Patterns of Evolution

As you have learned, natural selection leads to predictable outcomes:

- Closely related species share many homologous structures, even though they no longer serve the same function.
- Species have vestigial structures and pseudogenes that once served a useful purpose in their ancestors.
- Remote islands are inhabited by unique species that are descended from a few individuals of species able to reach them across wide expanses of ocean.

When considered on a grander scale, these and other predictable outcomes lead to recognizable patterns.

Adaptive Radiation

Adaptive radiation occurs when a single species evolves into a number of distinct but closely related species. Each new species fills a different ecological niche. This process usually occurs when a variety of new resources become available—resources that are not being used by other species.

adaptive radiation the relatively rapid evolution of a single species into many new species, filling a variety of formerly empty ecological niches

Consider the example of Darwin's finches (**Figure 1**). Here, a group of 13 species that live in the Galapagos Islands evolved from a single species. Let us assume that the original species of finch living on the mainland of South America had a medium-sized bill ideally suited to feed on certain medium-sized seeds. Individuals born with slightly smaller bills might have been better at eating smaller seeds, but they might have faced stiff competition from other bird species that were already specialized in feeding on the smaller seeds. Finches eating larger seeds would also face similar competition. The result

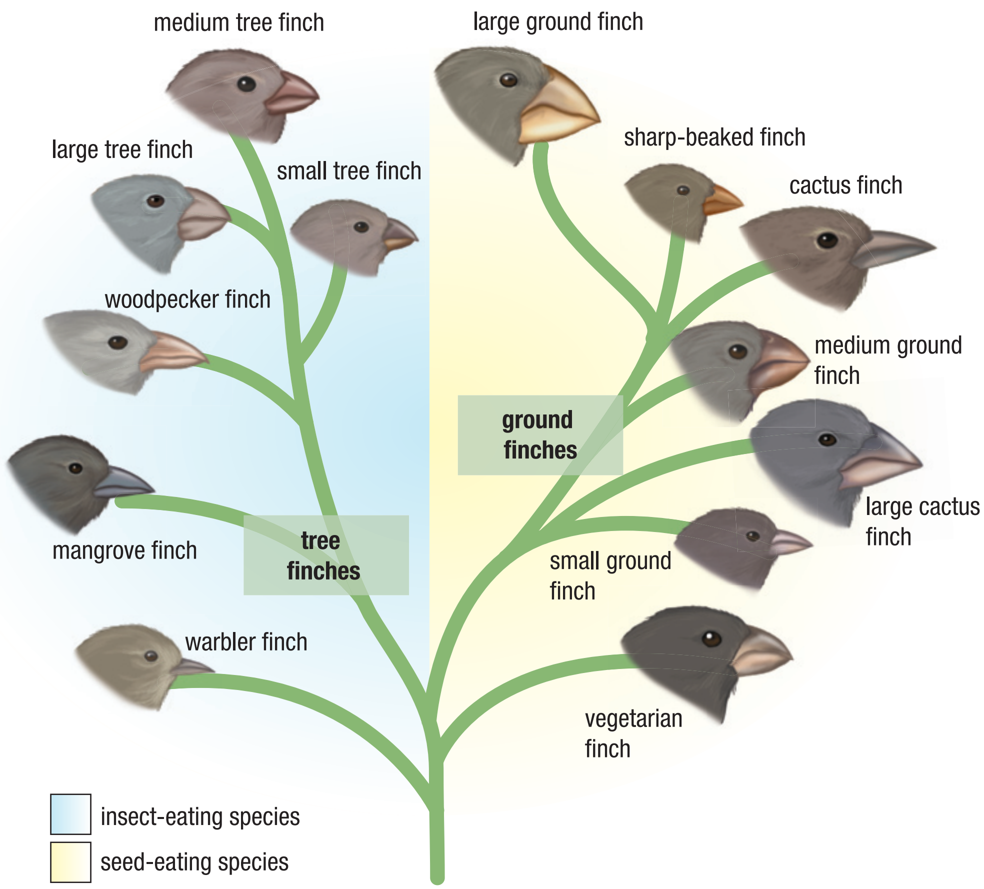

Figure 1 Thirteen species of Darwin's finches are the result of recent adaptive radiation and fill many different ecological niches. Genetic evidence shows they all evolved from a single common ancestor species.

Figure 2 The Galapagos Islands are home to a rich diversity of habitats, from (a) moist forests to (b) dry deserts.

was stabilizing selection on the mainland finches to stay in their specialized ecological niche. An entirely different fate awaited individuals of this finch species once they reached the Galapagos Islands (**Figure 2**). Instead of hundreds of other species of land bird, there were few or none. Their only competition was with each other—individuals of the same species—for medium-sized seeds.

The islands might already have been teeming with populations of many plant and insect species that could have arrived long before. The different habitats would have harboured a diverse array of food resources, such as various-sized seeds and different insects. With no insect-eating birds on the islands, the finches had an opportunity to exploit a new food source with no competition. In such a setting, any finches born with a different bill size or feeding behaviour would have been rewarded with a rich supply of food and little competition from other birds. The result of adaptive radiation was seven seed-eating species, one of which feeds primarily on other plant parts, and six insect-eating species.

The most spectacular case of adaptive radiation is witnessed in the cichlid fishes of lakes Victoria, Malawi, and Tanganyika in Africa. Each lake is quite isolated from other bodies of water, making it very difficult for new species to arrive. Each lake, however, is home to hundreds of unique species, all descended from one or a few initial species. Lake Malawi alone has nearly 1000 species of cichlid. All but two of these species are found nowhere else on Earth.

WEB **LINK**

To learn more about the fascinating evolution of African cichlids,

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In each case of adaptive radiation, an initial species evolves into a variety of new species that differ to varying degrees from the original species. In this way, adaptive radiation contributes to biodiversity. A similar pattern can be seen on a much larger scale when we consider entire groups of organisms and very large ecosystems.

Divergent Evolution

In any ecosystem, there are a number of major ecological roles. All natural ecosystems, for example, have producers, consumers, decomposers, and scavengers. These major roles are never filled by a single species. Consider the ecological role of herbivores. Not surprisingly, natural selection has favoured the evolution of a wide variety of herbivores. For example, herbivorous mammals come in a variety of shapes, sizes, and specialties. Natural selection has favoured their **divergent evolution** into a great variety of species. Northern Ontario forests are home to many rodents, the largest taxon of mammals (**Figure 3**). These rodents provide an excellent example of divergent evolution. All of these species evolved from a single common ancestor that existed millions of years ago.

divergent evolution the large-scale evolution of a group into many different forms

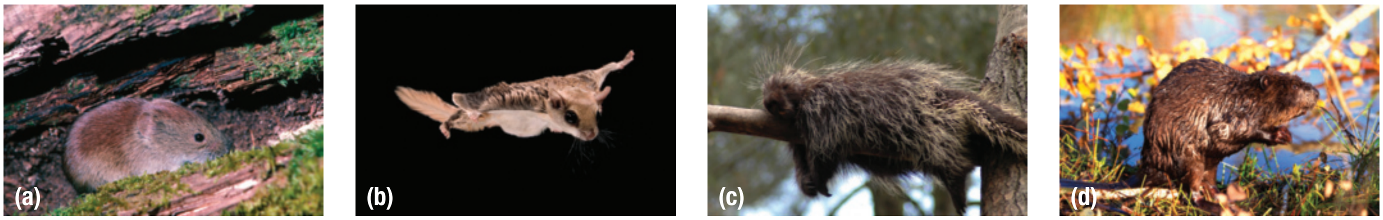

Figure 3 Ontario has over 20 species of closely related rodents, a group of mammals that has undergone significant divergent evolution. Species include the (a) deer mouse, (b) flying squirrel, (c) porcupine, and (d) beaver.

Red squirrels have evolved as tree-climbing seed specialists that are active during the day, while northern flying squirrels fill a similar ecological niche but are active only at night. Chipmunks spend much of their time foraging for seeds at ground level. The smallest forest rodents include deer mice and red-backed voles. Deer mice prefer small seeds and insects and usually nest in trees, while voles nest on the ground and eat roots and buds. Porcupines are the largest tree-climbing rodents and feed on twigs and the thin bark of conifers. Beavers, the largest of all Canadian rodents, prefer the twigs and bark of angiosperm species and cut them down and drag them into the water before feeding on them. The unique characteristics of each of these species have proven successful and have been selected for by the environment.

Divergent evolution leads to two predictable outcomes. First, competition between species is minimized as new species diverge to fill specialized ecological niches. Second, given enough time, new species continue to evolve until most available resources are used. The result is an overall increase in biodiversity as a single species or group evolves to fill available ecological niches.

Convergent Evolution

Evolutionary biology predicts that when a single species is placed under two different sets of selective pressures, it is likely to undergo divergent evolution. What if the situation were reversed? What if two species were placed under similar selective pressure? **Convergent evolution** occurs when two *different* species, or taxa, evolve to occupy similar ecological niches. Patterns of convergent evolution are often most obvious when you compare different geographic regions.

convergent evolution the evolution of similar traits in distantly related species

One of the clearest examples is observed in two groups of plants (**Figure 4**). Cacti evolved in the deserts of South America and are native only to the Americas. Euphorbia look similar to cacti, but first evolved in the deserts of South Africa and now occur in Africa, Eurasia, and Australia. Both groups have species with features that have evolved in response to extremely dry conditions. Many cactus and euphorbia species have sharp spines and thick green stems that perform photosynthesis and store water. During dry conditions, some euphorbia have no leaves but, unlike cacti, are able to grow green leaves when ample water is available. Although both plant groups have evolved spines that serve the same protective function, the spines of cacti evolved from leaves, while those of euphorbes evolved from the outward growth of stem tissues.

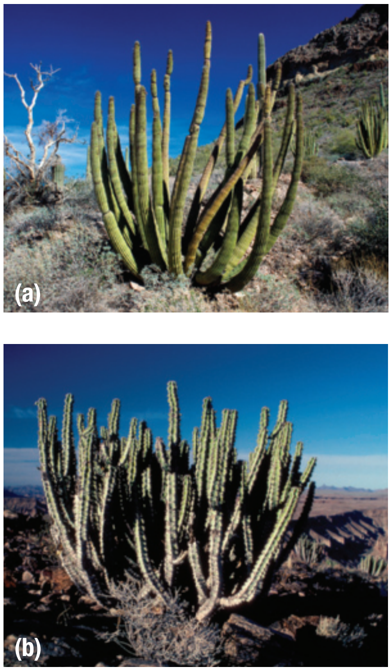

Figure 4 (a) Cacti and (b) euphorbia have evolved similar features in response to their hot dry environments.

Sharks and dolphins are another example of convergent evolution. Both have evolved very similar streamlined bodies well suited for their high-speed carnivorous behaviour. Natural selection favoured the same body shapes in two very distantly related species (**Figure 5**). Sharks evolved from a primitive fish with a cartilaginous skeleton and a side-to-side body motion that powers a vertical tail. Dolphins are recently evolved, warm-blooded marine mammals with a bony skeleton. They power their horizontal tail flukes with an up-and-down motion inherited from their land-living ancestors.

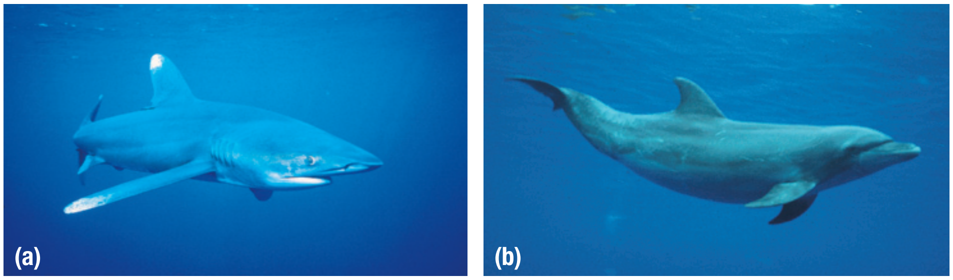

Figure 5 Convergent evolution resulted in the similar body shapes of (a) sharks and (b) dolphins.

Convergent evolution can result in similar features evolving in very distantly related organisms. The selective advantage of detecting and responding to light, for example, resulted in the evolution of a range of light-detecting organs. Protists have simple eye spots, while arthropods, mollusks, and vertebrates have complex and varied eyes (**Figure 6**).

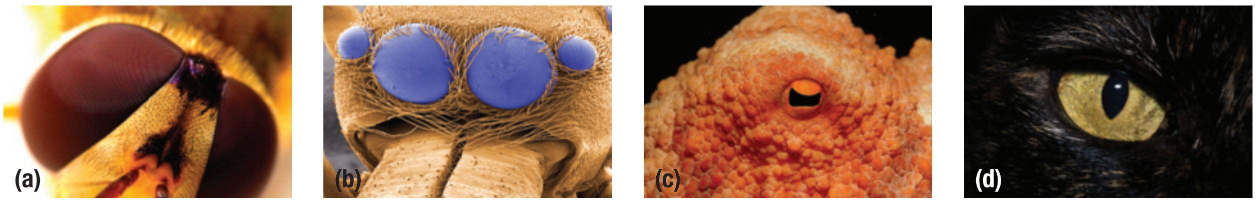

Figure 6 Complex eyes have evolved independently in many animal groups including (a) insects (fly), (b) arachnids (spider), (c) mollusks (octopus), and (d) vertebrates (cat).

Just as the patterns of divergent evolution can be predicted, so can the outcomes of convergent evolution. We can predict two common outcomes. First, natural selection will favour the evolution of similar traits in similar environments. Second, while some traits will converge in form or function, each species will retain other features that provide evidence of their distinct evolutionary past.

Coevolution

coevolution a process in which one species evolves in response to the evolution of another species

A species experiences **coevolution** when its evolutionary success is closely linked to that of another species. For example, certain plants have evolved hard protective shells to protect their seeds, while some seed-eating mammals have evolved powerful jaws and teeth for chewing through hard shells (**Figure 7**). Any seeds surrounded by a hard shell might be better protected from herbivores and better able to survive than seeds with thin shells. Similarly, any herbivore with a slightly more powerful jaw might be able to acquire more food than a herbivore with a less powerful jaw. This result is sometimes called an "evolutionary arms race."

As species coevolve, one or both species may become increasingly dependent on the other. In these situations, a threat to one species may be a threat to the other. In extreme cases the extinction of one species can lead to the extinction of the other.

Coevolution is most pronounced in symbiotic relationships. Certain orchid species, for example, are completely dependent on one species of moth to pollinate their flowers. The moths, in turn, depend on the orchid nectar for food. Over time, the flowers of some orchid species have evolved extremely long tubes, called spurs, which contain the nectar. Biologists hypothesize that natural selection has favoured longer spurs because obtaining nectar from a longer spur requires moths to expend more time and effort, making them more likely to pick up pollen. For the moths, natural selection favoured individuals with slighter longer tongues that could reach the nectar at the bottom of the longest spurs. The ultimate result has been the evolution of a most extreme pair. The Madagascar long-spurred orchid has nectar at the end of a 30 cm long spur (**Figure 8**). Its only pollinator, a hawk moth, has a tongue the same length!

Figure 7 (a) Brazil nut trees have evolved extremely hard protective shells. (b) The agouti is the only mammal with jaws and teeth strong enough to bite open the shell.

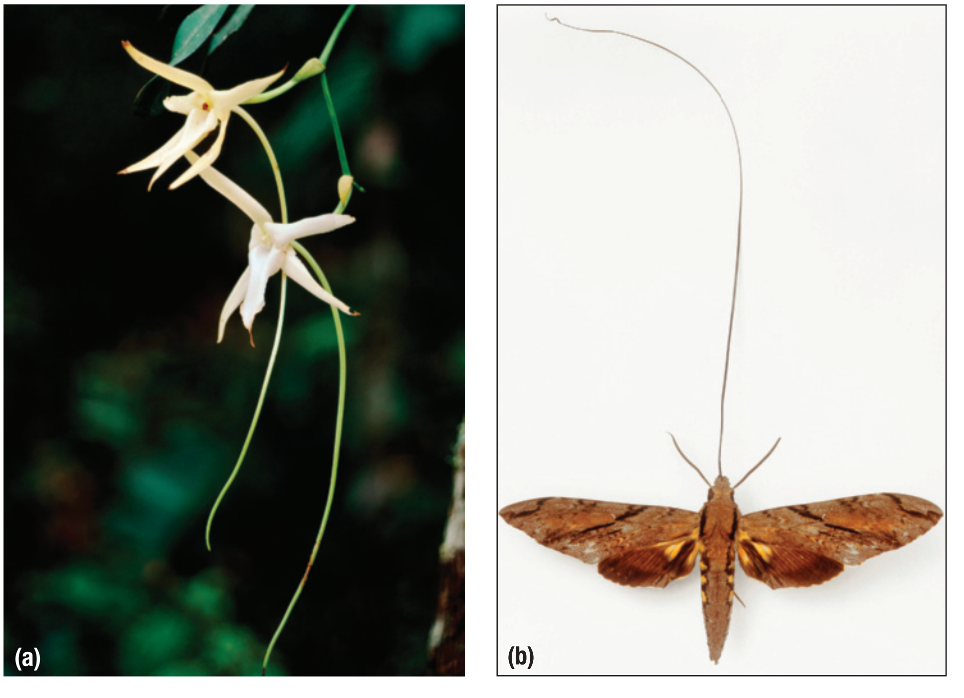

Figure 8 (a) The Madagascar long-spurred orchid is pollinated by (b) a hawk moth whose tongue is about 30 cm long.

Research This

Convergent Evolution Down Under

Skills: Researching, Analyzing, Communicating

SKILLS HANDBOOK A2.1, A5.1.

Australia is home to many unique species and is famous for its diversity of marsupials. These unusual mammals include the kangaroo and the koala. Why do so many marsupials live in Australia, and how do they compare to mammals in other parts of the world?

1. Research the marsupials of Australia, considering the following topics:
   - the anatomical differences between marsupial mammals and placental mammals
   - the relationship between the separation of Australia from the Gondwana land mass, and the evolution of marsupial and placental mammals
   - how convergent evolution influenced the marsupial mammals and the placental mammals
   - how introduced placental mammals have become invasive species in Australia

A. Explain how the isolation of Australia led to the evolution of its unique collection of marsupial mammals. T/I

B. Compare the physical appearance and ecological niches of several marsupials to similar placental mammals. For example, compare Tasmanian wolves and grey wolves or flying phalangers and flying squirrels. T/I

C. Outline the current status of invasive mammals in Australia. Which species are of greatest concern? What is being done to try and mitigate the situation? T/I A

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8.3 Summary

- Adaptive radiation increases biodiversity, as a single species evolves into many new species filling a number of different ecological niches.
- Adaptive radiation occurs rapidly when a species is able to exploit a wide variety of new resources with little or no competition from other species.
- Divergent evolution increases biodiversity and leads to predictable large-scale patterns of evolution as major ecological roles are filled by a variety of species—each with their own specializations.
- Convergent evolution occurs when different species or groups evolve similar adaptations under similar conditions.
- Coevolution occurs when the evolution of two species becomes linked. Coevolution often strengthens symbiotic relationships.

8.3 Questions

1. Explain why a species is most likely to undergo adaptive radiation when there is little competition for resources. K/U
2. The Hawaiian Islands are home to about 30 species of very closely related plants called silverswords. Some are tree-like while others are dwarf shrubs. They are found nowhere else on Earth. Use your understanding of adaptive radiation to describe their likely evolutionary past. K/U T/I
3. Compare and contrast divergent and convergent evolution. Include examples to illustrate the similarities and differences. K/U
4. Many species of fish and waterfowl are darker on their upper surface and lighter coloured below. T/I
   (a) What pattern of evolution is most likely at work?
   (b) Suggest possible selective advantages for this coloration.
5. Most remote oceanic islands have at least one unique species of flightless bird that shows little or no fear of humans or other large predators. Account for this observation. T/I A
6. As dolphins swim, they arch their backs with an up-and-down motion of their tail flukes. Land mammals such as horses use a similar arching motion as they run. Fish, however, use a side-to-side motion to move their tails. Do online research to find out how amphibians and reptiles flex their backbones as they move. T/I
7. Snakes are not the only legless terrestrial vertebrates. Caecilians are a group of amphibians that also lack legs (**Figure 9**). Is this an example of convergent or divergent evolution? Explain your reasoning.

Figure 9

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