2018 Lake Michigan Lake Trout Working Group Report [1,2]

This report provides a review on the progression of lake trout 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). We also include lake trout stocking and mortality data to portray progress towards lake trout rehabilitation.

The Lake Michigan Lake Trout Working Group (LMLTWG)

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[1] The U. S. Geological Survey data associated with this report are available at: 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 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. Harvest information was supplied by the Lake Michigan Extraction database. More detailed reporting of harvest and mortality within 1836 Treaty Waters of Lake Michigan was based on stock assessment models for northern and eastern Lake Michigan management units to approximate harvest and mortality in the proximate southern rehabilitation priority areas. 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). In recent years several agencies have supplemented traditional LWAP surveys with monofilament nets; note at this time the reported CPUE trends are based on multifilament gillnet survey data only. We also included spring surveys performed under the modified LWAP design, 1.5-6.0" mesh, used by some agencies and 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. Fall adult CPUE was determined from the 4.5-6.0" graded multifilament mesh spawner surveys completed at selected reefs during October – November. Estimates of natural reproduction were determined from the proportion of unclipped lake trout from all lake trout sampled within a management unit (including spring - fall surveys). 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. 2019). We conservatively infer natural reproduction when the percentage of unclipped fish exceeds 3% of all lake trout recoveries. Data sources for lake trout recoveries included gillnet assessment surveys and Great Lakes Fish Tagging and Recovery Lab samples from the recreational 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 $\geq$ 30 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 2018, salmon and trout (SAT) harvest was 2.64 million kg and for the fourth consecutive year has been below the 2.7 million kg minimum threshold of the FCO harvest objective (Figure 1). Lake trout harvest in 2018 was 0.71 million kg. The lake trout harvest objective (0.54 - 1.7 million kg) was previously met from 1985 – 2001 and more recently from 2013 – 2017 (Figure 1). Lake trout comprised 26.72% of the total salmonid catch in 2018 and thus exceeded the FCO harvest objective 20 - 25% (Figure 2).

Natural Reproduction: A total of 690 (10.6%) of the 6,528 lake trout examined for fin clips from 2018 gillnet assessments were unclipped and presumed to be wild. Wild fish accounted for 37% of lake trout in Illinois waters, and 10 – 23% in Wisconsin (WM3, WM4, and WM5) and southern Michigan (MM6, MM7 and MM8) waters of the lake (Figure 3). Fewer wild fish, between 0 and 9% of lake trout, were present in northern Michigan (MM2, MM3, MM4, and MM5) waters of Lake Michigan. An additional data source, recreationally caught fish that were examined by the Great Lakes Fish Tagging and Recovery Lab, reported

745 (30.2%) of 2465 lake trout examined were wild. In that survey, wild fish accounted for 50% of lake trout in Illinois waters, 18 - 46% in Wisconsin (WM4, WM5, and WM6) and southern Michigan (MM6, MM7 and MM8), and 0 - 13% in northern Michigan (MM2, MM3, MM4 and MM5). The proportion of wild fish from recreational catches in southern Lake Michigan was roughly double that reported from assessment surveys in management units ILL, IND, MM7, MM8, WM4, WM5, and WM6 (Figure 3). This discrepancy was primarily caused by differences in the length distribution of fish from each data source: the recreational fishery was comprised of a higher proportion of small fish ($\leq$ 580 mm) than the gillnet assessments. A higher percentage of smaller, younger fish are wild relative to larger, older fish because wild recruitment is a relatively recent development in Lake Michigan (see Figure 3), and stocking rates have declined in southern management units since 2015. It is possible that the recreational catch includes smaller fish that have yet to recruit to the assessment surveys, or that anglers selectively harvest smaller fish; data are not available on fish that anglers release. Notably, the percentage of wild fish are more comparable between the assessment surveys and the recreational fishery for fish > 580 mm, and the trajectories of percentage wild from both surveys track one another over time.

We inferred temporal patterns in natural reproduction from the age structure of wild lake trout recoveries; at this time ages are only available from gillnet assessment surveys (n=300 fish). Wild lake trout had a modal age of 5 and were represented by all consecutive age-classes between 1 to 13 years of age, and also included two fish that were 19 years of age (Figure 4). We conclude that natural reproduction has contributed to the lake trout population since 2005.

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 Committee reduced this interim target to 2.54 million though actual stocking within $\pm$10% of the interim target is allowed. Roughly 65% of the fish are stocked in first priority areas (Northern and Southern Refuges) with rehabilitation as the primary objective. The remaining fish are stocked in second priority areas to support local fishing opportunities in addition to rehabilitation. Stocking reductions since 2017 have been achieved through reduced stocking of nearshore secondary priority areas in southern Lake Michigan. Higher stocking rates could be adopted when Federal hatcheries are capable of more production but only with Lake Committee consensus.

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 2018, 2.52 million lake trout yearlings were stocked with 96% of these raised in U.S. Fish and Wildlife Service hatcheries. Lean strains, consisting of Lewis Lake, Seneca Lake, and Huron Parry Sound, represented 92% of all lake trout stocked. Klondike Reef strain, a humper morphotype from Lake Superior, were also stocked (n = 200,797) 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 Island reef complexes in or near the Northern Refuge and the Southern Refuge reef complex including Julian's Reef) received 76% of the lake trout. The Service's M/V *Spencer F. Baird* was used to stock 97% of all stocked lake trout in offshore waters.

Lake Trout Mortality: Estimating and attributing mortality experienced by lake trout stocks is best accomplished with stock assessments conducted for the sport and commercial fisheries within the 1836 Treaty waters. Total mortality is partitioned into natural mortality, sea lamprey-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 equal to 40%, corresponding to an instantaneous mortality of 0.51 (Bronte et al. 2008; Dexter et. al. 2011).

In northern Lake Michigan management units MM1, MM2, and MM3, the 2017 estimate of total annual mortality was 45.4% for lake trout ages 6-11 (Figure 6, upper panel; Modeling Subcommittee of the Technical Fisheries Committee 2018). This is higher than the 40% annual mortality target and increased from 2016 due to higher commercial harvest. Commercial fishing is the primary source of mortality. Previously in the 2000s there was an extended period of elevated sea lamprey mortality owing to additional recruitment of parasitic adults produced after spawners breached the dam on 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 7, upper panel; Modeling Subcommittee of the Technical Fisheries Committee 2018).

Annual mortality rates in the Southern Refuge priority area have not been estimated, but those estimated from the proximal waters of MM6/7 have been at or below 40% since 2003 (Figure 6, bottom panel). Prior to 2003, recreational fishing was the main source of lake trout mortality in MM6/7. Fishing mortality decreased following a reduction of recreational fishing effort beginning in the 1990s and sea lamprey-induced mortality exceeded fishing mortality in MM6/7 until 2014, though combined these sources were still less than assumed natural mortality. As in northern Lake Michigan, sea lamprey lamprey-induced mortality in MM6/7 has also declined in recent years, and in 2017 total annual mortality is below target at 31%.

Evaluation Objective 1: Increase the average catch-per-unit-effort (CPUE) to ≥25 lake trout 1000 feet of graded mesh gill net (2.5-6.0 inch) set overnight and then lifted the following day during spring assessments pursuant to the lakewide assessment in MM3, WM5, and at Julian's Reef by 2019.

In 2018, 159 gillnet lifts were completed lakewide to assess spring lake trout abundance. This included at least 6 lifts at most nearshore LWAP sites; no lifts occurred at the Washington Island LWAP site in 2018. Increased effort was again directed at the offshore reef complexes with 6 lifts on Northeast Reef and 6 lifts on East Reef within the Southern Refuge reef complex and a total of 34 lifts at 6 reefs within the Northern Refuge reef complex (Charlevoix, Dahlia Shoal, Fox Islands, Ile aux Galets, Irishman's Ground, and Middle Ground). About 36% of the lifts stemmed from FIWS sampling that added additional effort to sites between Saugatuck and Manistique (Map 1).

Increased stocking in the Northern Refuge complex since 2009 and a concomitant reduction in sea lamprey mortality has rapidly increased CPUE in the Northern Refuge, from <1 fish per 1000' in 2009 to more than 15 since 2016. In the Southern Refuge, CPUE measured 25.3 in 2018 and met the spring density objective of 25 fish per 1000' (Figure 8). Non-refuge CPUEs were lower; northeastern Lake Michigan (Arcadia and Leland) and the southern site of Waukegan reported CPUEs of 10 to 15 fish per 1000' while all other sites, including MM3 nearshore waters proximate to the Northern Refuge, were <10.

Evaluation Objective 2: 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 2018, 42 spawner survey lifts from 8 regions were performed during October-November. Over the last decade, spawner CPUE in the Northern Refuge has been historically low (<5 fish) but has rapidly increased the last few years to 76 spawners per 1000' net in 2018 (Figure 9). Spawner abundance at the Southern Refuge remains high (CPUE = 128), and is above the fall benchmark of 50 spawners per 1000' net in all surveyed regions except Grand Traverse Bay (CPUE = 48).

Evaluation Objective 3: 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.

Percent Female and Age Composition: Since 1998, the percentage of females captured during the fall spawner surveys has generally exceeded the 25% benchmark (Figure 10). However in 2018, the percentage of females at the Northern and Southern Refuges was low (14-17%). In the Northern Refuge the age-structure of spawners is relatively young with a modal age of 7 (Figure 11). However, spawners in southern populations (MM6 data used as a surrogate for the Southern Refuge) are older with a modal age of 9 and a right-skewed distribution towards older age-classes. Since the age at which 50% of females attain maturity is between 5 and 6 (Modeling Subcommittee of the Technical Fisheries Committee 2018), the low percentage of females in the Northern Refuge is likely an artifact of a young spawning population. We cannot account for the low percentage of females in the Southern Refuge spawn surveys. The proportion of females in spawner surveys was near or above the 25% benchmark in all other surveyed regions.

Evaluation Objective 4: 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.

Egg Deposition: Egg deposition rates have remained below target densities at the four sites where egg deposition has been measured in northern Lake Michigan during 2000–2017. However, during 2014–2017, egg deposition in Little Traverse Bay increasing rapidly and approached 140 eggs per m^2 in 2017 (Figure 12). Egg deposition rates at four monitored sites in northern Lake Michigan were lower than 10 viable eggs/m^2 in 2018 (Figure 12). Estimates of egg deposition have been below the target of 500 eggs/m^2 throughout the time-series.

Egg Thiamine Concentration: Recent mean thiamine concentrations for lake trout eggs sampled in fall spawner surveys are not available. Reported trends from 2001 – 2013 indicate thiamine concentrations exceeded 4 nmol/g in most areas of the lake in 2005 – 2010 (Riley et al. 2011; Figure 13). In 2013, thiamine concentrations fell slightly and were at or below the 4 nmol/g threshold in southern and eastern Lake Michigan waters, including reefs near Waukegan (ILL), Michigan City (IND), Milwaukee (WM5), and Portage Point and Ludington (MM6).

Conclusions: 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. Over the last few years lake trout annual mortality in MM1/2/3 has approached the 40% target level due to recent reductions in sea lamprey-induced mortality and regulation of fishing mortality through Consent Decree oversight. Due to increased lake trout survival and elevated stocking, Northern Refuge populations are currently building. However northern populations remain below spring abundance targets though these areas have achieved fall abundance metrics. Northern spawning populations are relatively young. Further, the proportion of wild fish in MM3 recovered from either assessment surveys or sport-caught fish 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 must demonstrate continued progress towards population objectives to achieve recovery.

In the Southern Refuge and at Julian's Reef, population objectives have been achieved more consistently compared with northern populations. Lake trout in these areas are characterized by high spawner densities, a more diverse age structure including older age-classes, and mortality rates in proximate areas below 40%. Assessment surveys in the Southern Refuge also met the spring abundance metric, which was last achieved in 2013. Most importantly, the proportion of wild fish caught in the recreational fishery for these management units is increasing and currently ranges between 30-50%. However, these populations are not considered self-sustaining yet as they are still stocked and the proportion of wild fish in assessment surveys is lower (10 -37%) than that observed in the recreational fishery.

Detectable and sustained natural reproduction since 2004 by lake trout in Lake Michigan, as documented by Hanson et al. (2013) and Patterson et al. (2016), continues to increase among sport-caught fish caught in southern Lake Michigan. Large increases in the proportion of wild fish, based on ages of recovered wild fish, began with 2005-2013 year classes, especially in areas with denser and older parental stocks. Large increases in natural reproduction in northern Lake Huron also coincided with relatively high densities and high age diversity of the adult lake trout population that were attained by a reduction in total mortality (Modeling Subcommittee of the Technical Fisheries Committee 2018).

The initial onset of natural reproduction in Lake Michigan coincided with reduced alewife abundance that has remained low since the mid-2000s (Madenjian et al. 2016). 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), although by 2013 egg thiamine concentrations had dropped below 4 nmol/g at selected sites in eastern and southern Lake Michigan. Whether alewives reduce lake trout recruitment through diet-mediated thiamine deficiencies is equivocal, as recent evidence suggests that wild lake trout fry may be able to mitigate thiamine deficiency with early feeding on thiamine-rich zooplankton (Ladago et al. 2016).

In summary, widespread recruitment of wild fish is now occurring in the southern Lake Michigan where evaluation objectives for spawner abundance, spawner age composition, percent spawning females, target mortality, and thiamine egg concentrations (in most years) have generally been achieved. Recruitment of wild fish, albeit lower, is now evident with wild fish comprising 20 - 40% of all recreationally caught lake trout in mid-latitude management units on both the eastern and western shores, but, remains inconsequential in northern Lake Michigan based on the recent gillnet assessments. Therefore, we conclude that lake trout populations are still in the early stages of recovery, and we recommend adhering to the implementation strategy objectives, which are appropriate management tools to measure continued progress toward lake trout rehabilitation in Lake Michigan.

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MM3 Ages

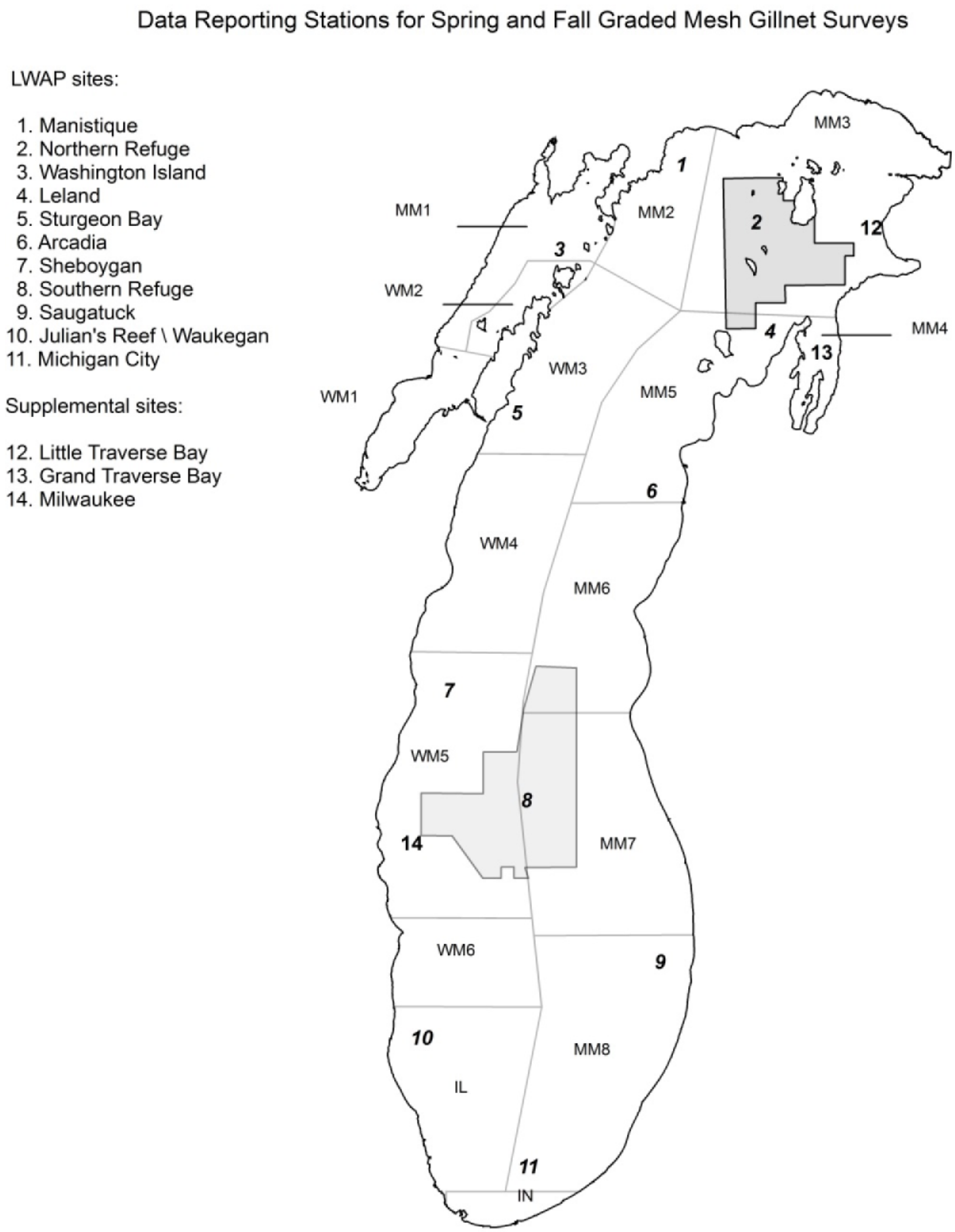
Age	Hatchery	Wild
3	4	0
4	44	0
5	82	0
6	169	3
7	290	0
8	147	2
9	26	4
10	6	3
11	1	0
12	0	0
13	1	0
14	1	0
15+	3	0

MM4 Ages

Age	Hatchery	Wild
3	8	0
4	24	8
5	46	8
6	85	3
7	83	2
8	41	4
9	25	2
10	7	2
11	5	1
12	5	0
13	0	0
14	0	0
15+	2	0

MM6 Ages

Age	Hatchery	Wild
3	0	0
4	0	2
5	0	7
6	0	0
7	0	1
8	0	0
9	7	0
10	5	0
11	2	0
12	0	1
13	1	0
14	0	0
15+	1	0



Map 1. Reporting of spring and fall graded mesh gillnet data has been aggregated into the 11 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.

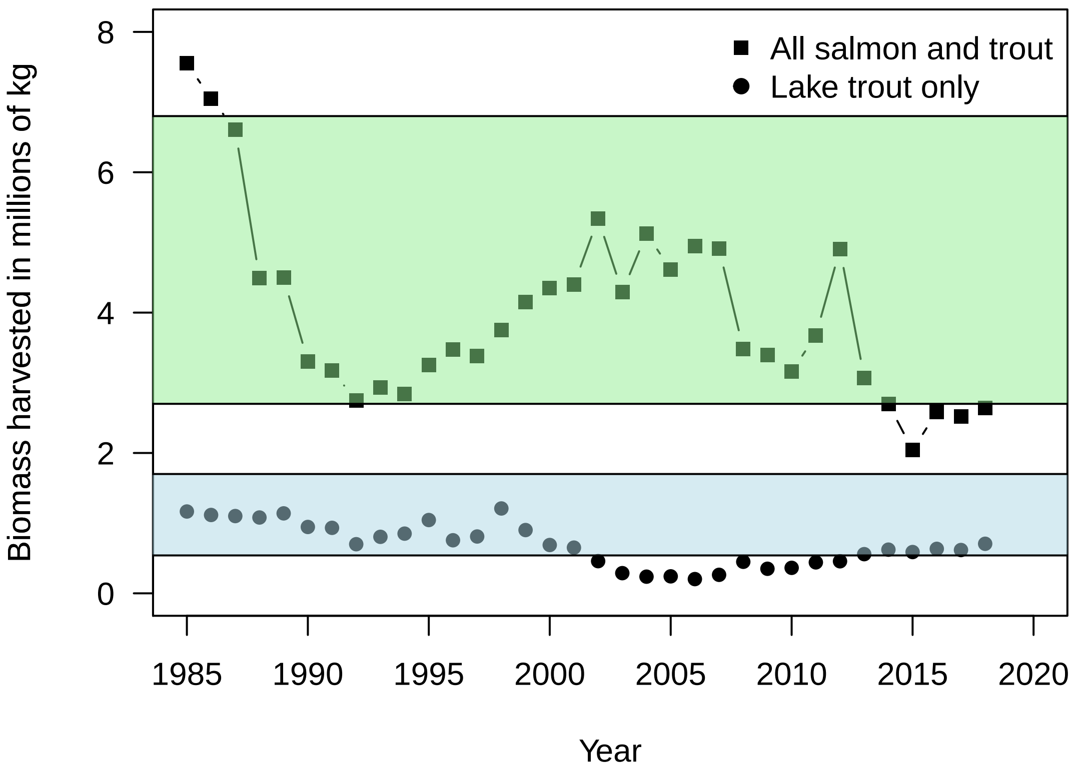


Figure 1: Lake Michigan total harvest (1985 – 2018) of lake trout and all other species of salmon and trout (SAT). Green-shading depicts the range of SAT harvest in the FCO while blue-shading depicts the 20-25% range of SAT harvest reserved for lake trout.

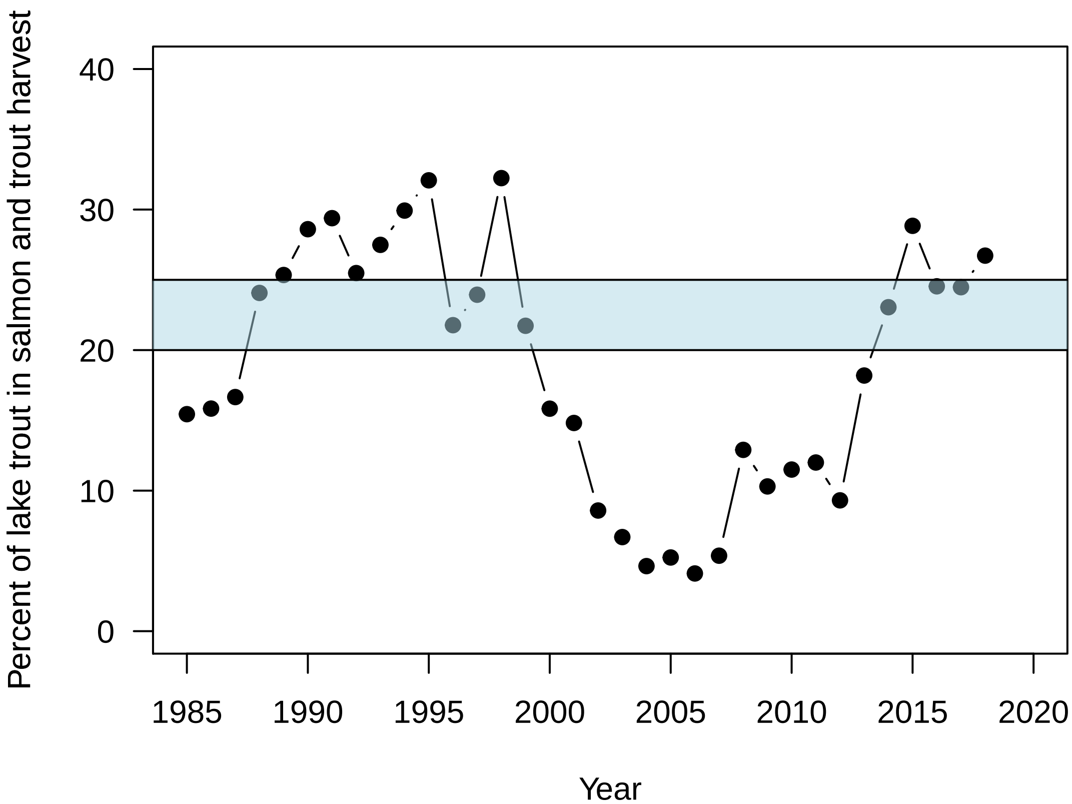


Figure 2: The percentage of SAT harvest (1985 – 2018) comprised of lake trout; blue shading represents the 20 – 25% specified in the FCO.

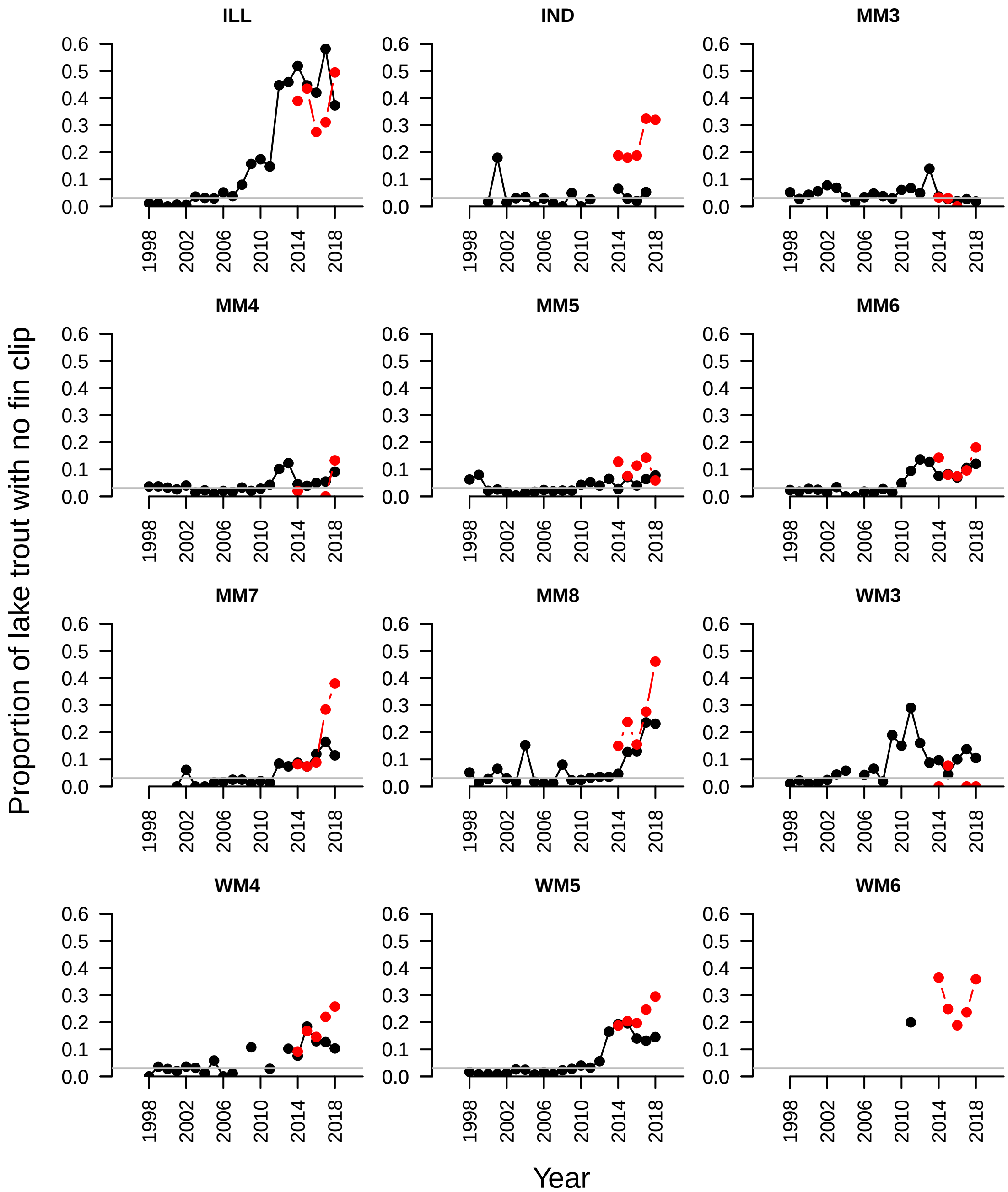


Figure 3: The proportion of wild (unclipped) lake trout captured in assessment surveys within each statistical district (black lines). Data points are only included when at least 30 lake trout per year were examined. Red circles show the proportions of wild lake trout examined from the Great Lakes Fish Tagging and Recovery Lab sampling between 2014 and 2018. The gray line represents 3% marking error, e.g. hatchery origin fish that were stocked with no fin clip.

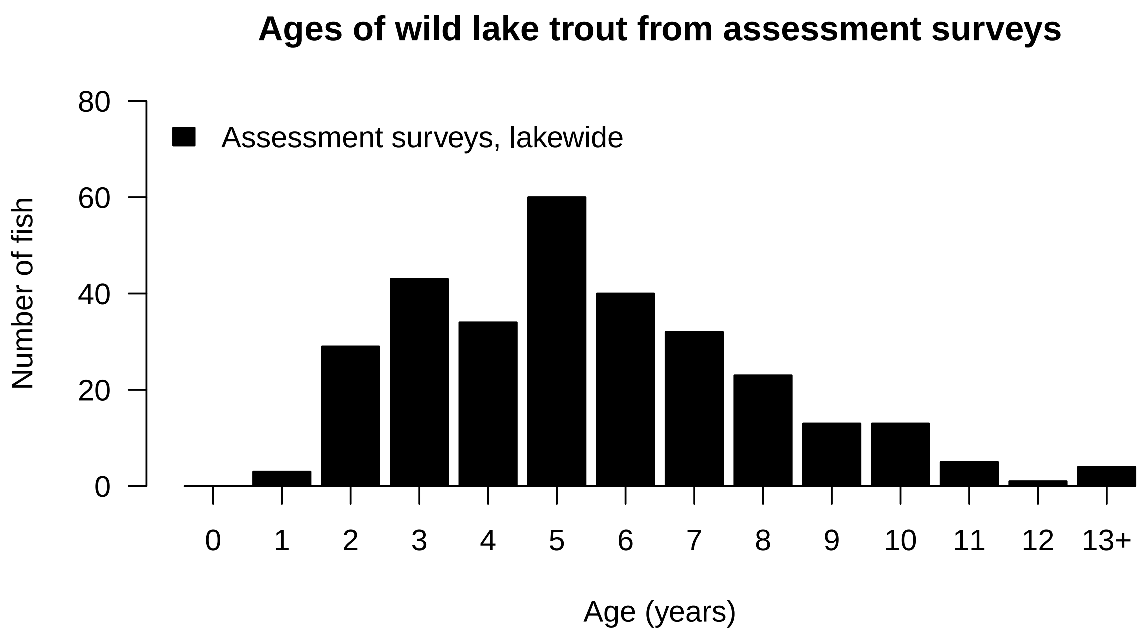


Figure 4: Wild lake trout age structure determined from assessment surveys in 2018; age estimates were derived from 300 fish (42% of all wild lake trout captured in assessment surveys).

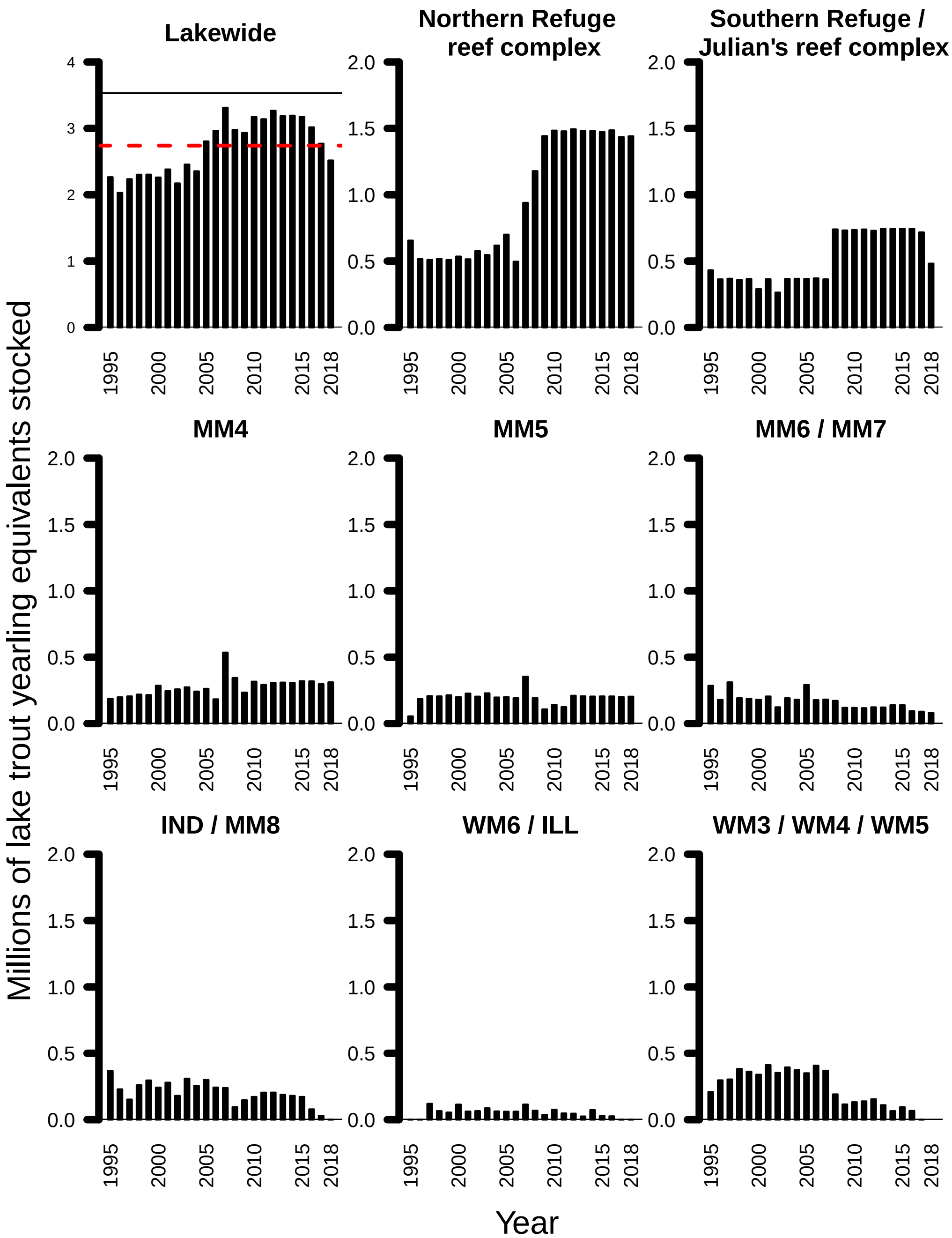


Figure 5: Number of lake trout (yearling equivalents) stocked in Lake Michigan by region, 1995 – 2018. In the lakewide panel, the black line represents the 3.53 million maximum stocking target prescribed in the Strategy while the red line represents the 2.74 million interim target that was reduced to 2.54 million in 2017 by the Lake Committee.

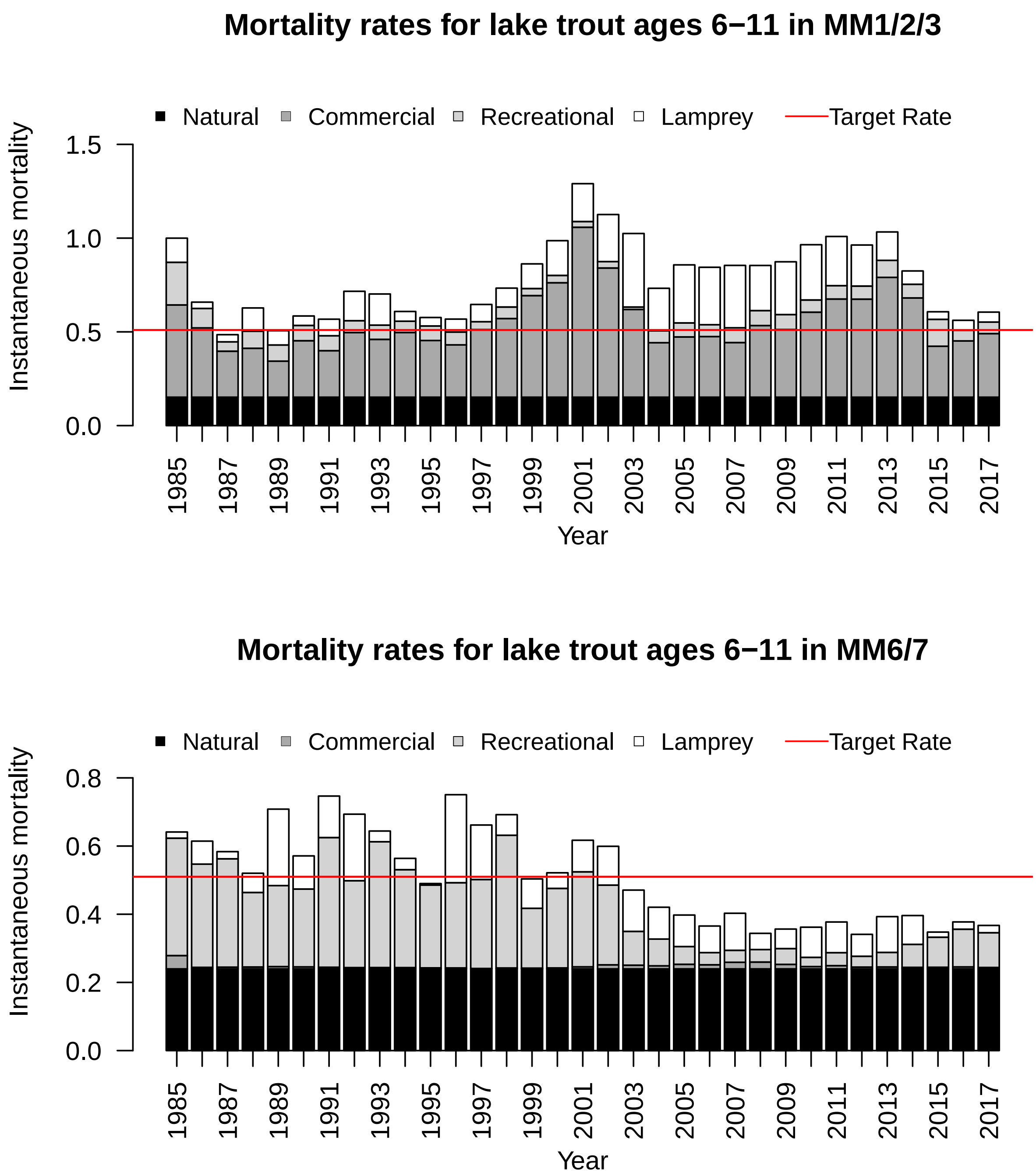


Figure 6: Instantaneous mortality rates for lake trout ages 6-11 in northern Lake Michigan and in MM67 waters proximal to the Southern Refuge. The red line represents an instantaneous mortality rate of 0.51 that is equivalent to a 40% annual mortality rate.

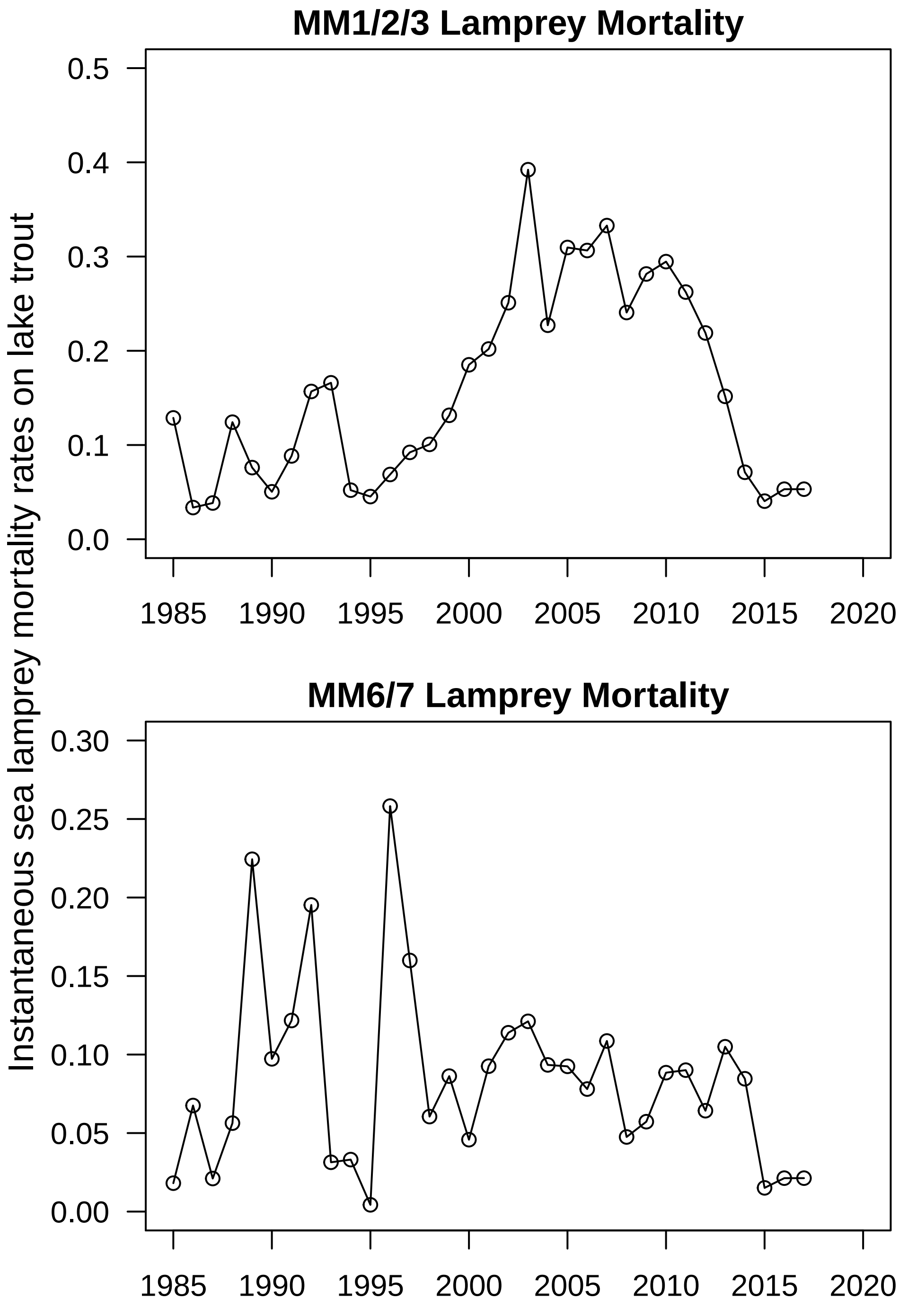


Figure 7: Instantaneous sea lamprey-induced mortality on lake trout ages 6-11 for Lake Michigan management units MM1/2/3 and MM6/7.

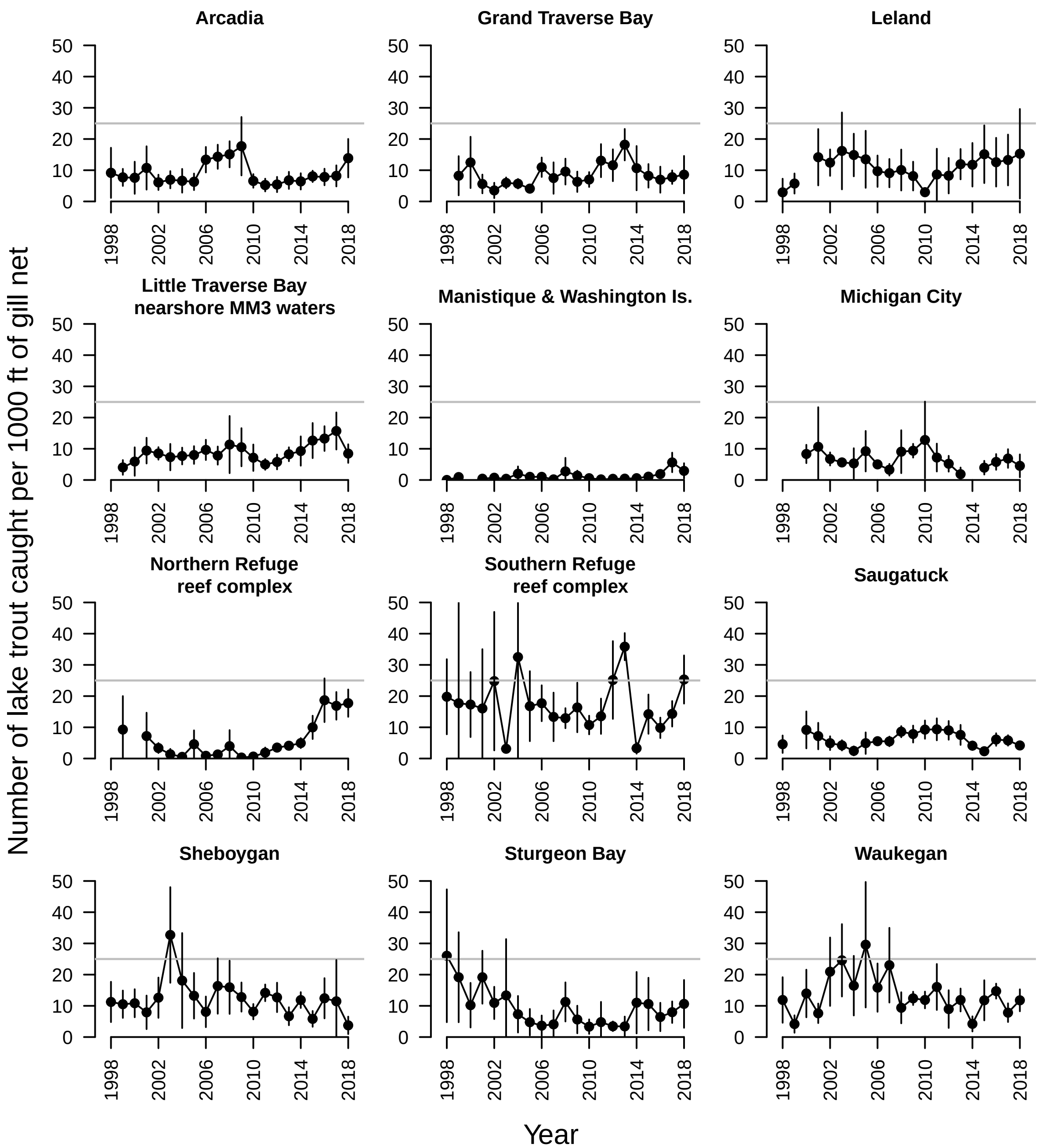


Figure 8: Time series of spring survey lake trout catch per effort (mean number of fish/1000 ft of graded mesh gill net) for the 11 LWAP sites plus 2 supplemental sites with comparable data (Grand Traverse Bay, Little Traverse Bay including nearshore MM3 waters). Vertical bars represent ±2 SE and the horizontal gray line shows the spring CPE benchmark of 25 fish per 1000'.

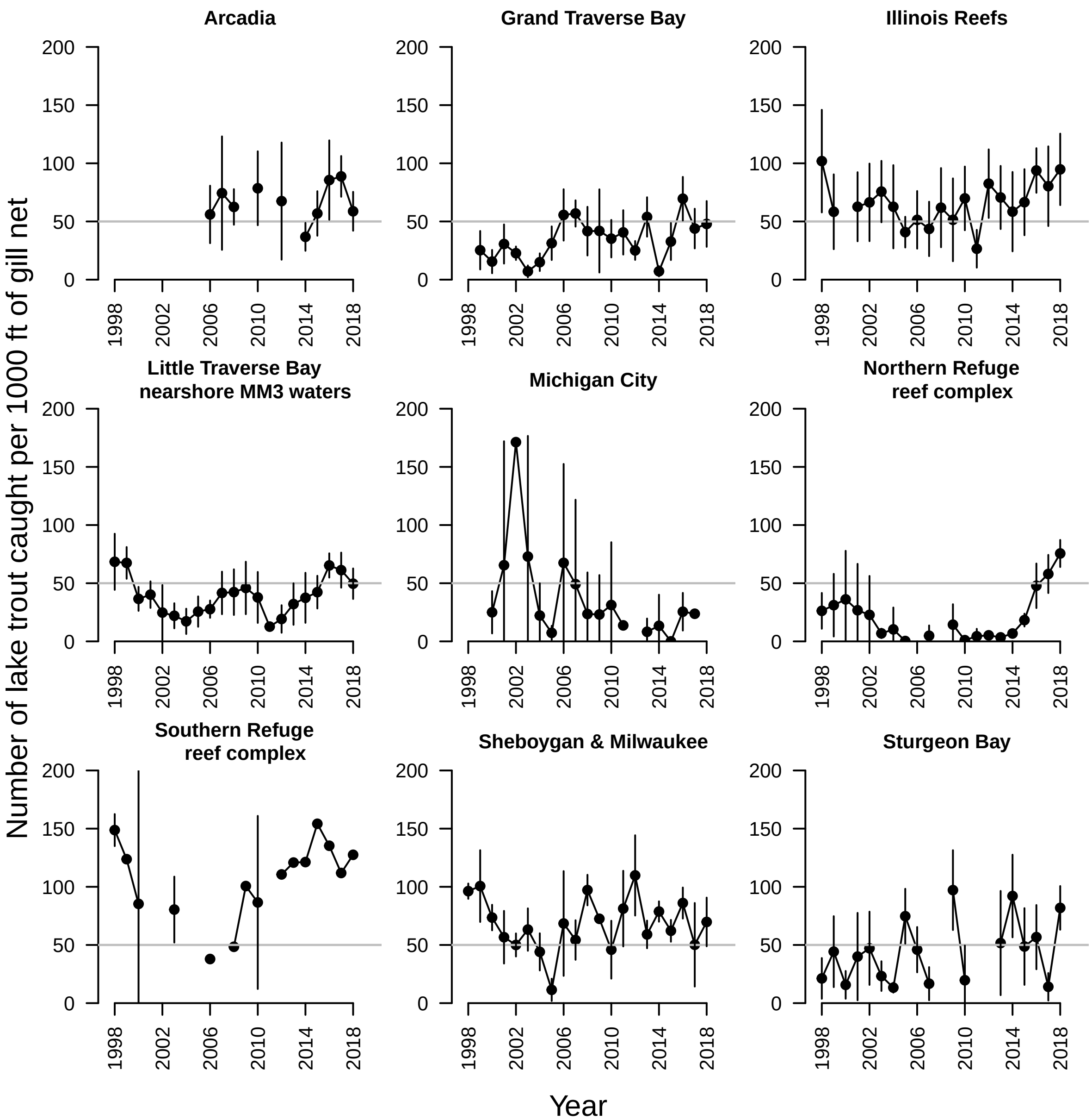


Figure 9: Time series of fall lake trout spawner survey catch per effort (mean number of fish/1000 ft of graded mesh gill net) for reefs within or near the spring LWAP stations. Vertical bars represent ±2 SE and the horizontal gray line shows the fall CPE benchmark of 50 fish per 1000'.

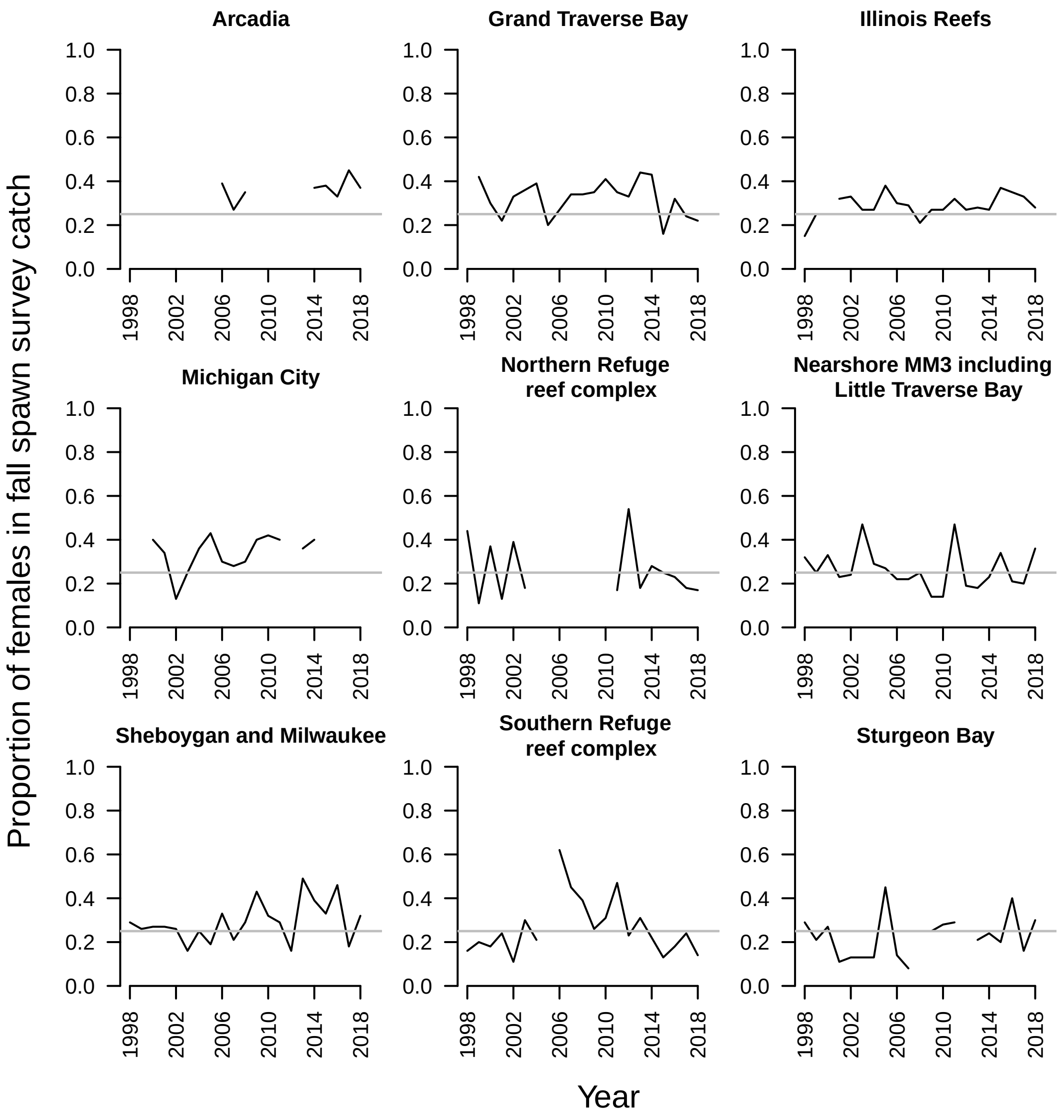


Figure 10: Proportion of females in fall spawner survey catches; the horizontal gray line portrays the Strategy evaluation objective of 25% females.

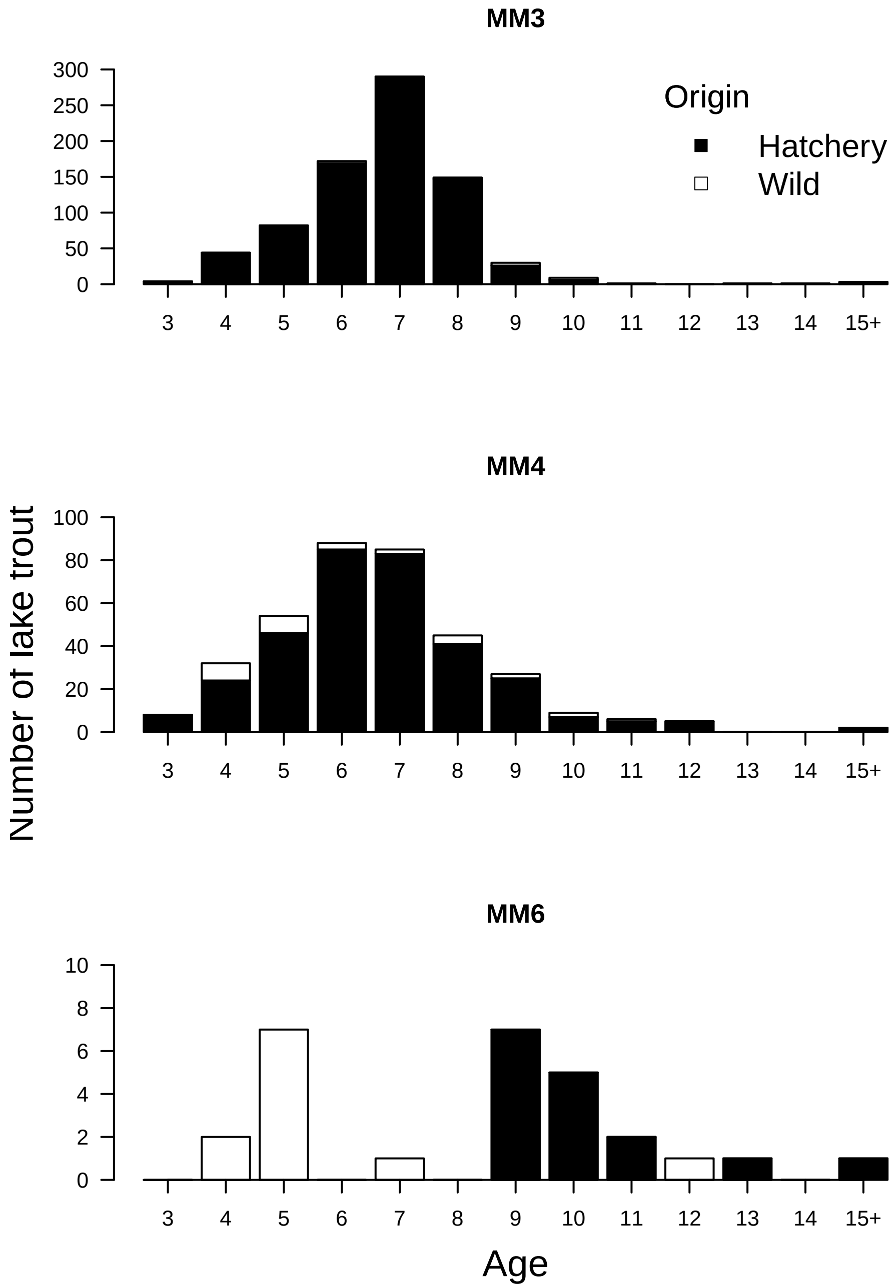


Figure 11: Number of lake trout captured during 2018 spawner surveys, by age-class and management unit. Fall survey ages were not available from other management units.

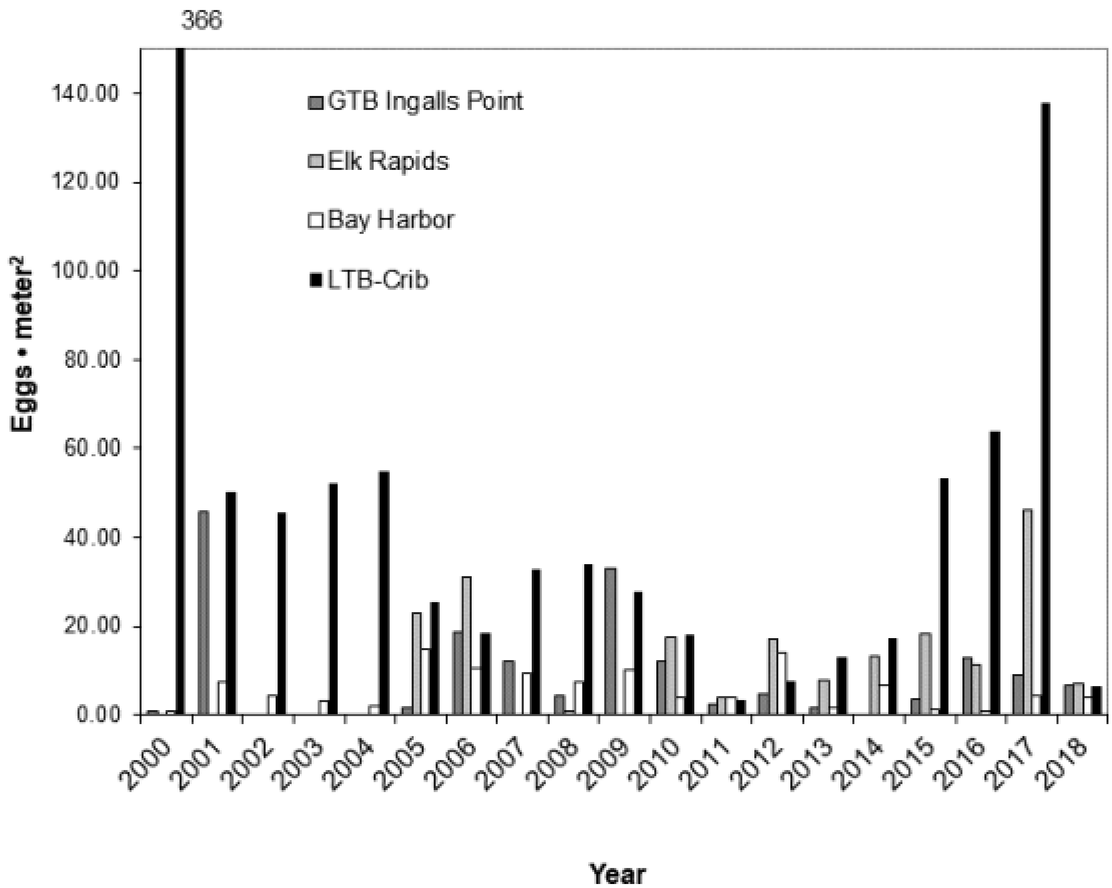


Figure 12: Numbers of lake trout eggs observed per square meter in northern Lake Michigan fall egg deposition surveys, 2000–2018. Egg deposition was measured using standard egg bag methodologies (Jonas et al. 2005).

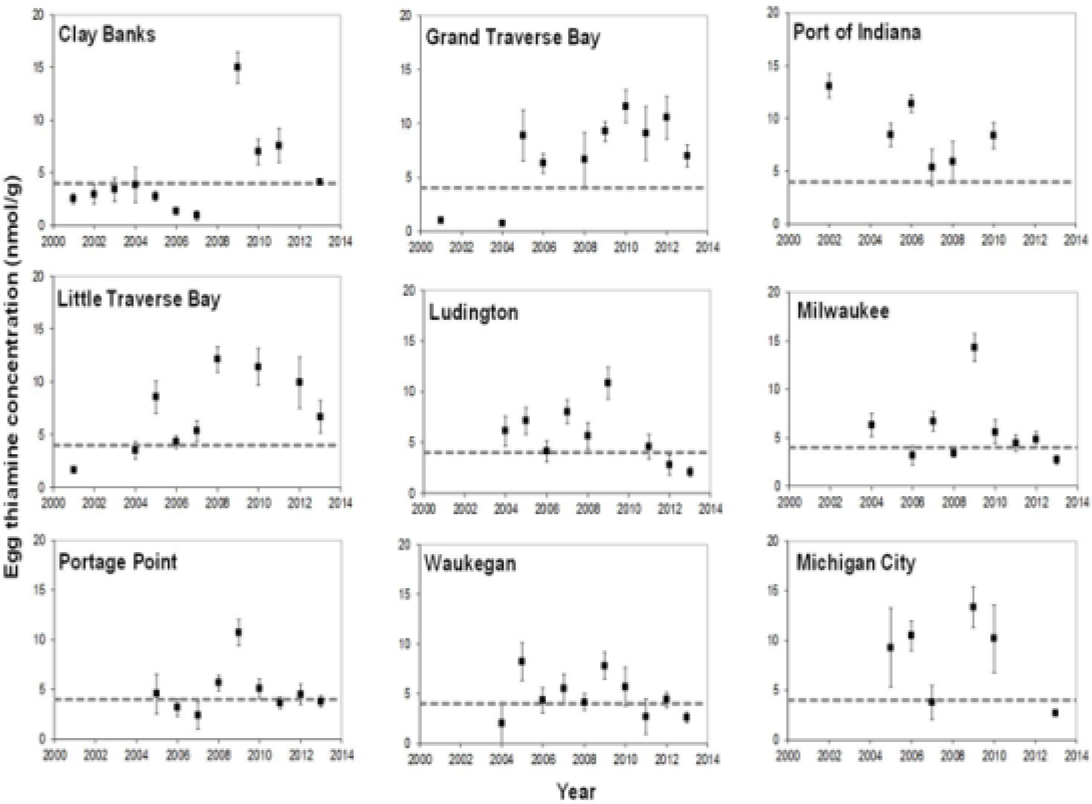


Figure 13: Mean egg thiamine concentrations (nmol/g) for ovulated lake trout females sampled in Lake Michigan fall spawner surveys, 2001 – 2013 (Riley et. al 2011). Larvae produced from eggs with thiamine concentrations ≤4 nmol/g are often correlated with observations of thiamine deficiency complex (TDC).