FOCUS QUESTIONS

- Why are island ecosystems so vulnerable to introduced invasive species?
- How did 51 different species of Hawaiian honeycreepers end up on the Hawaiian archipelago?
- How are scientists using a unique reproductive phenomenon in mosquitoes to depress the populations of the mosquito species that carry avian malaria?

OVERVIEW

“We’re at the precipice of having a tool to address avian disease. All the work we’re doing has really invigorated us and given us a type of hope that we haven’t had in decades.” - Christa Seidl, Disease Ecologist and Conservation Biologist at the University of California, Santa Cruz

At least 51 species of honeycreepers used to thrive on the Hawaiian archipelago, but introduced invasive species, human development, and avian malaria have driven two-thirds of the species to extinction. Only 17 species of Hawaiian honeycreepers remain and 11 of them are listed as endangered species. Fortunately, conservation biologists and disease ecologists like Christa Seidl and ornithologist Laura Berthold of the Maui Forest Bird Recovery Project have initiated a coordinated and hopeful effort to restore and protect lost habitat and they are helping employ a unique method for reducing the populations of disease-carrying mosquitoes.

KEY CONCEPTS

- Threatened and Endangered Species: The International Union for the Conservation of Nature lists more than 45,000 species threatened with extinction, and 41% of the animals on this list live and/or breed on islands. Introduced invasive species, habitat loss, and disease are the primary drivers of this crisis.
- Natural selection: The immense diversity of habitats on Earth have helped drive the evolution of the planet’s organisms primarily through the process of natural selection. Like the finches of the Galapagos Islands, the honeycreepers of the Hawaiian archipelago are an example of nature sifting through variation among individuals and producing more than 50 species of honeycreeper that once thrived on the islands.
- Adaptive radiation: A common pattern of evolution is adaptive radiation where several species evolve quickly from a single ancestral lineage. The Hawaiian honeycreepers likely evolved into dozens of species from a single population of finch-like birds that migrated to the newly formed volcanic islands of Ni'ihau and Kauai around 6 to 7 million years ago.
- Biodiversity: Even though islands make up only about 6.7% of the Earth’s landmass, they harbor a disproportionate 20% of the Earth’s biodiversity. Unfortunately, 75% of all recorded extinctions that have occurred since human civilization have occurred on islands and 50% of island plant and animal species are listed as endangered.
- Mutualistic symbiosis: The Hawaiian honeycreepers play an important role in the island ecosystems as mutualistic symbionts with plants. Not only do the honeycreepers assist many island plants with pollination while harvesting nectar, they also help disperse the seeds of many plant species and protect them from herbivory by eating their insect enemies.
- Reproductive ecology: Scientists are using a unique reproductive phenomenon in mosquitoes to depress the populations of the mosquito species that carry avian malaria.
- 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

Islands make up only about 6.7% of the Earth's landmass yet they harbor a disproportionate 20% of the Earth's biodiversity. This outstanding biodiversity along with their isolation from mainland ecosystems make islands important model systems for research in ecology, evolution, biogeography, and conservation. In fact, the islands of the Malay and Galapagos archipelagos, respectively, were critical in helping Alfred Russel Wallace and Charles Darwin establish evidence of evolution by natural selection. For example, the finches of the Galapagos islands originally made famous by Darwin have functioned for well over a century as a model for ongoing evolution by natural selection. And for the last half century Peter and Rosemary Grant of Princeton University have used their data collected on specific species of Galapagos finches to show how quickly variable traits like beak size can evolve as their food resources change.

Moreover, when habitat variability is high on islands as well as between near islands the evolutionary process of adaptive radiation can rapidly produce several species from a single ancestral lineage. For example, the Hawaiian honeycreepers likely evolved into dozens of species from a single population of finch-like birds that migrated to the newly formed volcanic islands of Ni'ihau and Kauai from mainland Asia around 6 to 7 million years ago. With the arrival of new species from mainland populations and the origin of new species from adaptive radiation also comes the natural process of extinction. Robert MacArthur and E. O. Wilson showed in the 1960s that more species on islands means more competition for resources which puts naturally small island populations at risk of extinction; a dynamic balance of immigration and evolution of new species with extinction is ultimately reached. Unfortunately, human activity adds another variable to island ecosystems that throws off this natural balance. Ocean island ecosystems were some of the last land areas discovered and colonized by humans but they are uniquely vulnerable to disturbances by humans. For example, 75% of all recorded extinctions that have occurred since human civilization have occurred on islands and 50% of island plant and animal species are listed as endangered. At least 51 species of honeycreepers used to thrive on the Hawaiian archipelago, but introduced invasive species, human development, and avian malaria have driven two-thirds of the species to extinction. Today only 17 species of Hawaiian honeycreepers remain and 11 of them are listed as endangered species.

Fortunately, in ***Birds on the Brink*** we meet disease ecologist Christa Seidl and ornithologist Laura Berthold of the Maui Forest Bird Recovery Project and learn that all is not lost; we can be optimistic about the future ecological health of islands. Christa and Laura help lead teams with various ecological expertise in a coordinated and hopeful effort to restore and protect lost habitat. The teams are also helping employ a unique method for reducing the populations of mosquitoes that carry the avian malaria disease. Avian malaria came to the Hawaiian Islands when mosquitoes of various species from Asia and Africa were accidentally introduced during the late 19th and early 20th Centuries. One mosquito species in particular, *Culex quinquefasciatus*, carries the parasite *Plasmodium relictum*, which when transmitted to birds causes avian malaria and kills individuals through the destruction of their red blood cells. The particular strategy for reducing avian malaria we learn about is ***Birds on the Brink*** is informally called the "incompatible insect technique." This approach focuses on a group of bacteria called *Wolbachia* that use various types of animals as their hosts. In arthropods, like mosquitoes, *Wolbachia* infections can be essential for the survival of some species but also cause sterility of other species. For example, in some insect species *Wolbachia* live in their reproductive tissues and can be transmitted by way of egg and sperm cytoplasm. When individual males and females of a species are infected with different strains of *Wolbachia* they often cannot produce viable offspring together. Ecologists in Hawaii are rearing and releasing male mosquitoes—male mosquitoes do not bite and thus cannot transmit disease—that have been infected with a different strain of *Wolbachia* than occurs in females in the wild. The incompatible strains of *Wolbachia* cause the females to produce infertile eggs which in turn drives down the overall mosquito population and the incidence of avian malaria. The "incompatible insect technique" and habitat restoration are giving the remaining Hawaiian honeycreeper species a fighting chance and a hopeful 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 ***Birds on the Brink*** we learn that habitat loss from human development has indeed been a factor in driving more than half of the Hawaiian honeycreeper population to extinction, but introduced species to the islands like rats and disease-carrying mosquitoes have played an even larger role.

DISCUSSION QUESTIONS

- [Before showing the film] Have students brainstorm and discuss what they already know about island ecosystems, including ideas they have about how plant and animal species initially colonize islands of volcanic origin like the Galapagos and Hawaiian archipelagos.
- [Before showing the film] Have students discuss what they know about the effects human colonization of islands has had on island biodiversity.
- Review with students the evolutionary process of adaptive radiation, then have them discuss how the Hawaiian honeycreepers are an example of this phenomenon.
- Have students discuss why island ecosystems are so vulnerable to human habitation and activities.
- Have students create a model or diagram that illustrates how the incompatible insect technique is being used to reduce the incidence of avian malaria in the Hawaiian honeycreepers.

Curriculum Connections

NGSS

HS-LS2 Ecosystems: Interactions, Energy, and Dynamics
- LS2.A: Interdependent Relationships in Ecosystems
- LS2.C: Ecosystem Dynamics, Functioning, and Resilience
- LS4.D: Biodiversity and Humans

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-1: Evolution is characterized by a change in the genetic makeup of a population over time and is supported by multiple lines of evidence.
  - EVO-2: Organisms are linked by lines of descent from common ancestry.
  - EVO-3: Life continues to evolve within a changing environment.
- Energetics (ENE)
  - 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.
- Systems Interactions (SYI)
  - 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.
- 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.
- C3.2 Defence against disease
- C4.1 Populations and communities

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.
- D3.1 Reproduction
- D3.2 Inheritance
- D4.1 Natural selection
- D4.2 Stability and change
- D4.3 Climate change

REFERENCES
Atkinson, C. T. (2023). Avian Malaria and the Extinction of Hawaiian Forest Birds. *Wildlife Disease and Health in Conservation*.

Fernández-Palacios, J. M., Kreft, H., Irl, S. D., Norder, S., Ah-Peng, C., Borges, P. A., ... & Drake, D. R. (2021). Scientists' warning–The outstanding biodiversity of islands is in peril. *Global Ecology and Conservation*, *31*, e01847.

Grant, P. R., & Grant, B. R. (2024). From microcosm to macrocosm: Adaptive radiation of Darwin's finches. *Evolutionary Journal of the Linnean Society*, kzae006.

MacArthur, R. H., & Wilson, E. O. (1963). An equilibrium theory of insular zoogeography. *Evolution*, 373-387.

Spatz, D. R., & Holmes, N. D. (2023) Islands: Fragile showcases of biodiversity. The UNESCO Courier. https://courier.unesco.org/en/articles/islands-fragile-showcases-biodiversity. Accessed on 30 July 2024.

Villena, O. C., McClure, K. M., Camp, R. J., LaPointe, D. A., Atkinson, C. T., Sofaer, H. R., & Berio Fortini, L. (2024). Environmental and geographical factors influence the occurrence and abundance of the southern house mosquito, *Culex quinquefasciatus*, in Hawai 'i. *Scientific Reports*, *14*(1), 604.

Werren, J. H., Windsor, D., & Guo, L. R. (1995). Distribution of *Wolbachia* among neotropical arthropods. *Proceedings of the Royal Society of London. Series B: Biological Sciences*, *262*(1364), 197-204.

CREDIT
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