Great Lakes lake trout (*Salvelinus namaycush*) thiamine monitoring program annual report

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Abstract

Thiamine deficiency in lake trout eggs has been identified to induce early life-stage mortality in the Great Lakes in the 1960s through the 1990s and potentially affecting lake trout recruitment. As a results, the U.S. Geological Survey's Great Lakes Science Center (GLSC), Eastern Ecological Science Center, and Columbia Environmental Research Center (CERC), and the State University of New York (SUNY) Brockport, in collaboration with partner agencies, have conducted a cooperative program to monitor thiamine concentrations in lake trout *Salvelinus namaycush* eggs since the late 1990s. In 2023, egg thiamine concentrations were highly variable at each sampling site. No egg samples with thiamine concentrations less than the 4 nmol/g threshold recommended for successful lake trout reproduction were collected in Lakes Superior or Huron. In contrast, 3 to 52% of the lake trout collected at sites in Lakes Michigan, Huron, Ontario and Champlain, and Cayuga Lake had eggs below 4 nmol/g. Time series of mean lake trout egg thiamine concentrations showed high temporal and spatial variability within the Great Lakes region.

Introduction

Lake trout *Salvelinus namaycush* were extirpated from Lakes Michigan, Erie, and Ontario and were greatly reduced in Lakes Huron and Superior by the 1950s, and rehabilitation efforts have been underway since the 1960s (Krueger et al. 1995; Krueger and Ebener 2004). Very little natural reproduction of lake trout was observed in the Great Lakes outside of Lake Superior until recently (e.g., Riley et al. 2007; Hanson et al. 2013; Roseman et al. 2020), suggesting that recruitment failure might be limiting rehabilitation. Low early life-stage survival of lake trout was observed in the Great Lakes in the 1960s through the 1990s and was thought to be a potential cause of the lack of natural recruitment of lake trout (Eshenroder et al. 1984; Harder et al. 2018). In the 1990s, it was determined that this mortality could be mitigated by thiamine (vitamin B_1) treatments (Fitzsimons 1995), suggesting that it was caused by insufficient thiamine, an essential nutrient. Subsequent research has demonstrated that low thiamine concentrations are common in Great Lakes lake trout and other salmonines (e.g., Fitzsimons et al. 2007; Futia et al. 2017; Futia and Rinchard 2019). This phenomenon, known as *Thiamine Deficiency Complex* (TDC; Riley and Evans 2008; previously referred to as Early Mortality Syndrome, or EMS), results in early life stage mortality of salmonines in the Great Lakes and may also decrease the performance and/or survival of juveniles and adults (Brown et al. 2005; Ketola et al. 2009).

Correlative studies have shown that diets consisting of mainly alewife (*Alosa pseudoharengus*) can result in TDC (Fitzsimons et al., 2010; Riley et al., 2011), and laboratory studies have induced thiamine deficiencies in salmonines by providing alewife-rich diets (Honeyfield et al., 2005). In addition, following the collapse of alewife in Lake Huron, lake trout egg thiamine concentrations increased and coincided with large increases in wild recruitment of lake trout (Fitzsimons et al., 2010; Riley et al., 2011).

Thiamine deficiency complex may be an impediment to natural recruitment by lake trout in the Great Lakes presenting a potential obstacle to lake trout restoration programs, and egg thiamine concentrations greater than 4 nmol/g have been recommended for successful lake trout reproduction (Fitzsimons et al. 2007; Bronte et al. 2008). The egg thiamine concentration associated with 20% fry mortality (ED20) for lake trout has been estimated to be 2.63 nmol/g (Fitzsimons et al. 2007), whereas sublethal effects (i.e., 20-50% reductions in foraging and growth rates) of low thiamine on lake trout fry occur when thiamine concentrations are less than approximately 3-8 nmol/g (Fitzsimons et al. 2009). More recently, Futia and Rinchard (2019) determined that the lethal concentration inducing 50% fry mortality was 2.32 nmol/g.

The U.S. Geological Survey's Great Lakes Science Center (GLSC), Eastern Ecological Science Center (EESC), and Columbia Environmental Research Center (CERC), and the State University of New York (SUNY) Brockport have conducted a cooperative program to monitor thiamine concentrations in lake trout eggs since the late 1990s. Partner agencies include Illinois Department of Natural Resources (DNR), Indiana DNR, Michigan DNR, Wisconsin DNR, Little Traverse Bay Bands of Odawa Indians, Grand Traverse Band of Ottawa and Chippewa Indians, Little River Band of Ottawa Indians, Illinois Natural History Survey, U.S. Fish and Wildlife Service, U.S. Geological Survey (USGS), New York State Department of Environmental Conservation, University of Vermont, SUNY Brockport, Chippewa Ottawa Resource Authority, and Ontario Ministry of Natural Resources and Forestry.

The 2023 data associated with this report are in review and will be released publicly at https://doi.org/10.5066/P1JUOZ3B. Data used in this report collected prior to 2023 are publicly available (Honeyfield et al. 2020, Tillitt et al. 2021). 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 (Use of Fishes in Research Committee 2014 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

In 2023, collections of unfertilized eggs from lake trout took place at sites in Lakes Superior, Michigan, Huron, Erie, Ontario, and Champlain, and Cayuga Lake by partner agencies during fall spawning assessments (Figure 1 and Table 1). Lake trout egg collections from Lake Champlain and Cayuga Lake were included in the analyses because both lakes contain alewives, are sources of lake trout stockings in the Great Lakes, and present contrast with the Great Lakes in terms of lake size and productivity, levels of natural reproduction, and strains present. Eggs were frozen soon after collection and shipped to SUNY Brockport for thiamine analysis. Eggs from individual females at each site were processed for thiamine analysis. Free thiamine (TH), thiamine monophosphate (TMP), and thiamine pyrophosphate (TPP) were extracted following Brown et al. (1998) using 1 g of eggs (about 8-10 eggs) homogenized in a 2% trichloroacetic acid solution. Lake trout egg thiamine extracts were then quantified using high-performance liquid chromatography (HPLC) according to Brown et al. (1998) with modifications following Futia et al. (2017). All samples were analyzed in duplicate. Two method blanks were included after every 15 samples for quality assurance. A six-point standard curve with known concentrations of thiamine (0, 1, 2.5, 5, 10, and 30 nmol/g) was generated at the start of each group of samples run. All thiamine concentrations reported here represent total thiamine (sum of the three vitamers, TH, TMP, and TPP). Thiamine concentrations in lake trout eggs are reported for each site (individual data, mean, box plot with minimum, maximum, median, first and third quartiles) as well as the estimated proportion of egg samples that were below the threshold of 4 nmol/g thiamine. Longterm changes in thiamine concentrations are also presented for select sites in this report (Data courtesy of: Dale Honeyfield - USGS Eastern Ecological Science Center, Stephen Riley – USGS Great Lakes Science Center, Donald Tillitt – USGS Columbia Environmental Research Center, Ellen Marsden – University of Vermont, and Jacques Rinchard – SUNY Brockport). From 2005 to 2020, thiamine concentrations were measured using the rapid solid phase extraction fluorometric method (RSPE) developed by Zajicek et al. (2005). Thiamine concentrations measured using the RSPE method were not adjusted to be comparable to the HPLC results in the time series presented. However, results from both methods were found to be highly correlated (Zajicek et al. 2005, Riley et al. 2011).

Results and Discussion

Egg thiamine concentration in lake trout eggs collected in 2023 ranged from 5.3 to 24.4 nmol/g in Lake Superior, from 1.1 to 22.7 nmol/g in Lake Michigan, from 5.3 to 27.3 nmol/g in Lake Huron, from 3.5 to 40.8 nmol/g in Lake Erie, from 2.2 to 29.8 nmol/g in Lake Ontario, from 3.1 to 8.3 nmol/g in Lake Champlain, and from 2.3 to 12.0 nmol/g in Cayuga Lake (Figure 2 and Table 1). Egg thiamine concentrations were highly variable at each sampling site (Figure 2). No egg samples with thiamine concentrations less than the 4 nmol/g threshold recommended for successful lake trout reproduction were collected in Lakes Superior and Huron (Figure 3, Table 1). One egg sample collected from the eastern basin of Lake Erie had its thiamine concentration below 4 nmol/g. In Lake Michigan, all the sites had females with eggs below 4 nmol/g. However, the percentage of spawning females with egg thiamine concentrations below the 4 nmol/g threshold was less than 20% except at Waukegan Reef (25%) and Grand Traverse Bay (43%) (Figure 3, Table 1). The three of the five sites sampled in Lake Ontario (Hamlin, Fairhaven, and Oswego) had eggs below 4 nmol/g (Figure 3, Table 1). Fifty-two and thirty percent of fish collected in Cayuga Lake and Lake Champlain had their egg thiamine concentrations below 4 nmol/g (Figure 3, Table 1).

Time series of egg thiamine concentrations (nmol/g, individual data and mean per site) in lake trout eggs collected at selected sites are reported in Figures 4 to 10. These figures showed high temporal and spatial variability in egg thiamine concentrations within the Great Lakes region. Continued annual monitoring will enable evaluation of the effects of TDC on lake trout recruitment.

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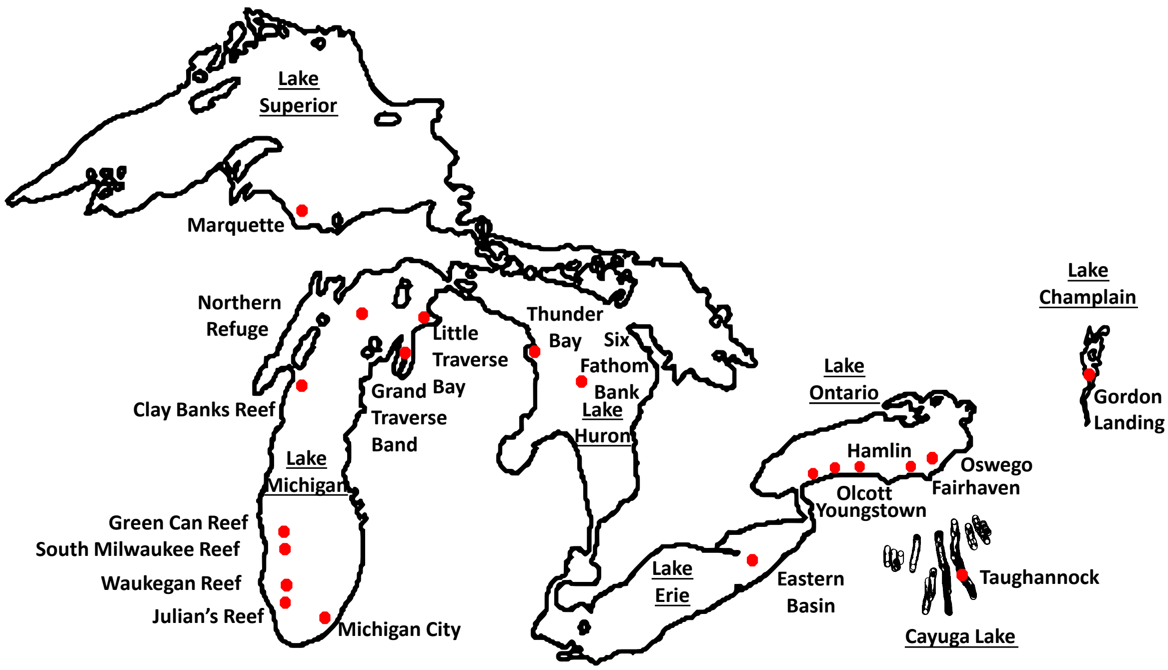

Figure 1: Lake trout (*Salvelinus namaycush*) egg sampling sites in 2023. A total of 350 egg samples were collected in 2023 throughout the Great Lakes region.

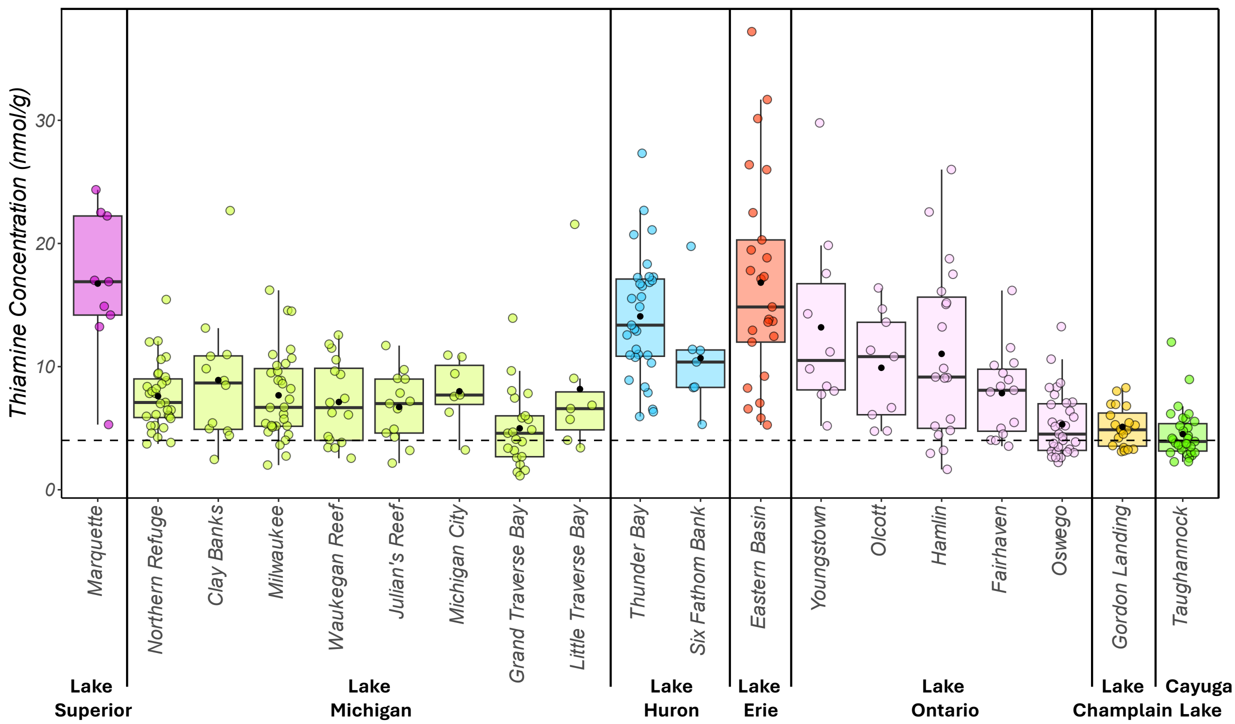

Figure 2: Thiamine concentrations in lake trout (*Salvelinus namaycush*) eggs (each color dot represents a measurement from a separate female, box plot with average – black dot, minimum, maximum, median, first and third quartiles) collected in 2023 at 19 locations across 7 lakes within the Great Lakes region. Milwaukee includes Green Can Reef and South Milwaukee Reef. The dashed black line represents the recommended egg thiamine threshold of 4 nmol/g for successful lake trout recruitment (Bronte et al. 2008).

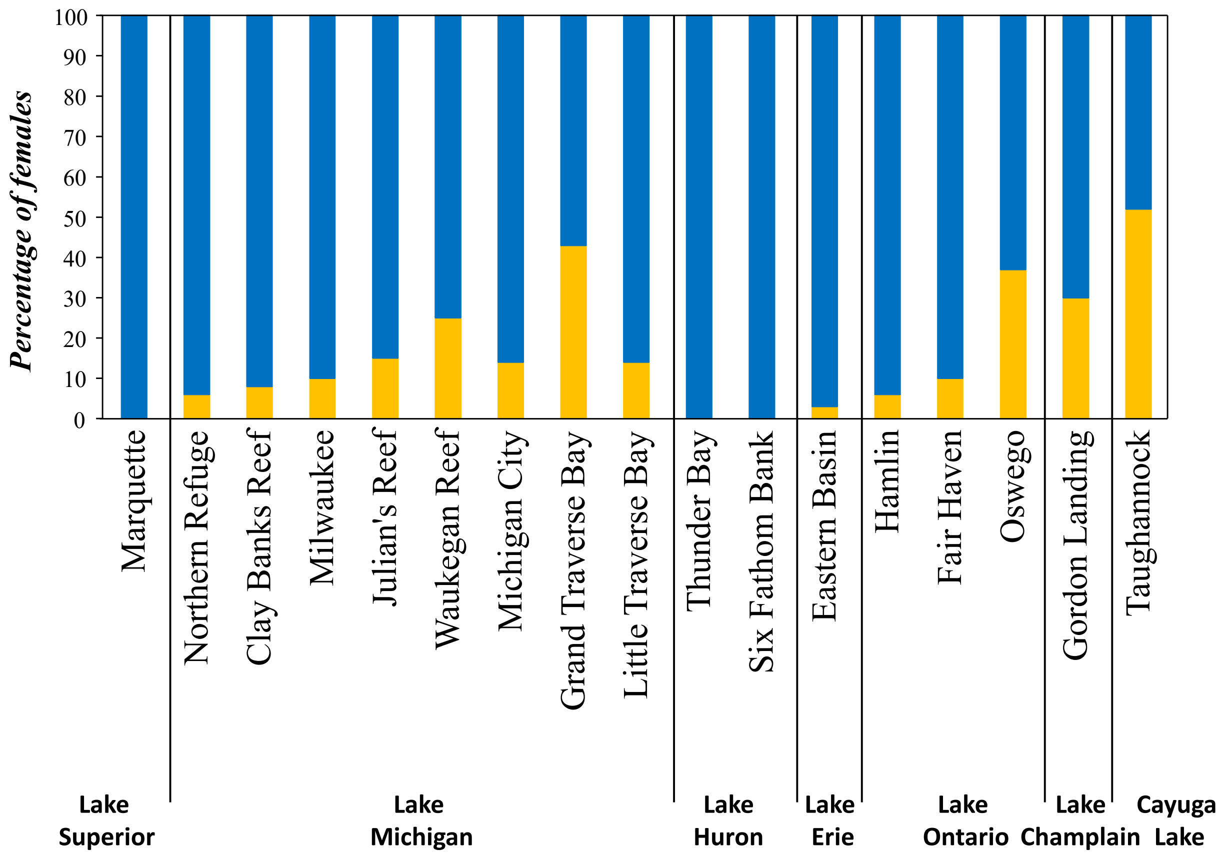

Figure 3: Percentage of lake trout (*Salvelinus namaycush*) females collected in 2023 at 19 locations across 7 lakes within the Great Lakes region with egg thiamine concentration below (orange) or above (blue) the recommended threshold of 4 nmol/g for successful lake trout recruitment (Bronte et al. 2008). Milwaukee includes Green Can Reef and South Milwaukee Reef.

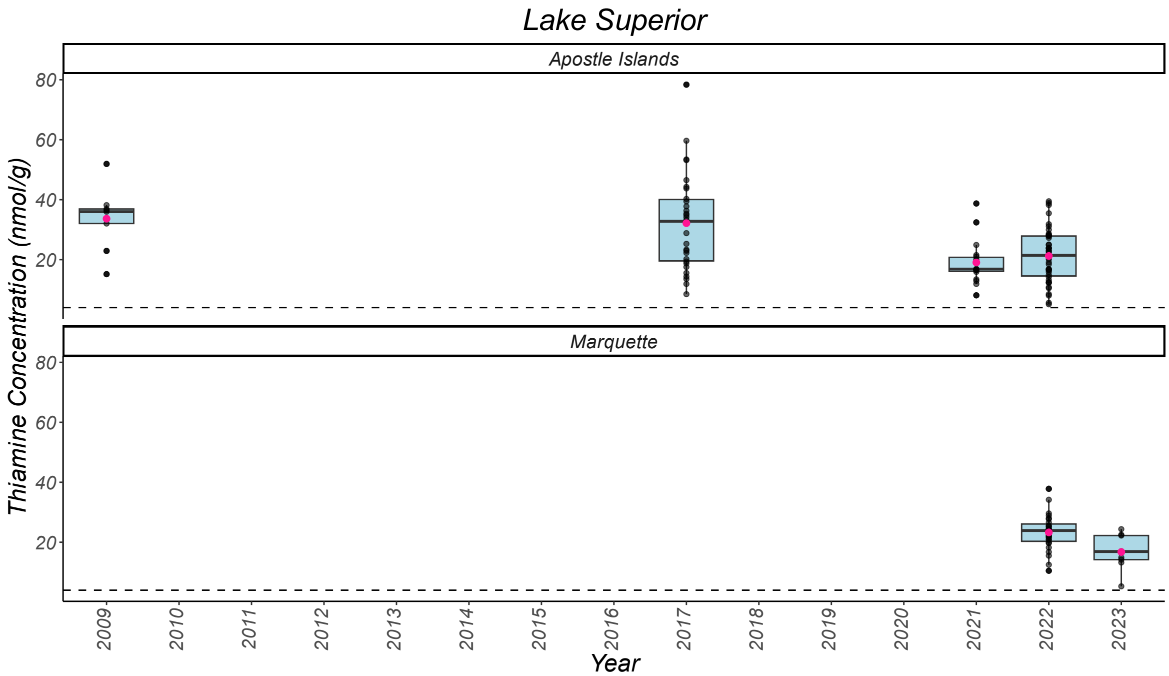

Figure 4: Thiamine concentrations in lake trout (*Salvelinus namaycush*) eggs (each black dot represents a measurement from a separate female, box plot with average (pink dot), minimum, maximum, median, first and third quartiles) at 2 sampling sites in Lake Superior from 2009 to 2023. The dashed black line represents the recommended egg thiamine threshold of 4 nmol/g for successful lake trout recruitment (Bronte et al. 2008).

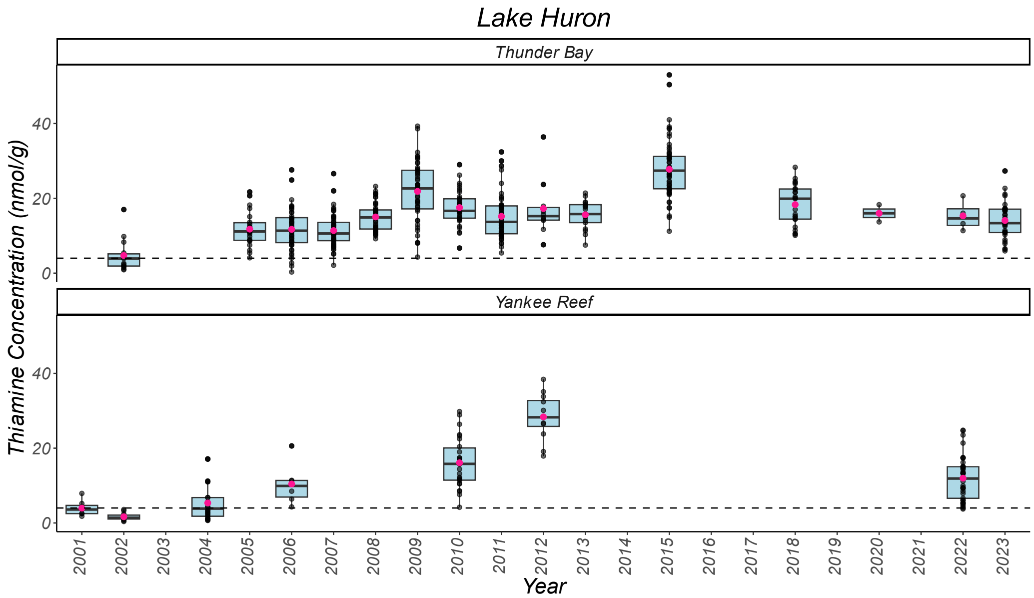

Figure 5: Thiamine concentrations in lake trout (*Salvelinus namaycush*) eggs (each black dot represents a measurement from a separate female, box plot with average (pink dot), minimum, maximum, median, first and third quartiles) at 2 sampling sites in Lake Huron from 2001 to 2023. The dashed black line represents the recommended egg thiamine threshold of 4 nmol/g for successful lake trout recruitment (Bronte et al. 2008).

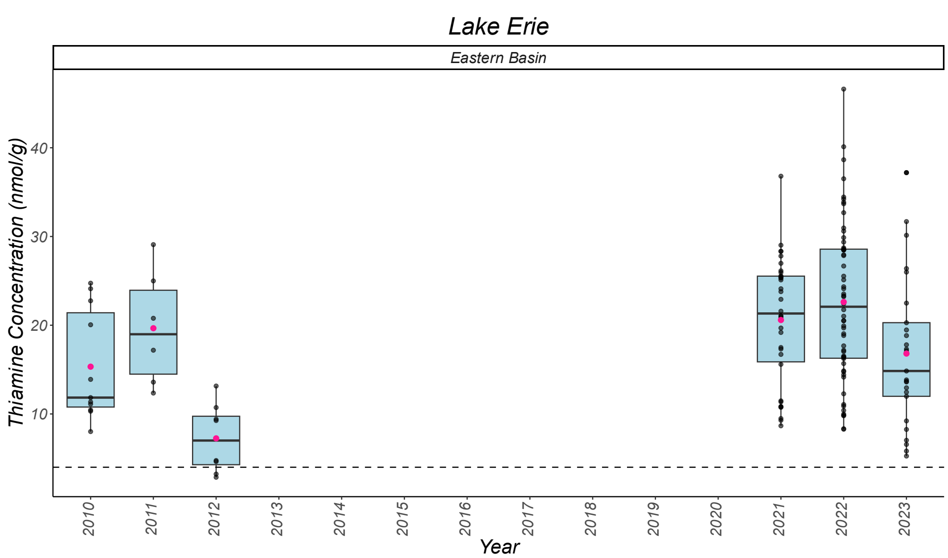

Figure 6: Thiamine concentrations in lake trout (*Salvelinus namaycush*) eggs (each black dot represents a measurement from a separate female, box plot with average (pink dot), minimum, maximum, median, first and third quartiles) in the eastern basin of Lake Erie from 2010 to 2023. The dashed black line represents the recommended egg thiamine threshold of 4 nmol/g for successful lake trout recruitment (Bronte et al. 2008).

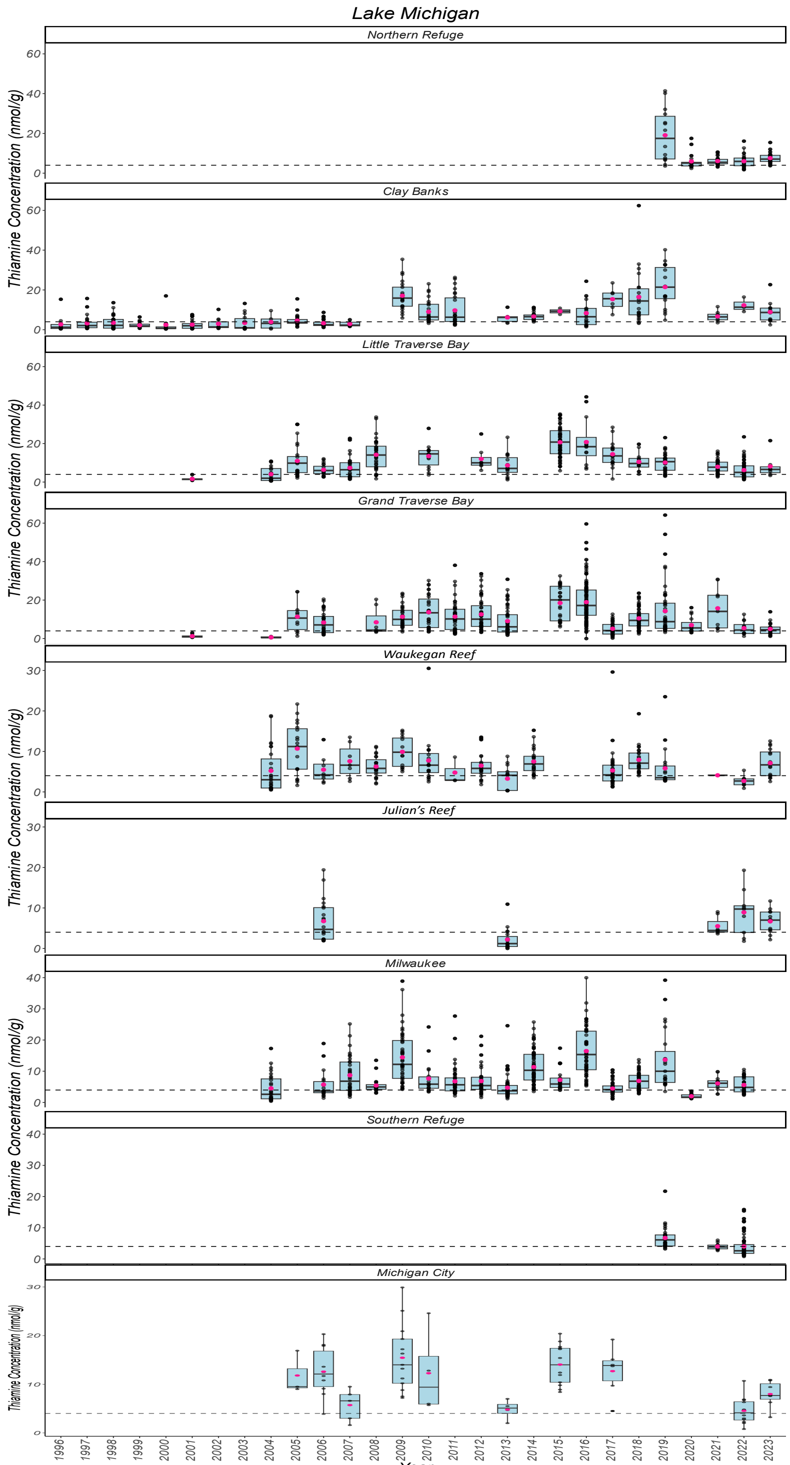

Figure 7: Thiamine concentrations in lake trout (*Salvelinus namaycush*) eggs (each black dot represents a measurement from a separate female, box plot with average (pink dot), minimum, maximum, median, first and third quartiles) at 9 sampling sites in Lake Michigan from 1996 to 2023. The dashed black line represents the recommended egg thiamine threshold of 4 nmol/g for successful lake trout recruitment (Bronte et al. 2008).

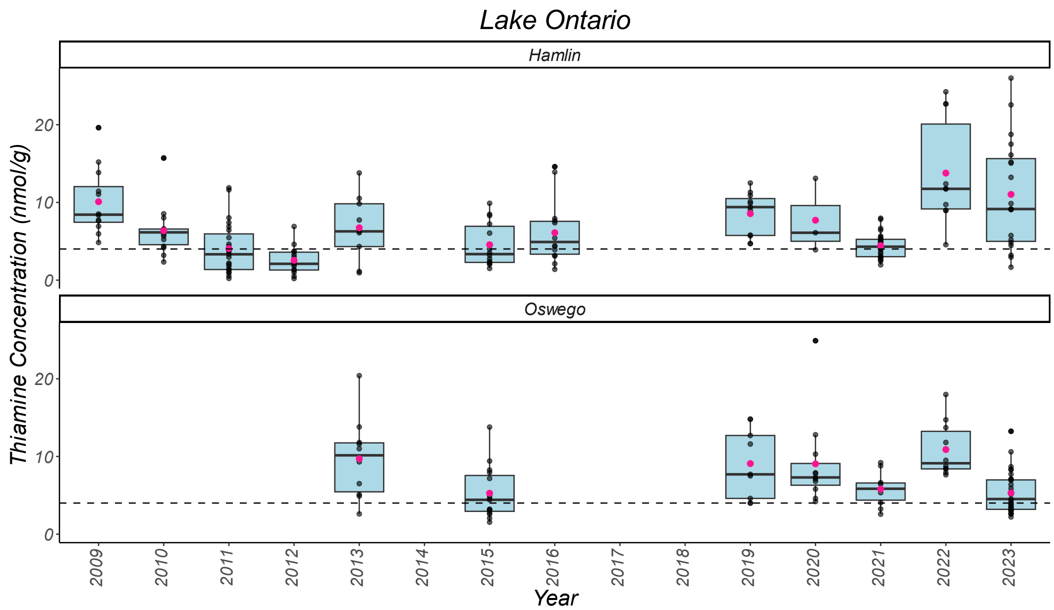

Figure 8: Thiamine concentrations in lake trout (*Salvelinus namaycush*) eggs (each black dot represents a measurement from a separate female, box plot with average (pink dot), minimum, maximum, median, first and third quartiles) at 2 sampling sites in Lake Ontario from 2009 to 2023. The dashed black line represents the recommended egg thiamine threshold of 4 nmol/g for successful lake trout recruitment (Bronte et al. 2008).

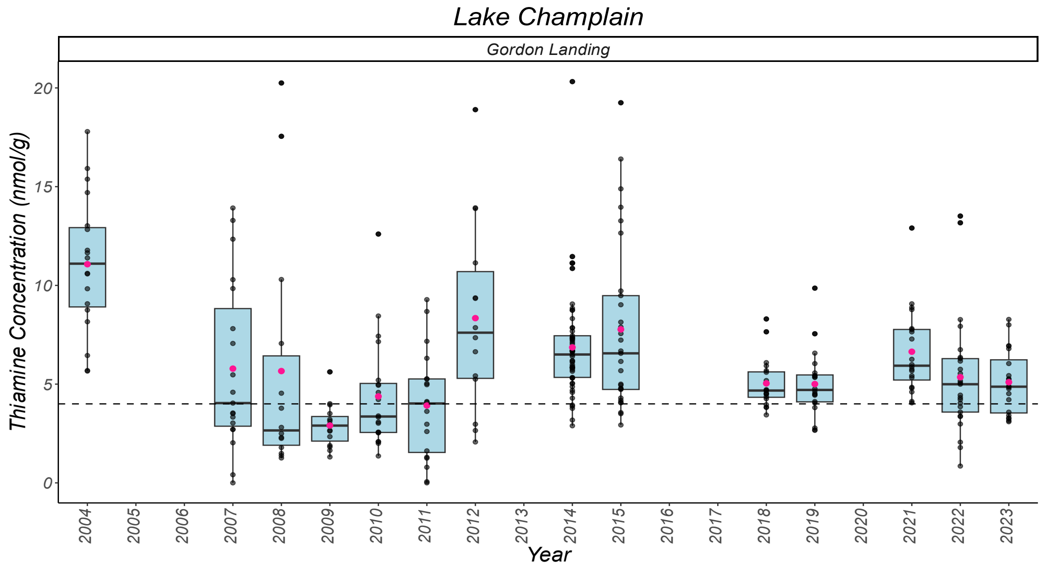

Figure 9: Thiamine concentrations in lake trout (*Salvelinus namaycush*) eggs (each black dot represents a measurement from a separate female, box plot with average (pink dot), minimum, maximum, median, first and third quartiles) at 1 sampling site in Lake Champlain from 2004 to 2023. The dashed black line represents the recommended egg thiamine threshold of 4 nmol/g for successful lake trout recruitment (Bronte et al. 2008).

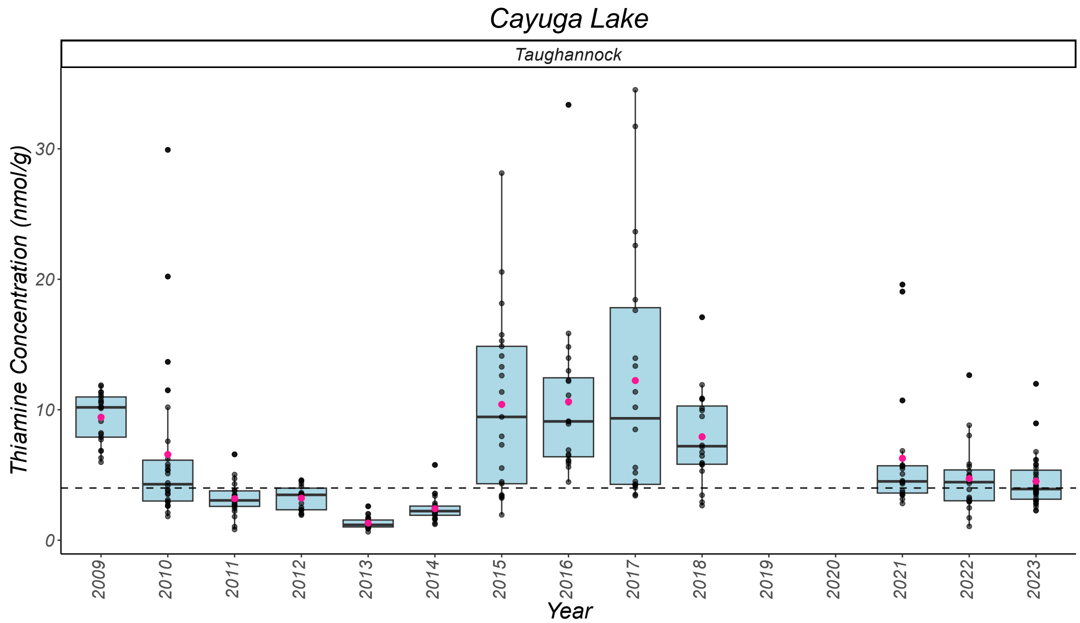

Figure 10: Thiamine concentrations in lake trout (*Salvelinus namaycush*) eggs (each black dot represents a measurement from a separate female, box plot with average (pink dot), minimum, maximum, median, first and third quartiles) at 1 sampling site in Cayuga Lake from 2009 to 2023. The dashed black line represents the recommended egg thiamine threshold of 4 nmol/g for successful lake trout recruitment (Bronte et al. 2008).

Table 1: Lake trout (*Salvelinus namaycush*) mean egg thiamine concentration (nmol/g) collected in 2023 at 19 sampling sites across 7 lakes within the Great Lakes region. n = sample size, T = mean total thiamine concentration, SD = standard deviation, Min = minimum thiamine concentration, Max = maximum thiamine concentration. See Figure 1 for site locations.

Locations	n	T	SD	Min T	Max T	% Females < 4 nmol/g
<u>*Lake Superior*</u>						
Marquette	8	17.0	6.2	5.3	24.4	0
<u>*Lake Michigan*</u>						
Northern Refuge	31	7.6	2.7	3.7	15.4	6
Clay Banks Reef	12	8.9	5.4	2.5	22.7	8
Milwaukee (Green Can/South Milwaukee. Reefs)	31	7.7	3.5	2.0	16.2	10
Julian's Reef	13	6.7	2.8	2.2	11.7	15
Waukegan Reef	16	7.1	3.4	2.6	12.6	25
Michigan City	7	8.0	2.7	3.2	10.9	14
Grand Traverse Bay	21	5.0	3.1	1.1	13.9	43
Little Traverse Bay	7	8.2	6.2	3.4	21.5	14
<u>*Lake Huron*</u>						
Thunder Bay	31	14.1	5.1	5.9	27.3	0
Six Fathom Bank	7	10.7	4.5	5.3	19.8	0
<u>*Lake Erie*</u>						
Eastern Basin	31	16.6	9.3	3.5	40.8	3
<u>*Lake Ontario*</u>						
Youngstown	10	13.8	7.5	5.2	29.8	0
Olcott	9	9.9	4.5	4.8	16.4	0
Hamlin	16	12.5	6.7	3.0	26.0	6
Fairhaven	10	7.8	3.5	3.5	16.2	10
Oswego	35	5.3	2.6	2.2	13.2	37
<u>*Lake Champlain*</u>						
Gordon Landing	20	5.1	1.6	3.1	8.3	30
<u>*Cayuga Lake*</u>						
Taughannock	31	4.5	2.0	2.3	12.0	52