2017 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, 2018, Great Lakes Research Vessel Operations 1958-2017 (ver. 2.0, March 2018): 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 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 Michigan DNR 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. Roughly 3% of recently stocked lake trout were released without a fin clip (Hanson et al. 2013), and therefore we infer natural reproduction when percentage of unclipped fish exceeds 3% of all lake trout recoveries. Data sources for lake trout recoveries included LWAP surveys, lake trout spawner surveys, Great Lakes Fish Tagging and Recovery Lab samples from the recreational fishery, and assessment surveys targeting other species that also captured lake trout. 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 2017, salmon and trout (SAT) harvest was 2.52 million kg and for the third consecutive year has been below the 2.7 million kg minimum threshold of the FCO harvest objective (Figure 1). Lake trout harvest in 2017 was 0.62 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). In 2017 lake trout comprised 24% of the total salmonid catch and met the FCO harvest objective of 20 – 25% (Figure 2).

Natural Reproduction: A total of 809 (11.7%) of the 6,938 lake trout examined for fin clips from 2017 gillnet assessments were unclipped and presumed to be wild. Wild fish accounted for 58% of lake trout in Illinois waters, and 10 – 24% in Wisconsin (WM3, WM4, and WM5) and southern Michigan (MM6, MM7 and MM8) waters of the lake (Figure 3). Fewer wild fish, between 2 and 7% of lake trout, were present in Indiana and 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 26.4% of 2,120 lake trout examined were wild. In the southern half of Lake Michigan the proportion of wild fish from recreational catches was generally higher than that reported from assessment surveys (Figure 3). This was especially true in Indiana, 32% versus 5%, but this trend also occurred in WM4—WM6 and MM7—MM8; only Illinois waters had a substantially higher proportion of wild lake trout reported from assessment surveys.

We inferred temporal patterns in natural reproduction from the age structure of wild lake trout recoveries. Age estimates from sectioned otoliths were derived from 458 wild lake trout recovered from the recreational fishery and 354 fish from assessment surveys (all assessment net catches are reported, including surveys using 38-mm mesh). Assessment surveys caught wild fish as young as age 1 while age 3 was the minimum age from the recreational fishery. For both data sources, the modal age occurred at age 5 or 6 years and had a right-skewed distribution with relatively few fish older than age 12 (Figure 4).

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 Committee reduced this interim target to 2.54 million though actual stocking within ±10% of the interim target is allowed. About 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. The stocking reduction in 2017 was 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 2017, 2.77 million lake trout yearlings were stocked with 99% of these raised in U.S. Fish and Wildlife Service hatcheries. Lean strains, consisting of Lewis Lake, Seneca Lake, and Huron Parry Sound, represented 93% of all lake trout stocked. Klondike Reef strain, a humper morphotype from Lake Superior, were also stocked (n = 199,319) 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 78% of the lake trout. Over 97% of Service lake trout were stocked in offshore waters using the M/V *Spencer F. Baird*.

Lake Trout Mortality: Mortality experienced by lake trout stocks is best estimated by 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% (Bronte et al. 2008; Dexter et. al. 2011).

In northern Lake Michigan, total annual mortality has now declined to 40.4% for lake trout ages 6-11 and is near the 40% target for the first time since 1990 (Figure 6; upper panel; Modeling Subcommittee & Technical Fisheries Committee, 2017). 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 & Technical Fisheries Committee, 2017).

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 1999 (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 the 2017 total annual mortality is below target at 31%.

<u>Evaluation Objective 1 :</u> Increase the average catch-per-unit-effort (CPUE) to <u>></u>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 2017, 176 gillnet lifts were completed lakewide to assess spring lake trout abundance. This included at least 6 lifts at most nearshore LWAP sites; 3 lifts were made at Sheboygan and no lifts at Washington Island. 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 (Dahlia Shoal, Fisherman's Island, High Island, Ile aux Galets, Irishman's Ground, and Trout Island Shoal). About 20% of the lifts stemmed from FIWS sampling that added additional effort to sites between Saugatuck and Manistique (Map 1).

Survey CPUEs in the Northern and Southern Refuge reef complexes were below the 25 fish per 1000' benchmark (Figure 8). However 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. An increasing trend in the nearshore waters of MM3 (CPUE = 15.7 in 2017) has also been observed and to a lesser extent this trend also exists in other northern sites of Leland, Arcadia, Sturgeon Bay, and Manistique. Increased stocking in the Northern Refuge does not appear to have influenced lake trout densities in Grand Traverse Bay, as CPUEs have declined below 10 fish per 1000' in recent years. The Southern Refuge and southwestern Lake Michigan waters of Waukegan and Sheboygan briefly met the spring CPUE benchmark in the early 2000s however in recent years CPUE has fluctuated at lower levels of roughly 10 fish per 1000' in these sites. CPUEs are even lower at Saugatuck and Michigan City in southeastern Lake Michigan.

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 2017, 43 spawner survey lifts from 9 regions were performed during October-November. Among northern sites, adult CPUE continues to increase (Figure 9). For the first time since 1995 (see Madenjian and DeSorcie 1999), spawner densities met the 50 fish per 1000' benchmark at Northern Refuge reefs (CPUE = 58). Nearshore MM3 waters including Little Traverse Bay, Grand Traverse Bay, and Arcadia also reported sufficiently high adult abundances. Sturgeon Bay was the only northern site with low spawner abundance (CPUE = 14), though this was likely attributable to survey timing (November 2nd) after spawning had peaked. At southern Lake Michigan sites, low spawner densities were observed at Michigan City (CPUE = 24) but spawner densities at the Southern Refuge (CPUE = 112), reefs near Milwaukee (CPUE = 50), and Illinois reefs (CPUE = 80) all exceeded the benchmark (Figure 9).

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 2017, the percentage of females at Northern Refuge and nearshore MM3 reefs fell to roughly 20%. Reasons for this drop in the percentage of females are not clear. The maximum age recorded for spawners at these sites was nine years and the modal age was six (Figure 11, upper panel). Lowered sex ratios were also observed in 2017 at reefs near Milwaukee and Sturgeon Bay, where approximately 20% of fish captured in spawner surveys were female. Age compositions were not reported in 2017 for these reefs, and, outside of MM3, fall survey ages were reported only for MM4 and MM6. Neither of these units contained ten or more age-classes older than age seven (Figure 11).

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, in the last three years egg deposition in Little Traverse Bay has been increasing rapidly and approached 140 eggs per m^2 in 2017 (Figure 12).

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 (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).

<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 two 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. As a result of increased lake trout survival and elevated stocking, northern populations are currently building. However northern populations remain below spring abundance targets though some have now met fall abundance metrics. These spawning populations are young and do not meet the evaluation objective regarding the presence of older age-classes. 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, the 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, an increasing trend in the proportion of wild fish, and mortality rates in proximate areas below 40%. However, these populations are not considered self-sustaining yet as they are still stocked and generally comprised of $\geq$ 50% hatchery fish. Further, spring surveys in the Southern Refuge and Waukegan, the LWAP site most proximate to Julian's Reef, have shown that the spring abundance metric has not been met since 2013, despite recruitment of wild fish.

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 particularly 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 substantial increases in the densities and age composition of the adult lake trout that occurred after total mortality was reduced (Modeling Subcommittee & Technical Fisheries Committee, 2017).

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 in mid-latitude management units on both the eastern and western shores, but, remains inconsequential in most areas of northern Lake Michigan. Overall, based on recent gillnet assessments, the percentage of wild lake trout within the lake trout population remains below 20% in all areas of Lake Michigan except Illinois waters and MM8. Therefore, we conclude that lake trout populations are 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.

References

Bronte, C. R., C. C. Krueger, M. E. Holey, M. L. Toneys, R. L. Eshenroder, and J.L. Jonas. 2008. A guide for the rehabilitation of Lake Trout in Lake Michigan. Great Lakes Fishery Commission, Miscellaneous Publication 2008-01, Ann Arbor, Michigan.

Dexter Jr, J. L., Eggold, B. T., Gorenflo, T. K., Horns, W. H., Robillard, S. R., & Shipman, S. T. (2011). A fisheries management implementation strategy for the rehabilitation of lake trout in Lake Michigan. Rep. Np: Lake Michigan Committee, GLFC.

Elrod, J. H., Ostergaard, D. E., & Schneider, C. P. (1988). Comparison of hatchery-reared lake trout stocked as fall fingerlings and as spring yearlings in Lake Ontario. North American Journal of Fisheries Management, 8(4) 455-462.

Eshenroder, R.L., M. E. Holey, T.K. Gorenflo, and R. D. Clark Jr. 1995. Fish-community objectives for Lake Michigan. Great Lakes Fish. Comm. Spec. Pub. 95-3. 56 p.

Hanson, S.D., M.E. Holey, T. J. Treska, C.R. Bronte, and T.H. Eggebraaten. 2013. Evidence of Wild Juvenile Lake Trout Recruitment in Western Lake Michigan. North American Journal of Fisheries Management 33:186–191.

Jonas, J. L., R. M. Claramunt, J. D. Fitzsimons, J. E. Marsden, and B. J. Ellrott. 2005. Estimates of egg deposition and effects of lake trout (Salvelinus namaycush) egg predators in three regions of the Great Lakes. Canadian Journal of Fisheries and Aquatic Sciences 62(10):2254-2264.

Krueger, C.C., Perkins, D. L., Mills, E. L., and Marsden, J.F. 1995. Predation by alewives on lake trout in Lake Ontario: role of an exotic species in preventing restoration of a native species. Journal of Great Lakes Research 21 (suppl 1): 458-469.

Ladago, B.J., Marsden, J.E. and Evans, A.N., 2016. Early feeding by lake trout fry. Transactions of the American Fisheries Society, 145(1), pp.1-6.

Madenjian, C. P. and T. J. DeSorcie. 1999. Status of Lake Trout Rehabilitation in the Northern Refuge of Lake Michigan. North American Journal of Fisheries Management 19:658–669.

Madenjian, C. P., D. B. Bunnell, T. J. Desorcie, M. J. Kostich, M. A. Chriscinske, and J. V. Adams. 2016. Status and trends of prey fish populations in Lake Michigan, 2016. A report to the Great Lakes Fishery Commission, Lake Michigan Committee, Milwaukee, Wisconsin.

Modeling Subcommittee, Technical Fisheries Committee. 2017. Technical FisheriesCommittee Administrative Report 2017: Status of Lake Trout and Lake Whitefish Populations in the 1836 Treaty-Ceded Waters of Lakes Superior, Huron and Michigan, with Recommended Yield and Effort Levels for 2017.

Patterson, K.A., Stein, J.A. and Robillard, S.R., 2016. Progress Toward Lake Trout Rehabilitation at a Stocked and Unstocked Reef in Southern Lake Michigan. North American Journal of Fisheries Management, 36(6), pp.1405-1415.

Riley, S. C., Rinchard, J., Honeyfield, D. C., Evans, A. N., & Begnoche, L. (2011). Increasing thiamine concentrations in Lake Trout eggs from Lakes Huron and Michigan coincide with low Alewife abundance. North American Journal of Fisheries Management 31(6), 1052-1064.

Schneeberger, P., M. Toneys, R. Elliott, J. Jonas, D. Clapp, R. Hess, and D. Passino-Reader. 1998. Lakewide assessment plan for Lake Michigan fish communities. Great Lakes Fishery Commission, Lake Michigan Technical Committee, Ann Arbor, Michigan.

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.

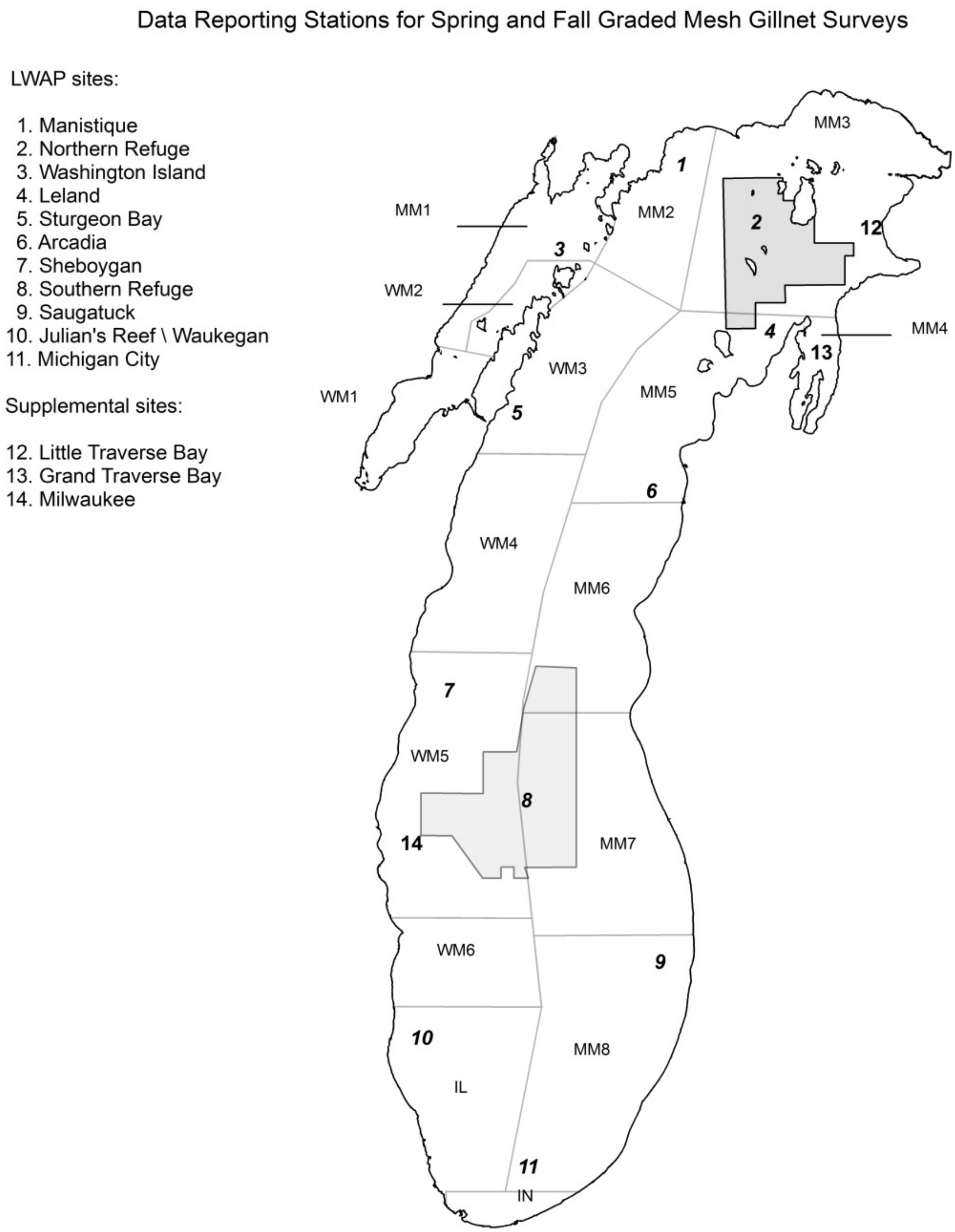


Figure 1. Lake Michigan total harvest (1985 – 2017) of lake trout and all other species of salmon and trout (SAT); green-shading depicts the range of SAT harvest in the FCO while blue-shading depicts the 20-25% range of SAT harvest reserved for lake trout.

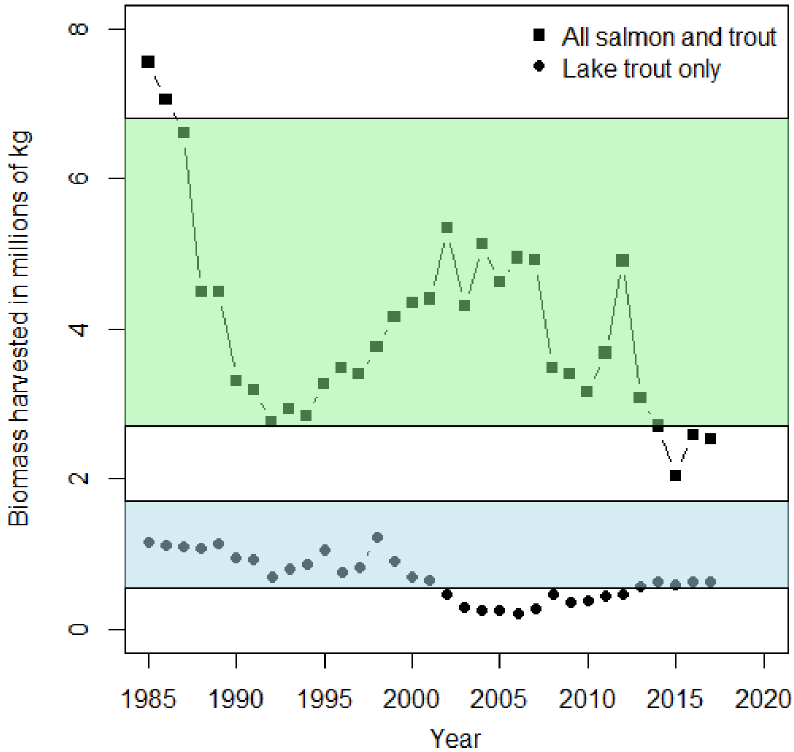


Figure 2. The percentage of SAT harvest (1985 – 2017) comprised of lake trout; blue shading represents the 20 - 25% specified in the FCO.

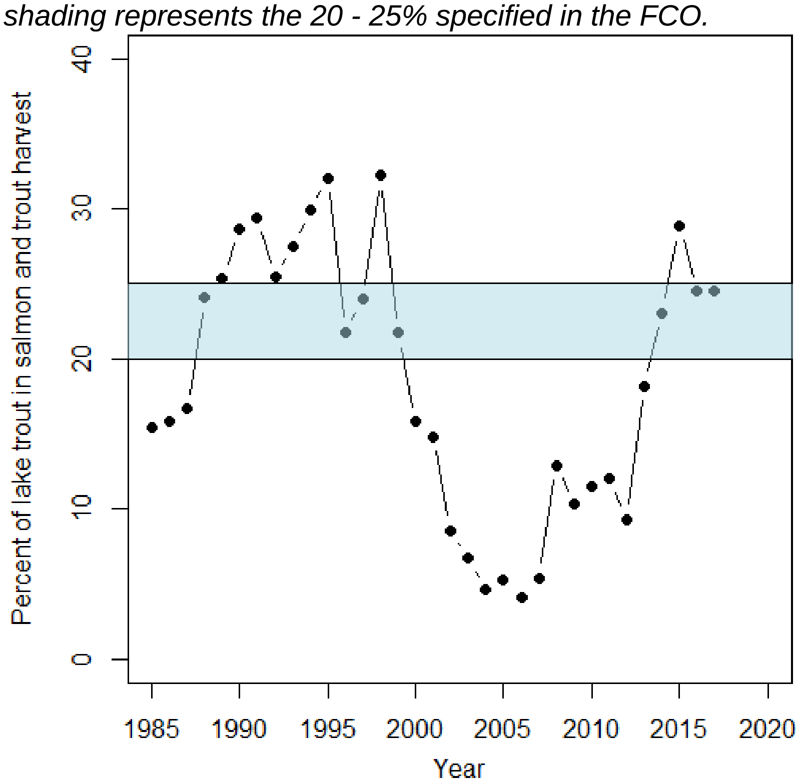


Figure 3. The proportion of wild (unclipped) lake trout captured in assessment surveys within each statistical district (black lines). Data points are only included when at least 30 lake trout per year were examined. Red circles show the proportions of wild lake trout examined from the Great Lakes Fish Tagging and Recovery Lab sampling between 2014 and 2017. The gray line represents 3% marking error, e.g. hatchery origin fish that were stocked with no fin clip.

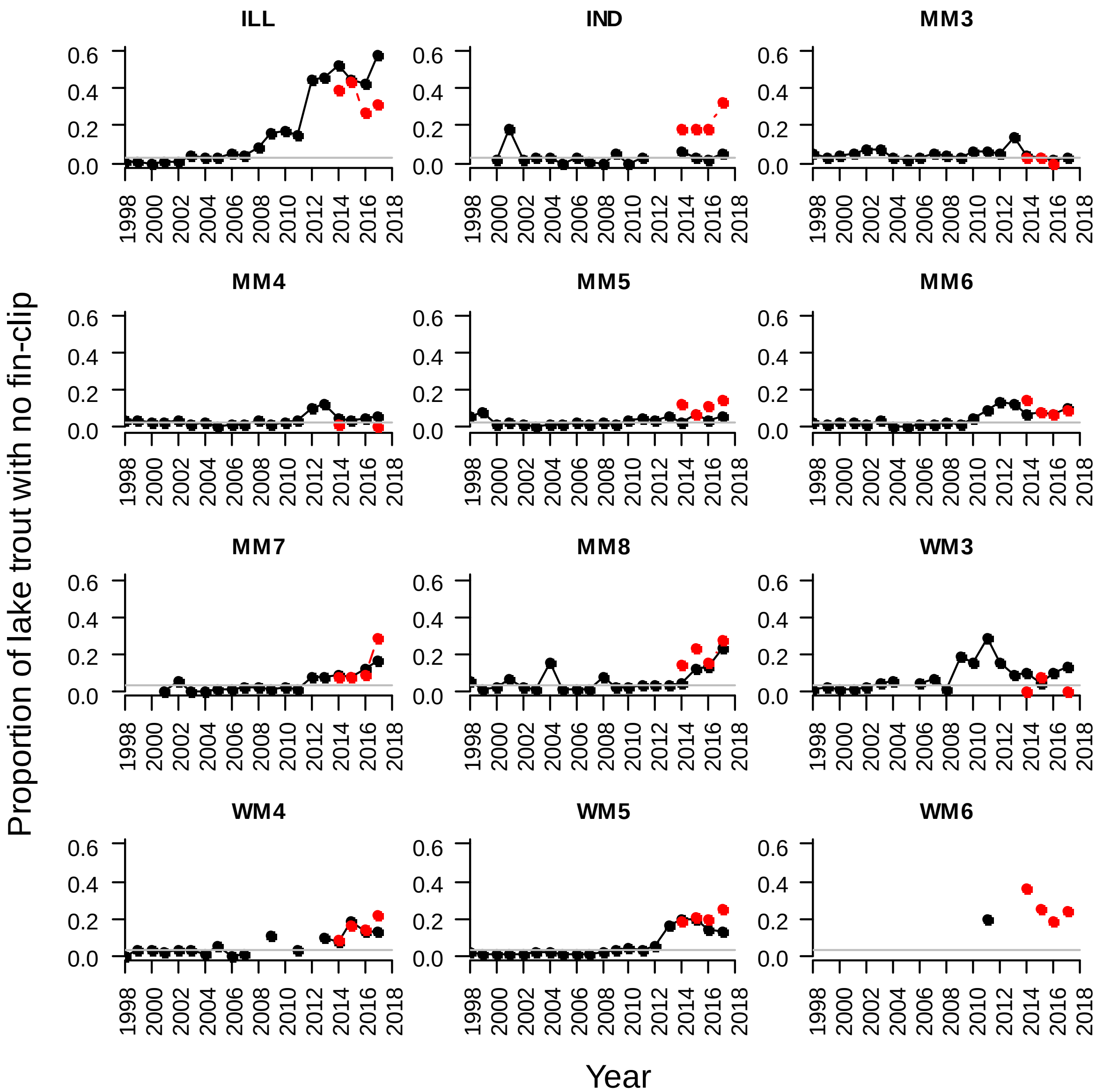


Figure 4. Wild lake trout age structure determined from recreationally caught fish creeled by the Great Lakes Fish Tagging and Recovery Lab (upper panel; n = 458) in 2017 and wild lake trout caught in assessment surveys (lower panel; n = 351) in 2017. Of the wild lake trout recoveries, ages were determined from 82% of the recreational fish and 42% of the assessment fish.

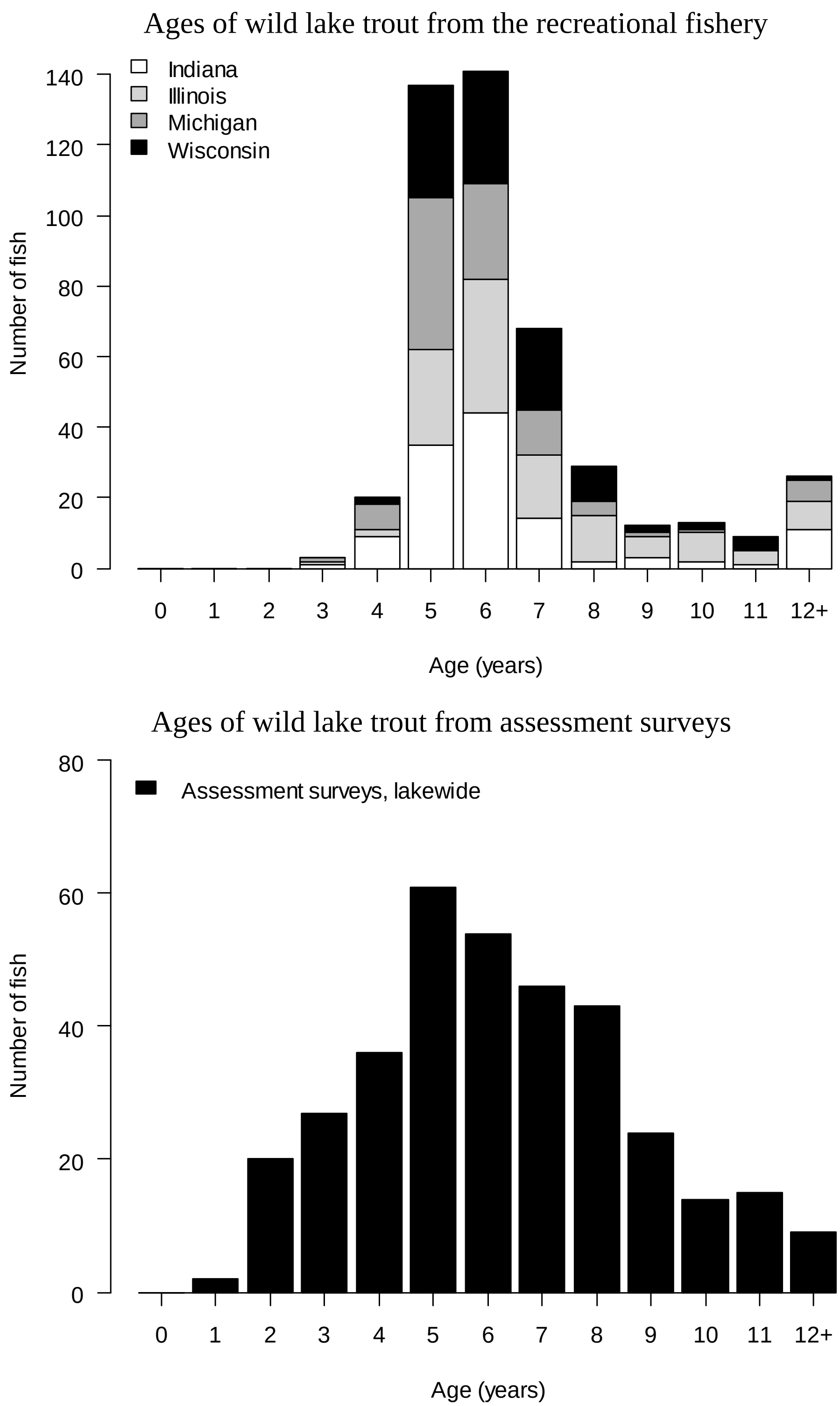


Figure 5. Number of lake trout (yearling equivalents) stocked in Lake Michigan by region, 1995 – 2017. In the "lakewide" panel, the black line represents the 3.53 million maximum stocking target prescribed in the Strategy while the red line represents the 2.74 million interim target that was reduced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

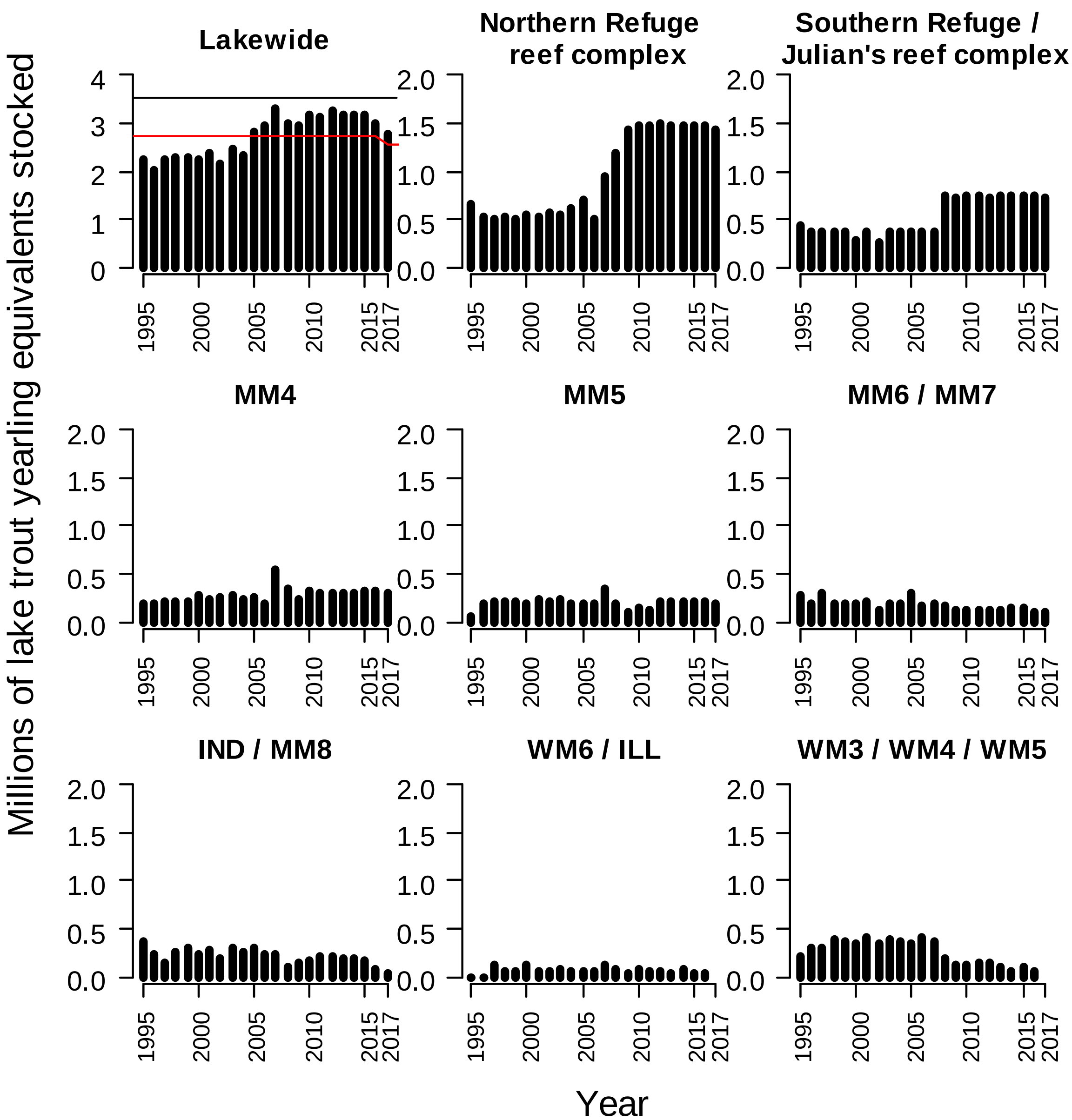
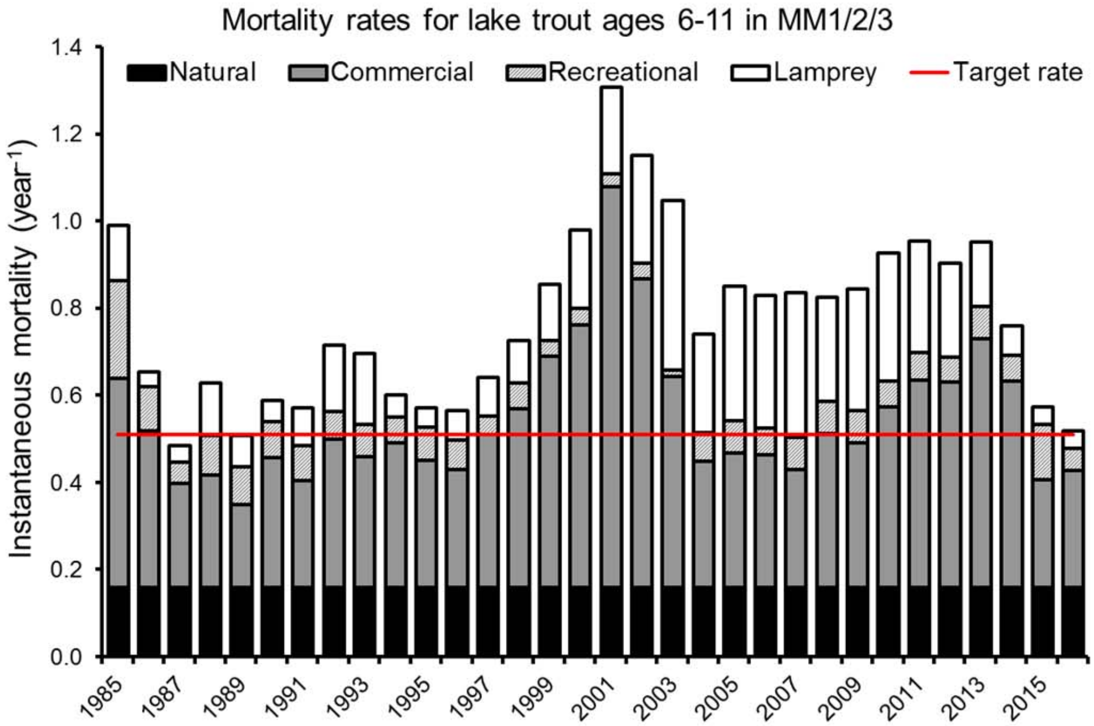


Figure 6. Instantaneous mortality rates for lake trout ages 6-11 in northern Lake Michigan and in MM6/7 waters proximal to the Southern Refuge. The red line represents an instantaneous mortality rate of 0.51 that is equivalent to a 40% annual mortality rate.



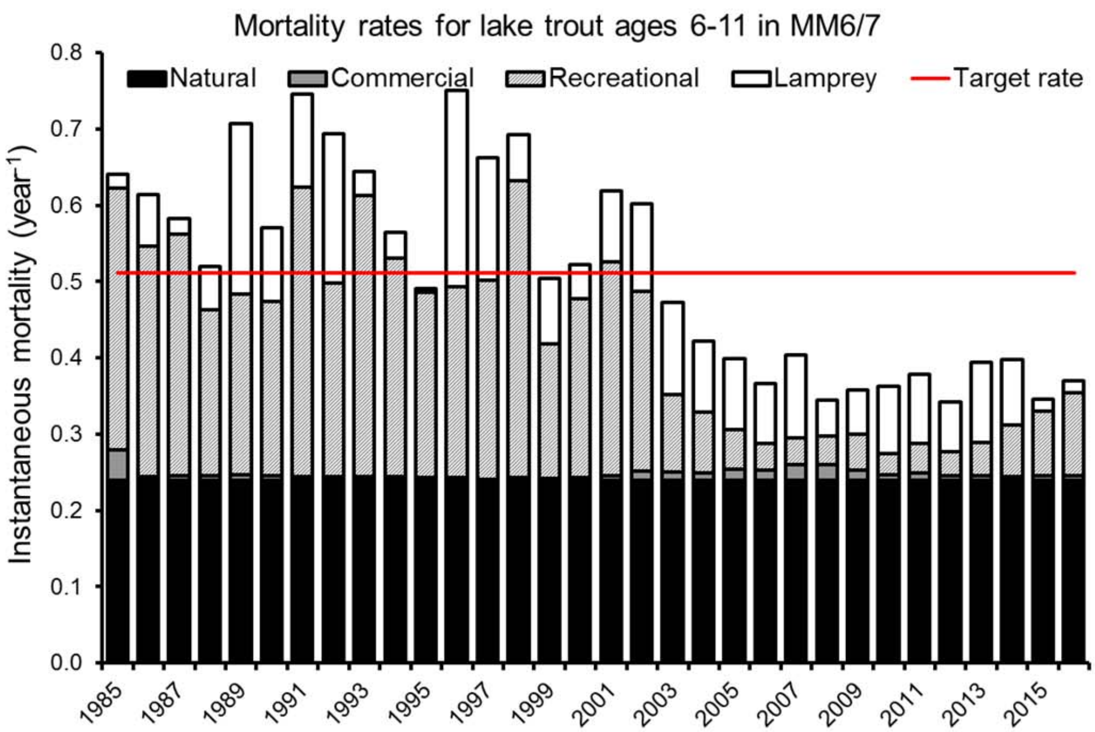


Figure 7. Sea lamprey-induced mortality on lake trout ages 6-11 for Lake Michigan management units MM1/2/3 and MM6/7.

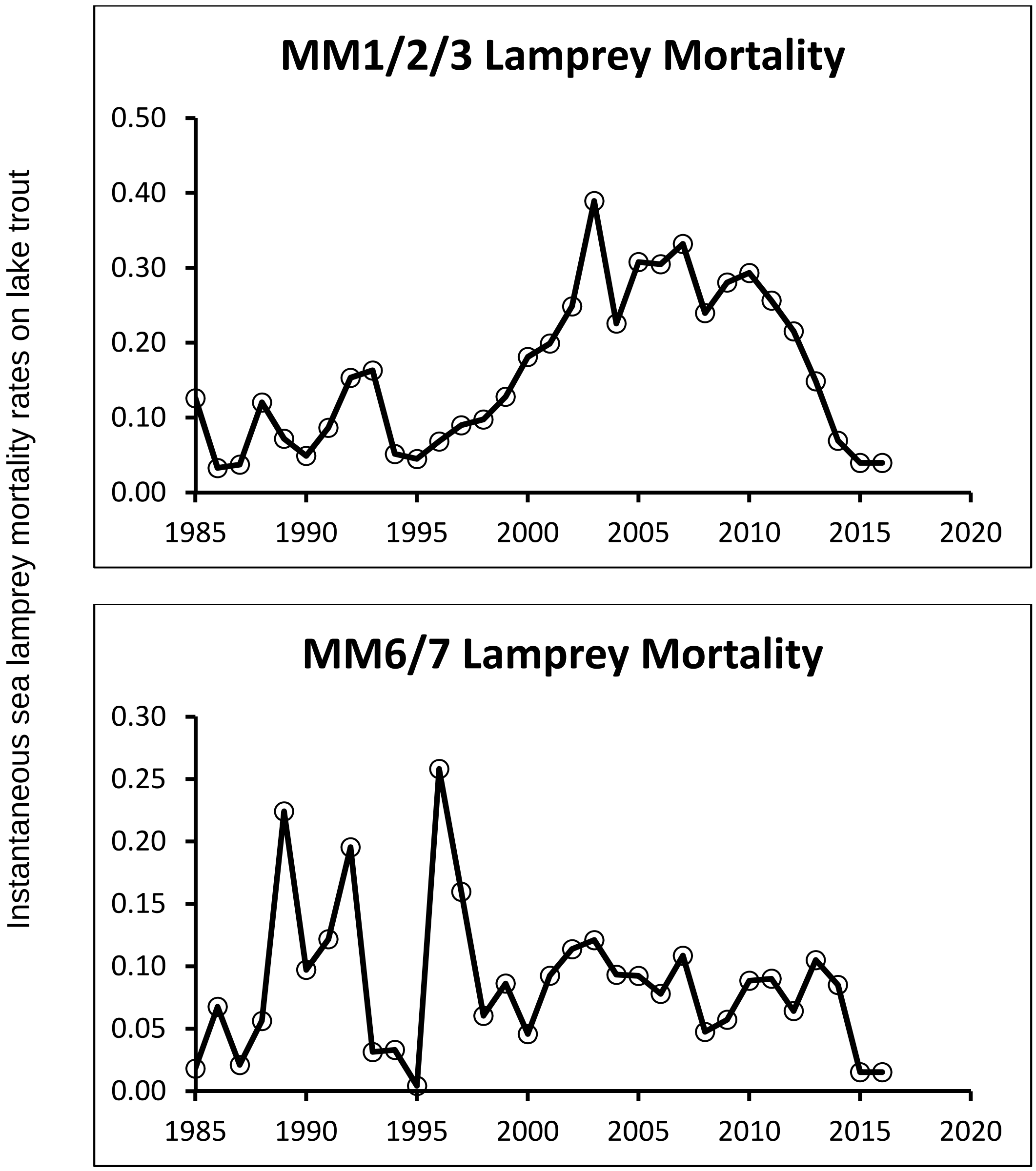


Figure 8. Time series of spring survey lake trout catch per effort (mean number of fish/1000 ft of graded mesh gill net) for the 11 LWAP sites plus 2 supplemental sites with comparable data (Grand Traverse Bay, Little Traverse Bay including nearshore MM3 waters). Vertical bars represent ± 2 SE and the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

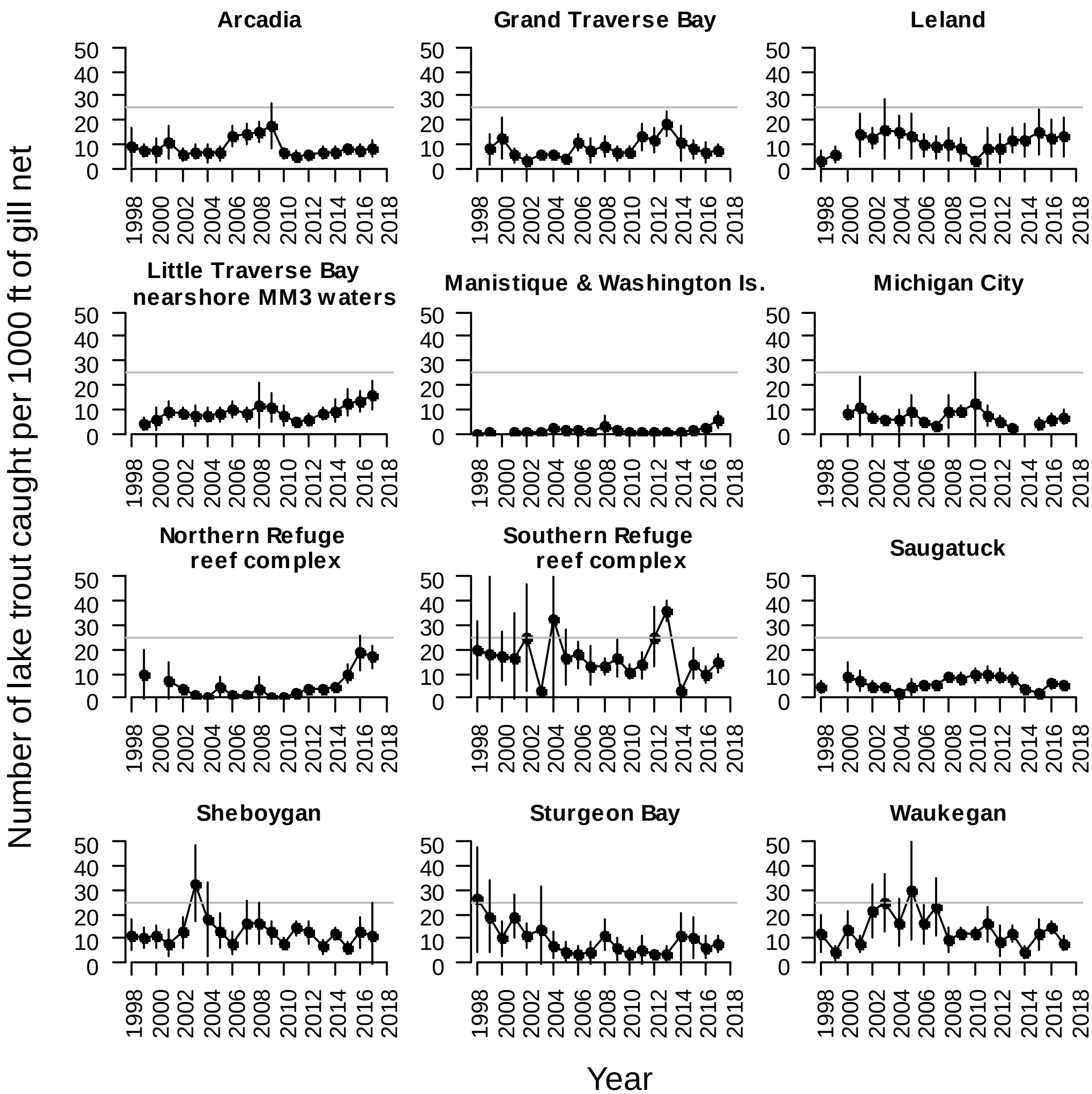


Figure 9. Time series of fall lake trout spawner survey catch per effort (mean number of fish/1000 ft of graded mesh gill net) for reefs within or near the spring LWAP stations. Vertical bars represent ± 2 SE and the horizontal gray line shows the fall CPE benchmark of 50 fish per 1000'.

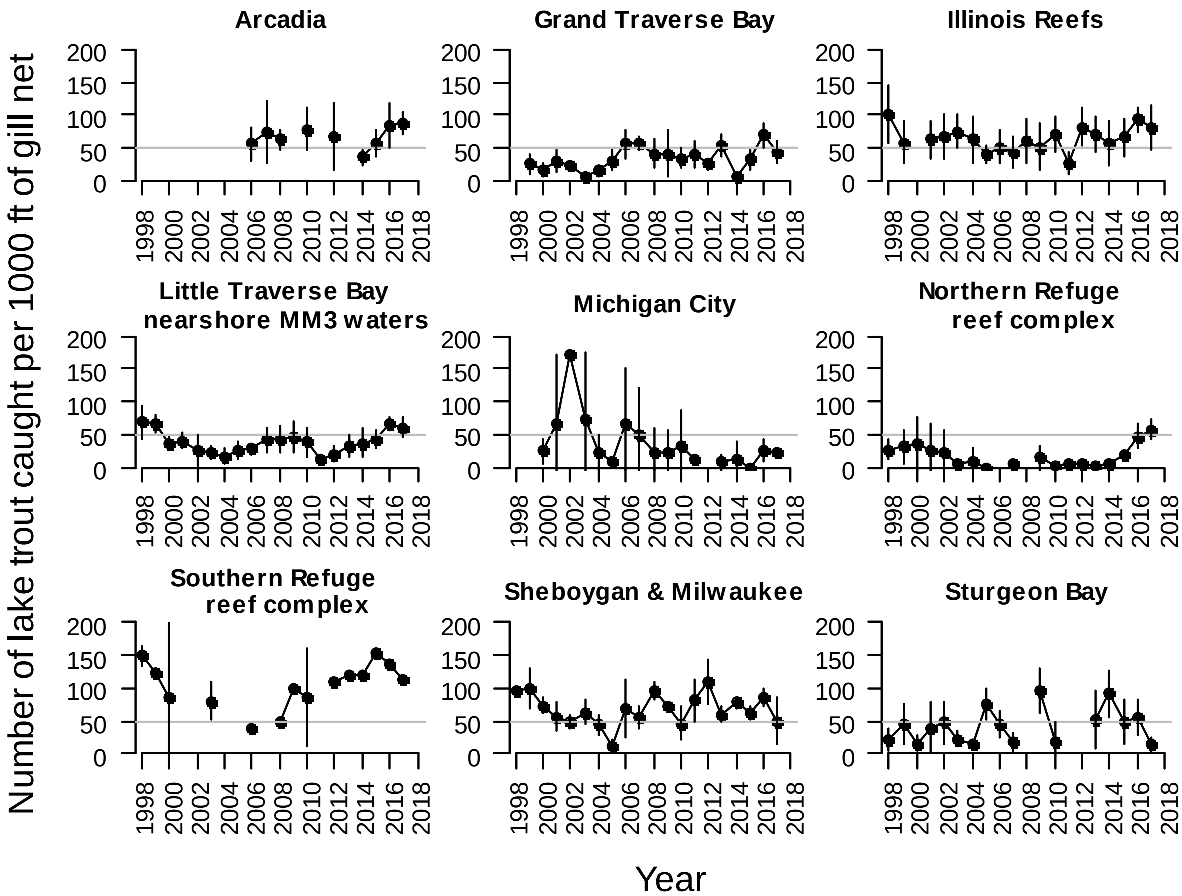


Figure 10. Proportion of females in fall spawner survey catches; the horizontal gray line portrays the Strategy evaluation objective of 25% females.

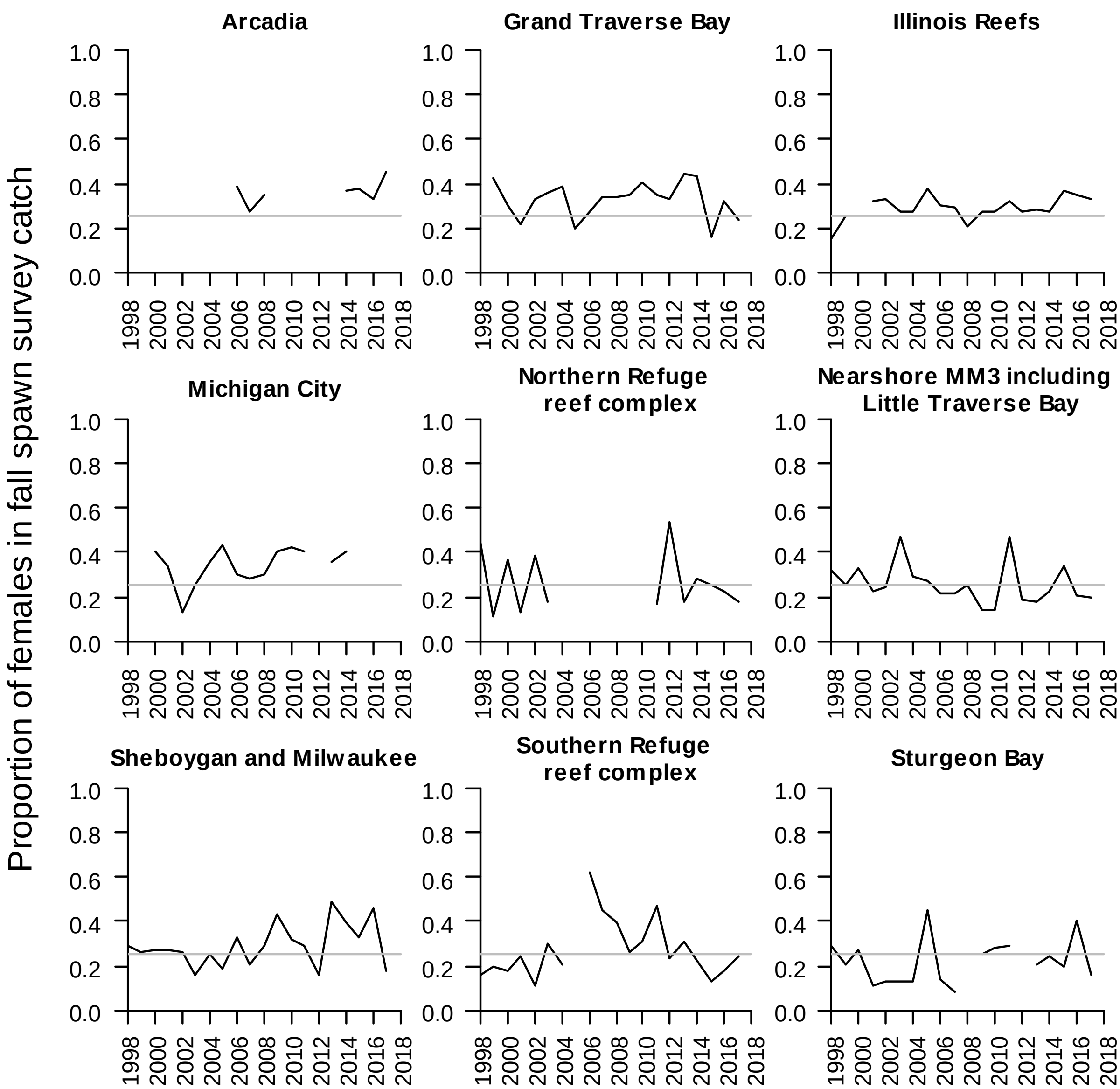


Figure 11. Number of lake trout captured during 2017 spawner surveys, by age-class and management unit. Fall survey ages were not available from other management units.

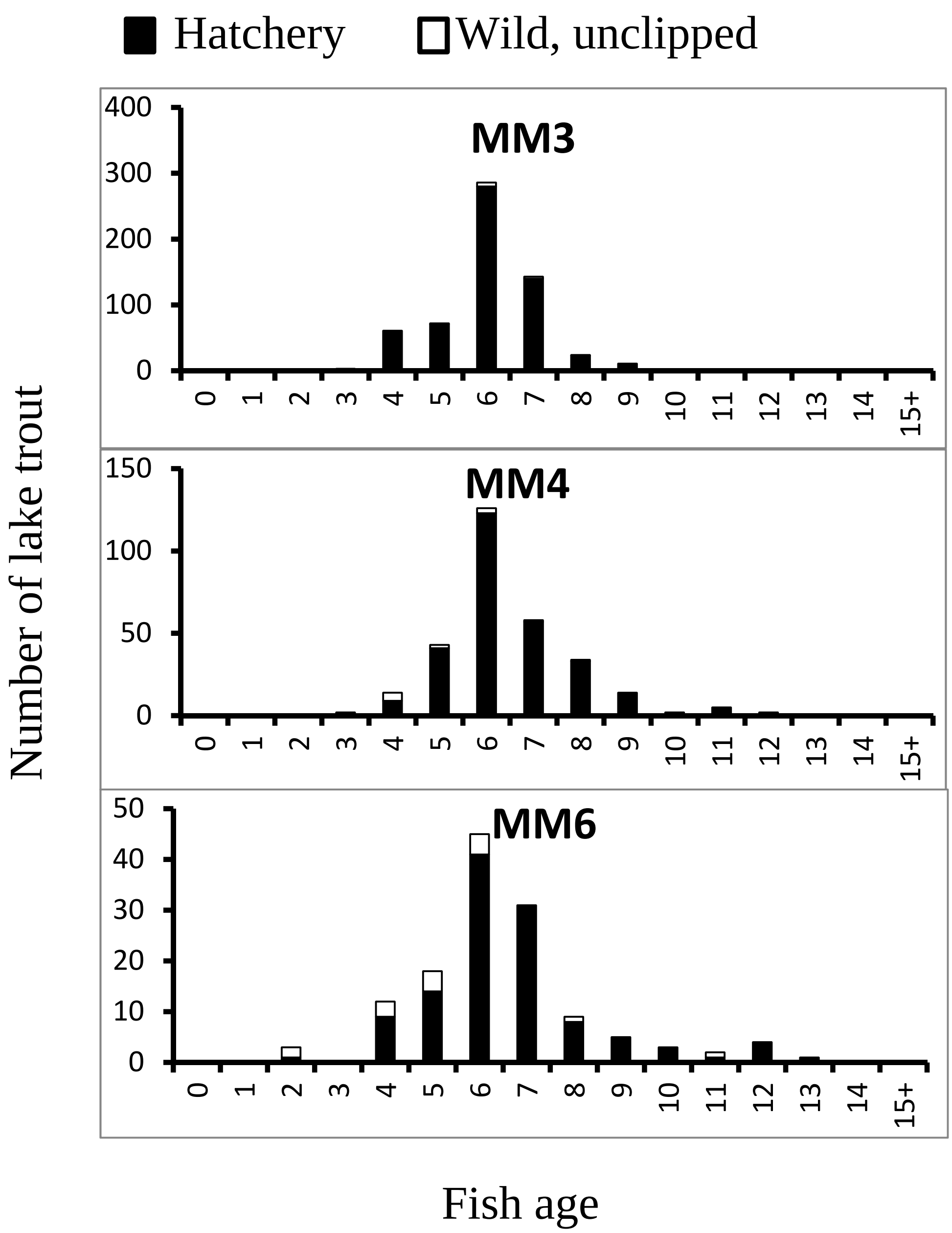


Figure 12. Numbers of lake trout eggs observed per square meter in northern Lake Michigan fall egg deposition surveys, 2000-2017. Egg deposition was measured using standard egg bag methodologies (Jonas et al.2005).

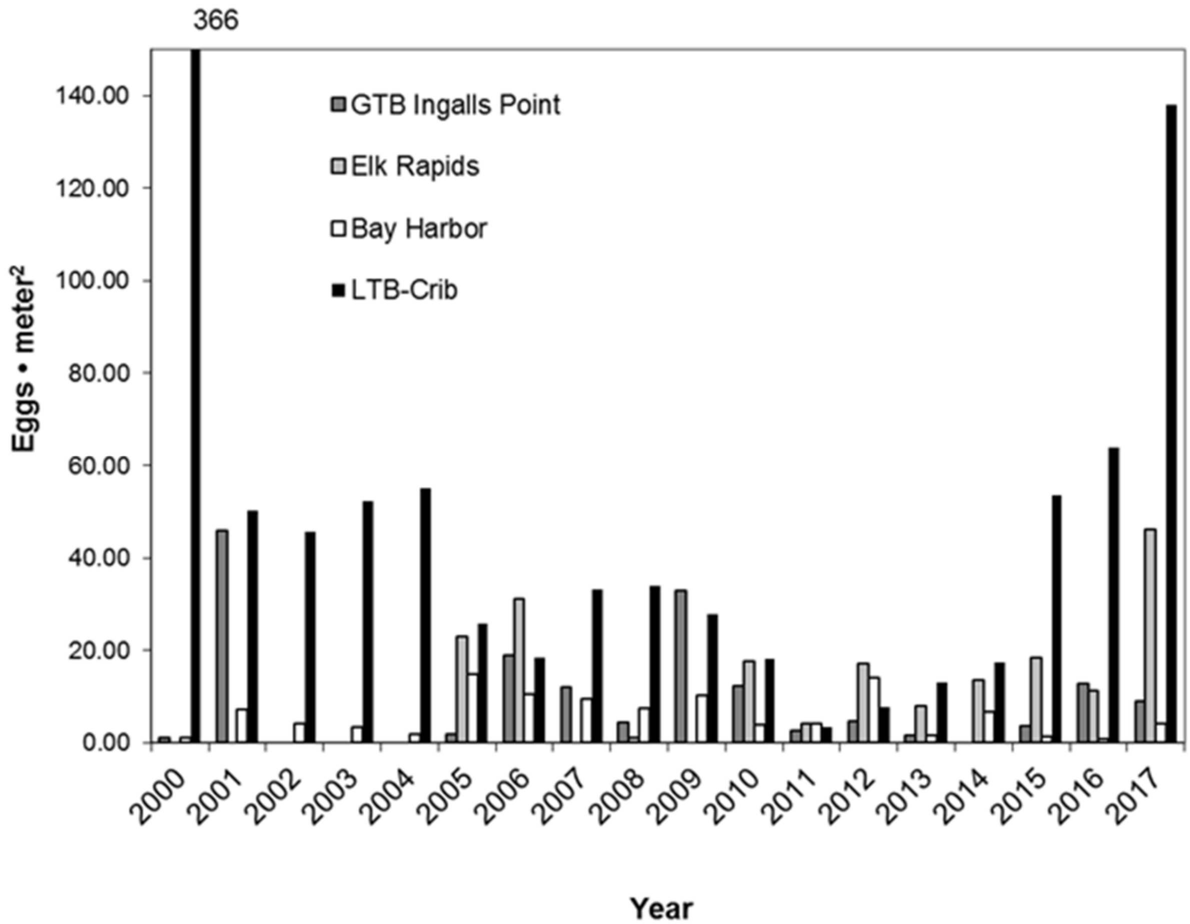


Figure 13. Mean egg thiamine concentrations (nmol/g) for ovulated lake trout females sampled in Lake Michigan fall spawner surveys, 2001 – 2013. Larvae produced from eggs with thiamine concentrations ≤ 4 nmol/g are often correlated with observations of thiamine deficiency complex (TDC).