2019 Lake Michigan Lake Trout Working Group Report [1,2]

This report provides a review on the progression of lake trout (*Salvelinus namaycush*) rehabilitation towards meeting the Salmonine Fish Community Objectives (FCOs) for Lake Michigan (Eshenroder et. al. 1995) and the interim goal and evaluation objectives articulated in *A Fisheries Management Implementation Strategy for the Rehabilitation of Lake Trout in Lake Michigan* (hereafter the "*Strategy*"; Dexter et al. 2011).

The Lake Michigan Lake Trout Working Group (LMLTWG)

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[1] The U. S. Geological Survey (USGS) data associated with this report have not received final approval by the agency 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 2019 and make those publicly available. Please direct questions to our Information Technology Specialist, Scott Nelson, at snelson@usgs.gov. For data up to 2018, please see the following cited data release: U.S. Geological Survey, Great Lakes Science Center, 2019, Great Lakes Research Vessel Operations 1958-2018. (ver. 3.0, April 2019): U.S. Geological Survey data release, https://doi.org/10.5066/F75M63X0.

[2] All USGS Great Lakes Science Center 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).

Methods: We drew from several data sources in preparing this report. Lake trout stocking data were taken from the Great Lakes Fishery Commission's online stocking database (http://www.glfc.org/fishstocking/). Harvest information was supplied by the Lake Michigan extraction database (Redman 2020). More detailed reporting of harvest and mortality within 1836 Treaty waters of Lake Michigan was based on stock assessment models for northern Lake Michigan management units (Modeling Subcommittee, Technical Fisheries Committee 2017). In addition, based on a new research initiative from the Quantitative Fisheries Center at Michigan State University, stock assessment models have recently become available for western Lake Michigan management units, one of which includes roughly half of the Southern Refuge. Trends in spring catch-per-unit-effort (CPUE) were based on the spring (April – June) lakewide assessment plan (LWAP) gillnet survey that employs 2.5-6.0" graded nylon multifilament mesh at nine nearshore and two offshore locations distributed throughout the lake (Schneeberger et al. 1998; Map 1). We also included spring surveys performed under the modified LWAP design, 1.5-6.0" mesh, used by some agencies, as well as spring surveys following the Fishery Independent Whitefish Survey (FIWS) protocols for the 1836 Treaty waters that employ 2.0-6.0" graded multifilament mesh in locations between Saugatuck and Manistique, Michigan. In recent years, several agencies have replaced some or all of their traditional LWAP multifilament nylon nets with monofilament nylon nets; at this time, the CPUE trends are reported separately for multifilament and monofilament survey data. Fall adult CPUE was determined from the 4.5-6.0" graded multifilament mesh spawner gillnet surveys completed at selected reefs during October-November. The database containing all the gillnet assessment survey data is maintained by the U.S. Fish and Wildlife Service (USFWS) in New Franken, Wisconsin. Data sources for wild lake trout recoveries included spring and fall gillnet assessment survey samples and USFWS Great Lakes Fish Tag and Recovery Lab (New Franken, Wisconsin) samples from the recreational sport fishery. In general, these surveys sampled several hundred lake trout annually in most management units, but we only report data for management units with sample sizes ≥ 30 lake trout recoveries. Prior to 2011, roughly 3% of stocked lake trout were released without a fin clip (Hanson et al. 2013), but since 2011 hatchery lake trout have been clipped and tagged in automated trailers and fewer than 1% of lake trout are stocked without a fin clip (Webster et al. 2020). We conservatively infer natural reproduction when the percentage of unclipped fish exceeds 3% of all lake trout recoveries.

EVALUATION OF ATTAINMENT OF FISH COMMUNITY OBJECTIVES

Salmonine (Salmon and Trout) Objectives for Lake Michigan (Eshenroder et al. 1995):

> *Establish a diverse Salmonine community capable of sustaining an annual harvest of 2.7 to 6.8 million Kg, of which 20-25% is lake trout.*
>
> *Establish a self-sustaining lake trout population.*

Harvest: In 2019, salmon and trout (SAT) harvest was 2.49 million kg and for the fifth consecutive year was below the 2.7 million kg minimum threshold of the FCO harvest objective (Figure 1). Lake trout harvest in 2019 was 0.77 million kg. The lake trout harvest objective (0.54-1.70 million kg) was previously met during 1985-2001 and more recently during 2013-2019 (Figure 1). Lake trout comprised 30.7% of the total salmonid harvest in 2019 and thus exceeded the FCO harvest objective of 20-25% (Figure 2), due mostly to a simultaneous decline in harvest of Chinook salmon (*Oncorhynchus tshawytscha*) and increase in harvest of lake trout.

Natural Reproduction: A total of 1,205 (21.0%) of the 5,726 lake trout examined for fin clips from 2019 gillnet assessments were unclipped and presumed to be wild. This overall percentage is skewed by higher survey effort in the MM3 statistical district where proportions of unclipped fish were below the 3% threshold necessary to infer natural reproduction. However, natural reproduction is evident throughout the other surveyed management units with many areas reporting substantive increases in the proportion of wild fish; jumps were most evident in Illinois and MM7 waters, with increases of 26.9% and 32.2%, respectively, over the previous year (Figure 3). Wild fish now account for 64% of assessment surveyed lake trout in Illinois, 33% in northern Wisconsin (WM3, WM4), and 37-44% in southern Michigan (MM7 and MM8). In MM4, MM5, MM6, and WM5, the proportions of wild fish increased between 2018 and 2019 but remained at modest levels (9-18%). An additional data source, recreationally caught fish that were examined by the Great Lakes Fish Tag and Recovery Lab, reported 442 (38.0%) of 1,163 lake trout examined were wild. Among these recreationally caught fish, wild fish accounted for 37-47% of lake trout in Illinois and Indiana waters, 29-37% in Wisconsin (WM4, WM5, and WM6), 34-56% in southern Michigan (MM6, MM7, and MM8), and 9% in northern Michigan (MM3).

The first evidence of sustained natural reproduction was reported in Illinois assessment survey data beginning in 2008 and over the last five years has spread northward to include all management units of Lake Michigan, though wild fish in MM3 were only detected in the recreational fishery. In past years, recreational fishery data generally provided an earlier indication that natural reproduction was spreading among adjacent management units compared with assessment survey data (Figure 3). This discrepancy was primarily caused by a difference in length distributions of fish between the two data sources: the recreational fishery was comprised of a higher proportion of small fish ($\leq$ 580 mm) that had yet to fully recruit to the assessment surveys. At this time, ages from wild lake trout caught in 2019 are only available from some of the assessment caught wild lake trout (n = 429); wild fish had a modal age of 4, a maximum age of 17, and were represented by all consecutive age-classes between 1 to 14 years of age (Figure 4). Notably, the proportions of wild fish in assessment and recreational data sources are beginning to converge in several units (MM6, MM7, MM8, and WM4), as would be expected when wild recruitment is sustained across consecutive years.

EVALUATION OF ATTAINMENT OF INTERIM STOCKING TARGETS, MORTALITY TARGETS, AND IMPLEMENTATION STRATEGY EVALUATION OBJECTIVES

Fish Stocking: Stocking hatchery-reared fish to achieve rehabilitation is the primary tool of the *Strategy.* The maximum stocking target is 3.31 million yearlings and 550,000 fall fingerlings, or 3.53 million yearling equivalents where one fall fingerling = 0.4 yearling equivalents (Elrod et al. 1988), however the Lake Michigan Committee adopted an interim stocking target not to exceed 2.74 million yearling equivalents when the *Strategy* was approved. In 2017, the Lake Michigan Committee reduced this interim target to 2.54 million though actual stocking within $\pm$10% of the interim target is allowed. Over 80% of the fish are stocked in first priority areas of the Northern and Southern Refuge reef complexes with rehabilitation as the primary objective. The remaining fish are stocked in second priority areas to support local fishing opportunities in addition to rehabilitation. The stocking reduction in 2017 and thereafter was achieved through reduced stocking of nearshore secondary priority areas in southern Lake Michigan.

Since 2008, lake trout have been stocked according to the *Strategy* and this has substantially increased the numbers of fish stocked in high priority rehabilitation areas (Figure 5). In 2019, 2.44 million lake trout yearlings were stocked by USFWS hatcheries. Lean strains, consisting of Lewis Lake, Seneca Lake, and Huron Parry Sound, represented 90% of all lake trout stocked. Klondike Reef strain, a humper morphotype from Lake Superior, was also stocked (n = 120,248) at Sheboygan Reef within the Southern Refuge following a *Strategy* recommendation to introduce a deep-water morphotype to occupy deep-water habitats. Priority rehabilitation areas (Charlevoix, East and West

Beaver reef complexes in or near the Northern Refuge and the Southern Refuge reef complex including Julian's Reef) received 83% of the lake trout. Over 97% of USFWS lake trout were stocked in offshore waters using the M/V *Spencer F. Baird*.

<u>Lake Trout Mortality:</u> Detailed estimates of mortality experienced by lake trout stocks come from stock assessments conducted within the 1836 Treaty waters using survey, sport, and commercial fishery data. Total mortality is partitioned into natural mortality, sea lamprey (*Petromyzon marinus*) induced mortality, and fishing (both sport and commercial) mortality. The *Strategy* requires management agencies to "adjust local harvest regulations if appropriate when mortality rates exceed target levels", and the target annual mortality rate has been set to 40-45% (Bronte et al. 2008; Dexter et. al. 2011).

At the time of writing this report (March 2020), year-specific mortality estimates generated from statistical catch at age (SCAA) models applied to the lake trout population in MM1/2/3 and the lake trout population in WI3/4/5 were available up to 2017. Nearly all of the Northern Refuge falls within the boundaries of MM1/2/3, whereas about half of the Southern Refuge is located within the boundaries of WI5 (Map 1). In northern Lake Michigan (MM1/2/3), total annual mortality in 2016 and 2017 was equal to 43% and 45%, respectively, and total annual mortality during 2015-2017 was considerably lower than that during 1998-2014 (Figure 6, upper panel; Modeling Subcommittee, Technical Fisheries Committee 2017). In the north, commercial fishing is the primary source of mortality. During the 2000s, there was an extended period of elevated sea lamprey mortality owing to additional recruitment of parasitic juveniles produced after sea lamprey spawners breached the dam on the Manistique River. In recent years, lamprey mortality has dropped precipitously after several years of intensive lampricide treatments on the Manistique River and other Lake Michigan tributaries (Figure 6, upper panel; Modeling Subcommittee, Technical Fisheries Committee 2017), and this decrease also coincided with a rapid increase in lake trout spawner abundance.

Annual mortality rates in the Southern Refuge priority area, as indexed by the SCAA estimates for the WI3/4/5 population, have been below 40% since 1999 (Figure 6, bottom panel). Prior to 2003, recreational fishing was the main source of lake trout mortality in WI3/4/5 during most years. Fishing mortality decreased following a reduction of recreational fishing effort beginning in 2003, and sea lamprey induced mortality exceeded fishing mortality in most years during 2003-2013. As in northern Lake Michigan, sea lamprey induced mortality in WI3/4/5 has also declined in recent years. Total annual mortality in WI3/4/5 in 2017 was equal to 14%, which is well below the target level of 40%.

<u>Evaluation Objective 1:</u> Increase the average catch-per-unit-effort (CPUE) to $\geq$25 lake trout per 1000 feet of graded mesh gill net (2.5-6.0 inch) over-night set lifted during spring assessments pursuant to the lakewide assessment in MM3, WM5, and at Julian's Reef by 2019.

In 2019, 107 multifilament gillnet lifts were completed lakewide to assess spring lake trout abundance. This included at least six lifts at most nearshore LWAP sites except that no surveys occurred at Manistique, Washington Island or Michigan City. LWAP effort in the Southern Refuge included six lifts each on Northeast Reef and East Reef. Within the Northern Refuge, a total of 18 lifts were made at Big Reef, Boulder Reef, and Trout Island Shoal. An additional 16 lifts were completed at first priority (stocked) reefs that lie outside of the Refuge (Charlevoix, Dahlia Shoal, and Ile aux Galets reefs); these data are reported under non-Refuge MM3 waters. In previous reports, data from these reefs outside of the Refuge were pooled with data from Refuge reefs under the category of the Northern Refuge reef complex. Beginning with this report, however, CPUE data for the Refuge reefs are presented separately from those data for non-Refuge reefs. About 37% of LWAP lifts stemmed from FIWS sampling that added additional effort to sites between Saugatuck and Grand Traverse Bay. Lastly, since 2014 some agencies have been conducting LWAP lifts with monofilament gill nets. In 2019, LWAP surveys included 59 additional lifts utilizing monofilament gill nets along the Michigan coastline.

For multifilament nylon gill nets, lifts at the Southern Refuge had a mean lake trout catch-per-unit-effort (CPUE) of 34.5 fish per 1,000' of gill net and met the spring evaluation objective of 25 fish per 1,000' of gill net (Figure 7), whereas the Northern Refuge fell short with a CPUE of 10 fish per 1,000'. However, nearby LWAP sites in northern Lake Michigan (Arcadia, Grand Traverse Bay, and non-Refuge MM3 waters) exhibited higher catch rates with CPUEs between 13 and 20 fish per 1,000'. At Waukegan, CPUE was also 10 fish per 1,000' and remains well below levels observed in the early 2000s. Mid-latitude LWAP sites (Saugatuck, Sheboygan, and Sturgeon Bay) all reported low CPUEs of 5 fish per 1,000'. For LWAP sites sampled with supplemental monofilament nylon nets, CPUE trends were similar to multifilament nylon net trends at Arcadia, Leland, and Saugatuck; however, monofilament nets generally caught more fish in Grand Traverse Bay but fewer in non-Refuge MM3 waters (Figure 7). Recent paired comparison studies have shown that overall, mean catch of lake trout in multifilament nets is nearly equal to that in monofilament nets. In terms of wild lake trout, 2019 spring survey CPUEs were low (0.2-2.5 fish per 1000') throughout the lake.

<u>Evaluation Objective 2:</u> **Increase the abundance of adults to a minimum catch-per-unit-effort of 50 fish per 1000 feet of graded mesh gill net (4.5-6.0 inch) fished on spawning reefs in MM3, WM5, and at Julian's Reef by 2019.**

In 2019, 42 spawner survey lifts from nine regions were performed during October-November (Figure 8). Spawner CPUE in the Northern Refuge has been increasing dramatically since 2015; in 2019 CPUE was 74.2 fish per 1,000' and for the third straight year met the fall evaluation objective of 50 fish per 1,000' of gill net. This dramatic increase was in accord with the prediction by Madenjian and Desorcie (2010), who forecasted a disproportionately high increase in spawner CPUE with a doubling of the lake trout stocking rate in the Northern Refuge. Spawners at Northern Refuge reefs were of hatchery origin, however in the Southern Refuge wild fish supported high spawner densities (CPUE of wild fish = 43.8 fish per 1,000' versus the total spawner CPUE of 128.1 fish per 1,000'). At Illinois Reefs, lake trout CPUE was 108.1 fish per 1,000' with 70% of spawners being wild fish. High spawner densities (CPUE > 50 fish per 1,000') were also observed at Arcadia, Grand Traverse Bay, Little Traverse Bay and MM3 non-refuge waters, and Sturgeon Bay; however, of these only Sturgeon Bay reported relatively high (19.1 fish per 1,000') CPUE of wild spawners.

<u>Evaluation Objective 3:</u> **Significant progress should be achieved towards attaining spawning populations that are at least 25% females and contain 10 or more age groups older than age-7 in first priority areas stocked prior to 2007. These milestones should be achieved by 2032 in areas stocked after 2008.**

<u>Percent Female and Age Composition:</u> Since 1998, the percentage of females captured during the fall spawner surveys has generally exceeded the 25% benchmark at most sites, on an overall average basis (Figure 9). However, at the Northern Refuge, Southern Refuge, Little Traverse Bay and non-refuge MM3, and Sturgeon Bay sites, the 25% benchmark was exceeded in approximately half of the years. In 2019, sex ratios of spawners were such that at least 25% of the fish were females at all four of these sites including both the Northern and Southern Refuges (Figure 9). In MM3, the spawner age distribution reflects a relatively young population with a modal age of eight years and

few fish older than 11 years (Figure 10). Generally, spawners in southern populations (MM6 data used as a surrogate for the Southern Refuge) are older; however, the MM6 spawner surveys in 2019 were unusual as the modal age was six years and fish in the age 14+ group were sparse. Additional age data from Southern Refuge spawn surveys, which are presently not aged, are needed to address this evaluation objective in the southern priority area.

<u>Evaluation Objective 4:</u> Detect a minimum density of 500 viable eggs/m^2 (eggs with thiamine concentrations of >4 nmol/g) in previously stocked first priority areas. This milestone should be achieved by 2025 in newly stocked areas.

<u>Egg Deposition:</u> Egg deposition rates have remained below target densities at four sites sampled in northern Lake Michigan during 2000-2019 (Figure 11). In 2019, three sites were evaluated, and egg deposition was less than 30 eggs/m^2. Estimates of egg deposition at these sites have been below the target of 500 eggs/m^2 throughout the time series.

<u>Egg Thiamine Concentration:</u> Over the time series, mean egg thiamine concentrations have generally trended upwards at all spawning survey locations outside of southwestern Lake Michigan (Figure 12). In 2018, Waukegan and Milwaukee spawn survey eggs generally contained thiamine levels near the 4 nmol/g threshold; levels below this are correlated with an elevated risk of egg and larval mortality.

<u>Conclusions</u>: Since 2013, lake trout harvest from Lake Michigan has partly met the specified Fish Community Objectives, as lake trout annual harvest has exceeded 0.54 million kg. The majority of lake trout harvest has been from northern Lake Michigan. Within the last few years, lake trout annual mortality in MM1/2/3 has declined toward the 40% target level due to recent reductions in lamprey induced mortality and regulation of fishing mortality through Consent Decree oversight, in conjunction with the near tripling of the stocking rate in northern Lake Michigan beginning around 2009 (Figure 5). The Consent Decree is an agreement that governs allocation, management, and regulation of State and Tribal fisheries in the 1836 Treaty waters of the Great Lakes (https://www.fws.gov/midwest/fisheries/library/post-usvmi.pdf). Owing to elevated stocking rates and increased lake trout survival, northern populations are currently building. However, northern populations remain below spring abundance targets, though these populations have recently been meeting the fall abundance metrics. These spawning populations are relatively young. Further, the proportion of wild fish in MM3 recovered from assessment surveys is indistinguishable from the 3% fin-clipping error rate. Therefore, initial progress toward lake trout rehabilitation in this northern priority area is recently evident but continued progress towards population objectives must be demonstrated to achieve recovery. In the Southern Refuge and at Julian's Reef, the population objectives have been achieved more consistently compared with northern populations. Lake trout in these Priority 1 areas are characterized by high spawner densities, an increasing trend in the proportion of wild fish, and mortality rates in proximate areas below 40%.

Detectable and sustained natural reproduction in southern and western Lake Michigan has occurred since roughly 2005 (Hanson et al. 2013; Patterson et al. 2016), and there is now evidence that natural reproduction is occurring throughout the Lake Michigan basin, albeit with a decreasing gradient of intensity from southern to northern waters. In 2019, spawning surveys at reefs in Illinois and the Southern Refuge reported CPUEs of 75.6 and 43.6 wild lake trout per 1,000' net, respectively. In contrast, spring LWAP CPUEs indicate wild fish abundance is low (CPUE < 2.5) across all management units. Reasons for this discrepancy in trends of wild fish relative abundance between the spring and fall assessment data remain unclear.

The initial onset of natural reproduction in Lake Michigan coincided with reduced alewife (*Alosa pseudoharengus*) abundance that has remained low since the mid-2000s (Madenjian et al. 2018). Reduced densities of alewives may facilitate natural reproduction by lake trout through decreased potential for alewife predation on lake trout larvae (Krueger et al. 1995). Continued declines in alewife densities since 2004 were also weakly correlated with an increase in mean thiamine content within lake trout eggs (Riley et al. 2011). Thiamine deficiency in wild lake trout fry may be mitigated by the fry beginning to feed on thiamine-rich zooplankton (Ladago et al. 2016).

In summary, widespread recruitment of wild fish is now occurring in Lake Michigan. Evaluation objectives for spawner abundance, percent spawning females, target mortality, and thiamine egg concentrations (in most years) have generally been achieved. Recruitment of wild fish is well established in the first priority area of the Southern Refuge reef complex but is just beginning within the Northern Refuge reef complex. Outside of the first priority areas, lake trout generally exhibit low (<25) CPUEs during spring assessments and high (>50) CPUEs in the fall spawning season. We conclude that lake trout populations are proceeding towards recovery and that adherence to the implementation strategy objectives, which are appropriate management tools to measure progress toward lake trout rehabilitation in Lake Michigan, should help ensure continued recovery.

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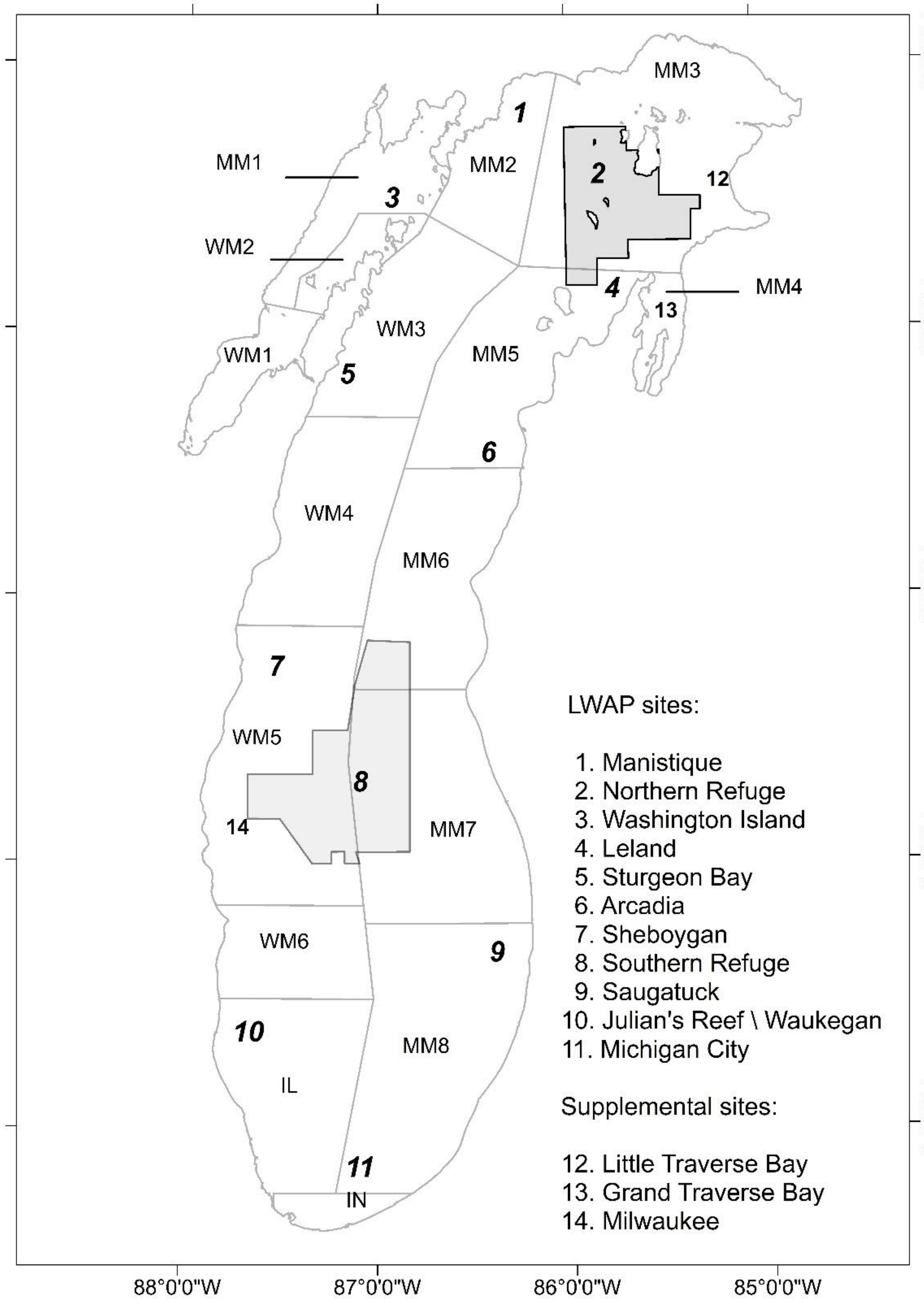
Data Reporting Stations for Spring and Fall Graded Mesh Gillnet Surveys



Map 1. Reporting of spring and fall graded mesh gillnet data has been aggregated into the 11 lakewide assessment plan (LWAP) sites and 3 supplemental sites. Generally, each reported lift is within 18 km of the site numerical label. Statistical district boundaries are outlined, and shading is used to outline the Northern and Southern Refuges of Lake Michigan.

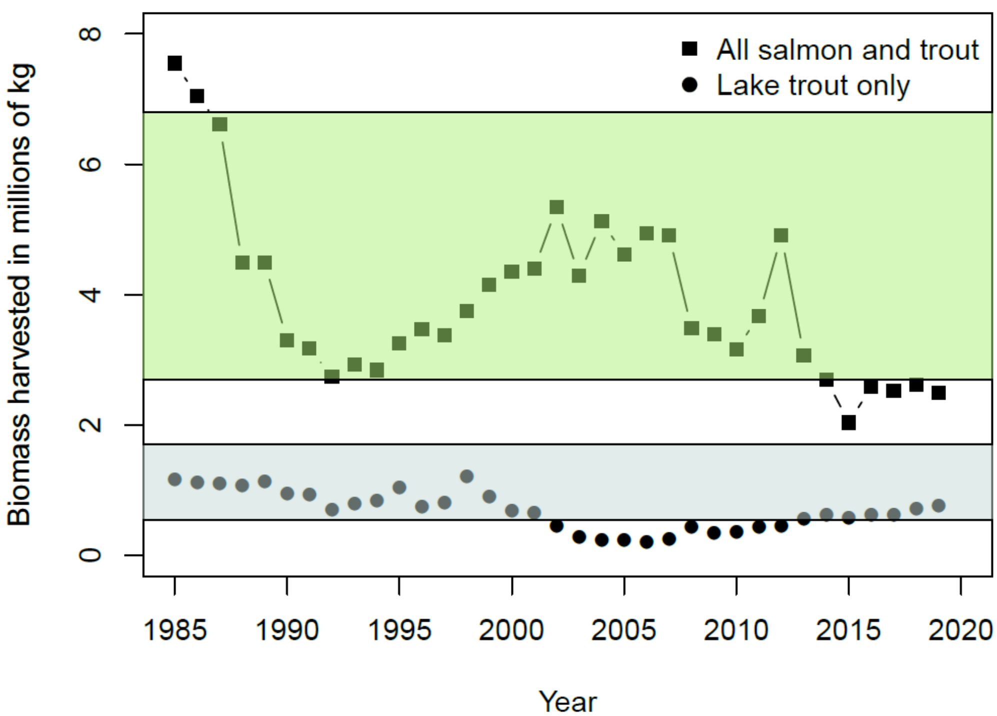


Figure 1: Lake Michigan total harvest (1985-2019) of lake trout and all species of salmon and trout (SAT); green-shading depicts the range of SAT harvest specified in the Fish Community Objectives while blue-shading depicts the 20-25% range of SAT harvest reserved for lake trout.

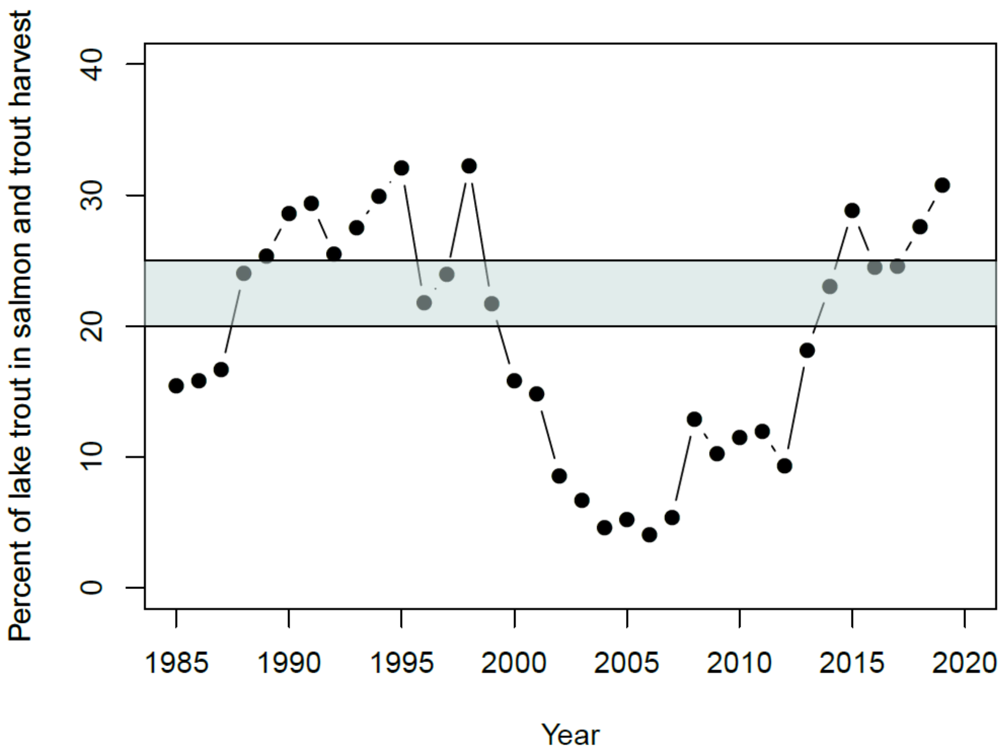


Figure 2: The percentage of all salmon and trout harvest in Lake Michigan comprised of lake trout; blue shading represents the 20-25% range specified in the Fish Community Objectives.

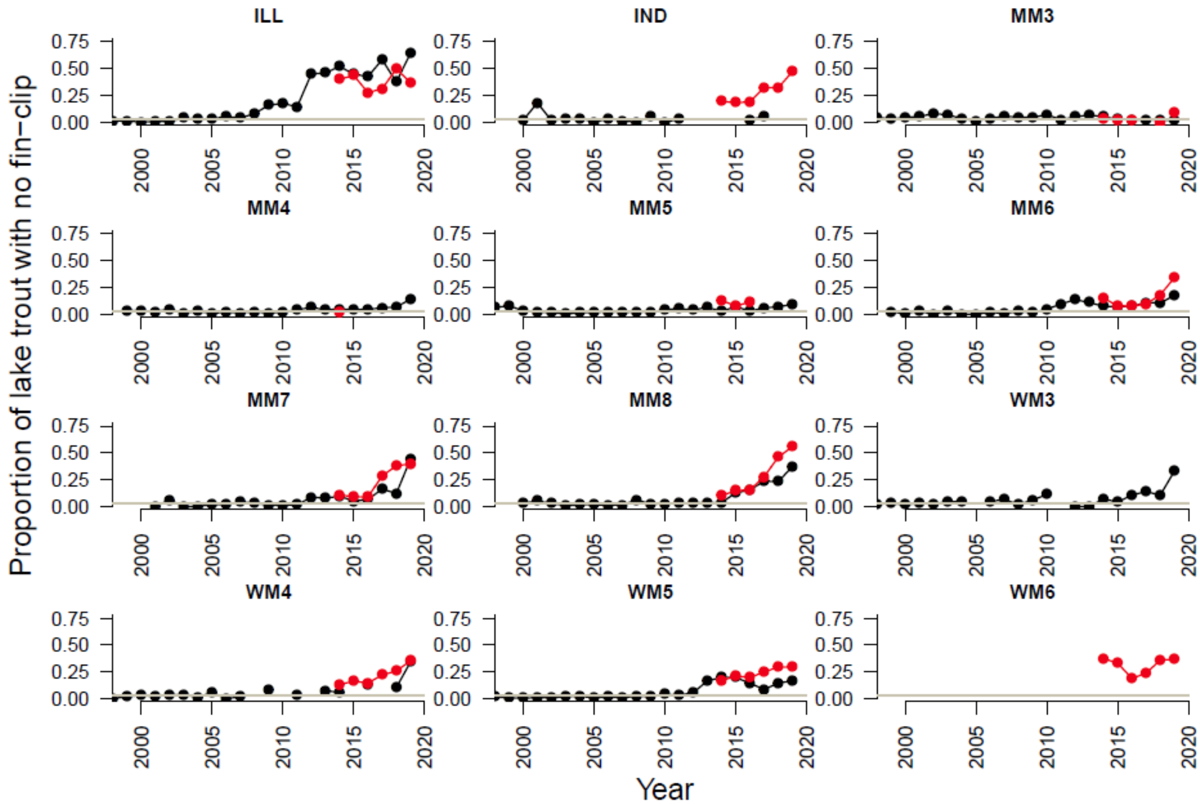


Figure 3: The proportion of wild (unclipped) lake trout captured in Lake Michigan assessment surveys within each statistical district (black lines). Red lines show the proportions of wild lake trout examined from the Great Lakes Fish Tag and Recovery Lab sampling between 2014 and 2019. Data points are only included when at least 30 lake trout per year were examined. The gray line represents 3% marking error, i.e. hatchery origin fish that were stocked with no fin clip.

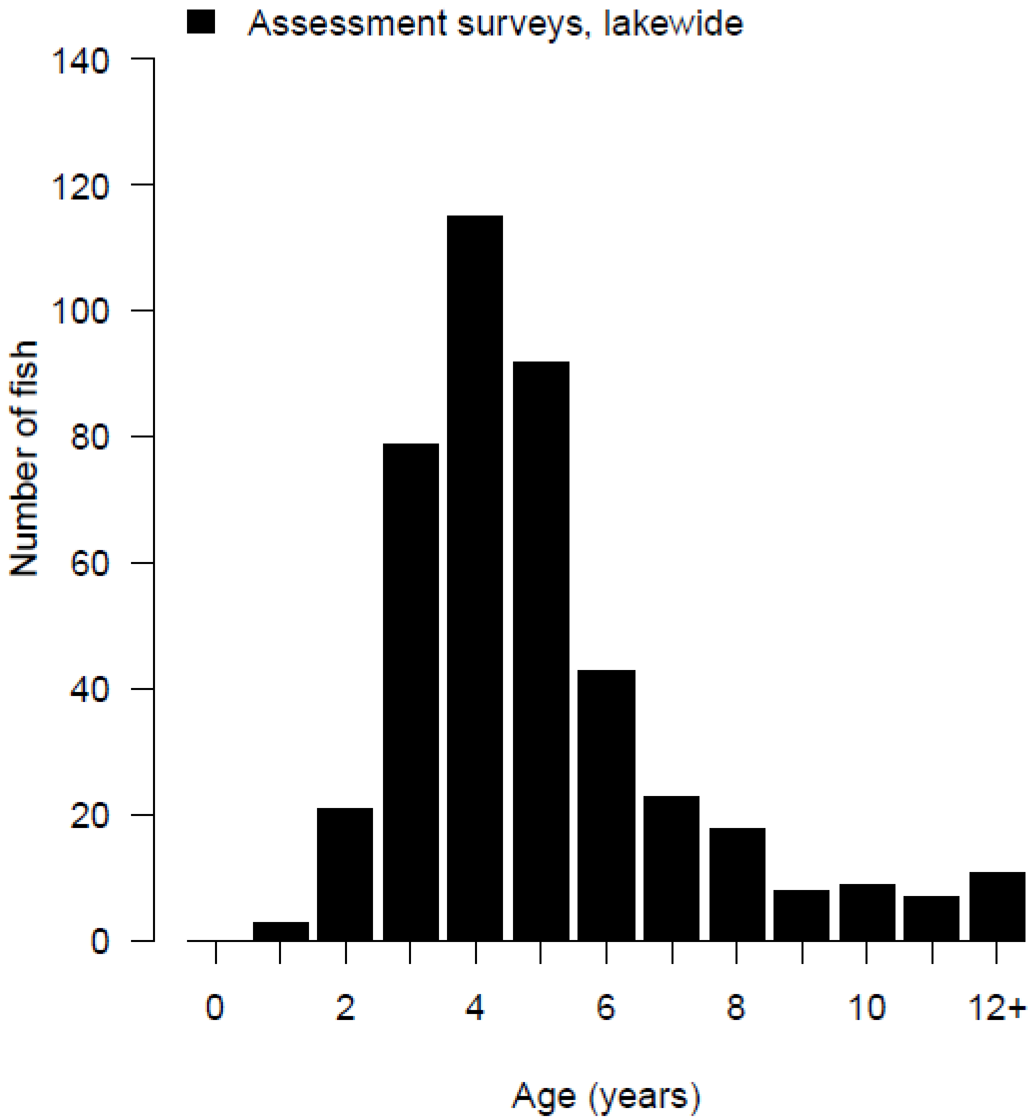


Figure 4: Wild lake trout age structure determined from Lake Michigan assessment surveys in 2019 (n = 429). Ages were determined for 36% of the wild fish caught in the assessment surveys.

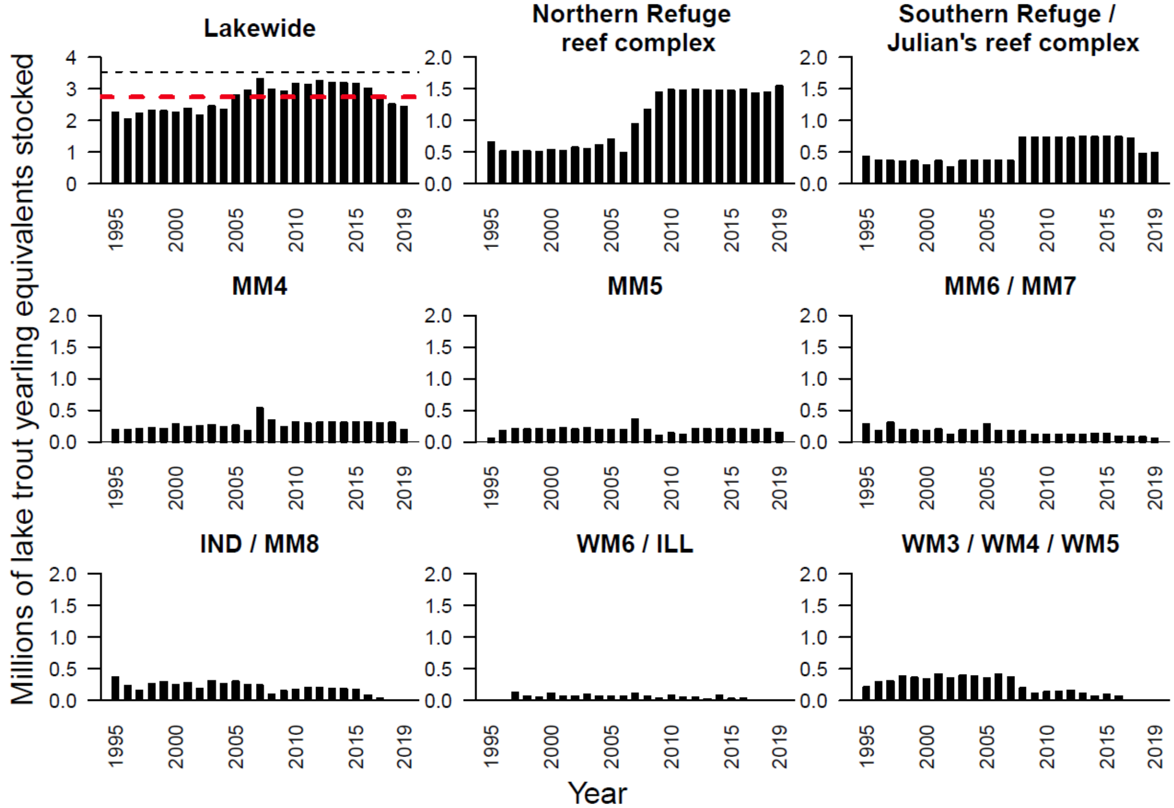
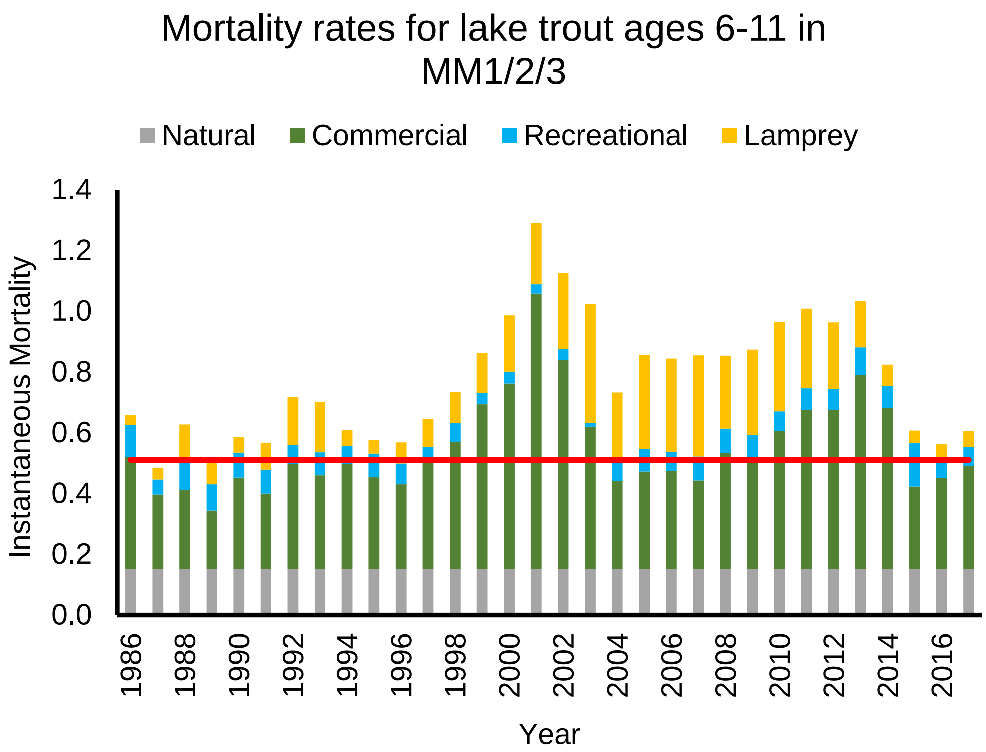


Figure 5: Number of lake trout (yearling equivalents) stocked in Lake Michigan by region, 1995-2019. In the "lakewide" panel, the black dashed line represents the 3.53 million maximum stocking target prescribed in the Strategy while the red dashed line represents the 2.74 million interim target that was reduced to 2.54 million in 2017 by the Lake Michigan Committee.



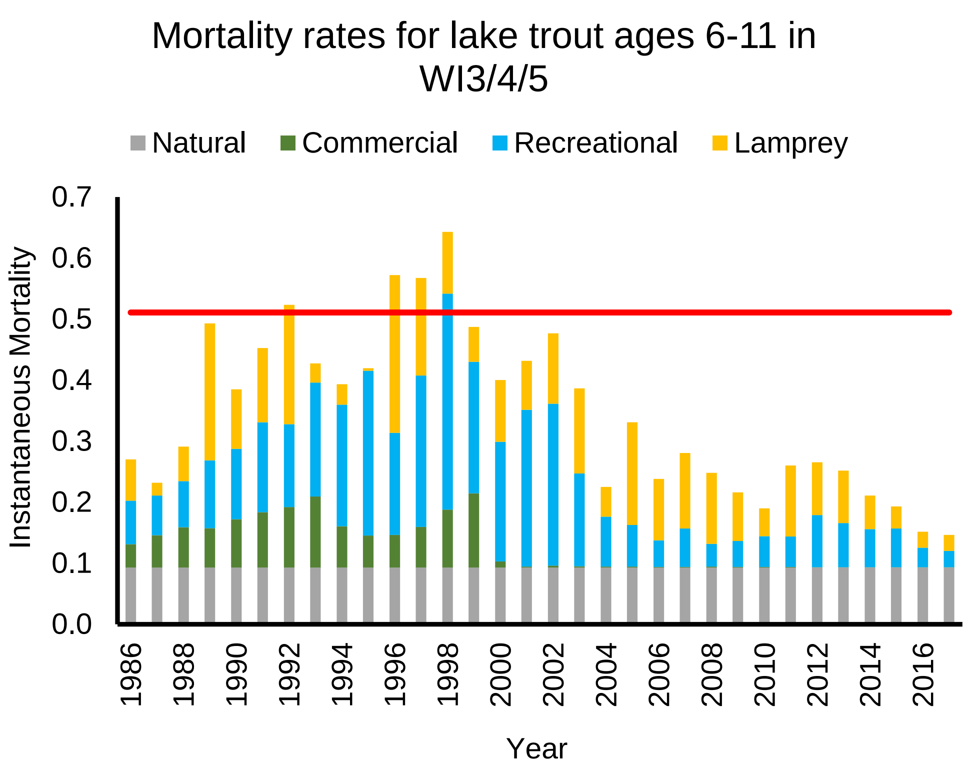


Figure 6: Instantaneous mortality rates for lake trout ages 6-11 in northern Lake Michigan (MM1/2/3) and in WI3/4/5 (WI5 contains roughly half of the Southern Refuge). The red line represents an instantaneous mortality rate of 0.51 that is equivalent to a 40% annual mortality rate.

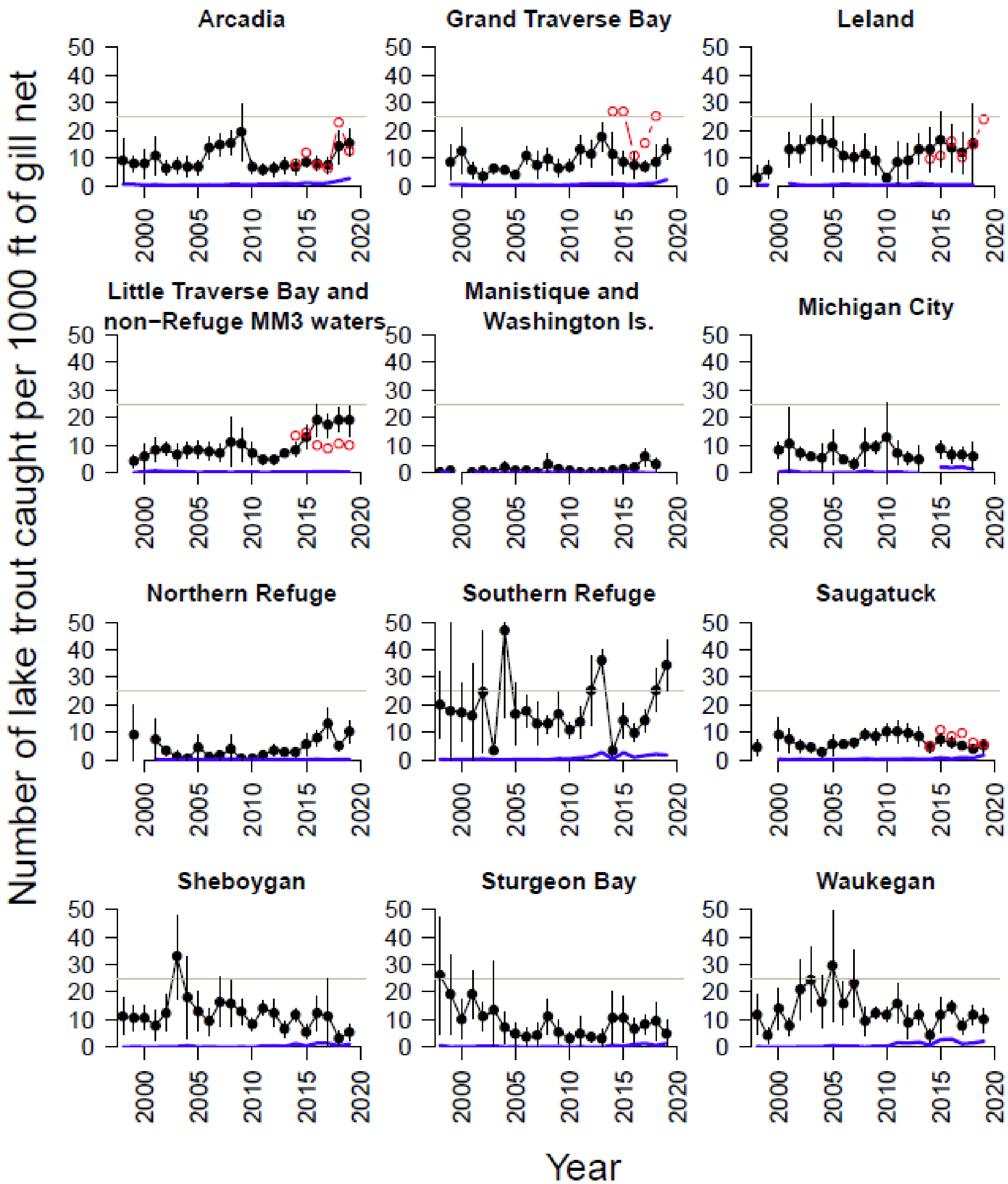


Figure 7: Time series of spring survey lake trout catch per effort (mean number of fish/1000 ft of graded mesh gill net) in Lake Michigan for the 11 LWAP sites plus 2 supplemental sites with comparable data (Grand Traverse Bay, Little Traverse Bay including non-Refuge MM3 waters). Vertical bars represent $\pm$ 2 SE and the horizontal gray line shows the spring CPUE benchmark of 25 fish per 1000'. Black points represent the LWAP multifilament data, while red points represent the recent LWAP monofilament data. The blue line represents CPUE of wild lake trout.

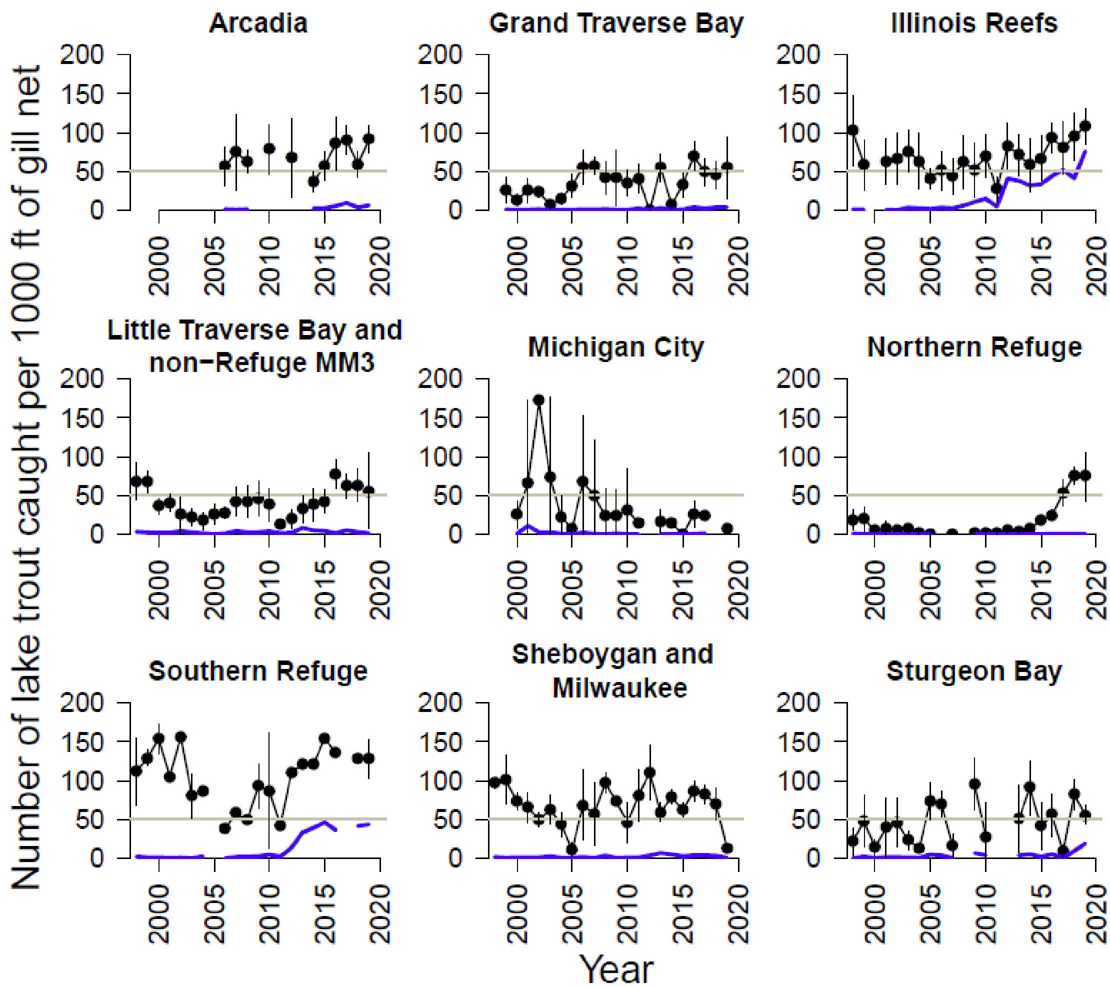


Figure 8: Time series of fall lake trout spawner survey catch per effort (mean number of fish/1000 ft of graded mesh multifilament gill net) in Lake Michigan for reefs within or near the spring LWAP stations. Vertical bars represent ± 2 SE and the horizontal gray line shows the fall CPUE benchmark of 50 fish per 1000'. The blue line represents CPUE of wild lake trout.

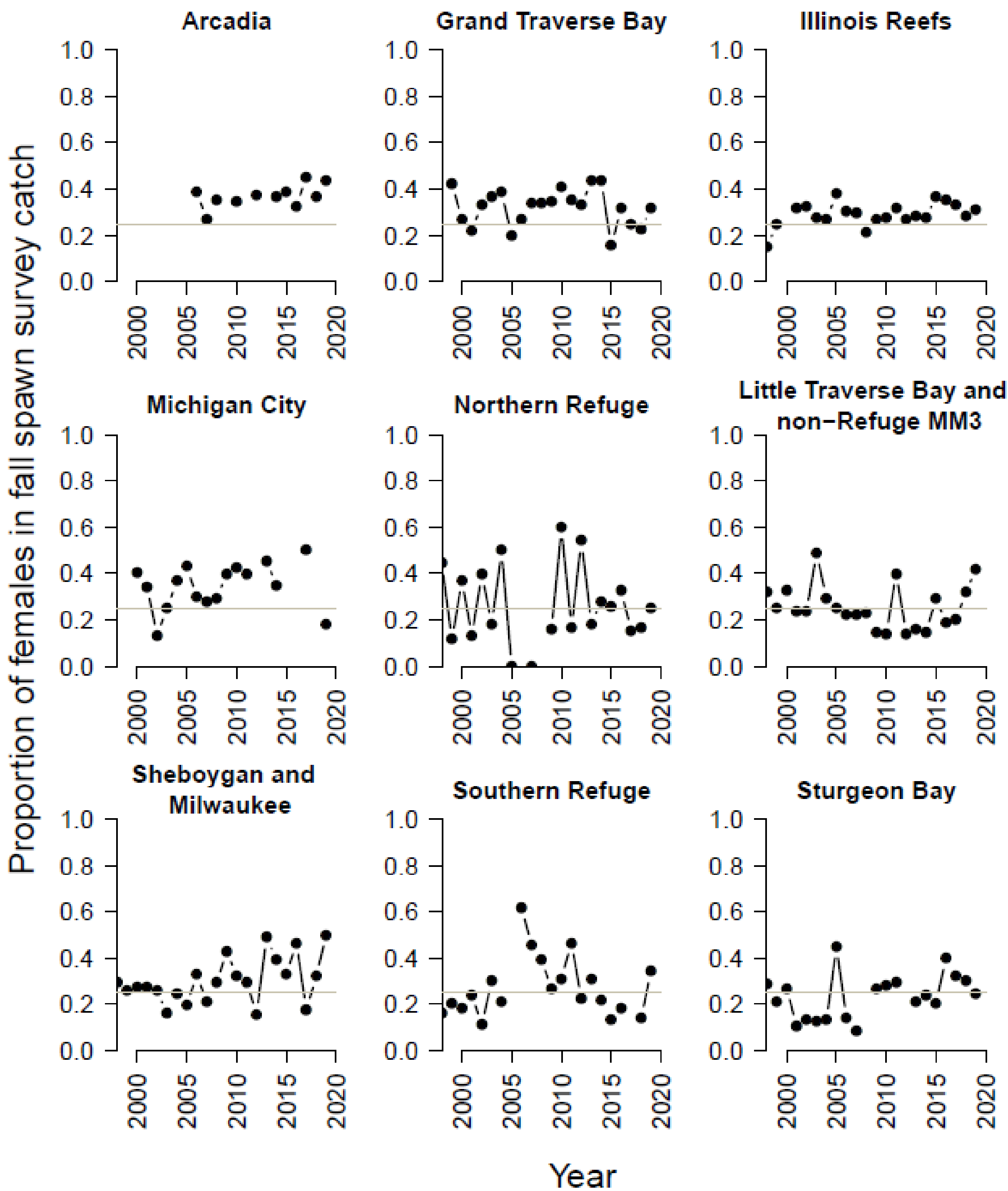


Figure 9: Proportion of females in fall spawner survey catches in Lake Michigan; the horizontal gray line portrays the Strategy evaluation objective of 25% females.

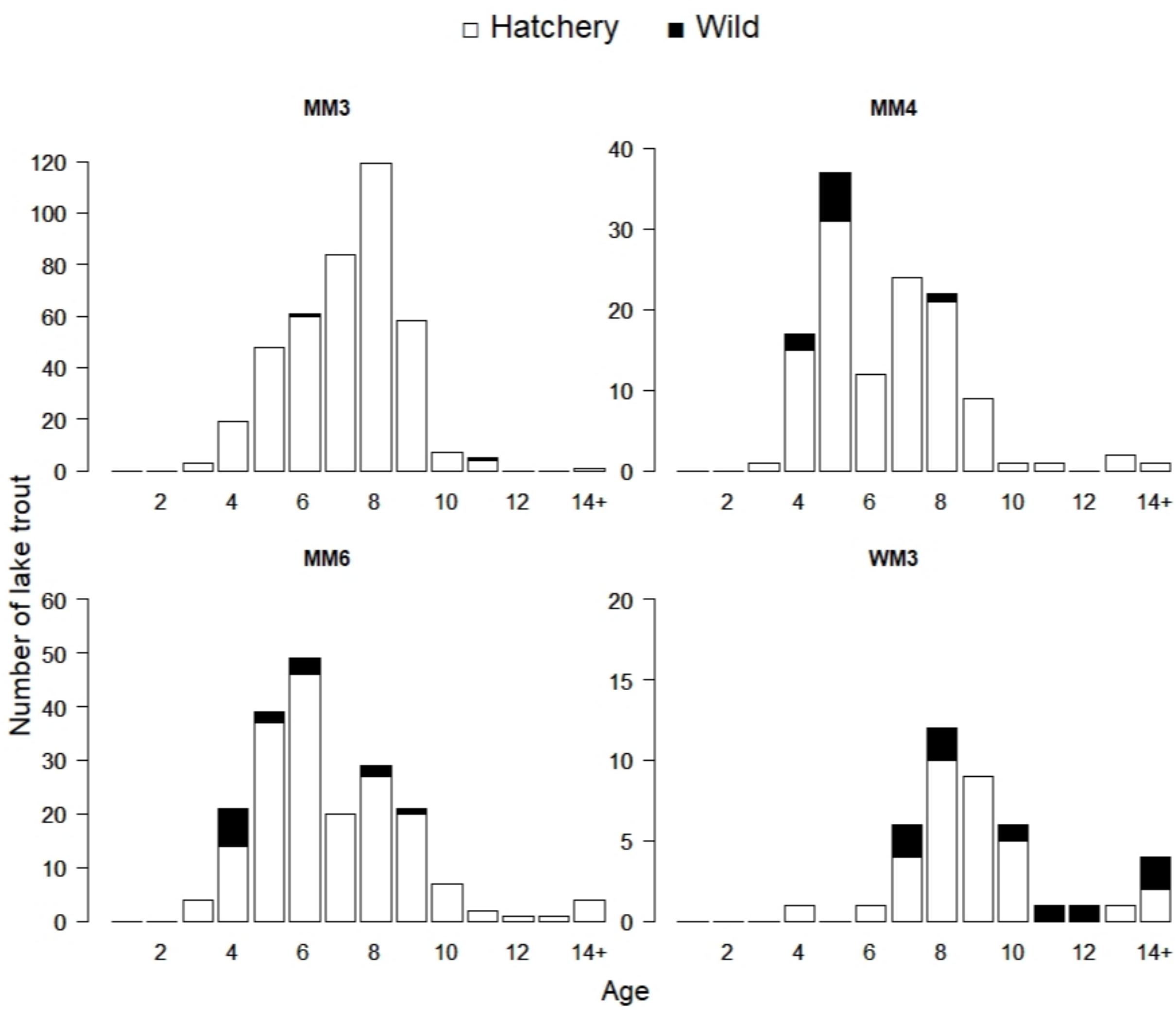


Figure 10: Number of lake trout captured during 2019 spawner surveys in Lake Michigan, by age-class and management unit. Fall survey ages were not available from other management units. Note that y-axis scaling varies from one panel to another.

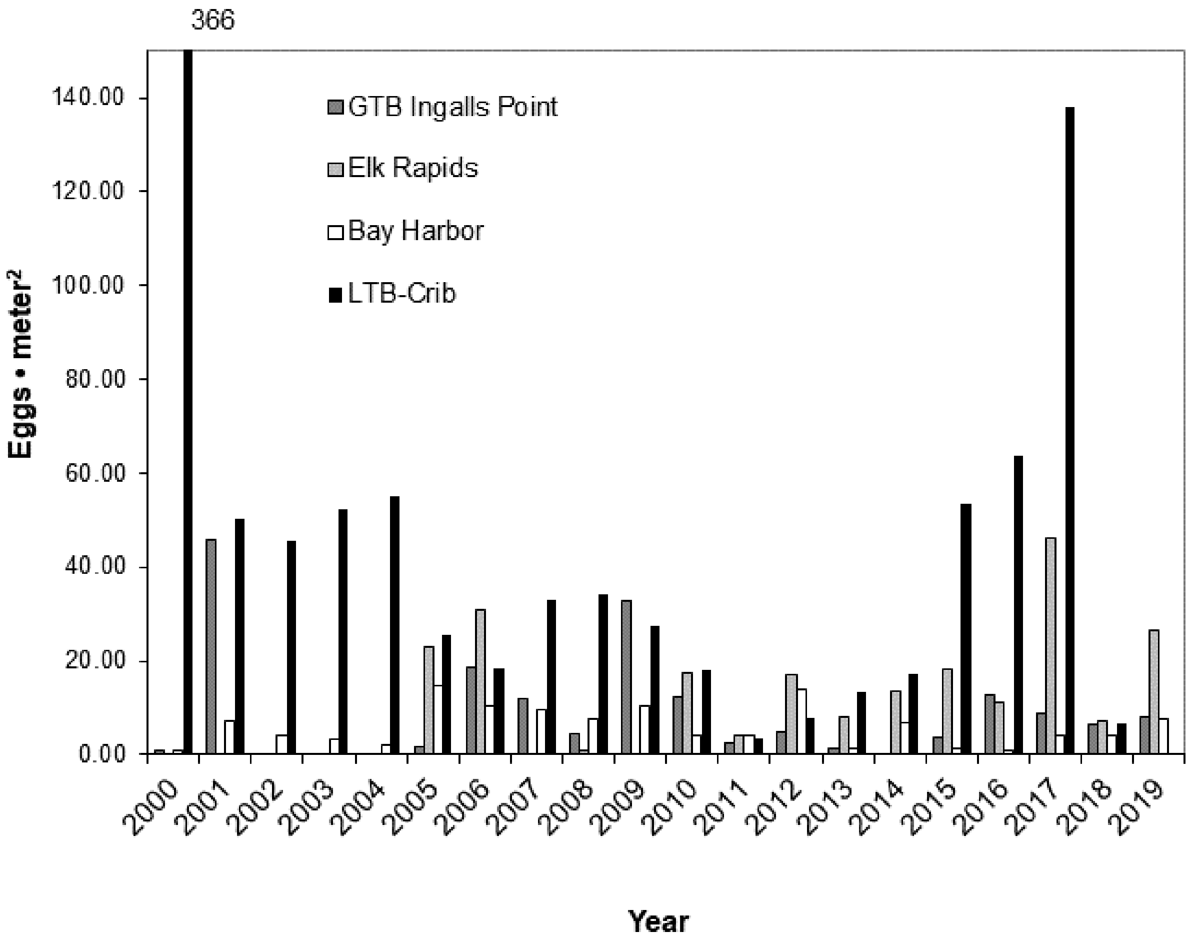


Figure 11: Number of lake trout eggs observed per square meter in northern Lake Michigan fall egg deposition surveys, 2000-2019. Egg deposition was measured using standard egg bag methodologies (Jonas et al. 2005).

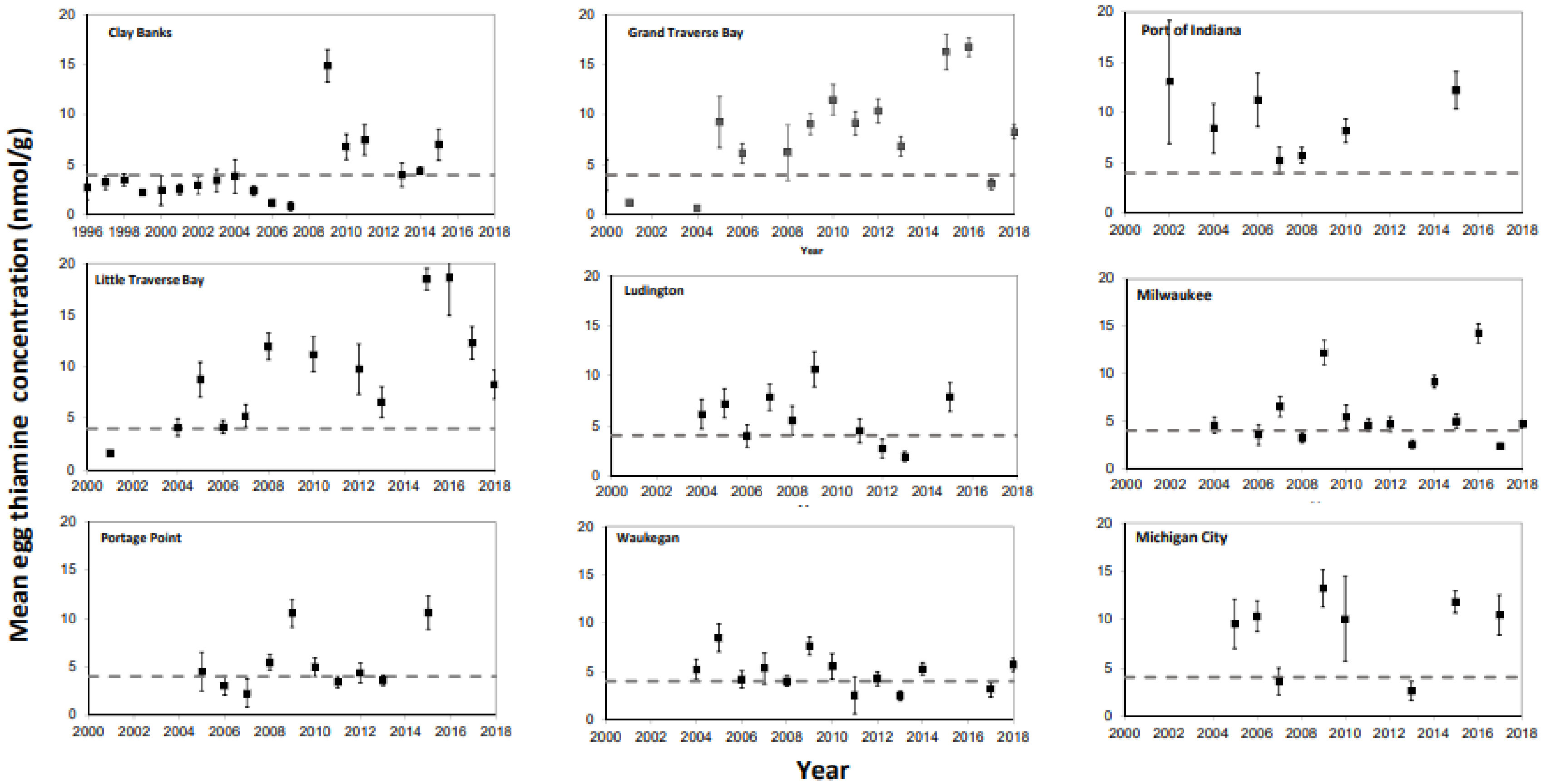


Figure 12: Mean egg thiamine concentrations (nmol/g) for ovulated lake trout females sampled in Lake Michigan fall spawner surveys, 1996-2018. Larvae produced from eggs with thiamine concentrations ≤ 4 nmol/g are often correlated with observations of thiamine deficiency complex (TDC). Data are provided by Don Tillitt, USGS Columbia Environmental Research Center.