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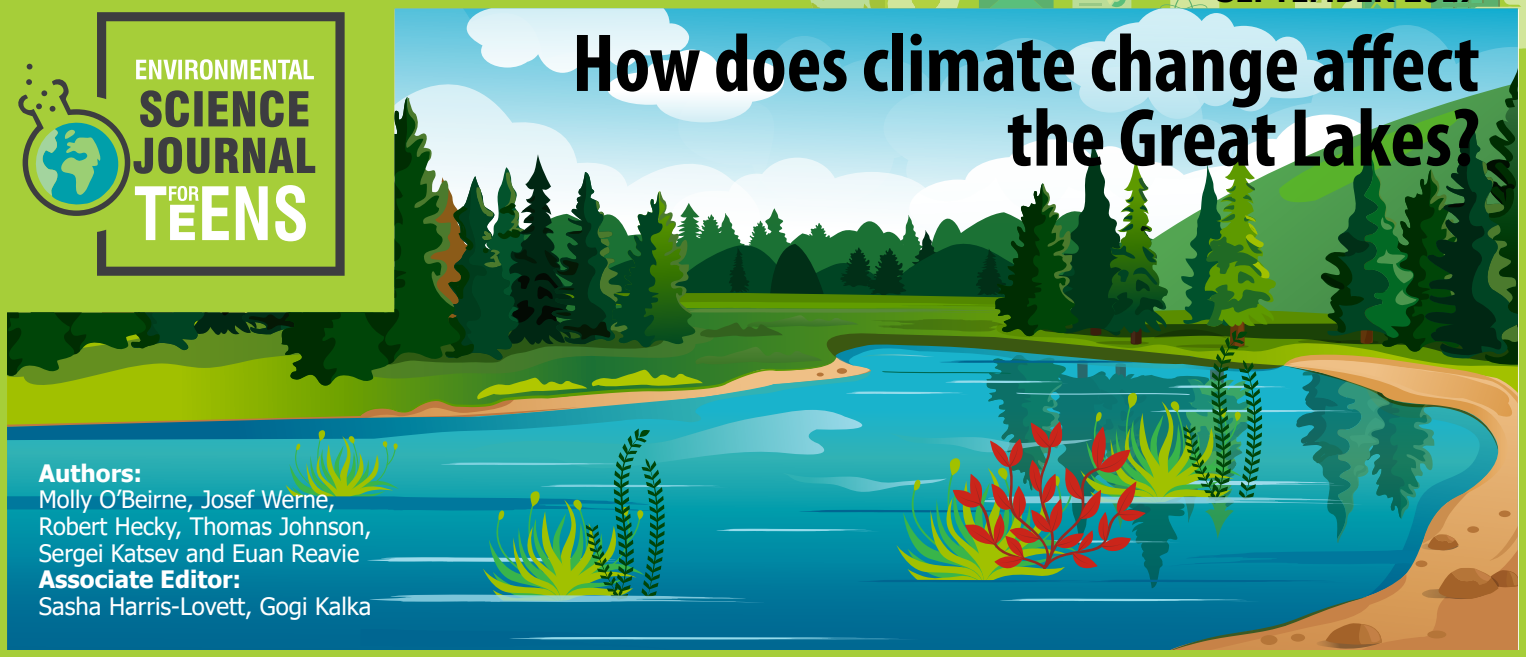
How does climate change affect the Great Lakes?



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Abstract

Scientists agree that some human activities, like burning fossil fuels, cause the Earth's atmosphere to trap more heat, leading to *climate change*. We wanted to find out how climate change affected large freshwater lakes, so we took a series of *sediment cores* in Lake Superior (the biggest of the Great Lakes in North America) to study samples of the mud at the lake bottom. Back in the lab, we analyzed tiny bits of dead plants and *algae* trapped within the sediments. From these samples, we could see that the amount of algae in Lake Superior has slowly increased over time. However, in the past hundred years, the amount of algae and plants in the Lake has increased dramatically. We think this recent drastic change happened because human-caused climate change led to warmer temperatures and longer ice-free periods in the lake. This made it easier for algae and plants to grow in the water.

Introduction

The Earth has become warmer – and our climate continues to change – since humans began burning fossil fuels and releasing large quantities of *greenhouse gases*, like *carbon dioxide*, into the air. How do these atmospheric changes affect the *ecology* of large freshwater lakes, which provide important wildlife habitat and essential water supplies for people? To answer this question, we studied Lake Superior, which has the largest surface area of any lake in the world and is considered relatively *pristine*. (Fig. 1)

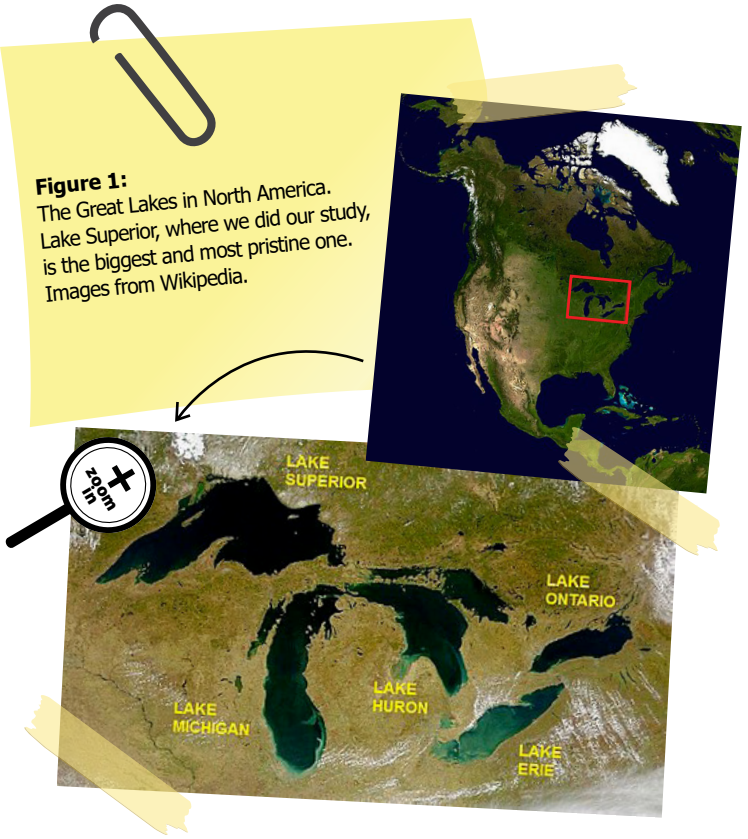

Figure 1:
The Great Lakes in North America. Lake Superior, where we did our study, is the biggest and most pristine one. Images from Wikipedia.

To look at how Lake Superior has changed over time, we needed to know what it was like in the past. Luckily, muddy sediments at the bottom of lakes store a record of all the plants and algae that have ever lived in the water. Here's why: when algae and tiny floating plants in the water (called *phytoplankton*) die, they sink down to the bottom of the lake and accumulate there. Just as a messy desk has piles of newer papers on top of older ones, the bottom of a lake has many layers of sediment, with the oldest stuff at the bottom and the newest on top. Studying the changes in sediments can help us understand how the ecology of the lake has changed over time, a field of science called *paleolimnology*.

Methods

We went out on multi-day boat trips with a sediment coring machine to take cores (tube shaped samples) from different parts of the bottom of Lake Superior (Fig. 2, 3).

To take a sediment core, we lowered a clear plastic pipe down to the lake bottom and pushed it all the way into the mud. Then we closed off the top of the pipe to create suction, which trapped the sediment inside the pipe as we hauled it back onto the boat. The process is similar to getting ice cream out of a milkshake – you poke a straw (the plastic pipe) into a milkshake (the lake sediments), put a finger over the top of the straw (the coring machine caps the pipe to create suction and trap the sediments), and then extract the straw with the ice cream (lake sediments) trapped inside (Fig. 4).

After extracting the sediment cores, we froze them (so bacteria wouldn't change the composition of what was in the mud) and brought them back to the lab for analysis. There, we looked at different forms of *carbon*, called *isotopes*, along the length of the sediment core. This analysis allowed us to see how much algae and phytoplankton lived in the lake at any given time.

A)

B)

Figure 2:
A) Our research vessel, the R/V Blue Heron. **B)** A crew of scientists and marine technicians from the Large Lakes Observatory and the University of Pittsburgh is taking sediment cores from Lake Superior using a multi-coring system (which takes 4 cores at once)

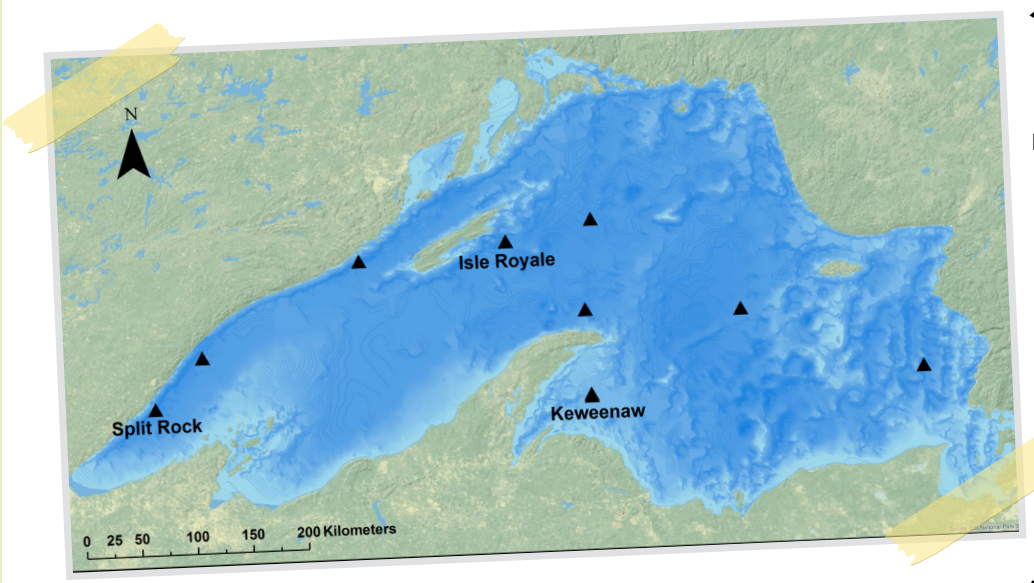

Figure 3:
We studied sediment cores from nine different locations in Lake Superior, marked by black triangles

Figure 4:
A sediment core we took from Lake Superior just offshore from Split Rock Lighthouse State Park, Minnesota. Note changes in color of the different layers of the sediment. In this core, the thick green layer is from taconite mining debris washed into the lake in the mid 20th century. Below are darker brown "normal" sediments for this region of Lake Superior before human influences on the lake. At the top, the reddish brown sediments were still impacted by human activities, but not as much as the green layer.

Results

In all of the sediment cores we studied, we found that the amount of algae and phytoplankton living in Lake Superior slowly increased year by year since the lake formed, until approximately the year 1900. Then, the amount of algae and phytoplankton abruptly and dramatically increased in the 20th century (Fig. 5). This increase was significantly greater than any of the fluctuations in the amount of the lake's plant life in the previous 10,000 years!

How does the increasing amount of the carbon-13 isotope ($\delta^{13}C$) tell us more about algae/phytoplankton growth? To understand this, it is important to realize that the algae and phytoplankton don't like the 2 different forms of carbon the same. Think of the two different carbon isotopes (carbon-12 or ^{12}C and carbon-13 or ^{13}C) as candy in a piñata. Your favorite candy to eat, the one you'll grab the most of and eat first when the piñata is broken, is like ^{12}C for algae/phytoplankton – they really like to eat ^{12}C! But once all of your favorite candy is gone, you'll start eating more of your less favorite candy, which is like ^{13}C for algae/phytoplankton. For algae/phytoplankton, ^{13}C is "just OK". So as algae/phytoplankton grow more and more they have to start eating more and more ^{13}C. And we can see their growth by the increased amount of ^{13}C in our sediments, even centuries after they ate it and are long dead - which is pretty cool!

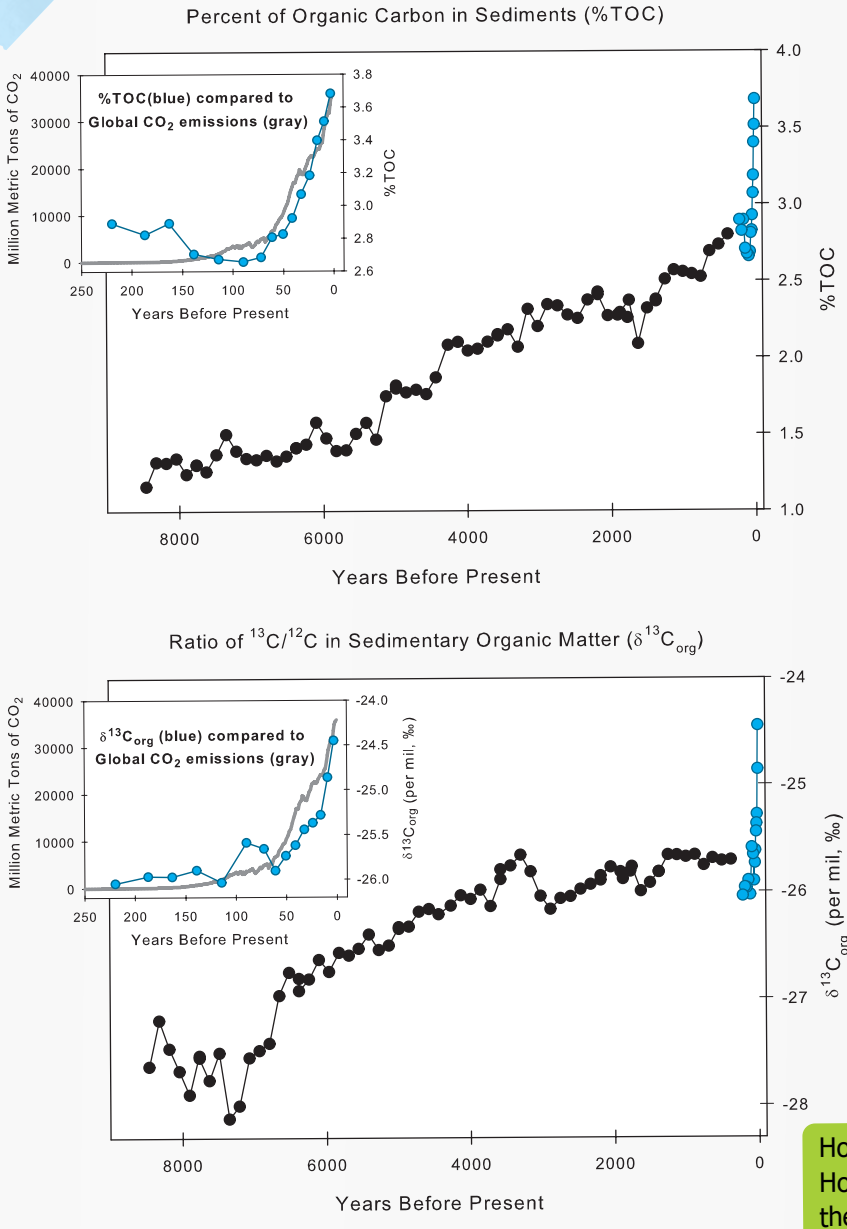

Figure 5:
A sediment core showing increases of carbon-containing organisms like phytoplankton and algae in Lake Superior over the last 9000 years. Note how both total organic carbon (TOC) and the ratio of carbon-13 to carbon-12 ($\delta^{13}C_{org}$) (both measures for the amount of phytoplankton/algae in the lake) increased very slowly for thousands of years, but then drastically increased in the last century (in blue).

The inserted smaller graphs show how the carbon we measured in the lake compares to the global amount of CO_2 (in gray) that has entered the atmosphere due to human activities over the past 250 years. Can you see how they match?

How do lake sediments reveal the lake's history? How has human-caused climate change altered the ecology of the lake in the past century?

- sediment formed on the lake bottom recently (between now and 200 years ago)

x- axes: Years before present. Note how the oldest sediment samples are to the left and advance to present day as you move to the right.
y- axis TOP: Percent of organic carbon (%TOC). This is the percentage of sediment formed by organisms living in the lake (like phytoplankton and algae) compared to mud.
y-axis BOTTOM: The ratio of carbon-13 to carbon-12 measured in the organic matter within the sediments that was originally formed by organisms living in the lake. The ratio is known as $\delta^{13}C_{org}$ and is represented in units of per mil (‰) or parts per thousand.

Discussion

The gradual growth in the amount of phytoplankton and algae living in Lake Superior was likely caused by the addition of nutrients (which phytoplankton and algae use to grow) from rocks crumbling slowly into the water. The drastic increase in plant life in the past one hundred years in Lake Superior has happened at the same time as human-produced greenhouse gases have begun changing the climate. Other scientists have documented that these climatic changes have resulted in Lake Superior's surface waters getting warmer and having longer ice-free seasons in the lake. Our research adds to this understanding by documenting how plant life in the lake increases along with water temperatures and longer ice-free periods – and drives home the point that even enormous, relatively pristine lakes are not immune to a changing climate.

Changes in algae and phytoplankton in Lake Superior are important to the whole ecology of the lake. Fish and bigger animals rely on these plants for food, so any changes at the base of the *food web* are likely to have a cascade of effects – though we don't know yet whether these changes will help or hurt fish populations. In addition, Lake Superior is also the first in a chain of several other Great Lakes (Fig. 3). And because of the physical connection among the lakes, any ecosystem changes within Lake Superior would also be felt by Lake Michigan, Lake Huron, Lake Erie, and Lake Ontario.

Conclusion

Our research shows that human-caused climate change can have dramatic effects even in areas that we assume are pristine. But it's important to remember that the magnitude of climate change in the future depends on our actions today—notably, on how much human societies continue to burn fossil fuels. Consuming less electricity (by turning off the lights and appliances when you're not using them) and less gasoline (by choosing to walk or bike rather than ride in a car) can help minimize the greenhouse gas emissions associated with our lifestyle.

Glossary of Key Terms

Algae – Plant-like organisms (they use sunlight to make food, as most plants do) that grow in or near the water.

Carbon – An element that is part of all life on Earth.

Carbon dioxide – A gas found in the atmosphere, which plants take in during photosynthesis. It is also emitted by humans when we breathe and when we burn fossil fuels. It acts in the atmosphere like the glass in a greenhouse, heating up the planet.

Climate change – A change in climate patterns of rainfall or temperature, due to either natural or human-induced causes. A dramatic change in climate is apparent since the mid-20th century and attributed largely to the increased levels of carbon dioxide in the atmosphere produced by the use of fossil fuels by humans.

Ecology – The interactions and relationships between plants, animals, other organisms, and their environment.

Food web – An interlocking set of species that eat and are eaten by each other in an ecosystem.

Greenhouse gas – A gas in the atmosphere that traps heat from the sun close to the Earth, just as glass traps heat inside a greenhouse. Increasing quantities of greenhouse gases, including carbon dioxide, in the atmosphere are causing warming temperatures and climate change on Earth.

Isotopes – Forms of an element, like carbon, that contain the same number of protons but different numbers of neutrons.

Paleolimnology – The study of sediments and fossils to determine the history of lakes.

Phytoplankton – Microscopic plants drifting in water.

Pristine – Unpolluted, unspoiled and free from human influence.

Sediment – Material that settles to the bottom of a lake or other liquid.

Sediment core – A tube-length sample of sediment which shows the history of sediment accumulation in a lake bottom, where the oldest sediment is at the bottom of the core and the newest is at the top.

Check your understanding

1. How can scientists study lake sediments to understand the historical ecology of a lake?

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2. Why has the quantity of plants and algae in Lake Superior gone up dramatically in the past hundred years?

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3. Scientists in this study used sediment cores to check plant and algae growth in a lake. What else do you think you could learn from studying sediment cores?

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4. After learning that climate change will cause increased algae and phytoplankton growth in Lake Superior, you may still have questions about what this means for people who depend on the Great Lakes for food, water supply, and shipping. What other topics could you research to better understand how algae and phytoplankton growth would affect people in the region?

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