Office of National Marine Sanctuaries
National Oceanic and Atmospheric Administration

Calcifiers and Non-Calcifiers: Impacts of Ocean Acidification on Marine Organisms

P Artwork: Laurie Mahan Sawyer

Grade Level

6-12

Timeframe

70 Minutes

Materials

- NOAA's video "What is Ocean Acidification?" (1:04 min)
- Calcifiers and non-calcifiers: Images for Sorting Activity
- Calcifiers and non-calcifiers: Directions for Sorting Activity
- Chart: "Summary of Ocean Acidification Impacts Among Key Taxonomic Groups"
- Student Worksheet

Artwork: Laurie Mahan Sawyer

Activity Summary

This lesson focuses on ocean acidification and how it affects a variety of marine organisms. Students will learn the difference between calcifying and non-calcifying organisms and investigate impacts of ocean acidification on key taxonomic groups.

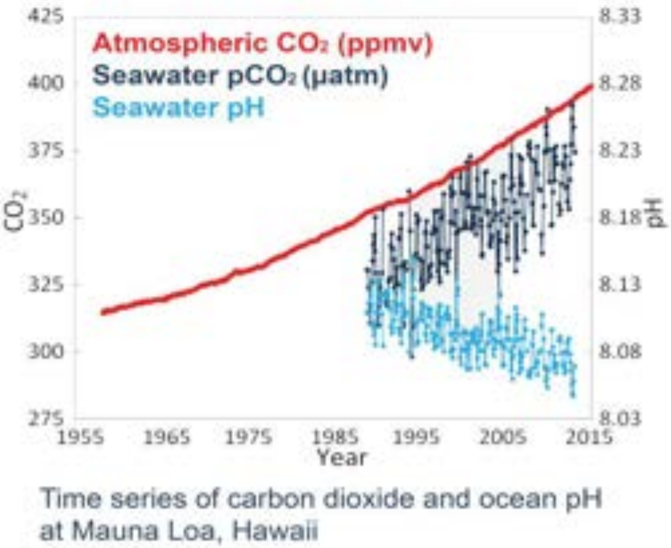
Learning Objectives

Students will be able to:

- Describe what is causing the ocean to increase in acidity;
- Explain the difference between calcifying and non-calcifying marine organisms;
- Describe various ways marine organisms are affected by ocean acidification; and
- Discuss ideas for possible solutions to the problem of ocean acidification.

Background Information

Ocean acidification (OA) is occurring around the world because our ocean is absorbing increasing levels of carbon dioxide gas (CO_2) from the atmosphere. Since the start of the Industrial Revolution, the burning of fossil fuels like coal, oil, and gas and changing land use have caused a sharp increase in atmospheric CO_2 concentration from 280 to over 410 parts per million. The ocean absorbs much of this rampant (or excess and increasing) carbon dioxide, leading to lower pH (greater



NOAA Ocean Acidification Program

acidity). This is causing a fundamental change in the chemistry of the ocean around the world.

Ocean acidification refers to this change in ocean chemistry in response to the increasing atmospheric carbon dioxide. The ocean surface is tightly linked with the atmosphere absorbing huge amounts of CO2. This exchange, in part, helps to regulate the planet's atmospheric CO2 concentrations, but comes at a cost for the ocean and life within it; from the smallest, single celled algae to the largest whales.

Ocean Chemistry-

Increases in carbon dioxide (CO2) in the atmosphere drive corresponding increases in dissolved CO2 within the surface waters of our ocean. This dissolved CO2 reacts with seawater to form carbonic acid (H2CO3). The complex chemistry of carbon dioxide and carbonic acid in the ocean causes the seawater to become more acidic, and makes carbonate ions (CO_3^{2-}) relatively less abundant. Carbonate is a very important building block of calcium carbonate structures such as shells and coral skeletons made by marine animals. Decreases in seawater carbonate ions can make building and maintaining shells and other calcium carbonate structures more difficult for calcifying marine organisms such as shellfish, coral, and certain groups of plankton (pteropod mollusks, foraminifera, and coccolithophores).

Ocean Acidification Impacts on Marine Organisms-

Research suggests that ocean acidification will directly affect a wide variety of organisms from calcifying shellfish and coral to fish and plankton. How marine organisms respond to ocean acidification will be influenced by their reaction to the chemistry change and their interactions with others species, such as their predators and prey. In addition to the impact on calcium carbonate structures, negative responses of marine organisms from lowered pH of seawater include: decreased survival and abundance in many species, as well as reduced growth, development, and reproduction rates; impaired olfactory sense in juvenile salmon and other fish species; and changes in fish behavior to predators. Research results demonstrate increased negative effects to ocean acidification when organisms are exposed to an additional stressor, including increased temperatures, overfishing, pollution, eutrophication, and available food supply. The degree of impacts to marine populations will most likely result in a patchwork of ocean acidification hotspots along our coastlines.

Key Words

- Carbon dioxide
- Ocean Acidification
- Carbonic Acid
- Calcium Carbonate
- Calcifying organisms
- Coral Skeletons Stressors

Dogwhelks preying on mussels and barnacles.

Vocabulary

Ocean chemistry: The chemical properties and composition of seawater.

Ocean Acidification: A change in ocean chemistry in response to the absorption of excess carbon dioxide from the atmosphere.

Calcium Carbonate: A white crystalline compound that occurs naturally in coral skeletons and mollusk shells, as well as limestone and marble. Chemical symbol $CaCO_3$. It is a building block for shells of marine organisms

Calcifiers: Marine organisms that make their shell or part of their body using calcium carbonate from the seawater.

Multiple stressors: Factors such as increased temperature, overfishing, eutrophication, and pollution, which together can interact to create challenges to the survival of organisms.

For species like the California mussel (*Mytilus californianus*), a keystone species in rocky intertidal ecosystems along the West Coast, OA can mean thinner shells, making them more vulnerable to predators like the dogwhelk, a marine snail that preys on mussels by drilling through their shells. As pH lowers, it takes more energy to build a strong shell, so it makes the available food supply critical in determining how well mussels can cope with OA.

Numerous studies on the response of marine organisms to ocean acidification are summarized in the handout, *Summary of impacts of ocean acidification among key taxonomic groups, based on Kroeker et al. 2013*.

Ocean acidification also affects human communities, with major impacts on coastal Tribal groups and other communities that depend on shellfish harvest for food, economic livelihood, and traditional ceremony.

Preparation

- Download NOAA's video "What is Ocean Acidification?"
- Calcifier and Non-calcifiers Sort Activity:
  Print a copy of "Directions for Sorting Activity" for each small student group.
  Print a copy of "Images for Sorting Activity" for each group.
  Cut up each organism image (with title) to make a set of cards for each student group.
  Option: Laminate copies for repeated use.
- Organism Response to Ocean Acidification:
  Print "Summary of Ocean Acidification Impacts…" for each student.
  Print Student Worksheet for each student.

Procedure

Start by briefly introducing background information on the problem of ocean acidification (the other carbon dioxide problem), how it is caused, and how it is impacting some organisms in the ocean. Option: Create a (KWL) Know/Want to Learn/Learned chart and capture what they think they know already and want to know. (15 minutes)

1. Sorting Activity: "Calcifiers and Non-Calcifiers" (10min)

First ask students: What do you think the word "calcifier" means? If needed, encourage more questions and explanations to fill in holes in their description. Ask for an example of a marine calcifying organism. How about a non-calcifier? Say to the students: "Let's look at these examples of marine organisms and see if we can sort calcifiers from non-calcifiers."

- Divide the class into groups of two; each group at a shared desk or table.
- Distribute a set of shuffled image cards to each group.
- Direct the students to lay out the cards on the table in random order.
- Ask students if they are familiar with all of the organisms. Explain briefly what any unfamiliar organisms are to the class.
- Direct the students to sort the images on the table into two groups: calcifiers on one side and non-calcifiers on the other.
- Ask students: Why did they make their choices? Can you think of additional calcifiers and non-calcifiers?

2. Show video: NOAA's "What is Ocean Acidification?" (1:04)
After the video, ask students: How did viewing this video change your understanding of the impacts of rising carbon dioxide levels in our atmosphere? What organisms in the video were featured as being impacted? Were any on your calcifier list?

3. Worksheet and Research on impacts of ocean acidification to marine organisms.
(40 min)

- Using the summary handout, have students (in same groups of two) fill out the accompanying worksheet and research individual marine species and summarize possible effects of ocean acidification.
- Direct each group of two students to extend what they learned about organism impacts to the level of ocean ecosystem and food web. Write a paragraph and draw a labeled diagram on how impacts of ocean acidification on marine organisms could affect the ocean ecosystems and food web.
- Each group reports what they learned and what they predict to the class. If using a KWL chart, update the "L" part of the chart.
- Brainstorm together: In what ways could ocean acidification affect people? What can people do to address the problem? Discuss ways students and the class can reduce CO_2 emissions and reduce the use of energy in their homes, at school, and in their community.

Resources

Climate Literacy and Energy Awareness Network
http://cleanet.org/index.html

NOAA's Ocean Acidification Program
https://oceanacidification.noaa.gov

NOAA National Marine Sanctuaries
Climate Change and Ocean Acidification

NOAA Pacific Marine Environmental Laboratory
Ocean Acidification: The Other Carbon Dioxide Problem

NOAA/PMEL Global OA Observing Network
The Carbon Program

Ocean Acidification Network
Ocean Acidification

California Current Acidification Network (C-CAN)

National Resources Defense Council:
Reduce Ocean Acidification

What You Need to Know About Ocean Acidification

Olympic Coast National Marine Sanctuary
Climate Change and Ocean Acidification

California Academy of Sciences
Video: Demystifying Ocean Acidification and Biodiversity Impacts

Scholarly Papers

Kroeker, K.J., Kordas, R.L., Crim, R., Hendriks, I.E., Ramajo, L., Singh, G.S., Duarte, C.M., and Gattuso, J.P. 2013. *Impacts of ocean acidification on marine organisms: quantifying sensitivities and interaction with warming*. Global Change Biology, 19 (67): 1884-96. https://www.ncbi.nlm.nih.gov/pubmed/23505245

Fabry, V.J., Seibel, B.A., Feely, R.A., and Orr, J.C. 2008. *Impacts of ocean acidification on marine fauna and ecosystem processes*. ICES Journal of Marine Science, 65: 414-432 (pdf available free online)

Acknowledgements

"This lesson was developed by NOAA's Office of National Marine Sanctuaries and pulls from activities authored by Karen Matsumoto, and Olympic Coast and Cordell Bank national marine sanctuaries. It also pulls from scholarly papers published by Kroeker et. al 2013. The artwork included in this lesson was created by Laurie Mahan Sawyer/newcompassdesigns.com and is used with permission. This lesson is in the public domain and cannot be used for commercial purposes. Permission is hereby granted for the reproduction, without alteration, of this lesson on the condition its source is acknowledged. When reproducing this lesson, please cite NOAA's Office of National Marine Sanctuaries as the source, and provide the following URL for further information: http://sanctuaries.noaa.gov/education. If you have any further questions or need additional information, email sanctuary.education@noaa.gov."

Education Standards

Next Generation Science Standards	**Grades 6-8: Matter and Energy in Organisms and Ecosystems** MS-LS2-1 Analyze and interpret data to provide evidence for the effects of resource availability on organisms and populations of organisms in an ecosystem. 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 **Cross-cutting Concepts:** Cause and Effect Stability and Change **Grades 9-12: Structure and Function** HS-LS1-2 Develop and use a model to illustrate the hierarchical organization of interacting systems that provide specific functions within multicellular organisms. **Science and Engineering Practices:** Constructing Explanations and Designing Solutions **Crosscutting Concepts:** System and System Models Stability and Change **Grades 6-8 and 9-12: Interdependent Relationships in Ecosystems** MS-LS2-2 Construct an explanation that predicts patterns of interactions among organisms across multiple ecosystems. HS-LS2-6 Evaluate claims, evidence, and reasoning that the complex interactions in ecosystems maintain relatively consistent numbers and types of organisms in stable conditions, but changing conditions may result in a new ecosystem. HS-LS2-7 Design, evaluate, and refine a solution for reducing the impacts of human activities on the environment and biodiversity. **Science and Engineering Practices:** Engaging in Argument from Evidence Scientific Knowledge is Open to Revision in Light of New Evidence **Cross-cutting Concepts:** Cause and Effect and Stability and Change **Grades 9-12: Natural Selection and Evolution** HS-LS4-4 Construct an explanation based on evidence for how natural selection leads to adaptation of populations. HS-LS4-5 Evaluate the evidence supporting claims that changes in environmental conditions may result in 1)increases in the number of individuals of some species, 2) the emergence of new species over time, and 3) the extinction of other species. **Science and Engineering Practices:** Analyzing and Interpreting data Obtaining, Evaluating, and Communicating Information **Cross-cutting Concepts:** Cause and Effect
Ocean Literacy Principals	5 The ocean supports a great diversity of life and ecosystems. 6 The ocean and humans are inextricably interconnected.
Climate Literacy Principals	3 Life on Earth depends on, is shaped by, and affects climate. A,C,E 6 Human activities are impacting the climate system. C,D,E

SUMMARY OF OCEAN ACIDIFICATION IMPACTS AMONG KEY TAXONOMIC GROUPS

	CALCIFERS		
 **Calcifying algae**	Survival	Not tested or too few studies	Early life stages more susceptible to OA. Most susceptible of all calcifers to OA. Reduction in abundance could affect coral establishment.
	Calcification	Little or no effect	
	Growth	Not tested or too few studies	
	Photosynthesis	Reduced -28%	
	Abundance	Reduced -80%	
 **Deep-sea corals**	Survival	Little or no effect	Major effect on coral abundance due to reduction in settlement of coral larva.
	Calcification	Reduced -32%	
	Growth	Little or no effect	
	Photosynthesis	Little or no effect	
	Abundance	Reduced -47%	
 **Cocolithophores**	Survival	Not tested or too few studies	Results vary between different species.
	Calcification	Reduced -23%	
	Growth	Little or no effect	
	Photosynthesis	Positive effect for some species	
	Abundance	Little or no effect	
 **Mollusks**	Survival	Reduced -34%	Will have significant impact on pteropod growth and development, as well as early life stages of other shell-forming species.
	Calcification	Reduced -40%	
	Growth	Reduced -17%	
	Development	Reduced -25%	
	Abundance	Little or no effect	

 **Echinoderms**	Survival	Little or no effect	Significant reduction in development of early life stages of sea urchins and other echinoderms.
	Calcification	Little or no effect	
	Growth	Reduced -10%	
	Development	Reduced -11%	
	Abundance	Not tested or too few studies	
 **Crustaceans**	Survival	Reduced	This group relatively resistant to pH changes. However, research is beginning to show significant impact on Dungeness crab, krill, and barnacle populations.
	Reproduction	Reduced	
	Calcification	Not tested or too few studies	
	Growth	Reduced	
	Development	Little or no effect	
	Abundance	Little or no effect	
NON-CALCIFERS			
 **Fin Fish**	Survival	Not tested or too few studies	Affects olfactory senses of some fish species, affecting signals for food, predators, schooling behaviors; loss of habitat/food supply; larval survival.
	Behavior	Yes	
	Growth	Reduced for larva	
	Development	Not tested or too few studies	
	Abundance	Not tested or too few studies	
 **Fleshy algae**	Survival	Not tested or too few studies	Increased CO_2 increases fleshy algal growth (seaweeds).
	Calcification	Not tested or too few studies	
	Growth	Enhanced +22%	
	Photosynthesis	Little or no effect	
	Abundance	Little or no effect	

 **Seagrasses**	Survival	Not tested or too few studies	Seagrass growth may be increased with increased CO_2. Seagrasses may act as a habitat buffer from OA for shell-forming organisms.
	Calcification	Not tested or too few studies	
	Growth	Enhanced +22%	
	Photosynthesis	Little or no effect	
	Abundance	Not tested or too few studies	
 **Diatoms**	Survival	Not tested or too few studies	Diatoms are generally positively affected by increased CO_2. Effects vary depending on the size of the diatoms.
	Calcification	Not tested or too few studies	
	Growth	Enhanced +17%	
	Photosynthesis	Enhanced +12%	
	Abundance	Little or no effect	

Adapted from Kroeker et al 2013.

STUDENT WORKSHEET **Name** ___________________________

Using the chart ***Summary of Effects of Ocean Acidification Among Key Taxonomic Groups*** and online research, answer each question in the corresponding box.

CALCIFERS	
	**Calcifying algae** Which life stages are calcifying algae most susceptible to OA? What affect does OA have on calcifying algae abundance?
	**Deep-sea corals** How is deep sea coral abundance affected by OA?
	**Cocolithophores** Cocolithophores are producers – how will their rates of photosynthesis change due to increased atmospheric CO_2?

	**Mollusks** Name one species where OA will have a significant impact. Which categories will be affected by OA for mollusk species?
	**Echinoderms** What life stages are affected by OA in sea urchins? Which categories will show a reduction due to OA?
	**Crustaceans** Although crustaceans are relatively resistant to OA, what are some possible effects on Dungeness crab populations?

NON-CALCIFERS	
	**Fin Fish** List three ways fin fish species may be affected by OA
	**Fleshy algae** Why is growth of fleshy algae enhanced by OA?
	**Seagrasses** How will enhanced growth of seagrasses benefit shell-forming marine organisms?
	**Diatoms** Why will growth and photosynthesis of diatoms be enhanced by OA?
Summarize in one sentence how OA will negatively affect calcifying marine organisms.	

Directions for Sorting Activity

Shells serve as a protective structure for both marine and terrestrial organisms. Marine ecosystems and organisms that depend upon calcium-carbonate to make shells, such as coral reefs or oyster beds, can be impacted by changes in ocean pH due to increased carbon dioxide. Do you know which of these organisms uses calcium carbonate for shell and reef building and which do not?

Sort the images into two groups:

Calcifiers and Non-calcifiers

(Calcifiers are organisms that make their shell or part of their body using calcium carbonate from the seawater).

Record your answers in the following table:

CALCIFIERS	NON-CALCIFIERS

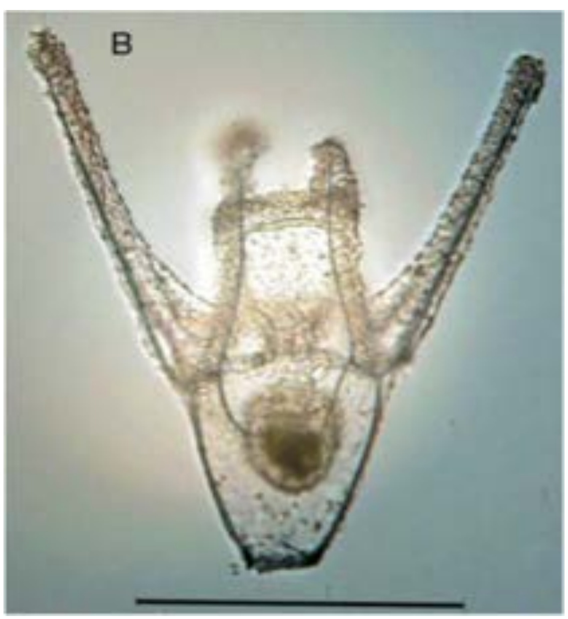
Images for Sorting Activity

WA Dept. Fish and Wildlife

Blue Mussel

USDA.gov

Clams



Source: O'Donell et al. (2010)

Urchin Larvae

NOAA

Brown Sea Nettle

Dungeness Crab

Cordell Expeditions

California Hydrocoral

NOAA

Coccolithophores

Greater Farallones NMS/NOAA

Coralline Algae

NOAA

Nudibranch (Sea slug)

NMFS/NOAA

Squid

NOAA

Salmon

NOAA

Kelp

Pete Naylor / REEF

Pelagic Tunicate

NOAA

Pacific White-sided Dolphin