An Ocean of Oxygen Producers

Grade Level

6–8 or higher

Timeframe

Two 45-minute class periods

Materials

- Computer, projector and screen
- Presentation (available to download)
- Text documents (available to download)
- Lab materials (described below)

Key Words

Atmosphere, algae, autotroph, carbon dioxide, kelp forest, macroalgae, oxygen production, marine photosynthesis, seagrass

Standards

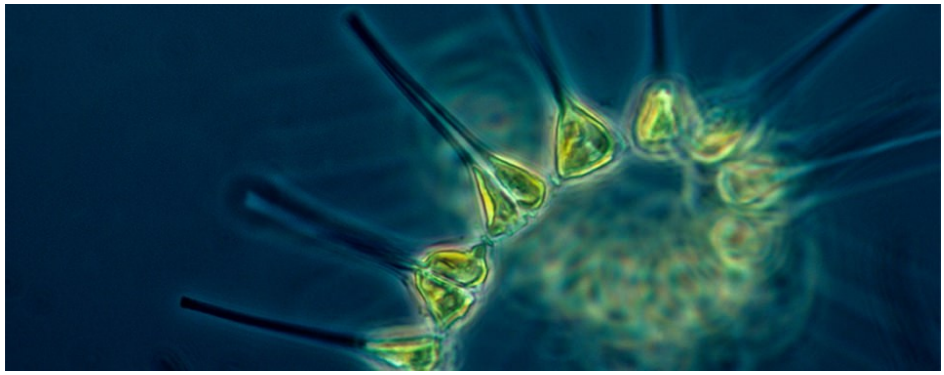
NGSS: MS-LS1-6.
CCSS: W.6.10. SL.6.4.
Ocean Literacy Principles: 4, 5.
Climate Literacy Principles: 3.
Details at end of lesson

Funding support provided by:

National Geographic Society

&

National Marine Sanctuary Foundation



Magnified phytoplankton, also known as microalgae, is one of many ocean producers that creates at least half of Earth's oxygen. Photo: NOAA

Activity Summary

This lesson focuses on how marine photosynthetic organisms contribute oxygen to our atmosphere. Students will design and conduct a lab experiment using an aquatic plant and a chemical indicator of carbon dioxide, bromothymol blue (BTB) solution. They will discover that land plants are not the only organisms that photosynthesize. Students will research and present about a marine organism that photosynthesizes and consider the importance of those organisms as historic and current contributors to atmospheric oxygen.

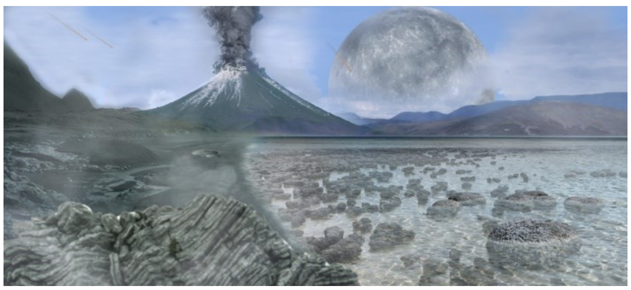
Learning Objectives

Students will:

- Design and conduct an experiment to test if photosynthesis occurs in an aquatic organism
- Argue from evidence about how photosynthesis by marine organisms could impact atmospheric oxygen levels
- Discuss how the ocean produced enough oxygen over eons to make Earth habitable for oxygen-breathing organisms
- Explain the importance of marine autotrophs in the production of oxygen, orally and in writing
- Explain the importance of national marine sanctuaries for protecting highly productive seagrass beds and kelp forests

Background Information

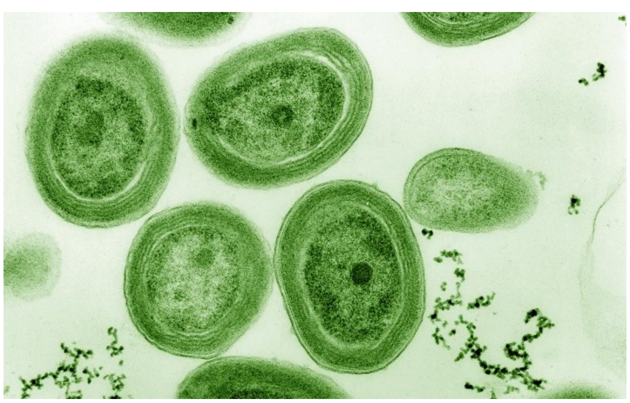
Early Earth was inhospitable to life and its atmosphere was radically different from today's. Scientists believe the early atmosphere was made up of hydrogen and helium. The planet likely consisted almost entirely of molten magma—too hot for known life forms. As Earth's crust began to form, volcanic eruptions occurred frequently. Volcanic activity added ammonia, water vapor and carbon dioxide into the atmosphere. Gradually, the planet cooled and the ocean began to form over millions of years.



Artist's impression of the Archean Eon (about 4 billion years ago to about 2.5 billion years ago) Illustration: Tim Bertelink CC BY-SA 4.0

Where and How Did Our Life-Giving Oxygen Originate?

Approximately 2.2 billion to 2.7 billion years ago, photosynthesizing cyanobacteria evolved in the ocean. As a by-product of photosynthesis, they released oxygen into the atmosphere.



Magnified *Prochlorococcus* cyanobacteria: Their ancient ancestors were likely the first organisms to photosynthesize. Photo: Luke Thompson and Nikki Watson from MIT CC0 1.0

Until 600 million years ago, Earth's atmosphere had less than five percent oxygen. It was mainly a mix of nitrogen and carbon dioxide. Very slowly, over millions of years, cyanobacteria and single-celled algae changed the composition of the atmosphere into what we have today: 78 percent nitrogen and 21 percent oxygen, among other gases. More abundant oxygen set the stage for aquatic animals and plants to make the transition onto land.

Modern Oxygen Producers

Seagrasses, flowering plants found in shallow ocean waters, have been called the "lungs of the sea" because one square meter of seagrass can produce 10 liters of oxygen every day through photosynthesis ("Seagrass and Seagrass beds"). Seagrasses include eelgrass, manatee grass and turtle grass and are found along the East and West Coasts, as well as the Gulf of Mexico and Hawaiian Islands.

A bed of manatee grass *(Cymodocea filiformis)* in Florida Keys National Marine Sanctuary: Seagrass meadows can grow large enough to be seen from space. Photo: NOAA

Marine plants are just one group of ocean-based photosynthetic organisms. Marine algae and some bacteria are also photosynthetic and significant oxygen producers. Single-celled marine algae (phytoplankton), such as diatoms, are powerhouses. Seasonal phytoplankton blooms account for over half the photosynthesis and subsequent atmospheric oxygen production on Earth. Scientists estimate that the oxygen in one of every five breaths we take comes from diatoms. Minuscule *Prochlorococcus*, the photosynthetic cyanobacteria shown above, is the smallest and most abundant photosynthetic cell on the planet. In the ocean they photosynthesize as much as all the crops on land, and up to 20% of the oxygen in our entire biosphere!

The Phenomenal Photic Zone

Because photosynthesis requires sunlight, marine photosynthesizers must live in what is called the "photic zone," the sunlit layer at the top of the ocean. The photic zone extends down to about 656 feet (200 meters) below the ocean's surface. Different photosynthesizers have adapted to live in different light conditions. In contrast with seagrass, which typically grows 3–20 feet (1-6 meters) deep, kelp, a large type of algae, forms undersea forests. They can extend 49–131 feet (15–40 meters) deep and grow up to 18 inches a day!

Sunlight powers a towering kelp forest *(Macrocystis pyrifera)* Photo: NOAA

Dissolved Oxygen: Essential for Animals

Although water (H_2O) molecules contain oxygen atoms, this oxygen is not accessible to fish and other organisms because it is locked up in the water molecule. Dissolved oxygen refers to the oxygen that is dissolved between the molecules of water and is available to organisms for breathing.

Oxygen enters the water through two natural processes:

- Diffusion from the atmosphere and
- Photosynthesis by aquatic plants

The mixing of surface waters by wind and waves increases the rate at which oxygen from the air can be dissolved or absorbed into the water.

Organisms that live in the ocean must have enough dissolved oxygen to survive. Cold water can generally hold more dissolved oxygen than warm water.

Not all oxygen produced in the ocean ends up in the atmosphere. Marine organisms use some in respiration. Decomposition uses up oxygen, as well. Some dead organisms, instead of decomposing, sink deep into the ocean and settle on the bottom. That leaves a tiny amount of oxygen behind, which over time, adds significant amounts to our atmosphere.

Harmful Algal Blooms

Under the right conditions, tiny phytoplankton (algae) may grow out of control and create harmful algal blooms (HABs) in coastal areas. Of thousands of known species of phytoplankton, only a few dozen are known to produce toxic chemicals that can harm fish, shellfish, marine mammals, seabirds and humans. Other algae are nontoxic, but consume all of the oxygen in the water as they decay, clog the gills of fish and invertebrates or smother corals and submerged aquatic vegetation. One benefit of HABs is that higher amounts of carbon dioxide (a greenhouse gas) are removed from the atmosphere. Climate change and increasing nutrient pollution potentially cause HABs to occur more often and in locations not previously affected. Scientists study HABs to better understand how and why these blooms form, and to improve detection and forecasting of these seasonal events.

National Marine Sanctuaries

National marine sanctuaries are a network of underwater areas in the ocean and Great Lakes that protect America's most iconic natural and cultural marine resources. Sanctuaries harbor large areas of highly productive marine photosynthetic organisms. For example, seagrass beds are found in Channel Islands, Florida Keys, Gray's Reef, Greater Farallones, Hawaiian Islands Humpback Whale and Monterey Bay national marine sanctuaries.

All sanctuaries located on the West Coast harbor vast kelp forests, including Monterey Bay, Greater Farallones, Channel Islands and Olympic Coast national marine sanctuaries. The underwater forests not only produce oxygen, but also provide important habitat for many organisms.

A sea lion in the kelp forest at Channel Islands National Marine Sanctuary. Explore the environment in 360 degrees and a supporting lesson plan at https://sanctuaries.noaa.gov/vr/channel-islands/sea-lion-encouter. Photo: NOAA

It is estimated that we have lost 50% of seagrass from our coastlines over the last century, and kelp forests have also been declining in recent years. Thus, protecting these areas is critical to maintaining healthy marine ecosystems, as well as sustaining global oxygen production on which we all depend.

Learn more:

"Formation of Earth." National Geographic Society: https://education.nationalgeographic.org/resource/formation-earth

"How much oxygen comes from the ocean?" NOAA: https://oceanservice.noaa.gov/facts/ocean-oxygen.html

"How seagrass and kelp support habitats' resilience in a changing ocean." Monterey Bay Aquarium: https://www.montereybayaquarium.org/stories/seagrass-kelp-help-climate-change-ocean-acidification

"How has the ocean made life on land possible?" NOAA: https://oceanexplorer.noaa.gov/facts/oceanproduction.html

"Seagrass and Seagrass Beds." Smithsonian: https://ocean.si.edu/ocean-life/plants-algae/seagrass-and-seagrass-beds

"What is a harmful algal bloom?" NOAA: https://www.noaa.gov/what-is-harmful-algal-bloom

Vocabulary	
Atmosphere	A layer of gas and suspended solids extending from the Earth's surface up many thousands of miles, becoming increasingly thinner with distance but held by the Earth's gravitational pull
Autotroph	An organism that makes its own food from light energy or chemical energy without eating: Most green plants, many protists and most bacteria are autotrophs. Autotrophs are the base of the food chain and can also be called producers.
Carbon dioxide	The gas that photosynthetic organisms use for producing carbohydrates and that aerobic organisms produce as a waste product of respiration: It is also produced by burning fossil fuels and is an important greenhouse gas.

Dissolved oxygen	The amount of oxygen dissolved in a given volume of water at a particular temperature and pressure that is available to aquatic organisms
Kelp forest	Towers of kelp (a brown macroalgae) that provide food and shelter for thousands of marine species
Macroalgae	Multicellular marine algae or seaweed, including brown, green and red types
Oxygen cycle	Movement of oxygen through the atmosphere, ocean, biosphere (living things) and the lithosphere (Earth's crust and upper mantle)
Photosynthesis	The process of using energy in sunlight to convert water and carbon dioxide into carbohydrates and oxygen: $CO_2 + 6H_2O$ yields $C_6H_{12}O_6 + 6O_2$
Phytoplankton	Unicellular microscopic marine algae, also called microalgae: They contain chlorophyll and require sunlight in order to live and grow. The two main classes of phytoplankton are dinoflagellates and diatoms. They play a huge role in the marine food web.
Plankton	Small (usually microscopic) plants and animals that drift in ocean tides and currents: They include algae, bacteria, small crustaceans, eggs and larval stages of some larger animals.
Seagrasses	Flowering plants that grow underwater; 60 species are found worldwide

Preparation

- Download (or prepare to show) all the slideshow and text materials for this lesson.
- Gather/prepare materials for a demonstration on day 1:
    - Test tube with spring water and bromothymol blue (BTB) solution, diluted to 0.04%; one option is https://www.carolina.com/specialty-chemicals-b-c/bromothymol-blue-reagent-grade-1-g/849150.pr

      Note: BTB is a weak acid that works as a chemical indicator of pH. It turns blue in alkaline (basic) conditions and yellow-green in acidic conditions.
    - Straw
    - Goggles
    - Disposable gloves
- Prepare these recommended materials for each section/period of students:
    - Light bank, grow lights, windows with blinds up or other full-spectrum light
    - Dark location (an empty cabinet per period works well)
    - Tape (divide space under light bank for each section/period of students)
    - Test tube rack under a light bank or next to a window
    - Test tube rack for the dark location
    - 7-mL dropping pipets
    - 200 mL diluted 0.04% bromothymol blue (BTB) solution

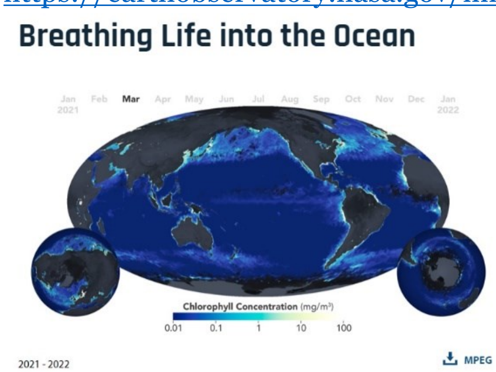
- Forceps
- Test tubes (25 x 150 mm) and test tube stoppers (three of each for each group of students)
- Graduated cylinder
- Markers or wax pencils (one for each group)
- Spring water (Poland Spring works well, due to its mineral composition)
- Carbonated water (can of seltzer with a cover works for multiple groups)
- *Elodea canadensis*, commonly called Canadian waterweed or Canadian pondweed, is a perennial aquatic plant considered invasive in some parts of the U.S., so be mindful of disposal. Let *Elodea* dry out completely and dispose of it on dry land. Tell students not to break it into small pieces.

- Suggested materials for each group of 2–4 students:
  - Disposable gloves
  - Goggles for each student
  - Wax pencil or permanent marker
  - Test tube rack
  - 3 Test tubes and 3 stoppers
  - 2 6-cm sprigs of *Elodea*
- Paper towels
- *Optional:* Dissolved oxygen test kits, such as CHEMetrics Water Test Kits, or dissolved oxygen probe(s), such as those from Vernier

Procedure

Engage

- Show students an animated map showing seasonal change of chlorophyll concentration in the ocean: https://earthobservatory.nasa.gov/images/150656/breathing-life-into-the-ocean.



- Ask students what chlorophyll is, why it's important and why it might be in the ocean. In a think-pair-share, ask students to discuss their ideas. After a minute, ask a couple to share their ideas with the class.
- Conduct a brief demonstration:
  - Put on goggles and gloves.
  - Pour a solution of spring water with 0.04% bromothymol blue (BTB) into a beaker, test tube or other clear container.
  - Using a straw, very gently blow bubbles into the solution to add carbon dioxide to it. (The solution should turn green then yellow.) A quick video demo (0:24) is here: https://youtu.be/VYw2csIBngY
- Ask the following questions, which you could project on the screen or write on the board:
  - What did you observe happening in the test tube as I exhaled?
  - Why might the change have occurred?
  - What gas do we breathe out? How does BTB react when carbon dioxide is present?
- Ask students to think about the questions and discuss them with a partner (think-pair-share). Pass out the "Investigating Oxygen Producers" handout, one for each student, or share the link to it. Ask students to record their responses to questions 1 and 2 on their handouts or in science notebooks.
- After a minute, ask students to share their ideas. Help them understand that adding carbon dioxide causes the color change. (See the Explain section for a more complete explanation.)

Explore

- Day 1
  - Ask students to form science teams of 2–4 students. (Consider if you have enough materials for smaller groups.) Ask them to read question 3 and record what they already know about photosynthesis on the handout or in their science notebook with words and pictures.
  - Show the groups two 6-cm sprigs of *Elodea* and ask them to think about how they might design an experiment to test if small cuttings of plant material like those are able to photosynthesize in water. Also show them the available equipment options like test tubes, test tube racks, spring water and BTB solution. Suggest to the groups that they use #4 on the handout to help them plan their investigations.
  - Circulate through the groups and tell them that they should explain their plans to you before gathering materials and starting their experiments. Inform them that the BTB solution stains skin and clothing. They should wear gloves and goggles while handling materials.
  - One option for an experiment, which you can share with groups if they need help, is to have them label three test tubes with their names and period number noted:

        - Test tube A (control, in regular classroom lighting)
        - Test tube B (experimental, dark condition)
        - Test tube C (experimental, light condition—either under a lamp bank or next to a window)
    - Instruct students to place the appropriate test tube in the light and dark locations.
- Day 2 (48 hours after experiments have been started)
    - Ask students to retrieve their experiments and record any changes they observe on their handouts or in science notebooks.
    - Ask students to answer the remaining questions on the handout and be ready to discuss them with the class.

Explain

- Review answers to questions and use the PowerPoint presentation to engage students in additional critical thinking questions and discussion. The Slide Notes provide additional information, which you can use to add to student ideas.
- Ask them which ecosystem they typically think of when they hear about oxygen production. Discuss how at least half of the oxygen production on Earth comes from the ocean, and 20% comes from *Prochlorococcus* cyanobacteria alone! Explain that most oxygen produced in the ocean is consumed by marine life; land animals breathe oxygen produced over millions of years. More info: https://oceanservice.noaa.gov/facts/ocean-oxygen.html
- Discuss how the atmosphere has changed from hundreds of millions of years ago, when it was only about 5% oxygen (compared to 21% today). More info: https://www.whoi.edu/know-your-ocean/did-you-know/does-the-ocean-produce-oxygen
- *Optional:* Show one or both of these videos to help explain important concepts:
    - "The Ocean is Earth's Oxygen Bank" (4:30). Woods Hole Oceanographic Institution: https://youtu.be/BmLcy5Rcd4g
    - "Today I Learned: 20% of Our Oxygen Comes from a Bacteria" (1:49). National Geographic Education: https://education.nationalgeographic.org/resource/til-20-our-oxygen-comes-bacteria (Prochlorococcus and its contribution to oxygen production)
- Add to the explanation of what happened when you blew into the BTB solution. Share that carbon dioxide creates carbonic acid when it reacts with water molecules. This causes a dissociation of hydrogen ions that makes the BTB solution more acidic (and lowers the pH). Ask students to think about what impact extra carbon dioxide added to the atmosphere might have on the ocean. Discuss their ideas and how the ocean has been absorbing about half of the extra CO2 humans have been adding to the atmosphere through the burning of fossil fuels. This is making the ocean more acidic and threatening marine food webs. Fortunately, marine producers like seagrass, kelp and phytoplankton can reduce the problem, including at local levels. For instance, seagrass has been shown to make the area around it less acidic, supporting growth of oyster larvae and other shellfish in the critical

first days of their life cycle when they are most vulnerable to ocean acidification. Learn more from Smithsonian: https://ocean.si.edu/ocean-life/invertebrates/ocean-acidification.

- Ask students to reflect on why it is important to have marine sanctuaries. Discuss how the future might look if these ecosystems are both protected and conversely unprotected from human-caused threats. Invite students to brainstorm actions that people can take to mitigate these threats and how marine plant communities might benefit from special protection.
- Introduce the research project on marine photosynthetic organisms.
    - Pass out the "Ocean of Oxygen Presentations" handouts, one for each student or pair of students if you would like them to work with a partner. Optional: Distribute photographs of different phytoplankton (diatoms and dinoflagellates), cyanobacteria, macroalgae and marine plants.
    - Ask students to choose organisms they would like to research, ranking them in order in the blanks provided. Then go around the class and assign organisms based on students' choices. Ask students to locate information about their marine organism and answer the assigned questions using online and print resources. The following websites are good options reviewed by scientists:
        - National Marine Sanctuaries: https://sanctuaries.noaa.gov
        - NOAA: https://www.noaa.gov
        - National Geographic Education: https://www.nationalgeographic.org/society/education-resources
    - Discuss the "Ocean of Oxygen Presentations" rubrics, which can be printed on the back of the handouts, so students know how they will be assessed. Tell them that they should complete the "Your Score" column and hand it in to you when they are ready to present to the class about their organisms that are so critical to life on Earth.
    - When students turn in their rubrics, ask them to share their presentations with the class. Note: The next lesson in the series includes a poster presentation project. Students may not all need to present this project; those students may present in the next lesson.

Enrich/Extend

- If you live near the coast or Great Lakes, contact your local national marine sanctuary's education staff to arrange a field study on marine/aquatic photosynthesis. Remote field studies or guest speakers may also be possible via the internet.
- Ask students to research the importance of seagrasses or kelp to Indigenous people from the region. For example, in Hawaii, students may research the significance of limu (algae/seaweed) in Hawaiian culture and ecosystems. Or, ask them to research how cattails benefit estuary and freshwater ecosystems and the ways they have been important to Indigenous cultures since time immemorial.
    - Details about different edible limu species and how they are used: http://www.hawaii.edu/reefalgae/publications/ediblelimu

- “Taking a Closer Look at Seaweeds” lesson plan: https://coast.noaa.gov/data/SEAMedia/Lessons/G4U3L4%20Taking%20a%20Closer%20Look%20at%20Seaweeds.pdf

- Offer one or more marine macroalgae species (e.g. Acetabularia, Polysiphonia, Rhodymenia) as options with which students can experiment. The species are available from biological supply companies or they may be purchased from a pet store that maintains salt water fish. You might also provide one or more macroalgae species from a local tidal zone.
- Ask students to measure dissolved oxygen levels in their test tubes using dissolved oxygen test kits or probes. These levels can be graphed over time and compared between experimental setups.
- Ask students to create visual models of marine food webs that show how photosynthetic organisms are a critical part of them. Information can be found at https://www.noaa.gov/education/resource-collections/marine-life/aquatic-food-webs. An exemplar is here: https://oceanservice.noaa.gov/education/marine-ecosystem-modeling-vr/ocean-food-webs/activity-2.html. One for the Gulf of Mexico is here: https://response.restoration.noaa.gov/ecosystem-components-and-food-web-gulf-mexico.

Evaluate

- Review student experimental design plans and answers to the handout questions.
- Evaluate students’ presentations with the “Ocean of Oxygen Producers” rubrics. Provide feedback to students. You might offer them the opportunity to revise their projects, if necessary.

Education Standards	
Next Generation Science Standards	Matter and Energy in Organisms and Ecosystems • MS-LS.1.C: Organization for Matter and Energy Flow in Organisms: Plants, algae (including phytoplankton), and many microorganisms use the energy from light to make sugars (food) from carbon dioxide from the atmosphere and water through the process of photosynthesis, which also releases oxygen. These sugars can be used immediately or stored for growth or later use. • MS-LS1-6: Construct a scientific explanation based on evidence for the role of photosynthesis in the cycling of matter and flow of energy into and out of organisms. Science and Engineering Practices: • Asking Questions (for science) • Analyzing and Interpreting Data • Developing and Using Models • Engaging in Argument from Evidence • Obtaining, Evaluating and Communicating Information • Planning and Carrying Out Investigations Crosscutting Concepts: • Cause and Effect • Energy and Matter • Structure and Function
Common Core State Standards	Writing: W.6.10 Write routinely over extended time frames (time for research, reflection, and revision) and shorter time frames (a single sitting or a day or two) for a range of discipline-specific tasks, purposes, and audiences. Speaking and Listening: SL.6.4 Present claims and findings, sequencing ideas logically and using pertinent descriptions, facts, and details to accentuate main ideas or themes.
Ocean Literacy Principles	4. The ocean makes Earth habitable. (a) 5. The ocean supports a great diversity of life and ecosystems. (a)
Climate Literacy Principles	3. Life on Earth depends on, is shaped by, and affects climate. (e)

Additional Resources

"Meet the obscure microbe that influences climate, ocean ecosystems, and perhaps even evolution." *Science* video (3:28): https://youtu.be/grmMBbHcu_Q

"Oxygen and Carbon Dioxide." Michigan Sea Grant: https://www.michiganseagrant.org/lessons/lessons/by-broad-concept/earth-science/water-quality/oxygen-and-carbon-dioxide

"The tiny creature that secretly powers the planet | Penny Chisholm." TED: https://youtu.be/ylOlZz7s52Q

“What is seaweed?” NOAA: https://oceanservice.noaa.gov/facts/seaweed.html

“Seaweeds.” Olympic Coast National Marine Sanctuary: https://olympiccoast.noaa.gov/living/marinelife/seaweed

“Seagrass Beds in Tomales Bay.” Greater Farallones National Marine Sanctuary: https://nmsfarallones.blob.core.windows.net/farallones-prod/media/archive/eco/tomales/pdf/tomalesbay_seagrass_lecture.pdf

“Kelp Forest and Rocky Subtidal Habitats.” Monterey Bay National Marine Sanctuary: https://montereybay.noaa.gov/sitechar/kelp1.html

“With Every Breath You Take, Thank the Ocean.” Smithsonian: https://ocean.si.edu/ocean-life/plankton/every-breath-you-take-thank-ocean

“Does the ocean produce oxygen?” Woods Hole Oceanographic Institute: https://www.whoi.edu/know-your-ocean/did-you-know/does-the-ocean-produce-oxygen

For More Information

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