19
Types of Selection

Learning Objectives

In this chapter, you will learn:

→ Evidence of Evolution
→ Natural Selection
→ Artificial Selection
→ Sexual Selection

Overview

Mutations generate genetic variation in a population. These genetic variations lead to different phenotypes in a population. Different types of selection act upon these variations in phenotypes, leading to differential reproductive success. Populations evolve when some members of the population have greater reproductive success than other members of the population. This chapter will review the evidence of evolution and the different types of selection that may affect a population.

Evidence of Evolution

Evidence of evolution can be found in both extant (living) and extinct species. Some categories of evidence of evolution include:

- **Molecular evidence**—Comparing DNA sequences and amino acid sequences in proteins from different organisms provides evidence of evolution. When comparing the DNA sequence of a gene that is shared by different organisms, the more recently the organisms share a common ancestor, the more similar their DNA sequences will be. For example, the *GAPDH* (glyceraldehyde-3-phosphate dehydrogenase) gene in humans and in chimpanzees is over 99% similar in sequence, but the similarity in the *GAPDH* gene in humans and in dogs is only about 91% similar. This indicates that humans and chimpanzees share a more recent common ancestor than humans and dogs. Molecular evidence is considered very strong evidence since environmental factors do not usually change an organism's DNA sequence.

- **Morphology**—Homologous structures, which have common ancestry but different functions, also provide evidence of evolution. For example, the number and arrangement of bones in human hands, bat wings, and whale fins are very similar, indicating common ancestry and evidence of evolution.
- **Fossils**—The existence of fossils from organisms that no longer live on Earth also provide evidence of evolution. Transitional fossils show intermediate states between ancestral and modern species. Fossils can be dated by studying the age of the rock layers in which they are found or by using radioactive isotopes to date the fossils.
- **Vestigial structures**—Some organisms contain anatomical features that no longer seem to have a purpose in the modern organism but may have had a function in an ancestral organism. An example of this in humans is the tailbone, which currently serves no function in humans but may have helped our tree-dwelling ancestors balance upon or travel between branches.
- **Convergent evolution**—Species that live in similar environments may evolve similar adaptations even though they may not have a recent common ancestor. Sharks (cartilaginous fish) and dolphins (mammals) do not share a recent common ancestor, but they have evolved similar body shapes due to their similar environments.
- **Biogeographical evidence**—Biogeography is the study of the distribution of species. Species on islands off the coast of South America are more similar to species found in South America than to species found in North America.

- **Observations of evolution in current species**—When repeatedly exposed to antibiotics, bacteria populations evolve resistance over time. Mosquito populations have evolved resistance to pesticides like DDT.

TIP

The details of how the radioactive dating of fossils works will not be tested on the AP Biology exam.

Natural Selection

One of the most important things to remember about evolution is that individuals do not evolve; populations evolve. Charles Darwin was not the first person to propose that populations evolve, but he was the first to explain a mechanism for evolution, **natural selection**, that was supported by evidence for how populations evolve.

Jean-Baptiste Lamarck was also an early proponent of the idea that biological evolution occurs. Lamarck's theory of inheritance of acquired characteristics emphasized changes to individual organisms during their lifetimes (acquired characteristics) and the inheritance of these acquired characteristics by their offspring. While modern epigenetics (discussed in Chapter 17) shows that some changes to an organism's DNA during its lifetime (such as methylation patterns in the genome) may be inherited by its offspring, most acquired characteristics are not inherited by the next generation.

Darwin's Theory of Natural Selection

Here are the core principles of Darwin's theory of evolution by natural selection that you should understand and be able to apply on the AP Biology exam:

- Variations in populations lead to different phenotypes in members of a population.

- Competition for limited resources, or predation, leads to some members of a population surviving while other members of a population do not.
- The environment determines which phenotypes are favorable.
- Individuals with phenotypes that give them a survival advantage are more likely to survive and reproduce (**differential reproductive success**).
- Over time, favorable phenotypes will become more prevalent in a population as members of the population without those favorable phenotypes do not survive.

This is how Darwin’s theory of evolution by natural selection would explain the evolution of long necks in giraffes (see Figure 19.1):

- Variations in populations resulted in some giraffes having longer necks and others having shorter necks.
- Giraffes with longer necks can reach more food and therefore are more likely to survive and reproduce (differential reproductive success).
- Over time, only giraffes with longer necks will be present in a population because giraffes with shorter necks will not survive.

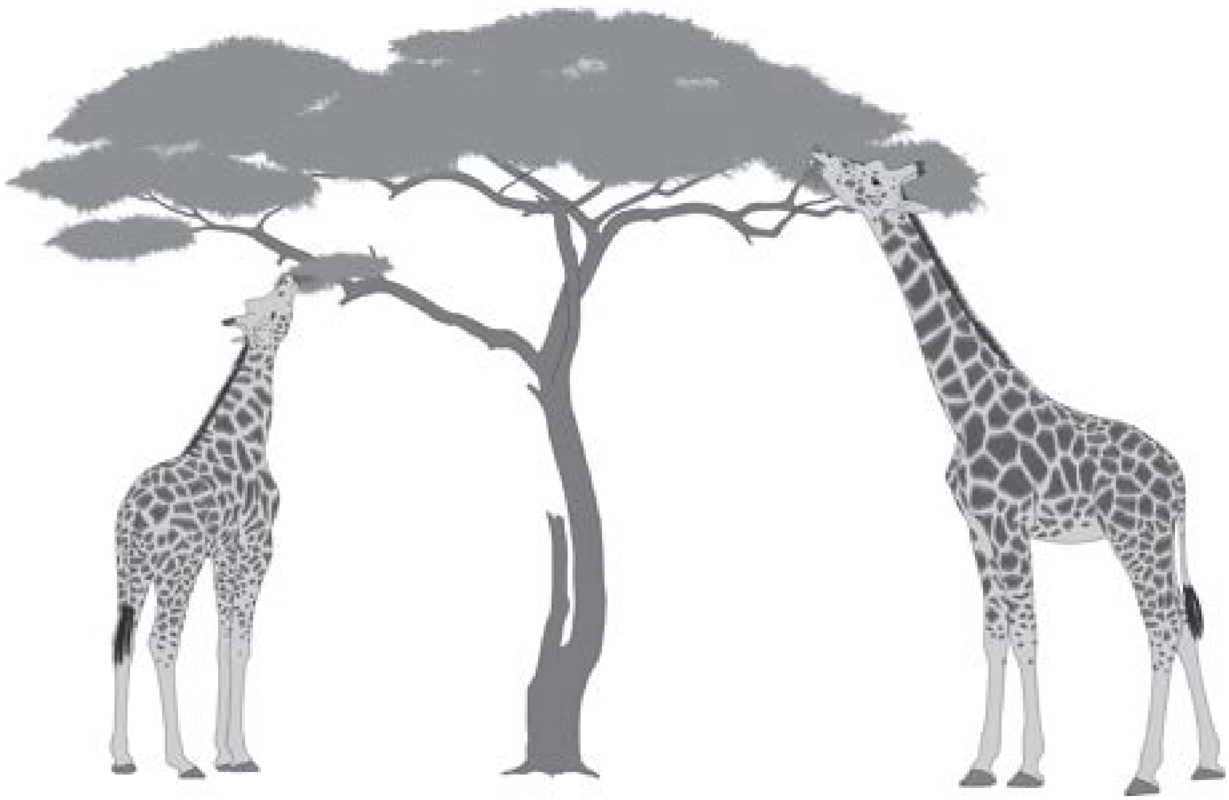


Figure 19.1 Natural Selection in Giraffes

Examples of Evolution by Natural Selection

There are many examples of evolution by natural selection. One example is antibiotic-resistant bacteria. In a bacteria population, some bacteria will have genotypes that cause them to be sensitive to an antibiotic; others have genotypes that confer resistance to an antibiotic. As antibiotics are applied to the environment of a population of bacteria, individual bacterium that are sensitive to the antibiotic will die out while bacteria that have resistance to the antibiotic will survive and reproduce. With continued exposure to the antibiotic, over time, only the antibiotic-resistant bacteria will survive and be present in the population. Note that individual bacterium do not evolve or "learn" to be resistant to the antibiotic; some bacteria already possess the variation that gives them resistance. Initially, these antibiotic-resistant bacteria are less prevalent in the population, but these bacteria are more likely to survive and reproduce in an environment that contains the antibiotic than those that are not antibiotic resistant. Over time, as these bacteria reproduce in the presence of the antibiotic, the frequency of bacteria with antibiotic resistance will increase.

TIP

Avoid using the term *fitness* on the AP Biology exam without explaining what it means (differential reproductive success).

Another example is the peppered moth found in England in the 1800s. Peppered moths have variations in wing color; some moths have darker wings, while others have lighter wings. The coloration of moth wings is an inherited trait. Birds eat the moths, and moths with wing coloration that blends in with their environment are more difficult for birds to see; therefore, those moths are less likely to be eaten by the birds. Prior to the Industrial Revolution in England, trees in the moths' habitat were covered with a light-colored lichen that allowed the lighter-colored moths to blend in with the trees. This made lighter-colored moths more difficult for birds to find and eat, and these lighter-colored moths were predominant in the moth population. During the Industrial Revolution in England in the 1800s, however, sulfur dioxide emissions from factories killed much of the light-colored lichen on the trees. Lighter-colored moths no longer had an advantage, and moths with darker wings were able to blend in with the darker tree bark. This made darker moths more difficult for birds to find and eat. By the 1950s, over 90% of the moths in the population had darker wings. As pollution controls were introduced during the 1960s, the light-colored lichen again covered the trees. Lighter-colored moths once again had a survival advantage and became more prevalent over time. (See Figure 19.2.)

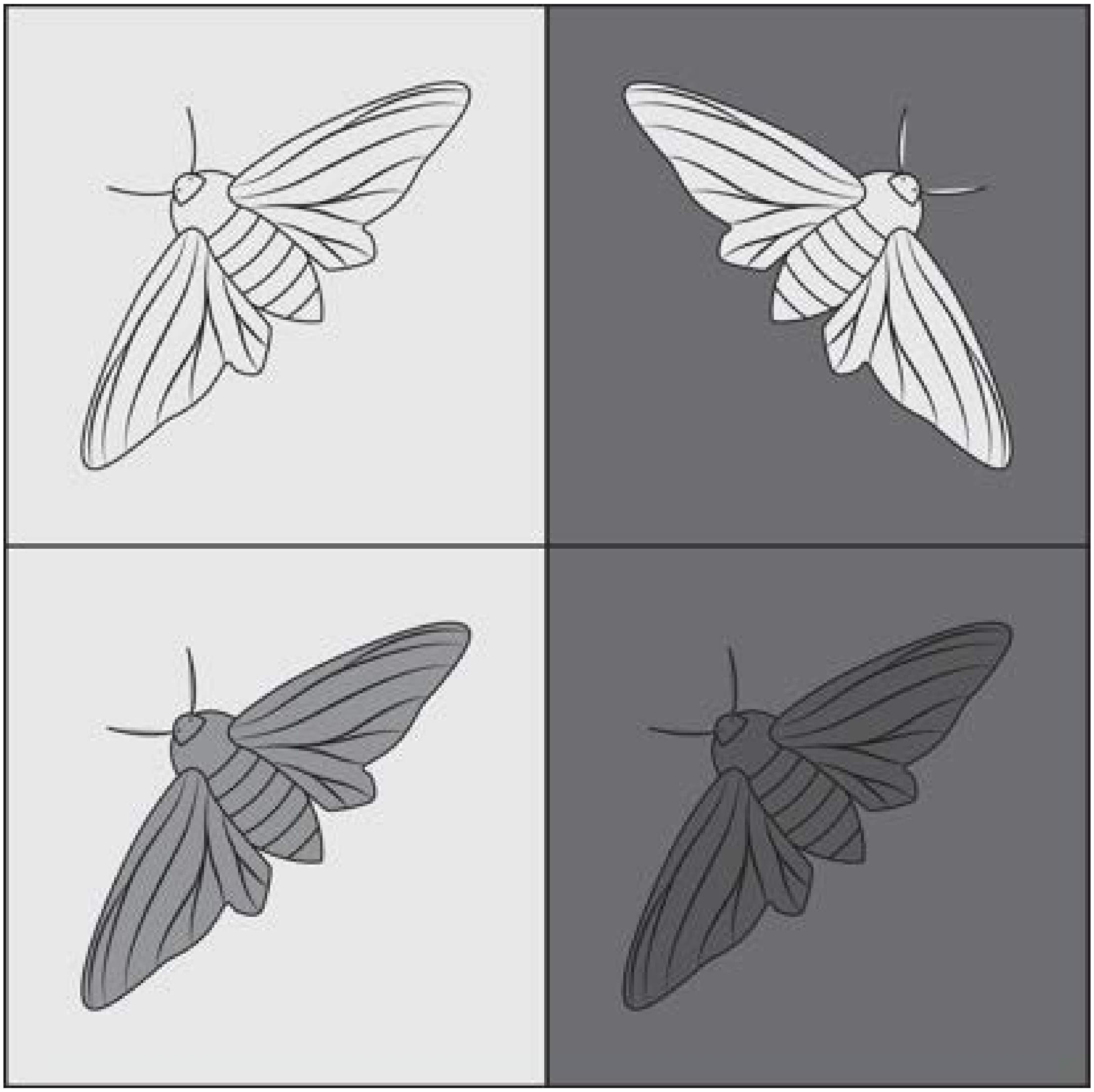


Figure 19.2 Peppered Moths

TIP

A common mistake on the AP Biology exam is to describe evolution with Lamarckian statements, which describe *individuals* evolving in response to their environment. Remember that *populations* evolve; individuals do not.

Darwin's theory of evolution by natural selection would explain this by saying that there were natural variations in the moth population, with some moths having darker wings and some having lighter wings. The moths with darker wings had a survival advantage during the Industrial Revolution and became more prevalent in the population due to natural selection. When the environment changed in the second half of the 20th century, the moths with darker wings no longer had an advantage, so the moths with lighter wings then became more common.

According to the theory of natural selection, the environment selects for individuals with phenotypes that confer a survival advantage in that environment. If the environment changes, different phenotypes may confer an advantage, and the changing environment can change the direction of evolution, as was seen in the peppered moths example.

Remember, evolution is the result of changes in a population over multiple generations. Individuals with characteristics that provide a survival advantage are more likely to survive and reproduce than individuals without those characteristics. With each generation, the proportion of the population with characteristics that provide a survival advantage will increase, leading to the evolution of the population.

Directional Selection

The type of selection that was seen in the peppered moths example is directional selection. **Directional selection** occurs when one end of the range of phenotypes is favored by natural selection, causing the frequency of that phenotype to increase over time. Directional selection is represented by the graph in Figure 19.3.

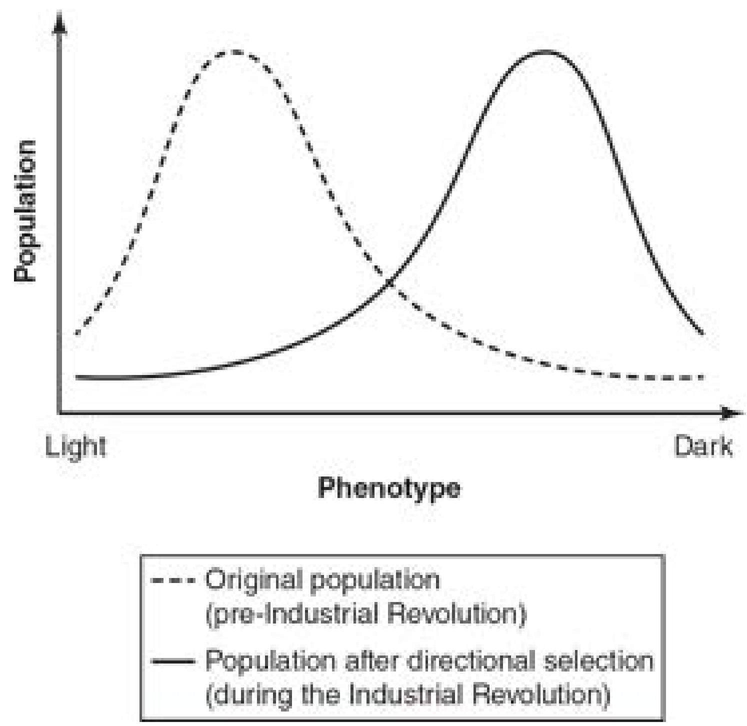


Figure 19.3 Directional Selection

Stabilizing Selection

Natural selection can also lead to **stabilizing selection**, where the intermediate phenotype is favored and extreme phenotypes are selected against. Clutch size (the number of eggs produced per reproductive cycle by birds) exhibits stabilizing selection. If a bird lays a large number of eggs, that bird may have too many offspring to care for and feed, leading to poor reproductive success. However, if the bird lays only one or two eggs per reproductive cycle, there is a risk that none of the offspring may survive. In robins, the average clutch size is five to six eggs per nest. Figure 19.4 shows a graph that represents stabilizing selection.

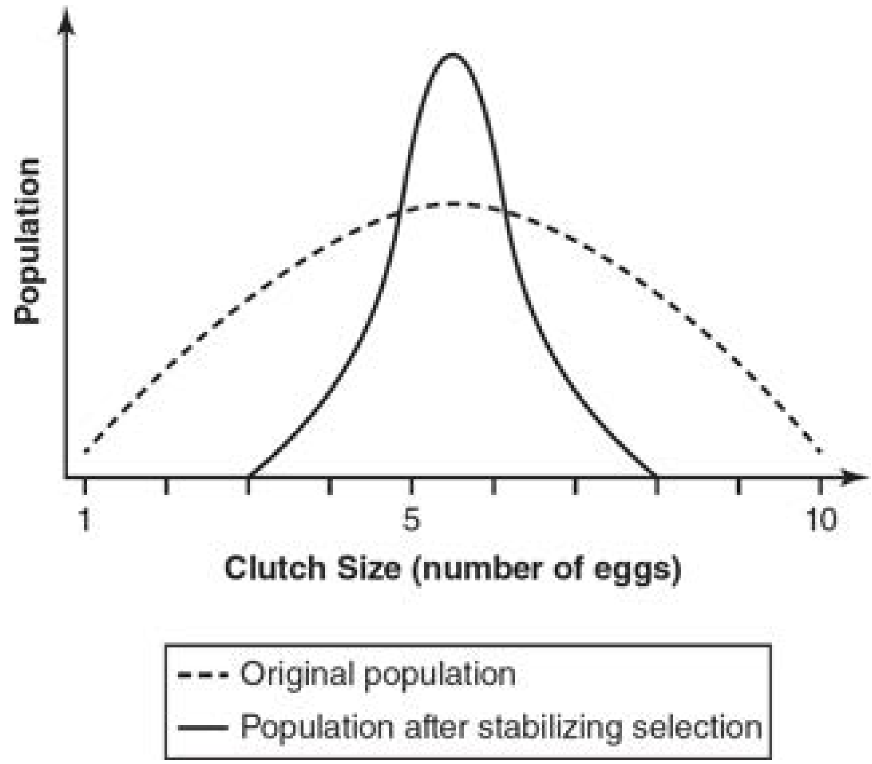


Figure 19.4 Stabilizing Selection

Disruptive Selection

Sometimes, natural selection can lead to **disruptive selection**, where individuals on both extremes of the phenotypic range are more likely to survive and reproduce than individuals with an intermediate phenotype. Consider a habitat with light-colored sandy soil that is interspersed with dark, rocky patches. Mice with light-colored fur in this habitat could blend in with the sandy soil and be less visible to predators. Mice with dark-colored fur could hide in the dark-colored rocks. Mice with an intermediate fur color could not blend in with either the soil or the rocks; they would be more visible to predators and less likely to survive and reproduce. Figure 19.5 represents disruptive selection.

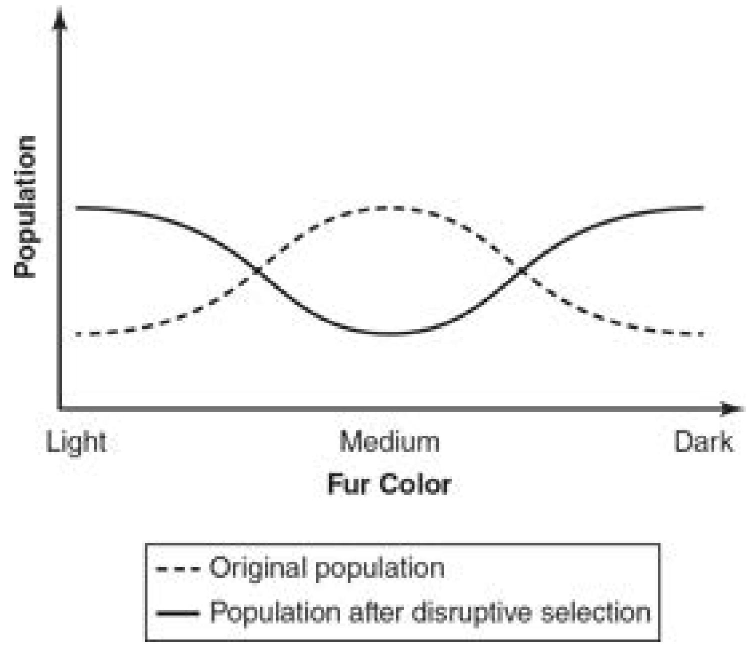


Figure 19.5 Disruptive Selection

Directional, stabilizing, and disruptive selection all rely on the mechanisms of natural selection. Differential reproductive success in different environments results in changes in populations.

Artificial Selection

Individuals in a population can also experience differential reproductive success through artificial selection. In **artificial selection**, humans selectively breed domesticated plants or animals to produce populations with desired traits. Instead of the environment selecting for individuals with favorable phenotypes, humans select which individuals in a population survive and reproduce.

An example of artificial selection in plants can be seen in *Brassica oleracea* wild cabbage. Over the years, farmers have selectively bred wild cabbage for desired traits, as shown in Figure 19.6. By selectively breeding plants with bigger leaves, farmers have developed kale. Selecting for plants with more flower clusters led to cauliflower. Crossbreeding plants with lateral buds has produced Brussels sprouts. Broccoli was produced by selectively breeding plants with both stems that are more robust and have more flowers.

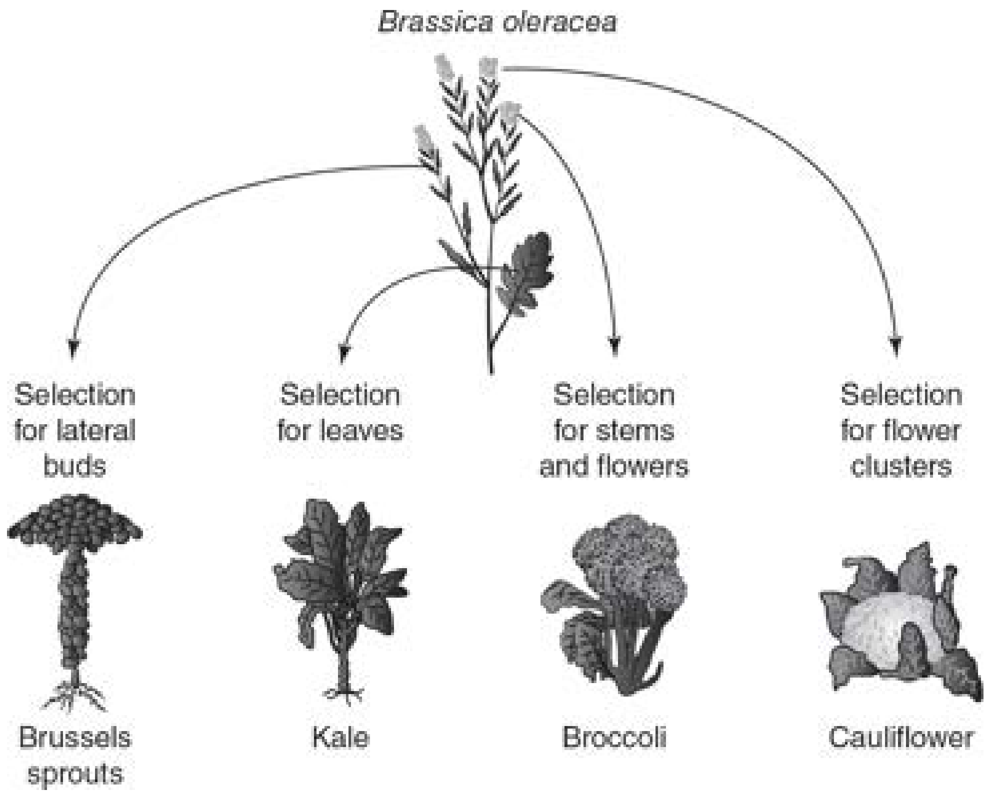


Figure 19.6 Artificial Selection in Wild Cabbage (*Brassica oleracea*)

Humans have used artificial selection to produce desired traits in animals as well. Dog breeds are also a result of artificial selection. Domesticated wolves were selectively bred for particular traits, leading to the wide variety of dog breeds seen today. Over the last 10,000 years, human populations have selectively bred members of the aurochs (the wild bovine related to oxen) to obtain the many breeds of domestic cattle seen today.

Sexual Selection

Sexual selection occurs when individuals with certain characteristics are more likely to attract mates than other individuals. Over time, individuals with traits that are more likely to attract mates become more prevalent in the population.

In intersexual selection, individuals of one sex are particular in selecting mates from the other sex. Mate choice may be based on perceived fitness of the members of the other sex, with members who seem stronger or healthier being more likely to produce offspring that will survive. Many bird behaviors involve mate choice. Birds may choose mates based on coloration, bird songs, mating dances, or nesting behaviors. An example of this is seen in *Pavo cristatus* (the peacock). Peacocks with brighter plumage are more likely to attract mates than their counterparts with duller plumage. Female members of *Sula nebouxii*, the blue-footed booby bird, select mates with the brightest blue feet. Younger males have brighter blue feet and are more likely to have higher fertility.

In intrasexual selection, members of one sex compete for mates of the other sex. This may involve asserting dominance to ward off competitors and gain better access to mates.

Practice Questions

Multiple-Choice

Questions 1 and 2

Drs. Peter and Rosemary Grant have studied the rate of evolutionary change in the finch populations of the Galapagos Islands. Beak size in these finches determines which types of seeds the finch populations feed on. Finches with larger beaks eat thick-walled seeds, while finches with smaller beaks eat thin-walled seeds. During a drought from 1981 to 1987, the number of plants that produced thin-walled seeds decreased. It was determined that the average beak size (both length and mass) of finches increased dramatically during the drought.

1. Which type of selection most likely led to the change in beak size during the drought?

   (A) directional selection
   (B) disruptive selection
   (C) stabilizing selection
   (D) sexual selection

2. During the years 1988 to 1995, the average beak size of the finches decreased. Which of the following is the most likely explanation for this change?

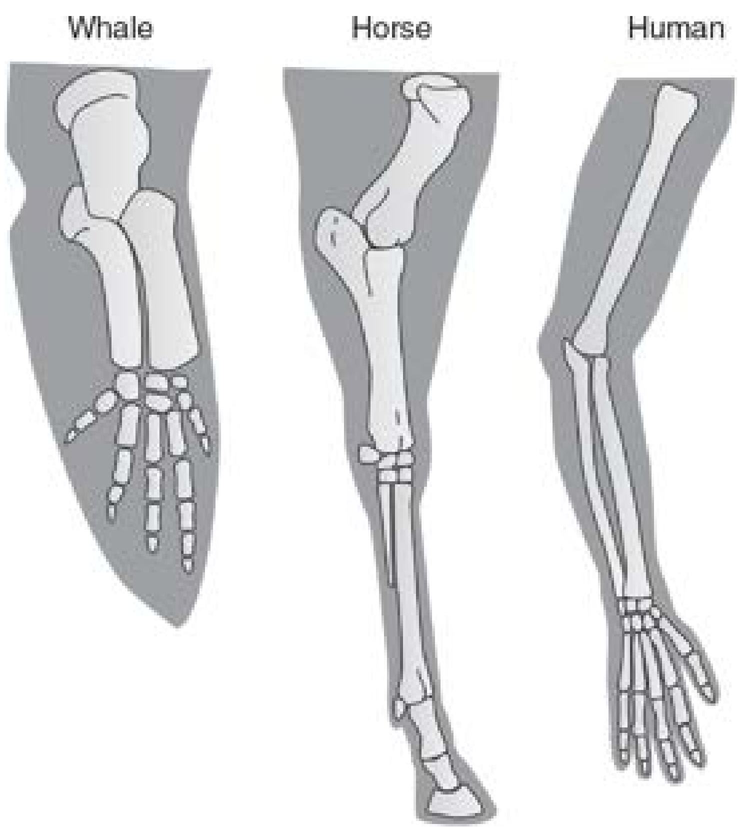
   (A) Female finches prefer to mate with males with smaller beaks.
   (B) The drought ended, and the average rainfall returned to predrought levels.
   (C) Predator populations increased.
   (D) Finches with larger beaks were more susceptible to diseases.

---

3. Which of the following would best determine whether two species of birds have a recent common ancestor?

(A) DNA sequences
(B) fossil record
(C) habitat distribution
(D) mating behaviors

4. The following figure shows the bone structures of the limbs of a whale, a horse, and a human.



These are examples of which types of structures?

(A) analogous
(B) convergent
(C) homologous
(D) vestigial

5. Triclosan is an antibacterial chemical that is used in some household products to reduce bacteria levels. Which of the following is the most

likely result of increased use of products that contain triclosan over time?

(A) All household bacteria species will be eliminated.
(B) Household bacteria species will become resistant to triclosan.
(C) Individual bacteria will learn how to resist the effects of triclosan.
(D) Increased triclosan levels will increase the frequency of mutations in household bacteria.

6. Snakes feed on toads. Cane toads (*Rhinella marina*) excrete a toxic substance on their skin that is poisonous to many, but not all, snake species. If cane toads are introduced to a new environment, predict the most likely effect on the snake species in that environment.

(A) All snake species in the environment will die out due to the cane toads' toxin.
(B) Snake species that are resistant to the cane toads' toxin will increase in numbers.
(C) Snakes that are susceptible to the cane toads' toxin will acquire resistance to the toxin.
(D) All snake species will learn to avoid eating cane toads.

7. The human *TAS2R38* gene encodes a cell membrane protein that influences the ability to taste bitter compounds. Individuals who possess at least one *TAS2R38* allele have the "taster" phenotype and can taste certain types of bitter compounds. It is estimated that about 70% of humans have the taster phenotype. Which of the following best explains the frequency of the taster phenotype?

(A) Many toxic compounds have a bitter taste, so the *TAS2R38* allele provided a survival advantage in ancestral humans.
(B) Ancestral humans with the *TAS2R38* allele were more likely to consume bitter-tasting foods.
(C) Bitter-tasting foods have a higher nutrient content and were more likely to be consumed by ancestral humans who did not have the

TAS2R38 allele.

(D) A lack of the *TAS2R38* allele provided a survival advantage in ancestral humans.

8. The Aztecs were some of the first humans to slowly change teosinte, also known as wild corn, into the current form of corn eaten today. Which process did the Aztecs most likely use?

(A) artificial selection
(B) frequency-dependent selection
(C) natural selection
(D) sexual selection

9. Which of the following assertions (about how evolution by natural selection occurs) is incorrect?

(A) There are variations among individuals of a species.
(B) Some variations provide a survival advantage.
(C) Variations acquired during an individual's lifetime are passed on to the individual's offspring.
(D) Over time, the frequency of individuals with variations that provide a survival advantage will increase.

10. Rock pocket mice (*Chaetodipus intermedius*) are found in rocky outcrops in the desert of the southwestern United States. Some rock pocket mice have light-colored fur, while others have dark-colored fur. A population of rock pocket mice lives in a desert with both light-colored sand dunes and dark-colored rocks. Owls and hawks prey on the rock pocket mice they see. The initial ratio of light-colored to dark-colored mice in this population is approximately 1:1. A sandstorm occurs in the habitat of this population of rock pocket mice, and it covers all of the habitat in a thick layer of light-colored sand. Predict the most likely effect of this on the rock pocket mouse population.

(A) The relative frequency of dark-colored rock pocket mice would increase.

(B) The relative frequency of light-colored rock pocket mice would increase.

(C) The numbers of both dark-colored and light-colored rock pocket mice would decrease.

(D) The numbers of both dark-colored and light-colored rock pocket mice would increase.

Short Free-Response

11. Three new species (A, B, and C) of fossilized crocodile are discovered. The characteristics of these species are compared to those of the saltwater crocodile, *Crocodylus porosus*. The saltwater crocodile is found in Southeast Asia and Australia, and adults range in length from 5.5 to 5.8 meters and have 66 teeth. Data comparing the characteristics of the three fossilized crocodile species are shown in the table.

	A	B	C
Location of Fossils	Africa	Europe	Asia
Number of Teeth	48	56	72
Nose to Tail Length (m)	4.7	5.5	6.3
Percent of Homology of DNA with *Crocodylus porosus*	93%	90%	98%

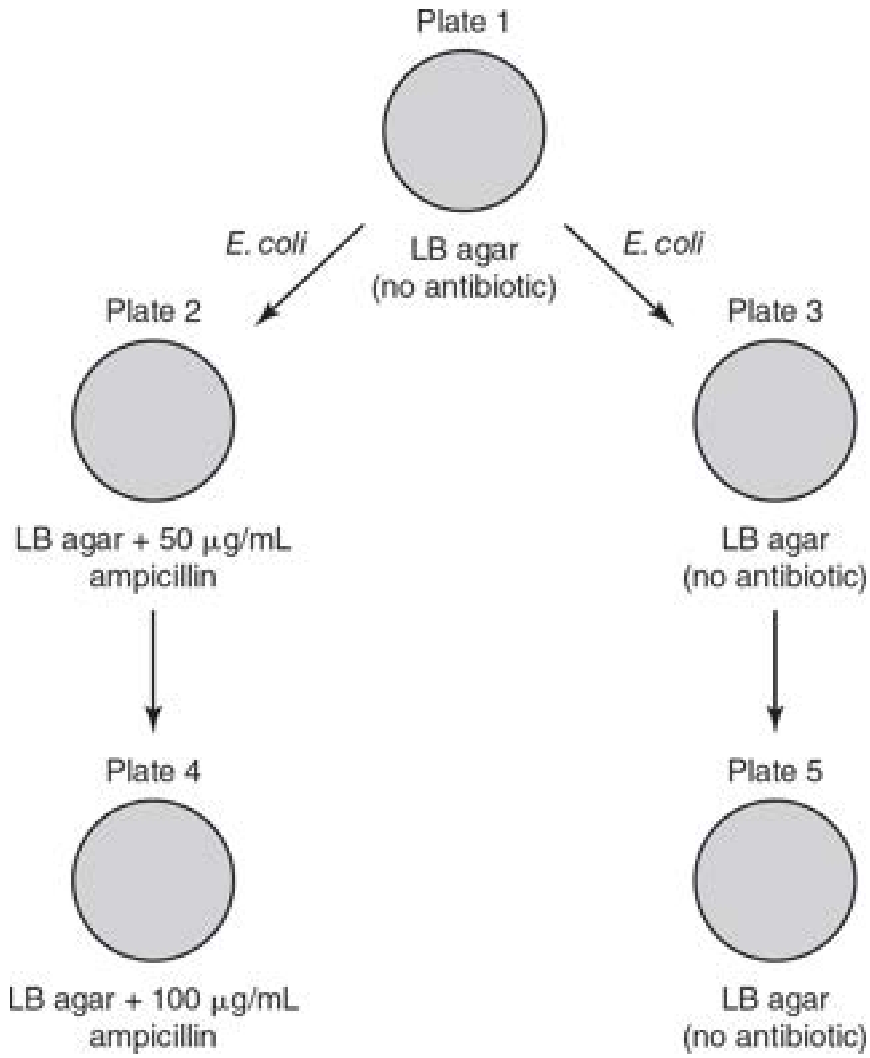
(a) Based on the data given, **identify** the fossil species that has the most in common with *Crocodylus porosus*.

(b) The number of teeth in a crocodile jaw correlates with increased predator efficiency. **Identify** the crocodile(s) that would be less efficient predators than *C. porosus*.

(c) **Evaluate** the claim that species B shares a more recent common ancestor with *C. porosus* than do species A or species C.

(d) **Explain** your reasoning for your response from part (c).

12. A student performs an experiment to study the effects of repeated exposure to antibiotics on bacteria. A strain of *E. coli* that is not antibiotic resistant is grown on an antibiotic-free LB agar plate (plate 1), the starter plate. Some of the *E. coli* from the starter plate are then spread on a plate that contains LB agar and 50 ug/mL of the antibiotic ampicillin (plate 2), and some of the *E. coli* are spread on a plate that contains LB agar without antibiotic (plate 3). *E. coli* from plate 2 are then spread on a plate that contains LB agar and 100 ug/mL of the antibiotic ampicillin (plate 4). *E. coli* from plate 3 are then spread on a plate that contains LB agar without antibiotic (plate 5). A diagram of the experimental plates is shown in the figure.



(a) **Describe** whether *E. coli* that are all susceptible to ampicillin, all resistant to ampicillin, or a mix of both will grow on the starter plate. **Explain** your answer using the principles of natural selection.

(b) **Identify** the plates that serve as controls in this experiment. **Identify** the independent variable in the experiment.

(c) **Predict** the relative amount of *E. coli* growth on plates 2, 3, 4, and 5.

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

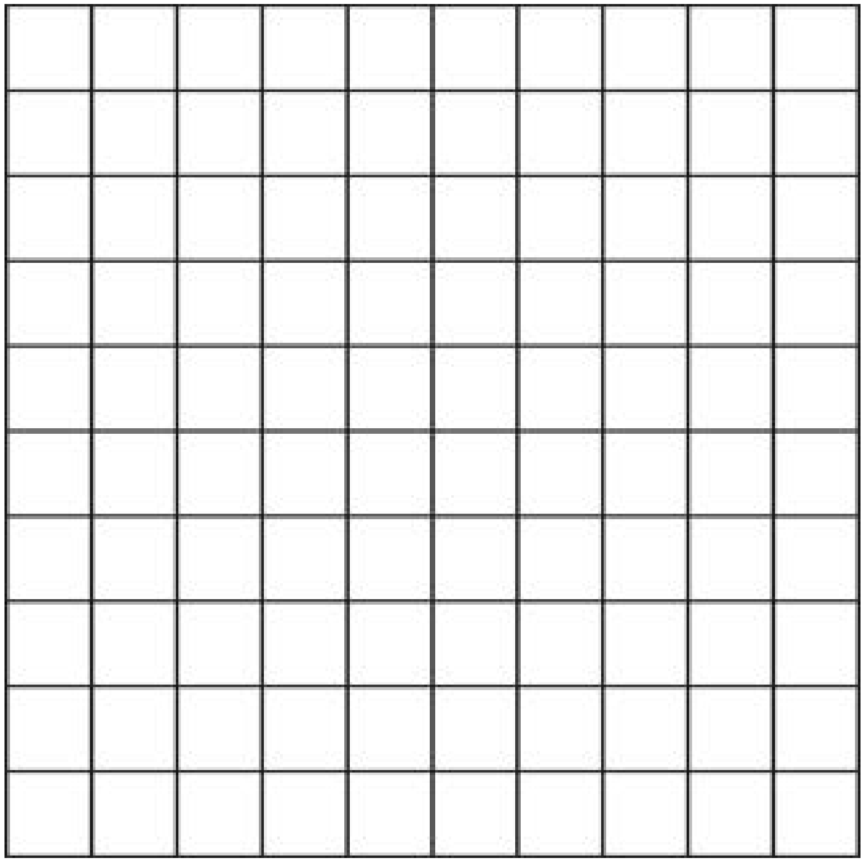
Long Free-Response

13. Wild guppies (*Poecilia reticulata*) live in ponds on the island of Trinidad. Male guppies have great variation in the number and colors of spots, leading to a wide variety of color patterns among male guppies. Female guppies do not express these spots and are drably colored. Female guppies will more often choose to mate with males who possess bright color patterns. However, males with brighter color patterns are more visible to predators. An experiment was performed to measure the effect of the presence of a guppy predator (*Cichlidae alta*) on the number of spots in male guppies. Guppies were placed into two different environments: one with no predators and the other in which *C. alta* was present. Guppies were allowed to reproduce in both environments for 20 generations. After 20 generations, the number of spots on each male guppy was counted. The mean number of spots on male guppies is shown in the table.

Total Number of Spots per Male Guppy		
	Mean	Standard Error of the Mean
No Predators	13	0.5
Presence of *C. alta*	9	0.5

(a) **Describe** the type of selection (directional, stabilizing, or disruptive) that is caused by the presence of *C. alta*.

(b) On the axes provided, **construct** a graph of the mean number of spots per male guppy for each group. Include 95% confidence intervals on your graph.



(c) Use the graph you constructed in part (b) to **make a claim** about the mean number of spots per male guppy in the no-predator environment as compared to the mean number of spots per male guppy in the environment with *C. alta*. **Support** your claim with evidence from the graph.

(d) As a follow-up experiment, some of the guppies in the environment with *C. alta* were removed and placed in an environment with no predators. They were allowed to reproduce for 20 generations. **Predict** what you would expect to happen to the mean number of spots per male guppy in this new predator-free environment after the guppies were allowed to reproduce for 20 generations. **Justify** your prediction.

Answer Explanations

Multiple-Choice

1. **(A)** Directional selection occurs when one end, or extreme, of the range of phenotypes has a survival advantage. In this example, birds with larger beaks were more likely to survive. Disruptive selection occurs when both extremes of the range of phenotypes increase in frequency; since only large beaks increased in frequency and small beaks decreased in frequency, choice (B) is incorrect. Choice (C) is incorrect because stabilizing selection favors the middle range of the phenotype, which did not occur in this case. There is no evidence in the question that suggests that mate preference is dependent on beak size, so choice (D) is incorrect.

2. **(B)** Before the drought, there were more thin-walled seeds and therefore more food available for finches with smaller beaks. Therefore, the end of the drought would increase food availability for finches with smaller beaks and allow more finches with smaller beaks to survive. There is no evidence in the question that suggests females have a mate preference that is dependent on beak size, so choice (A) is incorrect. Choice (C) is incorrect because there is no evidence for predators killing more finches of either beak size. The question does not give any information about disease susceptibility or resistance, so choice (D) is incorrect.

3. **(A)** DNA sequences are generally considered stronger pieces of evidence of evolution because environmental factors are far less likely to change the DNA sequence of a fossil. Choice (B) is incorrect because geological events can change the relative positions of fossils in rock layers and make the original location of the fossil position less certain. Birds can fly and move to new habitats, so choice (C) is incorrect. Choice (D) is incorrect because mating behaviors of birds may be influenced by their environments or by learning these behaviors from other birds.

4. **(C)** Homologous structures indicate common ancestry but may have different functions. Whales, horses, and humans are all mammals and

share common ancestry, but their limbs have different functions. Analogous structures have similar functions. However, whale limbs are used for swimming, horse limbs are used for trotting or running, and human limbs are used for reaching and grasping; they do not have similar functions, so choice (A) is incorrect. Choice (B) is incorrect because convergent evolution results in analogous structures and does not indicate common ancestry. Vestigial structures are structures in an organism that have no current function but may have had a function in an ancestral species, so choice (D) is incorrect.

5. **(B)** Increased use of products that contain triclosan will create an environment in which triclosan-resistant bacteria have a survival advantage, so over time the relative numbers of triclosan-resistant bacteria will increase. Choice (A) is incorrect because there is no evidence that triclosan kills all bacteria. Individuals do not evolve, populations evolve, so choice (C) is incorrect. Choice (D) is incorrect because there is no evidence in the question that the use of triclosan increases the frequency of mutations in bacteria.

6. **(B)** Snakes that are resistant to the cane toads' toxin would be more likely to survive and reproduce, so their relative numbers would be expected to increase over time. Choice (A) is incorrect because not all snakes are susceptible to the cane toads' toxin, so not all the snakes would die. Individual snakes cannot acquire resistance to the cane toads' toxin, so choice (C) is incorrect. Choice (D) is incorrect because there is no evidence in the question that snakes would learn to avoid eating cane toads.

7. **(A)** Since *TAS2R38* is present in the population at a higher frequency, it probably did provide a survival advantage and allowed individuals who possessed this allele to survive and reproduce at a greater rate than individuals who did not possess the allele. Choice (B) is incorrect because *TAS2R38* does not cause individuals to consume bitter foods; it just influences their ability to taste bitter foods. Bitter foods do not necessarily have a higher nutrient content than other foods, so choice (C) is incorrect. There is no evidence in the question that the *TAS2R38* allele lowered an individual's chance of survival, so choice (D) is incorrect.

8. **(A)** Artificial selection occurs when humans selectively breed organisms for desired traits. Frequency-dependent selection occurs when the survival of an organism depends on its frequency in an environment, so choice (B) is incorrect. Choice (C) is incorrect because in natural selection, the environment selects for which individuals survive and reproduce. There is no evidence for mate choice in the question; plants usually depend on the wind or animal pollinators to exchange gametes, so choice (D) is incorrect.

9. **(C)** Variations that individuals acquire during their lifetime are called acquired characteristics and are not passed on to the individual's offspring. There are variations among individuals of a species, so choice (A) is not the answer. Choice (B) is not the answer because some variations do provide a survival advantage. Over time, natural selection will increase the frequency of individuals who possess variations that give them a survival advantage, so choice (D) also not the answer.

10. **(B)** The light-colored mice will blend in with the sandy background and be less visible to predators, so their numbers would increase. Choice (A) is incorrect because dark-colored mice would be more visible to predators against the sandy background, and their numbers would decrease. Choices (C) and (D) are incorrect because the sandy background would increase the survival of light-colored mice and decrease the survival of dark-colored mice.

Short Free-Response

11. (a) Species C has the most in common with *Crocodylus porosus* because they are both found in Asia, the number of teeth in species C is closest to the number of teeth in *C. porosus*, and the DNA sequence of species C has the highest percentage of homology with *C. porosus*.

    (b) Species A and species B would be less efficient predators than *C. porosus* because they both have fewer teeth than *C. porosus*.

(c) The data do not support the claim that species B shares a more recent common ancestor with *C. porosus* than do species A or species C. In fact, species C has the most in common with *C. porosus*.

(d) The DNA from species B only has 90% homology with the DNA from *C. porosus*, while species C's DNA has 98% homology with the DNA from *C. porosus*. Thus, species C likely has a more recent common ancestor with *C. porosus* than species B does.

12. (a) It is likely that the *E. coli* on the starter plate (plate 1) contain mostly bacteria that are susceptible to ampicillin and some bacteria that are resistant to ampicillin. Natural selection acts upon variations in populations, and it is likely that there are varying degrees of resistance to ampicillin in the bacteria population.

(b) The controls are plates 3 and 5 (the plates without ampicillin). The independent variable is the concentration of ampicillin on each plate.

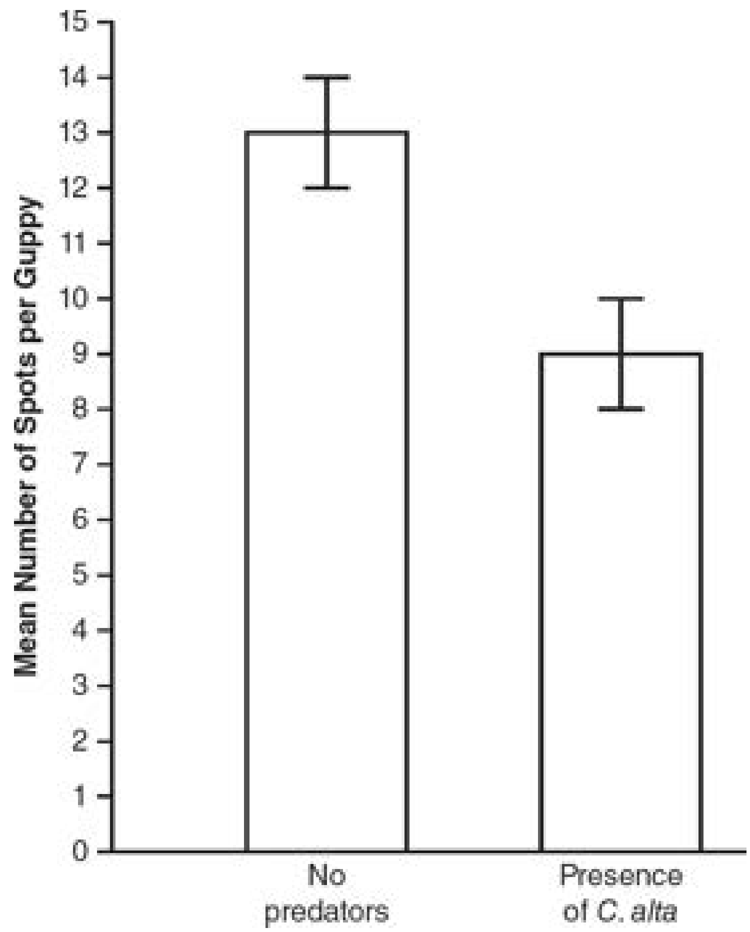
(c) Plates 3 and 5 will have many bacteria, perhaps a solid "lawn" of bacteria on each of those plates. Plates 2 and 4 will have very few bacteria growing on them.

(d) Since the starter plate did not contain ampicillin, there was no selection for ampicillin resistance on that plate, and so the majority of the bacteria on the starter plate are expected to not have resistance to ampicillin. Therefore, very few bacteria are expected to grow on plates 2 and 4, which contain ampicillin. Many more bacteria will grow on plates 3 and 5 since those plates do not contain ampicillin.

Long Free-Response

13. (a) This is an example of directional selection because in the presence of the predator *C. alta*, the mean number of spots per male guppy decreases.

(b)



(c) There is a statistically significant difference between the mean number of spots per guppy in the environment without predators and in the environment with *C. alta*. This claim is supported by the data because the 95% confidence intervals of the two groups do not overlap.

(d) If the guppies were moved out of the environment that had the predator *C. alta* and were placed into an environment without predators, over time, it would be expected that the mean number of spots per male guppy would increase. This is because there would no longer be a disadvantage to having spots, and spots would attract mates, increasing the likelihood that the guppies with spots would reproduce.