COASTAL PROTECTION

CORAL RESILIENCE LAB

HAWAIʻI INSTITUTE OF MARINE BIOLOGY

HIGH SCHOOL LEVEL

OBJECTIVE

Students will be able to understand the value of coral reefs and identify the role they play in protecting us and our coastlines from natural disasters and loss of property. Students will also examine the interconnection between evolution, anthropogenic climate change, and the effects of abiotic factors on marine environments.

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This curriculum was developed in accordance with the NGSS. Next Generation Science Standards (NGSS):

HS-LS2-6	Evaluate the claims, evidence, and reasoning that the complex interactions in ecosystems maintain relatively consistent numbers and types of organisms in stable conditions, but changing conditions may result in a new ecosystem
HS-LS2-7	Design, evaluate, and refine a solution for reducing the impacts of human activities on the environment and biodiversity
HS-ESS2-2	Analyze geoscience data to make that claim that one change to Earth's surface can create feedbacks that cause changes to Earth's other systems
HS-ESS2-5	Plan and conduct an investigation of the properties of water and it effects on Earth materials and surface processes
HS-ESS3-1	Construct an explanation based on evidence for how the availability of natural resources, occurrence of natural hazards, and changes in climate have influenced human activity

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Vocab

Biodiversity hotspot

Endemic

Atolls

Sea Walls

Artificial Reef

Hybrid Reef

Sedimentation

Thermally Tolerant

Acidification

Anthropogenic

Introduction

Coral reefs are essential to the marine ecosystem. Even though corals cover less than 1% of the ocean floor, they provide habitat for roughly 25% of marine species, and benefit us on land by providing the physical barrier that is the first line of defense against strong wave action and natural disasters. Hawaiʻi's and Florida's reefs are placed at the highest dollar value in terms of coastal protection, due to the physical barrier that these reef systems provide. It is estimated that each kilometer of reef grants around $10 million in flood protection[1].

Background

Corals benefit humans and marine organisms in many ways. Nearly half a billion people worldwide rely on coral reefs for food, jobs, and protection. The three-dimensional structures that corals create are filled with nooks and crevices that provide homes and shelter for

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marine life. Coral reefs are also a **biodiversity hotspot**. This biodiversity ensures that the ecosystem is able to function properly, makes it more resilient against natural and human-caused stressors, and helps to provide clean air, clean water, and consistent temperatures around the globe. The coral reefs in the Papahānaumokuākea National Marine Monument in the Northwest Hawaiian Islands alone supports over 7,000 species of marine organisms, almost ¼ of which are **endemic** and found nowhere else in the world[2].

This biodiversity also is beneficial for fishermen. If managed correctly, the fish and other species found on coral reefs provide a source of food and food security for coastal communities. Some organisms and bacteria found on reefs aid in the development of medicines used to treat cancer, arthritis, Alzheimers, viruses, and other ailments[3]. It is hypothesized that there are many undiscovered compounds on the reef that can help scientists to develop medications for these and other illnesses. As such, it is also important that we maintain biodiversity so that in time we might discover these compounds. We also rely on coral reefs for jobs and income, and reef ecosystems bring in tourist dollars to the Hawaiian economy. Beyond that, corals are of great cultural importance, especially in Hawaiʻi. All that being said, arguably one of the most important benefits we get from coral is coastal protection.

Coral reefs create complex structures you can even see from space, and are our first line of defense against natural disasters. Reefs form **atolls** like those found in the Northwestern Hawaiian Islands, and provide a safe haven for species that prefer a calm lagoon over the higher wave energy of the ocean. These atolls formed the same way that reefs around the main Hawaiian Islands do– corals are attracted to the shallow waters that surround volcanic islands in an otherwise deep sea. Over time, these corals grow and a coral reef is formed. As the islands themselves erode back into the sea, they leave behind the reef structure that continues to grow up and out from its original position. Once the island has been completely eroded, an "atoll" is left behind in its place. This atoll is essentially a pool of calm water protected from waves and storms by a reef. Around the main Hawaiian Islands, reef structures buffer around 97%[4,5] of wave energy, reducing property damage and coastal erosion caused by large storms. Reefs provide nearly $1.8 billion in flood-risk benefits to United States property owners every year[6], and globally around 200 million people rely on healthy coral reefs for protection[6].

A 2021 study in Hawaiʻi puts a dollar value on the reefs across Oʻahu from annual flood protection[7]. Each kilometer of reef studied provides over a million dollars in protection from damage, and across Oʻahu collectively valued at over $575 million. These reefs include:

South Shore (Diamond Head, Waikīkī, & Kakaʻako) at $154.3 million
East Honolulu (Maunalua Bay)- $78.4 million
Kailua (Lanikai to Mokapu) - $83.0 million
Waiʻanae - $92.4 million
ʻEwa - $77.5 million
Koʻolau Loa (Punaluʻu to Kahuku) - $62.0 million
North Shore (Pūpūkea) - $18.1 million
Waialua - $12.1 million

One option being discussed in terms of protecting the coastline is that of **sea walls**. This is another means of providing a physical barrier protecting houses and other on-shore structures from ocean waves and rising sea levels. Though these walls do provide coastal protection against storm surges, they can often have adverse effects on the surrounding ocean ecosystems. The most obvious of these is the loss of intertidal habitat. When a wall is built directly where the waves are

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breaking, all of the organisms– including mollusks, algae, birds, etc– lose their habitat[8]. This essentially wipes out all of the organisms that call the intertidal zone their home. Sea walls also impact the way that sand naturally moves through the water, and often the areas directly in front of the wall, or to either side of the wall erode more quickly than they would otherwise[8]. This occurs because waves hit the sea wall with more force than they would a beach; the sloping nature of the beach dissipates wave energy more slowly than a vertical sea wall. When this wave energy bounces off the wall and back into the ocean, it has so much force that it often scoops up sand with it and takes it further out to sea. The areas around the sea wall therefore erode faster than if the sea wall wasn't there. This is one of the reasons that reef structures specifically are so vital for coastal protection. The nooks and crevices of a reef that provide habitat for organisms also serves to dissipate wave energy more slowly and therefore reduce erosion to the surrounding areas.

Artificial reefs– normally made from sunken car bodies, concrete pipes, barges, etc– are also employed as a means of providing coastal protection and habitat. If these structures are designed and implemented correctly, they have the potential to serve as one approach to restoring reef habitat. Artificial reefs must be made of large stable structures that won't leach toxins or chemicals into the environment, but if designed correctly they can be a boon for the environment. Billions of dollars are being put towards building artificial reefs, as these structures often provide habitat and protection that may otherwise be lost. However, a better long-term option is the restoration of natural reef habitats, which often provides better quality habitat for marine organisms. Reef enhancement of natural infrastructure increases over time as coral reefs continue to expand from growth and reproduction. It also provides a more realistic habitat for the species looking to make the coral reefs their home. The creation of artificial reefs is also much more costly than restoring natural reefs. The cost to restore a meter of natural reef is an average of $1,300, but the average cost to build an artificial reef is a whopping $19,800 per meter.[4] All this being said, research is being done to see

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whether there is a way to create a **hybrid reef** that encourages natural growth of coral and other organisms. This project is called “Reefense”, and serves as a means of more quickly restoring reef systems that perform all the ecosystem functions of a natural reef and provide more habitat for ocean organisms. Studies are being done into the efficacy of different shapes and complexities of artificial reefs, with the hope of finding a structure that is able to mimic the ecosystem function of a natural reef.

Currently, local and global stressors are adversely impacting the health of coral reefs. On a local level, coral reefs are being degraded from overfishing, pollution, **sedimentation**, and habitat destruction from boat anchors, etc. Globally, coral bleaching as a result of a changing climate and ocean warming have led to mass mortality of coral reefs worldwide. Over time, evolutionary pressures have resulted in the increasing prevalence of **thermally tolerant** corals. These individuals are better able to withstand the bleaching that results from warmer ocean temperatures. However, the evolution of these corals is occurring much more slowly than the rate at which the ocean ecosystem is changing, meaning that overall the coral reef ecosystem continues to degrade.

Corals also have to contend with the increasing **acidification** of the ocean. As the ocean absorbs more atmospheric CO_2, the water and carbon dioxide combine to form a weak acid called carbonic acid (H_2CO_3). This acid then breaks apart into positively charged hydrogen ions (H+), and negatively charged bicarbonate ions (HCO_3^-). Organisms such as oysters and corals manufacture their skeletons using the carbonate ions (CO^{2-}_3) that naturally occur through this process. However, as the acidification of the ocean increases, these carbonate ions are increasingly bonding with excess hydrogen ions, leaving fewer carbonate ions to bind with calcium to make the calcium carbonate ions that corals and mollusks rely on to make their skeleton. In fact, corals are already showing decreased lateral thickening as a result of acidification. This means that even though corals are continuing to grow, their skeletons aren’t as thick, making them more prone to breakage. If oceans become too acidic, their skeletons may even slowly start to dissolve. In the past 200 years, oceans have become roughly 30% more acidic[9] as a result of **anthropogenic** processes, and scientists estimate that if trends continue corals will begin to dissolve around 2085[10].

Despite the increasing prevalence of these thermally tolerant corals in some areas, the global climate crisis has drastically decreased live coral cover, with some areas of the world's coral formations decreasing by as much as half since 1950[11], and some scientists estimate that if we do not deviate from our current path we will lose roughly 90% of our corals by 2050[12]. By employing appropriate mitigation strategies, this can be avoided, but even losing 27% of coral cover is too much to truly offer shoreline protection and other ecosystem services. If we lose just the top meter of the reef as a result of these or other factors, the natural barrier that coral reefs provide would be diminished so much that costs from flood damages would double[13].

As human activity continues to result in a changing climate, storm surges and natural disasters are becoming more severe. In tropical climates, heat from the top layer of the ocean helps to fuel these extreme storms. For every 1.8 degrees Fahrenheit that ocean surface water temperatures increase above 82 degrees Fahrenheit, the number of extreme storms has gone up by roughly 21%[14]. As the atmosphere and the oceans continue to warm, storms will continue to increase in severity, and the importance of coral reefs becomes even more apparent. Further, because coral reefs only grow around 1 inch per year, it is critical that we work to protect the coral and reef structures that are already present.

If we take action and adopt sustainable habits now to protect our coral reefs, future generations will be able to enjoy the beauty of coral reefs and be able to utilize these invaluable resources.

Maunalua Bay

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Maunalua Bay has a rich history, and plays a vital role in Native Hawaiian culture. The Bay extends from the back side of Diamond Head by Black Point to Koko Head by Portlock. It is one of Hawaiʻi's most shallow and broad fringing reefs. Historically, Maunalua Bay was well known for its abundance of fish, and was home to multiple fishponds. The Bay had the largest fishpond in all of Polynesia, which was able to support the entire population of Oʻahu during that time. However, with rapid urbanization and an increase in human activity, Maunalua Bay is not what it used to be. The coral reefs in the area have been severely impacted by anthropogenic effects. In 2002, Maunalua Bay was declared an impaired water body by the United States Health Department, and its fish population is one of the most depleted in Hawaiʻi.

Overview

Students will be guided through the creation of their own hybrid reef. Working in small groups, they will brainstorm which materials and design will be best suited to dissipate wave energy, and use recycled materials to construct the reef. They will then test their design and observe how their reef performs on a small scale.

Materials

- Tubs or pans
- Sand or another type of sediment
- Recycled Materials (brought by students or provided by teacher)
- Water
- Blue food dye (optional)

Teacher Prep

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- Gather materials needed for each activity
- Print out the student worksheets

Procedure/Instructions

Build Your Own Hybrid Reef

Explain to students that they will be making a model of a reef, with the purpose of designing a reef that best protects their coastline from wave action. Have students explain why they chose the design that they did, and what the expected outcome will be. They will observe and be able to explain how this reef can decrease wave activity, and which materials and designs are most effective at protecting the shoreline. Additionally, you may have them construct a smaller and larger version of the reef, to represent a “degraded” and “healthy” reef respectively.

1. Instruct students they will work in pairs or small groups.
2. Explain to students that they will be making a model of a hybrid reef, and attempting to find the best design in order to create this reef.
3. Have them brainstorm which materials would be best for creating their reef. If time allows, they may bring in their own recycled materials from outside the classroom to construct their reef.
4. Pass out containers, sand, and worksheets to students.
5. Have them build their reef using the shapes they think are most appropriate, making sure that it fits inside the container.
    a. If doing, have them construct a taller and shorter reef. Explain that the former represents a healthy reef, and the latter a degraded reef.
6. Before putting their structure in the container, students will fill one half of the container with sand, going about halfway up the side of the container.

Fill the containers with water so it hits just under the sand. The sand will represent the coastline, and the water is the ocean.

7. Instruct the students to make waves in their container before putting their reef in. They'll do this by rocking the container back and forth gently, so the water starts to move to the coast. This will represent waves hitting a shoreline without any coastal protection.
8. Instruct the students to record their observations. Specifically, instruct them to take note of how much the sand is moving.
9. Next, have the students put their barriers in the containers. This will represent their hybrid reef.
10. Have them run the experiment again, this time with their reef in place, and record any differences.
11. If students made a degraded and healthy reef, have them test each before moving on.
12. Make sure students record their observations as they run their experiments.
13. Come back together and discuss. Which structures were most and least effective at dissipating wave energy? Why? What was the difference in protection between the healthy and degraded reef?

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Coastal Protections:
Build Your Own Hybrid Reef

Student Worksheet

You will be working in small groups, making your own model of a hybrid reef, and finding the best structure, design and material to protect the coastline.

1. Start off by brainstorming which materials are best for creating your hybrid reef. If time allows, you may bring in your own recycled materials from outside the classroom to construct their reef.
2. Construct your reef using the shapes you think would best protect your coastline, making sure that it fits inside the container provided by your teacher.
    a. If doing, construct taller and shorter reefs. The former represents a healthy reef, and the latter a degraded reef.
3. Before putting your structure in the container, fill

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one half of the container with sand, going about halfway up the side of the container. Bank the sand against one side of the container so that you can still see the bottom through the other half.

4. Fill the containers with water so it hits just under the sand. The sand will represent the coastline, and the water is the ocean.
5. Make waves in the container before putting the reef in. Do this by rocking the container back and forth gently, so the water starts to move to the coast. This will represent waves hitting a shoreline without any coastal protection.
6. Record your observations. Take note of how much the sand is moving.
7. Put your barrier in the container. This represents the hybrid reef.
8. Run the experiment again, this time with your reef in place, and record any differences.
9. If you made degraded and healthy reefs, test each and record your observations.

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Build Your Own Hybrid Reef

Student Worksheet

1. Obtain materials from your teacher and fill out the chart below with observations from each coastline model.

Predict what you think will happen			
	Do the waves reach the shoreline?	How do waves affect the beach?	Notes
Container with no coral reef			
Container with healthy reef			
Container with degraded reef			

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Observe and Record what happened			
	Do the waves reach the shoreline?	How do waves affect the beach?	Notes
Container with no coral reef			
Container with healthy reef			
Container with degraded reef			

Additional observations:

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Dive in deeper…

1. What happened when waves hit your beach and there was no coral present?

2. What would happen to **coastlines** if the coral reefs were to diminish? Why?

3. What would happen to **humans** if coral reefs were to diminish?

4. Why did you choose the **material** and **structure** that you did in designing your reef?

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5. How do you think that impacted your reef's ability to protect the coastline? Do you think ocean organisms had much habitat in the structure you created?

6. Using what you already know about global climate change, what are some factors that are causing the rise of global temperatures?

7. Based on what you've learned, what do you think will happen to the number and type of organisms present on the reef if it continues to degrade? How will this impact the ecosystem overall?

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8. What are some ways humans might reduce their impact on ocean environments and biodiversity?

9. What are some ways that changes in the availability of natural resources, occurrence of natural hazards, and changes in climate may influence human activities? Think of things that you have observed and how they relate to ocean ecosystems.

10. Based on what you've learned in this lesson, what is one way that one change to Earth's surface might catalyze changes in one of Earth's other systems?

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Sources Cited

1. Reguero, Borja G., et al. “The Value of Us Coral Reefs for Flood Risk Reduction.” *Nature Sustainability*, vol. 4, no. 8, 2021, pp. 688–698., https://doi.org/10.1038/s41893-021-00706-6.
2. PMNM Webmaster. “Aloha! Welcome to Papahānaumokuākea Marine National Monument – Where Nature and Culture Are One.” *Papahānaumokuākea Marine National Monument*, National Ocean Service; Office of National Marine Sanctuaries; National Oceanic and Atmospheric Administration, 30 July 2020, https://www.papahanaumokuakea.gov/about/.
3. “What Does Coral Have to Do with Medicine?” *NOAA's National Ocean Service*, US Department of Commerce, 1 Mar. 2014, https://oceanservice.noaa.gov/facts/coral_medicine.html.
4. Nuwer, Rachel. “Coral Reefs Absorb 97 Percent of the Energy from Waves Headed toward Shore.” *Smithsonian.com*, Smithsonian Institution, 15 May 2014, https://www.smithsonianmag.com/smart-news/coral-reefs-absorb-almost-all-energy-crashing-waves-headed-toward-shore-180951462/.
5. The Coral Reef Alliance. “Coastal Protection.” *Coral Reef Alliance*, Coral Reef Alliance, 1 Sept. 2021, https://coral.org/en/coral-reefs-101/why-care-about-reefs/coastal-protection/.
6. Beck, Michael. “Coral Reefs Provide Flood Protection Worth $1.8 Billion Every Year – It's Time to Protect Them.” *The Conversation*, The Conversation US, Inc, 13 Sept. 2022, https://theconversation.com/coral-reefs-provide-flood-protection-worth-1-8-billion-every-year-its-time-to-protect-them-116636.
7. Storlazzi, C.D., Reguero, B.G., Cole, A.D., Lowe, E., Shope, J.B., Gibbs, A.E., Nickel, B.A., McCall, R.T., van Dongeren, A.R., and Beck, M.W., 2019, Rigorously valuing the role of U.S. coral reefs in coastal hazard risk reduction: U.S. Geological Survey Open-File Report 2019–1027, 42 p., https://doi.org/10.3133/ofr20191027.
8. Balaji, R., et al. “Understanding the Effects of Seawall Construction Using a Combination of Analytical Modelling and Remote Sensing Techniques: Case Study of Fansa, Gujarat, India.” *The International Journal of Ocean and Climate Systems*, vol. 8, no. 3, 2017, pp. 153–160., https://doi.org/10.1177/1759313117712180.
9. “Ocean Acidification.” *National Oceanic and Atmospheric Administration*, National Oceanic and Atmospheric Administration, 1 Apr. 2020, https://www.noaa.gov/education/resource-collections/ocean-coasts/ocean-acidification

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Curriculum Funded by NOAA’s Bay Watershed Education Program (BWET)

10. The Ocean Portal Team Reviewed by Nancy Knowlton. “Corals and Coral Reefs.” *Smithsonian Ocean*, The Smithsonian, Apr. 2018, https://ocean.si.edu/ocean-life/invertebrates/corals-and-coral-reefs.
11. Ashworth, James. “Over Half of Coral Reef Cover across the World Has Been Lost since 1950.” *Natural History Museum*, The Trustees of the Natural History Museum , 26 Sept. 2021, https://www.nhm.ac.uk/discover/news/2021/september/over-half-of-coral-reef-cover-lost-since-1950.html.
12. Advocate, Responsible Seafood. “Experts: World's Coral Reefs Could Vanish by 2050 without Climate Action - Responsible Seafood Advocate.” *Global Seafood Alliance*, Global Seafood Alliance , 20 Apr. 2022, https://www.globalseafood.org/advocate/experts-worlds-coral-reefs-could-vanish-by-2050-without-climate-action/.
13. Beck, Michael W., et al. “The Global Flood Protection Savings Provided by Coral Reefs.” *Nature Communications*, vol. 9, no. 1, 2018, https://doi.org/10.1038/s41467-018-04568-z.
14. “Warming Seas May Increase Frequency of Extreme Storms – Climate Change: Vital Signs of the Planet.” *NASA*, NASA, 23 July 2019, https://climate.nasa.gov/news/2837/warming-seas-may-increase-frequency-of-extreme-storms.

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