7.4 The Evidence for Evolution

Charles Darwin returned to England in 1836, ending his voyage on the HMS *Beagle*. Darwin had spent five years making countless observations and gathering thousands of specimens. He was now filled with new ideas and questions about species.

In July of 1837 Darwin began writing his first notebook on what he called the "transmutation of species." It would mark the beginning of Darwin's far-reaching investigations on the evolution of species. In a letter to his friend Sir Joseph Hooker in 1844, Darwin described his approach: "I was so struck . . . that I determined to collect blindly every sort of fact, which could bear [in] any way on what are species. I have read heaps of agricultural and horticultural books, and have never ceased collecting facts." In the years that followed, Darwin stayed true to his words, continuing to consult experts, conduct numerous experiments, and spend long hours contemplating his findings.

This section will present the many forms of evidence that convinced Darwin of the evolution of species and enabled him to formulate his theory.

Biogeography

biogeography the scientific study of the geographic distribution of organisms based on both living species and fossils

Some of the most compelling evidence for evolution comes from **biogeography**, the observed geographic patterns of distribution of species. Darwin's observations of both living and fossilized species during the voyage of the *Beagle* laid the foundation for this new science. Darwin was particularly surprised by the unusual assortment of species he found on the Galapagos Islands. Though not witnessed by Darwin, other remote islands, including New Zealand and Hawaii, held odd collections of very similar species (**Figure 1**).

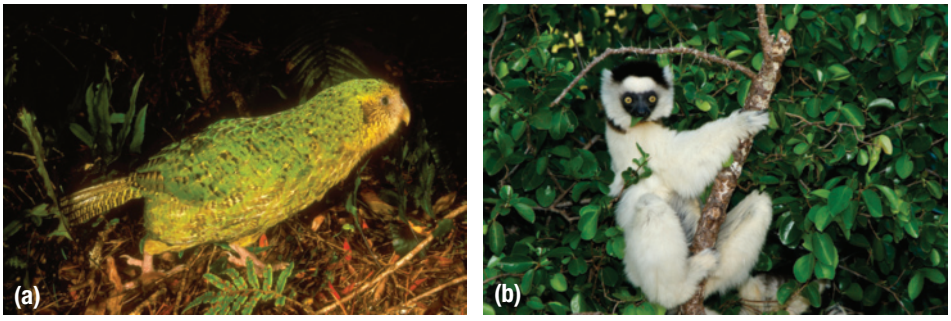

Figure 1 (a) The New Zealand kakapo is a giant nocturnal parrot and the world's largest and only flightless parrot. It is critically endangered. (b) All 99 lemur species, including this sifaka, live only on the island of Madagascar, but there are lemur fossils in India.

Figure 2 Many species, such as this Galapagos tortoise, that live on remote islands show no fear of humans.

Remote islands are also associated with unusual examples of animal behaviour. Many species are unusually fearless (**Figure 2**). Such behaviour surprised Darwin and is immediately apparent to any present-day tourist visiting these remote environments. Birds may land on your head, iguanas will allow themselves to be picked up, and sea lions are content to have you sit next to them on the beach. Darwin believed that this lack of fear of people could also be accounted for by evolution. Perhaps these species, living and evolving in a location with no natural predators, had lost their instinctive fear.

WEB **LINK**

To learn more about the fascinating species that live on the Galapagos and other remote islands,

GO TO NELSON SCIENCE

Darwin's Hypotheses

Darwin realized that the patterns he had observed regarding the distribution of species, both living and extinct, were evidence that species might have evolved. He hypothesized that remote oceanic islands became populated by species that arrived by water or air. After the species became established, many evolved into new species over time.

Darwin considered evolution to be the best explanation for why isolated islands had many species that were found nowhere else, and why these species bore a resemblance to species on the nearest continental land mass. **Table 1** lists some key observations regarding the species inhabiting the Galapagos Islands. Each observation is matched with Darwin's corresponding hypothesis for all remote islands, based on the theory that species evolve.

Table 1 Species on Remote Islands

Observations from the Galapagos Islands	Darwin's hypotheses regarding remote islands
many species of plants, birds, insects, and, in some cases, reptiles	Only these kinds of organisms are able to reach remote islands by crossing large expanses of open ocean.
no native amphibians and very few land mammals	Amphibians and most mammals are unable to cross open ocean and will not be found on remote islands.
many unique species found nowhere else on Earth	Over time, ancestral species have evolved into new geographically isolated species.
unique species most closely resemble species on the nearest continental land mass	Unique species are descendants of ancestral species from the nearest continental land masses and will exhibit some similarities.

Testing Darwin's Hypotheses

Darwin's hypotheses were tentative explanations for his observations. If correct, these hypotheses would apply to similar situations. The strength of any hypothesis is determined by how well it is supported by future tests and observations. In this case, the Hawaiian islands provide an excellent test case of Darwin's hypotheses. Like the Galapagos, the Hawaiian islands were formed from volcanoes that rose directly from the ocean floor (**Figure 3**). They have a wide range of habitats and have never been connected to any other land mass.

Figure 3 The Galapagos and Hawaiian islands were formed by volcanoes that rose from the bottom of the Pacific Ocean.

An examination of the native species of Hawaii supports Darwin's hypotheses. There are no native amphibians or mammals, with the exception of bats and sea lions. There are many species of unique plants, birds, and insects. Unlike the Galapagos, however, there are no native terrestrial reptiles. The only Hawaiian reptiles are marine species: a sea snake and five species of sea turtles. This difference can be accounted for by the fact that the Galapagos lie within 1000 km of the coast of South America, whereas the Hawaiian islands are much more remote—more than 4000 km from the coast of North America. No land reptile could be expected to survive such a long ocean crossing.

In testing a hypothesis, it is important to consider alternative explanations that might account for your findings. What if remote islands lack certain groups of organisms because these species are not able to live in such settings? Perhaps mammals and amphibians, for example, simply cannot survive on large oceanic islands. This alternative hypothesis has been put to the test when non-native species are introduced to islands. Introduced species have not only thrived in these new environments, but have also had a devastating impact on many native species. Rats, dogs, and pigs have wreaked havoc on native bird and tortoise populations. They eat the eggs and young of tortoises and ground-nesting bird species, which exhibit no fear or defensive behaviours. The impacts have been particularly damaging in Hawaii, where an estimated 271 species have become extinct since the arrival of Europeans in 1778. The black mamo (*Drepanis funerea*), for example, a species of honeycreeper, became extinct in about 1907. Of the original 41 species of Hawaiian honeycreeper, 17 are probably extinct, 14 are endangered, and only 3 species have large healthy populations (**Figure 4**). Therefore, mammals and amphibians are indeed able to survive on remote islands once they are introduced, and we cannot accept the alternative hypothesis. To date, Darwin's hypotheses have been supported by the observations of life on all remote islands.

Figure 4 The black mamo was extinct by 1907.

Research This

Investigate Darwin's Research

Skills: Researching, Analyzing, Evaluating

SKILLS HANDBOOK A5.1

Darwin was aware that not all seeds could have been carried to remote islands by the wind or birds. He hypothesized that some seeds must have reached the islands by floating in ocean currents. If his hypothesis was correct, the seeds must have been able to withstand exposure to salt water for days or weeks on end.

1. Find out how Darwin attempted to test his hypothesis. Read Darwin's own writings in which he describes his experimental results.
2. Use the Internet and other sources to find information regarding Darwin's hypothesis. Is there good evidence that some seeds can withstand a long time at sea?

A. Did Darwin's experiments support or refute his hypothesis? T/I A

B. Many historians of science consider Darwin to be extraordinarily thorough and meticulous. Did your research support this characterization? T/I A

C. Based on your research, does it seem reasonable to think that some seeds might have reached remote islands by drifting there on ocean currents? A

D. How else can seeds be naturally transported to remote islands? A

GO TO NELSON SCIENCE

Homologous and Analogous Features

homologous feature a structure with a common evolutionary origin that may serve different functions in modern species (for example, bat wing and human arm)

If all living things are related to each other, as the theory of evolution suggests, then we should expect to find evidence for such relationships by examining their anatomy. Darwin and others were struck by the numerous instances in which similar structures of two organisms could have entirely different functions (**Figure 5**). These **homologous features** puzzled Darwin, who wrote: "What can be more curious than that the hand of a man, formed for grasping, that of a mole for digging, the leg of the horse, the paddle of the porpoise, and the wing of the bat, should all be constructed on the same pattern, and should include the same bones, in the same relative positions?" Imagine an engineer being asked to design a robotic hand, a canoe paddle, and an aircraft wing, and choosing the same internal frame design for each device!

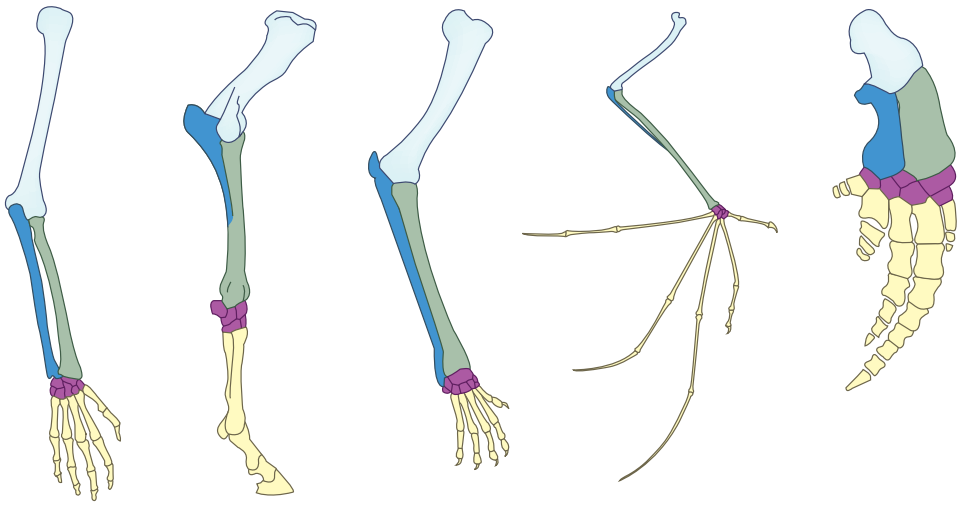

Figure 5 The forelimbs of these organisms are each adapted to carry out very different functions, yet they all possess very similar bone structure.

It struck Darwin as unreasonable to think that finger bones would serve any useful purpose inside the stiff flipper of a whale. He also wondered why almost all mammals would have precisely 28 skull bones and 7 neck bones, regardless of the size of their skull or length of their necks. If species had been created in their present forms, why would the skull of a whale have the same number of bones as the skull of a mouse, and why would the giraffe not be given more neck bones than mammals with the shortest necks? Indeed, why were the bones in all mammals, including bats, whales, horses, and humans, so similar in number and arrangement (**Figure 6,** next page)?

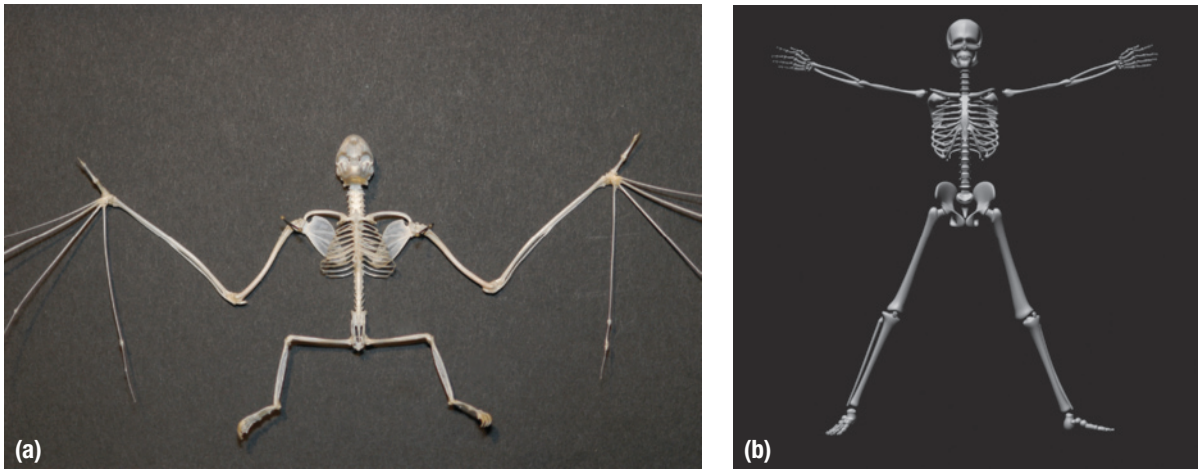

Figure 6 All mammals have an almost identical number and arrangement of bones. (a) This tiny bat skeleton is very similar in many respects to that of (b) a human.

Although Darwin had no understanding of chromosomes and genes, he knew that many traits were inherited from generation to generation. Darwin was also aware that artificial breeding of animals and plants could, over many generations, produce dramatic results. For example, he knew that dog skeletons had changed through the efforts of breeders. Darwin concluded that the homologous features he observed could be explained by evolution. Closely related species had homologous features because they shared a common ancestor. Over time original structures were modified as each species evolved.

Closely related species share homologous developmental processes and patterns as well. In early developmental stages, the embryos of all vertebrates, including humans, chickens, and fish, possess a short bony tail (**Figure 7**). Human embryos also have gill slits even though, by the time we are born, we do not have gills.

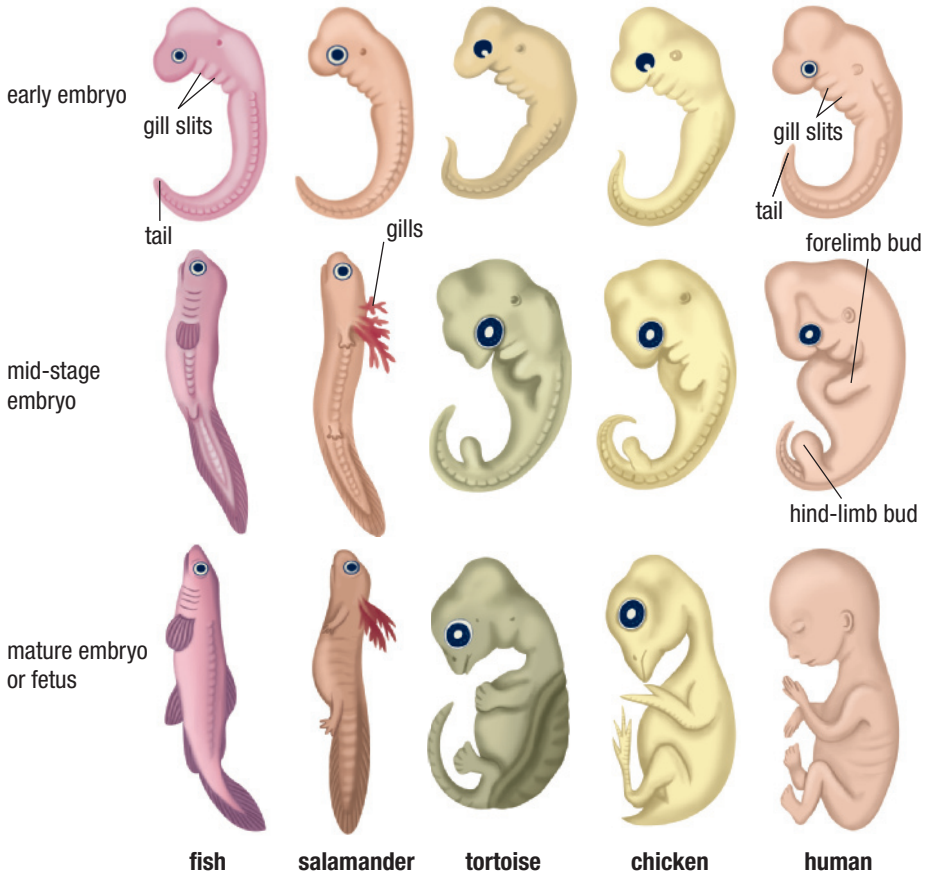

Figure 7 The early embryos of all vertebrates share many homologous features, including tails and gill slits.

analogous feature a structure that performs the same function as another but is not similar in origin or anatomical structure; for example, bird and insect wings

Evolutionary relationships can also account for the observed differences in the structure of **analogous features**—features that perform similar functions. For example, the eyes and wings of flying insects serve the same function as the eyes and wings of flying birds yet are completely different in structure. Insects and birds are only distantly related and have evolved these features quite independently of each other.

Vestigial Features and Anatomical Oddities

vestigial feature a rudimentary and non-functioning, or only marginally functioning, structure that is homologous to a fully functioning structure in closely related species

What would you say if you discovered a fish with eye sockets but no eyes, or a running animal with toes that never touch the ground? These species would be displaying **vestigial features**—features that no longer serve the function they do in similar species. Several species of cave fish in the family Amblyopsidae live in perpetual darkness (**Figure 8**). They have no eyes or tiny vestigial eyes. A number of mammals, including pigs, horses, and dogs, possess vestigial toes that serve no useful purpose (**Figure 9**).

Figure 8 Some species of cave-dwelling fish have vestigial eyes or no longer develop eyes at all.

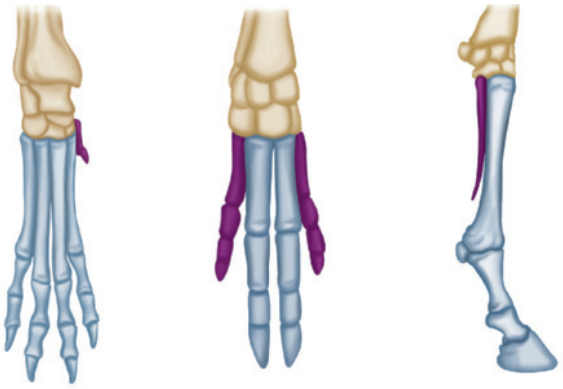

Figure 9 (a) Dogs have a vestigial toe, or "dew claw," on each front limb. The toe serves no useful function. (b) Pigs have two well-developed toes and two vestigial toes that hang behind them. (c) Horses have one greatly enlarged toe. The others are vestigial or missing entirely. Vestigial toes are shown in purple.

There are many striking examples of vestigial features and anatomical oddities. For example, the upland goose and frigate bird have webbed feet but never enter the water. Some large snakes and whales have vestigial hip bones, which are homologous to the hip bones that support the hind limbs of other vertebrates (**Figure 10**).

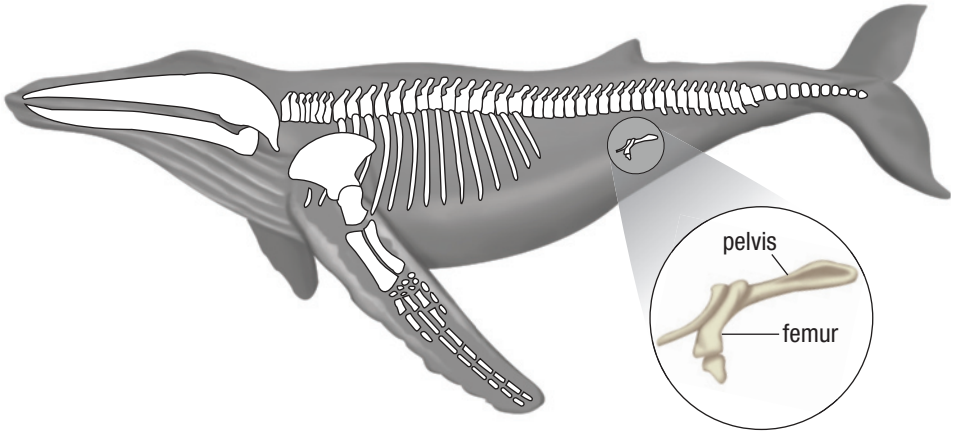

Figure 10 Many species of large whales have vestigial hip bones.

A fascinating example of an anatomical oddity is found in the nervous system of vertebrates. In fish, a particular nerve exits the brain and follows a short and direct pathway to a gill located close to the heart. In all mammals, the same nerve exits the brain, but it follows an indirect path. The nerve passes close to the heart, but then travels back up the neck and enters the larynx, or voice box. In giraffes, the trip is

quite lengthy: the nerve leaves the brain, travels the full length of the neck, down to the heart and back again, before entering the larynx. The distance from a giraffe's brain to its larynx is a few centimetres, but the pathway travelled is more than 4 m!

Darwin recognized that such features were highly suggestive of an evolutionary past. Vestigial features could be explained as evolutionary baggage—features that, in an ancestor, had served a useful purpose, but had become useless or greatly distorted as the species evolved.

Humans also possess numerous vestigial features. You may have experienced goosebumps in a cool breeze or when you were watching a scary movie. Humans, like most mammals, have body hair. Each hair is attached below the surface of the skin to a tiny muscle. Goosebumps are the result of these tiny muscles contracting and lifting up the hair. For mammals with thick hair, this action serves two functions: in response to cold temperatures, it increases the insulation value of the hair, making the animal warmer, and, in response to a threat, it makes the mammal look larger. For a deer on a cold winter day, this is a way of staying warm. For a cat confronted by a large dog, this is a way of looking large and menacing. For humans, raising our hair does nothing to keep us warm and certainly does not make us look any larger.

WEB **LINK**

To learn more about human vestigial features,

GO TO NELSON SCIENCE

Competition within Populations

The anatomical features of different species, biogeography, and the fossil record provided Darwin with evidence that species had changed over time and that species appeared to share a common ancestry. Breeders of domesticated animals and plants repeatedly demonstrated that species could change by selecting individuals with favoured traits to be the parents of each new generation. Darwin wondered if nature, like human breeders, might be able to favour certain individuals in a population over others. He found the answer in October of 1838 while reading a mathematics paper on populations, *Essay on the Principle of Population*, written by the Reverend Thomas Malthus.

In his essay, Malthus showed that all populations were limited in size by their environment—and in particular their food supply. Whatever the conditions, populations could not continue to grow indefinitely. Darwin was struck by the implications this had for individuals within populations. Many species produce large numbers of offspring, but not all survive (**Figure 11**). There is a limit to the size of the population that an environment can support. The result is competition for survival between members of the same species.

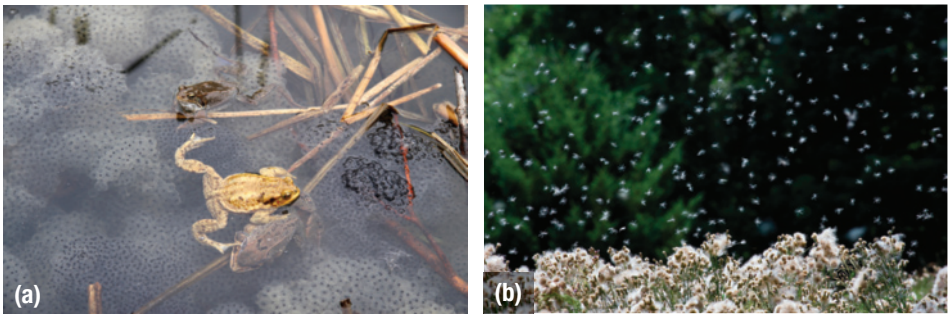

Figure 11 (a) Frogs and toads produce hundreds of eggs, but few will reach maturity. (b) Similarly, many plants produce thousand of seeds.

Competition between individuals of the same species is intense because they are vying for the same resources. Consider a population of 1000 robins that returns to Ontario in the spring. These 1000 robins form breeding pairs that may lay two or three batches of eggs each summer. If they all hatched and survived, the robin population would jump from 1000 in the spring to more than 5000 by the end of the summer. Of these 5000 robins, only about 1000 will return the next spring. Under these conditions, only one out of every five robins survive each year.

Darwin wondered if the environment might be favouring certain individuals in this struggle for survival.

Mini **Investigation**

The Elephant Problem

Skills: Researching, Performing, Analyzing, Evaluating

SKILLS HANDBOOK A2.1

Species that produce large numbers of offspring experience intense competition. Darwin wondered if this applied to even slow-breeding populations, such as elephants. His question is known as "the elephant problem." In this activity you will compare the breeding potential of different species and the population sizes that would result if there was unlimited growth (**Figure 12**).

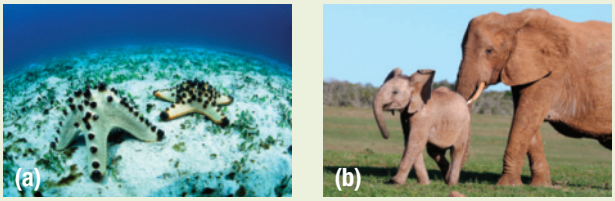

Figure 12 (a) A starfish can produce 2 billion offspring per year whereas (b) a female elephant has one offspring every four or more years.

Table 2 includes sample estimates of changes in population size for two different situations: under natural conditions with competition and under ideal conditions with no competition based on the assumption that all offspring live and reproduce. For example, in the case of elephants, the latter value is based on the assumption that all elephants live to be 90 years old and each female has six offspring in her lifetime.

1. Examine Table 2 and compare the initial population sizes with the estimated final population sizes under natural conditions. Note that under natural conditions populations often remain relatively stable over modest periods of time. Calculate the percentage change in the population size.
2. Compare the initial population sizes with the final population sizes under ideal conditions where there is no competition. Calculate the percentage change in the population size.

A. What might cause a change in population size under natural conditions? T/I

B. How do these data provide evidence that species do not live under ideal conditions? T/I

C. Choose one species from Table 2 and conduct online research to determine some of the resources this species requires to survive (such as types of food, space, and shelter). Which of these resources do you think would cause the greatest degree of competition between individuals of the same species? T/I A

D. Imagine a dog breeder who makes a living selling champion show dogs. Do think the breeder would attempt to produce the maximum number of pups each year? What might be the advantages and disadvantages of doing so? T/I A

Table 2 Population Potential

Species	Initial population	Elapsed time	Final population under natural conditions	Final population under ideal conditions
elephant	100	300 years	84	24 300
robin	100	10 years	120	3 300 000
deer mouse	100	10 years	96	320 000 000
starfish*	2	5 years	2	10 000 000 000

*Female starfish of some species can produce 2 billion eggs per year.

GO TO NELSON SCIENCE

Assessing the Evidence

Darwin spent more than 20 years gathering and examining evidence on the question of whether species had evolved or had been created in their present forms. In the end he was convinced that the preponderance of evidence supported the evolution of species, but he also knew that his ideas would be controversial and conflict with the common religious beliefs of society. Many other scientists, including Linnaeus, Lamarck, and Darwin's own grandfather, believed species were not immutable. What set Darwin apart were the great insights he had gained while amassing the evidence. Darwin believed not only that species *had* evolved, but also that his theory could explain *how* they evolved. In the next section you will learn the circumstances leading to Darwin's publication of *On the Origin of Species* and be introduced to his famous and elegant theory.

UNIT TASK **BOOKMARK**

As you work on your Unit Task consider how evidence of evolutionary change can provide valuable information to scientists.

7.4 Summary

- Biogeography provides compelling evidence that remote islands are populated by species that evolved from species that had travelled from the closest major land mass.
- Patterns in embryonic development provide evidence of the evolutionary relationships between species.
- The structures of numerous anatomical features provide strong evidence that they have evolved from an original, homologous structure.
- Vestigial features are rudimentary structures that once performed important functions in ancestral species.
- All species produce more offspring than can survive to reproduce. This results in competition for resources between members of the same species.

7.4 Questions

1. Which of the following would you expect to find on remote islands? Explain your reasoning. K/U T/I
   (a) a variety of hummingbirds OR a variety of larger seed-eating birds
   (b) large lizards OR large mammals
   (c) some species that are genetically similar OR most species that are genetically very distinct
   (d) species found nowhere else on Earth OR species that are also found on other remote islands
2. The coqui frog, *Eleutherdactylus coqui*, was accidentally introduced to Hawaii, where it has no natural predators, in 1988. The population has risen dramatically, and the frogs now pose a threat to native species, particularly insects and spiders. If these frogs are so successful, why are there no native frog species on these large islands? T/I A
3. The brown tree snake, *Boiga irregularis*, was introduced to the remote Pacific island of Guam sometime shortly after World War II. Use the Internet and other sources to answer the following: T/I A
   (a) What native species have been lost or threatened by this snake?
   (b) How might the loss of these species influence the entire ecosystem on the island?
   (c) How might an understanding of evolution enable scientists to predict which species might be most vulnerable to invasive species?
4. Which of the following pairs represent homologous features and which represent analogous features? Explain your answers. A
   (a) the claw of a lobster and the hand of an ape
   (b) the wing of a bat and the wing of a bird
   (c) the eyes of a fly and the eyes of a hawk
   (d) the tusks of an elephant and the teeth of a mouse
   (e) the webbed feet of an otter and the fins of a fish
5. Explain how the bones within dolphin flippers, arranged in a pattern of five toes, provide evidence of evolutionary change. K/U A
6. Describe the evidence of evolution revealed by the embryonic development of different species. K/U
7. For each of the following vestigial features, state the likely original function of the structure and suggest a reason why it may have become vestigial: K/U A
   (a) the muscles and hairs that cause goosebumps in humans
   (b) short wing "stubs" in some insects such as earwigs
   (c) webbed feet in frigate birds that never enter the water
   (d) rudimentary hip bones in some large snake species
8. Explain how Darwin knew that competition occurs between individuals of the same species. Include a numerical example to illustrate your answer. K/U T/I


GO TO NELSON SCIENCE