Lake Trout (*Salvelinus namaycush*) Rehabilitation in Lake Ontario, 2020

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Preface

As was the case for all Great Lakes fisheries management and research agencies, the impacts of the COVID-19 pandemic on the Center's deepwater science work were significant. The most severe impacts were related to deepwater science cruises scheduled in the spring/early summer, and those requiring extended overnight stays on vessels. In addition, USGS vessels could not get clearance to cross into Canadian waters as a result of the pandemic, reducing the scope of data normally collected by cruises that were able to get underway. Because of these limitations, reporting for 2020 deepwater science surveys will be limited in scope, and in some cases, limited in the ability to make meaningful comparisons to data from previous years. All USGS personnel involved in deepwater science cruises are looking forward to the return of a more normal sampling schedule in 2021, pandemic conditions permitting.

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). Response to the COVID-19 pandemic limited survey effort such that spring and summer bottom trawl surveys and the creel survey were not completed in 2020, and sites sampled during the fall gillnet survey were limited to those east of Rochester, NY. 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 2020. The 2020 rate of wounding by sea lamprey (*Petromyzon marinus*) on lake trout caught in gill nets was 2.27 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 1983-2020 time series. Reproductive potential for the adult stock indexed from the CPUE of mature females ≥ 4000 g was again above the target in 2020 continuing a trend observed in nine of the last ten years. The 2020 catch of young wild lake trout marked the 26th observation in the last 27 years, however the low numbers of native adults observed during that time period continues to indicate substantial restoration impediments still exist.*

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 Natural Resources and Forestry [OMNRF]) 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), will guide future efforts. This report documents progress towards restoration by reporting on management plan targets and measures through 2020.

The data associated with this report have not received final approval by the U.S. Geological Survey (USGS) and are currently under review. The Great Lakes Science Center is committed to complying with the Office of Management and Budget data release requirements and providing the public with high quality scientific data. We plan to release all USGS research vessel data collected between 1958 and 2020 and make those publicly available. Please direct questions to our Information Technology Specialist, Scott Nelson, at snelson@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

During September 1983-2020, adult lake trout were collected with gill nets at random transects within each of 14 to 17 geographic areas distributed uniformly within U.S. waters of 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).

During September 2020, an abbreviated survey was conducted due to concerns over the COVID-19 pandemic. In the 2020 survey, the NYSDEC R/V Seth Green and the USGS R/V Kaho fished standard monofilament gill nets for adult lake trout at the eight standard geographic locations from Rochester to Cape Vincent along the U.S. shore in Lake Ontario, and one new location on the north side of Galloo Island in the eastern outlet basin that was added in 2019 (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 5 sites in the lake's main 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. At the three sites in the eastern basin, two nets per site were fished due to thermocline depth. In the Black River Channel two nets were fished between 38 m and 43 m (124.7 – 141.1 ft); in the St. Lawrence Channel two nets were fished between 42 m and 51 m (137.8 – 167.3 ft); and north of Galloo Island two nets were fished between 42 to 52 m (137.8 – 170.6).

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. 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 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 forwards 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. When the first year-class (2008) of SKWs reached maturity in 2014, however, their age-6 Fulton's K value (1.07) was almost identical to Seneca Lake strain (SEN's; 1.08), 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).

Strain-specific survival indices were calculated separately for ages 3, 6 and 10 lake trout to index early post-stocking survival, survival to maturity and survival to advanced ages, respectively. The age and strain specific indices were calculated as the CPUE for each age (3, 6 and 10) of each year-class (1980-2017) for which the strain was stocked divided by the number of that strain stocked from that particular year-class and multiplied by 100,000.

Several strains were stocked over discrete time periods and thus indices for those strains did not appear across all year-classes. Individuals from the 2015-2020 year-classes had not reached age 6 by 2020 and from the 2012-2020 year-classes had not reached age 10 by 2020, and thus did not appear in this analysis.

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 and therefore, survey results are only presented through 2019.

Indices of Natural Reproduction

For indices of natural reproduction based on juveniles, only unclipped and untagged ages-0 to -2 lake trout captured in all USGS and NYSDEC bottom trawl surveys were used to calculate CPUEs (Lantry et al. 2019; Weidel et al. 2021). The CPUEs were calculated as the number caught per standard tow (per 10 minutes of tow time). Only ages 0-2 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). For indices of natural reproduction based on adult lake trout catches, records for unclipped-untagged mature lake trout from the September gill net assessments were examined (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 (2000) and Connerton (2020).

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 million for the 1973 year-class to 0.28 million for the 1975 year-class (Figure 2). By 1978 (1977 year-class) the USFWS ANFH was raising all lake trout stocked in U.S. waters of Lake Ontario and annual releases exceeded 0.60 million fish. In 1983, the first official Lake Ontario lake trout rehabilitation plan (Schneider et al. 1983) was formalized and it called for an annual U.S. stocking target of 1.25 million yearlings. The stockings of the 1979-1986 year-classes approached that level, averaging about 1.07 million annually. The number of yearling equivalents released declined by about 22% between the stockings of the 1981 and 1988 year-classes. Stocking declined by 47% in 1992 (1991 year-class) due to problems encountered at the hatchery.

In 1993, fishery managers reduced the lake trout stocking target to 500,000 yearlings in response to recommendations from an international panel of scientists and extensive public review concerning predator-prey imbalance in Lake Ontario (Lantry et al. 2014). Annual stockings were near the revised 1993 target level in 18 of 26 years during 1993-2016 (Figure 2). In April of 2005, power failures at ANFH resulted in losses of about 45% of the spring yearlings scheduled to be stocked leading to a stocking total of 224,150 for May 2005. Later in the fall of 2005, ANFH was closed due to an outbreak of infectious pancreatic necrosis and remained closed for fish production through summer 2011. Completion of disinfection, renovation and disease trials permitted fish production to resume at ANFH in fall 2011. After the closure of ANFH, the NYSDEC Bath Fish Hatchery was able to provide 117,820 lake trout for stocking in 2006, leaving the US stocking 76% below the 500,000 fish target. Lake trout for 2007 and 2008 stockings were raised at the USFWS ENFH (the name was changed from Pittsford to Eisenhower in 2009) and WRNFH in Vermont. In 2010, 94% of the stocked lake trout were raised at WRNFH and 6% were raised at NYSDEC Bath Fish Hatchery. All lake trout destined for stockings in 2009 and 2011 were raised at the USFWS WRNFH. In late August 2011, flooding of WRNFH from the adjacent White River during tropical storm Irene led to the USFWS decision to depopulate the hatchery over serious concerns of raceway contamination with didymo (*Didymosphenia geminata*) from the adjacent White River. As a result, no lake trout from the 2011 year-class were stocked into Lake Ontario in May 2012. Combined production of the 2012 year-class at ANFH and ENFH resulted in stocking of nearly 123,000 fall fingerlings and over 520,000 spring yearlings. During 2014, combined production of the 2013 year-class at ANFH and ENFH resulted in stockings of approximately 442,000 spring yearlings. That same year, fish managers increased the lake trout stocking target to 800,000 spring yearling equivalents (Lantry et al. 2014). Combined production of the 2014 year-class at ANFH and ENFH resulted in stockings of nearly 528,000 fall fingerlings in October 2014 and 521,000 spring yearlings in May 2015. Combined ANFH and ENFH production of the 2015 year-class fish resulted in stockings of nearly 454,000 fall fingerlings in October 2015 and 384,000 spring yearlings in May 2016.

In fall 2016, fish managers reduced lake trout and Chinook salmon stocking targets to reduce predatory demand on alewife (Connerton 2020). The planned target stocking number of the 2016 year-class was 400,000 spring yearlings. No fall fingerling lake trout from the 2016 year-class were stocked. A mortality event at ANFH beginning in late fall 2016 further reduced the number of fish available for stocking, resulting in a combined ANFH and ENFH May 2017 stocking of 200,843 spring yearlings. The need to refresh broodstock at the Berkshire National Fish Hatchery also resulted in the release of 304 Klondike strain (SKW) adults from the 2012 year-class into the lake in December 2017. The 400,000 fish target was met for the 2017 year-class by stocking a combination of four strains of yearling lake trout in 2018 including 40,405 LCD produced at ENFH, and 119,227 SEN, 118,729 SKW, and 79,439 HPW from ANFH (Figure 2). Barge stocking was planned in 2018 at five sites, but bad weather forced shore stocking at Sodus and Olcott (Figure 1). The production target was met for the 2018 year-class by stocking a combination of four strains of yearling lake trout in 2019 including 121,500 LCD produced at ENFH, and 80,000 SEN, 40,000 SKW, and 160,000 HPW from ANFH (Figure 2). All fish were barge stocked at five sites in 2019.

The 2020 stocking target, which was further reduced by managers to 320,000, was nearly met during the May 2020 stocking of 302,035 yearlings which were released at four of the five traditional locations with only the Oswego site not receiving any lake trout (Connerton 2020). At two of the sites, Sodus and Stony Island, all lake trout were barge stocked and at the other two sites, Olcott and Oak Orchard, half were barge stocked and half were stocked from shore (Figure 1). The shore stocked fish for the Olcott site were released just west of there at Wilson. Strain totals for 2020 included 71,909 HPW, 77,246 LCD, 39,680 SEN and 113,200 SKW.

Stocking Evaluations

Recruitment of stocked lake trout from age-1 (at release) to ages 2 and 3 declined sharply in the early 1990s (Elrod et al. 1993; Lantry et al 2018). Results of comparing shoreline stockings to offshore stockings suggested that predation had a role in post-stocking mortality (Elrod 1997; Lantry et al. 2011). Preliminary analyses in 2003 indicated that if site-specific stockings exceeded 130,000 SYs, the July bottom trawl catch per number stocked at the three trawling locations nearest to the stocking site were higher than for stockings between 80,000 and 120,000 SYs. Interpretations of those early comparisons however were compromised by the fact that a substantial portion of fish stocked between 1997 and 2004 did not receive coded wire tags and nearly all stockings exceeding 130,000 per site occurred before the early 1990s recruitment declines.

From 2004 to 2014 pulsed stockings (>130,000 SYs stocked at a location totaled across all strains) were attempted at one stocking location per year. Comparisons were limited to one pulse per year because of the continued need to stock all sites and the limited number (≈ 500,000 SYs per year) of lake trout stocked. Corrected catches for all 2004-2014 stockings were represented as the sum of the CPUE of ages 3, 4, 5, and 6 lake trout originating from a year-class released at a stocking location divided by the total year-class and release location specific stocking number and multiplied by 100,000. Comparisons of corrected catch vs total number stocked for the 2004 to 2014 stockings indicated no survival advantage over stocking levels varying from 38,000 to 224,150 SYs per site (Figure 3). Strain and year-class appeared to be more important drivers of post-stocking survival than total numbers stocked. The greatest CPUEs per number stocked over ages 3 to 6 were driven by catches of SKWs from the 2008 and 2013 year-classes stocked at Oswego and Sodus and survival advantages for those fish persisted through at least age 10 (see Figure 10 and the last paragraph of the survival section on page 14). The next highest group of survival values were for all strains stocked from the 2008 and 2009 year-classes stocked at Olcott and Oak Orchard which: 1) were released during a period when numbers of large lake trout in the population were low and just beginning to recover from the population declines that occurred during 2005-2007; and 2) those year-classes were reaching desirable sizes for sea lamprey predation (>432 mm or about ages 3 or 4) when sea lamprey numbers, which had been above target since 2003, were just beginning to return to target values (2012 and after).

Abundance Indices

A total of 454 lake trout were captured in 26 nets set at 8 sites during the September 2020 gill net survey, resulting in a total CPUE of mature adults of 14.56 (Figure 4). 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 9.2% and 10.7% respectively, for the entire data series (Figure 5). The RSE for immature lake trout was at its peak in 2018 (28.7), and was 115% greater than the 2017 value and was likely related to 2018 having a reduced numbers of nets fished, a higher mean CPUE, and an expanded range in catch totals that included the largest single catch of immature lake trout in one net (n = 32) since 1992. The RSE for immatures in 2020 was 17.6, which was lower than the peak in 2018, and only 10% greater than the 1996-2020 means despite being calculated from an abbreviated survey in which, similar to 2018, only half of the sites were fished. The CPUE of mature lake trout had remained relatively stable from 1986 to 1998, but then declined by 31% between 1998 and 1999 due to the poor recruitment of the 1993 year-class. 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), appearing to reflect a new stable equilibrium established subsequent to the stocking reductions in 1993, but then abundance declined further (by 54%) in 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 8 and the sea lamprey section on page 13) 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. Results from the reduced effort deployed in the 2018 survey indicated adult abundance rose by 51% from 2017 value. Abundance was similar in 2019 and 2020 and 60% greater than the 2017 value. Current abundance between 2018 and 2020 are similar to the value in 2014 before the declines between 2015 and 2017 occurred. 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 2015, 2016 and 2017 respectively.

The CPUE for immature lake trout captured in gill nets (generally ages 2 to 5) declined by 64% between 1989-1993 (CPUE: 8.0) and 1995 (CPUE: 2.6) and remained at the lower level thereafter with a mean of 2.6 for 1995-2017. Similar to adult values, the 2018 CPUE for immature fish from the reduced 2018 survey increased by 1.7-fold over the 2017 value. However as adult values recovered from the effects of the missing 2011 year-class during 2018 to 2020, immature CPUE declined and in 2020 (2.1) was 56% and below the 2018 value.

Schneider et al. (1997) established a target gillnet 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 6). 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 2010-2020, 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 7). Predicted mean weight declined by 158.8 g (5.6 oz) between 1999 and 2006 but increased again in 2007 and remained high through 2015. Predicted mean weight rose sharply after 2015 so that 2016-2020 mean (3822.0 g, 8.4 lb) was at the highest level for the data series. The trend of improving condition through 1996 and from 2007 to 2020 corresponded to periods when the abundance of older lake trout in the population was increasing. Our data suggested that for lake trout of similar length, older fish were heavier. To examine whether age was the primary driver of recent 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 7). Values of K for age-6 males, however, 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) has remained low since the mid-1980s, however, wounding rates (Figure 8) 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 (441) of host-sized lake trout was 53% lower than that in 2019.

Angler Catch and Harvest

In 2020, the NYSDEC fishing boat survey was not conducted because of the COVID pandemic. Herein we report on catch and harvest trends through 2019 and expect to resume creel data collection again in 2021.

Fishing regulations, lake trout population size, and availability of other trout and salmon species influenced angler harvest through time (Connerton et al. 2020). Since 1988, managers instituted a slot size limit to decrease harvest of mature lake trout and increase the number and ages of spawning adults in the population. In 1992, the regulation permitted 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 gillnetting survey (Figure 4). 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 rates and total catch and harvest increased for six consecutive years, then were relatively stable 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, during 2013-2016 harvest exceeded the U.S. 10,000 lake trout target (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. Harvest in 2019 was 58% below the 2013-2016 average (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), which may have reduced fishing effort directed at lake trout in those years.

Adult Survival

Survival of SEN strain lake trout (ages 7 to 11) was consistently greater (20-51%) than that of the SUP strain for the 1980-1990 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 were similar to the SUP strain, suggesting that those strains may also be highly vulnerable to sea lamprey. Ontario strain (ONT) lake trout were progeny of SEN and SUP strains (Appendix 1) and their survival was intermediate to that of their parent strains.

Survival for all strains combined (hereafter referred to as population survival) was based on all fish captured for the 1983-1995 and 2003-2010 cohorts, as all fish stocked during those periods received coded wire tags. Population survival generally increased with successive cohorts through the 1985 year-class, 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. Population survival of the 2003-2010 cohorts were all above target (there was no 2011 stocked cohort). For the 2004 and 2005 year-classes, the population survival was identical to the SEN strain survival because the stockings for both year-classes were predominantly SEN. Stockings for both of those year-classes were also far below the 500K target with all 224K of the 2004 year-class being stocked at one site in the eastern basin and all 118K of the 2005 year-class released at one site in the western part of the lake. The SUP strain was no longer available in 2006 and while stockings for the 2006 to 2008 year-classes were back near the 500K target and more evenly distributed between SEN and SUP-like strains, those strains from Lake Superior were now Traverse Island strain (STW) and Apostle Island strain (SAW). Strains from Seneca Lake origins now included SENs and feral (LCW) and domestic Lake Champlain strains (LCD). Survival for SENs (2006-2009 year-classes) continued to be high (≥74%) and survival for LCD 2008-2010 year-class (71-78%) resembled their mostly SEN origins. Only one year-class of LCWs 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) were observed in survey catches at ages 7 and 8 in 2019 and 2020. 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 reaching age-7 in 2020, the first survival estimates for those year-classes will be presented in 2022.

Strain-specific survival advantages were further analyzed by examining CPUEs corrected for the number stocked evident at ages 3, 6 and 10 reflecting survival post-stocking, to maturity and to later life stages respectively. Strain-specific differences were consistently present across time and among all ages examined. Post-stocking survival appeared greatest (Figure 10, Age-3 panel) for SUP and SKW strains with all other strains showing similar survival. Survival indices to maturity (Figure 10, Age-6 panel) were again similar for most strains with SUPs continuing to hold a slight advantage and SKWs remaining substantially higher. By age 10, SENs, with their demonstrated resistance to sea lamprey predation (Schneider et al. 1996; Lantry et al. 2015), moved into the position of highest survival (Figure 10, Age-10 panel); and ONTs and LCDs at all three ages had similar performance as SENs likely reflecting their shared genetic origins. LEWs had survival similar to SUPs at all ages underscoring the potential for increased diversity in stockings for lakes with effective sea lamprey control.

Natural Reproduction

Evidence of survival of naturally produced lake trout past the fall fingerling stage occurred only once 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 for each year during 1994-2019 (Figure 11) except in 2008 and 2020, representing production of 26 year-classes. Numbers reported in previous reports represented the total capture of age-0 to age-2 unclipped and untagged lake trout from the entire annual bottom trawl catch from four surveys occurring during April, June, July and October (for a description of the surveys see O'Gorman et al. 2000 and Owens et al. 2003). Catch was not corrected for effort 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 are most often encountered in Lake Ontario (Figure 11).

Changes in recent annual survey design and effort necessitated a change in the way we report the catch. In 2013, effort in the July juvenile lake trout survey was reduced and only 9 of 14 trawling locations were fished because no yearling lake trout were stocked in 2012. Effort returned to normal for the July survey during 2014-2017 and 2019, but was once again reduced in 2018 and 2020. In 2015, the June bottom trawl survey was discontinued, and the annual April survey was broadened, which resulted in a net decrease in annual trawling effort in U.S. waters by approximately 60 tows (Weidel et al. 2016). Because of these changes in the 2018 report we began reporting combined CPUE from all bottom trawling effort rather than total catch. The CPUE data in 2018 were presented for five lake regions along the southern shore from the Niagara River in the west to the mouth of the St Lawrence River in the eastern basin, grouping them by geographic location and patterns in catch through the years that we suspect are related to the proximity to suitable spawning habitat. The regions, from west to east, were two sites near the mouth of the Niagara River (region 1), four sites located between Olcott and Rochester (region 2), four sites between Smoky Point and Fair Haven (region 3), three sites between Oswego and Southwick (region 4), and two sites in the eastern outlet basin (region 5). For the 2019 and 2020 reports we continued to present CPUE, but simplified the regional structure with just three regions presented: the Western region representing the two westernmost sites adjacent to the mouth of the Niagara River where the greatest catches of wild lake trout occurs; the Central region encompassing all eleven main lake sites from Olcott to Southwick; and the Eastern region representing all trawling locations in the eastern basin where much of the historically described spawning habitat occurs (the locations bounding the regions appear in figure 1). There were no April or July bottom trawl surveys in 2020 due to safety concerns associated with the COVID-19 pandemic. The October survey did occur in 2020 (Weidel et al. 2021), but only sites east of Rochester, NY in the central and eastern portions of the lake were fished. Thus, caution should be exercised in interpretation of the 2020 CPUEs due to greatly reduced effort.

The distribution of catches of age-0, 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 (Western region, Figure 11). Age-0 lake trout (<100 mm, 3.9 in) observed early in the time series disappeared from catches by the early 2000s and may have been due, in part, to a change in our trawl gear that was necessary to avoid abundant dreissenid mussels. The four largest total lake-wide catches of the 31-year time-series occurred during 2014-2017 with 47 age-1 (93-186 mm, 3.7-7.3 in) and 70 age-2 wild lake trout (176-291 mm, 6.9-11.5 in) caught in 2014; 24 age-1 (94-147 mm, 3.7-5.8 in) and 48 age-2 (167-262 mm, 6.6-10.3 in) caught in 2015; 21 age-1 (87-169 mm, 3.5-6.6 in) and 30 age-2 (178-245 mm, 7.0-9.6 in) caught in 2016; and 8 age-1 (90-133 mm, 3.5-5.2 in) and 62 age-2 (148-265 mm, 5.8-10.4 in) caught in 2017. The relatively low catch (25 age-1 and age-2 sized wild fish) in 2018 was in part due to reduced effort during the July bottom trawl survey, however, the 2019 catch was nearly identical (24 age-1 and age-2 sized wild fish) when July effort returned to normal. With bottom trawling effort truncated from three surveys to one in 2020, only one age-1 wild lake trout was caught.

Catches from at least 26 cohorts of wild lake trout since 1994 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 there has declined since 2014. Lack of a similar trend of expanding production of wild lake trout near the reputed spawning habitat in the eastern basin indicates that drivers of local spawning success (e.g., spawning habitat) need to be further explored.

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 (1993-2020) that young naturally reproduced lake trout were being caught in bottom trawls, an annual average of eight (range 0-17) unclipped/untagged mature lake trout were observed in September gillnet catches (Figure 12). That low number of unclipped/untagged individuals represented a mean of 1.75% of all mature lake trout sampled with a range of 0% - 5.98%. The slight increasing trend during 2004-2010 for the percentage of unclipped/untagged individuals might be expected from an accumulation and aging of naturally produced cohorts produced since 1993. Subsequent declines after 2010 follow the population-wide abundance declines that occurred during 2005-2008 and the low levels of juvenile unclipped-untagged lake trout observed during that time. 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.

Acknowledgements

The long histories of survey data we present herein depend on the efforts of the vessel crews of the RV Kaho and RV Seth Green whose professionalism and willingness to adapt to challenging working conditions make the data collection possible. Recent vessel operations were ran by Captain Lewchanin and MMR Strang on the RV Kaho (USGS), and by Captain Fairbanks on the RV Seth Green (NYSDEC). We also thank the numerous biologists and technicians from USGS, NYSDEC and USFWS who have assisted in sample collection and data analysis, and provided insight and edits for the report. For the 2020 reporting we thank from USGS: Brian O'Malley, Stacy Furgal, and Sydney Phillips; and from NYSDEC: Russell Moore, Nicholas Farese, and Edward Scheppard. We especially thank the retired biologists, Cliff Schneider and Thomas Eckert from NYSDEC, and Joseph Elrod, Robert O'Gorman and Randall Owens from USGS (formerly USFWS), who shaped the early surveys and guided the initial reporting.

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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 brood stock (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 brood stocks derived from "lean" Lake Superior lake trout. Brood stock 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 brood stock 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).

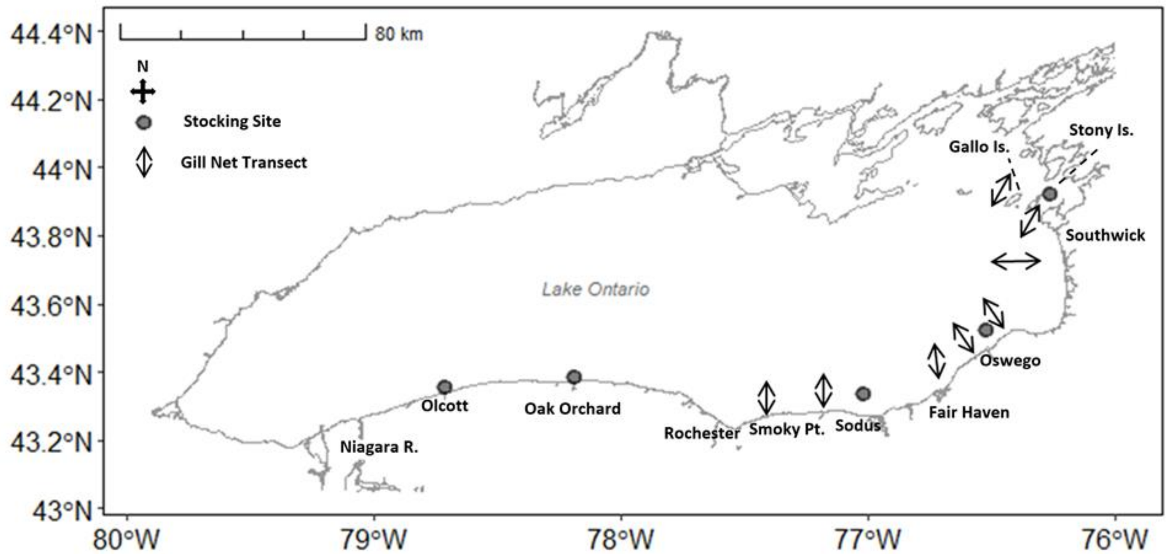

Figure 1. Lake Ontario map displaying 2020 sample locations for the USGS-NYSDEC assessment gillnetting (arrows), and stocking locations (circles).

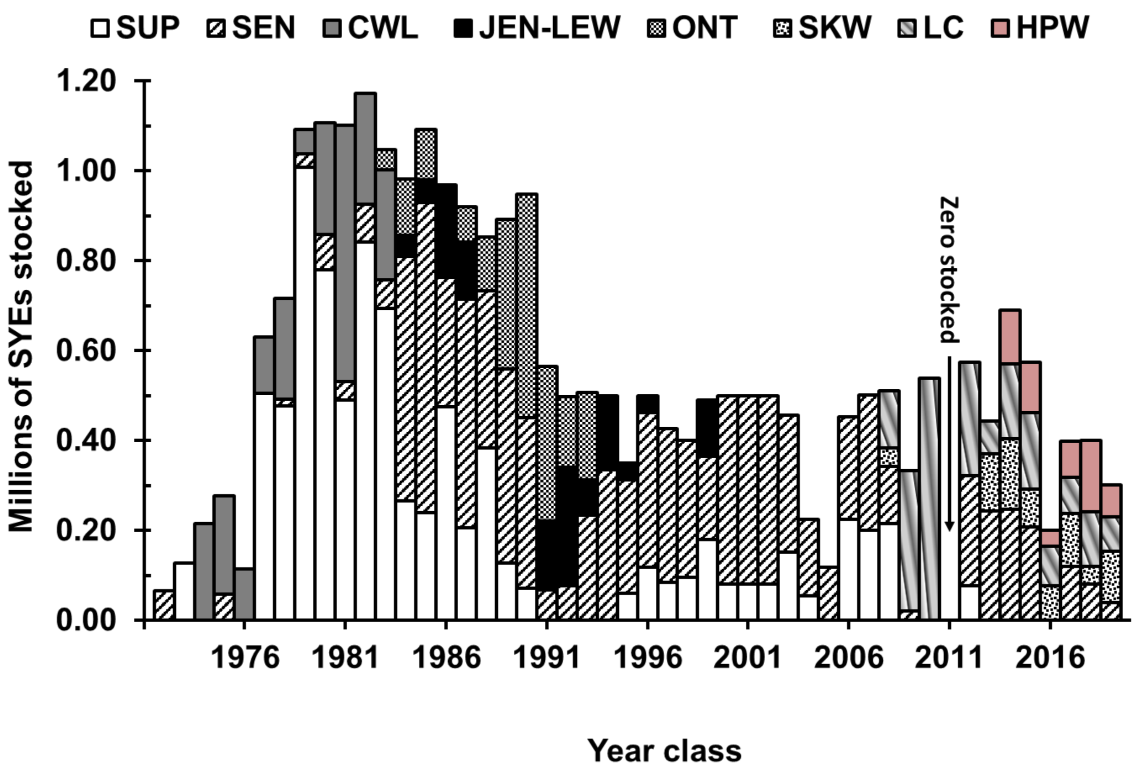

Figure 2. Total spring yearling equivalents (SYE) for lake trout strains (strain descriptions for ONT, JEN-LEW, CWL, SEN, LC, SUP, SKW, HPW appear in Appendix 1) stocked in U.S. waters of Lake Ontario for the 1972 – 2018 year-classes. For year-classes beginning in 2006, SUP refers to Lake Superior lean strains (SAW and STW) 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.

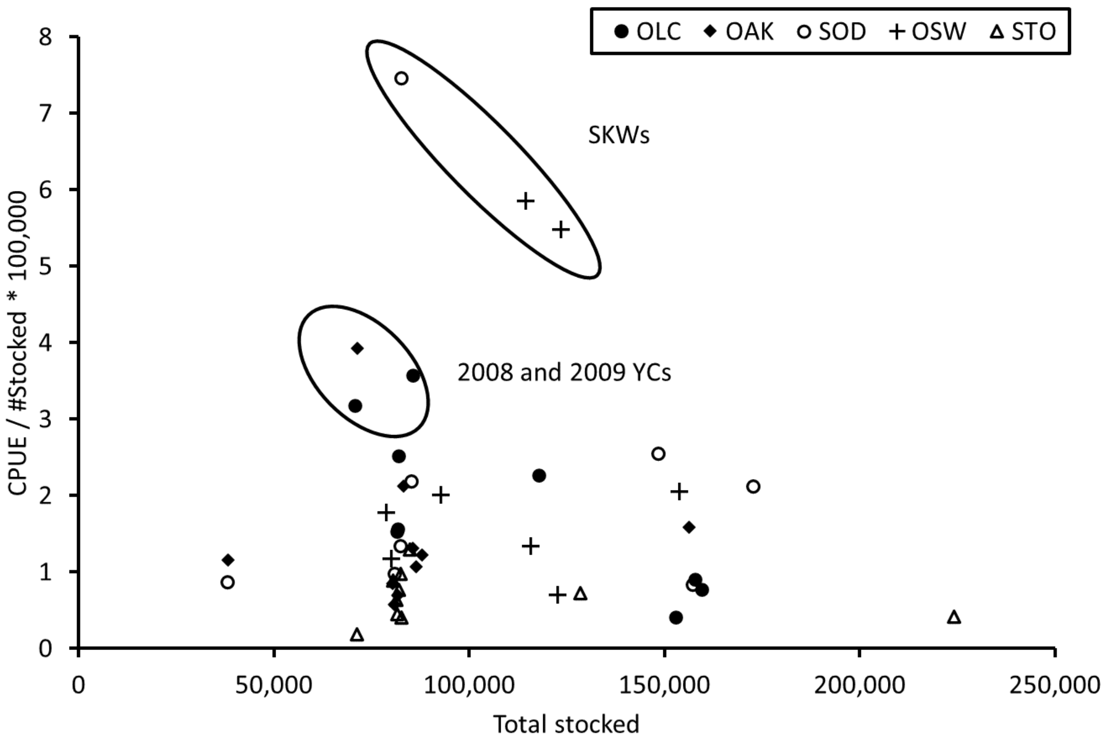

Figure 3. Pulse stocking survival index (year-class and stocking location specific, catch per unit effort (CPUE) of ages 3-6 lake trout corrected for number stocked from that year-class at that stocking location) of lake trout compared to total stocking level for each year-class. Stocking locations occurred along the New York shoreline proceeding from west to east with abbreviations indicating OLC = Olcott, OAK = Oak Orchard, SOD = Sodus Point, OSW = Oswego and STO = Stony Point. Data are presented by stocking site because stocking numbers varied by site and year. The absence of a trend indicates no effect of stocking numbers on survival. SKWs are the Klondike strain described in Appendix 1.

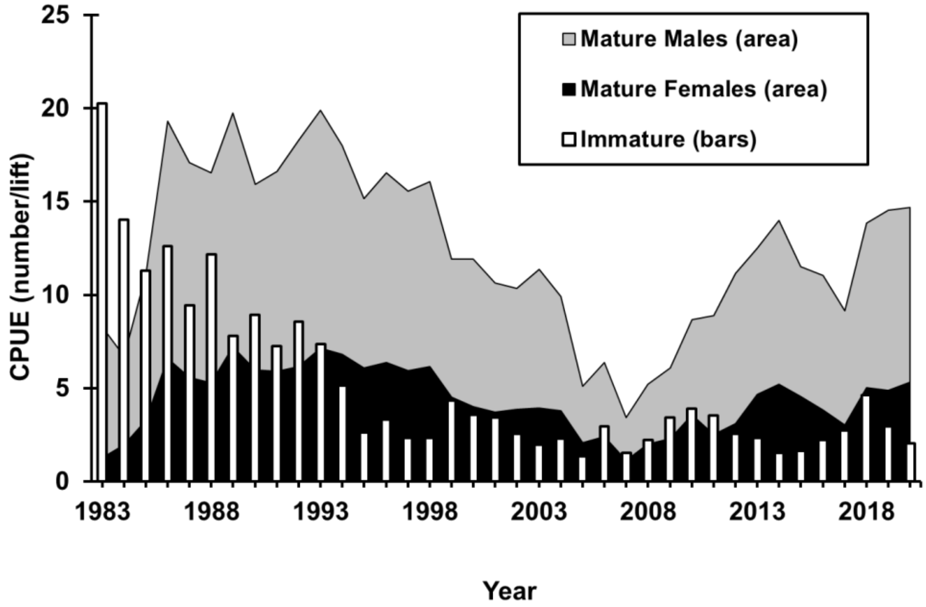

Figure 4. Abundance of mature (generally males ≥ age 5 and females ≥ age 6) and immature (sexes combined) lake trout calculated from catches made with gill nets set in U.S. waters of Lake Ontario, during September 1983-2020. CPUE (number/lift) was calculated based on four strata representing net position 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.

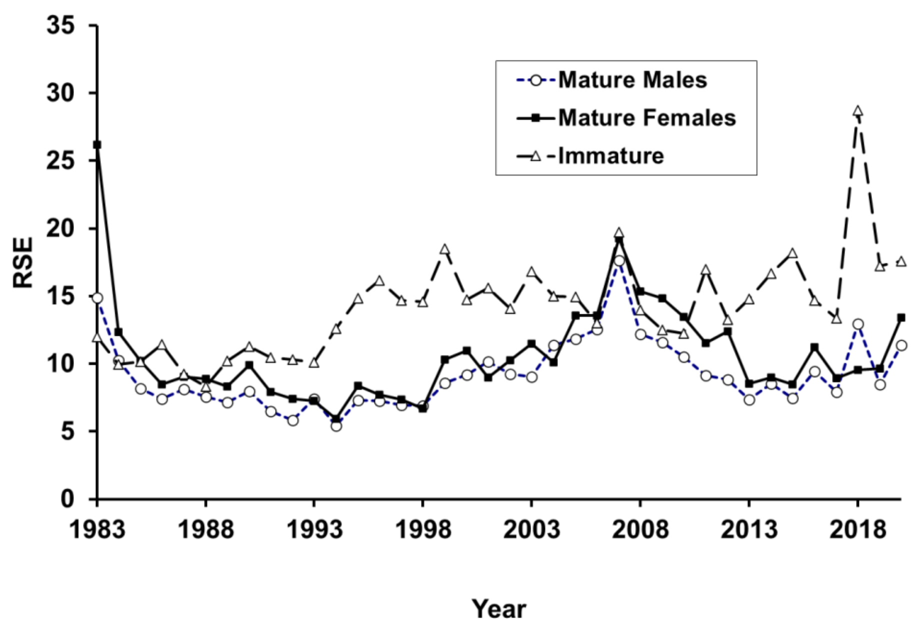

Figure 5. Relative standard error (RSE = {SE / Mean}*100) of the annual CPUE for mature males, mature females and immature (sexes combined) lake trout caught with gill nets set in U.S. waters of Lake Ontario, during September 1983-2020. RSE increases after 1993 are in part due a reduction in the number 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.

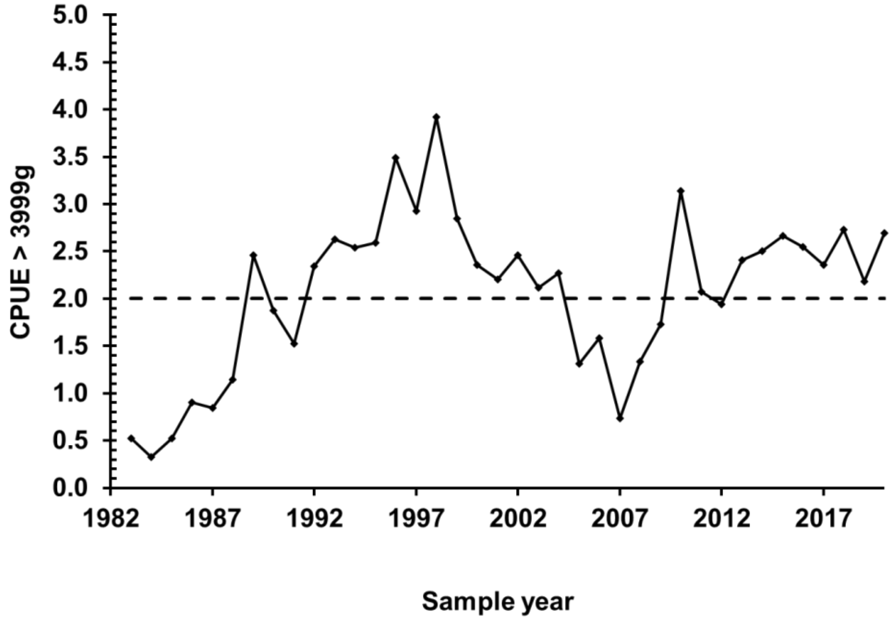

Figure 6. Abundance of mature female lake trout ≥ 4000 g calculated from catches made with gill nets set in U.S. waters of Lake Ontario, during September 1983-2020. The dashed line represents the target CPUE from Schneider et al. (1997) and Lantry et al. (2014).

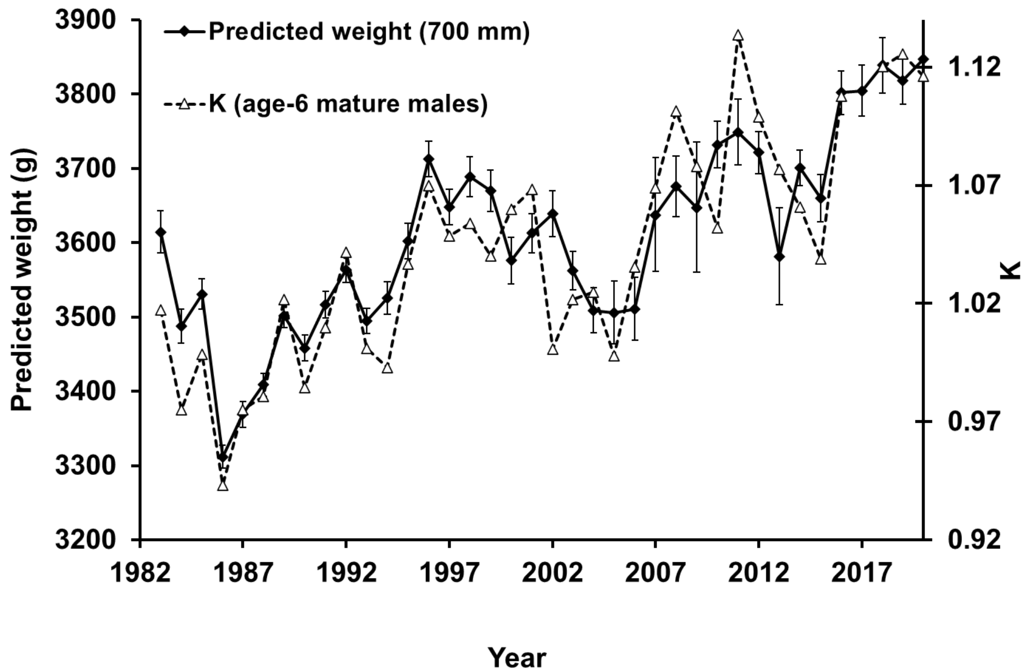

Figure 7. Lake Ontario lake trout condition (K) for age-6 mature males and predicted weight at 700-mm (27.6 in) TL from weight-length regressions calculated from all fish collected during each annual gill net survey, September 1983–2020. There were no fish stocked from the 2011 year-class in 2012 so age-6 K was not available in 2017. Error bars represent the regression confidence limits for each annual value.

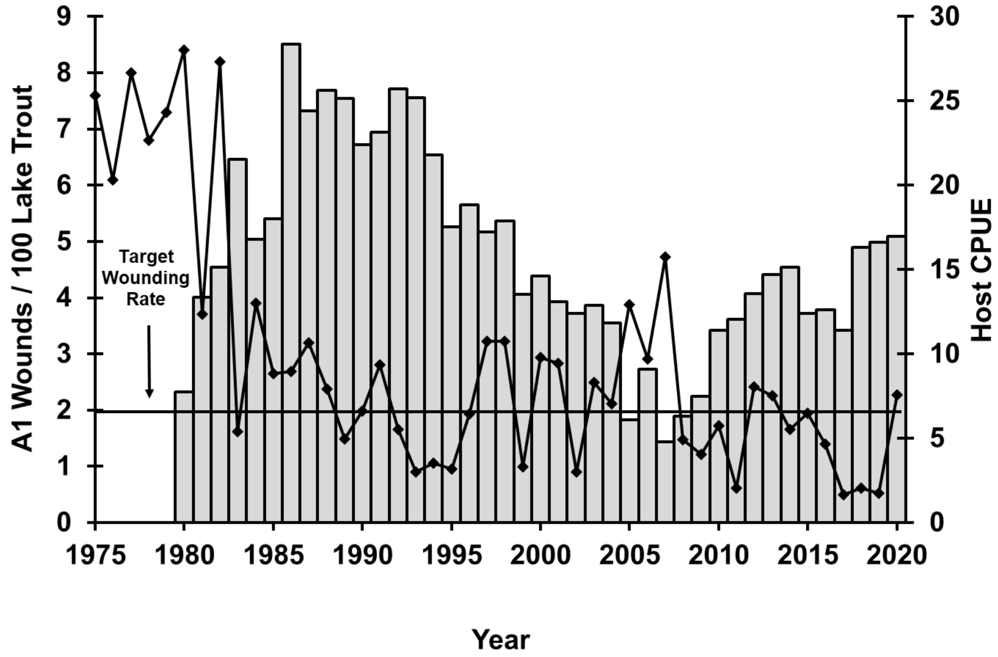

Figure 8. Wounding rates (A1 wounds per 100 lake trout, line) inflicted by sea lamprey on lake trout ≥ 433 mm (17.1 in) TL and the gill net CPUE of lake trout hosts (≥ 433 mm TL, bars) collected from Lake Ontario in fall, 1975-2020.

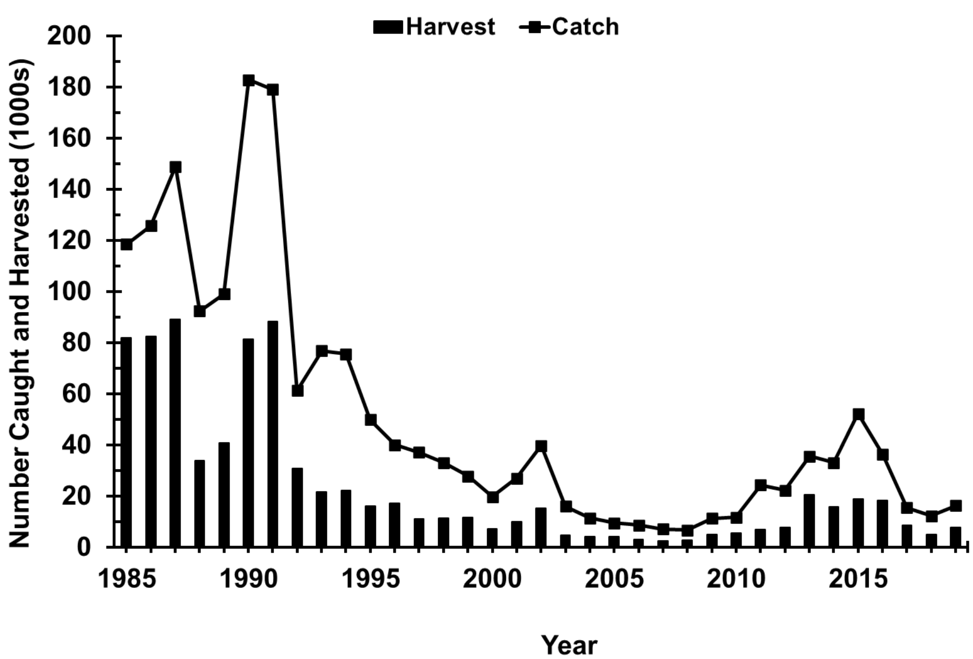

Figure 9. Estimated numbers of lake trout caught and harvested by boat anglers from U.S. waters of Lake Ontario, during April 15 – September 30, 1985-2019 (Connerton et al. 2020). Beginning with the 2012 report, all values have been reported reflecting a 5.5-month sampling interval. Prior reports were based on a 6-month sampling interval (April 1 – September 30).

Table 1. Annual survival of various strains (strain descriptions appear in Appendix 1) of lake trout, sampled from U.S. waters of Lake Ontario, 1985-2020. 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) or because they only occurred before successful sea lamprey control was established (1974-1983 cohorts of CWL). Reduced survey effort contributed to missing values in 2020 for strains from the 2009 and 2010 year-classes; and there were no lake trout stocked in 2012 from what would have been the 2011 year-class.

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	7-10	-	-	-	-	-	-	-	0.78		0.78
2011	No fish	-	-	-	-	-	-	-	-	-	-

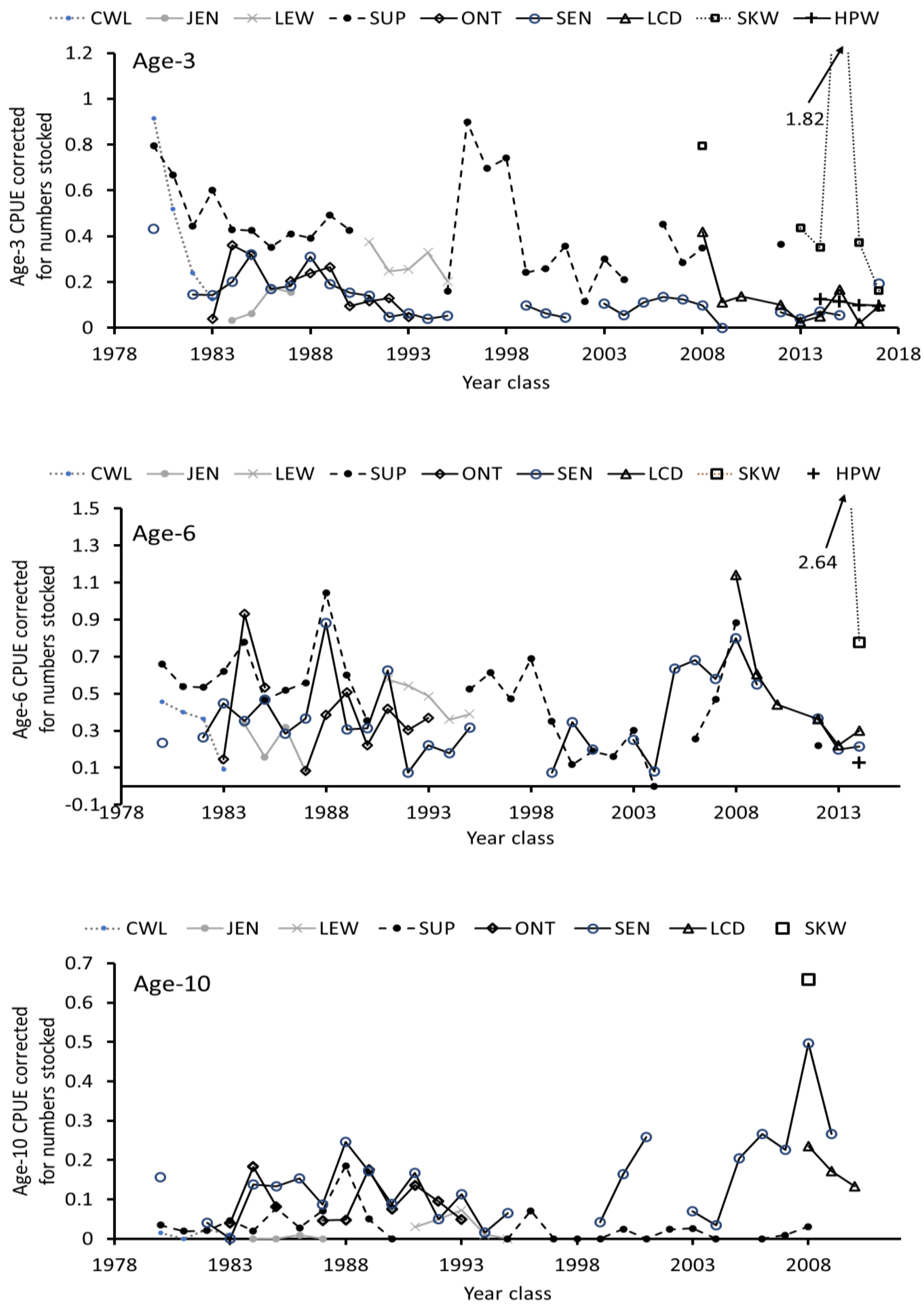

Figure 10. Strain performance indexed by the strain-specific CPUE of ages-3, -6 and -10 lake trout by year-class and corrected for the number stocked. Each panel represents strain performance at a specific age (ages 3, 6 and 10). Some strains are absent from some years due to stocking history. Year-classes from some strains (especially SKW and HPW) had not reached age-6 (2014-2020 YCs) or age-10 (2012-2020 YCs) by 2020 and do not appear in the age-6 or age-10 panels. Strain descriptions for ONT, JEN-LEW, CWL, SEN, LC, SUP, SKW, HPW appear in Appendix 1.

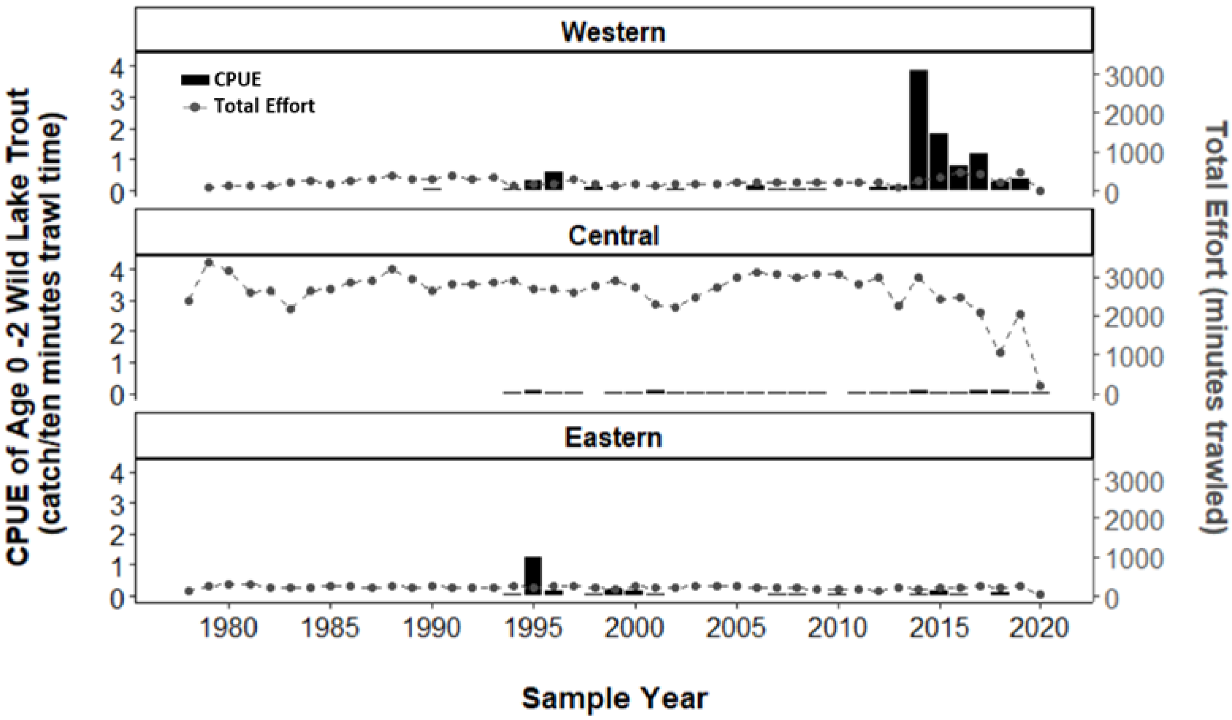

Figure 11. CPUE of naturally produced (wild) age-0 to age-2 lake trout captured during annual spring, summer and fall bottom trawl surveys in Lake Ontario conducted by NYSDEC and USGS, 1990-2020 (only one fall bottom trawl survey was conducted in 2020 due to COVID). Panels represent regional groupings of bottom trawl locations: two sites near the mouth of the Niagara River (Western), eleven sites located between Olcott and Southwick (Central), and two sites in the eastern outlet basin (Eastern).

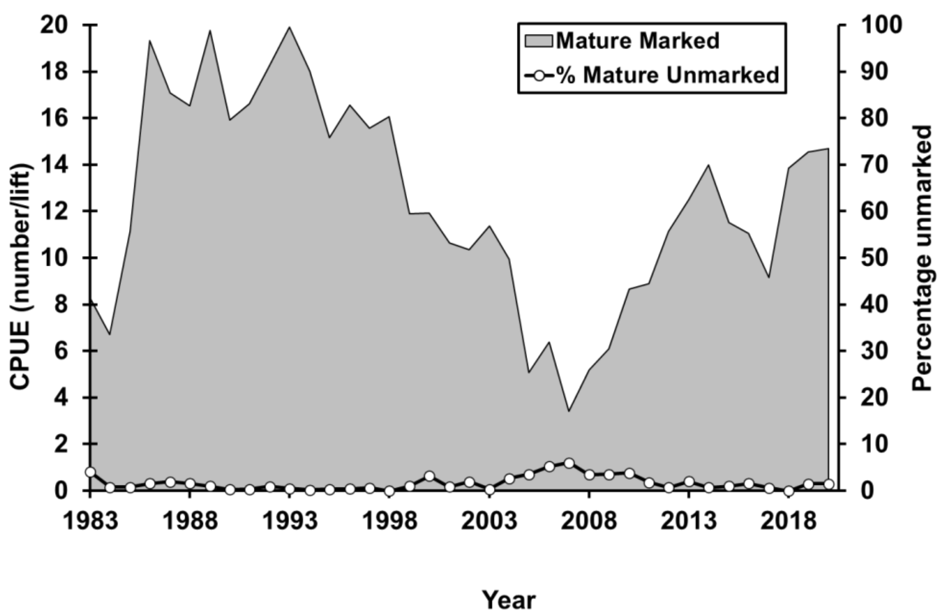

Figure 12. Percentage of unmarked (no clips or tags) sexually mature lake trout captured during annual September gill net surveys in Lake Ontario conducted by NYSDEC and USGS, 1983-2020 (black line with white markers). The percentage of unmarked fish is presented against the backdrop of the CPUE of all mature lake trout caught per year (gray shaded area) and for the period from 1993-2020 represents on average 1.75% of the CPUE (range 0 to 5.98%).