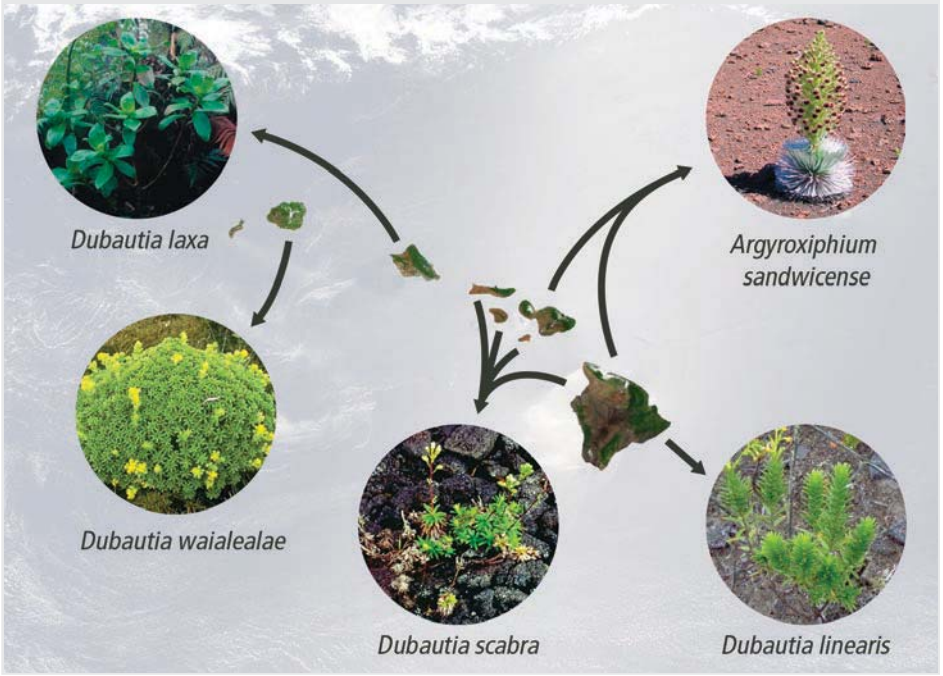
9.2

Changes in Species

Islands often have unique populations of species.

CAN YOU EXPLAIN IT?

FIGURE 1: Plants in the silversword alliance are closely related and yet show remarkable diversity.



Gather Evidence As you explore the lesson, gather evidence that supports the claim that changes in environmental conditions result in the emergence of new species over time and the extinction of other species.

If you were asked to compare the plants in Figure 1, you might note that each of them looks very different from one another. These plants are all members of the silversword alliance, a group of over 30 related species native to the Hawaiian Islands. Like other groups of related species, the silversword alliance shows huge variety in appearance even though the plants are closely related. In fact, all of the plants in this group are thought to be descended from a single tarweed species found in the dry shrublands of California and Mexico.

Predict These plants have a common ancestor. How did they develop different characteristics?

Mechanisms of Speciation

In general, a species is a group of similar organisms that can breed and produce fertile offspring. The millions of species that live on Earth today emerged over time, with each new species arising from an already existing species. This diversification of one species from another is supported by genetic, developmental, and anatomical similarities among species. In addition, geological and fossil evidence show how species have changed over time.

Collaborate Kaibab and Abert's squirrels live on opposite sides of the Grand Canyon. Though closely related, they do not share all of the same characteristics. How did these differences come about? Make a list with a partner to explain your reasoning.

FIGURE 2: These squirrels are closely related but have different characteristics.

a Kaibab squirrel

b Abert's squirrel

Speciation

Where do new species come from? Speciation is the rise of two or more species from a single existing species. Experiments can be used to model speciation. In one such experiment, an existing population of fruit flies, *Drosophila melanogaster*, was divided into two groups. One group was given maltose-based food and the other was given starch-based food. The goal of the experiment was to determine what changes would occur from the isolation of species and the presence of different food sources.

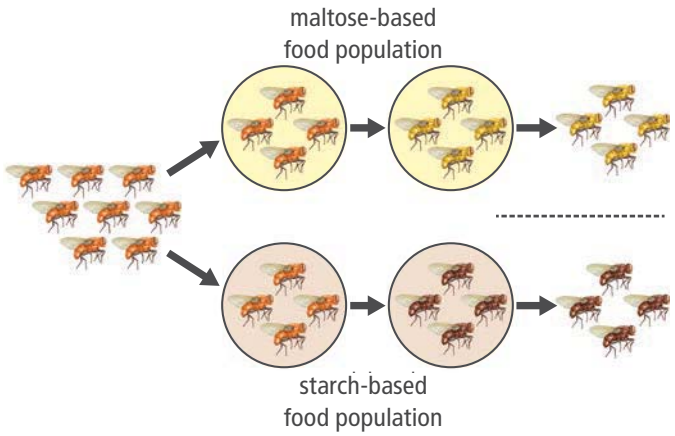


FIGURE 3: Changes in fruit flies can occur due to differing food sources.

Many generations later, the mating preference of the flies was analyzed. The scientists found that the flies raised on maltose-based food, called maltose flies, preferred to mate with other maltose flies. The flies raised on starch-based food, called starch flies, preferred to mate with other starch flies. However, cross-breeding between the two groups could still occur. This experiment shows a distinct mating preference and the beginning of reproductive isolation within a species. If the two groups of fruit flies were eventually unable to breed successfully, then speciation would occur.

Analyze What happened during the many generations that these flies were kept separated? How might this period of isolation have contributed to the mating preferences shown?

Reproductive Isolation

Predict How can reproductive isolation lead to speciation?

If gene flow is interrupted between two populations of the same species, the populations are said to be isolated. Isolated populations are prevented from mating and exchanging genes. This means natural selection acts upon a different gene pool for each population. Different mutations will accumulate, different variations will be selected for or against, and eventually adaptations will occur that prevent mating between the two populations. Isolated populations that are in different environments, and therefore exposed to different selective pressures, will diverge from one another more quickly. It becomes more likely that reproductive isolation will occur as the two populations become more different. Even isolated populations in similar environments can undergo speciation if genetic drift takes the two gene pools in opposite directions.

Reproductive isolation occurs when members of different populations can no longer mate successfully. Sometimes members of the two populations are not physically able to mate with each other. In other cases, they cannot produce offspring that survive and reproduce. Reproductive isolation is the final step of becoming a separate species.

Physical Separation

An isthmus is a strip of land with sea on both sides that links two larger landmasses. The Isthmus of Panama formed through a combination of volcanic island formation and uplift of the ocean floor. These two geological factors made solid land where there was once an open passage between the Atlantic and Pacific oceans.

Collaborate With a partner, make a list of other physical barriers that can lead to geographic isolation as happened with snapping shrimp.

Around 3 million years ago, the isthmus closed in, permanently separating populations of snapping shrimp. Once separated, each population of shrimp adapted to a different environment and became genetically different. Over time, the groups became different enough to be reproductively isolated and speciation occurred. The physical separation of two or more populations can lead to speciation through geographic isolation.

FIGURE 4: Speciation in snapping shrimp occurred due to geographic isolation.

Source: Carl Hansen and Nancy Knowlton, 2001, The Smithsonian Institution, as quoted by PBS, Evolution Library; Arthur Anker, 2016, Smithsonian Newsdesk

Behavior and Timing

Behavioral isolation is caused by differences in courting or mating behaviors. If two populations do not use the same courting or mating behaviors, then mating, and therefore gene flow, between the two groups is unlikely to occur. When gene flow is interrupted, natural selection acts upon the different gene pools. Reproductive isolation and speciation may eventually occur.

Male songbirds sing to defend their territories and attract mates. An eastern meadowlark and a western meadowlark are shown in Figure 5. As you can see, they look almost the same. The major difference between these species is their songs. The eastern and western meadowlarks use completely different songs to attract mates. This means eastern meadowlark males cannot successfully attract western meadowlark females, and western meadowlark females cannot give eastern meadowlark males the correct breeding cues. The two species have become behaviorally isolated.

FIGURE 5: The eastern meadowlark and western meadowlark look almost identical but use different songs to attract mates.

Explore Online

a Eastern meadowlark

b Western meadowlark

The red-legged frog and the yellow-legged frog are closely related. The development of mating seasons that occur at different times caused these species to become temporally isolated. Temporal isolation occurs when timing prevents reproduction between populations. Red-legged frog populations breed from January to March while yellow-legged frog populations in the same area breed from late March to May. Speciation from a common ancestor occurred as the overlap in mating seasons shrank. The flow of genes between the two groups also shrank and the two groups diverged.

FIGURE 6: Red-legged frogs and yellow-legged frogs have different mating seasons.

a Red-legged frog

b Yellow-legged frog

Data Analysis Draw a graph to explain why different mating seasons were likely the cause of red-legged frog and yellow-legged frog speciation.

Adaptive Radiation

Speciation through the diversification of one ancestral species into many descendant species is called adaptive radiation. Adaptive radiation typically happens quickly as species benefit from less competition, new niches, or specializations that give a selective advantage.

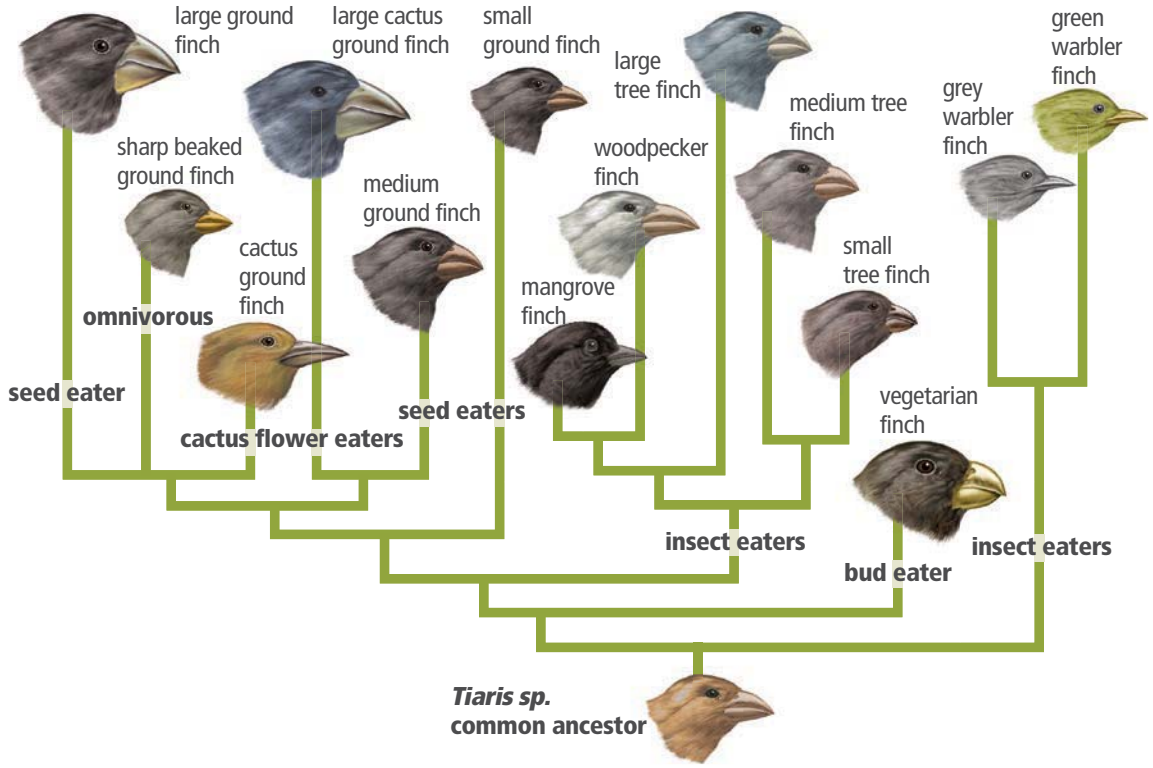


FIGURE 7: The diverse finches of the Galápagos Islands came from a common ancestor.

Darwin's finches are an example of adaptive radiation that occurred on an island system. The 14 species of finch found on the Galápagos Islands came from a common ancestor. The descendants have diversified and specialized to take advantage of different niches. The finch species minimize competition among themselves by specializing in different food sources. For example, populations of finches with larger beaks can crack harder and larger seeds. Populations of finches with smaller, pointy beaks can catch insects. Darwin's finches are a classic example of changes in environmental conditions driving the adaption and expansion of species.

Analyze What factors would support the idea that adaptive radiation occurred in the finches of the Galápagos Islands?

For adaptive radiation to take place, there must be adaptation by a species that leads to speciation. For example, dinosaur extinctions led to more resources and fewer predators for mammals. The open niches left by dinosaurs may have been the trigger for adaptive radiation of mammals after dinosaurs became extinct. Mammals diversified and adapted to new niches producing new species in many cases. This is an example of a catastrophic change in the environment leading to the expansion of an entire family of species.

Explain Which type of reproductive isolation could have led to the speciation of plants in the silversword alliance? Use evidence to support your claim.

Expansion of Species

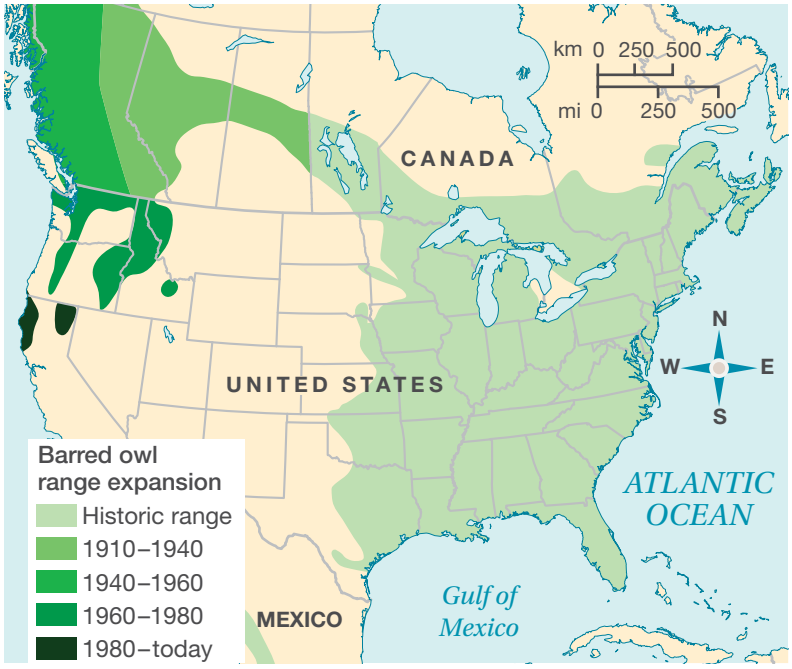
Natural environmental changes such as droughts can lead to the expansion of a species' range. For example, a long-lasting drought can change an ecosystem to make it more suitable for plants adapted to dry conditions. These plants could expand into the ecosystem and outcompete plants that are less well-adapted to the dry conditions. Humans can also cause environmental changes that lead to the expansion of species.

Increasing Populations

Historically, the barred owl lived in the eastern United States. The Great Plains served as a barrier to the westward expansion of many species that lived in forests, including the barred owl. The Great Plains were maintained in part due to regular burning by Native Americans and the disturbance caused by massive herds of buffalo. Much has changed in these ecosystems over the past 100 years. The plains are no longer burned, herds of buffalo no longer shape the landscape, wildfires are put out, and the climate has warmed. These environmental changes are potential causes for the barred owl range expansion across British Columbia in Canada into Washington, Oregon, and northern California in the Pacific Northwest region of the United States. The warming climate could have made Canada's northern boreal forests more suitable for the barred owl. The owls may have used this habitat as a bridge to reach the Pacific Northwest. Another possibility is that the barred owl worked its way across the plains as settlers planted trees and encouraged tree growth along streams. The owls could have used these intermediate habitats to journey from eastern forests to western forests.

Gather Evidence
Why might it be easier for plants than animals to expand their ranges?

FIGURE 8: Barred owls benefited from environmental changes that increased suitable habitat.



Source: The University of Minnesota and *The Oregonian* as quoted by Bryant, Peter J., "Draft Recovery Plan for the Northern Spotted Owl" 26 August 2016 <http://darwin.bio.uci.edu/~sustain/issueguides/Northern Spotted Owl/index.htm>.

Climate Change and Species Expansion

Climate change is affecting different areas in different ways, from rising sea levels to an increase in average global temperature. As areas warm, they may become more suitable for organisms that were previously kept out due to uninviting habitat conditions. For example, polar bear habitat in northern Canada was once too cold and inaccessible for grizzly bears. As this area warms, it becomes more suitable habitat for grizzly bears. Because of these environmental changes, grizzlies have expanded their range into polar bear habitat. This movement could lead to a wider expansion of grizzly bear populations in the long term.

Language Arts Connection Using library and Internet resources, research the potential long-term effects of grizzly bears moving into polar bear habitat. Is this a problem? Write a short magazine-style article detailing your findings and position. Use images, graphs, and data to support your claims.

FIGURE 9: Grizzly bears have expanded their range into polar bear habitat.

Analyze How can climate change lead to the expansion of a species?

The expansion of species into new territories can also lead to hybridization. Hybridization occurs when two distinct, but closely related, species are able to successfully mate together. Sometimes, the features shown by the hybridized species fall within the range of characteristics shown by one or both of the original populations. Over time, as the two species continue to interact with one another, they may become a single species.

In the case of grizzly bears, as climate change lets them expand their territories northward, they are interacting more and more with polar bears. Because both bear species are closely related, they are able to successfully mate and produce viable offspring. Some scientists worry that this inbreeding may result in the disappearance of the polar bear as a separate species, particularly as it is already being threatened by habitat loss due to climate change.

Explain How would population expansion most likely occur in the silversword alliance, assuming these plants underwent adaptive radiation?

Extinction of Species

Just as birth and death are natural events in the life of an individual, the rise and fall of species are natural processes of evolution. The elimination of a species from Earth is called extinction. Extinction often occurs when a species as a whole cannot adapt to a change in its environment.

FIGURE 10: The northern spotted owl is native to the Pacific Northwest region of the United States.

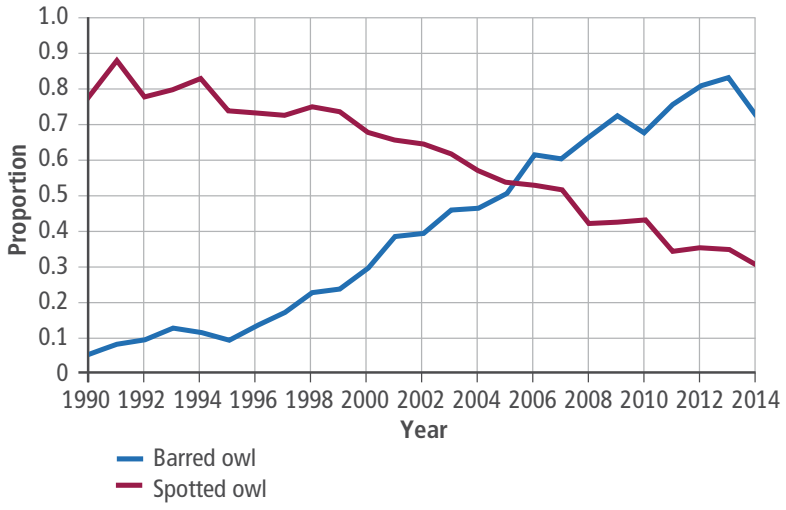
Causes of Extinction

Let's return to the example of the barred owl territory expansion. The expansion has been good for the barred owl, as seen by its increasing success and growing population numbers. Unfortunately, the appearance of the barred owl in the forests of the Pacific Northwest has negatively impacted a closely related species, the northern spotted owl. This bird is listed as a threatened species under the Endangered Species Act. Historically, the northern spotted owl has been most threatened by habitat loss due to logging, land development, and natural disasters. Now, the small amount of northern spotted owl habitat that remains is being invaded by the barred owl.

Barred owls and northern spotted owls use the same habitat in many of the same ways. Both species use old growth forests for food and nesting. Advantages of the barred owl over the northern spotted owl include a larger body, more aggressive behavior, smaller overall territory needs, the hunting of a wider range of prey, and more breeding success. In short, the barred owl is outcompeting the northern spotted owl. If the northern spotted owl is driven from its entire range, then the species could become extinct.

Comparing Owl Populations

FIGURE 11: The northern spotted owl is being displaced by the larger barred owl.



Source: Forsman, Eric D. et al. Demographic characteristics of spotted owls in the Oregon Coast Ranges, 1990-2014.

Source: Smithsonian Magazine, 2009

Collaborate Discuss with a partner how the expansion of a species into a new habitat might affect the native species that are already living there.

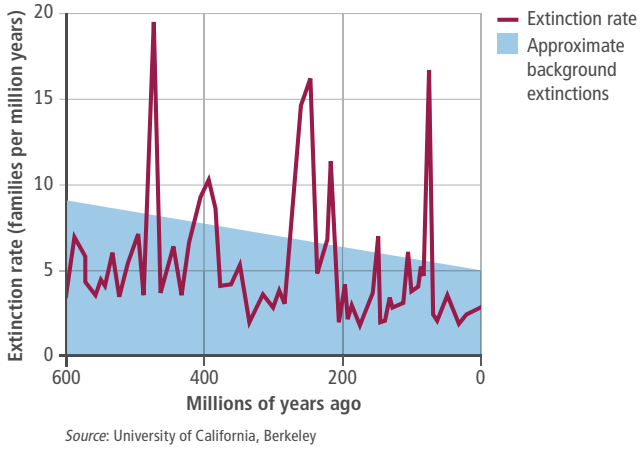
Extirpation, or local extinction, occurs when a species no longer exist in a specific portion of their range but still can be found elsewhere. For example, wolves have been extirpated from much of their historic range due to overhunting and habitat loss. Extinctions have occurred throughout time as shown in the fossil record. Natural events such as droughts, volcanic eruptions, and floods can cause extinctions if species cannot adapt to the new environment.

Background Extinctions and Mass Extinctions

Extinctions that occur continuously but at a very low rate are called background extinctions. These extinctions occur at roughly the same rate as speciation. This type of extinction typically affects one or a few species in relatively small areas. Background extinction is common and occurs due to factors such as disease, loss of habitat, or loss of a competitive advantage. Mass extinctions are more rare, but have a larger impact on Earth's biodiversity. Entire orders or families may be wiped out by mass extinction events. Mass extinctions are thought to occur suddenly in geologic time, usually because of a catastrophic event such as an ice age or asteroid impact. An example of a mass extinction is the K-T event that occurred at the end of the Cretaceous period 65 million year ago. A large meteor that crashed on Earth triggered this mass extinction. The aftermath of the meteor strike caused the extinction of 70 percent of Earth's species. The fossil record confirms that there have been at least five mass extinctions in the past 600 million years.

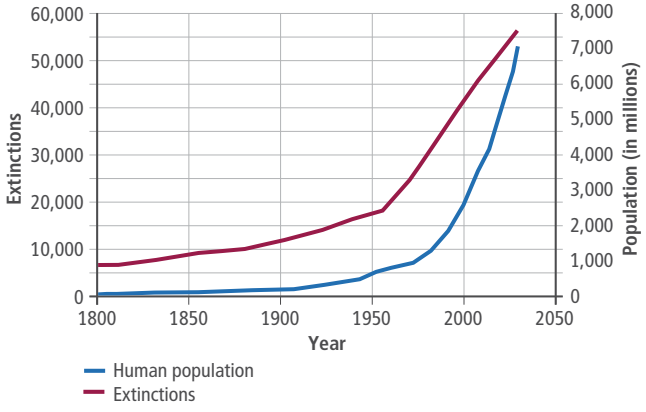
Cause and Effect

FIGURE 12: Comparing Extinction Rates



Source: University of California, Berkeley

a Extinction Rates Through Time



Source: Scott, J.M. 2008. *Threats to Biological Diversity: Global, Continental, Local*. U.S. Geological Survey, Idaho Cooperative Fish and Wildlife, Research Unit, University of Idaho.

b Human Population Growth and Extinction Rates

Analyze Use the graphs in Figure 12 to answer the following questions:

1. What patterns or trends are shown in the first graph (a)? What is the cause of these patterns?
2. What patterns or trends are shown in the second graph (b)? What is the cause of these patterns?
3. Is there a relationship between the two graphs? Explain your answer.

Climate Change and Extinction

Many scientists think that Earth is currently experiencing a sixth mass extinction. The sixth mass extinction is characterized by extinction rates that are 1000 to 10,000 times the background rate. The current extinction event is caused almost entirely by human behaviors such as the burning of fossil fuels, destruction of habitat, and introduction of invasive species.

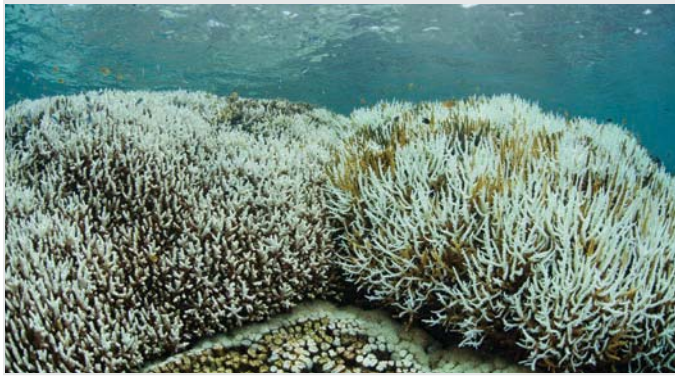
Analyze What is the cause-and-effect relationship between humans and the sixth mass extinction? Describe the relationship in terms of the growing human population and the causes and effects of climate change.

Climate change is caused by the release of large amounts of greenhouse gases—such as carbon dioxide—into the air, mostly from the burning of fossil fuels. Climate change is causing rapid changes to environments, from increasing temperatures to rising sea levels. Some species may find an increase in suitable habitat due to climate change. Other species may go extinct if their populations cannot adapt quickly enough to the changing environmental conditions. Corals are an example of a group of species that are being negatively affected by climate change.

Increasing Sea Temperature

Coral bleaching is a stress response in corals. When conditions are poor, the corals lose the symbiotic algae living inside of them. The photosynthetic algae are the corals' main source of food. Without the algae, the corals weaken and turn white. Rising sea temperatures are the leading cause of bleaching events on coral reefs. Other causes include pollution, increased intensity of sunlight, and extremely low tides.

FIGURE 13: Coral Bleaching



Ocean Acidification

Ocean acidification occurs when carbon dioxide is absorbed by seawater. The reaction between carbon dioxide and seawater also uses dissolved carbonate ions, which results in a decreased concentration of carbonate ions in the water. Many corals need carbonate in the form of calcium carbonate to build their skeletons. Coral reef growth will decline without enough carbonate for skeleton formation. If reef growth is slower than reef erosion, the reef could eventually stop functioning.

Extreme Weather Events

Many coral reefs are located in areas with extreme weather events such as hurricanes. The reef structure and species have adapted to recover after storms, though the recovery period can take a long time. It is predicted that climate change will increase the frequency and intensity of severe storms in some areas. Corals affected by more frequent storms may be unable to maintain reef structures. The increasing effects of coral bleaching, ocean acidification, and extreme weather present a bleak outlook for coral reefs in the future.

Explain What might happen if a species that is well adapted to lower pH and higher temperatures was introduced to coral reefs in the Hawaiian Islands?

Language Arts Connection

Patterns in Evolution and Speciation

FIGURE 14: The stinging ant *(Pseudomyrmex ferrugineus)* and acacia are an example of coevolution.

Species interact with each other in many different ways. For example, they may compete for the same food source or be involved in a predator-prey relationship. Most of these interactions do not involve evolutionary changes. However, sometimes the evolutionary paths of two species become connected.

Coevolution

The process of coevolution occurs when two or more species evolve in response to changes in each other. These relationships might be mutually beneficial, or they might be good for one species, but bad for the other, such as predator-prey or parasite-host relationships.

Many types of flowers and pollinators have coevolved to maximize pollination success for the plants and nectar capture for the pollinators. The plant-pollinator dynamic is typically mutually beneficial. The plants gain the pollination necessary for reproduction and the pollinators gain a food source. For example, the hawk moth has an especially long tongue that lets it drink from the narrow, nearly foot-long structure of a star orchid that holds the flower's nectar.

The bullhorn acacia is a plant species found throughout Central America that has branches covered in hollow thorns. Although the thorns protect the plant from being eaten by large animals, small herbivores such as caterpillars can fit between them. A species of stinging ants (*Pseudomyrmex ferrugineus*) is a key part of the plant's defense against these smaller predators. As shown in Figure 14, these wasp-like ants live inside the plant's thorns and feed on its nectar. The ants protect the plant by stinging animals that try to eat the leaves. In turn, the acacia plant provides the ants with both the shelter and food resources they need to survive.

The relationship between the acacia and the ants is much more than a simple cooperation between two species. The acacia and the ants share an evolutionary history. The hollow thorns and nectar-producing leaves of the acacia and the stinging of the ants have evolved due to the beneficial relationship between the two species. Relatives of these species that are not involved in this type of relationship do not have these same traits.

Evolutionary Arms Race

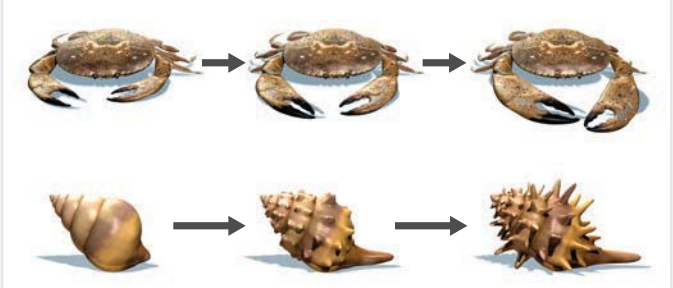
Coevolution does not just occur in species that share a beneficial relationship. It also occurs in two species that have a competitive relationship with one another. These competitive interactions can lead to "evolutionary arms races," in which each species responds to pressure from the other through a series of adaptations over the course of many generations.

For example, many plants produce defense chemicals to discourage plant-eating species from nibbling on them. Natural selection then favors herbivores that can overcome the effects of the chemicals. After many generations, some herbivore species may build up a level of resistance to the chemicals and are again able to safely eat the plant without getting sick. Natural selection then favors plants that have evolved even more potent chemicals to thwart their herbivore predators.

One researcher is using a mustard plant and a fruit fly relative to model coevolution in insects and plants. The research shows that the flies use the plants for all stages in their life cycle. The plant has developed proteins that cause the digestive tract in the flies to malfunction. Now it's up to the fly population to develop a resistance to this latest defense mechanism.

Arms races can be seen in animals as well, as shown in Figure 15. Crabs are predators that feed on snails as their prey. This makes a selective pressure for the snails to develop spines and a harder shell as a defense from crabs. As a result, the crabs then develop bigger claws and more powerful jaws to break into the harder shells. This pattern in speciation continues as evolution is influenced by evolution in another species.

FIGURE 15: Evolutionary Arms Race



Patterns in Speciation

Speciation often occurs in patterns, including gradualism and punctuated equilibrium. Gradualism is the steady, gradual change of species as mutations slowly give rise to variations and adaptations. Gradualism is closest to the type of evolution predicted by Charles Darwin that supports his ideas of descent with modification. That is, each generation is slightly different than the last, individuals with increased fitness preferentially breed, and advantageous alleles slowly build in a population. These small changes add up to become the wide variety of characteristics seen among species on Earth today.

Punctuated equilibrium is characterized by long periods of no change interspersed with short periods of big change. Punctuated equilibrium is often tied to speciation events, such as a natural disaster, in which species are forced to adapt or die off. For example, the isolation of a small population in a new environment with unique selective pressures can drive short bursts of evolution as beneficial and harmful traits are selected for or against.

A new species can arise through either gradualism or punctuated equilibrium. Some lines of evolution show gradualism patterns and some lines of evolution show punctuated equilibrium patterns. Gradualism occurs at a constant background rate, much like the rate of background extinction. Punctuated equilibrium occurs irregularly and is more intense, much like mass extinctions.

Language Arts Connection Does evidence support the claim that species can evolve through either gradualism or punctuated equilibrium?

Find support for the information given in this text by researching and finding evidence of gradualism and punctuated equilibrium in Earth's history.

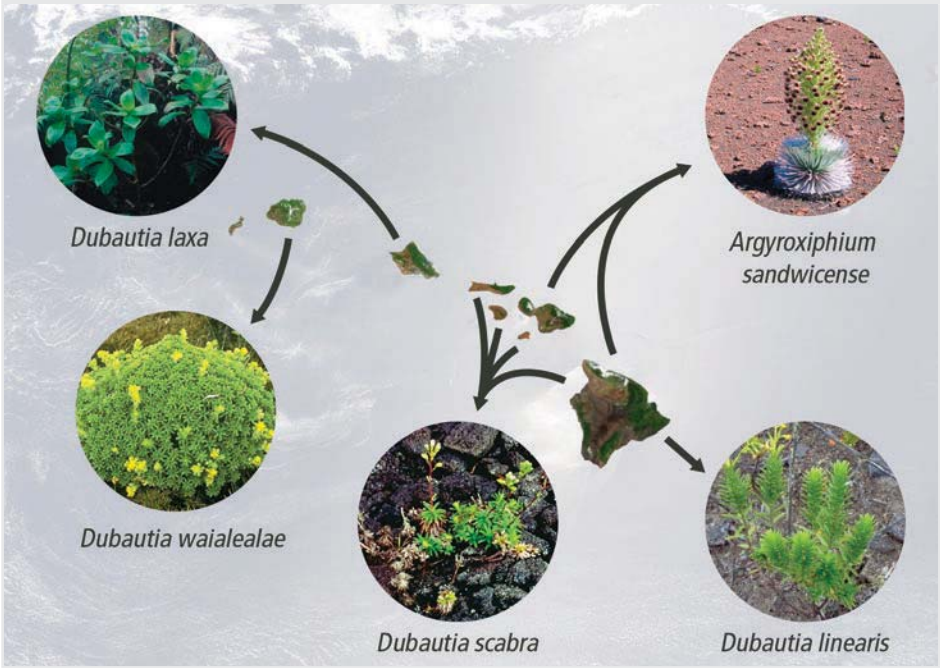
Prepare a one-page blog post that analyzes how two different species evolved (one through gradualism and one through punctuated equilibrium), and include an image that represents the pattern of speciation each species experienced.

CAREER: BIOINFORMATICS | MIMICRY | HYBRIDIZATION | Go online to choose one of these other paths.

Lesson Self-Check

CAN YOU EXPLAIN IT?

FIGURE 16: Plants in the silversword alliance are descendants of a common ancestor.



The silversword alliance in the Hawaiian Islands is the product of the adaptive radiation of a tarweed ancestor. Each species in the silversword alliance is adapted to use a particular ecological niche. The radiation has caused extreme differences in the characteristics of each plant even though they are all very closely related.

Explain The plants in the silversword alliance have a common ancestor. Refer to the notes in your Evidence Notebook to explain how they developed different characteristics. In your answer, consider how changes or differences in the environment affect the emergence and disappearance of species.

Scientists think that this plant family came from a species similar to Muir's tarweed. This alpine shrubland species is found in California and Mexico. It has barbed fruits, and scientists think that it might have been carried to Hawaii by a bird. Over the course of millions of years, this single ancestral species evolved into over 30 separate species.

Three distinct lines of genetic evidence—including analyses of nuclear ribosomal DNA, chloroplast DNA, and a comparison of two specific developmental gene sequences—support the idea that this group of plants came from a mainland ancestor. Because there were so few species that originally colonized the newly formed Hawaiian Islands, there were plenty of habitats open to new species. Over time, the original tarweed species adapted to the conditions in these different environments, leading to a diversification of characteristics. Each plant is well adapted to its habitat as shown by their diverse sizes and shapes, ranging from small shrubs and mat-like formations to large trees and vines.

CHECKPOINTS

Check Your Understanding

1. Two tree species that grow on the Monterey Peninsula in California are very closely related. However, they have different pollination periods. Which type of reproductive isolation do these two tree species exhibit?
   - **a.** adaptive radiation
   - **b.** geographic isolation
   - **c.** temporal isolation
   - **d.** physical isolation

2. What environmental changes caused by climate change may be leading to the extinction of corals? Select all correct answers.
   - **a.** extreme weather
   - **b.** air pollution
   - **c.** ocean acidification
   - **d.** rising sea temperature

3. What adaptations in an isolated population would likely contribute to speciation? Select all correct answers.
   - **a.** higher-pitched alarm call
   - **b.** adoption of daytime feeding over nighttime feeding
   - **c.** female enzyme targets eggs fertilized by individuals outside of the isolated populations
   - **d.** development of different sexual anatomy
   - **e.** higher temperature range tolerance

4. Why are island systems favorable to adaptive radiation?

5. How can extinctions and expansions occur in the same habitat? Explain your answer.

6. Give examples of how climate change may lead to the emergence, expansion, and extinction of species.

7. Draw a map that shows a parent population, a geographically isolated population, a behaviorally isolated population, and a temporally isolated population of the same species.

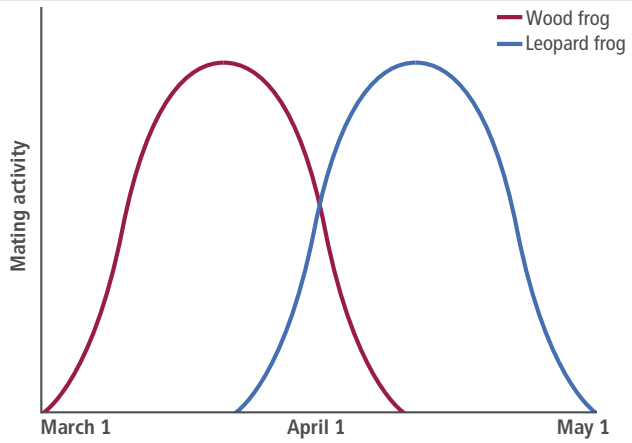
8. What are some of the causes of background and mass extinctions?

9. What process keeps the number of total species on Earth from growing exponentially through speciation?

10. Use the following words to complete this statement:
    adapted, common ancestor, niches
    A species of lizard arrived on an island after a big storm. The population expanded into all of the empty _____ on the island. Speciation occurred as populations _____ to different environments. Over 20 descendant species trace their lineage back to a _____.

Use the graph in Figure 17 to answer Question 11.

FIGURE 17: Reproductive Isolation



11. Wood frogs and leopard frogs are found in the same ecosystems, but they do not interbreed. Use evidence from the graph to explain what type of reproductive isolation these frogs exhibit.

MAKE YOUR OWN STUDY GUIDE

In your Evidence Notebook, design a study guide that supports the main idea from this lesson:

Changes in the environment can lead to the emergence of a new species, the expansion of some species, and the extinction of some species.

Remember to include the following information in your study guide:

- Use examples that model main ideas.
- Record explanations for the phenomena you investigated.
- Use evidence to support your explanations. Your support can include drawings, data, graphs, laboratory conclusions, and other evidence recorded throughout the lesson.

Consider how cause and effect is demonstrated by the sequences of events that lead to speciation, expansion, and extinction.