

Reconstructing hypolimnetic oxygen concentrations in Limerick Lake, an Ontario Lake Trout  
lake, using sedimentary chironomid assemblages

Jennie Moe

An undergraduate thesis submitted to the Department of Biology in partial fulfillment of the  
requirements for the degree of Bachelor of Science (Honours)

Queen's University  
Kingston Ontario, Canada

April 2018

## ABSTRACT

Lake Trout (*Salvelinus namaycush*) are an important resource within Canada with specific habitat requirements that make them especially sensitive to environmental stressors. Nutrient loading and climate warming threaten Lake Trout habitat by resulting in prolonged periods of reduced end-of-summer dissolved oxygen concentrations [DO]. Limerick Lake contains a native Lake Trout population and has been stocked since the 1930s. The lake is of management concern because of significant shoreline development pressures, as well as hypolimnetic [DO] values reported as below the Ontario provincial guideline of 7 mg/L. This paleolimnological study used changes in the chironomid and chaoborid assemblages over the past ~180 years in a dated sediment core to determine whether recent hypolimnetic [DO] conditions in Limerick Lake reflect a change from pre-industrial conditions. The reconstruction revealed that volume weighted hypolimnetic oxygen (VWHO) was typically below the 7 mg/L guideline throughout the study period. Slight decreases in the VWHO profile around 1910 and after 1940 coincide with increased regional agricultural and shoreline development. The 1940s VWHO decrease also coincides with an increase in the chlorophyll-*a* profile, indicating an increase in primary production in the mid-1900s. Slight increases in the relative abundances of common littoral taxa (*Dicrotendipes nervosus* and *Psectrocladius*) and decreases in common profundal taxa (*Micropsectra*) after the 1940s may be indicative of decreasing hypolimnetic [DO], because survival of profundal taxa may be reduced under anoxic conditions. Conditions for Lake Trout in Limerick Lake have likely been suboptimal throughout most of the past century, so recent conditions do not appear to be outside the range of this variability. However, continued monitoring of the lake is warranted due to the potential for regional climate warming and nutrient loading to deteriorate conditions further.

## ACKNOWLEDGMENTS

I would like to thank my supervisor Dr. John Smol for his guidance and for providing me with this opportunity. I would also like to thank my mentor Dr. Adam Jeziorski for his encouragement and support throughout this project. Further thanks to my committee member Dr. Brian Cumming, to Clare Nelligan and Brigitte Simmatis for their helpful advise with data collection, presenting and writing, and to all the members of the Paleoecological Environmental Assessment and Research Laboratory (PEARL) for their kindness and encouragement. Lastly, I would like to thank NSERC for the funding.

## TABLE OF CONTENTS

ABSTRACT.....	2
ACKNOWLEDGMENTS.....	3
TABLE OF CONTENTS.....	4
LIST OF COMMON ABBREVIATIONS.....	5
INTRODUCTION.....	7
Lake Trout Habitat.....	7
Significance.....	13
Field Methods.....	14
<sup>210</sup> Pb Dating.....	14
Chironomid Processing and Identification.....	14
Chlorophyll- <i>a</i> and TOC.....	15
Chlorophyll- <i>a</i> .....	15
Total Organic Carbon.....	15
Downcore analysis.....	16
RESULTS.....	17
Chironomid Assemblage Analysis.....	17
Chironomid-Inferred VWHO.....	18
Chlorophyll- <i>a</i> .....	18
TOC Reconstruction.....	19
DISCUSSION.....	20
Chironomid Assemblage Analysis.....	20
Chironomid-inferred VWHO and Chlorophyll- <i>a</i> .....	22
Limitations.....	24
Conclusion.....	24
REFERENCES.....	26
FIGURES.....	29
APPENDIX 1.....	35
APPENDIX 2.....	36
APPENDIX 3.....	37
APPENDIX 4.....	38
APPENDIX 5.....	39

## LIST OF COMMON ABBREVIATIONS

Dissolved oxygen - DO

Volume-weighted hypolimnetic oxygen - VWHO

Ontario Ministry of Natural Resources and Forestry – OMNRF

Total organic carbon - TOC

## LIST OF FIGURES

Figure 1: Map of Limerick Lake

Figure 2: Timeline of events in the vicinity of Limerick Lake

Figure 3: Monitoring data of measured DO in Limerick Lake

Figure 4: Chironomid stratigraphy with chironomid inferred VWHO, VRS-inferred chlorophyll-*a*, and VRS-inferred TOC in the Limerick Lake sediment core

Figure 5: Density of chironomid head capsules in the Limerick Lake sediment core

Figure 6: Density of littoral and profundal chironomid head capsules in the Limerick Lake sediment core

## INTRODUCTION

### Lake Trout Habitat

Lake Trout (*Salvelinus namaycush*) are an important ecological and economic resource within Canada. The contribution of recreational and commercial fisheries to Ontario's economy is valued at over 2.5 billion dollars annually (OMNRF, 2015a). Ontario has ~ 20-25% of the world's supply of Lake Trout lakes, the largest number for any jurisdiction (OMNRF, 2015b). Lake Trout have specific habitat requirements due to their slow growth and late maturity, and therefore are especially sensitive to environmental change (Plumb and Blanchfield, 2009). Alarming, extirpation of this taxon has already occurred in 5% of Ontario Lake Trout lakes (OMNRF, 2015b). Therefore, the province must effectively manage the Lake Trout population. The Ontario Ministry of Natural Resources and Forestry (OMNRF) maintain records of lakes that are currently designated for Lake Trout Management, classifying whether each lake has a naturally reproducing Lake Trout population or if it has been stocked (OMNRF, 2015b). Management strategies vary depending on lake classification and characteristics. For example, put-grow-take lakes with stocked Lake Trout populations are managed to provide fishing opportunities and direct angling effort away from lakes containing a natural Lake Trout population (OMNRF, 2015b).

Lake Trout are typically restricted to the cold, oxygen-rich waters of the hypolimnion (the deepest layer of a thermally stratified lake). Usable Lake Trout habitat is defined as waters with temperatures  $<15^{\circ}\text{C}$  and dissolved oxygen (DO) concentrations  $>4\text{ mg/L}$  (Plumb and Blanchfield, 2009), whereas optimal habitat requires temperatures of  $<10^{\circ}\text{C}$  and  $>6\text{ mg/L}$  DO (Evans, 2007; Guzzo and Blanchfield, 2016). The provincial guideline for [DO] in Lake Trout lakes is  $7\text{ mg/L}$ , as concentrations  $<7\text{ mg/L}$  decrease juvenile survival (Ontario Municipal Board, 2005). However, as the hypolimnion is isolated from the atmosphere during thermal stratification, it may become low in [DO], resulting in hypoxia (an oxygen deficiency in a biotic environment; 2 - 4

mg/L). Hypoxia can be exacerbated by algal decomposition as oxygen is consumed in the process, thus nutrient loading can impact oxygen conditions by stimulating algal growth (Mallin, 2006). Nutrient loading can come from many sources including septic waste, agricultural runoff and urban development, with a common result of reduced oxygen availability in summer negatively impacting the Lake Trout population (Smol, 2008).

Climate warming may further limit Lake Trout to a narrow habitat boundary as the top (epilimnetic) and shallow (littoral) waters are often above their optimal temperature requirements. Higher temperatures may also lead to earlier spring turnover as a result of a shorter period of ice cover. This results in longer periods of reduced oxygen in end-of-summer [DO] since the oxygen in the hypolimnion at the time of spring/summer stratification has to persist until fall turnover (Stainsby *et al.*, 2011).

Hypoxia has negative impacts on Lake Trout populations, through a decrease in Lake Trout metabolism, limiting their ability to swim, feed and avoid predators (Evans 2007). In warmer years, their specific temperature requirements can result in reduced growth and fitness due to reduced access to prey in the littoral zone (Guzzo *et al.*, 2017). Additionally, reduced habitat area can lead to increased interaction, competition and potential for cannibalism (OMNRF, 2015a). These stresses impact Ontario Lake Trout lakes, especially those in Southern Ontario, as they are near the southern limit of the species' range and thus contain narrow oxygen and temperature boundaries in which the species can survive.

#### Limerick Lake

Limerick Lake (44° 53' 35" N, 77° 36' 57" W) is located in Southern Ontario, 85 km north of Belleville, and 25 km south of Bancroft (Figure 1). The lake is located on the Precambrian



Shield, has a maximum depth of 36 m, and thermally stratifies in the summer months (Ontario Municipal Board, 2005). Limerick Lake contains a native Lake Trout population, but it was also stocked from the 1930s to the mid-1990s (Ontario Municipal Board, 2005). In the 1970s, the native population represented about 60 - 80% of all Lake Trout, whereas in the 1990s this value fell to less than 20% (Ontario Municipal Board, 2005). The lake is now considered 'at capacity', meaning that there should be no development within 300 m from the lake since it is very susceptible to low levels of dissolved oxygen (Ontario Municipal Board, 2005).

Limerick Lake is of management concern because of significant shoreline development pressures, as well as reported hypolimnetic [DO] values below the provincial guideline of 7 mg/L (V. Castro, Pers. Comm.). The history of Limerick Lake over the past ~180 years can be broadly divided into general periods: Initial Settlement (1852-1867), Lumber Period (1867-1950), Mining Period (1950-1990), and Cottage Period (1990-2014) (Figure 2). Historically, Bancroft (~25 km north west of the lake) was settled in 1852 by United Empire Loyalists (Kehoe, 2017). This was followed by the arrival of settlers from Ireland in the late-1850s, leading eventually to an increase in agricultural development. The large number of hardwood forests in the Bancroft district attracted lumber industrialists, and much of the lumber was cleared for timber with the opening of the Harris and Bronson Lumber Company in 1867 (Kehoe, 2017). As the lumber industry slowed in the 1950s, uranium mining started up. The Faraday Uranium mine was operated from 1954 to 1964 and was reopened as the Madawska Mine from 1975-1982. During this time, 9.5 million pounds of triuranium octoxide were mined (Kehoe, 2017). However, the mine was not located directly in Bancroft, but was located 49.3 km away from Limerick Lake and not connected by any water body. Following closure of the mine, the Bancroft area began attracting tourists and cottagers. Today, Limerick Lake is surrounded by seasonal residences, with few if any permanent

homes. The water level is mainly controlled by a dam downstream located on St. Ola Lake, built in 1934 for flood control, and in use until it was rebuilt in 2004 due to significant cracking (Ontario Municipal Board, 2005).

Monitoring data from 1977-1991 indicate that end-of-summer hypolimnetic oxygen conditions have been consistently near or below the provincial guideline (V. Castro, Pers. Comm.). Limnological data show that, in all recorded years, the thermocline occurred between ~9 - 12m depth at the end-of-summer. In September of 1977, 1985, and 1991, the hypolimnion was below the Lake Trout DO optimum of 6-7 mg/L for most of its depth (Figure 3). In 1977, the hypolimnetic DO concentrations were below the usable habitat threshold of 4 mg/L for all but the uppermost 0.6 m of the hypolimnion. In 1985 and 1991, the hypolimnetic DO concentrations were above the usable habitat threshold for all but the bottommost 1-2 m of the hypolimnion. Based on a recent diatom-based paleolimnological reconstruction, Limerick Lake is currently oligotrophic, but may have been slightly more nutrient-rich historically (C. Nelligan, Pers. Comm.). A prominent shift in the diatom assemblage data occurred in the 1950s and was characteristic of enhanced thermal stability and reduced water column mixing associated with regional climate warming (C. Nelligan, Pers. Comm.).

The available limnological data for Limerick Lake is relatively recent (post-1977), with little knowledge about baseline conditions. Paleolimnological inferences are therefore required to determine whether the lake has always been near the Lake Trout survival threshold or whether this is a recent development.

## Chironomids as Paleolimnological Indicators of DO

Due to the lack of long-term monitoring data, a paleolimnological analysis was used to determine whether recent hypolimnetic [DO] conditions in Limerick Lake reflect a change from pre-industrial conditions in the early-1800s. Paleolimnology is the study of chemical, physical and biological microfossils preserved in lake sediments to determine historical changes in water quality (Smol, 2008). Sediment profiles contain a wide variety of indicators that record information on lake conditions at the time of deposition, and thus can be analyzed to determine changes in environmental conditions through time (Smol, 2008).

The chitinous remains of the larvae of non-biting midges (Chironomidae) are useful to reconstruct hypolimnetic oxygen conditions. Chironomids have an aquatic larval stage, during which they develop in fresh water. Their chitinous head capsules are typically well preserved and abundant in lake sediments. Chironomids are a diverse group with well-known optima and tolerances to different oxygen conditions (Broderson and Quinlan, 2006). This allows changes in the chironomid assemblages to be used to infer changes in oxygen conditions through time. Chironomids have physiological, behavioral and morphological adaptations that make them tolerant of a variety of environmental conditions, including some taxa that are well adapted to low dissolved oxygen concentrations (Broderson and Quinlan, 2006). For example, an ability to tolerate low DO concentrations is present in chironomids that have a high hemoglobin concentration in the haemolymph, allowing them to bind oxygen in low oxygen conditions (Czeczuga, 1960; Weber, 1980). Additionally, the ability to migrate through the water column allows some chironomids to move away from the hypolimnion when it becomes hypoxic and towards shallower oxygen rich waters (Bazzanti *et al.*, 1998).

Qualitative changes in chironomid assemblages have long been used to infer changes in oxygen through time, and several transfer functions have been developed to quantitatively infer these changes (Smol 2008). For instance, transfer functions have been developed to determine late-summer hypolimnetic oxygen values such as the Quinlan and Smol (2001a) volume-weighted hypolimnetic oxygen model. This model consists of 44 chironomid taxa from 59 south-central Ontario lakes (Quinlan and Smol, 2001a). The model incorporates measured total phosphorus (TP) and oxygen levels from lakes with a range of characteristics to determine what environmental variables explained variation in the chironomid assemblages. This model can be used to reconstruct VWHO in lakes through time (Quinlan and Smol, 2001a). The model also takes into account the ratio of *Chaoborus* to chironomid remains. *Chaoborus* mandibles are another paleolimnological indicator of hypolimnetic [DO], as their chitinous mandibles also preserve well in sediments, and they too have adaptations to low oxygen concentrations. For instance, *Chaoborus* can use haemolymph as a source of energy in hypoxic environments with limited predators (Quinlan and Smol, 2010). The incorporation of chaoborids into the chironomid-inferred VWHO model through the ratio of chaoborid to chironomid remains (chaob:chir ratio) improves the accuracy of the VWHO model, as using solely chironomids may underestimate the extent of hypoxic conditions (Quinlan and Smol, 2010).

I will use the chironomid and chaoborid remains present in Limerick Lake sediments to infer volume weighted hypolimnetic oxygen (VWHO) concentrations from ~1830-2014, by applying the Quinlan and Smol (2001a; 2010) VWHO model to the sedimentary assemblages. This study will determine: i) How have the sedimentary chironomid assemblages and [VWHO] in Limerick Lake changed over the past ~180 years; and ii) Do any reconstructed trends in [VWHO] have implications for the management of the local Lake Trout population?

## Significance

The paleolimnological reconstruction of VWHO for Limerick Lake will have important implications for future Lake Trout management. Knowledge of baseline oxygen conditions will provide managers with information regarding how recent human disturbances have influenced Lake Trout habitat and can aid forecasts of potential future conditions. This can assist managers to develop measures to reduce these disturbances, and perhaps determine how to restore the lake to its original condition. Furthermore, an understanding of baseline conditions will allow managers to determine the effectiveness of any measures to reduce the effects of human disturbances, based on whether the lake is shifting back to original conditions. These measures can be applied to all Lake Trout lakes, with important implications given that Lake Trout are valuable in both economic and ecological terms.

## MATERIALS AND METHODS

### Field Methods

A sediment core was collected from the deepest basin of Limerick Lake (36m) in September 2014 using a Glew (1989) gravity corer. The core measured 30 cm and was sectioned at 0.5 cm intervals using a Glew (1988) extruder. The sediments were stored in a cold room at the Paleocological Environmental Assessment and Research Laboratory (PEARL) at Queen's University before being processed.

### $^{210}\text{Pb}$ Dating

An ORTEC Gamma Counting System was used to date the sediment by measuring  $^{210}\text{Pb}$  and  $^{137}\text{Cs}$  activities using the methods described by Schelske *et al.* (1994). The core dates were determined based on  $^{210}\text{Pb}$  concentrations using the Constant Rate of Supply (CRS) model (Appleby, 2001).  $^{137}\text{Cs}$  activities were used as an independent marker for the peak in radioactive fallout in 1963 after the test-ban treaty.

### Chironomid Processing and Identification

Approximately 2 g of wet sediment from each sample were added to 80 mL beakers containing 5% potassium hydroxide and deionized water, and heated on a hot plate for ~20 minutes at 80° C. The samples were then poured onto a 100 µm mesh sieve and the sediments were rinsed to remove KOH and small sediment particles. The sediments retained on the sieve were then transferred back into the 80 mL beaker using ~20 mL deionized water, and several drops of 95% ethanol were added before covering with Parafilm®. This liquid was then poured into a Bogorov tray, and fine forceps were used to pick out chironomid head capsules and *Chaoborus* mandibles under a dissecting scope and transfer them to a slide. A total of four passes were made

through each tray. A minimum of 40 whole head capsules for each interval was the target count to confidently characterize the sedimentary assemblage (Quinlan and Smol, 2001b). Slides were mounted for identification using Entellan<sup>®</sup>. Chironomid and *Chaoborus* remains were identified using a Leica microscope at 40X magnification. Identifications were made to the lowest possible taxonomic level using Brooks *et al.* (2007).

### Chlorophyll-*a* and TOC

In order to determine past trends in lakewater productivity and related variables, chlorophyll-*a* and total organic carbon (TOC) reconstructions were completed. This will allow a greater understanding of how industrialization and deposition have impacted the lake and its changes in [DO] through time.

### Chlorophyll-*a*

Chlorophyll-*a* concentrations in Limerick Lake were reconstructed to determine past levels of aquatic primary production using visible reflectance spectroscopy (VRS). A small amount of sediment from each interval was freeze-dried and sieved through a 125 µm mesh to remove large particles. Samples were then run through a FOSS NIRS 6500 series Rapid Content Analyzer to determine sediment reflectance spectra. Chlorophyll-*a* concentrations, which include their main diagenetic products, were inferred using a linear regression with spectral absorbance wavelengths between 650 and 700 nm as the reflectance metric (Michelutti *et al.*, 2010).

### Total Organic Carbon

Total organic carbon concentrations (TOC) were inferred using visible-near-infrared (VNIR) spectroscopy. Sediment samples were freeze-dried and then sieved through a 125 µm mesh to remove large particles. Samples were run through a FOSS NIRS Rapid Content Analyzer

in diffuse reflectance mode. The measured diffuse reflectance for each sample was transformed to apparent absorbance and TOC concentrations were inferred using the lake water TOC model from Meyer-Jacob *et al.* (2017).

#### Downcore analysis

To infer past VWHO in Limerick Lake, the relative abundances of chironomid and *Chaoborus* in the sedimentary assemblages were applied to a VWHO model consisting of 44 chironomid taxa from 59 south-central Ontario lakes (Quinlan and Smol, 2001a). The density of head capsules in the sediment for each interval and the ratios of *Chaoborus* to chironomids were also determined. This model was built using the “WA” function provided by the “rioja” package for the R software environment (R Core Team 2017). A constrained sum of squares (CONISS) cluster analyses (Grimm 1987), and the broken stick model (Bennett 1996) were used to identify any stratigraphic zones in the chironomid assemblages. The CONISS analysis was performed using the “vegan” package (Oksanen *et al.*, 2016) for the R software environment (R Core Team 2017).



## RESULTS

### Chironomid Assemblage Analysis

A total of 60 chironomid taxa were identified in the Limerick Lake sediment core (Appendix 3) and the 21 taxa with relative abundances greater than 3% in at least two intervals were included in the stratigraphy, with some taxonomic groups being merged for clarity (Figure 4). *Micropsectra* was the most abundant profundal taxon, with ~30-50% abundance in most intervals and a DO optima of 6.1 mg/L (Quinlan and Smol, 2001a). Other abundant profundal taxa included *Sergentia coracina* (DO Optima = 5.3mg/L) (Quinlan and Smol, 2001a) with ~5-20% abundance throughout the core, and *Macropelopia* and *Procladius* (3.72 mg/L) (Quinlan and Smol, 2001a) with ~5-10% abundance throughout most of the core (Figure 4). Of the littoral taxa, *Paratanytarsus* were the most abundant, with ~5-10% abundance throughout much of the core. *Dicrotendipes nervosus* (4.1 mg/L) (Quinlan and Smol, 2001a) and *Polypedilum nubeculosum* (4.3 mg/L) (Quinlan and Smol, 2001a) were also consistent throughout the core with ~5% abundance. Indistinguishable *Tanytarsini* (no pedestal) and *Chironomini* (indistinguishable) were also abundant, with a ~10% relative abundance throughout the core due to damaged head capsules.

The CONISS analysis did not determine any zonations within the chironomid assemblages through time; however, there were minor changes present throughout the core (Figure 4). At the start of the 20<sup>th</sup> century around 1910, the most common profundal taxon, *Micropsectra*, declined in relative abundance, while the littoral taxon *Dicrotendipes nervosus-type* (4.1 mg/L) and *Psectrocladius (psectrocladius) undifferentiated* (4.3 mg/L) increased. *Micropsectra* were then very common until ~1940 where they began to exhibit a slight decrease in relative abundance, while the littoral taxa *Psectrocladius (psectrocladius) undifferentiated* and *Dicrotendipes nervosus-type* increased.

There was an increase in density of chironomid head capsules per grams of dry sediment that persisted from ~1906-1982 (Figure 5). Prior to 1906, density was consistently ~70-90 head capsules per grams of dry sediment, but it increased to ~130 head capsules/gram around 1910 and reached a maximum of 463 head capsules/gram in ~1970. Density of profundal taxa was consistently at least 40 head capsules/gram higher than littoral until ~1980 when the density of profundal began to drop to densities ~5-20 head capsules/gram lower than littoral in some recent years (Figure 6). *Chaoborus* were present in low abundances throughout the core, with the chaob:chir ratio exhibiting variation between 0-0.08 throughout (Appendix 2).

#### Chironomid-Inferred VWHO

The chironomid-inferred VWHO ranged from ~4.9-8.0 mg/L throughout the core (Figure 4). Intervals 0.0-0.5 and 0.5-1.5 and 1.5-2.5 cm were combined to reach over 40 head capsules, and interval 5.0-5.5 did not meet the minimum of 40 head capsules, reaching only 39.5. From ~1830-1899, the VWHO ranged from ~5.5-7 mg/L before dropping to below 5 mg/L at ~1910 (Figure 4). There was a large increase in VWHO around 1920, reaching a maximum of ~8.0 mg/L. VWHO then dropped back to between ~6-7 mg/L before experiencing two decreases to below 5 mg/L around 1970 and 2000 (Figure 4).

#### Chlorophyll-*a*

Sedimentary-inferred chlorophyll-*a* concentrations remained steady at ~0.019 mg/g from the mid-1800s to the mid-1900s (Figure 4). This was followed by an increase through the second half of the 1900s, reaching a maximum of ~0.05 mg/g in recent decades.

## TOC Reconstruction

The TOC concentration in Limerick Lake was initially ~5 mg/g and decreased to ~4 mg/g from ~1830-1920 (Figure 4). TOC then increased to ~5 mg/g from ~1935-1955 and remained relatively stable until 2014.

## DISCUSSION

### Chironomid Assemblage Analysis

The sedimentary chironomid assemblages of Limerick Lake were relatively stable throughout the sediment core, indicating relatively little long-term changes in deepwater oxygen concentrations. The profundal taxon *Micropsectra* was the most abundant with a 30-50% relative abundance throughout the core (Figure 4). *Micropsectra* occur in mesotrophic to oligotrophic lakes, and are cold stenotherms (Brooks *et al.*, 2007). They have an oxygen optimum of 6.1 mg/L (Quinlan and Smol, 2001a), indicating oxygen was fairly abundant through the years and the lake was not low in oxygen for long periods.

In the period of Initial Settlement from 1852-1867, the chironomid assemblages in Limerick Lake were dominated by the profundal taxa *Micropsectra* and *Sergentia coracina*, and many littoral taxa were present in low abundance. *Sergentia coracina* occur in mesotrophic to oligotrophic lakes, and are cold stenotherms (Brooks *et al.* 2007), with an oxygen optimum of 5.3 mg/L (Quinlan and Smol, 2001a). The high relative abundances of both *Sergentia coracina* and *Micropsectra* throughout the Initial Settlement Period indicate oxygen was fairly abundant at this time. Following the Initial Settlement Period, a decrease in abundance of *Micropsectra* to ~30% relative abundance was exhibited in ~1910 during the Lumber Period, representing a time of increased lumber and agricultural activity (Figure 4). This coincides with a slight increase in the common littoral taxa *Dicrotendipes nervosus* (4.1 mg/L) and *Psectrocladius* (4.3 mg/L) to ~10% relative abundance (Quinlan and Smol, 2001a) (Figure 4). *Dicrotendipes nervosus* occurs in the littoral zone of lentic environments, and is often associated with macrophytes (Brooks *et al.*, 2007). These common littoral taxa are associated with low oxygen environments, as although littoral taxa do not directly indicate hypoxia, littoral chironomids often dominate in anoxic periods due to a reduced abundance of profundal taxa (Clerk *et al.*, 2000).

Slight changes in the chironomid assemblages towards the end of the Lumber Period and beginning of the Mining Period may be indicative of declining hypolimnetic [DO]. During the early-1940s, there were observed decreases in common profundal taxa such as *Micropsectra* and *Sergentia*, with both reaching minimum relative abundances in the early 2000s (Figure 4). These decreases again coincide with increases in common littoral taxa such as *Dicrotendipes nervosus* and *Psectrocladius*, reaching maximum relative abundances of ~5-10% around the 1990s (Figure 4). *Polypedilum* also exhibited an increase post 1940s, reaching a 10% relative abundance in recent years (Figure 4). This group is found in eutrophic, temperate lakes (Brooks *et al.*, 2007). This replacement of profundal taxa with littoral taxa is also evident in the decrease in density of the profundal taxa observed in the Mining period in ~1980 (Figure 5), again possibly indicating declining deepwater oxygen levels. Littoral taxa are present in a higher density than profundal taxa in multiple years after the 1980s, particularly in the Cottage Period in the 1990s. This observed replacement of profundal taxa with littoral taxa may indicate that hypolimnetic [DO] has decreased in recent years due to slight nutrient loading associated with shoreline development.

Climate warming may also have had an impact on the chironomid assemblages, with warmer temperatures lengthening the summer stratification period, leading to more DO depletion in the hypolimnion (Stainsby *et al.*, 2011). This is harmful for profundal taxa that are sensitive to changes in hypolimnetic oxygen, explaining the increase in littoral taxa, which also may experience more benefits with the warming such as increased macrophyte growth, providing them with shelter (Clerk *et al.*, 2000). Sedimentary diatom assemblage data from Limerick Lake suggest warming may have altered lake thermal properties post-1950s (C. Nelligan, Pers. Comm.). The diatom assemblage change roughly coincides with the observed increase in the relative abundance of littoral taxa beginning in the 1940s, and may suggest that declining hypolimnetic oxygen may

be associated with warming. However, it is important to note that the chironomid assemblage changes are relatively subtle, and likely deepwater lake conditions have not changed dramatically during these time periods.

#### Chironomid-inferred VWHO and Chlorophyll-*a*

The VWHO was typically below the provincial guideline of 7 mg/L throughout much of the record, indicating that Limerick Lake likely supported sub-optimal habitat for Lake Trout for some time (Figure 4). There were short periods where the VWHO dropped below 5 mg/L and above 7 mg/L (Figure 4). For example, there was a slight decrease in the VWHO profile around the Lumber Period in ~1910 (Figure 4), potentially due to increased agricultural development and activity from the lumber industry which began clearing the forests of Bancroft in 1867 (Kehoe, 2017). This may have resulted in increased nutrients and other allochthonous material entering the lake, resulting eventually in a slight decrease in hypolimnetic [DO]. This coincides with a slight decrease in the common profundal taxon *Micropsectra*, and a slight increase in the littoral taxon *Dicrotendipes*, linked to this decrease in oxygen. However, during this period chlorophyll-*a* concentrations were fairly steady, and inferred TOC was decreasing slightly (Figure 4), indicating that primary production was not drastically increasing in the lake. Regardless, the chironomid-inferred changes are slight.

Following the drop in VWHO exhibited in ~1910, VWHO then exhibited an increase in 1930 to ~8 mg/L. Although this still occurs in the Lumber Industry Period, this may be due to the beginning of a slowing in the agricultural and lumber industry, as much of the forests had already been cleared for timber (Kehoe, 2017) (Figure 4). However, following this period, the VWHO began to drop during the Mining Period around 1960, and has ranged between ~4.5-6.5 mg/L since then up until the present day (Figure 4).

The drop in VWHO around 1960 coincided with an increase in chlorophyll-*a* from ~1940-1970, and TOC from ~1935-1955 (Figure 4). These increases are indicative of an increase in lake production and may be due to increasing nutrients and/or the influence of regional warming. The chironomid-inferred VWHO does not indicate a consistent decrease in DO after the 1940s, however periods of decline in the VWHO profile during this time may coincide with increasing nutrients and regional warming (Figure 4). Although these increases in lake production and increasing nutrients occur in part during the Mining Period, it is likely that these increases are more a result of continued agriculture, shoreline development and warming, as the mine likely had little impact due to its distance from the lake (Kehoe, 2017). Following the Mining Period, in ~1990 at the start of the Cottage Period, chlorophyll-*a* and TOC both exhibit a slight additional increase and VWHO decreases to below 5 mg/L (Figure 4). This period indicates increased shoreline development as the Bancroft area began to attract many cottagers (Kehoe, 2017), potentially leading to additional nutrients entering the lake.

The increases in chlorophyll-*a* and TOC that occur after the 1940s coincide with the replacement of some of the common profundal taxa by littoral taxa (Figure 4), indicating a slight deterioration in hypolimnetic [DO], likely due to increasing primary production as a result of climate warming. The diatom data suggest the influence of enhanced thermal stability and reduced mixing as early as the 1950s, but does not suggest any large changes in nutrients (C. Nelligan, Pers. Comm.). Thus, increases in chlorophyll-*a* may be due to a longer ice-free season (Michelutti *et al.*, 2010), an ice trend observed across many southern Ontario lakes (Futter, 2003). This longer ice-free season is a result of regional warming, and leads to an increased period for primary production as well as the potential for increased algal growth due to warmer water temperatures (Paterson *et al.*, 2006). Increases in primary production can be independent of phosphorus loading,

and this similar increase in chlorophyll-*a* without a large increase in nutrient concentrations has been observed in another southern Ontario Lake Trout lake (Nelligan *et al.*, 2016).

### Limitations

Potential limitations exist within this paleolimnological analysis of Limerick Lake. Firstly, the large number of unidentifiable *Tanytarsini* and *Chironomini* taxa add to the uncertainty associated with the interpretation of the chironomid assemblages, potentially impacting the inferred VWHO. Additionally, four of the top intervals did not meet the target head capsule count, and thus interpretation of recent conditions must be taken with caution. Lastly, it is possible that true background was not reached with the CRS dating, and there are large error bars associated with the dates, particularly at the bottom of the core. Thus, interpretation of specific timing should also be taken with caution as there is a lack of annual accuracy. In order to strengthen interpretation, a multi-proxy approach is being used, and a diatom analysis to infer past TP concentrations is currently underway. Regardless, a major conclusion of my study is that changes were relatively subtle.

### Conclusion

Over the past ~150 years, the chironomid-inferred VWHO of Limerick Lake has typically been below the Ontario provincial Lake Trout guideline. Although the lake has never gone hypoxic during the reconstructed period, it has dropped below the optimal range of >6 mg/L multiple times. Thus, the lake likely does not contain ideal conditions for the survival of the local Lake Trout population. However, decreases in common profundal taxa and increases in littoral taxa since the 1940s may be indicative of declining hypolimnetic [DO] coinciding with increases in primary production and TOC in recent years. As Limerick Lake appears to have a long history of conditions below the provincial guideline for [DO], continued monitoring of the lake is



warranted, as there is potential for future regional climate warming and nutrient loading to deteriorate conditions further with negative consequences for the Lake Trout population.

Monitoring and limiting of nutrient inputs into the lake is recommended in order to ensure that further shoreline development doesn't exacerbate the depletion of DO. In addition, using this paleolimnological data in order to model future conditions may assist in better understanding further effects of climate warming, and the management decisions required to minimize these effects.

## REFERENCES

- Appleby, P.G. 2001. Chronostratigraphic techniques in recent sediments. In: Last, W. M., Smol, J.P. (Eds.), *Tracking Environmental Change Using Lake Sediments*. Kluwer Academic Publishers, Dordrecht, pp 171–203.
- Bazzanti, M., M. Seminara, S. Baldoni, and M.G. Dowgiallo. 1998. Assessing hypolimnetic stress in a monomictic, eutrophic lake using profundal sediment and macrobenthic characteristics. *Journal of Freshwater Ecology* 13:405-412.
- Broderson, K.P., and R. Quinlan. 2006. Midges as paleoindicators of lake productivity, eutrophication and hypolimnetic oxygen. *Quaternary Science Reviews* 25:1995-2012.
- Brooks, S.J., P.G. Langdon, and O. Heiri. 2007. The identification and use of Palaearctic Chironomidae larvae in palaeoecology. QRA Technical Guide No. 10, Quaternary Research Association, London, pp 1-276.
- Clerk, S., R.I. Hall, R. Quinlan, and J.P. Smol. 2000. Quantitative inferences of past hypolimnetic anoxia and nutrient levels from a Canadian Precambrian Shield Lake. *Journal of Paleolimnology* 23:319-336.
- Czeczuga, B. 1960. Haemoglobin content of the larvae of *Tendipes* fl. *plumous* L. from various levels of bed sediment. *Nature* 186:484.
- Evans, D.O. 2007. Effects of hypoxia on scope-for-activity and power capacity of Lake Trout (*Salvelinus namaycush*). *Canadian Journal of Fisheries and Aquatic Sciences* 64:345-361.
- Futter, M.N. 2003. Patterns and trends in southern Ontario lake ice phenology. *Environmental Monitoring and Assessment* 88:431-444.
- Glew, J.R. 1988. A portable extruding device for close interval sectioning of unconsolidated core samples. *Journal of Paleolimnology* 1:235-239.
- Glew, J.R. 1989. A new trigger mechanism for sediment samples. *Journal of Paleolimnology* 2:241-243.
- Grimm, E.C. 1987. CONISS: A FORTRAN 77 program for stratigraphically constrained cluster analysis by the method of incremental sum of squares. *Computers & Geosciences* 13:13-35.
- Guzzo, M.M., P.J. Blanchfield, and M.D. Rennie. 2017. Behavioral responses to annual temperature variation alter the dominant energy pathway, growth, and condition of a cold-water predator. *Proceedings of the National Academy of Sciences* 114:9912-9917.
- Guzzo, M.M., and P.J. Blanchfield, 2016. Climate change alters the quantity and phenology of habitat for lake trout (*Salvelinus namaycush*) in small Boreal Shield lakes. *Canadian*

Journal of Fisheries and Aquatic Science 74:871-884.

Juggins, S. 2015. rioja: Analysis of Quaternary Science Data, R package version (0.9-7). (<http://cran.r-project.org/package=rioja>).

Kehoe, D. 2017. Bancroft and Area History. Retrieved from Bancroft and Area History website: <http://www.baah.ca/>

Mallin, M.A., V.L. Johnson, S.H. Ensign, and T.A. MacPherson. 2006. Factors contributing to hypoxia in rivers, lakes and streams. *Limnology and Oceanography* 51:690-701.

Meyer-Jacob, J., N. Michelutti, A.M. Paterson, D. Monteith, H. Yang, J. Weckström, J.P. Smol, and R. Bindler. 2017. Inferring past trends in lake water organic carbon concentrations in northern lakes using sediment spectroscopy. *Environmental Science & Technology* 51:13248-13255.

Michelutti, N., J.M. Blais, B.F. Cumming, A.M. Paterson, K. Rühland, A.P. Wolfe, and J.P. Smol. 2010. Do spectrally inferred determinations of chlorophyll a reflect trends in lake trophic status? *Journal of Paleolimnology* 43:205-217.

Nelligan, C., A. Jeziorski, K.M. Rühland, A.M. Paterson and J.P. Smol. 2016. Managing lake trout lakes in a warming world: a paleolimnological assessment of nutrients and lake production at three Ontario sites. *Lake and Reservoir Management* 32:315-328.

Oksanen, J., F.G. Blanchet, M. Friendly, R. Kindt, P. Legendre, D. McGlinn, P.R. Minchin, R.B. O'Hara, G.L. Simpson, P. Solymos, M. Henry, H. Stevens, E. Szoecs, and H. Wagner. 2016. vegan: Community Ecology Package. R package version 2.4-0. <https://CRAN.R-project.org/package=vegan>

Ontario Municipal Board. 2005. Limerick Lake Estates Subdivision Case: PL980499.

Ontario Ministry of Natural Resources and Forestry. 2015a. Ontario's Provincial Fish Strategy fish for the future. (ISBN #978-1-4606-5621-1). Retrieved from Ontario Ministry of Natural Resources and Forestry website: <https://dr6j45jk9xcmk.cloudfront.net/documents/4538/ontarios-provincial-fish-strategy.pdf>

Ontario Ministry of Natural Resources and Forestry. 2015b. Inland Ontario lakes designated for Lake Trout management. (ISBN #978-1-606-6257-1). Retrieved from Ontario Ministry of Natural Resources and Forestry website: <https://dr6j45jk9xcmk.cloudfront.net/documents/4922/inland-ontario-lakesfinal-english.pdf>

Paterson, A.M., K.M. Rühland, C.V. Anstey, and J.P. Smol. 2017. Climate as a driver of increasing algal production in Lake of the Woods, Ontario, Canada. *Lake and Reservoir Management* 33:403-414.

Plumb, J.M., and P.J. Blanchfield. 2009. Performance of temperature and dissolved oxygen criteria

to predict habitat use by Lake Trout (*Salvelinus namaycush*). Canadian Journal of Fisheries and Aquatic Sciences 66:2011-2023.

- Quinlan, R., and J.P. Smol. 2001a. Chironomid-based inference models for estimating end-of-summer hypolimnetic oxygen from south-central Ontario shield lakes. Freshwater Biology, 46:1529-1551.
- Quinlan, R., and J.P. Smol. 2001b. Setting minimum head capsule abundance and taxa deletion criteria in chironomid-based inference models. Journal of Paleolimnology 26:327-342.
- Quinlan, R., and J.P. Smol. 2010. Use of subfossil *Chaoborus* mandibles in models for inferring past hypolimnetic oxygen. Journal of Paleolimnology 44:43-50.
- R Core Team. 2017. R: A language and environment for statistical computing. R Foundation for Statistical Computing, Vienna, Austria. <https://www.R-project.org/>.
- Schelske, C.L., A. Peplow, M. Brenner, and C.N. Spencer. 1994. Low background gamma counting: applications for  $^{210}\text{Pb}$  dating of sediments. Journal of Paleolimnology 10:115-128.
- Smol, J.P. 2008. Pollution of lakes and rivers: A paleoenvironmental perspective. 2<sup>nd</sup> edition. Oxford: Blackwell Publishing, pp 1-73.
- Stainsby, E., J. Winter, H. Jarianazi, A. Paterson, D. Evans, and J. Young. 2011. Changes in thermal stability of Lake Simcoe from 1980 to 2008. Journal of Great Lakes Research 37:55-62.
- Weber, R.E. 1980. Functions of invertebrate hemoglobins with special reference to adaptations to environmental hypoxia. American Zoologist 20:79-101.

## FIGURES

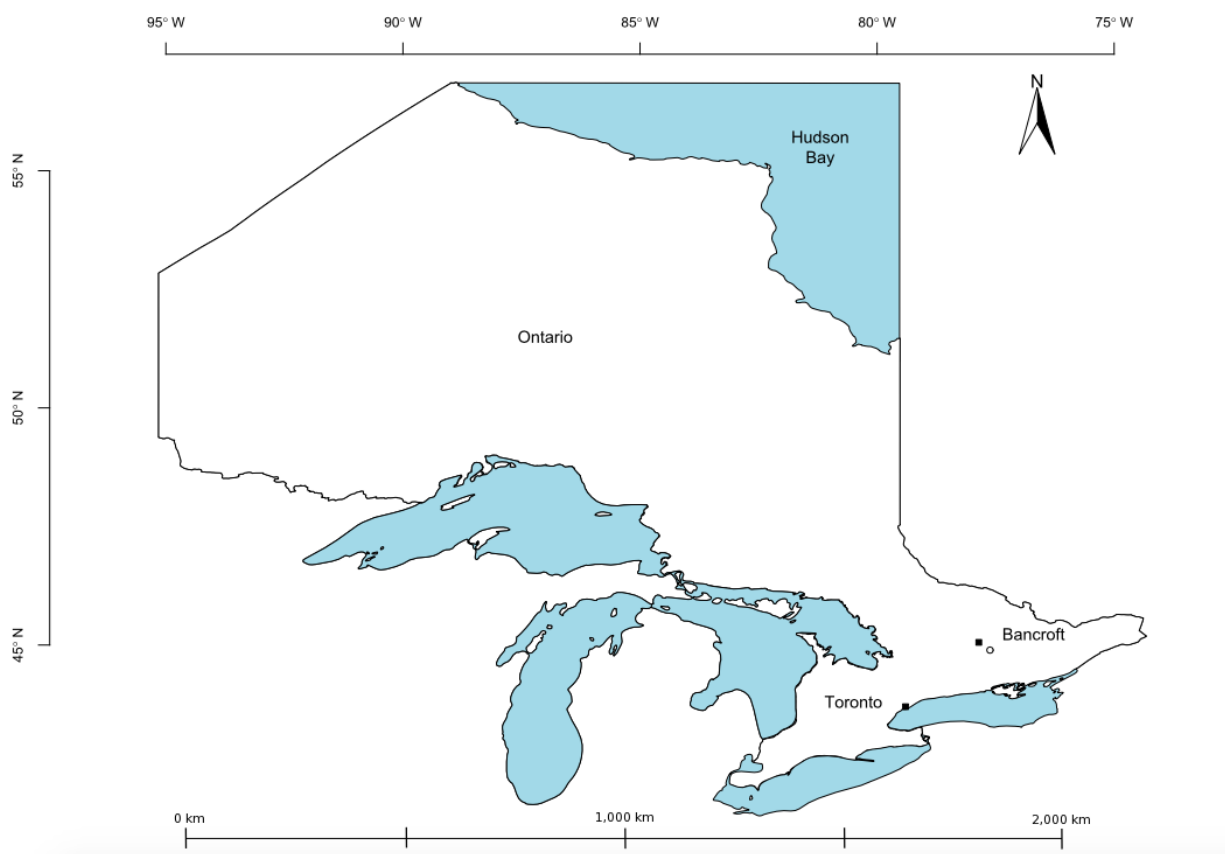


Figure 1: Map showing the location of Limerick Lake and Bancroft in Ontario. The circle marks the location of Limerick Lake.

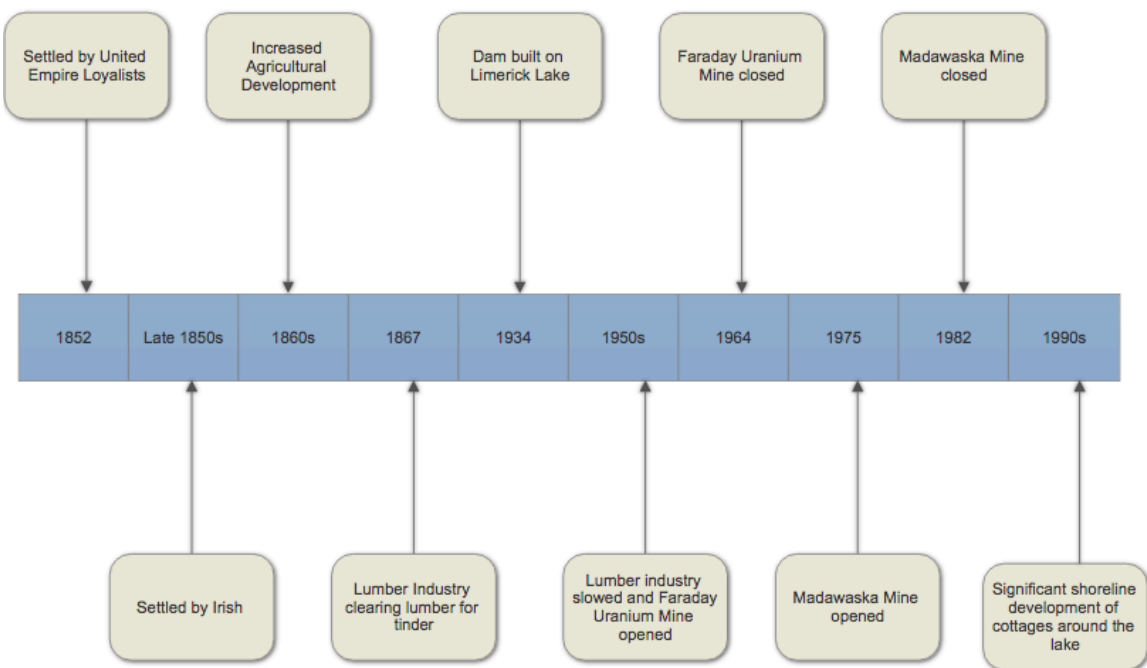


Figure 2: Timeline of events in the vicinity of Limerick Lake from 1852-1990s (Kehoe, 2017).

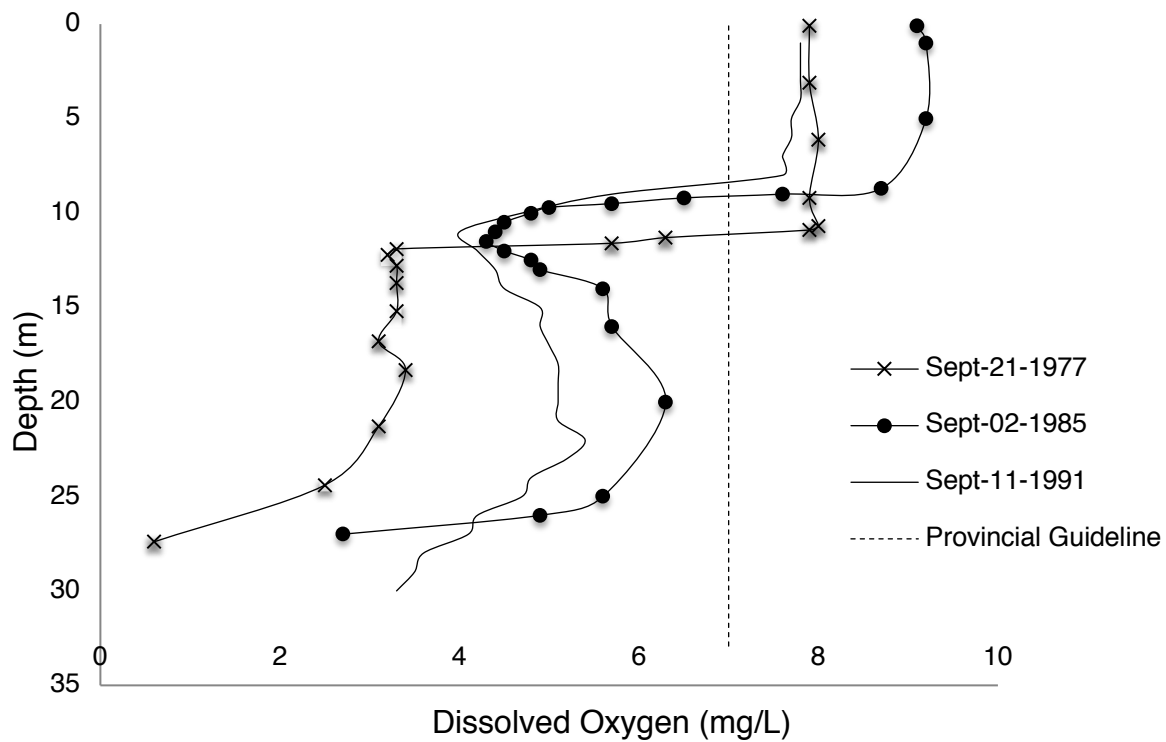


Figure 3: End-of-summer measured dissolved oxygen (mg/L) at increasing depths (m) in Limerick Lake from years 1977, 1985 and 1991 (V. Castro, Pers. Comm.).

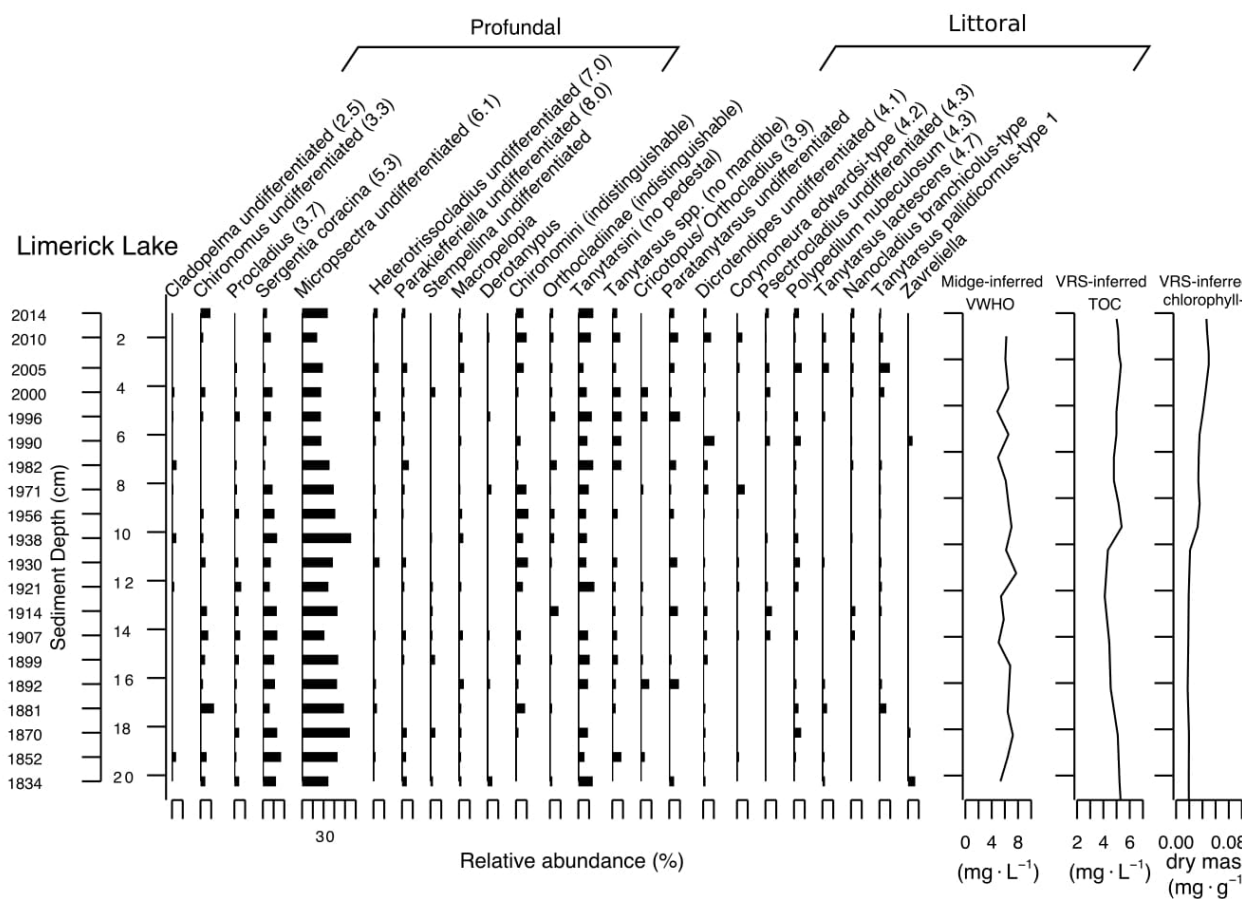


Figure 4: Relative abundances of chironomid (Diptera:Chironomidae) microfossils identified in Limerick Lake. Taxa are grouped by habitat preference (littoral and profundal) (Brooks *et al.*, 2007) and ordered by DO optima indicated in parentheses. Taxa with >3% relative abundance in at least two intervals are included in the stratigraphy (Quinlan and Smol, 2001a). Chironomid-inferred VWHO, Visible Reflectance Spectroscopy (VRS)-inferred Total Organic Carbon, and VRS-inferred chlorophyll-*a* are displayed on the right.



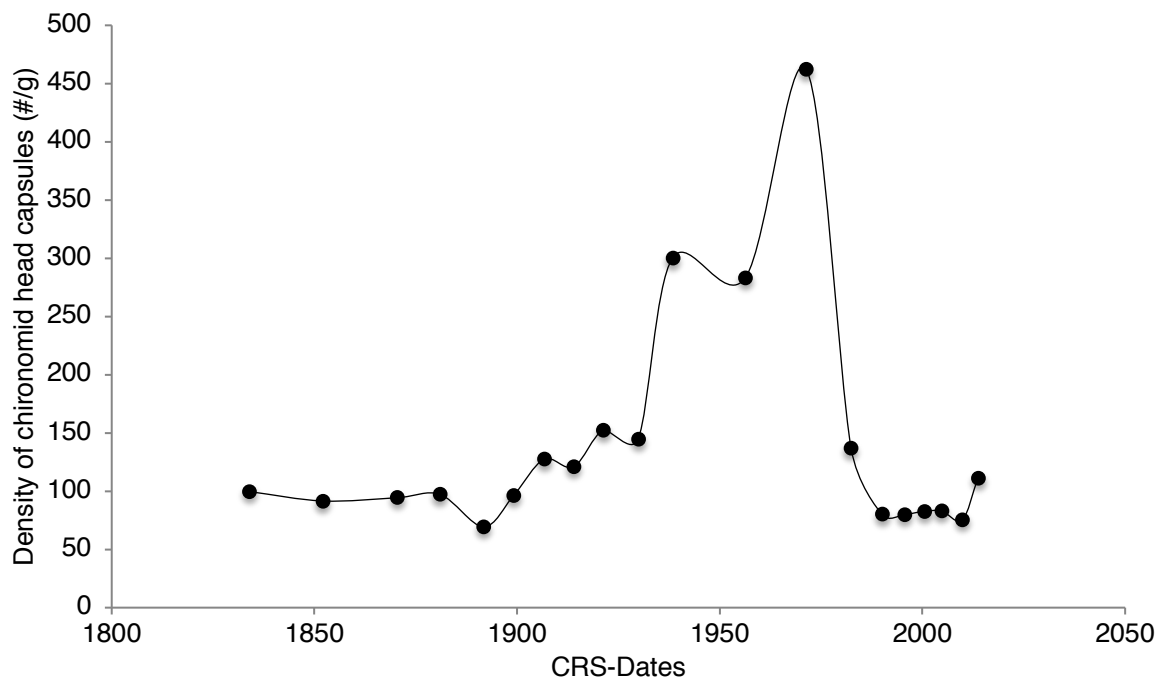


Figure 5: Density of chironomid head capsules (#/ g of dry sediment) in Limerick Lake from ~1830-2010.

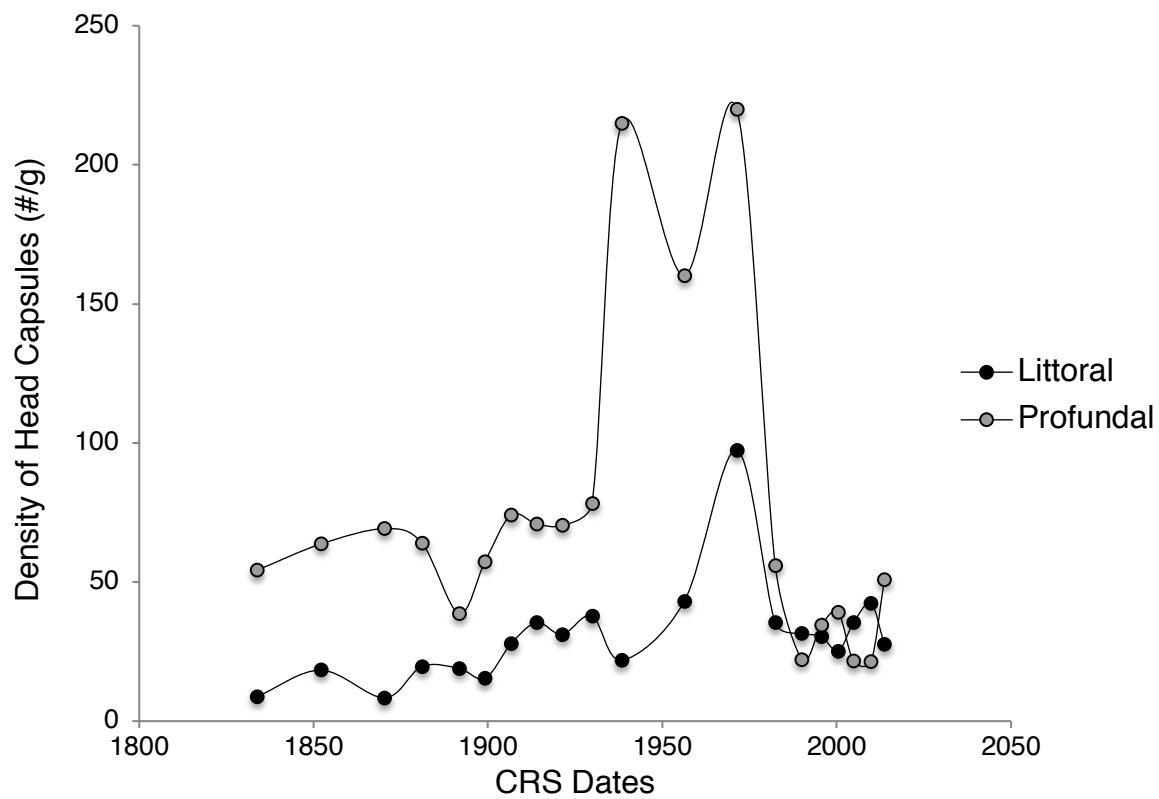


Figure 6: Density (#/g dry sediment) of littoral and profundal chironomid head capsules in Limerick Lake from ~1830-2010.

## APPENDIX 1

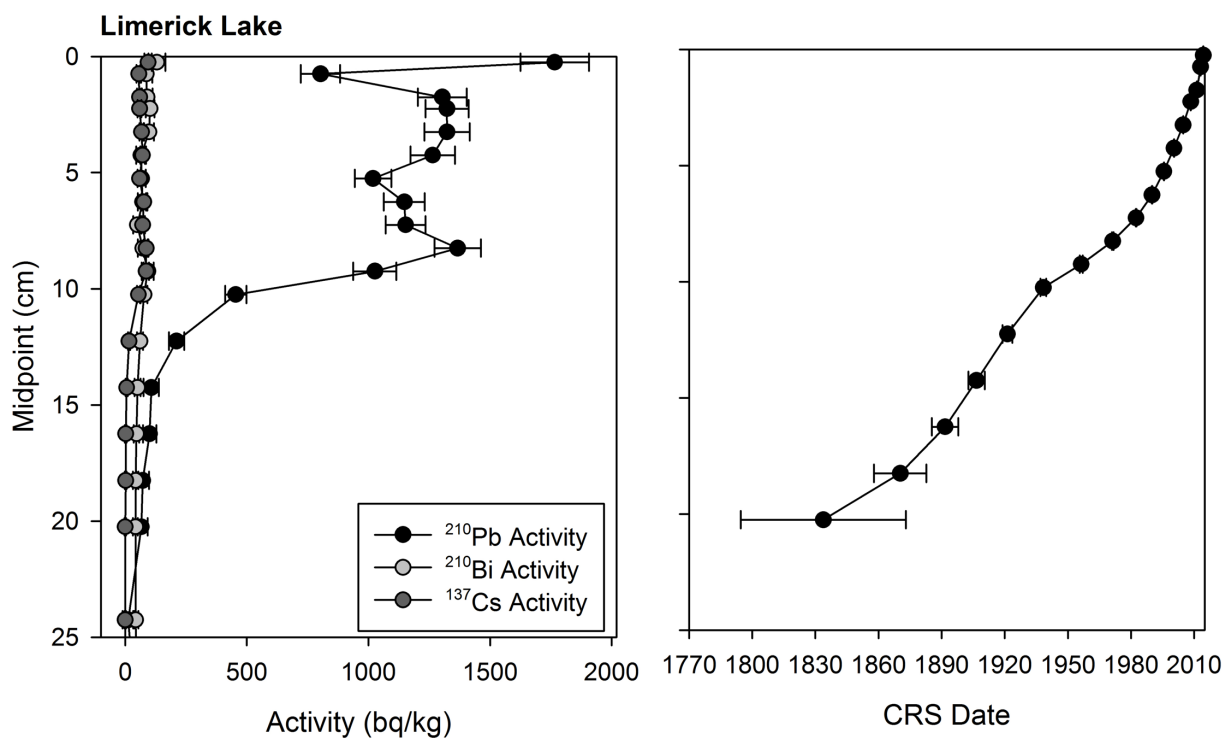


Figure A. 1: Unsupported  $\text{Pb}^{210}$  activity at relative depths in Limerick Lake on the right, and the CRS dates with their respective error bars on the left.

## APPENDIX 2

Table A. 1. VWHO model output for Limerick Lake.

Interval	Midpt (cm)	Age	VWHO (mg/L)	Proportion Inference Taxa (%)	Chaob:Chir Ratio	Chiro Total	Density (#/g)
X0.1.5	1	2013.69	6.23	95.49	0.030	64.5	111.32
X1.5.2.5	2	2009.81	6.08	93.39	0.008	60.0	75.20
X3.0.3.5	3.25	2004.81	6.52	93.02	0.047	41.0	82.89
X4.0.4.5	4.25	2000.44	4.86	95.79	0.063	44.5	82.73
X5.0.5.5	5.25	1995.61	6.56	95.06	0.025	39.5	80.04
X6.0.6.5	6.25	1989.98	4.95	93.62	0.000	47.0	80.19
X7.0.7.5	7.25	1982.39	6.14	91.84	0.051	46.5	136.89
X8.0.8.5	8.25	1971.31	6.54	97.08	0.029	83.0	462.19
X9.0.9.5	9.25	1956.30	7.02	92.91	0.021	69.0	283.24
X10.0.10.5	10.25	1938.37	6.17	91.36	0.068	75.5	300.40
X11.0.11.5	11.25	1929.835	7.74	98.15	0.009	53.5	144.50
X12.0.12.5	12.25	1921.30	5.41	95.83	0.031	46.5	152.42
X13.0.13.5	13.25	1913.96	5.83	92.31	0.048	49.5	120.97
X14.0.14.5	14.25	1906.62	5.05	96.67	0.083	55.0	127.36
X15.0.15.5	15.25	1899.16	6.82	95.83	0.021	47.0	96.35
X16.0.16.5	16.25	1891.70	6.63	95.70	0.052	44.0	69.47
X17.0.17.5	17.25	1881.025	6.43	93.88	0.041	47.0	97.13
X18.0.18.5	18.25	1870.35	7.22	97.78	0.000	45.0	94.37
X19.0.19.5	19.25	1852.095	6.38	96.33	0.037	52.5	91.60
X20.0.20.5	20.25	1833.84	5.76	91.84	0.082	45.0	99.71

## APPENDIX 3

Table A. 2. VRS-inferred chlorophyll-*a* and TOC raw data for Limerick Lake at each interval.

Depth (cm)	Chl-a mg/g	TOC mg/g
0.25	0.046	5.000
0.75	0.047	5.116
1.75	0.050	5.179
2.25	0.050	5.326
3.25	0.045	5.164
4.25	0.041	4.991
5.25	0.036	4.987
6.25	0.034	4.790
7.25	0.034	4.797
8.25	0.036	5.152
9.25	0.033	5.387
10.25	0.021	4.340
12.25	0.019	4.098
14.25	0.018	4.446
16.25	0.017	4.552
18.25	0.019	5.088
20.25	0.019	5.220
24.25	0.020	5.647

## APPENDIX 4:

## List of chironomid taxa found in the Limerick Lake sediment core

- *Chironomus anthracinus*-type
- *Chironomus plumosus*-type
- *Cladopelma laccophila*-type
- *Cladopelma lateralis*-type
- *Dicrotendipes nervosus*-type
- *Dicrotendipes notatus*-type
- *Einfeldia dissidens*-type
- *Endochironomus albipennis*-type
- *Glyptotendipes barpipis*-type
- *Lauterborniella*
- *Microchironomus*
- *Microtendipes pedellus*-type
- *Pagastiella*
- *Polypedilum nubeculosum*-type
- *Sergentia coracina*-type
- *Sergentia longiventris*-type
- *Stictochironomus rosenschoeldi*-type
- *Stictochironomus spp.*
- *Tribelos*
- *Zavreliella*
- *Chaetocladius dentiforceps*-type
- *Chaetocladius piger*-type
- *Corynoneura edwardsi*-type
- *Corynoneura* Type A
- *Cricotopus cylindraceus*-type
- *Cricotopus (Isocladius) sylvestris*-type
- *Cricotopus (Isocladius) type C*
- *Heterotrissocladius grimshawi*-type
- *Heterotrissocladius maeaeri*-type
- *Heterotrissocladius marcidus*-type
- *Hydrobaenus conformis*-type
- *Nanocladius (Plecopteracoluthus) branchicolus*-type
- *Orthocladius* Type S
- *Parakiefferiella bathophilia*-type
- *Parakiefferiella triquetra*-type
- *Psectrocladius (Mesopsectrocladius) barbatipes*-type
- *Psectrocladius (Monopsectrocladius) calcaratus*-type
- *Psectrocladius (Psectrocladius) psilopterus*-type
- *Psectrocladius (Psectrocladius) sordidellus*-type
- *Thienemanniella clavicornis*-type
- *Derotanypus*
- *Labrundinia*
- *Macropelopia*
- *Procladius*
- *Cladotanytarsus mancus*-type 1
- *Cladotanytarsus mancus*-type 2
- *Corynocera oliveri*-type
- *Micropsectra contracta*-type
- *Micropsectra insignilobus*-type
- *Micropsectra pallidula*-type
- *Micropsectra radialis*-type
- *Paratanytarsus austriacus*-type
- *Paratanytarsus pencillatus*-type
- *Stempellina*
- *Stempellina-Zavrelia*
- *Tanytarsus chinyensis*-type
- *Tanytarsus lactescens*-type
- *Tanytarsus lugens*-type
- *Tanytarsus mendax*-type
- *Tanytarsus pallidicornis*-type 1

## APPENDIX 5

Table A. 3. Total chironomid and chaoborid counts in Limerick Lake for each interval.

Column1	Limerick Lake	Interval	0-0.5	0.5-1.5	1.5-2.0	2.0-2.5	3.0-3.5	4.0-4.5	5.0-5.5	6.0-6.5	7.0-7.5	8.0-8.5	9.0-9.5	10.0-10.5	11.0-11.5	12.0-12.5	13.0-13.5	14.0-14.5	15.0-15.5	16.0-16.5	17.0-17.5	18.0-18.5	19.0-19.5	20.0-20.5
		Midpt (cm)	0.25	0.75	1.75	2.25	3.25	4.25	5.25	6.25	7.25	8.25	9.25	10.25	11.25	12.25	13.25	14.25	15.25	16.25	17.25	18.25	19.25	20.25
		Age	2014.3	2013.08	2011.24	2008.38	2004.81	2000.44	1995.61	1989.98	1982.39	1971.31	1956.3	1938.37		1921.3		1906.62		1891.7		1870.35		1833.84
C	Chironomus anthracinus-type	CHIRON			1				2				2	4	2		2	8			12		6	2
C	Chironomus plumosus-type	CHIRON	2	10		2		4											4	2				2
C	Chironomus spp.	CHIRON																						
C	Cladopelma laccophila-type	CLADOP												2										
C	Cladopelma lateralis-type	CLADOP						2	1		4	2		6		2							4	
C	Cryptochironomus	CRYPCH																						
C	Cryptotendipes	CRYPTE																						
C	Demicrochironomus	DEMICR																						2
C	Dicortendipes nervosus-type	DICROT		2	2	4	2	2		4	2	4	2				2	4	4		2	2	2	2
C	Dicortendipes notatus-type	DICROT	2			1				6		2				2	2							2
C	Dicortendipes spp.	DICROT				2					2	2												
C	Einfeldia dissidens-type	GLYPTO																						
C	Endochironomus albipennis-type	ENDOCH								4														
C	Endochironomus impar-type	ENDOCH																						
C	Endochironomus spidens-type	ENDOCH																						
C	Endochironomus spp.	ENDOCH																						
C	Glyptotendipes barpapes-type	GLYPTO									2		2											
C	Glyptotendipes pallens-type	GLYPTO																						
C	Glyptotendipes severini-type	GLYPTO																						
C	Harnischia	CYPHOM																						
C	Lauterborniella	LAUTER		2																		4		2
C	Microchironomus	MICROC																						
C	Microtendipes pedellus-type	MICROT							2	4		2			1	2				2				
C	Microtendipes spp.	MICROT																						
C	Pagastiella	PGASTL															2		2					
C	Parachironomus varus-type	PARACH																						
C	Paraclopedelma	CYPHOM																						
C	Paratendipes albimanus-type	PARATE																		2				
C	Paratendipes nudisquama-type	PARATE																						
C	Phaenopspectra flavipes-type	SERGEP																						
C	Phaenopspectra type A	SERGEP																						
C	Polypedilum convictum-type	POLYPE																						
C	Polypedilum nubeculosum-type	POLYPE		6	2		6		3	6	2	4	2	6	6	4		4		2	4	6	2	4
C	Polypedilum nubifer-type	POLYPE																						
C	Polypedilum sordens-type	POLYPE																						
C	Sergentia coracina-type	SERGEN	2	3	4	5	2	8	6	3	2	15	15	20	8	6	13	15	10	12	6	12	18	11
C	Sergentia longiventris-type	SERGEN						1																
C	Stenochironomus	STENOC																		2				
C	Stictochironomus rosenschoeldi	STICTO					2					2												
C	Stictochironomus type B	STICTO																						
C	Stictochironomus spp.	STICTO											2											
C	Tribelos	TRIBEL								2														
C	Xenochironomus	XENOCH																						
C	Zavreliella	LAUTER								4												2		2
C	Chironomini (Indistinguishable)	CHRSPP	6	3	3	9	6	2		4	2	16	16	10	12	6		5	4	2	8	2		6
O	Abiskomyia	ABISKO																						
O	Brillia	BRILLI																						
O	Chaetocladius dentiforceps-type	CHAETO				2											2							
O	Chaetocladius piger-type	CHAETO		2		2							2											
O	Corynoneura arctica-type	CORYTH																						1
O	Corynoneura carriana-type	CORYTH																						
O	Corynoneura edwardsi-type	CORYTH			4	2	2		2			12	2		2	2		2				2		2
O	Corynoneura lobata-type	CORYTH																						
O	Corynoneura Type A	CORYTH										4												
O	Corynoneura spp.	CORYTH								2											2			
O	Cricotopus bicinctus-type	CRICOR																						
O	Cricotopus cylindraceus-type	CRICOR						4	1			2									3			
O	Cricotopus trifascia-type	CRICOR																						
O	Cricotopus (Isocladius) intersectu	CRICOR																						
O	Cricotopus (Isocladius) laricomali	CRICOR																						
O	Cricotopus (Isocladius) sylvestris-	CRICOR							2															2
O	Cricotopus (Isocladius) type C	CRICOR											2								2			
O	Cricotopus type B	CRICOR																						
O	Cricotopus spp.	CRICOR							2															
O	Doncricotopus	DONCRI																	2	2			2	
O	Eukiefferiella claripennis-type	EUKIEF																						
O	Eukiefferiella devonica-type	EUKIEF																						
O	Eukiefferiella fittkaii-type	EUKIEF																						
O	Tvetenia bavarica-type	EUKIEF																						
O	Georthocladius	GEORTH																						
O	Heterotanytarsus	HTRTNY																						
O	Heterotrissocladius grimshawi-ty	HTRTRS		2	1		4															3		
O	Heterotrissocladius maeaei-type	HTRTRS							2															
O	Heterotrissocladius marcidus-ty	HTRTRS	2	1			2	3			3	4	1	6			2			2			2	
O	Heterotrissocladius subpilosus-ty	HTRTRS																						
O	Heterotrissocladius spp.	HTRTRS																						
O	Hydrobaenus conformis-type	HYDROB																		2				

