HOW TO USE THIS RESOURCE

The images for this resource show the effects of a coral bleaching event, which can serve as phenomena to explore the key concepts described below.

The pedagogical practice of using phenomena to provide a context for understanding science concepts and topics is an implementation practice supported by the Next Generation Science Standards (NGSS). Phenomena are observable occurrences that students can use to generate science questions for further investigation or to design solutions to problems that drive learning. In this way, phenomena connect learning with what is happening in the world while providing students with the opportunity to apply knowledge while they are building it.

The "Implementation Suggestions" and "Teaching Tips" sections provide options for incorporating the images into a curriculum or unit of study and can be modified to use as a standalone activity or to supplement an existing lesson. The "Student Handout" includes reproductions of the images and the "Background Information" and "Extension Information" sections.

Additional information related to pedagogy and implementation can be found on this resource's webpage, including suggested audience, estimated time, and curriculum connections.

KEY CONCEPTS

- Coral reefs are colonies of animals that rely on symbiotic algae for survival.
- Coral bleaching is a process in which corals force out their symbiotic algae, which reduces coral survival.
- Coral bleaching is caused by stressful environmental conditions, such as heat stress and deoxygenation, that are often exacerbated by human activities.

BACKGROUND INFORMATION

Although they may look like plants or rocks, **corals** are animals related to jellyfish and anemones. Many coral species have a hard outer skeleton and live in large groups called colonies. The skeletons of all the corals in a colony create the structures of coral reefs.

Most corals form a **symbiosis** (a close, long-term relationship between organisms of different species) with tiny **algae** (organisms that perform photosynthesis and typically live underwater). These algae live within the coral's cells and provide the coral with most of the food it needs.

Stressful environmental conditions — such as sudden or prolonged changes in temperature, sunlight, or oxygen — can disrupt the symbiosis between the corals and their algae. Corals may then force the algae out of their cells in a process called **coral bleaching**. Since the algae give corals their color, corals turn white after bleaching.

Though corals can survive short-term bleaching, their risk of disease and death increases. Human activities have led to an increase in coral bleaching worldwide. This impacts corals, coral reef ecosystems, and human communities that rely on coral reefs.

Figures a and c show two different species of corals from a reef off the Caribbean coast of Panama. Parts of both corals have undergone bleaching, which is indicated by the arrows pointing to the white areas.

EXTENSION INFORMATION

All these images are from a reef in Bahía Almirante, a bay on the Caribbean coast of Panama, in 2017. At this time, Bahía Almirante experienced sudden **deoxygenation**, or loss of oxygen. This may have been caused by ocean pollution or changes in water temperature and wind activity.

Similar to heat stress, deoxygenation is a stressful environmental condition that can cause coral bleaching. Figures a and c, which were shown at the beginning of this activity, are of corals that bleached after deoxygenation.

Figure b shows other corals covered in a **microbial mat** (a group of many microbes, typically bacteria), which looks like thin white threads. These microbial mats thrive when oxygen is low, allowing them to grow over corals.

Figure d is a map of Bahía Almirante shortly after the 2017 deoxygenation event. The colors indicate the levels of dissolved oxygen (DO) in the water. The white triangle shows the location of the reef where the photos were taken.

Figure e shows dying **brittle stars** (a type of invertebrate that lives on coral reefs) gathered on some corals. Brittle stars are just some of the many reef organisms that were impacted by the loss of oxygen.

IMPLEMENTATION SUGGESTIONS

The following suggestions outline several options for incorporating the images into a unit of study as phenomena:

Engagement, establishing prior knowledge, and providing context:

- Begin the lesson by telling students that they will be examining photographs taken after an event that affected a coral reef.
    - Explain to students that corals are animals that live underwater in large groups called colonies. Some corals build hard structures that house those colonies, which make up coral reefs. The photos will show some of these hard coral structures.
    - The photos were taken on a reef in Bahía Almirante, a bay on the Caribbean coast of Panama. It may be helpful to show students a map of where this is.
- Show students the first image (Figure a). Ask students to make observations using the sentence stems “I notice…”, “It reminds me of…”, and “I wonder…”.
- Use a think-pair-share protocol to have students share their observations and questions about the image. Record class observations, noting when students make similar observations and drawing attention to the range of student-generated questions.
    - Students may observe that:
        - The coral structure appears to have different layers.
        - The structure appears to have a rough texture and might look like a rock.
        - Some parts of the structure are white, and others are orange/brown.
        - An arrow is pointing to a white part of the structure.
    - Students may wonder:
        - What does the arrow indicate?

- What is the difference between the white and orange/brown parts of the structure? Did something cause the colors to change, or are the different colors normal?
- Are the coral animals in this coral structure alive?
- Other questions about coral animals, which may include:
  - How big are the coral animals compared to the coral structure?
  - What do coral animals eat?
- Other questions about coral structures and reefs, which may include:
  - What is a coral structure made of?
  - What other animals are found around coral reefs?
  - Why should I care about coral reefs?

- To orient students to corals and reefs, show the first segment (0:00–1:05) of the Scientists at Work video *Steve Palumbi & Megan Morikawa Study Coral Reef Damage in American Samoa*. Tell students that even though this video is about a different location (American Samoa rather than the Caribbean), the same general information applies to corals/reefs in both locations. As students are watching, they should note:
  - what coral reefs are
  - why coral reefs are important
  - the kinds of living things shown in/around the coral reefs
  - what coral bleaching is

- Show students the second image (Figure c). Tell them that both this image and Figure a show corals after an event that caused coral bleaching. Ask students to make additional observations, again using the sentence stems "I notice…", "It reminds me of…", and "I wonder…".
- Use a think-pair-share protocol, similar to the one above, to have students share their observations and questions about the images.
  - Students may observe that:
    - In both figures, the coral structures have multiple layers or tiers. In Figure a, the structure has thin, wavy layers. In Figure c, the structure has rounded lumps.
    - In both figures, the structures have some white parts and some orange/brown parts. In Figure a, the white parts are at the top. In Figure c, the white parts are at the bottom.
    - Both figures have arrows pointing to white parts of the coral structures.
  - Students may wonder:
    - Do the corals in Figure a belong to a different species from the ones in Figure c?
    - What event caused the bleaching of these corals?
    - Why does bleaching make the coral structures change color?
    - Does bleaching kill the coral animals?
    - Can coral reefs recover from bleaching? If so, how?
    - How might human activities contribute to coral bleaching? What actions could be taken to reduce bleaching?
- Have students read the "Background Information" for the images.
- Transition to the "Exploration/Investigation" section by telling students that they'll be investigating some of their initial questions about corals.

Exploration/Investigation:

- Have students explore their questions using the *Interactive Exploration of* Coral Bleaching resource. This resource uses the *Coral Bleaching* animation and provides additional information through embedded pause points and self-assessment questions. It may be helpful to assign students (or groups of students) specific questions that they must report back on to the class, such as:
  - Where are coral reefs located?
  - What ecosystem services do reefs provide?
  - What are corals, and how do they engage in symbiosis?
  - How do changes in temperature trigger coral bleaching events?
- Have students return to their original set of questions, noting which questions have been answered and which remain. Have students also consider, and possibly revise, their questions related to coral bleaching. These questions may include:
  - Under what circumstances does coral bleaching occur?
  - Is the rate of coral bleaching accelerating?
  - Are there ways to mitigate or stop bleaching from occurring?
- To further investigate these questions, have students complete the "Coral Reefs and Global Warming" activity (or selected portions, depending on student readiness/grade level). In this activity, students analyze temperature data for coral reefs around the world and evaluate the effects of heat stress.
  - It is helpful to work through this activity on your own prior to classroom implementation.
  - The activity has students graph the data using a computer and spreadsheet software. If these are unavailable, you can skip the graphing and provide students with the prepared graphs from the "Temperature Graphs" PDF.
  - The activity uses a jigsaw approach where different students/groups are assigned to different coral reef locations. Students/groups can be responsible for as many (or as few) locations as appropriate.
  - Students may struggle with how to calculate and interpret degree heating weeks (DHW). It may be helpful to perform several sample calculations as a class and to give students time to practice these calculations prior to attempting to interpret their data.
- Have students return to their original set of questions, noting which questions have been answered and which remain. Student questions may include:
  - Why are coral bleaching events increasing over time?
  - What can humans do to mitigate or stop the current rate at which coral reefs are bleaching?
- Transition to the "Assessment" section by telling students that they will be watching a video about scientists studying why some corals can tolerate more heat stress than other corals.

Assessment:

- Watch the remainder of the Scientists at Work video *Steve Palumbi & Megan Morikawa Study Coral Reef Damage in American Samoa*. (It may be helpful to replay the video from the beginning.) Use the accompanying "Student Worksheet" to guide students through the video.
  - Have students read through the worksheet questions before watching the video. Depending on your class structure and objectives, students can either complete these questions independently or as part of a small group discussion.
  - Tell students to focus on Questions 5 and 8 (about the formulation of claims) and Question 10 (about the formulation of new scientific questions).

- Student claims should be supported by evidence, including data, information from the interactive exploration or video, reliable external sources, etc.
- Student scientific questions should demonstrate an understanding of Palumbi and Morikawa's experiment, including the use of control groups as a basis for comparison. (If students need additional scaffolding, Questions 4 and 7 address the experimental setup.)

- As a culminating assessment, have students complete Question 11, which connects human activities to changing ocean temperatures and effects on reefs and biodiversity.
  - Student responses should include evidence, such as data and information from the previous activities/experiences. It may be helpful to give students more space to respond than is provided in the worksheet.
  - You may want to use the NGSS "Evidence Statements" for HS-LS2-6 to help assess student responses. The evidence statements are not themselves a rubric but can be used to generate one.

Extension:

- Have students explore another major cause of coral bleaching: ocean deoxygenation (loss of oxygen).
  - Begin by telling students that coral bleaching can be caused by environmental stresses other than heat stress. For example, the corals in Figures a and c bleached due to a sudden loss of oxygen. Students will now look at more images of the same reef after this event: two photos and a map showing levels of dissolved oxygen (DO).
  - Show students the "Extension" images (Figures b, d, and e). Ask students to make additional observations, again using the sentence stems "I notice…", "It reminds me of…", and "I wonder…".
  - Use a think-pair-share protocol, similar to the one in the "Engagement" section above, to have students share their observations and questions about the images.
  - Have students read the "Extension Information" for the images.
  - Transition to additional resources by telling students that they'll be investigating some of their initial questions. These resources could include the following:
    - The Data Point activity "Dead Zones in Coastal Ecosystems" can be used to explore the causes and effects of low-oxygen areas in the ocean, called "dead zones."
    - The International Union for Conservation of Nature (IUCN) provides multiple reports, summaries, and graphics on their "Ocean Deoxygenation" webpage.
    - The scientific paper that Figures a–e were originally from (Johnson et al. 2021) provides more information about the deoxygenation event that caused the corals to bleach and its effects on the reef community.
- Have students engage with primary literature describing Palumbi and Morikawa's work. This may be more appropriate for students in advanced high school biology classes or undergraduates.
  - The scientific paper for this research is Palumbi et al. (2014). An annotated version of the paper, "Take the Heat," is provided by Science in the Classroom; it includes supplemental notes and videos to help students engage with and interpret the paper.
  - Figure 2 from this paper can be explored using the Data Point activity "Resistance to Coral Bleaching." The accompanying "Educator Materials" contain potential assessment questions that ask students to analyze an experiment and interpret data related to coral temperature acclimation.
- Have students further explore the mechanisms and consequences of global climate change.
  - Students can watch the short film *The Science of Climate Change* to learn more about climate change and associated research.

- Students can use the interactive tool *Understanding Global Change* to construct and revise models of how climate change affects Earth's systems.

TEACHING TIPS

- Present students with the images first, before they read the background information.
- Encourage students to draw upon their prior experiences and knowledge to interpret the image and generate questions.
- Provide opportunities for students to explore outside sources to promote their independent explorations and discussions.
- Background information may be edited to support student proficiency, course sequence, etc.
- The images may be projected in lieu of handouts.
- Printed images can be laminated for use in multiple classes.
- Pair or group students to work through one or more of the implementation suggestions.

CREDITS

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Johnson, Maggie D., Jarrod J. Scott, Matthieu Leray, Noelle Lucey, Lucia M. Rodriguez Bravo, William L. Wied, and Andrew H. Altieri. "Rapid ecosystem-scale consequences of acute deoxygenation on a Caribbean coral reef." *Nature Communications* 12, 4522 (2021). https://doi.org/10.1038/s41467-021-24777-3. Used under CC BY 4.0.