SMILE TEACHER
WORKSHOP
FALL 2022

Interdisciplinary Coastal Simulation

Evidence shows ocean oxygen has declined in the open and coastal waters by 2% over the past fifty years due to human induced climate change. The pacific northwest coast of the United States has been called an “early impact” system, meaning the reality of climate change is looming overhead and poses a major threat to biodiversity, fisheries, and coastal the economy. This lesson introduces students to coastal ecosystems, ocean oxygen and how microbes in the ocean impact the carbon cycle and the humans who rely on natural resources. Students engage in an interdisciplinary role playing mystery activity where they take on the identity of three stakeholders in a crab fishery on the Oregon coast: a fisherperson, policymaker and scientist. Together, students use their skills to brainstorm and propose local solutions for a coastal community.

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Oregon State University

OREGON MARINE SCIENTIST AND EDUCATOR ALLIANCE

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STATION 1A

introduction

In this simulation, you can find the materials you will need to solve the conundrum of crabs mysteriously dying. You will soon take on a new identity to become problem solvers on the Oregon Coast. For the duration of the activity, try to think like this person! At the end of the activity, you will be asked to create a product based on the strengths of your role. Read through the roles on the next page and choose a role based on your skillset.

Throughout the activity, you will find QR codes that link to videos, games, and other resources. You may also access the online version of this lesson by following the QR code at the end of your packet on the "additional materials" page.

If you're working in a group of 3 or less: each person should select a role that suits their qualifications.
If you're working solo: go ahead and choose any role that you feel called to.

**TIP: Get into it! Play the video below to hear the sounds of the Oregon Coast!*

Dr. Seeksalot

SCIENTIST

Qualifications	curious, problem solver, loves to read, attention to detail
Things you care about	being accurate, understanding the cause of phenomena
Product	summary of the science and ideas for experiments

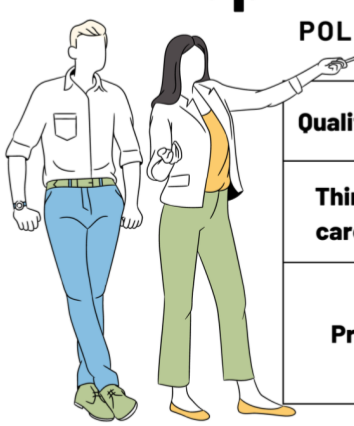
Fisher Crabbins

FISHERPERSON

Qualifications	patient, observant, ocean lover, adventurous
Things you care about	the future of fisheries, coastal economy, conservation
Product	community engagement project idea

Rep. Wordsmith

POLICYMAKER



Qualifications	good at writing, enjoy contemplating a better world
Things you care about	creating actionable change to help people and ensure the future is sustainable
Product	public service announcement to raise awareness about climate change and the coastal ocean

STATION 1B

what's going on?

Something strange has been going on at the Oregon Coast. **Fisher Crabbins** takes us out on his boat to his usual crabbing spot. He drops his crab "pot", or basket with bait, into the water. After waiting, we help him pull it back up onto the boat. But the crab pot is empty. This is bad for the fisherman, who sells his catch to the local restaurants for tourists to eat.

Fisher decides to reach out to a marine scientist, **Dr. Seeksalot**, at Oregon State because this has been happening more often, especially during the summer. He decides to try another crabbing spot, and takes the boat to a different location. After dropping the crab pot and waiting for crabs to take the bait, he struggles to pull up the heavy crab pot. This time, it's full of crabs. There seem to be many of them gathered in this location.

Curious, he decides to take the boat back to the first spot he dropped his crab pot. Perhaps we can find a clue about what may be going on. When we arrive, we look down into the water. Where the crabs were gathered, we saw many fish swimming around. But here the water is empty of fish. He continues to look around, searching for signs of life. The water is murky like broth, and down below, there seem to be a few dead organisms you can't quite identify.

It looks like marine organisms are struggling to survive in this area. He then contacts the office of a local policymaker, **Representative Wordsmith** because he is concerned about the economic consequences of this strange phenomenon. To figure out what might be going on, we need to get to know the area and check out the available data.

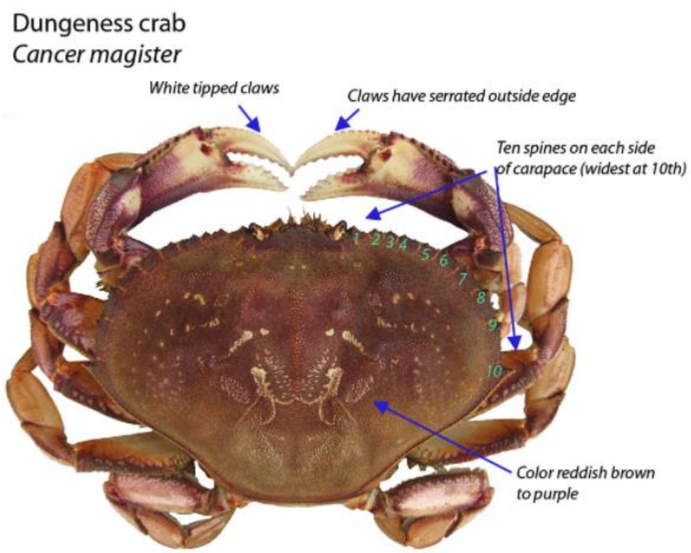
Why do we care about dungeness crabs on the Oregon coast?

Dungeness crab (*Cancer magister*) is an iconic species of the West Coast, sought after by humans and non-humans alike for their delicious and abundant meat. Considered the most valuable single-species commercial fishery in Oregon, 14 million pounds of crab are caught each season from coastal Oregon and the Columbia River estuary.

Crab season along the Oregon coast begins in late fall and continues through the end of summer. Peak harvest occurs during the first eight weeks of the season with up to 75% of the crabs caught annually during this period.

Dungeness crab biology

- Life expectancy: 8-13 years old but commercially caught crabs are usually about 4 years old.
- Claws are used for defense and to tear apart large food items.
- As adults, dungeness crabs primarily eat bivalves, crustaceans, and fish. As a juvenile it feeds on fish, shrimp, mollusks, and crustaceans.
- Predators include seals, sea lions, a variety of fish and humans.
- Adults prefer living in eelgrass beds, sandy or muddy bottom areas.



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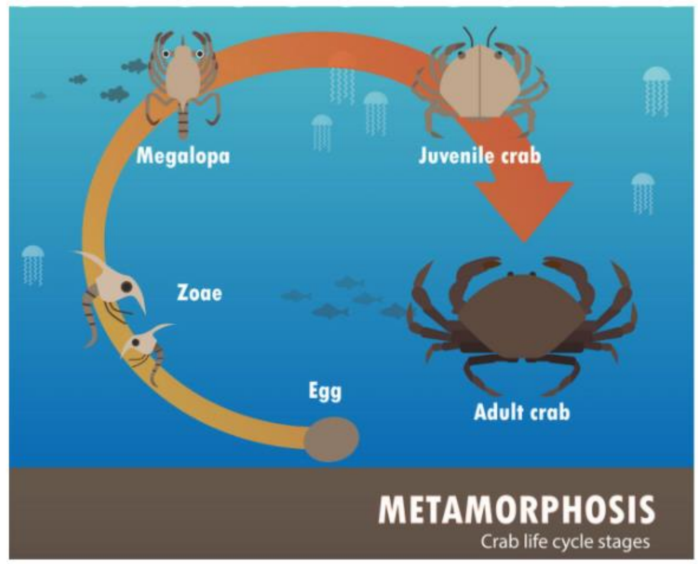


Source: VectorStock

DID YOU KNOW?

- A female crab can carry up to 2.5 million eggs
- Dungeness crabs can live in water and on land. They prefer to live in salty seawater but sometimes come up to the beach to rest under the sun.
- Crabs walk sideways, and if they lose a leg, they can grow a new one!

Video:
Watch Dungeness Crabs underwater!

Activity: Let's think money

How does crabbing impact Oregon's economy?

Here are publicly available data from the National Oceanic and Atmospheric Administration (NOAA) showing the amount of crabs caught and sold per year from 2000 to 2020 in the state of Oregon.

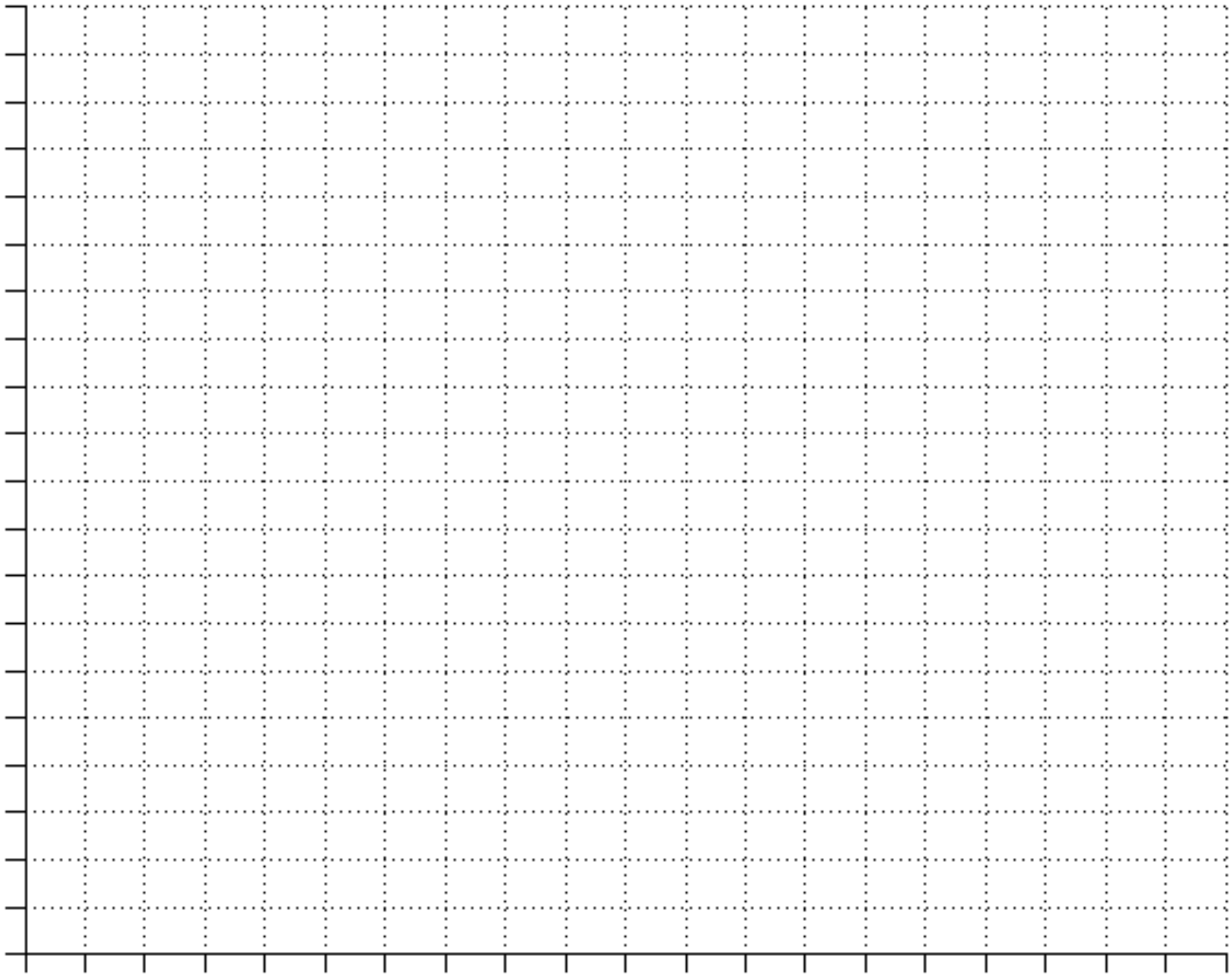
With this data, do the following:

A. Calculate dollars per pound by year

B. Calculate mean, median and mode for dollars per pound.

C. Graph dollars per pound over time using the next page or the downloadable spreadsheet.

Year	Dollars ($)	Pounds (lbs.)	Dollars per pound ($/lb.)
2020	$72.808.543	19.892.507	
2019	$67.929.755	19.035.130	
2018	$74.521.972	23.135.062	
2017	$58.723.397	19.015.068	
2016	$55.730.714	15.714.311	
2015	$12.106.313	2.293.246	
2014	$48.146.905	11.917.735	
2013	$71.208.124	26.033.696	
2012	$29.172.280	8.691.273	
2011	$44.689.979	17.260.411	
2010	$32.747.868	15.868.634	
2009	$42.408.366	21.856.162	
2008	$29.196.238	13.907.404	
2007	$38.201.827	17.026.280	
2006	$53.806.817	33.316.217	
2005	$26.522.935	17.730.436	
2004	$42.826.662	27.272.472	
2003	$37.117.157	23.930.034	
2002	$20.760.761	12.443.601	
2001	$19.296.245	9.689.688	
2000	$23.709.255	11.180.495	
Total			



STATION 2

marine microbes

Crabbins contacts **Dr. Seeksalot** at Oregon State expressing his concern about the unpredictability of crabbing season in the past 20 years. Dr. Seeksalot studies how microbes react to changing ocean conditions, such as ocean acidification, warming, wind patterns, deoxygenation, overfishing, + more.

Invisible to the naked eye, there are a bunch of microbes living in the ocean. They include bacteria, viruses, archaea, protists, and fungi. If you weighed ALL the living organisms in the ocean, 90 percent of that weight would be from microbes! Just because these microbes can't be seen doesn't mean they are aren't important.

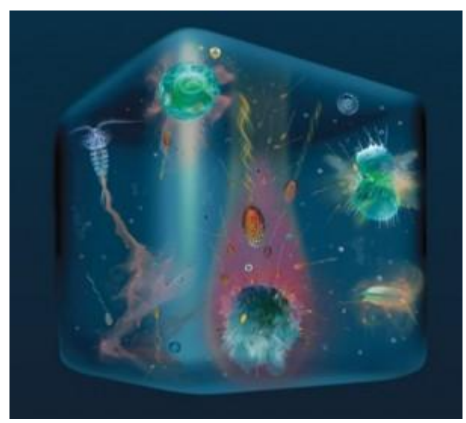
Microbes are often the engines of ecosystems that otherwise would not have access to the food and nutrients they need. Many are also the keepers of healthy ecosystems, cleaning the ocean of waste and often defending against disease rather than spreading it. Microbes live in some of the most extreme environments, from boiling hydrothermal vents to underground glacial lakes in the Antarctic. They were even the first life on the planet, living without oxygen in an ancient ocean. Microbes are essential for a thriving ocean ecosystem. Without them, the world we know would not exist.

It's time to learn about microbes and how Dr. Seeksalot's expertise in microbiology may help us form hypotheses about the crab problem. Our approach is to start small and work our way up to bigger processes in the ocean.

DID YOU KNOW ?

In a single drop of seawater, you can find:

- 1,000 small protozoans and algae
- 1 million bacteria
- 10 million viruses

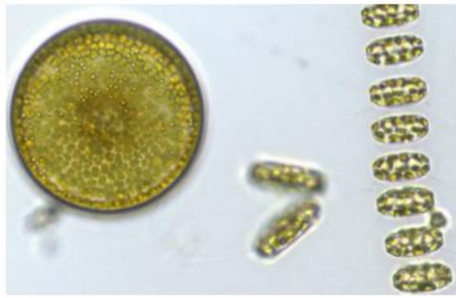


Microbes are often referred to as ***plankton***. The word plankton comes from the Greek word, *planktos*, meaning drifter or wanderer.

Below are the different types of microscopic plankton:

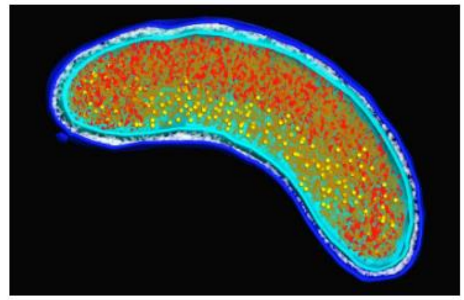
Zooplankton

"Zoo" means animal. Zooplankton are plankton consisting of small animals and the immature stages of larger animals.



Phytoplankton

"Phyto" means plant. Phytoplankton are plankton consisting of microscopic plants



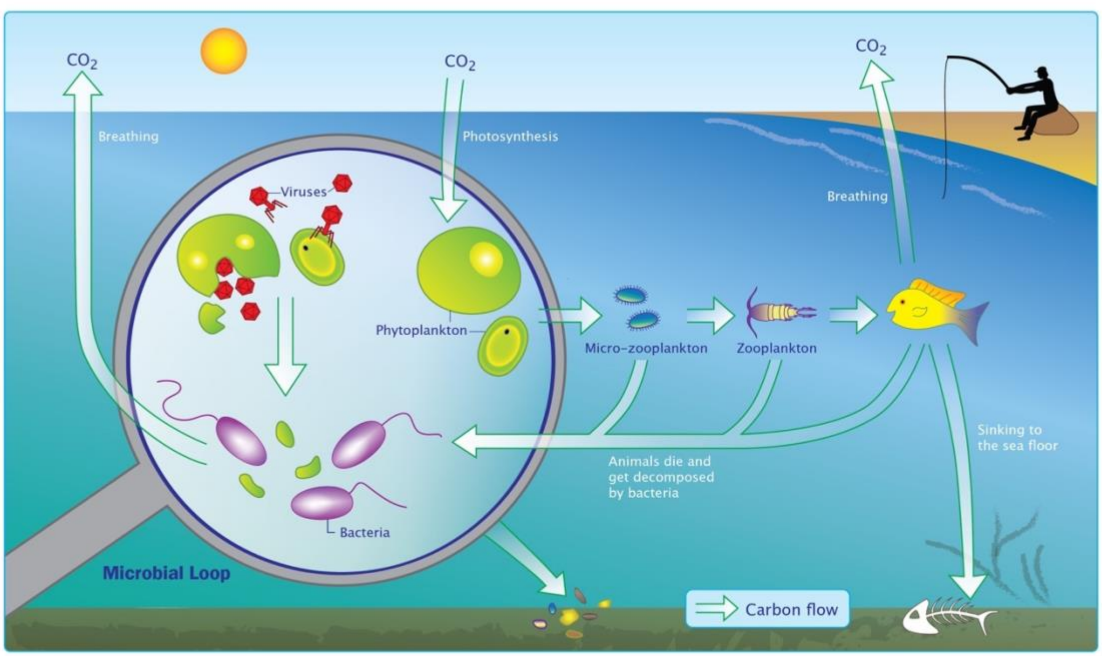
Bacterioplankton

"Bacteria" is latin for staff or cane. The first bacteria to be discovered were rod-shaped but microbes come in different shapes (circles, spirals, etc.) Bacterioplankton are the bacteria drifting in the water.

How do zooplankton, phytoplankton and bacterioplankton interact?

You've probably seen an image of a food chain where the big animals eat the smaller animals. Microbes play a huge role in the ocean food web. Watch the video below to learn about how zooplankton (or "grazers") feed on a phytoplankton while bacterioplankton transform nutrients.

Video: The Microbial Loop



If you are unable to see these organisms without a microscope, how do scientists study them?

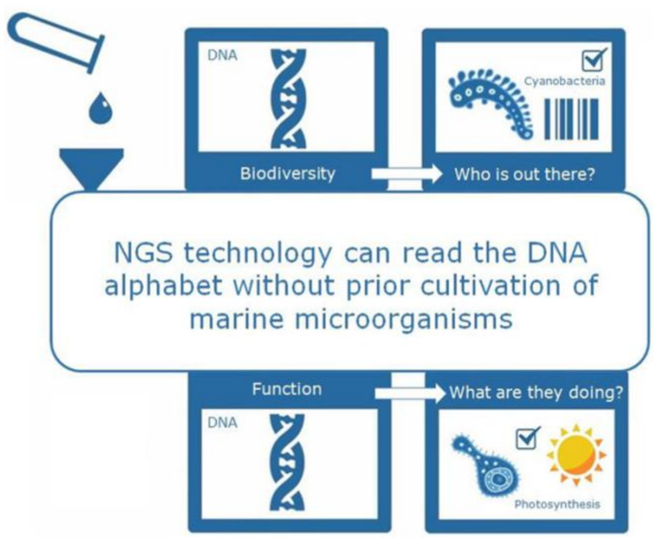
There are a few approaches to studying microbes. We can study them in the lab through "culturing" where we actually grow the bacteria on a petri plate. Or we can study them on the computer where we analyze their genetic code.

All the information about a microbe, or any kind of cell, exists in the cell's DNA. DNA is the molecule that contains the genetic code of organisms and is akin to the "blueprint" of the cell, since it tells the cell what to do and when to do it.

DNA is the building plan of an organism and includes instructions for all that organism's features and functions. If scientists can "read" the data coded in the DNA, they can obtain a great deal of knowledge about that organism.

This can be challenging but combining our findings from both genomic research and laboratory culture studies provides us with a great deal of information about how bacteria function.

Read the article, "**Understanding Marine Microbes: The Driving Engines of the Ocean"**, to learn more about the methods marine microbiologists use to make new discoveries. Article can be found in additional materials.



Test your knowledge!

1. Rank the following organisms below: phytoplankton, bacterioplankton, zooplankton
   a. Smallest: ___________________________ Bacterioplankton

   b. ___________________________Phytoplankton

   c. Largest: ___________________________Zooplankton
2. What does the world plankton mean?
   a. Plant
   b. Wanderer
   c. Snow
   d. Soup
3. What forms the basis (bottom) of the ocean food web?
   a. Small fish
   b. Worms
   c. Phytoplankton
   d. Zooplankton
4. Where does the majority of the oxygen on earth come from?
   a. Marine plants (phytoplankton)
   b. The Amazon Rainforest
   c. The Redwoods
5. What does Next Generation Sequencing tell us about a community of marine microbes?
   a. Who's there – what species of microbes are present
   b. What they need to grow in lab (culturing)
   c. None of the above
6. What percentage of the human population lives within 200km (~125 miles) of a coastline worldwide?
   a. 100%
   b. 75%
   c. 50%
   d. 25%

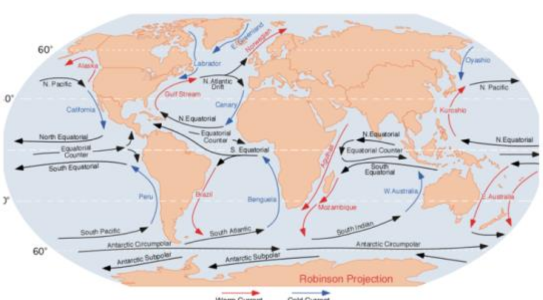
STATION 3

coastal dynamics

First, **Dr. Seeksalot** should review the physical factors that affect the Oregon Coast. Where does the water come from? What does wind have to do with it? Does the water look the same from year to year? Is the water changing due to climate change? What's different about this crabbing season compared to last years? Understanding ocean circulation is critical to understanding the chemistry and biology happening in the ocean.

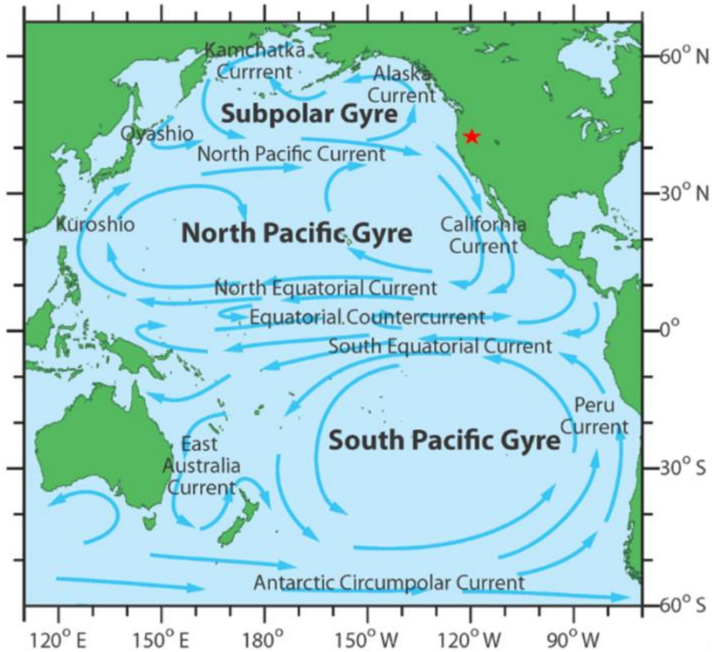
Perhaps answering these questions can give us a clue about the problem we are trying to solve for **Fisher Crabbins**. How can we answer these questions? Scientific research isn't free and collecting data is *expensive*. Thankfully, there are databases with all kinds of data from the ocean online! But where does the data come from? Scientists at Universities are funded by money distributed by government organizations. But in order for those government organizations to fund researchers (i.e. **Dr. Seeksalot**)--policymakers have to agree on a budget and allocate money for scientific advancement. Funding science research is a way to keep the economy thriving by providing jobs and developing new technologies to address the world's problems.

Dr. Seeksalot has worked closely with the office of **Representative Wordsmith**. If **Rep. Wordsmith** has the power to influence budgets.. but isn't a scientist... and funding is critical for research and the advancement of society... how does **Rep. Wordsmith** decide who to give money to?! Scientists collaborate with policymakers to share what's so important about their work. This relationship between the scientist and policymaker can influence the types of research the state of Oregon or the federal government is most interested in funding. Luckily, here in Oregon, marine science research has been generously funded meaning there is a lot of publicly available data for us to analyze to solve the problem of the missing crabs.

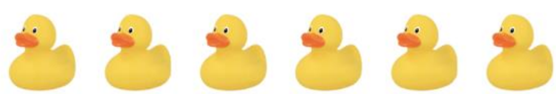


Ocean Currents

First things first. We need to think about *how* water moves in the ocean before we think about the organisms living in the water. Ocean currents are the continuous, predictable, directional movement of seawater driven by gravity, wind, and the density of water →



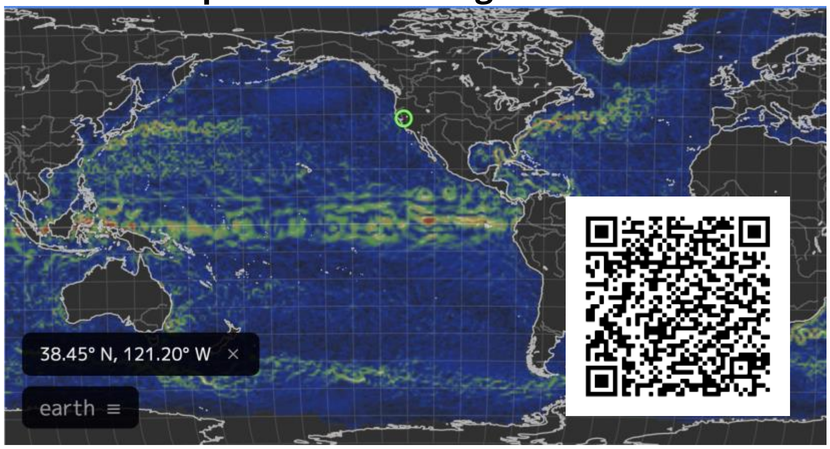
Ocean currents are an integral part of the Earth system. Knowledge of currents provide us with a better understanding of global climate and weather patterns, as well as living conditions, migration patterns, and life cycle journeys of plants and animals, including humans. Studying ocean currents can also be useful in ship navigation, which has a direct impact on the economy, in search and rescue operations, and in tracking oil spills.



In 1992, an accidental experiment began when a container ship in the North Pacific accidentally released over 28,000 bath toys. Because the toys float, the yellow ducks began their journey around the world's oceans, aided only by the ocean's current and where it would take them. Named the "Friendly Floatees", these bath toys have helped oceanographers map the currents and are still being discovered today (30 years later!).

Video:
Friendly Floatees and how ocean currents work.

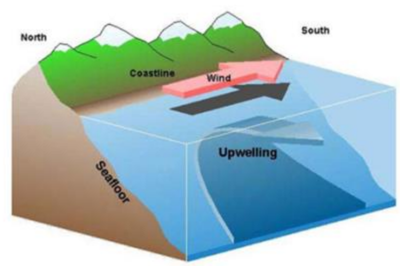
Check out the ocean currents in real time at the link below.
Zoom in and toggle with the map to view the Oregon Coast.



Now that we know about global currents, we can start to think about the water off the Oregon Coast. This water is part of the **"California Current"** system in the North Pacific. Watch the video on the left to see how water from across the ocean makes its way to Oregon's shores.

In a later part of this lesson, you will discover how ocean currents and wind patterns can influence life cycles of microbes and animals in the ocean.

Video:
Watch min 2:22-3:30



Source: NOAA Ocean Explorer

Currents in the open ocean aren't obstructed by land. But what happens when there is a windy coastline? Winds can push the water from the shore and deeper water rises to fill the gap. This process is called **upwelling**. Coastal upwelling occurs along the west coast of the U.S. and a few other places in the ocean. Coastlines where upwelling occurs are some of the most productive ecosystems and support many of the world's most important fisheries.

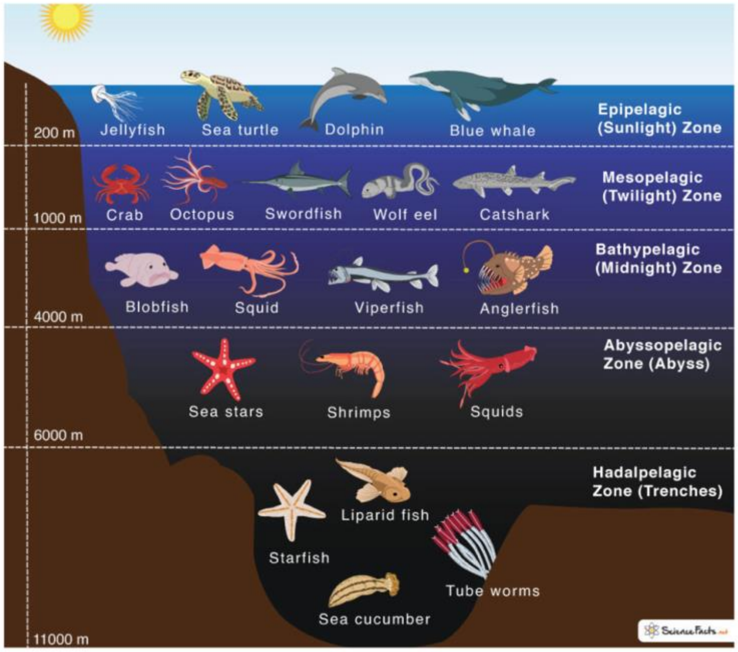
Ocean Temperature

You've probably heard that the ocean is warming. This is due to excess greenhouse gas emissions. The video below is a good explanation for how the Earth is warming. Think about how this may be contributing to the observations **Crabbins** is noticing.

Video:
Giant tetris

Ocean Layers

While you may think the ocean is just a big bathtub that's sloshed around randomly, that's not true! The ocean has layers that are driven by both temperature and density. Warmer waters lie on top of the colder, deeper waters. The layers do mix but in an orderly fashion that's driven by currents.



Now that you know about marine microbes and the physical ocean, isn't it remarkable how abundant these tiny yet adaptable these organisms are? Microbes are swept away and forced to survive wherever the current takes them. Unlike a shark or an octopus, it's very difficult for bacteria to move around in the water because they are so small (but being small isn't all bad. Can you think of some advantages to being a small organism in the open ocean?)

These are the types of topics **Dr. Seeksalot** has been pondering - how might microbes or ocean currents be involved with the missing crabs reported by **Crabbins**? There's been a lot of buzz in the news about hypoxia here in Oregon. Perhaps there is some publicly available data on oxygen concentrations that would help us inch closer to a solution.

Test your knowledge:

1. Water coming up from the depths of the ocean is high in NUTRIENTS and low in OXYGEN.
2. What are 3 effects of climate change from rising levels of carbon dioxide in the atmosphere and ocean?

    Warmer temperatures
    Stratification (separation of layers)
    Slower global circulation

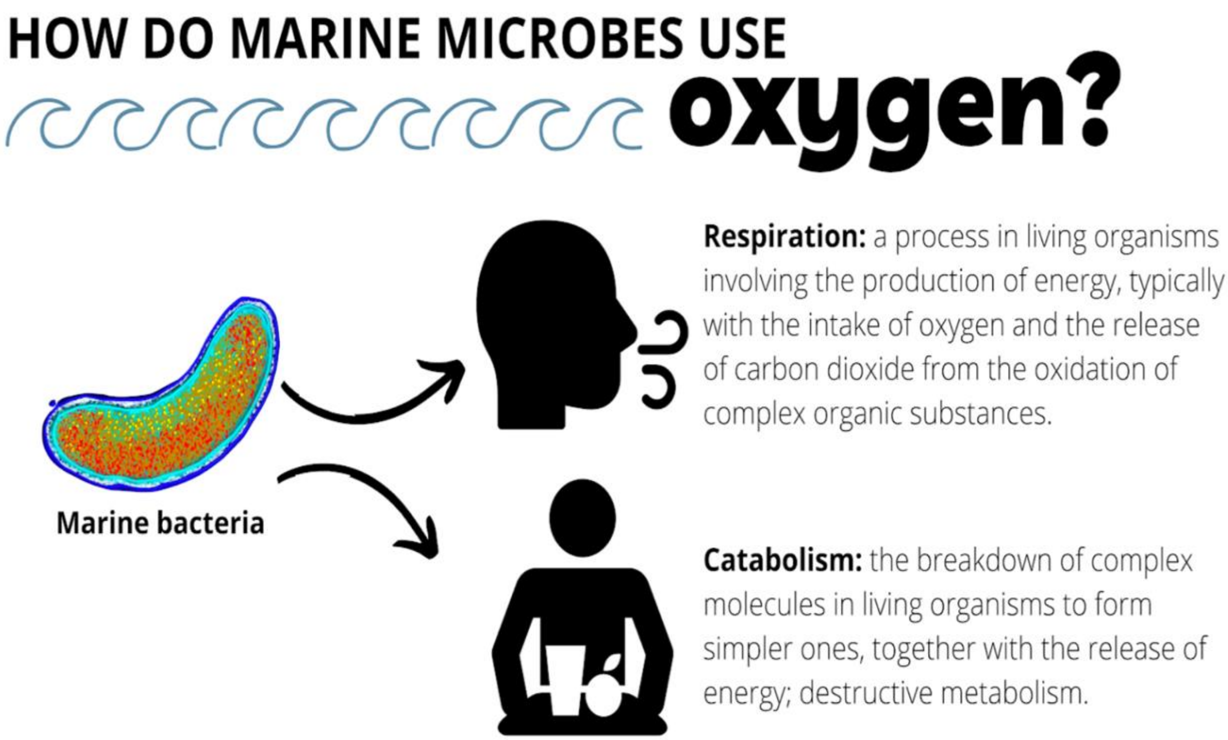
STATION 4

ocean oxygen

Now you know about **Dr. Seeksalot's** expertise in marine microbes and what the environment is like, let's think about other factors that may be contributing to the problems that **Crabbins** is encountering. Mentioned before, **Rep. Wordsmith** has been a strong advocate for ocean data collection and marine science on the Oregon Coast. Researchers in Oregon have been funded to monitor things like oxygen and temperature of the coast on a regular basis. This data has been put into online databases for other scientists and the public to access.

Oxygen makes up about 21% of Earth's atmosphere. But there's also dissolved oxygen in ocean water, and it's constantly being produced by microscopic phytoplankton. Scientists estimate that 50-80% of Earth's oxygen production comes from the ocean! As you learned at the last station, marine plants use sunlight energy to create oxygen through photosynthesis. Though they are invisible to the naked eye, they produce more oxygen than the largest redwood trees!!

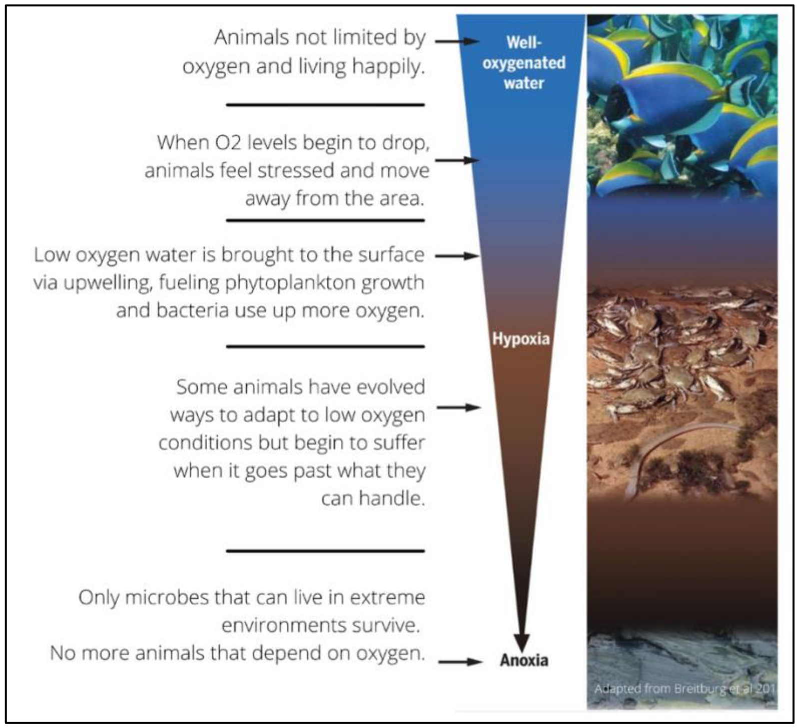
Both microorganisms and larger marine organisms require oxygen to function. It's been reported that ocean oxygen levels are declining due to global climate change. How does this affect microbes? And how does this affect larger organisms like crabs, sharks, or other types of fish? Is this happening in Oregon?



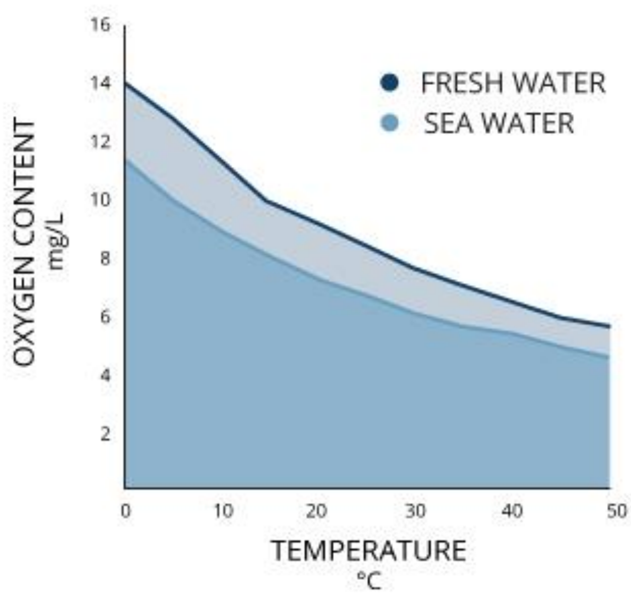
But what happens to the ecosystem (and larger organisms) when oxygen drops?

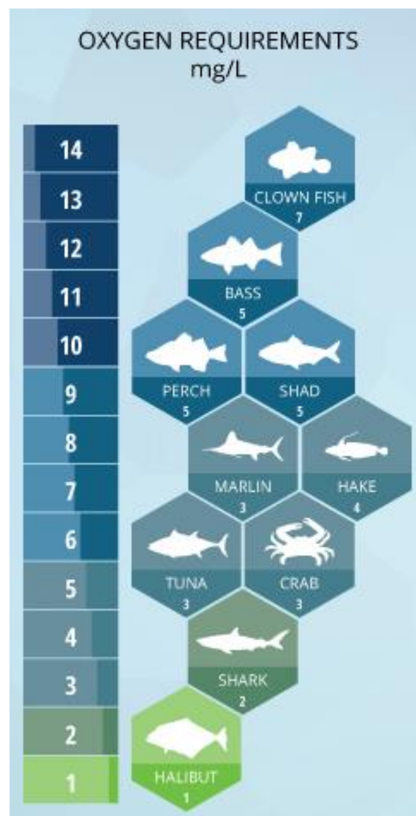
Different organisms have minimum oxygen requirements, this means that below a certain level of oxygen... animals can't maintain their normal functions. On the right you can see oxygen levels change from well-oxygenated water to hypoxia (low oxygen) and anoxia (NO oxygen), organisms suffer and only tiny microbes can survive.

Scientists collect oxygen concentration data on the coast. In chemistry, the term *concentration* refers to the measure of the amount of a substance in a solution. So when we measure oxygen, we are measuring the given amount of oxygen in the seawater.



What do you notice about the oxygen concentration of the water as the temperature increases? How does decreasing oxygen concentrations affect crabs?





Upwelling and oxygen

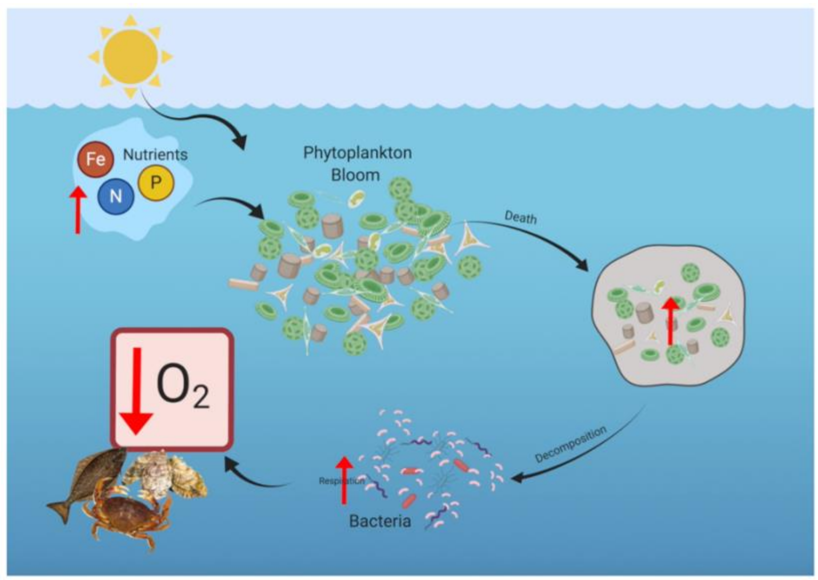
At the previous station, you learned about the physical dynamics of the ocean and how the currents bring water to the Oregon Coast. But how does the water become low in oxygen?

Watch the video below to learn more about coastal upwelling. This is a process that helps phytoplankton grow and maintain the ocean food web. But too much of anything can be bad...

Because of climate change, we are experiencing stronger winds and more sluggish currents. And the water at the surface of the ocean is warmer, this means it's more stratified (more layered). This prevents the water from mixing and warmer water holds less oxygen (as shown on the previous page). When the cold, deep water that's rich in nutrients but low in oxygen gets upwelled onto the shelf, there is a spike in the phytoplankton community (called a "bloom"). A phytoplankton bloom means more phytoplankton die and become food for the bacteria.

Remember how bacteria use oxygen? When they eat organic matter (dead phytoplankton), they use up oxygen in the process. When bacteria use up too much oxygen in the water, what would happen to other organisms who depend on that oxygen to maintain their basic functions?

Video: Upwelling

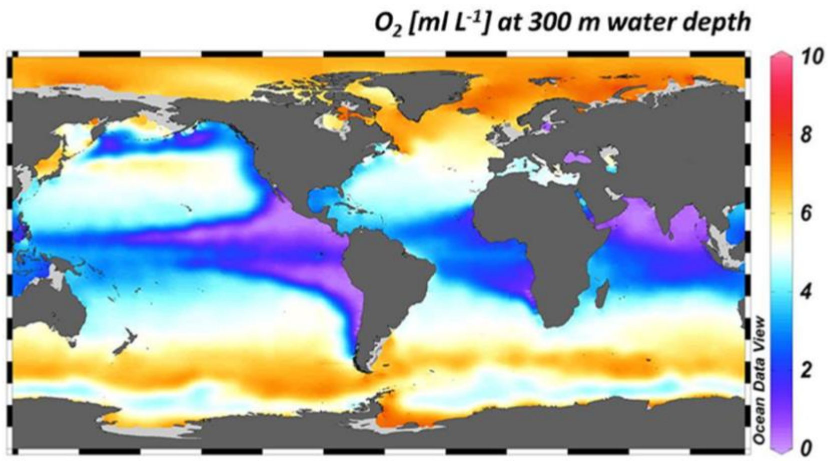


Global Ocean Oxygen

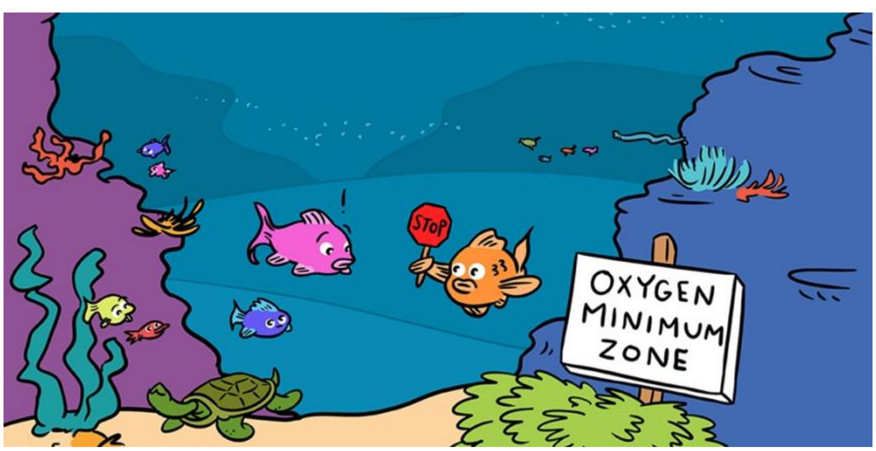
Let's look at the concentrations of oxygen in the ocean on the figure below. The scale on the right shows the oxygen concentration in the water, measured in milliliters of oxygen per liter of water. There are regions in the Ocean where there is a lot of oxygen in the water, mostly in the Polar regions, and this is shown in the orange/red.

Blue/purple colors mark the regions where oxygen is low. These regions can be called oxygen minimum zones. In large parts of the Pacific and the Indian Oceans, there is barely any oxygen left (shown in purple). Those are the strongest oxygen minimum zones in the Ocean.

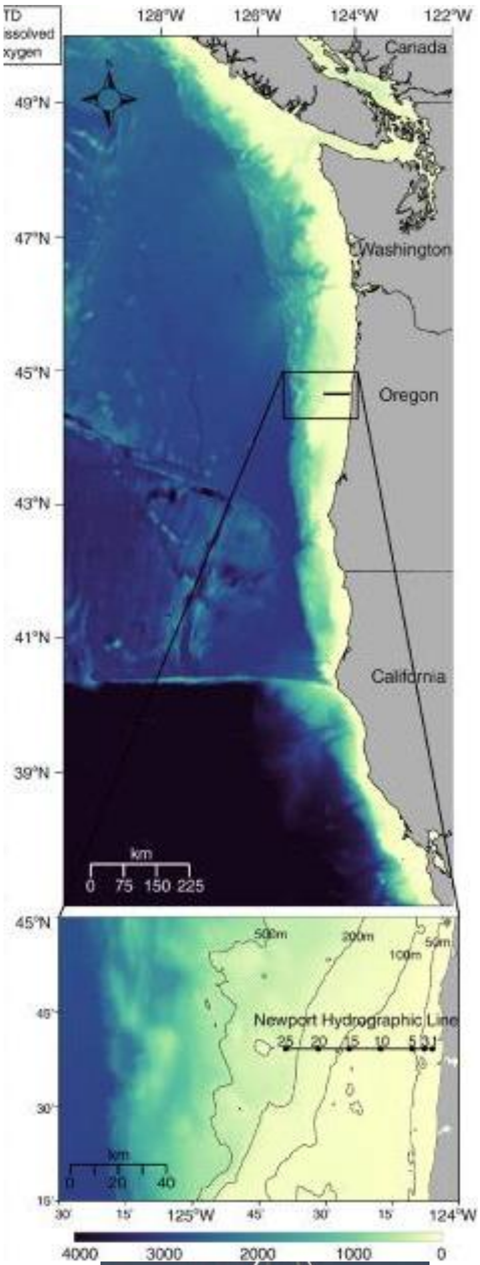
Look at North America and find the Oregon Coast. What do you observe about oxygen there?



Source: World Ocean Atlas



Let's look at some data from dissolved oxygen concentrations from the coast near the city of Newport, Oregon.
This data is compiled from the years 1997-2021.

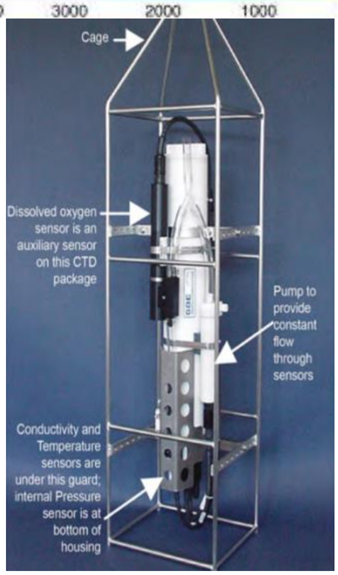


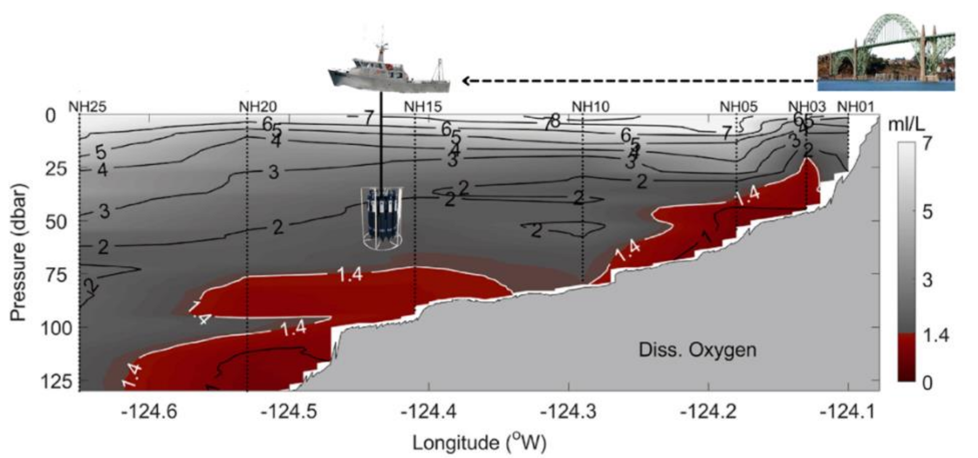
On the top left, you can track the sampling locations along the Newport Hydrographic Line (NHL). Water samples have been collected on a biweekly to monthly schedule from each of the locations along the NHL (labeled as 1, 3, 5, 10, 15, 20, 25). These data are collected using something called a Conductivity, Temperature, Depth (CTD) profiler with dissolved oxygen sensors (image on the bottom left). So when the CTD goes overboard, as it sinks through the depths of the water, it's sensors can collect both data and the "carousel" can trap water from the deep ocean for us to bring back to the lab to do experiments with.

Look below to see a profile for dissolved oxygen. Imagine a research boat was gliding along the top of the water outward from Newport and the CTD sensor was being dropped into the water at different points. The large light gray shape on the bottom right is the “continental shelf”. The shelf is the area of seabed around a large landmass where the sea is relatively shallow compared with the open ocean.

Remember “the drop off” in Finding Nemo? That is where the continental shelf meets the open ocean.

The concentrations are labeled on the left legend with red showing low oxygen (concentrations below 1.4 ml/L) and the gradient of gray showing up to 7 ml/L.

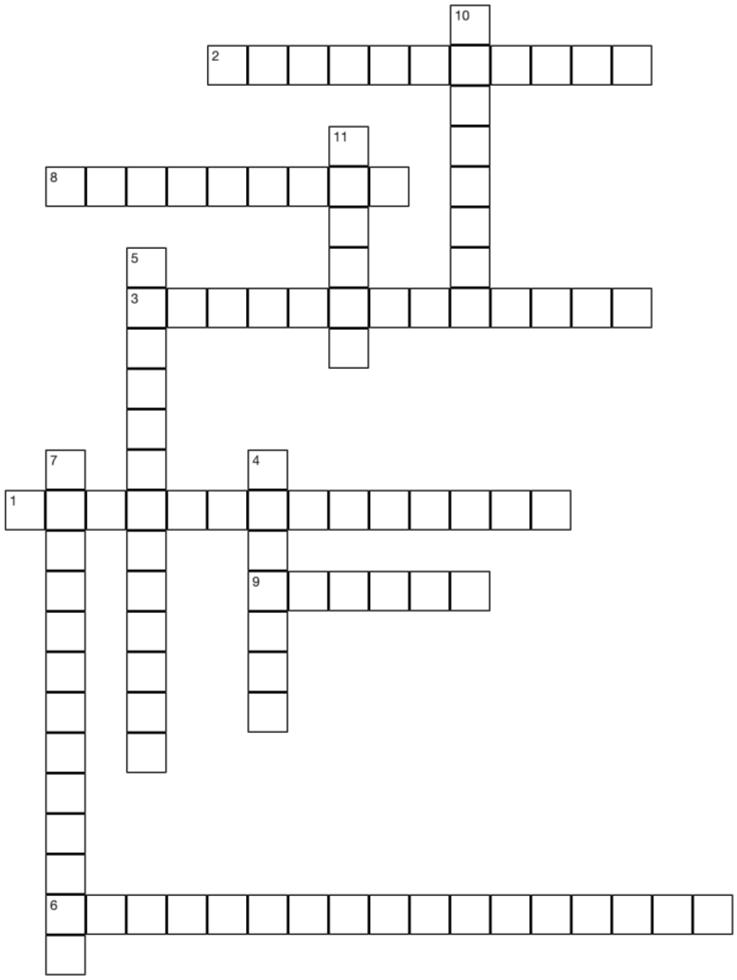




Source: Adapted from Risien et al 2022

Oxygen in the ocean

The crossword below contains words used to describe coastal oxygen dynamics and marine microbial processes.



Created by https://www.crossword-puzzle-online.com

Horizontal

2. A chemical reaction that occurs in all cells using glucose and oxygen while producing carbon dioxide and water
8. Process where deep water is brought up to the surface
3. Matter that comes from living or once living organisms
1. Process by which green organisms use sunlight to make their own food
9. A life supporting gas found in the atmosphere
6. Areas of the ocean with low oxygen with the potential to become dead zones

Vertical

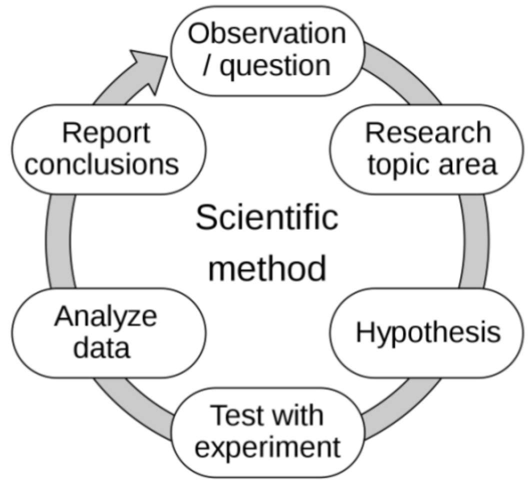
10. Microscopic single celled organisms that exist in all environments
11. Absence of oxygen
5. The amount of a substance in a defined space
7. Photosynthetic organisms that make most of the oxygen we breathe
4. Low levels of oxygen in an environment

STATION 5

forming hypotheses

Crabbins made an observation. He reported this to **Dr. Seeksalot** and **Rep. Wordsmith** and they used their research area expertise to approach the problem.

As a group, come up with a *hypothesis* for what's happening. A hypothesis is a prediction or possible explanation for a question that needs to be investigated. Coming up with a hypothesis is one step in the scientific method, which we use when we perform scientific experiments. It uses what you already know in order to make a well-thought out prediction (an educated guess).



A hypothesis is *testable* meaning there is a way to test if there is evidence for or against it. This test can be an investigation through a set of experiments.
A hypothesis is often an "if...then" statement.
For example, ***If*** *humans do not reduce carbon emissions,* ***then*** *the ocean will continue to warm.*

Fill out the following as a group:

Observation:

Research topic area:

Hypothesis:

Now it's time for each person to use their roles skills to help address the problem!

Follow instructions for each role and create your products.

Then come back together as a group and prepare to share your products with the class.

***Goal**: Use research to combat ocean deoxygenation.*

As a group, you've learned about several factors that affect the chemistry, biology, economics, and physics of the coastline and you've come up with a hypothesis. Can you think of an experiment to test your hypothesis for why the crabs are "missing" on a coast that experiences the effects of climate change? What other types of data may be useful to collect?

***Goal**: Engage your community to work together.*

You're the one seeing these changes from day to day on the water when you're out crabbing. Make a list of the ways these problems you experience as a fisherman could affect your local community and then think of ways this could affect the global community. With this information, come up with an engagement strategy to mobilize your community – use your imagination to think of a fun event one could host to raise awareness, create a song, come up with an idea for a compelling documentary, draw a comic to feature in the local newspaper, or write a short children's story to share with kids in your community at a local library. What will get your community excited to work together?

***Goal**: Raise awareness and relate to communities across Oregon (who may not live on the coast).*

Being in public office means representing your "constituents" (people who live in the area you serve) and communicating with them to best meet their needs. It's your job to create a "Public Service Announcement" about this issue on the coast. This could be in the form of a Tiktok or Instagram reel, a social media post or an article that would be published in the local newspaper. Imagine you are the governor of Oregon and must connect this to people who don't live on the coast. How does this problem affect them? Be creative and communicate your message to *<u>all</u>* people in your state!

This simulation was adapted from a TRUE story of how fishermen made observations of dungeness crabs, communicated with scientists at Oregon State and how scientists are working with policymakers to protect our coastal community, biodiversity and livelihoods.

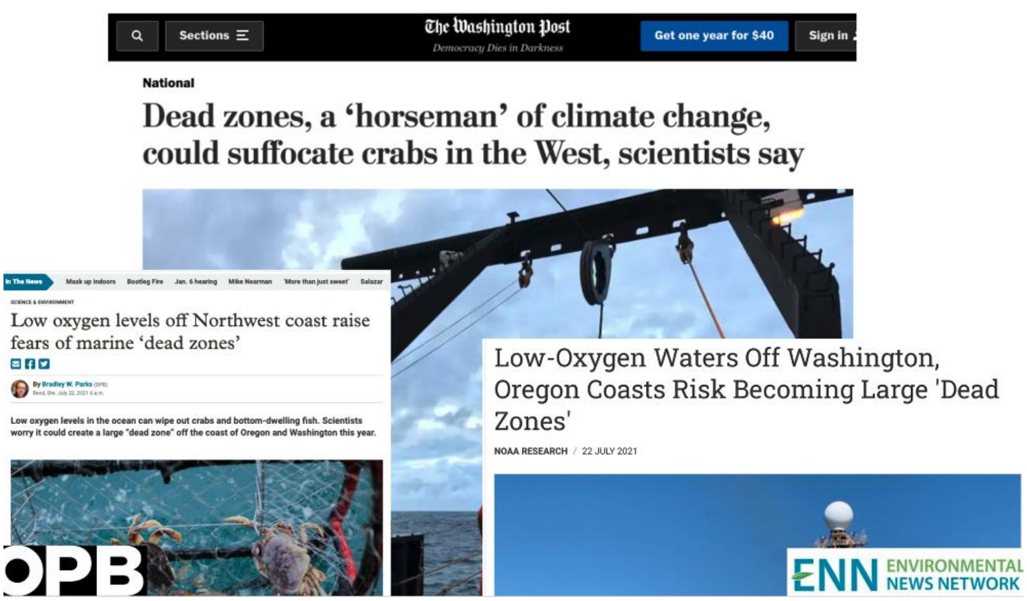
STATION 6

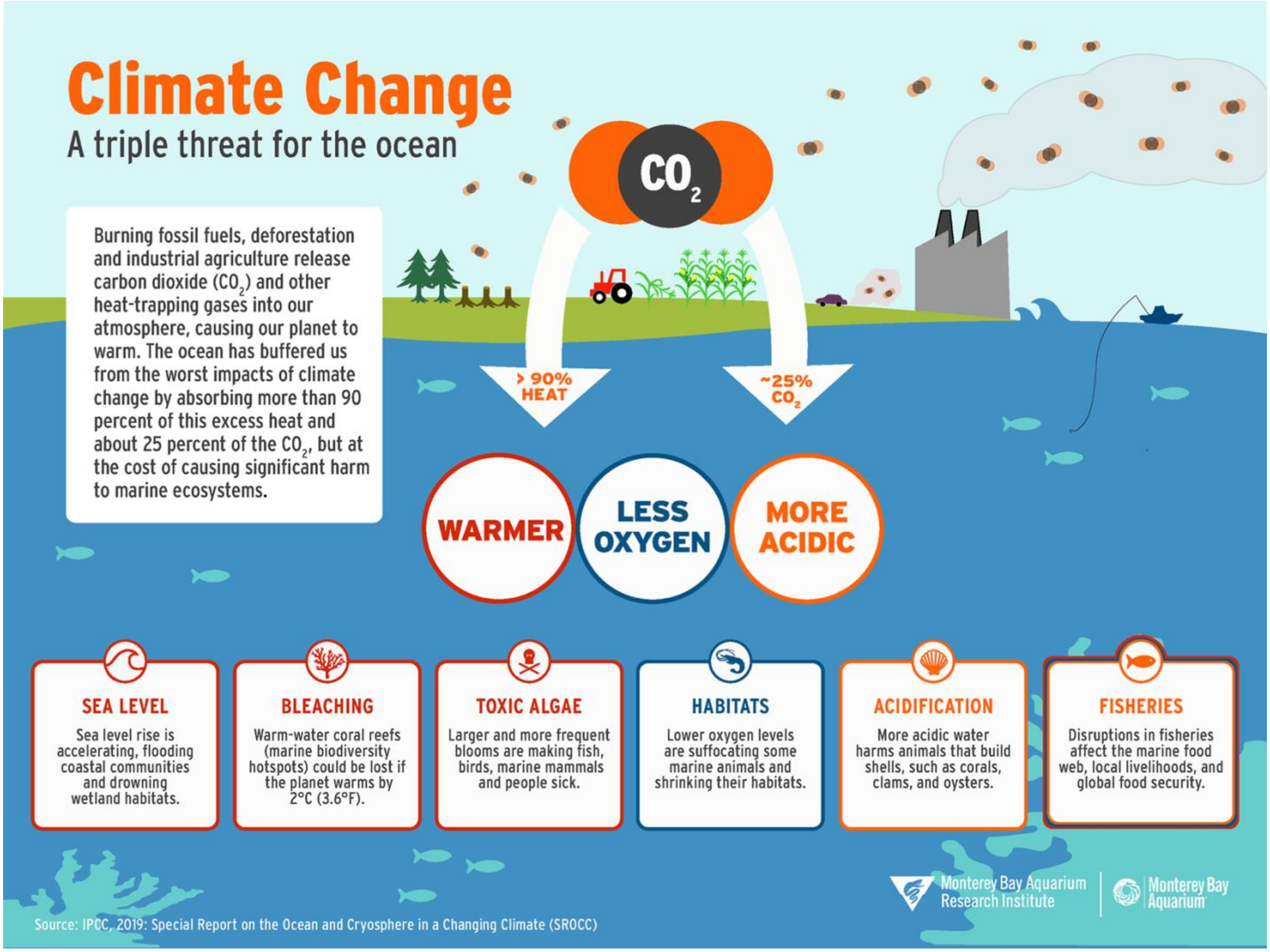
solutions

Scientists began observing low oxygen levels on the Oregon Coast starting in the early 2000s. Observations and research have led scientists to determine Oregon now has a “hypoxia season” just like it has a fire season — and in 2021, the hypoxia season came far earlier than usual.

These hypoxia events can result in “dead zones” that occur as winds pick up in the spring and summer, driving cold water from the bottom of the ocean toward the surface. That contributes to blooms of phytoplankton, which later die and sink to the ocean floor. Bacteria consume oxygen while decomposing the plankton. “Place bound” marine creatures or those who cannot relocate quickly, like crabs, can’t escape the low-oxygen zone and left to die. This is the most likely hypothesis for why **Crabbins** wasn't seeing crabs in his crab pots!

Here are some news stories of dead zones on the Oregon coast:





The loss of oxygen in our oceans is just one of the ways rising carbon dioxide levels in the atmosphere reveals itself. Without a serious reduction in carbon dioxide, scientists predict the ocean will eventually become a hot, sour and breathless place.

That sounds depressing.

So what can we do?

1. Collect data. We can't fight something we don't understand.
2. Develop new technology.
3. Work together to reduce carbon dioxide emissions worldwide.

Activity: Taking positive climate action!

We've learned a lot about the *challenges* that we encounter on the Oregon Coast.

This is just ONE story and ONE of the ways climate change affects communities across the world. Choose one of the following prompts:

1. Search online for a positive climate story that shares how a community has overcome the challenges they face due to climate change.
2. Get creative and come up with an idea for a product, company, phone application, etc. with the potential to help combat global ocean deoxygenation.
3. Use the information you've gathered here and think about your own local community. Think of a climate driven challenge that faces the community **you** live in and try to come up with a solution / experiments / product that would help your community combat climate change.

additional materials

ARTICLE:

FRONTIERS FOR YOUNG MINDS

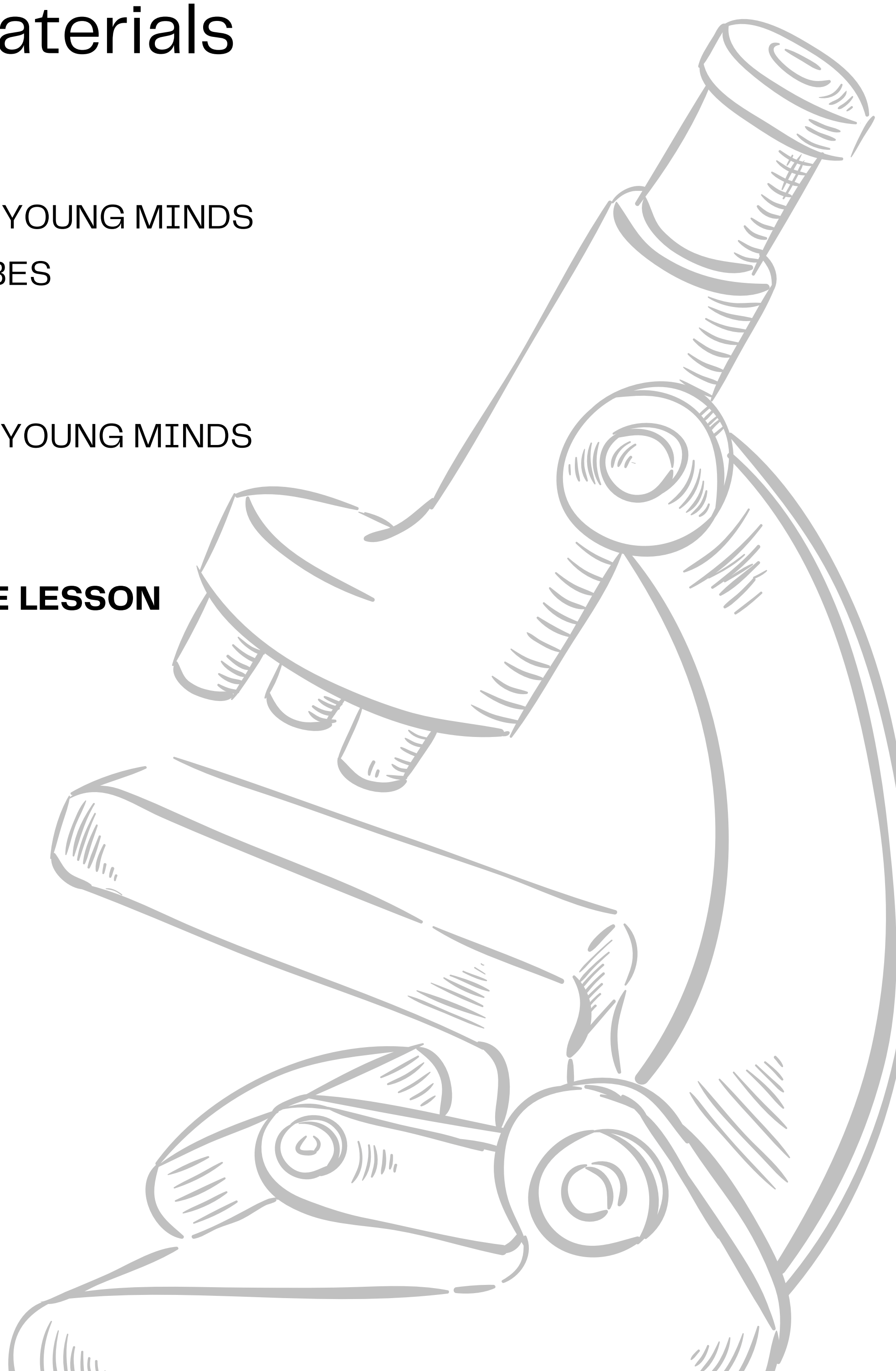
MARINE MICROBES

ARTICLE:

FRONTIERS FOR YOUNG MINDS

OXYGEN

ACCESS ONLINE LESSON



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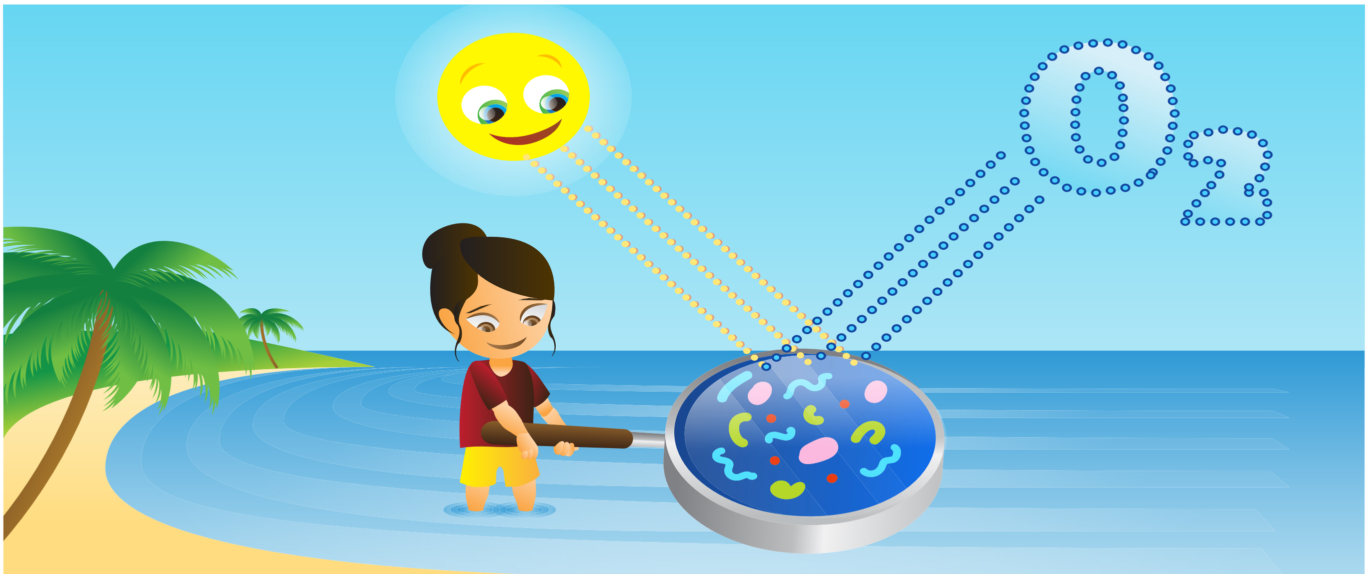

UNDERSTANDING MARINE MICROBES, THE DRIVING ENGINES OF THE OCEAN

***Anna Kopf*[1,2], *Julia Schnetzer*[1,2] and *Frank Oliver Glöckner*[1,2*]**

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CONNISTON MIDDLE SCHOOL
14–15 YEARS OLD

When you hear the word microbes, what comes to your mind? Something much too small to see and that makes you fall ill? Just because some microbes cause diseases that does not mean they are all evil. For example, in the marine (ocean) environment, the vast majority of microbes are good ones. They are the "driving engines" of the ocean and are essential for the health of our whole planet. Unfortunately, most of the marine microbes and their interactions with the marine environment are poorly understood. So, it is important to get an idea of which microbes are helping us and how they are doing this. These data will provide scientists with the knowledge to fight against big global challenges, such as climate change and environmental pollution. Unfortunately, it is very hard to study marine microbes due to their microscopic size, huge diversity, and their big home – the ocean. Therefore, we would like to engage "citizen scientists" in this project to help us to sample marine microbes so that we can identify them.

MARINE MICROBES, THE DRIVING ENGINES OF THE OCEAN

When you hear the word microbes, what comes to your mind? Something that we cannot see with the naked eye? Invisible organisms that can invade our bodies and make us fall ill? Almost everyone has heard about bad things that microbes can do, such as cause dental cavities – the breakdown of teeth caused by bacteria. Pertussis, also known as whooping cough, is another well-known bacterial disease. The dislike that humans generally feel toward microbes is strong and in many cases understandable. However, this does not mean that all microbes are all evil. It may sound strange, but most of the microbes that exist are actually very helpful. Many of the "good" microbes can be found in the ocean (Figure 1), among other places. These marine microbes are microscopic single-celled organisms that include bacteria and archaea. Archaea are bacteria look-alikes, but with some special features such as the ability to live in extreme environments, for example, in extremely hot or extremely cold places. Moreover, marine microbes also include single-celled organisms, such as microscopic algae and even viruses. Marine microbes are tiny, but they exist in very large numbers and can be found all throughout the ocean, from the deepest parts up to the surface layers. It has been estimated that just one drop of seawater contains millions of microbes! In other words, there are more marine microbes in the oceans than there are people living on earth. In addition to being the unseen majority in the ocean, which is the world's biggest ecosystem, marine microbes also form the basis of the marine food web, are responsible for the recycling of nutrients, and are involved in all types of important activities. For this reason, they are also called the "driving engines" of the ocean, meaning that they are essential to functioning of the

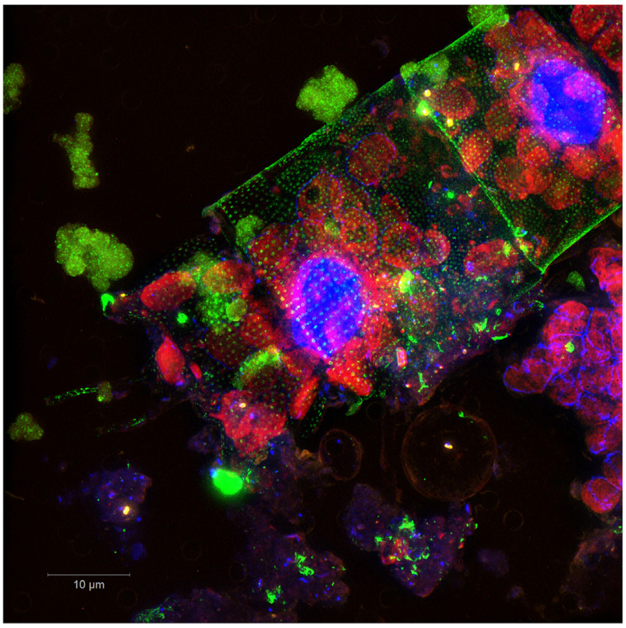

FIGURE 1

FIGURE 1

Image illustrating the microbial diversity in the ocean. It shows diverse microbial cells located on and around an algae. The microbes have been visualized using a colored dye. Image provided by Gomez-Perreira and Fuchs. (Picture courtesy of P. Gomez-Perreira and B. Fuchs, Max Planck Institute for Marine Microbiology, Bremen, Germany).

ocean and the ocean cannot survive without them. Because they are a part of so many different processes, marine microbes have an important impact on our daily life and well-being, no matter where we live. One example of a function performed by marine microbes that influences humans is photosynthesis, a process you might have heard of in connection with plants. Like plants, some marine microbes, like Cyanobacteria, can use the light energy from the sun to convert carbon dioxide (CO_2) and water into sugar. During this process, oxygen (O_2) is produced and released into the environment. It has been estimated that about half of the world's oxygen production takes place in the ocean, while the other half comes from terrestrial habitats. In other words, marine microbes are responsible for the oxygen in every second breath you take. Another example of the importance of microbes in the ocean is the ability of some microbes to break down oil. Some marine microbes feed on oil, which can be very useful for clean-up after an oil spill.

So, it is obvious from these examples that marine microbes are not just the driving engines of the ocean, they are also essential for the health of humans and the whole planet. The interaction between these microbes and the larger organisms on the planet is in a delicate balance, and could be threatened by factors, such as pollution and changing environmental conditions. In order to protect and maintain a healthy environment, we need to gain deeper knowledge about the kinds of microbes that exist, what are they doing, and how they interact with each other and with the environment. Unfortunately, collecting this information is not as easy as it sounds.

WHY DO WE KNOW SO LITTLE ABOUT MARINE MICROBES?

Until recently, scientist needed a pure culture of microbes to get an answer to simple questions, such as what they are like and what functions they are capable of. A pure culture means that a single microbe has to grow in the lab in the absence of any other species. Since conditions in the lab are very different from those in the oceans, it is extremely difficult to grow marine microbes. It has been estimated that only around 1–10% of marine microbes can be cultured in the laboratory [1]. We still do not know the exact reasons for this difficulty, but luckily, over the past few years, new techniques have been invented to allow the study of marine microbes without the need to grow them in pure culture in the lab first. One of these techniques is called **Next Generation Sequencing (NGS)**.

NEXT GENERATION SEQUENCING (NGS)

This is a fairly new method for reading and recording the DNA. It allows scientists to read large amounts of the DNA letters with and without growing the organisms in a lab. Sometimes it is also called massive parallel high throughput sequencing.

HOW DOES NGS HELP SCIENTISTS TO UNDERSTAND MARINE MICROBES?

All the information about a microbe, or any kind of cell, exists in the cell's **DNA**. DNA is the molecule that contains the genetic code of organisms and, thus, can be described as the "blueprint" of the cell, since it tells the cell what to do and when to do it. In can further be divided in small subsections called genes. There are thousands of genes in the DNA of an organism and each **gene** has a specific function. For example, the human DNA contains about 25,000–35,000 genes, but only a very few genes are responsible for the color of your eyes. The NGS technology allows scientists to "read" the DNA from a whole microbial community without the need for pure cultures of the microbes. This approach is called "Metagenome **sequencing**" and it provides the scientist with a list of the genes of all the microbes living in a particular area.

Some genes exist in all organisms on earth but have small differences between organisms. One example of this type of gene is the one for "ribosomal RNA" (rRNA). Because this gene is unique for each species, scientists can use it as a kind of fingerprint of a microbial species. You might have heard of fingerprint analysis being used as part of a criminal investigation. Law enforcement offices, such as the police, store all fingerprints in large databases for comparison with fingerprints taken at crime scenes. This allows the police to identify people who commit crimes. Scientists do the same with the gene fingerprint of microbes obtained through research. They use the **rRNA gene** to search in a specific database, such as the SILVA [2] database, for a positive match. With this approach, they can identify the microbes obtained in their samples and find an answer to the question "What kind of marine microbes are out there?"

But the DNA contains so much more than just a fingerprint. As mentioned above, it is the building plan of an organism and includes instructions for all of that organism's features and functions. If scientists are able to "read" the data coded in the DNA, they can obtain a great deal of knowledge about that organism. Unfortunately, deciphering the DNA data obtained from marine microbes is like trying to understand an ancient language or to put together a puzzle. It takes a while, and the scientists might need to gather some additional "pieces," but sooner or later they are able to solve it. Every day scientists discover a new piece of the puzzle and more and more information about marine microbes is revealed. Although NGS is still a fairly new method, this technology is clearly helping us to reach a new level of understanding of marine microbes from all parts of the ocean. However, the knowledge we have gained so far about marine microbes is just "a drop in the ocean" – there is so much more to learn! The Ocean Sampling Day (OSD) project [3] aims to greatly increase our knowledge of marine microbes by bringing people together to study the microbes in ocean ecosystems all around the world.

DNA

Abbreviation for deoxyribonucleic acid. Can be described as the instruction manual or "blueprint" of every microbe or any other living cell. The information is stored as a sequence of four different molecules that are represented as letters (A, G, C, T).

GENE

Each DNA contains subsections called genes, which tells each cell what to do and when to do it. There are thousands of genes in the DNA of an organism and each gene has a specific function.

SEQUENCING

In genetics, sequencing means to read and record the sequence of letters (A, G, C, T) of the DNA of a cell.

rRNA GENE

This gene codes for the "ribosomal RNA" of a cell. The rRNA gene is very important for the cellular metabolism by playing a key role in the production of proteins. Every organism on earth has this gene in its DNA and it is unique for each species; thus, it can be used as a marker for the genetic fingerprint.

THE OCEAN SAMPLING DAY

Researchers working on a project called Micro B3 (Marine Microbial Biodiversity, Bioinformatics, Biotechnology)[1] organized an OSD [3] on June 21 in both 2014 and 2015 with the aim of studying marine microbes worldwide with the help of a large international group of scientists. June 21 is known as the solstice, meaning that it is the longest day of the year in the northern hemisphere and the shortest day of the year in the southern hemisphere. The solstice was chosen for microbe collection to see if day length influences the kind of microbes that are collected [4]. For the OSDs events in June 2014 and 2015, scientists around the world collected marine microbial samples. Each team filtered sea water through a specific filter called Sterivex™ that contains very tiny holes that are smaller than microbes, so the microbes get stuck on the surface of the filter. This is how scientists capture microbes from the ocean or any aquatic system. Next, the scientists removed the microbes from the filter and used some chemicals to collect the DNA from all of the organisms obtained. Then, the DNA information was analyzed with the NGS technology.

The aim of OSD is to answer several questions: "what kind of microbes are out there?" (**biodiversity** analysis based on the DNA "fingerprint"); "what are those microbes doing?" (functional analysis based on **metagenomics**); and "how do those microbes interact with each other and the environment?" (Figure 2). Scientists are still analyzing the OSD data, so there are no reliable results to show yet. Hopefully, the data we obtain from OSD will help us to

[1]www.microb3.eu

BIODIVERSITY

This term describes the variety of different types of life found on earth.

METAGENOMICS

This term describes the study of DNA recovered directly from environmental samples. The resulting data set contains the DNA of all microbes in the sample and not just a single species.

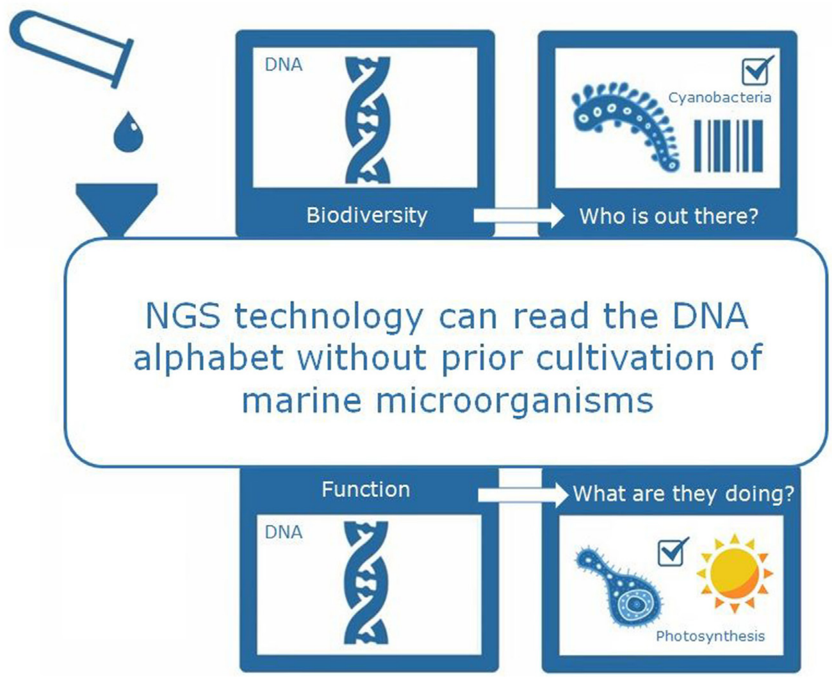

FIGURE 2

FIGURE 2

Next generation sequencing (NGS) technology is a powerful tool. It allows scientists to rapidly read the DNA from millions of microbes without prior culture in the lab. Microbial DNA is obtained from marine microbes in the ocean water samples and can be read using the NGS method. The DNA, as the "blueprint" of the microbial cell, contains all the information we need to answer questions such as "Which microbes are out there?" (Biodiversity) and "What are those microbes doing" (Function).

understand things such as how microbes differ between tropical and polar environments and how microbes can survive in contaminated environments, such as after oil spills.

Humans have a very close and important relationship with the ocean. Not only does around half of the world's population live within 200 km of the coastline [5], but the ocean is also important to the economy as a place for tourism, recreation, fishing, and other activities. All of these human actions affect and change coastal regions. As the majority of the OSD sampling sites are located in coastal areas (Figure 3), we want to study the ways in which human activities and lifestyles influence marine microbial communities. For example, we can study the way that various types of pollution (heavy metals, antibiotics, and fertilizers) affect the health of marine microbes.

Did you know that more than 70% of the earth surface is covered by the ocean [6]? As we move forward, we will continue expand the scope of OSD to explore more of the ocean. OSD 2014 and 2015 already involved more than 150 scientific teams from all continents, collecting samples from subtropical waters in Hawaii to polar environments, such as the Fram Strait in the Arctic Ocean. However, there are still many unexplored areas on the OSD map (Figure 3). To increase our efforts, we also invite "citizen scientists," like you, to join our citizen science project called MyOSD. We developed a MyOSD Sampling Kit and an OSD Citizen Smartphone App, which allows citizen scientists to make a real contribution to science. The kit contains all the equipment anyone would need to collect marine microbes, as well as other material to measure additional important data, such as water temperature and salinity (saltiness) (Figure 4). Each kit comes with clear directions describing each step in detail. The con-

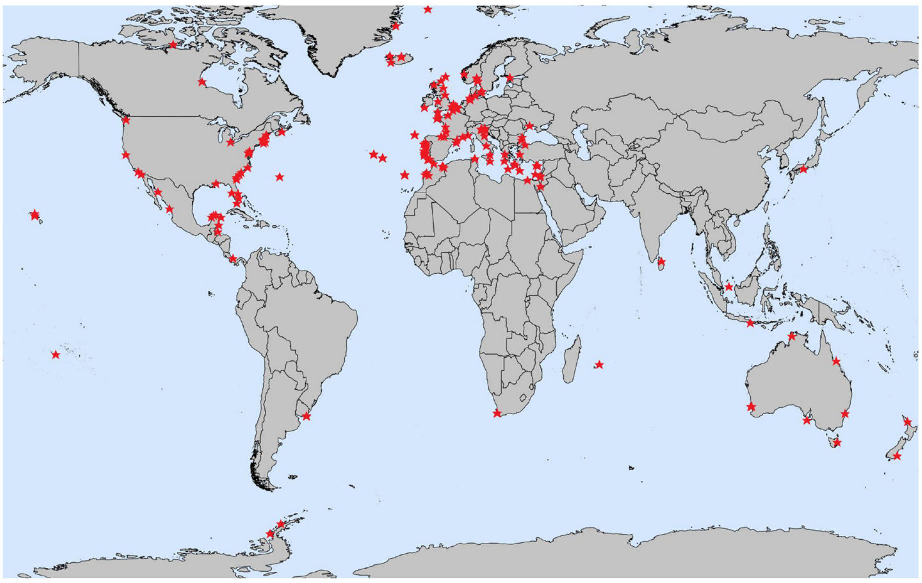

FIGURE 3

FIGURE 3

Map showing registered sites for OSD 2014. These sites are typically located in coastal regions. The red stars mark the locations at which scientists went out to collect seawater samples during Ocean Sampling Day.

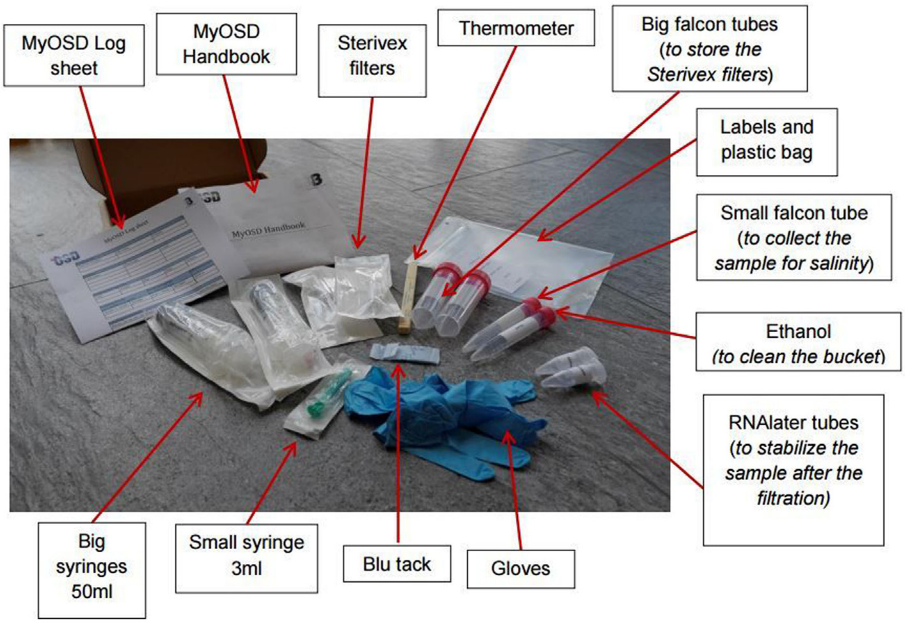

FIGURE 4

Contents of the MyOSD sampling kit. The materials provided in the kit include all of the necessary supplies a citizen scientist needs to collect samples of ocean water that can then be sent back to headquarters and analyzed by OSD.

cept is easy and straightforward, meaning that everyone can join MyOSD. Sampling kits are available for free through registration with MyOSD, and are distributed by MyOSD "hubs" or centers, to citizen scientists in their area or country. A list of all hubs can be found on the MyOSD homepage.[2] After collecting samples, the citizen scientists need to return their samples to the MyOSD hub, which will send them all back to the OSD headquarters at the Max Planck Institute for Marine Microbiology[3] in Bremen, Germany. Here, all the samples are processed and data analysis is coordinated. If there is no MyOSD hub in your area, you can still participate by measuring environmental parameters, such as water temperature and/or salinity. All data can be submitted via the OSD Citizen Smartphone App or the online form available on the website. Every data point counts! For example, if your data help to identify a unique temperature profile for a certain marine area, which might get the attention of scientists who will then design follow-up studies. In the end, all data will be freely available for everyone on the Internet, so that the OSD data can help generations of researchers and citizens. OSD 2014 and 2015 marked just the beginning of this project, and we hope to engage even more people for the upcoming event in June 2016!

[2]http://www.my-osd.org
[3]http://www.mpi-bremen.de

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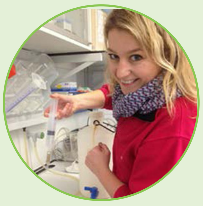
CONNISTON MIDDLE SCHOOL, 14–15 YEARS OLD

Take 28 bright young minds, give them the tools to excel, then get out of the way, and watch them shine! That is Experimental Science Honors at Conniston. Our class is focused on analyzing the many fields of science and reviewing the experimental process, specifically the design or construct of experiments. We also work on problem-based learning pieces to create solutions, including our IB service project: Water for India, where we are working with Water for People to build sustainable infrastructure on the ground in rural parts of India to provide clean drinking water and sanitation. We are excited to join forces with Frontiers for Young Minds and learn the publishing side of science.

AUTHORS



ANNA KOPF

I am a molecular microbiologist by training. In 2012, I finished my Ph.D. degree with a specialization in marine microbiology and continued my work in the research group of Prof. Dr. Frank Oliver Glöckner at the Jacobs University and the Max Planck Institute for Marine Microbiology in Bremen, Germany. I am currently managing the Ocean Sampling Day (OSD) project, which is a global mega-sequencing campaign to characterize the microbial diversity of the world's oceans.

JULIA SCHNETZER

I did my Bachelors in biology at the University of Cologne, Germany with a focus on coral genomics. After some internships at UC Merced (USA) and STRI (Panama), I finished my Masters degree in marine microbiology at the Max Planck Institute for Marine Microbiology in Bremen, Germany with a focus on marine viruses and continued working as a Ph.D. student in the group of Prof. Dr. Frank Oliver Glöckner. In December 2015, I defended my Ph.D. thesis on gathering, sharing, and enrichment of data as part of the Ocean Sampling Day (OSD) and the citizen science project MyOSD.

FRANK OLIVER GLÖCKNER

I was trained in molecular biology and microbiology at the Technical University in Munich and finished my Ph.D. thesis in 1998. Since biology has become a data-intensive science, I decided to extend my skills toward computer science. In 2001, I became the head of a newly established research group at the Max Planck Institute for Marine Microbiology in Bremen, which focuses on Bioinformatics, a combination of computer science and microbiology. In 2004, I became a Professor for Bioinformatics at the Jacobs University Bremen. I always like to explore new things and think "outside the box." **fog@mpi-bremen.de*

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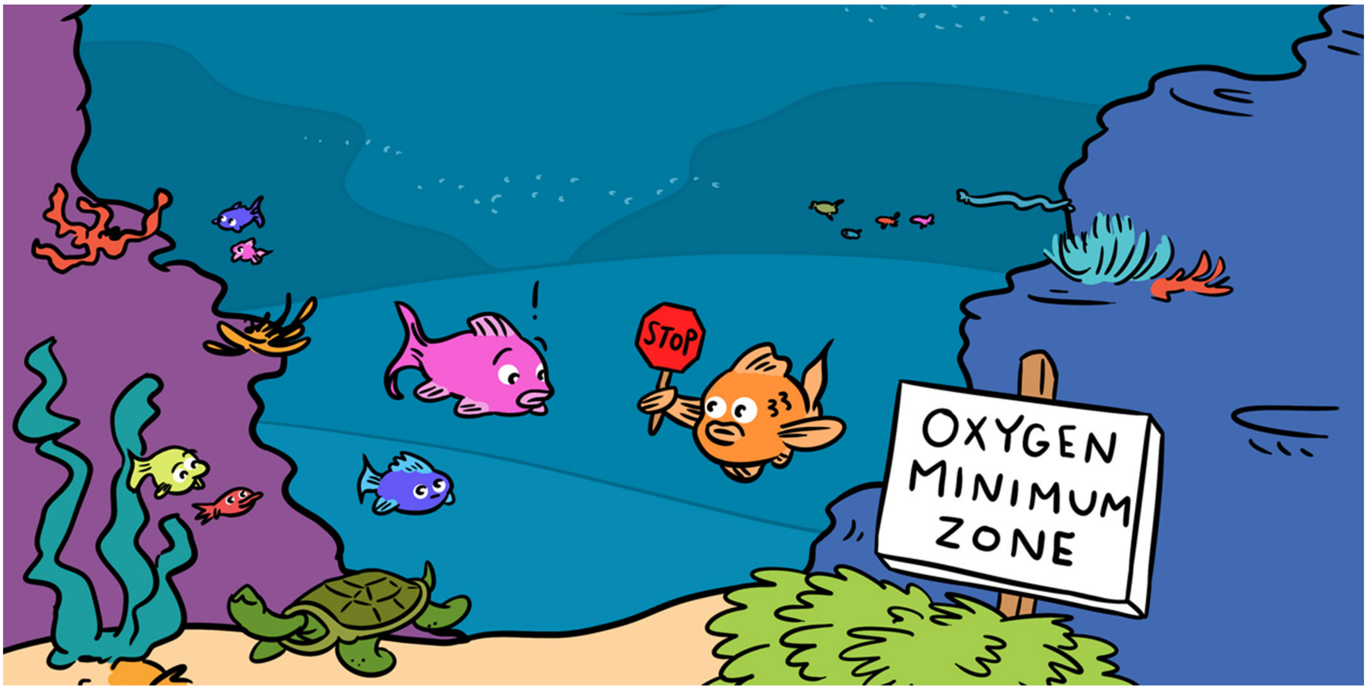

DOES THE OCEAN LOSE ITS BREATH?

Carolin R. Löscher and Andreas Canfield*

Department of Biology, Nordcee, The Danish Institute for Advanced Study, University of Southern Denmark, Odense, Denmark

YOUNG REVIEWERS:

STRETTON STATE COLLEGE
AGES: 12-13

GREG
AGE: 15

We usually do not think about how we breathe unless our breath becomes labored, like when we have a cold or have been exercising. Of course, we all know that breathing is essential for human life and many life forms on Earth, because it brings oxygen (O_2) into our bodies. Why do we need oxygen? Our food can only be converted to energy when oxygen is available. When the food we eat is processed in our bodies, it gets converted to carbon dioxide (CO_2), amongst other things, and the CO_2 is exhaled. The Ocean also breathes: it inhales oxygen at certain places, but it also loses it in others. This happens naturally, through a combination of physical and biological processes. Nowadays, we humans produce increasing amounts of CO_2; because we burn a lot of fuels in our industries, we drive cars, and we do many other things that increase the amount of CO_2 in our atmosphere. This disturbs the natural functioning of the Earth, because CO_2 contributes to global warming. Droughts, floods, and the melting of the polar ice caps are some of the consequences of global warming, but global warming may also disturb the way the Ocean breathes.

HOW DOES THE OCEAN BREATHE IN?

In this article, we are going to talk about the different ways that the Ocean can breathe. First there are tiny organisms; including **cyanobacteria** and **phytoplankton**, which take up CO_2 from the atmosphere and produce oxygen in a process called **photosynthesis** (see Figure 1). Since photosynthesis needs light, this process can only occur in the water layers closest to the surface, about the top 10–100 meters of the Ocean. Even though this area seems very thin, photosynthesis in the Ocean is very important for the Earth, as it is estimated to produce up to 70% of the oxygen on our planet [1] and to remove 30% of human-made CO_2 from the atmosphere [2]. It is important that the Ocean keeps doing this, to keep our planet in a stable condition where the life we know today can continue to exist.

Another way that oxygen gets into the Ocean is when the waves break, and small air bubbles are pushed down into the water. This mechanism mostly takes place in surface waters and at the coasts, and the air bubbles in the water are the main reason waves look white when they break on the beach.

However, there is a place in the Ocean where oxygen is inhaled so deeply that it is taken down into the deep waters where it can stay for thousands of years. This happens in the very north of the Atlantic Ocean, in the Greenland Sea and the Labrador Sea [3], but also in the Southern Ocean in the Weddell and Ross Seas off the Antarctic coast (see Figure 2). Here, oxygen dissolves in the cold water, and the colder the water is,

CYANOBACTERIA

Bacteria that can perform photosynthesis and produce oxygen. They have different shapes; some are small round cells, others are chain-like colonies (one of those chain-like colonies is shown in Figure 1A).

PHYTOPLANKTON

Free-floating tiny organisms, living in the Ocean and other waters, which can perform photosynthesis. Phytoplankton contains a pigment called chlorophyll, which gives them their green color. They have many different shapes and can consist of one or many cells. They are different from cyanobacteria because phytoplankton cells have a nucleus and a cell wall, and their cells also contain other special structures.

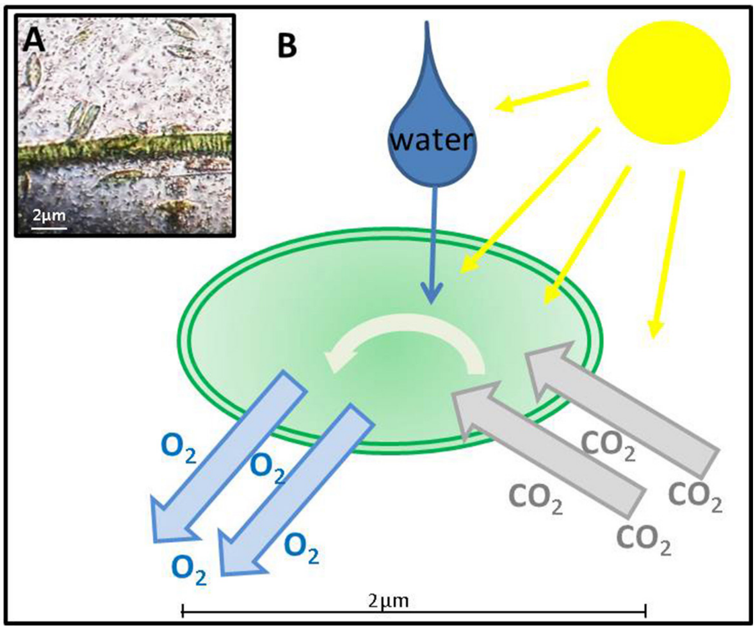

Figure 1

Figure 1

(A) Microscopic picture of a drop of seawater, which contains cyanobacteria and phytoplankton. These organisms produce oxygen in the ocean surface waters, where enough sunlight is available to provide energy for this process. **(B)** This is a model of a cell, for example a cyanobacterium, which takes up CO_2 during photosynthesis. By doing so, it removes some human-made CO_2 from our planet and helps to reduce global warming. The cell needs water and sunlight for photosynthesis, and it produces oxygen, which is released into the environment. The bar at the bottom of each figure indicates the size. A μM is 1/1,000 of a millimeter.

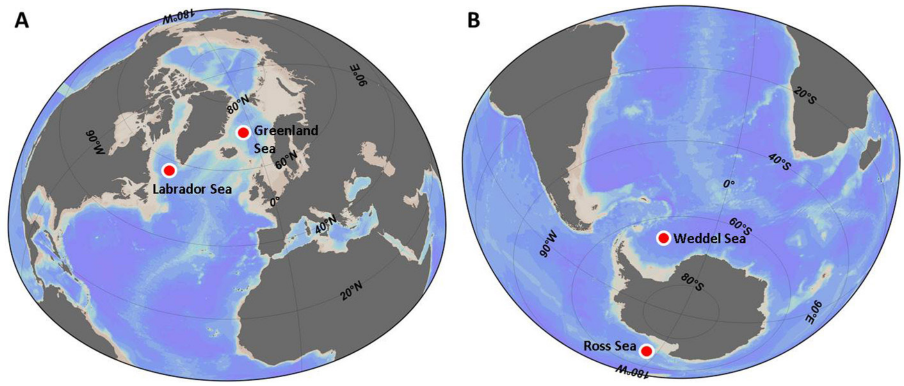

Figure 2

Figure 2

(A) In the Northern hemisphere, surface water is drawn into the deep ocean in the Greenland and Labrador Seas. **(B)** In the Southern hemisphere, the same happens around the Antarctic coast, in the Ross Sea, and the Weddell Sea. The areas where the water is taken down into the deep Ocean by the process of deep convection are marked with red dots.

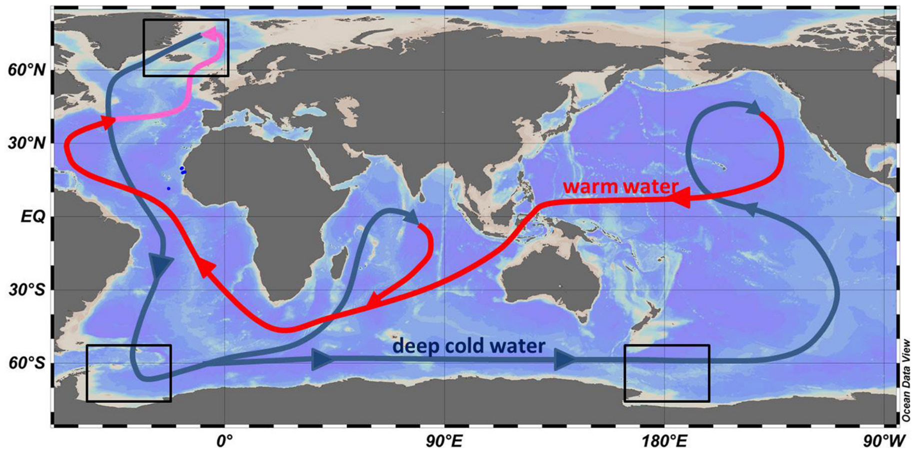

Figure 3

Figure 3

After the water takes up oxygen from the air in the Polar regions, it starts its journey through the deep Ocean (blue lines), where it passes through the Atlantic, Indian, and Pacific Oceans. When the water comes to the surface again, it warms up and travels back through the Oceans at the surface (red lines). In the Atlantic, the Gulf Stream transports the water back to the Labrador and Greenland Seas (pink line), and the travel can start again. This big circulation system, called the global conveyor belt, is the most important circulation system in the Ocean. By transporting oxygen down into the deep waters, it allows animals to live there. The regions where deep convection occurs are indicated with black boxes.

the more oxygen can dissolve (The opposite happens when you boil water, for example when making pasta. There you can see that gases, including oxygen, start to bubble out of the water, and the warmer the water is, the more bubbles come out). Most of the oxygen is therefore taken up in the winter, and because cold water is also denser than warm water, the cold water with oxygen in it sinks down into the deep Ocean, where oxygen would otherwise be rather scarce. This process is called **deep convection**.

The way the water circulates through the Oceans is called "the **global conveyor belt**" and is shown in Figure 3. This movement of water through the ocean starts in the areas of deep water (Figure 2), such as the Labrador Sea, where warm water from the Gulf Stream (see Figure 3) heats the atmosphere in those cold regions. When the water cools down, it becomes denser. This cold, dense water then sinks down to ocean floor. More and more warm surface water is transported to the Labrador Sea by wind currents, where the cold water is continuously sinking down to the deep sea, thus making room for the incoming warm water. When

PHOTOSYNTHESIS

The process by which organisms, such as plants and algae, and microorganisms like cyanobacteria and phytoplankton, take CO_2 from the atmosphere and turn it into oxygen and sugar. Photosynthesizing organisms are usually found only in the top 10–100 meters of the ocean, because these organisms need sunlight as an energy source for photosynthesis.

the deep water reaches the bottom of the ocean, it flows south and passes through the Atlantic Ocean, then through the Indian Ocean, and then through the Pacific Ocean. In the end, the cold water returns to the surface mostly through mixing and a process called upwelling. When the cold water reaches the surface, the water warms up and is transported back to the Labrador Sea by the winds. Thus, the global conveyor belt is a big circulation system connecting all the Oceans.

HOW DOES THE OCEAN LOSE ITS BREATH?

Deep convection in the Ocean depends on the water temperature, but also on the salinity (the "saltiness") of the water. The colder and the saltier the water is, the more oxygen it can take up. Now that the Earth is warming up, snow, glaciers, and the polar ice caps may melt. This is particularly bad in the Polar regions, because the fresh water from this melting ice flows into the sea and forms a layer of water that is far less salty than the seawater. This may lead to less oxygen being taken up by the ocean, which means there will be less oxygen for life in the oceans.

Another reason that the Ocean is losing its breath is that, if the surface layer of water becomes warmer, it does not mix that well with deeper water layers. When the layers stop mixing, the oxygen that is produced by photosynthesis and by exchange with the air cannot get into deeper waters anymore. A lot of life forms in the deeper Ocean breathe oxygen, including fish, starfish, shrimps, jellyfish, and microbes. Particularly in areas where there is a lot of life around, this leads to the formation of **oxygen minimum zones**, which are areas where the water has little or no oxygen left (Figure 4). Those oxygen minimum zones are mostly found in the tropical Oceans, where most of the fish are living. If those

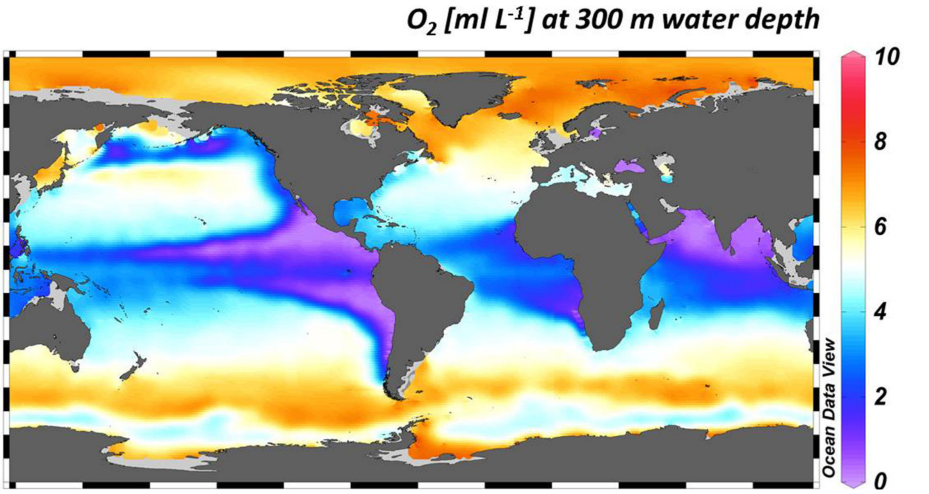

Figure 4

Figure 4

This is the distribution of oxygen in the Ocean at a water depth of about 300 m (data from data from the World Ocean Atlas, WOA09). The scale on the right shows the oxygen concentration in the water, measured in milliliters of oxygen per liter of water. There are regions in the Ocean where there is a lot of oxygen in the water, mostly in the Polar regions, and this is shown in the orange/ red. Blue colors mark the regions where oxygen is low. These regions are called oxygen minimum zones. In large parts of the Pacific and the Indian Oceans, there is no oxygen left (shown in purple). Those are the strongest oxygen minimum zones in the Ocean. The oxygen minimum zone in the Pacific Ocean is also one of the most important fishing areas in the world.

waters lose more and more oxygen, and if less oxygen reaches deeper waters, there is not much space left for fish and other animals to live. This also means that there will be fewer and fewer fish left that humans can eat. The decrease in fish is a big problem, since fish make up 16% of the animal protein consumed by humans around the world [4]. Fish also provide healthy fatty acids that are not found in any other foods. When the oxygen supply of the world's fish is threatened, so is one of our primary food sources [5].

WHAT WILL HAPPEN IF THE OCEAN LOSES ITS BREATH?

We do not know what will happen. Scientists have confirmed that the Ocean is indeed losing its breath, which is to say that oxygen concentrations are going down, at least in certain areas of the Ocean. This means that the oxygen minimum zones are expanding [6]. It is hard to predict what else will happen, mainly because we only have data from the last 50–60 years. This is not a whole lot of time, if you compare it with how long it takes for water to move all the way through the global conveyor belt (thousands of years) or if you compare it with the age of our planet, which is around 4.6 billion years.

One way that scientists try to understand the situation is to compare Earth's present to its past: the Earth and the Oceans have been through similar or worse times, in terms of **global warming** and CO_2 levels. For example, massive changes occurred in the **Cretaceous**, a time in Earth's history that started 145 million years ago and ended 65 million years ago. In this period, there was more than three times as much CO_2 in the Earth's atmosphere than there is now. This CO_2 came from volcanic eruptions [7]. The ocean surface waters had temperatures of up to 40°C, which is more than twice as high as today's ocean temperatures. In the Cretaceous, large amounts of oxygen were lost from the Ocean, until it had no oxygen left for two long episodes called ocean anoxic events. During these events, many life forms became extinct. However, afterwards, new life evolved and the Earth and the Oceans recovered again.

Considering all of this, most people understand why scientists want to find ways around the problem of global warming and stop the Ocean from losing its breath. We want to do something about climate change because we do not want to become extinct. So, we as humans need to become active and stop global warming. This is not so easy to do, because we must drastically reduce the amount of CO_2 we produce; each one of us currently produces tons of CO_2 per year. Everything in our life that needs electricity, like our fridges and computers, as well as wearing clothes that are industrially produced, using cars, eating meat, and many more things in our daily life all produce CO_2.

DEEP CONVECTION

When surface waters in the polar seas cool down, they absorb oxygen and sink to the bottom of the ocean. This process provides oxygen rich water for the global conveyor belt to transport around.

GLOBAL CONVEYOR BELT

When waters circle through first the Atlantic Ocean, then through the Indian Ocean, and then through the Pacific Ocean, we think of the water as traveling along the global conveyor belt. This conveyor belt provides oxygen for a variety of life forms in the ocean.

OXYGEN MINIMUM ZONE

A zone of the ocean that is very low in oxygen.

GLOBAL WARMING

When gases, such as CO_2 increase in quantity in the Earth's atmosphere, the Earth heats up. This effect is known as global warming. CO_2 can come from volcanos, but these days it often comes from burning fossil fuels, which include the oil that was buried deep under the ocean. Fossil fuels are used to generate electricity, fuel our cars, and produce/run a lot of things in our daily lives, such as clothing, fridges, computers, etc.

CRETACEOUS

A time in earth's history that started 145 million years ago and ended 65 million years ago. During this period the Earth was very warm, CO_2 levels are high, and the Ocean turned anoxic several times.

WHAT CAN WE DO TO HELP THE OCEAN CONTINUE TO BREATHE?

The most important way to help keep oxygen in the oceans is to slow down global warming. Around the world, there are several groups working on this. One initiative to track climate change and to study the impact of global warming on the Earth and its oceans is called the Intergovernmental Panel on Climate Change (IPCC). This group collects data, predicts what exactly could happen if the climate keeps getting warmer, and gives recommendations to politicians [8]. By doing these things, the IPCC hopes to directly reduce the CO_2 output on our planet. Many countries also signed an agreement called the Kyoto protocol [9]. This protocol contains guidelines on how much every country has to reduce its CO_2 emissions in order to reduce global warming. By doing these things, scientists and politicians hope to reduce global warming, so that, among other things, the polar ice will stop melting and the Ocean can continue to breathe so that oxygen minimum zones will stop expanding and ocean life will continue to exist.

If you would like to check how much CO_2 you are producing in your daily life, to see if you can do your own part to reduce global warming and help the oceans continue to breathe, you can use these links: https://www.earthday.org/take-action/footprint-calculator, https://www.carbonfootprint.com/calculator.aspx.

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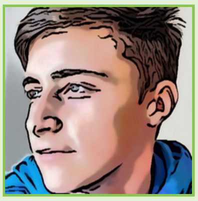
CONFLICT OF INTEREST STATEMENT: The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

YOUNG REVIEWERS

STRETTON STATE COLLEGE, AGES: 12–13

Stretton State College is a school outside Brisbane, Australia with a strong values base which strives to ensure a culture of high expectations for students and staff. Our school is one where students look forward to the challenges and opportunities each day, with an increasing focus on eLearning and the advancements of digital learning. The students who performed this review were enthusiastic 12–13 year olds.



GREG, AGE: 15

Hi, I am 15 years old and having a Transition Year (year out from school between exam courses) from home. My main interest is in physics but I am happy to read most science information that comes my way.

AUTHORS

CAROLIN R. LÖSCHER

I am an Assistant Professor of Marine Biogeochemistry at the University of Southern Denmark, and I am most interested in how climate change influences life in the Ocean and how it will change in the future. I am particularly fascinated by investigating the effects of warming, Ocean acidification, and the loss of oxygen on microbes in the Ocean, because those microbes are very important for all life in the Ocean. *cloescher@biology.sdu.dk

ANDREAS CANFIELD

I am a student at the University of Southern Denmark, currently studying Psychology. I do not have a lot of finished thoughts about my field of study (Psychology) but I am curious to learn and to explore more. I am 23 years old, and still feel as if I have barely scratched the surface of what there is to discover. I am the son of Donald Canfield, an important Earth Scientist, and Marianne Olsen, who has a Degree in Biology. As such, I find myself at an intersection between the "hard" sciences and the "softer" sciences.