

How Populations Evolve

Objectives

Introduction Describe five adaptations that help blue-footed boobies survive.

Evidence of Evolution

- 13.1 Briefly describe the history of evolutionary thought.
- 13.1 Explain how Darwin's voyage on the *Beagle* influenced his thinking.
- 13.1 Describe the ideas and events that resulted in Darwin's 1859 book.
- 13.2 Explain how fossils form, noting examples of each process.
- 13.2 Explain how the fossil record provides some of the strongest evidence of evolution.
- 13.3 Explain how biogeography, comparative anatomy, comparative embryology, and molecular biology document evolution.

Darwin's Theory and the Modern Synthesis

- 13.4 Describe Darwin's assumptions in developing the concept of natural selection.
- 13.4 Explain how artificial selection supports natural selection.
- 13.5 Describe two examples of natural selection that are known to occur. Note three key points about how natural selection works.
- 13.6 Define a population and a species.
- 13.6 Explain the significance of the modern synthesis.
- 13.7 Explain how microevolution occurs.
- 13.8, 13.9 Explain the significance of Hardy-Weinberg equilibrium to natural populations and in public-health science.
- 13.10 Describe the five conditions required for Hardy-Weinberg equilibrium.
- 13.11 Explain how the bottleneck effect, the founder effect, gene flow, and mutation influence microevolution.
- 13.12 Explain how natural selection results from changes in genetic equilibrium.

Variation and Natural Selection

- 13.13 Explain why only some variation is heritable. Explain how genetic variation is measured.
- 13.14 Explain how mutation and sexual recombination produce genetic variation.
- 13.14 Explain why multiple-drug "cocktails" are more likely to be effective against HIV than single-drug treatments.
- 13.15 Explain how genetic variation is maintained in populations.
- 13.16 Explain what is meant by neutral variation.
- 13.17 Explain why genetic bottlenecks threaten the survival of certain species.
- 13.18 Define Darwinian fitness. Explain why "survival of the fittest" can be misleading.
- 13.19 Describe the three general outcomes of natural selection.
- 13.20 Define and compare intrasexual selection and intersexual selection.
- 13.21 List four reasons why natural selection cannot produce perfection.
- 13.22 Explain why antibiotic resistance has evolved.

Key Terms

evolutionary adaptation	artificial selection	gene flow
evolution	population	mutation
fossil	population genetics	polymorphic
descent with modification	modern synthesis	cline
paleontologist	species	heterozygote advantage
fossil record	gene pool	neutral variation
biogeography	microevolution	Darwinian fitness
comparative anatomy	Hardy-Weinberg	stabilizing selection
homologous structure	equilibrium	directional selection
comparative embryology	genetic drift	diversifying selection
molecular biology	bottleneck effect	sexual dimorphism
natural selection	founder effect	

Word Roots

bio- = life; **geo-** the Earth (*biogeography*: the study of the past and present distribution of species)

homo- = like, resembling (*homology*: similarity in characteristics resulting from a shared ancestry)

muta- = change (*mutation*: a change in the DNA of genes that ultimately creates genetic diversity)

paleo- = ancient (*paleontology*: the scientific study of fossils)

poly- = many; **morph-** = form (*polymorphism*: the coexistence of two or more distinct forms of individuals in the same population)

Lecture Outline

Introduction Clown, Fool, or Simply Well-Adapted?

A. *Review: Evolution* is the central theme of biology. **Evolutionary adaptation** is a universal characteristic of living things (see Module 1.6).

NOTE: More than any other idea in biology, evolutionary theory serves to tie the discipline together. T. Dobzhansky: “Nothing in biology makes sense except in the light of evolution.”

B. If you look at any organism critically, you are first struck by the differences from other organisms.

1. Further observation often reveals that an organism’s features show some relationship to where the organism lives and what it does in its environment.
2. The blue-footed booby has enormous webbed feet, a nostril that can close under water, preventing water from entering the lungs, a gland that secrets salt from consumed sea water, and a torpedolike body—all adaptations that make life on the sea feasible (Figure 13.0A and B).

I. Evidence of Evolution

Module 13.1 A sea voyage helped Darwin frame his theory of evolution.

- A. Awareness of each organism's adaptations and how they fit the particular conditions of its environment helps us appreciate the natural world (Figure 13.1A).
- B. Early Greek philosophers held various views. Anaximander (about 2500 years ago) suggested that life arose in water and that simpler forms preceded more complex forms of life. On the other hand, Aristotle, who strongly influenced later thinkers, believed that species were fixed and did not evolve.
- C. This latter view was advanced by the Judeo-Christian tradition that all species were created in a single act of creation about 6000 years ago.
- D. Buffon (mid-1700s) suggested that Earth was much older and raised the possibility that different species arose from common ancestors, although he later argued against this point.

NOTE: Buffon also believed in catastrophism: Following natural disasters, some species die off, while populations of others (already present in lower numbers) increase in numbers to become more dominant than they had been.

- E. Lamarck (early 1800s) was the first to strongly support the idea of evolution, but he believed the mechanism for change was the inheritance of acquired characteristics.
- F. Born in 1809, Darwin joined the crew of the surveying ship *Beagle* as a naturalist for a world-encircling voyage in 1831 (Figure 13.1B).
- G. Comparisons of South American fossils with living species there and fossils elsewhere, and observations of organisms and their distributions on the Galápagos Islands, made particularly strong impressions on him.
- H. Darwin was influenced by Lyell's *Principles of Geology*, which promoted the idea of continual, gradual, consistent geological change.
- I. After his return, Darwin began work on an essay to document his observations and his new theory of evolution.
- J. In the mid-1850s Wallace conceived essentially the same theory, based on his observations in Indonesia. He contacted Darwin, and presentations of both their works were made to the scientific community in 1858.
- K. Darwin's *On the Origin of Species by Means of Natural Selection* was published in 1859 and contains a well-constructed argument for natural selection, backed by considerable evidence. He uses the phrase "descent with modification," which encapsulates the concept of evolution.
- L. Darwin's view of evolution: The history of life is like a tree, with multiple branching from the base of the trunk to the tips of the branches. Species on a given branch are more closely interrelated than related to species on other branches.

Module 13.2 The study of fossils provides strong evidence for evolution.

- A. Hard parts, such as skeletons and shells, remain after other organic matter has decomposed. Such parts fossilize easily (Figure 13.2A).
- B. Petrified fossils form by the slow mineralization of organic materials (Figure 13.2B).
- C. Fossilized molds of organisms form when a covered area decays and fills in with other sediment (Figure 13.2C).
- D. Some fossils, such as those of leaves, retain remnants of organic matter with molecular fragments that can be analyzed (Figure 13.2D).

- E. Organisms trapped in tree resin can be fossilized intact, within the fossilized amber, protected from decomposition by bacteria and fungi (Figure 13.2E).
- F. Other media have preserved organisms. The “Ice Man” found in 1991 was preserved in ice some 5000 years ago (Figure 13.2F).
- G. The **fossil record** is an array of fossils appearing within the layers of sedimentary rocks. Sedimentary rocks form from accumulations of waterborne sediments. Sedimentary deposits occur in strata. Each layer contains fossils of organisms among the deposits, with younger strata on top of older strata (Figure 13.2G).
- H. The fossil record shows an historical sequence of organisms from the oldest known fossils, prokaryotes, dating from \approx 3.5 billion years, through the subsequent appearance of eukaryotes, on through many intermediate steps to modern forms—a sequence that has an overall pattern of change from simple to more complex forms.

NOTE: Such a sequence, whereby links are seen between extinct organisms and species alive today, is predicted by evolutionary theory (Figure 13.2H). One of the best documented series is the evolution of modern horses.

Preview: The fossil record chronicles macroevolution (Module 15.1).

Module 13.3 A mass of evidence validates the evolutionary view of life.

- A. **Biogeography** makes observations about the distribution of different but obviously related life forms around the world and in neighboring geographical regions. Island forms are most similar to forms found on the closest mainland, rather than those found on ecologically similar but more distant islands.
- B. **Comparative anatomy of homologous structures** (Figure 13.3A). For example, all mammals have the same basic limb structure.

Preview: Module 15.11.

- C. **Comparative embryology** shows that different organisms go through similar embryonic stages. For example, evidence that all vertebrates evolved from a common ancestor is that all have an embryonic stage in which gill pouches appear in the throat region.

NOTE: In addition to pharyngeal gill pouches, vertebrates, along with all chordates, also have in common the presence of, at some point in their life cycle, a notochord (a cartilaginous supporting rod), a dorsal hollow nerve cord (spinal cord), and a post-anal tail.

- D. **Molecular biology** demonstrates the universality of the genetic code (Module 10.8), the conservation of amino acid sequences in proteins such as hemoglobin, and the presence of very similar homeotic genes in very different species (Module 11.12).
- E. The picture shown by the fossil record is supported by other observations (biochemical, cellular) of existing life forms (Figure 13.3B).

II. Darwin’s Theory and the Modern Synthesis

Module 13.4 Darwin proposed natural selection as the mechanism of evolution.

Review: Evolution as an explanation for the unity and diversity of life was first discussed in Module 1.6.

- A. Darwin observed that species tend to produce excessive numbers of offspring, that the expression of traits varies among the individuals of a population, and that many of these traits are heritable.
- B. English economist Thomas Malthus’s essay discussed the inevitable human suffering resulting from populations growing faster than supplies of resources.

- C. Darwin had personal knowledge of and interest in **artificial selection** (Figure 13.4A, B) and compared the results of artificial selection to the variation seen among closely related species (Figure 13.4C).
- D. Two important points can be drawn from Darwin's theory of **natural selection**:
 - 1. Ancestral species gave rise to the diverse life forms by transfer of heritable traits to offspring that best promote reproduction. He called this "descent with modification."
 - 2. Over vast amounts of time, the gradual accumulation of changes in the characteristics among the individuals in a population occurs.

Module 13.5 Connection: Natural selection results in evolutionary adaptations.

- A. Two good examples of the effects of the process can be seen in the mantid. In both cases, new populations have resulted, but not new species (Figure 13.5A).
- B. Natural selection is a work in progress and has been documented over 100 times. A frightening case that is frequently repeated is the response of insects to insecticides. Those that have the predisposition for resistance will survive and pass on this trait (a gene) to their offspring (Figure 13.5B).

Preview: The same concept will be discussed with bacteria and the resistance to antibiotic therapy (Module 13.22).

- C. Natural selection is regional and timely. Populations tend to evolve in response to local environmental conditions during one time period. A particular adaptation may be pointless in the context of other locales or times.
- D. Significant evolutionary change can occur in very short periods of time.

Module 13.6 Populations are the units of evolution.

- A. A **population** is a group of individual organisms living in the same place at the same time.
- B. Evolution is measured as the change in frequency of a given characteristic within a population over a succession of generations.
- C. Darwin realized this, but he did not know about the genetic mechanisms.
- D. During the 1920s **population genetics** was combined with Darwinian principles into a comprehensive theory of evolution known as the **modern synthesis**.
- E. Central to this synthesis is the **sexual species** concept. A sexual species is a group of populations whose individuals have the potential to interbreed and produce fertile offspring. A given sexual species has an overall range, with concentrations of individuals in local populations.

NOTE: This is the same as the biological species concept introduced in Chapter 14.

Preview: Since the sexual (biological) species concept concerns actually or potentially interbreeding populations, it is difficult to apply it to the fossil record. Another species concept that is more readily applied to the fossil record is the evolutionary species concept.

- F. Opportunities for breeding among populations of the same species vary, depending on the species and on the extent of isolation of the populations.

Module 13.7 Microevolution is change in a population's gene pool over time.

Review: The basic concepts of Mendelian genetics (Chapter 9).

- A. A population's **gene pool** consists of all the alleles in all the individuals making up the population.

- B. Most gene loci are represented by two or more alleles across a population, and individuals (of most eukaryotes) carrying two alleles can be homozygous or heterozygous for the locus.
- C. During **microevolution**, the relative frequencies of the alleles governing characteristics change. For example, those insects with a gene that confers resistance to an insecticide will outnumber those insects without this particular gene. Thus, the allele frequency for insecticide resistance will be higher in fields sprayed with insecticide than in untreated fields.

Module 13.8 The gene pool of a nonevolving population remains constant over generations.

NOTE: This example is entirely arbitrary and will work with any numbers. Have students verify this fact by trying other examples.

- A. Use the example of a hypothetical population of 500 blue-footed boobies. Nonwebbed feet (*WW* or *Ww*) are dominant over webbed feet (*ww*), and a single gene (alleles *W* and *w*) governs the characteristic: 320 have *WW*, 160 have *Ww*, and 20 have *ww* genotypes.
- B. The Hardy-Weinberg equation shows that allele frequencies are stable in a population not undergoing microevolution: $p^2 + 2pq + q^2 = 1$. That is, the population is made up of: homozygous dominant genotypes (p^2) + heterozygous genotypes ($2pq$) + homozygous recessive genotypes (q^2). Also note that $p = 1 - q$.
NOTE: If you have the patience it may be worth the effort of taking your students through the derivation of the Hardy-Weinberg equation. Using the example given here: There are only two alleles of this particular gene, thus their frequencies must sum to 1 ($p + q = 1$). The probability of *WW* is $p \times p = p^2$; the probability of *ww* is $q \times q = q^2$; there are two ways of being heterozygous, *Ww* and *wW*; thus the frequency of the heterozygote is $2pq$. Continuing, many of your students will be familiar with the FOIL method from their math classes; have them apply it to the following: $p + q = 1$; since $1 \times 1 = 1$ ($p + q$) ($p + q$) = 1. FOILING this gives us $p^2 + 2pq + q^2 = 1$.
- C. The frequencies of *WW*, *Ww*, and *ww* in the first generation are 0.64, 0.32, and 0.04. Since blue-footed boobies are diploid, there are 1000 alleles in the population, and their frequencies are $p = 0.80$ *W* and $q = 0.20$ *w* (Figure 13.8B).
- D. If random matings occur between various members of this population, then the laws of probability will predict the genetic makeup of the next generation (see Module 9.7).
- E. On average, the next generation will have $p \times p$ *WW* individuals ($= 0.64$), $(p \times q) + (q \times p)$ *Ww* individuals ($2pq = 0.32$, since there are two ways to get pq in a zygote, depending on whether the *q* is in the sperm or in the egg), and $q \times q$ *ww* individuals ($= 0.04$) (Figure 13.8C). The allele frequencies remain the same.

Module 13.9 Connection: The Hardy-Weinberg equation is useful in public health science.

- A. Estimating frequencies of harmful alleles among the population at large helps public health scientists assess and prioritize their efforts.
- B. For example, if PKU occurs in one out of 10,000 babies ($q^2 = 0.0001$), then $q = 0.01$, $p = 0.99$, and $2pq$ (the frequency of carrier heterozygotes) = 0.0198.

NOTE: This exercise can be used with any of the frequencies of genes from Table 9.9.

Module 13.10 Five conditions are required for **Hardy-Weinberg equilibrium**.

NOTE: Hardy-Weinberg equilibrium rarely exists in natural populations (in this sense it can be viewed as a control, Module 1.3), but understanding the assumptions behind it gives us a basis for understanding how populations evolve.

- A. The population is very large.
- B. The population is isolated (no migration of individuals, or gametes, into or out of the population).
NOTE: No gene flow (Module 13.11).
- C. Mutations do not alter the gene pool.
- D. Mating is random.
- E. All individuals are equal in reproductive success (no natural selection).
NOTE: No fitness differences (Modules 13.11, 13.18)

Module 13.11 There are several potential causes of microevolution.

NOTE: Approach this by asking your students to identify situations that will violate the conditions listed in Module 13.10.

- A. **Genetic drift** is a change in a gene pool of a small population due to chance. The effect of a loss of individuals from a population is much greater when there are fewer individuals. The **bottleneck effect** is genetic drift resulting from a disaster that reduces population size (such as the example of the elephant seals; Figure 13.11A, B). The **founder effect** is genetic drift resulting from colonization of a new area by a small number (even one) of individuals (likely important in the evolution of animals and plants on the Galápagos Islands). Another good example of the founder effect is the high rate of retinitis pigmentosa among the residents of Tristan da Cunha (Figure 13.11C).
NOTE: Genetic drift is evolution by sampling error.
- B. **Gene flow** is a gain or loss of alleles from a population due to immigration or emigration of individuals or gametes.
- C. **Mutations** are rare events, but they do occur constantly (as often as one per gene locus per 10^5 gametes). Mutation provides the raw material on which other mechanisms of microevolution work. Mutation is rarely, if ever, directly responsible for evolutionary change.
- D. Nonrandom mating is more often the case, particularly among animals, where choice of mates is often an important part of behavior but does not change allele frequency and therefore does not affect microevolution.
- E. Differential success in reproduction is probably always the case for natural populations. The resulting natural selection is the factor that is likely to result in adaptive changes to a gene pool.
NOTE: Differential reproductive success is measured in terms of fitness differences (Module 13.18).

Module 13.12 Adaptive change results when natural selection upsets genetic equilibrium.

- A. The amount and kind of genetic variation in the population limit the degree of adaptation that can occur.

III. Variation and Natural Selection**Module 13.13** Variation is extensive in most populations.

- A. Variation in a single characteristic can be caused by the effect of one or more genes or from the action of the environment inducing phenotypic change.
- B. A population is **polymorphic** for a characteristic if two or more morphs (contrasting forms) are noticeably present; these may be visible or biochemical characteristics

(Figure 13.13). Much of this variation can be attributed to polygenic inheritance.
Review: Polygenic inheritance is discussed in Module 9.16.

- C. Most populations exhibit geographic variation in the distribution of characteristics. This variation may show stratification or be **clinal**, varying smoothly across the population.
- D. Genetic variation can be measured in two ways: first, by determining the average percent of gene loci that are heterozygous (gene diversity); second, by determining the nucleotide diversity of DNA sequences.

Module 13.14 Connection: Mutation and sexual recombination generate variation.

- A. *Review:* Mutation (Module 10.16) and meiosis (especially Modules 8.16, 8.17, and 8.18).
NOTE: Mutation is the ultimate source of all variation.
- B. Mutations normally are harmful, but they may improve an organism's adaptation to an environment that is changing. Organisms with very short generation spans, like bacteria, can evolve rapidly by mutation alone.
- C. Sexual recombination shuffles the mixture of alleles in diploid organisms. Independent assortment, crossing over, and random fertilization of sperm and egg all play a role. Organisms that reproduce sexually tend to have longer life spans, and sexual recombination is necessary to increase the variation stemming from single mutations (Figure 13.14).

Module 13.15 Overview: How natural selection affects variation.

- A. An ancestral population is varied, with individuals having characteristics suited for many types of environments.
- B. Over successive generations, those individuals with the characteristics best suited for the environment leave more offspring. These characteristics increase in the subsequent generations.
- C. Those individuals with characteristics not suited for the environment leave fewer offspring. These characteristics decrease in subsequent generations.
- D. The effects of recessive alleles are not often displayed in diploid organisms. Recessive alleles may be "hidden" from natural selection when they are found in combination with a dominant allele. Thus, variation is retained in a population subject to selection.
NOTE: Since such variation is hidden it takes many generations to eliminate (if they are eliminated at all) disadvantageous recessive alleles from a population.
Review: Cystic fibrosis is only expressed in individuals who are homozygous recessive for this disorder (Module 9.9).
- E. **Heterozygote advantage** is a situation in which the heterozygote is favored over either homozygote. As a result, variation is maintained in the population. An example of this is the sickle-cell allele where one homozygote is susceptible to malaria, the other homozygote suffers from sickle-cell disease, and the heterozygote is resistant to malaria and normally does not suffer from sickle-cell disease (Module 9.14).
- F. A second mechanism that promotes balanced polymorphism is frequency-dependent selection. For example, if too many of one type (or morph) of organism is present in a population, that type will be selected against, reducing that type's total numbers.

Module 13.16 Not all genetic variation may be subject to natural selection.

- A. Some characteristics showing **neutral variation** (such as human fingerprints) apparently provide no selective advantage (Figure 13.16).

- B. The frequency of these characteristics may change as a result of genetic drift, but not by natural selection.
- C. It is impossible to demonstrate that an allele brings no benefit to an organism, and it may be that some supposedly neutral variations provide benefits in some environments.

Module 13.17 Connection: Endangered species often have reduced variation.

- A. This is becoming more and more of a problem as human activity (habitat destruction, the introduction of exotic [nonnative] species, unregulated hunting) endangers wild populations, particularly those that are small to begin with.

NOTE: The consequences of such human activity are discussed in Chapter 38.

- B. There is about 0.04% heterozygosity in the gene loci of the South African population of the cheetah, and 1.4% heterozygosity in the East African population. These animals suffered bottlenecks due to disease, hunting, and drought.

NOTE: This is an extremely high degree of genetic uniformity—higher than some strains of highly inbred laboratory mice.

- C. The high degree of heterozygosity exhibited by cheetahs, coupled with loss of habitat, leaves the cheetah's future in the wild open to question.

NOTE: Ask your students if cheetahs should be preserved by human intervention. Sooner or later species go extinct; perhaps it is the preservation, not the extinction, of the cheetah that will be due to human interference.

Module 13.18 The perpetuation of genes defines evolutionary fitness.

- A. Emphasize that it is the survival of genes and the phenotypic traits expressed by the genes, not individual organisms, that are important. It is the genes that survive through the passage of time, not the individual organism(s), that are important.
- B. **Darwinian fitness** is defined as the relative contribution that an individual makes to the gene pool of the next generation.

Module 13.19 There are three general outcomes of natural selection (Figure 13.19).

- A. **Stabilizing selection** tends to narrow the range in population variability toward some intermediate form. This occurs in relatively stable environments.

Preview: An example of stabilizing selection is the birth weight of human babies, which tends to be in the 6.5–9-pound range (Module 27.17).

- B. **Directional selection** tends to move the modal (most common) form toward one of the extremes. This is most common during times of environmental change, or when organisms find themselves in new habitats.

Preview: A good example of the effects of directional selection on life history patterns can be found in the discussion of guppies subject to different selective pressures (Module 35.7).

- C. **Diversifying selection** occurs when environmental conditions are varied in a way that favors both extremes over the intermediate form.

Module 13.20 Sexual selection may produce sexual dimorphism.

- A. **Sexual dimorphism** is illustrated by two examples of secondary sexual characteristics.
- B. Competition between males for the privilege to mate with a female may depend on the strength of the male and his superior ability compared to other males (Figure 13.20A).

- C. Other characteristics such as plumage in birds may actually be detrimental to the survival of the male due to increased risk of predators. The reward of mate selection due to a larger plumage than other males, however, may outweigh the potential risk factors (Figure 13.20B).

Module 13.21 Natural selection cannot fashion perfect organisms.

- A. There are four reasons that account for imperfections in organisms in spite of natural selection:
 - 1. Organisms are locked into historical constraints; nature doesn't start from scratch each time there is a need for change.
 - 2. Adaptations are often compromises; some adaptations to change provide an advantage along with a disadvantage.
 - 3. Not all evolution is adaptive; nature's ways are not always in the best interest of the organism in question.
 - 4. Selection can only edit existing variations; if an adaptation to change is needed and none is available in a population, that population may become extinct.
- B. Natural selection operates on a "better than" basis and it would be unreasonable to expect perfection from a process with such limitations.

Module 13.22 Connection: The evolution of antibiotic resistance in bacteria is a serious public health concern.

- A. Antibiotics were first developed in the 1930s and became standard medical practice for the prevention of infectious diseases during WWII.
- B. Forces of evolution (natural selection) have accelerated the development of antibiotic-resistant strains of bacteria.
Review: Antibiotic resistance is carried on plasmids that are easily transferred between bacterial cells (Module 12.2).
- C. Overuse and misuse of antibiotics has contributed to the proliferation of antibiotic-resistant strains of bacteria.
- D. Multidrug-resistant strains of the organism that causes tuberculosis (*Mycobacterium tuberculosis*) have appeared at alarming rates in the United States and are ravaging other parts of the world (Figure 13.22).

Class Activities

1. As pointed out in Module 13.9, the Hardy-Weinberg equation plays a role in public health science. This role can be demonstrated by having students, working in groups, choose a health issue that has a genetic basis (e.g., PKU, cystic fibrosis, sickle-cell disease, Tay-Sachs, etc.) and see how it applies to public health planning in the community in which they live. The current and projected population size of the community must be considered when completing this exercise.
2. Point out that one of the major health care crises humans are facing is the development of antibiotic-resistant bacteria. Ask your students how many of them, when given prescription antibiotics, finish the entire prescription. There will, almost inevitably, be at least one student who does not. Point out how this contributes to the increase in the numbers of antibiotic-resistant strains of bacteria. Further, as discussed in Chapter 12, bacteria can exchange plasmids; thus, bacteria never exposed to a particular antibiotic can be resistant to that antibiotic as a result of plasmid exchange.

Transparency Acetates

Figure 13.1B The voyage of the *Beagle* (1831–1836). The insets show a young Charles Darwin and his ship.

Figure 13.2H *Basilosaurus*, an extinct whale whose hind legs link living whales with their land-dwelling ancestors

Figure 13.3A Homologous structures: vertebrate forelimbs

Figure 13.3B Evolutionary relationships between humans and five other vertebrates, based on hemoglobin comparisons

Figure 13.4B Five breeds of dogs (all members of the same species), the results of hundreds to thousands of years of artificial selection

Figure 13.4C Five different species of canines, the results of thousands to millions of years of natural selection

Figure 13.5B Evolution of insecticide resistance in insect populations

Figure 13.8A Imaginary blue-footed boobies, with and without foot webbing

Figure 13.8B Gene pool of original population of boobies

Figure 13.8C Gene pool of next generation of boobies

Figure 13.11A The bottleneck effect

Figure 13.14 Shuffling alleles by sexual recombination

Figure 13.19 Three possible effects of natural selection on a phenotypic character (Layer 1)

Figure 13.19 Three possible effects of natural selection on a phenotypic character (Layer 2)

Figure 13.19 Three possible effects of natural selection on a phenotypic character (Layer 3)

Media

See the beginning of this book for a complete description of all media available for instructors and students. Animations and videos are available in the Campbell Image Presentation Library. Media Activities and Thinking as a Scientist investigations are available on the student CD-ROM and web site.

Animations and Videos

	File Name
Dome-Backed Tortoise Video	13-01A-TortoiseVideo-B.mov
Dome-Backed Tortoise Video	13-01A-TortoiseVideo-S.mov
Galápagos Islands Overview Video	13-01B-GalapagosVideo-B.mov
Galápagos Islands Overview Video	13-01B-GalapagosVideo-S.mov
Marine Iguana Video	13-01B-MarineIguanaVideo-B.mov
Marine Iguana Video	13-01B-MarineIguanaVideo-S.mov
Galápagos Sea Lion Video	13-01B-SeaLionVideo-B.mov
Galápagos Sea Lion Video	13-01B-SeaLionVideo-S.mov
Grand Canyon Video	13-02G-GrandCanyonVideo-B.mov
Grand Canyon Video	13-02G-GrandCanyonVideo-S.mov

Activities and Thinking as a Scientist	Module Number
Web/CD Activity 13A: <i>Darwin and the Galápagos Islands</i>	13.1
Web/CD Activity 13B: <i>The Voyage of the Beagle: Darwin's Trip Around the World</i>	13.1
Web/CD Activity 13C: <i>Reconstructing Forelimbs</i>	13.3
Web/CD Thinking as a Scientist: <i>How Do Environmental Changes Affect a Population?</i>	13.4
Biology Labs On-Line: <i>EvolutionLab</i>	13.5
Web/CD Thinking as a Scientist: <i>How Can Frequency of Alleles Be Calculated?</i>	13.8
Web/CD Activity 13D: <i>Causes of Microevolution</i>	13.11
Biology Labs On-Line: <i>PopulationGeneticsLab</i>	13.11
Web/CD Activity 13E: <i>Genetic Variation from Sexual Recombination</i>	13.14
Web/CD Thinking as a Scientist: <i>Connection: What Are the Patterns of Antibiotic Resistance?</i>	13.22