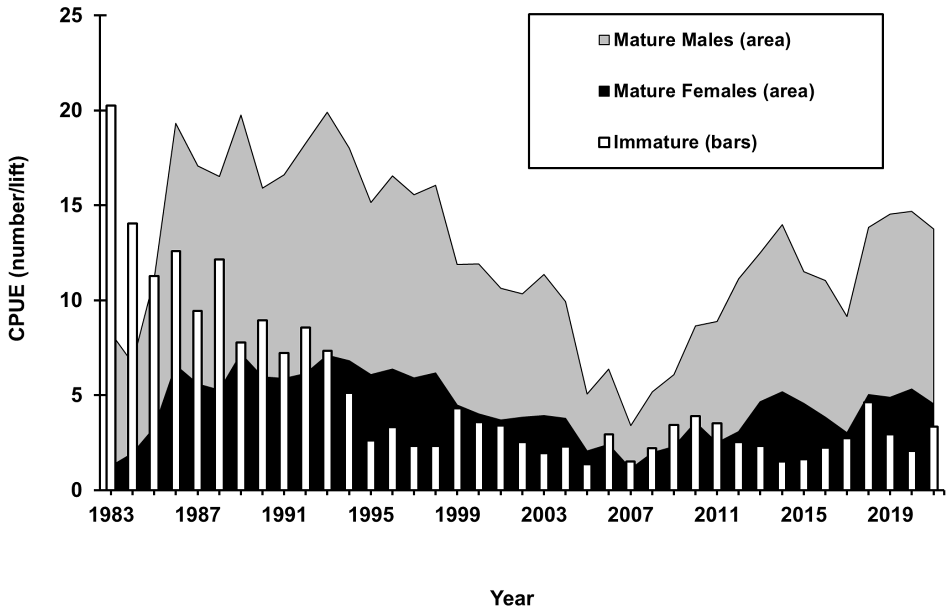

Figure 3. Abundance of mature (generally males ≥ age 5 and females ≥ age 6) and immature (sexes combined) lake trout calculated from catches made with USGS-NYSDEC gill nets set in U.S. waters of Lake Ontario during September 1983-2021. CPUE (number/lift) was calculated based on four strata representing net position in relation to depth of the sets. Abbreviated surveys occurred in 2018 and 2020 in which approximately half of the sites were fished and most effort occurred east of Rochester, NY.

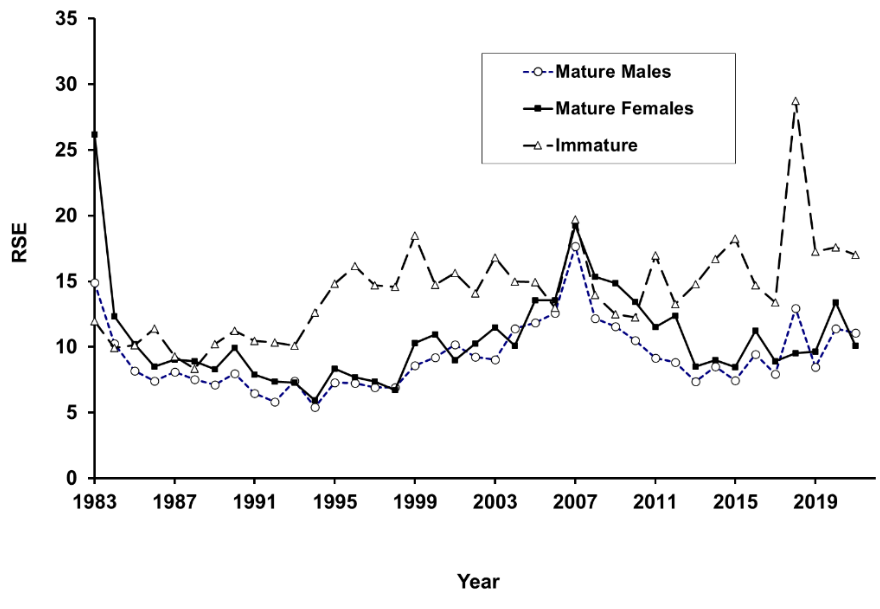

Figure 4. Relative standard error (RSE = {SE / Mean}*100) of the annual CPUE (number/lift) for mature male, mature female and immature (sexes combined) lake trout caught with USGS-NYSDEC gill nets set in U.S. waters of Lake Ontario during September 1983-2021. RSE increases after 1993 are in part due a reduction in the number of sites sampled declining from 17 to 14 in 1994. Reduced effort in 2018 and 2020 (only 8 sites fished in each year) contributed to the in RSE for those years.

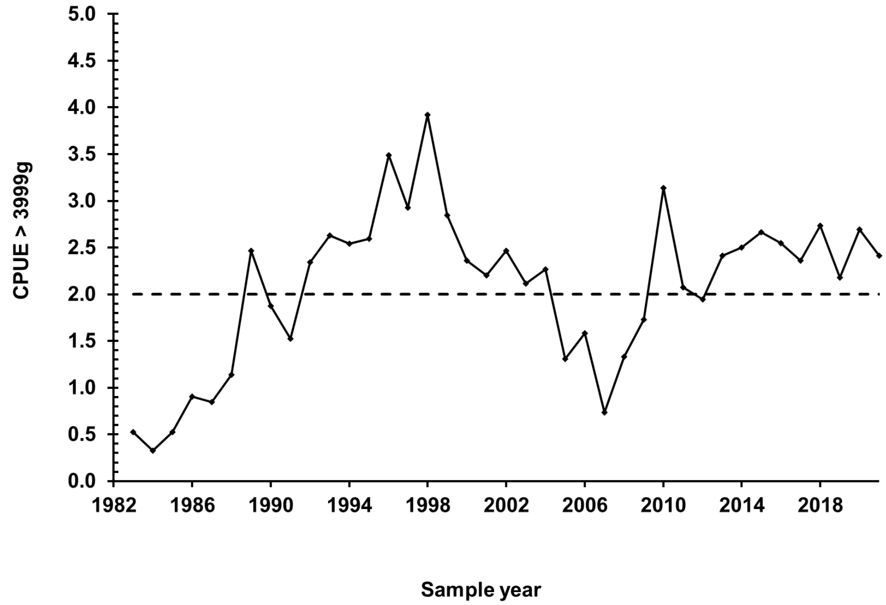

Figure 5. Abundance of mature female lake trout ≥ 4000 g calculated from catches made with USGS-NYSDEC gill nets set in U.S. waters of Lake Ontario during fall 1983-2021. The dashed line represents the target CPUE (number/lift) from Schneider et al. (1997) and Lantry et al. (2014).

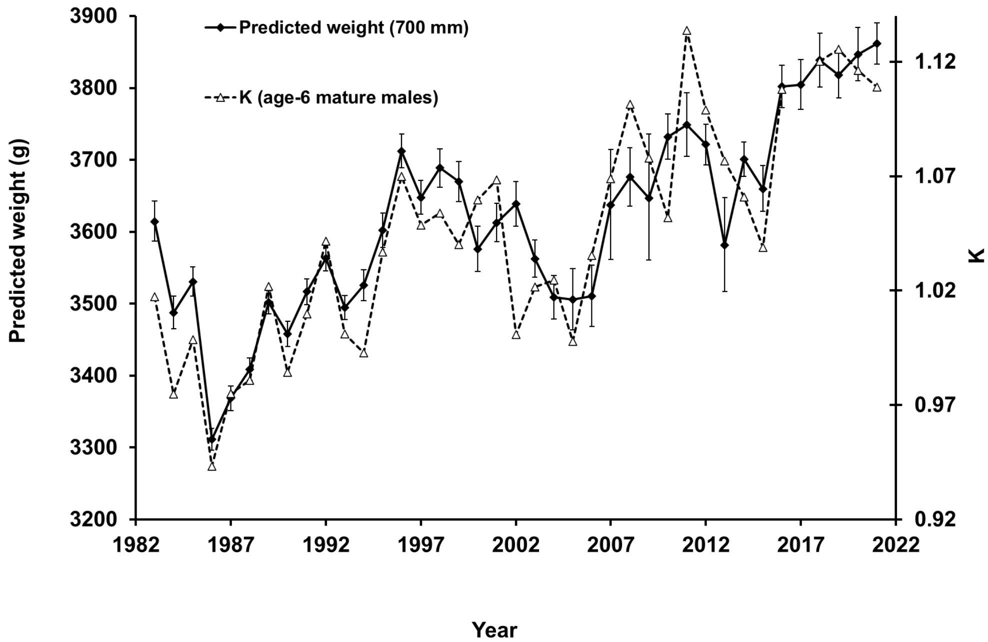

Figure 6. Lake Ontario lake trout condition (K) for age-6 mature males and predicted weight at 700-mm TL (27.6 in) from weight-length regressions calculated from all fish collected during each annual USGS-NYSDEC gill net survey during fall 1983–2021. There were no fish stocked from the 2011 year-class in 2012 so age-6 K was not available in 2017. Error bars represent the regression confidence limits for each annual value.

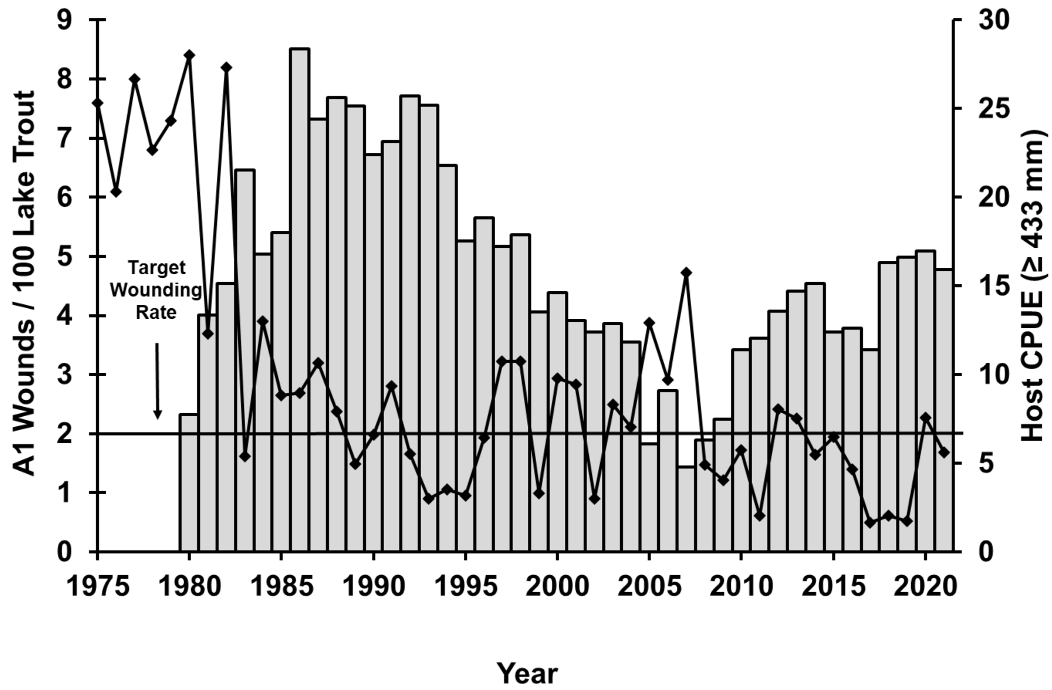

Figure 7. Wounding rates (A1 wounds per 100 lake trout, line) inflicted by sea lamprey on lake trout ≥ 433 mm (17.1 in) TL and the USGS-NYSDEC gill net CPUE (number/lift) of lake trout hosts (≥ 433 mm TL, bars) collected from Lake Ontario during fall 1975-2021.

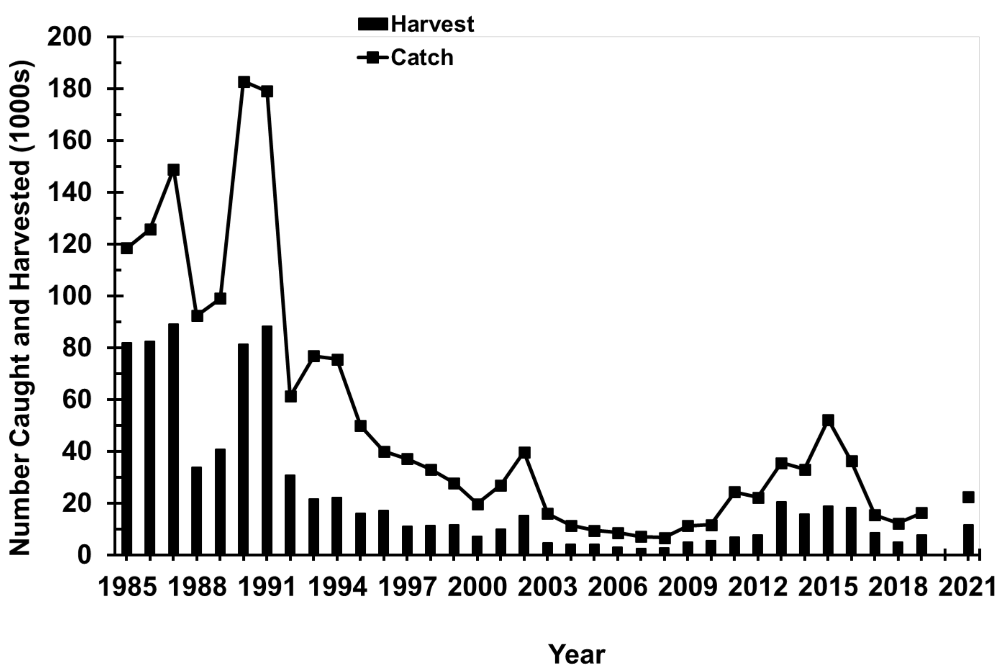

Figure 8. Estimated numbers of lake trout caught and harvested by boat anglers from U.S. waters of Lake Ontario, during April 15 – September 30, 1985-2021 (Connerton et al. 2022). Beginning with the 2012 report, all values have been reported reflecting a 5.5-month sampling interval. Prior reports were based on a 6-month sampling interval (April 1 – September 30).

Table 1. Annual survival of various strains of lake trout sampled from U.S. waters of Lake Ontario during the USGS-NYSDEC fall gill net surveys, 1985-2021. Strain descriptions for JEN (Jenny Lake), LEW (Lewis Lake), ONT (Lake Ontario), SUP (Lake Superior), SAW (Lake Superior, Apostle Islands), STW (Lake Superior, Traverse Island), SEN (Seneca Lake), LCD (Lake Champlain Domestic), SKW (Lake Superior Klondikes), OXS (Lake Ontario backcross with Seneca Lake), LCW (Lake Champlain Wild) and CWL (Clearwater Lake) appear in Appendix 1. Dashes represent missing values due to no or low numbers of tagged lake trout stocked for the strain, or when the strain was not in the US federal hatchery system. ALL is population survival of all strains combined using only coded wire tagged fish. Values for ALL in some years are influenced by strains not included in the table because they only appeared in the lake for a short while (e.g., the 1991-1993 cohorts of OXS; the 2009 cohort of LCW) or because they only occurred before successful sea lamprey control was established (1974-1983 cohorts of CWL). Missing survival values for 1997, 1998 and 2002 year-classes were caused by low tagged proportions of total stockings and there were no lake trout stocked from the 2011 year-class. Reduced survey effort in 2020 contributed to missing values for the 2009 year-class of SENs at age 11.

YEAR		STRAIN									
CLASS	AGES	JEN	LEW	ONT	SUP	SAW	STW	SEN	LCD	SKW	ALL
1978	7-10	-	-	-	0.40	-	-	-	-	-	-
1979	7-11	-	-	-	0.52	-	-	-	-	-	-
1980	7-11	-	-	-	0.54	-	-	0.85	-	-	-
1981	7-11	-	-	-	0.45	-	-	0.92	-	-	-
1982	7-11	-	-	-	0.44	-	-	0.82	-	-	-
1983	7-11	-	-	0.61	0.54	-	-	0.90	-	-	0.57
1984	7-11	0.39	-	0.61	0.48	-	-	0.70	-	-	0.65
1985	7-11	-	-	0.80	0.47	-	-	0.77	-	-	0.73
1986	7-11	0.57	-	-	0.43	-	-	0.81	-	-	0.62
1987	7-11	0.50	-	-	0.50	-	-	0.80	-	-	0.73
1988	7-11	-	-	0.77	0.61	-	-	0.73	-	-	0.68
1989	7-11	-	-	0.78	0.59	-	-	0.86	-	-	0.81
1990	7-11	-	-	0.64	0.60	-	-	0.75	-	-	0.68
1991	7-11	-	0.56	0.62	-	-	-	0.70	-	-	0.70
1992	7-11	-	0.51	-	-	-	-	0.81	-	-	0.60
1993	7-11	-	0.64	-	-	-	-	0.72	-	-	0.71
1994	7-11	-	0.73	-	-	-	-	0.45	-	-	0.56
1995	7-11	-	0.50	-	-	-	-	0.76	-	-	0.72
1996	7-10	-	-	-	0.43	-	-	-	-	-	-
1999	7-11	-	-	-	-	-	-	0.84	-	-	-
2000	7-11	-	-	-	-	-	-	0.90	-	-	-
2001	7-11	-	-	-	-	-	-	0.73	-	-	-
2003	7-11	-	-	-	0.53	-	-	0.72	-	-	0.68
2004	7-11	-	-	-	-	-	-	0.78	-	-	0.78
2005	7-11	-	-	-	-	-	-	0.85	-	-	0.85
2006	7-11	-	-	-	-	-	-	0.74	-	-	0.72
2007	7-11	-	-	-	-	-	0.36	0.91	-	-	0.84
2008	7-11	-	-	-	-	0.53	0.41	0.96	0.76	0.82	0.79
2009	7-11	-	-	-	-	-	-	0.74	0.71	-	0.66
2010	7-11	-	-	-	-	-	-	-	0.75		0.75
2012	7-9		-	-	-	0.60	-	0.93	0.89	-	0.87

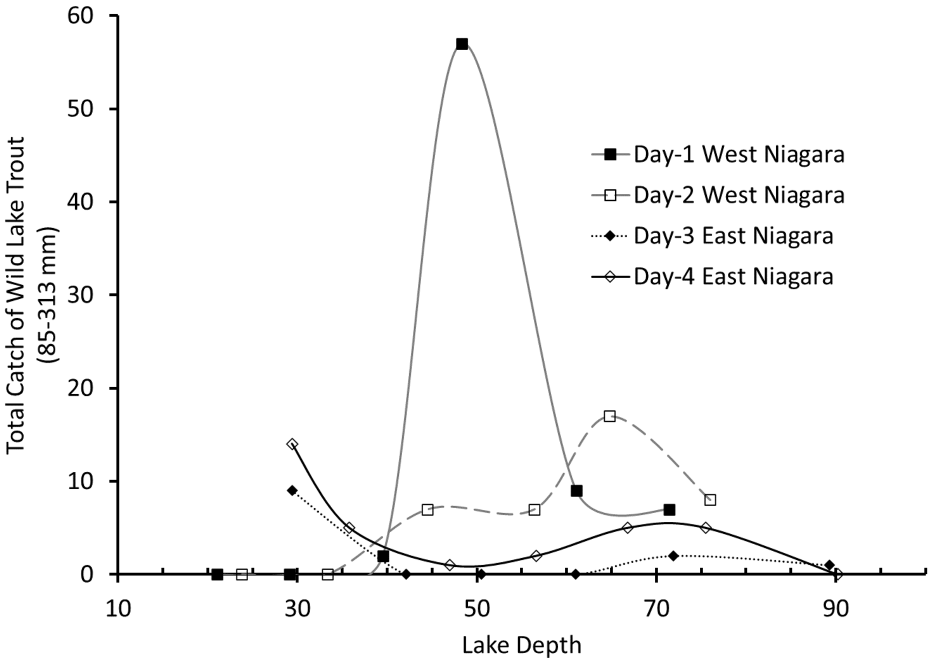

Figure 9. Total catch of naturally produced (wild) lake trout (85-300 mm TL) captured in USGS bottom trawls towed for 10 mins on consecutive days at two sites off the mouth of the Niagara River during July 2021.

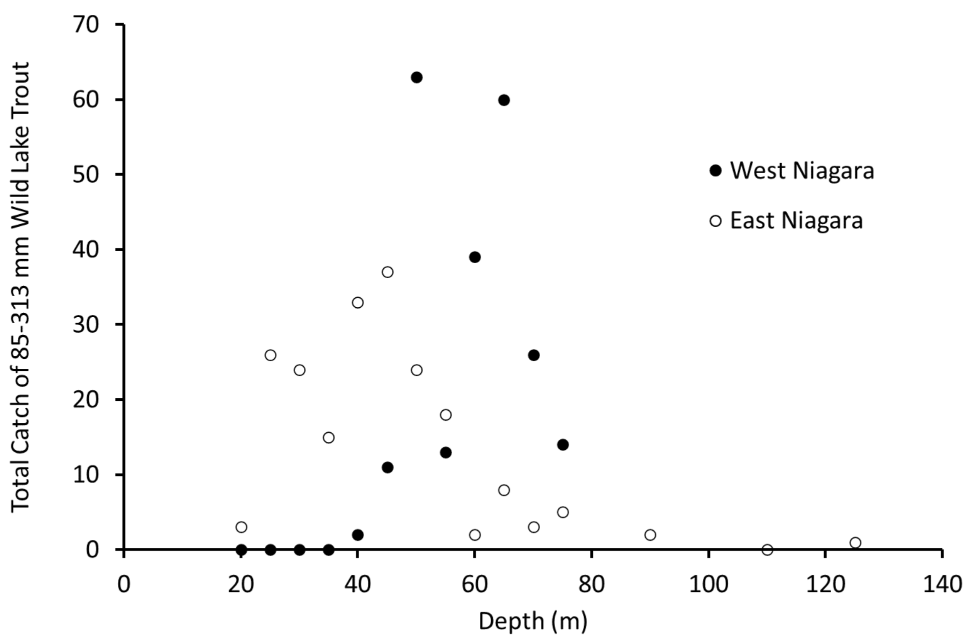

Figure 10. Total catch versus depth of naturally produced (wild) lake trout (85-300 mm TL) captured at two sites off the mouth of the Niagara River in annual USGS-NYSDEC July bottom trawl surveys during 2014-2021 (no data were available in 2018 or 2020). During this period consistent effort was expended at depths between 30 and 75m, fewer tows were conducted at shallower and deeper depths.

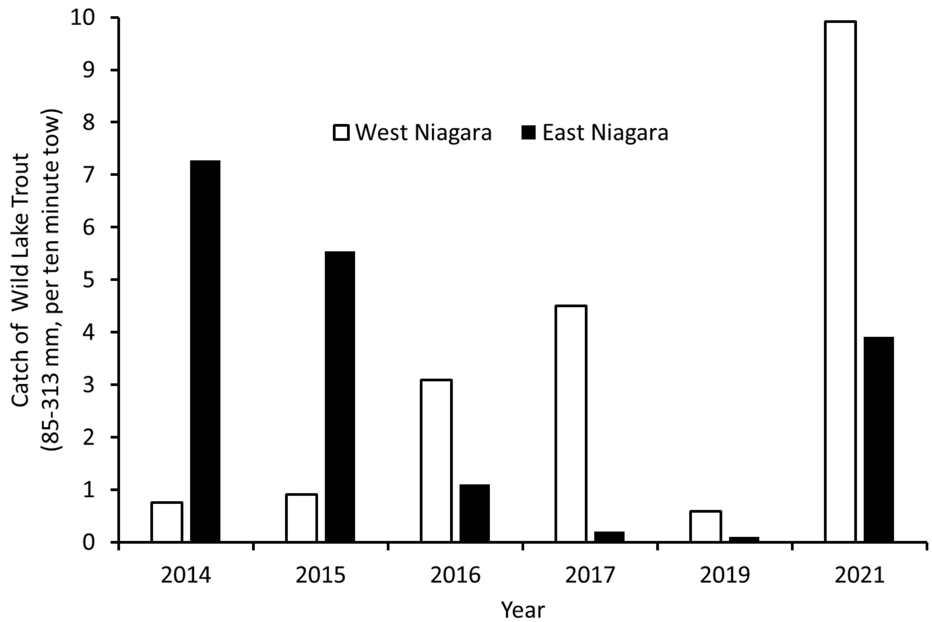

Figure 11. CPUE of naturally produced (wild) lake trout (85-300 mm TL) captured in annual USGS-NYSDEC July bottom trawl surveys in Lake Ontario during 2014-2021 (no data were available in 2018 or 2020). The two sites represented were both near the mouth of the Niagara River.

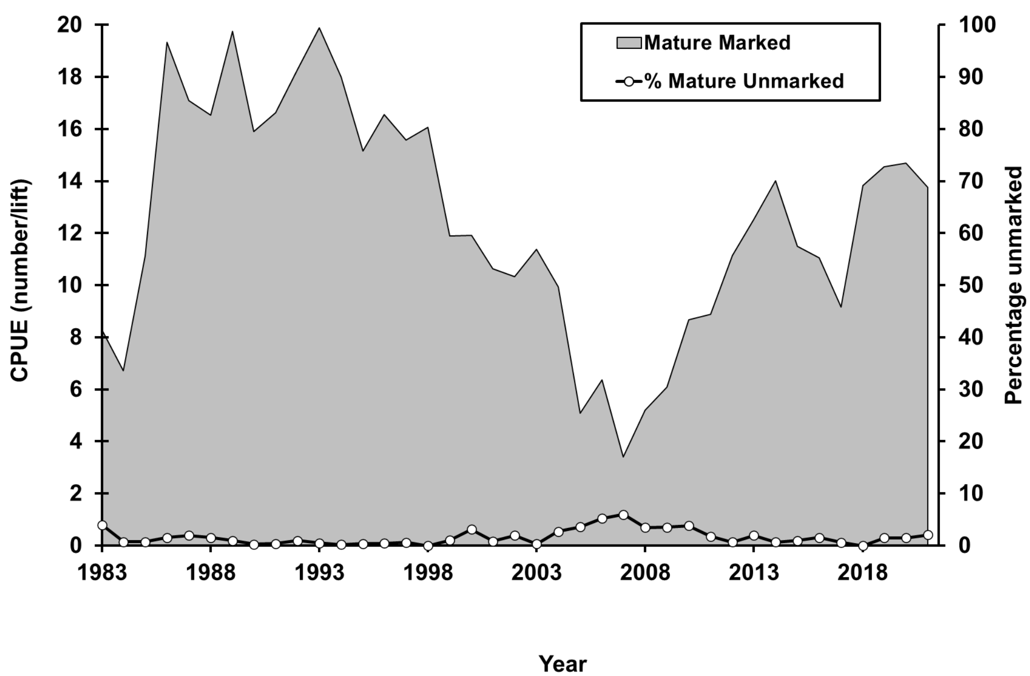

Figure 12. Percentage of unmarked (no clips or tags) sexually mature lake trout captured in annual USGS-NYSDEC September gill net surveys in Lake Ontario during 1983-2021 (black line with white markers). The percentage of unmarked fish is presented against the backdrop of the CPUE (number/lift) of all mature lake trout caught per year (gray shaded area) and for the period from 1993-2021 represents on average 1.64% of the CPUE (range 0 to 5.98%).