The Mystery of the Disappearing Shells

Grade Level

5–8 and up

Timeframe

Two 45-minute class periods

Materials

- White vinegar, bivalve shells, salt, glass containers (see Explore section for full list)
- Computer, projector and screen
- Interactive presentation (available to download)

Key Words

Bivalve, carbon dioxide, fossil fuels, ocean acidification, pH, shell-building organisms

Standards

NGSS: MS-LS2-4.
CCSS: W.6.10. SL.6.4.
Ocean Literacy Principles: 5, 6.
Climate Literacy Principles: 6, 7.
Details at end of lesson

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&

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Shellfish like this razor clam near Olympic Coast National Marine Sanctuary have been an important food and economic engine of Indigenous communities since time immemorial. How does changing ocean chemistry threaten these important fisheries? What can we do about it? Photo: David J. Ruck/NOAA

Activity Summary

Students conduct an experiment to examine the effects of acidic solutions on shells. They explore causes of ocean acidification and impacts on marine life, including the impacts of acidified seawater on bivalves, such as clams, mussels and oysters. They also discuss ways of reducing levels of carbon dioxide in the atmosphere to mitigate the problem.

Learning Objectives

Students will:

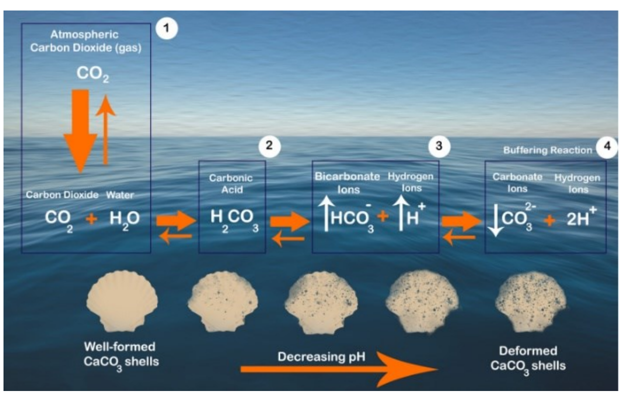
- Analyze results from an experiment on bivalve shells placed in acidic and neutral solutions.
- Argue from evidence about how a change in ocean acidity alters bivalve biology.
- Describe how increased greenhouse gases in the atmosphere results in more acidic ocean water.
- Propose solutions to limit the impacts of greenhouse gases on the ocean environment.
- Explain the cultural importance of bivalves to Indigenous peoples and other communities.

Background Information

Fundamental changes in seawater chemistry are occurring throughout our global ocean. Burning fossil fuels for energy production, manufacturing and transportation have driven the level of carbon dioxide (CO_2) in the atmosphere to levels 30% greater than prior to the Industrial Revolution. The ocean absorbs about a quarter of the CO_2 we release into the atmosphere every year, so as atmospheric CO_2 levels increase, so do the levels in the ocean.

Ocean Acidification

Initially, many scientists focused on the benefits of the ocean removing this greenhouse gas from the atmosphere. However, decades of ocean observations now show that there is also a downside; the CO_2 absorbed by the ocean is lowering its pH, a process called ocean acidification. The ocean's average pH is now around 8.1, which is basic (or alkaline), but more acidic than historical levels. By the end of this century the surface waters of the ocean could have a pH around 7.8.



Adding CO_2 lowers the pH of ocean water. It makes it harder for marine creatures to build shells and skeletons with calcium. Graphic: Maryland Sea Grant/NOAA

As shown in the chemical formula above, when carbon dioxide dissolves in seawater, it creates carbonic acid, which releases bicarbonate ions (HCO_3^-) and hydrogen (H^+) ions into the water. The hydrogen ions make the seawater more acidic (lowering its pH). In addition, some of the hydrogen ions react with carbonate ions ($CO_3^{=}$) already in the seawater to create more bicarbonate. This reduces the amount of carbonate dissolved in the seawater, which is an important mineral for building shells.

Impacts on Organisms

Many organisms are very sensitive to either direct or indirect effects of changes in acidity (or H^+ concentration) in the marine environment. Respiration, photosynthesis and reproduction may be impacted. Lower carbonate ion concentrations in the environment can result in reduced growth of organisms that form calcareous skeletons or shells, such as corals, pteropods (free swimming marine snails) and bivalves (such as oysters, clams and mussels).

Acidified water corrodes calcium carbonate minerals—an essential ingredient for shell-building and skeleton-building organisms. Acidified water off the West Coast is eating away at the shells of tiny pteropods that swim near the ocean's surface and provide food for a variety of fishes. Oyster spawning failures in Washington state have been linked to periodic upwelling of more acidic ocean waters. A variety of fisheries are stressed by fluctuating ocean pH.

Cultural and Economic Importance

Clams and other shelled mollusks are culturally important to many coastal Indigenous peoples, providing food, income and communal activities. Razor clams have sustained the Quinault Indian Nation, a Coastal Treaty Tribe located in Washington state along the Olympic Coast, for generations. Direct impacts of acidification to Pacific razor clams *(Siliqua patula)* have not yet been shown, but Liang et al. (2022) observed negative impacts on the digestive systems of another species of razor clams. Quinault tribal members have also observed increased shell breakage when harvesting. Scientists continue to monitor for changes within this area that is now designated Olympic Coast National Marine Sanctuary, as well as in other sanctuaries.

The jobs and livelihoods of many U.S. fishermen, restaurant workers and seafood retailers depend on healthy clam and shellfish populations. A recent study showed the vulnerability of the $1 billion U.S. shellfish industry to ocean acidification.

A Hopeful Future

National marine sanctuaries are sentinel sites used to better understand the threats facing the ocean, including acidification. Research at the sites enhances our understanding of natural and historical resources and how they are changing. They also provide an early warning capability to detect changes to ecosystem processes and conditions.

NOAA's national marine sanctuaries are:

- Actively eliminating and reducing risks to the ocean by working with communities through focus groups, advisory councils, education, outreach and resource protection programs.
- Supporting and conducting research that brings experts together to safeguard habitats and maintain healthy fisheries for people.
- Protecting shellfish habitat encompassed in thousands of square miles of ocean conservation space by prohibiting oil and natural gas exploration and extraction, deep sea mining and reducing water pollution.

We can all work toward reducing ocean acidification. Individuals can reduce their carbon footprint by using less energy generated by fossil fuels, like coal, oil and natural gas. We can help remove carbon from the atmosphere by planting trees and shrubs and restoring marine ecosystems like eelgrass beds and kelp forests. Find out what your local government, businesses and schools are doing to reduce use of fossil fuels and transition to renewable, clean energy. Advocate for change in your community and help empower our young people to take action for healthy ecosystems that will sustain them and future generations.

A tiny sea butterfly, or pteropod, floats in the kelp forest of Channel Islands National Marine Sanctuary. Photo: Evan Barba

Learn more:

Liang, J. et al. (2022). "Impact of Ocean Acidification on the Physiology of Digestive Gland of Razor Clams *Sinonovacula constrict*a." Frontiers in Marine Science: https://www.frontiersin.org/articles/10.3389/fmars.2022.1010350/full

"Ocean Impacts of Climate Change." National Geographic Society: https://education.nationalgeographic.org/resource/ocean-impacts-climate-change

"Ocean Acidification." NOAA: https://www.noaa.gov/education/resource-collections/ocean-coasts/ocean-acidification

"Sanctuary Sentinel Site Program." NOAA: https://sanctuaries.noaa.gov/science/sentinel-site-program

"What is Ocean Acidification?" NOAA: https://www.pmel.noaa.gov/co2/story/What+is+Ocean+Acidification%3F

"Understanding Ocean Acidification." NOAA Fisheries: https://www.fisheries.noaa.gov/insight/

understanding-ocean-acidification

Vocabulary	
Bivalve	An aquatic mollusk that has a body enclosed within a hinged shell, such as oysters, clams, mussels and scallops
Carbon dioxide	A colorless, odorless gas present in the atmosphere and produced by the combustion of fuels
Fossil fuels	Any combustible organic material (e.g., oil, coal or natural gas) derived from the remains of former life
Ocean acidification	Decrease in pH of the ocean caused by the uptake of atmospheric carbon dioxide
pH	A logarithmic scale of hydrogen ion concentration

Preparation

- Download (or prepare to show) the "Mystery of the Disappearing Shells" presentation and associated videos listed below.
- Assemble and prepare the materials for the experiment.
  - Four or more glass jars with airtight lids (e.g., Mason jars, empty tomato sauce jars) 16 oz. or larger to contain the different solutions and shells.
  - At least 600 ml (about 20 oz.) of white vinegar
  - At least 250 ml (about 8 oz. or 1 cup) of carbonated water (e.g., seltzer or sparkling water)
  - At least 11.4 grams (2 teaspoons) of salt
  - At least 12 empty bivalve shells from clams, mussels or oysters (or a combination of these). Clean them of all organic matter and pat dry.
    - With a permanent marker, label three (or more) shells so you know which shell will be placed in which solution. (This is important if students weigh shells in the Enrich/Extend portion of the activity.)
  - A measuring cup, 1 teaspoon, stirring rod
  - pH test strips or a digital pH meter/probe
  - *Optional* (for Enrich/Extend activity): digital scale

Procedure

Engage

- Show students the images on slide 2 of the "Mystery of the Disappearing Shells" presentation. Ask the questions on the screen:
  - What type of organism might these be?

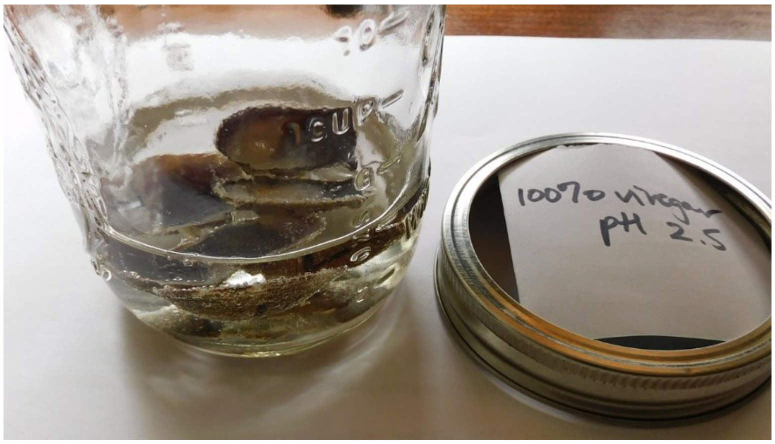
- What differences do you observe?

- Ask students to turn to a neighbor and discuss the questions in a think-pair-share, recording their ideas in science notebooks. After a minute or two, ask them to share their ideas with the class. Discuss student ideas, then click the presentation to reveal that they are pteropods (sea butterflies).
  - Explain that they are free-swimming sea snails about the size of a pin head that make up an important part of plankton. They are a critical component of ocean food webs, eaten by larger animals such as juvenile salmon and huge whales.
  - You might show the short video "Swimming pteropods – *Limacina helicina antarctica*" (0:10) from the Ocean Carbon & Biogeochemistry (OCB) program: https://youtu.be/I2qFleu3aXY.
- Advance to slide 3. Ask:
  - What do you think is happening to the pteropod shell in the series of images? Why?
- Discuss student ideas and tell them that this is a phenomenon scientists have observed around our global ocean, especially in certain areas. Scientists hypothesized changing ocean chemistry altered pteropod shells and they will investigate a similar phenomenon today.
- Show them the shells to be used in the experiment. Ask:
  - Do you know what organisms created these shells? Where do they live?
  - What are the shells composed of?
  - How do the organisms get the materials to build shells?

Explore

- Advance to the "Let's Experiment!" slide. Ask students to form science teams of four.
- Either as a demonstration or with students' help, create four solutions that vary in acidity.
  - In one jar, add 250 ml (about 1 cup or 8 oz.) of white vinegar. (If you plan to add more than three shells to each solution, ensure there is enough vinegar to cover all shells.)
  - In a second jar, add 125 ml (about 1/2 cup or 4 oz.) of white vinegar + 125 ml (about 1/2 cup or 4 oz.) of tap water.
  - In a third jar, add 250 ml (about 8 oz.) of carbonated water.
  - In a fourth jar, create a saltwater solution by adding 11.4 grams (2 level tsp.) of salt to 250 ml (about 1 cup) of tap water. Stir in the salt until it dissolves.
  - Label each jar as "100% vinegar," "50% vinegar," "carbonated water" and "saltwater."

- Ask a student assistant to measure the pH of each solution by dipping a test strip and removing it immediately from the solution. (Follow the instructions for your specific test strips.) Or, use a digital pH meter to measure the pH levels.
- Take photos of the shells so you have a record of what they look like before placing them in solutions. Share the photos with students so they can compare them with the post-experiment shells.
- Place three or more labeled bivalve shells into each solution.
- Ask student groups to observe what is happening in each jar immediately after the shells have been added. They should record their observations in science notebooks, taking care to record the solution type, the pH and associated observations.



- Ask students to share their observations in a class discussion. Then ask them questions such as those below to get them thinking, which you could project or write on the board:
    - Is vinegar an acid or a base? What is an acid? How does pH relate to acids? Note: Scientists caution about equating acid and pH, as explained in "A Primer on pH" from NOAA's PMEL Carbon Program: https://www.pmel.noaa.gov/co2/story/A+primer+on+pH
    - Which of the solutions do you think are acidic? Why?
    - What do you hypothesize will happen to the shells after sitting in each solution for one week?
    - What causes the bubbles in a carbonated beverage? Are carbonated beverages acidic?

  Ask students to discuss the questions in their groups and record ideas in science notebooks.
- Set aside the jars in a safe location for one week.
- After one week, ask student groups to observe changes in each of the jars. They should record their observations in science notebooks.

Explain

- In a full class discussion, ask one or more groups to share their observations. Ask:

- In which solution did you see the most change? What happened? In which solution did there appear to be the least amount of change?
- How does an acidic solution (with a low pH) impact organisms with shells? Why are they particularly vulnerable?
- Ask students if they have heard of the term “ocean acidification” and encourage them to share what they know about it. Fill in details, as necessary, with the support of the graphic on slide 5.
- Share that vinegar (acetic acid) has an extremely low pH, which is not representative of conditions in the ocean. (Acetic acid is not responsible for ocean acidification. It is used in this experiment to show change over a short period of time.)
- Discuss student ideas about why bubbles appear in acidic solutions. Fill in details, as necessary, such as:
  - Acetic acid in the vinegar reacts with the calcium carbonate in the shell, releasing a gas. Ask students to think about what gas it is and discuss how carbon dioxide is released and the shell is weakened by the chemical reaction. (Bubbles produced in the jars with vinegar are carbon dioxide.)
  - Explain that pH is measured on a logarithmic scale (like earthquakes) and a small change in pH from 8.2 to 8.1 corresponds to an increase in acidity of about 30%.
  - Values of 7.8–7.9 are expected in the ocean by 2100, representing a doubling of acidity.

- Show students the “Earth is Blue” video (or a clip) about the Quinault Indian Nation’s razor clam dig in Olympic Coast National Marine Sanctuary and/or ask them to read the story: https://sanctuaries.noaa.gov/magazine/2/quinault-razor-clam-dig.
  - Ask students to reflect on how a change in pH in the ocean might affect the shelled organisms that live there, especially in their larval form.
  - Ask: How might ocean acidification affect the cultural practices of the Quinault people?
  - Ask students if they know of other areas where clams, mussels, oysters or scallops are harvested. How might ocean acidification affect those local economies? Discuss student ideas and how fisheries are stressed by acidification.
- Show slide 5 that describes how ocean acidification occurs and affects marine organisms. Depending on your class you might briefly talk students through the chemical equation.
  - Ask students to describe in their own words how a change in ocean pH alters bivalve biology. They should use observations from the experiment to support their argument.
- Advance to slide 6 and ask students: “What is this graphic model showing?” Discuss their ideas. You might ask them to make their own model that explains the process of ocean acidification—and what we can do about it—in science notebooks.

- Advance to the slide showing the map of national marine sanctuaries and monuments. Discuss which of the sanctuaries might be impacted by ocean acidification in the coming years. This can be done as a think-pair-share, then students can share their ideas with the class.
- Close with small group discussions that give students a chance to reflect on ways society can reduce carbon dioxide in the atmosphere and ocean. Students can brainstorm local actions that can be taken to address the problem.

Enrich/Extend

- Participate in a service-learning project such as tree planting in your schoolyard or another nearby area that will help to reduce the problem of too much carbon dioxide in the atmosphere. Reach out to local organizations and governmental agencies that might want to partner on the project that will help your students feel empowered to reduce the urgent problems of too much carbon dioxide in the atmosphere and ocean acidification.
- If you live near the West Coast, where Dungeness crabs are found, consider using pieces of crab shell instead of or in addition to shells in each solution. A Dungeness crab case study with slides and infographics is at https://sanctuaries.noaa.gov/education/crab-toolkit.html.
- If you have a sensitive digital scale, ask students to weigh each dry shell before placing shells in the solutions. (Ensure each shell is labeled clearly with a permanent marker.) After one week, ask students to remove the shells from the solutions and dry and weigh the shells. They should record their measurements in science notebooks.
    - Have students calculate the percent weight change over the duration of the experiment (ending weight-beginning weight)/beginning weight X 100. Example: (6-7) / 7 X 100 = -14% change from beginning weight
    - Have the class make a line graph with pooled classroom data with pH on the x-axis and percent weight loss on the y-axis.
- Advance to slide 10 of the presentation. Discuss how scientists are able to understand changes in ocean chemistry through a worldwide network of scientific buoys and other data collection devices. See the "Global Ocean Acidification Observing Network (GOA-ON)" (http://www.goa-on.org/home.php) and GOA-ON Explorer to learn more: http://portal.goa-on.org/Explorer.
- When you are discussing pteropods at the beginning of the lesson and/or in the Explain section, show one or both of these short videos (or a clip):
    - "The Effects of Ocean Acidification on Pteropod Shells" (0:29). NOAA: https://youtu.be/6H_VDhXiFk4
    - "Pteropods: Swimming Snails of the Sea" (2:45). MBARI: https://youtu.be/3-40RU3iSkA

Evaluate

- Ask students to summarize what they learned about ocean acidification in science notebooks and/or a class discussion. Encourage students to add illustrations with labels to their written accounts.
- Ask groups to draw a model of how ocean acidification occurs and its impact on organisms with shells.
- Review science notebooks and assess contributions to group and class discussions.

Education Standards	
Next Generation Science Standards	Ecosystems: Interactions, Energy, and Dynamics • MS-LS2-4: Construct an argument supported by empirical evidence that changes to physical or biological components of an ecosystem affect populations. Science and Engineering Practices: • Engaging in Argument from Evidence • Planning and Carrying Out Investigations Crosscutting Concepts: • Cause and Effect • Systems and System Models
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	5. The ocean supports a great diversity of life and ecosystems. (f) 6. The ocean and humans are inextricably interconnected. (d, e)
Climate Literacy Principles	6. Human activities are impacting the climate system. 7. Climate change has consequences for the Earth system and human lives.

Additional Resources

"Understanding Ocean & Coastal Acidification: Teacher Resources." NOAA: https://dataintheclassroom.noaa.gov/ocean-acidification/understanding-ocean-coastal-acidification-teacher-resources

"Acidification Impedes Shell Development of Plankton off the U.S. West Coast." NOAA: https://research.noaa.gov/article/ArtMID/587/ArticleID/2705/Acidification-impedes-shell-development-of-plankton-off-the-US-West-Coast

"Acidifying Waters Corrode Northwest Shellfish." PBS NewsHour video: https://www.pmel.noaa.gov/co2/story/Ocean+Acidification%27s+impact+on+oysters+and+other+shellfish

Kennedy, C. (2014). “Ocean Acidity Dissolving Tiny Snails’ Protective Shell.” Climate.gov: https://www.climate.gov/news-features/featured-images/ocean-acidity-dissolving-tiny-snails%E2%80%99-protective-shell

“Vinegar is to an Eggshell What Ocean Acidification is to Marine Ecosystems.” NOAA Science on a Sphere: https://sos.noaa.gov/education/phenomenon-based-learning/vinegar-eggshells-and-ocean-acidification

“The Olympic Coast as a Sentinel Video.” NOAA Ocean Acidification Program and partners: https://www.pmel.noaa.gov/co2/story/The+Olympic+Coast+as+a+Sentinel+Video

For More Information

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