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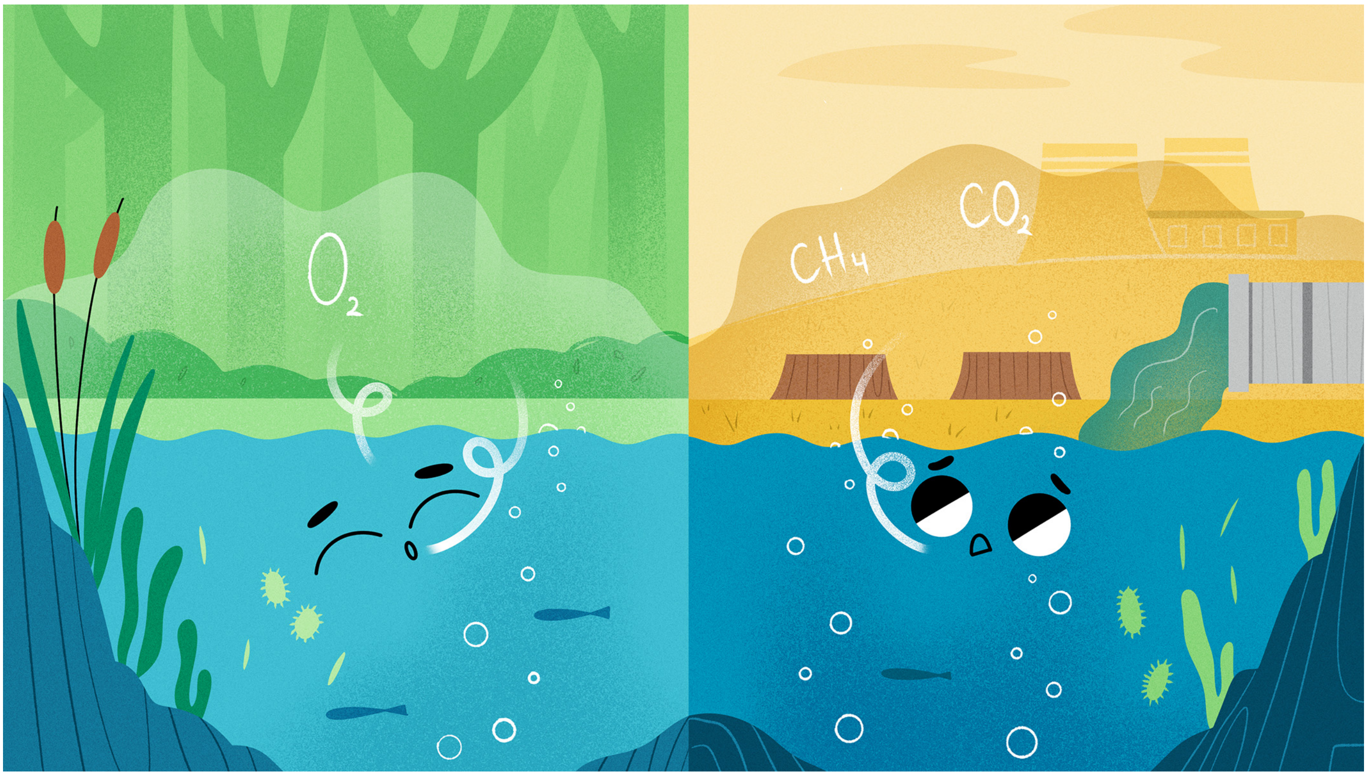

DO LAKES BREATHE? THE ROLE OF LAKES IN THE GLOBAL CARBON CYCLE AND CLIMATE

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YOUNG REVIEWERS:


CALEB
AGE: 12


MOMO
AGE: 13

Lakes may seem quiet and still, but they host bustling ecosystems where organisms produce and consume greenhouse gases, influenci ng Earth's climate and the global carbon cycle. Carbon is present in the cells of every organism and in two powerful greenhouse gases that trap heat in the atmosphere: carbon dioxide and methane. In lakes, tiny organisms called phytoplankton use sunlight and carbon dioxide for photosynthesis, generating oxygen and other substances crucial for lake life. Many other lake organisms produce carbon dioxide and some also produce methane. So, just like humans do when they exhale, lakes also emit carbon; but due to human interference, lakes are emitting *more* carbon than they would naturally. Understanding these processes and reducing human impact is vital for preserving lakes and slowing climate change. Lakes

are not just beautiful landscapes; they are essential components of Earth's carbon cycle and climate!

WHAT DO LAKE ORGANISMS DO?

Have you ever seen a lake that looked as calm as a painting on a wall? That peaceful surface hides a bustling ecosystem underneath, where all sorts of organisms live and thrive. Like us, most organisms living in a lake—from the tiniest bacteria to the biggest fish—use oxygen (O_2) for their life functions. This process is called **aerobic respiration**. Some tiny organisms, called **phytoplankton**, can make their own food by photosynthesis using the sunlight that penetrates the water, just like plants do on the land (more information here!). During photosynthesis, organisms use sunlight, carbon dioxide, and water to produce oxygen and energy-rich compounds, which they use for their growth. Therefore, phytoplankton play two important roles in lakes: they help replenish oxygen levels in the water and they form the base of the lake food chain. At night, when there is no sunlight, photosynthesis stops and organisms only do aerobic respiration, consuming oxygen and releasing carbon dioxide (Figure 1).

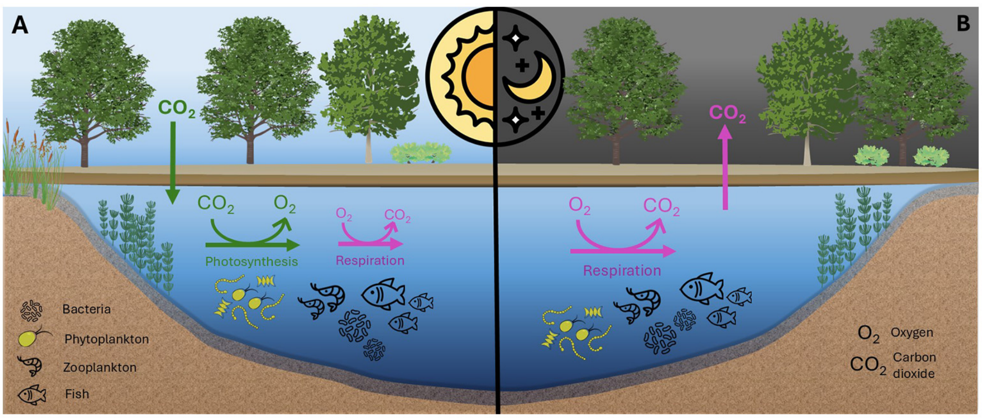

Figure 1

As you may have noticed, an important **greenhouse gas** containing carbon, carbon dioxide (CO_2), is produced by aerobic respiration during the day and during the night, but it is consumed by photosynthesis during daylight hours only (Figure 1). Aerobic respiration and photosynthesis happen within each drop of lake water and affect the oxygen levels and the **carbon cycle** of the whole lake. In turn, these determine the amount of oxygen and food available to all lake animals, including the largest predators!

But there is more going on in lakes than respiration and photosynthesis. Have you ever stepped into a lake or pond and seen bubbles come up? In the muddy sediments at the bottom of the lake where there is no

AEROBIC RESPIRATION

The biological process by which organisms use oxygen to break down food and produce energy, with the consequent release of carbon dioxide.

PHYTOPLANKTON

Tiny water organisms that use sunlight to make food. They take in carbon dioxide, release oxygen, and form the base of the aquatic food chain for other creatures.

Figure 1

Photosynthesis and respiration processes in a lake **(A)** during the day and **(B)** at night. During the day, all organisms consume O_2 and produce CO_2 through aerobic respiration, and some organisms (phytoplankton) also consume CO_2 through photosynthesis. At night, when there is no sunlight, photosynthesis stops and only respiration happens, consuming O_2 and producing CO_2 (*Tree and bush symbols from Dylan Taillie and Jane Hawkey, respectively, and emergent macrophyte symbols from Tracey Saxby, Integration and Application Network, University of Maryland Center for Environmental Science*).

GREENHOUSE GAS

A gas that traps heat in the Earth's atmosphere.

oxygen, certain tiny organisms called **methanogens** produce methane (Figure 2). Methane is another strong and important greenhouse gas that contains carbon in its molecule and is even more powerful at trapping heat than carbon dioxide (to learn more about methane and how it affects climate, see this or this Frontiers for Young Minds articles). The methane produced by methanogens can bubble up directly to the surface (a process called ebullition), can dissolve in the **water column** and be released at the lake surface (diffusion), or can be transported through aquatic plants from the sediment directly into the atmosphere (plant-mediated flux; Figure 2). In the lake's water column, there are other tiny microorganisms (called **methanotrophs**) that gobble up most of the methane in zones that contain oxygen, in a process called methane oxidation. Through methane oxidation, methanotrophs acquire carbon and energy from methane for their growth, and release carbon dioxide (a less potent greenhouse gas). Therefore, they work as natural methane filters, helping reduce the amount of methane released from lakes [1].

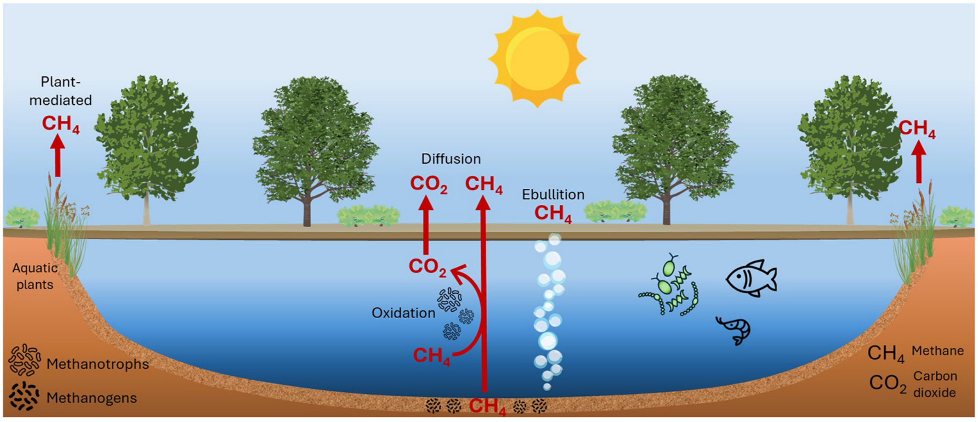

Figure 2

Figure 2

Methane (CH_4) is produced in the sediments by methanogens and is released to the atmosphere by ebullition, diffusion, or plant-mediated flux. Ebullition is the release of CH_4 as bubbles, that we can see popping up at the water surface. Diffusion is the "invisible" release of gas into the atmosphere, where the water and air meet. Plant-mediated flux is also invisible: CH_4 produced in the sediments enters plant roots and escapes into the atmosphere, like blowing air through a straw. Some of the CH_4 produced in the sediments is oxidized to CO_2 by methanotrophs, and is therefore released as CO_2 to the atmosphere (*Tree and bush symbols from Dylan Taillie and Jane Hawkey, respectively, and emergent macrophyte symbols from Tracey Saxby, Integration and Application Network, University of Maryland Center for Environmental Science*).

HOW DO LAKE ORGANISMS AFFECT THE GLOBAL CARBON CYCLE?

As carbon dioxide and methane are greenhouse gases that contain carbon, all the mentioned processes (respiration, photosynthesis, and producing or consuming methane) affect the total amount of carbon present in the lake. Scientists make their best effort to track all these processes to determine if a lake is giving off more carbon to the atmosphere than it takes in (meaning the lake is a *source* of carbon) or if the lake takes in more carbon than it gives off to the atmosphere (meaning the lake is a *sink* of carbon). Determining if a lake is a carbon source or sink involves measuring how much carbon is going into the lake (for example, from the surrounding land), how much carbon is produced and consumed inside the lake, how much is released to the atmosphere, and how much is stored in the lake sediment (Figure 3)—not an easy task! This process is called assessing the lake's

CARBON CYCLE

The movement of carbon through the air, water, plants, animals, and soil. It includes processes like respiration and photosynthesis, within other natural processes.

METHANOGENS

Microorganisms that live in the sediment of lakes and produce methane through a process called methanogenesis.

carbon budget (you can learn more here). By determining the carbon budget, scientists can infer the role of lakes in the global carbon cycle and their impact on the climate.

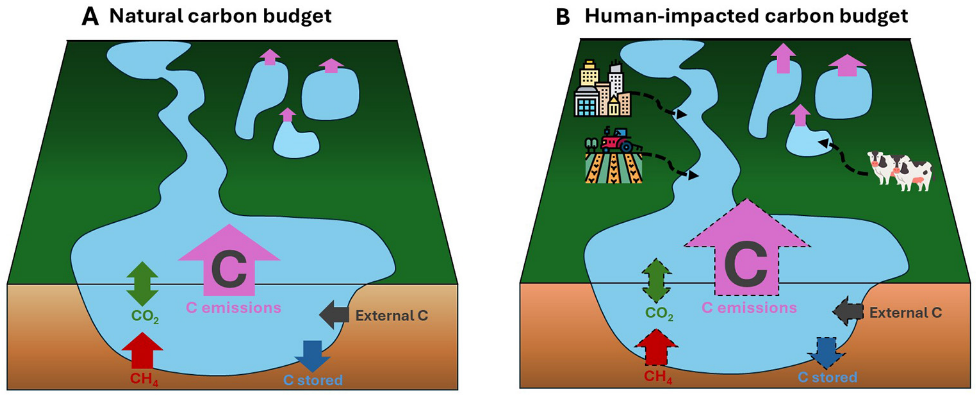

Figure 3

Figure 3

(A) Natural vs. **(B)** human-impacted carbon budget of a lake. In **(B)**, notice that the arrows indicating the various carbon processes are surrounded by dashed lines, meaning these processes are affected by human activities. The larger pink arrows in the human-impacted lakes show that these lakes usually release more carbon to the atmosphere than non-impacted lakes do.

Not too long ago, lakes were thought to be ecosystems where there was no carbon transformation. However, nowadays it is well-known among scientists that lakes (and freshwater ecosystems in general) play a significant role in the global carbon cycle [2]. While they can store carbon in their sediments, they can also act as carbon sources, releasing globally important amounts of carbon dioxide and methane into the atmosphere. In fact, after decades of measurements in lakes from different parts of the globe, scientists learned that most lakes are natural carbon sources, releasing carbon dioxide and methane into the atmosphere [3]. Now imagine hundreds of millions of lakes around the globe all emitting greenhouse gases [4]. This is a lot of carbon being released into the atmosphere every day!

WATER COLUMN

The water that stretches from the top of the lake (where the water meets the air) all the way down to the bottom (where the muds and rocks are).

METHANOTROPHS

Microorganisms that live in the water column of lakes, consuming methane and producing carbon dioxide through a process called oxidation.

ARE HUMAN ACTIVITIES CHANGING THE NATURAL CARBON BUDGET OF LAKES?

Yes! Human activities, such as pollution from farms and cities or deforestation, can disrupt the delicate carbon budget of lakes. These disruptions usually lead to increased greenhouse gas emissions from these ecosystems (Figure 3).

CARBON BUDGET

The accounting of how much carbon enters, is produced, consumed, and released by an ecosystem. Like a financial budget in which carbon is the currency.

For example, when sewage (liquid waste) from cities is released into water bodies without being previously cleaned, lake organisms are affected. The organic matter in our toilet waste is used by aquatic organisms for respiration, to produce even more carbon dioxide, and for methane production. Deforestation and agriculture have a slightly different impact on lakes. These processes can lead to more nutrients going into lakes, which can increase photosynthesis. More photosynthesis also increases the amount of organic matter in the lake (produced by the phytoplankton) and can lead to more carbon dioxide and methane. In both sewage and deforestation/agriculture scenarios, increased carbon dioxide and methane production is likely followed by increased emissions of these greenhouse gases from lakes to the atmosphere (Figure 3).

These are just a few simple examples, but there are many ways that human activities can affect the carbon cycle of lakes, and the consequences are often complex. Climate warming is another human-caused disturbance that has complicated consequences for the carbon cycle of lakes. In this case, a phenomenon called positive feedback can happen: the warmer climate leads to higher respiration and methane production in lakes, which in turn leads to more greenhouse gas emissions by these ecosystems, boosting climate warming even more. It is like a loop—the cause of the disturbance is a warming climate, and the effect is that the climate keeps warming.

CAN WE HELP SLOW DOWN CLIMATE CHANGE BY PRESERVING LAKE ECOSYSTEMS?

Understanding the carbon processes of lakes is necessary for their conservation and management. Preserving the land around lakes is also important, to keep them clean and limit the amount of greenhouse gases they release. If we protect lake ecosystems and try to reduce human impacts on them, we can help slow down climate change while also preserving these valuable ecosystems for future generations [5]. So, next time you are at a lake, remember: it is not just a pretty picture of still water—it is a living, breathing ecosystem that plays a crucial role in the Earth's carbon cycle and climate!

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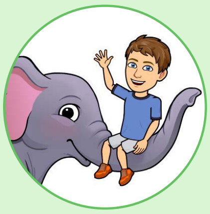

CALEB, AGE: 12

Caleb enjoys all things science, animals, reading, exploring the outdoors, playing the violin, and curling. When he grows up, Caleb wants to be an architect focusing on eco-friendly and animal oriented buildings. He has tried four sports and is always up for trying something new. Caleb's favorite foods are macaroni and cheese or lasagna. He enjoys traveling and would like to go to an animal reserve.

MOMO, AGE: 13

Momo loves to travel the world and see new places. Even so, she is a self-proclaimed couch potato when she is at home. The two extremes can coexist in one person! Her favorite couchmate is her fuzzy and affectionate dog, Lita.

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