LECTURE PRESENTATIONS

For CAMPBELL BIOLOGY, NINTH EDITION

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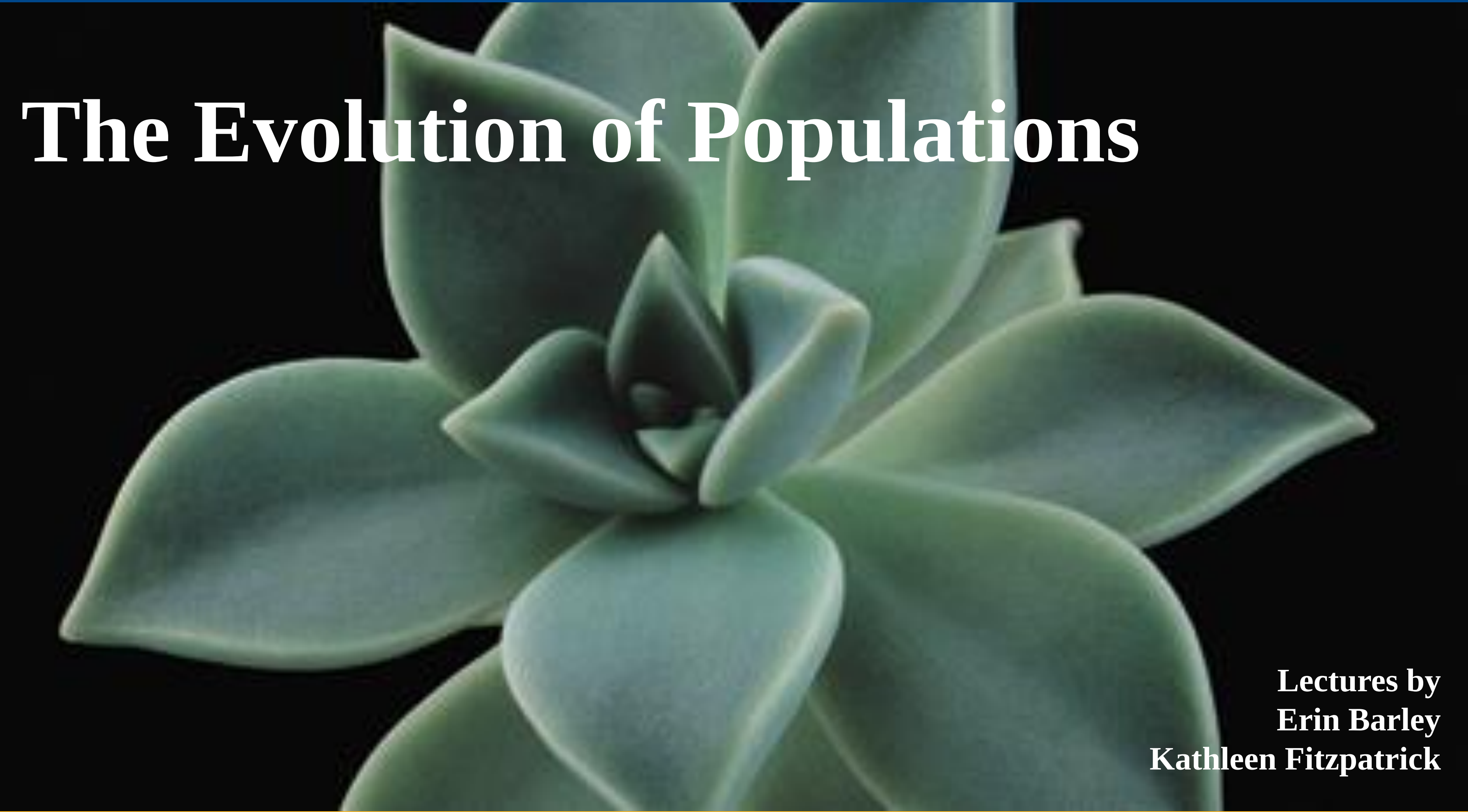
Chapter 23

The Evolution of Populations



Lectures by
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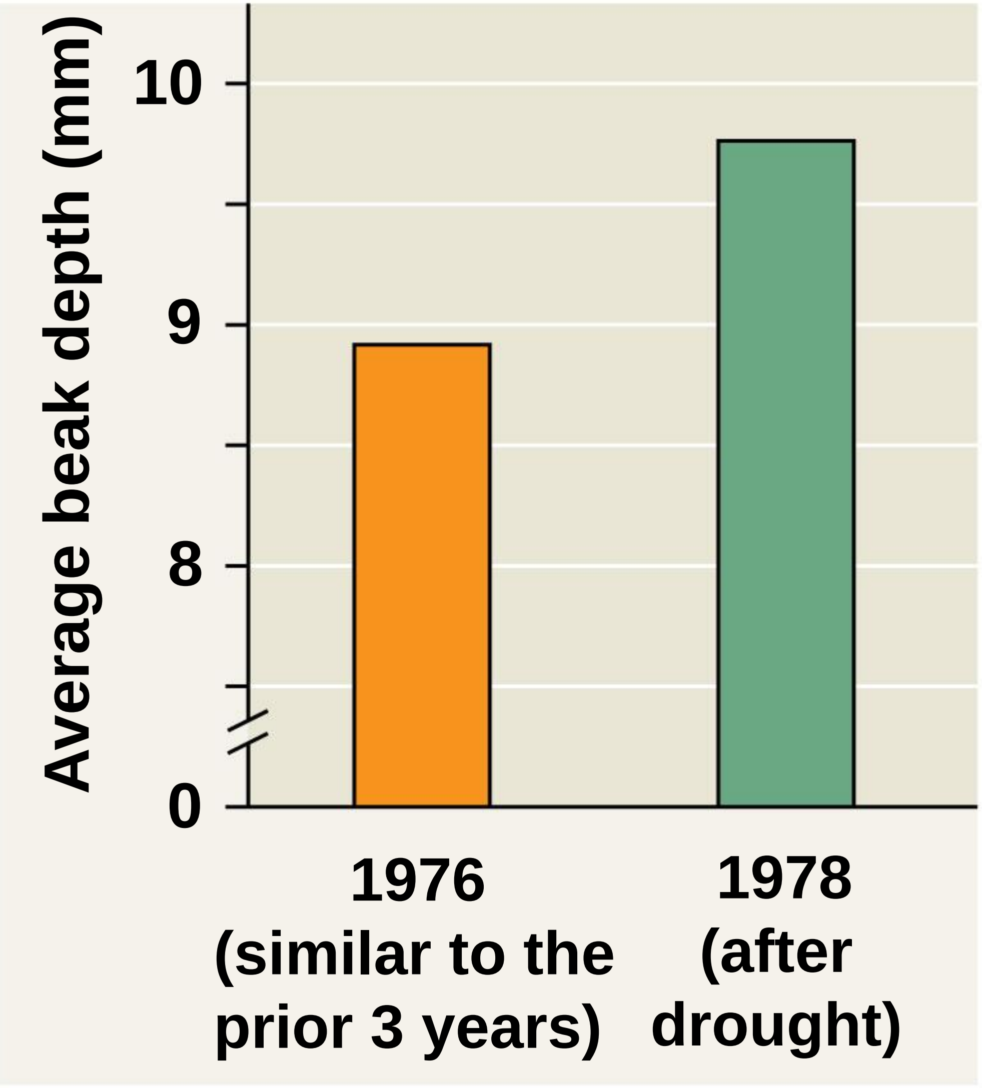
Overview: The Smallest Unit of Evolution

- One misconception is that organisms evolve during their lifetimes
- Natural selection acts on individuals, but only populations evolve
- Consider, for example, a population of medium ground finches on Daphne Major Island
  - During a drought, large-beaked birds were more likely to crack large seeds and survive
  - The finch population evolved by natural selection

Figure 23.2


Average beak depth (mm)
10
9
8
0
1976
(similar to the
prior 3 years)
1978
(after
drought)

- **Microevolution** is a change in allele frequencies in a population over generations
- Three mechanisms cause allele frequency change:
  – Natural selection
  – Genetic drift
  – Gene flow
- Only natural selection causes adaptive evolution

Concept 23.1: Genetic variation makes evolution possible

- Variation in heritable traits is a prerequisite for evolution
- Mendel's work on pea plants provided evidence of discrete heritable units (genes)

Genetic Variation

- Genetic variation among individuals is caused by differences in genes or other DNA segments
- Phenotype is the product of inherited genotype and environmental influences
- Natural selection can only act on variation with a genetic component

Variation Within a Population

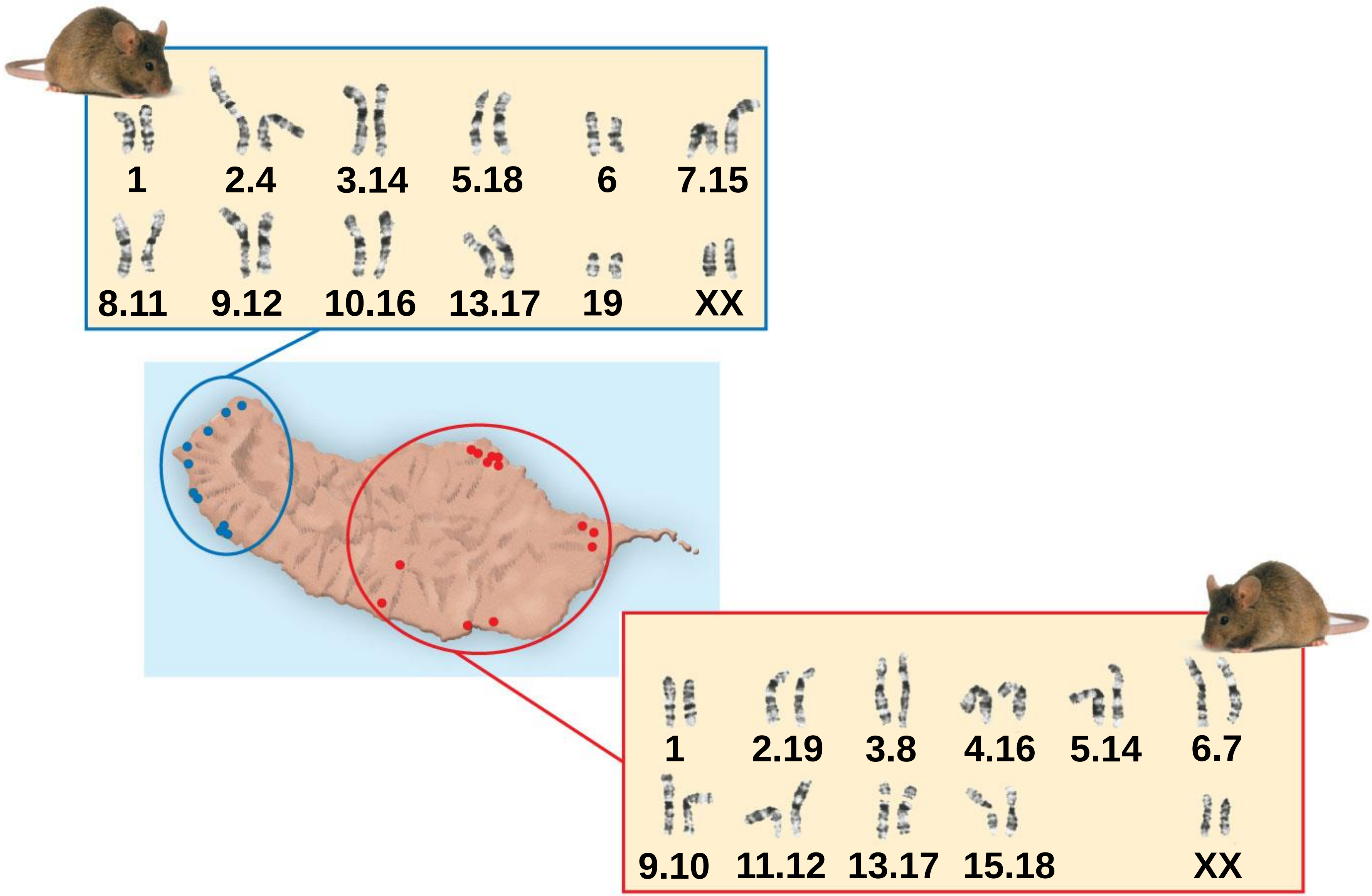
- Both discrete and quantitative characters contribute to variation within a population
- Discrete *characters* can be classified on an either-or basis
- Quantitative characters vary along a continuum within a population

- Genetic variation can be measured as gene variability or nucleotide variability
- For gene variability, **average heterozygosity** measures the average percent of loci that are heterozygous in a population
- Nucleotide variability is measured by comparing the DNA sequences of pairs of individuals

Variation Between Populations

- Most species exhibit **geographic variation**, differences between gene pools of separate populations
- For example, Madeira is home to several isolated populations of mice
  - Chromosomal variation among populations is due to drift, not natural selection

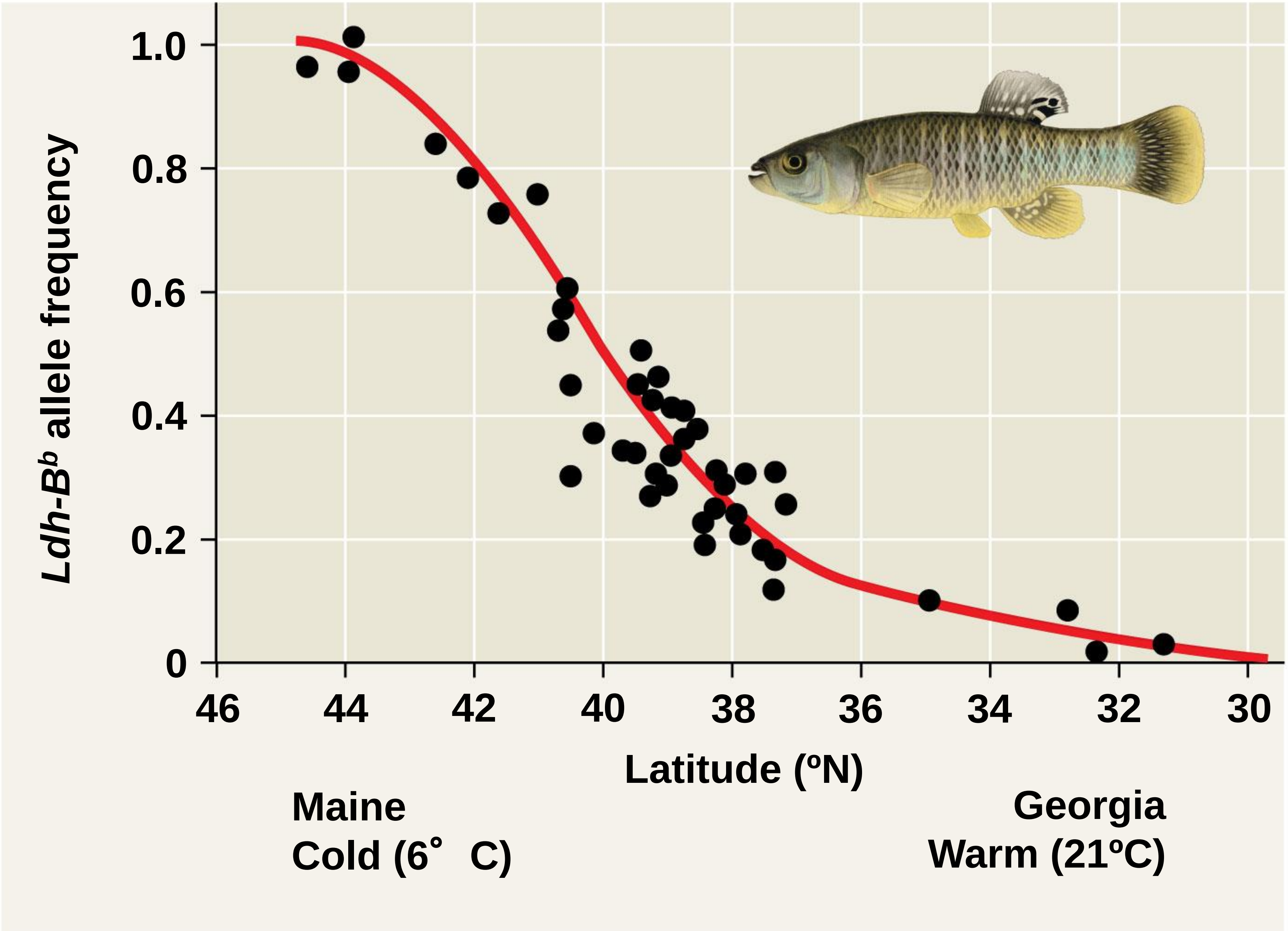
Figure 23.4



1
2.4
3.14
5.18
6
7.15
8.11
9.12
10.16
13.17
19
XX
1
2.19
3.8
4.16
5.14
6.7
9.10
11.12
13.17
15.18
XX

- Some examples of geographic variation occur as a **cline**, which is a graded change in a trait along a geographic axis
- For example, mummichog fish vary in a cold-adaptive allele along a temperature gradient
  - This variation results from natural selection

Figure 23.5



1.0
0.8
0.6
0.4
0.2
0
Ldh-B^b allele frequency
46
44
42
40
38
36
34
32
30
Latitude (ºN)
Maine
Cold (6° C)
Georgia
Warm (21ºC)

Sources of Genetic Variation

- New genes and alleles can arise by mutation or gene duplication

Formation of New Alleles

- A mutation is a change in nucleotide sequence of DNA
- 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 to genes can be neutral because of redundancy in the genetic code

- The effects of point mutations can vary:
  - Mutations that result in a change in protein production are often harmful
  - Mutations that result in a change in protein production can sometimes be beneficial

Altering Gene Number or Position

- Chromosomal mutations that delete, disrupt, or rearrange many loci are typically harmful
- Duplication of small pieces of DNA increases genome size and is usually less harmful
- Duplicated genes can take on new functions by further mutation
- An ancestral odor-detecting gene has been duplicated many times: humans have 1,000 copies of the gene, mice have 1,300

Rapid Reproduction

- Mutation rates are low in animals and plants
- The average is about one mutation in every 100,000 genes per generation
- Mutation 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

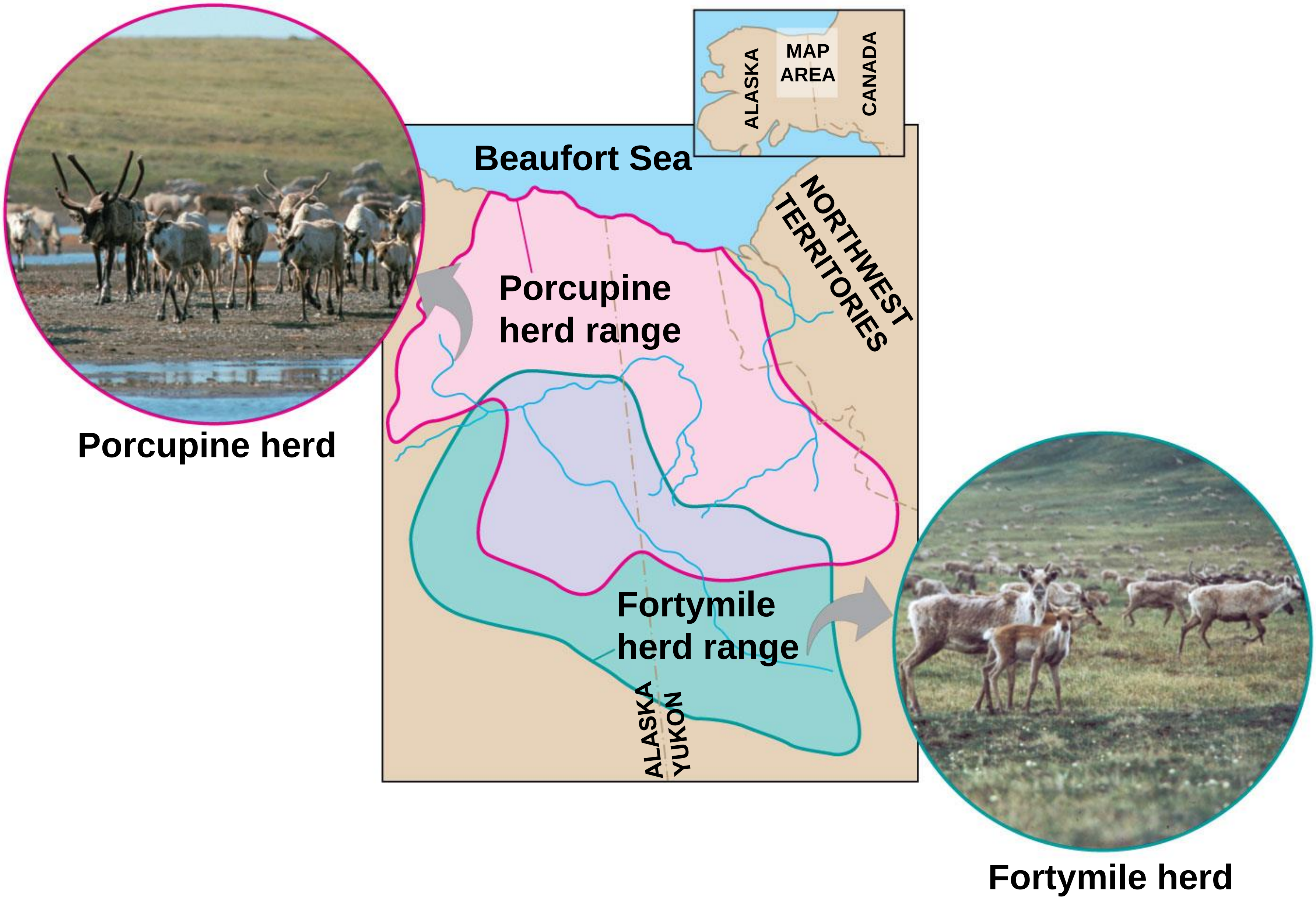
Concept 23.2: The Hardy-Weinberg equation can be used to test whether a population is evolving

- The first step in testing whether evolution is occurring in a population is to clarify what we mean by a population

Gene Pools and Allele Frequencies

- A **population** is a localized group of individuals 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

Figure 23.6


Porcupine herd
Beaufort Sea
MAP AREA
ALASKA
CANADA
NORTHWEST TERRITORIES
Porcupine herd range
Fortymile herd range
ALASKA
YUKON
Fortymile herd

- The frequency of an allele in a population can be calculated
  - For diploid organisms, the total number of alleles at a locus is the total number of individuals times 2
  - The total number of dominant alleles at a locus is 2 alleles for each homozygous dominant individual plus 1 allele for each heterozygous individual; the same logic applies for recessive alleles

- By convention, 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
  - For example, $p + q = 1$

- For example, consider a population of wildflowers that is incompletely dominant for color:
  - 320 red flowers (C^RC^R)
  - 160 pink flowers (C^RC^W)
  - 20 white flowers (C^WC^W)
- Calculate the number of copies of each allele:
  - $C^R = (320 \times 2) + 160 = 800$
  - $C^W = (20 \times 2) + 160 = 200$

- To calculate the frequency of each allele:
  - p = freq C^R = 800 / (800 + 200) = 0.8
  - q = freq C^W = 200 / (800 + 200) = 0.2
- The sum of alleles is always 1
  - 0.8 + 0.2 = 1

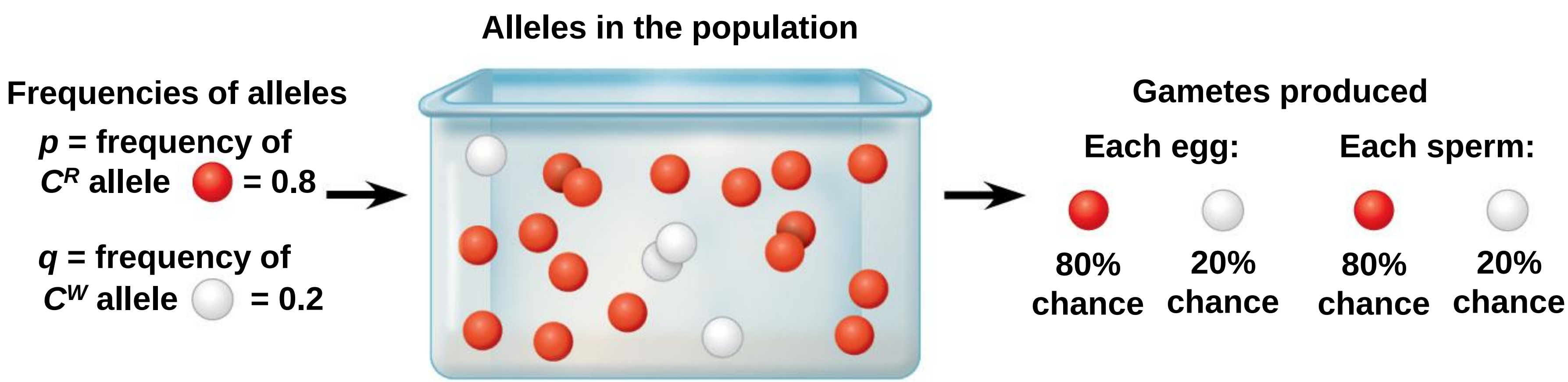
The Hardy-Weinberg Principle

- The Hardy-Weinberg principle describes a population that is not evolving
- If a population does not meet the criteria of the Hardy-Weinberg principle, it can be concluded that the population is evolving

Hardy-Weinberg Equilibrium

- The **Hardy-Weinberg principle** states that frequencies of alleles and genotypes in a population remain constant from generation to generation
- In a given population where gametes contribute to the next generation randomly, allele frequencies will not change
- Mendelian inheritance preserves genetic variation in a population

Figure 23.7

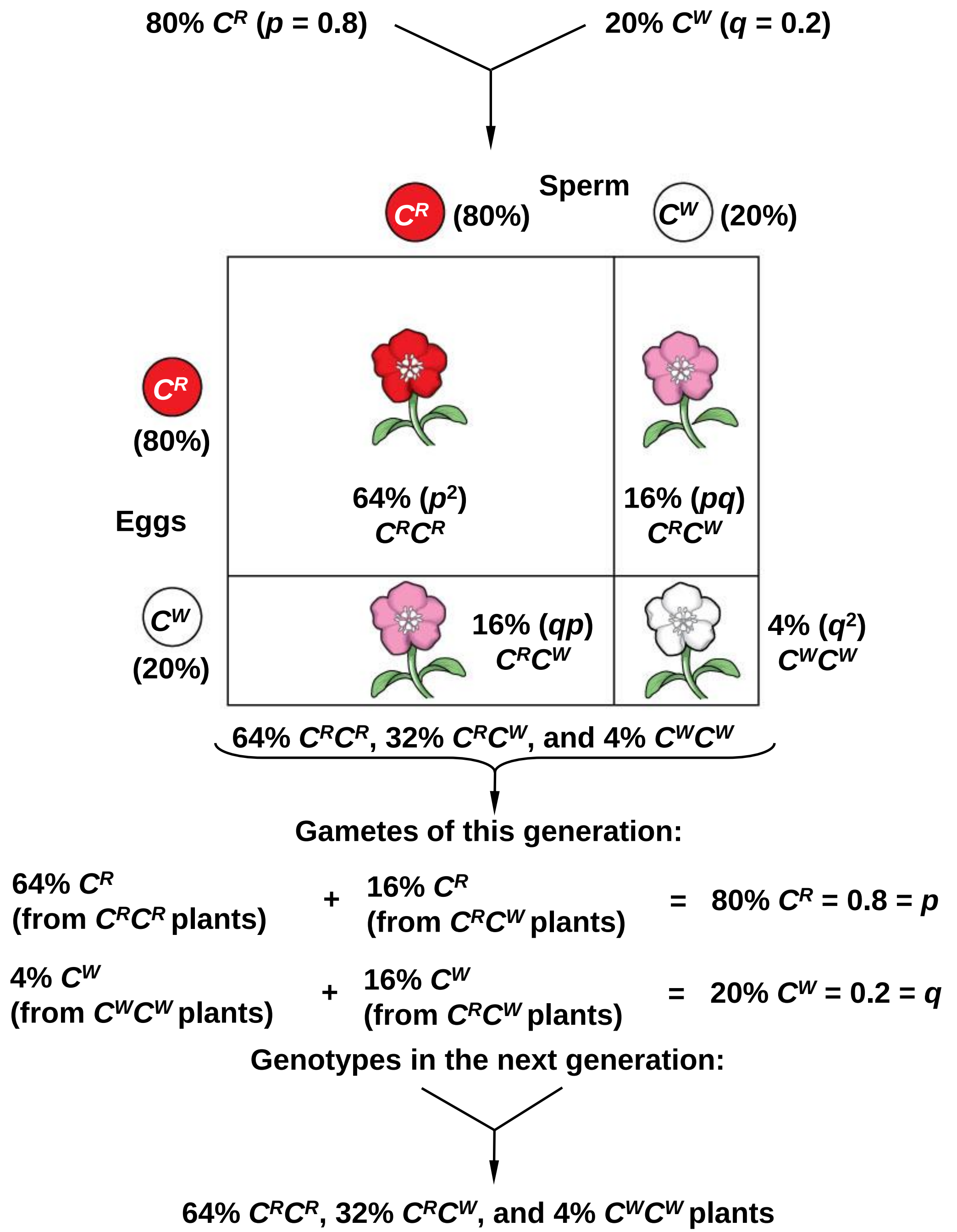


Alleles in the population
Frequencies of alleles
p = frequency of
C^R allele = 0.8
q = frequency of
C^W allele = 0.2
Gametes produced
Each egg:
Each sperm:
80% chance
20% chance
80% chance
20% chance

- Hardy-Weinberg equilibrium describes the constant frequency of alleles in such a gene pool
- Consider, for example, the same population of 500 wildflowers and 1,000 alleles where
  - p = freq C^R = 0.8
  - q = freq C^W = 0.2

- The frequency of genotypes can be calculated
  - $C^RC^R = p^2 = (0.8)^2 = 0.64$
  - $C^RC^W = 2pq = 2(0.8)(0.2) = 0.32$
  - $C^WC^W = q^2 = (0.2)^2 = 0.04$
- The frequency of genotypes can be confirmed using a Punnett square

Figure 23.8


80% C^R (p = 0.8)
20% C^W (q = 0.2)
Sperm
C^R (80%)
C^W (20%)
Eggs
C^R (80%)
C^W (20%)
64% (p^2) C^RC^R
16% (pq) C^RC^W
16% (qp) C^RC^W
4% (q^2) C^WC^W
64% C^RC^R, 32% C^RC^W, and 4% C^WC^W
Gametes of this generation:
64% C^R (from C^RC^R plants) + 16% C^R (from C^RC^W plants) = 80% C^R = 0.8 = p
4% C^W (from C^WC^W plants) + 16% C^W (from C^RC^W plants) = 20% C^W = 0.2 = q
Genotypes in the next generation:
64% C^RC^R, 32% C^RC^W, and 4% C^WC^W plants

- If p and q represent the relative frequencies of the only two possible alleles in a population at a particular locus, then
  - $p^2 + 2pq + q^2 = 1$
  - where p^2 and q^2 represent the frequencies of the homozygous genotypes and $2pq$ represents the frequency of the heterozygous genotype

Conditions for Hardy-Weinberg Equilibrium

- The Hardy-Weinberg theorem describes a hypothetical population that is not evolving
- In real populations, allele and genotype frequencies do change over time

- The five conditions for nonevolving populations are rarely met in nature:

1. No mutations
2. Random mating
3. No natural selection
4. Extremely large population size
5. No gene flow

- Natural populations can evolve at some loci, while being in Hardy-Weinberg equilibrium at other loci

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
  - Genetic drift
  - Gene flow

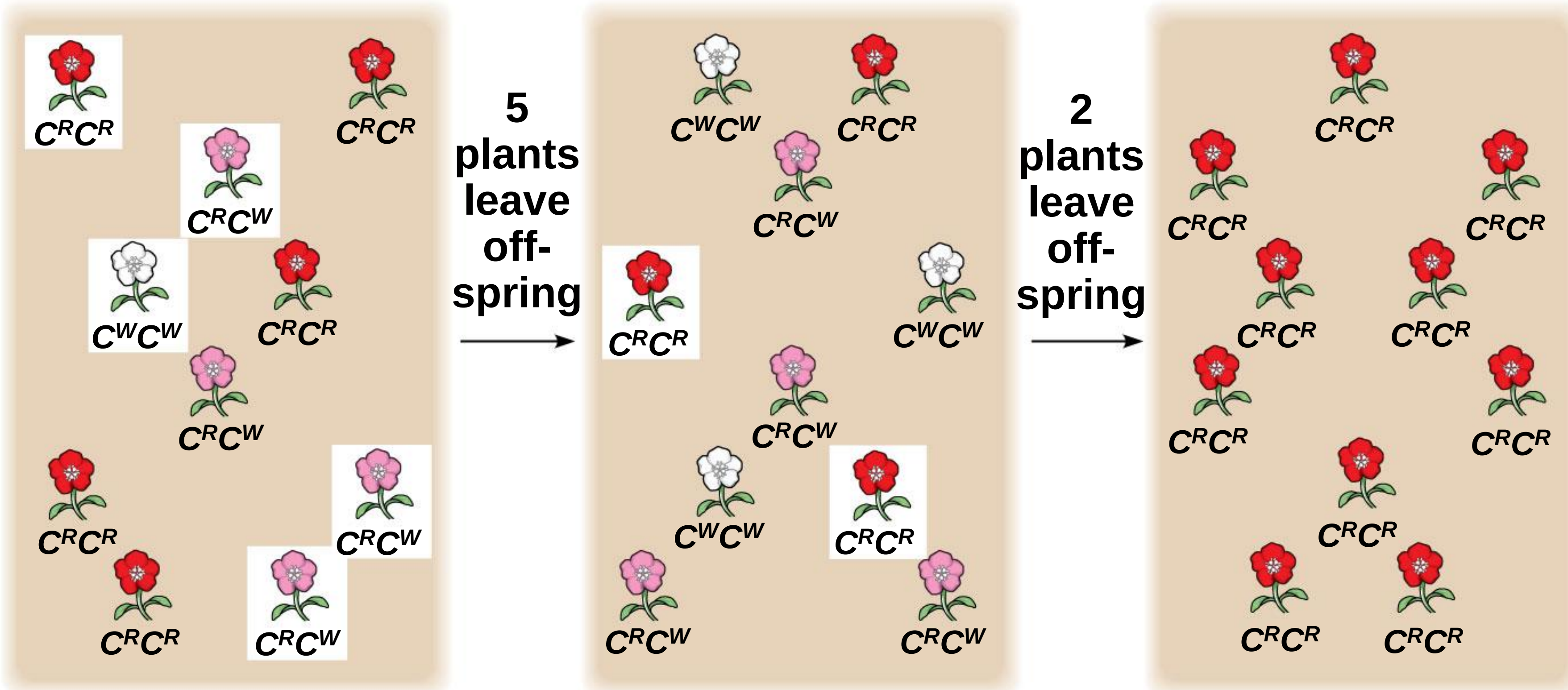
Natural Selection

- Differential success in reproduction results in certain alleles being passed to the next generation in greater proportions
- For example, an allele that confers resistance to DDT increased in frequency after DDT was used widely in agriculture

Genetic Drift

- The smaller a sample, the greater the chance of deviation from a predicted result
- **Genetic drift** describes how allele frequencies fluctuate unpredictably from one generation to the next
- Genetic drift tends to reduce genetic variation through losses of alleles

Figure 23.9-3



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
$p = 1.0$
$q = 0.0$

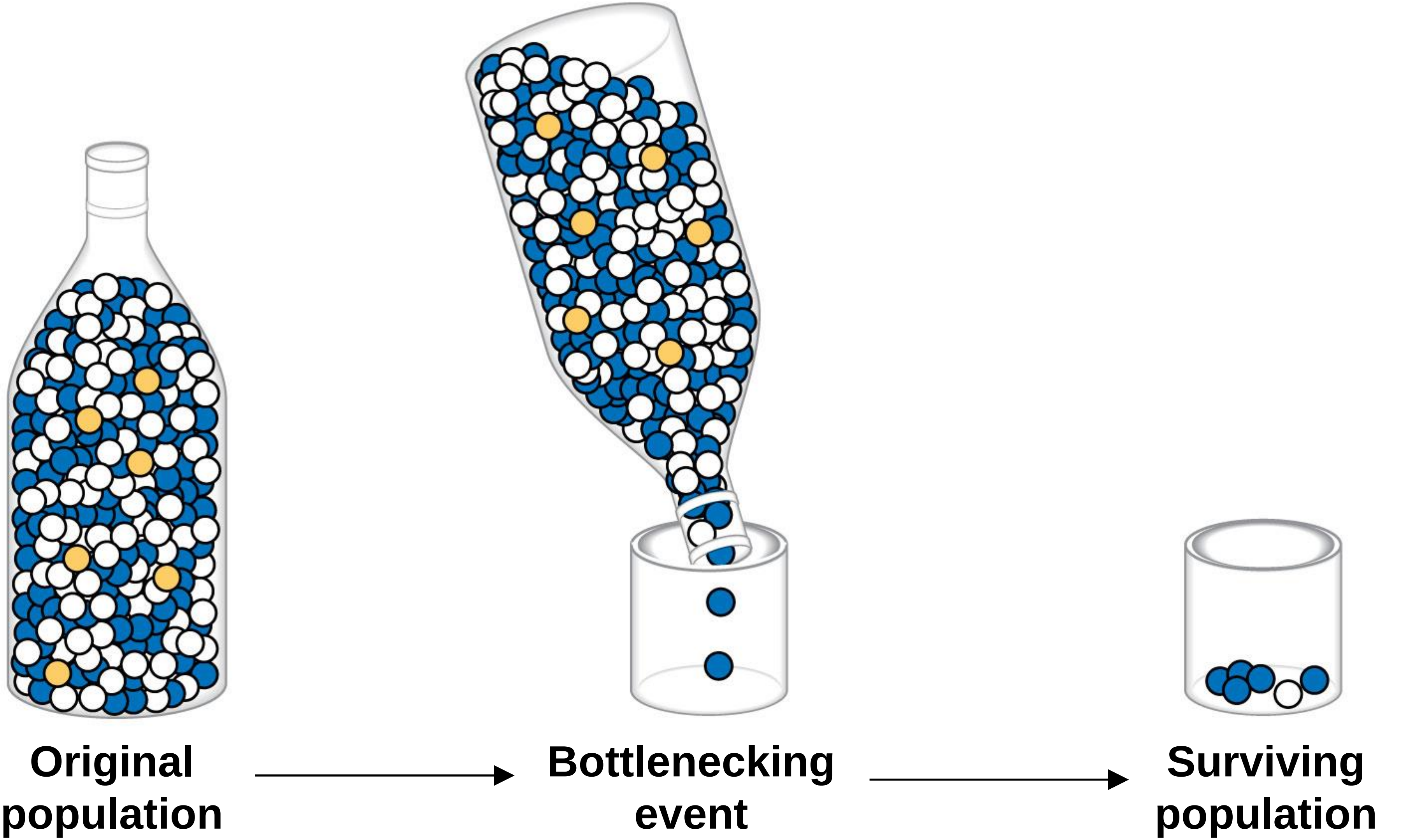
The Founder Effect

- 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

The Bottleneck Effect

- The **bottleneck effect** is a sudden reduction in population size due to a change in the environment
- 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

Figure 23.10-3

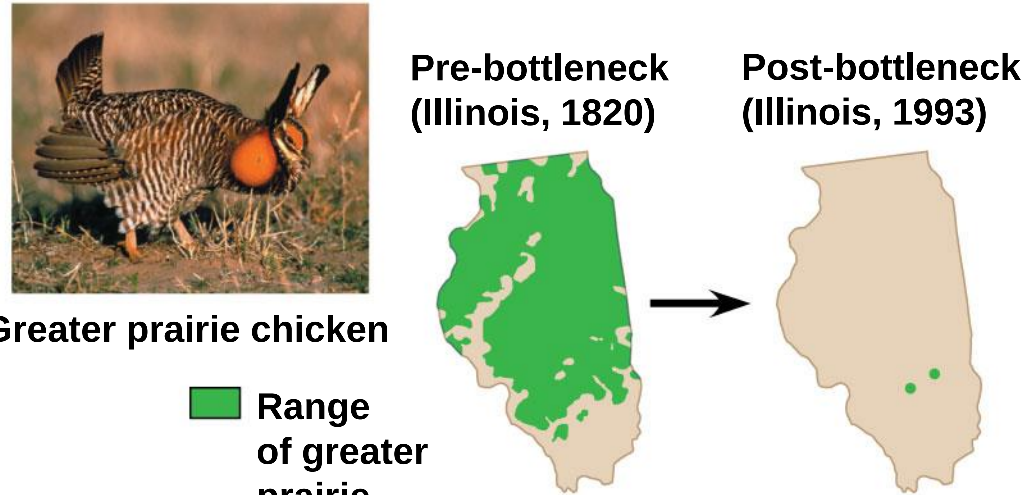


- Understanding the bottleneck effect can increase understanding of how human activity affects other species

Case Study: *Impact of Genetic Drift on the Greater Prairie Chicken*

- Loss of prairie habitat caused a severe reduction in the population of greater prairie chickens in Illinois
- The surviving birds had low levels of genetic variation, and only 50% of their eggs hatched

Figure 23.11



Greater prairie chicken

Range of greater prairie chicken

(a)

Location	Population size	Number of alleles per locus	Percentage of eggs hatched
Illinois 1930–1960s 1993	 1,000–25,000 <50	 5.2 3.7	 93 <50
Kansas, 1998 (no bottleneck)	750,000	5.8	99
Nebraska, 1998 (no bottleneck)	75,000–200,000	5.8	96

(b)

- Researchers used DNA from museum specimens to compare genetic variation in the population before and after the bottleneck
- The results showed a loss of alleles at several loci
- Researchers introduced greater prairie chickens from populations in other states and were successful in introducing new alleles and increasing the egg hatch rate to 90%

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

- **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 variation among populations over time

- Gene flow can decrease the fitness of a population
- Consider, for example, the great tit (*Parus major*) on the Dutch island of Vlieland
  - Mating causes gene flow between the central and eastern populations
  - Immigration from the mainland introduces alleles that decrease fitness
  - Natural selection selects for alleles that increase fitness
  - Birds in the central region with high immigration have a lower fitness; birds in the east with low immigration have a higher fitness

- Gene flow can increase the fitness of a population
- Consider, for example, the spread of alleles for resistance to insecticides
  - Insecticides have been used to target mosquitoes that carry West Nile virus and malaria
  - Alleles have evolved in some populations that confer insecticide resistance to these mosquitoes
  - The flow of insecticide resistance alleles into a population can cause an increase in fitness

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

- Evolution by natural selection involves both chance and "sorting"
  - New genetic variations arise by chance
  - Beneficial alleles are "sorted" and favored by natural selection
- Only natural selection consistently results in adaptive evolution

A Closer Look at Natural Selection

- Natural selection brings about adaptive evolution by acting on an organism's phenotype

Relative Fitness

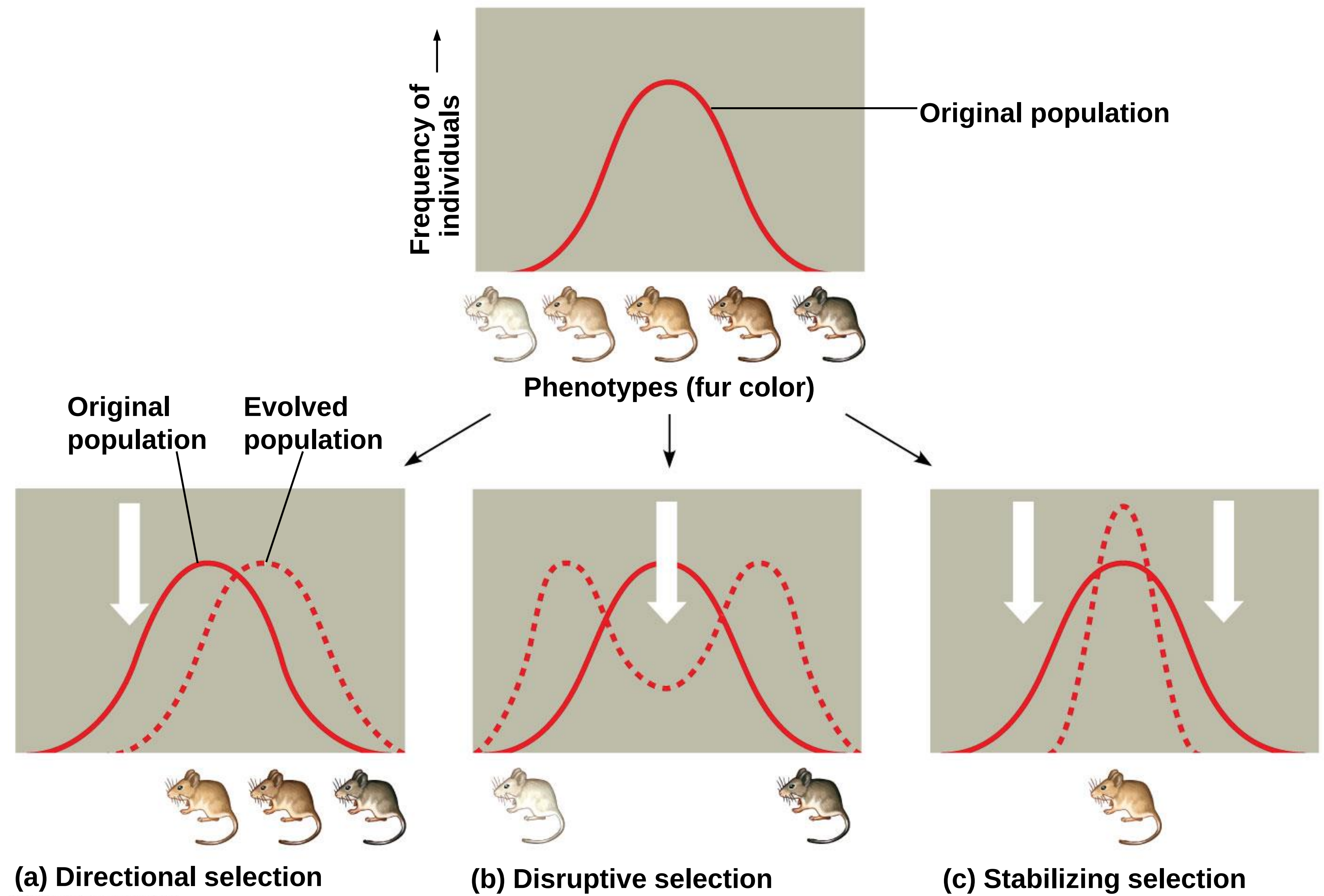
- The phrases "struggle for existence" and "survival of the fittest" are misleading as they imply direct competition among individuals
- Reproductive success is generally more subtle and depends on many factors

- **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 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

Figure 23.13

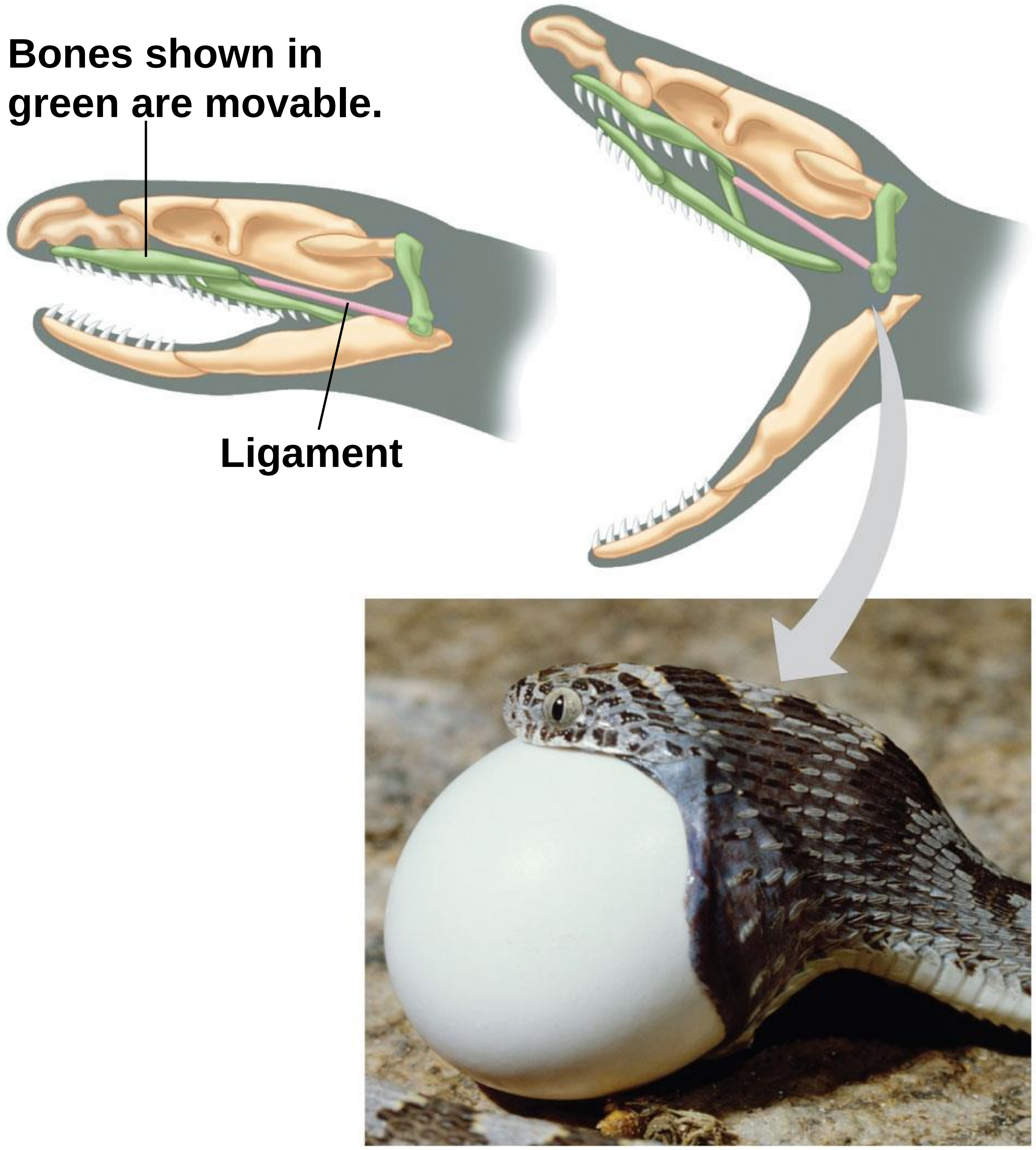


Frequency of individuals
Original population
Phenotypes (fur color)
Original population
Evolved population
(a) Directional selection
(b) Disruptive selection
(c) Stabilizing selection

The Key Role of Natural Selection in Adaptive Evolution

- Striking adaptations have arisen by natural selection
  - For example, cuttlefish can change color rapidly for camouflage
  - For example, the jaws of snakes allow them to swallow prey larger than their heads

Figure 23.14



- Natural selection increases the frequencies of alleles that enhance survival and reproduction
- Adaptive evolution occurs as the match between an organism and its environment increases
- Because the environment can change, adaptive evolution is a continuous process

- Genetic drift and gene flow 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

Figure 23.15

- **Intrasexual selection** is competition among individuals of one sex (often males) for mates of the opposite sex
- **Intersexual selection**, often called mate choice, occurs when individuals of one sex (usually females) are choosy in selecting their mates
- Male showiness due to mate choice can increase a male's chances of attracting a female, while decreasing his chances of survival

- 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 increase in frequency

Diploidy

- Diploidy maintains genetic variation in the form of hidden recessive alleles
- Heterozygotes can carry recessive alleles that are hidden from the effects of selection

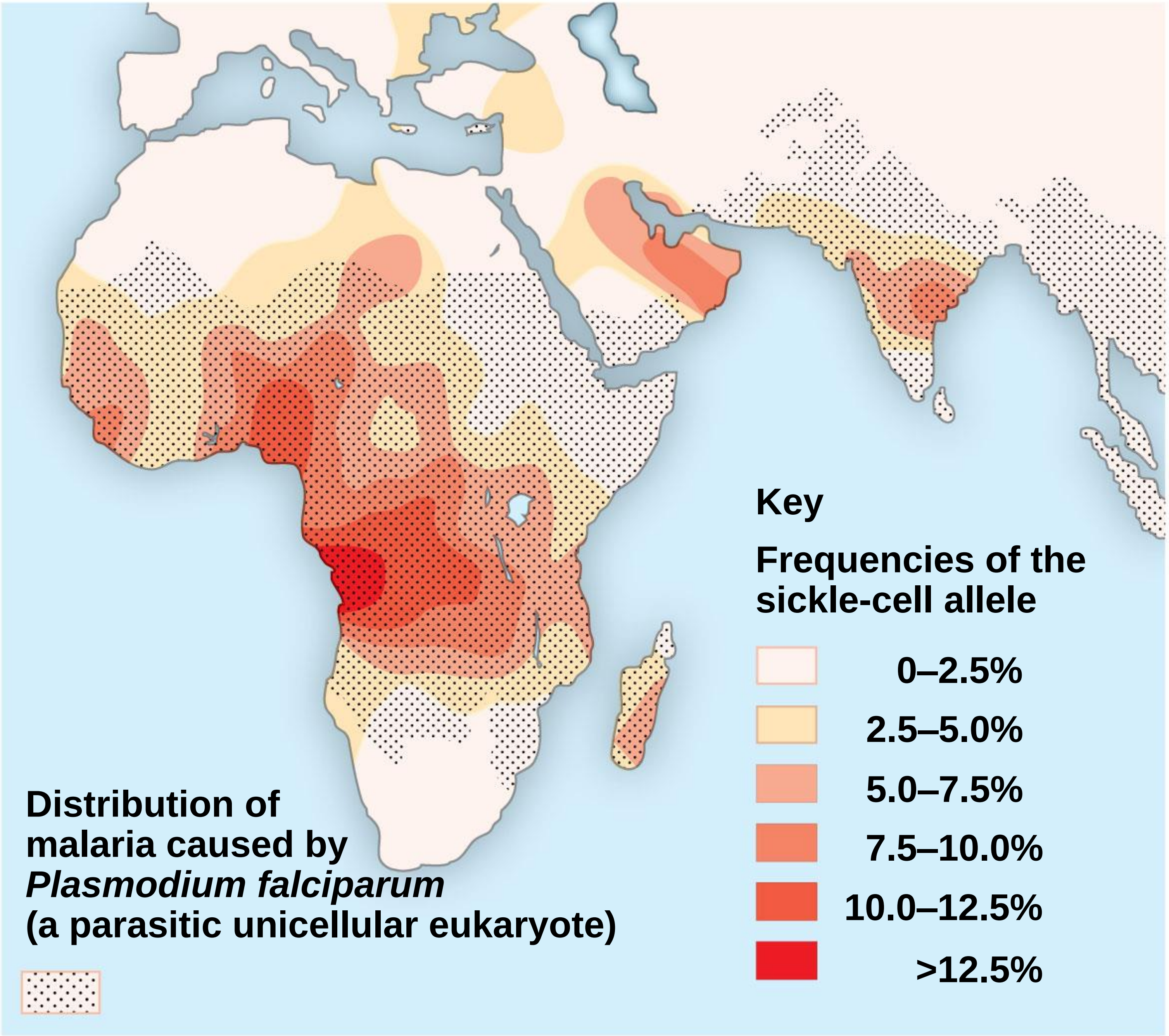
Balancing Selection

- **Balancing selection** occurs when natural selection maintains stable frequencies of two or more phenotypic forms in a population
- Balancing selection includes
  - Heterozygote advantage
  - Frequency-dependent selection

Heterozygote Advantage

- **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

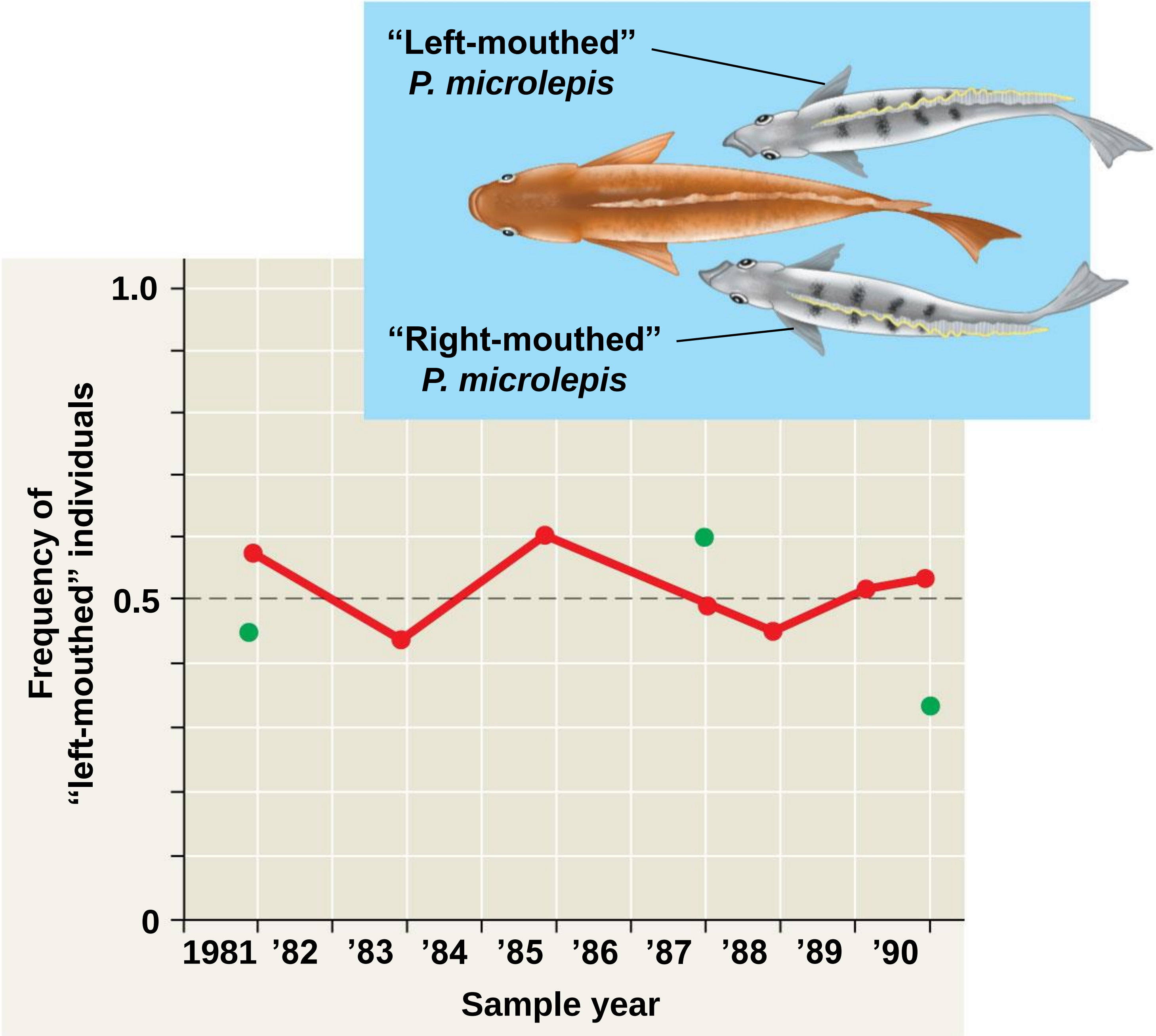
Figure 23.17


Key
Frequencies of the sickle-cell allele
0–2.5%
2.5–5.0%
5.0–7.5%
7.5–10.0%
10.0–12.5%
>12.5%
Distribution of malaria caused by *Plasmodium falciparum* (a parasitic unicellular eukaryote)

Frequency-Dependent Selection

- In **frequency-dependent selection**, the fitness of a phenotype declines if it becomes too common in the population
- Selection can favor whichever phenotype is less common in a population
- For example, frequency-dependent selection selects for approximately equal numbers of “right-mouthed” and “left-mouthed” scale-eating fish

Figure 23.18



"Left-mouthed"
P. microlepis
"Right-mouthed"
P. microlepis
Frequency of
"left-mouthed" individuals
1.0
0.5
0
1981
'82
'83
'84
'85
'86
'87
'88
'89
'90
Sample year

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