Stable Carbon and Nitrogen Isotopes as Indicators of Environmental Changes in Lacustrine Systems: A Case Comparison of Connecticut and Ireland Lakes

Rebecca Downer

Faculty Advisor: Timothy Ku

Introduction

Human activities have contributed significantly to environmental degradation within lake systems. Land use changes, industrial activity, and excess nutrient input from fertilizers and septic systems have all caused changes to carbon and nitrogen cycling within lakes. Amos Lake (CT), Lough Cara (Ireland), Lake Waramug (CT), and Lake Wononscopomuc (CT) have all experienced significant changes due to human activities. To investigate the history of these events, lake sediment cores were analyzed for a range of geochemical measurements (% C, % N, C/N, $\delta^{13}C$, $\delta^{15}N$). Prior work used sediment mercury profiles, Pb-210 dating, and radiocarbon dating to identify individual time zones for each lake. Interpretations of these past changes in sediment chemistry across these four lakes will aid in evaluating the effectiveness of different remediation policies, isolating the variables that contribute to the different trends in these geochemical values, and tailoring future efforts to the individual characteristics of each lake. This work has two primary objectives:

1. Interpret sediment organic $\delta^{13}C$ and $\delta^{15}N$ depth trends in these four lakes.
2. Investigate why $\delta^{13}C$ and $\delta^{15}N$ values vary across these lakes in Connecticut and Ireland. What can modern sediment chemistries tell us about the effectiveness of remediation efforts?

Study Areas

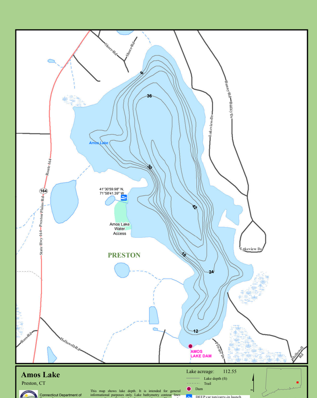

Fig. 1 Bathymetry Map of Amos Lake (CT DEEP, 2011).

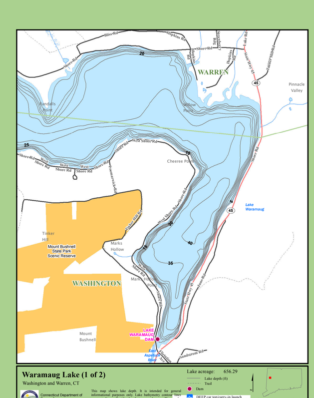

Fig. 2 Bathymetry Map of Lake Waramug (CT DEEP, 2011).

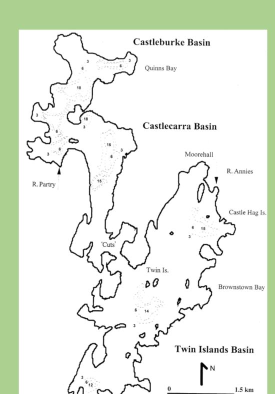

Fig. 3 Bathymetry Map of Lough Carra (King & Champ, 2000).

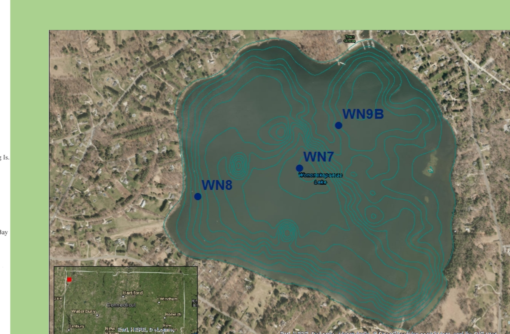

Fig. 4 Bathymetry Map of Lake Wononscopomuc (Capers & Selsky, 2004).

Methods

- A push or gravity corer was used to collect sediment cores.
- Sediments were divided into 2-4 cm intervals, dried, and homogenized with a mortar and pestle.
- A CE Elantech Flash Elemental Analyzer was used to determine concentrations of total C and N.
- Organic matter stable carbon and nitrogen isotope values were determined by standard techniques at the U of Florida or University of California – Davis after the removal of $CaCO_3$ if necessary.

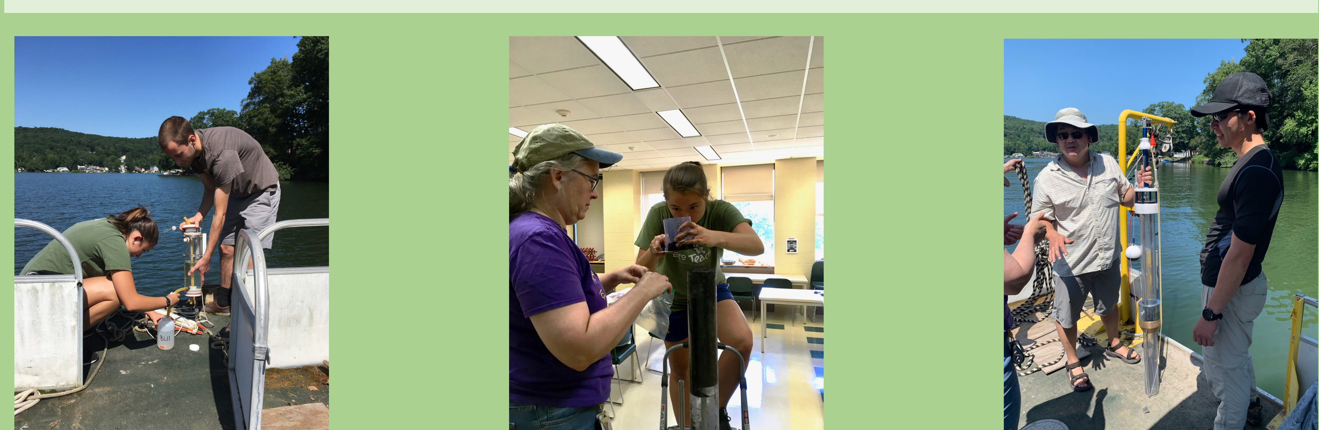

Fig. 5 a,b,c Field and lab photos taken from another study at Lake Beseck, CT, similar methods were followed for the other lakes in this study

Background

MAR- OC/ %C	-Dissolved O in the bottom and pore waters is enough to oxidize OC -Larger lake volume	-Increased autochthonous and/or allochthonous OM -Reduced O in bottom and pore waters	-Decreased autochthonous and/or allochthonous OM
MAR- ON/ %N	-Steady nutrient input, generally follows OC levels	-Nutrient loads high in N, including inept septic systems and fertilizer use -Increased atmospheric N levels	-Decreased nutrient input
C/N	-Nutrient input to lake most likely sourced from both terrestrial and algal OM	-Nutrient input to lake most likely sourced from terrestrial OM -During diagenesis, C/N ratios of algae (normally lower values), increase	-Nutrient input to lake most likely sourced from algae stimulated within the lake -During diagenesis, C/N ratios of terrestrial plants decrease
$\delta^{13}C$	-Nutrient input may be significant, but not high enough to expend DIC reservoir and change δ13C values	-Increased production within lake, DIC is taken up, due to preference of ^{12}C to ^{13}C -Depletion of available aqueous CO_2, plants shifting to isotopically heavier bicarbonate	-Decreased sedimentation rate -Decreased nutrient input -Source of nutrient input could come primarily from C3 plants -Suess effect
$\delta^{15}N$	-May be a N-limited ecosystem -Mostly N_2 fixation by cyanobacteria	-N may not be limiting nutrient -N fixers take up nitrate and ammonium causing an increase in $\delta^{15}N$ values -Anoxia in hypolimnion and increased denitrification	-OM produced by N_2 fixing cyanobacteria -C3 land plants taking in atmospheric N with lower isotopic ratio

Fig. 6 %C, %N, C/N, $\delta^{13}C$, $\delta^{15}N$ Trends

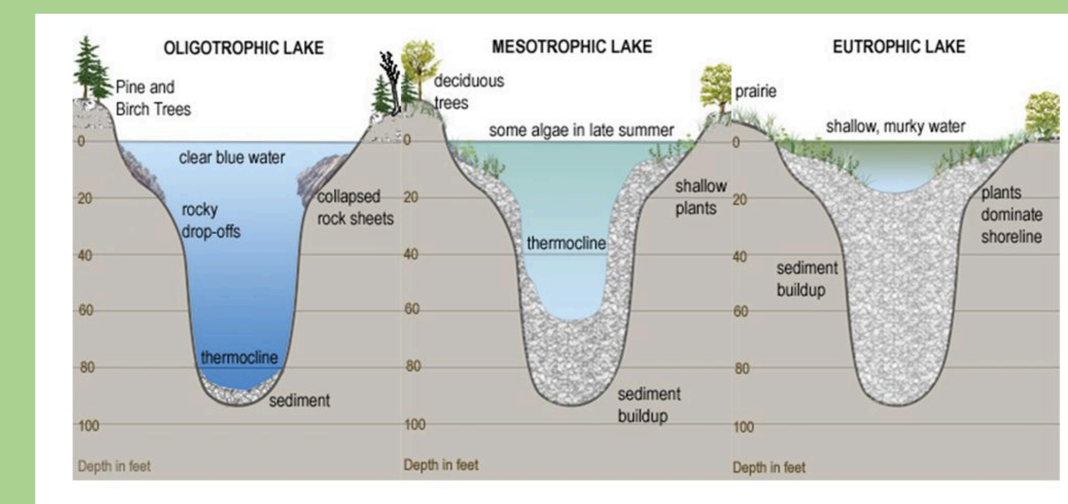

Fig. 7 Lake Eutrophication Diagram (RMB Environmental Labratories, 2020)

- In a typical eutrophic lake, one would expect to see increasing values of OC, ON, $\delta^{13}C$, and $\delta^{15}N$. As nutrient input increases, OC and ON would increase. Algae and other aquatic plants would draw down the DIC and DIN reservoirs, resulting in higher $\delta^{13}C$ and $\delta^{15}N$ values. C/N values would indicate the source of OM within the lake (terrestrial or aquatic).

Fig. 6 (Assumes MAR-OC/MAR-ON and %C/%N covary and indicate same values)

%C, %N, and C/N $\delta^{13}C$ and $\delta^{15}N$ Analyses

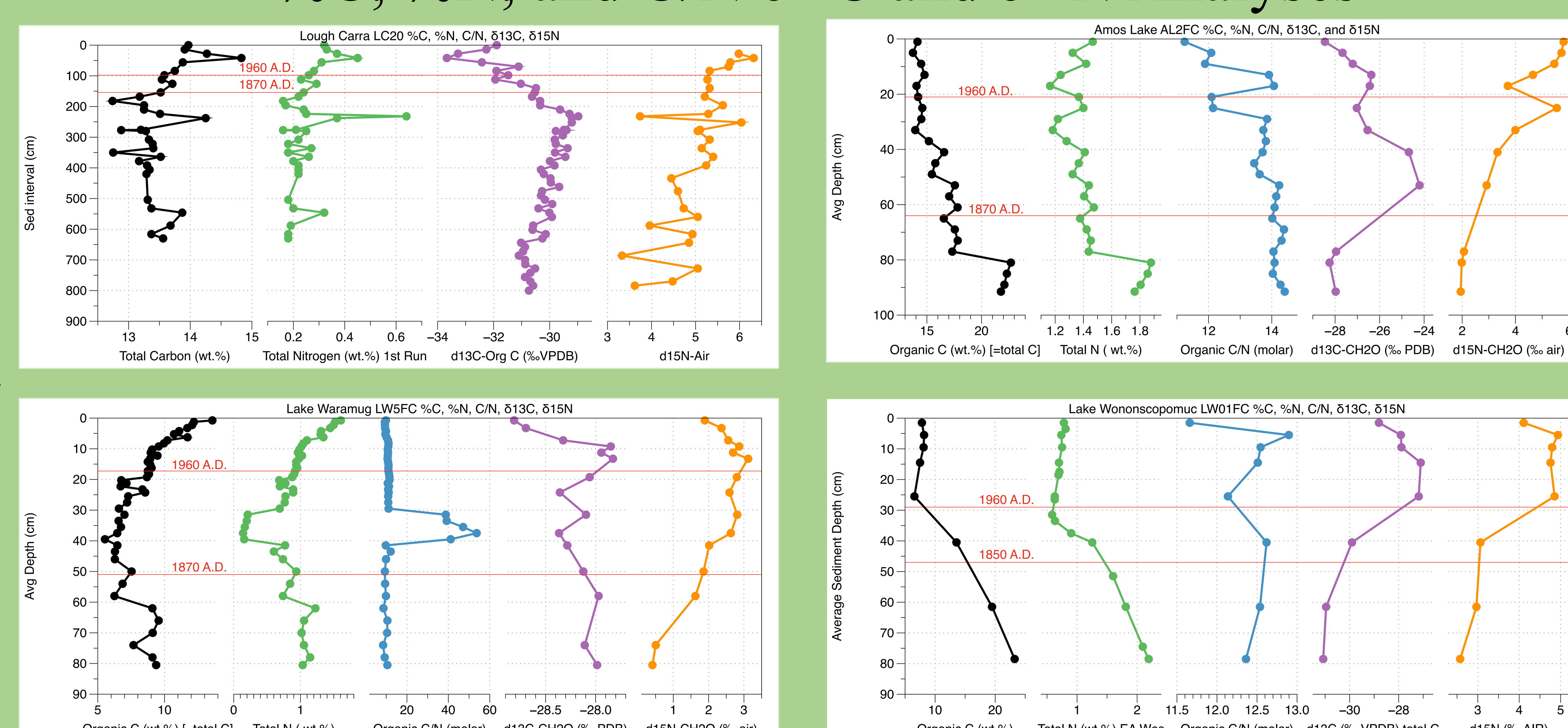

Fig. 8 a,b,c.d. Sediment Depth vs MAR C, Total N, $\delta^{13}C$, $\delta^{15}N$ **Fig. 8 d.** (Age is estimated from a core collected in the same area)

- **Lough Carra:** TC and TN begin to increase in the mid-late 1800s, indicating that human anthropogenic activities, such as farming and application of fertilizers led to eutrophication. $\delta^{15}N$ values follow this trend, where eutrophication causes the DIN reservoir to become more depleted, and $\delta^{15}N$ values subsequently increase. However, $\delta^{13}C$ values decrease, which was not expected. From 800-250 cm, the increase in $\delta^{13}C$ values may have been due to increasing eutrophication from farming and other human-caused changes in the area. Increased eutrophication would have caused the DIC to become depleted, increasing $\delta^{13}C$ values. However, from 250-0 cm, there appears to be a decline in $\delta^{13}C$ values. This may have been due to some changes to the source of carbon in the lake, resulting in the DIC not being depleted, due to factors such as faster circulation within the water column.

- **Amos Lake:** OC and TN stay fairly stable, without increasing in recent years, but their OC and TN MAR are higher than that of the other 3 lakes. The area may have shifted from a more swamp-like environment to more of a lake environment. A dam was established in the area to raise the water level, so decreases in OC may have been due to this lake level rise and decreasing C/N values may have been due to a shift to more algal OM as the main source of OM. $\delta^{13}C$ and $\delta^{15}N$ values have opposite trends. Lower $\delta^{13}C$ values could also be attributed to sewage depleted in ^{13}C. Higher $\delta^{15}N$ values may be due to human activities (sewage systems, fertilizers) causing eutrophication, which would explain lower C/N values as well.

- **Lake Waramug**: OC and TN stay fairly stable until 1960 A.D. when they increase upcore, most likely due to increased eutrophication in more recent years. C/N ratio shows a sharp increase from approximately 1900-1930 A.D., which may have been caused by significant land use changes, causing an increased input of terrestrial OM. Both $\delta^{13}C$ and $\delta^{15}N$ values decrease around 1980 A.D., indicating that remediation efforts to reduce nutrient loading must have been effective. The Lake Waramug Association Task Force implemented in-lake aeration systems that worked to isolate anoxic bottom waters. This would have enabled bottom waters to be oxidized to CO_2, thus decreasing $\delta^{13}C$ values. The decrease in $\delta^{15}N$ values may have been due to remediation efforts that prevented runoff (with high $\delta^{15}N$ values) from farms, septic systems, and lawns from entering the lake.

- **Lake Wononscopomuc:** OC generally decreases upcore, potentially due to changes in land use. Lake Wononscopomuc experienced various remediation efforts in the 1980s to combat eutrophication, which may explain the fairly stable OC values in shallower depths. $\delta^{13}C$ and $\delta^{15}N$ values for Lake Wononscopomuc appear to mirror one another, following remediation efforts in the area to limit eutrophication. This follows the patterns explained by **Fig. 6,** with decreased eutrophication, the drawdown of DIC and DIN would be less intense, resulting in more negative $\delta^{15}N$ values.

Conclusion

Analyzing the paleoenvironmental history of a lake system is critical in order to measure the impact humans have had on these environments. Though each of these lakes has experienced cultural eutrophication due to human activities, it is also clear that remediation efforts can be effective. Lake Wononscopomuc and Lake Waramug have undergone various procedures to combat eutrophication, and continue to be monitored annually. The results of these efforts can be shown with decreasing $\delta^{13}C$ and $\delta^{15}N$ values upcore. These lower values demonstrate that DIC and DIN reservoirs have not been significantly depleted in these lakes. On the other hand, Amos Lake and Lough Carra represent areas that have had less remediation and interference, which may explain their increased $\delta^{13}C$ and $\delta^{15}N$ values. Continued research studies include measurements of P in conjunction with measurements of C and N. Efforts to reduce internal loading as well as external loading are essential.

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Acknowledgements

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