Chapter 23

The Evolution of Populations

PowerPoint® Lecture Presentations for

Biology

Eighth Edition

Neil Campbell and Jane Reece

Lectures by Chris Romero, updated by Erin Barley with contributions from Joan Sharp

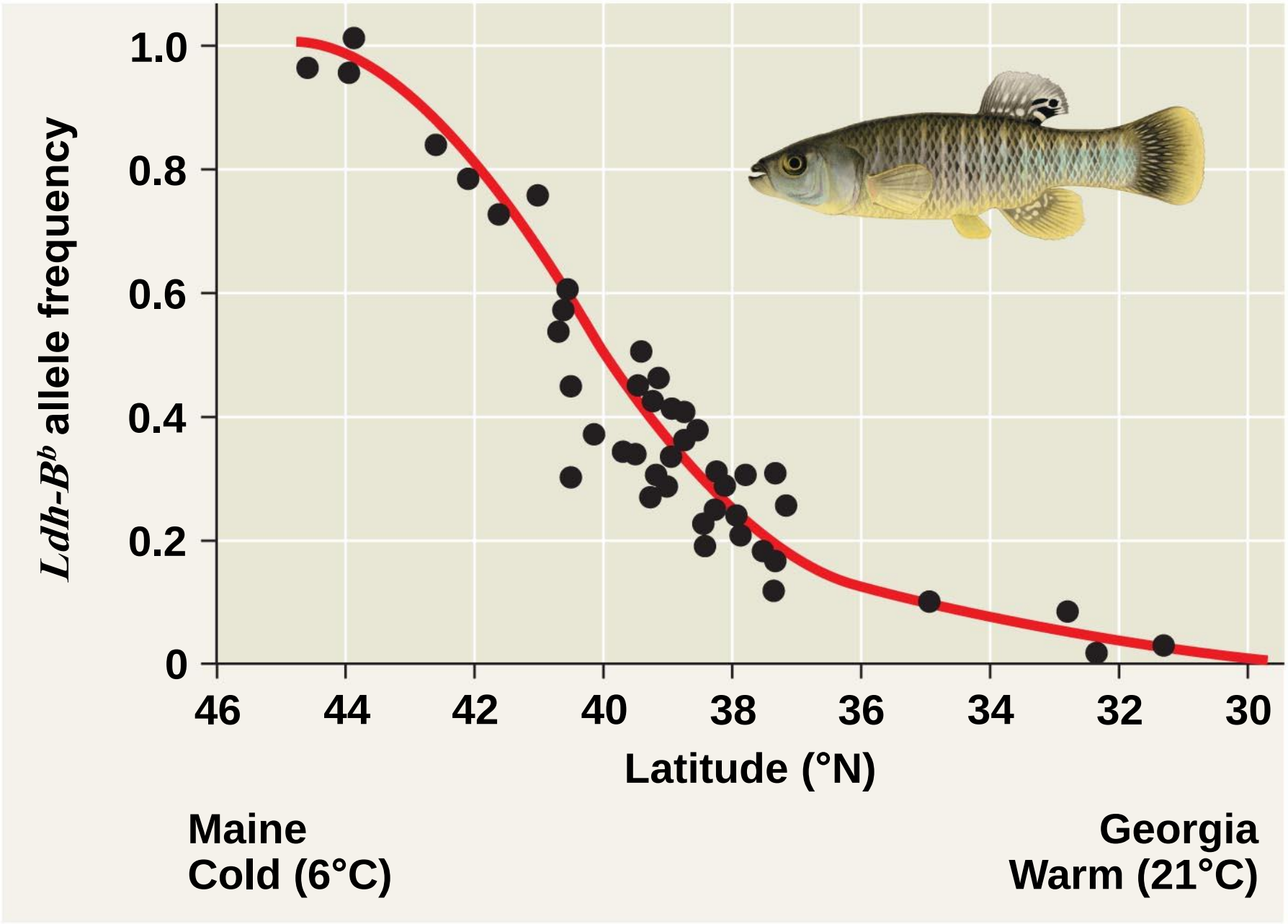
Overview: The Smallest Unit of Evolution

- **Natural selection** acts on individuals, but only populations evolve.
- Genetic variations in populations contribute to evolution.
- **Microevolution** is a change in allele frequencies in a population over generations.
- Two processes, **mutation** and **sexual reproduction**, produce the **variation** in gene pools that contributes to differences among individuals.

Genetic Variation

- Population geneticists measure polymorphisms in a population by determining the amount of heterozygosity at the gene and molecular levels.
- **Average heterozygosity** measures the average percent of loci that are heterozygous in a population.
- Most species exhibit **geographic variation**, differences between gene pools of separate populations or population subgroups.
- Some examples of geographic variation occur as a **cline**, which is a graded change in a trait along a geographic axis.

Cline



Mutation

- **Mutations** are changes in the nucleotide sequence of DNA.
- Mutations cause **new genes** and alleles to arise.
- Only mutations in cells that produce gametes can be passed to offspring.
- A ***point mutation*** is a change in one base in a gene.

- The effects of point mutations can vary:
  - Mutations in noncoding regions of DNA are often harmless.
  - Mutations in a gene might not affect protein production because of redundancy in the genetic code.
  - Mutations that result in a change in protein production are often harmful.
  - Mutations that result in a change in protein production can sometimes increase the fitness of the organism in its environment.

Mutations That Alter Gene / Chromosome Number or Sequence

- **Chromosomal mutations** that delete, disrupt, or rearrange many loci are typically harmful.
- Mutation rates are low in animals and plants.
- Mutations rates are often lower in prokaryotes and higher in viruses.

Sexual Reproduction

- **Sexual reproduction** can shuffle existing alleles into **new combinations**.
- In organisms that reproduce sexually, recombination of alleles is more important than mutation in producing the genetic differences that make adaptation possible.

Hardy-Weinberg equation tests whether a sexually reproducing population is evolving

- A **population** is a localized group of individuals (*a species in an area*) capable of interbreeding and producing fertile offspring.
- A **gene pool** consists of all the alleles for all loci in a population.
- A locus is fixed if all individuals in a population are homozygous for the same allele.

Hardy-Weinberg equations

- The ***frequency of an allele*** in a population can be calculated.
- If there are 2 alleles at a locus, *p* and *q* are used to represent their frequencies.
- The ***frequency of all alleles in a population*** will add up to 1:

$$p + q = 1$$

The Hardy-Weinberg Principle: a Population

- The ***Hardy-Weinberg principle*** describes an ideal population that is not evolving.
- The closer a population is to the criteria of the Hardy-Weinberg principle, the more stable the population is likely to be.
- Calculating ***Genotype Frequencies***

$$p^2 + 2pq + q^2 = 1$$

where p^2 and q^2 represent the frequencies of the homozygous genotypes and $2pq$ represents the frequency of the heterozygous genotype.

Hardy-Weinberg Ideal Conditions

- The five conditions for nonevolving populations are rarely met in nature:
  - ***No mutations***
  - ***Random mating***
  - ***No natural selection***
  - ***Extremely large population***
  - ***No gene flow***

Applying the Hardy-Weinberg Principle

- We can assume the locus that causes phenylketonuria (PKU) is in Hardy-Weinberg equilibrium given that:
  - The PKU gene mutation rate is low
  - Mate selection is random with respect to whether or not an individual is a carrier for the PKU allele
  - Natural selection can only act on rare homozygous individuals who do not follow dietary restrictions
  - The population is large
  - Migration has no effect as many other populations have similar allele frequencies

- The occurrence of PKU is 1 per 10,000 births
  - $q^2 = 0.0001$
  - $q = 0.01$
- The frequency of normal alleles is
  - $p = 1 - q = 1 - 0.01 = 0.99$
- The frequency of *heterozygotes* / carriers is
  - $2pq = 2 \times 0.99 \times 0.01 = 0.0198$
  - or approximately 2% of the U.S. population.

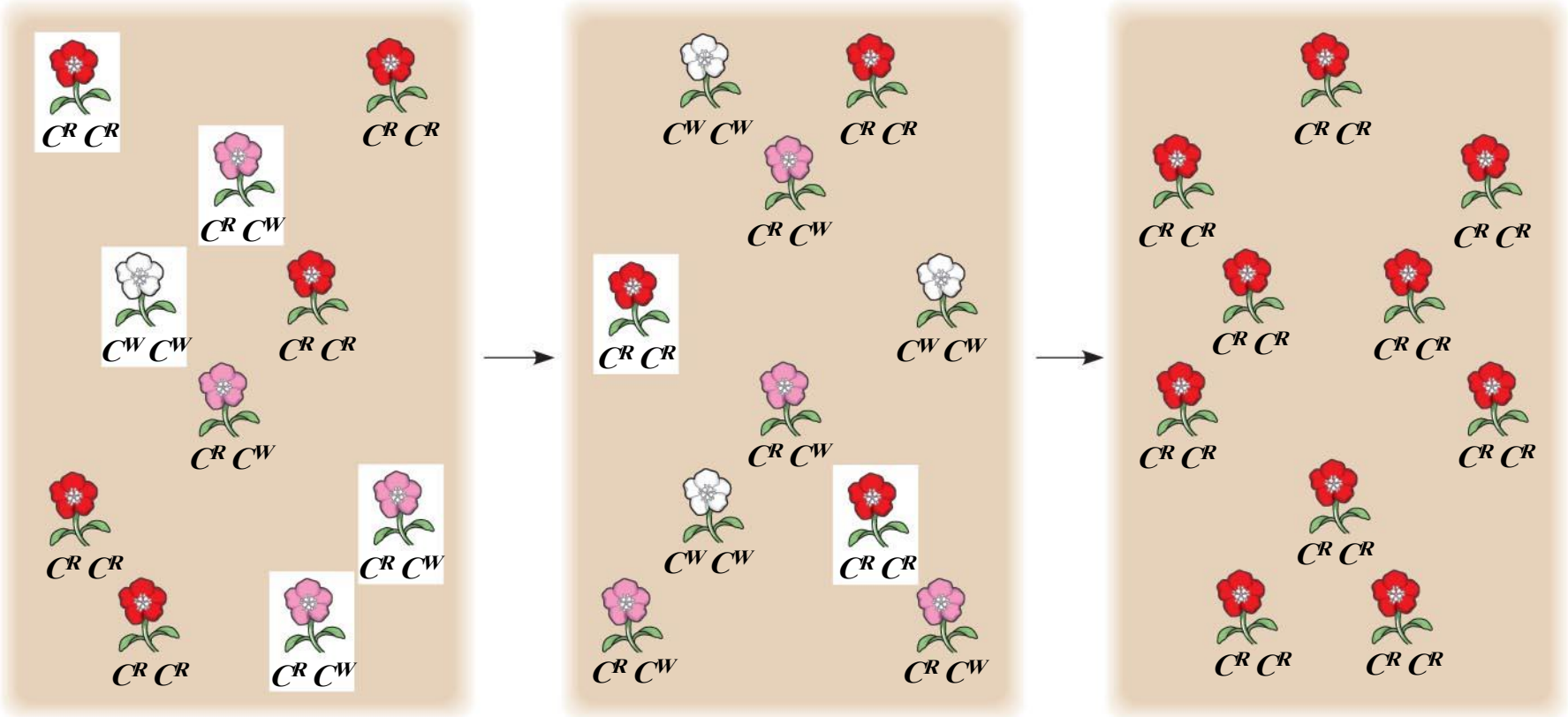
Concept 23.3: Natural selection, genetic drift, and gene flow can alter allele frequencies in a population

- Three major factors alter allele frequencies and bring about most evolutionary change:
  - Natural selection - **non**random
  - Genetic drift - random
  - Gene flow - random

Natural Selection and Genetic Drift

- **Natural Selection**: Differential success in reproduction results in certain alleles being passed to the next generation in greater proportions by the more fit individuals.
- **Genetic drift**: describes how allele frequencies fluctuate randomly from one generation to the next.
- The smaller a sample, the greater the chance of deviation from a predicted result.
- Genetic drift tends to reduce genetic variation through losses of alleles.

Genetic Drift



Generation 1

p (frequency of C^R) = 0.7

q (frequency of C^W) = 0.3

Generation 2

p = 0.5

q = 0.5

Generation 3

p = 1.0

q = 0.0

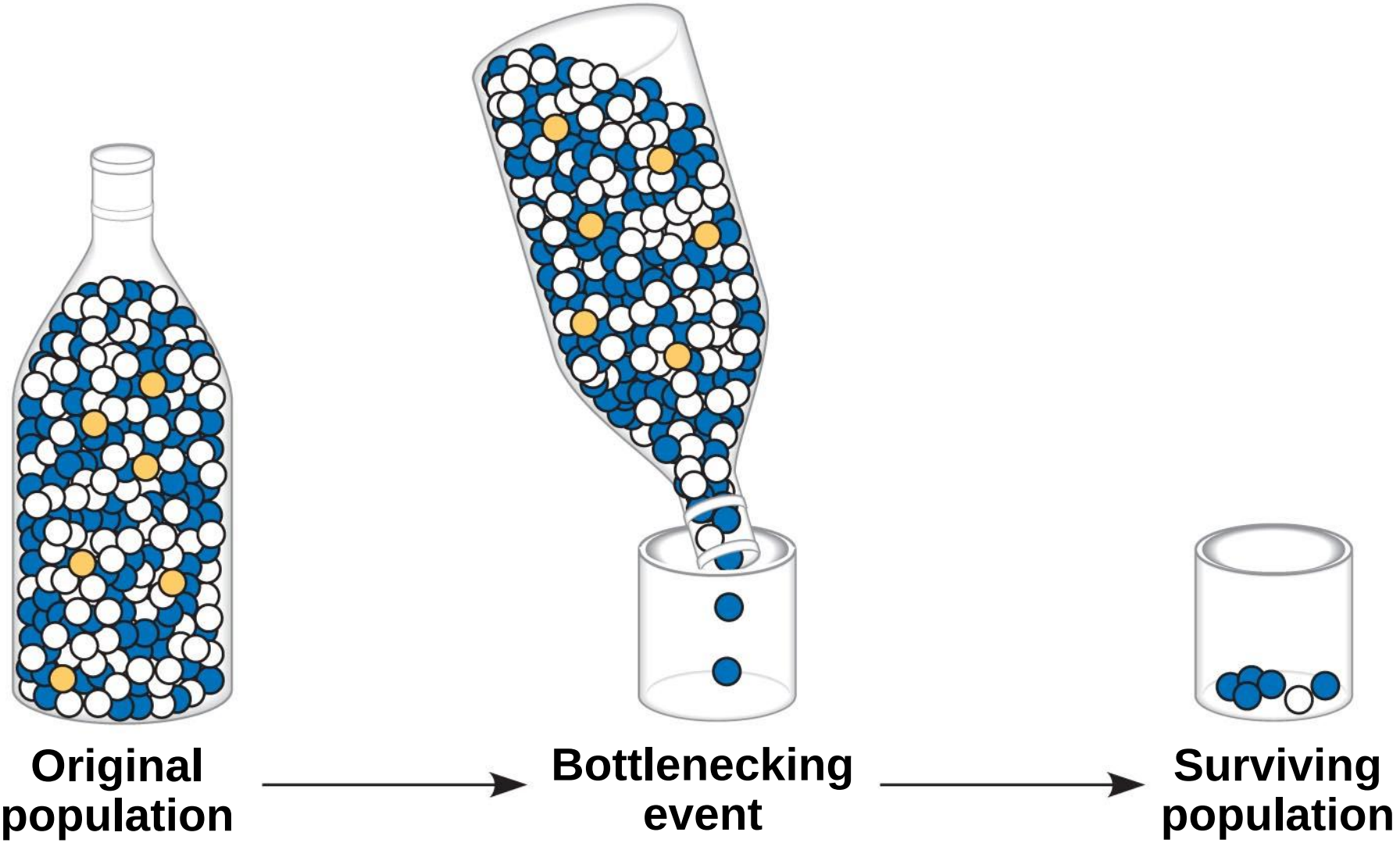
Genetic Drift: The Founder Effect

- The **founder effect** occurs when a few individuals become isolated from a larger population.
- Allele frequencies in the small founder population can be different from those in the larger parent population.

Genetic Drift: The Bottleneck Effect

- The **bottleneck effect** is a sudden reduction in population size due to a change in the environment, such as a natural disaster.
- The resulting gene pool may no longer be reflective of the original population's gene pool.
- If the population remains small, it may be further affected by genetic drift.

Genetic Drift: The BottleNeck Effect



Effects of Genetic Drift: A Summary

1. Genetic drift is significant in small populations.
2. Genetic drift causes allele frequencies to change at random.
3. Genetic drift can lead to a loss of genetic variation within populations.
4. Genetic drift can cause harmful alleles to become fixed.

Gene Flow: Immigration & Emmigration

- **Gene flow** consists of the movement of alleles among populations.
- Alleles can be transferred through the movement of fertile individuals or gametes (for example, pollen).
- *Gene flow tends to reduce differences between populations over time*.
- Gene flow is more likely than mutation to alter allele frequencies directly.

Gene Flow

Concept 23.4: Natural selection is the only mechanism that consistently causes adaptive evolution

- Only natural selection consistently results in adaptive evolution.
- Natural selection brings about adaptive evolution by acting on an organism's phenotype.

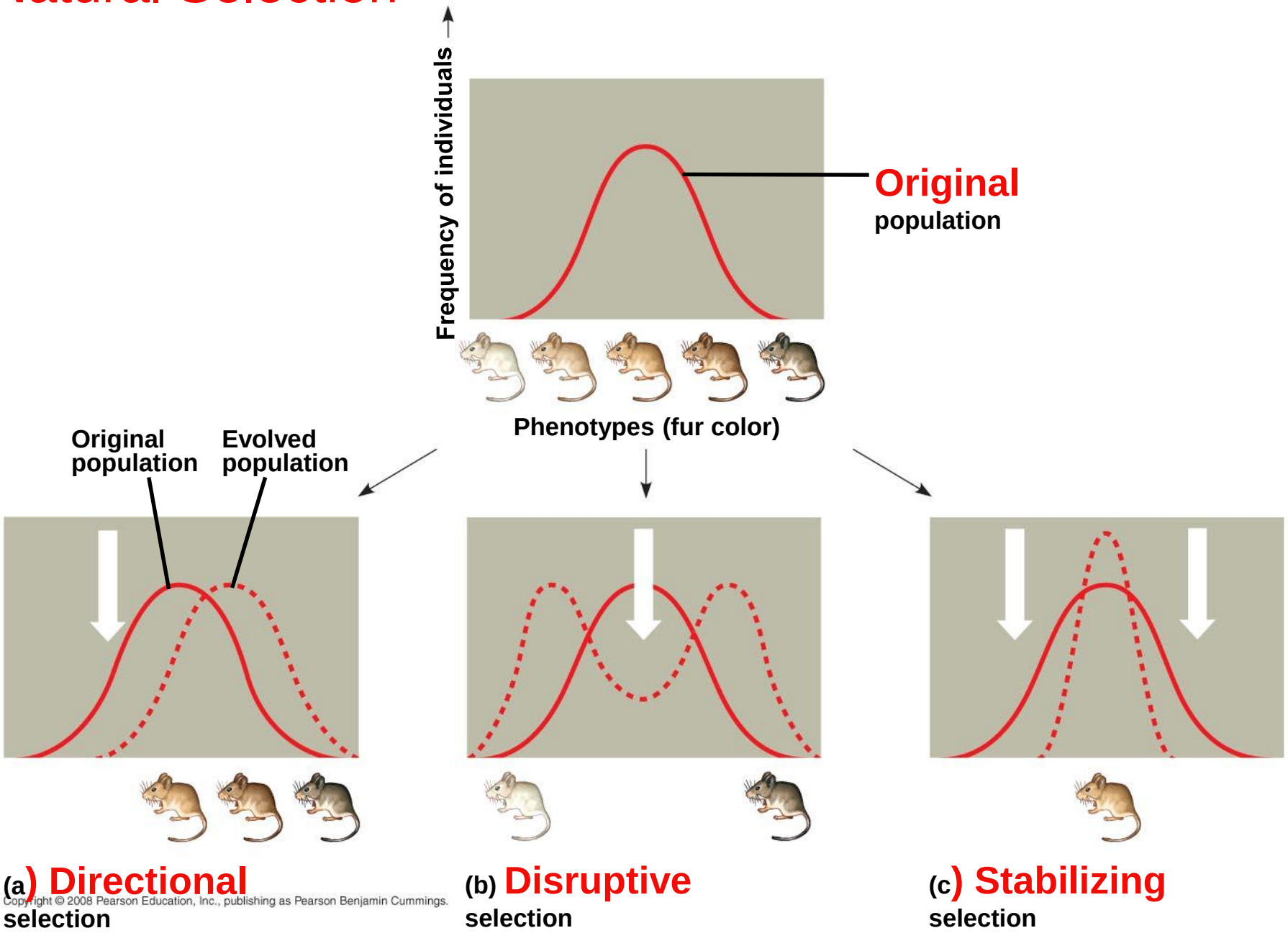
Natural Selection: Relative Fitness

- The natural selection phrases "struggle for existence" and "*survival of the fittest*" are misleading as they imply direct competition among individuals.
- Reproductive success is generally more subtle and depends on many factors.
- ***Relative fitness*** is the contribution an individual makes to the gene pool of the next generation, relative to the contributions of other individuals.
- Selection favors certain genotypes by acting on the phenotypes of certain organisms.

Directional, Disruptive, and Stabilizing Selection

- Three modes of natural selection:
  - **Directional selection** favors individuals at one end of the phenotypic range.
  - **Disruptive selection** favors individuals at both extremes of the phenotypic range.
  - **Stabilizing selection** favors intermediate variants and acts against extreme phenotypes.

Natural Selection

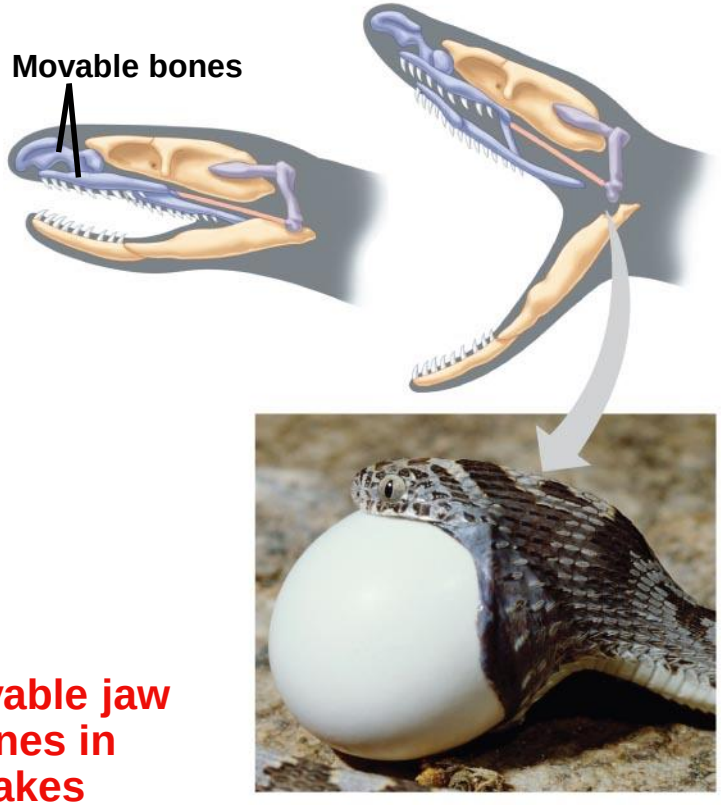


The Key Role of Natural Selection in Adaptive Evolution

- ***Natural selection increases*** *the* ***frequencies of alleles that enhance survival and reproduction.***
- ***Adaptive evolution =*** ***the match between an organism and its environment*****.**

Natural Selection - Adaptive Evolution

(a) Color-changing ability in cuttlefish



(b) Movable jaw bones in snakes

- Because environments change, adaptive evolution is a continuous process.
- Genetic drift and gene flow are random and so do not consistently lead to adaptive evolution as they can increase or decrease the match between an organism and its environment.

Sexual Selection

- **Sexual selection** is natural selection for mating success.
- It can result in **sexual dimorphism**, marked differences between the sexes in secondary sexual characteristics.
- Male showiness due to mate choice can increase a male's chances of attracting a female, while decreasing his chances of survival.

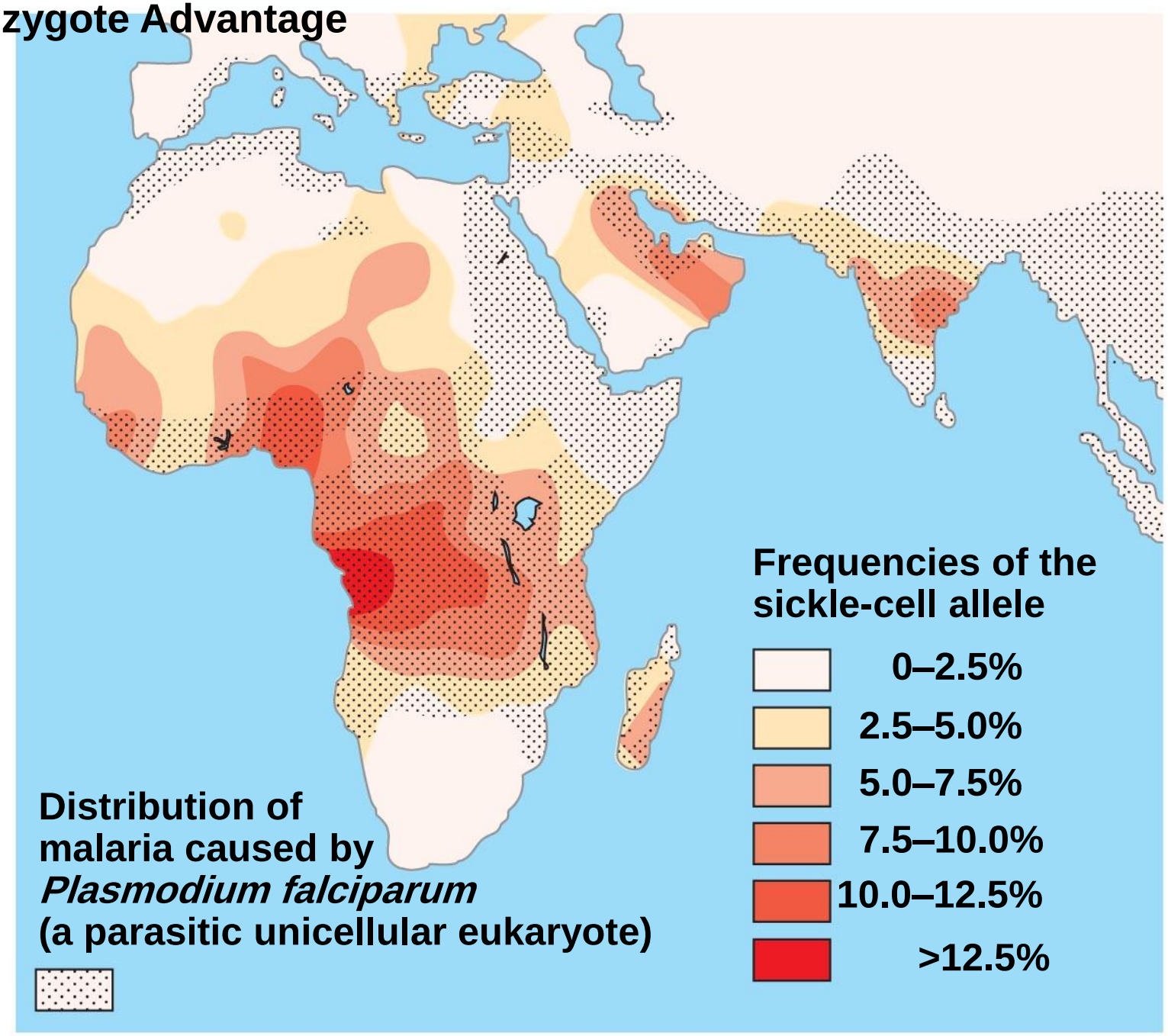
Sexual Selection

- How do female preferences evolve?
- The good genes hypothesis suggests that if a trait is related to male health, both the male trait and female preference for that trait should be selected for.

The *Preservation of Genetic Variation*

- Various mechanisms help to preserve genetic variation in a population:
- ***Diploidy*** maintains genetic variation in the form of hidden recessive alleles.
- ***Heterozygote advantage*** occurs when heterozygotes have a higher fitness than do both homozygotes. Natural selection will tend to maintain two or more alleles at that locus.
- The *sickle-cell allele* causes mutations in hemoglobin but also confers *malaria resistance*.

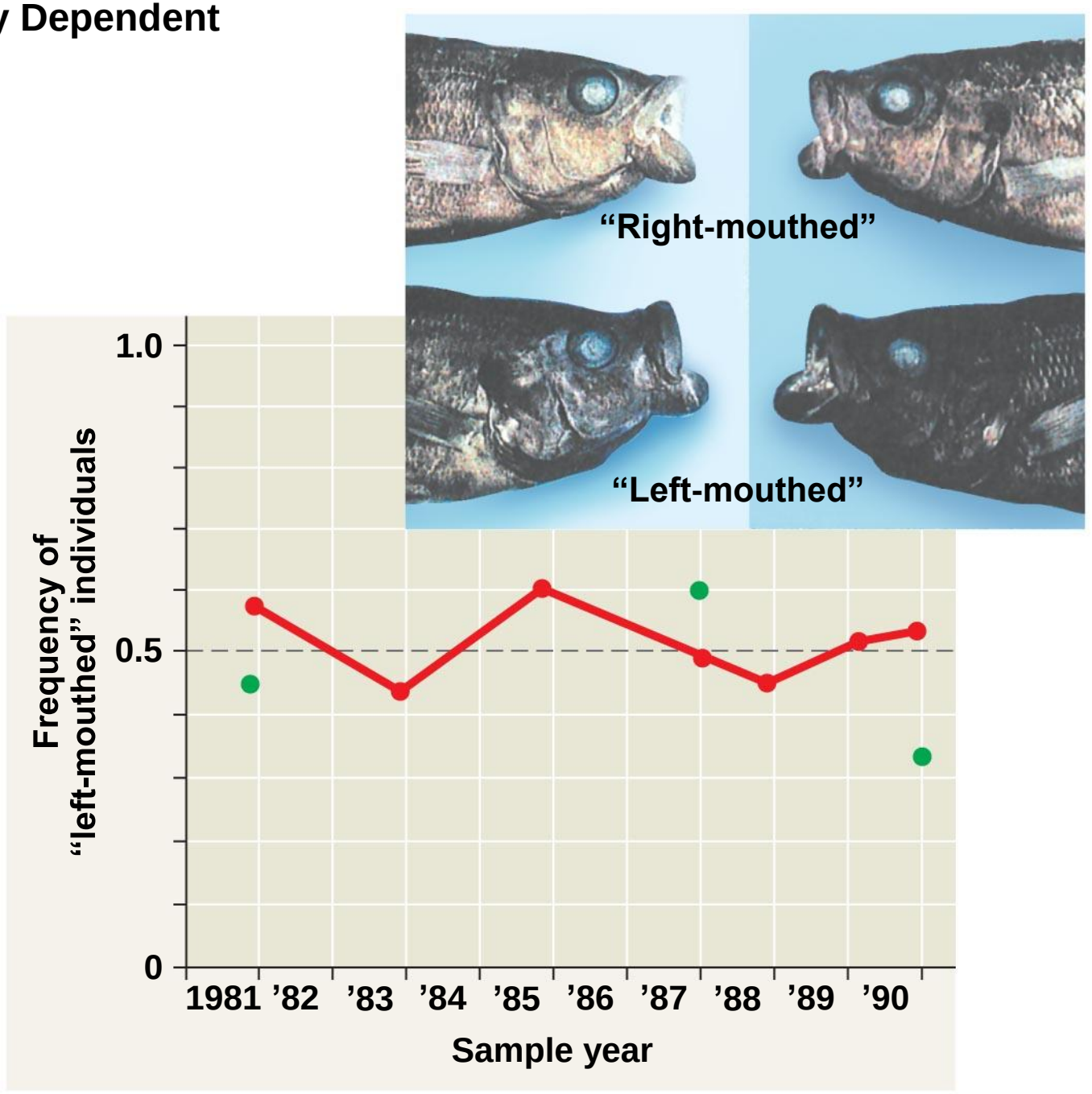
Heterozygote Advantage



Frequency-Dependent Selection

- In frequency-dependent selection, the fitness of a phenotype declines if it becomes too common in the population.
- Selection favors whichever phenotype is less common in a population.

Frequency Dependent Selection



Neutral Variation

- **Neutral variation** is genetic variation that appears to confer no selective advantage or disadvantage.
- For example,
  - Variation in noncoding regions of DNA
  - Variation in proteins that have little effect on protein function or reproductive fitness.

Why Natural Selection Cannot Fashion Perfect Organisms

1. Selection can act only on existing variations.
2. Evolution is limited by historical constraints.
3. Adaptations are often compromises.
4. Chance, natural selection, and the environment interact.

You should now be able to:

1. Explain why the majority of point mutations are harmless.
2. Explain how sexual recombination generates genetic variability.
3. Define the terms population, species, gene pool, relative fitness, and neutral variation.
4. List the five conditions of Hardy-Weinberg equilibrium.

5. Apply the Hardy-Weinberg equation to a population genetics problem.

6. Explain why natural selection is the only mechanism that consistently produces adaptive change.

7. Explain the role of population size in genetic drift.

8. Distinguish among the following sets of terms: directional, disruptive, and stabilizing selection; intrasexual and intersexual selection.

9. List four reasons why natural selection cannot produce perfect organisms.