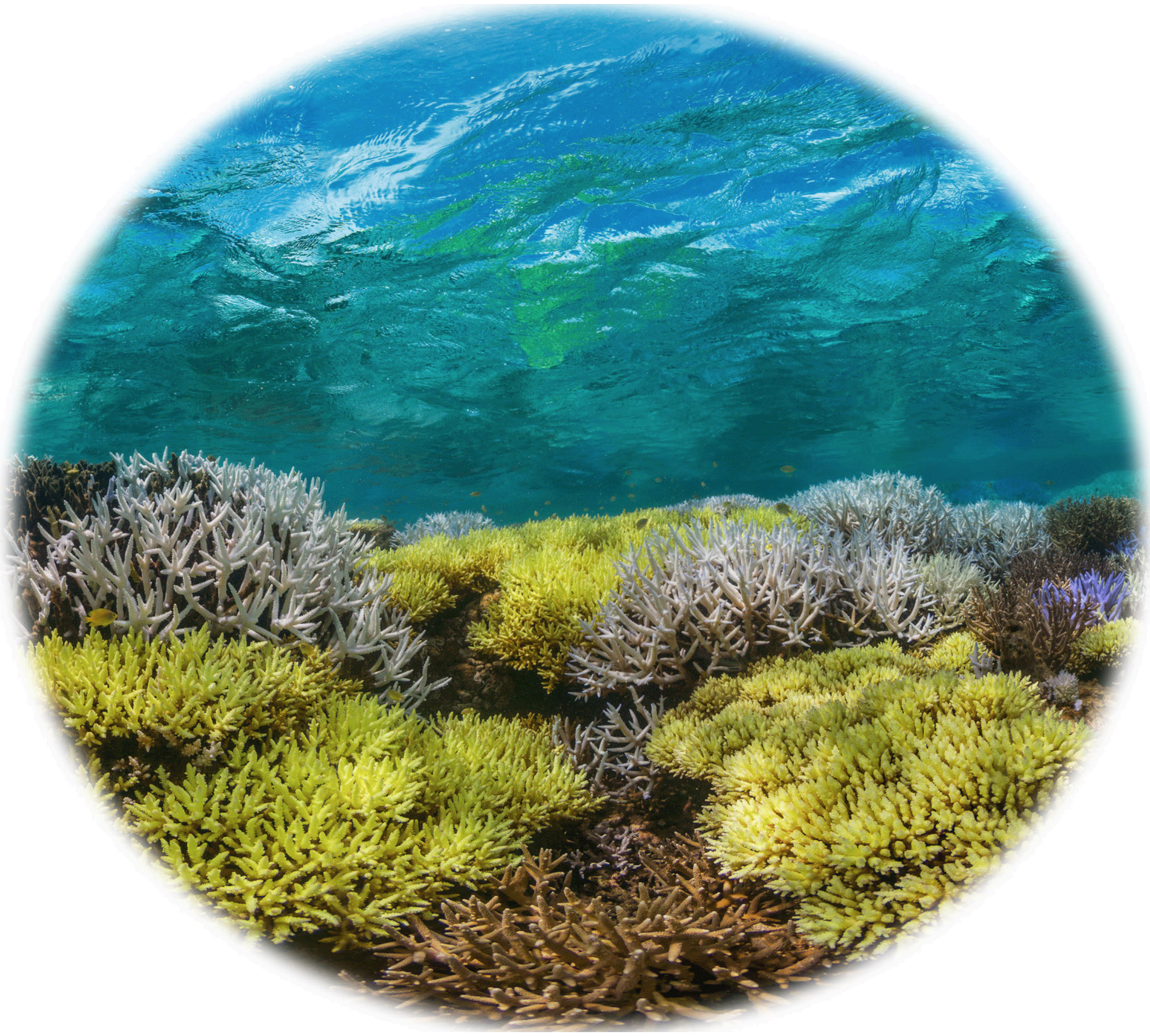
DATA IN THE CLASSROOM

INVESTIGATING CORAL BLEACHING



4th Edition (2024)

This curriculum module was originally developed for the NOAA Ocean Data Education (NODE) Project. This 4th edition (2024) 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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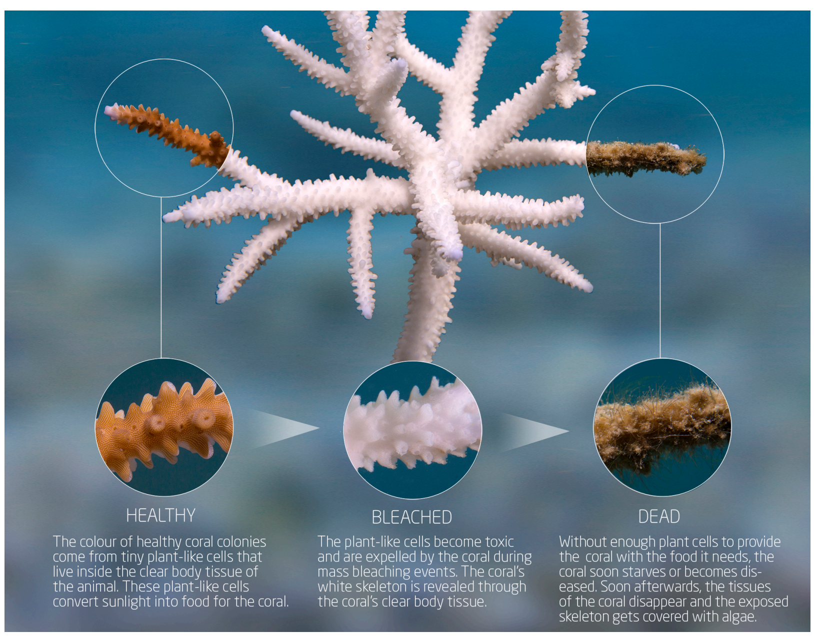
INTRODUCTION

Coral reefs are one of the most diverse ecosystems on the planet. Found throughout tropical regions, they support an estimated 500 million people (one in every 15 people) in terms of food, livelihoods and other benefits.[1] Even though coral reefs face numerous threats, rising temperatures associated with climate change is one of the greatest. In this module, students will use real data to investigate the consequences of rising ocean surface temperature on coral reefs. They will also consider the importance of coral reefs in their own lives.

Coral Reef Basics

Corals are marine invertebrates that can become stressed by changes in conditions such as temperature. Warmer water temperatures can result in coral bleaching. When ocean water becomes too warm, corals expel the algae (zooxanthellae) living in their tissues causing the coral to turn completely white. This is called coral bleaching.

Reef-building corals do need warm, tropical water. Generally, most corals cannot grow in oceans where the water temperature dips below 18°C (64°F) for extended periods in the winter. But how warm is too warm? Scientists discovered that corals start getting stressed if the water gets only 1°C warmer than the highest temperature expected in the summer. This temperature is called the "bleaching threshold," because the stress caused by warmer-than-normal water can cause the corals to bleach.



What happens to coral when it bleaches? Each polyp in the coral community has tiny algae, called zooxanthellae, that grow in the polyp's body tissue. Normally, these algae absorb energy from the sun and use it for photosynthesis. When the water gets too warm, however, these plants cannot use the sun's energy as efficiently. The algae turn this excess energy from sunlight into chemicals that can damage them and their host polyps. While polyps normally need the zooxanthellae, they have to get rid of them to survive the temperature stress. As a result, a polyp will expel most of the zooxanthellae from its body. The polyp's body tissue is transparent, and the rock underneath it is white, so when the zooxanthellae are expelled, what you see is the polyp's white skeleton instead of the normal golden-brown of the zooxanthellae that were in the interconnecting tissue. Because the entire coral soon looks pale or white, we say that it is "bleached."

Curriculum Overview

This curriculum module offers activities at five different levels of student interaction, sometimes referred to as Entry, Adoption, Adaptation, Interactivity and Invention. Levels 1 and 2 are very directed and teacher driven. Levels 3-5 of Adaptation through Invention are more student directed and open up opportunities to design lessons featuring student inquiry. This chart illustrates the five levels of this module, *Investigating Coral Bleaching Using Real Data.*

5	**INVENTION: Designing Your Own Investigation –** Students will design their own plan to answer a research question. They will describe how they will use data and consider the limitations of the data.
4	**INTERACTIVITY: Identifying a Bleaching Event –** Students evaluate the latest, real-time bleaching predictions and in-the-field monitoring observations to determine how ocean surface temperature is affecting the health of Florida's coral reefs.
3	**ADAPTATION: Monitoring the Health of Coral Reefs –** Students will learn how to identify coral bleaching and understand how scientists measure bleaching at reefs around the world.
2	**ADOPTION: Measuring Coral Heat Stress –** Students will examine data from ocean surface temperature graphs and maps to assess the extent to which corals on the Great Barrier Reef were at risk of bleaching due to heat stress.
1	**ENTRY: Identifying and Mapping Coral Reef Locations –** Students will learn how to read and interpret ocean surface temperature maps. This is a teacher-led discussion and activity.

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 2017, the module was updated and adapted to incorporate the innovations described in the NGSS[1] where possible. An alignment document has been developed to help teachers and educators understand how the activities in this module align with the new standards. You can learn more about how this module relates to specific NGSS components by visiting the Data in the Classroom website.

Climate Literacy

Climate plays an essential role in the overall health of coral reefs. School curricula usually point out the differences between weather and climate, with weather being specific atmospheric conditions expected for a location in the short-term future, whereas climate shows long-term averages of conditions in the atmosphere or oceans, which are described by statistics such as means and extremes. The *Investigating Coral Bleaching Using Real Data* module examines coral health over a long period of time. The module integrates *Climate Literacy, The Essential Principles of Climate Sciences*[2] by NOAA partners as a guide to understand how climate can influence coral health seasonally or change reef health due to extreme events over time.

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 Climate Literacy, The Essential Principles of Climate Sciences; March 2009, A Climate-Oriented Approach for Learners of All Ages, US Global Change Research Program.

LEVEL 1: ENTRY
WHAT FACTORS AFFECT CORAL REEF DISTRIBUTION?

SUMMARY

- Grade Level: 6-8 (*appropriate for grades 5-12, with modification*)
- Teaching time: 20–30 minutes
- Activities: a) Examine a map of coral reef locations around the world, b) understand how to interpret maps of ocean surface temperature and c) use a map to identify at least three physical factors that appear that limit the distribution of coral reefs around the world.
- Vocabulary:
    - Climate - the long-term 30-year average of conditions in an area—atmosphere, oceans, ice sheets—described by statistics, such as means and extremes.
    - Coral Reef - a seafloor biological community that forms a solid limestone (calcium carbonate) structure, built upon many generations of dead coral. The predominant organisms in most reef communities are corals.
    - False-Color Map - an image that uses colors, rather than true appearance, to represent differences in measured values. The color is “false” in that the land, water, or other surface shown is not really the color on the map.
    - Range - determined by upper and lower limits. All living things have a range of conditions in which they thrive. Corals thrive within a temperature range of 18°C to 29°C.
    - Ocean surface temperature - the temperature at the uppermost layer of the ocean, only a few millimeters deep. It can be globally monitored through satellite remote sensing. This term is also referred to as ‘sea surface temperature.’
    - Weather - The specific conditions of the atmosphere at a particular place and time, measured in terms of variables that include temperature, precipitation, cloudiness, humidity, air pressure, and wind.

LESSON PLAN – LEVEL 1

Objectives

Students will develop skills in using and interpreting data maps of ocean depth, temperature, latitude, and longitude to analyze and determine how these factors influence the location of coral reefs around the world.

Background

Coral reefs have a very limited distribution around the planet. Reef-building corals are typically located in tropical and subtropical waters between 30° N and 30° S latitudes. Generally, corals need shallow, sunlit and clear water to survive. They also need warm water. Though different species of coral can withstand different amounts of temperature fluctuations, most corals survive in temperatures ranging from 18°C to 29°C.

Corals are very sensitive to changes in ocean temperature. Small increases in temperature can cause corals to expel their symbiotic algae, called zooxanthellae, responsible for both their coloration and nutrition. This process is called coral bleaching and when frequent or severe enough, it causes coral mortality and an overall decrease in coral abundance.

Due to changes in climate, ocean temperatures have been increasing over time. As a result, coral bleaching has become a significant threat to coral ecosystems worldwide. To carefully monitor the ocean temperatures that coral reefs are exposed to, scientists use highly detailed maps of ocean surface temperature. These data are continuously recorded using instruments on satellites that measure heat from the surface of the ocean. By plotting the data values as colors on a map, called a false-colored map, it is easy to spot patterns of temperature.

In Level 1, students learn to read and interpret satellite-generated maps of ocean surface temperature that will enable them, in Levels 2-5, to use these data to answer this question:

What causes coral bleaching? How can data help us better understand and predict these events and their impacts on coral reef ecosystems worldwide?

Teacher Prep

There are a variety of ways to implement this activity. Decide which works best for your classroom, and prepare as appropriate.

- Go to the *Data in the Classroom* website, open the module, familiarize yourself with the Level 1 activities, and access the student worksheet from the *For Teachers* page.

Procedure

Introduction:

Engage students in this module by explaining that they will be looking at an important environmental issue – coral bleaching.

Where in the World?

Students will begin their study of corals and coral bleaching by exploring the distribution of coral reefs around the world. Use the Level 1 worksheet to help guide the students through this task, if desired.

1. Project Level 1 of the online module onto a screen in your classroom to help guide students through the activity.
2. Scroll down to the section titled 'Where in the World?' Here, you'll find a map displaying the locations of coral reef communities around the world. In addition to reef locations, the map also shows ocean depth (dark gray colors are very deep and light gray are shallow.)
3. Point out that coral reefs are distributed around the planet but only in limited locations. Zoom in and out on the map, as desired, as you explore the following questions with your students.
4. Ask: where do coral reefs seem to be located?
   Possible answer: Waters near the shore or on either side of the equator.
5. Ask: where do corals seem to be absent?
   Possible answers: Large areas on the west coast of South and Central America, and

the west coast of Africa. Upper parts of the North American continent, Greenland, Asia, and to the south near Antarctica.

6. Give students time to complete the questions on the worksheet. Check student understanding of the main concepts in this section by completing the online multiple choice questions at the end of this section.
   Answer - Question 1: Waters near the shore and on either side of the equator.

Readings Ocean Surface Temperature Maps

Before students can start using data to understand coral bleaching events, they need to learn how to read ocean surface temperature maps.

1. In this section, you'll find a map displaying ocean surface temperature measurements. This type of map, called a false color map, uses a variety of colors to represent different temperature measurements across the ocean's surface.
2. Using the projected image, discuss the key features of the map:
   - The map displays information about ocean temperature taken from instruments on satellites orbiting the earth.
   - The geographic area of the map is defined using lines of latitude and longitude.
     - X axis = longitude, degrees east and west.
     - Y axis = latitude, degrees north and south of the Equator.
   - The land areas on the map are colored gray.
   - The Pacific Ocean is colored various shades of red and blue. The colors represent temperature at the ocean surface.
   - Locate the color legend below the text in the left sidebar. This legend indicates the surface temperature in both degrees Fahrenheit and Celsius.
   - Ask students what color indicates the warmest water (dark red) and the coldest water (dark blue) on the map.

5. Ask: How can using satellite data help researchers to study water conditions over time? Why is it important for researchers to look at data for more than one year to determine ocean surface temperature changes?
   Possible answers: Researchers can track changes in temperature year to year and look for patterns. Using satellite data helps reveal long-term changes in climate.

6. Give students time to complete the questions on the worksheet. They can complete the same questions within the online module in order to check their answers.
   Answer - Question 2, part 1: 82 °F / 28 °C
   Answer - Question 2, part 2: 30°S to 30°N

How Does Temperature Limit the Distribution of Coral Reefs?

Now that students can read a temperature map, they can use this skill to determine the relationship between coral distribution and ocean surface temperatures.

1. In this section, you'll find two maps positioned side-by-side. Students can click and drag the swipe bar (in the center of the map) to compare two web maps using the Swipe Tool.

2. Zoom in and out on the map, as desired, as you explore the following question with your students: why do you think corals are limited to certain locations on the planet?
   Possible answers:
   - water too cold or too hot
   - water too shallow
   - water too deep
   - not enough sunlight
   - too much salt
   - too much sediment in the water

3. Tell students that they have hit on some of the major physical factors that limit coral reef development: depth, light, salinity, sedimentation, the emergence of coral into air, and temperature.

4. Give students time to answer the last section of the worksheet and answer the question at the end of the online activity to summarize their learning.

LEVEL 2: ADOPTION
MEASURING CORAL HEAT STRESS

SUMMARY

- Grade Level: 6-8 (*appropriate for grades 5-12, with modification*)
- Teaching time: 30-45 minutes
- Activities: Use temperature data to assess the extent to which corals on the Great Barrier Reef are at risk of bleaching due to heat stress.
- Vocabulary:
    - Accumulated heat stress - a system used to measure the cumulative effect of heat exposure on corals over a 12-week period. It accounts for both the intensity of the heat and the duration of exposure, recognizing that even moderate temperatures can become hazardous when sustained over long periods.
    - Bleaching threshold - the temperature at which corals experience heat stress and begin to bleach. This value is one degree Celsius (1 °C) above the monthly average maximum surface temperature for a particular region.
    - Heat Stress – For corals, heat stress is experienced when ocean temperatures rise above the normal range that corals can tolerate. This stress disrupts the symbiotic relationship between corals and the algae living within their tissues.

LESSON PLAN – LEVEL 2

Objectives

Students will analyze graphs and maps to evaluate how often and to what extent ocean temperatures on the Great Barrier Reef exceeded the threshold levels that corals can tolerate.

Background

Lots of living things, including us, can get stressed out when exposed to 'higher than normal' temperatures. Imagine getting into a bathtub filled with water that is too hot for your comfort. If the water is only slightly warmer than you normally like it, you may be able to tolerate it for a minute or two before getting out. If the water is really hot, you may not be able to tolerate it for long at all. Both of these situations cause heat stress. Heat stress can come from prolonged exposure to water that is only a bit warmer than ideal, or shorter, more intense periods of extreme heat (almost like a heatwave).

Remember from Level 1, corals have a limited temperature range within which they can live. When it gets too warm, they get stressed out. In other words, corals are extremely sensitive to heat stress. When corals experience warmer than usual ocean temperatures, they expel the symbiotic algae living in their tissues, causing them to 'bleach' or turn completely white. When corals bleach, they are not dead. But if 'warmer than usual' conditions persist, corals can die. Other threats, like disease and pollution, can cause bleaching; however, the leading cause of coral bleaching worldwide is heat stress. As surface ocean temperatures have already increased and are projected to continue increasing by at least another 2 °C under a business as usual scenario by the year 2100, coral bleaching events are expected to increase in frequency and intensity over the coming decades.[3]

In this level, students learn to assess coral bleaching risk by measuring the extent to which corals are exposed to abnormally warm conditions, or heat stress. Scientists use ocean temperature data to estimate how much heat stress corals have been exposed to over a period of time. Because many coral reefs are in very remote areas, temperature data provided by satellites provide a much easier way to collect this data.

Reefs around the world experience their warmest conditions at different parts of the year. For example, in the southern hemisphere, the ocean heats up the most in January-March, in the northern hemisphere its July-September. In the tropics, the warmest temperatures may occur at any time during the year.

Coral polyps become stressed once they experience ocean temperatures that exceed 1°C above the warmest average summertime temperature. For example, if a reef in Australia experiences its warmest summer season in January, and that mean monthly temperature is 28°C, we can expect the coral in that area to becomes stressed and possibly bleach once temperatures are above 29°C. In this activity, we call this temperature the *bleaching limit*.

Due to the effects of climate change, surface ocean temperatures have exceeded bleaching limits along the Great Barrier Reef, causing mass bleaching events in 1998, 2002, 2016, 2017, 2020, and 2024. The events in 2016 and 2017 were so severe that they led to the death of 50% of the reef. Record high temperatures have occurred not just around the Great Barrier Reef, but globally, and have triggered repeated global episodes of coral bleaching since mass bleaching was first documented in the 1980s.

Prolonged and severe heat stress, like the kind that corals from the Great Barrier Reef have experienced, can add up. This accumulation of stress makes significant bleaching more likely and recovery more difficult, and on the Great Barrier Reef it has led to widespread bleaching, coral decline and habitat loss. In this activity, students examine NOAA satellite data and products in order to predict and analyze the severity of coral bleaching on the Great Barrier Reef.

Teacher Prep

There are a variety of ways to implement this activity. Decide which works best for your classroom, and prepare as appropriate.

- Go to the *Data in the Classroom* website, open the module, familiarize yourself with the Level 2 activities, and access the student worksheet from the *For Teachers* page.

Procedure

Introduction

1. Navigate to Level 2 of the Investigating Coral Bleaching online activities. Project Level 2 onto a screen to help guide students through the activity, if desired.
2. Give students time to explore the information in the 'Introduction' and 'What is Heat Stress' and "Using Satellites to Gather Data' sections.

3. Ask: Do you remember the temperature range within which corals are typically found?
   Answer: Corals live in a tropical climate where the ocean temperature can range from 18°C to 29°C.
4. Ask: At what time of the year might corals experience the warmest ocean temperatures?
   Possible answer: During summer months.
5. Ask: How long could a summer 'heat wave' last (days, weeks, months)? And how could the duration of a heat wave matter to corals?
   Possible answers: Accept any answer. If it lasts a few hours, it most likely won't hurt the corals, but if it lasts for weeks or months, the corals are in danger of bleaching.
6. Ask students to think about and share their own experiences with extreme temperatures. Tell them to imagine working outside on a hot day. Then ask: Does the stress you feel working in hot conditions get worse with time? What can you do to bring yourself into a comfortable temperature range?
   Possible answers: Limit physical activity, stay in shaded areas or move indoors to air conditioned locations, go swimming or take a cool shower.

Measuring Heat Stress

Satellite data has become an essential tool for scientists who study coral bleaching caused by heat stress. Here, students will explore the same ocean surface temperature data used by scientists to determine the extent to which corals on the Great Barrier Reef are at risk of bleaching.

1. Give students time to read the text in this section of the module. Ask: How warm does the ocean temperature need to be before corals might bleach?
   Answer: Bleaching may occur if temperatures exceed 1°C above the warmest average summertime temperature (for that specific location).

2. The graph in this section shows summertime ocean surface temperature data for a location on the Great Barrier Reef. If needed, explain how to read the graph (the axes, the legend, etc).

3. In groups or as a class, give students time to answer the questions on the corresponding section of the worksheet. Answer Question 1 of the online activity.

5. Discuss: Are the corals on the Great Barrier Reef at high risk, moderate risk or low risk of bleaching due to heat stress?
   Possible Answer: In Jan-Mar, corals were at high risk of bleaching because they were exposed to prolonged 'higher than normal' temperatures that were above the bleaching limit nearly every week over the first three months of the year.
6. If desired, start a class list of questions that students have about coral bleaching.

Calculating Accumulated Heat Stress

Next, students will learn that heat stress 'adds up' or accumulates over time and how this accumulation of stress is measured.

1. In groups or together as a class, complete this section. Use the worksheets to help guide the students through this task, if desired. Answer Question 2 of the online activity.

2. Ask: why would it be important to measure accumulated heat stress? What might the data be used for?
   Possible answers:
   - The calculations measure not only how far the temperature is above the *bleaching limit* but how long it has stayed above that point. This enables scientists to consistently measure bleaching risk and compare risk over time.
   - The calculations can be used to better understand and predict coral bleaching events around the world. *Note:* NOAA uses these calculations to assess risk and alert scientists and reef managers when the thermal stress rises to dangerous levels.

Understanding Maps of Accumulated Heat Stress

Scientists assign a value, or a number, to bleaching risk - called *Accumulated Heat Stress* (also known as *Degree Heating Weeks)*. We know, from looking at the temperature data from the Great Barrier Reef, that corals were at risk of bleaching in Jan-Mar 2024. Now, students will learn to assess the extent to which corals on the Great Barrier Reef were at risk of bleaching by analyzing maps of *Accumulated Heat Stress.*

1. Help students to understand the key features of the map in section:

a. Much like the ocean surface temperature maps in Level 1, this map uses a variety of colors to represent different values that correlate to accumulated heat stress in corals.
b. The different colors represent how much thermal stress has 'added up' over the previous 12 weeks (3 months). Because this is a data map from April, it is showing accumulated heat stress from the previous 12 weeks, Jan-Mar.
c. Ask students what color indicates no thermal stress (blue). Have students find a blue area on the map. In these areas, corals have not accumulated thermal stress over the 3 months prior to April 1; in other words, the temperature did not cross the local bleaching limit.
d. Ask students when they might expect to see significant coral bleaching, especially in more sensitive species.
Answer: When thermal stress reaches a value of 4 or higher (yellow and light orange regions of the map).
e. Ask students when they might expect to see widespread bleaching and mortality from the thermal stress.
Answer: When thermal stress reaches a value of 8 or higher (dark orange, red or purple regions of the map).

2. Give students time to answer Question 3 at the end of this section, as well as respond to the claim at the bottom of the worksheet.
3. If desired, encourage students to explore the map and compare the bleaching risk at the Great Barrier Reef with other regions. What do they notice?
4. Ask: What questions could you ask (and answer) using the types of data you explored in Level 2? Give students time to discuss and summarize their ideas.

3 Schoepf, V et al. 2015. Limits to the thermal tolerance of corals adapted to a highly fluctuating, naturally extreme temperature environment. Scientific Reports (5) 17639.

LEVEL 3: ADAPTATION
MONITORING THE HEALTH OF CORAL REEFS

SUMMARY

- Grade Level: 6-8 (*appropriate for grades 5-12, with modification*)
- Teaching time: 45-60 minutes
- Activities: a) Learn how to identify healthy vs. bleached corals, b) use quadrat sampling to estimate the extent of bleaching events, and c) conduct surveys of reefs around the world
- Vocabulary:
    - Coral bleaching - loss of zooxanthellae due to prolonged or extreme exposure to heat stress.
    - Indicator: an organism so intimately associated with particular environmental conditions that its presence indicates the existence of those conditions.
    - Monitoring - sampling and measuring something in the environment (air, water, soil, vegetation, animals) over time and comparing findings with baseline samples.
    - Mutualism - mutually beneficial association between two species of organism.
    - Polyp - a single coral organism that secretes calcite, which forms a corallite shell or skeleton. Many polyps together make up a coral colony.
    - Quadrat sampling - a classic tool for the study of ecology; in general, a series of squares of a set size are placed in a habitat, and the species within those quadrats are identified and recorded.
    - Symbiosis - a close and long-term biological interaction between two different biological organisms.
    - Variable - a component of the ecosystem, physical or biological, that has an effect on other components of the ecosystem.
    - Zooxanthellae - a group of dinoflagellates (single-celled algae) that lives inside of the body tissues of various invertebrates, including corals. In corals, these dinoflagellates provide carbohydrates through photosynthesis, which serve as a source of energy for the coral polyps. They also give corals their color and aid in recycling waste materials.

LESSON PLAN – LEVEL 3

Objectives

Students will learn how to identify coral bleaching and understand how scientists measure bleaching at reefs around the world.

Background

This teacher-led lesson invites students to become scientists and scuba divers who will monitor bleaching at coral reef locations around the world. The lesson will introduce students to coral reef biology, how to identify conditions of stress in coral reefs, and how researchers monitor coral reef health.

As highlighted in the previous lesson, scientists use ocean surface temperature data to determine the extent to which corals are stressed and at risk of bleaching. However, how do scientists know exactly how corals respond to changes in ocean surface temperature? And how does the entire coral reef system respond to bleaching? In-the-field research and monitoring are needed in order to systematically measure a variety of variables (such as bleaching).

Coral reef monitoring is the gathering of data and information on coral reef ecosystems. An important aspect of monitoring is that it should be repeated on a regular basis, preferably over an extended period of time. In this activity, students will be learning to collect data on one variable - percent bleaching. A *variable* is a component of the ecosystem, physical or biological, that has an effect on other components of the ecosystem. For monitoring, the variables are the components or species that we collect data on, e.g. percentage cover of hard coral. It is impossible to measure every variable on a coral reef, therefore *indicators* are used to detect change or impacts, or show reef 'health'. Indicators are either ecologically or economically important. Examples of ecological indicators include percent hard coral cover, which is an indicator of coral reef health because many other organisms rely on hard coral for their survival.

Corals are made up of a symbiosis between an animal (the coral polyp) and a plant-like organism called *zooxanthellae* (pronounced zoh-xan-thell-ee). The coral receives food from the zooxanthellae, and the zooxanthellae receive protection and nutrients from the coral. Since both organisms benefit from this relationship, it's called *mutualism*.

However, when conditions are not ideal, this mutualism breaks down, and the zooxanthellae are expelled by the coral. The result is a much weaker coral since it does not have its usual food supply. This process of expelling the zooxanthellae is called *bleaching* since without the zooxanthellae, the coral turns a bright white color, compared to the brown, green, red, etc when it is healthy.

If the coral stays bleached for too long, it may actually die, just like a human would of starvation. When that happens, the coral skeleton breaks down and other creatures begin to grow on it, leaving an encrusted rubble of a reef.

Teacher Prep

There are a variety of ways to implement this activity. Decide which works best for your classroom, and prepare as appropriate.

- Go to the *Data in the Classroom* website, open the module, familiarize yourself with the Level 3 activities, and access the student worksheet from the *For Teachers* page.

Procedure

Identifying Differences Between Healthy, Bleached & Dead Corals

In order to monitor coral bleaching, students need an introduction to coral biology, which includes the important process of symbiosis between corals and certain algae.

1. Give students time to read the first two sections, as well as record their observations on the worksheet.
2. Ask: What are zooxanthellae? What do they do for corals? And what do corals do for zooxanthellae?
   Possible answer: Zooxanthellae are single-celled algae that live within the tissues of corals. The most important thing that the algae do is provide food, in the form of

carbohydrates, to the corals through photosynthesis. The corals provide protection and nutrients for the zooxanthellae.

3. Ask: What is coral bleaching? Are bleached corals dead?
   Possible answers: When water temperatures become warmer than normal, corals can become stressed out. Stressed corals expel the algae (zooxanthellae) living in their tissues causing the coral to turn completely white, thus the term 'bleached.' When a coral bleaches, it is not dead. Corals can survive a bleaching event, but they are under more stress and are subject to mortality.
4. Ask: How can you tell the difference between a healthy coral, a bleached coral and a dead coral?
   Possible answers: Healthy corals come in shades of olive green, brown, tan and pale yellow; bleached corals appear white; dead coral often becomes covered in algae.

Observing the Effects of Bleaching on Coral Reefs

In this section, students make broad-scale observations to better understand and define the effects of bleaching on reef ecosystems.

1. Give students time to use the map tool in this section to explore each of the four coral reefs in the western Pacific Ocean.
2. At each of these reefs, students will compare two photos taken at different times at the exact same location on each reef, recording their observations on the worksheet.
3. Observations about each of the coral reef sites may include the following:
   - Phoenix Islands: In 2004, the reef was healthy. In 2016, the reef was mostly dead. *Note: this occurred after a severe bleaching event.*
   - Pago Pago, American Samoa: In December 2015, the reef was healthy. In February 2016, the reef was bleached. *Note: these photos were taken before and after an intense bleaching event. Notice how much can change in only two months.*
   - Great Barrier Reef, Australia: In March 2016, the coral head was bleached. In May 2016, the coral died and is covered in algae. *Note: The Great Barrier Reef*

suffered the worst bleaching on record in 2016. One of the worst-hit areas was around Lizard Island, where around 90% of the coral died.

- Maui, Hawaii: In August 2015, the reef was healthy and in November 2015, the reef was bleached. *Note: these photos were taken before and after an intense bleaching event, one of the first to ever hit the Hawaiian Islands.*

4. Review and give students time to record their observations on the worksheet and answer 'Question 1' at the end of this section.

Monitoring Coral Health Using Quadrat Sampling

In this section, students will learn how to use a common monitoring technique called a quadrat to measure how much of a reef is healthy, bleached or dead. This interactive activity challenges students to apply the broad-scale observational skills practiced in Part 2, as they learn how to collect the quantitative data that is needed to track bleaching over time.

1. Optionally project the photo of the diver and the white quadrat at the beginning of Level 3. Explain that scientists monitor coral reefs using a number of different tools and methods. Scientists sometimes use a tool called a quadrat inside which they can count and measure things. In this virtual activity, students will be using quadrats to estimate how much of an area is affected by bleaching. Note, scientists use quadrats that are big enough to get a good estimate of 'density' or 'cover' yet small enough so that they can collect data in a reasonable amount of time.
2. Scroll down to the section titled 'Monitoring Coral Health Using Quadrat Sampling'. Select Reef #1. The photo shows a white quadrat superimposed on an image of a coral reef. The quadrat is divided into 100 small squares of equal size. Note that each square is numbered. Students will monitor a random subset of 10 squares, outlined in yellow.
3. Give each student team a copy of the Level 3 worksheet. Demonstrate how to complete the table, using the example given. Give student teams time to virtually monitor one of the reefs.

4. The expected results for each of the reef locations can be found on the *Answer Key* found on the *For Teachers* page of the website.

Extend Your Learning

The type of monitoring activities that students learned to conduct in Part 3 can be expensive and time consuming. Many countries do not have the resources required to regularly conduct scuba surveys that monitor the health of their coral reef ecosystems. As a result, there is often limited data across entire regions of the world.

In this section, students can explore high-resolution, 360 degree images that are part of a vast collection of coral reef visuals and data from the Catlin Global Reef Record (2012-present). Computers, rather than people, analyze these images quickly. As a result, a lot more data can be gathered to increase our understanding of the health of corals around the world. For more information about this project, visit globalreefrecord.org.

1. Give students time to take a virtual dive at one or more of the reef locations.
2. Discuss: Are there any disadvantages to using computers to analyze coral health?
3. If desired, students can select one reef location of interest and write an essay or poem using observations from the virtual dive and/or additional online research.

Supplemental Student Activity – *Building a Model Coral Head*

The following hands-on activity could optionally be used to support the online activities in Levels 1-3. In this activity, students build model coral polyps and a coral head to learn about the structure and biological interactions of coral polyps and the ongoing symbiosis in the coral community.

Materials

- Bulletin board
- White egg cartons
- Paper towel rolls cut into 3 sections (1 per student)
- Construction paper divided in half (1/2 per student)
- Colored pencils (green)
- Long balloons (4 per student)
- Colored and white tissue paper
- Scotch tape
- Teacher Master: Cross-Section of a Coral Polyp
- Photocopies of Student Worksheet: Build a Model Coral Head (1 per student)

Preparation

1. Build a bulletin board display of a coral reef. Before students construct their individual coral polyp models, prepare a space on a bulletin board to display built coral heads. Title the bulletin board display: *What Is Coral Bleaching?*

2. Turn white egg cartons upside down with the bottom cups facing up, and cut a hole in each cup the diameter of a paper towel roll. Staple sets of egg cartons on opposite sides of the bulletin board. Label one side *'Living Coral'* and the other side *'Bleached Coral.'* The egg cartons represent the skeletal structure where students will attach their coral polyp models to make coral heads. The 'living' coral head will contain colored twisted tissue paper surrounding the coral polyps attached by the students. The 'bleached' coral skeletal remains of the polyps will have no soft body parts, only white twisted tissue paper woven around the egg carton cups attached by students.

Note: Reef-building corals exhibit a wide range of shapes. To make different coral head shapes (branching, foliase, etc.) for the insertion of student made polyps, refer to NOAA's National Ocean Service Education webpage, *'How Do Stony Corals Grow?'*

Procedure

1. Display Teacher Master: Cross-Section of a Coral Polyp on a computer screen and use the bulletin board display "What Is Coral Bleaching?" as a teaching tool for the model coral heads presentation.

2. Point out key features of the coral polyp:

   - The coral polyp is an animal that has tentacles, mouth, gut, body, cavity, interconnecting tissues, and a limestone skeleton.
   - The coral polyp is mostly transparent with no pigment of its own.
   - At night, tentacles come out of the polyp and capture food. During the day, the tentacles move into the body cavity.
   - The inside wall of the polyp is attached to the outside wall with interconnecting tissue.
   - Zooxanthellae live in the walls of the interconnecting tissue.
   - Limestone builds up where the polyp secretes calcite, forming the reef skeleton.
   - The skeleton houses millions of polyps on a reef system. (Point out the egg cartons representing the reef structure in the bulletin board display.)

3. Discuss the symbiotic relationship between coral polyps and microscopic algae called zooxanthellae. The zooxanthellae live in the polyp's interconnective tissue (point this out on the projected image) and use photosynthesis to make food from sunlight, water, and carbon dioxide, which the polyp and zooxanthellae share.

4. Tell students that they will build a model of a coral polyp. Distribute the student worksheet and materials for building a coral polyp.
5. Once students have assembled their coral polyp models, ask them to:

    - Identify the coral polyp structure.
    - Explain the process of the symbiotic relationship between corals and zooxanthellae.
    - Explain why the process of symbiosis helps keep the coral reef Healthy.

6. Divide the students into teams and have each team attach their coral polyps to a coral head represented by one egg carton on the *'Living Coral'* side of the bulletin board.
7. Have students recall what they learned about ocean surface temperature in the satellite mapping activity (Level 1).
8. Ask: What is the average temperature range corals need to live?
   Answer: 18°C to 29°C
9. Make a label for the bulletin board, "Water Temperature: Range 18°C to 29°C." Attach it to the *'Living Coral'* side of the board.
10. Ask students what they think would happen if the ocean surface temperature rose above 29°C by 1° or more.

    - For one hour?
    - For 2 days?
    - For 2 months?

11. Explain that when the water is too warm the coral polyp expels the zooxanthellae. Ask: What happens when the zooxanthellae are no longer inside of the coral?
    Possible answers: They can't carry on photosynthesis to feed the coral and take away the polyp's waste products; the color of the coral is lost and it turns white; the coral is under stress; the coral and zooxanthallae are no longer in a symbiotic relationship.

12. Explain that the loss of the zooxanthellae leads to coral bleaching. The zooxanthellae are the source of the coral's color. So when coral polyps, under environmental stress, expel the symbiotic zooxanthellae from their bodies, the affected coral colony appears to whiten. If the bleaching persists, the lack of algae and food stresses the coral, restricting growth and eventually bleaching the polyps. Point to the right side of the board that contains the bleached coral.
13. Have the students look at the model coral reef on the bulletin board. Ask: Is there any evidence of serious coral bleaching anywhere on the display?
    Possible answers: On the *'Bleached Coral'* side, there is no color, only the polyp skeletons.
14. Make another label for the bulletin board, "Water Temperature: 1°C Higher Than Highest Summer Temperature." Attach it to the *'Bleached Coral'* side of the board.
15. As a class, go over the discussion questions at the end of the student worksheet. *Why are coral polyps important to coral health? Why is the symbiotic relationship between animal and plant important to coral health?*
    Possible answers: When two species form a partnership with one another, the relationship is called symbiosis; the coral polyp gets much of its food energy from the zooxanthellae, and the zooxanthellae, in turn, get a safe place to live and the nutrition they need to grow; the zooxanthellae help recycle the coral's carbon dioxide and waste.

TEACHER MASTER – LEVEL 3, *SUPPLEMENTAL ACTIVITY*

CROSS-SECTION OF A CORAL POLYP

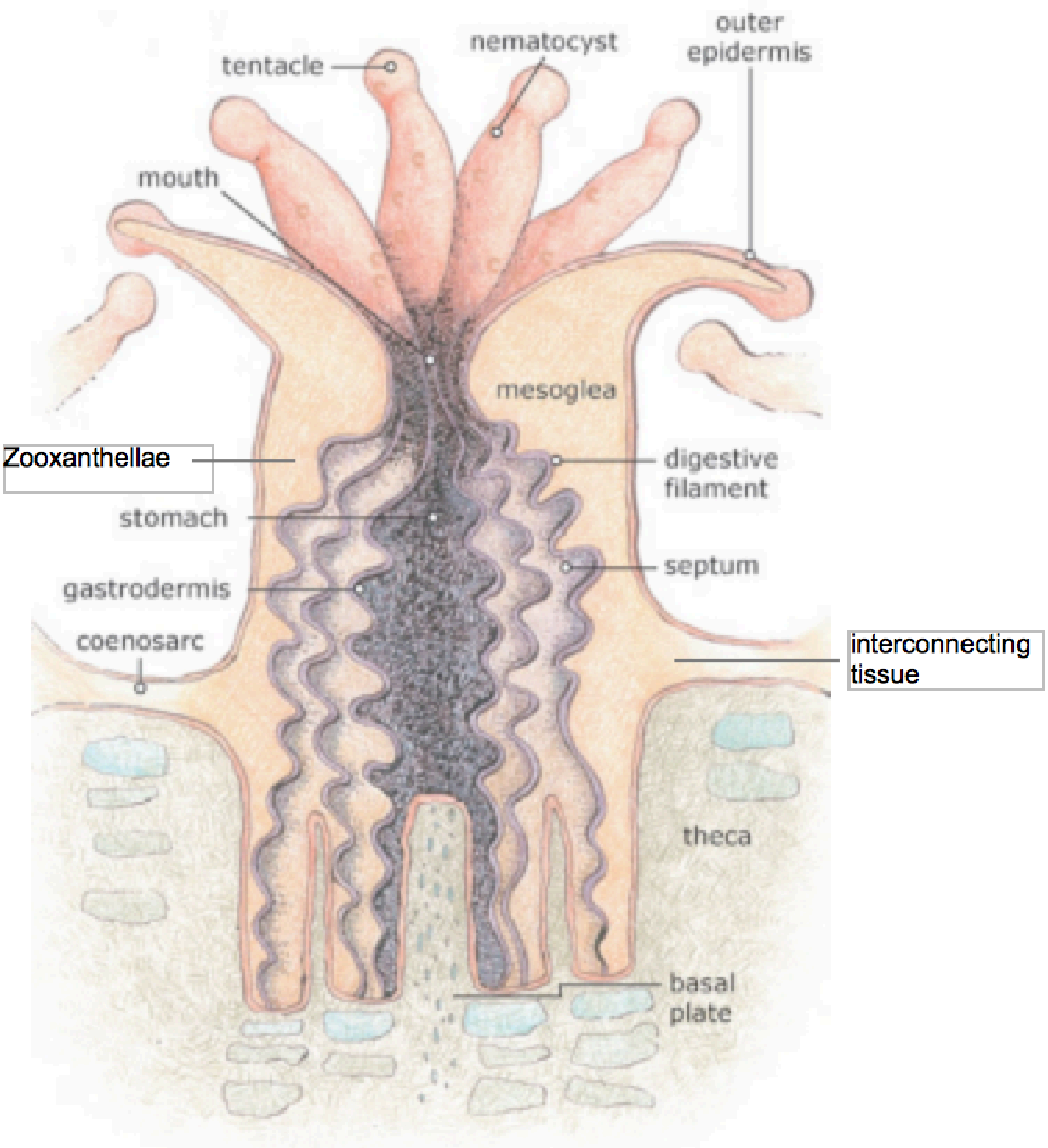
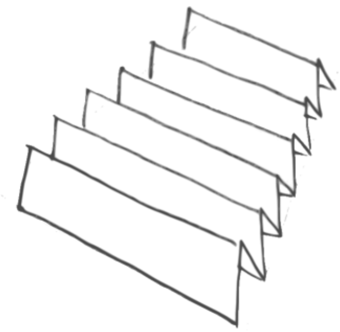


Image: NOAA

STUDENT WORKSHEET – LEVEL 3, *SUPPLEMENTAL ACTIVITY*

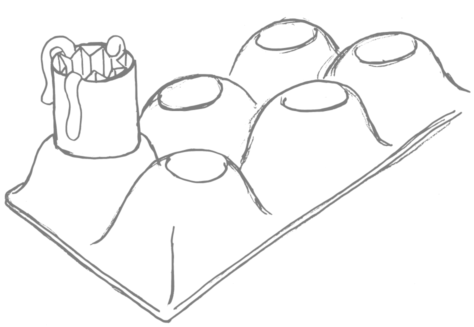
BUILD A MODEL CORAL HEAD



Instructions:

- Fold a piece of construction paper in half and accordion pleat it. Use a green colored pencil to draw circles on one side of the paper. These circles represent zooxanthellae. Zooxanthellae are algae that live inside of corals. They provide carbohydrates through photosynthesis, which give energy and color to the corals.

- Hold the ends of the accordion-pleated construction paper together to form a cylinder with the zooxanthellae on the outside. Next, adjust the cylinder to fit inside of the paper towel roll. Cut off any excess paper from the top and bottom of the tube. The accordion-pleated inside of the cylinder forms the gut of the polyp.
- Tape four long, un-inflated balloons to the inside of the cylinder at one end. These are the tentacles. The tentacles feed the coral at night when there is no sun to allow the zooxanthellae to carry out photosynthesis.
- To build a coral head, insert your coral polyp into the skeletal structure (egg carton) on the '*What Is Coral Bleaching?*' bulletin board display. Put tentacles inside of the polyp to signify day time when the zooxanthellae is making food. Before leaving class or school, put tentacles outside of the polyp for nighttime feeding.



Discussion Questions:

1. Why are coral polyps important to coral health?
2. Why is the symbiotic relationship between animal and plant important to coral health?

LEVEL 4: INTERACTIVITY
IDENTIFYING A BLEACHING EVENT

SUMMARY

- Grade Level: 6-8 (*appropriate for grades 5-12, with modification*)
- Teaching time: 45-60 minutes
- Activities: a) analyze a graph to predict the occurrence, timing and severity of coral bleaching in the Florida Keys and b) determine the relationship between the predictions and how much bleaching was actually observed on the reef.
- Vocabulary:
    - Degree Heating Weeks: this term is equivalent to the term “accumulated heat stress.” It is a system used to measure the cumulative effect of heat exposure on corals over a 12-week period. It accounts for both the intensity of the heat and the duration of exposure. NOAA data products use the term Degree Heating Weeks to describe the accumulation of heat stress.

LESSON PLAN – LEVEL 4

Objectives

Students will evaluate the latest, real-time bleaching predictions and in-the-field monitoring observations to determine how ocean surface temperature is affecting the health of Florida’s coral reefs.

Background

Oceanographers, marine biologists, scuba divers, and enthusiasts of tropical coral reefs are increasingly concerned about the health of these biologically rich yet delicate marine ecosystems. Your students have learned that coral bleaching is a significant threat to coral reefs and the fragile ecosystems they support. But what happens if these reefs don't recover? Why is it important to care? It's crucial for students to understand that studying the health of coral reefs—comparing their past and present conditions—can inspire thoughtful actions to better protect these vital ecosystems in the face of a warming planet.

So far, students have learned to generate, read, and interpret different kinds of data related to coral bleaching. Now, they will apply what they have learned in order to examine the relationship between bleaching predictions (from Level 2) and how much bleaching is actually observed on a reef (from Level 3).

Evidence-based predictions are useful as long as they are accurate. Students will evaluate the latest, real-time bleaching predictions from the Florida Keys, home of one of the largest reef communities in the world. They will use these data to make predictions about the timing and intensity of the bleaching. And finally, students will determine if their predictions were accurate by examining scientific reports and media accounts of bleaching observations during the time that bleaching was predicted.

Teacher Prep

There are a variety of ways to implement this activity. Decide which works best for your classroom, and prepare as appropriate.

- Go to the *Data in the Classroom* website, open the module, familiarize yourself with the Level 4 activities, and access the student worksheet from the *For Teachers* page.

Procedure

Introduction

1. Find and project a news report from a recent coral bleaching event in the Florida Key.

2. Explain that students will continue their investigations of coral bleaching by evaluating the latest, real-time bleaching predictions from the Florida Keys.

Analyzing Data from the Florida Keys

1. Navigate to Level 4 of the module.

2. Demonstrate how to use the map tool to access a graph of accumulated heat stress from the Florida Keys. Let students know that on the y-axis of this graph the term *Degree Heating Weeks* is equivalent to the term *Accumulated Heat Stress*.

3. Here are a few features and reminders to help students interpret the graph:

    a. Degree Heating Weeks (DHW) values are plotted along the y-axis, time along the y-axis.
    b. Remind students, from Level 2, that these values are calculated using ocean surface temperature data to predict the timing and intensity of coral bleaching.
    c. When values are 4 or higher: bleaching is expected.
    d. When values are 8 or higher: widespread bleaching and mortality is expected.
    e. When values are 12 or higher: mass mortality is expected.

4. Instruct students to use their worksheets to guide them through the evaluation of both a) accumulated heat stress data – used to make predictions about coral bleaching, and b) in-the-field coral observations – used to determine the extent and severity of bleaching. The simplest way to gather these in-the-field coral observations is to access Mote Marine Lab's Condition Reports, published online every two weeks throughout the summer. Level 4 contains a link to these reports. Make sure to scroll down the page to find the reports. After accessing and evaluating their data, students should work together to answer the questions and complete the conclusion section at the end of the worksheet.

5. A sample conclusion may include the following: accumulated heat stress values were extremely high during the summer of 2023, exceeding a value of 20 for a duration of at least 3 months. I predict that mass coral bleaching and mortality was therefore very likely during this period. In-the-field observations in Aug 2023 from Mote Marine Lab report that the majority overall percentage of corals exhibiting signs of thermal stress was 76-100%. 29 of the 39 reports from observers in Sept 2023 noted extensively bleached reefs. In conclusion, the duration and intensity of heat stress was significant during the summer of 2023, and caused extensive bleaching at the majority of reefs throughout the Florida Keys.

LEVEL 5: INVENTION
DESIGN YOUR OWN INVESTIGATION

SUMMARY

- Grade Level: 6-8 (*appropriate for grades 5-12, with modification*)
- Teaching time: varies, depending on the investigations
- Activities: Design an investigation using real data to examine a research question

LESSON PLAN – LEVEL 5

Objectives

Students will apply what they have learned to consider the issue of coral bleaching on a larger scale. To do this, students will ask questions, collect and analyze data and construct an argument that shows how data supports their conclusions.

Background

Students have used data to begin to understand how warmer than normal ocean surface temperature affects the health of coral reefs at specific locations around the world. Now, it is time to examine this issue on a global scale. How does the health of coral reefs compare from one location to another? And how is changing ocean surface temperature affecting the health of coral reefs over time?

Students should be encouraged to develop their own research questions for this activity. In general, questions that lead them to considering changes in the frequency or intensity of coral bleaching over time will provide a good starting point.

Sample research questions with links to data tools are available in the online Level 5 activity. Students can be challenged to apply what they have learned about reading and understanding data to interpret a variety of data products.

Teacher Prep

There are a variety of ways to implement this activity. Decide which works best for your classroom, and prepare as appropriate.

- Go to the *Data in the Classroom* website, open the module, familiarize yourself with the Level 5 activities, and access the student worksheet from the *For Teachers* page.

Procedure

This activity challenges students to think like scientists by designing a scientific investigation in which data collection and analyses are important parts of the process. Students are challenged to engage in a number of scientific practices, including asking questions, analyzing data and constructing explanations using data.

1. Assign students to work in teams of two and give each team a copy of the student worksheet, *Design Your Own Investigation*.

2. Project Level 5 and ask, “What kinds of things do you think should be considered when asking scientific questions?”
   Possible answers: Formulate questions that are clear and focused. Avoid vague or broad questions. Ensure your question aligns with the type and scope of available data. For instance, if you have access to temperature and bleaching data, ask questions related to those variables. Good scientific questions often involve measurable or quantifiable elements. For example, "How has the frequency of coral bleaching events changed over the last decade?" is measurable, whereas "Why are corals suffering?" is too broad.

3. Prior to developing a question, students will need to understand what types of data are available to them. The data tools and visualizations that are available in Level 5 are described below. Instructions to use the tools can be found by clicking the ‘Get Data’ tab in the upper navigation bar. With students, discuss these data and demonstrate how to use the data tools, if needed.

    a. Degree Heating Weeks - Map Viewer: NOAA data products use the term Degree Heating Weeks to describe the accumulation of heat stress. This tool can be used to identify where accumulated heat stress is highest around the globe as well as short and long-term changes in heat stress over time.

   b. Coral Reef Station data tool (2013 - present): This data tool will enable students to explore bleaching risk (Degree Heating Weeks values) at five different locations since 2013. Locations include the Great Barrier Reef, Figi, Hawaii, the Galapagos and the Florida Keys.

4. Guide students through the selection of a research question.
5. Next, in their small groups, students should determine what data are needed to answer their question, making a list on their worksheet.
6. Using the data tools on the website, students can then access, save and/or print the graphical displays of data. If necessary, help students determine if they have enough data to answer their question and identify areas where they may need to seek out additional sources of information.
7. After accessing and reviewing their data, students should work together to write a detailed interpretation of what their data shows and complete the conclusion section at the end of the worksheet.
8. After students complete their research, provide time for them to present their findings to the class.
9. Use student presentations as an opportunity to relate their investigations to the current news and debate about coral bleaching and global climate change.