Chapter 15: How Organisms Evolve

OVERVIEW

In this chapter, you will learn about the basic principles of population genetics, including how to calculate gene and genotype frequencies and the Hardy-Weinberg principle. The authors examine the major forces causing evolution, which are mutation, migration, small population size, nonrandom mating, and natural selection. The authors also discuss the three ways that natural selection acts on populations, which are called stabilizing, disruptive, and directional selection. The authors also enumerate the results of natural selection.

In 1999, four children died of pneumonia and blood infections caused by an antibiotic-resistant "supergerm" called *Staphylococcus aureus* (or staph) contracted in the children's homes and communities. Antibiotics are losing their effectiveness against many bacterial diseases, raising the specter of incurable diseases, resistant to all known treatments. Ironically, the spread of resistance among bacteria is a response to humans using antibiotics to fight these bacteria, obviously not the outcome doctors wished to occur.

1) How Are Populations, Genes, and Evolution Related?

Evolutionary changes occur from generation to generation so that descendants are different from their ancestors. Evolution is a property not of individuals but of **populations** (all individuals of a species living in a given area). Inheritance provides the link between the lives of individuals and evolution of populations. **Population genetics** is the study of the frequency, distribution, and inheritance of alleles in populations. The **gene pool** is the sum of all the genes in a population. The relative frequencies of various alleles in a population are the **allele frequencies**. Evolution is changes in gene frequencies that occur in a gene pool over time.

The **Hardy-Weinberg principle** states that under certain conditions, allele and genotype frequencies in a population will remain constant over time (evolution will not occur). Such an evolution-free population is an **equilibrium population** that will remain in **genetic equilibrium** as long as: (1) there is no mutation; (2) there is no **gene flow** (migration) between populations; (3) the population is extremely large; (4) all mating is random; and (5) there is no natural selection (all genotypes reproduce equally well). Few natural populations are in genetic equilibrium.

2) What Causes Evolution?

There are five major causes of evolutionary change: mutation, gene flow, small population size, nonrandom mating, and natural selection. Mutations (changes in DNA sequence) are the ultimate source of genetic variability.

Mutations occur at rates between 1 in 100,000 and 1 in 1,000,000 genes per individual per generation. Although mutation by itself is not a major evolutionary force, without mutations there would be no evolution and no diversity among life forms. Mutations are not goal-directed, but random. Mutations provide potential for change; other forces, especially natural selection, act on that potential and may favor the spread or the elimination of a mutation within a population.

Gene flow, or migration between populations, changes allele frequencies. It spreads advantageous alleles throughout a species, and helps maintain all the organisms over a large area as one species since the populations cannot become very different in allele frequencies as long as gene flow occurs.

Small populations are subject to random changes in allele frequencies, a process called **genetic drift**. In large populations, chance events are unlikely to significantly alter the overall gene frequencies.

However, in small populations, chance events could reduce or eliminate alleles, greatly altering in a random way its genetic makeup. Genetic drift tends to reduce genetic variability within small populations, and genetic drift tends to increase genetic variability between or among populations. A **population bottleneck**, which is a drastic reduction in numbers followed by expansion in numbers from the few survivors, may cause both changes in allele frequencies and reduction in genetic variability, not allowing the population to evolve in response to environmental changes. Examples of this include the northern elephant seal and the cheetah. In the **founder effect**, some isolated populations are founded by a small number of individuals who may have different allele frequencies than the larger parent population due to chance, and this may lead to a sizable new population that differs greatly from the original. Populations occasionally become very small, and these may contribute significantly to major evolutionary changes.

Random mating rarely occurs within populations, and often individuals will seek mates with similar traits to themselves, a behavior known as assortative mating. All genotypes are not equally adaptive. Any time an allele confers a slight advantage to some individuals, natural selection will favor the enhanced reproduction of those individuals. Four important points about natural selection and evolution are: (1) natural selection does not cause genetic changes in individuals; (2) natural selection acts on individuals (causing unequal reproduction) but evolution (changes in gene frequencies) occurs in populations; (3) evolution is a change in the allele frequencies of a population, owing to unequal reproduction among organisms bearing different alleles (the **fitness** of an organism is a measure of its reproductive success); and (4) evolutionary changes are not "good" or "progressive" in an absolute sense, just relative to the environmental circumstances present at any particular time and place.

3) How Does Natural Selection Work?

Natural selection is primarily an issue of **differential reproduction**: organisms with favorable alleles leave more offspring (who inherit those alleles) than do other individuals with less favorable alleles. Natural selection acts on the phenotype, which reflects the underlying genotype. Natural selection can influence populations in three major ways.

Directional selection shifts character traits in a specific direction: it favors individuals at one end of a distribution range for a trait and selects against average individuals and those at the opposite extreme of the distribution. An example might be that directional selection favors small size against both average and large individuals in a population. If the environment gets colder, then a species may evolve in a constant direction for thicker fur.

Stabilizing selection acts against individuals who deviate too far from the average: it favors individuals having an average value for a trait and selects against individuals with extreme values due to opposing environmental pressures. An example might be that small lizards have a hard time defending territories, but large lizards are more likely eaten by owls. Opposing environmental pressures may produce **balanced polymorphisms**, in which two or more alleles are maintained in a population because each is favored by a separate environmental force. For example, in Africa, malaria is a health problem. People homozygous for the sickle cell anemia allele are unhealthy. People homozygous for the normal allele are susceptible to severe malaria. Heterozygous people suffer only mild anemia and are more resistant to malaria.

Disruptive selection adapts individuals within a population to different habitats: it favors individuals at both ends of the distribution of a trait and selects against average individuals. For example, in African birds called black-bellied seedcrackers, some have large beaks for cracking hard seeds, and others have small beaks for cracking soft seeds, but there are few birds with medium beaks.

A variety of processes can cause natural selection. Organisms with reproductively successful phenotypes have the best **adaptations** (characteristics that help an individual survive and reproduce) to their particular environments. **Competition** for scarce resources favors the best-adapted individuals. When two species interact extensively, as seen with predators and their prey, each exerts strong selection pressure on the other. When one evolves a new feature or modifies an old one, the other typically evolves new

adaptations in response, a constant mutual feedback situation called **coevolution**. **Predation** includes any situation where one organism (the predator) eats another (the prey). Predation often leads to coevolution between predator and prey species. **Symbiosis** (individuals of different species live in intimate contact for long periods) leads to the most intricate coevolutionary adaptations. Sexual selection favors traits that help an organism mate.

Kin selection favors altruistic behaviors. **Altruism** is any behavior that endangers an individual or reduces its reproductive success but benefits other members of the species. If the altruistic individual helps relatives who possess the same alleles, this is called kin selection. Altruistic behaviors make sense in evolution when you consider the relationship of the organisms involved and you consider **inclusive fitness**. Inclusive fitness is determined by an individual's success at contributing its genes to the next generation. If an individual is not reproducing and directly adding its own genes, they can at least ensure that the genes of close relatives are passed on.

Case study revisited. The evolution of antibiotic resistance in bacterial populations is a direct consequence of natural selection applied by widespread use of antibiotic drugs, killing the sensitive bacteria and allowing the resistant ones to gain a reproductive advantage, producing disproportionally more offspring with resistant genes in the next generation. Physicians prescribe more antibiotics than is necessary, antibiotics are fed to farm animals, and antibiotic soaps and cleansers are used in households. How can further evolution of antibiotic resistance be prevented?

KEY TERMS AND CONCEPTS

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

adaptation	disruptive selection	genetic drift
allele frequency	evolution	Hardy-Weinberg principle
altruism	fitness	kin selection
balanced polymorphism	founder effect	population
coevolution	gene flow	predation
Darwin	gene pool	prey

1. _______________ is a trait that helps an organism survive and reproduce in a particular environment.

2. The prolonged maintenance of two or more alleles in a population is called _________________.

3. When __________________ occurs, alleles move from one population to another due to the migration of organisms.

4. ___________________ is the change in the allele frequencies of a small population purely by chance.

5. _______________ favors a certain allele because it increases the survival or reproductive success of relatives bearing the same allele. The behavior that endangers an individual but benefits other members of its species is called _______________.

6. ______________________ represents significant changes in allele frequencies over time in a population and ___________________ is the evolution of adaptations in different species due to extensive interactions with each other.

7. When ________________ occurs, both extremes are favored over the average phenotype.

8. ______________ wrote *On the Origin of Species* in 1859.

9. The ___________________ occurs when an isolated population is founded by a small number of individuals, this population may develop allele frequencies that are very different from those of the parent population.

10. Under certain conditions, allele and genotype frequencies in a population will remain constant over time. This is called the ________________.

11. A ________________ is a group of individuals of the same species found in the same time and place.

12. The ___________________ is defined as the relative proportion of each allele of a gene found in a population.

13. The total of all alleles of all genes in the population is the __________________.

14. _________________ is the measure of the reproductive success of an organism.

15. Any situation involving one organism eating another is ________________. The organisms that are eaten by predators are called ________________.

Key Terms and Definitions

adaptation: a trait that increases the ability of an individual to survive and reproduce compared to individuals without the trait.

allele frequency: for any given gene, the relative proportion of each allele of that gene in a population.

altruism: a type of behavior that may decrease the reproductive success of the individual performing it but benefits that of other individuals.

balanced polymorphism: the prolonged maintenance of two or more alleles in a population, normally because each allele is favored by a separate environmental pressure.

coevolution: the evolution of adaptations in two species due to their extensive interactions with one another, such that each species acts as a major force of natural selection on the other.

competition: interaction among individuals who attempt to utilize a resource (for example, food or space) that is limited relative to the demand for it.

differential reproduction: differences in reproductive output among individuals of a population, normally as a result of genetic differences.

directional selection: a type of natural selection in which one extreme phenotype is favored over all others.

disruptive selection: a type of natural selection in which both extreme phenotypes are favored over the average phenotype.

equilibrium population: a population in which allele frequencies and the distribution of genotypes do not change from generation to generation.

fitness: the reproductive success of an organism, usually expressed in relation to the average reproductive success of all individuals in the same population.

founder effect: a type of genetic drift in which an isolated population founded by a small number of individuals may develop allele frequencies that are very different from those of the parent population as a result of chance inclusion of disproportionate numbers of certain alleles in the founders.

gene flow: the movement of alleles from one population to another owing to the migration of individual organisms.

gene pool: the total of all alleles of all genes in a population; for a single gene, the total of all the alleles of that gene that occur in a population.

genetic drift: a change in the allele frequencies of a small population purely by chance.

genetic equilibrium: a state in which the allele frequencies and the distribution of genotypes of a population do not change from generation to generation.

Hardy-Weinberg principle: a mathematical model proposing that, under certain conditions, the allele frequencies and genotype frequencies in a sexually reproducing population will remain constant over generations.

inclusive fitness: the reproductive success of all organisms that bear a given allele, normally expressed in relation to the average reproductive success of all individuals in the same population; compare with *fitness*.

kin selection: a type of natural selection that favors a certain allele because it increases the survival or reproductive success of relatives that bear the same allele.

natural selection: the unequal survival and reproduction of organisms due to environmental forces, resulting in the preservation of favorable adaptations. Usually, natural selection refers specifically to differential survival and reproduction on the basis of genetic differences among individuals.

population: all the members of a particular species within an ecosystem, found in the same time and place and actually or potentially interbreeding.

population bottleneck: a form of genetic drift in which a population becomes extremely small; may lead to differences in allele frequencies as compared with other populations of the species and to a loss in genetic variability.

population genetics: the study of the frequency, distribution, and inheritance of alleles in a population.

predation (pre-dā´-shun): the act of killing and eating another living organism.

sexual selection: a type of natural selection in which the choice of mates by one sex is the selective agent.

stabilizing selection: a type of natural selection in which those organisms that display extreme phenotypes are selected against.

symbiosis (sim´-bī-ō´sis): a close interaction between organisms of different species over an extended period. Either or both species may benefit from the association, or (in the case of parasitism) one of the participants is harmed. Symbiosis includes parasitism, mutualism, and commensalism.

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.

16. _____ Individual plants or animals <u>change</u> in response to selection.

17. _____ For a population to remain at equilibrium, it must be <u>large</u>.

18. _____ <u>Mutation</u> is the factor that controls the direction of evolution.

19. _____ Genetic drift is a characteristic of <u>large</u> populations.

20. _____ Natural selection acts on <u>genotypes</u> directly.

21. _____ Stabilizing selection results in <u>change</u>.

22. _____ Gene flow tends to <u>decrease</u> differences between populations.

23. _____ Both large-beaked and small-beaked varieties of a single species of birds can be maintained in an area by <u>disruptive</u> selection.

24. _____ Behavior that endangers an organism but benefits its close relatives is <u>symbiosis</u>.

25. _____ Most species eventually <u>give rise to new species</u>.

Short Answer:

A population of 600 plants contains 294 *AA*, 252 *Aa*, and 54 *aa* individuals. The *AA* and *Aa* plants produce purple flowers while the *aa* plants produce white flowers. What are the frequencies of the following?

26. ______________ allele *A*

27. ______________ allele *a*

28. ______________ genotype *AA*

29. ______________ genotype *Aa*

30. ______________ genotype *aa*

31. ______________ purple-flowered plants

32. ______________ white-flowered plants

Matching: Evolutionary mechanisms.

33. _____ selection for giraffes with longer necks
34. _____ the frequencies of white and brown guinea pigs in a population change because a large number of white animals enters the population
35. _____ a small number of organisms begins a new colony that becomes large and has gene frequencies very different from the parent population and other neighboring populations
36. _____ provides "genetic potential" to a population, upon which natural selection acts
37. _____ chance loss of genetic variation from a population due to its small size
38. _____ temporary restriction in population size due to short term unfavorable environmental conditions
39. _____ causes the evolution in males of elaborate structures and behaviors related to reproduction
40. _____ average individuals survive and reproduce best since the population is well-adapted to a stable environment
41. _____ selection involving sickle cell anemia in Africans
42. _____ selecting a mate with traits similar to your own
43. _____ selection favoring both extreme phenotypes and not favoring average individuals
44. _____ a change in a prey species forces a change in a predator species
45. _____ selection of one extreme phenotype in populations living in a rapidly changing environment
46. _____ selection for sickle cell heterozygotes in environments with malaria
47. _____ behavior that endangers an organism or reduces its reproductive success but benefits others in the population
48. _____ selection within a bird species encountering only large and small seeds
49. _____ antibiotic resistance evolves in a population
50. _____ the total of all populations of organisms that interbreed under natural conditions

Choices:

a. sexual selection
b. population bottleneck
c. gene flow
d. mutation
e. altruism
f. assortative mating
g. founders effect
h. species
i. genetic drift
j. coevolution
k. disruptive selective
l. stabilizing selection
m. directional selection

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

51. All of the following are true except
    a. differential reproduction leads to a change in allele frequency
    b. evolution occurs in populations
    c. evolution is a change in allele frequency
    d. natural selection causes genetic changes in individuals
    e. with stabilizing selection, population averages do not change.

52. All of the following meet the Hardy-Weinberg requirements for equilibrium in a population except
    a. no random mating may occur
    b. no mutations may occur
    c. no migrations may occur
    d. no natural selection may occur
    e. populations must be very large

53. A population that meets the Hardy-Weinberg requirements
    a. evolves
    b. is small and usually isolated
    c. has allele frequency in equilibrium
    d. changes genotypic distribution from generation to generation
    e. always has 75% *A* and 25% *a* allele frequencies

54. In a hypothetical population, the frequency of the dominant *A* allele is 80% and the frequency of the recessive allele *a* is 20%. What percentage of the population would you expect to be heterozygous (*Aa*) in genotype?
    a. 4%
    b. 16%
    c. 32%
    d. 50%
    e. 25%

55. Which of the following is more likely to occur in a small population than in a large population?
    a. gene flow
    b. immigration
    c. genetic drift
    d. nonrandom mating
    e. natural selection

56. A characteristic that better enables an organism to survive and reproduce is
    a. a mutation
    b. an adaptation
    c. a bottleneck gene
    d. a stabilizing factor

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.

57. In certain parts of Africa, the frequency of sickle cell anemia among newborn African infants is about 2% and holding steady, while in the United States, the frequency of sickle cell anemia among newborn African-Americans is about 0.2% and slowly declining. Why are these populations behaving differently in evolutionary terms regarding sickle cell anemia?

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58. What are the five conditions that Hardy and Weinberg stated were necessary to keep a population in genetic equilibrium?

59. Explain why mutation by itself is not a major force in evolution but that mutation is necessary for evolution to occur.

60. Explain why population size greatly influences the potential for chance events to change allele frequencies.

61. In a particular apple orchard, a large population of fruit flies exists in which 36% of the flies have dark bodies and 64% have light bodies. Birds have been observed feeding on the flies, and studies have shown that a typical bird will consume 60 dark flies and 40 light flies a day. What do you think is likely to happen to the fruit fly population over time?

62. In each of the following situations, one particular force that may cause evolutionary change in a population is acting. Determine which force is in effect in each case, and the probable consequence for the population:

(a) An avalanche killed all but a random few members of a mouse population;

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(b) Because of the planting of trees on the Great Plains by human settlers, an increase in the frequency of interbreeding between birds from two different populations of orioles occurred;

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(c) Because of the leakage of radioactive material from a nuclear power plant, the incidence of genetic changes in a local population of mice increased dramatically;

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(d) Because of the use of DDT as an insecticide in a certain country, there was an dramatic increase in the frequency of grasshoppers that showed genetic resistance to DDT.

____

63. Name three common practices by humans that collectively have contributed to the increase in the frequency of antibiotic resistance displayed by bacteria during the past 20 years.

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

64. Antibiotic resistance is reaching crisis proportions. Diseases which were all but eradicated only a few years ago are back and resistant to all known treatments. There are two main categories of antibiotics and four mechanisms of antibiotic resistance. What are they?

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