12.3 The Patterns of Evolution

EXPECTATIONS

- Explain the mechanisms of speciation.
- Describe the different patterns of evolution.
- Compare two models describing the pace of evolution.

Types of Speciation

Speciation is the process by which a single species becomes two or more species. Biologists generally recognize two modes of speciation, the definitions of which are based on how gene flow is disrupted within a population.

Sympatric Speciation

When populations become reproductively isolated — even when they have not become geographically isolated — **sympatric speciation** occurs. In sympatric speciation, factors such as chromosomal changes (in plants) and non-random mating (in animals) alter gene flow. This type of speciation is far more common in plants than in animals.

Given the right set of conditions, a new species can be generated in a single generation if a genetic change results in a reproductive barrier between the offspring and the parent population. For example, errors in cell division that result in extra sets of chromosomes (a mutant condition called **polyploidy**) can lead to speciation.

A polyploid organism has three or more sets of chromosomes in the nucleus of each of its cells. Most animals are diploid — they have one set of chromosomes inherited from each parent. While it is quite rare for animals to be polyploid, this condition is relatively common in plants, particularly among flowering plants. (Polyploidy in plants is possible because many species are able to self-fertilize and reproduce vegetatively.)

Recall that during reproduction, a sequence of events must occur during meiosis in order for organisms to reproduce successfully. If errors occurred during meiosis and chromosomes did not separate, the gametes produced would have two sets of chromosomes (diploid, $2n$), instead of one set (haploid, $1n$). Then, if two diploid gametes fuse, the offspring would have four of each chromosome (tetraploid, $4n$). If tetraploid offspring survive, they could undergo normal meiosis and produce diploid gametes. The plant can now self-pollinate or reproduce with other tetraploids. However, it cannot produce viable seeds when crossed with diploid plants from the original population, since any offspring from this mating would be triploid ($3n$) and therefore sterile (because unpaired chromosomes result in abnormal meiosis). In just one generation, a reproductive barrier has been established in a population, because gene flow is interrupted between a small population (as small as one individual) of tetraploids and the parent population.

Figure 12.11 shows the stages in speciation by polyploidy. Many species, including cotton, apples, day lilies, and chrysanthemums, have been developed by plant breeders who artificially double

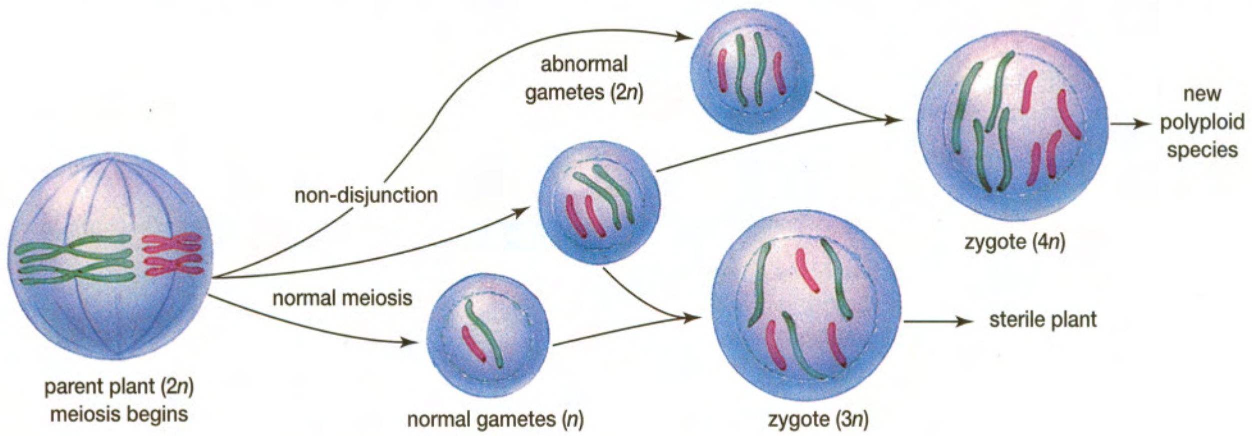


Figure 12.11 Polyploidy can lead to the formation of new species.

the chromosomes in a plant and hybridize the resulting polyploids.

BIO FACT

Polyploidy is one way that plant breeders can create seedless fruit, such as watermelon. Plant breeders produce triploid watermelon seeds by crossing a normal diploid parent with a tetraploid parent. (The tetraploid plants are created by genetically manipulating diploid plants to double their chromosome number.) The resulting watermelons are triploid, and thus sterile — they do not have seeds, yet they still produce fruit.

In another model of sympatric speciation, two species can interbreed to produce a sterile offspring. Although the offspring is infertile, it can reproduce asexually — resulting in the formation of a separate population. Through mechanisms such as errors in meiosis, the sterile hybrids can be transformed into fertile polyploids in subsequent generations, thus forming a new, fertile species even though geographical isolation has not occurred. Figure 12.12, for example, shows the evolution of wheat. Chromosome analysis has shown that wheat is the result of two hybridizations of wheat with wild grasses, and two instances of meiotic error. As a result, a new species — the wheat that has been used to make bread for 8000 years — arose. Many other species grown for agriculture, including cotton, oats, and potatoes, are polyploids.

Sympatric speciation may also occur in the evolution of animals, but it is much less common. The mechanisms for sympatric speciation in animals are also different from those in plant populations. Generally, animals will become reproductively isolated within the geographical range of a parent population as they begin to use resources not used by the parent population. This, in turn, will lead to non-random mating and eventual speciation. For example, Lake Victoria in Africa holds almost 500 species of closely related fishes called cichlids (some cichlids are shown in Figure 12.13). Each species has a feature that makes it unique from other species in the lake, and none of these species are found anywhere else on Earth. It is thought that this incredible explosion of diversity happened as small groups of the parent population began to exploit different food sources and habitats in the lake. The speciation of cichlids has resulted in a remarkable variety of cichlids with a fascinating diversity of teeth, jaws, mating behaviours, and coloration. What makes this example even more astounding is that all of this diversity evolved from a single ancestor in less than 14 000 years — a relative blip in the geological time scale.

Figure 12.13 Several species of cichlids. Almost 500 species of cichlids live in Africa's Lake Victoria.

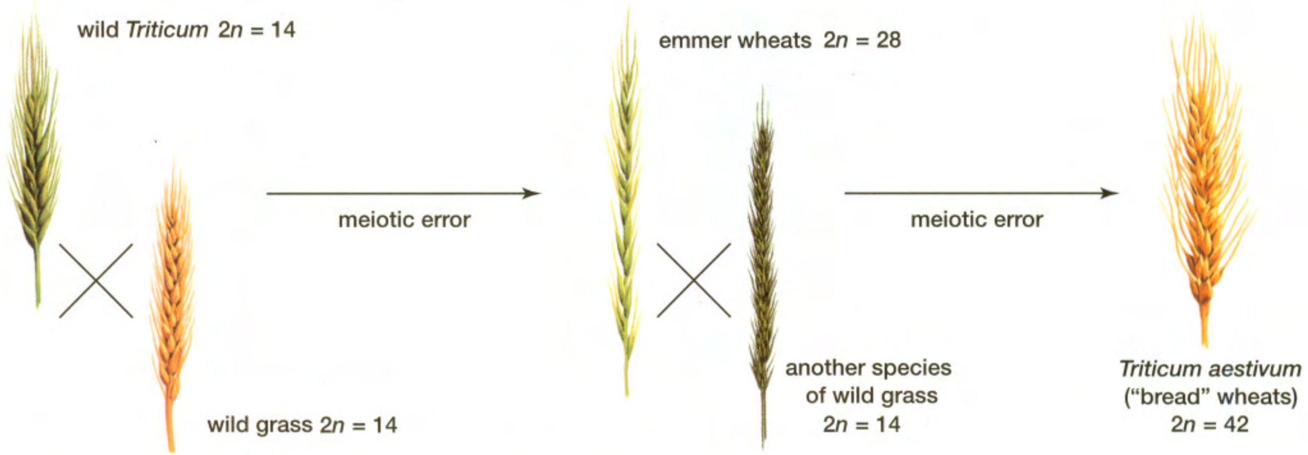


Figure 12.12 Wheat that is used to make bread evolved as a result of two hybridizations and two instances of meiotic error.

Biologists studying the speciation of and genetic differences among cichlids are running out of time. In the 1950s, the Nile perch, a fish that lives in other east African lakes, was introduced as a source of food for people living near Lake Victoria. This huge fish can grow up to two metres long, primarily by preying on cichlids. As well, farming and logging around the lake have resulted in massive soil erosion. The soil erodes into the lake and has turned the once clear waters muddy. Since cichlids cue on the distinct markings of potential mates, they are having difficulty clearly identifying potential mates and, as a result, have been mating with other closely related species. This interbreeding is eroding the reproductive isolation that was leading these fishes into hundreds of new forms.

Allopatric Speciation

Also called geographic speciation, **allopatric speciation** occurs when a population is split into two or more isolated groups by a geographical barrier. (Figure 12.14 illustrates the concept.) Eventually, the gene pool of the split population becomes so distinct that the two groups are unable to interbreed even if they are brought back together. For example, a glacier or lava may isolate populations, fluctuations in ocean levels could turn a peninsula into an island, or a few colonizers may reach a geographically separate habitat. Once populations are reproductively isolated, gene frequencies in the two populations can begin to diverge due to natural selection, mutation, genetic drift, or gene flow. This geographic isolation of a population does not have to be maintained forever for transformation to occur. However, it must be maintained long enough for the populations to become reproductively incompatible before they are rejoined.

The effect of a geographical barrier relates in large part to an organism's ability to disperse. The mobility of animals or the ease with which seeds or plant spores are dispersed limits gene flow, affects the cohesive influence of a common gene pool, and affects the impact of a geographical barrier. For example, while birds easily cross the Grand Canyon, it is impassible to rodents. As a result, the same bird species inhabit either side of the canyon, yet different species of squirrels inhabit opposite sides of the canyon.

Generally, small populations that become isolated from the parent population are more likely to change enough to become a new species. Part of the reason for this is that populations usually become geographically isolated at the periphery, or edges, of their range. It has been shown that groups of individuals at the periphery of a population already have a slightly different gene pool than that of the parent population. So, if this population splinters off, it is subject to the founder effect, since it already has a gene pool not representative of the parent population. As well, until the peripheral population becomes a large population it is subject to the effects of genetic drift. Because of the small population size, new mutations or new combinations of alleles may become fixed in the population simply by chance. This fixing of alleles would cause the genotype and phenotype to diverge from those of the parent population. Finally, because the isolated population may inhabit an environment that is slightly different from that of the parent population, natural selection through selective pressure may change the population in a different way. Note that isolated groups within populations will not automatically survive and thrive when separated into a new population. Many isolated

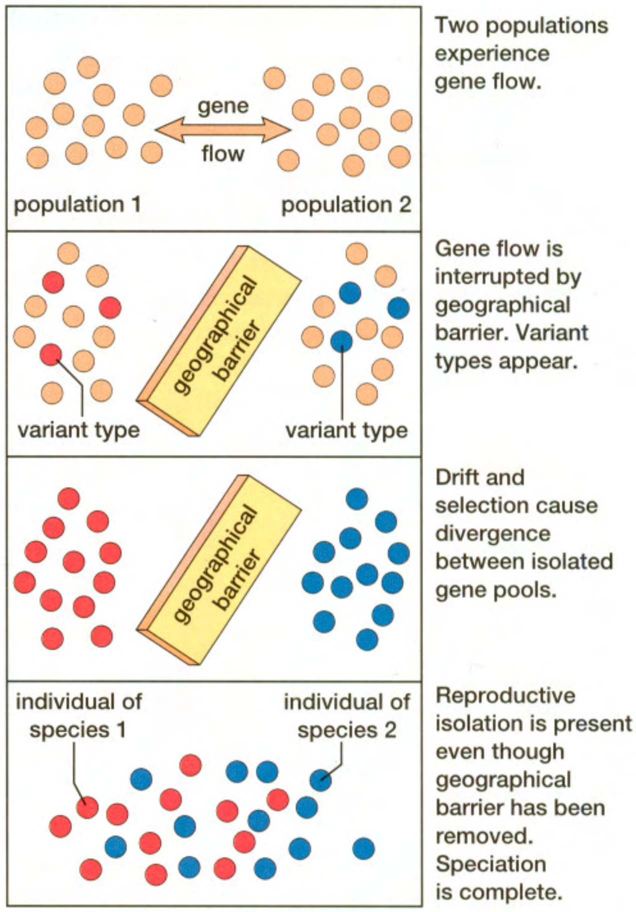


Figure 12.14 Allopatric speciation occurs after a geographical barrier prevents gene flow between populations that originally belonged to a single species.

populations do not last long enough or even change enough to become new species.

The population of finches being studied in the Galápagos is an example of speciation "in action." (You learned about the study of these finches by Peter and Rosemary Grant in Chapter 10.) Members of the ancestral species reached one of the islands in the Galápagos, possibly as a result of being blown off course in a tropical storm. Unable to return to the mainland, the ancestral species evolved differently than their mainland relative. The ancestral birds or their successive generations have since spread through the islands. New species developed as they evolved in response to the unique environments on individual islands.

By observing the finches now present in the islands, measuring features such as beak length, and analyzing the DNA of the birds, the Grants have been able to develop an evolutionary (phylogenetic) tree showing the descent of 14 species from one common ancestor. This phylogenetic tree is shown in Figure 12.15. The length of each branch of the tree reflects how much the DNA of each species has mutated from the group's common ancestor. The figure illustrates how the ancestral population initially gave rise to four lineages of finches. Over time, different lineages began to break off on their own. For example, the first branch to split off were the warbler finches, which used their slender beaks to specialize in eating insects. Next to diverge were the vegetarian finches, which use a stubby beak to eat flower blossoms, buds, and fruit. Finally, two more lineages evolved — tree finches adapted to catching insects in trees and ground finches adapted to eating seeds. Evolutionary biologists

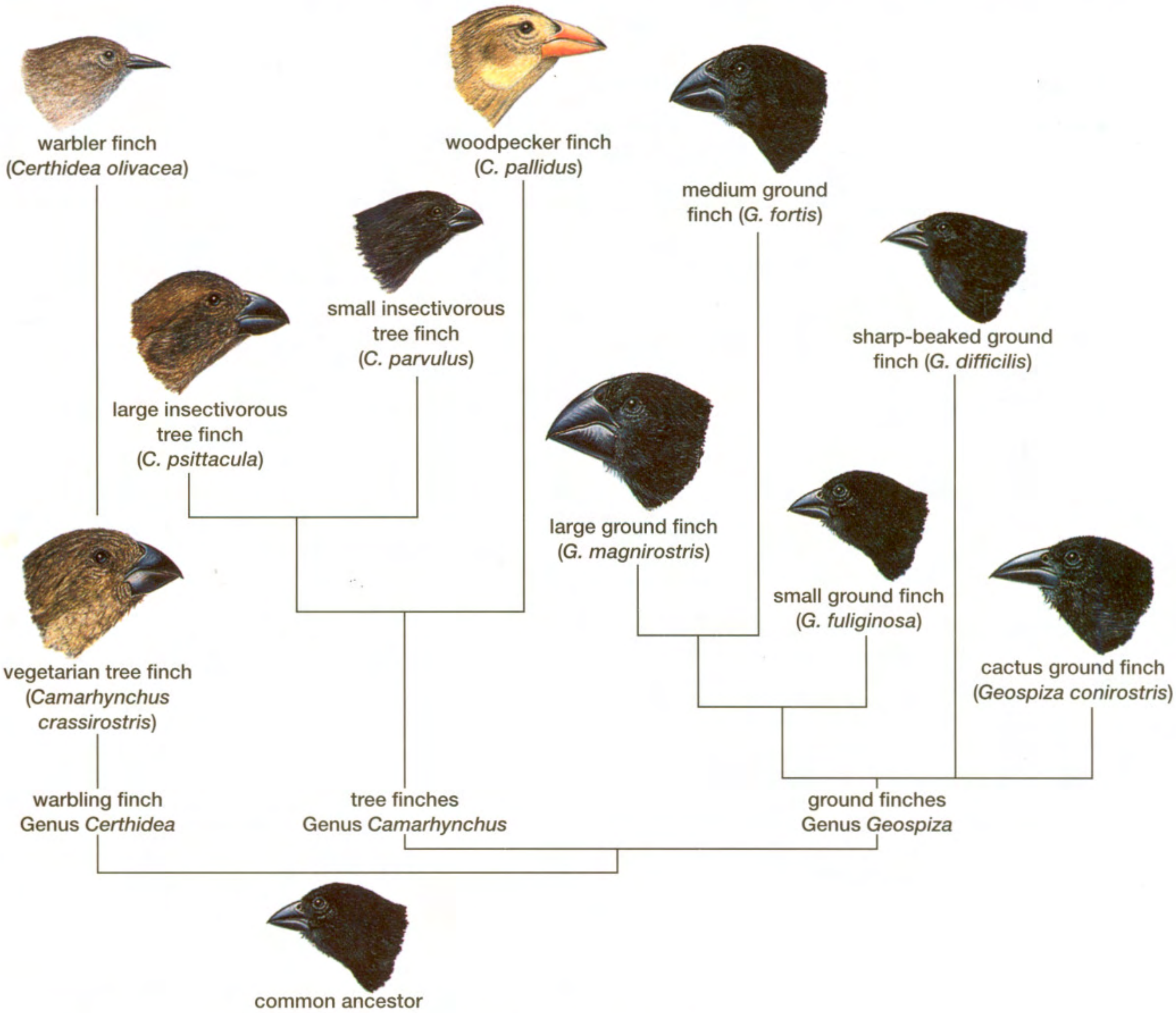


Figure 12.15 A phylogenetic tree for finches from the Galápagos Islands.

and paleontologists have used similar techniques in trying to determine the evolutionary relationships in primates. You looked at some techniques that are used to determine similarities and differences in primates in Investigation 12-A on pages 408–409.

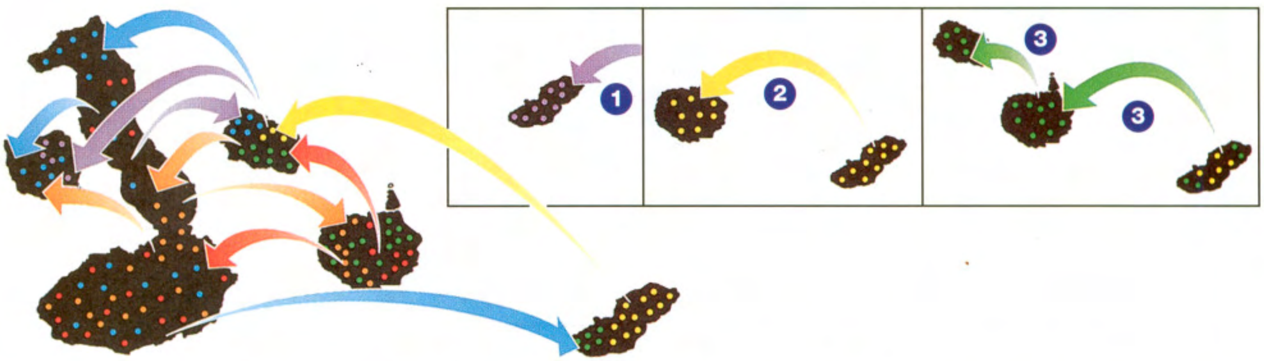
Adaptive Radiation

The diversification of a common ancestral species into a variety of species, all of which are differently adapted, is called **adaptive radiation**. Adaptive radiation is illustrated in Figure 12.16. The speciation of finches throughout the Galápagos Islands is an example of adaptive radiation. As the descendents of the ancestral birds proliferated on the first island they inhabited, individuals began to disperse to other islands. The islands were ecologically different enough to have different selective pressures acting on the individuals, which resulted in the different feeding habits and morphological differences of the finches.

Islands are excellent places to study speciation and biologists sometimes refer to them as living laboratories. Islands give organisms that have dispersed from a parent population the opportunity to change in response to new environmental conditions in relative isolation. The Hawaiian Islands are one of the best places in the world to study evolution and speciation. The archipelago is about 3500 km from the nearest continent, and the islands, which are volcanic, vary in age. The islands were born devoid of living organisms. They were gradually populated by species travelling by ocean currents or by winds. Since each island has different physical characteristics, adaptive radiation has caused an explosion of diversity. Most of the thousands of species of animals and plants that live in the Hawaiian Islands are found nowhere else in the world. Hawaiian honeycreepers (as seen in Figure 11.13 on page 381), for instance, are found only in Hawaii. Approximately 28 species of honeycreepers are believed to have evolved from ancestors that probably crossed the ocean from the American mainland about five million years ago.

Adaptive radiation does not occur solely on islands, however. Two evolutionary biologists at the University of British Columbia studied a particular type of finch, called a red crossbill, which is found throughout southern Canada, to demonstrate speciation (see Figure 12.17 on the next page). There are about 25 species or subspecies of crossbills in North America, Europe, and Asia. The twisted beak of the crossbill allows it to pry open closed conifer cones. Different sized crossbills open different sized cones. Small-beaked crossbills feed primarily on softer larch cones; crossbills with a medium-sized bill feed on harder spruce cones; and heavy-beaked crossbills feed on tightly closed, and very hard, pines cones.

Anna Lindholm and Craig Benkman experimented on seven red crossbills that specialize in eating the cones of western hemlock. (This species lives in coastal forests from Alaska to California.) Lindholm and Benkman "uncrossed" the beaks by trimming them with nail clippers. (This is as painless for the bird as trimming your fingernails is for you.) The birds with clipped bills



1 The ancestral population reached an outer island.

2 The ancestral population adapted to its new home and a new species eventually arose. This species began to spread to other islands in the archipelago.

3 Speciation again occurred as part of this population became adapted to a different habitat and feeding niche.

Figure 12.16 Speciation of the Galápagos finches occurred through adaptive radiation.

were just as effective as those with crossed bills when it came to getting seeds from open cones, but they could no longer open closed cones. As their bills grew back and began to cross again, they became progressively better at opening the tightly closed cones. The experiment demonstrated beautifully how small changes (even those too small to see with the naked eye) can provide a valuable advantage.

WEB LINK

www.mcgrawhill.ca/links/biology12

Paleontologists and evolutionary biologists have contributed to our understanding of the speciation events that led to the evolution of humans, *Homo sapiens*. New discoveries continue to be made as new fossils are unearthed and our understanding of DNA (specifically mitochondrial DNA) advances. To learn more about the contributions from paleontology and biology, go to the web site above, and click on **Web Links**. After exploring the sites, summarize the known evolutionary history of the human lineage in a phylogenetic tree. Note the contributions made by paleontologists and biologists.

The crossed bill did not arise all at once, just as the human eye did not arise at once. The crossed bill changed gradually by selective pressure, one generation after the next, until the birds were quite expert in opening tightly closed cones. The novelty of a crossed bill gave the birds an advantage over others in the same habitat, because it allowed them to eat food no other bird could. The finches with this simple variation were then able to radiate into other habitats, since they had perfected a feeding technique for which they had no competitors.

Figure 12.17 Crossbills use their crossed bill to open tightly closed cones.

Major episodes of adaptive radiation often occur after the evolution of a novel characteristic. For example, the evolution of limbs in vertebrates, and wings in insects, opened up new possibilities for habitat and food supplies. Insect wings resulted in the evolution of hundreds of thousands of variations on the basic insect body plan, making this group the most successful and widespread type of animal on Earth.

Periods of rapid adaptive radiation often occur after **mass extinction** events in Earth's history, too. Extinction is inevitable, and there have been several mass extinctions where life on Earth changed dramatically. For example, the Cretaceous extinction of 65 million years ago marks the boundary between the Mesozoic and Cenozoic eras. During this mass extinction, more than half the existing marine species and many families of terrestrial plants and animals, including the dinosaurs, were exterminated. The climate cooled and sea levels changed. While this event sounded the ultimate death knell for dinosaurs, it was the catalyst for the adaptive radiation of mammals which, up until that time, were probably not much larger than mice.

Divergent and Convergent Evolution

The patterns of speciation and adaptive radiation that were discussed in the preceding pages are examples of **divergent evolution**, a pattern of evolution in which species that were once similar to an ancestral species diverge, or become increasingly distinct. Divergent evolution occurs when populations change as they adapt to different environmental conditions. The populations become less and less alike as they adapt, eventually resulting in two different species.

In contrast, in some instances two completely unrelated species share similar traits. For example, both birds and bees have wings, yet they have different ancestors. In **convergent evolution**, similar traits arise because each species has independently adapted to similar environmental conditions, not because they share a common ancestor. Birds and bats evolved independently and at different times, yet natural selection favoured variations suitable for the same environment — air. But since they do not share a common ancestor, birds and bats evolved quite different wings. Similarly, cacti and a group of plants called euphorbs have both independently evolved thick, water-storing stems and modified leaves in response to their desert habitats.

Coevolution

Nature is full of examples of the **coevolution** of organisms. Some organisms are tightly linked with one another and have evolved gradually together, each responding to the changes in the other. Predators and prey, pollinators and plants, and parasites and hosts all influence each other's evolution. Many insects, for example, have extraordinarily long tongues, which they use to drink the nectar from the extraordinarily long tubes in some flowers.

Plants provide many examples of coevolution. Most of the world's 290 000 species of plants rely on animals to spread their pollen, and there are many wonderful strategies to entice insects (and other animals that feed on nectar) to the plants. Plants pollinated by birds usually have bright red petals; they are generally not attractive to insects, because insects are colour-blind. (But insects can see patterns that humans cannot, because of their ability to see some ultraviolet wavelengths.) As well, bird-pollinated plants are usually scentless, since birds have a poor sense of smell. (Insect-pollinated plants, such as the orchid in Figure 12.18, are often scented to attract their pollinator.) Bird-pollinated plants also have their nectar in long, wide tubes to suit the long, stiff beaks of birds.

One specific example of coevolution between an insect and a plant is that of the monarch butterfly and the milkweed. The milkweed species have a toxin in their leaves, which monarchs eat. This toxin also makes monarch butterflies toxic, so most bird species avoid eating them.

Figure 12.18 Many flowers, including orchids, have coevolved with their pollinators.

The relationships between predator and prey also show examples of coevolution. The constant threat of predators can cause prey species to evolve faster legs, stronger shells, or more effective camouflage. As well, prey species can develop an impressive arsenal of poisons. Newts, spiders, and many snakes use venoms to produce powerful toxins. The rough-skinned newt, an amphibian that lives in the wet forests of the northwest coast of North America, produces a poison so strong it can apparently kill 17 adult humans. Since only a small amount of poison would be needed to kill most of its predators, why has this amphibian evolved such a toxic chemical? The answer lies with the newt's predator — the red-sided garter snake. This snake has evolved a genetic resistance to the newt's poison, so it remains a threat. Evolution has driven both the creation of a strong toxin in rough-skinned newts and the enhanced ability to block the poison in red-sided garter snakes.

Plants have been evolving natural pesticides and defences against insects for hundreds of millions of years. Almost since the earliest time when humans began to farm, we have applied poisons to protect crops from insects. In addition, insects are subject to the natural, plant-produced chemical defences. Just as insects coevolved with plants to develop new ways of feeding in response to the plants' development of new defences, insects are also coevolving with human-applied pesticides. And, thanks to evolution, insects seem to be winning this arms race. New pesticides continue to be produced but there is a great deal of concern about how pesticides affect crops, other insects, soil organisms, and the people who produce and apply the poisons. As previously discussed in Chapter 9 (see section 9.3), new crops that carry the genes from a bacterium (*Bacillus thuringiensis*, or Bt) have been developed. These bacteria live naturally in the soil and attack insects by producing a protein that destroys an insect's gut. These bacteria have been inserted into the genes of several plants, including cotton, corn, and potatoes; these plants can now produce Bt in their own tissues.

If farmers planted only Bt crops, coevolution would continue and eventually a population of insects resistant to the Bt would develop. Instead, farmers are being asked to plant non-Bt crops on at least 20 percent of their land. The theory is that these patches will become havens for the insects that are not resistant to the Bt crops. While these insects *may* mate with Bt-resistant insects, the fact that there is still a healthy population of non-resistant insects in the fields minimizes the chance of the resistant genes being perpetuated in the population. In order for the idea to work, the farmers must co-operate by giving up part of their fields to insects. If this does not occur and fields are planted solely with Bt-resistant crops, the chance of the insects becoming Bt-resistant is high, which means that new kinds of toxins will probably need to be produced and applied in the future.

The constant struggle between parasites and their hosts is another example of coevolution. Parasites include bacteria, protozoa, fungi, algae, plants, and animals. Since parasites consume their hosts to survive, the hosts must develop ways to defend themselves. The resistance of many bacteria to antibiotics is a clear example of coevolution (see Figure 12.19). Bacteria can divide several times an hour, so they are able to alter the genetic make-up of a population with incredible speed. Unlike insects, which become resistant to pesticides and acquire resistant genes only from their parents, bacteria can also acquire DNA from other bacteria. For example, they can incorporate the genes of dead bacteria into their own DNA. As described in Chapter 9, section 9.2, this incorporation is called bacterial transformation. (Note that bacterial transformation, in which non-pathogenic bacteria become pathogenic, is not the same thing as the transformation that occurs when two or more species are formed from one, or when one species is transformed into another.)

Although antibiotics were introduced only in the 1940s, already several strains of bacteria (including *Escherichia coli*, a bacteria that has caused water contamination disasters in Canada) resist most available antibiotics. Pharmaceutical companies are now working on new antibiotics, but there are questions as to how long this new round of drugs will be effective against the incredible rate at which bacteria evolve. When people do not complete the course of antibiotic treatment for bacterial infections, the surviving bacteria (which are more resistant to the medication) proliferate. Over-prescription of antibiotics and their inappropriate use (for example, when antibiotics are taken to fight viral infections) also adds to the problem of rapid bacterial resistance to antibiotics.

There is also concern that the antibiotics fed to livestock may be adding to the problem. For example, since 1994 the use of antibiotics called quinolones has been permitted in chickens to fight an intestinal bacteria called *Campylobacter jejuni*. Since that time, the presence of quinolone-resistant *Campylobacter* cultures in humans has risen from one percent to 17 percent.

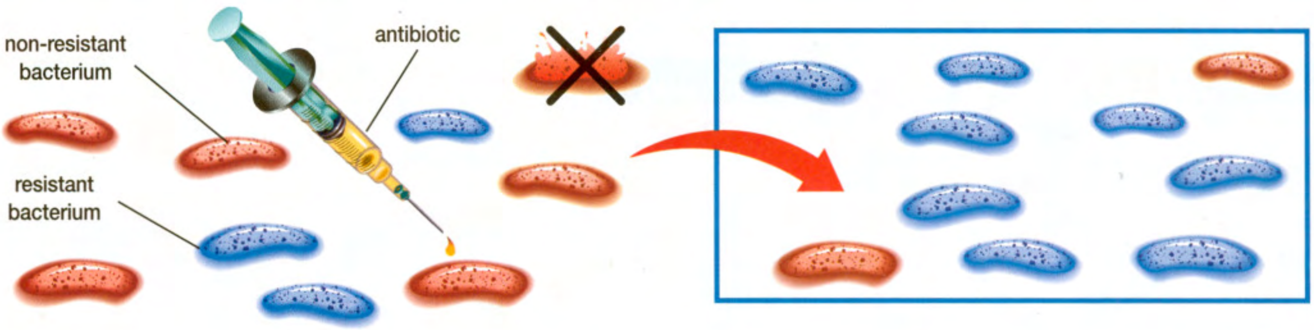
WEB LINK

www.mcgrawhill.ca/links/biology12

The resistance of bacteria to many antibiotics is a pressing concern in health care. Several groups have been formed to educate the public about the dangers of antibiotic resistance. To learn more from these groups, go to the web site above, and click on **Web Links** to find out where to go next.

The Pace of Evolution

How fast does evolutionary change happen? There are currently two hypotheses about the pace of evolution. Both models, which are illustrated in Figure 12.20 on page 414, have looked primarily at the fossil record to explain their ideas. Since Darwin's time, evolutionary biologists have supported the model of **gradualism**, which says that change occurs within a lineage, slowly and steadily, before and after a divergence. According



A The bacteria in a population vary in their ability to resist antibiotics.

B When the population is exposed to an antibiotic, only the resistant bacteria survive.

C The resistant bacteria live and produce more resistant bacteria.

Figure 12.19 Bacteria can quickly become resistant to antibiotics.

to this model, big changes occur by the accumulation of many small changes. The fossil record, however, rarely reveals fossils that show this gradual transition. Instead, paleontologists most often find species appearing suddenly in the fossil record, and then disappearing from the record equally as suddenly.

As well, the rate of evolution seems to vary. Paleontologist George Gaylord Simpson, whose work spanned from the 1920s to the 1980s, pointed out that some groups of animals seem to persist relatively unchanged for millions of years. The African lungfish, for example, has experienced few evolutionary changes over the past 150 million years. Simpson noted that other groups, such as mammalian species, were relatively short-lived. An average life for a mammalian species is about 200 000 years.

The different rates of evolution and fossil record evidence of periods of rapid change (for example, periods of rapid adaptive radiation after mass extinctions) led two biologists — Niles Eldredge of the American Museum of Natural History and Stephen Jay Gould of Harvard University — to develop an alternative model called **punctuated equilibrium**. This model proposes that evolutionary history consists of long periods of stasis, or equilibrium, "punctuated" or interrupted by periods of divergence. According to the model of punctuated equilibrium, most species undergo most of their morphological change when they first diverge from the parent species. After that, they change relatively little, even as they give rise to other species. Given this model, the fossil history should consist primarily of fossils from the long periods of time when little or no change occurred, with only a few fossils from the periods of rapid change.

Polyploidy is one mechanism for sudden speciation, as are mutations in genes that regulate the development of embryos. Supporters of the

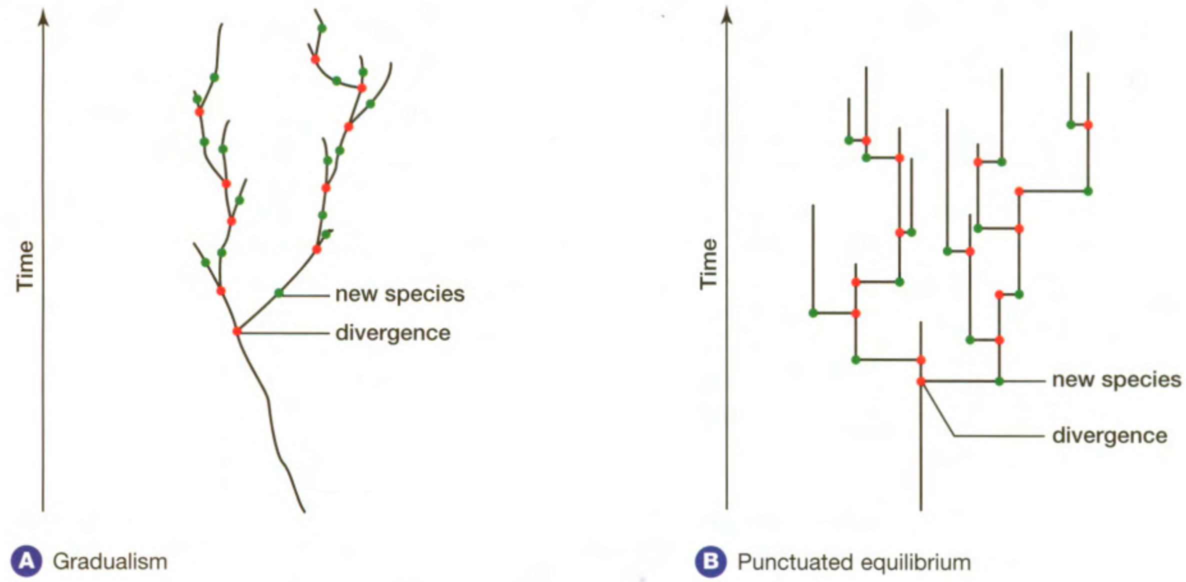


Figure 12.20 Two modes of evolution have been proposed: (A) gradualism and (B) punctuated equilibrium.

THINKING LAB

Partners in Evolution

Background

Plants and their pollinators provide some of the best examples of coevolution. Colours, shapes, scents, and other characteristics of most plants have more than likely evolved in tandem with pollinators; each has shaped the anatomy and/or behaviour of the other over time. For example, the sugar maple is adapted for wind pollination. It has flowers with pistils and stamens but no petals or sepals.

You Try It

1. Choose a plant to investigate. (It is best to choose a species that you can actually see somewhere, such as a garden, park, or flower shop.)
2. Using observation and library and/or Internet resources, learn how this plant is pollinated.
3. Sketch and label a diagram showing the relationship between pollinator and prey.
4. Has this plant coevolved with its pollinator? Explain your answer.

punctuated equilibrium idea note that allopatric speciation can also be very rapid, with genetic drift and natural selection causing dramatic changes in a few thousand, or even a few hundred, years.

Some scientists question the use of the term "sudden" in this context, given that an abrupt episode of speciation may, in fact, take place over 50 000 years or so. If a species survives for five million years, the punctuated equilibrium model says that most of its change would have taken place in the first one percent of its lifetime.

Once a species is created, it may actually remain unchanged if the environment to which it is adapted does not change. (Recall that this is called stabilizing selection.) When stabilizing selection occurs, a population *is* in equilibrium.

The debate surrounding the pace of evolution has stimulated much discussion and research, as all good scientific questions do. More work by both paleontologists and evolutionary biologists will continue to shed light on our understanding of speciation and evolution.

THINKING LAB

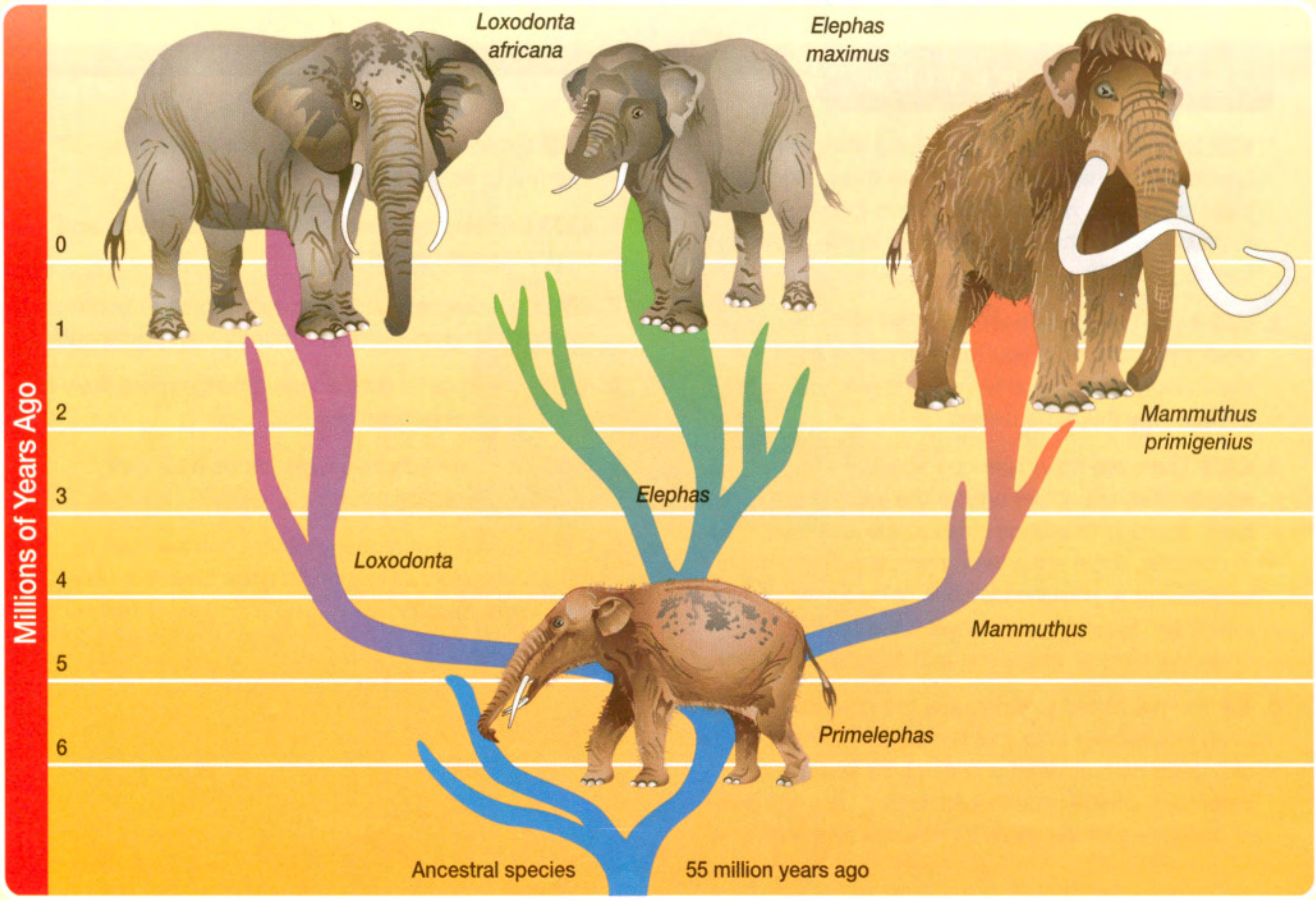
Elephant Evolution

Background

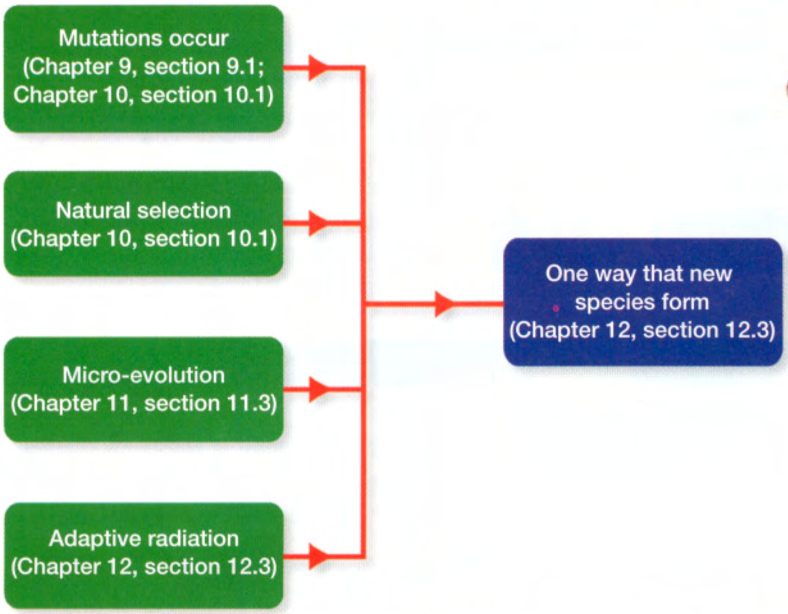
Today only two species of elephants exist — the African elephant and the Asian elephant. The mammoth became extinct only about 5000 years ago. These three elephant species were thought to evolve from an ancestral species, *Primelephas*, that lived about five million years ago.

You Try It

1. Using library and/or Internet resources, investigate the evolutionary history of elephants.
2. Does the evolutionary history of elephants provide better support to the idea of punctuated equilibrium or to the idea of gradualism? Explain your answer.
3. Explain the role of the environment in the pace of speciation.
4. In *Darwin's Ghost: The Origin of Species Updated*, Steve Jones wrote, "When one referee in nature's race is used to a stopwatch and the other to Big Ben, disputes are to be expected. An instant to a paleontologist may appear an infinity to those who study life today." Explain.



CONCEPT ORGANIZER One Way That New Species Are Formed



Individuals from a species of South American finch found their way to the Galápagos Islands, and some survived in their new environment. As these birds foraged on the islands, their ability to survive the environmental conditions of their surroundings resulted in some individuals surviving and reproducing. (Mutations ensure that the genetic make-up of each individual in a species is slightly varied.) Those producing offspring passed on the characteristics that enabled them to survive in the new environment. Through natural selection, the descendants of the ancestral population of finches began to change. Over time, new species arose. As well, as the finches moved to different islands the populations changed further through adaptive radiation.

SECTION REVIEW

1. **MC** Shoppers generally prefer food without any blemishes or markings. To achieve this perfect-looking produce, farmers often have to use pesticides. Explain the role that shoppers play in the evolution of insect "pests."
2. **MC** If you have ever been given an antibiotic, your doctor probably told you to finish taking all of the medication, even if you were starting to feel better. Explain why this is necessary.
3. **K/U** There are no indigenous species (that is, no species that are native only to the area) in the Florida Keys, a group of islands close to the U.S. mainland. In contrast, there are a large number of indigenous species in the Hawaiian Islands. Why do you think this is so? Explain your answer based on your understanding of speciation and adaptive radiation.
4. **I** You are asked to catalogue the species of birds living in a remote area that has never been visited by biologists before. What criteria could you use to determine whether the individual birds you observe or collect are of the same or different species?
5. **K/U** Explain why archipelagos are sometimes referred to as living laboratories.
6. **K/U** Explain the difference between allopatric and sympatric speciation.
7. **C** Use a diagram and point-form notes to contrast the ideas of gradualism and punctuated equilibrium.
8. **K/U** Why is rapid evolutionary change more likely to occur in small populations?
9. **K/U** Describe adaptive radiation as a form of divergent evolution.
10. **MC** Colchicine is a chemical that can be used to induce polyploidy. How might plant breeders use such a chemical?