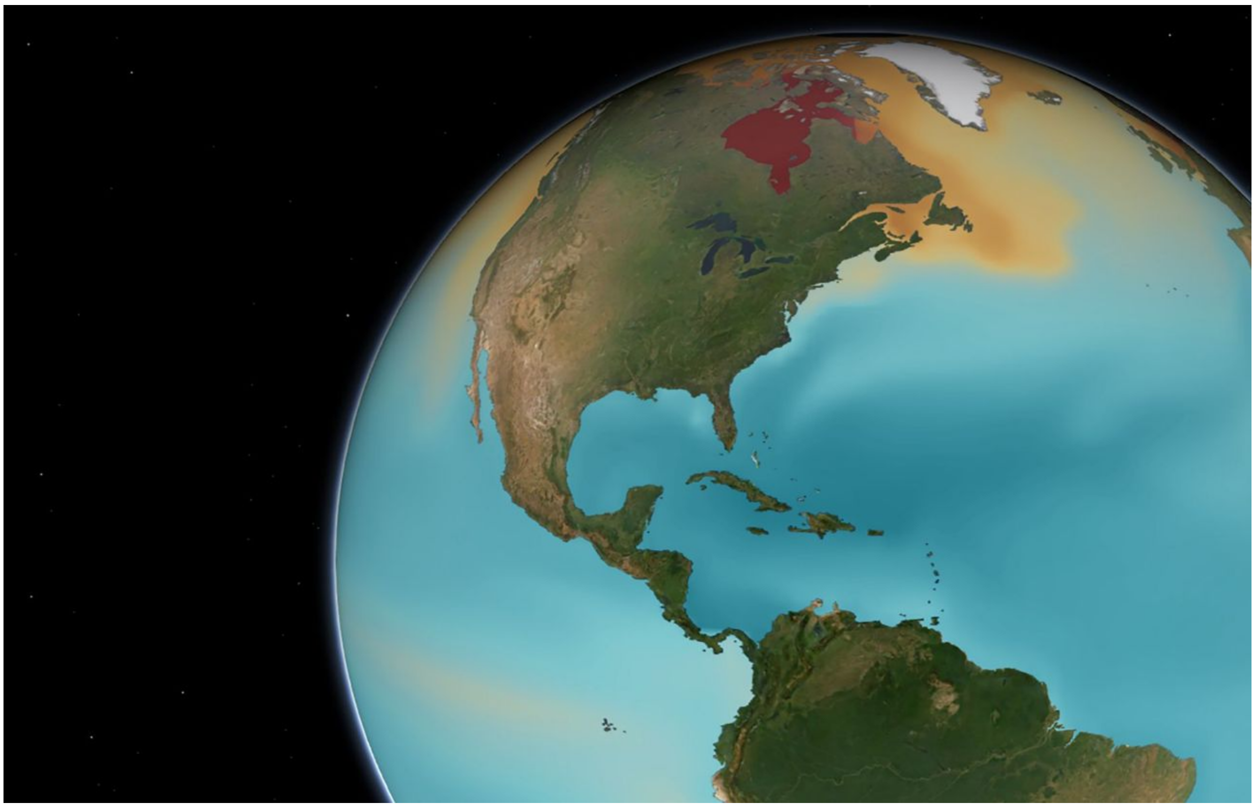
DATA IN THE CLASSROOM

UNDERSTANDING OCEAN AND COASTAL ACIDIFICATION



2nd Edition (2019)

This curriculum module was originally developed for the NOAA Ocean Data Education (NODE) Project. This 2nd edition (2019) was completed under contract by Amy Dean. Data in the Classroom is a collaboration of many NOAA programs and offices including: National Environmental Satellite, Data, and Information Service (NESDIS), National Estuarine Research Reserve System, National Oceanographic Data Center and the Office of National Marine Sanctuaries.

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INTRODUCTION

The amount of carbon dioxide (CO_2) in the atmosphere is increasing, due to the burning of fossil fuels and other human activities. How do these changes, as well as other human activities, affect the chemistry of the ocean? The lessons and accompanying data tools in this module will introduce students to *ocean and coastal acidification*. Students will use real data to investigate both short and long-term changes in ocean chemistry and the effect that these changes have on the organisms living in coastal areas. The goal is for students to experience different kinds of data and data accessing tools, so that, by the end of the module, they can continue to explore data sets driven by their own inquiry.

The Basics of Ocean and Coastal Acidification

Burning fossil fuels, and other human activities, releases CO_2 into Earth's atmosphere. This not only leads to a warmer Earth (i.e., global climate change, the greenhouse effect), but also changes the chemistry of Earth's oceans. The ocean is a "carbon sink," which means that it removes CO_2 from the atmosphere. The ocean currently absorbs approximately 26% of human-caused CO_2 emissions from the atmosphere. When CO_2 dissolves in seawater, a series of chemical reactions occur resulting in the increased concentration of hydrogen ions. This increase causes the seawater to become more acidic. *Ocean acidification* refers to a reduction in the pH of the ocean over an extended period of time, caused primarily by uptake of carbon dioxide (CO_2) from the atmosphere. *Coastal acidification* refers to the same processes resulting from the absorption of atmospheric CO_2, as well as a number of additional, local-level processes, including the excess input of nutrients from shore (from fertilizers, wastewater, animal manure and more). Coastal acidification generally exhibits more variability over shorter time scales relative to open-ocean acidification. Acidification is affecting the entire world's oceans. As the pH of ocean water decreases, there is a resulting decrease in the amount of carbonate ions available for many marine organisms to form their calcium carbonate shells. Oysters, clams, corals and other shell-building creatures are less able to precipitate the mineral aragonite, which they use to build or rebuild their skeletons. As marine life are impacted, so too are economies that are dependent on fish and shellfish for food.

Curriculum Overview

This curriculum incorporates a scaled approach to learning. Each module offers activities at five different levels of student interaction, sometimes referred to as Entry, Adoption, Adaptation, Interactivity, and Invention. The early levels are very directed and teacher-driven, which provides important first steps when learning something new. The levels of Adaptation through Invention are more student-directed and open up opportunities to design lessons featuring student inquiry.

The levels serve a dual purpose. They are designed to engage students in increasingly sophisticated modes of understanding and manipulating data. They are also intended to help you, as a teacher, familiarize yourself with online tools for accessing data and to provide you with models for integrating the use of real data into your classroom practice.

The chart below illustrates the five levels of this module.

				5	**INVENTION: Designing Your Own Investigation:** Students will design their own plan to answer a research question.
			4	**INTERACTIVITY: Acidification's Impact on Shell-building Animals:** Students will examine carbonate data in a coastal ecosystem and will explain the relationships between global increases in CO_2, ocean pH and aragonite saturation state.	
		3	**ADAPTATION:Examining Acidification Along the Coast:** Students will analyze ocean chemistry data to compare coastal and ocean acidification.		
	2	**ADOPTION: Measuring Changes in Ocean pH:** Students will use data and models to understand the relationship between ocean carbon dioxide and pH.			
1	**ENTRY: How Does Rising CO_2 Impact Ocean pH? –** Students learn to read and interpret graphs of atmospheric and ocean CO_2. Students predict the likely effect of changes in CO2 on ocean pH.				

Next Generation Science Standards (NGSS)

This module was developed to build data literacy, engaging students in increasingly sophisticated modes of understanding and manipulation of data. In 2019, the module was updated and adapted to incorporate the innovations described in the NGSS[1] where possible. You can learn more about how this module relates to specific NGSS components by visiting the Data in the Classroom website.

Ocean Literacy

This curriculum module also supports the following Essential Principles of Ocean Sciences.[2]

1. The Earth has one big ocean with many features.
    e. Most of Earth's water (97%) is in the ocean. Seawater has unique properties. It is salty, its freezing point is slightly lower than fresh water, its density is slightly higher, its electrical conductivity is much higher, and it is slightly basic. Balance of pH is vital for the health of marine ecosystems, and important in controlling the rate at which the ocean will absorb and buffer changes in atmospheric carbon dioxide.

2. The ocean, and life in the ocean, shape the features of the earth.

    d. The ocean is the largest reservoir of rapidly cycling carbon on Earth. Many organisms use carbon dissolved in the ocean to form shells, other skeletal parts, and coral reefs.

5. The ocean supports a great deal of diversity of life and ecosystems.

    f. Ocean habitats are defined by environmental factors. Due to interactions of abiotic factors such as salinity, temperature, oxygen, pH, light, nutrients, pressure, substrate, and circulation, ocean life is not evenly distributed temporally or spatially, i.e., it is "patchy." Some regions of the ocean support more diverse and abundant life than anywhere on Earth, while much of the ocean is considered a desert.

6. The ocean and humans are inextricably interconnected.

    e. Changes in ocean temperature and pH due to human activities can affect the survival of some organisms and impact biological diversity (coral bleaching due to increased temperature and inhibition of shell formation due to ocean acidification).

1 NGSS Lead States. 2013. Next Generation Science Standards: For States, By States. Washington D.C.: The National Academies Press. Next Generation Science Standards is a registered trademark of Achieve. Neither Achieve nor the lead states and partners that developed the Next Generation Science Standards was involved in the production of, and does not endorse, this product.

2 Ocean Literacy Network (2005). Ocean Literacy - The Essential Principles of Ocean Sciences K-12. Washington, D.C.

LEVEL 1: ENTRY
How Does Rising CO_2 Impact Ocean pH?

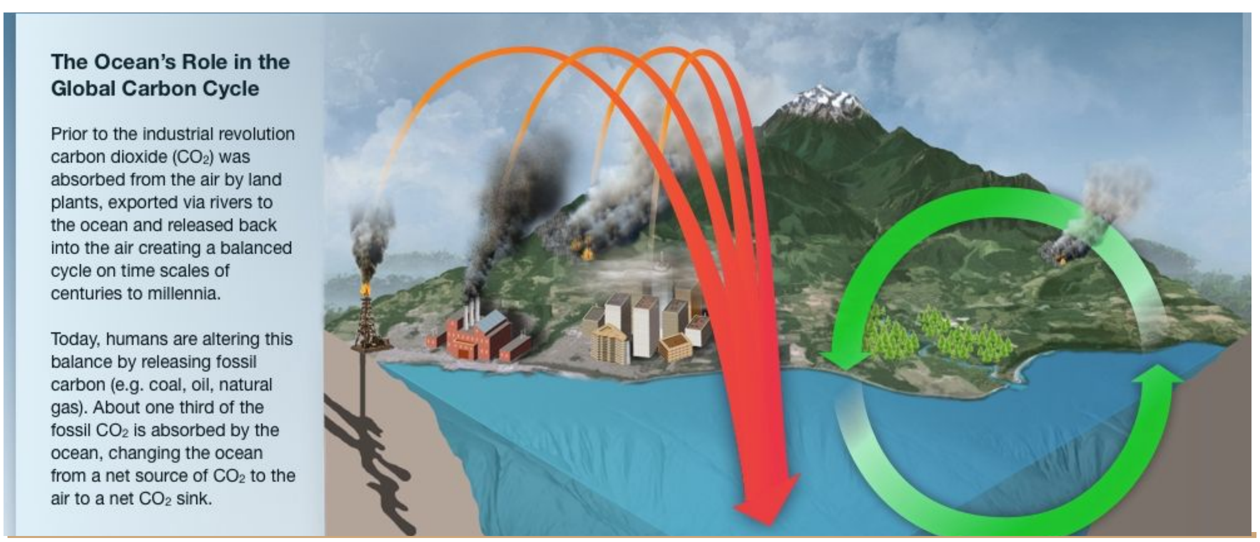
Objectives

Students will understand that rising atmospheric CO_2 contributes to rising CO_2 concentrations in the ocean. Students will predict the likely effect of changes in CO_2 on ocean pH.

Background

Carbon cycles naturally between the atmosphere, the land and the ocean due to a number of processes, including photosynthesis and respiration. Since the industrial revolution, carbon dioxide levels in the atmosphere have increased by 30%. This increase is primarily the result of fossil fuel emissions and deforestation. Some of the excess, human-caused CO_2 is absorbed, like a sponge, by the ocean. As CO_2 dissolves into the ocean, a series of chemical reactions occur that result in the increased concentration of hydrogen ions and the reduction of pH. This process is called ocean acidification. From long-term ocean measurements and observations, we know that ocean surface waters have become 30% more acidic over the last 150 years as they have absorbed large amounts of CO_2 from the atmosphere (Feely et al, 2004).

Image credit: Center for Environmental Visualization & NOAA PMEL Carbon Group



Materials

- Projector, computers and internet access
- Photocopies of student worksheets (Levels 1-4) from the Teacher Guide tab of the *Ocean & Coastal Acidification module*.

Procedure

Launch the *Ocean & Coastal Acidification module*, and click on 'Level 1.' Use the background text and image to discuss or review the ocean's role in the global carbon cycle.

Part 1 - Measuring Changes in CO_2

1. Scroll down to the next section. Here, students will take a virtual trip to Mauna Loa, on the Big Island of Hawaii, to see how carbon dioxide has changed over time. The interactive graph shows the history of atmospheric carbon dioxide from 1958 to current. Note that the y-axis shows CO_2 in parts per million (ppm). A measurement of 300 ppm means that for every 1 million grams of well-mixed atmospheric gases, 300 grams would be CO_2.
    - Ask students to describe and explain the short-term variability in the data. *The regular ups and downs are caused by seasonal variations in photosynthetic activity. During the spring, plants and algae absorb a lot of carbon dioxide through photosynthesis, removing it from the atmosphere. During fall and winter, carbon dioxide is released back into the atmosphere as some plants and algae die. Bacteria decompose the dead algae and give off CO_2 as they respire.*
    - Ask students to describe and explain the long-term trend in the data. *The upward trend is caused by human activities such as burning of fossil fuels.*
    - Students answer the questions at the end of this section.
      Answer - Question 1: photosynthesis and respiration
      Answer - Question 2: burning of fossil fuels

Part 2 - The fate of human-caused CO_2 emissions?

1. Scroll down to the next section. Use the schematic to discuss the fate of human-caused CO_2 in the atmosphere (Le Quere et al, 2012). You may ask your

students to calculate how many billion tonnes of carbon enters the ocean per year from human-driven emissions.

Part 3 - Making Predictions – How does CO_2 impact ocean pH?

1. Demonstrate how to read (and interact with) the graph. Then, give students time to answer Question 3. If needed, go over percent change (%) calculation.

   Percent change (%) = $\frac{\text{(Final - Initial)}}{\text{Initial}} \times 100 = \frac{389 \text{ ppm} - 330 \text{ ppm}}{330 \text{ ppm}} = 17.8\%$

   Answer - Question 3: 15%

2. Student teams should then use the information from this section (and any prior knowledge) to complete the Level 1 worksheet. They will make a prediction about how changes in CO_2 have changed ocean pH, from 1980 to current. You may wish to have student teams present and discuss their predictions with the whole class. An answer key to this worksheet can be found at the end of this Teacher Guide.

LEVEL 2: ENTRY
Measuring Changes in Ocean pH

Objectives

Students will use data and models to understand the relationship between ocean carbon dioxide, pH and ocean acidification.

Background

pH is the measure of the hydrogen ion concentration in a solution. pH is used to express acidity or alkalinity on a scale of 0 to 14. The pH of pure water is considered neutral, and has a pH value of 7. Values above 7 are basic, or alkaline. Values below 7 are acidic. pH is measured on a logarithmic scale, where small changes have increasingly greater effects. A solution with a pH of 5 is ten times more acidified than a solution with a pH of 6 and 100 times more acidified than solution with a pH of 7.

Earth's oceans are naturally slightly alkaline. Historically, the pH of the surface ocean was approximately 8.1. Since the Industrial Revolution, the global average pH of the surface ocean has decreased by 0.11 pH units. This change may not seem like much, but because the pH scale is logarithmic, it represents a 30 percent increase in acidity. For more background information, check out "A Primer on pH" from NOAA's PMEL Carbon Program.

Materials

- Projector, computers and internet access
- Photocopies of student worksheets (Levels 1-4) from the Teacher Guide tab of the *Ocean & Coastal Acidification module*.

Procedure

Launch the *Ocean & Coastal Acidification module*, and click on 'Level 2.' Use the background text and image to discuss or review the pH scale. Make sure to review the logarithmic nature of the pH scale. For example, students should understand that a pH value of 7 is ten times more acidic than a value of 8 and 100 times more acidic than a value of 9.

Part 1 - Measuring Changes in Ocean pH

Scroll down to the next section. Here, students will compare their predictions from Level 1 with actual changes in ocean pH at one location off the coast of Hawaii.

1. Demonstrate how to read (and interact with) the graph. Point out the two y-axes, stressing that pH is on the right axis. Note: show students that they can click on "Ocean CO_2" and "Atmospheric CO_2" in the legend to make these data disappear on the graph. This will simplify the graph and may help students focus on patterns and trends in ocean pH.

2. After students have had time to interact with the graph, they can answer Questions 1 and 2.
   Answer - Question 1: decreased by 0.05 pH units
   Answer - Question 2: When CO2 increases, pH decreases and acidity increases

Part 2 - Short vs Long-term Changes in Ocean pH

1. Follow the instructions in this section to 'zoom in' to the graph. It may be helpful to click on "Atmospheric CO_2" in the legend to make these data disappear.

2. In order to help students examine the year-to-year patterns in the data, you may demonstrate that, by moving your cursor over the peaks in ocean CO_2, you can see WHEN (during the year) the peak occurred. You can also see the pH value.

3. Generally, students should notice that there are regular seasonal patterns in CO_2 and pH. More specifically, they may notice that:

   - peaks in ocean CO_2 occur every year around Aug and Sept

- when ocean CO_2 is high, the pH is low (and water is more acidic)
- ocean CO_2 is lowest every year around the month of March.

4. Challenge students to make sense of these patterns, given what they know about photosynthesis and respiration.
   The regular peak in CO_2 *in the springtime (around the month of March) is likely caused by photosynthetic activity of algae. As algae draw* CO_2 *from the water, CO2 decreases and the water becomes less acidic and more alkaline.*
5. Students can then answer Question 3 to check for understanding.
   Answer - Question 3: seasonal changes in both photosynthesis and respiration

Part 3 - Forecasting Future Changes in pH

Here, students will have an opportunity to run a scientific model and observe how pH is expected to change over the next century.

1. If needed, demonstrate how to run (and interact with) the model. Then, give students time to answer Question 4.
   Answer - Question 4: 7.7 pH units
2. Student teams should then complete the Level 2 worksheet. An answer key to this worksheet can be found at the end of this Teacher Guide.

LEVEL 3: ADAPTATION
Examining Acidification Along the Coast

Objectives

Students will analyze ocean chemistry data to compare coastal and ocean acidification.

Background

While ocean acidification is caused by the uptake of carbon dioxide (CO_2) from the atmosphere, coastal acidification is a slightly different mechanism. Near the coast, a number of other factors can contribute to even greater changes in ocean chemistry. The excess input of nutrients from shore (from fertilizers, wastewater, animal manure and more) promote acidification by stimulating algae growth. This in turn leads to intense respiration by animals that eat them, and the respiration drives up the local CO_2 concentration in the water. Along the West Coast of the US, coastal acidification can also be impacted by the process of upwelling. Deep waters that 'rise up' during upwelling are naturally enriched with CO_2 because respiration processes dominate in the deep. Deep waters are also enriched with excess (human-caused) CO_2 that was absorbed from the atmosphere when last in contact with the surface. Coastal acidification generally exhibits more variability over shorter time scales relative to open-ocean acidification.

Materials

- Projector, computers and internet access
- Photocopies of student worksheets (Levels 1-4) from the Teacher Guide tab of the *Ocean & Coastal Acidification module*.

Procedure

Launch the [Ocean & Coastal Acidification module](), and click on 'Level 3.' Ask students to consider what additional factors might influence acidification closer to shore. Then, play the coastal acidification interactive.

Part 1 - Detecting Acidification Near the Coast, Part 1

Moorings have become useful tools for studying ocean chemistry. Scientific moorings typically consist of a float that contains a huge battery and scientific equipment that can relay data via satellite. Instrumental advances over the past 15 years have led to moorings capable of sampling ocean chemistry with high frequency and accuracy. Students will access one of these moorings, off the coast of Washington, in order to examine changes in ocean chemistry.

1. Students will use the map in this section to access ocean pH data from coastal WA and from Hawaii. Note: the pH data from WA has large gaps, caused by issues such as sensor or battery failure.

2. Student teams should complete the Level 3 worksheet. An answer key to this worksheet can be found at the end of this Teacher Guide.

3. When they are finished, they should answer the questions at the end of the section to check for understanding.
   Answer - Question 1: 7.9 and 8.4
   Answer - Question 2: A combination of factors (natural and human-caused), including all of the above.
   Answer - Question 3: is more variable, with extreme changes in pH

Part 2 - Detecting Acidification Near the Coast, Part 2

Students may find the dataset from coastal Washington frustrating to work with. There is a great deal of variability in the data. It also contains a number of large gaps. Though it is not possible to detect gradual, long term declines in pH (yet), it may be possible to detect these types of trends over a longer time period (10-20 years). What students should be able to see from this 8-year dataset is the extreme variability in pH over short time periods. They should understand that while carbon dioxide emissions from humans are the driving force behind ocean acidification, additional, local factors that are both natural and human-caused can cause greater acidification near the coast. For a brief overview of the differences between ocean and coastal acidification, visit NOAA's Ocean Acidification Program website, https://oceanacidification.noaa.gov/OurChangingOcean.aspx.

LEVEL 4: INTERACTIVITY
Acidification's Impact on Shell-building Animals

Objectives

Students will examine carbonate data in a coastal ecosystem and will explain the relationships between global increases in CO2, ocean pH and aragonite saturation state.

Background

Coastal ecosystems are some of the most productive ecosystems in the world. These areas support important fisheries that we rely on for food. Oyster farming is big business in the US. In Washington, oyster hatcheries and farms produce more shellfish than any other state, contributing around $270 million to the state economy. In 2005, larval oysters at hatcheries began dying at an alarming rate. This was the first indication that acidification was beginning to take its toll on the local marine life. The 6-minute PBS video at the beginning of this section is meant to engage students in a real-world problem involving coastal acidification, Pacific Coast oysters, and the shellfish industry.

The data activities in this section will focus on the effects of acidification on shell building creatures, particularly oysters, both now and in the future. Oysters use a chemical compound called aragonite (a form of calcium carbonate) to build their shells. Scientists measure the availability of aragonite in seawater by calculating the aragonite saturation state. This is a measure of the tendency for aragonite to form or to dissolve.

Materials

- Projector, computers and internet access
- Photocopies of student worksheets (Levels 1-4) from the Teacher Guide tab of the *Ocean & Coastal Acidification module*.

Procedure

Launch the *Ocean & Coastal Acidification module*, and click on 'Level 4.' Ask students to predict how ocean and coastal acidification may affect marine life. A few ideas are listed below:

- Mollusks, crustaceans, and corals have greater difficulty forming hard parts such as shells and skeletons when seawater pH declines.
- Shells of some marine life may dissolve.
- Metabolic rate and immune responses may be affected.
- With more carbon dioxide in seawater, algae may photosynthesize and grow more quickly.

Play the 6-minute PBS video to engage students in this section's topic - the impact of acidification on Pacific Coast oysters.

Part 1 - Acidification's Effect on Shell-building Animals

1. Here, students explore an illustrated graphic to learn how changes in ocean chemistry reduce the ability of some animals to build their calcium carbonate ($CaCO_3$) shells.

2. Students can then answer the questions at the end of the section.
   Answer - Question 1: bicarbonate
   Answer - Question 2: decreases

Part 2 - How is Acidification Impacting Oysters

To help understand how much aragonite is available for shell building, scientists measure the aragonite saturation state (Ω) of seawater. This measurement describes the tendency for calcium carbonate to form or to dissolve. Ω values greater than 1.0 indicate supersaturation. Calcifying organisms require well over 1.0 to produce shells or skeletons. Ω values less than 1.0 indicate undersaturation. Shells or other body parts made from aragonite may begin to dissolve. For juveniles, this can lead to death.

1. Demonstrate how to read (and interact with) the box plots. Click on 'What is a box plot?' in the introduction of this section. Help students learn to read and analyze data displayed in this format.
2. If needed, help students interpret the plot in this section titled "Monthly Aragonite at La Push."
    a. This plot shows month-to-month measurements of aragonite saturation state at a location (La Push) in coastal Washington.
    b. Aragonite saturation state is along the y-axis.
    c. Time is plotted along the x-axis. For each month, there have been many measurements of aragonite saturation state. The box and whiskers above each month shows the range of measurements for that month. Bigger boxes and longer whiskers mean greater variability in Ω during that month.
    Ask students: which month has the greatest variability (answer: July); which month has the least variability? (answer: February)
    d. Point out the adjustable blue line. Demonstrate how to move it up and down, if needed. This adjustable line is meant to provide a tool for assessing thresholds. For example, setting the line to Ω 2.0 helps to assess monthly exposure of Pacific oyster larvae to effects that are not lethal. In other words, oyster larvae may have trouble growing or building their shells at levels below this 2.0 threshold.
    e. Finally, point out the monthly pie charts above the x-axis. These represent the % of observations that fall below a particular threshold (the blue line). For example, if you drag the threshold line down to Ω 1.5, the pie chart will show you how many observations fall below that line for each month. In January, 8% of observations fell below the Ω 1.5 threshold.
3. Student teams should complete the activities using the Level 4 worksheet. An answer key to this worksheet can be found at the end of this Teacher Guide.

4. When they are finished, answer the questions at the end of the section to check for understanding.
   Answer - Question 3: December - March
   Answer - Question 4: sometimes

Part 3 - Predicting Future Changes in Aragonite

Here, students will have an opportunity to run a scientific model and observe how aragonite saturation state is expected to change over the next century.

1. If needed, demonstrate how to run (and interact with) the model. Then, give students time to answer Questions 5 and 6.
   Answer - Question 5: 0.8
   Answer - Question 5: all of the above are possible

2. Student teams should complete the last part of question 13 on their worksheet after running the model.

LEVEL 5: INVENTION
DESIGNING YOUR OWN INVESTIGATION

Objectives

Students will apply what they have learned about ocean acidification along the Pacific Coast to a new ecosystem, the Gulf of Maine.

Background

The soft-shell clam, *Mya arenaria*, is commercially harvested on tidal mudflats of the western Gulf of Maine. In laboratory experiments, soft-shelled clam larvae are unable to grow or build their shells when the aragonite saturation state (Ω) is less than 1.6. What effect will acidification have on these clams and other shell-building creatures? Students will use what they have learned in Levels 1-4 to answer this question.

Materials

- Projector, computers and internet access
- Photocopies of student worksheets (Level 5) from the Teacher Guide tab of the *Ocean & Coastal Acidification module*.

Procedure

Launch the *Ocean & Coastal Acidification module*, and click on 'Level 5.' Ask students to predict how ocean and coastal acidification may be affecting shell-building animals off the coast of Maine. Brainstorm what types of data would be needed to begin to answer this question.

1. Use the map tool to show students what types of data are available. Ocean CO_2, pH and aragonite data are available by clicking on the marker located in the Gulf of Maine.
2. Students can work in teams to develop their own questions, collect evidence and draw conclusions. The Level 5 worksheet can be used to help guide their investigations.