Winter Severity Influences Carbon Availability and Microbial Activity in The Laurentian Great Lakes

Connor O'Loughlin[1], Gordon Paterson[1], Nicole Wagner[2], Hunter Carrick[3], Jonathan Doubek[4], Donald Uzarski[3], Trista J. Vick-Majors[1], with the Winter Grab Network

[1]Michigan Technological University, [2]Oakland University, [3]Central Michigan University, [4]Lake Superior State University

Abstract

- Ice cover is used as an indicator for winter severity.
  - Creates a barrier between lake water and the surrounding atmosphere and terrestrial ecosystem.
- Understanding how ice drives ecological biogeochemical processes is important due to the interseasonal effects produced by winter processes.
- Recent studies have shown that differences in winter severity can influence carbon cycling and microbial activity.
- We present our findings that show how microbial activity and carbon availability are influenced by winter severity.

Hypotheses

- More severe winters will result in reduced dissolved organic carbon (DOC) concentrations and reduced quality of organic carbon substrates.
- Microbial activity will shift toward bacterial maintenance with increasing winter severity, marked by a larger uptake of leucine relative to thymidine.

Methods

- Surface water samples were taken from the Laurentian Great Lakes (see Figure 1).
- DOC concentrations were measured using a Shimadzu TOC-L.
- Fluorescent dissolved organic matter (fDOM) was characterized using a Horiba Aqualog. The resulting excitation-emission matrices were used to calculate the humification index (HIX) and other spectral indices.
- Bacterial production was measured via tritated leucine and thymidine incubations, and was quantified using liquid scintillation.
- Ice and snow thickness were measured at each site.

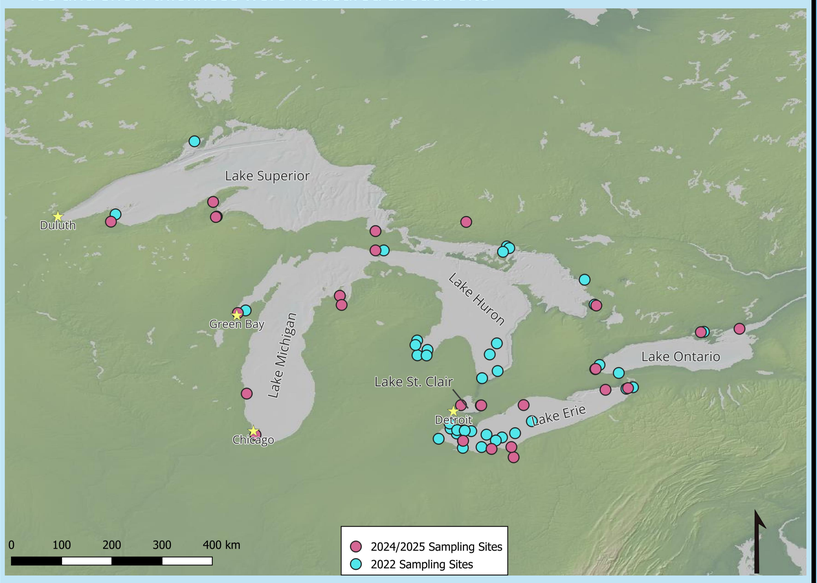


Figure 1. Map showing the geographical distribution of sampling sites for the winters of 2022, 2024, and 2025.

Snow and Ice Cover

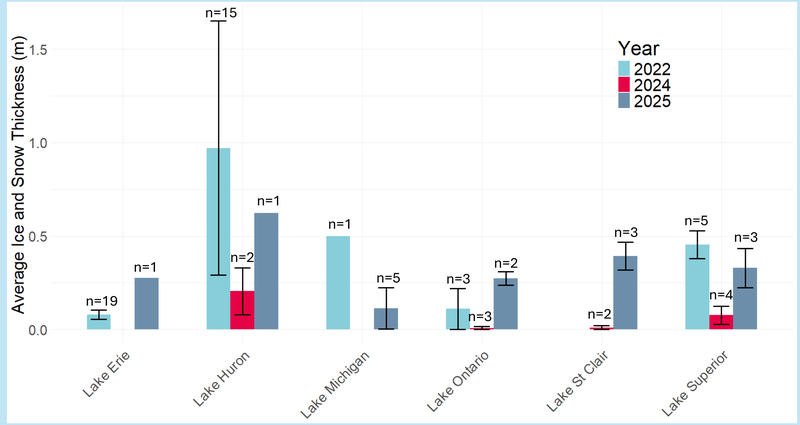


Figure 2. Snow and Ice thickness was calculated as the total of snow and ice thickness at each site averaged within each lake. Error bars were calculated as the standard error of the average ice and snow thickness. In 2024, lakes Erie and Michigan had no ice cover. Lake St. Clair was not sampled in 2022.

DOC concentration and Carbon Quality

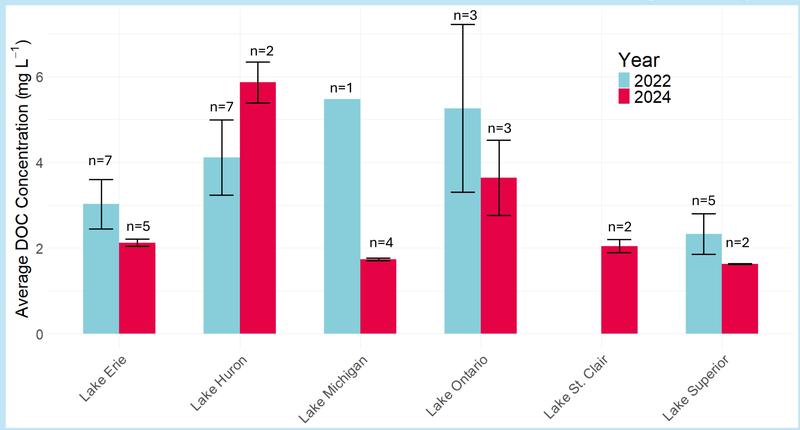


Figure 3.Average DOC concentrations averaged within lake. Error bars indicate standard error and replicates are shown above each bar.

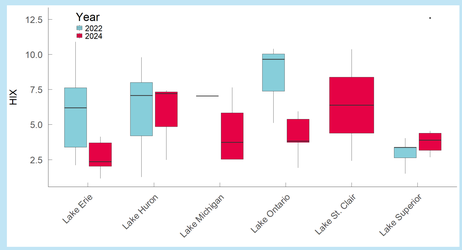
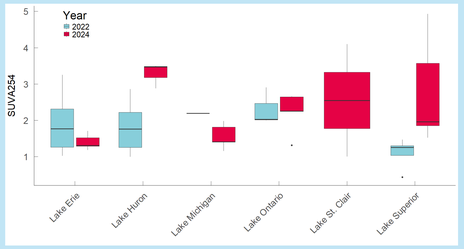


Figure 4. Boxplots showing the humification index (HIX) for each lake. HIX is a spectral index that compares relative aromaticity of humic substances. The lower the number the less humic and "fresher" the carbon is. The higher the number the more complex and aromatic the carbon substrate is. Horizonal lines indicate median, vertical lines indicate interquartile range, and points indicate outliers.

Figure 5. Boxplots showing specific ultraviolet fluorescence at 254 nm (SUVA254) for each lake. SUVA254 is an absorption index that looks at the relative aromaticity of DOC but considers the concentration of substrate. The higher the value, the higher the aromaticity and the higher the likelihood that the carbon is terrestrial in origin.



Microbial Activity

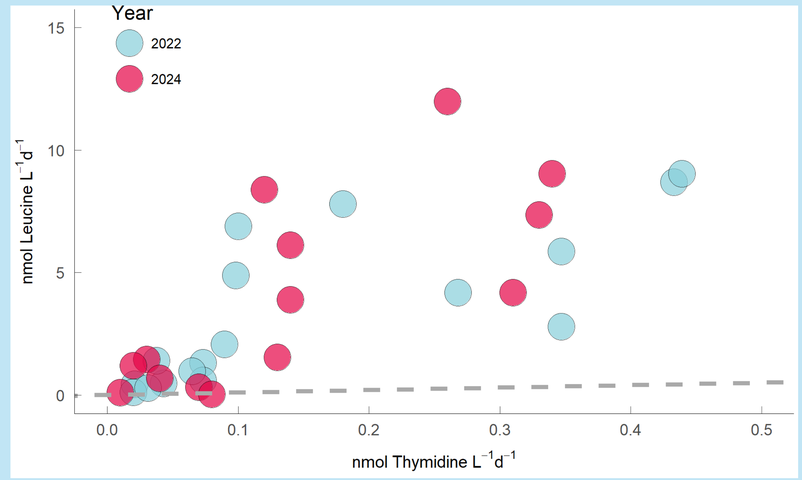


Figure 6. The ratio of leucine uptake relative to thymidine uptake is indicative of microbial activity, with a larger value suggesting microbial maintenance as opposed to growth. The grey dotted line represents a 1:1 relationship.

Conclusions

- Winter 2024 was less severe compared to 2022 and 2025, because it had lower ice and snow cover on average (Figure 2).
- Microbial activity did not appear to be directly impacted by winter severity (Figure 6).
- DOC concentrations (Figure 3) were higher in 2022 (more severe winter).
  - DOC may be excluded from the ice as it forms, resulting in more concentrated DOC in the surface water (Figure 3).
- Higher HIX values in 2022 vs. 2024 suggest that the organic carbon substrate in 2022 was more complex and less bioavailable and, therefore, of poorer quality.
- Comparing the SUVA254 values from 2024 to those in 2022 (Figure 5) suggests that carbon in 2024 was more aromatic than carbon in 2022. Additionally, this could also mean that more of the carbon in 2024 was terrestrial in origin in comparison to 2022.
  - Reduced ice cover in 2024 may have increased connectivity to the watershed and allowed greater contributions from the terrestrial environment.

Future Directions

- Process winter 2025 DOC, fDOM, and leucine and thymidine incubation samples and investigate how a comparatively moderate winter impacts carbon concentration, carbon quality, and microbial activity.
- Examine winter severity as a driver for microbial community assemblage since our microbial activity data show the same trend in different winter severity conditions. Microbial community response regarding bacterial production is resilient, but community composition remains unknown.
- Employ quantitative methods to assess relationships between winter severity, microbial activity, carbon quality, and DOC concentration.

Acknowledgements

We would like to thank Maci Quintanilla, Garrett Lukosavich, Mitch Kehne, Allen Cureton, Mari Leland, K.M. Shafi, and An Nguyen for assistance with sample collection, the Great Lakes Research Center for providing logistical support, and the Great Lakes Winter Network for support. Special thanks to the Winter Grab network for participating in sample collection. This work is supported by a Michigan Sea Grant award to TVM (SUBK00020867).