FOCUS QUESTIONS

- Why are corals considered a keystone species in ocean ecosystems?
- What is coral bleaching and what role does it play in the function of coral reef ecosystems?
- What is selective breeding and how is this technique used to conserve coral reef ecosystems?

OVERVIEW

"If we prepare the reefs now for the future, then they have a better chance at surviving." - Kira Hughes, Marine Biologist

As global warming drives up ocean temperatures and extreme near-shore heat events become more frequent, corals have become increasingly vulnerable to coral bleaching events. In ***Coral Comeback*** we learn how marine biologist Kira Hughes and other researchers at the Coral Resilience Lab at the University of Hawaii in Oahu are working to reverse the effects of coral bleaching. The team is providing hope for the future of corals and the reef ecosystems they build by selectively breeding corals to be able to withstand ever-increasing amounts of heat stress, both for now, and in the future.

KEY CONCEPTS

- Threatened and Endangered Species: The International Union for the Conservation of Nature lists more than 44,000 species threatened with extinction, which includes 36% of coral species. Loss of livable near-shore ocean conditions (habitat loss) through warming waters and ocean acidification are the primary drivers of this crisis.
- Biodiversity: Coral reefs harbor the greatest biodiversity of any global ecosystem; they support about 4,000 species of fish along with hundreds of other marine organisms; over 25% of all marine life. However, coral reefs are currently among the most threatened ecosystems on Earth, largely due to a warming planet and changes in tropical climates. A loss of coral reef ecosystems through bleaching events and other ocean stressors has a significant impact on marine biodiversity.
- Ecosystem engineers: Coral polyps sequester carbonate ions and calcium from seawater to build their hard exoskeletons. By doing so, corals thus engineer the underlying framework of coral reef ecosystems.
- Keystone species: Marine biologists estimate that coral reefs maintain the greatest species richness per unit area than any other marine environment. In this way, corals are keystone species because they have a disproportionate impact on the structure of the biodiversity that coral reefs support. As coral reefs disappear thousands of species lose the habitat required for their survival.
- Ecosystem Services: Nature provides humans with benefits that are essential for human health and well-being. These free ecosystem services range from bees and other insects that pollinate crops to the provision of timber and clean water, climate regulation, and atmospheric carbon sequestration. Coral reefs provide a substantial first line of coastal protection against flooding from ocean storms. Scientists predict that without coral reefs the annual expected global damages from flooding would double, and costs from frequent storms would triple.
- Mutualistic symbiosis: The nutritional symbiosis between corals and their endocellular dinoflagellate algae (known as zooxanthellae) has been key to the success of corals and the reefs they build. For at least 210 million years corals have provided their algae with a protected environment and the compounds they need for photosynthesis while the algae produce oxygen, help the coral to remove wastes, and most importantly supply the coral with the excess products of photosynthesis like glucose, glycerol, and amino acids.
- Conservation biology: The practice of conservation biology recognizes the intrinsic value of the Earth's natural diversity of organisms. Conservation biology works to understand how the natural world operates, how humans affect nature, and how we can use collective scientific and cultural knowledge to conserve Earth's biological diversity.

BACKGROUND

Coral reefs are considered by some estimates to harbor the greatest biodiversity of any global ecosystem, more so even than tropical rain forests. For example, over 25% of all marine life including about 4,000 species of fish and hundreds of other ocean organisms depend on coral reefs for resources and habitat. While in their polyp stage, corals engineer this habitat by sequestering carbonate ions and calcium from seawater to build their hard exoskeletons. By building the underlying framework of coral reef ecosystems and having a disproportionate impact on the entire reef community, corals function as both ecosystem engineers and keystone species.

Coral reefs also provide a substantial first line of coastal protection against flooding from ocean storms. Scientists predict that without coral reefs the annual expected global damages from flooding would double, and costs from frequent storms would triple. However, corals cannot maintain these critical functions by themselves. For survival, most corals depend on a 210-million-year-old nutritional symbiosis with dinoflagellate algae (known as zooxanthellae) that live inside the cells of their tissues and give the corals their unique colors. The corals provide their algae with a protected environment and the compounds they need for photosynthesis while the algae produce oxygen, help the coral to remove wastes, and most importantly supply the coral with the excess products of photosynthesis like glucose, glycerol, and amino acids. When corals experience extreme temperature increases in their near-shore waters they react by ejecting their zooxanthellae algae, turning their tissues white (bleaching) and losing the essential benefits the algae provide. The corals and algae can reestablish their relationship, but frequent or prolonged bleaching events can ultimately kill the corals. Fortunately, there is a hopeful evolutionary answer to the bleaching phenomenon, but it requires some careful and focused human research and intervention.

In ***Coral Comeback*** we meet marine biologist Kira Hughes who is spearheading coral bleaching resistance research at the Coral Resilience Lab at the University of Hawaii in Oahu. The effort is dependent on the assistance from local communities to help collect corals for temperature tolerance and breeding trials. The research team is using a strategy that in the film is referred to as selective breeding, an age-old process of identifying specific desired traits expressed by individuals in a population and then breeding those individuals so that the traits are passed on to all individuals of the next generation. However, the technique the researchers are using takes the basic idea of selective breeding to another level. Most traits are complex because they are under the influence of multiple genes (polygenic) as well as the environment (multifactorial). Complex traits tend to produce phenotypes with continuous variation across a range of expressions. Thus the researchers are systematically exposing corals to increasing intensities of heat stress to identify those individuals in the population that may already be preadapted with the ability to survive extreme water temperatures. Within the framework of evolutionary science this technique is called *assisted evolution* and can promote the directional selection of a trait within its continuum.

This fascinating scientific strategy coupled with the essential involvement of the local community is providing a hopeful model for conserving corals and the reef ecosystems they build, both for now, and in the future.

BIODIVERSITY THREATS

The major threats to the Earth's biodiversity can be grouped into seven categories that spell the easily recalled acronym H.I.P.P.O.: **H**abitat destruction and fragmentation, **I**ntroduced species, **P**ollution, **P**opulation growth, and **O**verharvesting. Many species are threatened by a combination of these factors, but habitat loss is the greatest threat to biodiversity. In ***Coral Comeback*** we learn that the loss of livable near-shore ocean conditions (habitat loss) through climate change-driven warming waters is a primary threat to corals and the biodiversity that coral reef ecosystems support.

DISCUSSION QUESTIONS

- [Before showing the film] Have students brainstorm and discuss what they already know about coral reef ecosystems, especially their biodiversity and economic benefits to humans.
- [Before showing the film] Have students discuss what they know about the process of selective breeding in plants and animals. What are the benefits of selective breeding? What are the costs? How is selective breeding an evolutionary mechanism?
- In the film we learn that researchers use selective breeding to help make future generations of corals more tolerant of and resistant to heat stress. Have students discuss the role that natural variation in genotypes and phenotypes plays in this approach the researchers are taking.
- A more technical term for the selective breeding approach illustrated in the ***Coral Comeback*** film is *assisted evolution*. If the film is shown in a more advanced course, students could be challenged to determine which pattern of natural selection the corals are experiencing through this research technique: stabilizing selection, disruptive selection, or directional selection.
- Go to Biointeractive.org and search “coral bleaching.” Here teachers will find several activities students can engage in to enhance their understanding of the coral bleaching phenomenon. Teachers can preview these activities and consider using one or two as either an anchoring phenomenon or a way to review coral bleaching after showing the ***Coral Comeback*** film.
- Coral bleaching is not the only threat to corals from climate change. As much as 30% of the CO_2 released by humans ends up dissolved in the oceans where it reacts with seawater to release hydrogen ions. Since ~1850 seawater pH has dropped 0.1 (from 8.2 to 8.1) and is projected to decline another 0.3 by 2100. This phenomenon is called ocean acidification. As an extension activity, have students investigate the implications of ocean acidification for corals.

Curriculum Connections

NGSS

HS-LS2 Ecosystems: Interactions, Energy, and Dynamics
- LS2.A: Interdependent Relationships in Ecosystems
- LS2.B: Cycles of Matter and Energy Transfer in Ecosystems
- LS2.C: Ecosystem Dynamics, Functioning, and Resilience
- LS4.D: Biodiversity and Humans
- PS3.D: Energy in Chemical Processes

HS-LS3 Heredity: Inheritance and Variation of Traits
- LS3.A: Inheritance of Traits
- LS3.B: Variation of Traits

HS-LS4 Biological Evolution: Unity and Diversity
- LS4.A: Evidence of Common Ancestry and Diversity
- LS4.B: Natural Selection
- LS4.C: Adaptation

ETS1.B: Developing Possible Solutions

AP Biology (2021)

Enduring Understandings
- Evolution (EVO)
  - EVO-3: Life continues to evolve within a changing environment.
- Energetics (ENE)
  - ENE-1: The highly complex organization of living systems requires constant input of energy and the exchange of macromolecules.

    - ENE-3: Timing and coordination of biological mechanisms involved in growth, reproduction, and homeostasis depend on organisms responding to environmental cues.
    - ENE-4: Communities and ecosystems change on the basis of interactions among populations and disruptions to the environment.
- Information Storage and Transmission (IST)
    - IST-1: Heritable information provides for continuity of life.
    - IST-2: Differences in the expression of genes account for some of the phenotypic differences between organisms.
    - IST-4: The processing of genetic information is imperfect and is a source of genetic variation.
    - IST-5: Transmission of information results in changes within and between biological systems.
- Systems Interactions (SYI)
    - SYI-1: Living systems are organized in a hierarchy of structural levels that interact.
    - SYI-3: Naturally occurring diversity among and between components within biological systems affects interactions with the environment.

IB Biology (First Exam May 2025)

A. Unity and Diversity: Common ancestry has given living organisms many shared features while evolution has resulted in the rich biodiversity of life on Earth.
    - A1.1 Water
    - A2.2 Cell structure
    - A3.1 Diversity of organisms
    - A4.1 Evolution and speciation
    - A4.2 Conservation of biodiversity

B. Form and Function: Adaptations are forms that correspond to function. These adaptations persist from generation to generation because they increase the chances of survival.
    - B4.1 Adaptation to environment
    - B4.2 Ecological niches

C. Interaction and Interdependence: Systems are based on interactions, interdependence and integration of components. Systems result in emergence of new properties at each level of biological organization.
    - C1.3 Photosynthesis
    - C4.1 Populations and communities
    - C4.2 Transfers of energy and matter

D. Continuity and Change: Living things have mechanisms for maintaining equilibrium and for bringing about transformation. Environmental change is a driver of evolution by natural selection.
    - D2.2 Gene expression
    - D3.2 Inheritance
    - D3.3 Homeostasis
    - D4.1 Natural selection
    - D4.2 Stability and change
    - D4.3 Climate change

REFERENCES

Beck, M. W., Losada, I. J., Menéndez, P., Reguero, B. G., Díaz-Simal, P., & Fernández, F. (2018). The global flood protection savings provided by coral reefs. *Nature Communications*, *9*(1), 2186.

Figuerola, B., Hancock, A. M., Bax, N., Cummings, V. J., Downey, R., Griffiths, H. J., ... & Stark, J. S. (2021). A review and meta-analysis of potential impacts of ocean acidification on marine calcifiers from the Southern Ocean. *Frontiers in Marine Science*, *8*, 584445.

Frankowiak, K., Wang, X. T., Sigman, D. M., Gothmann, A. M., Kitahara, M. V., Mazur, M., ... & Stolarski, J. (2016). Photosymbiosis and the expansion of shallow-water corals. *Science Advances*, *2*(11), e1601122.

National Academies of Sciences, Engineering, and Medicine. (2019). *A Research Review of Interventions to Increase the Persistence and Resilience of Coral Reefs*. Washington, DC: The National Academies Press. https://doi.org/10.17226/25279.

National Ocean Service of the National Oceanic and Atmospheric Administration. (2024). *Corals Tutorial*. https://oceanservice.noaa.gov/education/tutorial_corals/. Accessed on 4 June 2024.

Wilson, S. K., Robinson, J. P., Chong-Seng, K., Robinson, J., & Graham, N. A. (2019). Boom and bust of keystone structure on coral reefs. *Coral Reefs*, 38(4), 625-635.

United States Environmental Protection Agency. (2024). *Understanding the Science of Ocean and Coastal Acidification*. https://www.epa.gov/ocean-acidification/understanding-science-ocean-and-coastal-acidification. Accessed on 4 June 2024.

CREDIT

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