

Chapter 16: The Origin of Species

OVERVIEW

In this chapter, you will learn about species and speciation. After defining biological species, the authors describe the general mechanisms of allopatric and sympatric speciation, and premating and postmating mechanisms for maintaining reproductive isolation. Within the last ten years, three new species of mammals have been found in the isolated forested mountains of Vietnam: the saola, a large (200 pound) hoofed, horned quadruped, called the giant muntjac (the "barking deer") and a rabbit with short ears and a brown-striped coat. How do species like these arise?

1) What Is a Species?

Biologists define **species** (Latin for "appearance") as groups of actually or potentially interbreeding natural populations, which are reproductively isolated from other such groups. So, two organisms are the same species if they interbreed in nature and have normal, vigorous, fertile offspring. This definition does not apply to asexually reproducing species, however.

2) How Do New Species Form?

Speciation is the process by which new species form. Speciation depends on two factors: (1) isolation (gene flow between diverging populations must be small or nonexistent); and (2) genetic divergence of two populations (they must evolve large genetic differences so that they cannot interbreed or produce normal offspring).

Hypothetical mechanisms of speciation are **allopatric speciation**, in which the populations are geographically separated from each other and thus isolated from gene flow, and **sympatric speciation**, in which the populations share the same area but are isolated from gene flow. There is some debate as to whether genetic drift or natural selection normally plays the major role in allopatric speciation, but geographic isolation is involved in most cases of speciation in animals.

Allopatric speciation can occur in populations that are physically separated by an impassible barrier. If two or more populations become geographically isolated for any reason, little or no migration (gene flow) can occur between them, and the populations may accumulate genetic differences. Alternately, genetic differences may arise if one or more of the separated populations is small enough for genetic drift to occur (the founder effect). In either case, genetic differences between the separated populations may eventually become large enough to make interbreeding impossible.

Sympatric speciation can occur in populations that live in the same area. With sympatric speciation, two likely mechanisms can reduce gene flow. Ecological isolation occurs when a geographical area contains two distinct types of habitat and different members of the same species begin to specialize in one habitat or the other. This reduces gene flow. Chromosomal aberrations, specifically changes in chromosome number, can cause immediate reproductive isolation of a population. A common speciation mechanism in plants is **polyploidy**, the acquisition of multiple copies of each chromosome. If a fertilized egg duplicates its chromosomes but does not divide into daughter cells, the chromosome number can rise from diploid ($2n$, or pairs of chromosomes) to become tetraploid ($4n$, or 4 doses of each chromosome). Healthy $4n$ plants produce $2n$ gametes. Tetraploids breed successfully with other tetraploids. But if $4n$ breeds with $2n$, sterile $3n$ (triploid) offspring result. So, tetraploid plants and their diploid parents form distinct reproductive communities that cannot interbreed successfully. Speciation by polyploidy is common in plants (which can reproduce by self-fertilization and asexually), but rare in animals.

Change over time within a species can cause apparent “speciation” in the fossil record. Speciation events lead to forking branches in the evolutionary tree of life, as one species splits into two species. However, changes within a species over time also occur. Over time, the members of a species may come to be very different from their distant ancestors, even if no speciation occurs. Since fossils cannot breed, it is difficult to determine whether they were reproductively isolated from other fossils. Consequently, paleontologists typically assign extinct organisms to species without reference to the biological-species concept. During **adaptive radiation**, one species gives rise to many in a relatively short time. This occurs when populations of a single species invade a variety of new habitats and evolve in response to the differing environmental pressures.

3) How Is Reproductive Isolation Between Species Maintained?

Speciation occurs through the evolution of mechanisms that prevent interbreeding. Genetic divergence during a period of isolation is necessary for new species to arise, but speciation will occur only if mechanisms ensuring **reproductive isolation** also develop. **Isolating mechanisms** are structural and/or behavioral modifications that prevent interbreeding.

Premating isolating mechanisms include geographical isolation, ecological isolation, temporal isolation, behavioral isolation, and mechanical incompatibility. **Geographical isolation** prevents members of different species from meeting each other and usually is considered to be a mechanism that *allows* new species to form. **Ecological isolation** involves populations having different resource requirements involving the use of different local habitats within the same general area; thus, they are not likely to meet during the mating season. **Temporal isolation** occurs between species that breed at different times of the year. Even if two species occupy similar habitats, they cannot interbreed if they have different breeding seasons. **Behavioral isolation** involves species with different courtship rituals. Courtship rituals involve recognition and evaluation signals between males and females and also aid in distinguishing among species. Colors and songs of birds, frog croaks, cricket chirping patterns, and firefly flashing colors and frequencies are examples of signals used in courtship rituals. **Mechanical incompatibility** occurs when physical barriers between species prevent fertilization. For example, male and female sex organs of different species may not fit together properly for sperm transfer in animals, or different flower sizes or structures of different species may prevent pollen transfer in plants.

Postmating isolating mechanisms prevent production of vigorous, fertile offspring, and include gametic incompatibility, hybrid inviability, and hybrid inferiority. **Gametic incompatibility** occurs when sperm from one species are unable to fertilize eggs of another. **Hybrid inviability** occurs if hybrid offspring survive poorly. Hybrids may die during development or display behaviors that are mixtures of the two parental types and be unable to attract mates. **Hybrid infertility** occurs if hybrid offspring are unable to produce normal sperm or eggs. Most animal hybrids such as mules (horse mating with donkey) or ligers (lion mating with tiger) are sterile since their chromosomes do not pair properly during meiosis. Crosses between tetraploid ($4n$) and diploid ($2n$) plant species usually result in sterile triploid ($3n$) offspring.

4) What Causes Extinction?

Natural selection may lead to **extinction**, which is the death of all members of a species. Two characteristics predispose a species to extinction when the environment changes: extremely limited ranges (localized distribution), and very narrow structural or behavioral requirements (overspecialization). Wide-ranging species do not succumb to local environmental catastrophes, and species which feed on a variety of foods do not die off if one food supply vanishes. In addition, interactions with other organisms may drive a species to extinction, as happened when the Panama land bridge allowed North American species to migrate into South America, causing the extinction of most native South American species due to competition. Finally, habitat change and habitat destruction are the leading causes of extinction. Mass extinctions are disappearances of many varied species in a short time over a large area and may be caused by traumatic environmental events such as the effects of the impact of a large meteorite.

Case study revisited. In the Vietnamese mountains, the area covered by forests shrunk dramatically during the ice ages, becoming tiny "islands" of forest isolated from each other. In these isolated forests, allopatric speciation may have produced the saola, giant muntjac, striped rabbit, and other unique species. Heavy deforestation by the Vietnamese for economic development may possibly endanger these already rare animals, but the Vietnamese government has established a number of national parks and nature preserves in key areas. What benefit for humans is the search and discovery of new species?

KEY TERMS AND CONCEPTS

Fill-In: From the following list of key terms, fill in the blanks in the following story.

adaptive radiation	hybrid infertility	reproductive isolation
allopatric	mechanical incompatibility	speciation
behavioral isolation	polyploidy	species
ecological isolation	postmating isolating mechanisms	temporal isolation
geographic isolation	pre mating isolating mechanisms	

1. Michael took his son Zachary to the zoo. Zachary is taking a high school biology class and was loaded with questions for his dad. "How do we know that African lions and Asian tigers are different _____?" he asked. Mike replied: "Zach, they have different physical characteristics, but more importantly they show _____ since they don't try to interbreed in nature or even in zoos."

2. This led to another question: "Dad, since both lions and tigers are mammals and cats, how could _____ have occurred in such closely related organisms?" "Well, Zach, when a single group of organisms, like mammals, gives rise to many closely related species, it's called _____. In the case of lions and tigers, first there was _____ isolation since they evolved in different parts of the world, leading to _____ speciation. And even if they lived for a time in the same general area, there would have been _____ isolation since they would occupy different habitats there. Zach, these are examples of _____ isolating mechanisms since they prevent lions and tigers from mating."

3. They entered the amphibian and reptile house, where many different species of frogs were living. "Dad, the wood frogs and green frogs breed in the same areas each year, but are different species. How can this be?" "Well Zach, they don't interbreed because wood frogs mate during early spring and green frogs mate during late spring, a situation called _____ isolation. Also, the males of the two species have different sounding croaks and females are attracted only to males of their own kind. This is an example of _____ isolation because they have different courtship rituals."

4. When they looked at the lizards, Zach said: "Dad, I just thought of something weird. Suppose a large lizard of one species tried to mate with a small lizard of another species. Could they succeed?" "Probably not," replied Mike as he chuckled at the thought of such an unlikely liaison, "since their sex organs couldn't fit together properly. This is a situation called _____ isolation."

5. Moving to the building housing hoofed animals, Zach noticed the horses, donkeys and mules. "Dad, since horses and donkeys produce mules when farmers force them to mate, aren't they all members of the same species?" "Son, horses and donkeys would never interbreed under natural conditions, and besides, the mules they produce are sterile, an example of _____. This is an example of a _____ isolating mechanism since it acts after mating between different species takes place."

6. "Dad, this is all way cool, but now I have a really important question. When do we eat?" "Soon, just eat your banana right now. By the way, Zach, bananas don't have seeds and are sterile because they have three copies of each chromosome, a condition called _____." "Banana, smanana!" exclaimed Zach. "I want a burger and fries!"

Key Terms and Definitions

adaptive radiation: the rise of many new species in a relatively short time as a result of a single species that invades different habitats and evolves under different environmental pressures in those habitats.

allopatric speciation (al-ô-pat'-rik): speciation that occurs when two populations are separated by a physical barrier that prevents gene flow between them (geographical isolation).

behavioral isolation: the lack of mating between species of animals that differ substantially in courtship and mating rituals.

ecological isolation: the lack of mating between organisms belonging to different populations that occupy distinct habitats within the same general area.

extinction: the death of all members of a species.

gametic incompatibility: the inability of sperm from one species to fertilize eggs of another species.

geographical isolation: the separation of two populations by a physical barrier.

hybrid infertility: reduced fertility (typically, complete sterility) in the hybrid offspring of two species.

hybrid inviability: the failure of a hybrid offspring of two species to survive to maturity.

isolating mechanism: a morphological, physiological, behavioral, or ecological difference that prevents members of two species from interbreeding.

mechanical incompatibility: the inability of male and female organisms to exchange gametes, normally because their reproductive structures are incompatible.

polyploidy (pahî'-ê-ploid-ê): having more than two homologous chromosomes of each type.

postmating isolating mechanism: any structure, physiological function, or developmental abnormality that prevents organisms of two different populations, once mating has occurred, from producing vigorous, fertile offspring.

premating isolating mechanism: any structure, physiological function, or behavior that prevents organisms of two different populations from exchanging gametes.

reproductive isolation: the failure of organisms of one population to breed successfully with members of another; may be due to premating or postmating isolating mechanisms.

speciation: the process of species formation, in which a single species splits into two or more species.

species (spê'-sêz): the basic unit of taxonomic classification, consisting of a population or series of populations of closely related and similar organisms. In sexually reproducing organisms, a species can be defined as a population or series of populations of organisms that interbreed freely with one another under natural conditions but that do not interbreed with members of other species.

sympatric speciation (sim-pat'-rik): speciation that occurs in populations that are not physically divided; normally due to ecological isolation or chromosomal aberrations (such as polyploidy).

temporal isolation: the inability of organisms to mate if they have significantly different breeding seasons.

THINKING THROUGH THE CONCEPTS

True or False: Determine if the statement given is true or false. If it is false, change the underlined word(s) so that the statement reads true.

7. _____ Temporal isolation is isolation by distance.
8. _____ Polyploidy is most common in plants.
9. _____ Mechanical incompatibility is a postmating isolating mechanism.
10. _____ The most valid way to determine whether two organisms belong to different species is to look at mating behavior.
11. _____ Speciation depends on lack of isolation between populations.

12. _____ Populations physically separated are allopatric.
13. _____ Sympatric speciation can occur if chromosome aberrations occur.
14. _____ Geographic isolation is a pre mating isolating mechanism.
15. _____ Hybrid infertility is a post mating isolating mechanism.
16. _____ Adaptive radiation may occur when a species encounters a wide variety of unoccupied habitats.

Matching: Speciation.

17. _____ causes "instant speciation"
18. _____ causes most animal speciation
19. _____ populations are separated by a physical barrier
20. _____ causes much plant speciation but little animal speciation
21. _____ reduces genetic differences between populations, retarding animal speciation
22. _____ one species gives rise to many new species in a short time
23. _____ acquisition of more than two copies of each chromosome in the nucleus of cells

Choices:

- a. gene flow
- b. geographical isolation
- c. polyploidy
- d. adaptive radiation

Matching: Maintaining reproductive isolation.

24. _____ Interbreeding does not occur in nature between British peppered moths and Canadian peppered moths.
25. _____ Interbreeding does not occur between closely related species of fruit flies with slightly different courtship rituals.
26. _____ When horses and donkeys are forced to interbreed, sterile mules are produced.
27. _____ Leopard frogs and pickerel frogs that live in the same area with similar mating seasons do not interbreed because one species breeds in swamps and the other breeds in clear lakes.
28. _____ Closely related species of katydid insects do not interbreed because the male and female sex organs cannot fit together properly to allow sperm transfer to occur.
29. _____ Wood frogs and green frogs breed in the same lakes but do not interbreed because one species breeds in April while the other species breeds in May.
30. _____ Two closely related species of fruit flies sometimes mate but the female's immune system kills the male's sperm as though it were a foreign invading microbe.

Choices:

- a. geographical isolation
- b. ecological isolation
- c. temporal isolation
- d. behavioral isolation
- e. mechanical isolation
- f. gamete incompatibility
- g. hybrid inviability
- h. hybrid infertility

Multiple Choice: Pick the most correct choice for each question.

31. Among animals in particular, which of the following is the most common event necessary for speciation to happen?
 - a. geographic isolation
 - b. adaptive radiation
 - c. reproductive isolation
 - d. ecological isolation
 - e. migration
32. In plants, a common method of sympatric speciation is
 - a. ecological isolation
 - b. geographical isolation
 - c. adaptive radiation
 - d. polyploidy
 - e. nondisjunction
33. Two species of pines releasing pollen at separate times in the same habitat is an example of
 - a. geographical isolation
 - b. ecological isolation
 - c. temporal isolation
 - d. behavioral isolation
 - e. mechanical incompatibility
34. The Everglades kite is almost extinct because of
 - a. fire in the Everglades
 - b. saltwater intrusion in the Everglades
 - c. invasion of the walking catfish
 - d. disappearance of the apple snail
 - e. industrial melanism

APPLYING THE CONCEPTS

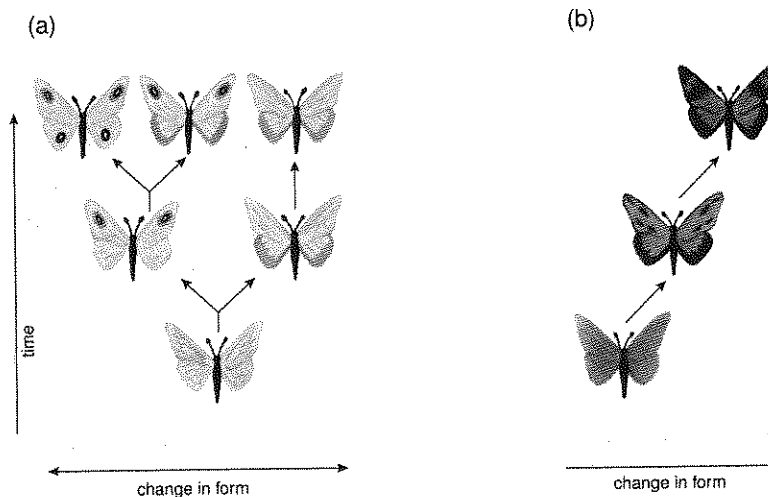
These practice questions are intended to sharpen your ability to apply critical thinking and analysis to biological concepts covered in this chapter.

35. Name and describe two genetic models for speciation.

36. Name the two general conditions necessary for speciation in animals.

37. Briefly describe three postmating reproductive isolating mechanisms.

Answer the following question, based on the figure below.



38. Compare parts (a) and (b) in the figure and comment on which evolutionary pattern is the result of speciation and which is not. Please briefly explain your answer.

39. Dogs (*Canis familiaris*) and coyotes (*Canis latrans*) are given different species names by biologists. Interestingly, dogs and coyotes will eagerly mate with each other in captivity and produce perfectly healthy, fertile offspring. What sorts of criteria do you think biologists have used to determine that dogs and coyotes are different species? Do you personally think that dogs and coyotes should be considered different species? Do you think that dogs and coyotes are closely related types of animals?

40. The drug colchicine disrupts formation of the mitotic spindle and prevents cell division after the chromosomes have doubled before the start of meiosis. Describe how you might use colchicine to produce a new polyploid species of plant.

41. Triploid varieties of fruits and vegetables produce larger fruits that are seedless. Explain why these varieties are seedless, and what is the consequence of not producing seeds?

42. Design a study to determine whether the Vietnam muntjac ("barking deer") is a species different than the typical deer in the US.

Use the Case Study and the Web sites for this chapter to answer the following questions.

43. The Annanite mountains of Vietnam/Laos are the home of a recently discovered species: the "saola." How was it discovered? What is its normal habitat? What is its survival status?
