Internal Stratification and Oxygen Fluxes of Provincial Lake Simcoe: A Sampling Paradox

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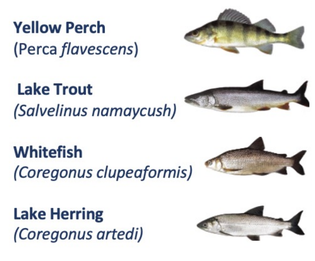
Introduction

- Lake Simcoe, a provincial Lake in Southern Ontario, provides important socio-economic benefits to local communities through recreational fishery activities.
- **Coldwater Pelagic fish** (figure 2) follow oscillations in the thermocline as they stay in preferred temperature and oxygen conditions of typically 15°C. [2]
- *Lake Simcoe protection Plan* aims to protect and restore ecological health of Lake Simcoe by regulating oxygen levels at end of summer.[3]



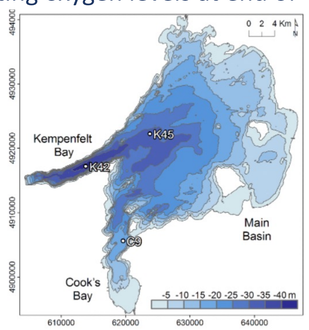


Fig. 1: Common Coldwater Pelagic fish species in Lake Simcoe [4]

Fig. 2: Bathymetry map of Lake Simcoe (44.46°N, 79.33°W) and location of sampling stations. Sampling station K42, at Kempenfelt Bay [1].

- Biweekly and High-frequency (15-minute intervals) measurements of **Dissolved Oxygen (DO) and Temperature** were taken from May 20th to October 14th to track internal waves and DO levels at the end of summers.

Objectives

1. **Find out if Dissolved Oxygen (DO) levels of Lake Simcoe at end of summer falls below *Lake Simcoe Protection Plan of 7mg O_2/L***
2. **Do biweekly sampling accurately predict internal waves of lake Simcoe?**

Methods

- The thermocline can be defined as the first moment of density gradient [5].

$$h = \int_0^H z\frac{\partial \rho}{\partial z}dz \Big/ \int_0^H \frac{\partial \rho}{\partial z}dz$$

h is the position of maximum density gradient (thermocline) and H is the maximum depth (here H=34m).

- The top of hypolimnion is defined as the depth where the temperature gradient is 20% below density of thermocline.

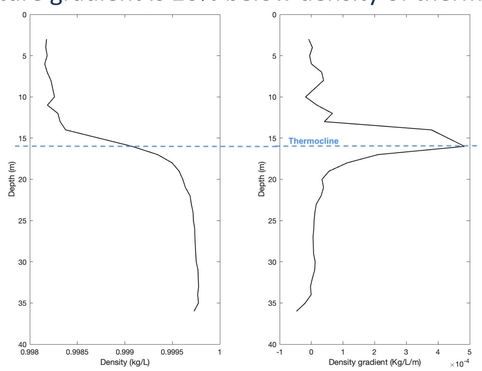


Fig. 3: Thermal Profile of Lake Simcoe on September 21st (Day 264). Thermocline defined as depth of maximum density gradient (ρt). Hypolimnion defined as depth of 20% of thermocline density (ρt - 0.2ρt)

Results

General Trends

- The surface temperature is highest around **September 7th (Day 250**), as temperatures in epilimnion reach 24°C. (*fig. a*)
- Dissolved Oxygen levels (*fig. b)* are the highest after the spring turnover and decrease uniformly throughout lake profile until beginning of August (~Day 220).
- DO first depletes in metalimnion in July and decreases to levels below 2.5mg/L by the end of summer 2021.

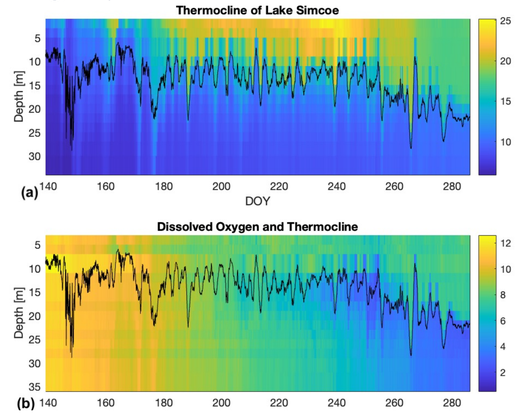


Fig. 4: Thermocline of Lake Simcoe at K42 station during summer 2021, plotted on temperature and DO profiles. Temperature in degrees Celsius (°C) and DO in milligram per volume (mg/L).

Comparison

- The high-frequency readings (*fig. a* & *c*) include daily temperature and DO level variations within the lake profile.
- Temperature and DO of Lake Simcoe of biweekly readings (*fig. b* & *d*) do not account for internal waves until July 19th (Day 200)
- The interpolated temperatures of the biweekly readings (fig. b) are slightly warmer compared to high-frequency data (*fig. a*)

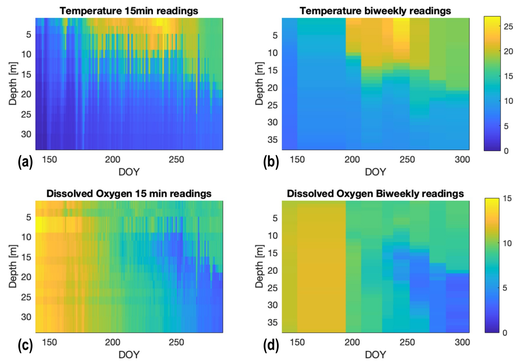


Fig. 5: Summer 2021 Temperature and Dissolved Oxygen profiles of lake Simcoe at Kempenfelt Bay Sampling Station. Biweekly and high frequency (15 minutes interval) sampling compared.

- The thermocline calculated from the biweekly data (red) does not fully capture the internal waves (high-amplitude oscillations) in lake Simcoe which are visible in high-frequency data (blue).

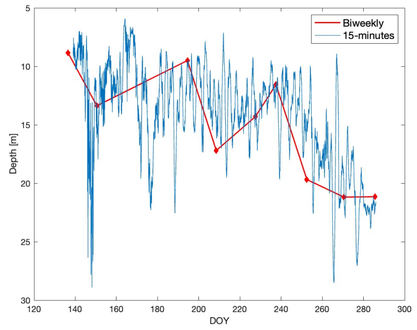


Fig. 6: Comparative plot of high-frequency (15-minute readings) and biweekly thermocline depths at K42 during Summer 2021.

Discussion

1 Find out if Dissolved Oxygen (DO) levels of Lake Simcoe at end of summer falls below *Lake Simcoe Protection Plan of 7mg O_2/L*

- We plotted the Volumetric Weighted Hypolimnetic Dissolved Oxygen levels[6] to estimate when/if levels went below *protection plan regulations* and thus were not optimal for deep-water cold-water pelagic fishes.
- According to figure 7, average DO levels under thermocline fall below 7 mg of O_2 per L around **August 8th (Day 220)**.

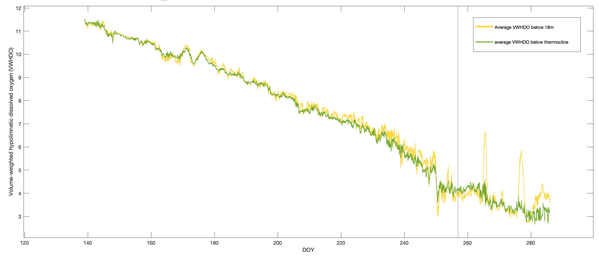


Fig. 7: Volumetric Weighted Hypolimnetic Dissolved Oxygen levels of Lake Simcoe at K42 station during summer 2021, plotted below 18m (yellow) and thermocline (green) depths.

2 Do biweekly sampling accurately predict internal waves of Lake Simcoe?

- Sampling of Ontario Government Protection Plan occurred around September 15th (Day 258) of each year.
- DO levels are highly variable (~3.5 mg/L to ~5mg/L) in high-frequency samplings and low-frequency data shows a DO measurement of about 5mg/L.
- Although both data show DO-levels below LSPP regulations during summer 2021. Biweekly sampling could result an can **overlook internal waves** and high-frequency oscillations of DO levels of about 1.5mgl/L in magnitude.

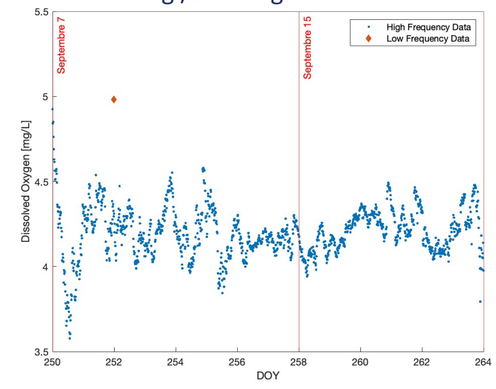


Fig. 8: Average VWHDO below thermoclines of high-frequency and low-frequency data around September 15 (Day 258).

References

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[2] Flood, B., Wells, M., Dunlop, E., & Young, J. (2021). Vertical oscillations of the thermocline caused by internal waves modify Coldwater pelagic fish distribution: Results from a large Stratified Lake. Journal of Great Lakes Research, 47(5), 1386–1399. https://doi.org/10.1016/j.jglr.2021.06.010

[3] Lake Simcoe Protection Plan . ontario.ca. (2009). Retrieved April 6, 2022, from https://www.ontario.ca/document/lake-simcoe-protection-plan

[4] https://www.fishingsimcoe.com/fish-species. (2022)

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[6] A. M. Paterson, R. Quinlan, B. J. Clark & J. P. Smol (2009) Assessing hypolimnetic oxygen concentrations in Canadian Shield lakes: Deriving management benchmarks using two methods, Lake and Reservoir Management, 25:3, 313-322, DOI: 10.1080/07438140903117688