21
Phylogeny, Speciation, and Extinction

Learning Objectives

In this chapter, you will learn:

- ➜ Phylogeny and Common Ancestry
- ➜ Speciation
- ➜ Extinction
- ➜ Modern-Day Examples of Continuing Evolution

Overview

The evolutionary history of life is driven by speciation and extinction. This chapter will review how scientists trace the evolutionary history of a species, the processes that lead to speciation and extinction, and modern-day examples of continuing evolution of species.

Phylogeny and Common Ancestry

Phylogeny is the history of the evolution of a species or group. Phylogeny shows lines of ancestry, common descent, and relationships among groups of organisms. **Phylogenetic trees** and **cladograms** are hypotheses about the history of evolution over time, with phylogenetic trees indicating the approximate time of evolutionary events. These phylogenetic trees and cladograms are created using morphological evidence from fossils and time

estimates from **molecular clocks** (changes in DNA and protein sequences over time). Generally, evidence from molecular clocks is considered more accurate than morphological characteristics because molecular data are less influenced by convergent evolution or external geological events.

Morphological evidence from fossils shows traits that are gained, or lost, over time that can be used to construct phylogenetic trees. Shared characteristics are traits that are present in more than one lineage. **Shared derived characteristics** are found in a group of related organisms called a **clade** and set the clade apart from other organisms. Shared derived characteristics indicate homology among organisms in a clade and are evidence of their common ancestry.

Nodes on phylogenetic trees represent common ancestors. The more recent the common ancestor of two species, the closer their degree of relatedness. In a phylogenetic tree, the **outgroup** is the least closely related member of the tree. The **root** of a phylogenetic tree represents the common ancestor of all members of the tree.

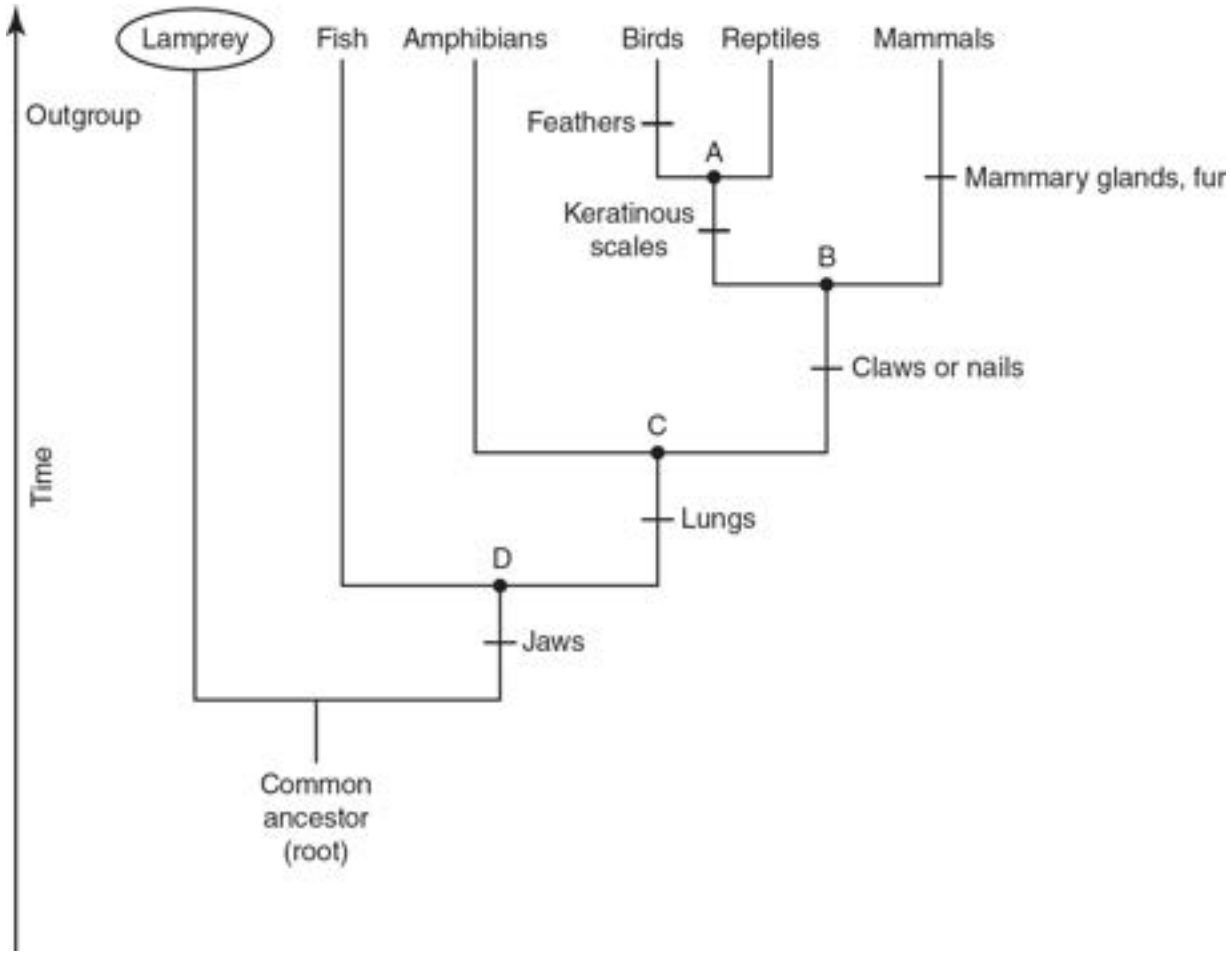


Figure 21.1 Phylogenetic Tree

In Figure 21.1, points A, B, C, and D represent nodes that indicate common ancestors. Point A represents the common ancestor of birds and reptiles, and point C represents the common ancestor of amphibians, birds, reptiles, and mammals. The phylogenetic tree indicates that birds and reptiles are more closely related than birds and amphibians because birds and reptiles share a more recent common ancestor (at point A) than do birds and amphibians (at point C). Keratinous scales are a shared derived characteristic that separate birds and reptiles into a clade. Keratinous scales are a characteristic shared by birds and reptiles that other organisms in this phylogenetic tree do not possess. Lampreys are the least closely related member of this phylogenetic tree and represent the outgroup in this example.

Phylogenetic trees and cladograms can also show speciation events (the evolution of new species) and extinction events (the death of all members of

a species), as shown in Figure 21.2.

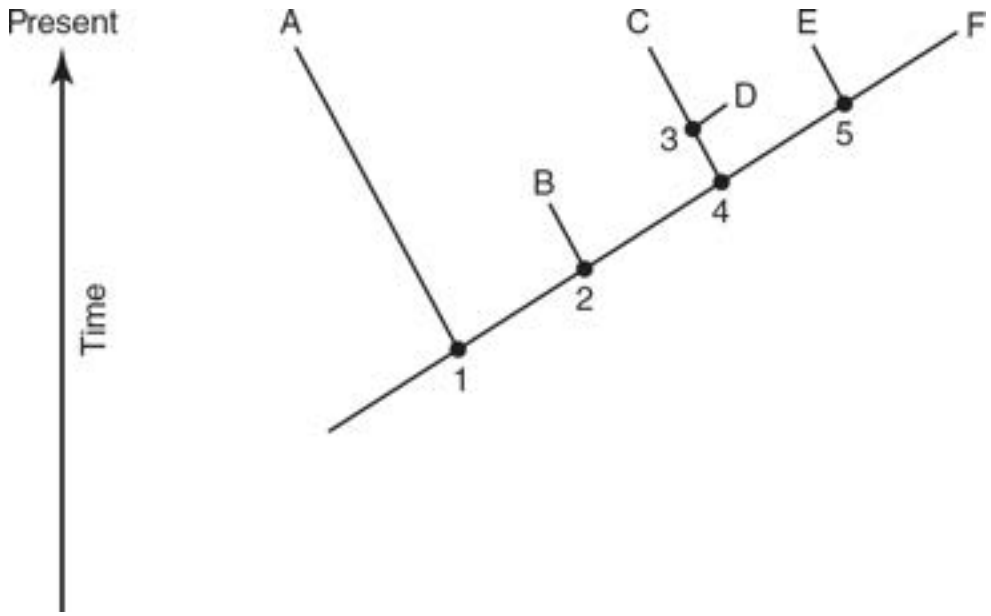


Figure 21.2 Phylogenetic Tree Showing Speciation and Extinction Events

In Figure 21.2, points 1, 2, 3, 4, and 5 represent speciation events that led to one ancestral lineage giving rise to two or more daughter lineages. Species B and D represent **extinct** species that did not survive to the present time, while A, C, E, and F represent **extant** species that have members that survived to the present time.

Organisms are linked by lines of descent, with a proposed common ancestor for all forms of life on Earth (**LUCA**—last universal common ancestor) estimated to have existed about 3.5 billion years ago. There are two major theories about how life on Earth originated:

1. Inorganic materials that were present in Earth's early atmosphere combined to make the building blocks of biological molecules. This theory is supported by evidence from the Miller-Urey experiment, in which a model of Earth's early atmosphere was constructed in a lab, and after a few weeks, amino acids and other components of biological molecules were found.
2. Another theory is that meteorites may have transported organic molecules (that are needed for life) to Earth. It is thought that early

Earth was bombarded with meteorites. Evidence for this theory includes the Murchison meteorite (found in Australia in 1969), which contained sugars and over 70 different amino acids.

The common ancestor for all eukaryotic life is thought to have evolved about 2.7 billion years ago. Evidence for a common ancestor of all eukaryotes includes:

- Membrane-bound organelles in all eukaryotes
- Linear chromosomes in all eukaryotes
- All eukaryotes have genes that contain introns

None of these shared characteristics of all eukaryotes are present in prokaryotes, indicating that there was a common ancestor of all eukaryotes.

Speciation

The current definition of a species is the biological species concept—that a **species** is a group of organisms that are capable of interbreeding and producing viable and fertile offspring. It is important to note that the definition of a species is a human construct that is meant to help classify organisms. As more data are gathered about an organism, the definition as to which species it belongs to may change.

Speciation is the evolution of new species. Speciation occurs when two populations are reproductively isolated from each other. This reproductive isolation prevents interbreeding, and as the environments where these isolated groups change, the evolution of new species may occur. Speciation can lead to **adaptive radiation**, the evolution of organisms into separate species that occupy different ecological niches. Adaptive radiation is evident in Darwin's finches in the Galapagos Islands. These finch species are descendants of one species but have evolved over time to occupy the different available niches on the Galapagos Islands.

Rates of speciation can vary. If an environment is relatively stable, there will be less selective pressure on populations, and the rate of speciation will be slower. This slow and constant pace of speciation is called **gradualism**. If an environment rapidly changes, as it would after an asteroid strike, a

volcanic eruption, or a rapid change in climate, rapid evolution may occur. A long period of stability in a species interrupted by periods of rapid evolution is called **punctuated equilibrium**.

Speciation can be allopatric or sympatric. In **allopatric speciation**, a larger population becomes geographically separated and the smaller subgroups diverge and become separate species over time. **Sympatric speciation** occurs in the same geographic area, but other factors lead to reproductive barriers between members of the groups. One mechanism of sympatric speciation is **polyploidy**, the replication of extra sets of chromosomes, which is a frequent method of sympatric speciation in plants. Plants that develop extra sets of chromosomes usually cannot interbreed with plants that maintained the original number of chromosomes and will thus become a separate species over time. **Sexual selection** in animals can also lead to sympatric speciation.

Reproductive barriers that can cause speciation can be prezygotic or postzygotic. **Prezygotic barriers** prevent the formation of a zygote, or a fertilized egg. **Postzygotic barriers** occur after the zygote is formed, and they prevent the zygote from developing into a viable and fertile adult organism.

Prezygotic barriers include:

- **Habitat isolation**—If organisms live in different habitats and do not come in contact with one another, they cannot mate and form zygotes and are thus reproductively isolated. An example of this would be the black-tailed deer found in the western United States and the white-tailed deer found in the eastern United States, which do not interbreed and are considered different species.
- **Temporal isolation**—Organisms can live in the same habitat, but if they are active at different times of the day or have breeding seasons during different times of the year, they will be temporally isolated and will not interbreed. Members of the cicada species *Magicicada tredecim* emerge to mate only once every 13 years, while members of the cicada species *Magicicada septendecim* emerge to mate once every 17 years. The mating cycles of these two species coincide only once every 221 years, which keeps them reproductively isolated.

- **Behavioral isolation**—Some species will interbreed only with others who perform compatible mating behaviors, such as mating calls or dances. Many bird species are reproductively isolated by their bird songs, which attract members of the same species but not others. The blue-footed booby birds of the Galapagos Islands will only mate with others that perform the correct mating dances.
- **Mechanical isolation**—If the sexual organs of the organisms are incompatible and prevent the transfer of gametes, the species will remain reproductively isolated. Many species of snails are mechanically isolated due to their reproductive organs being located in different parts of their shells. If their shell shapes are too different, the sex organs of the snails cannot successfully copulate.
- **Gametic isolation**—Even if two organisms are able to successfully copulate, if their gametes are incompatible, no zygote will be produced and the organisms will be reproductively isolated. Many examples of this are found in plants, in which the pollen of one plant species cannot successfully fertilize the ova of another plant species.

Postzygotic barriers include:

- **Reduced hybrid viability**—Two organisms that can form a zygote may still be reproductively isolated if that zygote does not survive to adulthood. A number of species of salamanders can interbreed and produce zygotes, but those zygotes do not survive to reproductive age, keeping the salamander populations reproductively isolated.
- **Reduced hybrid fertility**—Even if the zygote survives to adulthood, if the adult hybrid is infertile, the two species that created the hybrid will remain reproductively isolated. A male donkey can mate with a female horse to produce a mule. The hybrid mules are infertile, keeping horses and donkeys as separate species.
- **Hybrid breakdown**—In some plants, hybrids are viable and fertile, but with each subsequent generation, the hybrid becomes weaker and less robust and will cease to exist after a few generations. This hybrid breakdown keeps some plant species reproductively isolated.

Extinction

Extinction (the death of all members of a species) has occurred throughout Earth's history, as shown in evidence from the fossil record. The level of genetic variation in a population can affect the population's ability to survive environmental changes. More genetically diverse populations have a greater ability to adapt to changing environments because they are more likely to contain some individuals who can withstand the changing environmental pressures. Less genetically diverse populations are at a greater risk for declines in population sizes or extinction.

Ecological stresses created by human activities, such as habitat destruction or overhunting, can increase extinction rates. Some scientists hypothesize that Earth is currently experiencing a sixth major extinction event caused by human activities.

Species diversity depends on a balance between rates of speciation and extinction. If speciation rates are greater than extinction rates, species diversity will increase. If extinction rates exceed speciation rates, species diversity will decrease. While extinction may have negative consequences, extinction can also clear available habitats and niches for other species.

Modern-Day Examples of Continuing Evolution

Life on Earth continues to evolve in Earth's changing environment. Populations evolve when the conditions in which they live change. Some examples of continuing evolution include:

- Antibiotic resistance in bacteria
- Tumor cells developing resistance to chemotherapy drugs
- Pesticide resistance in insects
- Evolution of previously unseen viruses and other pathogens
- Genomic changes in organisms over time

Practice Questions

Multiple-Choice

1. In the 1950s, Stanley Miller performed an experiment to investigate the possible origin of the molecules required for life on Earth. Water vapor, methane, hydrogen gas, and ammonia were placed in a flask, and electric charges were applied to the system to simulate atmospheric conditions that were thought to be prevalent at the time. After many weeks, amino acids were produced in the system. Which of the following hypotheses is best supported by the results of this experiment?

   (A) The molecules needed for life on Earth were brought to Earth by a meteorite.
   (B) The molecules needed for life could have formed from inorganic compounds in Earth's early atmosphere.
   (C) The first molecules needed for life (that were formed in Earth's early atmosphere) were RNA.
   (D) The first molecules needed for life (that were formed in Earth's early atmosphere) were carbohydrates.

2. Which of the following pieces of evidence best supports the hypothesis that birds are more closely related to reptiles than to other animals?

   (A) Fossils of birds and reptiles are first seen in rock layers from the same time period.
   (B) Birds and reptiles live in similar habitats and occupy the same trophic levels.
   (C) Both birds and reptiles are the only animals with amniotic eggs.
   (D) Molecular studies show that the DNA from birds has a greater degree of homology with the DNA from reptiles than with the DNA from other animals.

3. Generally, which type of data is considered most reliable when constructing phylogenies?

(A) fossil evidence, because it shows when species originated
(B) biogeography, because it shows organisms' habitats
(C) morphological characteristics, because they show body structures
(D) molecular evidence, because it is less prone to convergent evolution or changes caused by geological events

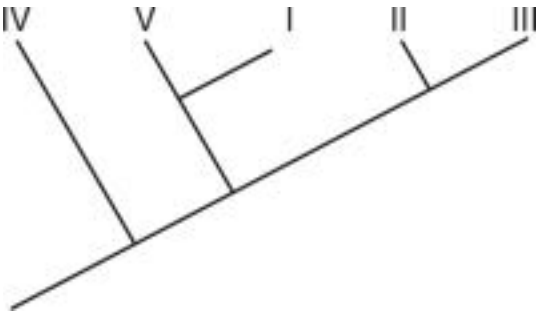
Questions 4 and 5

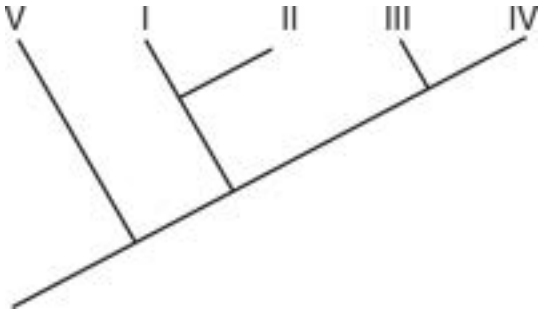
Five new bacterial species were discovered in the Mariana Trench in the Pacific Ocean. The glyceraldehyde 3-phosphate dehydrogenase (*GAPDH*) gene was sequenced in all five species, and the number of nucleotide differences in the *GAPDH* gene among the five species is shown in the table.

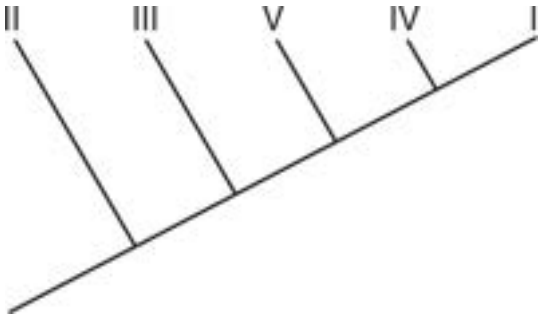
Number of Nucleotide Differences in the *GAPDH* Gene

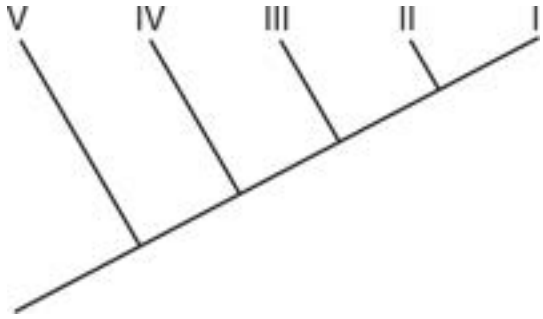
Species	I	II	III	IV	V
I	---	1	8	4	15
II		---	4	6	17
III			---	1	19
IV				---	20
V					---

4. Which of the following cladograms is best supported by the data in the table?

(A) 

(B) 

(C) 

(D) 

5. Based on the data in the table, which species is the outgroup?

   (A) II
   (B) III
   (C) IV
   (D) V

6. Which of the following best supports the existence of a common ancestor of all three domains of living organisms (Archaea, Bacteria, and Eukarya)?

   (A) All living organisms perform glycolysis in their cytoplasm.
   (B) All living organisms have membrane-bound organelles.
   (C) All living organisms have linear chromosomes.

(D) All living organisms have genes that contain introns.

7. Some species of birds have unique bird songs that only attract members of the same species. This is an example of which type of reproductive isolation?

(A) behavioral
(B) gametic
(C) habitat
(D) mechanical

8. Orchids that belong to the genus *Dendrobium* will flower in response to certain weather stimuli. One species of *Dendrobium* flowers on the 8th day and closes on the 9th day after the weather stimuli, while another species of *Dendrobium* flowers on the 10th day and closes on the 11th day after the weather stimuli. This is an example of which type of reproductive isolation?

(A) habitat
(B) mechanical
(C) temporal
(D) hybrid breakdown

9. Which of the following is an example of mechanical reproductive isolation?

(A) The sea urchin species *Strongylocentrotus purpuratus* and *Strongylocentrotus franciscanus* both live in the same marine habitat and release their gametes simultaneously into the surrounding water. However, the gametes cannot form a zygote.
(B) In some snail species, the direction of the coil of the shell is controlled by a single gene. Snails with left-coiling shells cannot mate with snails with right-coiling shells because their copulating organs do not align.

(C) The fruit fly species *Drosophila persimilis* breeds in the early morning, and the fruit fly species *Drosophila pseudoobscura* breeds in the late afternoon.

(D) The bullfrog species *Rana draytonii* and *Rana catesbeiana* can mate and produce a zygote, but the zygote is not viable.

10. Tigers (*Panthera tigris*) and leopards (*Panthera pardus*) can mate and produce a zygote. The zygote will undergo cell division a few times, but this fails to result in the production of a viable embryo. This is an example of which type of reproductive isolation?

(A) gametic

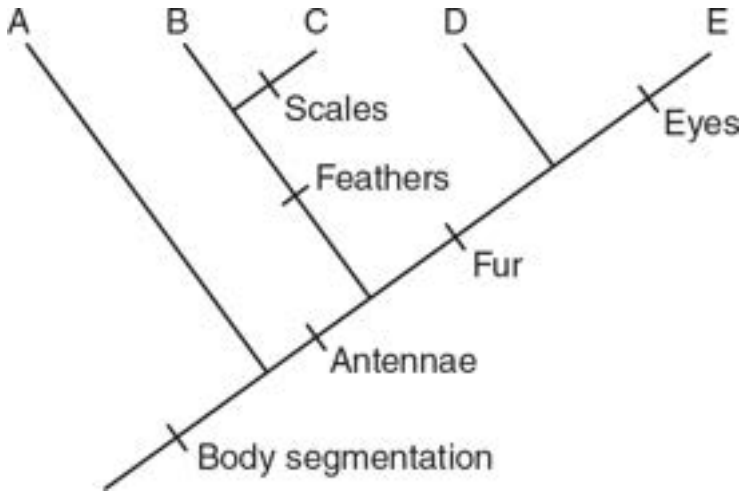
(B) reduced hybrid viability

(C) reduced hybrid fertility

(D) hybrid breakdown

Short Free-Response

11. The following figure is a cladogram that represents the suspected ancestry of five species.



(a) **Describe** the characteristic(s) of the species that is the outgroup on this cladogram.

(b) **Describe** the similarities and differences in the characteristics present in species B and species D.

(c) A new species (X) is discovered, which has body segmentation, antennae, and fur but does not have eyes or scales. **Construct** a line that represents the ancestry of species X on the cladogram.

(d) **Explain** why species C is placed off of the same branch as species B and not the same branch as species D.

12. Two species of ground squirrels are separated by a river that they cannot cross. Genetic analyses of the two species of ground squirrels indicate that 99.3% of their DNA is homologous.

(a) **Describe** the type of reproductive isolation that separates the two species of ground squirrels.

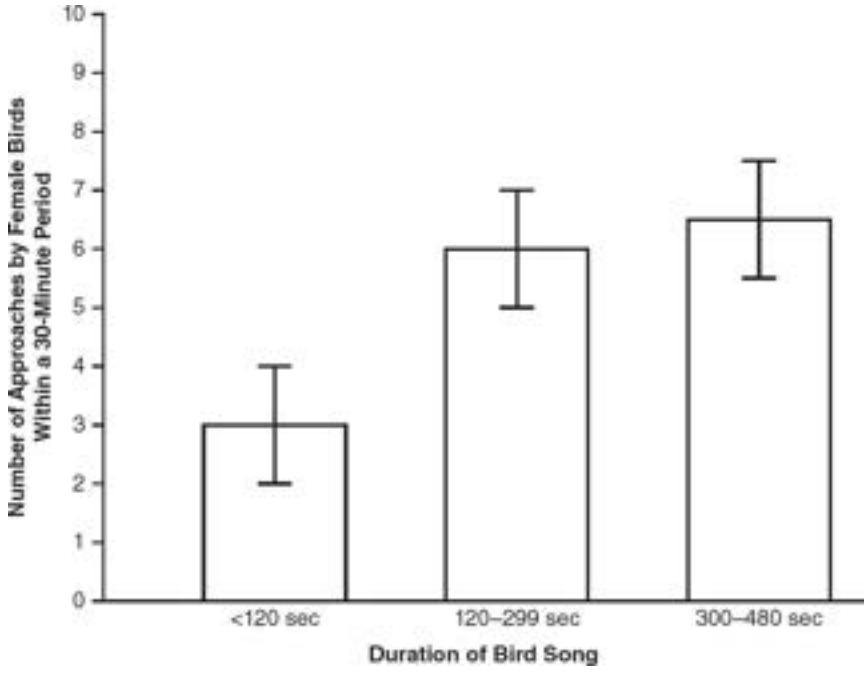
(b) **Explain** how homology in DNA is used to determine ancestry.

(c) Due to a severe drought, the decision is made to divert water away from the river to a reservoir that supplies water for a nearby city, and the river separating the two species dries up. **Predict** the effect this will have on the two species of ground squirrels in the area.

(d) **Justify** your prediction from part (c).

Long Free-Response

13. The males of a particular species of bird attract mates with their bird songs. Male birds were observed, and the duration of their bird songs were recorded. The durations of the bird songs were classified into three groups: less than 120 seconds, 120–299 seconds, and 300–480 seconds. The number of females that approached the male birds within the 30-minute period, including during and immediately following the bird songs, was recorded. A graph of the data with 95% confidence intervals follows.



(a) Based on the data provided, **make a claim** about how the duration of the bird songs affects the number of females approaching the males.

(b) **Describe** the type of reproductive isolation that bird songs are an example of. **Identify** one more example of this type of reproductive isolation.

(c) **Analyze** the data in the graph, and **determine** whether there is a statistically significant difference in the number of females approaching males with bird songs in the 120–299 second range and the number of females approaching males with bird songs in the 300–480 second range.

(d) **Predict** the number of females that would approach a male with a bird song that is longer than eight minutes (480 seconds). **Justify** your prediction.

Answer Explanations

Multiple-Choice

1. **(B)** Miller used molecules thought to have been present in Earth's early atmosphere, so the experiment supports this answer. Choice (A) is incorrect because there was no evidence from Miller's experiment that supports this theory about a meteorite. The molecules formed in Miller's experiment were amino acids, not RNA or carbohydrates, so choices (C) and (D) are incorrect.

2. **(D)** DNA evidence strongly supports a degree of ancestry of organisms. The location of fossils in rock layers can change due to geological events, so choice (A) is not the best answer. Choice (B) is incorrect because habitats and trophic levels do not necessarily indicate common ancestry. Mammals also have amniotic eggs, so choice (C) is incorrect.

3. **(D)** The DNA sequence of an organism is not affected by its environment or geological events, so it provides reliable evidence for ancestry of organisms. Fossils do not necessarily show when a species originated, so choice (A) is incorrect. Habitats and morphological characteristics can change during an organism's lifetime, so choices (B) and (C) are incorrect.

4. **(B)** Species V is the outgroup because it has the greatest number of amino acid differences from the other species. Species I and II have only one amino acid difference between them and are therefore closely related. Species III and IV have only one amino acid difference between them and are therefore closely related. Choice (A) is incorrect because species I is more closely related to species II (one amino acid difference) than species V (15 amino acid differences). Species II has fewer amino acid differences from the other species than does species V, so species II is not the outgroup. Thus, choice (C) is incorrect. Choice (D) is incorrect because species I has only four amino acid differences from species IV but eight amino acid differences from species III, so species IV should share a more recent common ancestor with species I.

5. **(D)** Species V is the outgroup because it has the greatest number of amino acid differences from the other four species.

6. **(A)** All living organisms perform glycolysis in their cytoplasm, indicating a common ancestor of all life-forms. Choice (B) is incorrect because not all living organisms have membrane-bound organelles. Prokaryotes do not have linear chromosomes or introns, so choices (C) and (D) are incorrect.

7. **(A)** Bird songs are an example of behavioral isolation. Choice (B) is incorrect because gametic isolation occurs when gametes are incompatible and cannot form a zygote. Habitat isolation involves separation by area, so choice (C) is incorrect. Mechanical isolation occurs when the genitalia of the male and female cannot successfully copulate, so choice (D) is incorrect.

8. **(C)** Temporal isolation is separation by time. Since the two species flower and are ready for pollination at different times, this is an example of temporal isolation. Habitat isolation is separation by area, so choice (A) is incorrect. Choice (B) is incorrect because mechanical isolation occurs when the male and female genitalia are incompatible. Hybrid breakdown occurs when two species can produce a viable and fertile offspring but each successive generation of the hybrid becomes weaker and weaker, so choice (D) is incorrect.

9. **(B)** Since their copulating organs do not align, these snails cannot exchange gametes, so this is an example of mechanical isolation. Choice (A) is an example of gametic isolation. Choice (C) is an example of temporal isolation. Choice (D) is an example of reduced hybrid viability.

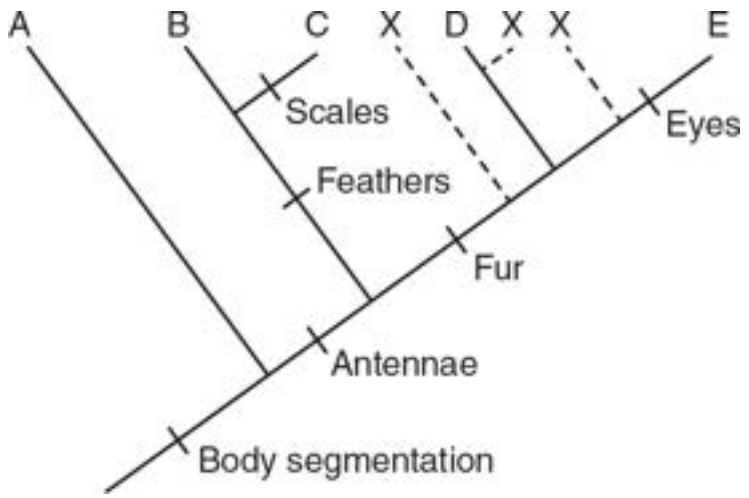
10. **(B)** Since tigers and leopards can mate and produce a zygote, but doing so does not result in any viable offspring, this is an example of reduced hybrid viability. It is not gametic isolation since their gametes can form a zygote, so choice (A) is incorrect. There is no infertile adult hybrid in this scenario, so choice (C) is also incorrect. No viable hybrid was produced, so there is no chance of hybrid breakdown, making choice (D) incorrect.

Short Free-Response

11. (a) Species A is the outgroup, and according to the cladogram, the only characteristic it possesses is body segmentation.

(b) Species B has body segmentation, antennae, and feathers. Species D has body segmentation, antennae, and fur.

(c)



(All three possible positions for species X on the above cladogram would be considered acceptable.)

(d) Species C has feathers, which is a characteristic that it has in common with species B. Species D has fur, which species C does not possess. Therefore, species C is placed off of the same branch as species B and not on the same branch as species D.

12. (a) This is a type of habitat isolation because the two species are separated by the river into different habitats.

(b) The greater the percentage of homology of DNA between two species, the more recently they shared a common ancestor.

(c) After the river that once separated the two species dries up, members of the two ground squirrel species will be able to interbreed with each other.

(d) Since the degree of homology in the DNA between the two species is very high, they probably diverged relatively recently, so there is a good likelihood they will be able to interbreed and produce fertile offspring. With the elimination of the river that once separated them, they will be able to come into contact with one another and interbreed.

Long Free-Response

13. (a) Males with bird songs of shorter durations (less than 120 seconds) will be approached by fewer females than males with bird songs of 120 seconds or more in duration.

(b) Bird songs are a type of behavioral isolation. Another example of behavioral isolation is the mating dance.

(c) The data are inconclusive because the 95% confidence intervals for the bird songs of 120–299 seconds and 300–480 seconds overlap. Therefore, there does not appear to be a statistically significant difference between the two groups.

(d) There is a large increase in the number of female birds that approach males with bird songs 120 seconds or longer (compared to those with songs that are less than 120 seconds). However, there does not appear to be a difference between the number of females approaching males with songs that are 120–299 seconds long and males with songs that are 300–480 seconds long. Therefore, it is unlikely that birds with songs longer than 480 seconds will attract significantly more females. Thus, a reasonable prediction would be that a song longer than eight minutes (480 seconds) would not attract significantly more female birds than songs that were 120–480 seconds long.