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The Ocean, Volume 2

Edited by
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Sanae Chiba and Emily King

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The Ocean, Volume 2

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Biodiversity

Earth and its Resources

About this collection

The ocean was the origin of life on earth billions of years ago and it is vital for the future of humanity. It is vast, deep, harsh and somehow "rebellious" to uncover its secrets and hence, there is much that is unexplored and misunderstood. Scientists need to study the ocean to better understand its functioning and properties, as well as how they shape our environment and impact us. For example, do you know what the role of the ocean is on weather and climate? There still remains so much to explore in ocean biodiversity and the diverse resources that can be found (for example, fish stocks, bio-molecules, and also minerals, oil, and gas). How can we make sure that our use of these resources is done sustainably and how can we minimize our impacts (e.g. pollution, acidification) on the ocean as our human population increases?

In this collection of Frontiers for Young Minds, scientists from various disciplines in oceanography share their knowledge and motivations, give insights in innovative tools and recent discoveries to better understand this ocean. The collection will target a large range of oceanic environments from the open ocean to the coast, the surface to the abysses also including specific areas like coral reefs or sea-ice environments. It will cover marine disciplines that range from physics to chemistry, from biology to ecology and from economy to conservation and policies. It will address innovative tools and methods that are used to observe and characterize oceanic properties and features: ships and satellites, the highly diverse variety of robots as well as genomics or artificial intelligence. Finally, it will encompass a great variety of scales, ranging from the diel to geological time-scales and from loco-regional to global scales and also from the tiniest cells to the biggest living animals on our planet.

The United Nations have declared the 2021-2030 period as the "Decade of Ocean Science for Sustainable Development", stressing the urgent need to approach fundamental issues related to the ocean and the future of humanity on well sounded scientific grounds and knowledge. This Ocean Collection aims to provide information to young readers that will help them to increase their understanding of the ocean and its central role in nature and our lives. We hope to empower them to make informed decisions in these challenging times and to engage to protect, study and enjoy its richness.

See here our previous Volume 1!

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EARTH AND ITS RESOURCES
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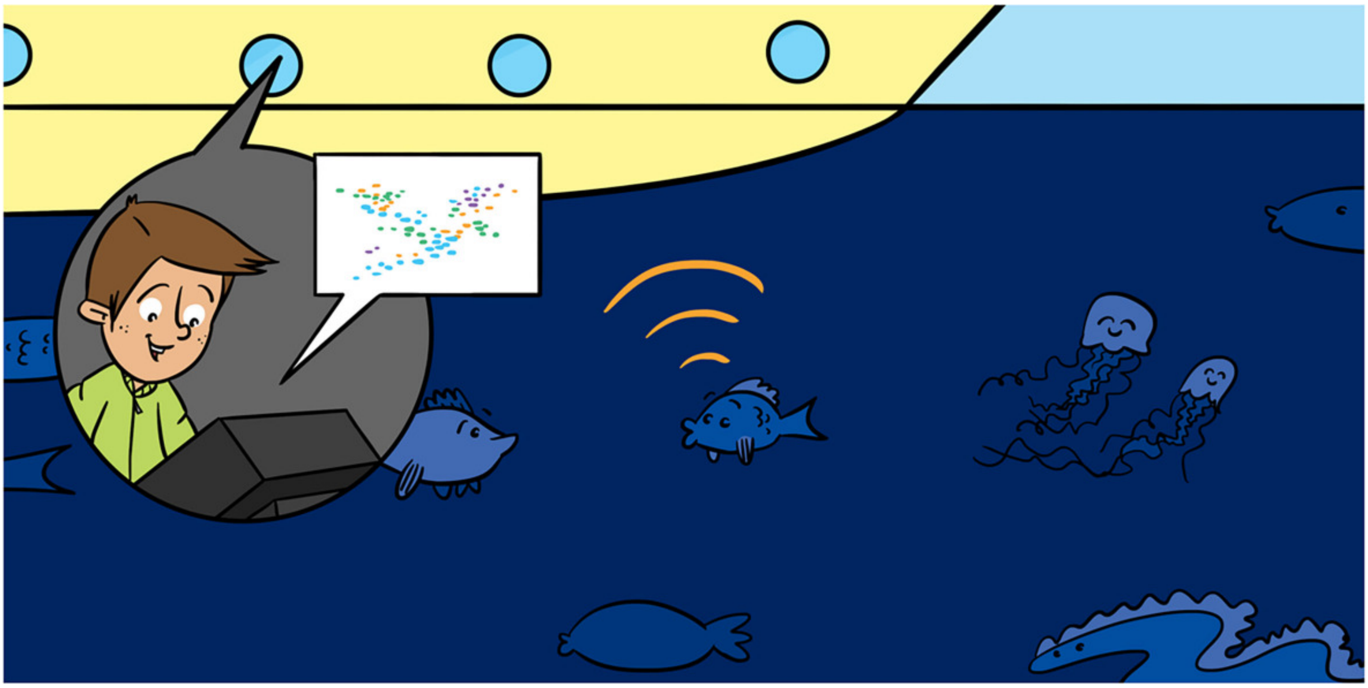

HOW DO SCIENTISTS USE SOUND TO COUNT FISH IN THE DEEP SEA?

Alina M. Wieczorek[1*], *Amanda Schadeberg*[2] *and David G. Reid*[1]

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YOUNG REVIEWERS:

LEA

AGE: 11

MAGNOLIA STUDENT CENTER

AGES: 9–10

MILI

AGE: 8

Humans love to eat fish, but we must be careful not to catch too many. To make the right rules about how many fish can be caught without decreasing the population too much, it is helpful to know how many fish are in the sea. It is difficult for scientists to go underwater to count fish, but technology can help. Animals like dolphins can use sound to “see” the world around them. Just like dolphins, scientists can send a sound into the ocean and measure the echo that comes back. They can even use the unique echoes of fish to get an idea of how many fish are in the sea. Scientists are now testing whether this technology can help them to explore the deep sea. While it is not always easy to see with sound, the challenges we face and the mistakes we make often lead to new discoveries!

ARE THERE PLENTY OF FISH IN THE SEA?

Humans love to eat fish. We have become so good at catching them that we must be careful not to catch too many. We can protect the

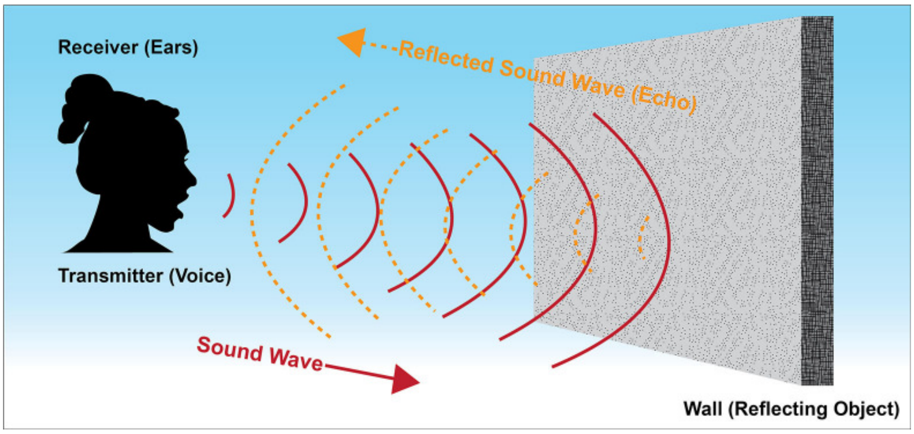

Figure 1

Figure 1

A transmitter (voice) sends out sound. The sound travels in waves that are reflected by an object, such as a wall. The reflected sound is called an echo or acoustic signal and can be picked up by the receiver (ears).

fish we like to eat by making rules about how many can be caught each year. If we leave enough fish behind, they will reproduce naturally so that there will be plenty to catch next time. If we have good rules to prevent overfishing, fish can be a valuable and **sustainable** food source [1].

SUSTAINABLE

Able to be used in a way that makes a resource available for future generations.

To make the right rules about how many fish can be caught sustainably, it is important to know how many fish are in the sea. The ocean covers over 70% of the planet, so it is an enormous area to study. If you have ever looked at the ocean or a lake, you may have noticed that it is difficult to see far beneath the surface. For that reason, scientists have come up with methods to help them learn about the underwater world. For instance, they can catch fish with nets, they can scuba dive underwater, and they can ask fishers what they have caught. Sound is another tool scientists can use. But how can scientists use sound to "see" what is happening underwater?

LOOKING WITH OUR EARS: USING SOUND TO SEE

Sound travels in waves of energy. Like a wave of water, sound can get reflected by a surface and travel in another direction. Think of an echo in a big empty room. The sound travels in waves away from the **transmitter**, which can be your voice or a loudspeaker. Sound becomes an echo when it reflects off something and travels back to a **receiver**, which can be your ears or a microphone (Figure 1). The sound that gets reflected back will not be a perfect copy of what you transmitted. Scientists call this an **acoustic signal**. Depending on the shape of the object, the echo will scatter in different ways, producing a different acoustic signal.

TRANSMITTER

Something that sends out sound, like a voice or a loudspeaker.

RECEIVER

Something that receives or listens to sound, like your ears or a microphone.

ACOUSTIC SIGNAL

Sound that gets reflected back from an object.

Some animals have learned how to use sound to "see" the world around them. For example, dolphins transmit high-pitched sounds as they navigate their way around the sea. They then listen to the

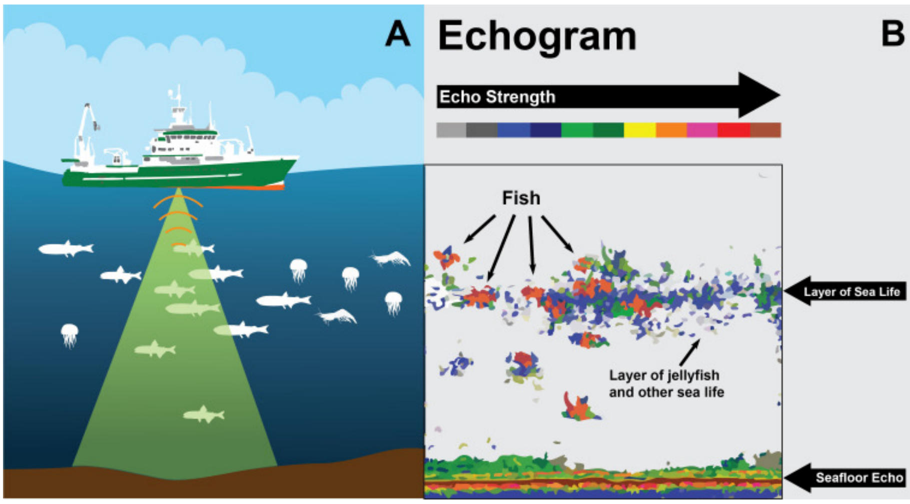

Figure 2

Figure 2

(A) Scientists on research boats send out sound from a transmitter (green beam) and measure the reflected echo or acoustic signal (orange lines). The sound scatters off the fish and other sea life in the water. **(B)** The echoes are processed into an image called an echogram, which shows the strength of the echoes by color. Interpreting echograms gives scientists clues about what is in the water below their boats.

returning echoes and their brains process the echoes into an image of the world around them. This helps dolphins to catch fish and avoid obstacles, even in pitch darkness.

"DISAPPEARING" SEA FLOORS: HOW A MISTAKE HELPED SCIENTISTS LEARN TO USE A NEW TECHNOLOGY

ECHOGRAM

Literally a "sound drawing;" a picture made by processing acoustic signals into an image.

Scientists have learned that, like dolphins, we can use sound to see objects underwater. Dolphins use their brains to process sound into a mental map. Our brains are not adapted to "seeing" with our ears, so we use technology to process sounds into images on paper or computers. We call these images **echograms**. The word "echogram" is a combination of the ancient Greek words for "sound" (echo) and "that is drawn" (-gram)—so, literally, an echogram is a "sound drawing." The shapes and colors on echograms reflect the strength and location of an acoustic signal. These echograms help us to "see" the sea floor, hundreds of meters below (Figure 2).

Interpreting echograms takes a lot of experience and sometimes scientists make mistakes. For example, echograms were used to make ocean maps to help prevent ships from running aground on the seafloor. Sometimes an echogram would show that a part of the sea was shallow enough to be dangerous for boats. These shallow areas were marked on a map so that other boats could avoid them. However, another captain returning to the same area would find that the water was much deeper than the map showed. Scientists later learned that some areas that were mapped as having shallow sea floors actually contained dense layers of sea life, made up of fish and jellyfish [2]. There was so much marine life in the water that the echo from all the animals together sounded the same as the echo from the sea floor! While scientists knew that they could use sound to locate fish in the water [3], they did not expect to find so many animals so close together. Luckily, mistakes in science can lead to new discoveries. In this case, scientists learned that what they thought was the sea floor was actually dense clusters of marine animals!

HOW IS A FISH LIKE A DRUM?

Scientists are constantly improving the quality of their instruments and learning more about how to use acoustic technology to observe fish. While acoustic signals were first used to simply measure depth, modern echograms can return much more detailed information. Today, scientists can often tell what type of fish is in a school by interpreting the details of an echogram. Scientists can do this because of the unique biology of fish. Fish have many similar organs to humans such as eyes, a brain, stomach, liver, and kidneys. They also have some different ones that are adapted to their environment. Gills are one example, which help fish to breathe underwater. Another adaptation that they have is something called an **air bladder** (also called a swim bladder). This is a sack of air that helps fish control their depth in the water. If they fill up the air bladder, they will float closer to the surface, and if they release some of the gas, they will stay deeper underwater.

AIR BLADDER

A small organ that fish and siphonophores can fill with air, to help them float and move up and down in the water.

Air bladders reflect sound particularly well. Just like a drum, an air bladder is an empty space filled with air. When it is hit by a sound wave, the air bladder produces a strong echo. The strength of the echo depends on the size and shape of the air bladder. This is the same with drums: a small drum will produce a short, high-pitched sound, and a large drum will produce a long, low-pitched sound. As you know, different species of fish have different shapes and sizes. Luckily for scientists, the shapes and sizes of their air bladders are also different. This causes fish to produce unique echoes, which appear quite different on an echogram.

For this technique to work, scientists must match the acoustic signal in the echogram with a particular species of fish. They do this by catching a small number of the fish with nets and recording what the echogram looks like when sound is reflected off them. The next time they see a similar signal on the echogram, they will know which fish species are swimming below them in the water—without having to catch them in a net!

GOING DEEPER: USING SOUND TO EXPLORE THE MESOPELAGIC ZONE

Scientists are interested in a deep part of the ocean known as the **mesopelagic zone**. This is the part of the ocean that is 200–1,000 m deep. Very little sunlight can penetrate the water at this depth. Because

MESOPELAGIC ZONE

The part of the ocean that is 200–1,000 m deep.

Figure 3

Mesopelagic fish (bottom) and siphonophores (top) both have air-filled organs called air bladders. Air bladders help the fish and siphonophores to control their depth in the water, and they reflect sound very well.

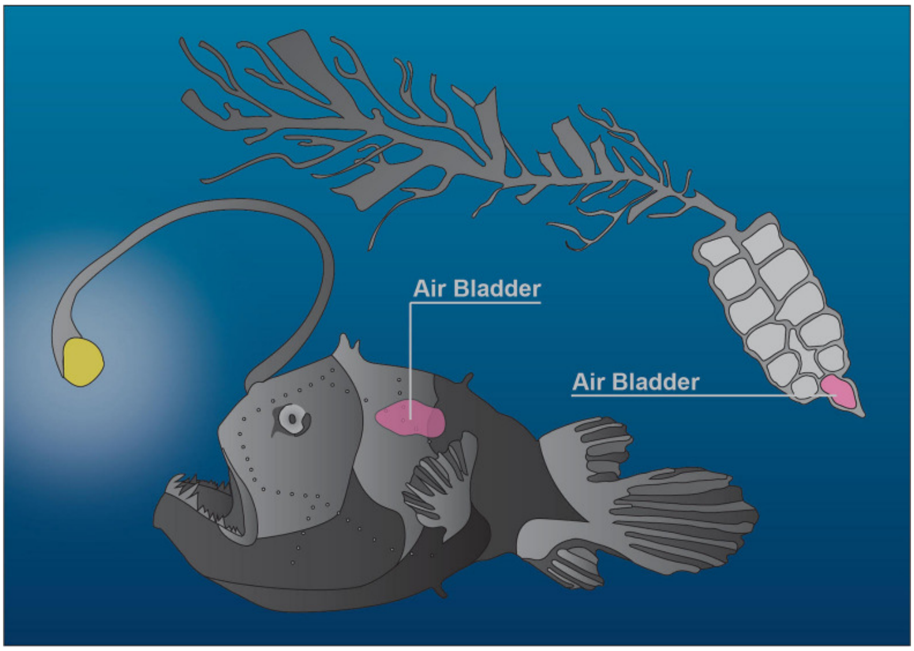

Figure 3

of the lack of light, it is sometimes referred to as the ocean's "twilight zone." Lots of fascinating creatures live there. However, because it is so difficult to reach, we do not know a lot about the mesopelagic zone of the ocean. To help imagine how deep the mesopelagic zone is, consider this: an Olympic swimming pool is 50 m long. To get to 1,000 m deep, you would have to swim 20 laps—straight down! This would take an average scientist around 45 minutes.

Luckily, sound travels much faster than a swimming scientist. Sound can get to 1,000 m *and back* in less than two seconds. Thanks to this, scientists can create lots of echograms telling them what is happening deep below their boats. This helps them to count how many fish live in the mesopelagic zone. Knowing how many fish are down there will be important in the future, if humans want to catch these fish.

SIPHONOPHORE

A soft underwater animal similar to a jellyfish.

As you have learned so far, it is not always easy to "see" using sound, especially not in the deep ocean. Trying to count fish here means overcoming many obstacles. For example, along with lots of fish, we can find **siphonophores** in the deep sea. Siphonophores are alien-looking animals similar to jellyfish. Like fish, they have air-filled organs that help them to move up and down in the water (Figure 3). Because of these organs, siphonophores produce echoes like those of fish [4]. To tell the difference between fish and siphonophores in echograms, scientists need to collect more detailed acoustic signals. To do so, they work with engineers to try to develop new acoustic instruments.

ACOUSTIC TECHNOLOGY HELPS US MAINTAIN A SUSTAINABLE OCEAN

Acoustic technology uses sound to help scientists estimate how many fish are in the sea. This knowledge is important for governments and other decision-makers because it helps them to create rules about how many fish can be caught. Limiting the number of fish that can be caught has helped many fish species recover from overfishing in the past. Scientists are working to collect information about fish that live in the deep sea, so that we can avoid overfishing them in the first place. Seeing with sound, using acoustic technology, can help deep-sea fishing to be more sustainable from the very beginning!

ACKNOWLEDGMENTS

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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 REVIEWERS

LEA, AGE: 11

Hi, I am Lea and I am in 5th grade in a STEM school. I have an 8 years old sister. I enjoy dancing, acting, drawing, and reading books. My favorite genre of books is mystery. My favorite animal is a dog and I have 3 guinea pigs. When I grow up I want to be an actress or a ballerina.

MAGNOLIA STUDENT CENTER, AGES: 9–10

We are a 4th grade class in Riverside, California. We enjoy learning about science, and our goal is to be lifelong learners.

MILI, AGE: 8

My name is Mili and I am 8 years old. I like reading and maths. I enjoy playing the piano. When I am older, I want to become a teacher.

AUTHORS

ALINA M. WIECZOREK

I am a post-doctoral scientist researching mesopelagic fish acoustics and ecology. I am based in the Marine Institute on the beautiful, but rainy, west coast of Ireland. I also went to university here and completed my Ph.D., studies on microplastics in ocean systems. *Alina.Madita@googlemail.com

AMANDA SCHADEBERG

I am a Ph.D. candidate studying the governance of mesopelagic fishing. I work at Wageningen University in the Netherlands. I like to research topics related to society and marine resources. I have previously worked on understanding fisher behavior and have contributed to projects about marine plastic, environmental risk assessment, and stakeholder consultation.

DAVID G. REID

I have worked for 30 years in fisheries management, starting out in fisheries acoustics in Scotland, working with some of the top scientists in the field. I now work on fisheries sustainability, fishing capacity and effort, industry collaboration, Integrated Ecosystem Assessment, and Ecological Risk Analysis. I am the Principle Investigator on Ecosystem Based Fisheries Management at the Irish Marine Institute and am adjunct professor at University College Cork, Ireland.

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PLASTICS AND PLANKTON IN OUR SEAS

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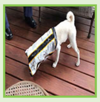
YOUNG REVIEWER:



MANUEL

AGE: 13

Plastic litter is found everywhere. Walk onto any beach around the world and you will almost certainly find plastic. The harm that large plastic litter can cause to marine animals is well-known; for example, you may have seen sad pictures of turtles eating plastic bags or seals tangled in discarded fishing nets. However, scientists are also concerned about microscopic-sized plastic that we do not normally see, and the problems these tiny plastic particles can cause to small marine animals called zooplankton. We focus on a group of zooplankton called copepods. These small-but-mighty crustaceans are amongst the most abundant animals on our planet, and they play a vital role in regulating Earth's climate. In this article, we will explain what happens when copepods encounter this microscopic plastic, why they eat plastic, and the impacts it has on their health and on the wider ecosystem.

THE MIX OF SMALL PLASTICS AND SMALL ANIMALS IN THE SEAS IS A BIG PROBLEM

Humans have been making plastic for over 100 years and, globally, we currently produce over 380 million metric tonnes of plastic each year, the equivalent weight of approximately 76,000,000 elephants! Plastic is an incredibly useful material; it is used to make things ranging from medical equipment to toys, cars, and mobile phones. However, almost half the plastic that is made is single-use plastic, which is designed to be used once and thrown away. For a material that is so durable, this really makes little sense. We are also not very good at recycling or disposing of plastic products when we have finished using them, so many plastics end up in our rivers, seas, and oceans. Scientists have found plastic litter everywhere, from the ocean surface to deep underwater trenches, and from deserted islands to the polar ice caps. Plastic litter pollutes the environment and is a threat to marine life, ecosystems, and possibly humans too (Figure 1).

Scientists are worried about the harm that small bits of plastic will cause when they are in our seas. These small plastics are called **microplastics** because they are microscopic in size (<5 mm). Microplastics include particles and fibres of various shapes, sizes, colours, and materials. Microplastics come from two main sources. Primary microplastics are manufactured to be of a microscopic size, and include small plastic pellets (known as nurdles or "mermaid's tears") that are the raw materials used to manufacture plastic goods, and the extremely small plastic beads used in toothpastes and in industry. Secondary microplastics are derived from the breakdown of larger plastic litter, through exposure to sun and by being scraped or worn away, or they are released into wastewater when we wash nylon or polyester clothing. Recent research has suggested there could be as many as 125 trillion pieces of microplastic floating in the oceans [1].

MICROPLASTICS

Very small pieces of plastic of various shapes, sizes, colours, and materials, 5 mm or smaller in size.

Our research on the risks that microplastics pose to marine life has concentrated on **zooplankton**, which are small animals found throughout our oceans that play critical roles in **marine food webs** and in regulating the Earth's climate. Considering there are so many microplastics and plankton in the sea, it led us to ask: "Do zooplankton eat microplastics and if so, is this a problem?"

ZOOPLANKTON

Microscopic animals that float, swim, or drift with the ocean currents.

MARINE FOOD WEB

An interconnected network describing what organisms in a community eat and what eats them.

WHAT ARE COPEPODS?

Copepods are small crustaceans, animals that are distantly related to crabs and shrimp. Copepods are amongst the most abundant animals on our planet. They are an important food source for many animals including fish, seabirds, and whales and are therefore a vital component of the marine food web. Copepods also play a very

COPEPODS

A group of small crustaceans found in nearly every freshwater and seawater habitat. Copepods are food for many fish, so they are key components of marine food webs.

Figure 1

Figure 1

Plastic litter on a beach. If you look closely at this picture of a high-water line, you will see there is plastic litter mixed up with the natural material. It is plastic like this, although even smaller, that is a problem for zooplankton and other marine animals.

important role in the marine **carbon cycle**. This is where carbon, vital for all life, dissolves from the atmosphere (CO_2) in the oceans and mixes through the ocean layers by physical (i.e., ocean circulation) and biological processes. It is the biological processes within the marine carbon cycle that the copepods contribute to. Microscopic marine plants called **phytoplankton** absorb CO_2 through photosynthesis, the copepods feed on the phytoplankton at the surface of the ocean at night and migrate to deeper water during the day to avoid being eaten by predators. In doing so copepods help to take carbon dioxide from the water's surface and store it in the deeper ocean through respiration (breathing) and the production of faecal pellets (poo). Microbes and other organisms use some of this carbon during respiration and some carbon gets buried in the seabed where it can form fossil deposits or

CARBON CYCLE

A combination of physical and biological processes that transfers carbon between Earth's biosphere (living things), hydrosphere (oceans, rivers, lakes), atmosphere (air), and geosphere (rocks, seabed).

PHYTOPLANKTON

Microscopic plants that live in the ocean and make their own food from sunlight and carbon dioxide through photosynthesis.

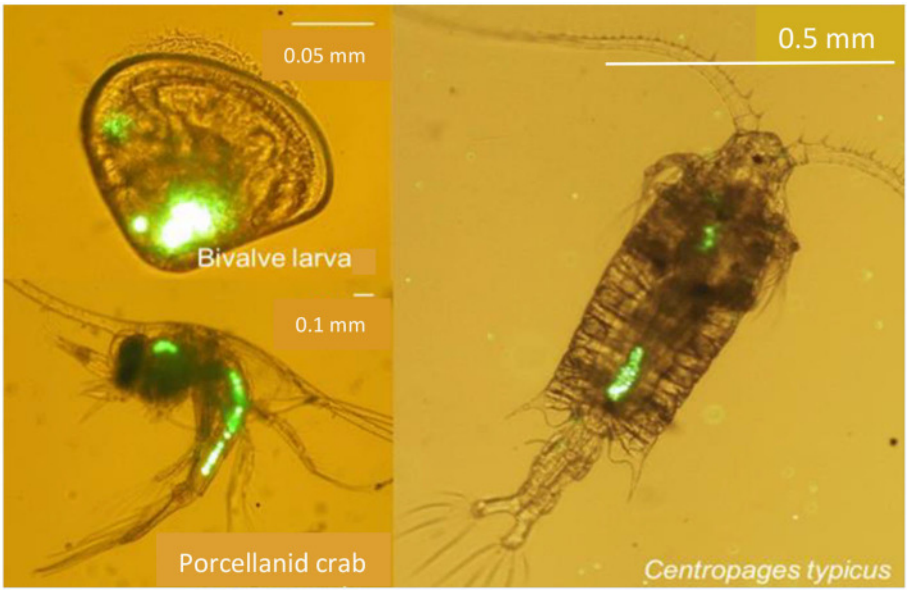


Figure 2

Figure 2
Three different types of zooplankton: larva of a bivalve shellfish, a Porcellanid crab larva, and an adult copepod (*Centropages typicus*). Bright green and fluorescent microplastics of various sizes can be seen inside each of the animals.

decompose and mix back to the surface. This is why we call copepods "small-but-mighty," by helping to transfer carbon from the sea surface to the ocean floor they help to sequester carbon into the deep ocean and therefore to regulate the Earth's climate.

WHY WOULD COPEPODS EAT PLASTIC?

Imagine eating plastic; it does not sound too tasty, right? Plastic is not normally on the menu for copepods, but when microplastics are mixed in with their food, the copepods can accidently eat them (Figure 2), especially since these microplastics often smell like their food. When microplastics enter the sea, bacteria and phytoplankton can attach to the surface of the plastic particles and grow there. Some species of phytoplankton produce a chemical called dimethyl sulphide (DMS). Do you get hungry when you smell freshly baked bread? That smell tells humans that there is food in the area. Similarly, DMS tells copepods that yummy phytoplankton is nearby. Humans can smell DMS too, only at much higher concentrations. If you have ever been to the beach and there is a really strong "smell of the sea," this is due to DMS.

In our research, we showed that copepods eat a lot more microplastics when the plastic particles are coated in DMS than when they are not. This means that copepods could eat more microplastics if the plastics mimic the scent of their normal food. But what exactly does eating microplastics do to copepods?

WHAT HAPPENS IF COPEPODS EAT PLASTIC?

If copepods eat really small amounts of plastic, it is unlikely to cause much of a problem. But if copepods keep eating plastic, they might stop eating as much actual food as they normally do. All animals need food to provide energy for movement and growth. We were concerned that microplastics could stop copepods from eating enough food, which might have an impact on their long-term health. We did some experiments in which we gave one group of copepods their normal food and a second group of copepods their normal food plus microplastics. We found that the copepods that got microplastics with food ate 40% less food than they usually would, and as a result these copepods produced smaller eggs that were less likely to hatch [2].

The chemicals in plastics may also pose a risk to marine wildlife. Plastics are full of chemicals that make them more colourful, resistant to fire, and easier to shape into various products. Sunlight can cause plastic litter to become brittle, allowing these chemicals to escape. Animals that eat plastics can be affected by these chemicals. For example, we found that a chemical called benzophenone, which protects plastics from breaking down in strong sunlight, may be released by nylon plastics. This chemical caused copepods to develop more quickly than normal [3].

WHAT IS THE IMPACT OF MICROPLASTICS ON THE MARINE CARBON CYCLE?

Even though copepods are very small, remember that these animals and their poo play a really important role in the marine carbon cycle. We found that, after eating microplastics, copepods poop these plastics out in their faecal pellets. The pellets carry the plastic down towards the seabed and to the hungry animals waiting there. We were curious to know whether these microplastics might affect the carbon cycle.

We carried out some experiments in which we fed copepods plastics, collected their poo, and then timed how quickly the poo sank! We found that, if the plastic that was eaten can float in seawater, the faecal pellets sank more slowly [4]. In the ocean, slow-sinking faecal pellets will spend more time in the warmer surface waters and will degrade faster, releasing the microplastics back into the water and preventing the movement of carbon into deeper water. When copepods eat microplastics that are denser than seawater, their faecal pellets sink much faster and reach the seabed quicker (Figure 3) [5]. Many animals living on or in the seabed rely on zooplankton poo and decaying carcasses for their food; if this poo contains microplastics, the animals on the seabed will also eat the plastics. Our latest research has shown that animals that live at the bottom of the sea can mix microplastic into the sediment as they feed and move, contributing to the permanent burial of microplastics in our oceans. Some scientists think plastics may be locked within sediments, without degrading, for hundreds or

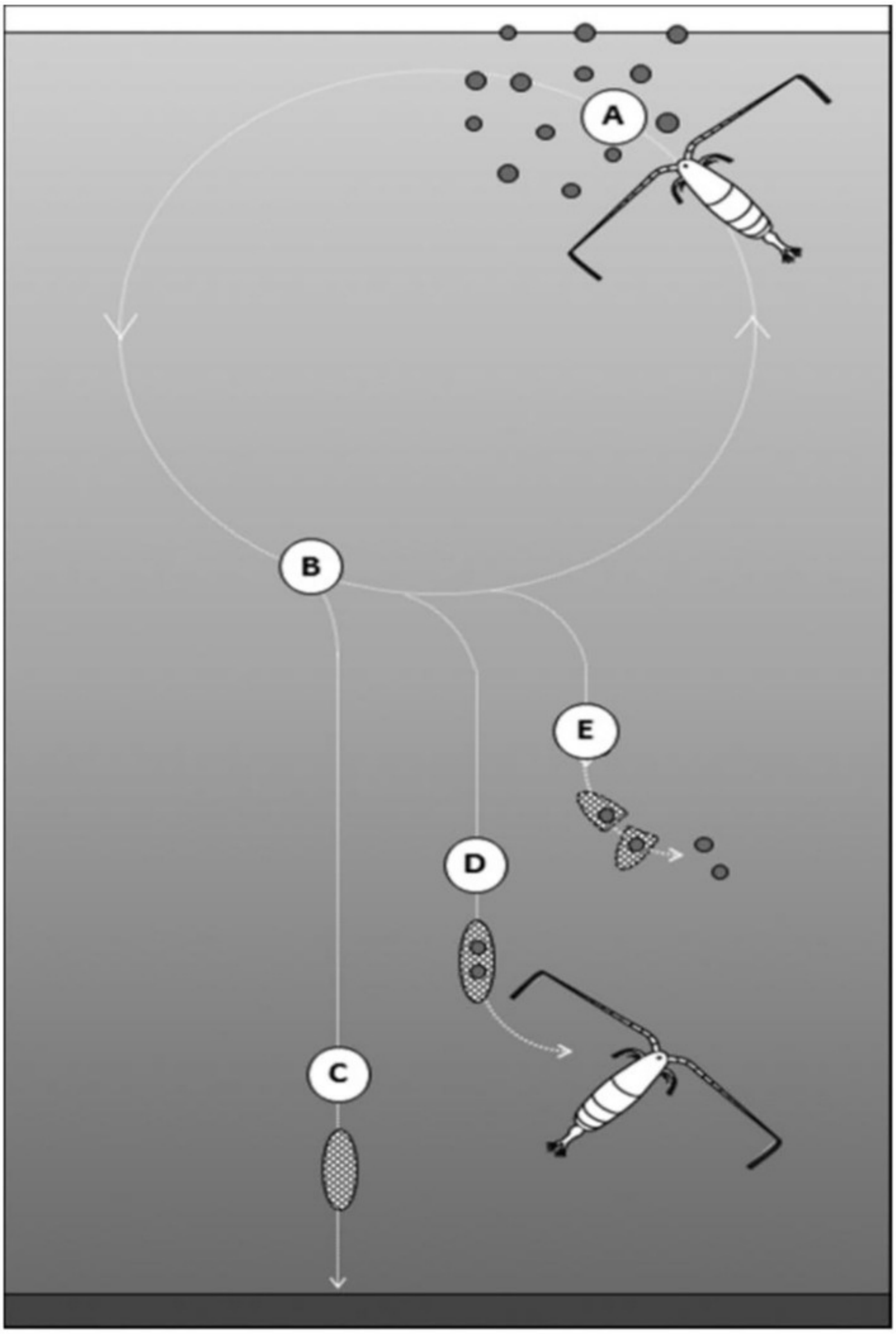


Figure 3

Figure 3

(A) A copepod eats microplastic at the surface of the ocean. **(B)** Some of the plastic will be pooped out in the copepod's faecal pellets. **(C)** Faecal pellets sink, transporting carbon to the depths of the ocean. **(D,E)** Faecal pellets containing microplastics may take longer to sink and may be eaten by different organisms or might break up and release the plastic back into the water [4].

even thousands of years. Microplastics could end up becoming part of the **fossil record**.

FOSSIL RECORD

History of life as documented by fossils.

HOW CAN EVERYONE HELP?

Our research is helping people understand the risks and concerns posed by microplastic pollution in our oceans. We have provided scientific evidence to politicians, which has led to charges for single-use plastic bags at the supermarket and the banning of microbeads in face scrubs and toothpaste, which get washed down the sink and eventually end up in the ocean. We are also exploring whether mussels and seagrasses can be used as part of a nature-based solution to help stop the flow of microplastic from their sources into the sea.

As for non-scientists, every little bit helps! There are over 7 billion people on this planet, so if everyone used *just one less* plastic bottle, think of how much less plastic would be used every single day. Reducing usage of single-use plastics wherever possible is a great place to start, from bringing your own reusable water bottle and shopping bags, or perhaps choosing food with less packaging at the supermarket. Next time you take a walk on the beach or in your local area, consider doing a 2-min litter pick-up. This will help prevent plastic pollution from entering the sea. Working together, scientists and non-scientists can help to reduce the threat of microplastic pollution. These efforts will benefit the environment and improve the lives of copepods and many other living things, including humans!

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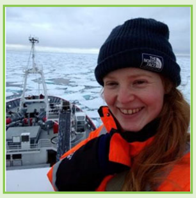
CONFLICT OF INTEREST: The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

YOUNG REVIEWER

MANUEL, AGE: 13
Hello! My name is Manuel, and I am an aspiring teenage boy. I was born in the U.S. of A and my parents are South American. I have always loved animals, so when I grow up, I hope to be a bio-engineer or a marine biologist. My hobbies include playing video games, reading and listening to true crime podcasts. I have always loved the unknown and mysterious, so I always try to learn more!

AUTHORS

PENELOPE K. LINDEQUE
I am a marine biologist at the Plymouth Marine Laboratory. My work focuses on zooplankton, small animals at the base of the marine food web. I develop and use molecular techniques to identify zooplankton, investigate what they eat and what eats them, and to look at their responses to environmental stress and pollution. I am also interested in the source, distribution, and impact of microplastics and microdebris on marine animals, including zooplankton. When I am not working, I love being near, on, or in the sea, rowing, paddle-boarding, or playing with my family and dogs. *pkw@pml.ac.uk



ZARA L. R. BOTTERELL
I am a marine biologist based at Plymouth Marine Laboratory. My research investigates why zooplankton eat microplastics, including what factors may affect their ingestion, such as size, shape, or smell. I am also very interested in what zooplankton currently eat in our oceans and how this may affect the wider ecosystem. My recent research focuses on microplastic ingestion by zooplankton in the Arctic seas.

RACHEL L. COPPOCK
As a marine ecologist at Plymouth Marine Laboratory, I am investigating the risks microplastics pose to marine life and the ecosystems they live in, and I help explore nature-based solutions to marine microplastic pollution. I am interested in the

impact of microplastic pollution in Arctic seas, which are warming faster than anywhere else on the planet. I have also developed a method to extract microplastics from marine sediments, to help figure out how much plastic is in the seabed and to understand the ultimate fate of microplastic litter around our coasts.

MATTHEW COLE

I am a marine ecologist at Plymouth Marine Laboratory. Over the past 10 years, I have been investigating how marine life interacts with microplastic debris. My research was the first to reveal that microplastics can be eaten by marine zooplankton. In recent years, our research group has been exploring how microplastics can have a negative impact on the health of zooplankton. Currently, I am exploring whether we could harness the power of mussels to help remove microplastics from estuaries!

frontiers FOR YOUNG MINDS

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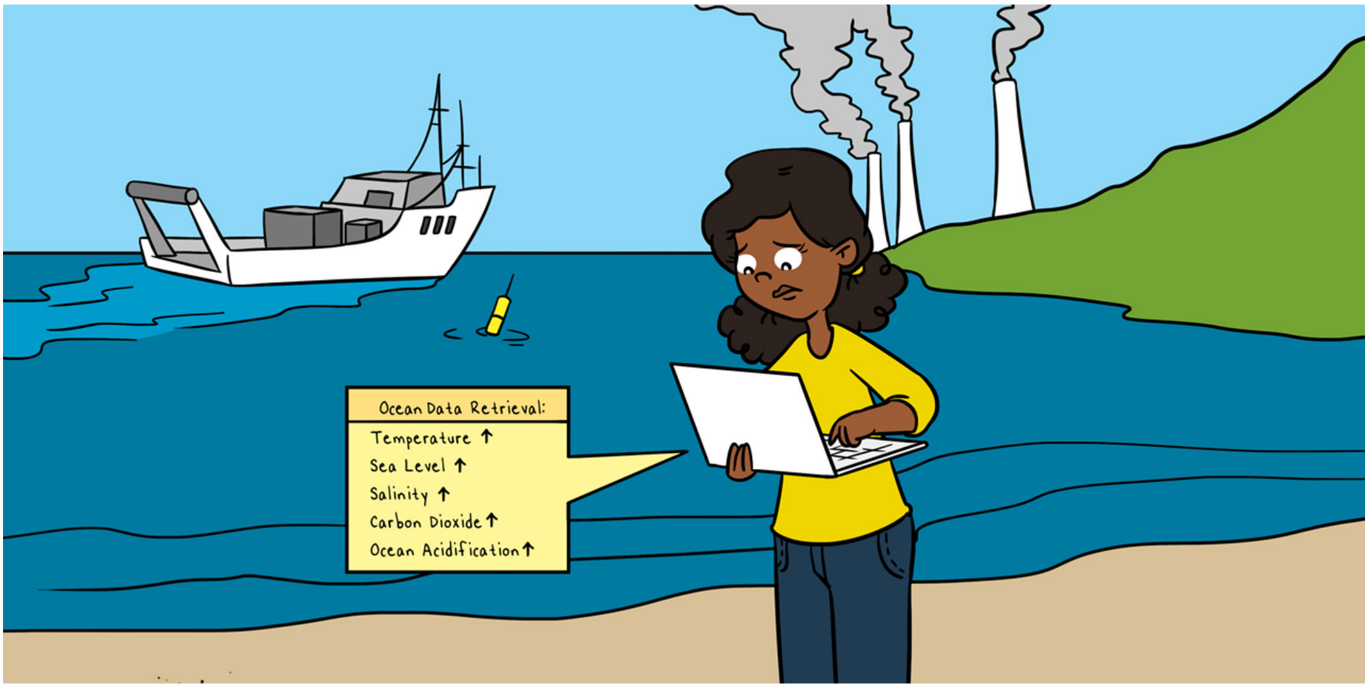

GLOBAL OCEAN CLIMATE CHANGE: OBSERVING FROM SHIPS

Lynne D. Talley *

Scripps Institution of Oceanography, University of California San Diego, La Jolla, CA, United States

YOUNG REVIEWERS:


ANDREI
AGE: 14


KRISH
AGE: 13


SHASHI-PREETHAM
AGE: 13

Have you stood on the beach or crossed the ocean on a plane, wondered at the enormous size of the ocean, and possibly thought about how it regulates our climate? Or how our climate is changing? Or what harm our extra carbon dioxide and heat are causing to life in the ocean? The oceans take up heat from the atmosphere and sun, they change their saltiness as they are either evaporated or rained on, and they exchange gases with the atmosphere, including some of the extra carbon dioxide that humans add to the atmosphere. Ocean currents and mixing carry heat and carbon for tens to hundreds of years, and as they move heat and carbon around, the currents alter the atmosphere above. We only have this knowledge because we have been observing the ocean from ships for a century, adding satellites, and drifting instruments in the last few decades.

OUR CLIMATE AFFECTS THE OCEANS

The oceans are huge: they cover 71% of Earth's surface and are 5 kilometers deep on average. And the oceans are changing. Humans

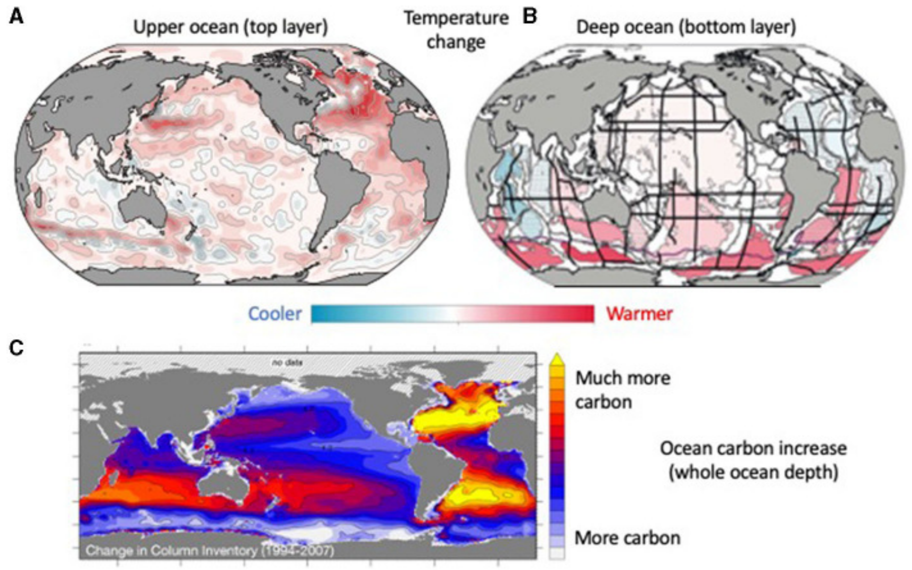

Figure 1

Figure 1

(A) The top layer of the ocean has warmed (red colors) based on our temperature measurements over 30 to 40 years. The biggest warming is in the Atlantic and the North Pacific. **(B)** Warming at the ocean bottom looks very different: most warming is in the Southern Hemisphere, around Antarctica. The black lines show where ship measurements were made. **(C)** The ocean has taken up extra CO_2 from the atmosphere since the 1990s. The Atlantic Ocean has the most extra carbon (yellow). Most of the extra CO_2 in each ocean is in the middle-latitudes because of ocean circulation. Source: Top left and right: Rhein et al. [1]. Bottom: After Gruber et al. [2].

CLIMATE CHANGE

Climate is the average weather (warm, cool, rainy, dry). Climate variability is the natural variations in climate. Climate change is the variation that is due to human activity.

SALINITY

The weight of salts dissolved in a kilogram of seawater. Units of salinity are usually written as grams of salt per kilogram of seawater.

ANTHROPOGENIC CARBON

Carbon in the ocean that results from humans' burning of fossil fuels.

have been increasing the amounts of greenhouse gases, mostly carbon dioxide (CO_2), in the atmosphere. This causes the atmosphere to warm and changes rainfall and evaporation. **Climate change** is causing ocean temperatures to rise, from the surface to the ocean bottom (Figure 1). Ocean **salinity** (the amount of salt dissolved in ocean water) is shifting over very large regions because of the rainfall/evaporation changes. Part of the atmosphere's extra CO_2 ends up in the ocean. This extra CO_2 is called **anthropogenic carbon**, which means "human carbon," because it comes from human activity, like from cars that use gasoline or factories that use coal or gas. These sources of energy are called fossil fuel. When CO_2 dissolves in seawater, the water becomes more acidic, which is harmful to shells and bones. Oxygen is another very important gas in the oceans and atmosphere. Many ocean organisms need oxygen, and we have seen that the amount of oxygen dissolved in seawater is going down, mostly due to climate warming.

How do we understand climate and predict its future? First, we observe the oceans, atmosphere, land, and sun. We observe how they are changing because of fossil fuel burning, land use changes, and other human impacts. Then we build, run, and improve huge computer models based on what we observe. These models allow us to test ideas about how the climate operates and predict the future of the climate. The more observations we have, the better the models and the better the predictions/forecasts.

WHAT CLIMATE CHANGES HAVE WE OBSERVED IN THE OCEAN?

Oceanographers have been measuring the ocean for hundreds of years. We have mostly used ships ("GO-SHIP[1]"). About 30 to

[1] http://www.go-ship.org/.

40 years ago, satellites started observing the surface ocean, and satellite communications began to allow robotic instruments to send information back to the lab, without the need for a ship. Robotic instruments now measure the top half of the world's oceans every 10 days [3]. But ship measurements are still needed to measure the oceans very accurately from top to bottom, and to measure the ocean chemistry that is important for life, such as the amounts of carbon, oxygen, and nutrients present.

Temperature Changes

Temperature is the most basic ocean property we measure from ships. In most places on Earth, temperatures in the upper part of the ocean has risen over the last 50 years (Figure 1A), because the atmosphere above the ocean is warming. We have also observed temperature changes all the way to the bottom of the ocean. The biggest bottom temperature warming is happening around Antarctica (Figure 1B). This is because, around Antarctica, it only takes a few years for cold, heavy surface water to sink to the ocean bottom, so changes happen fairly quickly in these waters. However, over the last few decades, there has been less and less very cold, heavy water along the coasts of Antarctica. Because there is less cold water, the bottom is warming up.

In these two ways—by the atmosphere warming the upper ocean almost everywhere and warming of the deep ocean mostly around Antarctica—the ocean has taken up more than 90% of the extra heat in Earth's climate system. What happens when the ocean warms? The water expands. This causes the ocean surface to rise, which is called sea level rise. Sea level is also rising because the warming atmosphere melts land ice, like glaciers and ice sheets, and this water goes into the ocean. These two effects contribute about equally to sea level rise.

Salinity Changes

Salinity is the second important physical quantity that we measure. The ocean is salty, as you know from a surprise mouthful of water at the beach. The total amount of salt in the ocean hardly changes at all, but where it rains a lot, the seawater is diluted by the freshwater and salinity goes down. Where there is a lot of evaporation, the seawater salts become more concentrated and salinity goes up. If seawater is saltier, then it is heavier. Salty water that is close to the freezing point is very heavy, and fills the bottom of the ocean.

Rain and evaporation are changing because the warmer atmosphere can hold more water vapor and move it from dry regions to rainy regions, including over the ocean. With ship and robotic measurements, we see that salty ocean regions are getting saltier and fresher ocean regions are getting fresher. This means that dry regions are getting drier and wet regions are getting wetter. This is

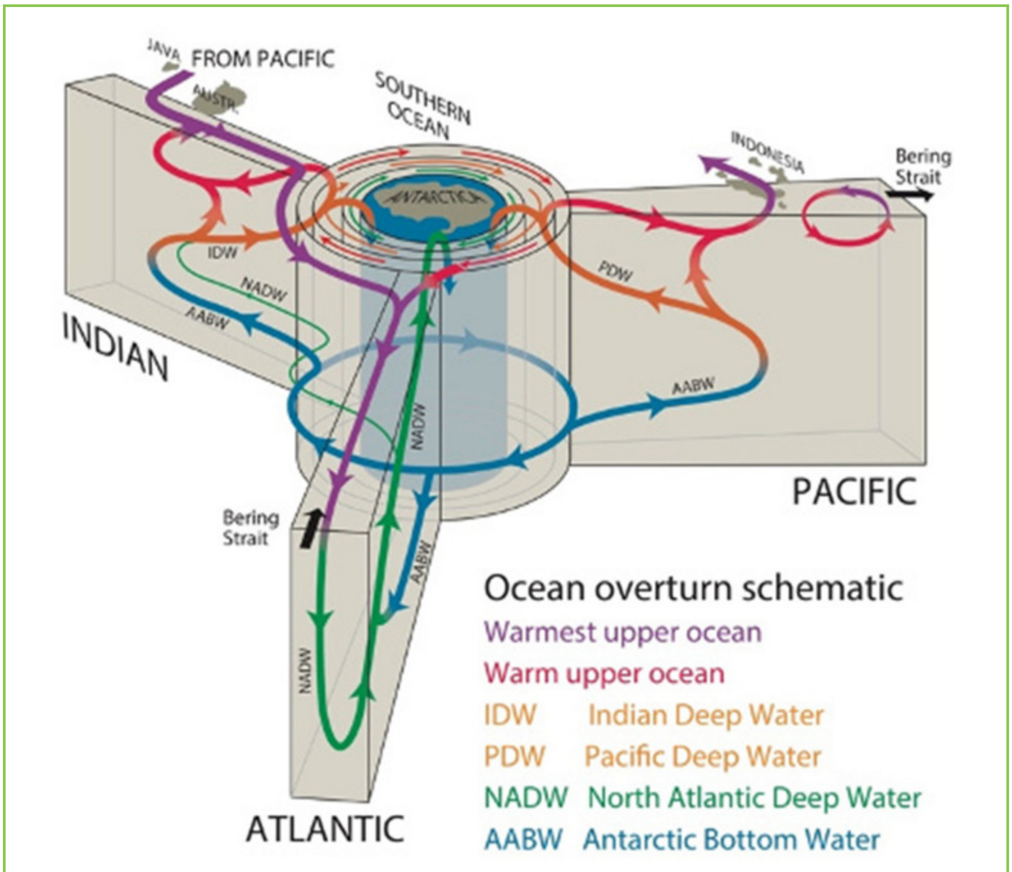

Figure 2

Figure 2

The overturning circulation that connects the ocean surface and ocean bottom. The Atlantic, Indian, and Pacific Oceans are connected around Antarctica. Surface water sinks in the cold, northern Atlantic and flows southward toward Antarctica. There, it rises to the sea surface, gets very cold, and sinks. This very cold water flows northward to fill the bottom of every ocean. Heat from the ocean surface trickles down and warms the cold waters, which rise toward the surface, some in the tropics, and some driven upward by winds in the south. The warm water flows back to the North Atlantic. Source: Adapted from Talley [4].

also happening on land, but it is much harder to measure rainfall and evaporation changes than to measure ocean salinity. Salinity measurements have become a rain gauge for the planet.

Carbon Dioxide (CO_2) Changes

Climate change is mostly driven by increasing CO_2 in the atmosphere. CO_2 is rising because humans are burning fossil fuels. From our ship measurements, we have seen that about 25 to 30% of this extra CO_2 enters the ocean, through air bubbles trapped in surface waves. This sounds like a good service that the ocean provides—it cleans up the atmosphere a bit. But when CO_2 dissolves in water, the water becomes slightly acidic. All seawater (and rainwater) is slightly acidic. When extra CO_2 from the atmosphere dissolves in seawater, it makes it even *more* acidic. This is called **ocean acidification**, and it can devastate some ocean organisms by causing shells and bones to dissolve more easily, which means organisms may end up smaller or deformed or even die.

OCEAN ACIDIFICATION

The increase in how acidic the seawater is, as a result of addition of anthropogenic carbon. Seawater is always slightly acidic because carbon dioxide is always present, dissolved from the atmosphere, but acidification is the increase in this acidity.

Ocean Current Changes

Ocean currents that connect large parts of the ocean (Figure 2) are changing slightly because of the changing ocean temperature and salinity, and because winds are changing. From ships measuring from one side of the ocean to the other (Figure 3C), we can say how much

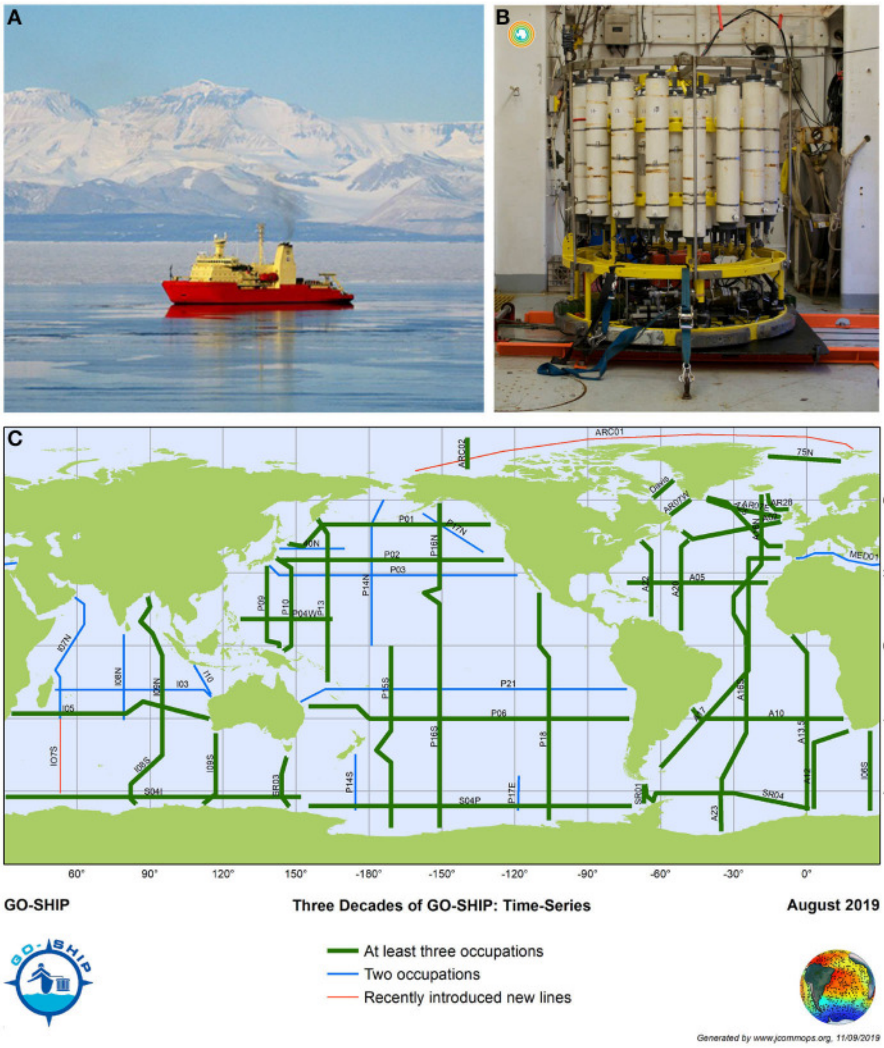

Figure 3

Figure 3

(A) An ice breaker research ship off the coast of Antarctica. **(B)** Equipment used on GO-SHIP cruises to measure the ocean temperature, salinity, carbon, and other chemicals. The "package" includes bottles in a circle around the frame (called rosette sampler), and several electronic instruments that lie across the bottom of the frame under the bottles. Some of these instruments measure temperature, salinity, and depth. The bottles in the rosette are ready to go into the ocean: the gray caps of the bottles are open, ready to sample. **(C)** Map of where research ships have made the carefully repeated measurements each decade since the 1990s. Data from these measurements was used to create the maps in Figure 1. Source: Top left: Holly Gingles (https://www.nsf.gov/geo/opp/support/nathpalm.jsp). Top right: Earle Wilson (https://www.flickr.com/photos/139764369@N07/27864642302/in/album-72157667622005814/). Bottom: Global Ocean Observing System website for global ocean observation efforts, https://www.ocean-ops.org/.

water moves from one ocean to another, how much moves down to the deep ocean in cold regions (near Greenland and Antarctica), how long it moves around in the deep ocean, and where it comes back up to the warm surface. These ocean currents are called the **overturning circulation** and sometimes also called the ocean conveyor belt. The overturning circulation is important for the climate because it carries heat and carbon around. Changes in the overturning circulation can warm and cool whole oceans.

ADVANCES IN OCEAN OBSERVATIONS FROM SHIPS

In the late 1800s, there were huge advances in observing the world's oceans. Ocean temperature was measured with mercury thermometers, and salinity was measured by evaporating sea water from samples and weighing the remaining dry salt. In the early 1900s, these measurements became much more accurate and easier to make: thermometers were improved and a laboratory method

OVERTURNING CIRCULATION

The currents of the world's ocean that connect the waters at the surface to the inside and bottom of the ocean, and connect the large oceans such as the Pacific, Atlantic, Arctic, Indian, and Antarctic region.

to measure salinity were invented. These methods were used until the 1950s.

Modern oceanography was born in the 1950s and 1960s, when digital sensors for temperature, salinity, and pressure (which is an indicator of depth) were developed. Carbon, oxygen, nutrient, and velocity measurements were also improved. In Figure 3B, you can see a frame with instruments and water sampling bottles attached to a wire. This equipment is lowered from the ship. The ship's computer lab receives signals from the instruments through the wire. The lab also sends commands to the bottles to collect water.

In the late 1980s, space agencies launched satellites to observe Earth[2]. Some satellites measure ocean surface temperature and other useful surface properties. Global observations within the ocean were made to match the satellites, as part of the World Ocean Circulation Experiment (WOCE[3]) of the 1990s. WOCE sampled every ocean basin, from the sea surface to the ocean bottom (Figure 3C). We understand a lot about temperature, salinity, carbon, oxygen, nutrients, and ocean currents because of WOCE.

[2] https://podaac.jpl.nasa.gov/CoreMeasurements.

[3] https://www.nodc.noaa.gov/woce.

In the 2000s and 2010s, we found out that the ocean was changing enough that its changes could be measured. We have kept measuring every 10 years along about half of the WOCE lines as part of the GO-SHIP program (Figure 3C), to document changes in the global ocean from top to bottom [5]. Our research ships (Figure 3A) move across the ocean basins at a top speed of about 10 knots (18 km/h, so bicycling speed). To collect data for GO-SHIP, the ships stop about every 60 km to lower their instruments to the ocean bottom and pull them back, which takes about 4 h. Completing "lines" across the ocean takes several months. GO-SHIP shipboard measurements are made by many different countries. National representatives talk often to coordinate. Big decisions about what to improve have been made at meetings called OceanObs every 10 years.

BECOME AN OCEANOGRAPHER

Ship observations will be our continuing information source for deep temperature, salinity, and full-ocean chemistry changes, and now also for looking at living organisms. And we need to do this every year during the following decades. So, we need you to become an oceanographer. You can become a physical oceanographer and study the global ocean currents, a chemical oceanographer and study salinity changes and nutrients, or a biological oceanographer and study the impacts of ocean acidification on organisms. The ocean waits for you!

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CONFLICT OF INTEREST: The author declares 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 REVIEWERS

ANDREI, AGE: 14

Hi there! My name is Andrei. I enjoy doing photography, skiing, and swimming. My favorite sport is badminton! I really enjoyed reviewing this article. I found it quite interesting.

KRISH, AGE: 13

My name is Krish and I am aged 13. My favorite subjects are maths, biology, electronics, geography, and chemistry. Hopefully when I am older I will go into finance.

SHASHIPREETHAM, AGE: 13

Hello, my name is Shashi, I am 13 years old and I go to Penglais School. I enjoy playing football and basketball. My favorite subjects are Maths and computers. I am currently studying year 8. I am a four times Guinness World Records holder in a game called Rocket League and my name is in 2018 Guinness World Record Gamers Edition.

AUTHOR

LYNNE D. TALLEY

Lynne Talley is an oceanographer who studies the world ocean's currents, temperature, salinity, and chemistry. She works on processes that connect all of the oceans together. She loves to be on the ocean, in the middle of nowhere, sitting atop 5 km of water. She is a Professor of oceanography at Scripps Institution of Oceanography in California, USA. She helps to organize two global ocean observing systems: GO-SHIP, which includes full-ocean observations from ships every 5 to 10 years, and Biogeochemical Argo, which is a new program for robotic observations of the world ocean's carbon, oxygen, and nutrients. She was a Lead Author for ocean observations for the Intergovernmental Panel on Climate Change.

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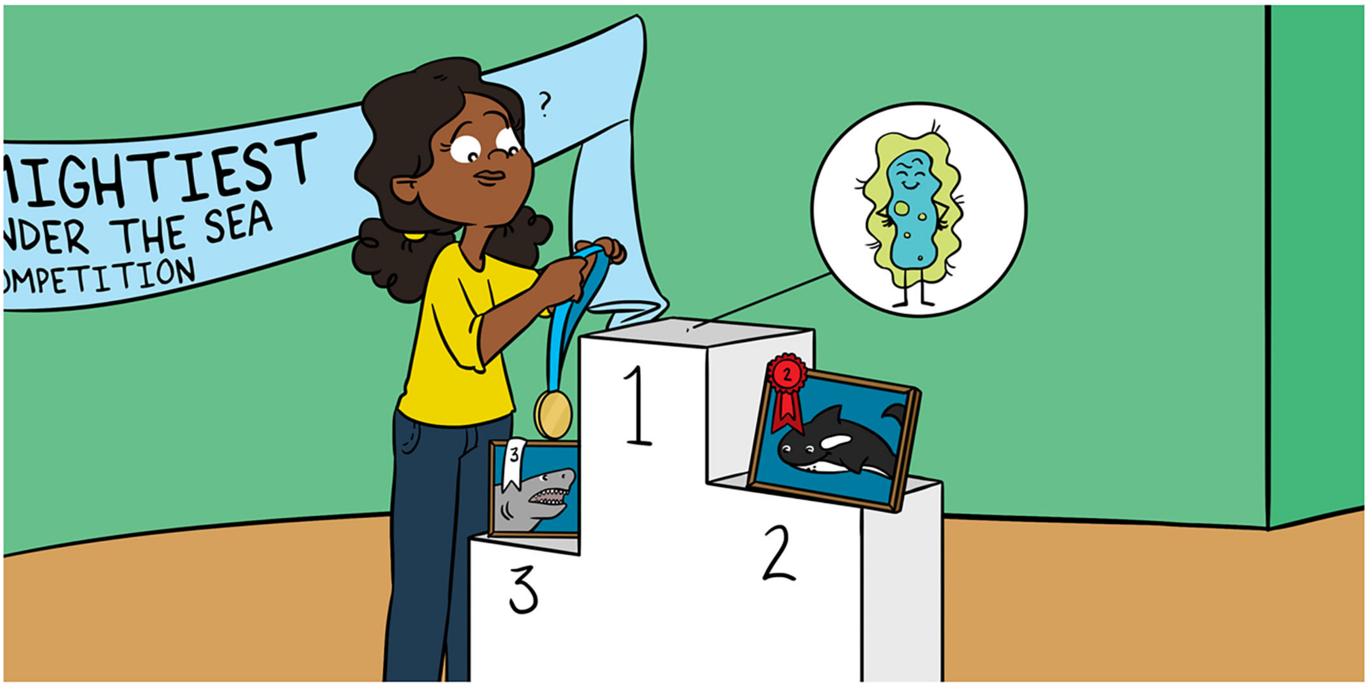

TINY PHYTOPLANKTON: THE MOST POWERFUL ORGANISMS OF THE OCEANS!

Patricia M. Glibert*

Horn Point Laboratory, University of Maryland Center for Environmental Science, Cambridge, MD, United States

YOUNG REVIEWER:

ARIA
AGE: 9

Although sharks, whales, and other large organisms come to mind when one thinks about the most important or most powerful organisms of the sea, in fact, the most powerful are the tiny phytoplankton. Phytoplankton, which are microscopic algae, hold this power because they harvest the light from the sun, making food for all other organisms. Phytoplankton are the foundation for the ocean ecosystem. Through the process of photosynthesis, they also make oxygen and are responsible for almost half of the oxygen in the world. However, some phytoplankton can also be harmful and can kill fish or damage ecosystems. These harmful phytoplankton can also make people sick. The phytoplankton are tiny but mighty!

WHAT ARE THE MOST POWERFUL ORGANISMS OF THE OCEAN?

When you think of the most powerful organisms in the sea, does a shark come to mind? Or maybe a huge killer whale? Other powerhouses of the ocean include the sailfish that use their jaws like

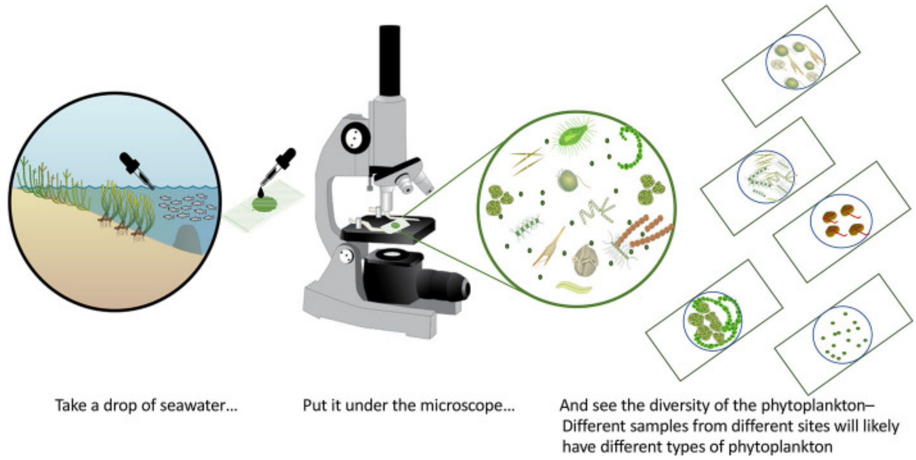

Figure 1

Figure 1

Every drop of seawater has thousands of microscopic plankton. A great diversity of phytoplankton is seen if one compares samples from different areas or different times. (Image credits: the symbol library of the University of Maryland Integration and Application Network.)

spears to catch their prey and glide like torpedoes! After all, it is the fastest of all the fish. All these organisms are amazing: strong, fast, and ferocious.

However, there is another group of organisms so powerful that the oceans could not function without them—but they are so tiny you have probably never seen them! These are the microscopic **plankton**. They are called plankton because they just drift with the sea. The smallest plankton can only be seen with a microscope and, even though you will see many different types of plankton with a microscope, some plankton are so small they may look like teeny-tiny dots (Figure 1). What gives these minuscule organisms such power? Why do we even care about something we cannot even see? They are not great swimmers. They do not have strong teeth—or any teeth at all, actually! They are important because they are the food on which all life in the sea depends (Figure 2). Without plankton, there would be no fish, no whales, no sharks, no turtles, and no clams or oysters.

PLANKTON

Microscopic organisms in the sea or in freshwater.

PHYTOPLANKTON ARE THE MOST POWERFUL TYPE OF PLANKTON

There are many types of plankton. **Phytoplankton** are the microscopic plant-like organisms, also often called algae or microalgae. Of all the plankton, phytoplankton are the most powerful ocean organisms because they can use sunlight for energy, and grow through the process of **photosynthesis**. Phytoplankton then become the food for other ocean organisms. The phytoplankton are not only responsible for making food for the oceans, but they are also responsible for almost half of all the oxygen in the world! By performing photosynthesis, they use carbon dioxide from the water and they make oxygen, which most living organisms, including humans, need to breathe. So, thank the phytoplankton the next time you eat seafood or take a breath!

PHYTOPLANKTON

Plant-like plankton that perform photosynthesis, turning light from the sun, along with CO_2 from the water, into oxygen and the energy needed to grow.

PHOTOSYNTHESIS

The process by which green plants and plant-like algae use sunlight, together with carbon dioxide and water, to make their own food.

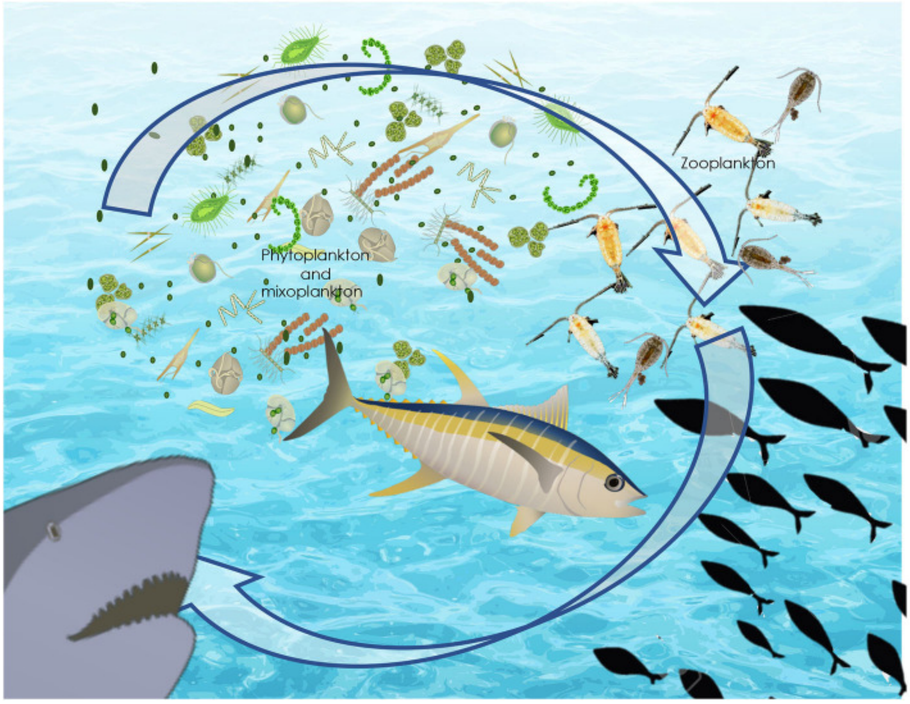

Figure 2

Figure 2

Food for the fish, sharks, and other ocean organisms begins with the growth of phytoplankton. Phytoplankton may be eaten by zooplankton, which are then eaten by small fish, and so on. (Image credits: the symbol library of the University of Maryland Integration and Application Network and open access images.)

Zooplankton are the tiny animal-like plankton. You can remember their name easily—just think of animals in a zoo! Zooplankton eat the phytoplankton (and some other types of plankton too). They are important in the food chain of the oceans (Figure 2). Zooplankton are eaten by small fish. Like a link in a chain, one organism eats another and then is eaten by another and so on. In reality, though, the chain is more like a spiderweb, as so many different types of organisms eat so many different kinds of things. Zooplankton do not perform the photosynthesis magic of phytoplankton, so while they form important links in the food chain, they do not make oxygen the way phytoplankton do.

ZOOPLANKTON

Animal-like plankton organisms that eat other plankton organisms—like phytoplankton, bacterioplankton, or mixoplankton.

Some plankton are a mix of both phytoplankton and zooplankton in one little body! These organisms can perform photosynthesis, but at the same time they can also eat other plankton [1] (Figure 3). These organisms are called **mixoplankton** because they are a "mix" of plankton types [3]. Mixoplankton do not have mouths, but they can gobble up entire organisms. Some mixoplankton use a sort of straw that they release to suck out the innards of their prey. Some can make their prey explode, leaving a nutritious soup that they can soak up. Some can even eat other organisms that are much bigger than themselves.

MIXOPLANKTON

Plankton that can combine photosynthesis (like a plant) and feeding (like an animal) for their nutrition.

There are also bacteria that are plankton, called **bacterioplankton**. Bacterioplankton do the recycling of the sea-and so they are also extremely important in the oceans. They help to decompose the bodies of other organisms and, in so doing, the important elements

BACTERIOPLANKTON

Aquatic bacteria that help to decompose detritus and dead organisms and recycle their nutrients.

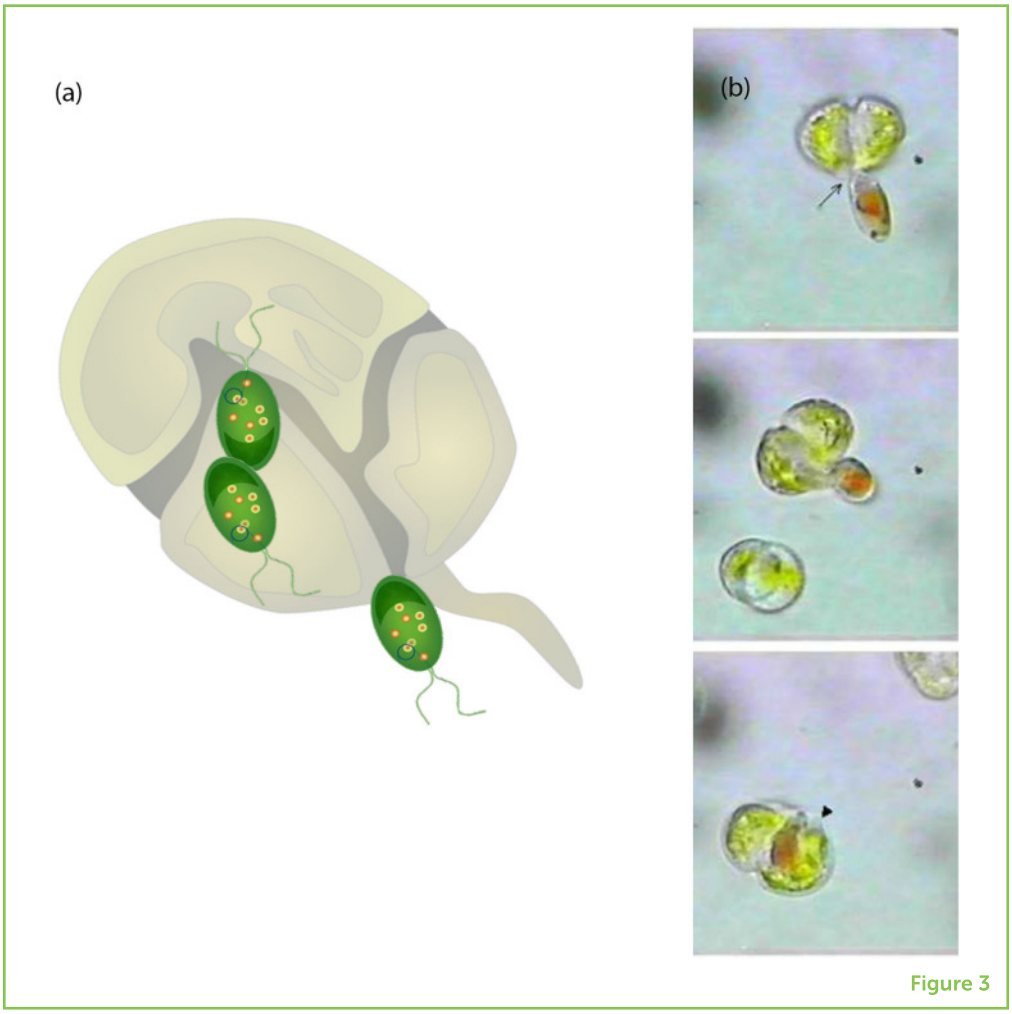

Figure 3

(a) A mixoplankton cell having a meal of another small phytoplankton cell. **(b)** Microscope images showing a mixoplankton cell capturing and then ingesting another small cell. (Image credits: **(a)** the symbol library of the University of Maryland Integration and Application Network and **(b)** Stoecker et al. [2]; reproduced with permission of Springer-Verlag).

are made available to new organisms. But they cannot perform photosynthesis. Lastly, there are some plankton that are viruses, called **viroplankton (or virioplankton)**, and they can infect other types of plankton, as well as other organisms.

VIROPLANKTON (OR VIRIOPLANKTON)

Viruses that can infect other types of plankton or other organisms.

All these different types of plankton interact with each other in complex ways. Together, the plankton make food and oxygen, and they recycle materials for new growth. However, the phytoplankton are the most powerful organisms in the sea, because they are the fuel that makes the whole ecosystem function, laying the foundation for the ocean ecosystem. When mixoplankton act like phytoplankton, carrying out photosynthesis, they too can be considered most powerful. But, like the foundation of a building, if the foundation weakens–or the wrong foundation was used, a building can collapse. Similarly, when there are not enough phytoplankton to make food, or if the wrong types of phytoplankton grow, the food chain of the sea can collapse, turning the ocean into a watery desert wasteland. Food chains–or food webs–of lakes and other freshwaters also depend on phytoplankton for their food. Phytoplankton are powerful in all the waters of the world.

NOT ALL PHYTOPLANKTON POWER IS GOOD

Different types of phytoplankton and mixoplankton are found in waters with different habitats. Some phytoplankton like to live in shallow, nearshore waters, others like to live in more deep or offshore waters. Some like warm waters like those that occur in late summer, some like cooler waters like those that are found in winter or in polar regions. Each species has its favored habitat. Just like the diversity of plants on land, there is a huge diversity of phytoplankton–and some are harmful. There are villains as well as superheroes in this microscopic world!

One way phytoplankton and mixoplankton can be harmful is when too many grow at once. When this occurs it is call a "bloom" (like the blooming of a flower), and this can change the color of the water as they accumulate, sometimes spectacularly. Another term for these events is "**harmful algal blooms**." Some blooms can turn seawater visibly red, which is the origin of the term "red tide" that is often used to describe such events [4]. Not all algal blooms are red, however—some are green or brown, depending on the pigmentation of the species causing the bloom.

HARMFUL ALGAL BLOOM

Growth of algae (phytoplankton and mixoplankton) that may cause fish kills or seafood contamination through toxins, or that may alter ecosystems in negative ways.

Once these blooms begin to die, their decomposition (by bacteria) uses up oxygen. If too much oxygen is used up, this can result in areas called **dead zones**. Dead zones are regions of the ocean where there is so little oxygen that most organisms–except some kinds of bacteria–cannot survive. Global occurrences of such dead zones are expanding [5] because more and more blooms are occurring in more and more parts of the oceans.

DEAD ZONES

Regions of oceans and lakes where oxygen levels are too low to support most aquatic life.

Another way that phytoplankton and mixoplankton can be harmful is when they make poisons. Just as some land plants can be poisonous, some phytoplankton and mixoplankton can be poisonous too. One mixoplankton species named *Karlodinium* can release its poisons into the water, destroying the gills of fish, killing them almost immediately. The *Karlodinium* plankton then eat these bits of fish for their dinner. Another mixoplankton species called *Karenia brevis* is common off the coast of Florida. It can produce a poisonous compound that can not only kill fish but is even strong enough to kill huge manatees and giant turtles [4]!

People can get sick from these plankton poisons, too. Different types of phytoplankton and mixoplankton make different types of poisons [6]. Sometimes people get rashes on their skin if they swim when these poisonous plankton are in the water. Of greater concern are the poisons that can get into seafood that is then eaten by people. Oysters and mussels eat phytoplankton, but when they eat the toxic types, the poisons can stay in their bodies. When we eat those oysters or mussels, we eat the poisons too. Some poisons may cause an upset stomach or diarrhea, but there are stronger phytoplankton poisons that can make us much sicker if we eat seafood contaminated with them. Some of these poisons may make you stop breathing. With too much of this poison people may die. Other poisons from these phytoplankton may cause cancer if people are exposed to them for a long time. Scientists are very interested in understanding what we can do to stop these tiny, toxic organisms from growing out of control and how we can keep people from getting sick.

PHYTOPLANKTON: TINY BUT MIGHTY!

Phytoplankton are tiny organisms with great power! They are the fuel for the whole ocean ecosystem, and they also have the power to harm or to kill. The next time you see a picture of a shark, a whale, or a huge fish, think about where that animal's food comes from: the mighty phytoplankton. Take a deep breath and thank the phytoplankton for the oxygen they produce. And the next time you see a beach sign warning you not to swim or to eat fish because of toxic or harmful algae, stay away! Respect the power of the phytoplankton and mixoplankton, and keep in mind that lakes, too, can have toxic microalgae. Sadly, we are polluting our lakes and oceans with the nutrients that make these blooms grow from our use of fertilizers on crops that runs off into lakes, rivers, and oceans, so there are many more harmful and toxic phytoplankton and mixoplankton growing today than there were years ago. Climate change is making the situation even worse because many harmful blooms grow very well in warm waters [7]. Let is all do our part to reduce water pollution and slow climate change, so that the good phytoplankton and mixoplankton can continue to grow, feed fish, and give us oxygen. By being good citizens of the planet and reducing pollution, we can all work to keep the poisonous plankton villains in check!

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YOUNG REVIEWER

ARIA, AGE: 9
Aria loves playing with her two guinea pigs and feeding birds and squirrels in her backyard. She gave each squirrel a unique name and lots of peanuts. Aria is always curious about science and she has a lot of questions about nature, animals, and the universe. She also likes singing and drawing in her spare time.

AUTHOR

PATRICIA M. GLIBERT
I study algae because I think they are beautiful and important in the world. Phytoplankton blooms are increasingly everywhere, and causing harm in more waters of the world. It used to be difficult to explain what I studied to my non-scientists friends and relatives; now, they read the headlines of water quality issues and algal blooms frequently. I study algae all around the world, from Chesapeake Bay to Florida, from Europe to China! *glibert@umces.edu

frontiers FOR YOUNG MINDS

EARTH AND ITS RESOURCES
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A MESSAGE IN A BOTTLE FROM THE NORTH POLE—HOW PLASTIC POLLUTES THE ARCTIC OCEAN

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YOUNG REVIEWERS:

EXPANDING YOUR HORIZONS

AGES: 12-15

Did you know that plastic waste is so widespread across our planet that it can be found even in the far north, in the Arctic Ocean? Plastic ends up in the environment in many different ways, and researchers are trying to figure out how this pollution affects the animals and plants living in environments that contain plastic waste. Here comes a message in a bottle from the North Pole, telling you a story about tiny pieces of plastic in the Arctic Ocean. How is it even possible for plastic waste to reach the Arctic Ocean? What happens to the plastic once it is there? Is the plastic harming Arctic animals? And how can we prevent plastic pollution? Join us on a chilling story about plastic pollution in our northernmost waters: the fascinating Arctic Ocean.

WHY IS PLASTIC POLLUTING THE OCEANS?

Plastic waste, also called plastic litter, is found in all oceans around the world—even as far north as the Arctic. But how does plastic get there? Let us start by looking at where plastic comes from. Have you thought about how many plastic items you use each day? Your toothbrush, water bottle, computer, and many clothes are likely made at least partly of plastic. But what is plastic? Plastic is the general name for a group of many different artificial materials, which is why plastic can have so many different properties and applications. Since we need plastic for many products, extremely high amounts of plastic are produced. Plastic products eventually wear out and become waste. Even though we try to collect, reuse, and recycle plastic waste, a very large amount of it is lost and ends up in the oceans. Maybe you have noticed that it is almost impossible to walk along a beach without finding plastic litter, like water bottles?

Plastic litter is not only found on beaches. It is everywhere in the oceans: floating on the surface, suspended in mid-level water, and lying on the seafloor. The majority of the plastic in the oceans comes from land, most from direct littering and mismanaged waste. This plastic litter is transported to the ocean by the wind or along rivers. Much plastic is also discarded directly at sea, for example abandoned fishing gear. Once in the environment, plastic litter starts breaking down into smaller pieces, but it takes hundreds of years for the plastic pieces to fully disappear. When the pieces have reached the size of a few millimeters or less, they are called **microplastics**. Sometimes microplastics are even produced intentionally, for use in soaps and toothpastes for example, and they can reach the environment when they are washed down the drain with the **wastewater** we produce in our homes [1].

MICROPLASTICS

Tiny pieces of plastic that are a few millimeters or less in size. They mainly stem from the breakdown of bigger plastic items.

WASTEWATER

Water coming from the drains of our homes and industries. Wastewater can be treated (cleaned) before it is released back to the ocean, lakes, or rivers.

HOW MICROPLASTICS TRAVEL THE WORLD'S OCEANS

Once microplastics reach the oceans, many different things can happen to them. If the plastic material is heavy, it can sink to the seafloor. Plastic can also become heavier and sink if animals, plants, or bacteria start growing on it. If the plastic material is light and floats in water, ocean currents can transport it over long distances [1]. All oceans on Earth are connected by water currents. Our smallest ocean, the Arctic Ocean, is a place that may seem far away, but microplastics are found even there. Aside from plastic pollution, the Arctic is also a region where climate change acts very quickly and where other environmental pollutants accumulate in high amounts. Many researchers are interested in the Arctic and hope to better understand how we humans impact the world's oceans.

The Arctic Ocean is mostly surrounded by land. Water enters the Arctic Ocean from the Atlantic and Pacific Oceans (Figure 1), as well as

Figure 1

Plastic litter is transported to the Arctic Ocean with water currents (orange) from the Atlantic and Pacific Oceans, and also with air currents. Plastic waste also comes from local land- and/or sea-based sources within the Arctic [2].

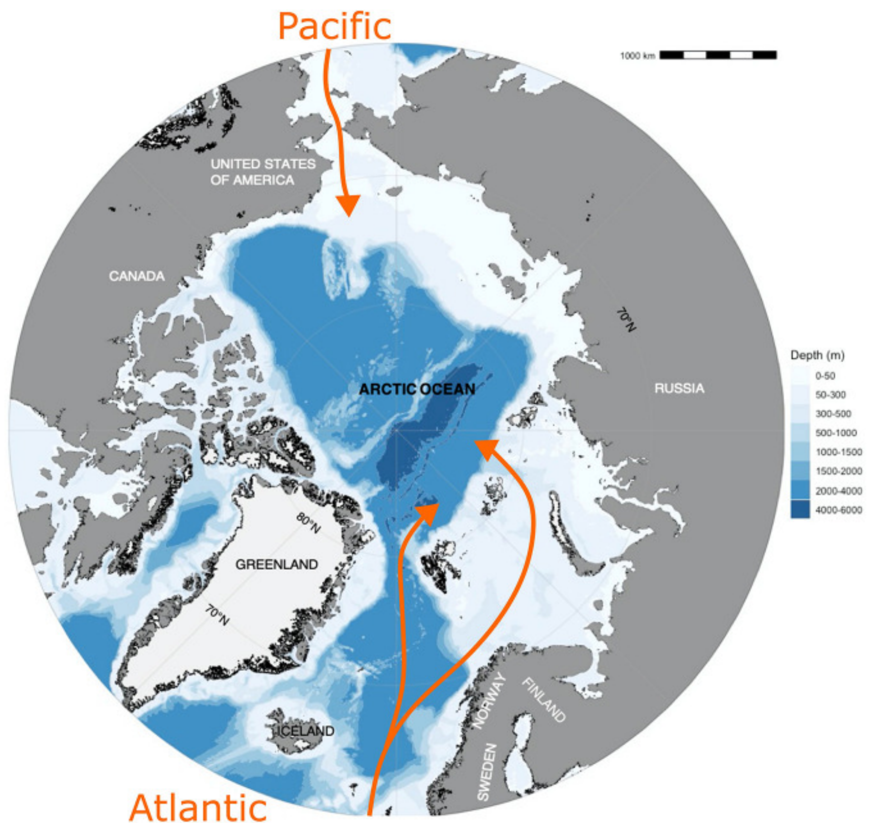

Figure 1

from large rivers, precipitation (snow and rain), and through meltwater from glaciers. Through these water sources, microplastics from more populated areas can reach the Arctic. Small microplastics can also be transported in the air (Figure 2). Similar to ocean currents, air currents circulating around Earth can transport small microplastics great distances. But not all microplastics in the Arctic come from faraway places. There are also sources of plastic litter and microplastics in the Arctic itself (Figure 2) [3]. About 4 million people live in the Arctic, and many tourists visit this area. Wastewater treatment is not common in the Arctic, which means that plastic litter and microplastics more easily reach the environment and the ocean through untreated wastewater. There are also industries in the Arctic, both at sea and on land, that generate plastic pollution. Plastic from fishing activities, for example, is commonly found on Arctic beaches.

THE ARCTIC OCEAN: POLAR BEARS, ICE AND... PLASTIC?!

Now that you know how microplastics end up in the Arctic Ocean, you might wonder where within the ocean they go. To find out, researchers collected samples of water, seafloor sediments, organisms, and ice, and carefully analyzed them for microplastics. They detected microplastics in seawater, sediment, **sea ice**, snow, on beaches, and

SEA ICE

Ice that is formed when seawater freezes.

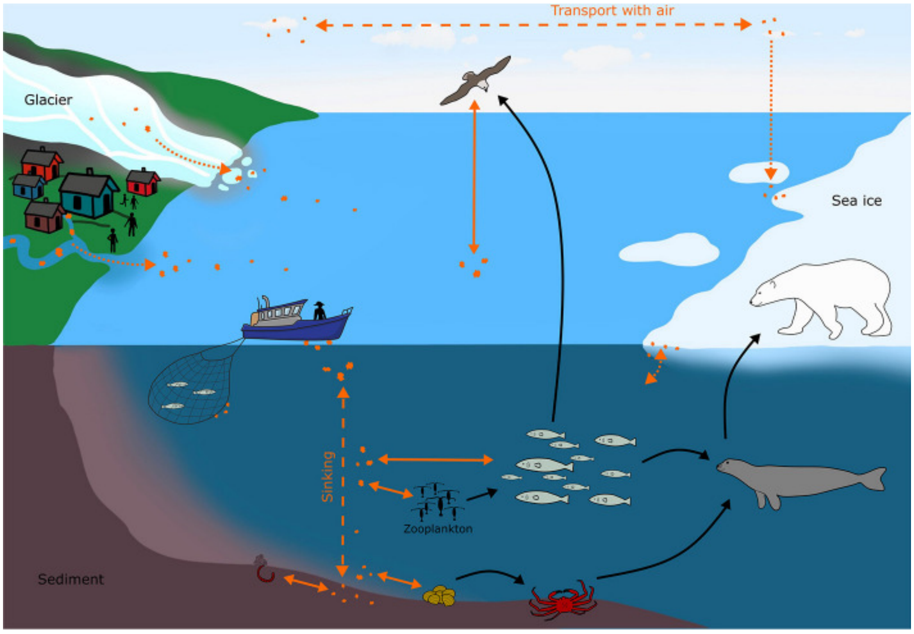

Figure 2

Figure 2

Microplastics (orange dots) move through the environment and interact with animals in the Arctic Ocean. They reach the ocean from land and air (orange dotted arrows), or they are released from ships at sea. In the ocean, most microplastics sink to the seafloor over time. Animals like zooplankton or mussels can ingest microplastics (orange solid arrows) directly from the water and worms can ingest them in sediment. Other animals can take up microplastics by eating prey that has previously ingested microplastics (black arrows). Microplastics can also be excreted after animals have eaten them.

even inside animals from the Arctic Ocean [4]. Especially high amounts were found within sea ice. Sea ice forms from seawater, in contrast to glacial ice that forms from snow or freshwater. The Arctic Ocean has a large floating cover of sea ice, but due to climate change that cover is decreasing rapidly. When sea ice melts in the summer, the microplastics within it are released into the seawater, where many organisms are present at that time of the year [3]. Sea ice is often covered with snow. Microplastics found in Arctic snow were probably transported in the air and settled with snow, rain, or just by gravity.

Microplastics in the Arctic Ocean have been found both far from shore and at the coasts. The amounts of microplastics in seawater close to some towns are higher than the amounts found further away, which tells us that microplastics might spread from the towns. Researchers have detected microplastics in fish, seabirds, starfish, crabs, and mussels in the Arctic Ocean. The northern fulmar, an important seabird in the Arctic, is known to be especially affected by plastic. It remains to be determined whether polar bears have microplastics in their bodies.

DO MICROPLASTICS HARM ANIMALS?

Animals can ingest microplastics accidentally as they eat their normal food. This can happen if they drink plastic-containing water or if their prey contain microplastics. For example, if a crab eats a mussel that has already ingested microplastics, the microplastics in the mussel are moved into the crab (Figure 2). This is called **trophic transfer**.

TROPHIC TRANSFER

Transfer of substances and/or particles, like microplastics, from the body of a prey organism to that of a predator, when the prey is eaten.

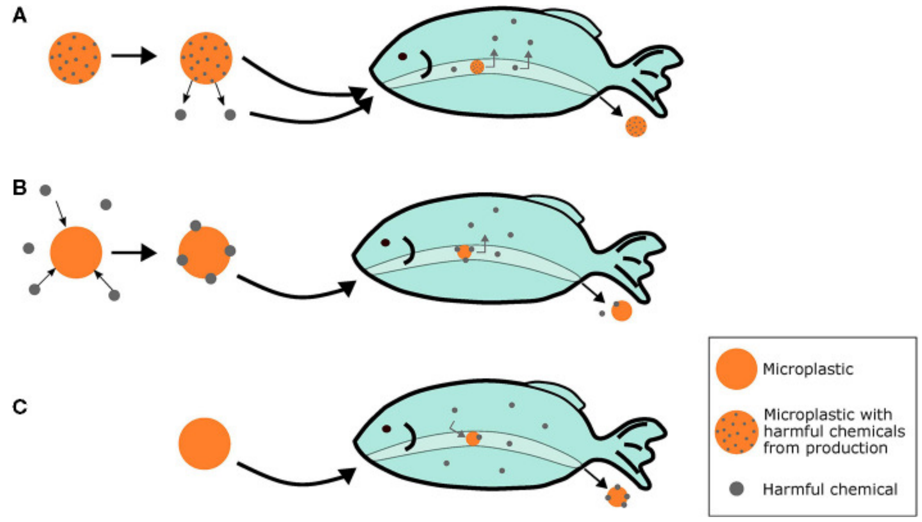

Figure 3

Figure 3

(A) Some microplastics carry harmful chemicals from their production, which can get released and come into contact with animals. **(B)** Microplastics can also collect harmful chemicals from the water and together they can be ingested by animals. **(C)** When an animal has harmful chemicals in its body and ingests clean microplastics, the plastics can sometimes collect those chemicals and they are excreted together.

Animals can also ingest microplastics directly, by mistaking them for food. When animals ingest microplastics, the tiny particles might harm them. Researchers have observed this in experiments performed in laboratories. For example, **zooplankton**, which are very small animals in the oceans, ate less of their normal food when a lot of microplastics were present, because their stomachs were partly filled with plastic particles. Since microplastics do not provide nutrition, animals eating microplastics cannot grow as much as animals eating normal food [5].

ZOOPLANKTON

Small animals, some of which are microscopic in size, that drift in oceans, lakes, and rivers.

Negative effects on animals can also come from chemicals that microplastics sometimes carry (Figure 3) [6]. Chemicals are used in almost any product you can think of. Although many are useful, some chemicals can be harmful to organisms. Harmful chemicals should be prevented from entering the environment. Many different chemicals are added to plastics during production, to make the plastics more flexible or give them color, for example. In the environment, these chemicals can be released from the plastics and come into contact with organisms (Figure 3A). Microplastics can also "collect" chemicals in nature, because certain chemicals in water can easily stick to the plastics (Figure 3B). If animals ingest these chemical-coated microplastics, the harmful chemicals can get into the animals. Surprisingly, this can also work in reverse: if an animal already has many chemicals in its body, then ingesting clean microplastics can actually help to "catch" some of the chemicals and remove them from the animal when the microplastics are **excreted** (Figure 3C).

EXCRETION

Release of waste products, such as urine and feces, from an organism.

A lot of this sounds pretty bad. Does this research mean that all animals in the Arctic are suffering ill effects from microplastics? No, most likely not. The amounts of microplastics that we find in the Arctic are much lower than the amounts that cause harmful effects in laboratory experiments. In addition, most of these experiments were done with animals from other parts of the world, not Arctic animals. So we still know very little about the possible effects of microplastics in the Arctic, but we do know that microplastics do not belong there.

CONCLUSIONS

The Arctic is a unique and vulnerable ecosystem, and is already under a lot of pressure from climate change, which is rapidly causing dramatic changes there. Human activity is also increasing in the Arctic, which is increasing the input of pollutants such as chemicals and microplastics. On top of climate change and chemical pollution, microplastics could be an additional threat that intensifies the total pressure on the Arctic ecosystem. We need to do more research to better understand the amount of microplastics present in the Arctic and the effects that these substances have. In the meantime, we all need to take action against the accumulation of plastic litter in our oceans, before it increases even more. Once microplastics are in the ocean, they are virtually impossible to remove and could stay there for centuries to come. Governments and municipalities need to improve their systems for handling plastic waste, including wastewater treatment, plastic waste collection, and recycling. At the same time, we can all help! Avoid buying and using unnecessary plastic products, reuse and recycle plastic items, collect plastic litter from the environment, and tell your friends and family all about what you have learned in this article. Let us spread this message in a bottle to work together for a future Arctic Ocean without plastic pollution!

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YOUNG REVIEWERS

EXPANDING YOUR HORIZONS, AGES: 12–15

Expanding Your Horizons has been active in Geneva since 2009 with the goal of encouraging girls in the Geneva region to explore STEM careers, and to continue with mathematics and science in school. The non-profit association runs the bi-annual EYH conference, supported by local organizations.

AUTHORS

LISA W. VON FRIESEN

I am a Ph.D. student at the University of Copenhagen. I am really fascinated about the Arctic Ocean and how humans impact it. I study tiny things in the ocean, such as microplastics and microorganisms. I try to better understand where in the Arctic Ocean microplastics and chemicals from plastics are found, and how they got there. I also study how microorganisms (like bacteria) impact the availability of nutrients that bigger organisms in the Arctic Ocean need to grow. I like sailing, horse-back riding and diving. *lisa.vonfriesen@bio.ku.dk

NANNA B. HARTMANN

I am a senior researcher at the Technical University of Denmark. My research is about how small particles, including nanomaterials and microplastics, behave in the environment. I am interested in understanding their distribution, if and how they degrade and how they affect animals. I am also interested in how we can avoid (or minimize) pollution. At the same time, I am passionate about communication and gender equality in science. I spend my free time on yoga, jewelry making and my family, which includes my husband, two sons, and two cats.

GEIR W. GABRIELSEN

I am a section leader in toxicology at the Norwegian Polar Institute and professor in biology at The University Center in Svalbard. My research relates to finding new pollutants in the Arctic environment, pollutants in marine food chains, and effects of pollutants on Arctic seabirds. Lately, I have investigated effects of plastic pollution on seabirds and marine mammals. I think communicating my science to young generations is important. I have produced two children's books (Arctic Seabirds and Plastic Sea). A third book about pollutants in the Arctic is under production.

SINJA RIST

I am a postdoctoral researcher at the Technical University of Denmark and I have been working on microplastics and their interactions with aquatic animals for many years. I am very interested in finding out how pollution from microplastics and chemicals impacts our ecosystems, especially in the changing conditions that come with climate change. I am especially passionate about the ocean and I work with some of the tiniest swimming animals (zooplankton). In my free time I love going diving and snorkeling. *siri@aqua.dtu.dk

EARTH AND ITS RESOURCES
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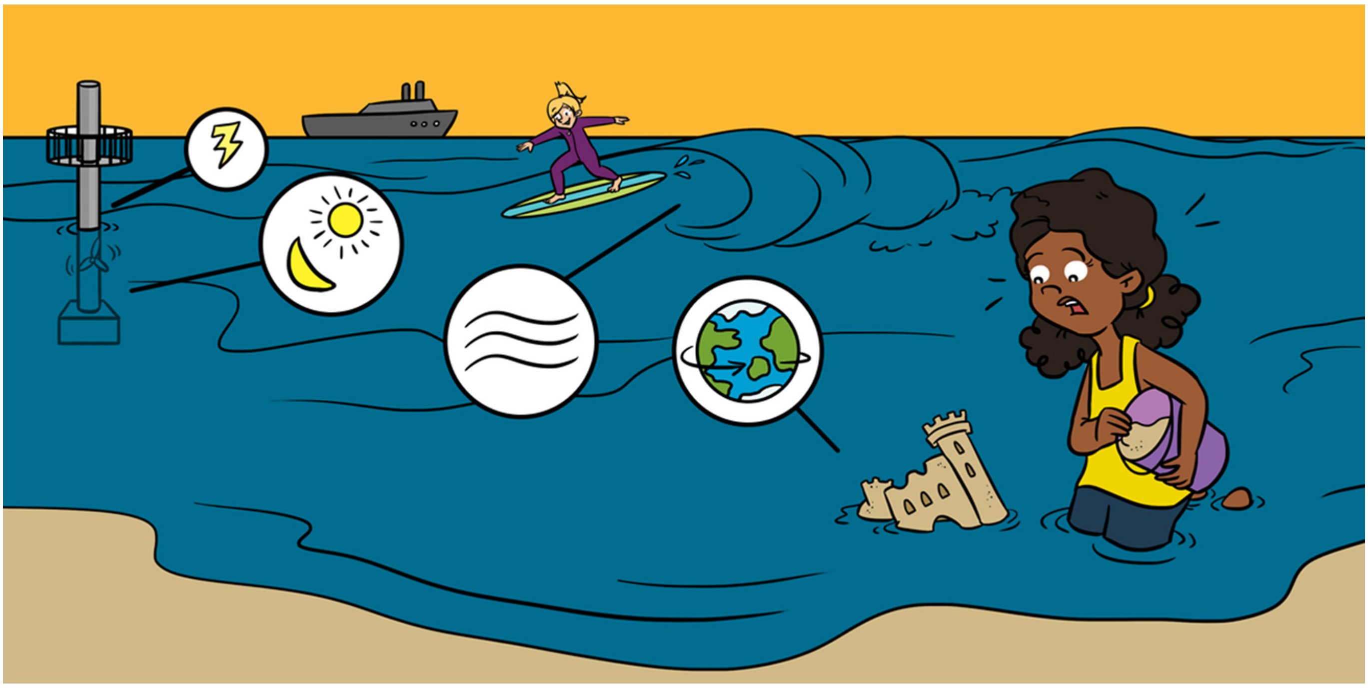

HOW CAN WE USE OCEAN ENERGY TO GENERATE ELECTRICITY?

M. Luisa Martínez[1], Rodolfo Silva[2] and Janaina Garcia[1]*

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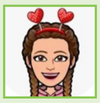
YOUNG REVIEWERS:

EMILKA
AGE: 15



MARYSIA
AGE: 15

The oceans represent almost 70% of the surface of our planet, and they are in constant movement through waves, tides, and currents. These movements are formed differently: waves develop because of the action of the wind; tides because of the moon and the sun, and currents because of differences in water temperature and the rotation of the planet. Ocean movements bring food and oxygen to the plants and animals that live in the oceans and on the coasts. Waves and tides also help shape the coastline by erosion and accumulation of sand. Ocean movement is also important for humans: we have fun swimming in the waves, the tides help with fishing, and the currents are useful for moving ships across the ocean. This unending movement of the ocean can also be used to produce clean, renewable electric power.

THE OCEAN AS A BATTERY?

More than 70% of the surface of our planet is covered by water. Of this, most water is found in the oceans and only 2% is freshwater in lakes, rivers, and ice. There are almost 200 countries in the world, and just over 150 have access to the sea. Many species live in the oceans, in ecosystems including coral reefs and seagrass beds near the coasts, and in the open water. The global scientific community is working hard to determine the number of species in the oceans, but the task is difficult. Currently, the Ocean Biodiversity Information System[1] reports a little more than 147,000 species. However, because it is estimated that more than 80% of the oceans remain unobserved, the number of species living in the ocean is expected to be *much* larger than what we know so far, maybe millions of species.

[1] https://obis.org/.

In addition to being home for many thousands of creatures, the sea is like a battery that constantly receives, absorbs, and releases energy. The sun is the main source of energy for the oceans, both directly, through light and heat energy, and indirectly, by heating the air to produce winds. The oceans also receive energy from the pull exerted on the Earth by the moon, planets, and the sun. These forces mean that the water of the ocean is in constant motion: waves rise and fall, tides come and go, and currents flow around the globe. These movements are very important for Planet Earth: they provide food and oxygen for the plants and animals of the seas and they also help mold the coastline through erosion and accretion, which is the buildup of sand. What if all this unending ocean movement could be used to produce a **renewable** source of electricity, too? This is more than just a scientist's dream—keep reading to learn more!

RENEWABLE

Renewable is a natural energy source such as tides, waves, and ocean currents which are always available.

THE FORMATION OF WAVES, OCEAN CURRENTS, AND TIDES

Waves are produced by winds blowing across the surface of the sea. The time between each wave varies from 4 to 30 s. Waves occur both far out at sea and close to the coasts. When the wind blows hard, as occurs during a storm, the waves become higher. Tsunamis are a different type of wave. They are produced by earthquakes, volcanic eruptions, and the impact of meteorites landing in the sea. For example, when the earth shakes during an earthquake, the water moves, and then gigantic tsunami waves form in the open sea and travel toward the coasts. In this article, we will be focusing on the types of waves that normally occur, not tsunamis.

Ocean currents are mainly formed by the rotation of the Earth, variations in the seabed, and the differences in the temperature and salinity (saltiness) of the waters in the sea. Some ocean currents are very strong and the major currents even have specific names. Some currents carry warm, or even hot water; others carry cold water. These currents affect the weather. For example, the Gulf Current starts in the warm waters of the Gulf of Mexico and travels to northern Europe, giving the places it passes warmer temperatures. Near the coast, we can find powerful, shorter currents due to the shape of the seabed. These currents keep the water oxygenated and transport nutrients away from the coast.

Tides are produced mainly by the magnetic attraction of the moon and the sun on earth's oceans. As the moon and the sun move, the water in the oceans is drawn toward or away from the coasts, producing a rise and a fall in the level of the sea. Depending on the coastline, high and low tides can occur once or twice a lunar day, 24 h 50 min, which is the time it takes the moon to go around the earth. The tidal changes in sea level are very small in some places, while in others they are extremely noticeable. For example, some islands, such as Mont Saint Michel in northern France, are joined to the mainland at low tide by a road that crosses the sands. But at high tide, the road is covered by deep water and the people on the island are cut off for about 9 h.

PRODUCING ELECTRICITY FROM WAVES, CURRENTS, AND TIDES

The unending movement of waves, currents and tides can be used to produce clean, renewable electricity for our homes, schools, and industries [1]. To harvest the energy from the ocean, special devices are used. To capture the energy, certain parts of these devices move as the water moves, and the movement generates electricity that is then transported to the coast. Buoys and turbines are two examples of devices that can be used to capture the energy from the ocean's movement.

Buoys are structures that float on the sea and move up and down with the motion of the waves. These buoys are attached to various mechanisms such as a cylinder that moves a **piston** driving a generator that can convert the movement into electricity. The buoys can be attached to long columns called **spars**, which are anchored to the seabed (Figure 1), or the entire device can be free-floating in the ocean (**Video 1**). These devices can be placed in the deep waters of the open sea, or closer to the coast.

Turbines can also be used to harness the energy of ocean currents (Figure 2, **Video 2**). Turbines have blades, kind of like propellers, that can be turned by the force of the ocean currents. The spinning turbine is attached to an electricity-generating device, and as the turbine spins like a propeller, a series of gears increase the rotation of the rotor allowing the turbine generator to produce electricity. Ocean currents are almost constant in direction, speed, and flow, and they carry large amounts of energy. Turbines can also be used to harvest the energy from currents that are produced by tides. Sometimes a type of dam

BUOY

Buoy is a floating structure that moves up and down with the motion of the waves.

PISTON

Piston is a tightly fitting cylinder or disk which moves within another cylinder, either to compress or move a fluid there, such as air or water, or to transform energy.

SPAR

Spar is a thick, strong pole to support a buoy.

VIDEO 1

Producing electricity from ocean waves.

TURBINE

Turbine is an engine that provides power because a rotor is continually turning due to pressure from fast moving water or wind.

VIDEO 2

Producing electricity from ocean currents and tides.

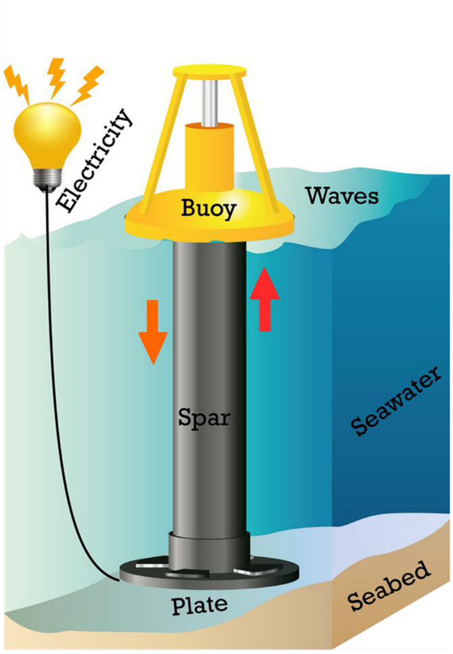


Figure 1

Figure 1

An example of how electricity can be generated using wave movement. The floating buoy is attached to a spar, which is a long column attached to the seabed containing electricity-generating machinery. Electricity is produced as the waves move the buoy up and down the spar, which moves a piston that drives a generator. Then the electricity is sent to the coast through an underwater cable.

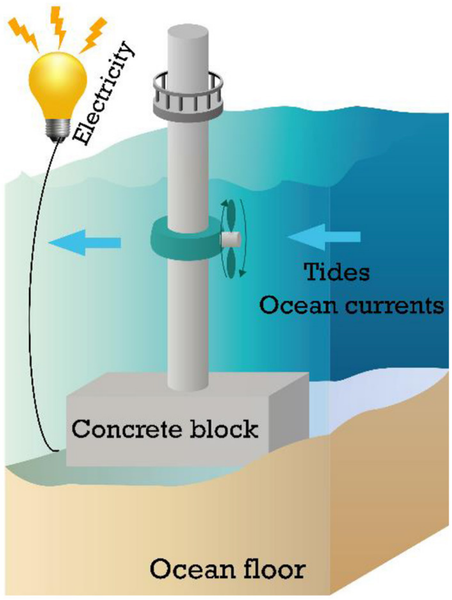


Figure 2

Figure 2

Energy can be generated from ocean currents and tides using turbines. The blades of the turbine are turned by the currents, and the energy is captured by an electricity-generating device which is attached to the blades.

BARRAGE

Barrage is a dam placed in a stream or river to increase the depth of the water.

called a **barrage** is constructed to store water at high tide; at low tide, the gates of the barrage are opened, and the stored water flows out fast enough to move a series of turbines.

Once electricity has been produced by these devices, it can be transported to the coast through an underwater cable or stored in special batteries.

OCEAN ENERGIES: CHALLENGES AND OPPORTUNITIES

While these devices may seem quite simple, inventing machines that will work in all weather conditions, sometimes in deep water, it is a real challenge for scientists. The costs involved in designing, installing, and maintaining these technologies can be extremely high. The ocean environment is often harsh and dangerous, and conditions can be unpredictable, meaning strong structures are required to withstand the aggressive nature of the ocean. Support and funding are still needed for further research, to test prototypes, and to develop full-scale devices that can provide a stable supply of clean, renewable electricity.

Additionally, precautions must be taken to avoid undesirable effects on the environment. For example, these devices may alter ocean currents, causing food and larvae to stop following their natural patterns. Also, if the turbines produce noise, it can disorientate marine animals, causing them to collide with devices or nearby land. Early research has shown that fish and marine mammals *can* avoid hitting the devices; but sometimes they do not. It is important for scientists continue to research how local plants and animals respond to these devices. As new information is collected, we will know how to build and install these devices so that energy production does not have a negative effect on the plants and animals of the ocean.

Despite these challenges, there is great potential for generating electricity using techniques that harvest the movement of the oceans. In theory, the energy of ocean movements could supply the world's energy demand many times over! Energy harvested from the movement of the oceans is renewable, meaning it will not run out like fossils fuels eventually will. Another big advantage is that creating electricity from ocean energy does not generate CO_2, and therefore does not contribute to global warming and climate change. Continued research into these electricity-generating technologies is worth the effort because climate change is a growing problem. It is critical that we reduce the emission of CO_2 into the atmosphere, to protect the future of the earth and all its creatures! So, the next time you are at the ocean, in addition to having fun and enjoying the fantastic beauty of the sea's natural features, remember that someday the ocean might even help us to obtain the electricity we use in our everyday lives! There are endless possibilities!

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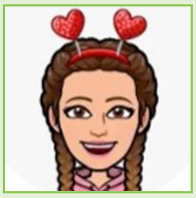
CONFLICT OF INTEREST: The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

YOUNG REVIEWERS

EMILKA, AGE: 15
Hi! My name is Emilka, but friends call me Emi. I am interested in biology and chemistry. I am also crazy about theater from a young age and I love watching series (my favorite one is *The 100*), I like to meet new people and study about different cultures from around the world. Traveling is the reason why I am learning English, but my dream is to speak fluently in more than 3 languages. *May we meet again!*



MARYSIA, AGE: 15
My name is Marysia and I am 15. I am really interested in math, but I also like geography. I started learning English long ago and I think it is the most useful thing I learned so far. I am also a dancer. I have been in a polish folk dance group since 2012 and I cannot see my life without it. I am a huge fan of "Hunger games," so may the odds be ever in your favor and have a nice day!

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BIODIVERSITY
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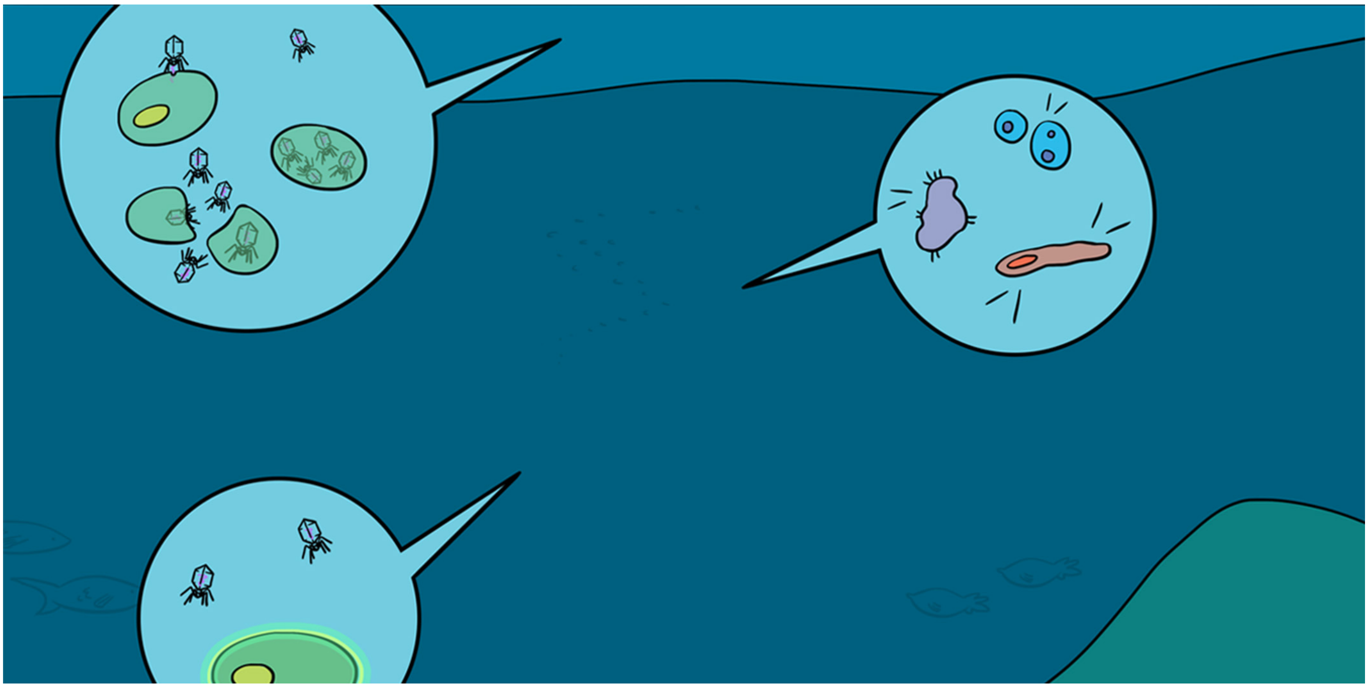

VIRUSES—AGENTS OF CHANGE IN THE OCEANS

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YOUNG REVIEWER:

SHASHIPREETHAM

AGE: 14

Viruses are usually thought of as the cause of countless diseases. However, in the oceans, viruses are part of the natural cycle of life and death. This article discusses marine viruses that infect phytoplankton—the tiny micro-algae that form the base of the marine food web and affect Earth's climate. Through an ongoing "arms race" between viruses and the cells they infect, viruses can promote the evolution of their hosts, and even help their hosts acquire genes that can help them survive. By killing phytoplankton species that become very abundant, viruses can allow other species to grow, promoting biodiversity. Finally, viruses affect global cycles of carbon and other elements, indirectly influencing the climate of our planet.

VIRUSES ARE EVERYWHERE, EVEN IN THE OCEANS

Everyone has heard of viruses. They cause diseases, such as the flu, Ebola, Smallpox, and of course the COVID-19 respiratory disease.

What is less often known is that viruses do not only cause diseases in humans—they are found everywhere and infect essentially every known form of life. More importantly, viruses affect not only the health of the organisms they infect but also entire ecosystems. In fact, viruses are an important contributor to the cycling of elements, such as carbon, nitrogen, and phosphorus. Viruses are also agents of change and renewal, affecting the genetics and evolution of their **host** organisms, and increasing the biodiversity of the ecosystems in which they are found.

HOST

Organism in which a virus can reproduce. Each virus reproduces in only one or a few related hosts. The host must have the right receptors that the virus can identify.

We know a lot about the ecology of viruses found in the ocean. Over the past 20 years or so, we have learned much about the viruses that infect single-celled micro-algae called **phytoplankton**, which dwell in the upper 200 m of the oceans where sunlight can penetrate. Phytoplankton are known as the "plants of the sea"—they are responsible for about half of the photosynthesis on Earth and they provide the food for many other marine organisms, from bacteria to whales. Because of the ecological importance of phytoplankton, the viruses that infect them have been studied in detail (Figure 1) [1, 2].

PHYTOPLANKTON

Microscopic organisms that obtain their energy from the sun by photosynthesis. They are an important component of all aquatic food webs.

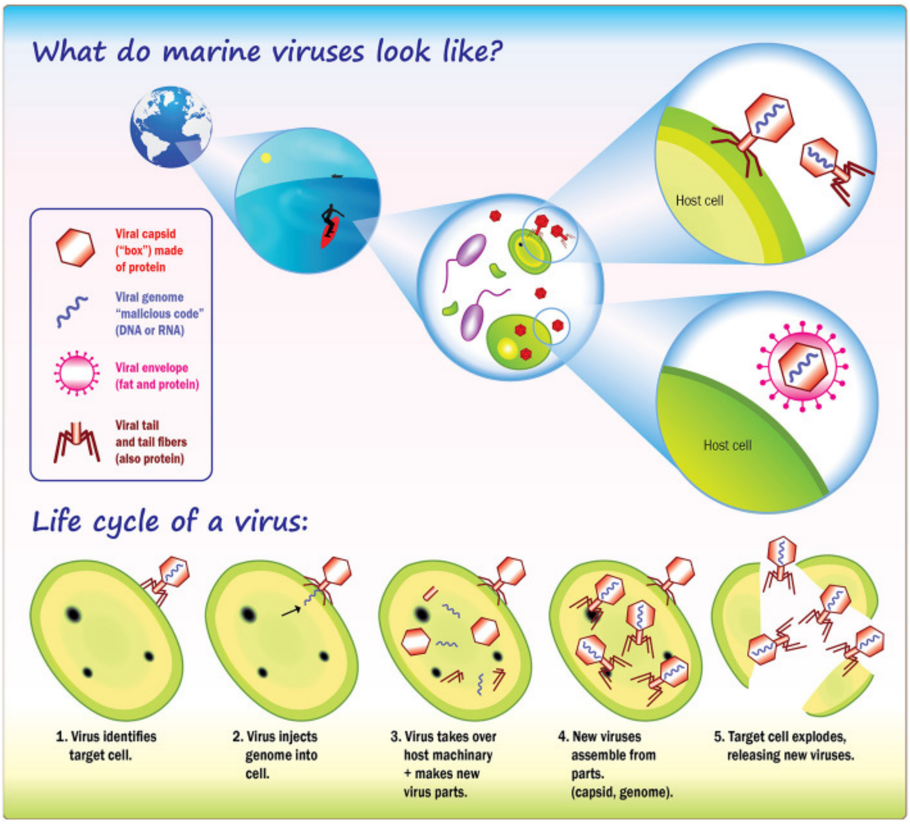

Figure 1

Figure 1

Example structures of two marine viruses and a summary of the viral life cycle.

WHAT IS A VIRUS?

Viruses can be thought of as biological nano-machines with one goal in life—to replicate. All viruses are built of an external "box" made of proteins, called a **capsid**, which protects the DNA or RNA that forms the **genome** of the virus. The capsid is sometimes surrounded by a second envelope that also includes fat molecules. This is why washing your hands with soap destroys some viruses including the SARS-CoV-2 virus—it dissolves the fat layer. Viruses do not infect every cell they meet—they have to encounter the appropriate host, recognizing it using specific molecules on the host cell surface called **receptors**. When the virus encounters its host, it either enters the cell or injects its genome inside. The virus is now only an empty shell, but its genome is like a malicious code that takes over the host cell and forces it to become a factory for producing new viruses. Once the new viruses are assembled inside the host, and ready to infect new cells, they are released while the host cell often explodes and dies.

CAPSID

A protein shell that protects the genomic material of the virus, during its search for a new host to infect.

GENOME

The complete set of instructions needed to build and maintain an organism. Each set of instructions is stored in a gene. The viral genome is made of DNA or RNA.

RECEPTORS

Various molecules on the surface of cells that may be used as recognition signals by viruses. Each virus identifies specific receptor/s on the surface of its host.

Many viruses are quite simple, with a malicious code that includes very few "commands" (genes in the genome). Some of these commands shut down the natural processes inside the cell, whereas other commands instruct the cell to produce the building blocks that assemble into new viruses—the viral genome, the proteins that build the capsid, and sometimes the fat layer. However, scientists have found that some viruses are much more complex. Some marine viruses have genes that allow them to modify cellular processes, such as photosynthesis, the production of specific cell components, or the ways that cells sense their environment [1]. This has led to the hypothesis that many viruses do not just shut down their target cells. The virus malicious code takes over the command center of an infected cell, changes the way the cellular machinery works, and transforms the host cell into a virus-cell hybrid called a virocell. The virocell is programmed to stay alive just long enough to produce as many viruses as possible [2].

AN "ARMS RACE" BETWEEN VIRUSES AND CELLS

Viruses can be fearsome parasites—taking over the host cell and making it a "zombie" virocell. The host cells, however, do not just sit by—they fight back (Figure 2). For example, some cells produce tiny cell-like structures that may be decoys for viruses. So, instead of infecting the real cell, the viruses attack the decoys. Another common way for host cells to avoid virus attack is using camouflage. Host cells may change the receptors on their surfaces such that the virus can no longer recognize the cell as a potential host [3].

Bacteria can also try and protect themselves after the virus has injected its malicious code, preventing the production of new viruses. For example, bacteria may break up the viral genome into small pieces,

Figure 2

Viruses and their host cells are continually changing and adapting, to find ways to counter each other's defenses to better survive (this is called an "arms race"). The top row shows cells that are sensitive to viruses and the bottom shows several defense mechanisms that cells use to protect themselves against viruses.

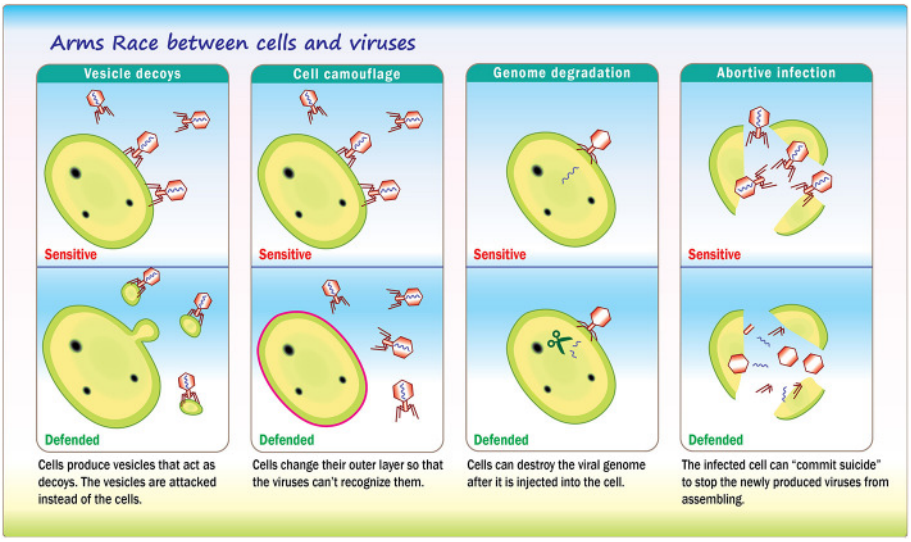

Figure 2

thus stopping the virus from taking over the cell. Finally, some cells "commit suicide" when they realize they are being taken over by viruses. If the cell dies quickly enough, the new viruses may not have time to assemble and be ready to infect new cells.

ARMS RACE

An ongoing cycle in which a predator develops an advantage over its prey, followed by the prey then developing its own advantage, and so on.

Since this is an **arms race**, the viruses also evolve ways to counter the cells' defenses. When the host cell changes its appearance, viruses can evolve to recognize new receptors on the disguised host. The virus can sometimes even evolve to recognize new hosts that it could not recognize previously. This is what probably happened with the SARS-CoV-2 virus that causes COVID-19. In this case, a virus that used to infect bats or pangolins gained the ability to infect humans. Also, viruses can sometimes evade the immune system of the host, for example by producing proteins that interfere with the cell's defense mechanisms. To survive, the host will have to change as well, to ensure its immune system can recognize the virus and stop it. This arms race between viruses and host cells is ongoing, with each side adapting and changing in response to the strategies of its opponent.

VIRUSES AS AGENTS OF CHANGE AND DIVERSITY

The ongoing arms race between viruses and their host cells may seem like a destructive process, but like other examples in nature, a destructive process can bring about new life. Just as a wildfire that burns a forest can allow new and potentially different trees to grow, a virus that infects and kills a population of bacteria or phytoplankton can enable other organisms to grow instead. In this process, viruses often infect the most abundant and successful organisms, because high abundance means it is easier to find host cells to infect. When an extremely abundant host is killed by viruses, the rarer organisms now have enough space and food to grow, with the result being an increase in biodiversity.

Viruses have another way of increasing diversity—they cause the exchange of genes between organisms. As viruses assemble inside a host cell, they sometimes pack a piece of host DNA into their capsids by mistake. When these faulty viruses infect a new cell they cannot kill it, because they do not have their entire malicious code to inject. Instead, they inject the DNA from their previous host, which can be incorporated into the new cell's code. This can lead to genetic change in the host. In fact, about 8% of our own human DNA is made of ancient pieces of DNA that came from ancient viruses (termed fossil viruses). These fossil viruses are involved in important processes in our bodies [4].

MARINE VIRUSES, FOOD WEBS AND ELEMENT CYCLING

Viruses may be tiny—more than 1,000 times smaller than the width of a human hair—yet when they infect phytoplankton cells, viruses can impact the entire marine **food web**, as well as the cycling of elements, such as carbon, nitrogen, and phosphorus (Figure 3). When phytoplankton perform photosynthesis, they harness the energy of the sun to turn carbon dioxide (CO_2) and water into sugar and oxygen. This process produces oxygen and removes CO_2 from the atmosphere. Oxygen is essential for most living creatures and CO_2 is a greenhouse gas. The sugar produced by photosynthesis, which is partly made from the CO_2 taken up by phytoplankton, is used to make other biological molecules, such as proteins. These proteins then serve as food for the entire marine ecosystem, including fish, **zooplankton**, whales, and humans. In this way, the carbon from the atmosphere becomes part of the food web (Figure 3). When viruses kill their phytoplankton hosts, they may disrupt this process, by releasing the photosynthetic products to the surrounding waters. This release prevents the consumption of phytoplankton by larger animals, and can potentially reduce the amount of carbon that moves up the food web. Each day, an estimated 10^{28} viral infections occur in the world's oceans (1 followed by 28 zeros, or 10 octillion) [2]. These infections release up to one billion tons of carbon from cells daily. Although each phytoplankton cell is tiny, the influence they have on our planet is massive.

FOOD WEB

A network of organisms that eat one another, so that energy and elements flow along the web, from prey to predators.

ZOOPLANKTON

Very small organisms that live in aquatic habitats. They feed on phytoplankton, bacteria, or other zooplankton. Micro-zooplankton are built of one cell. Larger zooplankton can reach a few millimeters.

Sometimes when viruses kill their phytoplankton hosts, they can increase the growth of other phytoplankton and bacteria. This is because when the virus-infected cell "explodes," it can release elements, such as nitrogen and phosphorus, which are then available for other phytoplankton and bacteria to recycle and use for their growth.

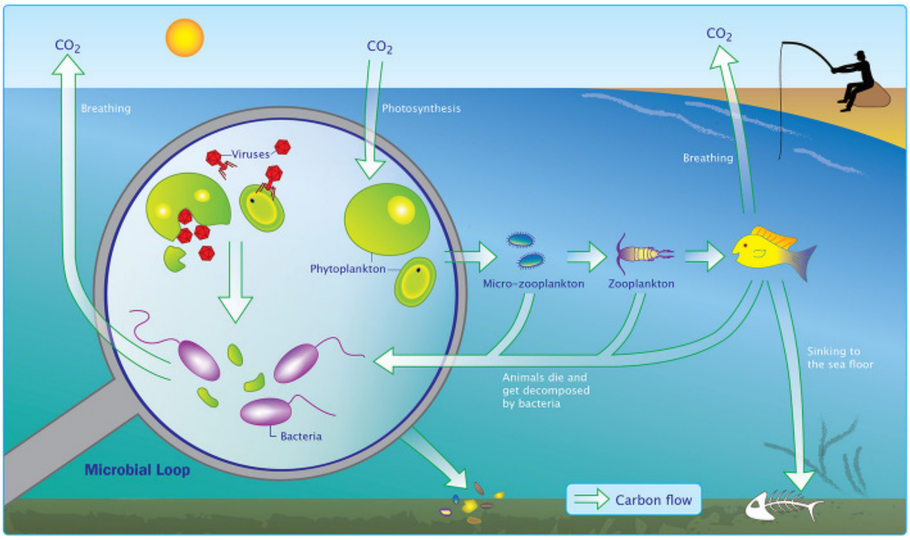

Figure 3

Figure 3

Viruses affect the marine carbon cycle. Through photosynthesis, phytoplankton turn carbon into the molecules that build living cells. Phytoplankton are eaten by larger organisms, such as micro-zooplankton, which are then eaten by larger zooplankton, and other animals, such as fish. This transfers the carbon up the food web. When larger animals breathe, they release some of the carbon back into the atmosphere as CO_2, and when they die their bodies sink to the ocean floor and are degraded by marine bacteria. In contrast, virus-infected phytoplankton die before they can be eaten, and their carbon is rapidly recycled by bacteria.

Finally, when phytoplankton, bacteria, and animals die in the oceans, some of the material that makes up their bodies sinks to the ocean floor. This includes the CO_2 that was originally taken up by phytoplankton, effectively removing this greenhouse gas from the atmosphere and reducing global warming. When viruses kill phytoplankton, the phytoplankton cells are broken to tiny pieces that rarely sink, and are not available for larger animals consumption. Therefore, marine viruses probably reduce the amount of CO_2 transported to the bottom of the oceans, thus impacting not only the lives of the cells they infect but also the entire marine food web and even, potentially, the climate of our planet [2, 5].

AN ARMS RACE IN A DROP OF WATER

The next time you go to the sea-shore (or to any lake, stream, or spring), remember that every drop of water is teeming with microscopic life, such as phytoplankton and bacteria, as well as their viruses. Within each drop of water, there is an ongoing arms race between the viruses and their hosts, that brings with it death but also growth and diversity. Indeed, marine viruses are part of the natural cycle of life and death in the ocean. In that way, the tiny marine viruses can be major players in the health of our planet.

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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

SHASHIPREETHAM, AGE: 14

Hello, my name is Shashi, I am 14 years old and I go to Penglais School. I enjoy playing football and basketball. My favorite subjects are Maths and computers. I am currently studying year 9. I am a four times Guinness World Records holder in a game called Rocket League and my name is in 2018 Guinness World Record Gamers Edition.

AUTHORS

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I am a lecturer at the Department of Evolutionary and Environmental Biology and the Institute of Evolution at the University of Haifa in Israel. In my lab, we study virus-host interactions in aquatic environments. We focus on the influence these interactions have on the ecology and evolution of both viruses and hosts. I think that viruses are very exciting due to their ability to affect their hosts and the environment in so many ways. Moreover, their small size is a benefit in experimental design. In my spare time, I love meeting my friends and spending time with my family. *savrani@univ.haifa.ac.il.

DANIEL SHER

I am a senior lecturer at the Department of Marine Biology, part of the Leon H. Charney School of Marine Sciences at the University of Haifa in Israel. In my lab, we study how microorganisms interact in the oceans and try to understand the chemical "languages" they use to communicate. The best part of doing research is sharing the excitement of science with students and colleagues. In my spare time, I love to hike, dive, take photographs, cook, and spend time with my family. *dsher@univ.haifa.ac.il.

THE EARTH AND ITS RESOURCES
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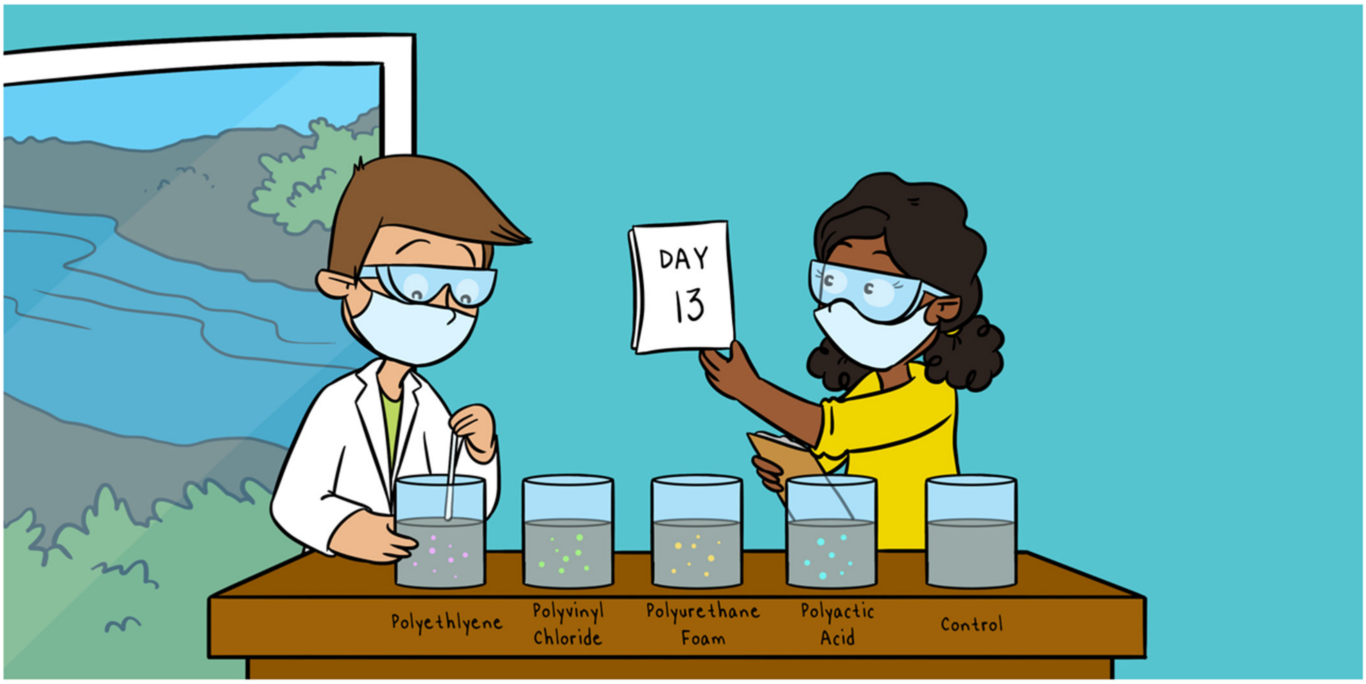

CAN MICROPLASTIC POLLUTION CHANGE IMPORTANT AQUATIC BACTERIAL COMMUNITIES?

Meredith Evans Seeley, Bongkeun Song and Robert C. Hale*

Virginia Institute of Marine Science, William & Mary, Gloucester Point, VA, United States

YOUNG REVIEWERS:


LAUREL
AGE: 9


SAMEEN
AGE: 15


ZAINAB
AGE: 12

Scientists have discovered that microplastics are polluting many environments worldwide, including our oceans and coastlines. Some of these plastics will make their way into a particularly important environment—coastal sediments, or the layer of mud below the water. This sediment is home to diverse bacterial life, which plays a key role in nutrient cycles of the ecosystem. These bacteria are critical for healthy environments, but are also easily affected by environmental pollution. Unfortunately, little is known about how the bacteria respond to microplastic pollution. We studied the effects of different microplastics on bacteria living in marine sediments, as well as the subsequent impacts on nutrient cycling. We found, for the first time, that different microplastics can significantly alter these bacterial communities and the nitrogen cycle, which should be studied further to understand lasting impacts on our natural environments.

MICROPLASTIC POLLUTION

You may have heard of **microplastics**, but you may not know what they are or why everyone seems to be talking about them. Microplastics are simple—they are small bits of plastic, generally 5 mm wide (about the size of a pencil eraser) or smaller. Plastics can be manufactured to be microplastic size, such as small beads that are added to skin care products or toothpaste. Most often, however, microplastics come from the breakdown of larger pieces of plastic. This is especially true in the ocean environment, where a lot of plastic trash accumulates over time and is exposed to wind, waves, and sunlight, eventually creating microplastics [1]!

MICROPLASTIC

A plastic particle that is <5 mm in the longest direction, often formed by the breakdown of larger pieces of plastic in the environment.

While this sounds simple, microplastics in the environment are extremely complex. This is because there are many different kinds of plastics. The building blocks or "backbone" of any plastic are called **polymers**. Common plastics are most often named after their polymer, for example, polyethylene or polyvinyl chloride. In addition, other chemicals are often added to help a plastic product serve its purpose. These so-called additives vary, but can include color dyes, for example. As such, no two microplastics are identical to each other [2].

POLYMER

Large chemicals that form the building blocks of plastics, often called the plastic "backbone."

In recent years, scientists have discovered that microplastic pollution is widespread, and is growing due to population rise and increasing plastic usage. Microplastics have been found in oceans, lakes, rivers, and soils, on remote mountain tops, inside glacier ice, and suspended in the air [1]! In aquatic environments, microplastics accumulate in **sediment**—the layers of mud and dirt that settle to the bottom, below the water. Many different animals live in the sediment and may interact with the microplastic pollution. Scientists have been working to understand the effects that diverse microplastics might have on living things [1].

SEDIMENT

The layers of mud and sand that settle below the water.

THE SEDIMENT BACTERIAL COMMUNITY

If you explore sediments in streams, lakes, and rivers, you will discover many living organisms—worms, clams, and crabs, to name a few. But if you explore sediment with a microscope, you will see that there is also a rich community of microbes (i.e., organisms that cannot be seen with the naked eye)! Bacteria are a type of microbe that are very abundant in sediments. Thousands of species of bacteria co-exist, forming a **bacterial community**. Scientists describe bacterial sediment communities by the kinds of species and how many of each species are present. These bacterial communities perform very important jobs for the entire ecosystem.

BACTERIAL COMMUNITY

A group of different species of bacteria that live in the same environment.

One of the roles of sediment bacterial communities is transforming nutrients. Nutrients are needed by plants and animals (including humans) to build essential biomolecules, including proteins and DNA.

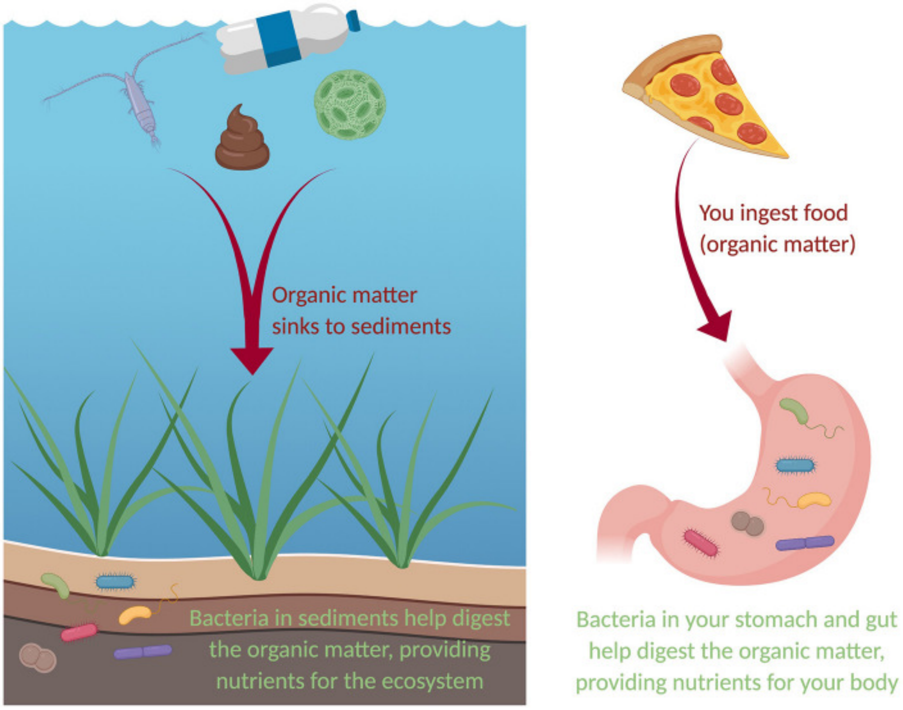

Figure 1

Figure 1

The bacteria in sediments and those in your gut serve similar roles—helping to process nutrients! The left side of the figure illustrates how this works in the aquatic environment, where organic matter (generally dead organisms and wastes, but more recently, plastic) is processed by bacteria in the sediments. The right side compares this to your gut, where bacteria help process the organic matter (i.e., food) that you eat every day! (Created with BioRender.com).

You get nutrients from food, with the help of bacteria inside your gut. When you eat food, bacteria in your digestive tract help process the food to release the nutrients that your body needs. Sediment bacteria do the same thing for organisms in the water. When organic material, such as dead organisms or feces, sink to the sediments, most nutrients are still trapped inside and not available for other living organisms to use. The bacteria in sediments break down organic material, releasing nutrients for themselves and for other organisms (Figure 1). At the same time, they also make sure there is not too much of any one nutrient, which may cause harm. Thus, the bacterial community affects the types and health of higher organisms that can live in that environment.

THE SEDIMENT NITROGEN CYCLE

An important nutrient that sediment bacteria help regulate is **nitrogen** [3]. The nitrogen cycle is complex, so we will only focus on a few of its features. In sediments and water, many different chemicals contain nitrogen, including ammonium (NH_4^+) and nitrate (NO_3^-). Different bacteria can transform these compounds from one form to another. Two very important transformations in sediments are **nitrification** and **denitrification**. Both processes can work in combination to convert ammonium to nitrate via nitrification, and nitrate to dinitrogen gas (N_2) via denitrification (Figure 2A).

NITROGEN

An essential element that is used to build many of the compounds that living things need to survive.

NITRIFICATION

A process that converts one form of nitrogen, ammonium (NH_4^+), to another form, nitrate (NO_3^-), which is made possible by microbes.

DENITRIFICATION

A process that converts one form of nitrogen, nitrate (NO_3^-), to another form, nitrogen gas (N_2), which is made possible by microbes.

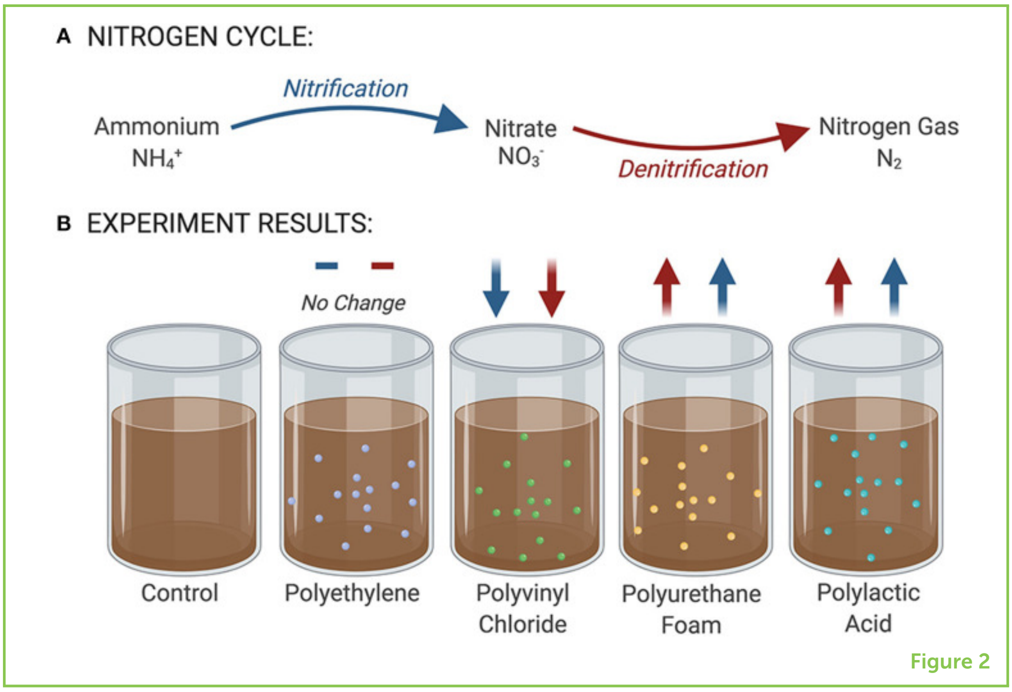

Figure 2

(A) Key components of the nitrogen cycle in aquatic sediments. **(B)** The changes to nitrification (blue) and denitrification (red) that we saw in our experiment are shown above the microcosms containing each type of plastic added to sediments. Both polylactic acid and polyurethane foam microplastics increased nitrification and denitrification; polyvinyl chloride decreased both processes; polyethylene did not significantly change either process compared to the control with no added microplastics (Created with BioRender.com).

Having the right bacteria in the right amounts ensures that the correct level of ammonium and nitrate are present in an ecosystem. If the balance is wrong, the ecosystem can be changed or harmed. Specifically, there should be sufficient bacteria that complete nitrification and denitrification to remove excess ammonium (which can harm the environment), but not too much to completely remove ammonium (which, in the right amount, is an important nutrient for other organisms). All bacterial species that are important for different steps of nitrogen cycling have a different genetic code. Scientists can read this code to see which bacterial species are present and what roles in the nutrient cycle they perform. We decided to use this tool to ask two important questions.

OUR EXPERIMENT

Our two questions were: Do different microplastics in sediments change the bacterial community composition? And if so, does this also affect nitrogen-transforming activities? To answer these, we set up an experiment! We collected sediment from a local marsh, distributed it into containers, and added water to create smaller replicas of the natural ecosystem, called **microcosms**. We added four different types of microplastics to the sediments in the different containers: polyethylene, polyvinyl chloride, polyurethane foam, and polylactic acid. These microplastics were made by grinding larger pieces of plastic in a specialized grinder. These microplastics are used for different purposes, so they contain different polymers and additives that could affect the bacterial community differently. We also made one container with no added microplastics, to represent a normal

MICROCOSM

A small replica of a natural environment, used by scientists to answer research questions about how different things may change that environment.

situation. This is called a control. The containers were monitored over 16 days.

We analyzed the bacterial communities in the sediments before, during, and after the experiment by reading the genetic codes of the bacteria present in each microcosm. First, we used this information to characterize the bacterial community—what species are present and how abundant are they? Then, we specifically looked for the parts of the genetic code responsible for nitrification and denitrification. We compared our findings between the different microcosms, to see if the microplastics changed the bacterial community or nitrogen cycling.

We discovered that the communities containing added microplastics were indeed different from the control, and the polymer types resulted in different changes! We also found that the microplastics affected nitrogen cycling activities; i.e., they altered the abundance of species capable of performing nitrification and denitrification. We found that polyvinyl chloride-treated sediments had the biggest change in the bacterial community at the end of the experiment. In sediments with polyvinyl chloride microplastics, nitrification and denitrification were significantly reduced. In the microcosms with polylactic acid and polyurethane foam microplastics, however, nitrification and denitrification were elevated. The microcosms with polyethylene microplastics were similar to our control, suggesting this plastic did not affect the sediment bacterial community as much as the other plastics (Figure 2B). This experiment told us that microplastic pollution in the environment may affect key bacterial communities and the nitrogen cycle.

WHY DOES THIS MATTER?

Scientists have long known that sediments play an important role in nutrient cycles, driven by the bacteria. Nutrient cycles are critical to organisms living in the sediments, but also those in the overlying water and beyond. Scientists have recently learned that large amounts of microplastics are polluting aquatic sediments globally, and our research is the first report that microplastics can affect the sediment bacterial community, and therefore affect their nitrogen-cycling activities. The balance of the nitrogen cycle in sediments keeps the nutrients at the right levels for the health of the animals present, including worms, fish, phytoplankton, and aquatic grasses! With this knowledge, we can follow up with important research questions: Which types of plastic cause the most harmful effects? Is that harm caused by the polymer or the additives? And how much plastic must be in those sediments to affect the bacterial community? When we have this knowledge, scientists can work with policy makers to help protect coastal zones from the harmful effects of microplastic pollution.

Most microplastics are formed when bigger pieces of plastic break down in the environment. So, if we want to stop microplastic pollution, we must stop plastic pollution! Plastic pollution does not only happen when we litter, though. Humans produce a lot of plastic trash and, sometimes, it escapes into the environment before it reaches the landfill. This can happen because of an overflowing trash can, a trash bag being lost off a truck, or trash that is swept away in a storm and reaches a local river, lake, or ocean. If we reduce our plastic waste, there will be less that can leak into the environment. You may think of some ways that you can reduce the plastic trash you generate every day, or places where plastic debris leaking into the environment could be captured. Both are critical steps toward reducing microplastic pollution!

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ORIGINAL SOURCE ARTICLE

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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 REVIEWERS

LAUREL, AGE: 9
I love reading Harry Potter books. My favorite characters are Ginny and Hermione. I also like animals. My favorite subjects in school are art, music, science, and math.

SAMEEN, AGE: 15
Hello, I am Sameen from Pakistan and I have a strong interest in science, and I like studying biology the most. I love to explore natural processes, particularly in aquatic ecosystems. I love to read science articles in the newspaper and learn new languages. Besides all this, I also participate in environmental clubs and am doing field trips. I want to study freshwater ecosystems and molecular biology when I grow up.

ZAINAB, AGE: 12
Hi, my name is Zainab, and I live in a small village. I am excited about species relationships and environmental changes, that is perhaps why I love learning about species and ecosystem biology. Apart from that, I want to learn about the history of species and their environment. I like to go to the countryside and see the variety of land plants and animal species. I am also doing online learning activities related to biology and ecosystems.

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Meredith Evans Seeley is a marine scientist interested in the fate and effects of pollutants, particularly microplastics. Currently, she is a Ph.D. student at the Virginia Institute of Marine Science. She previously studied oil spills as a Master's student at the University of Texas Marine Science Institute. She is interested in using her research to inform policy that can protect and preserve our oceanic ecosystems in the face of increasing human influence. In her free time, she loves traveling and exploring the outdoors. *meseeley@vims.edu

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Bongkeun Song is the Clark and Elizabeth Diamond Associate Professor of Marine Sciences at the Virginia Institute of Marine Science (VIMS) and William & Mary. He received his Ph.D. in Environmental Science at Rutgers, the State University of New Jersey. He has been studying a broad range of research topics, including microbiome responses to natural and human disturbances, the roles of microbiomes in marine organismal health, novel microbes and processes in the biogeochemical nitrogen cycle, microbial regulation of greenhouse gas emission in soils, and microplastic contamination in natural and engineered environments.

ROBERT C. HALE

Robert C. Hale is a Professor of Marine Science at the Virginia Institute of Marine Science (VIMS), William & Mary. He received his Ph.D. from William & Mary examining the levels in, and consequence of, contaminants on marine crustaceans. Over the last 37 years of research, most of his emphasis has been on aquatic environments, but his interests include terrestrial and human systems, as all are interconnected. Rob's work often melds chemistry, biology, and toxicology, and uses chemical analysis techniques to track pollutants, which include historic and emerging contaminants, such as microplastics and polymer additives.

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BIODIVERSITY
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DO YOU LIKE TO BREATHE? DIATOMS CAN HELP YOU WITH THAT!

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[2] *Tvärminne Zoological Station, University of Helsinki, Hanko, Finland*
[3] *Baltic Sea Centre, Stockholm University, Stockholm, Sweden*

YOUNG REVIEWERS:

FRESIA
AGE: 11

ROHAN
AGE: 10

Have you ever thought about why we never run out of oxygen even though there are so many of us breathing constantly? The answer is that there are plants and algae that produce new oxygen at the same rate as we use it. Surprisingly, the most important oxygen producers are not large trees but tiny algae that live in the water, and one of the most important groups among them are the diatoms. Because the diversity of life is now decreasing all over the world, we wanted to find out whether having many different species of diatoms is important for oxygen production, or if just a few species would be enough. Our results showed that species-rich communities of diatoms were more effective in providing oxygen. This means that we should work to avoid destroying our oceans, lakes, and rivers to make sure that we have healthy diatom communities also in the future.

Figure 1

Figure 1

Bubbles on the seafloor, produced by diatoms and other tiny organisms living in the water. These organisms make sure that we have enough oxygen to breathe.

WHO SHOULD WE THANK FOR THE OXYGEN WE BREATHE?

How long can you hold your breath? Not very long! Humans—you and I—need up to 2,000 l of oxygen every day. You probably know that all this oxygen in the world is produced by organisms, such as plants and algae that perform **photosynthesis**. In other words, they take carbon dioxide, water, and sun-light and use **chlorophyll**, which is a green-colored material inside them, to produce energy and oxygen. They keep the energy for themselves, but release the oxygen into the environment for all of us to breathe. Rainforests, with their large trees, have often been thought of as being "the lungs of the Earth," giving us most of the oxygen we need. However, guess what?! Actually, the large rainforest trees are outmatched by a tiny opponent! It is primarily the microscopic organisms living in water that we have to thank for the oxygen that we breathe (Figure 1). While there are many different kinds of these important little creatures in the world's waters, we will concentrate on one specific group, called **diatoms**.

PHOTOSYNTHESIS

A process where green plants, algae, and some other organisms use light energy to convert water, carbon dioxide, and minerals into oxygen and energy.

CHLOROPHYLL

A green pigment that enables photosynthesis.

DIATOM

A microscopic alga that has silica-containing cell walls.

DIATOMS—AQUATIC BEAUTY QUEENS

Diatoms are extremely small algae, <0.2 mm in size, which means that it takes more than fifty diatoms to equal the length of a mosquito. It also means that you need a microscope to see them. Looking at diatoms through a microscope is worthwhile, because they are incredibly beautiful and diversified—there are over 20,000 diatom species in the world and every species looks different (Figure 2). However, there is one specific feature that unites all diatoms and makes them unique among all the tiny aquatic inhabitants—a cell wall made of **silica**. Silica is what gave Silicon Valley its name since many electronic computer parts are held together by silica. Silica is also an element used by many plants and algae to strengthen their bodies. The silica-containing cell walls of diatoms are so hard that the diatoms can

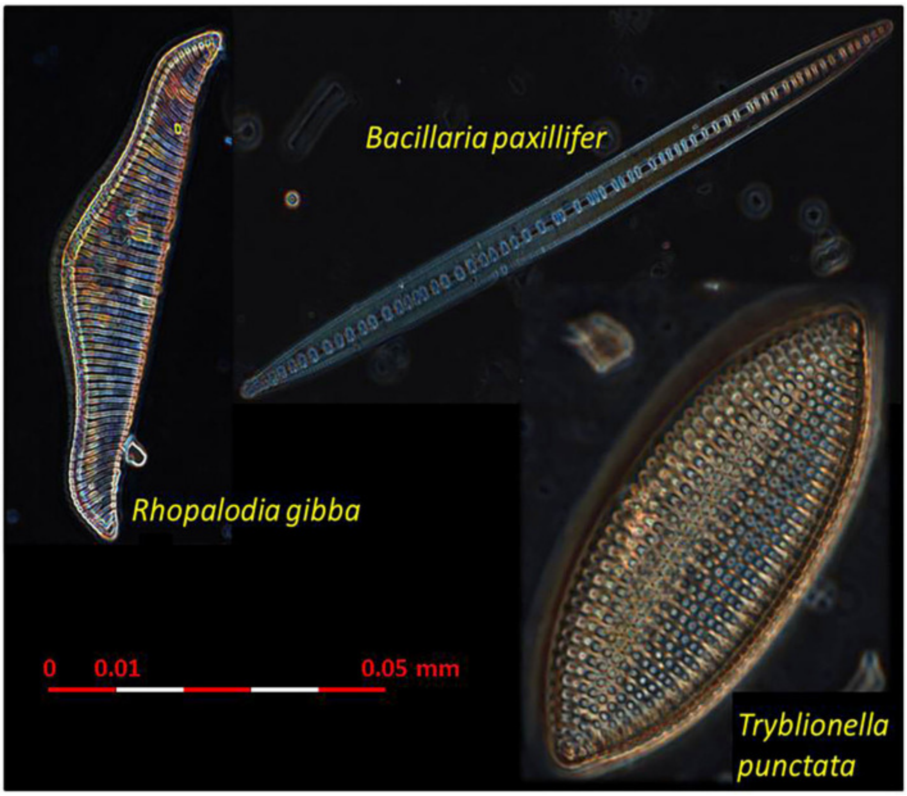

Figure 2

Figure 2

Diatoms as seen through a microscope. These are three of the several hundred diatom species that we found in the Baltic Sea in northern Europe. Although diatoms are tiny, each species looks different because of the unique features of the silica-containing cell wall. Diatom species only have Latin names.

remain buried in the sediment at the bottom of the ocean for millions of years and still remain in such good condition that researchers can identify the exact species! Diatoms live in all kinds of waters—oceans, seas, lakes, rivers, and even in the extreme conditions of hot springs or Antarctic ice. In all these environments, diatoms are the favorite food for many small animals, such as snails and mussels, and they help entire ecosystems to function effectively.

BIODIVERSITY

The entire variety of life on Earth, including every living thing.

There is still much that researchers do not know about diatoms because these organisms are so small that studying them is difficult. Researchers know that the world's **biodiversity**, which is the total number of species or habitats present on Earth, is very important for the health of our planet—and us humans. However, what about the diversity of diatoms? Do we need all the 20,000 diatom species, or would it be enough to have just a few?

THE BALTIC SEA: THE HIDDEN TREASURE OF NORTHERN EUROPE

To investigate the question of whether a high diversity of diatom species is needed for the healthy functioning of the Earth, we set out to take a closer look at the bottom-dwelling diatoms in the Baltic Sea, which is in northern Europe. Unless you live in the area, the Baltic Sea may be unfamiliar to you, because it is not famous for having corals or colorful fish. However, the Baltic Sea has many characteristics that make it special and fascinating. First of all, species in the Baltic Sea must cope with a mix of salty water and fresh-water, called **brackish** water. Because the Baltic Sea is connected to the ocean only by a narrow strait, the salinity of the Baltic Sea is lower than that of the oceans but higher than that of freshwater lakes and rivers. Therefore, the species living there have had to find ways to survive in these strange conditions. Second, the ice age, as the Ice Age movies show, formed an amazing up to 3 km thick glacier cover in the northern European latitudes where the Baltic Sea is nowadays located. Thus, the Baltic Sea was formed, and the current species were able to live there, only after the glacier cover melted about 11,000 years ago. Although that sounds like a very long time for a human being, it is a rather short time for an ecosystem, and the Baltic Sea and its species are still evolving. This means that new environments and new species are continuously being formed there.

BRACKISH

Water that has more salinity than freshwater but not as much salinity as seawater.

TEAMWORK MAKES THE DREAM WORK!

To take a closer look at how diatoms affect oxygen production, we used diving gear to dive to the bottom of the Baltic Sea, in shallow bays where there is plenty of light for the diatoms and other organisms to grow on the sediment surface. We collected samples using tubes that can be pushed into the soft sediment. Back on the surface, we analyzed the diversity of diatoms in the samples by using a microscope to identify all the diatom species present. We also measured the amount of chlorophyll in each sample. Because chlorophyll is important for photosynthesis, measuring the amount of chlorophyll can tell us how much oxygen the diatoms can produce. Finally, we compared the diversity of diatoms to the amount of chlorophyll in each sample, to see whether the diversity of diatoms was related to the amount of oxygen they could produce.

We found interesting results. The diversity of diatoms really seemed to matter (Figure 3)! When there were only a few species of diatoms in the community, the amount of chlorophyll was uneven, sometimes low and sometimes high, maybe because there were sometimes other organisms present that helped to boost the chlorophyll or because there were some specific diatom species that had a lot of chlorophyll inside them. However, when several different species of diatoms were present in the community, there was always plenty of chlorophyll, and the communities were able to produce a lot of oxygen. Thus, a higher diversity of diatoms ensured that the ecosystem at the bottom of the sea was able to function well and produce the oxygen that humans need to breathe. It seems that "teamwork makes the dream work" is a phrase that also applies to diatoms.

Figure 3

Figure 3

In our study, we found that the diversity of diatoms formed the lower limit to the amount of chlorophyll. This means that if there were only a few species of diatoms in the community, the amount of chlorophyll present and the amount of oxygen that the community could produce was uneven, but if there were many different species of diatoms in the community, the amount of chlorophyll and the oxygen production were increased and more stable.

HOW CAN WE HELP DIATOMS TO THRIVE?

As you probably are aware, the biodiversity of the whole world is at risk at the moment, because we humans are using too much space and too many of the planet's resources, making it difficult for other organisms to survive. While we usually tend to worry more about the cute and fluffy animals, in this study we showed that we should be just as concerned about the diversity of the tiny diatoms that help us to keep breathing. But how can we protect the diatoms? They are so small that protecting specific species is not feasible, but we can protect the diversity of entire diatom communities by making choices that reduce climate change and that keep the environment as healthy as possible. Many of these actions are the responsibility of adults, but you can also help. For example, you can try going to school by bike instead of a car, or you can do your best to keep the nature around you clean and healthy. If everyone does their part, we can preserve the world's biodiversity and keep the environment healthy for humans, diatoms, and all other species.

ORIGINAL SOURCE ARTICLE

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YOUNG REVIEWERS

FRESIA, AGE: 11

I love science and math, but I am not a fan of history and geography. My big passion is animals. I have a snake named Sacha Jr. and a rabbit named Luna, and I love to raise silkworms and search for lizards and other animals in the wild. I am also learning to ride horses and I love using creativity to make crafts.

ROHAN, AGE: 10

I am interested in airplanes, engineering, Richard Trevithick, Isambard Kingdom Brunel, dinosaurs, mixoplankton, and other mixotrophs, the deep sea, Lego. I enjoy reading science fiction (like 20,000 Leagues under the Sea), fantasy, and non-fiction. I like kayaking, cycling, and hockey.

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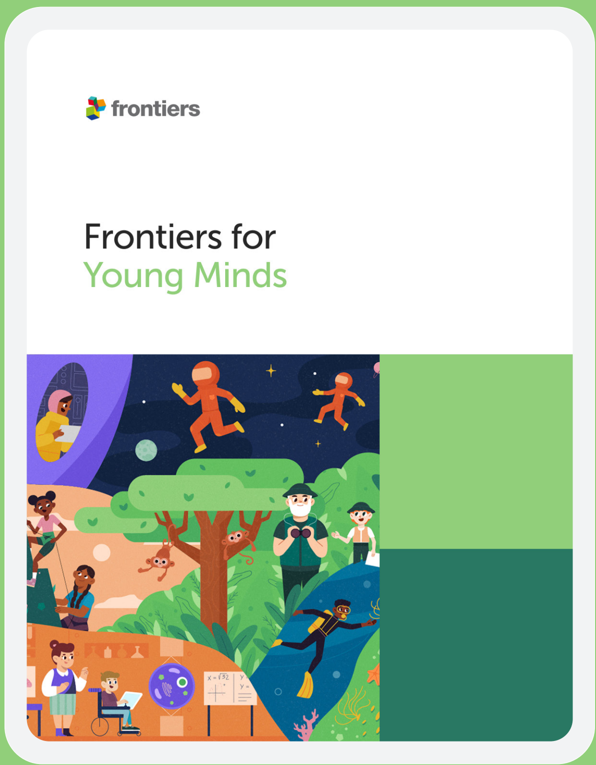

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