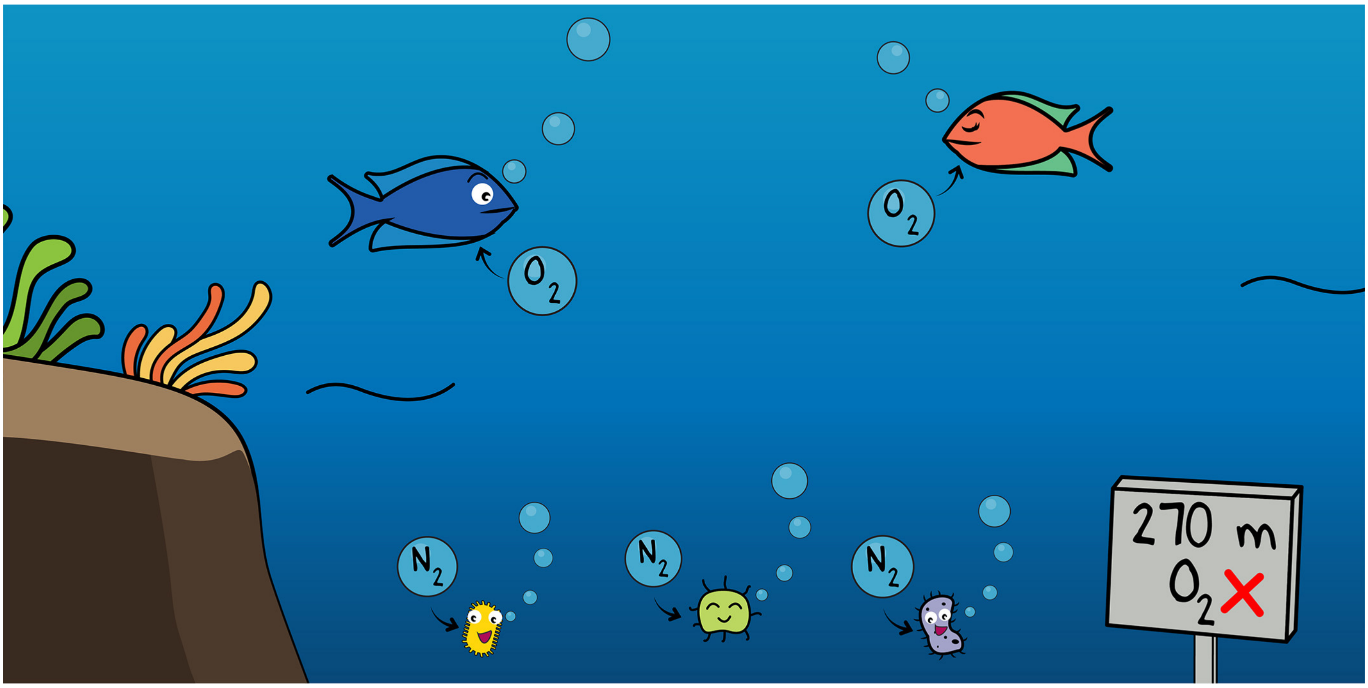
EARTH AND ITS RESOURCES
Published: 10 May 2022
doi: 10.3389/frym.2022.766134



WHERE DO OCEAN MICROBES WITH NITROGEN-BREATHING SUPERPOWERS LIVE?

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YOUNG REVIEWER:

UMBERTO

AGE: 12

All animals, including you, need oxygen to breathe. Many kinds of tiny microorganisms (microbes) also need oxygen. But some microbes have a superpower: they can breathe a different element called nitrogen! This means they can live in areas where there is no oxygen. But where are these areas? We wanted to figure out where these superpowered nitrogen-breathing microbes live in the ocean. In this article, we describe how we found a new way to estimate these areas. We made a map of the world that points out the areas in the deep ocean where nitrogen-breathing microbes are likely to live. Our work will help us to understand the role that nitrogen-breathing microbes play in the regulation of Earth's climate.

NITROGEN-BREATHING MICROBES

All living beings—like cats, dogs, trees, and you—are organisms. Very small organisms, like bacteria, are called **microorganisms (or**

microbes). Larger organisms like us are made up of millions or billions of cells joined together. Unlike us, most microbes consist of just one tiny cell. We often hear about the "bad side" of microbes. Many bacteria cause diseases or infections, like ear infections or sore throats. But there are many more good or harmless bacteria than there are bad bacteria. For example, there are millions of bacteria that live inside our digestive tracts that help us digest our meals. There are also bacteria living everywhere in the environment—in the dirt, and in lakes, rivers, and the ocean. These bacteria play important roles on planet Earth, as we will see.

MICROORGANISM/ MICROBE

A small, single-celled organism.

To survive, all organisms need food, water, and something to breathe. We humans, like all animals, need to breathe oxygen. When astronauts travel to outer space, they bring food, water, and oxygen with them, since there is no oxygen in space. This is why they have to wear space suits! Fish also need to breathe oxygen underwater. They use their gills to pull oxygen out of the water, just like we use our lungs to pull oxygen out of the air. Many microbes also use oxygen to breathe. But some kinds of microbes have superpowers: they can breathe things other than oxygen! For example, some microbes can breathe forms of another element called **nitrogen** (Figure 1).

NITROGEN

An element that certain microbes can breathe instead of oxygen.

Where do these nitrogen-breathing microbes live? Microbes can grow faster when they use oxygen instead of nitrogen. So, when there is oxygen, microbes will choose to breathe oxygen. But in some places in the ocean, there is very little oxygen (Figure 2A) [2]. Most fish cannot live in the areas where there is not much oxygen, and oxygen-breathing microbes can not live in many of those areas, either. But superpowered, nitrogen-breathing microbes *can* live in oxygen-poor areas of the ocean! There is plenty of nitrogen to breathe in the deep ocean.

NITROUS OXIDE

A greenhouse gas that can result from microbes breathing nitrogen.

GREENHOUSE GAS

A gas in the atmosphere that keeps Earth warm, like carbon dioxide or nitrous oxide.

These nitrogen-breathing microbes play an important role on Earth. Even though they live in the deep ocean, when these microbes breathe, they change the dissolved nitrogen into gases that end up in the atmosphere [3]. One of these gases, called **nitrous oxide**, is a **greenhouse gas.** Just like carbon dioxide, nitrous oxide helps keep the

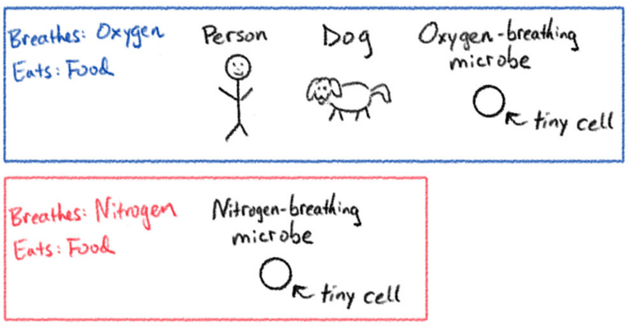

Figure 1

Figure 1

Oxygen-breathing organisms (blue box) and nitrogen-breathing organisms (red box). The tiny microbial cells are not drawn to scale: they are very tiny, so we need a microscope to see them (that is why they are also called microorganisms).

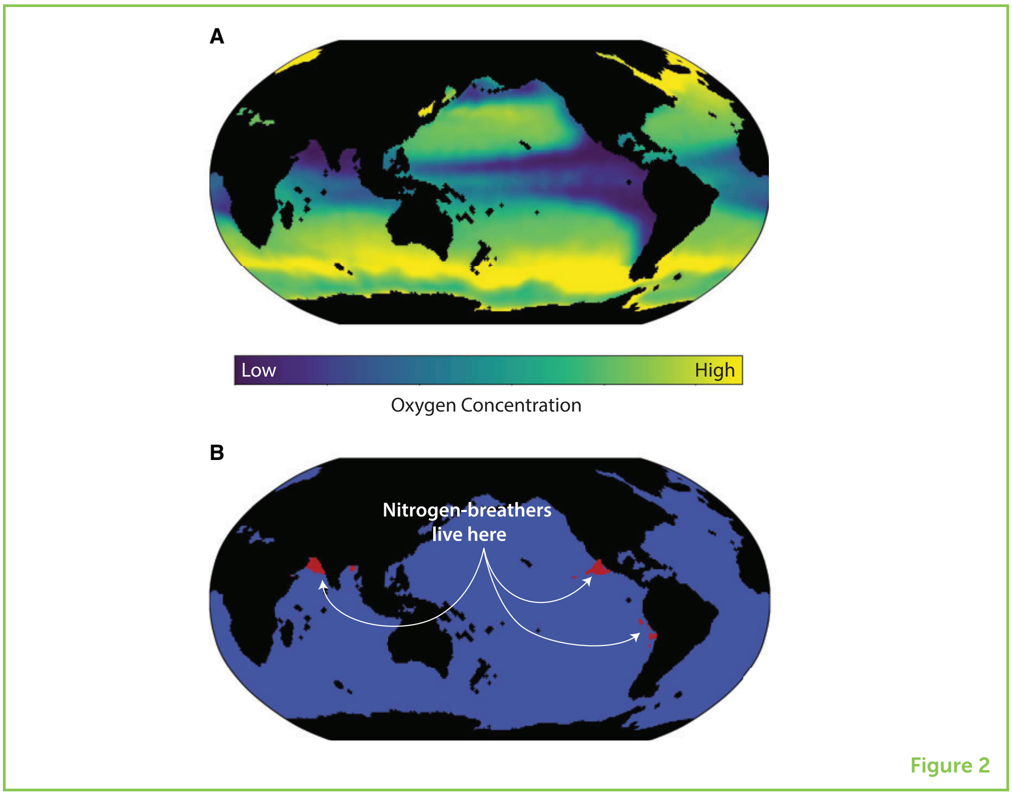

Figure 2

(A) Concentrations of oxygen in the ocean at 270 m depth. The dark blue areas of the map are where there is not much oxygen. **(B)** Our estimate of the locations where nitrogen-breathing microbes live (the red areas), also at 270 m depth (Figure based on [1]).

planet warm. But also like carbon dioxide, if there is too much nitrous oxide, there will be too much warming, which can cause the Earth's climate to change.

How many of these nitrogen-breathing microbes are there? How much nitrogen are they breathing? Will there be more nitrogen-breathing microbes in the future? We wanted to help answer these questions by figuring out exactly where nitrogen-breathing microbes live in the deep ocean. Where could we expect to find these nitrogen-breathers? Figure 2A gives us a general idea of where they live, but we wanted to know the exact areas. This knowledge could help us calculate how much nitrogen these organisms are breathing. Using this information, we could explore how much the nitrous oxide these organisms release, which might end up further warming the Earth.

HOW DID WE ESTIMATE WHERE NITROGEN-BREATHERS LIVE?

Since all organisms need food and something to breathe, we wanted to know how much food and oxygen were present in the ocean for oxygen-breathing microbes, and also how much food and nitrogen were present for nitrogen-breathing microbes. Both of types of microbes eat the same kinds of food, and we know that there is lots of nitrogen in the deep ocean, so we assumed that there was always plenty of nitrogen available for the nitrogen-breathers. So, we actually only had to make two estimates: the amount of food and the amount of oxygen available for microbes [1].

FLUX

The rate of change of something over time.

These estimates gave us the **fluxes** of food and oxygen in the ocean. What is a flux? A flux is how fast something changes over time. As an example of a flux of food, think about the flux of peanut butter at your house. How much peanut butter do you and your family have available? To answer this, you can estimate how often someone in your family buys peanut butter. If your family buys a jar of peanut butter once a week, then the flux is one jar per week. If your friend's family buys two jars of peanut butter a week, then the flux at their house is twice the amount at your house, two jars per week. Since your friend's house has a higher flux of peanut butter, this means that more peanut-butter eaters could live at your friend's house. If another friend's family does not buy any peanut butter at all, then there is no flux of peanut butter at that house. That house would not be a place that peanut-butter eaters would want to live. In your house and both of your friend's houses, if you looked in the cupboards at the end of the week, before grocery shopping, there might not be *any* peanut butter left in any of them! So, just counting the amount of peanut butter in the house at any one time is not as useful as estimating the flux of peanut butter.

DATASET

A large library of information about something, such as the amount of oxygen in the ocean.

We used the same reasoning to figure out where oxygen-breathing and nitrogen-breathing microbes can live. We calculated the fluxes of food and oxygen at all spots in the deep ocean. We used big **datasets**, which are like large libraries, compiled from other scientists' measurements, with information about oxygen and food in the ocean [4, 5]. We estimated where there was plenty of oxygen and food for the oxygen-breathing microbes to live. Then, using our calculations, we identified the places in the ocean where there was still food, but not enough oxygen. These are the places where we think nitrogen-breathing microbes can live.

SO, WHERE DO THEY LIVE?

Figure 2B shows a map of the locations in the deep ocean where nitrogen-breathing microbes can live [1]. These areas have plenty of food for microbes to eat, but not enough oxygen to breathe, so it is beneficial for microbes in these locations to be able to breathe nitrogen. We expect that if we took a ship out to these areas and dove down into the deep waters, we might be able to find nitrogen-breathing microbes.

If you compare the dark blue areas in Figure 2A with the red areas in Figure 2B, you will notice that they are in roughly the same spots in the ocean. Parts of the areas that have low amounts of oxygen also have a low flux of oxygen: these spots are like the house where no one buys peanut butter! Our calculation using the fluxes of food and oxygen identified the red areas in Figure 2B as good places for nitrogen-breathers to live.

WHY DO THESE RESULTS MATTER?

Now that we can estimate where nitrogen-breathing microbes live in the ocean, what can we do with this information? As we mentioned earlier, these nitrogen-breathers can change dissolved nitrogen into nitrous oxide, one of the greenhouse gases that keeps planet Earth warm. If the number of nitrogen-breathers in the ocean increases, then there could be more nitrous oxide released, and the Earth could become even warmer. We think the number of nitrogen-breathing microbes might increase because the total amount of oxygen in the ocean is going to decrease due to current climate change. One thing we can do to try to keep Earth as cool as it is now is to try to reduce the amount of other greenhouse gases released into the atmosphere. For example, when we ride our bikes instead of drive, we emit less greenhouse gases!

Our estimates of where nitrogen-breathers live in the ocean will allow us to better predict where and how many nitrogen-breathers there will be in the future ocean. We can combine prediction methods with **climate models**, which are computer simulations used to estimate what Earth's future climate will be like. So, the results we have obtained will hopefully help us figure out how much warmer Earth be in 50 years, when you are a grown-up. Superpowered nitrogen-breathing microbes are an important piece of the answer to this question!

CLIMATE MODEL

A simplified computer simulation of the Earth's weather and climate system that helps us to understand how Earth's temperature might change.

ORIGINAL SOURCE ARTICLE

Zakem, E. J., Lauderdale, J., Schlitzer, R., and Follows, M. J. 2021. A flux-based threshold for anaerobic activity in the ocean. *Geophys. Res. Lett.* 48:e2020GL090423. doi: 10.1029/2020GL090423

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SUBMITTED: 28 August 2021; **ACCEPTED:** 19 April 2022;
PUBLISHED ONLINE: 10 May 2022.

EDITOR: Dominik K. Großkinsky, Austrian Institute of Technology (AIT), Austria

SCIENCE MENTOR: Elisa I. García-López

CITATION: Zakem EJ, Lauderdale JM and Follows MJ (2022) Where Do Ocean Microbes With Nitrogen-Breathing Superpowers Live? Front. Young Minds 10:766134. doi: 10.3389/frym.2022.766134

CONFLICT OF INTEREST: The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

YOUNG REVIEWER

UMBERTO, AGE: 12
My name is Umberto. I like to study science, read manga, and play videogames with my friends. I love going to the beach to play with sand, adventures and drawing cartoons. In the future I would like to become a physicist.

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Emily J. Zakem is a postdoctoral fellow at the University of Southern California. She studies how microbes affect the cycling of nutrients and the climate on Earth. So far, she is studied the microbes that live in the open ocean. But she does not go out to the ocean to study them. She studies them using computers instead! She builds computer models of how microbes live and change the world around them. These models can help us better understand our planet and how it will change in the future. *emilyzakem@gmail.com

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Jonathan M. Lauderdale is a research scientist at the Massachusetts Institute of Technology. He studies how the ocean moves as well as the microbial life within it, and what those microbes enjoy eating. Like Emily, he uses computer models to study these topics but sometimes he goes out to the ocean to study these questions as well!

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Michael J. Follows is a professor at the Massachusetts Institute of Technology. He teaches classes about how planet Earth works, and how the tiny microbes living in the ocean affect it. Like Emily and Jon, he also uses computer models to study these things.