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

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Abstract

Thiamine deficiency in lake trout (*Salvelinus namaycush*) eggs has been linked to early life-stage mortality in the Great Lakes from the 1960s through the 1990s, potentially affecting lake trout recruitment. In response, 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, in collaboration with partner agencies, initiated a cooperative monitoring program in the late 1990s to assess thiamine concentrations in lake trout eggs. In 2024, egg thiamine concentrations continued to show high variability across sampling sites. No samples with thiamine concentrations below the 4 nmol/g threshold recommended for successful reproduction were observed in Lakes Superior or Huron. In contrast, between 11% and 88% of lake trout sampled from sites in Lakes Michigan, Ontario, Champlain, and the Finger Lakes had egg thiamine concentrations below this critical threshold. Time series data revealed substantial temporal and spatial variation in mean lake trout egg thiamine concentrations across 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). Until recently, natural reproduction of lake trout in the Great Lakes—outside of Lake Superior—was rare (e.g., Riley et al. 2007; Hanson et al. 2013; Roseman et al. 2020), suggesting that recruitment failure may have hindered their recovery. Low early life-stage survival was documented from the 1960s through the 1990s and was suspected to contribute to the lack of natural recruitment (Eshenroder et al. 1984; Harder et al. 2018).

In the 1990s, it was determined that this mortality could be mitigated through thiamine (vitamin B_1) treatments (Fitzsimons 1995), indicating a deficiency of this essential nutrient as a likely cause. Subsequent studies confirmed that low thiamine concentrations are widespread in lake trout and other salmonines in the Great Lakes (e.g., Fitzsimons et al. 2007; Futia et al. 2017; Futia and Rinchard 2019). This condition, known as Thiamine Deficiency Complex, or TDC (Riley and Evans 2008), and formerly referred to as Early Mortality Syndrome (EMS), results in early life-stage mortality in salmonines and may also impair performance and/or survival of juveniles and adults (Brown et al. 2005; Ketola et al. 2009).

Correlative studies have shown that diets dominated by alewife (*Alosa pseudoharengus*) are associated with the development of TDC in salmonines (Fitzsimons et al., 2010; Riley et al., 2011). Laboratory studies have further demonstrated that feeding salmonines alewife-rich diets can directly induce thiamine deficiency (Honeyfield et al., 2005). Notably, following the collapse of alewife population in Lake Huron, thiamine concentrations in lake trout eggs increased, coinciding with a marked increase in natural recruitment of wild lake trout (Fitzsimons et al., 2010; Riley et al., 2011).

Thiamine Deficiency Complex may hinder natural recruitment of lake trout in the Great Lakes, posing a significant challenge to ongoing restoration efforts. Egg thiamine concentrations above 4 nmol/g have been recommended to support successful reproduction (Fitzsimons et al. 2007; Bronte et al. 2008). The egg thiamine concentration associated with 20% fry mortality (ED_{20}) in lake trout has been estimated at 2.63 nmol/g (Fitzsimons et al. 2007), while sublethal effects—such as 20-50% reductions in foraging efficiency and growth—have been observed when egg thiamine concentrations fall below approximately 3–8 nmol/g (Fitzsimons et al. 2009). More recently, Futia and Rinchard (2019) reported that the concentration causing 50% fry mortality (LC_{50}) was 2.32 nmol/g.

The U.S. Geological Survey's Great Lakes Science Center (GLSC), Eastern Ecological Science Center (EESC), 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, Minnesota 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, New York State Department of Environmental Conservation, University of Vermont, Vermont Fish and Wildlife Department, Chippewa Ottawa Resource Authority, Chippewas of Nawash Unceded First Nation, and Ontario Ministry of Natural Resources and Forestry.

The 2024 data associated with this report are publicly at https://doi.org/10.5066/P13BDOYB. Data used in this report collected prior to 2024 are publicly available (Honeyfield et al. 2020, Tillitt et al. 2021, O'Malley et al. 2024). 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 2024, collections of unfertilized eggs from lake trout took place at sites in Lakes Superior, Michigan, Huron, Erie, Ontario, 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. This year additional egg samples were also collected in Seneca, Canadice, and Hemlock lakes. Eggs collected from individual females at each site were frozen and then shipped to SUNY Brockport 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. Long-term 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

A total of 443 lake trout egg samples were collected from 34 locations in 2024. Egg thiamine concentration varied widely across systems, ranging from 4.2 to 34.4 nmol/g in Lake Superior, 1.0 to 21.3 nmol/g in Lake Michigan, 4.6 to 34.4 nmol/g in Lake Huron, 2.7 to 26.2 nmol/g in Lake Erie, 0.8 to 19.4 nmol/g in Lake Ontario, 2.2 to 13.9 nmol/g in Lake Champlain, and 1.6 to 26.4 nmol/g in the Finger Lakes (Figure 2 and Table 1). Concentrations were highly variable within each site (Figure 2).

No egg samples from Lakes Superior and Huron had thiamine concentrations below the 4 nmol/g threshold recommended for successful lake trout reproduction (Figure 3, Table 1). In contrast, three egg samples from the eastern basin of Lake Erie fell below this threshold. In Lake

Michigan, all sites had at least some females with eggs below 4 nmol/g, with proportions ranging from 8% in Little Traverse Bay to 88% at Ludington Reef (Figure 3, Table 1). Similarly, in Lake Ontario, all sampled sites included eggs below the 4 nmol/g threshold, ranging from 13% in Youngstown to 63% in Hamlin (Figure 3, Table 1). In the Finger Lakes, low thiamine concentrations were also common, with 25% of egg samples in Hemlock Lake and 82% in Canadice Lake below the 4 nmol/g threshold. In Lake Champlain, no low-thiamine samples were found at Gordon Landing, while 11% of samples at Wallon Bay were below the threshold (Figure 3, Table 1).

Figures 4 through 8 present time series data of egg thiamine concentrations (nmol/g), including individual values and site means for lake trout eggs collected from selected sites in Lakes Michigan, Erie, Ontario, Champlain, and Cayuga Lake. These figures reveal substantial temporal and spatial variability in thiamine concentrations across the Great Lakes region. Continued annual monitoring is essential to assess the potential effects of TDC on lake trout recruitment.

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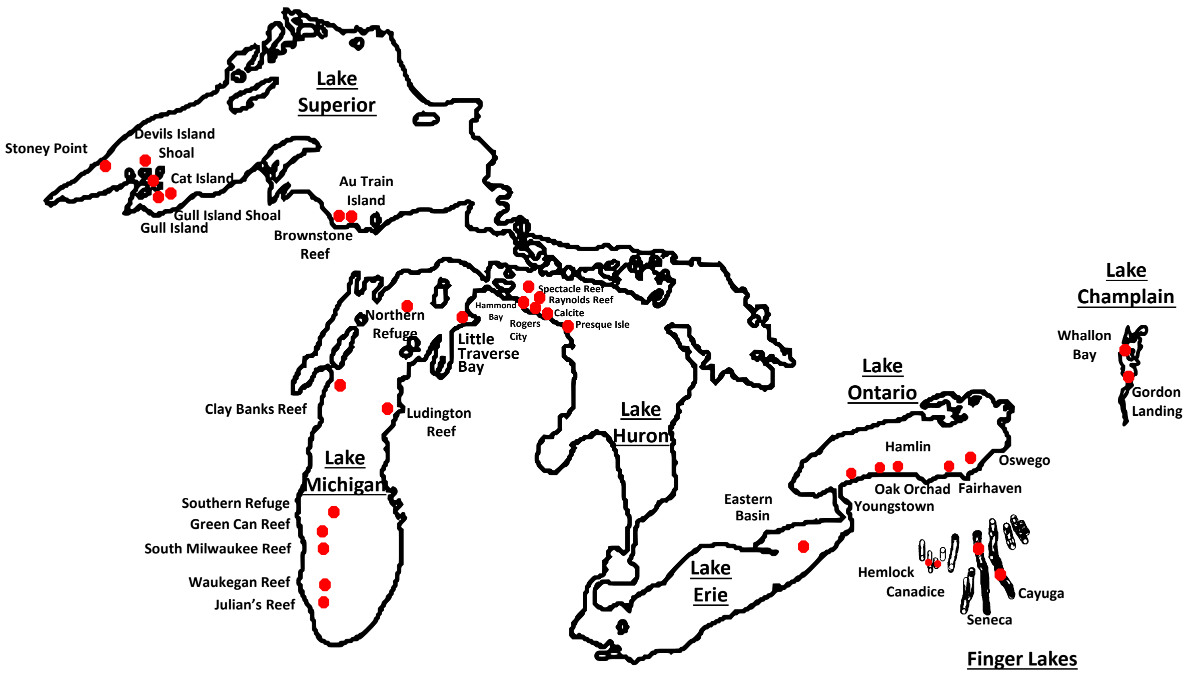

Figure 1: Lake trout (*Salvelinus namaycush*) egg sampling sites in 2024. A total of 443 egg samples were collected in 2024 throughout the Great Lakes region.

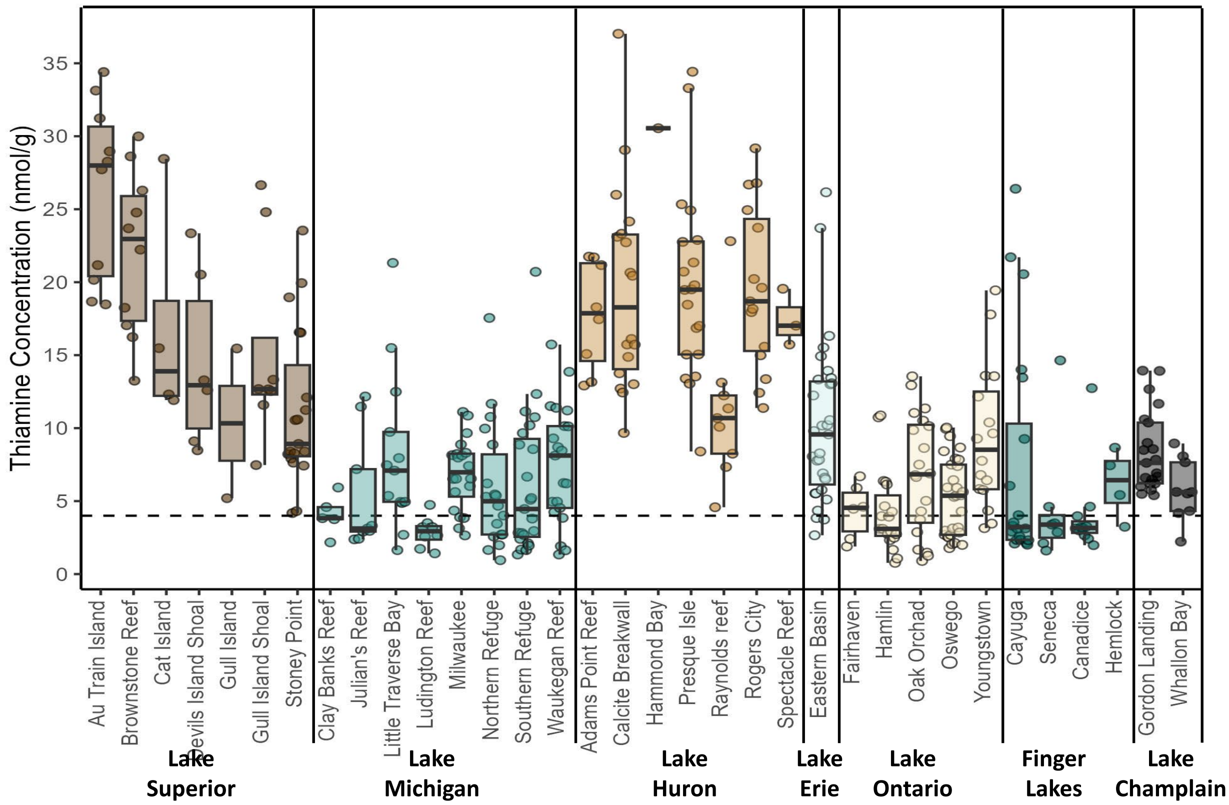

Figure 2: Thiamine concentrations in lake trout (*Salvelinus namaycush*) eggs (each color dot represents a measurement from a separate female, box plot with minimum, maximum, median, first and third quartiles) collected in 2024 at 34 locations across 10 lakes within the Great Lakes region. Milwaukee 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).

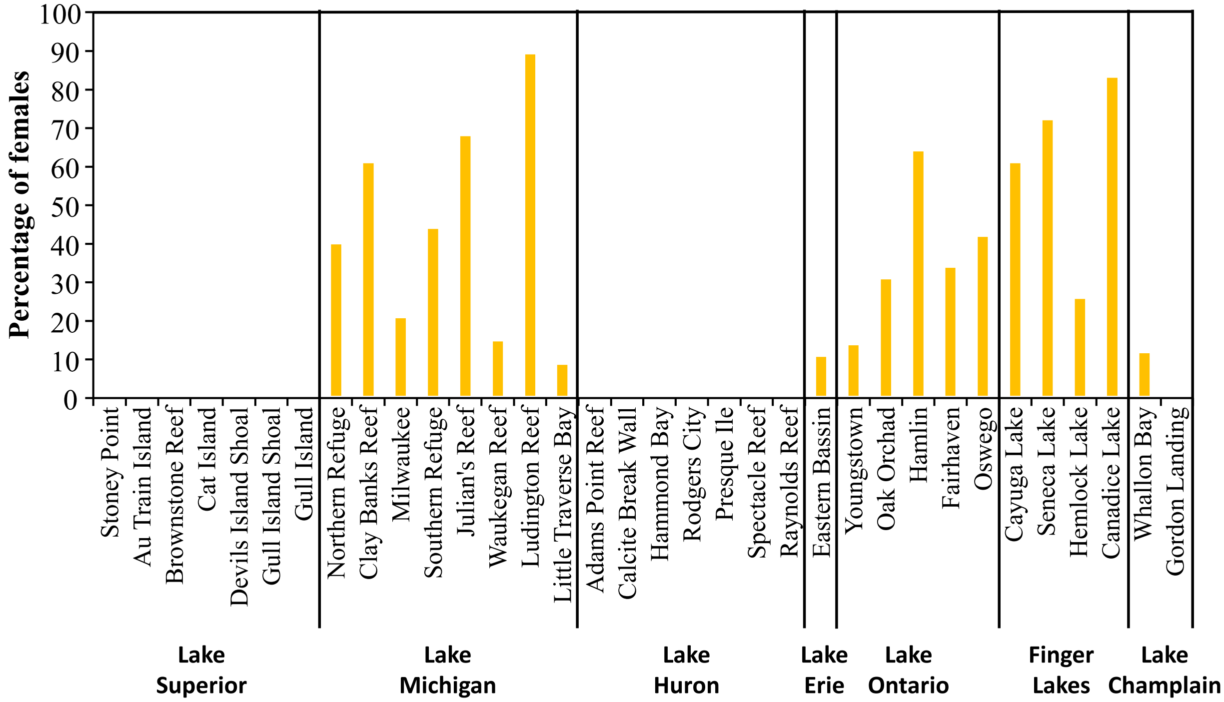

Figure 3: Percentage of lake trout (*Salvelinus namaycush*) females collected in 2024 at 34 locations across 10 lakes within the Great Lakes region with egg thiamine concentration below the recommended threshold of 4 nmol/g for successful lake trout recruitment (Bronte et al. 2008). Milwaukee includes Green Can Reef and South Milwaukee Reef.

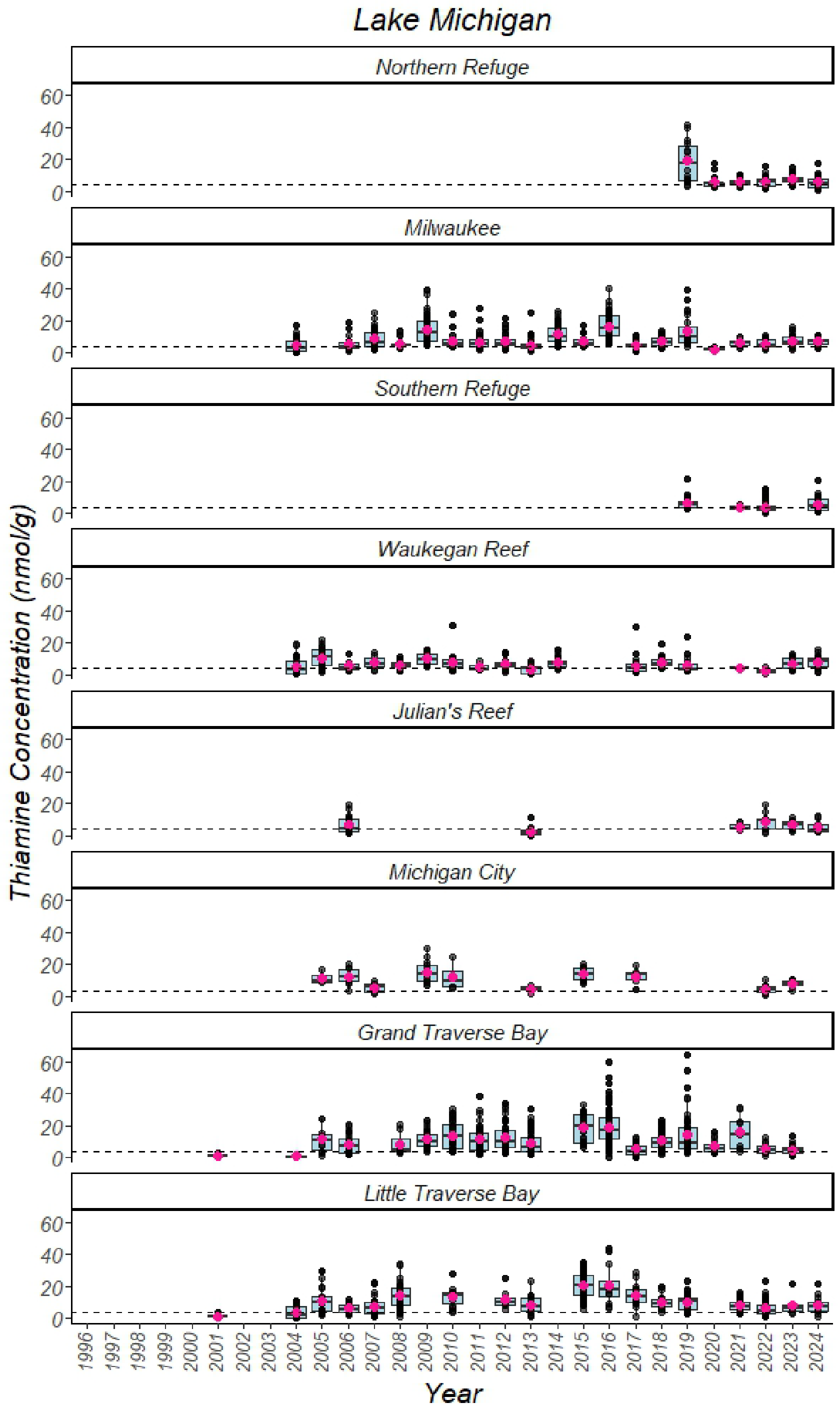

Figure 4: Thiamine concentrations in lake trout (*Salvelinus namaycush*) eggs (each black dot represents a measurement from a separate female, box plot with mean (pink dot), minimum, maximum, median, first and third quartiles) at 8 sampling sites in Lake Michigan from 1996 to 2024. The dashed black line represents the recommended egg thiamine threshold of 4 nmol/g for successful lake trout recruitment (Bronte et al. 2008).

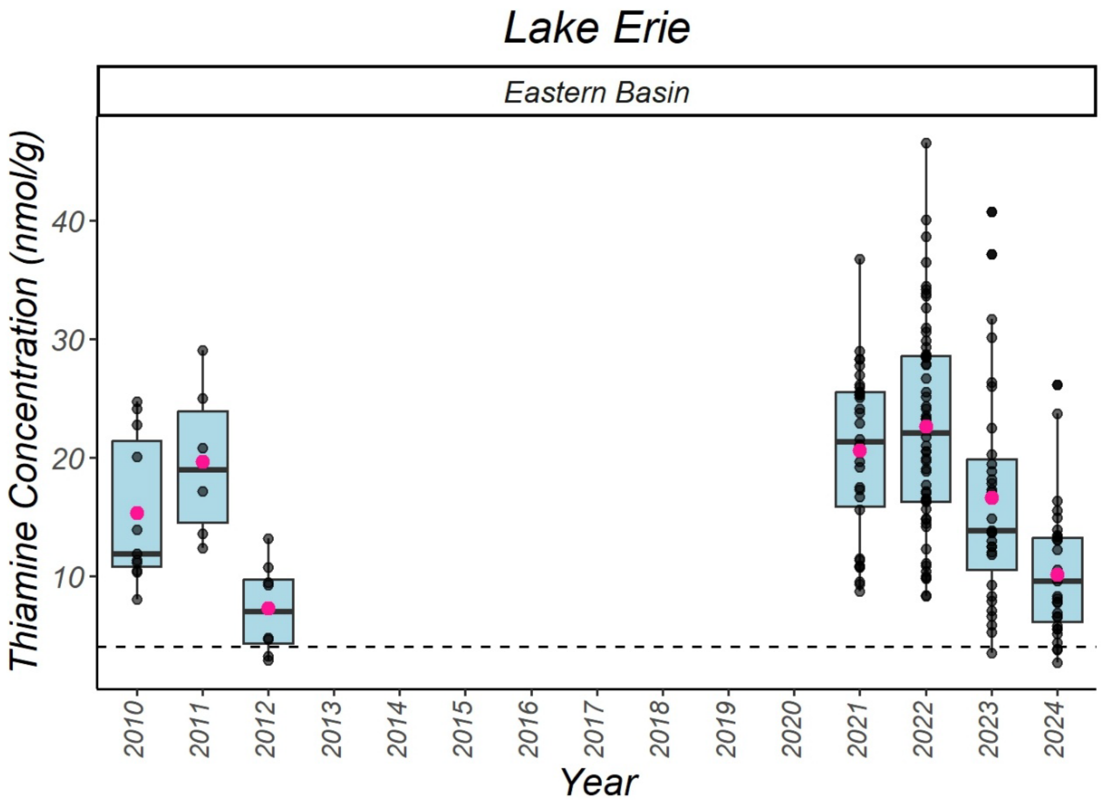

Figure 5: Thiamine concentrations in lake trout (*Salvelinus namaycush*) eggs (each black dot represents a measurement from a separate female, box plot with mean (pink dot), minimum, maximum, median, first and third quartiles) in the eastern basin of Lake Erie from 2010 to 2024. The dashed black line represents the recommended egg thiamine threshold of 4 nmol/g for successful lake trout recruitment (Bronte et al. 2008).

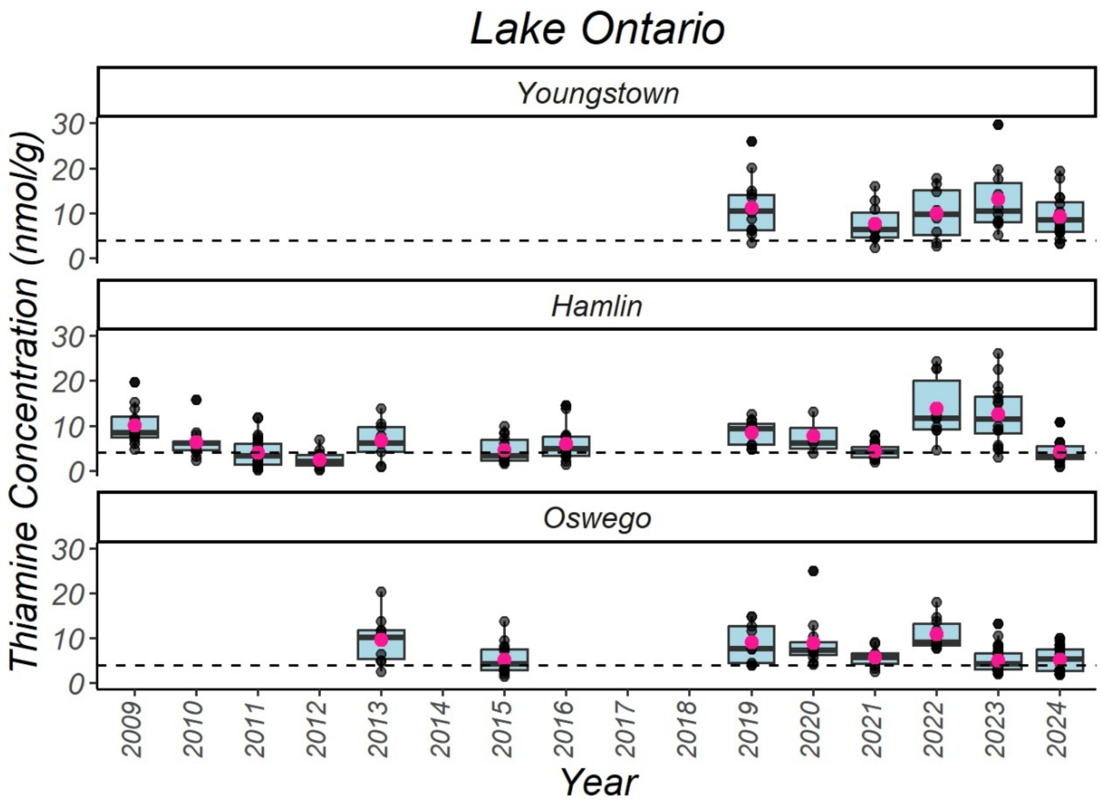

Figure 6: Thiamine concentrations in lake trout (*Salvelinus namaycush*) eggs (each black dot represents a measurement from a separate female, box plot with mean (pink dot), minimum, maximum, median, first and third quartiles) at 3 sampling sites in Lake Ontario from 2009 to 2024. The dashed black line represents the recommended egg thiamine threshold of 4 nmol/g for successful lake trout recruitment (Bronte et al. 2008).

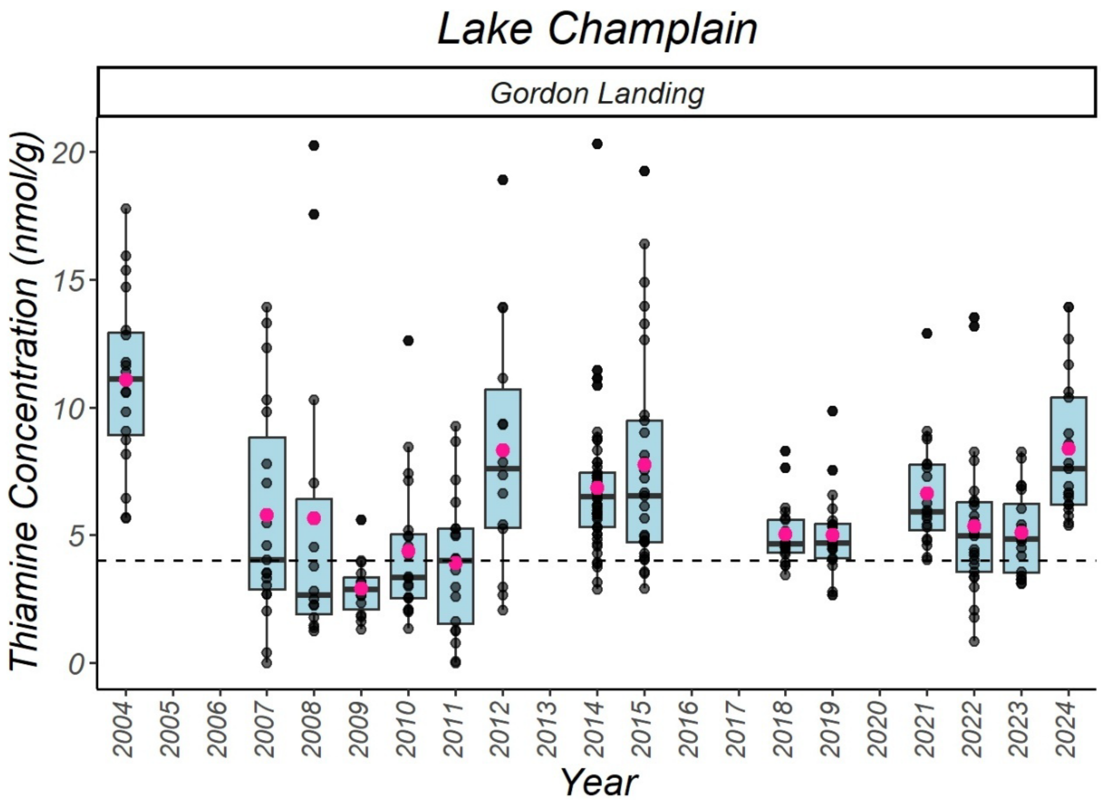

Figure 7: Thiamine concentrations in lake trout (*Salvelinus namaycush*) eggs (each black dot represents a measurement from a separate female, box plot with mean (pink dot), minimum, maximum, median, first and third quartiles) at 1 sampling site in Lake Champlain from 2004 to 2024. The dashed black line represents the recommended egg thiamine threshold of 4 nmol/g for successful lake trout recruitment (Bronte et al. 2008).

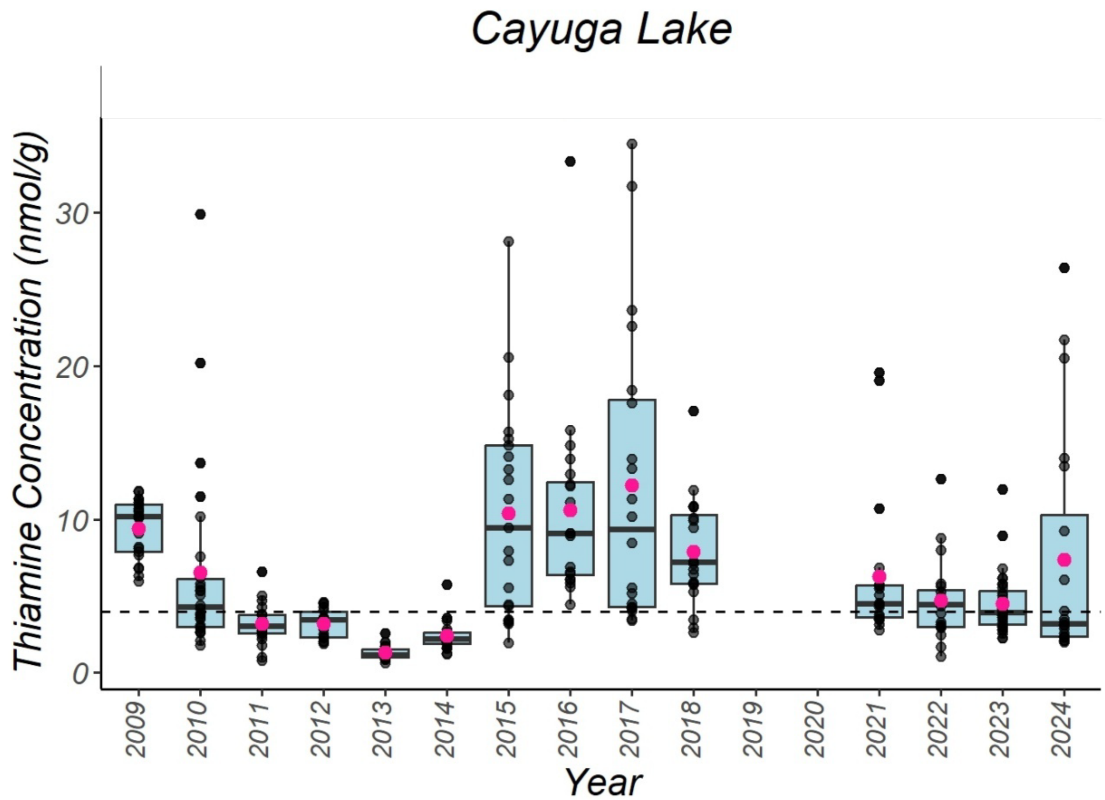

Figure 8: Thiamine concentrations in lake trout (*Salvelinus namaycush*) eggs (each black dot represents a measurement from a separate female, box plot with mean (pink dot), minimum, maximum, median, first and third quartiles) at 1 sampling site in Cayuga Lake from 2009 to 2024. The dashed black line 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 2024 at 34 sampling sites across 10 lakes within the Great Lakes region. n = sample size, T = mean total thiamine concentration, SD = standard deviation, Min T = minimum thiamine concentration, Max T = maximum thiamine concentration. Refer to Figure 1 for site locations.

Locations	n	T	SD	Min T	Max T	% Females < 4 nmol/g
Lake Superior						
Stoney Point	19	11.2	5.4	4.2	23.5	0
Au Train Island	10	26.2	6.1	18.5	34.4	0
Brownstone Reef	10	22.0	5.6	13.2	30.0	0
Cat Island	4	17.0	7.8	11.9	28.4	0
Devils Island Shoal	6	14.6	6.1	8.5	23.4	0
Gull Island Shoal	8	15.2	6.8	7.5	26.6	0
Gull Island	2	10.3	7.3	5.2	15.5	0
Lake Michigan						
Northern Refuge	18	5.9	4.3	1.0	17.6	39
Clay Banks Reef	5	4.1	1.4	2.2	5.9	60
Milwaukee (Green Can/South Milwaukee Reefs)	20	6.9	2.4	2.7	11.1	20
Southern Refuge (Northeast Reef)	23	6.1	4.8	1.3	20.7	43
Julian’s Reef	9	5.3	4.0	2.4	12.2	67
Waukegan Reef	21	7.5	4.0	1.3	15.7	14
Ludington Reef	8	2.9	1.0	1.4	4.7	88
Little Traverse Bay	13	8.2	5.5	1.6	21.3	8
Lake Huron						
Adams Point Reef	8	7.7	3.7	12.9	21.8	0
Calcite Break Wall	18	19.5	7.0	9.7	37.0	0
Hammond Bay	1	30.5	NA	30.5	30.5	0
Rodgers City	15	19.6	5.6	11.4	29.2	0
Presque Isle	18	19.3	6.6.	8.4	34.4	0
Spectacle Reef	3	17.4	1.9	15.7	19.5	0
Raynolds Reef	9	11.2	5.1	4.6	22.8	0
Lake Erie						
Eastern Basin	31	10.1	5.5	2.7	26.2	10
Lake Ontario						
Youngstown	16	9.3	4.9	3.2	19.4	13
Oak Orchad	20	6.9	4.1	0.9	13.6	30
Hamlin	19	4.2	2.8	0.8	10.9	63
Fairhaven	6	4.3	1.9	1.9	6.7	33
Oswego	29	5.2	2.7	1.8	10.0	41
Lake Champlain						
Whallon Bay	9	5.8	2.1	2.2	9.0	11
Gordon Landing	21	8.4	2.8	5.4	13.9	0
Finger Lakes						
Cayuga Lake	20	7.4	7.6	2.0	26.4	60
Seneca Lake	7	4.7	4.5	1.6	4.6	71
Hemlock Lake	4	6.2	2.4	3.2	8.7	25
Canadice Lake	11	4.0	3.0	2.4	12.7	82