CHAPTER 14

The Origin of Species

Objectives

Introduction Explain how the new underground species of mosquito evolved and how it is different from the above-ground species.

Concepts of Species

14.1 Compare the definitions and usefulness of the different species concepts.
14.2 Describe five types of prezygotic barriers and three types of postzygotic barriers that prevent populations belonging to closely related species from interbreeding.

Mechanisms of Speciation

14.3 Explain how geologic processes can fragment populations and lead to speciation.
14.4 Define adaptive radiation and explain why the Galápagos finches are a good example.
14.5 Explain how sympatric speciation can occur and how it typically happens in plants.
14.6 Explain why polyploidy is important to modern agriculture.
14.6 Explain how modern wheat evolved.
14.7 Explain how reproductive barriers might evolve in isolated populations of animals. Refer to the experiments on laboratory-raised fruit flies.
14.8 Compare the gradualist model and the punctuated equilibrium model of evolution. Explain which model best explains the fossil record.
14.9 Describe the work and discoveries of Peter and Rosemary Grant working with Darwin's finches.

Key Terms

speciation
taxonomy
biological species concept
morphological species concept
genealogical species concept
ecological species concept
reproductive barrier
temporal isolation
habitat isolation
behavioral isolation
mechanical isolation
gametic isolation
hybrid inviability
hybrid sterility
hybrid breakdown
allopatric speciation
adaptive radiation
sympatric speciation
polyploid cell
gradualist model
punctuated equilibrium

Word Roots

allo- = other; **-metron** = measure (*allometric growth:* the variation in the relative rates of growth of various parts of the body, which helps shape the organism)

sym- = together; **-patri** = father (*sympatric speciation:* a mode of speciation occurring as a result of a radical change in the genome that produces a reproductively isolated subpopulation in the midst of its parent population)

Lecture Outline

Introduction *Evolution in the London Underground*

A. Microevolutionary changes, as discussed in Chapter 13, show us how populations change over time. When do we know that distinctly new species have evolved?

B. Critical to determining the limits of a species is understanding if two populations are truly reproductively isolated. For example, two populations of mosquitoes exist in London with very little overlap in their respective habitats.

1. The mosquitoes that live above ground hibernate during the winter and breed during the warm months of spring and summer.
2. The mosquitoes that live in the London Underground breed all year round.
3. When the two types of mosquitoes were brought together to breed, no offspring were produced. Thus, the mosquitoes are truly different species.
   Preview: This is an example of **speciation** by temporal isolation (Module 14.3).

I. Concepts of Species

Module 14.1 What is a species?

A. **Taxonomy** is the science of naming and classifying organisms. These names are in the form of binomials, the forms first used by Linnaeus in the 1700s. The binomial for the human species is *Homo sapiens.*

B. A biological species is defined as a population or group of populations whose members have the potential to interbreed and produce fertile offspring.
   Review: This is the same as the sexual species concept introduced in Module 13.6.

C. Two different species can appear to be almost identical (for example, the mosquitoes in the opening essay or the western and eastern meadowlarks in Figure 14.1A).

D. A single species can exhibit considerable diversity of form (for example, humans, Figure 14.1B). But what defines a species is the ability to produce fertile offspring. This is called the **biological species concept.**

E. The mosquitoes in the opening essay could not produce any offspring, thus they are different species. Humans look very different, which is determined by our heritage. However, humans are one species because we can produce fertile offspring irrespective of our heritage.

F. An application of the biological species concept is with ring species, which is "a species whose distribution forms a ring as it extends its range around a geographic barrier" (Figure 14.1C). This is a useful method when looking for evolution in progress.

G. The biological species concept cannot be applied to asexually reproducing organisms, nor can it be applied to the fossil record. In these cases similarity of appearance, biochemical features, and the fossil record are used to distinguish among species.

H. Several other species concepts are presented in this module.

1. **Morphological species concept:** Species are classified based on phenotypic traits.
2. **Genealogical species concept:** Species are catalogued based on their evolutionary tree and molecular evidence from DNA and RNA sequence data.
3. **Ecological species concept:** Species are defined based upon their ecological niche.

Module 14.2 Reproductive barriers keep species separate.

A. Prezygotic barriers prevent mating or fertilization (Table 14.2).

1. Differential timing of mating **(temporal isolation),** such as the mosquito example *(Opening Essay),* or as is the case with many plants that reproduce at different times.
2. Reproductive habitat differences **(habitat isolation),** such as the differences between two related species of toad.
3. **Behavioral isolation** may involve differences in display (examples are the fireflies discussed in the opening essay of Chapter 5 or the courtship ritual of the blue-footed boobies [Figure 14.2A]) or pheromones.
4. **Mechanical isolation** concerns structural differences that prevent copulation or the transfer of gametes (e.g., the unique structures of the copulatory organs of many insect species) (Figure 14.2B).
5. **Gametic isolation** occurs when gametes fail to unite, such as different species of sea urchins all releasing their gametes into the oceans with only specific gametic pairings occurring.

B. Postzygotic barriers prevent the development of fertile adults.

1. **Hybrid inviability:** The hybrids do not live, as for example when two different species of frog mate but the hybrid does not survive.
2. **Hybrid sterility:** The hybrids are not fertile, such as when a female horse and a male donkey mate to produce a sterile mule (Figure 14.2C).
3. **Hybrid breakdown:** There is progressive weakening of successive generations of interbreeding hybrids. The first generation of hybrids is fertile, but with subsequent generations hybrid fitness declines.

II. Mechanisms of Speciation

Module 14.3 Geographic isolation can lead to speciation.

A. **Allopatric speciation** involves changes in allele frequencies in two or more geographically isolated populations stemming from one initial population, and is most likely in a small isolated population.

B. Changes occur by microevolutionary processes (mutation, genetic drift, and natural selection).

C. Many factors can produce geographical isolation: mountain formation, deep canyons, the removal of land bridges between continents, or continental drift (Figure 14.3).

D. The effectiveness of barriers depends on how effective dispersal is in the organisms that might speciate and on the size of the population. Small populations are more likely to develop into a new species than are large populations. Large mammals may find it easy to cross mountain ranges, while a wide river may stop small mammals.

E. Geographical isolation does not necessarily lead to speciation. Speciation occurs only after barriers to reproduction are established.

Module 14.4 Islands are living laboratories of speciation.

A. *Review:* The case of the increased incidence of hereditary deafness on the island of Martha's Vineyard shows how allele frequencies can change over relatively short periods of time on an island (Module 9.8).

B. Such islands must be close enough together or to the mainland to allow for occasional dispersion but far enough apart to provide isolation most of the time.

C. Darwin's finches (14 closely related species, distinguished by morphology and habitat) of the Galápagos Island chain are excellent examples of the results of island speciation (Figure 14.4A, B).

D. Evidence from further study suggests that the progression of speciation of four of the species occurred as indicated in Figure 14.4C.

E. A contrasting situation occurs on a more isolated island (Cocos), which has just a single, unique species of finch.

F. The emergence of numerous species from a common ancestor in one diverse environment (such as the Galápagos) is known as **adaptive radiation.**

Module 14.5 New species can also arise within the same geographic area as the parent species.

A. Such **sympatric speciation** seems to be rare among animal species, but has played an important role in plant evolution.

B. The most common type of sympatric speciation occurs when an accident during cell division (cells dividing by mitosis rather than by meiosis) results in an extra set of chromosomes **(polyploidy).**

C. Tetraploid plants can form by self-fertilization of diploid gametes in a flower where meiosis has not reduced the chromosome set (Figure 14.5A).

D. The plant that grows from the tetraploid zygote can reproduce by self- fertilization but cannot produce fertile offspring by mating with its diploid ancestors because these offspring would be triploid.

E. Sympatric speciation by polyploidy was first discovered in evening primroses by de Vries in the early 1900s (Figure 14.5B).

F. Most polyploid species are the result of the hybridization of two species with the resulting offspring being sterile. However the polyploid hybrid may reproduce asexually. Or an error in mitosis or meiosis could produce viable gametes, resulting in a new species.

Module 14.6 Connection: Polyploid plants clothe and feed us.

A. Scientists estimate that 25–50% of all plants are polyploid. Most commercially grown food and fiber plants are polyploid hybrids: oats, potatoes, bananas, peanuts, barley, plums, apples, sugarcane, coffee, wheat, and cotton.
NOTE: It has been natural for humans to select, for practical purposes, the better strains (from a human perspective) from among the offspring of chance matings.

B. The genetic diversity of polyploid hybrids is often advantageous.

C. The recent evolutionary history of bread wheat (*Triticum aestivum,* Figure 14.6A) is believed to have occurred by a series of steps involving hybridization, a failure of meiosis, an additional hybridization, and nondisjunction (Figure 14.6B).

D. Plant geneticists attempt to produce plant hybrids with special characteristics by exposing them to chemicals that induce errors in mitosis and meiosis.

Module 14.7 Reproductive barriers may evolve as populations diverge.

A. Reproductive barriers may result when populations are isolated and diverge due to environmental adaptations.

B. Diana Dodd tested this hypothesis using two populations of fruit flies (Figure 14.7A).

C. One population was fed maltose and the other was fed starch. After several generations, the fruit flies were allowed to mingle and mate. Preferences were observed for mates raised on the same food. Thus, reproductive barriers were in the process of developing between these two populations of fruit flies.

D. Evolutionary biologists have identified species that have developed reproductive barriers as a result of geographic isolation. The mosquitoes of London and the California salamanders are good examples. The unique species of pupfish in each isolated spring in Death Valley are thought to have evolved over a short time period as a result of geographic isolation (Figure 14.7B).

Module 14.8 The tempo of speciation can appear steady or jumpy.

A. In the **gradualist model,** populations isolated from the ancestral stock change slowly as their allele frequencies shift during adaptation by natural selection. Darwin's proposals incorporated this model.
NOTE: In Figure 14.8A and B, the sizes of the arrows' bases represent the population sizes.

B. Most of the fossil record does not support the gradualist model because most new species seem to appear suddenly in rock strata, without intermediary transitional forms (Figure 14.8A).

C. In the **punctuated equilibrium model,** periods of rapid evolutionary change (punctuation) and speciation are interrupted by long periods of little or no change (equilibrium or stasis) (Figure 14.8B).
NOTE: Using this definition, the amount of time considered a geological instant would vary with the age of the species.

D. Though once the subject of heated debate, most evolutionary biologists now see both models as having merit; even with some species evolving by a combination of these models.

Module 14.9 Talking About Science: Peter and Rosemary Grant study the evolution of Darwin's finches.

A. Peter and Rosemary Grant first tested the hypothesis put forth by Darwin that the 14 finch species on the Galápagos Islands resulted from food adaptations through natural selection.

B. The size and shape of the finch beak dictates the type of food that is consumed by the finch.

C. On a rare occurrence, a male of one species mates with a female of another species producing hybrids with intermediate beak sizes.

D. During drought years, the hybrids die because they cannot compete with either of the parent species for food, thus maintaining divergent evolution of the finches.

Class Activities

1. Have your students consider the question of whether or not dogs and wolves are two different species (as they are currently classified) or if they are actually a single species.

Transparency Acetates

Figure 14.1C	A ring species of salamander, *Ensatina eschscholtzii*
Table 14.2	Reproductive barriers between species
Figure 14.4B	Adaptive radiation on an island chain
Figure 14.5A	Sympatric speciation by polyploid formation
Figure 14.6B	The evolution of wheat
Figure 14.7A	Evolution of reproductive barriers in lab populations of fruit flies
Figure 14.8 A	Gradualist model
Figure 14.8B	Punctuated equilibrium model *(combined with Figure 14.8A)*

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.

Activities and Thinking as a Scientist	Module Number
Web/CD Activity 14A: *Exploring Speciation on Islands*	14.4
Web/CD Thinking as a Scientist: *How Do New Species Arise by Genetic Isolation?*	14.5
Web/CD Activity 14B: *Polyploid Plants*	14.6